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CENOZOIC PLANKTONIC FORAMINIFERAL ZONATION AND CHARACTERISTICS OF INDEX FORMS

R. M. Stainforth, J. L. Lamb, Hanspeter Luterbacher,
J. H. Beard, and R. M. Jeffords
EXXON Production Research Company

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CENOZOIC PLANKTONIC FORAMINIFERAL ZONATION AND CHARACTERISTICS OF INDEX FORMS

R. M. Stainforth[1], J. L. Lamb[2], Hanspeter Luterbacher[3],
J. H. Beard[2], and R. M. Jeffords[2]

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[1] Consultant; 925 Terrace Avenue, Victoria, British Columbia, Canada V8S 3V2.

[2] Exxon Production Research Company, Box 2189, Houston, Texas 77001.

[3] Esso Production Research – European Laboratories, 213 Cours Victor-Hugo, 33 321-Begles, France.

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[1] Pertinent data obtained after completion of final typescript are recorded in the Addendum.

FIGURES

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ORVILLE LEE BANDY
(1917 - 1973)

This volume on Cenozoic planktonic foraminifers is dedicated to the late DR. ORVILLE LEE BANDY, *whose recent untimely death terminated his active contribution to knowledge of foraminifers. Especially notable have been his efforts in training micropaleontologists at the University of Southern California for 25 years, in advancing interpretation of paleoecology in Neogene deposits, and in expanding practical applications of foraminifers generally. Certainly his influence should continue through the many who have been associated with him.*

This dedication seems particularly appropriate in the present report prepared by Exxon Production Research Company, an Exxon Corporation affiliate, because of long continued association of DR. BANDY *and Exxon.* DR. BANDY'S *early work on foraminifers at the well known Little Stave Creek locality in Alabama was partly supported by Humble Oil & Refining Company (now Exxon Company, U.S.A.), and more recently he was a valued and much used consultant in the field of paleoecology for Exxon Company, U.S.A. and Exxon Production Research Company. Additionally, one of the authors,* J. L. LAMB, *received initial training in foraminifers as a student in one of the first micropaleontology classes taught by* DR. BANDY *at the University of Southern California, and all of the authors have benefited from their many personal contacts with him.*

PREFACE

The present report was conceived initially and prepared by the Exxon Production Research Company for private distribution within the Exxon Corporation to facilitate Company-wide standardization in recognition, application, and age interpretation of Cenozoic planktonic foraminiferal zones. Recognition of the current and potential value to the scientific community in general and to micropaleontologists and biostratigraphers specifically, however, led to approval for publication. The original manuscript has been adjusted somewhat in format and style so as to facilitate publication.

The Paleontological Institute of the University of Kansas kindly agreed to accept the report as another of the Harold Norman Fisk Memorial Papers to be issued in the University of Kansas Paleontological Contributions article series under the editorship of DRS. RAYMOND C. MOORE *and* CURT TEICHERT. *The University of Kansas Paleontological Contributions comprise a well known and highly respected series of publications on paleontology and biostratigraphy and constitute an institutional rather than a commercial outlet so that use of the published material for scientific purposes is not restricted by copyright, and cost to users is minimized.*

Paleontological Contributions issued as Fisk Memorial Papers normally are edited and printed at the University of Kansas with screened plates being printed generally by Exxon Company, U.S.A. in Houston. The present report, however, was prepared for reproduction by Exxon Production Research Company in Houston using a format, style of type, and other features approximating (but not exactly matching in all details) those used routinely in Paleontological Contributions. This copy then was printed and prepared for distribution at Kansas with financial support from Exxon Production Research Company. Under these conditions, responsibility for editing and proofing had to be assumed by Exxon Production Research Company. Paleontological Contributions editors, therefore, are not accountable for deviations from style and practices normally inherent in Contribution articles and for expectable inadvertent errors.

Raymond C. Moore

(1892-1974)

When this Article was essentially in final typescript, DR. RAYMOND C. MOORE, *organizer and eminent director and editor of the University of Kansas Paleontological Contributions, died (April 16) after a long and distinguished career. His extensive contributions to understanding and developing concepts and practices in stratigraphy and stratigraphic paleontology, to initiating and furthering geological organizations, and to formulating editorial practices for geological publications will be cited elsewhere by others. Here we only add our tribute to this notably distinguished yet unpretentious colleague who, in late November immediately prior to final debilitating illness, spent two days arranging for publication of the present report.*

ABSTRACT

Markedly increased application of the floating planktonic foraminifers by petroleum-company micropaleontologists and biostratigraphers now clearly demonstrates the widespread utility of these forms for reliable and precise correlating and dating. Presently the entire Cenozoic time interval is zoned reliably in detail (i.e., to units of about 1 to 2 million years) using some 200 species (and subspecies). Each zone is a unique subdivision of the Cenozoic, and collectively they account for all Cenozoic time with neither gaps nor overlaps. Attempts at cross correlation between classical Cenozoic stages and planktonic foraminiferal zones reveal that conventional stage names (e.g., Aquitanian) and chronologic terms (e.g., late Early Miocene) are highly unsatisfactory currently for accurate correlation and age determination. This zonation, developed initially for tropical to subtropical areas, is recognized now also in temperate latitudes but not generally in sediments deposited from very cold water of Arctic and Antarctic regions. Where planktonic foraminifers occur in surface or subsurface sections of concern, they provide a notable basis for correlating and dating to a uniform time standard. Moreover, local application of this standard zonation yields consistent and exact age interpretations that are essential for detailed evaluation of correlative geologic, geochemical, and seismic data and selection of meaningful isochronous intervals for mapping structure and depositional environments. Even where sections contain only scattered assemblages of planktonic foraminifers, these provide a reliable age framework on which can be hung other locally useful zonations. Although still meriting greatly increased application, planktonic foraminifers certainly cannot entirely replace well-established benthonic foraminiferal and other zonations in regions where these can be applied advantageously. Also, planktonic foraminifers need, locally, to be supplemented by additional planktonic microfossils, such as coccoliths, dinoflagellates, and radiolarians.

Most of this report comprises 1) a somewhat pragmatic review of Cenozoic planktonic foraminiferal zonation as described in recent international literature and as practiced by many petroleum micropaleontologists, 2) presentation of a zonal scheme that has practical utility as a standard for industrial and academic paleontologists and biostratigraphers concerned with applying planktonic foraminifers in studies having broad geographic coverage or other requirements for detailed coherence in age determination, and 3) differentiation by description and illustration of those Cenozoic planktonic foraminifers deemed most useful in regional and interregional correlation and age determination. Other data (e.g., selected bibliography, range charts, and index to taxa) are included to facilitate use of the report by both experienced and inexperienced micropaleontologists.

INTRODUCTION

OBJECTIVES

Ever increasing acceptance of planktonic foraminifers as index fossils for dating on an essentially worldwide basis has affected profoundly the development and understanding of Cenozoic biostratigraphy during the past 20 years. The effects of this planktonic revolution on micropaleontology applied in petroleum exploration are of particular concern to us and to others currently using micropaleontology to resolve exploration problems. Accordingly, the present report is directed specifically toward four principal objectives.

1. To summarize the subscience of planktonic foraminiferal zonation of the Cenozoic as presented in the extensive modern international literature and as practiced by many petroleum micropaleontologists.

2. To list and differentiate (by description and illustration) Cenozoic planktonic foraminifers considered to be most useful in regional and interregional correlation.

3. To record a zonal scheme for the Cenozoic that has utility as a standard for industrial and academic paleontologists and biostratigraphers generally in applying planktonic foraminifers in studies having broad geographic scope or other requirements for detailed coherence in age determination.

4. To present data in a form useful both to inexperienced and experienced micropaleontologists.

Obviously, collation of the voluminous data presently available on planktonic foraminifers and their application to biostratigraphy involves numerous interpretations and resolution of many minor conflicting observations. The single word "pragmatic" serves, therefore, to describe our attitude. The overall aim is to present a workable approach that is based on objective data and unequivocal criteria.

The Cretaceous is omitted here mainly because its foraminiferal zonation already is well documented and firmly established. Papers of BARR (1962, 1972), VAN HINTE (1972), KLAUS (1961), LEHMANN (1966), PESSAGNO (1969), and SIGAL (1967) are representative of modern opinions. Planktonic and nektonic organisms (chiefly ammonites) long have been the index fossils on which the biostratigraphic framework of the Cretaceous is based. Consequently, the Cretaceous has experienced little of the confusion between ecologic and chronologic aspects of paleontology that has bedeviled Tertiary stratigraphy.

Planktonic foraminiferal zones here described (Fig. 1), or equivalents in schemes of other authors, are *bio*stratigraphic units. At the same time, because of their definition in terms of paleobiologic events which were virtually synchronous around the world, they serve as *chrono*stratigraphic units. Each zone is a unique subdivision of the Tertiary System, and collectively they account for the entire Tertiary with neither gaps nor overlaps. Potentially, identification of any zone within a set of sediments is a precise key to the age of the sediments. This age is expressed conventionally either by the name of a stage (e.g., Aquitanian, Jacksonian) or by a chronologic term (e.g., Middle Oligocene, late Early Miocene). The former used to be considered more precise, but modern investigations show that the stages used in classic Tertiary stratigraphy are, in fact, a highly unsatisfactory basis for accurate correlation and age determination. The defects of the existing scheme have been revealed largely by attempts at cross correlation between stages and planktonic zones.

Many qualitative and quantitative properties of planktonic foraminifers are studied readily because of the normal abundance of these forms in open-sea sediments. Variability within taxa is apparent from examination of single samples, and trends of morphologic (evolutionary) change are observed by study of sequential samples. Commonly available for study also are continuous successions of planktonic foraminiferal faunas from long and uninterrupted sections where ecology was uniform during deposition of the beds. Consequently, biostratigraphic interpretations based on Cenozoic planktonic foraminifers achieve even greater precision than interpretations derived from such important zonal markers as Mesozoic ammonites and Paleozoic conodonts, fusulinids, and graptolites.

HISTORICAL BACKGROUND

A basic principle since the earliest days of stratigraphy is that similar fossils imply similar ages for the rocks which contain them. As studies spread around the world, certain fossil groups were recognized gradually as providing especially precise and widespread indices (e.g., Paleozoic graptolites and Mesozoic ammonites). The dual reason underlying utility of such fossils is that, in life, the organisms drifted near the surface of the sea and thus were dispersed widely by oceanic currents; then, on death,

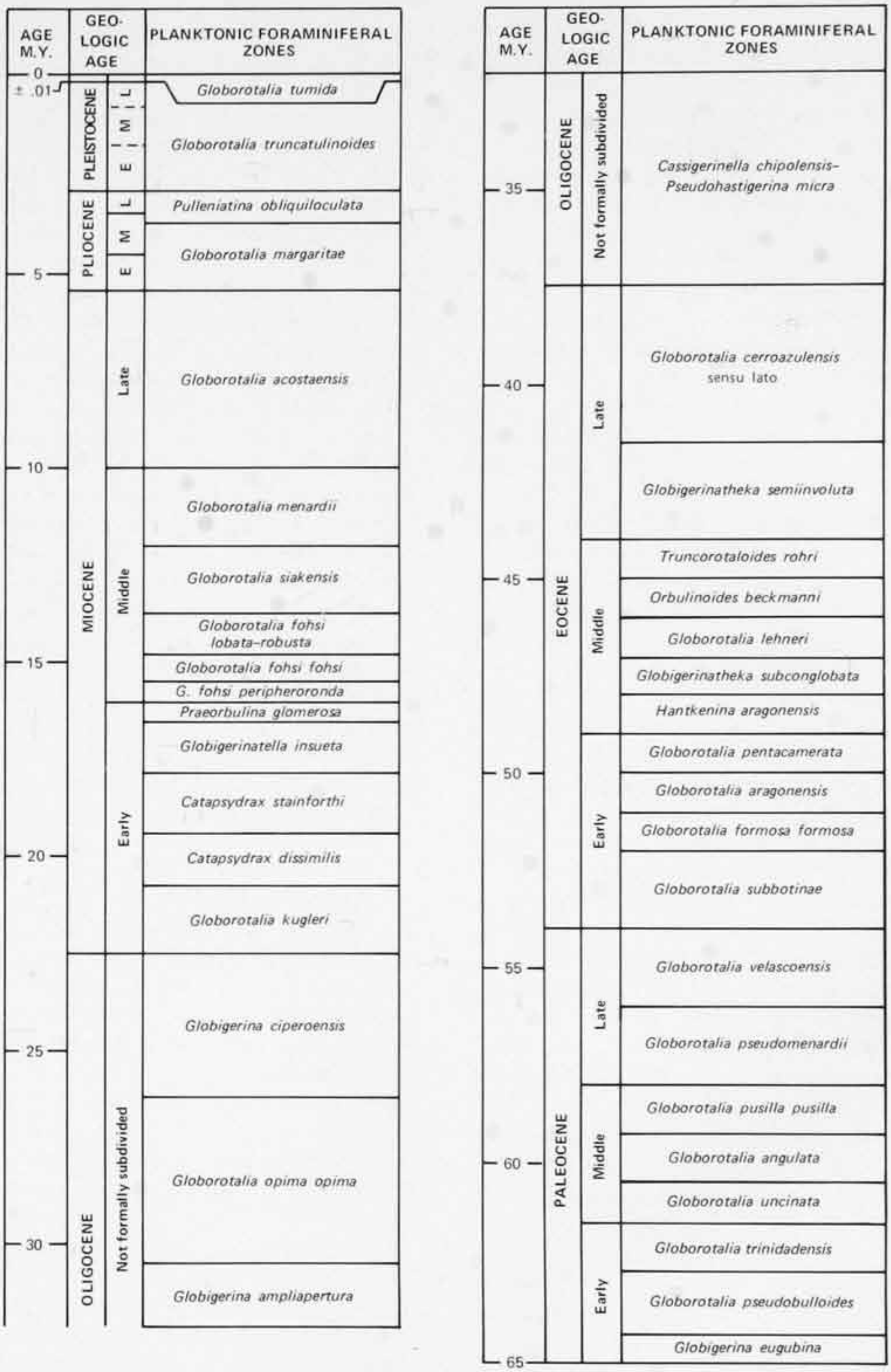

Fig. 1. Classification of Cenozoic deposits based on planktonic foraminiferal zones described in the present report.

they sank randomly to become a unifying element among sea-floor biotas (communities) which, because of susceptibility to local ecologic factors, differ widely and in extreme cases have no common species other than the extraneous planktonic forms.

The original axiom, therefore, has been modified to recognize that similarity of planktonic (surface- and near-surface-living) fossils is a reliable criterion of similar age, whereas resemblance of benthonic (bottom-living) fossils may reflect identity of environment as much as (or even more than) identity of age. The tendency to differentiate taxa more narrowly among planktonic than among some benthonic organisms also implements stratigraphic utilization of the former.

Industrial application of micropaleontology, starting half a century ago in the Gulf Coast region and quickly spreading through the principal oil-producing parts of the world, gave great impetus to study of fossil foraminifers. As more and more descriptions of microfaunas were published, certain genera and species were observed to be outstandingly useful in correlation because of their distinctive form, wide distribution, and short stratigraphic range. These well-known index foraminifers, including both benthonic and planktonic forms, were accepted generally for many years with little additional consideration of their validity as age indicators. For example, *Bulimina jacksonensis* and *Asterocyclina asterisca* (both benthonic) and *Hantkenina alabamensis* and *Globorotalia cocoaensis* (both planktonic) were given equal value as indicators of Late Eocene. GLAESSNER (1937a) was one of the first to give separate treatment to Tertiary planktonic foraminifers and to illustrate their application to zonation of the Paleogene. From his work developed more comprehensive studies by SUBBOTINA (1953, 1971), KRASHENINNIKOV (1965a,b, 1969), and other Soviet authors. Independently the Trinidad school started publication of a series of papers (see BRÖNNIMANN, 1952b; BOLLI, 1974) which culminated in detailed planktonic foraminiferal zonations of the entire Tertiary by BOLLI (1957a-c, 1966a).

Trinidad became a key area in planktonic foraminiferal stratigraphy for several interrelated reasons. Petroleum companies there needed accurate geological maps in their search for new oilfields. As the terrain defied orthodox geologic mapping techniques, strong reliance was placed on micropaleontology for distinguishing lithologically similar units. At first confusion arose from failure to realize that distinctive microfaunas had persisted side by side in parallel mid-Tertiary environmental belts (nearshore, shelf, basin, turbidites). This troublesome problem was resolved successfully by using only the planktonic species as age indicators. DR. HANS G. KUGLER, in a managerial position, was enlightened enough to press his staff to publish their findings.

By the end of the decade of the 50's the Trinidad zonation was established, had been applied successfully in other parts of the Caribbean region, and was recognized in western Europe even though published documentation was scanty. Furthermore, literature compilations used in reaching this conclusion about western Europe (e.g., DROOGER, 1956; AKERS & DROOGER, 1957; BOLLI, 1959; STAINFORTH, 1960) hinted at pronounced anomalies in long-accepted correlations between different sectors of Europe. The pressing interest of these two themes led many European paleontologists to pay belated attention to identification and analysis of their Cenozoic planktonic assemblages. Rather fortunately, the Committee on Mediterranean Neogene Stratigraphy was in a position to steer the main studies and to incorporate their results in periodic reports (1960-72). Paleontologists in other regions, such as the Far East and Australasia, likewise turned to planktonic foraminifers for the purpose of testing Cenozoic correlations.

A completely different impetus to the study of fossil microplankton arose somewhat later in the field of oceanography as techniques were perfected for extracting long cores from the floor of the deep ocean so that problems of a hitherto conjectural nature could be attacked. For this purpose the JOIDES and Deep-Sea Drilling projects pooled scientists and facilities of research institutions around the world. Exciting new concepts in the field of sea-floor spreading and plate tectonics were subject to check by study of the submarine cores which, being from oceanic depths, mostly are extremely rich in plankton.

The net result of the research just mentioned has been publication in the 60's of an astounding volume of literature on planktonic foraminifers. The essence of these studies has been extracted for the present report so that the user either may accept our condensation or may consult extensive sources indicated in the references.

INDUSTRIAL ASPECTS

In the context of industrially applied paleontology, planktonic foraminiferal zonation plays a unique role in resolving the multiplicity of geologic problems which arise during exploration and exploitation activities of petroleum companies. One constant need is accurate and detailed well-to-well correlation in order to facilitate interpretation and prediction of structure and localization of oil accumulations. Micropaleontology already is established as one of the main techniques used for this purpose because microfossils survive fragmentation of subsurface strata by drill bits and because readily distinguishable microfaunal changes commonly occur within sequences which appear uniform on lithologic and electric logs.

Many types of microfossils are employed regularly in subsurface correlation, but use of benthonic foraminifers far outranks that of all others. The basic technique for micropaleontologic correlation of boreholes was introduced independently in several countries toward the end of the 19th century. As records of these efforts were published only in local journals, most remained virtually unknown for half a century. Several authors having special interest in historical aspects (notably CRONEIS, 1941; GLAESSNER, 1945; POKORNÝ, 1958; HOWE, 1959; and CHARLTON DE RIVERO & BERMÚDEZ, 1963) later established that the pioneers included W. DAMES and L. G. BORNEMANN in Germany in 1874, F. KARRER in Austria in 1877, F. V. HOPKINS (at the instigation of E. W. HILGARD) in Louisiana in 1884, H. J. EUNSON and also J. W. JUDD and T. R. JONES in independent studies in England in 1884, W. HOWCHIN in Australia in 1891, and F. CHAPMAN in California in 1900.

The earliest studies were specially concerned with water wells; J. GRZYBOWSKI usually is credited with the first application of micropaleontology in the oil industry. By 1897 he had established several subsurface zones and key levels in the oilfields of Galicia (GRZYBOWSKI, 1898; BIEDA, 1969). Comparable studies in the United States were at first disjointed and somewhat academic but, through the perseverance of J. A. UDDEN in particular and others including J. A. CUSHMAN, J. J. GALLOWAY, and J. P. SMITH, applied foraminiferal micropaleontology became firmly established in geological operations of the Humble, Rio Bravo, Atlantic, and other major oil companies in the Gulf Coast region and California. Seven oil companies set up micropaleontological laboratories between 1919 and 1925 in these areas. Credit for bringing applied micropaleontology out of obscurity has justly been given to three women colleagues, ESTHER R. APPLIN, ALVA C. ELLISOR, and HEDWIG T. KNIKER, whose joint paper (1925) provided a striking case example in the petroleum geologists' own journal.

Between world wars the rapidly expanding demand for petroleum led to worldwide exploration and development of many new oil fields. Typically a standard foraminiferal zonation was developed for each field based on the subsurface distribution of benthonic assemblages and index species. A straightforward example (only one of many) is the sequence of zones applied to the subsurface Claiborne shale of Texas and Louisiana by ISRAELSKY (1935), named in downward succession of benthonic species: *Nonionella cockfieldensis, Eponides yeguaensis, Cristellaria mexicana, Ceratobulimina eximia, Cristellaris nudicostrata, Textularia smithvillensis,* and *Lamarckina claibornensis.*

Nevertheless, despite widespread and successful use of such schemes, no reliable correlation may be discernible in sequences of benthonic microfaunas under the special conditions of either very uniform or erratically diverse facies. In these cases and where strata are of marine origin, application of planktonic, instead of benthonic, foraminifers commonly yields a solution. Eastern Venezuela provides good examples of both types; for instance LAMB (in LAMB & DE SISTO, 1963; 1970) documented how, after all other techniques had failed, use of a planktonic zonation demonstrated that a deep subsurface structure at Quiriquire is an overturned fold (Fig. 2); and STAINFORTH (1971) showed how this technique provides correlations within the monotonous shales of the Carapita Formation, some 20,000 feet thick.

Well-to-well correlations are more or less local in scope, typically measurable only within distances of a few miles. A broader problem is involved in regional mapping of paleogeographic and environmental parameters which influence stratigraphic (as distinct from more obvious structural) controls of hydrocarbon distribution. Coverage of such maps differs but commonly extends to tens or even hundreds of miles. The accuracy and reliability of these maps depend on the precision with which

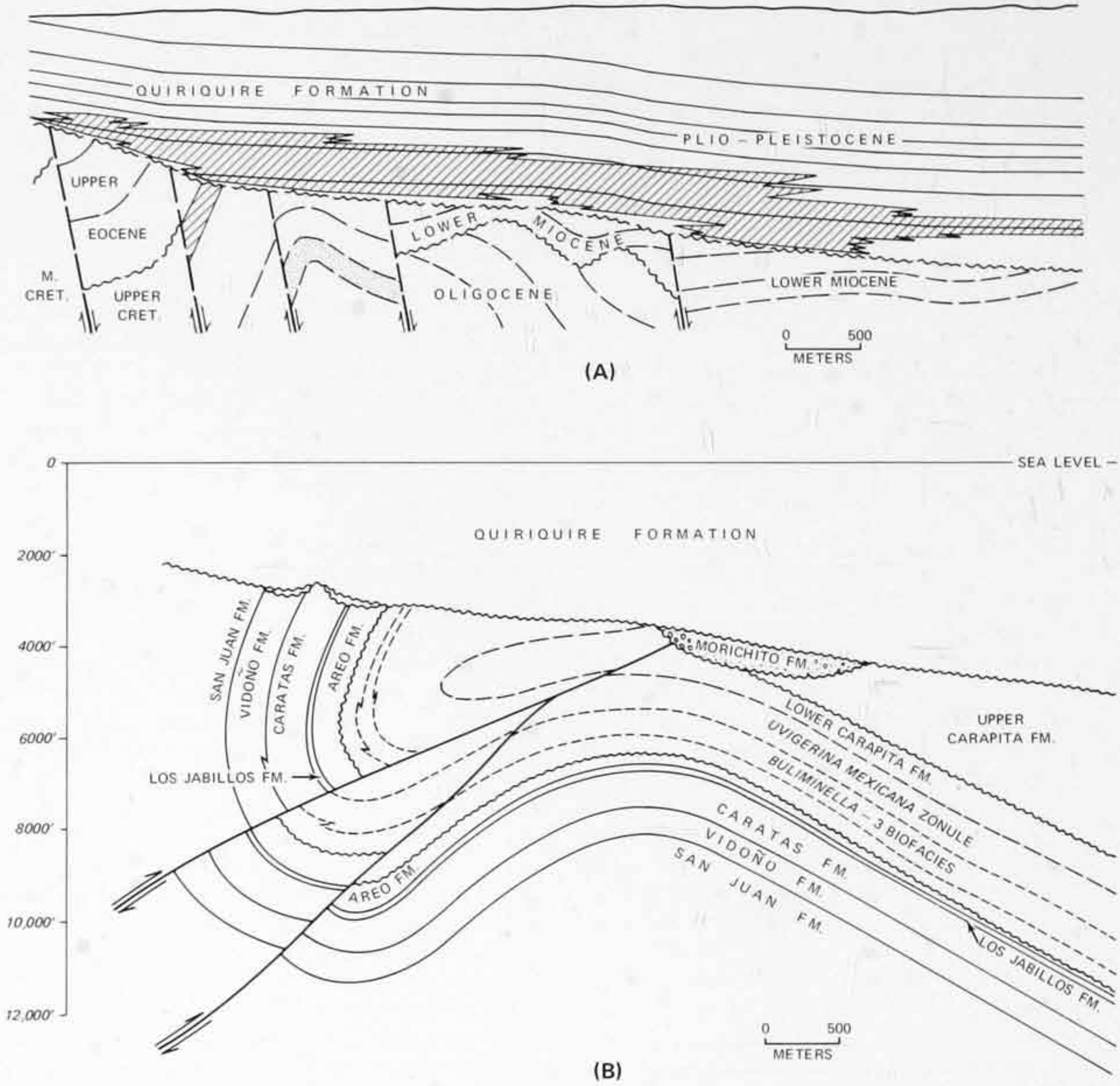

Fig. 2. Cross sections of the Quiriquire oil field, Venezuela, illustrating (A) a conventional interpretation of structural and stratigraphic relationships (after BORGER, 1952) and (B) later revised interpretation of structural relationships based on age analysis of planktonic foraminifers and environmental analysis of benthonic foraminifers (after LAMB, in LAMB & DE SISTO, 1963; 1970).

isochronous surfaces (time planes) can be identified. Use of benthonic fossils or lithostratigraphic data is liable to be misleading because a prominent change of fauna or rock type, though physically the same at many control points, commonly proves diachronous (Fig. 3). In contrast, properly interpreted changes of planktonic faunas do identify isochronous levels and intervals so that planktonic zones provide a logical time scale on which to base sets of regional paleogeographic maps (KRASHENINNIKOV, 1971). Moreover, micropaleontologists increasingly must have a biostratigraphic framework related

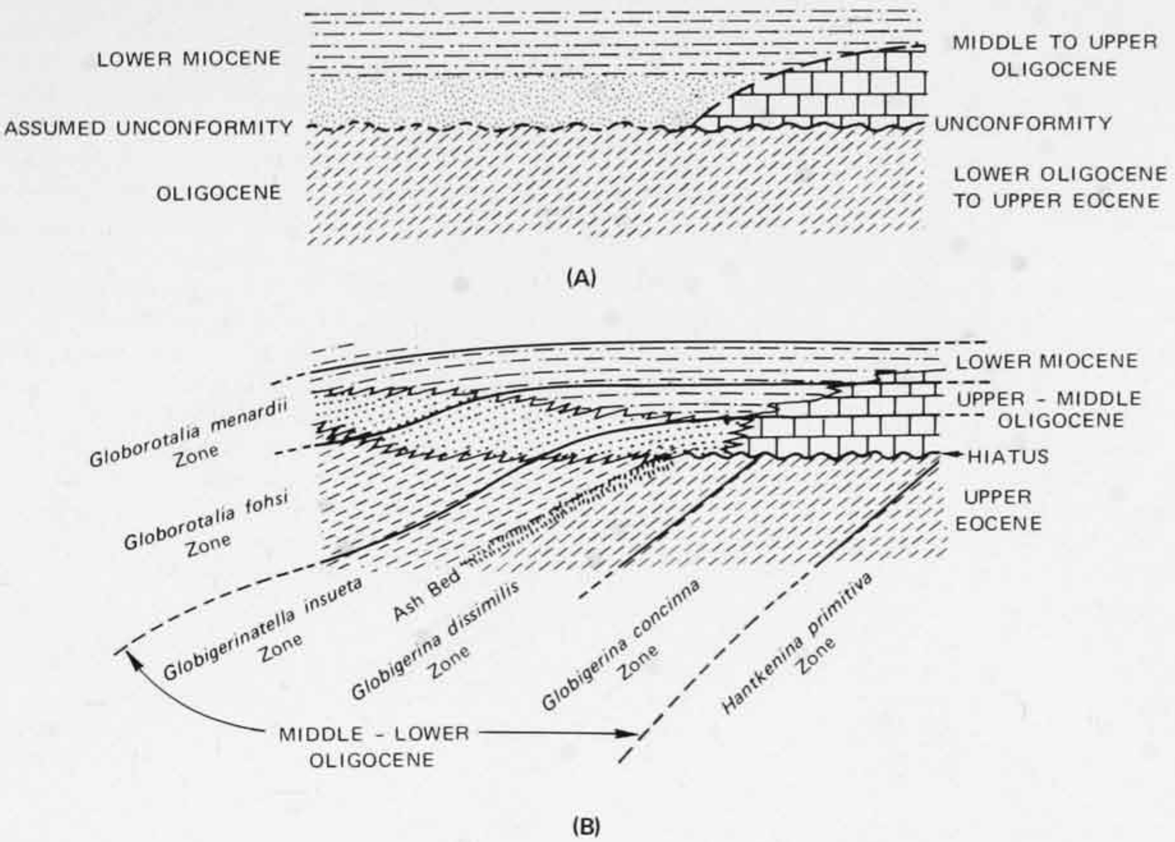

Fig. 3. Cross sections of flank of the Borbon basin in northwestern Ecuador showing how analysis of planktonic foraminifers permits detailed age correlation across lithologic (facies) boundaries. Conventional symbols denote general lithology. (From unpublished report by STAINFORTH about 1950; ages and zones not updated). **(A)** Initial interpretation after reconnaissance study of limited surface exposures and a few fossils. **(B)** Revised interpretation obtained by analysis of planktonic foraminifers that demonstrates the synchroneity of environmentally and lithologically different deposits.

consistently to a standard time scale so that other geological, geochemical, and geophysical studies can be utilized fully.

The great volume of recent literature on Tertiary planktonic foraminifers already has been mentioned. Many authors introduced zonal schemes which differ in scale from local to circumglobal. Potentially this is a source of confusion because two authors may select different markers and names for the same zonal interval or apply the same name to significantly different intervals. Since compilation of regional maps requires collaboration of paleontologists in widely separated laboratories, all must apply zonal indices and nomenclature in a uniform manner. For this reason we make one of our objectives the desirability for accepting a standard zonal scheme, such as here proposed.

ACKNOWLEDGMENTS

Early stages of this compilation were concerned with choice of index species and their respective determined ranges. Such information was supplied willingly and efficiently by many colleagues within the Exxon Corporation [formerly Standard Oil Company (New Jersey)]. We particularly acknowledge assistance given by H. W. ANISGARD, the late NOEL BROWN, ALEJANDRO EURIBE, M. A. FURRER, J. E. VAN HINTE, D. H. JONES, D. O. LEROY, L. C. MENCONI, R. W. PHILLIPS, I. L. POLSON, ROBERTO SARMIENTO, BENTON STONE, G. R. STUDE, J. A. SULEK, and R. P. ZINGULA. Later we benefited from several discussions of broad aspects of planktonic foraminiferal zonation, in particular with W. A.

BERGGREN, the late W. H. BLOW, P. H. ROTH, and especially H. M. BOLLI, who has been unstinting in his aid.

Acknowledgments for the Miocene to Holocene part of this compilation are given in a prior report (LAMB & BEARD, 1972).

For illustrations of index species, specimens were selected insofar as possible from material in our collections and those of Exxon Production Research Company in Houston and Bordeaux. For species not adequately represented there, however, topotypic material was kindly donated by J. P. BECKMANN, P. J. BERMÚDEZ, H. M. BOLLI, I. V. DOLITZKAYA, W. W. FAIRCHILD, W. W. HAY, V. A. KRASHENINNIKOV, H. G. KUGLER, BRIAN MCGOWRAN, E. K. SHUTSKAYA, BENTON STONE, G. R. STUDE, and N. N. SUBBOTINA. Most accompanying scanning electron microscope (SEM) photographs of Paleogene specimens were made by H. E. FRANZ at the Federal Institute of Technology in Zurich under the guidance of H. M. BOLLI. Others were kindly prepared by F. SAFFON and H. J. OERTLI of the Société Nationale des Pétroles d'Aquitaine in Pau. The SEM illustrations of Late Eocene and post-Eocene species were made mostly by R. D. HOCKETT of Exxon Production Research Company in Houston under the guidance of J. L. LAMB.

In finalizing the manuscript, supervisory assistance was provided especially by JAN HARDENBOL, L. A. SMITH, and J. F. VAN SANT of Exxon Production Research Company in Houston.

We are indebted to many other associates at Exxon Production Research Company; especially F. H. BROZ, MRS. M. H. BUCKHOLT, RON KELLEY, and MRS. M. I. THOMPSON who, under the direction of E. L. CHASE and MRS. A. H. FRAZIER, prepared the illustrations and very effectively carried out the many difficult steps required to translate the manuscript into report typescript. MRS. D. O. SMITH aided materially in checking the manuscript and proof and in expediting preparation of copy for printing. Appreciation is expressed also to the management of Exxon Production Research Company for permission to publish this article and for approval to include it in the Harold Norman Fisk Memorial Papers sponsored by Exxon Company, U.S.A.

R. C. MOORE, University of Kansas, assisted importantly by reviewing and editing part of the manuscript and by suggesting improvements in organization. Also, acceptance of the report for publication as a Paleontological Contributions article by editors R. C. MOORE and CURT TEICHERT is greatly appreciated in view of the procedures that were involved.

PROCEDURES AND FORMAT

The compilation presented here is the finalization of a project on which many of our colleagues were engaged jointly in earlier phases. In evaluating and compiling data for the present report, LUTERBACHER was principally concerned with preparation of the early Tertiary discussions of zonations and species, STAINFORTH with the middle Tertiary, and LAMB and BEARD with the late Tertiary to Holocene. STAINFORTH also coordinated efforts of the group and prepared introductory and general discussions. JEFFORDS collated the original manuscript and guided revisions, resolved nomenclatorial questions, and oversaw preparation of copy for printing. Nevertheless, we exchanged views freely in extensive correspondence and at several meetings in Houston and Bordeaux so that the result is a mutual responsibility.

Generalized schemes of planktonic foraminiferal zonation already exist in the literature. Those of BOLLI (1966a, and earlier) and BLOW (1969, in particular) have received general acceptance and are used frequently to provide a standard framework for local zonations. In point of fact Middle Tertiary divisions in these two schemes largely coincide [see, for instance, BLOW (1969, fig. 14-15) or POSTUMA (1971, chart 2-3)] and are adopted with slight change in the zonal scheme used here. The main differences are in mode of definition. On the one hand, BOLLI gave terse definitions of the zones based on ranges of relatively few marker species (41 for the whole Tertiary) and only briefly discussed associated planktonic foraminifers characteristic of each zone. Similarly POSTUMA (1971), although plotting many more Tertiary species (123) on his range charts, gave only brief diagnoses of zones without explanation of the eclecticism in selection of these units from various sources. On the other hand, BLOW exhaustively detailed the nature of assemblages, evolutionary lineages, and environmental factors related to his published zonations and discussed local sequences and allied aspects of zonation. In a treatment which excludes the older Paleogene (Paleocene into Middle Eocene), BLOW reviewed 228 Tertiary taxa, plotted most of them on range charts, and supplied individual annotations on their zonal significance. BLOW'S manuscript on the older Paleogene, which we reviewed informally with him in 1971, evidently will be published posthumously in a format similar to that of his 1969 paper.

The present paper reflects opinion that a demand exists for an intermediate treatment of the subject, less "cut and dried" than those of BOLLI and POSTUMA, yet not as voluminous and meticulously analyzed as BLOW'S. In our descriptions of zones the usual objective data are tabulated with supplemental notes on subjective aspects and controversial points. These annotations are accompanied by extensive references in which more detailed discussions can be consulted. Moreover, the very considerable amount of continuing effort by many workers on planktonic foraminifers increasingly permits refinement and other adjustment in ranges interpreted previously. In the Late Miocene to Holocene interval particularly, markedly different age interpretations of widely separated surface and subsurface sections led to selection of zonal intervals and stated ranges of index forms that are not substantiated by more recent detailed analyses. For example, intervals that BANNER & BLOW (1967) and BOLLI (1966a) considered as Late Miocene now are regarded as Pliocene.

The format of this report has been developed to provide maximum utility for users. Introductory general information on planktonic foraminifers and their employment in zonation, definition and discussion of age relationships of the zones combined with range charts for index species, literature references, and an index to taxa mentioned in the report form the main text. Descriptions and illustrations of index species comprise the appendix. Discussions of zones, range charts, and index species are subdivided consistently into units (Paleocene to Middle Eocene, Late Eocene to Middle Miocene, and Middle Miocene to Holocene). These units were most convenient in preparing the report, as they correspond to major changes in planktonic evolution and permit separation of discussions of stratigraphically grouped index forms as a convenience to persons concerned with only parts of the Cenozoic section.

The main text outlines some basic aspects of classification of planktonic foraminifers and their use in biostratigraphy. Brief reference is made to closely allied topics of nannofossil zonation, radiometric dating of zones, planktonic foraminiferal lineages, and paleoclimatic analysis. Reviews of the Paleocene-Middle Eocene, Late Eocene-Middle Miocene, and Middle Miocene-Holocene intervals follow, offering for each a standard zonation synthesized from what appear to be the best elements in the several schemes proposed by different authors. Explanatory diagrams are provided, perhaps the most important being range charts of index species which show their application to zonation. Some morphologic terminology applicable to zonation and commonly used in studies of Cenozoic planktonic foraminifers is reviewed briefly. The information given is stated as concisely as possible but is accompanied by reference citations of more detailed discussions. An extensive but selected list of references for all parts of the present report is included. An index facilitates the finding of citations given in the report of all mentioned names of planktonic foraminifers regardless of their status. This index is particularly useful for identifying species and genera widely accepted in the past but now regarded as junior synonyms and here recorded under unfamiliar names.

The systematic portion of the report (appendix) is concerned with morphologically distinctive species and subspecies which have been found most useful by us or our colleagues for zonation on a regional scale. Each form is treated in units which provide text information and discussion accompanied by selected illustrations. For a few interconnected species or subspecies (e.g., *Globorotalia fohsi* sensu lato and the *Globigerina linaperta* group) a special explanation is inserted to supplement items on individual variants. The standard text for each index species has the following sequence of entries: 1) currently accepted name plus author and date of first publication under this trivial name; 2) range expressed chronostratigraphically; 3) synonymy designed to give (in chronologic sequence) the range of generic assignments used by trustworthy authors, later names considered to be junior synonyms, significant misidentifications, and indications of geographic spread (not exhaustively complete); 4) diagnosis in telegraphic style defining morphologic features in a reasonably consistent sequence, accompanied by illustrations; 5) discussion including brief comparison with other species, basis for distinction, nomenclatural points, and other aspects of particular interest; and 6) distribution, including range in terms of age and standard planktonic zones, geographic spread, and other pertinent features, such as environmental control and provenance of types.

Meticulous distinctions within older Paleogene forms were found to be expedient, but published references differ so widely between loose and precise definition that lists are short to avoid lengthy annotations.

Uniform and widespread application of any zonation depends importantly on uniformity in concepts used to identify and designate the taxa constituting the marker fossils. This is true particularly for planktonic foraminifers because descriptions of new taxa and restricted definitions of previously defined taxa have been appearing recently in very many publications. Many species-group taxa, of course, are identified and named consistently by most workers, but others appear to be interpreted very differently with respect to name, diagnostic character, and stratigraphic occurrence because of important differences in recognition of synonymies, subdivision of transitional evolutionary lineages, and personal experience. Accordingly, we gave especial attention to our interpretation of the names, differentiating characteristics, and stratigraphic ranges of the planktonic foraminiferal species and subspecies here considered to have particular biostratigraphic significance.

As text descriptions and diagnoses rarely convey clearly the detailed morphologic characteristics of the many precisely defined species-group taxa of planktonic foraminifers, adequate illustrations are a necessary and integral part of a description. Concurrent analysis of the description and illustrations given for a species in many publications is impeded because of the grouping of illustrations on plates more or less separated from the related text. POSTUMA (1971) achieved the desired results by placing illustrations of a taxon opposite the corresponding descriptive text in what generally is termed a "catalog" style. A rather similar presentation is adopted here with illustrations for each taxon comprising one figure (rarely several figures); these are placed mostly on or opposite the page containing the applicable text description. Adjustment to an economical and attractive publication format lacking unused page space, however, necessitated placement of a few of the figures on pages immediately following the descriptive text. The presentation is similar to that of POSTUMA (1971) but more effort was made to show the intraspecific variation that is normal for most planktonic foraminiferal indices.

Until recently, descriptive classification of all so-called smaller foraminifers, both planktonic and benthonic, rested on their appearance under an optical microscope. Magnifications in the range of X30 to X100 customarily have been adopted for published illustrations, the upper limit being imposed by the loss of depth of focus as magnification is increased. With rare exceptions (e.g., FOURNIER, 1956, 1957; POSTUMA, 1971) photographs of planktonic species were unsatisfactory because depth of focus at higher magnifications is insufficient and resolution of fine details at lower powers is inadequate. Consequently, careful drawings, often made with a camera lucida, have been the main method of illustrating foraminiferal publications. These reached a high standard of artistry in such classic works as those of BRADY (1884), RHUMBLER (1911), and SUBBOTINA (1953).

More recently, techniques of illustration have been revolutionized by use of the scanning electron microscope (SEM). With this instrument enlargements of hitherto unimaginable clarity are made routinely at scales of X1000 and greater with virtually no problems in depth of focus or glare. Nevertheless, despite reasonably ready availability of these splendid photographs, the binocular microscope remains the standard instrument for routine study and identification of foraminifers, especially by industrial micropaleontologists. It follows, therefore, that illustrations intended for use in identification should resemble as closely as possible forms seen through an optical microscope. In general terms, traditional drawings serve this purpose better than the SEM enlargements, which, though undeniably precise, tend not to match the viewer's mental image as well. Our opinion is that SEM photos are invaluable tools for investigating the fine structures and affinities of foraminifers but that they are not automatically the best illustrations for any given species. For this reason a combination of drawings and SEM photographs is assembled here.

For most species illustrations include specially made SEM photographs of specimens selected by the compilers largely from topotype material. Illustrations also were culled eclectically from the literature choosing original type figures if of acceptable quality. Initial plans called for illustrations at only a few fixed magnifications (e.g., X50, X100, X200) so as to facilitate identifications and comparisons by making the size factor readily apparent. In practice, however, this procedure was found not only difficult to organize but unsatisfactory because of distortions introduced by reduction or enlargement of copied originals. Accordingly, figures are at comparable random magnifications for similar-sized species.

Specimens used in obtaining the original SEM photographs here reported are filed currently at Houston (Exxon Production Research Company) and at Bordeaux (Exxon Production Research Company–Europe). Presumably all these materials eventually will be integrated into the collection at Houston.

CLASSIFICATION OF PLANKTONIC FORAMINIFERS

PHILOSOPHICAL BASES

Benthonic (bottom-dwelling) and planktonic (floating) assemblages of fossil foraminifers were not distinguished particularly in early studies. In both groups genera were defined using gross morphologic attributes such as mode of coiling, shape of chambers, and position of the aperture. Also then no firm basis was recognized generally for differentiating benthonic and planktonic forms. A floating mode of life is suggested by thin-shelled or inflated globular chambers and is confirmed by presence of the same genera (e.g., *Globigerina, Orbulina*) in modern planktonic assemblages. On the other hand, genera known to be planktonic (e.g., *Globorotalia, Chiloguembelina*) may resemble closely some bottom-living forms (e.g., *Cibicides, Bolivina*), whereas some of the latter may appear suited to a floating existence (e.g., *Laticarinina*). *Globorotalites* BROTZEN (1942), for example, was introduced as a supposedly planktonic genus, but modern authors regard it as benthonic. Several extinct genera (e.g., *Hantkenina* and *Globigerinatheka* of Tertiary age) are deduced to have been planktonic because of their constant association with known plankton or their presence in euxinic beds devoid of benthonic organisms.

Many planktonic foraminifers were described and named by pioneer authors in such a broad manner that their names have become virtually meaningless today. This comment applies especially to innumerable forms having a simple globigerine coil of bulbous chambers. (Note subsequent discussion of descriptive terminology employed here.) Even after industrial application of micropaleontology led to a marked expansion of foraminiferal studies (Fig. 4), nomenclature within the planktonic group remained generalized and vague. In America, JOSEPH A. CUSHMAN, a leader in the study of fossil foraminifers, took little interest in the plankton. His monograph on Gulf Coast Upper Eocene Foraminifera (CUSHMAN, 1935), for example, omitted mention of the Globigerinidae and included

Fig. 4. Cumulative number of Cenozoic genera and subgenera of planktonic foraminifers proposed 1825-1973 illustrating marked increase in differentiation of taxa as appreciation of the stratigraphic usefulness of these microfossils expanded. The increase during 1925 to 1950 resulted rather directly from petroleum-industry interest in foraminifers generally, whereas acceleration subsequently reflects directly attention given to planktonic foraminifers.

descriptions of only two planktonic species (*Hantkenina alabamensis* and *Globorotalia cocoaensis*). Under CUSHMAN'S 1948 classification any planktonic foraminifer having slender digitate to clavate chambers was placed in the undivided genus *Hastigerinella*. Today at least eight generic and subgeneric names accommodate such forms. Early papers by the Trinidad school, though presaging the future importance of planktonic zonation, mentioned surprisingly few index species. For instance, CUSHMAN & STAINFORTH (1945) recognized only 15 planktonic species in the same Oligocene-Miocene interval in which BOLLI (1957b) identified 56 named species and subspecies; CUSHMAN & RENZ (1948) listed only 11 species (none of *Globigerina*) in the underlying Eocene interval whereas BOLLI (1957a,c) later recorded 44 forms (15 under *Globigerina*). In earlier independent studies GLAESSNER (1937a,b) applied only 19 planktonic species in zoning the Paleocene to Oligocene interval.

The recognition of rather few named forms resulted partly from the broad species concept then in favor. Commonly a single name was applied to variants which today are split into at least subspecies if not into different species. *Globorotalia cerroazulensis* and *Globorotalia cocoaensis* (both 1928) long were regarded as synonymous, and authors used whichever they preferred but not both names in a single list. The holotype of *Globorotalia barisanensis* (1939) proved to be so distinct from the form conventionally identified under this name that a new designation (*G. peripheroronda*) was introduced for the latter. The single name *Globigerina dissimilis* (1937) for a long time accommodated all planktonic foraminifers having an umbilical bulla.

Based on the foregoing observations made in studies of the literature and on recollections of early specialists, it is evident that in the 30's and 40's emphasis was on morphologically distinct species having limited stratigraphic ranges. Typically the forms distinguished were large and conspicuous components of the plankton and were readily identifiable without notice of what then seemed to be insignificant details. Their levels of appearance and disappearance served to identify a sequence of unequivocal but rather thick zones.

The next step, predictably, was refinement of the scheme by recognition of thinner zonal divisions. Achievement of this required study of less conspicuous faunal elements; this study then led to emergence of an important concept that had received only passing attention in older literature. A pioneer case was BOLLI'S recognition (1950) that four seemingly distinct species of *Globorotalia* occur both in stratigraphic order and in a consistent morphologically intergraded sequence of forms which logically could be treated as subspecies of *Globorotalia fohsi*. This particular example arose from the economic need for precise correlations in structurally complex oil pools producing from the Herrera sands of Trinidad. It set the stage, however, for intensive study of the concept of continuous evolution and, in particular, chronologically differentiated subspecies of planktonic foraminifers. BLOW (1956) introduced the concept that *Orbulina* evolved from *Globigerinoides* by way of several short-lived intermediate forms each of which has value for purposes of precise zonation. BOLLI (1957b) accepted BLOW'S conclusions, and himself distinguished zonally useful subspecies within previously undivided species (e.g., *Globigerina ciperoensis*, *Globoquadrina altispira*). The evolutionary aspects of classification are given further consideration subsequently in the present report with discussion of evolutionary lineages.

A decade after their initiation, studies of planktonic lineages were revolutionized by use of the scanning electron microscope. SEM photographs reveal with unmistakable clarity the finest details of foraminiferal tests; verifying some and disproving other ideas developed in studies using only optical microscopes. At the time of present writing (late 1972 to early 1973) the concept of evolutionary lineages is firmly accepted as a significant factor in investigation of planktonic foraminifers but actual examples postulated by several authors now are under scrutiny with aid of all-revealing SEM illustrations.

GENERA AND FAMILIES

Exclusive of forms confined to the Cretaceous, authors recognize 20 to 30 genera of planktonic foraminifers (BOLLI, LOEBLICH, & TAPPAN, 1957, p. 17-21; EL-NAGGAR, 1971, p. 447; JENKINS, 1971). Deserving immediate emphasis is the fact that acknowledged experts differ appreciably in accepting, merging, and subdividing proposed taxa of planktonic foraminifers. For example, BLOW (1969) used the single name *Globigerinita* for all globigerine species having a single umbilical bulla, whereas our present compilation differentiates two such genera

(Globigerinita, Catapsydrax) on the basis of different shell texture. Other authors, moreover, consider variation of the bulla to be a generic criterion and recognize, therefore, a third genus, *Tinophodella.* Another example is found in work by BERMÚDEZ (1952, 1960) and others who have recognized *Globorotalia* and *Turborotalia* as distinct genera, whereas BLOW (1969) treated them as subgenera of *Globorotalia* (s.l.) and JENKINS (1971) divided *Globorotalia* into six subgenera. We agree with numerous other authors (e.g., LUTERBACHER, 1964) in not dividing *Globorotalia* into subgenera.

Lack of uniformity in classifying and naming planktonic foraminifers results partly from demonstrable close morphologic intergradation between many species, genera, and even families. Type species of two genera, for example, may be distinct in all major respects (e.g., *Globigerina bulloides, Globorotalia tumida*) but linked by barely perceptible steps to transitional forms between *Globorotalia increbescens* and *Globigerina ampliapertura,* bridging the supposed boundary between the genera. This merging of genera into one another raises obvious difficulties when segregation into families is attempted. As classification at the family level has little biostratigraphic significance (at least within the Tertiary), it is not discussed here; various schemes are set forth in references just cited.

Traditionally, zoological and paleontological species are defined and identified solely on the basis of identical or near-identical morphology, for age factors play no part in naming fossil forms. Planktonic foraminifers provide a special case, however, and some modern authors seek to justify giving separate names to homeomorphs having different life ranges. Their reasoning is that a specialized mode of existence led to a reiterative tendency in diverse stocks to produce forms best adapted to flotation; hence, nonsynchronous homeomorphs must be expected and allowed for in classification of plankton. Examples are found in 1) the genus *Globigerinoides* (a *Globigerina* having apertures restricted to the spiral side) which appeared explosively in the Middle Tertiary where, therefore, it is a potentially valuable time marker, although the species *"Globigerinoides" index* unfortunately is likely to cause confusion by appearing in the Eocene [currently the species *G. index* is placed in *Globigerinatheka (=Globigerapsis),* an Eocene genus which to some extent is homeomorphic with the Miocene *Globigerinoides* but not directly related to it]; 2) the exclusively Eocene *Globorotalia centralis* of authors which is strikingly similar to *Globorotalia inflata* abruptly introduced in the later Neogene of Europe; 3) likewise the Oligocene *Globorotalia opima opima* and the Pliocene-to-Recent *Globorotalia acostaensis pseudopima* which are virtually indistinguishable except on the basis of associated species; 4) the Paleocene *Globorotalia velascoensis* and the Eocene *Globorotalia caucasica* which are a closely comparable pair; 5) the debated case of *Globorotalia siakensis* and *G. mayeri* which may be unrelated closely sequent homeomorphs; and 6) the early Paleogene *Globoquadrina* [or *Globigerina*] *primitiva* which are remarkably similar forms apparently unlinked to the *Globoquadrina dehiscens* group of the Neogene (the older form being referred by some authors to the monotypic genus *Pseudogloboquadrina*).

The foregoing aspects of classification and nomenclature of planktonic foraminifers are mentioned here to explain why their treatment, as encountered in literature, is appreciably less stable than that of some other fossil groups. As compilers, we have endeavored to steer a conservative course, choosing the simplest and most practical versions but drawing attention to alternative proposals.

CHARACTERISTIC FEATURES OF CENOZOIC PLANKTONIC FORAMINIFERAL GENERA AND SUBGENERA

Most generic and subgeneric names applied to Cenozoic planktonic foraminifers are noted in the following list. Names in large type are represented by index species applied in the zonation discussed herein. Broadly they are genera having greatest biostratigraphic importance in the Cenozoic. Names in small type represent forms which, for reasons given, have secondary importance in the present context.

Acarinina SUBBOTINA (1953, p. 219).

Type species: *Acarinina acarinata* SUBBOTINA (1953); by original designation.

Discussion: Originally used in broad sense to include smooth- and spiny-shelled forms. As *Turborotalia* CUSHMAN & BERMÚDEZ (1949) already was available for the smooth forms, *Acarinina* later was redefined to comprise unkeeled spiny-shelled globorotaliids. The name has limited use for a genus or for a subgenus of *Globorotalia* CUSHMAN (1927a).

Applinella THALMANN (1942, p. 812).

Type species: *Hantkenina dumblei* WEINZIERL & APPLIN (1929); by original designation.

Description: Characterized by spines on anterior of chamber but not encroaching on sutural cleft. Proposed as a subgenus of *Hantkenina* CUSHMAN (1925a).

Aragonella THALMANN (1942, p. 811).

Type species: *Hantkenina mexicana aragonensis* NUTTALL (1930); by original designation.

Description: Distinguished by almost symmetrically apiculate chambers prolonged centrally into spines. Proposed as a subgenus of *Hantkenina* CUSHMAN (1925a).

Astrorotalia TURNOVSKY (1958, p. 81).

Type species: *Globorotalia (Astrorotalia) stellaria* TURNOVSKY (1958); by original designation.

Discussion: A little known form introduced as a stellate subgenus of *Globorotalia* CUSHMAN (1927a). Treated by EL-NAGGAR (1971) as a genus including *Clavatorella* BLOW (1965) as a subgenus.

Beella BANNER & BLOW (1960b, p. 26).

Type species: *Globigerina digitata* BRADY (1879); by original designation.

Discussion: Trochospire of initially bulbous but later digitate chambers as in *Hastigerinella* of prior authors. Introduced as subgenus of *Globorotalia* CUSHMAN (1927a) but later interpreted as globigerinid genus by LOEBLICH & TAPPAN (1964) and BLOW (1965), subgenus of *Globigerina* D'ORBIGNY (1826) by BLOW (1969), or subgenus of *Schackoinella* WEINHANDL (1958) by EL-NAGGAR (1971).

Bifarina PARKER & JONES (1872, p. 198).

Type species: *Dimorphina saxipara* EHRENBERG (1854); by original designation.

Discussion: This is one of several cuneate genera in which a biserial early stage is followed by an uniserial part. LOEBLICH & TAPPAN (1964) reviewed the nomenclature of these forms, synonymized *Tubitextularia* SULC (1929) and *Rectoguembelina* CUSHMAN (1932) with *Bifarina*, and treated the latter as planktonic (contrary to prior authors).

Biglobigerinella LALICKER (1948, p. 624).

Type species: *Biglobigerinella multispina* LALICKER (1948); by original designation.

Discussion: Shell planispirally coiled; later chambers expanded bilaterally so as to initiate a double coil of side-by-side chambers. Generally regarded as a Cretaceous genus although its presence in basal Tertiary deposits has been recorded (LOEBLICH & TAPPAN, 1964, p. C656).

Biorbulina BLOW (1956, p. 69).

Type species: *Globigerina bilobata* D'ORBIGNY (1846); by original designation.

Discussion: Intended to accommodate forms similar to *Orbulina universa* D'ORBIGNY (1839) except for being bilobate or rarely trilobate. Not widely accepted as other authors regard such forms as congeneric, if not conspecific, with *O. universa* which is the type species of *Orbulina* D'ORBIGNY (1839). [For synonymy see BANNER & BLOW, 1960a.]

Bolliella BANNER & BLOW (1959, p. 12).

Type species: *Hastigerina (Bolliella) adamsi* BANNER & BLOW (1959); by original designation.

Discussion: Distinguished from *Hastigerina* (s.s.) by digitate adult chambers. Homeomorphic with the mainly Cretaceous *Hastigerinoides* BRÖNNIMANN (1952c) and with *Clavatorella* BLOW (1965) which supposedly have different apertures.

CANDEINA D'ORBIGNY (1839, p. 107).

Type species: *Candeina nitida* D'ORBIGNY (1839); by original indication (monotypy).

Description: Test a rather lofty trochospire of globose chambers with multiple apertural pores evenly spaced along sutures of adult portion, no primary aperture. Evolved from *Globigerinoides* CUSHMAN (1927a) in late Neogene (BLOW, 1969, p. 384).

Candorbulina JEDLITSCHKA (1934, p. 20).

Type species: *Candorbulina universa* JEDLITSCHKA (1934); by original indication (monotypy).

Discussion: The type species was asserted by

BRONNIMANN (1951b) to be congeneric with *Orbulina universa* D'ORBIGNY (1839), the type species of *Orbulina* D'ORBIGNY (1839). Thus, most modern authors reject *Candorbulina* as a junior synonym.

CASSIGERINELLA POKORNÝ (1955, p. 136).

Type species: *Cassigerinella boudecensis* POKORNÝ (1955); by original designation. [=*Cassidulina chipolensis* CUSHMAN & PONTON, 1932a.]

Description: Small involute biserial (cassiduline) coil of inflated chambers; aperture a simple arch directed alternately to right and left on successive chambers.

Discussion: Formerly included in *Cassidulina* D'ORBIGNY (1826) but differs in wall texture and in having planispiral embryont. *Islandiella* NØRVANG (1958) is a junior synonym.

Cassigerinelloita STOLK (1965, p. 264).

Type species: *Cassigerinelloita amekiensis* STOLK (1965); by original designation.

Discussion: Little known genus like *Cassigerinella* POKORNÝ (1955) but having supplemental apertures. Treated as planktonic by EL-NAGGAR (1971), but comparable *Stichocassidulina* STONE (1946) has been regarded as benthonic.

Originally proposed with format of a single description for "*Cassigerinelloita amekiensis*, n. gen., n. sp." which now is a rejected style for proposing new names for taxa (ICZN, Art. 13a,c vi). STOLK, however, seems to have validated the genus name (p. 265) and the species name (as in plate captions) by referring directly to these taxa within the overall framework of his discussion. If this interpretation is deemed incorrect, the names are not available. EL-NAGGAR (1971), for example, did not assign an available species to the genus (ICZN, Art. 13b).

CATAPSYDRAX BOLLI, LOEBLICH, & TAPPAN (1957, p. 36).

Type species: *Globigerina dissimilis* CUSHMAN & BERMÚDEZ (1937); by original designation.

Description: Test trochospiral, commonly with flat rotaliform embryont; later chambers ovate, elongated along trend of coiling, and surrounding pit covered by a bulla on umbilical side. Only visible apertures are one or more openings between bulla and umbilical part of coil; these openings may have arches or tubes aligned with intercameral sutures. Shell rather thick and noticeably cancellate.

Discussion: Classification of bullate planktonic foraminifers remains controversial; our preference is to follow PARKER (1962, 1964, 1967) and LIPPS (1964, 1965, 1966, 1967, 1969) in stressing shell texture. Among other specialists, BERMÚDEZ (1960) and BLOW (1969 and earlier) did not separate *Catapsydrax* from *Globigerinita* BRONNIMANN (1951a), whereas BOLLI, LOEBLICH, & TAPPAN (1957) and POSTUMA (1971) separated these genera on features of the bulla rather than shell texture. Some other authors, seemingly a minority, regard the bulla as a temporary attachment (such as a brood pouch or float chamber) having no genetic significance.

Chiloguembelina LOEBLICH & TAPPAN (1956, p. 340).

Type species: *Guembelina midwayensis* CUSHMAN (1940); by original designation.

Discussion: Although spiral forms are strongly dominant among Tertiary planktonic foraminifers, a small group of cuneate-biserial forms occurs. Commonest is *Chiloguembelina* having a simple, smooth, compact, biserial test in which later chambers are somewhat globose, and the aperture is a simple axially placed arch. It differs from the Cretaceous *Heterohelix (=Guembelina* of authors) in lack of a planispiral nucleus. Evolution from the *Chiloguembelina* stock to *Zeauvigerina* FINLAY (1939b) has been claimed by some authors (e.g., BECKMANN, 1957) but disputed by others (e.g., LOEBLICH, 1951; MONTANARO GALLITELLI, 1957).

Chiloguembelinella EL-NAGGAR (1971, p. 449).

Type species: *Chiloguembelina subtriangularis* BECKMANN (1957); by original designation.

Discussion: Genus distinguished from *Chiloguembelina* LOEBLICH & TAPPAN (1956) in that compression of later chambers forms angular periphery.

Cincoriola HAQUE (1958, p. 103).

Type species: *Punjabia ovoidea* HAQUE (1956); by original designation.

Discussion: Included (SINGH, 1971) in supposedly planktonic Indicolidae but regarded as benthonic by LOEBLICH & TAPPAN (1964, p. C680) and EL-NAGGAR (1971, p. 476).

Clavatorella BLOW (1965, p. 366).

Type species: *Hastigerinella bermudezi* BOLLI (1957b); by original designation.

Description: Very low trochospire, approaching a planispire of initially ovate and later digitate to clavate chambers. Reported to differ from *Bolliella* BANNER & BLOW (1959) and *Clavigerinella* BOLLI, LOEBLICH, & TAPPAN (1957) in the globorotaliid aperture.

CLAVIGERINELLA BOLLI, LOEBLICH, & TAPPAN (1957, p. 30).

Type species: *Clavigerinella akersi* BOLLI, LOEBLICH, & TAPPAN (1957); by original designation.

Description: Planispiral coil of loosely attached chambers, initially bulbous, later clavate; aperture a slit or arch in apertural face, elongated in plane of coiling, and bordered by flanges. Differs in its hantkeninid aperture and planispiral mode from the trochospiral *Hastigerinella* CUSHMAN (1927a) although chambers are similar.

Coscinosphaera STUART (1866, p. 328).

Type species: *Coscinosphaera ciliosa* STUART (1866); by original indication (monotypy).

Discussion: First classed as a radiolarian but subsequently regarded (LOEBLICH & TAPPAN, 1964, p. C675) as junior synonym of *Orbulina* D'ORBIGNY (1839).

Cribrogloborotalia CUSHMAN & BERMÚDEZ (1936, p. 63).

Type species: *Cribrogloborotalia marielina* CUSHMAN & BERMÚDEZ (1936); by original designation.

Discussion: Test as *Globorotalia* (i.e., *G. cerroazulensis* group) but has multiple cribrate apertures instead of usual arch or slit; considered nonplanktonic by BOLLI, LOEBLICH, & TAPPAN (1957, p. 18).

CRIBROHANTKENINA THALMANN (1942, p. 812).

Type species: *Hantkenina (Sporohantkenina) brevispina* BERMÚDEZ (1937) [not *H. brevispina* CUSHMAN (1925a)]; renamed *Hantkenina (Cribrohantkenina) bermudezi* THALMANN (1942) [modern authors regard *Hantkenina inflata* HOWE (1928) as a senior synonym]; by original designation.

Description: Test as in *Hantkenina* with strongly inflated chambers and large apertural face on which arched aperture is supplemented or replaced by one or more rows of large apertural pores.

Discussion: This subgenus of *Hantkenina* CUSHMAN (1925a) was first termed *Sporohantkenina* BERMÚDEZ (1937) but a species of *Hantkenina* (s.s.) was designated as type (for details see BOLLI, LOEBLICH, & TAPPAN, 1957). Although introduced as a subgenus of *Hantkenina*, it is treated generally as a genus. [See also discussion of *Sporohantkenina*.]

Dissimiloglobigerina REISS (1957a, p. 4).

Discussion: Name introduced informally and not validated (nomen nudum, no description and no type species); equivalent to *Catapsydrax* BOLLI, LOEBLICH, & TAPPAN (1957) of later authors. In addition to names for Tertiary forms noted here, REISS gave comparable informal (unavailable) names to several Cretaceous species groups or supraspecific groups of foraminifers.

Eoglobigerina MOROZOVA (1959, p. 1115).

Type species: *Globigerina (Eoglobigerina) eobulloides* MOROZOVA (1959); by original designation.

Discussion: A primitive subgenus of *Globigerina* D'ORBIGNY (1826) based on a diminutive form; name seldom used except by Soviet authors.

Eogloborotalia REISS (1957a, p. 4).

Discussion: Informal and undefined subdivision of *Globorotalia* CUSHMAN (1927a) [see discussion of *Dissimiloglobigerina* REISS (1957a)].

Fohsella BANDY (1972a, p. 297).

Type species: *Globorotalia (Globorotalia) praefohsi* BLOW & BANNER (1966), by original designation.

Discussion: This recently proposed subgenus of *Globorotalia* CUSHMAN (1927a) is not widely recognized at present.

Globalternina IVANOVA (in SUBBOTINA, GLUSHKO, & PISHVANOVA, 1955, p. 606).

Discussion: The species originally indicated as type species (by monotypy) (i.e., *Globalternina globoloculata* IVANOVA) then was an unavailable nomen nudum; thus the genus-group name was not made available in 1955 (ICZN, Art. 13b). Subsequently the species was validated as *Cassigerinella globolocula* in 1958 (IVANOVA, in BYKOVA ET AL., p. 57). REISS (1963, p. 76) and EL-NAGGAR (1971, p. 445) cited *Globalternina* as a synonym of *Cassigerinella* POKORNÝ (1955); the latter designated the type species as *"Cassigerinella globoloculata"* IVANOVA (1958), but this, however, did not make the genus name available (ICZN, Art. 11d).

Globanomalina HAQUE (1956, p. 147).

Type species: *Globanomalina ovalis* HAQUE (1956); by original designation.

Discussion: Low-spired, blunt-margined, smooth-shelled forms belonging to a group of Paleocene species which other authors place in *Globorotalia* CUSHMAN (1927a) (e.g., *G. compressa* and especially *G. chapmani*). LOEBLICH & TAPPAN (1964) proposed to recognize *Globanomalina* as a senior synonym of *Pseudohastigerina* BANNER & BLOW (1959), but this proposal was refuted effectively by BERGGREN, OLSSON, & REYMENT (1967) (also see ANDERSEN, 1971, and EL-NAGGAR & AL MEER, 1973).

Globigerapsis BOLLI, LOEBLICH, & TAPPAN (1957, p. 33).

Type species: *Globigerapsis kugleri* BOLLI, LOEBLICH, & TAPPAN (1957); by original designation.

Discussion: Based on a nonbullate species and originally considered distinct from bullate *Globigerinatheka* BRÖNNIMANN (1952a). Modern authors follow PROTO DECIMA & BOLLI (1970) in considering these genera as synonyms.

GLOBIGERINA D'ORBIGNY (1826, p. 277).

Type species: *Globigerina bulloides* D'ORBIGNY (1826); subsequent designation by PARKER, JONES, & BRADY (1865, p. 36).

Description: Trochospire of globose to ovate chambers, varying greatly in coiling parameters but characterized by its aperture, which is a simple opening into the umbilicus.

Discussion: This name is applied in a restricted sense by modern authors who recognize also many genera based on species formerly assigned to *Globigerina*. Because a few authors recognize subgenera of *Globigerina* [e.g., *Dissimiloglobigerina* REISS (1957a), *Eoglobigerina* MOROZOVA (1959), *Globigerinita* BRÖNNIMANN (1951a), *Subbotina* BROTZEN & POZARYSKA (1961)], the subgenus *Globigerina* (s.s.) has limited recognition (e.g., JENKINS, 1971).

GLOBIGERINATELLA CUSHMAN & STAINFORTH (1945, p. 68).

Type species: *Globigerinatella insueta* CUSHMAN & STAINFORTH (1945); by original designation.

Description: Test subglobular, initial trochospiral portion flush with surface and mostly embraced by final chamber; no primary aperture; characterized by bullas in form of irregular raised patches and sinuous strips, both types bordered by tiny closely spaced arches.

GLOBIGERINATHEKA BRÖNNIMANN (1952a, p. 27) [emended by PROTO DECIMA & BOLLI, 1970].

Type species: *Globigerinatheka barri* BRÖNNIMANN (1952a); by original designation.

Description: Test subglobular to globular, initially trochospiral but large enveloping final chamber covers original umbilicus; multiple apertures on sutures, especially at intersections of spiral and radial sutures; apertures may be covered or linked by bullas.

Discussion: *Globigerapsis* BOLLI, LOEBLICH, & TAPPAN (1957) was introduced specifically to accommodate nonbullate forms but now is regarded as synonymous. Some species now assigned to *Globigerinatheka* were referred to *Globigerinoides* CUSHMAN (1927a) and *Porticulasphaera* BOLLI, LOEBLICH, & TAPPAN (1957) by early workers.

Globigerinella CUSHMAN (1927a, p. 87).

Type species: *Globigerina aequilateralis* BRADY (1879); by original designation.

Discussion: Now generally regarded as a junior synonym of *Hastigerina* THOMSON (1876).

Globigerinita BRÖNNIMANN (1951a, p. 18).

Type species: *Globigerinita naparimaensis* BRÖNNIMANN (1951a); by original designation.

Description: Test a *Globigerina*-like trochospire, but umbilical pit is covered by a bulla; shell delicate, smooth, matte surfaced; few to many infralaminal openings may surround bulla.

Discussion: Note also discussion of *Catapsydrax* BOLLI, LOEBLICH, & TAPPAN (1957). The name *Tinophodella* LOEBLICH & TAPPAN (1957b) was introduced for forms with multiple infralaminal openings but lacks wide acceptance.

GLOBIGERINOIDES CUSHMAN (1927a, p. 87).

Type species: *Globigerina rubra* D'ORBIGNY (1839); by original designation.

Description: An umbilicate trochospire as in *Globigerina* D'ORBIGNY (1826) but at least one (and generally several) supplementary apertures on spiral side; these apertures range from small gaps where sutures intersect to conspicuous lunate openings along spiral suture.

Discussion: Immature and primitive forms of *Globigerinatheka* BRÖNNIMANN (1952a) may match the described features of *Globigerinoides*, but advanced forms differ in their enveloping globular adult chambers that conceal the umbilicus.

Globigerinoidesella EL-NAGGAR (1971, p. 476).

Type species: *Globigerina fistulosa* SCHUBERT (1910); by original designation.

Discussion: Brief original description apparently refers to forms like *Schackoinella* WEINHANDL (1958) but having supplementary apertures.

Globigerinoita BRÖNNIMANN (1952a, p. 26).

Type species: *Globigerinoita morugaensis* BRÖNNIMANN (1952a); by original designation.

Discussion: Similar to *Globigerinoides* CUSHMAN (1927a) except that umbilicus is covered by a bulla as in *Globigerinita* BRÖNNIMANN (1951a). Recorded only in Miocene of Trinidad, Venezuela, and Virginia.

Globigerinopsis BOLLI (1962, p. 281).

Type species: *Globigerinopsis aguasayensis* BOLLI (1962); by original designation.

Description: Initial spiral and entire umbilical portion as in *Globigerina* D'ORBIGNY (1826), but later chambers in adults detach along spiral suture which then merges into a wide spiral slit. Large evolute adult chambers tend toward planispiral or streptospiral mode.

Discussion: A distinctive genus but very restricted in distribution (HOOYBERGHS & MEUTER, 1972).

Globigerinopsoides CITA & MAZZOLA (1970, p. 470).

Type species: *Globigerinopsoides algeriana* CITA & MAZZOLA (1970); by original designation.

Discussion: Morphology similar to that of *Globigerinopsis* BOLLI (1962) but also supplementary apertures on spiral side as in *Globigerinoides* CUSHMAN (1927a).

Globoconusa KHALILOV (1956, p. 249).

Type species: *Globoconusa conusa* KHALIKOV (1956); by original designation.

Description: The type species comprises small forms not sharply distinct from *Globigerina* D'ORBIGNY (1826) having spinose shell surface, initial spire tending toward strongly convex; large pores may be discernible along spiral suture.

Discussion: Modern authors tend to regard the type species as synonymous with *Globigerina daubjergensis* BRÖNNIMANN (1953).

GLOBOQUADRINA FINLAY (1947, p. 290).

Type species: *Globorotalia dehiscens* CHAPMAN, PARR, & COLLINS (1934); by original designation.

Description: Test as in *Globigerina* D'ORBIGNY (1826) except that each aperture carries a flap which ranges from a narrow flange to an elaborate triangular tooth.

Discussion: Not clearly differentiated from *Globigerina* D'ORBIGNY (1826) and *Globorotalia* CUSHMAN (1927a) (e.g., BLOW, 1969, p. 338-339).

GLOBOROTALIA CUSHMAN (1927a, p. 91).

Type species: *Pulvinulina menardii* (D'ORBIGNY) *tumida* BRADY (1877); by original designation.

Description: Test very variable but basically a regular trochospire of closely packed, gradually enlarging chambers; aperture a slit or arch between umbilicus and periphery, directed forward rather than inward, commonly with some form of rim, lip, or flange.

Discussion: Position of aperture is regarded as major basis for differentiation from *Globigerina*

D'ORBIGNY (1826), but transitional forms are difficult to assign consistently. *Globorotalia* may be subdivided into morphologic groups that are sufficiently distinct to be named and to be used mainly as subgenera by some authors (e.g., *Acarinina* SUBBOTINA, 1953; *Astrorotalia* TURNOVSKY, 1958; *Eogloborotalia* REISS, 1957a; *Globanomalina* HAQUE, 1956; *Morozovella* MCGOWRAN, 1968; *Neotruncorotalia* REISS, 1957a; *Planorotalia* MOROZOVA, 1957; *Planorotalites* MOROZOVA, 1957; *Pseudogloborotalia* HAQUE, 1956; *Pseudotruncorotalia* REISS, 1957a; *Testacarinata* JENKINS, 1971; *Truncorotalia* CUSHMAN & BERMÚDEZ, 1949; *Turborotalia* CUSHMAN & BERMÚDEZ, 1949). These subgenera are not used here, however, because of complete gradation between extremes and because their recognition has limited biostratigraphic significance. The name *Globorotalia* (s.s.) applies to smooth, lenticular, and carinate species when it is applied in a subgeneric sense.

Globorotalites BROTZEN (1942, p. 31).

Type species: *Globorotalia multisepta* BROTZEN (1936); by original designation.

Discussion: An umbilicate, planoconical, trochospiral form; name applied polyphyletically (e.g., TEN DAM & MAGNÉ, 1948); excluded from plankton by modern authors.

GLOBOROTALOIDES BOLLI (1957b, p. 117).

Type species: *Globorotaloides variabilis* BOLLI (1957b); by original designation.

Discussion: Originally defined as a genus including forms that pass successively and irregularly through phases identifiable with *Globorotalia* CUSHMAN (1927a), *Globigerina* D'ORBIGNY (1826), and *Catapsydrax* BOLLI, LOEBLICH, & TAPPAN (1957). The original description and illustration of the type species of *Globorotaloides* are close to those of *Catapsydrax unicavus* in the same publication; this has not been clarified subsequently. Other authors differ in acceptance and systematic treatment of *Globorotaloides* (e.g., BLOW, 1969, p. 373-374; EL-NAGGAR, 1971, p. 447).

Guembelina EGGER (1899, p. 31) [as *Gümbelina*].

Type species: *Textularia globosa* EHRENBERG (1854); by subsequent designation (CUSHMAN, 1927c).

Discussion: Name formerly had wide use for biserial-cuneate forms, mainly Cretaceous but partly Tertiary. Found subsequently to be both a junior synonym of the Cretaceous *Heterohelix* EHRENBERG (1843) and a junior homonym of *Guembelina* KUNTZ (1895), which is a nonforaminiferal Paleozoic micro-organism (MONTANARO GALLITELLI, 1957; LOEBLICH & TAPPAN, 1961).

Guembelitria CUSHMAN (1933, p. 37) [as *Gümbelitria*].

Type species: *Guembelitria cretacea* CUSHMAN (1933); by original designation.

Discussion: A triserial member of cuneiform planktonic types. Mainly Mesozoic but recorded through the Eocene by LOEBLICH & TAPPAN (1964, p. C652) or Neogene (EL-NAGGAR 1971, p. 431).

Guembelitriella TAPPAN (1940, p. 115).

Type species: *Guembelitriella graysonensis* TAPPAN (1940); by original designation.

Discussion: A lofty-subcuneate spire of globular chambers; initially triserial, later multiserial. Related to *Guembelitria* CUSHMAN (1933) and likewise mainly a Cretaceous genus; recorded from the Eocene by SULEIMANOV (1971).

Guembelitrioides EL-NAGGAR (1971, p. 431).

Type species: *Globigerinoides higginsi* BOLLI (1957c); by original designation.

Discussion: Proposed for forms like *Guembelitria* CUSHMAN (1933) but distinguished by having supplemental apertures.

HANTKENINA CUSHMAN (1925a, p. 1).

Type species: *Hantkenina alabamensis* CUSHMAN (1925a); by original designation.

Description: Regular planispiral coil, commonly involute; sutures straight, radial, and deeply incised; chambers apiculate to triangular and bearing distinctive spines at tips; aperture a highly arched slit that may be bordered by lips or flanges.

Discussion: Evolutionary stages have been recognized and formerly were given subgeneric names (e.g., *Applinella* THALMANN, 1942; *Aragonella* THALMANN, 1942; *Cribrohantkenina* THALMANN, 1942; *Hantkeninella* BRÖNNIMANN, 1950b;

Sporohantkenina BERMÚDEZ, 1937) as, for example, by THALMANN (1942) and by BRÖNNIMANN (1950b). *Hantkenina* (s.s.) was applied to forms in which the base of each spine is enveloped by part of the following chamber. Most modern authors do not use these subgeneric names, but *Cribrohantkenina* is retained as a distinct genus. Additional information on evolution of *Hantkenina* is given by ZANEWA (1971) and others.

Hantkeninella BRÖNNIMANN (1950b, p. 399) [ex THALMANN, 1942, nomen nudum].

Type species: *Hantkenina alabamensis primitiva* CUSHMAN & JARVIS (1929); by original designation.

Discussion: Introduced as a subgenus of *Hantkenina* CUSHMAN (1925a); characterized mainly by lacking spines on initial chambers. See discussion of *Hantkenina.*

HASTIGERINA THOMSON (1876, p. 534) [emended by BANNER & BLOW, 1959].

Type species: *Hastigerina murrayi* THOMSON (1876) [=*Nonionina pelagica* D'ORBIGNY (1839)]; by original designation.

Description: Planispiral coil of bulbous to elongate chambers, aperture an arch or slit embracing inner coil. Immature and primitive individuals may have trochospiral tendency.

Discussion: *Globigerinella* CUSHMAN (1927a) is a subjective junior synonym. BANNER & BLOW (1959) divided *Hastigerina* into the subgenera *Hastigerina* (s.s.) and *Bolliella,* the latter distinguished by digitate adult chambers.

Hastigerinella CUSHMAN (1927a, p. 87).

Type species: *Hastigerina digitata* RHUMBLER (1911) [non *Globigerina digitata* BRADY, 1879] [=*Hastigerinella rhumbleri* GALLOWAY, 1933]; by original designation.

Description: Trochospire of initially bulbous but later digitate to clavate chambers; aperture a gaping arch at base of final chamber.

Discussion: Differs in trochospiral mode from planispiral *Hastigerina (Bolliella)* BANNER & BLOW (1959) although chambers may be similar. BANNER & BLOW (1960b) and BLOW (1965, 1969) asserted that the type species of *Hastigerinella* actually is streptospiral and applied the name *Beella* BANNER & BLOW (1960b) to the trochospiral form.

Hastigerinoides BRÖNNIMANN (1952c, p. 52).

Type species: *Hastigerinella alexanderi* CUSHMAN (1931b); by original designation.

Discussion: Introduced as a subgenus of *Hastigerinella,* homeomorphic with Holocene *Bolliella* BANNER & BLOW (1959) but generally regarded as restricted to the Cretaceous. BERMÚDEZ (1960) differed in applying name to Cenozoic species and, in synonymy of *Hastigerinoides digitatus* (BRADY), included figures that had been cited by BANNER & BLOW (1959) in synonymy of their *Hastigerina (Bolliella) adamsi.*

Hirsutella BANDY (1972a, p. 298).

Type species: *Rotalina hirsuta* D'ORBIGNY (in BARKER-WEBB & BERTHELOT, 1839); by original designation.

Discussion: This recently proposed subgenus of *Globorotalia* CUSHMAN (1927a) is not widely recognized at present.

Indicola SINGH & KALIA (1970a, p. 77).

Type species: *Indicola rajasthanensis* SINGH & KALIA (1970a); by original designation.

Discussion: Test as in *Globorotalia* CUSHMAN (1927a) but with multiple primary aperture and cellular infilling of deep umbilicus. Regarded as probably not a planktonic form by EL-NAGGAR (1971, p. 476).

Inordinatosphaera MOHAN & SOODAN (1967, p. 24).

Type species: *Inordinatosphaera indica* MOHAN & SOODAN (1967); by original designation.

Discussion: Test spherical with similarities to both *Globigerinatheka* BRÖNNIMANN (1952a) (as emended by PROTO DECIMA & BOLLI, 1970) and *Globigerinatella* CUSHMAN & STAINFORTH (1945). Not a planktonic form according to JAN HARDENBOL (personal communication, 1973). See MOHAN & SOODAN (1970) and EL-NAGGAR (1971).

Islandiella NØRVANG (1958 [1959], p. 26).

Type species: *Cassidulina islandica* NØRVANG (1945); by original designation.

Discussion: A junior synonym of *Cassigerinella* POKORNÝ (1955) according to HOFKER (1968) but unrelated according to ANDERSEN (1971).

Micraglobigerinella REISS (1957a, p. 4).

Discussion: Informal term (nomen nudum) equivalent to *Pseudohastigerina* BANNER & BLOW (1959) as used by later authors. See discussion of *Dissimiloglobigerina* REISS (1957a).

Morozovella MCGOWRAN (1968, p. 190).

Type species: *Pulvinulina velascoensis* CUSHMAN (1925c); by original designation.

Discussion: A name proposed as subgenus of *Truncorotaloides* BRÖNNIMANN & BERMÚDEZ (1953) for spiny-keeled, angular-conical globorotaliids of the Paleogene.

LUTERBACHER (1964, p. 641) first published the name and a description, and designated a type species using as a basis MCGOWRAN'S manuscript copy of a report then in press. LUTERBACHER assumed prior publication by MCGOWRAN and gave credit to him as author of *Morozovella;* other authors have credited the name as "*Morozovella* MCGOWRAN, in LUTERBACHER, 1964." Under regulations of the International Code of Zoological Nomenclature (Arts. 10, 50), however, the author of a name is the person who first publishes it in accordance with all requirements of the Code. Thus, LUTERBACHER (1964) would receive authorship except that he treated the name as a junior synonym (i.e., assigned the type species to *Globorotalia*). The code (Art. 11d) stipulates that "a name first published as a synonym is not thereby made available . . .". LIPPS (1966, p. 1266) also referred to the description of *Morozovella* (LUTERBACHER, 1964) and listed the type species, but he too regarded *Morozovella* as a junior synonym. Authorship is credited here to MCGOWRAN (1968) but all papers published after LUTERBACHER (1964) and before MCGOWRAN (1968) have not been checked to determine if another author has validated *Morozovella* inadvertently (e.g., used the name and referred to description of LUTERBACHER and fixed a type species).

Neoacarinina THOMPSON (1973, p. 470).

Type species: *Neoacarinina blowi* THOMPSON (1973); by original designation.

Description: Planoconvex globigeriniform trochospire distinguished from associated Late Pleistocene forms by its densely spinose wall.

Neogloboquadrina BANDY, FRERICHS, & VINCENT (1967, p. 152).

Type species: *Globigerina dutertrei* D'ORBIGNY (1839); by original designation.

Discussion: This genus was described as being distinguished from *Globigerina* D'ORBIGNY (1826) by the pitted and mostly nonspinose walls and, by evolutionary convergence, being like *Globoquadrina* FINLAY (1947) in having toothlike umbilical flaps.

Neotruncorotalia REISS (1957a, p. 4).

Discussion: Informal term (nomen nudum) introduced as undefined subdivision of *Truncorotalia* CUSHMAN & BERMÚDEZ (1949). See discussion of *Dissimiloglobigerina* REISS (1957a).

ORBULINA D'ORBIGNY (1839, p. 2).

Type species: *Orbulina universa* D'ORBIGNY (1839); by original indication (monotypy).

Description: Test spherical with only final chamber or final chamber plus small part of initial spire (flush with or protruding slightly through spherical surface) visible.

Discussion: Differs from *Praeorbulina* OLSSON (1964) in greater degree of envelopment and in large apertural pores scattered over test.

This genus has been treated differently by authors because the closely knit evolutionary succession is subject to different interpretations. Forms with projecting nucleus generally have been differentiated at species level *(Orbulina suturalis)* but were assigned to a different genus (*Candorbulina* JEDLITSCHKA, 1934) by some. Forms having two or even three loosely attached, spherical, adult chambers have been considered by different authors as a genus (*Biorbulina* BLOW, 1956), species *(Orbulina bilobata)*, or teratoid variants of *Orbulina universa* and *O. suturalis*.

ORBULINOIDES CORDEY (1968b, p. 373) [ex BLOW & SAITO] [emended by PROTO DECIMA & BOLLI, 1970].

Type species: *Porticulasphaera beckmanni* SAITO (1962); by original indication (monotypy).

Description: Globular to subglobular; initially simple trochospire but later chambers increase in size rapidly, assume hemispherical shape, and envelop whole umbilical region. Initial thin-walled test covered by thick wall which adheres closely except for spaces (vestibules) above incised sutures. Outer wall with numerous openings, mostly along contact with inner test but to lesser extent also along underlying spiral or other sutures; some individuals have randomly distributed openings. These openings may be grouped around or aligned along raised bullalike features.

Discussion: Forms having the characteristics of *Orbulinoides* were differentiated earlier as *Porticulasphaera* by BOLLI, LOEBLICH, & TAPPAN (1957). BLOW & SAITO (1968) later noted that *Porticulasphaera* actually is a junior synonym of *Globigerapsis* BOLLI, LOEBLICH, & TAPPAN (1957) because of inappropriate selection of type species and proposed the name *Orbulinoides* for the forms originally included in the concept of *Porticulasphaera.* CORDEY (1968b), however, used the manuscript name of BLOW & SAITO in a paper that inadvertently appeared slightly earlier than that of BLOW & SAITO (1968). Inasmuch as requirements for making a generic name available were met by CORDEY (and even though his paper assumed prior validation by BLOW & SAITO), CORDEY is the author of *Orbulinoides* (ICZN Arts. 10, 50).

PROTO DECIMA & BOLLI (1970) demonstrated direct evolution of *Orbulinoides* from *Globigerinatheka* BRÖNNIMANN (1952a) [including *Globigerapsis* of authors] but considered the more numerous, irregular apertures and double wall as diagnostic features of *Orbulinoides.* [Not *Orbulinoides* SAIDOVA (1970, p. 164), an agglutinate foraminifer.]

Planorotalia MOROZOVA (1957, p. 1110) [emended MCGOWRAN, *in* LUTERBACHER, 1964; 1968].

Type species: *Planulina membranacea* EHRENBERG (1854); by original designation.

Discussion: The type species was interpreted by MOROZOVA (as by most authors of about that time) to include smooth-shelled, lenticular globorotaliids occurring in Paleocene deposits. Subsequently (LOEBLICH & TAPPAN, 1964, p. C668; MCGOWRAN, 1968), *P. membranacea* was determined to be a Pliocene species (lectotype = EHRENBERG, 1854, pl. 26, fig. 43), the Paleocene forms were interpreted as representing *Globorotalia pseudomenardii* BOLLI, and the name *Planorotalia* could not include the Paleocene forms (MCGOWRAN, 1968).

Planorotalites MOROZOVA (1957, p. 1112).

Type species: *Globorotalia pseudoscitula* GLAESSNER (1937a); by original designation.

Discussion: Introduced to designate a group of small biconvex to planoconvex globorotaliids of the Paleogene.

Porticulasphaera BOLLI, LOEBLICH, & TAPPAN (1957, p. 34).

Type species: *Globigerina mexicana* CUSHMAN (1925b); by original designation.

Discussion: Intended for the forms now classed in *Orbulinoides* CORDEY (1968b), but a junior synonym of *Globigerapsis* BOLLI, LOEBLICH, & TAPPAN (1957) because of inappropriate selection of type species. Name also had short-lived application to partly homeomorphic Miocene genus now known as *Praeorbulina* OLSSON (1964).

Praeindicola SINGH (1971, p. 1177).

Type species: *Praeindicola bikanerensis* SINGH (1971); by original designation.

Discussion: Reported as form ancestral to *Indicola* SINGH & KALIA (1970a) with spongy instead of cellular infilling of umbilicus. EL-NAGGAR (1971, p. 476) regarded *Praeindicola* as probably synonymous with *Cincoriola* HAQUE (1958) which is not considered as a planktonic form (LOEBLICH & TAPPAN, 1964, p. C679).

Although the name *Praeindicola* was proposed and the taxon was described and illustrated by SINGH & KALIA (1970b), no species was mentioned. SINGH & KALIA (1970b), therefore, did not make the name available (ICZN, Art. 13b). The genus-group name *Praeindicola* then became available and has priority in the publication by SINGH in 1971 (ICZN, Art. 50).

PRAEORBULINA OLSSON (1964, p. 770).

Type species: *Globigerinoides glomerosa glomerosa* BLOW (1956); by original designation.

Description: Initially low trochospire but becomes globular to spherical because of rapidly increasing size and enveloping nature of adult chambers; final chamber covers 40 to 75% of earlier test. No primary aperture in adult stage, but numerous short slits or large pores occur along suture of last chamber.

Discussion: BLOW (1956) recognized species now assigned to *Praeorbulina* as transitional between *Globigerinoides* (i.e., *G. sicanus*) and *Orbulina* and assigned them to *Globigerinoides* CUSHMAN (1927a). BOLLI (1957c), however, transferred them to *Porticulasphaera* BOLLI, LOEBLICH, & TAPPAN (1957) because the primary umbilical apertures characteristic of *Globigerinoides* are lacking. Later OLSSON (1964) asserted that the Eocene and Miocene species are generically distinguishable and introduced the name *Praeorbulina* for the latter group of species. OLSSON'S concept is accepted generally although a few authors maintain that *Candorbulina* JEDLITSCHKA (1934) is a senior synonym of *Praeorbulina*.

Protentella LIPPS (1964, p. 122).

Type species: *Protentella prolixa* LIPPS (1964); by original designation.

Discussion: Introduced as a planispiral genus with radially prolonged chambers; asserted by BLOW (1965) to be a junior synonym of *Bolliella* BANNER & BLOW (1959).

Pseudogloboquadrina JENKINS (1965b, p. 1122).

Type species: *Globoquadrina primitiva* FINLAY (1947); by original designation.

Discussion: Virtually homeomorphic with *Globoquadrina dehiscens* group but separated by JENKINS because *G. primitiva* from the Paleogene apparently has no direct relationship with that Neogene lineage.

Pseudogloborotalia HAQUE (1956, p. 184).

Type species: *Pseudogloborotalia ranikotensis* HAQUE (1956); by original designation.

Discussion: This Paleocene supposedly globorotaliid genus was accepted as such by BERMÚDEZ (1960); other authors (particularly LUTERBACHER, 1964) assert that it is based on a benthonic foraminifer.

PSEUDOHASTIGERINA BANNER & BLOW (1959, p. 19).

Type species: *Nonion micrus* COLE (1927); by original designation.

Description: Small, regular, planispiral coil, almost involute, and somewhat appressed; sutures incised and recurved; aperture a low symmetrical arch at base of last chamber and extending to umbilicus on both sides.

Discussion: Early authors assigned the type species to several planispiral genera (e.g., *Hastigerina* THOMSON, 1876; *Globigerinella* CUSHMAN, 1927a), but the revision by BANNER & BLOW quickly gained acceptance. More recently LOEBLICH & TAPPAN (1964) classed *Pseudohastigerina* as a junior synonym of *Globanomalina* HAQUE (1956); this was refuted by BERGGREN, OLSSON, & REYMENT (1967).

Pseudotruncorotalia REISS (1957a, p. 4).

Discussion: Informal term (nomen nudum) for an undefined subdivision or homeomorph of *Truncorotalia* CUSHMAN & BERMÚDEZ (1949). See discussion of *Dissimiloglobigerina* REISS (1957a).

PULLENIATINA CUSHMAN (1927a, p. 90).

Type species: *Pullenia obliqueloculata* PARKER & JONES (1865); by original designation.

Discussion: Initially like *Globigerina* D'ORBIGNY (1826) but coiling later becomes streptospiral and chambers envelop original umbilicus; concurrently shell changes from thin and hispid to thick, smooth, and opaque. Evolution in *Pulleniatina* is reviewed by BANNER & BLOW (1967).

Punjabia HAQUE (1956, p. 152).

Type species: *Punjabia ovoidea* HAQUE (1956); by original designation.

Discussion: A junior homonym renamed *Cincoriola* HAQUE (1958).

Pylodexia EHRENBERG (1858, p. 27-28).

Type species: *Globigerina pusilla* EHRENBERG (1858); by original indication (monotypy).

Discussion: *Pylodexia tetratrias* EHRENBERG (1858) has been regarded as the type species (e.g., LOEBLICH & TAPPAN, 1964, p. C669) because that species was subsequently designated by CUSHMAN (1927b). The species was cited by EHRENBERG (1858, p. 27), however, as "——— ? *Tetratrias*" (where the dash represents the name *"Pylodexia"*). As a species questionably assigned to a new genus by the original author cannot be designated as the type species (ICZN, Art. 67h), the single other species *(P. pusilla)* must be accepted as the type species.

Pylodexia was regarded as a junior synonym of *Globigerina* D'ORBIGNY (1826) when interpreted on *P. tetratrias* and presumably will be treated similarly now.

Rectoguembelina CUSHMAN (1932, p. 6) [as *Rectogümbelina*].

Type species: *Rectoguembelina cretacea* CUSHMAN (1932); by original designation.

Discussion: A biserial-to-uniserial form regarded as synonymous with *Bifarina* PARKER & JONES (1872). See MONTANARO GALLITELLI (1957) and LOEBLICH & TAPPAN (1964).

Rhynchospira EHRENBERG (1845, p. 358).

Type species: *Rhynchospira indica* EHRENBERG (1845); by original indication (monotypy).

Discussion: Regarded as a junior synonym of *Globigerina* D'ORBIGNY (1826).

Rotaliatinopsis BANNER & BLOW (1967, p. 146).

Type species: *Pulleniatina? semiinvoluta* GERMERAAD (1946); by original designation.

Discussion: Separated from *Pulleniatina* CUSHMAN (1927a) on basis of microgranular shell texture and nature of aperture; inclusion among planktonic foraminifers is questionable.

Schackoinella WEINHANDL (1958, p. 141).

Type species: *Schackoinella sarmatica* WEINHANDL (1958); by original designation.

Discussion: Little known trochospiral form considered as planktonic by WEINHANDL (1958) and EL-NAGGAR (1971) but not by LOEBLICH & TAPPAN (1964). EL-NAGGAR interpreted *Beella* BANNER & BLOW (1960b) as a subgenus of *Schackoinella*.

Shastrina SINGH & KALIA (1970c, p. 167).

Type species: *Shastrina udbodhaka* SINGH & KALIA (1970c), by original designation.

Discussion: A form from the Eocene of India that was assigned to the Heterohelicidae.

Siphotextularia FINLAY (1939a, p. 510).

Type species: *Siphotextularia wairoana* FINLAY (1939a); by original designation.

Discussion: Generally accepted as name for arenaceous biserial foraminifers (LOEBLICH & TAPPAN, 1964), but name applied recently to calcareous forms in Late Eocene planktonic assemblages (JENKINS & ORR, 1972).

SPHAEROIDINELLA CUSHMAN (1927a, p. 90) [emended by BANNER & BLOW, 1959].

Type species: *Sphaeroidina bulloides dehiscens* PARKER & JONES (1865); by original designation.

Description: Like *Sphaeroidinellopsis* BANNER & BLOW (1959) but (analogously to evolution of *Globigerinoides* CUSHMAN, 1927a, from *Globigerina* D'ORBIGNY, 1826) develops supplementary apertures on spiral side. These apertures penetrate cortex as openings or slits with smooth, crenulate, or projecting lips.

Discussion: Pre-1959 usage of the term *Sphaeroidinella* includes *Sphaeroidinellopsis*. Some authors maintain that these corticate forms do not represent genera but instead belong to species (e.g., *Globigerinoides sacculifer*) which develop pronounced secondary thickening of their tests when they are affected by particular ecologic conditions. BLOW (1969, p. 415-418) offered a detail objection to such a concept, and his view was endorsed later by HOFKER (1972).

SPHAEROIDINELLOPSIS BANNER & BLOW (1959, p. 15).

Type species: *Sphaeroidinella dehiscens subdehiscens* BLOW (1959); by original designation.

Description: Trochospire, ranging from loose and umbilicate to appressed, ovoid, with umbilical slit; characterized by thick, imperforate to vitreous cortex that overlies primary perforate wall of test. This secondary layer, however, may be affected by solution or other alteration during fossilization.

Discussion: Evolution of *Sphaeroidinellopsis* into *Sphaeroidinella* is illustrated by LAMB & BEARD (1972).

Sporohantkenina BERMÚDEZ (1937, p. 151).

Type species: *Hantkenina brevispina* CUSHMAN (1925a); by original designation.

Discussion: Introduced as a subgenus of *Hantkenina* CUSHMAN (1925a) to include forms later included in *Cribrohantkenina* THALMANN (1942). The type species (but not specimens misidentified as belonging to it), however, belongs to *Hantkenina* (s.s.). [Cf. ICZN, Arts. 67j and 70 for unresolved possible reestablishment as senior synonym of *Cribrohantkenina*.]

Streptochilus BRÖNNIMANN & RESIG (1971, p. 1288).

Type species: *Bolivina tokelauae* BOERSMA (*in* KIERSTEAD ET AL., 1969); by original designation.

Discussion: Originally suggested as probably evolved from *Chiloguembelina* LOEBLICH & TAPPAN (1956).

Subbotina BROTZEN & POZARYSKA (1961, p. 160).

Type species: *Globigerina triloculinoides* PLUMMER (1926); by original designation.

Discussion: The single distinctive feature claimed for this subgenus of *Globigerina* D'ORBIGNY (1826) is a reticulate surface. The original diagnosis was sufficient to validate the name but is notably inadequate. A few authors (e.g., LOEBLICH & TAPPAN, 1964; HOFKER, 1968; JENKINS, 1971) have accepted *Subbotina.*

Tenuitella FLEISHER (1974, p. 1033).

Type species: *Globorotalia gemma* JENKINS (1966b), by original designation.

Discussion: Proposed for a closely related group of small Cenozoic forms (commonly referred to *Globorotalia* or *Turborotalia*) distinguished by wall having microperforate surface texture.

Testacarinata JENKINS (1971, p. 110).

Type species: *Globorotalia inconspicua* HOWE (1939); by original designation.

Discussion: Proposed as a monotypic subgenus of *Globorotalia* CUSHMAN (1927a). The type species is a very small planoconical form in which the carinate periphery tends to develop short spines.

Tinophodella LOEBLICH & TAPPAN (1957b, p. 113).

Type species: *Tinophodella ambitacrena* LOEBLICH & TAPPAN (1957b) [=paratypes but not holotype of *Globigerinita naparimaensis* BRÖNNIMANN, 1951a]; by original designation.

Discussion: Originally distinguished by numerous openings along edge of bulla. Most current authors treat this feature as having intraspecific significance and, therefore, regard *Tinophodella* as a junior synonym of *Globigerinita* BRÖNNIMANN (1951a).

Tosaia TAKAYANAGI (1953, p. 30).

Type species: *Tosaia hanzawai* TAKAYANAGI (1953); by original designation.

Discussion: Initially pointed coil of inflated chambers, mostly triserial but late chambers biserial. Morphology suggests relationship (TAKAYANAGI, 1953; LOEBLICH & TAPPAN, 1957c) to Paleocene planktonic genera *Guembelitria* CUSHMAN (1933) and *Woodringina* LOEBLICH & TAPPAN (1957c), but doubt is cast by Pliocene age of *Tosaia.* MONTANARO GALLITELLI (1957) regarded *Tosaia* as most likely buliminid rather than heterohelicid, and this genus was not mentioned in a later study of planktonic foraminifers from beds including those at the type locality (TAKAYANAGI & SAITO, 1962).

Truncorotalia CUSHMAN & BERMÚDEZ (1949, p. 35).

Type species: *Rotalina truncatulinoides* D'ORBIGNY (1839); by original designation.

Discussion: Intended to include umbilicoconvex globorotaliids with angular-rhomboid chambers. Not in general use now although some authors retain it as a subgenus.

TRUNCOROTALOIDES BRÖNNIMANN & BERMÚDEZ (1953, p. 817).

Type species: *Truncorotaloides rohri* BRÖNNIMANN & BERMÚDEZ (1953); by original designation.

Description: Test as in *Globorotalia* CUSHMAN (1927a), commonly with hispid surface; characterized by one or more small openings on spiral side at junction of intercameral and spiral sutures.

Discussion: Although the indefinite openings currently are considered to have taxonomic significance like functional secondary apertures in *Globigerinoides* CUSHMAN (1927a), they may merely result from a loose mode of coiling. Studies of unusually well preserved material demonstrate the occurrence of openings like those of *Truncorotaloides* in several species that traditionally have been assigned to *Globorotalia* and *Globigerina* D'ORBIGNY (1826) (e.g., *Globigerina topilensis* CUSHMAN, 1925b, as described by BOLLI, 1957c, p. 169-170). MCGOWRAN (1968) used a broader treatment of *Truncorotaloides* with *Acarinina* SUBBOTINA (1953), *Morozovella* MCGOWRAN (1968), and *Truncorotaloides* (s.s.) as subgenera.

Tubitextularia SULC (1929, p. 148).

Type species: *Pseudotextularia bohemica* SULC

(1929) [fide LOEBLICH & TAPPAN, 1964].

Discussion: Biserial-to-uniserial form accepted as planktonic (e.g., REISS, 1963) but synonymized with *Bifarina* PARKER & JONES (1872) by LOEBLICH & TAPPAN (1964).

Turborotalia CUSHMAN & BERMÚDEZ (1949, p. 42).

Type species: *Globorotalia centralis* CUSHMAN & BERMÚDEZ (1937); by original designation.

Discussion: Intended to include globose-to-inflated, almost nonumbilicate globorotaliids. Retained as a subgenus by some modern authors.

Turborotalita BLOW & BANNER (1962, p. 122).

Type species: *Truncatulina humilis* BRADY (1884); by original designation.

Description: Test as in *Globorotalia* CUSHMAN (1927a) (=*Turborotalia* of authors), but umbilicus and apertural face enveloped by bulla which has tubulose openings aligned with ventral sutures.

Velapertina POPESCU (1969, p. 105).

Type species. *Velapertina iorgulescui* POPESCU (1969); by original designation.

General appearance seems to be close to that of *Globigerinita* BRÖNNIMANN (1951). The original characterization, however, does not indicate features differentiating *Velapertina* from *Catapsydrax* BOLLI, LOEBLICH, & TAPPAN (1957) and *Globigerinita*. *Velapertina* was reported from the upper Tortonian of the Subcarpathians and Transylvania in Roumania.

Woodringina LOEBLICH & TAPPAN (1957c, p. 39).

Type species: *Woodringina claytonensis* LOEBLICH & TAPPAN (1957c); by original designation.

Discussion: Test tiny, cuneate, inflated; nucleus triserial, adult portion biserial.

Zeauvigerina FINLAY (1939b, p. 541).

Type species: *Zeauvigerina zelandica* FINLAY (1939b); by original designation.

Discussion: As *Chiloguembelina* LOEBLICH & TAPPAN (1956) but final chamber is subaxial and flask-shaped and bears an apertural neck. By some (e.g., BECKMANN, 1957) regarded as planktonic offshoot of *Chiloguembelina* but by others (e.g., LOEBLICH, 1951; MONTANARO GALLITELLI, 1957) as a buliminid genus and possibly a junior synonym of *Eouvigerina* CUSHMAN (1926).

EVOLUTIONARY LINEAGES

In early applications of planktonic foraminifers to stratigraphic zonation, the standard technique was to use distinctive marker species of limited range. These were chosen empirically with the aim of seeing that a new one appeared as closely as possible to where an older one died out. Representative examples are the selection of *Globigerina ciperoensis* (=*G.* sp. cf. *G. concinna*), *Catapsydrax* ["*Globigerina*"] *dissimilis*, *Globigerinatella insueta*, and *Globorotalia fohsi* (sensu lato) as indices of successive zones (CUSHMAN & STAINFORTH, 1945; CUSHMAN & RENZ, 1947). Possible evolutionary linkages of these were suggested only rarely and not examined in detail. Examples are found in discussions of what then were called *Globigerinoides conglobata*, *Candorbulina universa*, and *Globorotalia praemenardii* in CUSHMAN & STAINFORTH (1945) who also referred to *G. fohsi* and *Globorotalia barissanensis* [sic] without suggesting relationship.

BOLLI (1950, 1951), SUBBOTINA (1953), and BLOW (1956) are early authors who emphasized reconstruction of phylogenetic lineages, which by now have become part and parcel of planktonic zonation. More formal and comprehensive evolutionary schemes were proposed by BOLLI (1957a, p. 66) and by BLOW & BANNER (1962, p. 130-146) as part of a considerable body of literature on this theme which accumulated in subsequent years (Fig. 5, 6). Particularly valuable for their discussion of underlying principles, as well as for specific proposals on lineages, are BERGGREN'S papers (1968, 1971a).

The concept of evolutionary lineages is easy to comprehend, for it simply postulates an ancestral form succeeded by divergent progeny which changed gradually in one or more of their physical attributes. Representative trends might be change in average size, alteration of the periphery toward angulate and eventually keeled shapes, modification of the test in acquiring a more compact and finally globular form, derivation from a trochospiral coil of planispiral or streptospiral tests, and so forth. The stages of development of a given lineage from primitive to advanced provide clues to their stratigraphic levels (Fig. 7). By efficient codification and nomenclature of successive development phases of a lineage, its

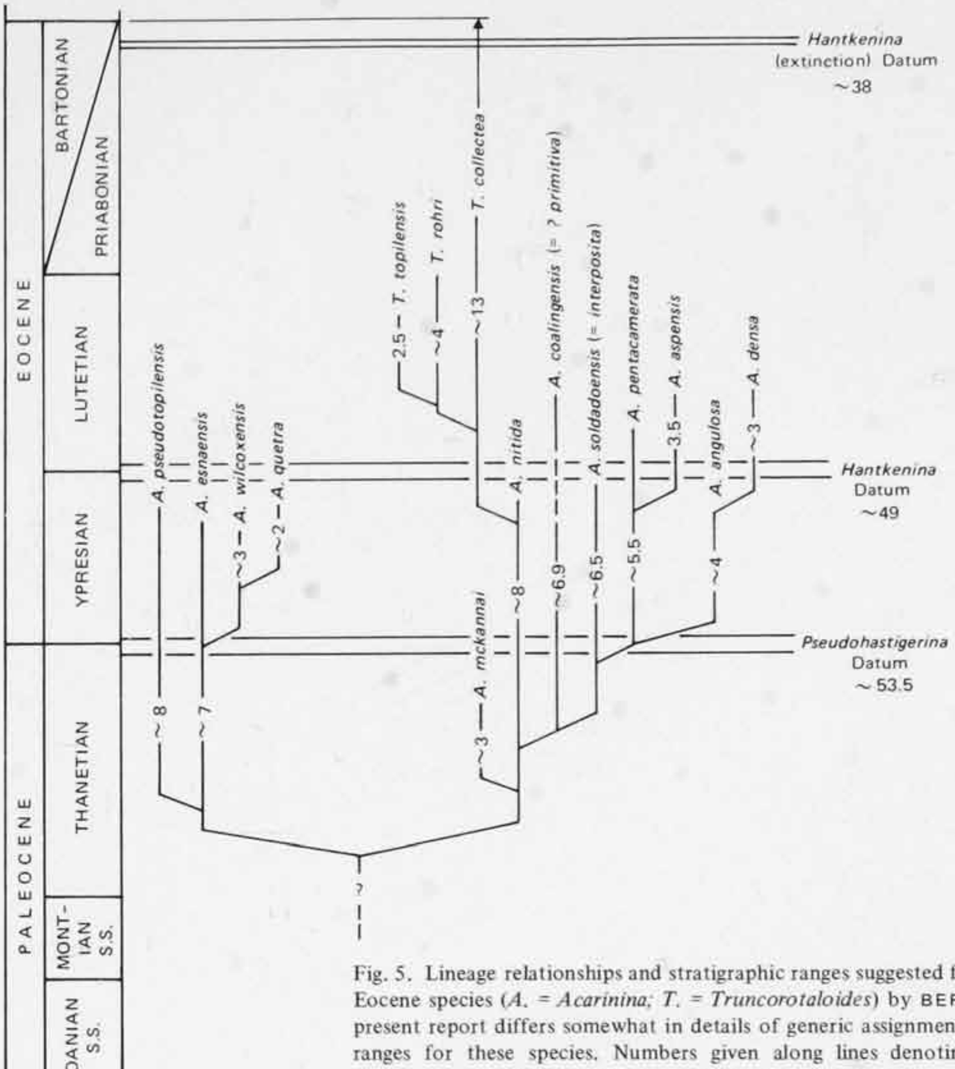

Fig. 5. Lineage relationships and stratigraphic ranges suggested for some Paleocene and Eocene species (*A.* = *Acarinina; T.* = *Truncorotaloides*) by BERGGREN (1969c). The present report differs somewhat in details of generic assignment and interpretation of ranges for these species. Numbers given along lines denoting stratigraphic ranges indicate approximate ranges of species in millions of years.

evolution can be utilized for definition of a precise zonal scheme. Combined use of several unrelated lineages is potentially the most reliable basis for zonation.

Although the concept of morphologic evolution holds much promise for refinement of zonal schemes (HAYAMI, 1973), actual practice in recognizing and defining evolutionary lineages has pitfalls rooted in the fact that such lineages start as subjective creations of authors which may not withstand the critical scrutiny of their colleagues (or, indeed, of the original author in later reviews of his own work). For instance, BOLLI (1950, 1957b, 1967) originated and maintained division of *Globorotalia fohsi* into four subspecies which appeared sequentially in the mid-Miocene. His basic idea is widely accepted and applied to zonation, but a good case can be made for considering the third form (*G. fohsi lobata*) as an aberrant, ecologically controlled variety. BLOW & BANNER (1962) discussed mid-Tertiary lineages and among other examples suggested that two deceptively similar homeomorphic lineages extend from the Late Eocene into the Oligocene (*Globorotalia increbescens-Globigerina ampliapertura, Globorotalia centralis-Globigerina pseudoampliapertura*). Other authors, however, have been slow to accept *G. pseudoampliapertura* as a recognizably distinct species. BLOW (1969) later reasserted the existence of these two lineages but withdrew or appreciably modified other lineages postulated in the 1962 paper.

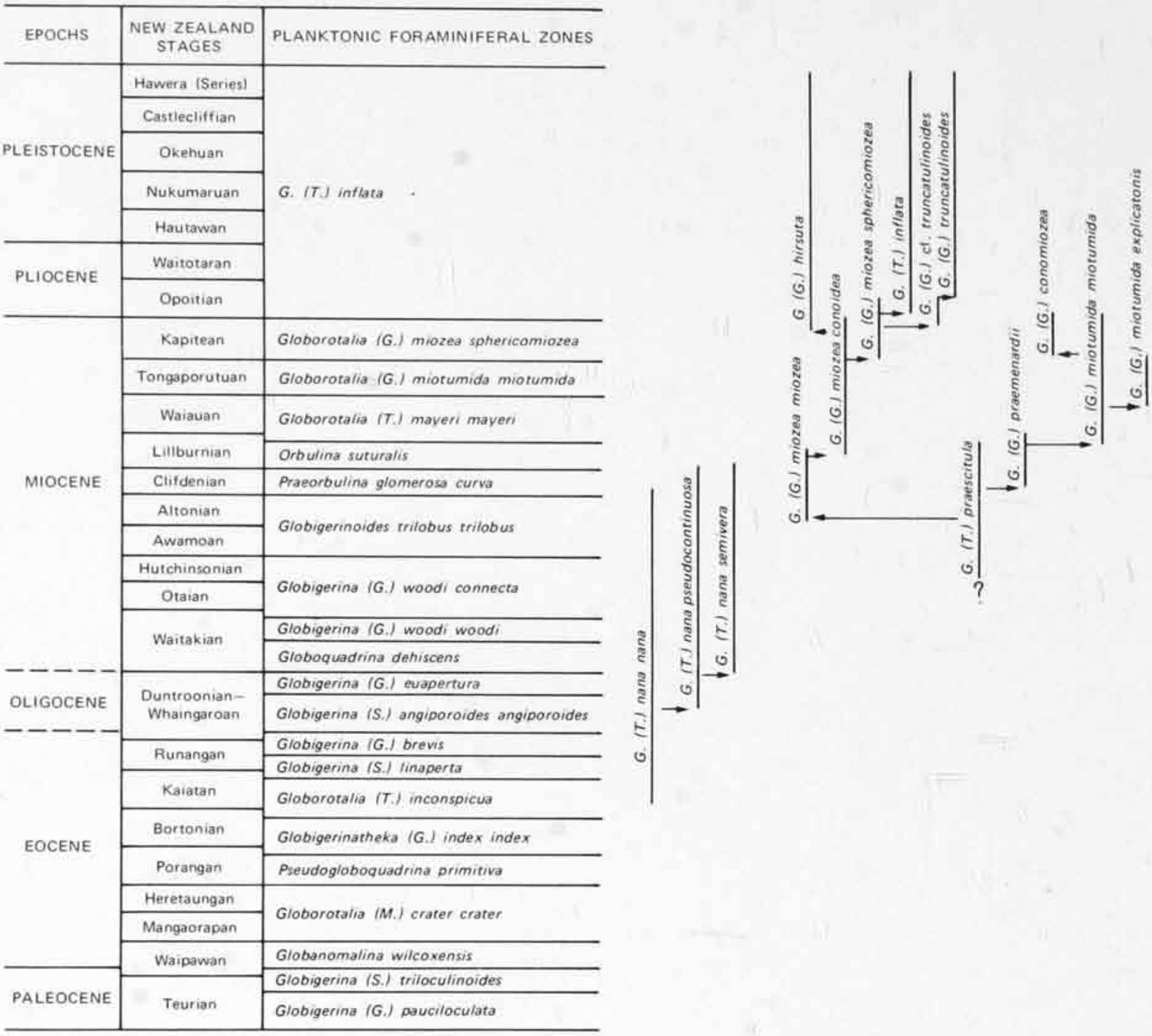

Fig. 6. Two evolutionary lineages in *Globorotalia* and stratigraphic ranges suggested by JENKINS (1971). Although details of age and nomenclature indicated here differ somewhat from interpretations in the present report, the basic concepts are in agreement.

Some groups of related foraminifers are subdivided into species or subspecies in what seems to be an overly meticulous manner. Seemingly very minor characters used for this splitting, however, are indicative of detailed stratigraphic position (e.g., subdivisions of the *Globorotalia fohsi* lineage). Other groups [e.g., *Globorotalia crassaformis* (GALLOWAY & WISSLER, 1927)] vary widely in morphology, but this variation is unrelated to precise stratigraphic position. Thus, by increasing experience we discover that the biostratigraphic aspect of such lineages as the latter is indefinable and that a purely academic approach in separating species using minor differing morphologic characters has little or no biostratigraphic value.

Discussions in the accompanying catalog of index planktonic species mention several genetic lineages postulated by various authors. Their subjectivity makes them suspect, and every worker is free to accept or reject them. Much desired is an objective basis for differentiating valid criteria for distinction of evolutionary change from those which are not

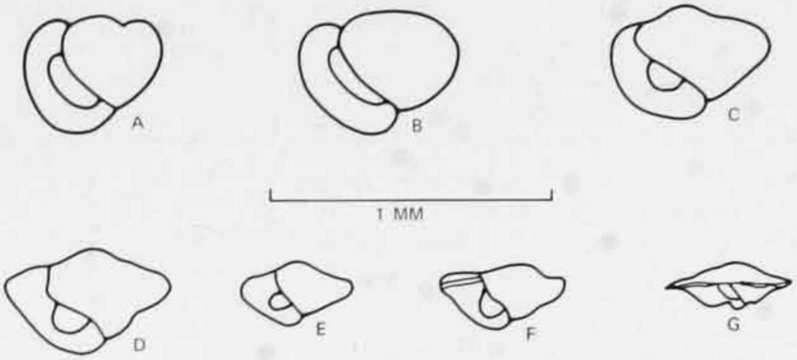

Fig. 7. Morphologic evolution of *Globorotalia cerroazulensis.* Evolution is expressed mainly by progressive sharpening of the peripheral shoulder and compression of test to a lenticular and eventually a carinate form. A, B – *G. cerroazulensis cerroazulensis;* C, F –transitional forms; D, E–*G. cerroazulensis cocoaensis;* G–*G. cerroazulensis cunialensis.* Tracings of apertural views of the later subspecies after TOUMARKINE & BOLLI (1970).

trustworthy. Wider use of the scanning electron microscope, perhaps coupled with laboratory studies of living cultures, eventually may provide a solution. Some recent investigations suggest that amino acids in the shell material of foraminifers may provide a quantitative test of suspected close relationships (KING & HARE, 1972). Meanwhile, some aspects to consider in assessing any postulated lineage are the following, arranged more or less in order of decreasing importance:

1) Obviously essential is appearance of supposedly primitive forms before presumed descendant (stratigraphically higher) advanced ones. BLOW (1969, p. 341) postulated and maintained that *Globoquadrina dehiscens* (sensu stricto) evolved from *Globigerina tripartita* by way of the intermediate subspecies *G. dehiscens praedehiscens,* but JENKINS (1964b, 1966a-b) asserted that at least in the south Pacific region typical *G. dehiscens* (s.s.) already existed before the earliest known occurrence of *G. praedehiscens.* Thus chronostratigraphic evidence appears to refute the postulated genetic linkage in this instance.

2) Individuals are subordinate to whole populations in discussing and assessing all postulated lineages (Fig. 8). Populations found at successively higher stratigraphic levels may contain virtually the same range of morphologic variants but in somewhat different proportions. The mode of populations differs with time and follows discernible trends at measurable rates. Corollaries to this basic precept include the following:

   a) The establishment of lineages should be based on, or at least backed by, detailed statistical analyses; in foraminiferal literature this is seldom the case although exceptions exist (e.g., SCOTT, 1966-1972a; LINDENBERG, 1969).
   b) To an appreciable extent experience leading to a developed sense for recognizing faunal changes may substitute for formal statistical studies. Thus, the opinion of a paleontologist accustomed to work with entire sequential assemblages deserves respect. In contrast, a lineage synthesized solely from type and other figures in the literature generally has little value.
   c) As in all statistics, the smaller the sample the greater the probable error. The evolutionary status of species cannot be assessed reliably from sparse or single specimens.

3) Empirical studies suggest that saltatory modifications of planktonic foraminiferal populations are exceptional; incipience of *Globigerinatella* is one of the few suspected cases. Aside from such rare exceptions, an essential of evolutionary change is that it be

gradual. Whatever trends of morphologic change may be postulated, specimens should be readily available which differ barely perceptibly, one by one, yet provide an unbroken linkage between extreme forms. When evolution is slow, a wide range of variants may occur in a single assemblage, as exemplified by BLOW & BANNER (1962, fig. 12b-e), who illustrated their concepts of certain lineages by specimens picked from single samples. On the other hand these same authors and BLOW alone (1969, p. 321, 381-382) attributed such wide and partly abrupt variability among their subspecies of *Globigerina praebulloides* that the genuineness of this lineage becomes suspect.

4) Evolutionary processes are affected by ecologic and climatic factors, among which temperature is especially influential. This is evident from the greater variety of fossil and living planktonic foraminifers in tropical and subtropical regions as compared with temperate to polar latitudes. A well-known example is *Globorotalia fohsi peripheroronda* and its descendant *G. fohsi fohsi* which are recorded in western Europe where the larger and more advanced subspecies *G. fohsi robusta* is unknown. In New Zealand some tropical lineages are discernible in northern but not southern areas (JENKINS, 1965b; KENNETT, 1967, 1968). Whereas development of a keel may typify advanced forms in a globorotaliid lineage, it also is symptomatic of warmer temperatures and of the lower latitudes (GLAÇON, VERGNAUD-GRAZZINI, & SIGAL, 1971). Adaptation of a species to different depth habitats may give rise to a suite of variants readily confusable with chronologic subspecies (e.g., *Globorotalia miozea-G. scitula-G. praemenardii* plexus reviewed by SCOTT, 1972b). Inhospitable living conditions may lead to wholesale stunting so that evolutionary trends cease to be evident, an example of which may be seen in fossils of the *Globigerina eugubina* Zone recorded in basal Tertiary beds of several areas and defined primarily by the very small and undistinctive nature of their planktonic fauna sandwiched between strata containing abundant large diversified species.

5) Homeomorphy is readily demonstrable among planktonic foraminifers, as is to be expected when unrelated groups evolve towards ideal adaptation to a free-floating existence. In some cases good evidence, both in morphologic details and stratigraphic separation, indicates the existence of two similar but unrelated suites as illustrated by the Eocene *Globigerinatheka-Orbulinoides* and the Miocene *Globigerinoides-Praeorbulina* lineages. In other examples there is danger that two or more lineages, less distinctive than the genera just mentioned and to some degree contemporaneous, may be confused with one another. A fertile field for such miscomprehensions is in the small globigerinas grouped under *G. bulloides, G. ciperoensis, G. officinalis, G. ouachitensis, G. parabulloides, G. praebulloides,* and similar forms. Carinate globorotalias of the Late Tertiary present some equally tantalizing problems, discussed by several authors so dogmatically as to make one forget that their opinions are only educated guesses.

6) Hypothetical but not ignorable in evaluating postulated foraminiferal lineages is the fact that these protistans are very simple organisms. Each test may be viewed as a geometric design susceptible of description by a few mathematical symbols suitable for expressing form of the spiral through midpoints of its chambers, fixed or changing shape of the chambers, their number in each whorl, and rate of their size increase (BERGER, 1968-1970; OLSSON, 1971). Small changes in these primary growth parameters, **whether rooted in natural variability or in progressive evolution of the species,** can lead to pronounced secondary differences between individuals of the same stock. As examples, a small versus large umbilicus may result from a rapid versus slow rate of increase of chamber size; deeply incised versus flush sutures may reflect loose versus tight coiling. Such secondary morphologic characters are applied commonly in classification of foraminifers at the generic level. For instance, a large umbilicus may be covered (protected) by a bulla (e.g., *Catapsydrax*) or by large triangular teeth (e.g., *Globoquadrina*), and

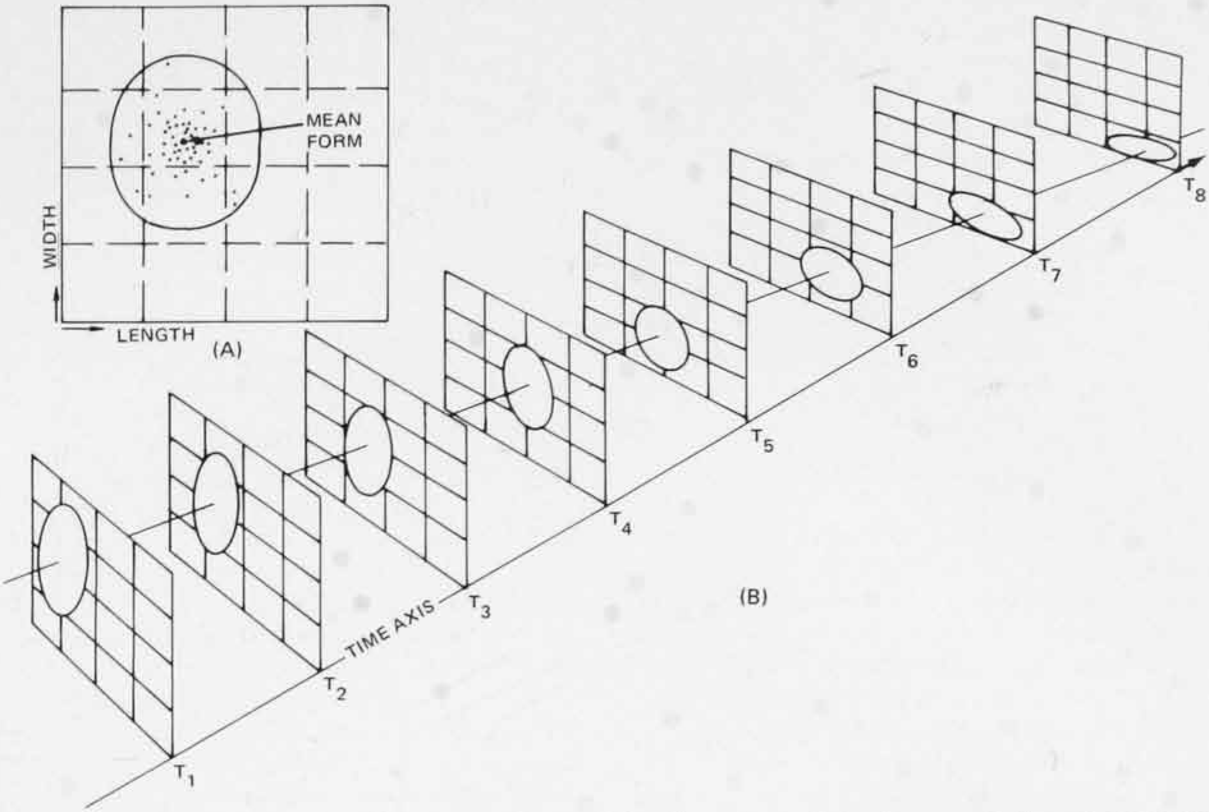

Fig. 8. Diagrammatic illustration of species concept. Characteristics of species tend to change gradually and progressively through time so that a purely objective definition of a species may be extremely difficult. (A) Characteristics of a species at one time indicated here by points denoting the length-width ratio for somewhat differing adult individuals; the concentration of points in a central position indicates the mean form and the oval outline indicates the interpreted range or maximum divergence of individuals. (B) The mean form (connected by line) and maximum divergence of individuals (oval) for such a form is indicated for successive times T_1, T_2, T_3, . . . ; although gradual change (evolution) results in only slight differences between adjacent times, early forms at T_1 and T_2 differ completely from late forms at T_7 and T_8. (From unpublished report by STAINFORTH.)

deeply incised sutures tend to be associated with openings on the spiral side of the test (e.g., *Globigerinoides, Truncorotaloides*). BLOW (1969, p. 339) pointed out that the use of apertural teeth as a prime criterion in defining *Globoquadrina* brings together a strange and long-ranging assortment of species. Joint possession of characteristics of the sort here called secondary is not necessarily proof of close relationship.

7) Authors have postulated numerous genetic lineages which appear plausible as judged by criteria discussed above. Although these lineages are chronologically and biologically separated, certain morphologic trends are repeated within them, for example the following:

a) A smoothly rounded periphery may change progressively to bluntly shouldered, subacute, acute, and finally keeled (e.g., *Globorotalia cerroazulensis* s. l., *Globorotalia fohsi* s. l.).

b) The aperture may migrate from an extra-umbilical (globorotaliid) to an intra-umbilical (globigerinid) position (e.g., *Globorotalia increbescens* changed to *Globigerina ampliapertura; Globorotalia acostaensis* to *Globigerina eggeri* or *Globoquadrina dutertrei*).

c) If successive chambers increase markedly in size, the final one envelops progressively more of the test which thus approaches a spheroidal form (e.g., *Globigerinoides-Praeorbulina-Orbulina, Globigerinatheka-Orbulinoides,* *Globigerina tripartita-Globigerina sellii/binaiensis*).

d) Limbation of sutures may typify advanced stages of globorotaliid evolution (*Globorotalia fohsi robusta, Globorotalia menardii* [*cultrata*] plexus).

The empirical suggestion emerges that these trends represent response to an inherent, irreversible life force in foraminifers. Consequently, reasonable doubt is justifiable when an author postulates evolution in an opposite direction.

NOMENCLATURE OF LINEAGES

The nomenclature of planktonic foraminiferal lineages presents several problems. As previously stated, a genuine linkage should be demonstrable by an intergrading series of morphologic variants between two extremes. In nature's scheme none of these variants is more important than another, and yet it is manifestly impracticable to apply a name or even a code designation to every one of them; thus some form of compromise is necessary. Among approaches found in the literature, the following are stated in order of increasing complexity.

1) Include all variants under one species name and designate their status informally (e.g., primitive, simple, median, advanced, etc.).

2) Same, but define successive stages more precisely, designating them sequentially by a code (e.g., as forma Alpha, forma Beta, etc.).

3) Recognize successive species and divide them into sequential subspecies, preferably designating them by names which convey a sense of evolution (e.g., *Globorotalia pierrei primordius, G. pierrei pierrei, G. pierrei praepauli, G. pauli postpierrei*, and *G. pauli pauli*).

4) Essentially the same, but give all recognized variants the rank of species.

5) Indicate morphologic development by use of generic and subgeneric names.

Simpler schemes are easier to use at the cost of less precision, whereas more precise schemes become difficult to apply because of the intricately fine distinctions between taxa that must be recognized.

A real problem faces an author who, after intensive study, may have a clear concept of fine distinctions between sequential stages in a lineage but finds objective communication of them through normal publication channels extremely difficult. Recourse then may be had to imprecise relative terms (e.g., more inflated, less acute) and to indefinite quantitative terms (e.g., moderately incised, large for the genus, etc.). Occasionally authors supply precise numerical data on dimensions, angles, ratios, and other features, but areas for misunderstanding still remain. For instance, forms in the sequence *Globigerinoides sicanus-Praeorbulina glomerosa-Orbulina suturalis* have been defined in part by percentage of the test occupied by the final spherical chamber–but who can measure this precisely?

ZONATION

GENERAL FEATURES OF PLANKTONIC FORAMINIFERAL ZONATION

Paleontological zonation is effected by dividing a sequence of sedimentary strata into units defined solely by their fossil content. Planktonic foraminifers have existed from at least middle Mesozoic time to the present, assemblages of them showing constant change with irreversible trends. Consequently, zones defined by fossil planktonic foraminifers, although biostratigraphic units, have direct application to chronostratigraphy. For instance, an autochthonous fauna containing globotruncanas and rugoglobigerinas may be confined to the Late Cretaceous, one with conical pustulose globorotalias to the Early Tertiary. By reference to the species and subspecies in an assemblage, age of the containing beds may be determined with great precision (Fig. 9). A compromise often must be made, however, between a coarse zonation based on unmistakable faunal criteria and an attempted finer one based on tenuous hairsplitting differences which may not be recognizable with certainty.

Of the many types of biozones which have been

SYSTEM	SERIES	SUB-SERIES	STAGE	ZONE	SUBZONE	CHARACTERISTIC ASSEMBLAGES OF FORAMINIFERA	REGIONS							
							Trini-dad	West Europe	Syria	Tanza-nia Madagas.	India	Japan	New Zealand	Pacific
NEOGENE	MIOCENE	LOWER	AQUITANIAN	*Globigerinita dissimilis*	*Globigerinita stainforthi*	*Globigerinoides trilobus primordius, Globigerina venezuelana, Globoquadrina praedehiscens*	●	●	●	?	●	?	●	●
					Globigerinita dissimilis									
PALEOGENE	OLIGOCENE	UPPER	CHATTIAN	*Globorotalia kugleri*		*Globorotalia kugleri, G. pseudokugleri, Globigerina juvenilis, G. bradyi*	●	?	?	?	?	?	●	●
				Globigerina ciperoensis		*Globigerina ciperoensis, G. angulisuturalis, Globorotalia opima nana*	●	?	●	●	●	?	●	●
		LOWER & MIDDLE	RUPELIAN	*Globorotalia opima opima*		*Globorotalia opima opima, Globigerina angulisuturalis, G. angustiumbilicata*	●	?	●	●	●	?	●	?
				Globigerina ampliapertura		*Globigerina ampliapertura, G. sellii, G. officinalis, G. rohri, G. turritilina*	●	?	●	●	●	?	●	●
	EOCENE	UPPER	PRIABONIAN	*Globigerina corpulenta*	*Globorotalia cerroazulensis*	*Globorotalia cerroazulensis, Globigerapsis semiinvoluta, G. tropicalis, Cribrohantkenina inflata, Globigerina corpulenta*	●	●	●	●	●	?	●	●
					Globigerapsis semiinvoluta		●	●	●	●	●			●
				Truncorotaloides rohri		*Truncorotaloides rohri, Acarinina rugosoaculeata, Globigerina incretacea*	●	?	●	●	●	?	●	●
				Hantkenina alabamensis (Orbulinoides beckmanni)		*Orbulinoides beckmanni, Hantkenina dumblei, Globorotalia centralis, G. spinulosa*	●	●	●	●	●	●	●	●
				Acarinina rotundimarginata (Globorotalia lehneri)		*Acarinina rotundimarginata, Globorotalia lehneri, Hantkenina liebusi, H. lehneri*	●	?	●	?	●	?	●	●
		MIDDLE	LUTETIAN	*Acarinina bullbrooki (A. "crassaformis")*	*Globigerapsis kugleri*	*Acarinina bullbrooki, Hantkenina aragonensis, Globigerapsis kugleri, Globigerina boweri, G. higginsi*	●	●	●	?	●	●	●	●
					Hantkenina aragonensis		●		●					
		LOWER	YPRESIAN	*Globorotalia aragonensis*	*Globorotalia palmerae*	*Globorotalia aragonensis, Acarinina pentacamerata, A. interposita, Globorotalia caucasica*	●	●	●	●	●		●	●
					Globorotalia aragonensis		●		●					
				Globorotalia subbotinae (G. wilcoxensis)	*Globorotalia marginodentata (G. formosa)*	*Globorotalia subbotinae, G. formosa, G. marginodentata, Pseudohastigerina wilcoxensis, Acarinina pseudotopilensis*	●	●	●	●	●	?	●	●
					Globorotalia subbotinae (= G. rex)		●	●	●		●			●
	PALEOCENE	UPPER	LANDENIAN	*Globorotalia velascoensis (Acarinina subsphaerica)*	*Globorotalia velascoensis*	*Globorotalia velascoensis, G. pseudomenardii, G. acuta, Acarinina mckennai, A. acarinata, Globigerina velascoensis*	●	●	●	●	●		●	●
			THANETIAN		*Globorotalia pseudomenardii*		●	●	●			●		●
		LOWER	MONTIAN	*Globorotalia angulata (G. pusilla)*	*Globorotalia conicotruncata*	*Globorotalia angulata, G. conicotruncata, G. pusilla, G. ehrenbergi*	●	●	●	●	●	?	●	●
					Globorotalia angulata		●	●	●					●
			?	*Acarinina uncinata (A. inconstans)*		*Acarinina uncinata, A. praecursoria, A. inconstans, A. schachdagica*	●	●	●	?	●	?	●	●
?	?		DANIAN	*Globorotalia trinidadensis (Globoconusa daubjergensis–Globigerina trivialis)*		*Globorotalia trinidadensis, G. pseudobulloides, Globigerina triloculinoides, G. trivialis*	●	●	●	●	●	●	●	●
				Globigerina (Eoglobigerina) taurica		*Globigerina taurica, G. eobulloides, G. tetragona, G. pentagona*	?	●	●	?	?	?	?	●
CRET.	UPPER		MAESTRICHTIAN	*Abathomphalus mayaroensis*		*Abathomphalus mayaroensis, Globotruncanella petaloidea*	●	●	●	—	●	—	—	●
				Globorotruncana stuarti		*Globotruncana stuarti, G. contusa, G. plummerae*	●	●	●	—	●	—	—	●

● Zonal interval recognized.
? Zonal interval doubtfully recognized.
— Zonal interval not recognized.

Fig. 9. Occurrence of age-significant zonal assemblages of planktonic foraminifers in the Paleogene of several widely separated parts of the world (after MENNER & KRASHENINNIKOV, 1970). Although details of nomenclature and age differ in the present report, practicality of applying narrowly defined indicator planktonic foraminifers extensively for differentiating narrow age intervals is indicated clearly. Moreover, many gaps and uncertainties indicated here are being resolved as adequate local studies are reported.

distinguished (HEDBERG, 1971, p. 10-22; note also VAN HINTE, 1969), the four most commonly based on planktonic foraminifers are the following:

1) Taxon-range zones – defined by stratigraphic interval within which some one selected taxon is distributed; generally, unless otherwise specified, the maximum (worldwide) range of the marker is implied.

2) Concurrent-range zones – defined by stratigraphic interval of overlap of two selected taxa, one of which became extinct soon after first appearance of the other. Exceptionally more than two markers may be designated, a procedure which introduces problems of their relative importance but may be justified by increased utility.

3) Interval zones – defined by interval between two arbitrarily selected biohorizons (datum levels) which may be based on first appearance, extinction, change of coiling direction, flood abundance, or any comparable characteristic of two selected taxa, which normally are unrelated.

4) Lineage zones (phylozones) – defined by segments of evolutionary lineages, with zonal boundaries generally placed at first appearance of successively more advanced forms, less commonly based on faunal statistics.

Examples of abrupt extinction of planktonic foraminiferal species and genera occurring synchronously over wide areas are plentiful, and such forms have been utilized in defining zones of the first three types just listed. The genus *Hantkenina* and the species *Catapsydrax dissimilis* are well-known cases. Especially valuable are the distinctive forms with short life ranges, such as *Globigerinatheka* and *Globigerinatella*.

In the fourth category (lineage zones) extinction levels become less important. On empirical evidence successive steps in an evolutionary lineage seem to occur synchronously, for practical purposes, throughout the geographic spread of the species concerned. As a simple and well-known example, appearance of the lenticular, partly carinate subspecies *Globorotalia cerroazulensis cocoaensis* and *G. c. cunialensis* was a clearly defined phase in the morphologic evolution of *G. cerroazulensis* (Fig. 7). Records show that the event was synchronous around the world and therefore is a reliable guide to the latest Eocene. On the other hand, simpler forms of a lineage do not disappear abruptly when more advanced ones evolve from them. To cite another familiar case, the successive appearances of the three subspecies *Globorotalia fohsi peripheroronda*, *G. f. fohsi*, and *G. f. robusta* were well separated in time, but the earlier forms lingered until near the extinction level of the entire species.

Arising from these observations, the normal application of lineages to zonation stipulates that **earliest appearance** of some physical characteristic most adequately defines a stratigraphic datum level within the zonal succession. Concurrent development of different lineages within the same assemblages serves as control, so that a zonation based on evolutionary steps tends to be better integrated and more reliable than the schemes (formerly in vogue) based on ranges of unrelated marker species. Nevertheless, validity of such a zonation depends entirely on an author's subjective interpretation of evolutionary processes.

The points already enumerated for assessing postulated lineages are equally applicable to evaluating phylozones based on them. Oil-company paleontologists, who normally must base subsurface correlations on study of drill cuttings, prefer a zonal scheme which emphasizes levels of extinction (downhole tops) (e.g., NOGUTI & SANTOS, 1972). For this reason the modern lineage zonations have less merit in oilfield practice than in other fields of biostratigraphy.

In recent years stratigraphers have tended to swing away from defining zones by their content (assemblages) of planktonic genera and species and, at least in the Tertiary, now concentrate more on precise definition of boundaries between zones. This change of emphasis is an offshoot of the researches of the Committee on Mediterranean Neogene Stratigraphy, which revealed deficiencies in the practical application of range zones and which also were aimed at establishing sharper boundaries between the standard Tertiary stages. As a result the concept of **paleontologic datums** has come to the fore.

A paleontologic datum is the stratigraphic level at which some widely recognizable change occurs within fossil faunas under study. Experience has shown that the most reliable criterion is first appearance of a distinctive form within a rapidly evolving lineage.

Examples which come to mind instantly are the *Globigerinoides* Datum and *Orbulina* Datum, both recognized around the world and used to define the bases of the Lower Miocene and Middle Miocene, respectively. It was noted above that extinction levels tend to be less sharply defined than incipience levels, but some which seem to involve phylogerontism are valid on a worldwide scale (e.g., extinction levels of genera *Hantkenina, Cribrohantkenina,* and *Globigerinatheka,* all close to the top of the Eocene). Zonal charts which accompany the subsequent stratigraphic discussion include columns showing datums[1] considered most useful in Cenozoic zonation and correlation.

Incipience and extinction of marker species are not the only criteria for defining datums, but generally they are the most reliable. Levels of exceptional abundance or large size of an index foraminifer may be useful locally but seldom can be traced over wide areas. Levels at which change occurs in coiling direction of a species are yet another type of datum which, being commonly related to temperature changes, is particularly applicable to zonation of beds accumulated at times of fluctuating climate (e.g., Pleistocene of California, New Zealand).

In local application of planktonic foraminiferal zones, care always must be taken to check on the nature of abrupt appearances or seeming extinctions of index species. If the overall aspects of lithology, benthonic fauna, and abundance of plankton remain constant above and below such levels, these can reasonably be accepted as valid for zonal purposes. If, on the contrary, an apparent planktonic datum coincides with an unconformity, pronounced change of facies, or structural anomaly, then due allowance must be made for the abnormality.

Misunderstandings sometimes arise when one of the zones within the standard sequence of an area is not identified in a particular surface or subsurface section. The tendency, especially among nonpaleontologists who have occasion to use zonal data, is to assume that beds representative of that zone are missing at this place. Such an assumption, however, is unwarranted because the reason for nonidentification of the zone may be any one of the following:

1) Samples too widely spaced (surface sections).

2) Too few cores taken (subsurface section) (especially if zone is defined by incipience levels not identifiable in drill cuttings).

3) Planktonic foraminifers not identifiable with precision because of poor preservation (leached, pyritized, or crushed).

4) Zone corresponds to an inshore or other facies lacking planktonic species.

5) Zone corresponds to a deep-marine facies but lithologically unsuited to identification of plankton (turbidite, chert, or lithified ooze).

6) Core mechanically mixed (especially in deep-sea cores of unlithified sediment in which a zone may be only a few centimeters thick).

Only if no such reason is applicable should a hiatus be postulated solely on the basis of zonal data.

LIMITATIONS OF PLANKTONIC FORAMINIFERAL ZONATION

Zonation based on planktonic foraminifers is not a panacea for all problems of stratigraphic correlation in deposits containing them. Even though this technique is credited with great achievements, such as determining true sequences and equivalents within classical Tertiary stages of western Europe and extending refined correlations to other continents and intervening ocean floors, the method has limitations, such as follow:

1) Planktonic foraminifers typify organisms of surface waters in open seas and oceans. Their tests sink to the bottom where they come to be a dominant constituent of the oceanic sediments commonly known as *Globigerina* ooze. On continental shelves they are numerically subordinate to benthonic micro-organisms, and in coastal waters planktonic forms disappear except under unusual conditions of landward currents (BELYAEVA, 1969). In many oilfield areas nonmarine to shallow-water sediments are dominant to the extent that planktonic zonation has little application in subsurface stratigraphy.

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[1] The anglicized plural form (datums) is used here as is customary in current publications because the Latin form (data) has a different connotation.

2) Specialization for planktonic existence led to homeomorphy of distantly related foraminifers to a much greater degree than is encountered among benthonic forms. Recognition of planktonic lineages has resulted in refinements of zonation, but only on the assumption that paleontologists can assess much subtler morphologic distinctions than was necessary formerly. In short, successful use of planktonic foraminiferal fossils in biostratigraphy calls for notably more skill and experience than had to be applied by earlier paleontologists who undertook to utilize these fossils in the oil industry.

3) Generally, distinctive features of any biologic subdivision (genus, species, or subspecies) are most pronounced in large, mature individuals and, conversely, delimitation is blurred and dubious when only small, immature specimens are available. For instance, large species known as *Globigerina eocaena* (=*G. yeguaensis*), *Globigerina tripartita*, *Globigerina venezuelana*, and *Globigerina gortanii* are distinct from one another; if the last two or three chambers are broken off to reveal the juvenile form, however, they are almost indistinguishable. Species represented naturally by small individuals are subject to confusion with juveniles of other species. Thus we have tried to avoid applying small forms to zonations despite use of the *Globigerina ouachitensis* and *G. officinalis* lineages by such authors as BLOW (1969) and BERGGREN (1971a).

4) Not uncommonly beds under study have undergone structural deformation or diagenesis or both so that their foraminiferal content has been affected correspondingly by crushing, shearing, leaching, pyritization, recrystallization, or allied processes. The result is that fine distinctions between closely similar marker species or subspecies may be unrecognizable.

5) Diversity of planktonic foraminifers consistently has been greater in tropical and subtropical regions than in temperate to polar latitudes. Many stratigraphically limited genera and species were confined to warmer seas, hence zones based on their distribution cannot be recognized in cooler regions to north or south. To a restricted extent it has proved possible to erect substitute zones based on foraminiferal species which, contrariwise, were confined to cooler oceans. Such forms are few and mostly long ranging, however, and the current tendency is to rely more on the nannoplankton for zonation in very high latitudes.

   New Zealand provides good examples of temperature-controlled variations in the sequence of planktonic foraminifers. On North Island the Caribbean zonal scheme is recognizable and, with some modifications, has been adopted. On the more temperate South Island, however, different index species must be used. Keeled species of *Globorotalia* generally are scarce or absent throughout New Zealand whereas several such forms are important zonal markers in the tropics (e.g., HORNIBROOK, 1967).

   A corollary to the temperature sensitivity of planktonic foraminifers is that worldwide climatic changes are reflected in latitudinal shifts of assemblages. Results may be confusing if sequential changes of assemblage are ascribed solely to chronologic evolution without regard for paleoclimatic factors. Modern studies of the Pleistocene interval, a time of unusually pronounced cyclical changes of climate, led to the special techniques for distinguishing between the chronologic and climatic implications of faunal data reviewed later. The methods are analogous to the oscillation chart devised by ISRAELSKY (1949) for correlation of benthonic assemblages within differing facies.

6) Preservation of calcareous microfossils in deep-sea sediments is affected adversely by increased solubility of calcium carbonate at high pressure and low temperature. This has been known at least since the *Challenger* expedition but has been mainly of academic interest except in rare cases, such as explanation of radiolarian oozes within the Oceanic Formation of Barbados.

Recent intensive studies of ocean floors by the JOIDES and other programs of oceanographic research reveal that solution factors must be assessed carefully before the stratigraphic significance of deep-sea microfaunas can be evaluated. PETERSON (1966) and BERGER (1968, 1970, 1973) published important studies, and CITA (1970, 1971a) provided a well-documented summary. The term carbonate compensation depth (CCD) is now used for the level below which the rate of solution of calcium carbonate exceeds the rate of replenishment by gravitational settling. Usually calcite is implied, but in certain cases it becomes significant that aragonite is more soluble and has a separate and shallower CCD. The compensation depth is deeper in the Atlantic than in the Pacific and is very shallow at high latitudes.

With reference to planktonic zonation the most important discovery is that foraminiferal genera and species differ markedly in susceptibility to solution, and planktonic genera are affected much more strongly than benthonic. Some planktonics which dissolve most readily are important zonal markers, such as *Globigerina nepenthes*, *Globorotalia margaritae*, and *Globorotalia miocenica*. Genera resistant to solution tend to be compact, thick-shelled, and finely perforate, such as *Sphaeroidinella*, *Sphaeroidinellopsis*, *Pulleniatina*, *Catapsydrax*, and *Globigerinatheka*. Any microfauna which has undergone carbonate solution is characterized by many broken planktonic tests, corroded chambers, unusually low ratio of planktonic to benthonic specimens, and absence of spinose and thin-shelled plankton to be expected in the zone represented. Scanning electron-microscope illustrations are strikingly diagnostic of the degree to which solution has affected an assemblage (CITA, 1970, 1971a).

7) Both locally and regionally, particular stratigraphic intervals may lack positive marker species so that they have to be defined negatively. To oversimplify for the sake of illustration, the Oligocene may be defined by the presence of species of large *Globigerina* in the absence of species of *Hantkenina* (an Eocene marker) or *Globigerinoides* (confined to Miocene and younger). A rich, diversified, well-preserved fauna of this type may be assigned confidently. Often, however, available material is deficient (e.g., small quantity, poor preservation, effects of solution) so that only a tentative zonal determination is justified. Discretion in use of negative criteria is one facet of population statistics, a commonly overlooked aspect of micropaleontology. Too often random (small) samples are assumed tacitly to represent reliably the diagnostic microfaunal assemblage of a zone even though these samples actually have the same inherent variability as any natural population. BOLTOVSKOY (1971) gave striking examples of abrupt changes in successive plankton tows in the south Atlantic. CARALP & PUJOL (1973) used comparable examples from the Oligocene-Miocene of Aquitaine to point out how uncritical acceptance of negative evidence can lead to false interpretation of ages and paleoclimates.

ANALYSIS OF CLIMATIC FACTORS

The greater diversity of planktonic foraminifers in warm regions as compared to cool regions long has been established by oceanographic studies and by comparison of Tertiary assemblages from tropical latitudes with their counterparts to north and south. More recently recognized, however, is the corollary that climatic fluctuations must result in geographic advances and retreats of temperature-sensitive species. Thus, during a sequence of climatic cycles, a warm-water species may be persistently present at Latitude 15°, appear and disappear three times at 30°, and make only one brief appearance at 45°. A cool-water species may have an opposite pattern. Fitting such discrepant occurrences directly into conventional zonal patterns clearly is impossible. Even if the ecologic cause is recognized, quantitative allowance or adjustment is not made readily.

BOLLI (1964) and BOLLI & BERMÚDEZ (1965) gave specific Miocene to Holocene examples of discrepant ranges of planktonic foraminifers that they attributed to ecologic factors. BOLLI introduced the important concept of **absolute** or **total range** of species and distinguished this from shorter (ecologically inhibited) local ranges. These authors also described abrupt changes in coiling direction which occur in assemblages affected by fluctuating temperatures and mark significant datum levels. Subsequent studies have revealed that distortion of simple biochronologic patterns of foraminiferal distribution may be analyzed to obtain detailed paleoclimatic information. The techniques are explained briefly below by reference to two idealized diagrams (Fig. 10, 11). Actual examples are mentioned in discussions on the Late Neogene and Pleistocene.

To illustrate relationships diagrammatically (Fig. 10), separate panels show effects of climatic fluctuation on three suites of planktonic foraminifers sensitive to different temperature extremes. For each suite the region is divided into an **optimum** environment where the species occurs throughout its life range, an **inimical** environment where the species is excluded at times by adverse temperature, and an **intolerable** environment where the species cannot penetrate and live. Space-time surfaces linking maximum extents of suites are conveniently termed **envelopes**; in practice these coincide with paleoisotherms. The diagram, therefore, represents cross sections of envelopes (two envelopes for the intermediate suite). The concept shown here has biostratigraphic importance because ranges of species within optimum environments for suites have direct chronologic significance and are applicable in zonation; they are **total ranges** (e.g., incipience of P and extinction of R). On the other hand, ranges within inimical environments are **local ranges** that may yield false results if applied indiscreetly to zonation (e.g., youngest occurrences of A at Stations 1 to 4, which define a distinctly diachronous surface). The diagrams of Figure 10 are highly idealized in order to convey basic concepts. In practice, of course, paleoisotherms may be neither equally spaced nor precisely parallel, individual species may react to temperature change in an individual manner and tend not to conform exactly to group patterns, and diurnal and seasonal variations in temperature also affect distributions.

The micropaleontologist's practical problem is the reverse of that shown in Figure 10, namely, determining separate but concealed chronologic and climatic patterns from faunal data. A basic technique for achieving this objective is reviewed here with reference to a diagrammatic example (Fig. 11). Gross effects of temperature fluctuation produce different sequences and combinations of cool, intermediate, and warm suites at each station (Fig. 11A). This, of course, appreciably limits direct faunal correlation (i.e., matching of ranges). Peaks of maximum and minimum temperatures recorded by envelopes define five synchronous levels; the abruptness and severity of a particular event, however, affect the precision (Fig. 11A).

Raw faunal data (as taxa listed in alphabetic or systematic order) commonly do not indicate fluctuations as obviously as does the diagram (Fig. 11A, which is a composite of the envelopes shown on Fig. 10). Faunal information needs, therefore, reprocessing to facilitate interpretation. A composite (Fig. 11B) of the distribution of species plotted in Figure 10 illustrates the basic type of raw data obtained in both onshore and offshore studies having broad geographic scope. In subsurface studies many more species are recorded generally, and these lack grouping into suites; a first impression obtained by inspecting such tabulated data is one of bewildering confusion.

An initial step is to note disappearances and reappearances of the same species at a given station (e.g., PQ at Station 1 and XY at Station 6); these suggest peak temperatures. Secondly, note geographically restricted species, such as A, B, and C at Stations 1 to 4 but not at Stations 5 to 7 and conversely for X, Y, and Z. The contrasts indicate adaptation to opposite ends of the temperature scale. A third clue is the short-lived presence at certain locations of species having long ranges elsewhere (e.g., A and B at Stations 3 and 4; QR at Station 7). These are additional indications of temperature peaks. Although differentiation between warm and cool phases is not important initially, the nature of the peaks commonly is identified by observing relative diversities of planktonic foraminiferal assemblages, nature of associated fossils, and geographic orientation of the area being analyzed.

Using these lines of evidence, original faunal plots are reorganized into orderly tabulations (Fig. 11B) with taxa arranged in order of temperature sensitivity. If data are too voluminous to handle readily, temperature-sensitive suites may be treated separately (as in Fig. 10). Retabulation is the key step because interpretation of adequately arranged data is

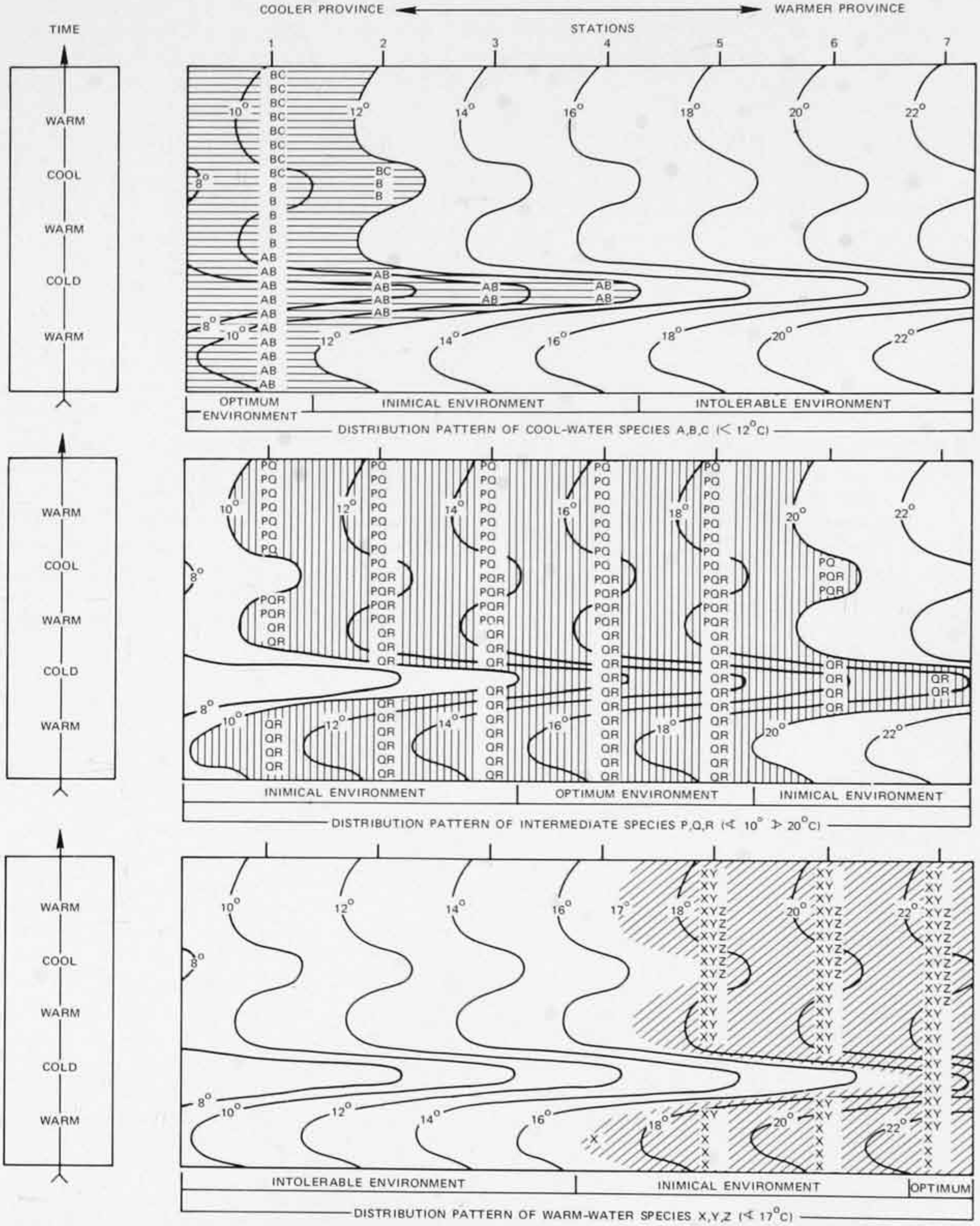
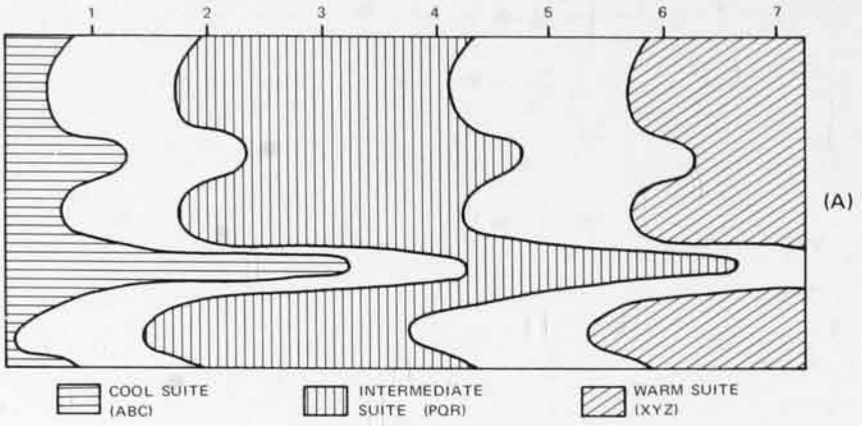


Fig. 10. Effects of climatic fluctuations on temperature-sensitive planktonic foraminifers. The base for each diagram represents climatic changes as lateral shifts of isotherms between a cool and a warm province. Note that **total ranges** applicable in zonation are determinable only in areas of optimum environment whereas **local ranges** determined in areas of inimical environment are unreliable for zonation.



(B)

STATIONS 1	2	3	4	5	6	7
BCPQ	PQ	PQ	PQ	PQ XY	XY	XY
BCPQ	PQ	PQ	PQ	PQ XY	XY	XY
BCPQ	PQ	PQ	PQ	PQ XY	XY	XY
BCPQ	PQ	PQ	PQ	PQ XYZ	XYZ	XYZ
BCPQ	PQ	PQ	PQ	PQ XYZ	XYZ	XYZ
BCPQ	PQ	PQ	PQ	PQ XYZ	XYZ	XYZ
BCPQ	PQ	PQ	PQ	PQ XYZ	XYZ	XYZ
BC	BCPQ	PQ	PQ	PQ XYZ	PQ XYZ	XYZ
B	B PQR	PQR	PQR	PQRXYZ	PQRXYZ	XYZ
B	B PQR	PQR	PQR	PQRXY	PQRXY	XY
B PQR	PQR	PQR	PQR	PQRXY	XY	XY
B PQR	PQR	PQR	PQR	PQRXY	XY	XY
B QR	QR	QR	QR	QRXY	XY	XY
AB QR	QR	QR	QR	QRXY	XY	XY
AB	AB QR	QR	QR	QR	QRXY	XY
AB	AB	AB	AB QR	QR	QR	QRXY
AB	AB	AB QR	AB QR	QR	QR	QRXY
AB	AB QR	QR	QR	QR	QRXY	XY
AB QR	QR	QR	QR	QRXY	XY	XY
AB QR	QR	QR	QR	QRX	X	X
AB QR	QR	QR	QRX	QRX	X	X
AB QR	QR	QR	QR	QRX	X	X
AB QR	QR	QR	QR	QRX	X	X

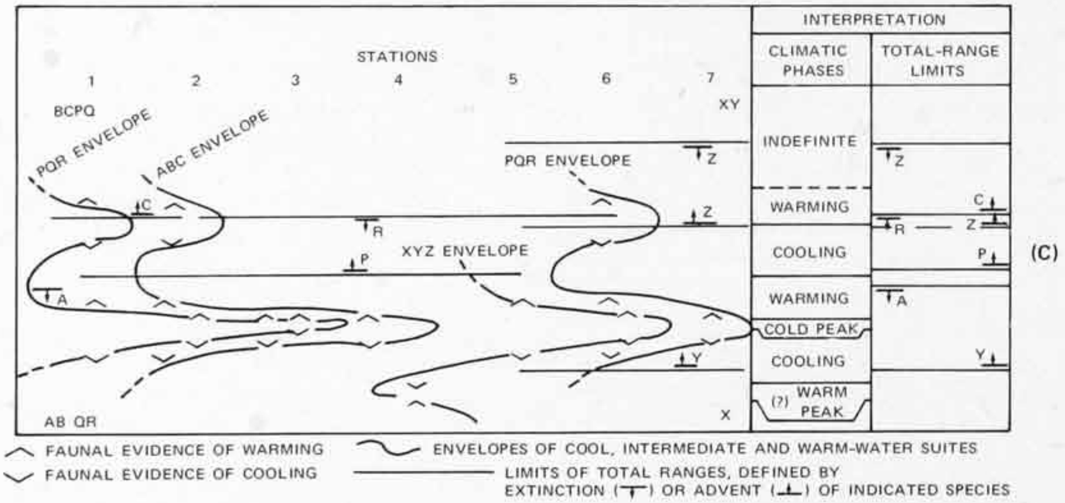


Fig. 11. Combined chronologic and climatic effects in sequences of planktonic foraminifers. **(A)** Composite of the three idealized diagrams of Figure 10 showing the different sequence and combination of cool, intermediate, and warm suites at different stations. **(B)** Distribution of species as shown on Figure 10. This is comparable to raw data observed in many operational studies except for including fewer species and for being grouped. **(C)** Interpretation of grouped data (B) showing envelopes and logically interpreted climatic phases and total ranges of species. The interpretations here compare well with climatic changes and species occurrences assumed in Figure 10.

largely mechanical. Lines and symbols are drawn on a transparent overlay (Fig. 11C) to indicate 1) distribution of envelopes for groups having similar temperature responses, 2) points of temporary appearance or disappearance of species which are indicative of warming or cooling, and 3) total ranges of species determined in optimum environments (Fig. 10) and extrapolated with discretion into inimical environments. The overlay then is interpreted both as to climatic phases and total ranges of species (Fig. 11C). This discussion necessarily is based on idealized conditions; in practice especial care is required to recognize misleading effects of differing sedimentation rates, solution of tests in deep water, missing parts of sections, and physico-chemical factors other than temperature.

Identification of climatic extremes is important because these worldwide episodes affect all forms of life and, potentially, are applicable in direct chronologic correlation of strata deposited in highly diverse environments. For instance, in the hypothetical example (Fig. 11) the concurrent-range zone of the planktonic foraminifers P and R coincides with a cooling phase that doubtlessly is detectable in facies lacking planktonic foraminifers by studies of pollen, mollusks, vertebrates, or other organisms.

Paleoclimatic interpretation of faunal data is greatly facilitated by plotting range charts listing taxa in order of temperature sensitivity. Such plots (including benthonic as well as planktonic foraminifers) reveal climatic cycles and fluctuations with striking clarity. Relative sensitivities may be established empirically as just described or may be derived from pertinent literature, especially papers on Pliocene-Pleistocene stratigraphy (e.g., ERICSON & WOLLIN, 1956; CITA & D'ONOFRIO, 1967; KENNETT, 1970; HERMAN, 1971; OLSSON, 1971; and BEARD, 1973).

NANNOPLANKTON ZONATION

Other planktonic organisms besides foraminifers potentially are applicable to zonation and circumglobal correlation of Cenozoic sediments. It is of historical interest, for example, that SENN (1935) recognized *Clio pulcherrina*, a planktonic mollusk (pteropod) of the European Miocene, in beds of Venezuela and Trinidad which on other evidence were long miscorrelated as Oligocene. In recent years a growing interest is evident in stratigraphic application of diatoms (e.g., WORNARDT, 1969, 1971), dinoflagellates (e.g., SARJEANT, 1967), and radiolarians (e.g., RIEDEL, 1971). The full potential of these three groups remains to be established, but that of a fourth, the calcareous nannofossils (coccoliths) already is well documented.

The term nannoplankton actually is inexact, meaning simply dwarf plankton, but has come to be applied (generally as calcareous nannoplankton) jointly to the coccoliths and discoasters. These microfossils have biostratigraphic utility comparable to that of the planktonic foraminifers and, in fact, have some advantages. Nannofossils are so small that a tiny pinch of sediment may provide a satisfactory sample, their latitudinal (climatic) distribution is broader than most microfossils so that they have been restricted less by paleoclimatic factors, they are more resistant than foraminifers to damage by solution in deep oceans (see striking illustrations by CITA, 1971a), and they appear in a sequence of distinctive forms leading to zonal divisions recognizable throughout much of the world. At the second international conference on planktonic microfossils (FARINACCI & MATTEUCCI, 1971) papers on nannoplankton far outnumbered those on foraminifers, reversing the trend of the first meeting (BRÖNNIMANN & RENZ, 1969).

There are two disadvantages to routine use of nannofossils in stratigraphic zonation. One is that their extremely small size renders the best of optical microscopes a crude instrument for distinguishing and identifying the different forms (but effective for identifications of short-ranging markers after their features have been recorded adequately). Electron microscopy reveals their structure in perfection, but this is not yet a routine tool. The second disadvantage is that these tiny silt-size fossils may undergo several cycles of sedimentation without acquiring physical signs of having been reworked; hence danger exists of dating beds too old.

Several zonal schemes based on nannoplankton have been published including one of the most comprehensive compilations (MARTINI, 1971), offered at the Rome conference. Further cooperative efforts discussed at the Committee on Mediterranean Neogene Stratigraphy (CMNS) meeting in Lyon (1971) are still in press at the time of writing. To a considerable extent the zones so far proposed (e.g., BAUMANN & ROTH, 1969; ROTH, 1970; BUKRY, 1971a,b, 1973; MARTINI, 1971; GOLL, 1972; HAYS ET AL., 1972) are based on spot samples rather than sequences, and boundaries are not yet firmly fixed. On current evidence it appears exceptional for boundaries of published nannofossil and planktonic foraminiferal zones to coincide, so that, after precisely interrelating nannofossil and planktonic foraminiferal zonations, finer biostratigraphic division can be envisaged if both schemes are used jointly than if either is used alone (HAY & MOHLER, 1969).

RADIOMETRIC DATING OF ZONES

The age of a rock (in years before present) potentially is determinable by analyzing ratios of parent and daughter isotopes of contained radioactive elements. Knowledge of the fixed rates of natural radioactive decay enables an analyzer to extrapolate backward to determine the time when radioactive material originated. This technique has been applied particularly to ancient crystalline rocks, and a high degree of refinement has been achieved by studying uranium/lead and rubidium/strontium ratios. For explanation and discussion readers are referred to KULP (1961), TILTON & HART (1963), and HARPER (1973) who gave extensive bibliographies.

Unfortunately, sedimentary rocks in general and younger ones in particular are not susceptible to such approach to determination of their age. Igneous activity productive of new mineral suites tended to metamorphose adjacent sediments, or at least to destroy their fossil content, so that paleontologic dating of igneous dikes and sills is seldom possible. A more indirect method must be used, namely to make radiometric measurements on micas and feldspars in ash beds and tuffs intercalated between fossiliferous beds and on other minerals found in sedimentary units. The more strongly radioactive elements cannot be used because they occur only as traces too minute for reliable measurement. The probable error is reduced by quantitative analysis of potassium-argon couplets. The isotope K_{40} is converted by electron capture to A_{40} with an annual decay constant of 5.85×10^{-11}, a rate well suited to calculation of ages in the Mesozoic and Cenozoic. K_{40} is normally scarcer than K_{39} by ratios of the order of 1:8000 but nevertheless it is sufficiently abundant to allow reliable mass-spectograph analyses. This approach has been used extensively in establishing a chronologic framework for subdivisions of the North American Tertiary adopted by vertebrate paleontologists. In the Pliocene and Quaternary the modern tendency is to base so-called absolute ages on local identification of a standard sequence of paleomagnetic events, which themselves have been dated by radiometric techniques.

Intercorrelation of zones defined by terrestrial vertebrates with those based on marine invertebrates necessarily is vague, so that existing Cenozoic chronology expressed in years contributes little to assessing radiometric ages of planktonic foraminiferal zones; a more direct method is required. To a limited extent water-laid tuffs and ash beds are available for radiometric analysis, but their exact zonal levels are reported for only a few (BANDY, HORNIBROOK, & SCHOFIELD, 1970; BANDY & INGLE, 1970). This difficulty has been removed by discovery that glauconite and biotite in marine sediments are satisfactory for measurement of K_{40}/A_{40} ratios provided that post-depositional history of deposits has been tranquil. As argon is a gas, it tends to diffuse and, therefore, its escape must be considered both in the selection of samples and in calculating their ages. The molecular lattices of biotite and glauconite appear to favor retention of argon; accordingly fresh specimens of these minerals are preferred. The effect of argon loss is to reduce computed ages, so that K/A determinations should be treated as minimal values. Authors presently agree on the order of magnitude for acceptable radiometrically determined ages in the Cenozoic but differ somewhat as to limiting values for samples collected at different datum levels. Without going further into this subject, the degree of accord is shown on Table 1.

The most valuable feature of age determinations given in Table 1, only slightly affected by internal discrepancies, is to provide an objective criterion for assessing subjective aspects of planktonic zonation. For instance, one is tempted to assume that the Cenozoic planktonic faunas as a whole were altered by evolution at an even rate and hence that zones based on their sequential changes represent essentially equal intervals of time. This assumption may be false, however, and thus lead to serious errors in paleogeographic, economic, or other applications of the zones. A means of estimating the duration of individual zones, therefore, is advantageous. The range and zone charts of the present report are drafted so that plotted heights of zonal divisions correspond directly to estimated time intervals expressed in millions of years. The columns then indicate relative duration of the different zonal intervals. This aspect of biostratigraphy may have major significance but is not considered in

Table 1. *Postulated Ages for Some Cenozoic Datums in Millions of Years.*

DATUM	KULP (1961), BANDY (1964b)	BLOW (1969, FIG. 20)	BERGGREN (1971b, FIG. 52.39)	BERGGREN (1971b, FIG. 52.40)	BERGGREN (1969c)	BANDY & INGLE (1970)	LAMB & BEARD (1972, TABLE 1)	BERGGREN (1972a)
Pliocene - Pleistocene	0.5 to 2.0	1.85	1.8	1.85	1.85	3	2.8	1.8
Miocene-Pliocene	13	6	5 to 6	5	5	9	6	5
Sphaeroidinellopsis subdehiscens (= N.12/13)	—	14	13 to 14	12 ca	14.5	14	12	14
Orbulina	—	20	20	14	18.5	19.25	—	16
Oligocene-Miocene, *(Globigerinoides)*	25	26	27	22.5	26	24.5	—	22.5
Early Oligocene *(Pseudohastigerina* extinction)	—	30	32	32	33.5	—	—	32
Late Eocene *(Hantkenina* s.l. extinction)	36 ca	37 ca	35 to 36	38 ca	38	—	—	37.5
Middle-Late Eocene *(Orbulinoides* extinction)	45	40 ca	40	46	45.5	—	—	44.5

conventional plots showing sequences of equidimensional zones. The desired objective is difficult to reach because data on radiometric (numerical) ages of Cenozoic rocks are scattered widely through the literature. They are not readily compiled to form a homogeneous sequence of dated events and are subject to differing interpretations. Experimental data, after conversion to age estimates, have a probable error generally of 5 to 10 percent. Other inaccuracies and contradictions arise from imprecise correlations, as between terrestrial and marine facies or between a dated lava in California or New Guinea and a stage boundary in Europe or a planktonic datum. We cannot delve deeply into this subject here, yet we do not wish readers to wonder how the time scales on the charts were derived. The solution adopted is to accept the time scale given by BERGGREN (1972a) in the latest of his series of papers which introduce successive modifications. We do not necessarily regard all parts of this base scale as reliably documented, however; in fact, interpretation of data available to us suggests that substantial modifications in several parts of the section are needed.

Some Tertiary time values extracted from the literature and averaged to derive maximum and minimum estimates for the duration of zones are given in Table 2.

Table 2 grossly confirms that zones have the same order of magnitude (1.9 ± 0.8 m.y.) with a variability of about 40 percent from the mean. The figures are affected by unavoidable subjectivity because ranking of subdivisions as superzones, zones, and subzones is arbitrary. For instance, the former *Globorotalia fohsi* Zone (s.l.) now is treated as a superzone and variously divided into three, four, and five zones, so that, depending on the scheme chosen, average duration of older Miocene zones ranges from 1.0 to 1.5 million years. Similar cases can be cited at all Tertiary levels. The over-all conclusion is that radiometric-age data support acceptance of existing planktonic foraminiferal criteria as defining comparable divisions of Tertiary time. In the standard zonation recommended here only a few zones are allotted durations greater than 3 million years, and these are divided into smaller units by some authors (e.g., BLOW, 1969; TOUMARKINE & BOLLI, 1970). Short zones having durations of less than 1 million

Table 2. *Estimates of Maximum, Minimum, and Mean for the Duration of Individual Zones within Different Tertiary Intervals.*

INTERVAL	DURATION (m.y.) MIN. a – MAX. b	NUMBER OF ZONES MIN. c – MAX. d	AVERAGE DURATION OF ZONE (m.y.) a/c	a/d	b/c	b/d	Mean
Late Miocene-Pliocene (N.15 – N.21)	10 to 13	7 to 10	1.4	1.0	1.9	1.3	1.4
Early-Middle Miocene (N.4 – N.14)	10 to 12	9 to 11	1.1	0.9	1.3	1.1	1.1
Oligocene	8 to 16	4 to 5	2.0	1.6	4.0	3.2	2.7
Eocene	15 to 22	11 to 16	1.4	0.9	2.0	1.4	1.4
Paleocene	5 to 13	4 to 8	1.2	0.6	3.2	1.6	1.7
Total Tertiary	63 to 70	35 to 50	1.8	1.3	2.0	1.4	1.6

years are noticeably grouped in the mid-Eocene and mid-Miocene.

The Oligocene and latest Eocene deserve notice as constituting a somewhat anomalous interval. BOLLI (1957b,c) interpreted the successive extinctions of *Hantkenina* and other forms and of *Globigerina ampliapertura* as defining parts of a single zone in Trinidad, called the *Globigerina ampliapertura* Zone. Although seldom physically conspicuous, this zone was recorded subsequently in many other countries. Later, on the basis of faunas encountered in east Africa, BLOW & BANNER (1962) proposed division of the same interval into four zones and suggested that beds of the older ones are missing in Trinidad. With certain modifications BLOW (1969) retained the four zones as his units[1] P.17, P.18, P.19, and P.20, but he abandoned his earlier conclusion that Oligocene deposits are missing in Trinidad. Still later (1970) he reduced the number of zones in this interval to three by amalgamating P. 19 and P. 20. In BOLLI'S revised scheme (1966a) the extinction level of *Pseudohastigerina* was accepted as a useful datum for subdivision of the original *Globigerina ampliapertura* Zone but other markers used by BLOW (in particular *Globigerina gortanii* [= *G. turritilina*], *Globigerina tapuriensis,* and *Globigerina sellii* [=*G. oligocaenica*]) were not adopted. A majority of authors judged BLOW'S scheme to be impracticable and used the simpler twofold division of BOLLI. Nevertheless, it is curious that the original *Globigerina ampliapertura* Zone had an estimated duration of 8 million years and so, by the criteria reviewed above, should be susceptible to division into half a dozen normal planktonic zones. BERGGREN'S data (1971a, 1972a) reinforce the suggestion, already apparent, that the Oligocene was a time of strikingly slow evolution in planktonic foraminiferal assemblages because he assigned durations of 4.0 and 3.5 million years, respectively, to the next succeeding two zones which complete the Oligocene interval. On the other hand, much depends on whose estimate is used for duration of the Oligocene inasmuch as published figures range from a low of 8 million to a high of 16 million years (Table 2).

A quite different application of geochemically determined ages has been the reevaluation of Neogene series and stages, units closely linked with planktonic foraminiferal zones through the work of the Committee on Mediterranean Neogene Stratigraphy (see in particular CITA ET AL., 1971; DROOGER & MARKS, 1971). The modern tendency is to divide the pre-Pleistocene part of the Neogene, which covered some 21 to 22 million years, into 10 stages (7 Miocene and 3 Pliocene). The average duration of these stages, therefore, is about 2 million years without making any adjustment for gaps and overlaps in the sequence. Biostratigraphic correlation is the most precise means of tracing and recognizing the stages, but under usual conditions of faunal variety

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[1] Explained later in section on "Development of Zonation" for the Eocene. Code designations of zones adopted by some authors utilize "P." and "N." for Paleogene and Neogene, respectively, and numbers in upward order within each for distinguishing zones.

and preservation a probable error of approximately 1 million years (at least one-half of an average zone) can occur. Universal recognition, therefore, of ten Neogene stages, no matter how precisely their stratotypes may be redefined, seems statistically unsound. The proposed alternative of recognizing four superstages, each having a duration of about 5 million years, provides a more realistic basis for regional correlations.

BERGGREN (1969c, 1971a) delved into quantitative aspects of the evolution of planktonic foraminifers. By combining radiometric ages with range charts he demonstrated that certain groups (notably keeled globorotaliids) evolved much more rapidly than others (e.g., hastigerinids) and showed that the taxonomic frequency rate of the whole group had significant maxima and minima during the Tertiary. A partial explanation is found in the direct relationship shown between this parameter and paleotemperatures (based on oxygen-isotype studies by DEVEREUX). BERGGREN suggested that the nadir of diversity in the Late Eocene and early Oligocene (alluded to in an earlier paragraph) was related to a considerable decrease in water temperature. Studies of FRERICHS (1971) and OLSSON (1972) support this conclusion. A common problem has been estimation of precise dates for one or more paleontologic datum levels when several million years separate the radiometrically dated control bracketing the interval. Quantitative data on evolutionary rates now provide a means of improving such estimates.

IMPACT OF PLANKTONIC FORAMINIFERAL ZONATION ON CLASSICAL TERTIARY STRATIGRAPHY

Throughout the nineteenth and first half of the twentieth century stratigraphers have worked toward a unified scheme of Tertiary correlations expressed by a supposedly continuous sequence of series and stages. Each individual stage (composed of rocks) was defined by the time interval during which these rocks were laid down. The criterion for defining and identifying any stage was its paleontology (in essence, same fossils, same stage; different fossils, different stage). The fossils referred to initially were almost exclusively megafossils, although megascopic foraminifers, such as nummulites, were included. Effects of climatic and environmental differences on faunal assemblages were recognized as a confusing factor but, in early literature, were mentioned as a theoretical possibility more often than as a demonstrable fact.

To typify each stage an area was chosen where beds crop out extensively and contain plentiful fossils. The name of this type area (sometimes latinized) was used to designate the stage. An example of the synthesis which resulted is representation of the Paleogene (Nummulitic) of northwestern Europe (Table 3) taken from the highly respected textbook of GIGNOUX.

Table 3. *Stages, Type Areas, and Typical Lithologies for the Paleogene of Northwestern Europe (*GIGNOUX*, 1950, Fig. 116).*

STAGE	TYPE AREA	TYPE LITHOFACIES
Rupelian	Belgium	Clay
Lattorfian	NE Germany	Greensand
Bartonian	England	Clay
Auversian	NC France	Sand
Lutetian[1]	NC France	Limestone
Cuisian	NC France	Sand
Ypresian	Belgium	Sand
Sparnacian[2]	NE France	Lignitic Clay
Thanetian	England	Sand
Montian	Belgium	Limestone

[1] Lutetia = Paris. [2] Sparnacum = Épernay

The defects of such composite schemes are self-evident. Outstanding is the probability that both gaps and overlaps exist at the postulated boundaries between stages and that faunal criteria accepted for distinguishing them must involve environmental as well as chronologic differences between the type sections.

At mid-twentieth century, planktonic foraminiferal zonation was gaining acceptance as a means of subdividing any sequence of open-marine Tertiary sediments and of defining precisely the chronologic status of any level within it, not only beds containing mollusks and other megafossils. Comparable precision already was well established in the Mesozoic by use of ammonite zones but hitherto had been impossible in the Tertiary. This new technique provided the needed key for determining how nearly the accepted scale of Tertiary stages matched an ideal time continuum, with neither gaps nor overlaps within the sequence. Since the late 1950's stratigraphers of western Europe have made a concerted effort to recorrelate and reassess the classical stages in their type regions. The same has been true of the Gulf Coast province of the United States where type areas of stages based originally on molluscan faunas are scattered from Texas to Florida. In New Zealand key foraminifers were utilized in the initial definitions of local Tertiary stages (FINLAY & MARWICK, 1940, 1947) so that refinements of planktonic zonation have had less impact there than elsewhere.

Particularly (but not exclusively) in the Neogene, application of planktonic foraminiferal zonation to the classical scheme of Cenozoic periods and series has revealed miscorrelations and defects of far greater magnitude than was anticipated (e.g., Table 4).

Table 4 provides a partial representation of the stratigraphic confusion which has appeared wherever planktonic foraminiferal zonation could be applied to assessing chronologic relationships of Tertiary stages in Europe. Because these stages have been the accepted basis during several decades of Tertiary chronology, the confusion has had a worldwide effect. Consequently, stratigraphers urgently need to agree on a more satisfactory standard for the Tertiary time scale. Three main approaches, as indicated below, have been advocated and discussed at recent international meetings, but none has gained majority acceptance.

1) Select from existing stages a sequence representative of all Tertiary time and use paleontologic data to modify boundaries so

Table 4. *Representative Example of Modification in Stage Relationships in the Miocene of Western Europe Resulting from Application of Planktonic Foraminifers in Age Correlations.*

STANDARD MIOCENE SEQUENCE PRIOR TO PLANKTONIC ZONATION (GIGNOUX, 1950)		CURRENT CORRELATION OF STRATOTYPES OF STANDARD STAGES (AFTER BLOW, 1969, FIG. 19; CICHA & SENES, 1971; CITA, 1971b-c)	
Pontian and other stages		Tortonian	
Vindobonian	Tortonian	▨ gap[1]	
	Helvetian	Helvetian	
Burdigalian		Burdigalian	Girondian[2]
Aquitanian[3]		Aquitanian	

[1] Prominent mid-Miocene gap results from marked chronologic separation of the type Helvetian and type Tortonian. In classical stratigraphy this gap was filled by beds incorrectly assigned to these stages, particularly upper Vindobonian of the Vienna basin and Elveziano of Italian authors. Retention of the Vindobonian as an international standard unit is undesirable because of deeply rooted misconceptions as to its status. The gap now is regarded as being neatly filled by the stratotypes of the Langhian Stage (which was misidentified in earlier work as an Italian equivalent of the Burdigalian) and the revived Serravallian Stage.

[2] The Bordeaux school of micropaleontologists led by PROF. VIGNEAUX has shown that classical differentiation between the Aquitanian and Burdigalian is based on facies-controlled faunal variations, so that the boundary is not a time plane; the name Girondian now is preferred for the combined Aquitanian and Burdigalian.

[3] GIGNOUX (1950, p. 510) preferred to treat the Aquitanian as part of the Oligocene but recognized that reasons exist for treating it as Miocene; modern stratigraphers have adopted the latter interpretation almost unanimously.

as to eliminate gaps and overlaps. This proposal would produce endless confusion and uncertainty because 1) familiar names then acquire new meanings and b) unfamiliar, little-used names (e.g., Bormidian) are revived. Thus, newly proposed stage terms seem to be just as useful.

2) Create new units, giving them fresh names regardless of proximity or equivalence to existing stratotypes, designating their boundaries to coincide with paleontologic datums, either in the scheme of planktonic foraminiferal zonation or within some other group characterized by morphologic evolution (e.g., venericors, miogypsinids). At the CMNS meeting in Bologna (1967) DR. C. W. DROOGER made a strong and warmly received plea for this approach, one of his arguments being that traditional stages define time intervals too short to be recognized precisely over wide areas. At the Lyon meeting (1971) he and DR. M. B. CITA independently made concrete proposals for standard Neogene superstages (Table 5), but because the make-up and feeling of listeners had changed in the meantime, the proposals received only lukewarm support. A related example (which must be regarded as premature pending closer agreement on a standard nannoplankton zonation) is the proposal (BUKRY, 1973, in press) of 11 new international stages representing the entire Tertiary and defined exclusively in terms of coccolith zones.

3) Eliminate stages as primary stratigraphic units, replacing them by planktonic foraminiferal zones and superzones. This proposal arose because planktonic zones are instrumental in establishing true chronologic relationships of classical stages and useful for direct assignment of any marine microfauna to one stage or another. The suggestion is practicable for those parts of a stage represented by deep-marine facies but not for parts consisting of terrestrial, marginal-marine, and other deposits lacking planktonic fossils. To refer a glacial moraine to the "*Globigerina minima* Zone" would be as inappropriate as to identify radiolarian oozes as belonging to the "*Elephas maximus* Zone." The conceivable outcome of worldwide biostratigraphic studies is a standard grid of intercorrelated zonations based on different phyla of fossils ranging laterally from terrestrial plants and animals, through denizens of nearshore marine environments, to planktonic organisms most representative of oceanic deeps. Even if granted such a Utopian scheme, the problem of naming major stratigraphic intervals would persist, leading full-circle to the concept of stages whose proposed rejection was the starting point of this discussion.

Resolution of the three approaches just described and emergence of a generally acceptable nomenclature for the age framework of Cenozoic deposits probably would require years of additional study and discussion. The planktonic foraminiferal zonation now available, however, has the inestimable advantage of accounting for all Cenozoic time with neither gaps nor overlaps. On the other hand, alternative schemes, such as redefined stages or zonations based on different groups of fossils, are largely miragelike hopes. As consequence, not only micropaleontologists but stratigraphers in general increasingly use planktonic foraminiferal zones informally for a basic Cenozoic time scale.

A phrase used above needs emphasis, namely, ". . . wherever planktonic foraminiferal zonation can be applied . . .". Stratotypes of classical stages were selected largely on the basis of plentiful marine fossils, such as mollusks, echinoids, corals or, locally, nummulites. Richly fossiliferous beds of this type are symptomatic of shallow, nearshore environments, whereas beds rich in planktonic microfossils typify deep, offshore facies; the two are mutually exclusive. One of the first attempts to equate the European stages with planktonic zones was by DROOGER (1956) who found a direct approach impossible in most cases and so applied indirect correlations based on miogypsinid evolution. Many difficulties of this sort remain unsolved, a good example of them being found in western France. There, wells in the Parentis oilfield and exploratory wells in this basin-axis sector encounter marine clay in which Late Eocene to Middle Miocene planktonic foraminiferal zones can be identified reasonably well. The Girondian Stage is typified by part of this sequence. Between the

Table 5. *Neogene Superstages Proposed (but Not Accepted) at the 1971 Lyon Session of the Committee on Mediterranean Neogene Stratigraphy.*[1]

	DROOGER & MARKS	CITA ET AL.
Pliocene	Ardian Superstage[2]	
	To be defined	Crisis of salinity
Upper Miocene	Castellanian Superstage	Perletian Superstage
	Globorotalia acostaensis Datum	
Middle Miocene	Bubbian Superstage	Cessolian Superstage
	Praeorbulina Datum	
Lower Miocene	Girondian Superstage[3]	
	Miogypsina gunteri Datum	
	Globigerinoides Datum	
Oligocene		

[1] All stratotypes of these new units are in northern Italy, and the two superstages of CITA ET AL. differ in little more than names from equivalents in the sequence of four of DROOGER & MARKS. In effect they represent the four classical units of Lower, Middle, and Upper Miocene and Pliocene, with boundaries redefined in an unequivocal manner.

[2] Homonym of Ardian as used by MOORE & THOMPSON (1949, p. 287) for a Lower Pennsylvanian unit.

[3] Adopted from VIGNEAUX and coworkers.

subsurface at Parentis and exposures around the rim of the Aquitaine basin, however, these offshore deposits merge into shallower facies which include the Aquitanian and Burdigalian stratotypes. Despite much detailed study and numerous publications in the past dozen years, adequate precisely documented correlation between surface and subsurface still is unavailable. A closely comparable case is observed in Miocene deposits of the American Gulf Coast region where stages are based perforce on shallow-marine facies in the outcrop belt and planktonic foraminiferal zones are recognizable only in a few tongues of marine shale deep in the subsurface to the south.

PALEOCENE TO MIDDLE EOCENE ZONATION

GENERAL

The end of Cretaceous time was marked by extinction of the genera *Globotruncana* and *Rugoglobigerina* and of the costate heterohelicids, all of which were abundant and conspicuous components of the Late Cretaceous plankton. The earliest assemblages assigned to the Paleocene Series of the Paleogene consist exclusively of very small individuals of *Globigerina* and *Globorotalia* characterized by globular to ovate chambers. Such faunas have been recorded widely but sporadically and are regarded generally as the root stock of the principal Paleogene planktonic foraminiferal lineages.

They also have been treated as a dwarfed relict of the Cretaceous plankton.

Larger but still simple species of *Globigerina* and *Globorotalia* began to appear in the Early Paleocene and these gave rise to lines of increasingly specialized forms which extended into the Eocene. Typical of the Paleocene were smooth, flattened globorotalias comprising plentiful long-ranging groups which became progressively more hispid to spiny, angular-conical, and eventually strongly keeled. The Paleocene-Eocene boundary is not defined sharply in the evolving sequences. More apparent is the division between Early Eocene and Middle Eocene where several strikingly distinct genera made their appearance (notably *Hantkenina, Globigerinatheka* including *Globigerapsis*, and *Clavigerinella*).

In the course of Middle Eocene time evolution of the new genera proceeded rapidly and precursors of Late Eocene and Oligocene lineages appeared. The Middle Eocene-Late Eocene boundary coincides with abrupt extinction[1] of the prominently hispid to spiny tests whose abundance typified Paleocene through Middle Eocene plankton.

Genera and species groups most typical of Paleocene and Eocene subdivisions in low and middle latitudes are used in foraminiferal zonations. Utility of planktonic species is greatly reduced in higher latitudes by the lack of most marker forms conspicuous in tropical, subtropical, and temperate areas. Consequently, other planktonic microfossils (nannoplankton, dinoflagellates) are being used more for subdivision of Paleogene deposits in high latitudes (e.g., North Sea basin in Europe).

DEVELOPMENT OF ZONATION

Increase in the use of planktonic foraminifers for guidance in subdividing and correlating Paleogene deposits is a good example of the interrelation of industrial and academic researches on microfossils. After the value of planktonic foraminifers in stratigraphic studies was demonstrated by a few academic workers (e.g., RENZ, 1936; GLAESSNER, 1937a,b), rapid expansion of interest was due mainly to industry in post-World-War II years. In the western hemisphere a group of micropaleontologists under H. G. KUGLER developed a detailed subdivision based on Paleogene planktonic foraminifers in the Caribbean region, especially Trinidad. Equivalent results in the eastern hemisphere were obtained by paleontologists of oil trusts in the Soviet Union especially in the northern Caucasus region. Papers by BOLLI (1957a-c) and SUBBOTINA (1953, 1960) deserve mention as major stepping stones between the obscurity of planktonic foraminiferal zonation developed by academic workers and worldwide acceptance of planktonic fossils as important new stratigraphic tools sharpened in the hands of industrial workers. Subsequent refinements of the pioneer zonal schemes were proposed by ALIMARINA (1963), BLOW & BANNER (1962), BLOW (1969), BOLLI (1966a), GOHRBANDT (1963), HILLEBRANDT (1962, 1965), SHUTSKAYA (1956, 1958, 1960a-b, 1962, 1965), and many others.

The present brief summary makes no attempt to review extensively all available literature on Paleocene to Middle Eocene planktonic foraminifers nor to discuss all proposed zonations (many merely for local use). Such reviews already exist in publications here cited in discussions and in the accompanying bibliography. An outstanding contribution is the compilation by KRASHENINNIKOV (1969), and other useful summaries include those of BERGGREN (1960b, 1965a), EL-NAGGAR (1969a,b), YANSHIN ET AL. (1960), SEROVA (1969), BRATU & GHETA (1972), KENAWY (1972), and SAMUEL (1972a,b). General agreement probably exists now on the main trends in evolution of Paleogene planktonic foraminifers and on major stratigraphic partitions based on this evolution. Although consensus may be hidden by the use of differing names for species and zones, basic validity of the schemes now appears to be established firmly (Fig. 12). Future work undoubtedly will lead to modifications, especially in taxonomy, and regrettably may necessitate abandonment of some very commonly used names (as has happened already in forms such as *Porticulasphaera mexicana, Globorotalia centralis,* and *Globigerina yeguaensis*).

Among the zonal schemes proposed for the Paleocene-Eocene interval under discussion, the most frequently cited appears to be that of BOLLI (1957a,c; 1966a). We have adopted it also in the present compilation so that our sequence of zonal divisions is identical with BOLLI'S, altered only in

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[1] In strict terms hispid-spinose forms did not disappear completely, but they did change suddenly from a conspicuous to insignificant element in the faunas.

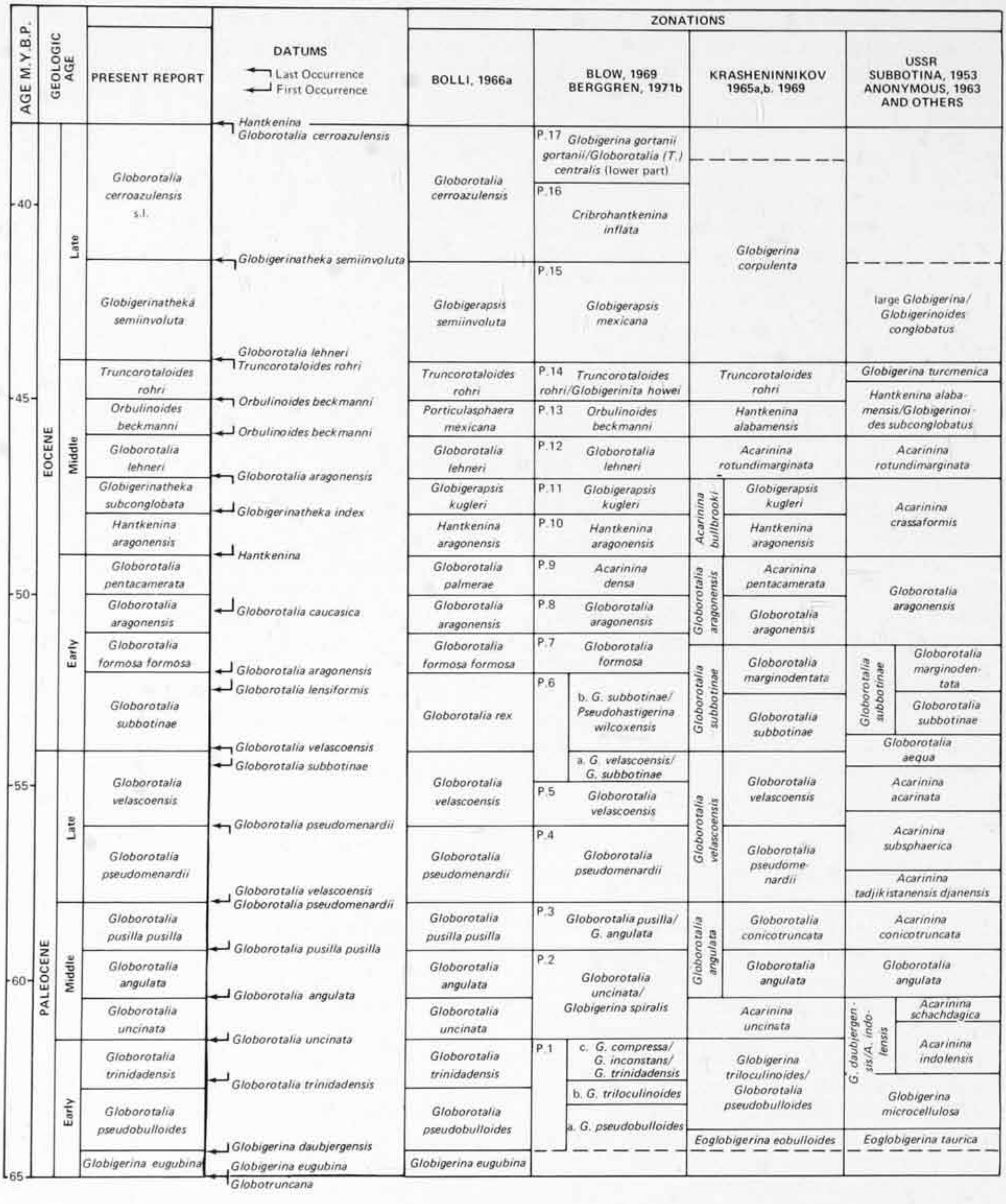


Fig. 12. Planktonic foraminiferal zonation and datums for the Paleocene and Eocene compared with several earlier planktonic foraminiferal zonations.

names given to four of his indices affected by taxonomic revisions. BOLLI (1957a,c) initially used range charts accompanied by generalized verbal descriptions to give faunal characteristics of his zones, but later (1966a) he provided succinct statements on diagnostic features of the zones. Meanwhile and subsequently authors working outside of the Caribbean region encountered difficulties caused by 1) absence or scarcity of index species used in Trinidad, 2) longer zonal ranges than shown on BOLLI'S charts, or 3) gaps or overlaps where the charts show coincidence of extinctions and appearances. Such observations led to modifications which, while minor in an overall sense, make BOLLI'S zonation more widely and accurately applicable to subdivision of Paleogene sediments.

Our zones and those of BOLLI (1966a) are shown (Fig. 12) together with earlier and current Soviet schemes and an undocumented zonation developed by BLOW and BERGGREN (BERGGREN, 1971b, 1972a,b). Close agreement of zonal divisions and species chosen as their markers in these schemes is evident. The datum planes represent faunal levels considered especially reliable for defining and identifying zones. Ranges of the selected index species (appendix) are shown (Fig. 13) in terms of the planktonic foraminiferal zonation which is plotted on a radiometric time scale.

Three of the units are range zones defined by the total life ranges of their index species (*Globigerina eugubina*, *Globorotalia pseudomenardii*, and *Orbulinoides beckmanni*). The remaining 14 are defined by levels of appearance or extinction of selected species and thus are interval zones except for a single concurrent-range zone. The globorotaliid markers, however, are linked genetically to some degree (e.g., BOLLI, 1957a, p. 65-69; LUTERBACHER, 1964, 1966; MCGOWRAN, 1968) so that some zones eventually may be reclassified as lineage zones (phylozones). Names applied to these 14 units serve simply as convenient labels; species so used are **not** necessarily confined to the zones which they designate.

In the following section the 17 Paleocene to Middle Eocene zones are discussed individually. Objective data for each zone are given with such interpretative notes as are deemed helpful. Brief mentions are made of particular cases where taxonomic revisions affect names and definitions of zones; more detailed discussion is given with subsequent reviews of index species. Neither breakdown into subzones nor grouping into superzones is recommended formally, but annotations indicate certain levels at which these procedures might be advantageous locally.

DESCRIPTION OF ZONES

PALEOCENE

Globigerina eugubina Zone

Category: Range zone. **Age**: Early Paleocene.
Author: LUTERBACHER & PREMOLI SILVA (1964).
Definition: Total range of *Globigerina eugubina*.
Characteristics: Typified by very small *Globigerina* with diameter less than 0.10 mm at base of zone, increasing to 0.15-0.20 mm at top; also plentiful small heterohelicids.
Note: First described from Italy but now known patchily around the world, a recent record being on the Nicaragua Rise in the Caribbean sea floor. The *Globigerina taurica* Zone of MOROZOVA (1960), which is the *Eoglobigerina eobulloides* Zone of some later Soviet authors (e.g., KRASHENINNIKOV, 1965a, 1969), contains a more evolved planktonic foraminiferal assemblage and corresponds to the lower part of our *Globorotalia pseudobulloides* Zone.

Locally this zone is not discernible between the Cretaceous and beds of the Paleocene *Globorotalia pseudobulloides* Zone. Authors tend to postulate a hiatus or condensed section, but possibly the characteristic dwarfing resulted from environmental deterioration of differing severity around the world.

A minority holds that the diagnostic fauna is an impoverished relic of the Late Cretaceous plankton (e.g., BERGGREN, 1965b, p. 1481) or even reworked from the Cretaceous (BLOW, 1971, oral suggestion at CMNS meeting in Lyon, 1971).

Globorotalia pseudobulloides Zone

Category: Interval zone. **Age**: Early Paleocene.
Author: LEONOV & ALIMARINA (1961) as *Globigerina pseudobulloides-Globigerina daubjergensis* Zone. Name shortened by BOLLI (1966a,b).
Definition: Interval from the first occurrence of *Globorotalia pseudobulloides* to first appearance of *Globorotalia trinidadensis*.

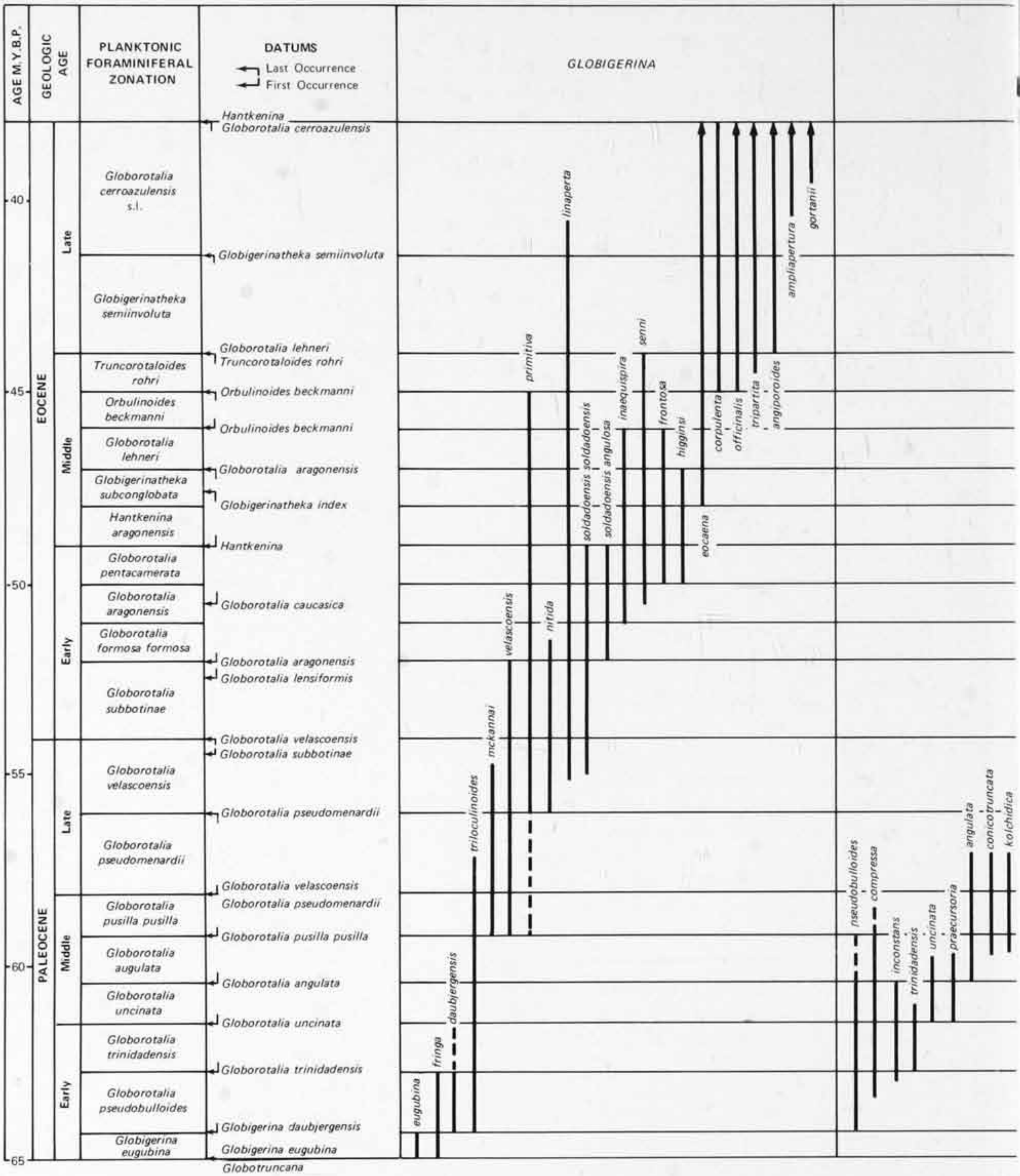
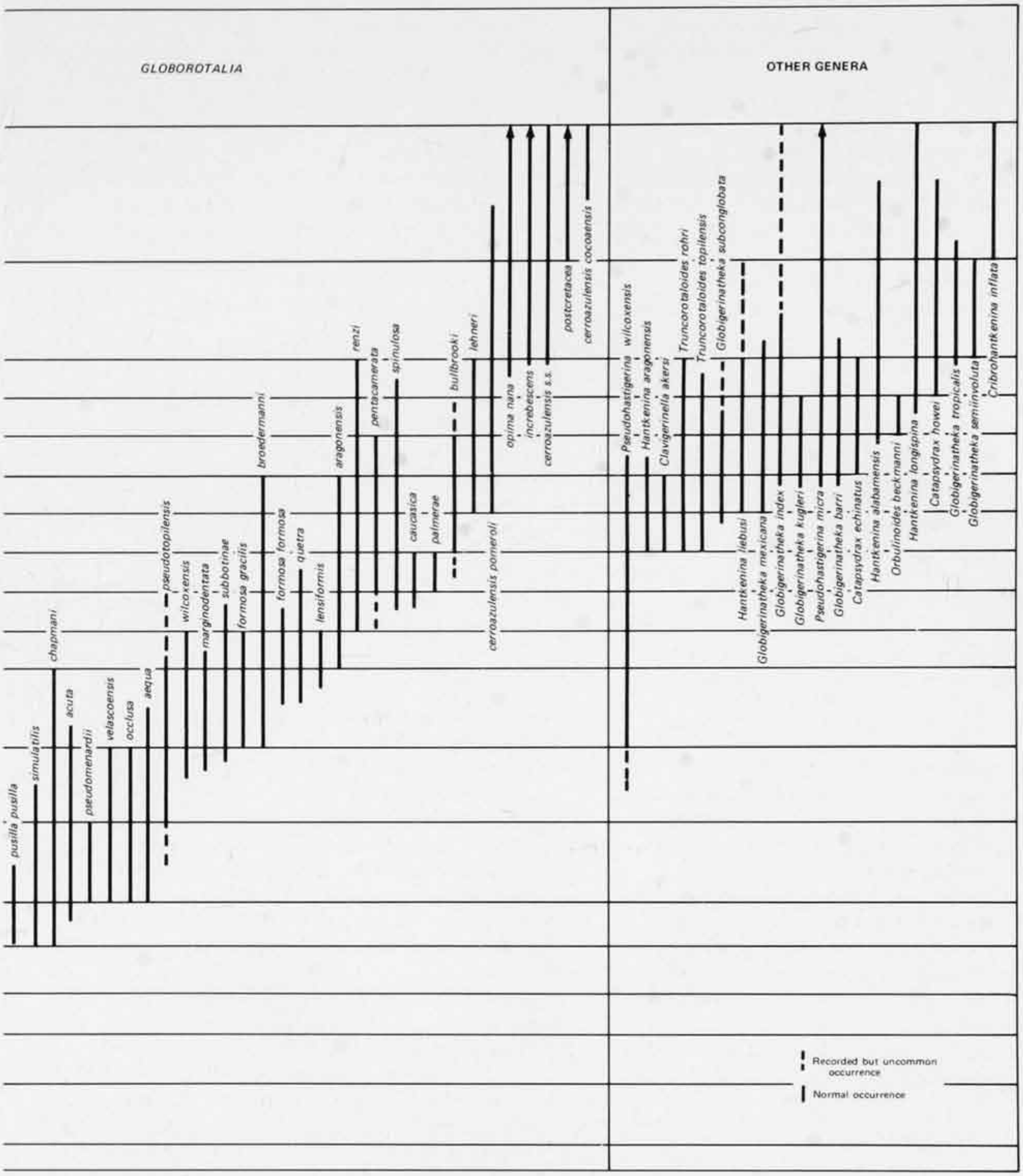


Fig. 13. Planktonic foraminiferal zonation for the Paleocene and Eocene with datums and ranges for selected index species.


GLOBOROTALIA
OTHER GENERA
pusilla pusilla
simulatilis
chapmani
acuta
pseudomenardii
velascoensis
occlusa
aequa
pseudotopilensis
wilcoxensis
marginodentata
subbotinae
formosa gracilis
broedermanni
formosa formosa
quetra
lensiformis
aragonensis
renzi
pentacamerata
spinulosa
caucasica
palmerae
bullbrooki
lehneri
cerroazulensis pomeroli
opima nana
increbescens
cerroazulensis s.s.
postcretacea
cerroazulensis cocoaensis
Pseudohastigerina wilcoxensis
Hantkenina aragonensis
Clavigerinella akersi
Truncorotaloides rohri
Truncorotaloides topilensis
Globigerinatheka subconglobata
Hantkenina liebusi
Globigerinatheka mexicana
Globigerinatheka index
Globigerinatheka kugleri
Pseudohastigerina micra
Globigerinatheka barri
Catapsydrax echinatus
Hantkenina alabamensis
Orbulinoides beckmanni
Hantkenina longispina
Catapsydrax howei
Globigerinatheka tropicalis
Globigerinatheka semiinvoluta
Cribrohantkenina inflata
Recorded but uncommon occurrence
Normal occurrence

Characteristics: Assemblages of *Globorotalia pseudobulloides, Globigerina triloculinoides*, and *Globigerina daubjergensis* within which evolutionary trends are applicable to further subdivision (HOFKER, 1962). *Globorotalia compressa* appears in upper part.

Notes: First described in Soviet Union and later recognized in the Mediterranean region (e.g., LUTERBACHER & PREMOLI SILVA, 1964; BECKMANN ET AL., 1969) but generally not discernible on American range charts of the Paleocene (e.g., BOLLI, 1957a; RENZ, 1962).

See second paragraph of notes for *Globigerina eugubina* Zone.

Globorotalia trinidadensis Zone

Category: Interval zone. **Age**: Early Paleocene.
Author: BOLLI (1957a).

Definition: Interval from the first occurrence of *Globorotalia trinidadensis* to the first occurrence of *Globorotalia uncinata.*

Characteristics: Joint occurrence of *Globorotalia trinidadensis, Globorotalia pseudobulloides, Globorotalia compressa, Globigerina triloculinoides*, and *Globigerina daubjergensis.*

Note: Originally recognized in Trinidad and later in several sectors of the Mediterranean region.

Globorotalia uncinata Zone

Category: Interval zone. **Age**: Middle Paleocene.
Author: BOLLI (1957a); modified BOLLI (1966a).

Definition: Interval from the first occurrence of *Globorotalia uncinata* to the first occurrence of *Globorotalia angulata.*

Characteristics: *Globorotalia uncinata* and *Globorotalia praecursoria* (which also appears for the first time) are transitional between primitive *Globigerina*-like forms of this genus and angular-conical forms about to become dominant.

Note: BOLLI'S original usage included this and the overlying zone.

Globorotalia angulata Zone

Category: Interval zone. **Age**: Middle Paleocene.
Author: ALIMARINA (1963) as *Acarinina angulata* Zone. Present name introduced by HILLEBRANDT (1965).

Definition: Interval from first appearance of *Globorotalia angulata* to first occurrence of *Globorotalia pusilla pusilla.*

Characteristics: The lowest interval containing species of *Globorotalia* having angular-conical to angular-rhomboidal chambers throughout their ontogeny; *G. angulata, G. conicotruncata,* and *G. kolchidica* are representative of the group.

Note: Originally described in Soviet Union and later recognized in Trinidad (BOLLI, 1957a, p. 63), Europe, and north Africa (BECKMANN ET AL., 1969; BERGGREN, 1969a).

Globorotalia pusilla pusilla Zone

Category: Interval zone. **Age**: Middle Paleocene.
Author: BOLLI (1957a).

Definition: Interval from first occurrence of *Globorotalia pusilla pusilla* to first occurrence of *Globorotalia pseudomenardii.*

Characteristics: *Globorotalia conicotruncata* tends to become the dominant species. The distinctive *Globorotalia chapmani*, ancestor of the genus *Pseudohastigerina*, first appears low in this zone as does *Globorotalia simulatilis.*

Note: First recognized in Trinidad and later recorded in Europe and north Africa.

Globorotalia pseudomenardii Zone

Category: Range zone. **Age**: Late Paleocene.
Author: BOLLI (1957a).

Definition: Total range of *Globorotalia pseudomenardii.*

Characteristics: *Globorotalia velascoensis* first appears near the base of this zone, which is commonly rich in this and other large and heavily ornamented species. *Globorotalia pusilla laevigata, Globorotalia acuta, Globorotalia occlusa,* and *Globorotalia aequa* are normal elements along with species of the *Globorotalia angulata* group persisting from lower zones.

Notes: First described in Trinidad and later recorded in many countries.

The several species that have strong ornamentation of spines, which fuse commonly into peripheral keels and umbilical collars, are restricted largely to tropical and subtropical areas. In more temperate regions their place is taken by spiny, globular species of *Globigerina*, such as *G. mckannai* and *G. nitida*, commonly in impoverished assemblages which cannot be attributed to one or other of the two Late Paleocene zones.

Globorotalia velascoensis Zone

Category: Interval zone. **Age**: Late Paleocene.
Author: BOLLI (1957a).

Definition: Interval from last occurrence of *Globorotalia pseudomenardii* to last occurrence of *Globorotalia velascoensis.*

Characteristics: The name fossil is not an ideal index because of climatic and ecologic limitations in distribution; it may be missing even in tropical and subtropical assemblages where the zone is recognized by presence of *Globorotalia occlusa* and *Globorotalia acuta* in the absence of species restricted to older or younger zones.

Note: First established in Trinidad but now is recognized internationally.

EOCENE

Globorotalia subbotinae Zone

Category: Interval zone. **Age**: Early Eocene.

Author: This is essentially the *Globorotalia rex* Zone of BOLLI (1957a, 1966a) although his original definition was not stated clearly and his later one assumed no overlap in ranges of *Globorotalia velascoensis* and *Globorotalia rex. Globorotalia subbotinae* MOROZOVA (1939) is a senior synonym of *G. rex* MARTIN (1943) and, in Soviet literature since 1953, is the accepted index for approximately (but not exactly) the same interval.

Definition: Interval from extinction of *Globorotalia velascoensis* to first occurrence of *Globorotalia aragonensis.*

Characteristics: A normal assemblage in this zone comprises *Globorotalia subbotinae, Globorotalia marginodentata, Globorotalia formosa gracilis, Globorotalia wilcoxensis, Globigerina soldadoensis soldadoensis,* and *Globigerina nitida.* In the lower part *Globorotalia aequa* generally appears frequently.

Notes: This zone is recognized around the world in a broad sense, but authors differ in definition of its boundaries because most faunal changes in this interval are gradual and evolutionary; examples are the presumed development of *Globorotalia subbotinae* and *Globorotalia formosa* from *Globorotalia aequa* and of *Pseudohastigerina wilcoxensis* from *Globorotalia chapmani.*

The single specimen figured by BOLLI (1957a, pl. 18, fig. 10-12) as the zonal marker is not, in fact, *Globorotalia subbotinae* (= *G. rex*) but rather an abnormal form of *Globorotalia aequa* (i.e., LUTERBACHER, 1964, p. 678).

Globorotalia formosa formosa Zone

Category: Interval zone. **Age**: Early Eocene.

Author: This zone was named by BOLLI (1957a) but later authors recommended different criteria for determining its boundaries (e.g., LUTERBACHER, 1964, p. 717; BOLLI, 1966a, p. 18; BECKMANN ET AL., 1969, p. 97).

Definition: Interval from first occurrence of *Globorotalia aragonensis* to first occurrence of *Globorotalia pentacamerata* (=*G. aspensis* of authors).

Characteristics: A normal assemblage contains the *Globorotalia formosa* group, *Globorotalia quetra, Globorotalia pseudoscitula, Globigerina soldadoensis soldadoensis, Globigerina soldadoensis angulosa,* and *Globigerina primitiva.* BOLLI defined the top as the first appearance of *Globigerina taroubaensis* and *Globigerina turgida,* but qualified these as rather indistinct; BECKMANN ET AL. recognized this level by a sharp decrease in frequency of the *Globorotalia formosa* group coincident with earliest appearance of conspicuous *Globigerina aspensis* (=*Globorotalia pentacamerata* herein) and common, typical *Globorotalia aragonensis.*

Note: This zone was established first in Trinidad and since has been recognized by many authors; it has not been adopted in Soviet Union zonations.

Globorotalia aragonensis Zone

Category: Interval zone. **Age**: Early Eocene.
Author: BOLLI (1957a).

Definition: Interval from first occurrence of *Globorotalia pentacamerata* (=*G. aspensis*) to first occurrence of *Globigerina frontosa* (=*G. boweri*) or *Globorotalia palmerae.*

Characteristics: The most common assemblage throughout the zone is *Globorotalia aragonensis, Globorotalia pentacamerata, Globigerina soldadoensis soldadoensis,* and *Globigerina soldadoensis angulosa. Globorotalia subbotinae* (=*G. rex*), *Globorotalia formosa formosa,* and *Globorotalia lensiformis* persist only into the lower part whereas the very conspicuous *Globorotalia caucasica* appears only in the upper part.

Notes: First established in Trinidad and now recorded internationally.

Criteria applied in Trinidad by BOLLI (1957a, 1966a) have not proved acceptable elsewhere as summarized by BECKMANN ET AL. (1969).

Globorotalia pentacamerata Zone

Category: Interval zone. **Age**: Early Eocene.

Author: Introduced by KRASHENINNIKOV (1965a-b) as a subzone corresponding to the *Globorotalia palmerae* Zone of BOLLI (1957c) which is not recognizable generally as such outside the Caribbean region.

Definition: Interval from first appearance of *Globigerina frontosa* (=*G. boweri*) to first occurrence of *Hantkenina aragonensis.* Alternative marker levels are appearance of *Globorotalia palmerae* at the base and extinction of *Globigerina soldadoensis soldadoensis* at the top.

Characteristics: The typical assemblage consists of *Globorotalia pentacamerata* (=*G. aspensis*), *Globorotalia aragonensis*, *Globorotalia spinuloinflata* (of authors), and *Globigerina frontosa;* the first named may be very abundant, forming almost monospecific assemblages. *Globorotalia palmerae* is restricted to this zone but has a limited geographic distribution.

Note: This interval has achieved worldwide recognition, but precise separation is difficult because most species typical of the zone had already appeared gradually within the preceding *Globorotalia aragonensis* zone. KRASHENINNIKOV (1965a-b) treated the two as subzones of an embracive *G. aragonensis* Zone. In an early phase of this compilation we contemplated a comparable recognition of *Globorotalia aragonensis* and *Globorotalia palmerae* Subzones comprising a *Globigerina soldadoensis* Zone. In New Zealand the Zone of *Globorotalia crater (?=G. caucasica)* seems to represent both our zones (JENKINS, 1965a-b, 1971).

Hantkenina aragonensis Zone

Category: Interval zone. **Age**: Middle Eocene.

Author: BOLLI (1957c).

Definition: Interval from first occurrence of *Hantkenina aragonensis* to first occurrence of *Globigerinatheka mexicana* (s. s.). Alternative criteria for the base are extinction of *Globigerina soldadoensis soldadoensis* and first appearance of common, typical *Globorotalia bullbrooki.*

Characteristics: An important feature of this zone is the first appearance of several new genera, notably *Hantkenina, Globigerinatheka, Clavigerinella,* and *Globorotaloides.* Dominant constituents of the assemblages are *Globorotalia bullbrooki, Globorotalia spinulosa, Globigerina senni,* and *Globigerina inaequispira.*

Notes: This zone was established first in Trinidad and now is recognized internationally.

The simple definition by BOLLI (1966a) as the total range of *Hantkenina aragonensis* has been modified because this species ranges into younger zones outside Trinidad. The patchy distribution of this and other species of *Hantkenina* makes them unreliable for precise delineation of zones so that some authors preferred to use *Globorotalia bullbrooki* as the main index for this interval.

This is the oldest of five zones applied to the Middle Eocene in warm-water regions. Paucity of zonal markers may hinder their recognition in temperate regions where the recommended division is into only two parts—the lower containing mainly *Globorotalia bullbrooki, Globorotalia spinulosa,* and *Globorotalia aragonensis* and the upper containing *Globorotalia lehneri, Globigerina corpulenta,* and *Globigerina eocaena.* An alternative zonation of the Middle and Late Eocene is based on evolution of the *Globorotalia cerroazulensis* group (TOUMARKINE & BOLLI, 1970).

Globigerinatheka subconglobata Zone

Category: Concurrent-range zone. **Age**: Middle Eocene.

Author: This interval is essentially the *Globigerapsis kugleri* Zone of BOLLI (1957c, 1966a) as slightly modified by BECKMANN ET AL. (1969). To accord with current taxonomic revisions, the name was changed to *Globigerinatheka kugleri* Zone almost simultaneously by PROTO DECIMA & BOLLI and by TOUMARKINE & BOLLI (both December 1970). BAUMANN (1970) renamed it *Globigerinatheka subconglobata* Zone without explanation, and BOLLI (1972a) revised the taxonomy of species of *Globigerinatheka* and renamed this interval the *Globigerinatheka subconglobata subconglobata* Zone because his earlier name had become inappropriate.

Definition: Interval from first occurrence of *Globigerinatheka mexicana* (s. s.) to last occurrence of *Globorotalia aragonensis*.

Characteristics: Typical of this zone are assemblages of *Globigerinatheka subconglobata* (s. s.), *Globorotalia bullbrooki*, *Globorotalia spinulosa*, *Globigerina senni*, and *Hantkenina mexicana*. The name species occurs throughout the zone but is not confined to it.

Notes: First established in Trinidad, this zonal interval is now recognized internationally.

In his revision of the genus *Globigerinatheka*, BOLLI (1972a) employed a subspecific nomenclature for precise expression of his concepts of lineages and evolution. Although agreeing with his ideas, we find our broad approach better served by treating the few forms mentioned here as species.

Globorotalia lehneri Zone

Category: Interval zone. **Age**: Middle Eocene.
Author: BOLLI (1957c).

Definition: Interval from last occurrence of *Globorotalia aragonensis* to first appearance of *Orbulinoides beckmanni* (=*Porticulasphaera mexicana* of BOLLI and others).

Characteristics: This zone typically contains assemblages of *Globorotalia lehneri*, *Globorotalia spinulosa*, *Globigerinatheka index*, *Globigerinatheka kugleri*, *Hantkenina mexicana*, and *Hantkenina dumblei*.

Note: First established in Trinidad, this zone has achieved limited recognition elsewhere. It corresponds to the *Acarinina rotundimarginata* Zone of Soviet authors.

Orbulinoides beckmanni Zone

Category: Range zone. **Age**: Middle Eocene.
Author: BOLLI (1957c, 1966a) as *Porticulasphaera mexicana* Zone. Name of index and zone changed to *Orbulinoides beckmanni* by CORDEY (1968b) and BLOW & SAITO (1968).

Definition: Total range of *Orbulinoides beckmanni*.

Characteristics: In addition to the index fossil this zone commonly contains *Globorotalia spinulosa*, *Globorotalia lehneri*, *Globigerinatheka mexicana*, *Globigerinatheka barri*, *Truncorotaloides rohri*, *Truncorotaloides topilensis*, and *Globigerina eocaena*. Early forms of *Globorotalia cerroazulensis* become increasingly frequent upward through the zone.

Note: Recognition of this zone has spread around the world from the Caribbean region (e.g., BECKMANN ET AL., 1969; PROTO DECIMA & BOLLI, 1970). The zonal index has not been reported from Soviet Union where this interval is known as the *Hantkenina alabamensis* Zone.

Truncorotaloides rohri Zone

Category: Interval zone. **Age**: Middle Eocene.
Author: BOLLI (1957c).

Definition: Interval from last occurrence of *Orbulinoides beckmanni* to last occurrence of *Truncorotaloides rohri*.

Characteristics: Assemblages from this zone are characterized by *Globorotalia spinuloinflata* (of authors), *Globorotalia lehneri*, *Truncorotaloides rohri*, representatives of the *Globorotalia cerroazulensis* group, *Globigerina eocaena*, and *Catapsydrax howei*.

Note: First defined in Trinidad, this zone since has been recognized in numerous other countries including Soviet Union. Some authors suggested that the correct specific name of the index is *pseudodubius*, based on *Globigerinoides pseudodubia* BANDY (1949). As emphasized by BECKMANN ET AL. (1969) care should be taken to base identification of this zone only on assemblages which are definitely younger than the *Orbulinoides beckmanni* Zone and not on impoverished assemblages of long-ranging Middle Eocene species.

In a normal marine sequence the abrupt disappearance of all conspicuously spinose to hispid species of planktonic foraminifers denotes the top of this zone and defines the generally accepted boundary between Middle and Upper Eocene. Very small spiny globigerinids may be found occasionally within the Upper Eocene but only in trivial quantities.

AGES OF ZONES

PROBLEMS IN EXPRESSING AGE

For present purposes ages of the Cenozoic zones are expressed preferably in terms of the standard time scale to avoid problems of stage terminology. As was explained in the general introduction, application of planktonic foraminifers to biostratigraphy provided a means of precisely correlating most classical Tertiary stages but, at the same time, demonstrated longstanding errors in their assumed relationships. The time scale based on Paleogene stages in western Europe has undergone much recent scrutiny and revision, but agreement has not been achieved. Since these stages have been used as standards for worldwide chronology, the problem is not confined to Europe. The reader desiring fuller discussion should consult HOTTINGER, LEHMANN, & SCHAUB (1964), POMEROL (1964), BLONDEAU ET AL. (1965), CURRY (1967), CITA (1969), BERGGREN (1971b), and the many references cited therein.

Attribution of planktonic foraminiferal zones to units of the standard time scale by BOLLI (1957a-c, 1966a) was based mainly on convenience and convention. Nevertheless, the scheme proposed by him was adopted by an overwhelming majority of workers and came into widespread general use. The zonally defined limits proposed by BOLLI, moreover, proved to be in reasonable agreement with subdivisions of the Paleogene based on the classical stages of western Europe and, therefore, are adopted as the basis for this compilation.

Because of emphasis on megascopic fossils in the early development of European stratigraphy, type localities of all Paleogene stages are defined in nearshore or even continental deposits containing fossil assemblages characteristic for the middle and higher latitudes. On the other hand, the standard planktonic foraminiferal zonation is based on evolution observed in open-sea deposits of tropical to subtropical latitudes. In most cases, therefore, direct correlation of the type sections of European stages with the planktonic foraminiferal zones is impossible. Instead, correlation of this newer zonation with the classical sequence of stages has to be indirect by comparison with zonations based on fossils which occur at the type localities of the several stages.

Correlation of zonal schemes based on the genera *Nummulites* and *Alveolina* (benthonic larger foraminifers) with the planktonic foraminifers is given on Figure 14. The former are firmly established as age indices in Tertiary stratigraphy because of pioneer studies, such as those of D'ARCHIAC, D'ORBIGNY, DE LA HARPE, and SCHWAGER which later were refined by the well-known work of ROSLOZNIK, BIEDA, LEUPOLD, SCHAUB, and HOTTINGER. Also shown (Fig. 14) is a zonation based on calcareous nannoplankton. As many details still require investigation, the chart presented here doubtless will undergo more or less important changes. Currently, a major point of disagreement is the correlation of planktonic foraminiferal zones and calcareous nannoplankton zones in the interval from the *Globorotalia aragonensis* to the *Globigerinatheka subconglobata* Zone.

CRETACEOUS-TERTIARY BOUNDARY

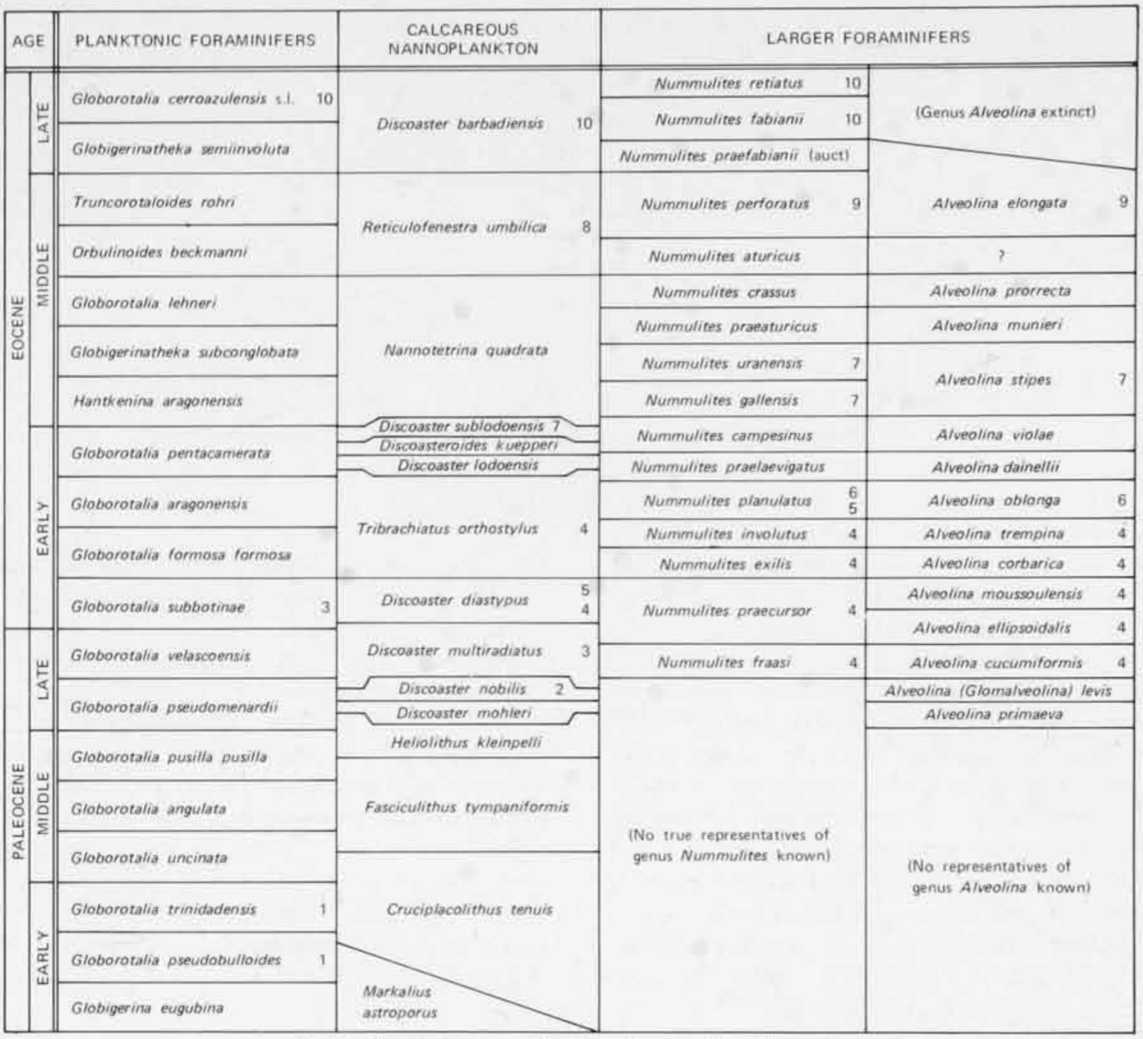
The Danian Stage now is accepted almost universally as earliest Tertiary in contrast to its former treatment as Late Cretaceous or transitional between Cretaceous and Tertiary [e.g., TROELSEN (1957) and references cited there; ROSENKRANTZ & BROTZEN (1960)]. The resulting definition of the Cretaceous-Tertiary boundary is highly convenient for foraminiferologists in making the base of the Paleocene coincide with a strongly defined datum, namely, the abrupt extinction of all the Globotruncanidae and some other exclusively Cretaceous genera.

PALEOCENE

The interval assigned to the Paleocene includes eight planktonic zones (Table 6) just as in the scheme of BOLLI (1966a). Correlation of these Paleocene zones with European stages has been discussed particularly by LUTERBACHER (1964), HILLEBRANDT (1965), and BERGGREN (1971b). It is shown in Figure 14 here.

PALEOCENE-EOCENE BOUNDARY

The most recent international discussions regarding the Paleocene-Eocene boundary were at the Colloque sur l'Eocène held in Paris in 1968 (POMEROL, 1969a). A majority of the participants at this meeting favored drawing the Paleocene-Eocene boundary at the base of the Ilerdian Stage. This datum corresponds to the first occurrence of *Nummulites* and *Assilina*, two genera of larger foraminifers which characterize Eocene deposits of the eastern hemisphere (Nummulitic of older authors). This proposed boundary seems to correspond approximately to the limit between the



Position of some stratotypes of European stages is indicated by numbers:
1 – Danian, 2 – Thanetian, 3 – Landenian, 4 – Ilerdian, 5 – Ypresian,
6 – Cuisian, 7 – Lutetian, 8 – Ledian, 9 – Biarritzian, 10 – Priabonian.

Fig. 14. Tentative correlation of Paleocene-Eocene zonations based on planktonic foraminifers, calcareous nannoplankton (coccoliths of authors), and larger foraminifers. Correlations by LUTERBACHER using particularly BUKRY (1971a) and MARTINI (1971) for the nannoplankton and HOTTINGER & SCHAUB (CITA, 1969) for larger foraminifers. Later interpretations of some zonal relationships are given in CARO ET AL. (in press, fig. 8).

Thanetian and Sparnacian Stages as recognized in the Paris basin. As these two stages are characterized by glauconitic sand in southeastern England and lignitic clay in northern France, their boundary obviously is ill-suited for chronologic interpretation.

One group of European workers who contributed to the Paris symposium favored adherence to the original Paleocene top which, despite ambiguity of its definition by SCHIMPER (1874) (see POMEROL, 1969b), they placed at the base of the Cuisian Stage. This boundary corresponds to the top instead of the base of the Ilerdian. The lower limit of the Cuisian is well defined by its correspondence to the base of the *Nummulites burdigalensis–N. planulatus* Zone and *Alveolina oblonga* Zone, the bottom of these two zones being close to the top of the *Globorotalia formosa formosa* Zone. Accepting these correlations, some European authors (e.g., HILLEBRANDT, 1965; LUTERBACHER, 1969) have included the *Globorotalia subbotinae* and *Globorotalia formosa formosa* Zones in the Paleocene.

In terms of planktonic foraminiferal zonation,

Table 6. *Paleocene Planktonic Foraminiferal Zones.*[1]

PALEOCENE	Late Paleocene	*Globorotalia velascoensis* Zone
		Globorotalia pseudomenardii Zone
	Middle Paleocene	*Globorotalia pusilla pusilla* Zone
		Globorotalia angulata Zone
		Globorotalia uncinata Zone
	Early Paleocene	*Globorotalia trinidadensis* Zone
		Globorotalia pseudobulloides Zone
		Globigerina eugubina Zone

zones up to and including that of *Globorotalia velascoensis* are almost universally agreed to belong in the Paleocene. Our present compilation leads us to agree with majority opinion in equating the Paleocene-Eocene boundary with the *Globorotalia velascoensis-Globorotalia subbotinae* (=*G. rex*) zonal boundary. This Paleocene top is close to the base of the Ilerdian Stage. Nominally this level corresponds to disappearance of the heavily ornamented *Globorotalia velascoensis* and its replacement by less elaborate forms, such as *Globorotalia subbotinae, Globorotalia aragonensis*, and *Globorotalia formosa.* In practice, however, owing to gradational lineages and to climatic control of distribution, this zonal boundary is somewhat obscure locally.

EARLY EOCENE

The Early Eocene, as traditionally interpreted by European authors, extends from the Paleocene top to the base of the Lutetian Stage, a unit based on the Calcaire Grossier which is lithologically prominent in the Paris basin. The base of the Lutetian in the type area is well characterized by *Nummulites laevigatus* (=*Nummulites gallensis* and *Nummulites uranensis* Zones indicated in Figure 14) and *Alveolina stipes.* Calcareous nannoplankton from the stratotype of the Lutetian Stage represents the *Discoaster sublodoensis* Zone. By correlation with more open-marine deposits, the base of the Lutetian falls within the *Hantkenina aragonensis* Zone.

In terms of planktonic foraminiferal zonation, the Early Eocene-Middle Eocene boundary in almost all published zonal schemes is drawn at the base of the *Hantkenina aragonensis* Zone, a level clearly defined in planktonic assemblages by first appearance of such distinctive genera as *Hantkenina, Clavigerinella*, and *Globigerinatheka.* Between this datum and the preferred Paleocene top are four zones which we date as Early Eocene (Table 7).

MIDDLE EOCENE

Classical Middle Eocene stratigraphic units are based on clearly defined sedimentary cycles observed in the Paris basin, collectively named the Lutetian Stage. This stage survived difficulties of lateral tracing through different facies and hiatuses marked by disconformities at both base and top of the section in the type area.

In zonations based on larger foraminifers the Middle Eocene extends from the base of the

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[1] Grouping of zones as Early, Middle, and Late Paleocene and formalization of this concept by capitalization of initial letters reflect an attempt at consistent usage that seems reasonable on the basis of currently available information and is convenient for the present report. General agreement on such formal age assignment presently is lacking for the Paleocene, however, and other interpretations well may gain wide acceptance or be preferred now by others.

Nummulites gallensis and *Alveolina stipes* Zones to the top of the *Nummulites perforatus* and *Alveolina elongata* Zones (Fig. 14). In terms of planktonic foraminiferal zonation the upper limit of the stage is drawn close to the boundary between the *Truncorotaloides rohri* and *Globigerinatheka semiinvoluta* Zones.

Although larger foraminifers and megafossils belonging to other phyla traditionally have provided criteria for recognizing the Middle Eocene, this interval happens also to be a clearly marked natural division in the hierarchy of planktonic foraminiferal zones (Table 8). As already noted, its base coincides with appearance of several distinctive genera and its top is marked by abrupt extinction of several lines of spiny to hispid planktonic foraminifers, which up to this level are a conspicuous element in Paleogene assemblages.

LATE EOCENE

Late Eocene zones are discussed in the following section because of their strong Oligocene affinities with respect to both faunal lineages and, in many places, sedimentary cycles. Broadly diagnostic characters of the Late Eocene planktonic foraminiferal assemblages are presence of smooth-shelled species of *Globorotalia* (notably *G. cerroazulensis* sensu lato), distinctive genera not known to persist into the Oligocene (particularly *Globigerinatheka*, *Hantkenina*, and *Cribrohantkenina*), and an intergrading plexus of large species of *Globigerina*, which we designate as the *Globigerina linaperta* group; all virtually lacking species having hispid tests.

Table 7. *Early Eocene Planktonic Foraminiferal Zones.*

EARLY EOCENE	*Globorotalia pentacamerata* Zone
	Globorotalia aragonensis Zone
	Globorotalia formosa formosa Zone
	Globorotalia subbotinae Zone

Table 8. *Middle Eocene Planktonic Foraminiferal Zones.*

MIDDLE EOCENE	*Truncorotaloides rohri* Zone
	Orbulinoides beckmanni Zone
	Globorotalia lehneri Zone
	Globigerinatheka subconglobata Zone
	Hantkenina aragonensis Zone

LATE EOCENE TO MIDDLE MIOCENE ZONATION

GENERAL

Planktonic foraminifers of this interval evolved partly gradually and partly spasmodically from antiquated to modern-looking assemblages. The earliest event, defining the Middle Eocene-Late Eocene boundary, was abrupt disappearance of the hitherto conspicuous group of spinose to hispid, commonly planoconvex species of *Globorotalia*. These were replaced by smooth-shelled species of the *G. cerroazulensis* and *G. increbescens* lineages and the less conspicuous *G. opima nana* and *G. postcretacea*. Several distinctive, almost experimental, genera which had appeared during the Middle Eocene flourished through the Late Eocene (e.g., *Globigerinatheka* [including *Globigerapsis* of authors] and especially *Hantkenina* with its seemingly phylogerontic offshoot *Cribrohantkenina*). Also a robust strain of large species of *Globigerina* appeared, rooted in the earlier *G. triloculinoides* and *G. linaperta* (note STAINFORTH, 1974). Pronounced but intergradational variability within this group makes nomenclature difficult at the species level, but dominance of the plexus (*Globigerina angiporoides, G. eocaena, G. tripartita, G. venezuelana*, and related forms) is strongly suggestive of Late Eocene.

The base of the Oligocene is marked by a second abrupt wave of extinctions which affected many forms already mentioned. In this instance the vanished genera and species were not replaced immediately, so that Oligocene assemblages commonly have a blandly negative aspect because neither Eocene indices nor equally distinctive Miocene markers occur. Nevertheless, a few species are either confined to or only abundant in the Oligocene, notably some species of *Globigerina* which partly are endforms of Eocene lineages (e.g., *G. ampliapertura, G. gortanii* s. s., *G. ciperoensis* s. s., *G. sellii, G. binaiensis*, and *G. angulisuturalis). Also important are *Globorotalia opima opima* and in very latest Oligocene *Globorotalia kugleri*.

Early Miocene planktonic faunas were distinguished by a great proliferation of foraminifers. Most conspicuous was the tribe of *Globigerinoides quadrilobatus* which was such a successful innovation that its main subspecies have persisted in living faunas. The genus *Globoquadrina*, possibly polyphyletic, suddenly became plentiful and diversified. *Globigerinatella insueta, Globigerinita incrusta*, and early forms of the *Globorotalia fohsi* and *Globorotalia scitula* lineages are other distinctive representatives of the Early Miocene. A negative aspect, however, is lack of any marker species of *Globigerina*.

The change from Early Miocene to Middle Miocene assemblages, gradual in many respects, was pinpointed by appearance of the genus *Orbulina*. This event constitutes the climax of the evolutionary sequence *Globigerinoides sicanus* to *Praeorbulina* spp. to *Orbulina suturalis* and *O. universa*.[1] Also diagnostic of the Middle Miocene is first appearance of the lenticular and eventually carinate *Globorotalia* lineages (*G. fohsi, G. scitula*, and *G. cultrata/G. menardii*) rooted in thicker discoidal species of the Oligocene and Early Miocene. Presence of species of *Sphaeroidinellopsis* suggests Middle or younger Miocene even though specimens of the *Sphaeroidinellopsis seminulina* group have been recorded at pre-*Orbulina* levels.

The stratigraphic interval under discussion is divided by modern authors into 12 to 18 planktonic foraminiferal zones, among which we find it convenient to recognize the 15 zones described here, including 2 from the Late Eocene, 4 from the Oligocene, 5 from the Early Miocene, and 4 from the Middle Miocene.

DEVELOPMENT OF ZONATION

Of numerous attempts to apply planktonic foraminifers to zonation of the Late Eocene to Middle Miocene interval, those of BOLLI (1957a-c, 1959, 1966a, and others) and of BLOW, in part with BANNER, (1962, 1965, 1969, and others) are judged by us to be pre-eminent (Fig. 15). The authors cited, with worldwide records and collections of major oil companies at their disposal, have presented integrated zonal schemes in which local anomalies and peculiarities were minimized. To an appreciable extent the same zonal intervals and boundary levels are indicated on charts published independently by BOLLI and BLOW and adopted by

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[1] This is the widely held opinion, but some authors disagree, regarding *Orbulina* as a polyphyletic endform (e.g., BANDY, VINCENT, & WRIGHT, 1969).

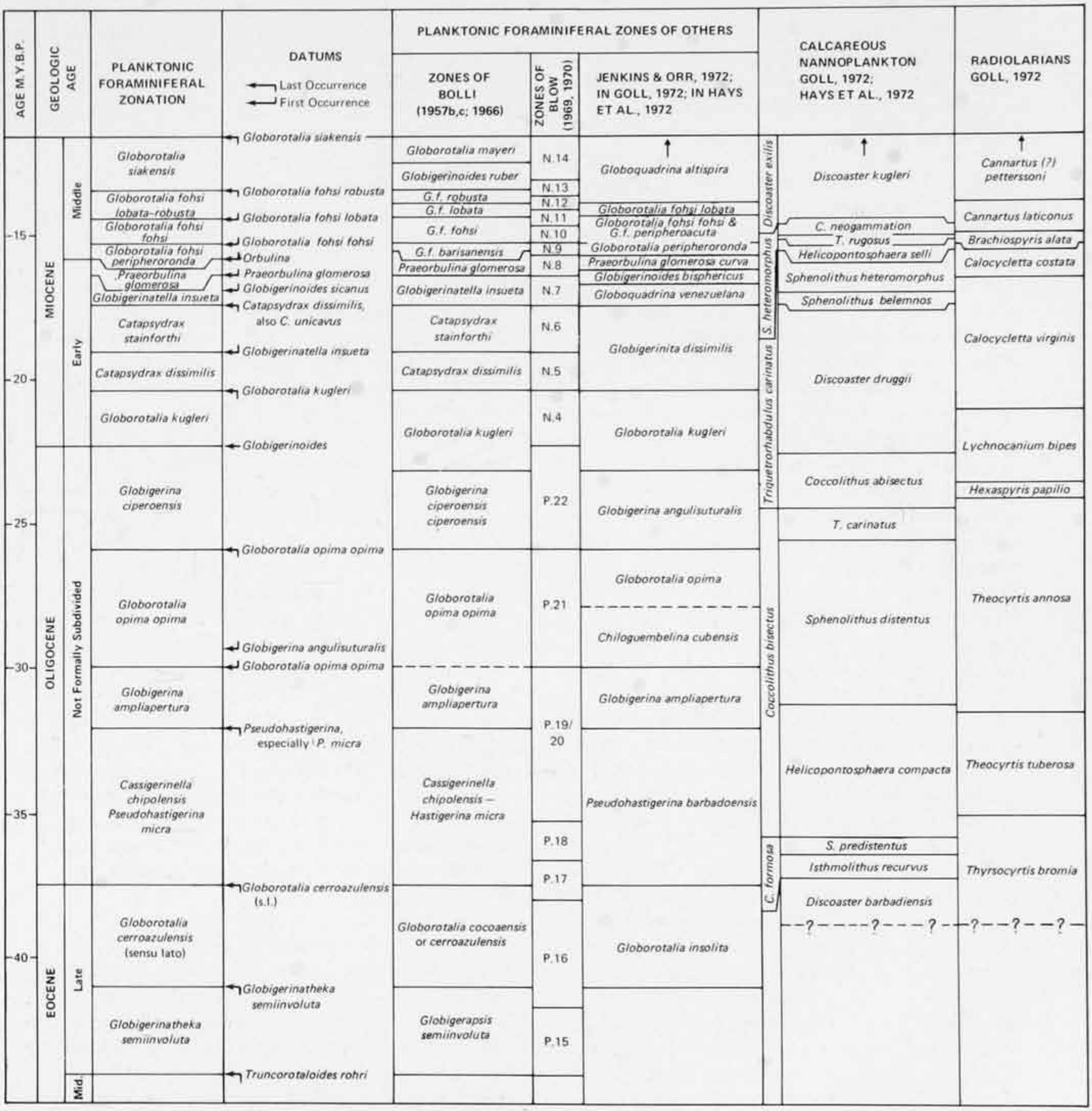

Fig. 15. Tentative correlation of present and earlier planktonic foraminiferal zonations for the Late Eocene to Middle Miocene with datums and nannoplankton and radiolarian zonations. Here the foraminiferal zonation of JENKINS & ORR is related to the present zonation, but the nannoplankton and radiolarian zonations are related only as done by GOLL.

many later authors (a notable example being POSTUMA, 1971). For present purposes it appears logical to accept without discussion the parts of their classification which coincide, but a decision must be made on which author to follow in differently treated stratigraphic intervals. Before considering this aspect in detail some general remarks are in order.

BOLLI has priority in the field. His 1957 zonation, although founded entirely on faunal sequences in Trinidad, became accepted as at least the basis of a worldwide scheme. It was used in this sense in early attempts at transatlantic correlation by BOLLI (1959) and STAINFORTH (1960). In 1966 BOLLI (1966a) condensed his Trinidad data into a master scheme and added tables showing the international validity of his zonal units.

BLOW and his colleagues offered several reasons for their introduction of new zones when a seemingly satisfactory set already existed. These reasons, applicable to different parts of their revision, include 1) supposed or demonstrable gaps in the sequences reported by BOLLI; 2) new evidence showing joint occurrence of species to which BOLLI assigned nonoverlapping ranges (e.g., *Globigerina ampliapertura*, *Globorotalia opima opima*); 3) desirability of emphasizing the *Globigerinoides* Datum and *Orbulina* Datum (which BOLLI did not apply to his definition of zones); 4) desirability of basing more zonal divisions on evolutionary steps in selected lineages (BLOW defined 9 out of 17 levels in this way and BOLLI 4 out of 16); and 5) desirability, as far as practicable, of selecting temperature-tolerant index species rather than strictly tropical forms (e.g., *Globorotalia fohsi robusta*, *Globigerinatella insueta*).

Although many of BLOW'S proposed modifications have undeniable merit, their effect on the **total** established zonation has been slight. Consequently, we here accept BOLLI'S zonal divisions, applying to them BLOW'S criteria mainly for definition and characterization of zones. Further, BLOW'S lead is followed in adjusting zonal contacts to coincide with both the *Globigerinoides* Datum and *Orbulina* Datum, which in BOLLI'S scheme fall within zones. Names applied to the zones are taken from BOLLI (1957b, c, 1966a) except where the name of an index species or subspecies has been changed in taxonomic revisions. Mostly a single name is used to designate each zone, and generally this is treated simply as a label derived from a species-group taxon that normally occurs commonly in the zone but is not confined to it. The category of each unit (range zone, concurrent-range zone, interval zone, lineage zone) is noted in the subsequent section describing the zones and is evident also from the formal definition; the unqualified term zone suffices for most practical purposes.

In contrast with BOLLI'S simple nomenclature, BLOW (1969) applied to every zone a formal and usually lengthy title[1] which served both to name and define the unit. This procedure eliminates any misunderstanding as to the scope of each zone, but the names are much too cumbersome for routine use. The difficulty was circumvented by applying a letter-number designation to each zone, using P. for Paleogene and N. for Neogene and numbering the zones sequentially upward within each subdivision (Fig. 15). This scheme is convenient but open to the general criticism that a code designation contains no inherent clue to stratigraphic level. A more specific defect, arising from controversy over the Oligocene-Miocene boundary, is that the oldest Neogene zone is coded N.4 instead of N.1.

Several apparent faunal anomalies have been encountered within the Oligocene, including differing relative ranges for *Globigerina ampliapertura* and *Globorotalia opima opima*, differing level of first appearance for specimens assignable to *Globigerinoides*, and restricted distribution of *Globigerina gortanii*. Although puzzling when first recorded, these are recognized now as symptoms of paleoclimatic change. The Oligocene generally was cooler than either the Eocene or the Miocene, and types of anomalies just cited reflect influence of temperature gradients on local ranges of stenothermal species. Because paleoclimatic factors affect zonation of the Late Neogene in an especially pronounced manner, temperature fluctuations are treated in some detail in subsequent discussion of that interval.

DESCRIPTION OF ZONES

Here 15 zones are defined and discussed in order of their decreasing age. The top of each zone automatically determines the base of the next higher one. Generally only one species appearance or extinction is nominated as the formal criterion and

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[1] A representative example, neither longest nor shortest in his list, is the "*Globigerinoides quadrilobatus primodius/Globorotalia (Turborotalia) kugleri* Concurrent-range Zone."

this is assigned priority over any other diagnostic features which may be mentioned. A chart showing ranges of the selected index species (described in detail in the Appendix) chosen so as to facilitate recognition of the zones is plotted at a radiometric time scale (Fig. 16).

EOCENE

Globigerinatheka semiinvoluta Zone

Category: Interval zone. **Age**: Late Eocene.

Author: BOLLI (1957c) as *Globigerapsis semiinvoluta* Zone; modified to present form by PROTO DECIMA & BOLLI (1970).

Definition: Base coincides with extinction of *Truncorotaloides rohri;* top defined by extinction of *Globigerinatheka semiinvoluta.*

Characteristics: Lowest interval with no hispid-to-spinose species of *Globorotalia.* Top is close to level of extinction of the genus *Globigerinatheka* (excepting *G. index*) and earliest appearance of *Cribrohantkenina.*

Note: See BOLLI (1972a) for clarification of the name of the zonal index which some authors have claimed to be synonymous with *'Globigerapsis' mexicana.*

Globorotalia cerroazulensis (s. l.) Zone

Category: Interval zone. **Age**: Late Eocene.

Author: BOLLI (1957c) as *Globorotalia cocoaensis* Zone; revised to *Globorotalia cerroazulensis* Zone by BOLLI (1966a) and to *Globorotalia cerroazulensis* (s. l.) Zone by BOLLI (1972a). The current term avoids confusion arising from the division of *Globorotalia cerroazulensis* into subspecies by TOUMARKINE & BOLLI (1970) and application of their ranges to a zonal scheme independent of that of BOLLI (1957b,c, 1966a).

Definition of top: Level of extinction of all subspecies of *Globorotalia cerroazulensis.*

Characteristics: The genus *Cribrohantkenina* and the lenticular subspecies *Globorotalia cerroazulensis cocoaensis* and *G. c. cunialensis* are confined to this zone. The genus *Hantkenina* dies out within the zone and *Cassigerinella chipolensis* first appears at or just above the top.

Note: Many authors considered that extinction of *Hantkenina, Cribrohantkenina, Globigerinatheka index, Globorotalia cerroazulensis* group, and some other forms marks a single event which defines the Eocene-Oligocene boundary. Others, including BLOW (1969), ascribed discrete levels of extinction to the indices and applied them to a fine zonation of the Late Eocene.

OLIGOCENE

Cassigerinella chipolensis-Pseudohastigerina micra Zone

Category: Interval zone. **Age**: Oligocene.

Author: BOLLI (1966a) as *Cassigerinella chipolensis/Hastigerina micra* Zone.

Definition of top: Level of extinction of species of *Pseudohastigerina.*

Characteristics: Joint presence of species of *Pseudohastigerina* and *Cassigerinella chipolensis* is diagnostic; *Globigerina ciperoensis, Globigerina gortanii* (s. s.), and *Globigerina sellii* first appear within this zone.

Note: Zonal division of the latest Eocene and earliest Oligocene has been controversial. We here follow BOLLI (1966a) in steering a middle course between the fine distinctions used by BLOW & BANNER (1962), BLOW (1969), and BERGGREN (1972a) and the over-simplified treatment by BOLLI (1957b-c) and POSTUMA (1971).

Globigerina ampliapertura Zone

Category: Interval zone. **Age**: Oligocene.

Author: Name introduced by BOLLI (1957b); redefined with restricted scope by BOLLI (1966a).

Definition of top: Level of first appearance of *Globorotalia opima opima.*

Characteristics: *Globigerina ampliapertura* usually is conspicuous.

Note: Extinction of *Globigerina ampliapertura* and earliest appearance of *Globigerina angulisuturalis* are useful guides to the top of the zone.

Globorotalia opima opima Zone

Category: Range zone. **Age**: Oligocene.

Author: BOLLI (1957b).

Definition of top: Level of extinction of *Globorotalia opima opima.*

Characteristics: Presence of *Globorotalia opima opima* is diagnostic of this zone; also extinction of *Globigerina gortanii* is a useful guide to its top.

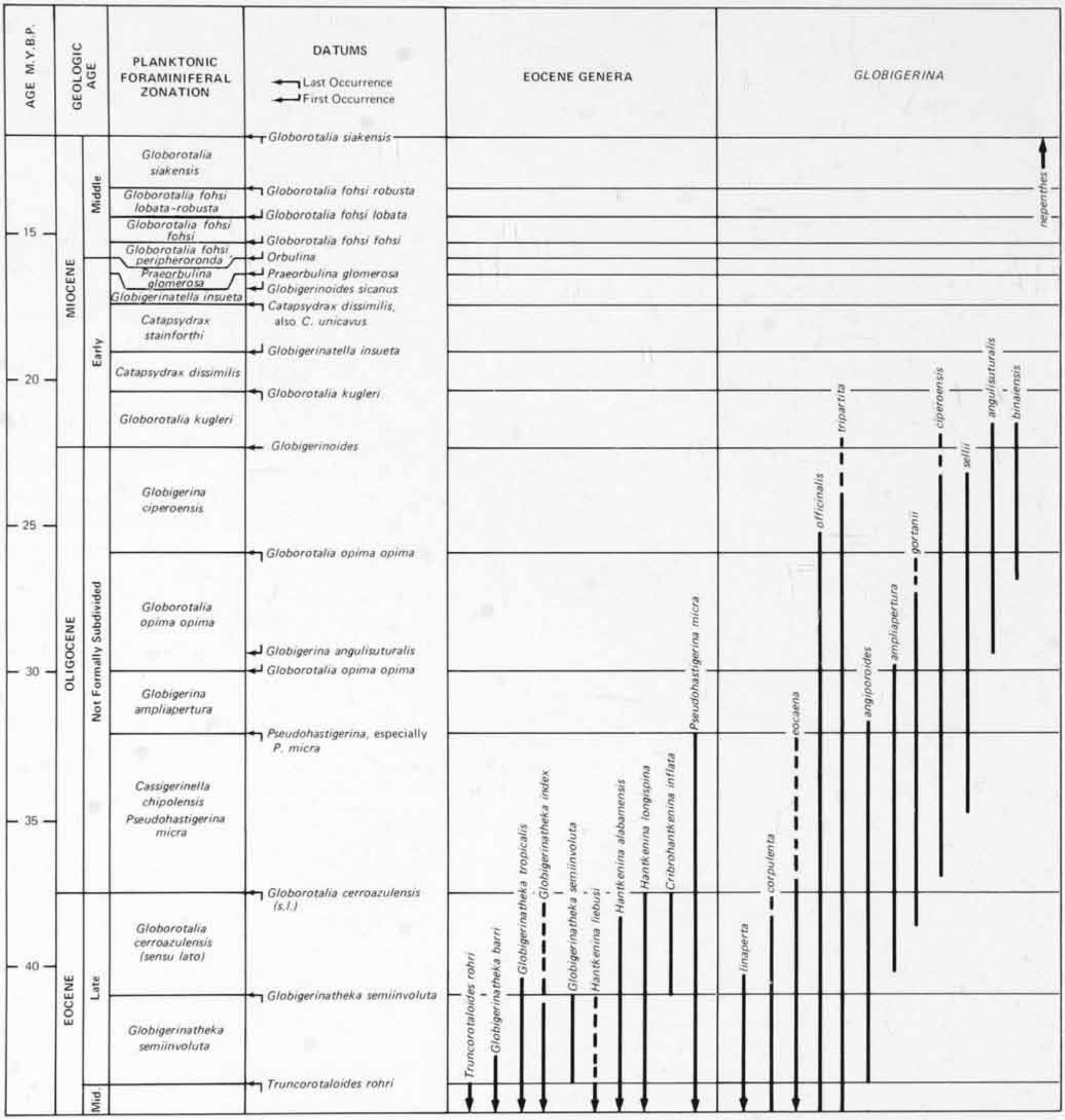
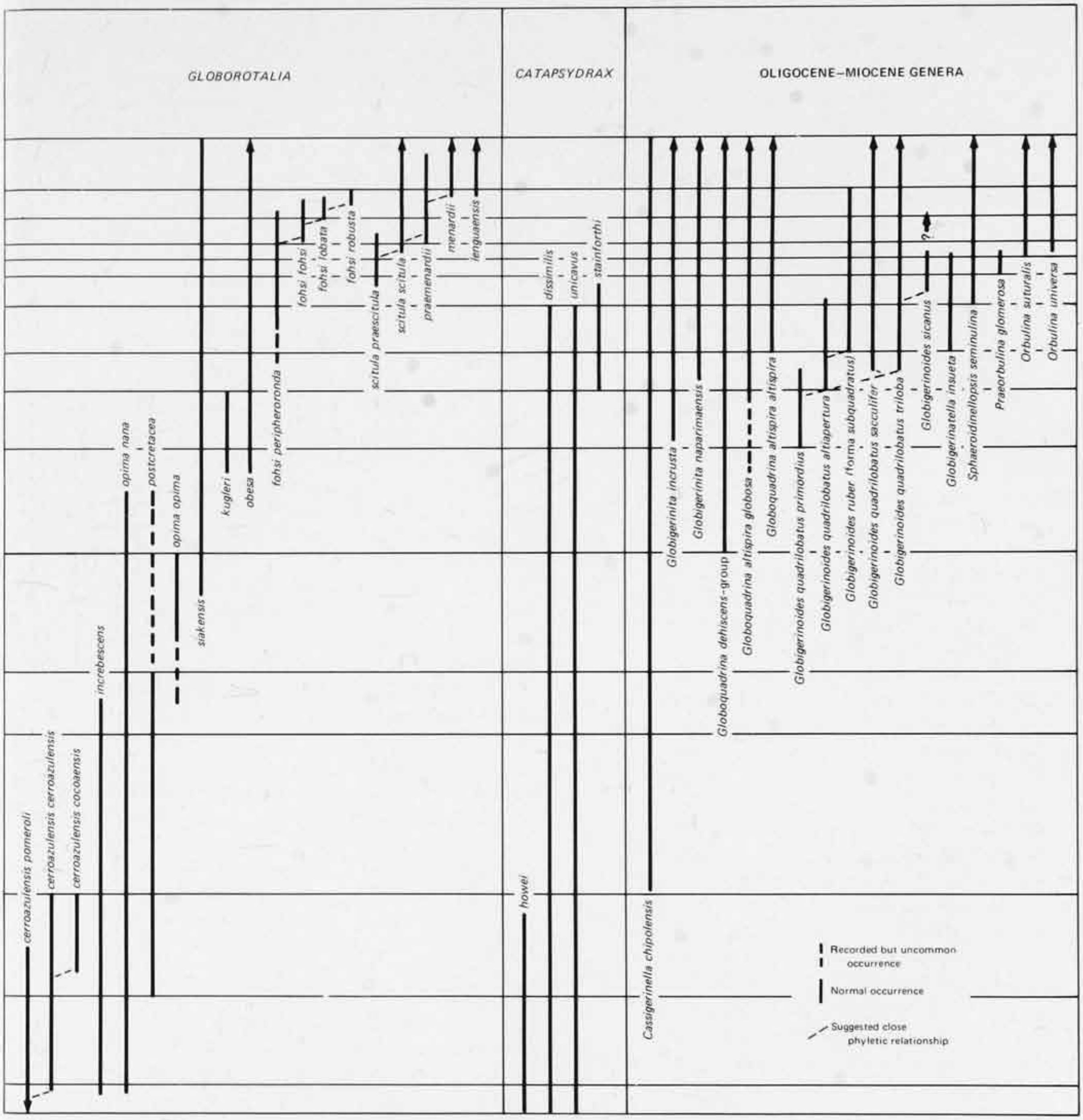


Fig. 16. Planktonic foraminiferal zonation for the Late Eocene to Middle Miocene with datums and ranges for selected index species.


GLOBOROTALIA
CATAPSYDRAX
OLIGOCENE–MIOCENE GENERA
cerroazulensis pomeroli
cerroazulensis cerroazulensis
cerroazulensis cocoaensis
increbescens
opima nana
postcretacea
opima opima
siakensis
kugleri
obesa
fohsi peripheroronda
fohsi fohsi
fohsi lobata
fohsi robusta
scitula praescitula
scitula scitula
praemenardii
menardii
lenguaensis
howei
dissimilis
unicavus
stainforthi
Cassigerinella chipolensis
Globigerinita incrusta
Globigerinita naparimaensis
Globoquadrina dehiscens-group
Globoquadrina altispira globosa
Globoquadrina altispira altispira
Globigerinoides quadrilobatus primordius
Globigerinoides quadrilobatus altiapertura
Globigerinoides ruber (forma subquadratus)
Globigerinoides quadrilobatus sacculifer
Globigerinoides quadrilobatus triloba
Globigerinoides sicanus
?
Globigerinatella insueta
Sphaeroidinellopsis seminulina
Praeorbulina glomerosa
Orbulina suturalis
Orbulina universa
Recorded but uncommon occurrence
Normal occurrence
Suggested close phyletic relationship

Note: As both *Globorotalia opima opima* and *Globigerina gortanii* typify deep-water sediments, identification of this zone may be difficult in shallow-water facies. Locally, presumably under the influence of exceptionally favorable ecologic conditions, large specimens referable to *G. opima opima* appeared unusually early, and we recorded them even within the uppermost range of *Pseudohastigerina micra*. To circumvent such anomalies, BLOW (1969) proposed to redefine the base of the zone at the level of first appearance of *Globigerina angulisuturalis*. This procedure may be preferable locally, but introduces the alternate difficulty of clearly distinguishing between *G. angulisuturalis* and the similar but earlier appearing *Globigerina anguliofficinalis* and *Globigerina ciperoensis*.

Globigerina ciperoensis Zone

Category: Interval zone. **Age**: Oligocene.

Author: The zonal index is the name-giving fossil of the *Globigerina concinna* Zone of CUSHMAN & STAINFORTH (1945). BOLLI (1954) introduced the name *Globigerina ciperoensis* for both species and zone and later (1957b) reduced the scope of the latter appreciably, as the *Globigerina ciperoensis ciperoensis* Zone.

Definition of top: Coincident with the *Globigerinoides* Datum of authors, commonly regarded as the level at which the genus *Globigerinoides* evolved from *Globigerina* (but see further discussion in the notes that follow).

Characteristics: Several distinctive species of *Globigerina* became extinct within this zone, notably *G. angulisuturalis, G. ciperoensis, G. sellii,* and *G. tripartita. Globorotalia kugleri* appeared toward its top.

Note: BOLLI (1957b, 1966a) defined the top of this zone by first appearance of *Globorotalia kugleri* and defined the overlying zone by the short life range of this distinctive species. Such procedure was perfectly reasonable but resulted in the *Globigerinoides* Datum falling within a zone. As this datum has come into such prominence in subsequent studies as a marker level recognizable around the world and now is generally used to define the Oligocene-Miocene boundary, it is illogical to reject it as a zonal boundary. Therefore, we follow the lead of BLOW (1969) in modifying BOLLI'S zonation of this interval.

The concept of many authors, well expressed by BLOW & BANNER (1962, p. 136-139) and BLOW (1969, p. 223-224), is that small trilobate globigerinas developed tiny supplementary apertures along their spiral sutures. From this starting point the *Globigerinoides quadrilobatus* plexus developed profusely and so rapidly that its incipience is an event of worldwide significance in biostratigraphy. It was named the *Globigerinoides* Datum, at first informally in investigations by the Committee on Mediterranean Neogene Stratigraphy. Close equivalence of this foraminiferal datum with the Oligocene-Miocene (basal Aquitanian) boundary in western Europe added to its importance, and it has come to be regarded as the most reliable single guide to this stratigraphic level.

Nevertheless, investigators experienced difficulty in defining the *Globigerinoides* Datum precisely. At the Bologna CMNS meeting in 1967 (CITA, 1968, p. 10-11) attending paleontologists agreed to represent this level on charts, logs, and diagrams by a wavy (sinusoid) line, distinct from the straight horizontal lines assigned to the *Orbulina, Praeorbulina,* and other datum levels which are rather sharply defined by appearance of morphologically distinct planktonic foraminifers. The first supplementary apertures are barely perceptible in *Globigerinoides*, and the level of their earliest recorded appearance differs appreciably from area to area. JENKINS (1960, 1971) indicated for New Zealand that the primitive form *Globigerinoides apertasuturalis* appeared within the Oligocene somewhat earlier than *Globorotalia opima opima,* although *Globigerinoides* did not become abundant there until after the extinction of *Globorotalia kugleri*. SEIGLIE (1973) reported *Globigerinoides trilobus* (sic) *primordius* from Puerto Rico in beds assignable to the Oligocene on other evidence. In material studied for the present compilation we encountered a similar situation in two widely separated submarine coreholes, one in the Gulf of Mexico and the other in the Atlantic Ocean. Small specimens which we treat as *Globigerinoides quadrilobatus primordius* (but are also close to *G. apertasuturalis*) were found consistently throughout the *Globigerina ciperoensis* Zone and occasionally in the top of the *Globorotalia opima opima* Zone. Nevertheless, we recorded neither large nor abundant specimens of *Globigerinoides* below the life range of *G. kugleri.* It may be anticipated that use of the scanning electron microscope will lead gradually to wider recognition of primitive forms of *Globigerinoides* mingled with small species of *Globigerina* in the later Oligocene.

Evidently, the *Globigerinoides* Datum cannot be defined rigidly as the level of earliest appearance of this genus (even though its definition here stated apparently is acceptable in many areas). The recommended alternative is to conceive the datum as the level at which species of *Globigerinoides* start to diversify and become a prominent element among the planktonic foraminifers. To pinpoint such a faunal horizon requires an arbitrary choice of criteria, differing from area to area. For instance, local ranges of associated planktonic species might be serviceable, or a minimum size might be set on specimens of *Globigerinoides* applied to zonation. From existing records the datum seems to fall consistently within the short life range of *Globorotalia kugleri* so the discrepancies are of minor scope.

For the present we prefer to maintain the *Globigerinoides* Datum as a zonal boundary coincident with the Paleogene-Neogene boundary, 1) because of its wide international acceptance in this role, and 2) because no other foraminiferal datum is as conspicuous or as widely applicable at this level. The range zone of *Globorotalia kugleri* (s. s.) brackets the *Globigerinoides* Datum and is a useful guide to the Oligocene-Miocene boundary but attempts to designate *G. kugleri* as the key index species would encounter difficulties already noted by BLOW (1969). This species developed transitionally, not abruptly, from ancestors ranging back into the *Globorotalia opima opima* Zone, and its distribution is affected erratically by ecologic and climatic factors. Currently the working groups of CMNS, fully aware of the specific problems and their setting in the broad field of Tertiary stratigraphy, are formulating a practicable solution to be presented at the sixth reunion, scheduled for Bratislava in 1975 (CMNS, 1971, 1972).

MIOCENE

Globorotalia kugleri Zone

Category: Concurrent-range zone. **Age**: Earliest Miocene.

Author: Name introduced by BOLLI (1957b) for the range zone of the index; here reduced in scope as explained in the preceding note.

Definition of top: Level of extinction of *Globorotalia kugleri.*

Characteristics: Faunas have a mainly negative aspect, lacking forms distinctive of either the preceding Oligocene or the ensuing Miocene.

Catapsydrax dissimilis Zone

Category: Interval zone. **Age**: Early Miocene.

Author: CUSHMAN & RENZ (1947) as *Globigerina dissimilis* Zone. Current name introduced and scope modified by BOLLI (1957b).

Definition of top: Level of first appearance of *Globigerinatella insueta.*

Characteristics: A strong influx of new planktonic forms occurred within this zone, notably the proliferation of species of *Globigerinoides* and *Globoquadrina* and first appearance of the *Globorotalia fohsi* lineage. First appearance of *Catapsydrax stainforthi* is a useful guide to the base.

Note: Sparse records and tropical habit of *Globigerinatella insueta* make its advent an unsatisfactory criterion for the top of this zone, but no satisfactory substitute is available. The first appearance of *Globoquadrina altispira altispira* is an approximate guide to the top of this zone.

Catapsydrax stainforthi Zone

Category: Concurrent-range zone. **Age**: Early Miocene.

Author: BOLLI (1957b).

Definition of top: Level of extinction of *Catapsydrax dissimilis.*

Characteristics: *Catapsydrax unicavus* became extinct at virtually the same level as *C. dissimilis*, and co-occurrence of either of these species with *Globigerinatella insueta* is diagnostic for the zone. *Catapsydrax stainforthi* may be plentiful but also occurs above and below.

Globigerinatella insueta Zone

Category: Interval zone. **Age**: Early Miocene.

Author: Name introduced by CUSHMAN & STAINFORTH (1945), redefined with reduced scope by BOLLI (1957b, 1966a).

Definition of top: Level of first appearance of *Praeorbulina glomerosa.*

Characteristics: Within this zone *Globigerinoides sicanus* appeared as an evolutionary link between its trilobate ancestors and the orbuline forms typical of younger levels. Extinction of *Catapsydrax stainforthi* serves as a guide to the top.

Note: The level of appearance of *Globigerinoides sicanus* was used by BLOW (1959) to divide BOLLI'S *Globigerinatella insueta* Zone into two subzones, later elevated to the rank of zones (BANNER & BLOW, 1965c; BLOW, 1969). We prefer not to formalize the *G. sicanus* datum but recognize its utility in certain basins where Early Miocene sedimentation was unusually rapid.

Praeorbulina glomerosa Zone

Category: Lineage zone (phylozone). **Age:** Early Miocene.

Author: Following demonstration by BLOW (1956) of the stratigraphic utility of the evolutionary sequence leading to *Orbulina,* authors applied it to zonation in varying ways. JENKINS (1960) apparently was the first to use advent of the genus *Praeorbulina* as a zonal datum; his *Candorbulina glomerosa curva* Zone, which he renamed *Praeorbulina glomerosa curva* Zone (1966b), corresponds exactly to our definition of the *Praeorbulina glomerosa* Zone. This shorter name was introduced by BOLLI (1966a), but his definition of its top has been modified for reasons given in the subsequent note.

Definition of top: Coincident with the *Orbulina* Datum, i.e., the level of evolutionary appearance of true *Orbulina,* namely *O. suturalis* closely followed by *O. universa.*

Characteristics: The planktonic assemblage remains almost constant except for evolutionary changes in the orbuline lineage.

Note: In earlier zonations (e.g., BOLLI, 1957b, 1966a; BLOW, 1959) the extinction level of *Globigerinatella insueta* was emphasized because it is conspicuous in the Caribbean region. Subsequently the *Orbulina* Datum proved to be more readily recognizable on a worldwide scale and has been accepted generally as defining the boundary between Early (Lower) and Middle Miocene. For this reason a slight modification is made to BOLLI'S zonation at this level, as already recommended by BLOW (1969).

Globorotalia fohsi peripheroronda Zone

Category: Interval zone. **Age:** Middle Miocene.

Author: BOLLI (1957b) as *Globorotalia fohsi barisanensis* Zone. Name of index was changed to *Globorotalia (Turborotalia) peripheroronda* by BLOW & BANNER (1966) and modified to above form by BOLLI (1967).

Definition of top: Level of evolutionary appearance of earliest forms of *Globorotalia fohsi fohsi* (sensu BOLLI) = *Globorotalia (Turborotalia) peripheroacuta* BLOW & BANNER.

Characteristics: Earliest interval containing true *Orbulina. Globorotalia scitula* (s. s.) evolved from *G. scitula praescitula* within this zone.

Note: As already observed, the original base of this zone has been revised to coincide with the *Orbulina* Datum.

Globorotalia fohsi fohsi Zone

Category: Lineage zone (phylozone). **Age:** Middle Miocene.

Author: BOLLI (1957b).

Definition of top: Level of first appearance of *Globorotalia fohsi lobata.*

Characteristics: *Globorotalia praemenardii* evolved from *Globorotalia scitula* early in this zone.

Note: This zone should not be confused with the *Globorotalia fohsi* Zone of CUSHMAN & STAINFORTH (1945) and some later authors, which today might be considered a superzone based on the range of *Globorotalia fohsi* (s. l.) above the *Orbulina* Datum.

We prefer to follow mainly BOLLI (1950, 1957b, 1966a, 1967) in applying subspecies of *G. fohsi* to zonation, rather than BLOW & BANNER (1966), whose proposed revision offers little practical improvement over the existing scheme.

Globorotalia fohsi lobata-robusta Zone

Category: Interval zone. **Age:** Middle Miocene.

Author: BOLLI (1957b) as two sequential zones based on ranges of advanced subspecies *Globorotalia fohsi lobata* and *G. f. robusta;* combined into a single zone by some later authors (e.g., STAINFORTH *in* BLOW & BANNER, 1966, p. 302; LAMB & SULEK, 1968).

Definition of top: Level of extinction of all subspecies of *Globorotalia fohsi,* notably the largest and most advanced form *G. fohsi robusta.*

Characteristics: First appearances of *Globorotalia lenguaensis, Globorotalia menardii* of authors (=*G. cultrata*), *Sphaeroidinellopsis subdehiscens,* and *Globigerina nepenthes* are approximate guides to the top of this zone.

Note: While recognizing that local exceptions exist, we do not find it advantageous for general purposes to adopt BOLLI'S twofold division of this zone, based on the faunal sequence in Trinidad.

In temperate regions where large, carinate end forms of the *Globorotalia fohsi* lineage failed to develop, secondary criteria must be used in recognizing this zone. OLSSON (1972) related maximum size of subspecies of *G. fohsi* to the peak of a warming cycle, a paleoclimatic event which might be discernible in the biometry of other planktonic species.

Globorotalia siakensis Zone

Category: Interval zone. **Age**: Middle Miocene.

Author: BRONNIMANN (1951b) as the *Globorotalia mayeri* Zone. The prior name of the index is now considered to be *Globorotalia siakensis* LEROY.

Definition of top: Level of extinction of *Globorotalia siakensis*.

Characteristics: In broad terms this zone is a level of transition between gradual disappearance of earlier Miocene planktonic suites and a surge of new lineages and genera which continued into the Pliocene and Pleistocene (e.g., range charts of BLOW, 1969, p. 265-277). It is, therefore, a convenient level at which to terminate this review of the older Neogene zonation.

AGES OF ZONES

PROBLEMS IN EXPRESSING AGE

For the middle and late Tertiary of western Europe, which provides the standard sequence of series and stages used in worldwide correlation and some local stages, several of the stages long held to be correlative are known now to differ appreciably in age (e.g., Helvetian of Switzerland, Elveziano of Italy), while others thought to be sequential (e.g., Langhian and Vindobonian) actually are correlative, at least in broad terms. These revisions in Europe also affect correlations and age determinations in other parts of the world. In America, use of the Gulf Coast stages as a standard has helped to maintain stability, but equivalence of these units (Jacksonian, Vicksburgian, etc.) with European stages has been debatable. For instance, paleontologists specializing in mollusks and foraminifers have disagreed markedly on placement of the Oligocene-Miocene boundary. A comparable situation existed in the Far East where use of the code-designated stages T_a through T_h (T for Tertiary; a-h, stages lettered in upward sequence) has facilitated regional correlation but avoided indication of equivalents in Europe and other parts of the world. The application of planktonic foraminiferal zonation has been highly beneficial in resolving correlation problems such as the examples just cited.

The long-standing miscorrelations in Europe arose largely from the failure of stratigraphers to pay attention to facies factors. Despite lip service to the contrary, they found it easier to claim faunal correlations between two coral-reef units, for example, than between a beach sand and deep-sea marl. It is difficult to pinpoint pertinent references in the literature, but GIGNOUX (1950, p. 6-12, 598-611, etc., including footnotes) has made cogent comments on this subject and chided his predecessors for their overreliance on pectens and oysters as time markers. Study of planktonic foraminifers during the past 25 years has played a pre-eminent role in detecting and rectifying errors of pioneer stratigraphers. Following some earlier contributions to the theme, GRIMSDALE (1951) prepared a graphic demonstration of the utility of planktonic foraminifers for interregional Tertiary correlations. Presented at a World Petroleum Congress, this paper had a widespread impact and can reasonably be considered the point of departure from which arose, in particular, the Committee on Mediterranean Neogene Stratigraphy (CMNS) responsible for most of the revisions alluded to above.

EOCENE-OLIGOCENE BOUNDARY

One stratigraphic datum in post-Mesozoic formations which has remained fairly constant is the Eocene-Oligocene boundary. This level, as originally defined in terms of the occurrence of mollusks and other megafossils, has proved to coincide with the extinction of many distinctive species and genera of foraminifers, including such planktonic forms as *Hantkenina* (s. l.) and *Globorotalia cerroazulensis* (s. l.) as well as benthonic forms treated by some early workers as equally significant (e.g., *Bulimina jacksonensis* and species of *Asterocyclina*). The validity of this datum was challenged briefly by British Petroleum paleontologists led with crusading zeal by F. E. EAMES, whose basic postulate was that over much of the world no Oligocene beds were preserved and that the Lower Miocene rested with strong unconformity on a truncated Eocene surface. In some places transgressive Miocene beds were found to be loaded with reworked Eocene fossils, resulting in previous misidentifications of their age. The Lindi area of East Africa was cited as an exception and several new zones were designated there, supposedly representing most of a hiatus (latest Eocene and entire Oligocene) postulated between the *Globorotalia cocoaensis* and *Globigerina ampliapertura* Zones as defined in Trinidad by BOLLI (1957c). The concerted attempt to reclassify strata previously regarded as Oligocene had the beneficial results of producing a book (EAMES ET AL., 1962) packed with up-to-date biostratigraphic information on the Middle Tertiary and of giving rise to intensive studies by W. H. BLOW and F. T. BANNER of the planktonic foraminifers of this interval. Nevertheless, the basic precept of widespread truncation at the top of the Eocene has not withstood criticism, as eventually admitted by EAMES and his coworkers (1968) and by BLOW (1969). Signs that a compromise explanation may arise are offered by current studies in the field of plate tectonics.

OLIGOCENE-MIOCENE BOUNDARY

The Oligocene-Miocene boundary historically has been indefinite, although general agreement on its placement is emerging from work by the Committee on Mediterranean Neogene Stratigraphy. Vagueness goes back to the first definition of Oligocene as a series readily discernible in Germany but obscure in France and elsewhere (GIGNOUX, 1950, p. 534). Subsequently dispute arose on placement of the Aquitanian Stage, whether in the Oligocene (advocated by vertebrate paleontologists) or in the Miocene (invertebrate paleontologists working mainly on mollusks; and also paleogeographers) (GIGNOUX, 1950, p. 508-510, 598). In American regions initial age determinations of planktonic foraminiferal zones were based perforce on ages then accepted for presumed equivalent formations in Trinidad. STAINFORTH (1948a) summarized the faunal evidence on which several expert paleontologists, both American and European, treated the Oligocene as extending upward to the *Globorotalia fohsi lobata-robusta* Zone of current usage. Evidently, however, they included the Aquitanian Stage in the Oligocene contrary to modern consensus. Interestingly in retrospect, the direct evidence of planktonic pteropods, suggesting a Miocene age for the *Globorotalia fohsi* Zone (s. l.), was then regarded as anomalous.

At about the same time LEROY (1948, 1952) introduced his concept that advent of *Orbulina* was a time plane of circumglobal validity; on the basis of this the Caribbean Oligocene was found to be correlative with the Miocene of other regions. EAMES (1953) used this as one of several lines of argument to support transfer of approximately one-half of the so-called Oligocene in the Caribbean region to the Miocene. A debate followed in the Geological Magazine with interventions by DROOGER (1954), EAMES (1954, 1955), KUGLER (1954), and STAINFORTH (1954); also pertinent data were published elsewhere (e.g., AKERS, 1955; DROOGER, 1956). The arguments persuaded BOLLI in his definitive treatment of Trinidad planktonic foraminiferal zones to lower the Oligocene-Miocene boundary tentatively to the top of the *Globorotalia kugleri* Zone (1957b, p. 102-103). BOLLI (1957b) noted that his revised placement of this boundary approximately coincides with the first appearance of the genus *Globigerinoides*. The importance of this faunal level again was pointed out by BOLLI (1959) and STAINFORTH (1960) in their early attempts to recognize the Caribbean planktonic zones in Europe. By 1964, at the third CMNS session in Berne, the term *Globigerinoides* Datum had come into use and, despite some local vagaries, has been accepted since then as the most reliable single criterion for recognizing the Oligocene-Miocene boundary around the world. BLOW (1969) formalized its status by making the datum a zonal boundary in his scheme. We consider this to be an improvement over BOLLI'S proposal to locate the discussed boundary in the middle of a zone. Accordingly we have modified the definition of the *Globorotalia kugleri* Zone to make its base coincident with the base of the Miocene (Table 9).

Table 9. *Ages Currently Interpreted for Late Eocene to Middle Miocene Planktonic Foraminiferal Zones.*

AGE	ZONE
MIDDLE MIOCENE	*Globorotalia siakensis*
	Globorotalia fohsi lobata-robusta
	Globorotalia fohsi fohsi
	Globorotalia fohsi peripheroronda
EARLY MIOCENE	*Praeorbulina glomerosa*
	Globigerinatella insueta
	Catapsydrax stainforthi
	Catapsydrax dissimilis
	Globorotalia kugleri
OLIGOCENE	*Globigerina ciperoensis*
	Globorotalia opima opima
	Globigerina ampliapertura
	Cassigerinella chipolensis–Pseudohastigerina micra
LATE EOCENE	*Globorotalia cerroazulensis* sensu lato
	Globigerinatheka semiinvoluta

OLIGOCENE

This preamble leads to the assertion that a fourfold sequence of zones, named in upward order 1) *Cassigerinella chipolensis-Pseudohastigerina micra*, 2) *Globigerina ampliapertura*, 3) *Globorotalia opima opima*, and 4) *Globigerina ciperoensis* Zones, embraces the entire Oligocene (Table 9). In the light of modern revisions retention of the customary threefold division of the Oligocene into Lower (Early), Middle, and Upper (Late) segments is not recommended. The European standard of Lattorfian-Rupelian-Chattian (or supposed local equivalents) has dubious value, as these stages are proving to be partly time equivalents of one another. The threefold subdivision is unnatural in North America where the Vicksburgian Stage and superjacent Chickasawhayan Stage represent the Oligocene (BLOW, 1969, p. 223, 294; POAG, 1972a).

EARLY TO MIDDLE MIOCENE

In upward sequence from the *Globorotalia kugleri* Zone to the *Globorotalia siakensis* Zone, the remaining units are certainly Miocene, but to place them more precisely has become increasingly difficult because of revisions still in progress. Until recently a generally accepted sequence of Miocene stratigraphic divisions has been as follows: 1) Early (Lower) Miocene, Girondian (=Aquitanian-Burdigalian); 2) Middle Miocene, Vindobonian (=Helvetian-Tortonian); and 3) Late (Upper) Miocene, Sahelian (=Sarmatian-Pontian). This seems to be satisfactorily simple and straightforward, but practical application of it has proved to be both difficult and very confused. The Aquitaine basin in France was a good choice for definition of the Early Miocene, but the Langhian of Italy was held to be correlative and virtually synonymous with the Burdigalian, whereas we now know that it is entirely younger. Similarly the Vindobonian of the Vienna basin was actually a good choice for the type Middle Miocene, but the bulk of its upper portion came to be labelled Tortonian and the deep-water marls of Tortona are distinctly younger. The Sahelian (a north African unit) was assumed to correspond jointly to the Sarmatian and Pontian Stages of southern Soviet Union, but effects of climatic differences and endemism make their faunas a poor biostratigraphic standard. Today the earliest Late Miocene seems preferably definable on a standard consisting of open-sea beds, such as the type Tortonian of Italy, which is fitted more readily into the European sequence than its African equivalent, the Sahelian (see TJALSMA & WONDERS, 1972).

BLOW (1969, p. 229-231, fig. 19) arbitrarily chose for definition of the Early Miocene-Middle Miocene boundary the *Orbulina* Datum, a faunal level recognized around the world and readily identified in the rapidly evolving sequence of *Globigerinoides sicanus* and *Praeorbulina glomerosa* leading up to the first appearance of true *Orbulina*. Acceptance in such recent compilations as those of KRASHENINNIKOV (1971, 1973) and BERGGREN (1972a) confirms that this is a reasonable decision because, within detectable limits, the *Orbulina* Datum appears to separate the Girondian and Langhian Stages. At the top of our sequence the *Globorotalia siakensis* Zone is somewhere near the top of the Middle Miocene (Table 9).

MIDDLE MIOCENE TO HOLOCENE ZONATION

GENERAL

Most information on the stratigraphic distribution of Late Neogene (i.e., Middle Miocene to Holocene) species of warm-water planktonic foraminifers has been obtained within the past decade. A major stimulus was study in Europe sponsored by the Committee on Mediterranean Neogene Stratigraphy (CMNS) under the aegis of the International Union of Geological Sciences (IUGS) to define reliably stratigraphic relationships of classical Neogene marine stages within type areas of the Mediterranean region. The work led to a widely recognized need for sound biostratigraphic subdivisions of stages that would provide a meaningful geologic time framework for the Mediterranean area and the remainder of the world as well (UJIIE, 1971). This has been accomplished to a high degree but only in very recent years. Progress made also by industry and institutions has been remarkable. Thus, not only is late Neogene planktonic foraminiferal biostratigraphy of warm-water regions well documented nearly worldwide, but calcareous nannoplankton and radiolarian biostratigraphies have advanced to a high level of stratigraphic utility (RIEDEL, 1973).

Studies of surface and well sections in the Caribbean region and Java revealed partial late Neogene sequences of planktonic foraminifers that were used in the early planktonic foraminiferal zonations of BOLLI & BERMÚDEZ (1965) and BANNER & BLOW (1965b). Cores taken recently from ocean depths by the Deep Sea Drilling Project provide large amounts of biostratigraphic data which add to the general body of knowledge on the late Neogene.

Stratigraphic ranges of most late Neogene species of planktonic foraminifers have been well documented by many workers in recent years so that reliable appraisal and interrelating of existing zonation schemes now is feasible. Further, the CMNS has provided a practical method for detailed biostratigraphic subdivision of the Mediterranean Neogene–datums based on first and last occurrences of widely ranging marker species and genera. This provides a basis for recognizing Neogene epochs and their subdivisions nearly worldwide (Fig. 17-18).

DEVELOPMENT OF ZONATION

Considering the relatively short time since planktonic foraminifers were first applied to late Neogene biostratigraphy, the large number of zonations proposed by many different authors for this time interval may seem surprising. Study of classical late Neogene sections in the Mediterranean region, however, proceeded concurrently with that of many other regions during a time when widespread confusion existed as to ages of beds yielding planktonic foraminifers and as to placement of stage and epoch boundaries. Further confusion resulted from anomalies and discrepancies which seemed inexplicable until their basic cause was identified as the effect of paleoclimatic factors on the occurrence and distribution of planktonic foraminifers.

A case in point is the undocumented statement by BANNER & BLOW (1965b) that *Sphaeroidinella dehiscens* occurs in the Zanclian Stage of Italy which they then considered to be earliest Pliocene. For some time thereafter a few authors placed the Miocene-Pliocene boundary in tropical regions at the first occurrence of *S. dehiscens.* It is clear now, however, that the Trubi Marls of Sicily (i.e., the Zanclian of BANNER & BLOW, 1965b) range from Early to Late Pliocene and that *S. dehiscens* (s.s.) does not occur either in Italy or in tropical regions until the Late Pliocene (Fig. 19). Another confusing element was the fine distinction between *Sphaeroidinella dehiscens* (s.s.) and other members of the *Sphaeroidinellopsis-Sphaeroidinella* lineage.

The early zonal schemes proposed by BOLLI & BERMÚDEZ (1965; emended BOLLI, 1966a), and BANNER & BLOW (1965b; emended BLOW, 1969) strongly influenced later workers because many used either the original or only slightly modified version of these zonations (Fig. 17-18). Although these zonations were found to be broadly useful for correlation, the soundness and utility of some zones were questioned so that subsequent emendations were necessary for the schemes of BOLLI (by BOLLI, 1970, 1972b) (Fig. 17) and that of BLOW (by BRÖNNIMANN & RESIG, 1971) (Fig. 18). Although these early zonations have been improved markedly by subsequent revision, they remain only partly acceptable for precise correlating and dating. For example, choice of such zonal marker species as *Globorotalia tegillata* and *Sphaeroidinella dehiscens immatura* by BRÖNNIMANN & RESIG (1971) is unsatisfactory inasmuch as these taxa are poorly defined and rather gradational forms. Difficulties encountered commonly in attempts to identify consistently such other zonal markers as *Globorotalia merotumida* and *Globorotalia plesiotumida* led many workers to search for an alternate basis for zonation. It would have been appropriate, for example, to have redefined all of BLOW'S zones following N. 15 by use of widely recognized zonal markers. Such a revision is essential before these letter zones can be applied consistently by different workers. Earlier authors just cited recognized differing local ranges for species but incompletely treated an important cause, paleoclimatic fluctuations. Modern revisers, however, tend to cope with this problem more satisfactorily as discussed subsequently.

The emended zonation of BOLLI (1970, 1972b) is not entirely clear, but intervals from his *Globorotalia menardii* Zone upward through his *Globorotalia margaritae* Zone show good continuity and applicability (Fig. 17). The younger zones, however, are not applied readily.

On the basis of studies on surface and subsurface sections in the Caribbean and Gulf of Mexico, LAMB & BEARD (1972) proposed a modified version of the zonation of BOLLI (1966a) but did not consider the revisions made by BOLLI (1970) and POSTUMA (1971) which became available only after the manuscript had been prepared. The practical application of this zonation (Fig. 17) was demonstrated for interregional correlating and dating and particularly for facilitating correlation with classical late Neogene stages in Italy. More recently, SMITH & BEARD (1973) applied this zonation to evaluate deep-sea cores taken in the Gulf of Mexico and also to confirm their biostratigraphic relationships with Italian sequences using planktonic foraminifers and nannoplankton.

Studies of surface exposures in northern Florida and Atlantic Coastal Plain by AKERS (1972) document planktonic successions in those areas. Similarly, biostratigraphy of cores taken in the southern Caribbean Sea and south Atlantic (BOLLI, 1970, 1972b; BANDY & WADE, 1967) and in the north Atlantic (KANEPS, 1970; POAG, 1972a; CITA, 1971d; PHILLIPS ET AL., 1968) has confirmed the overall late Neogene planktonic succession described for the Gulf of Mexico and reliably established this late Neogene planktonic foraminiferal succession for a broad area of the western hemisphere.

Many studies have contributed to knowledge of the succession of late Neogene planktonic foraminifers in warm-water parts of the Pacific region, e.g., especially HAYS ET AL. (1969) and JENKINS & ORR (1972) for eastern equatorial Pacific Ocean; PARKER (1967) and BRÖNNIMANN & RESIG (1971) for southwestern Pacific Ocean; IKEBE ET AL. (1972) for southern Japan; CHANG

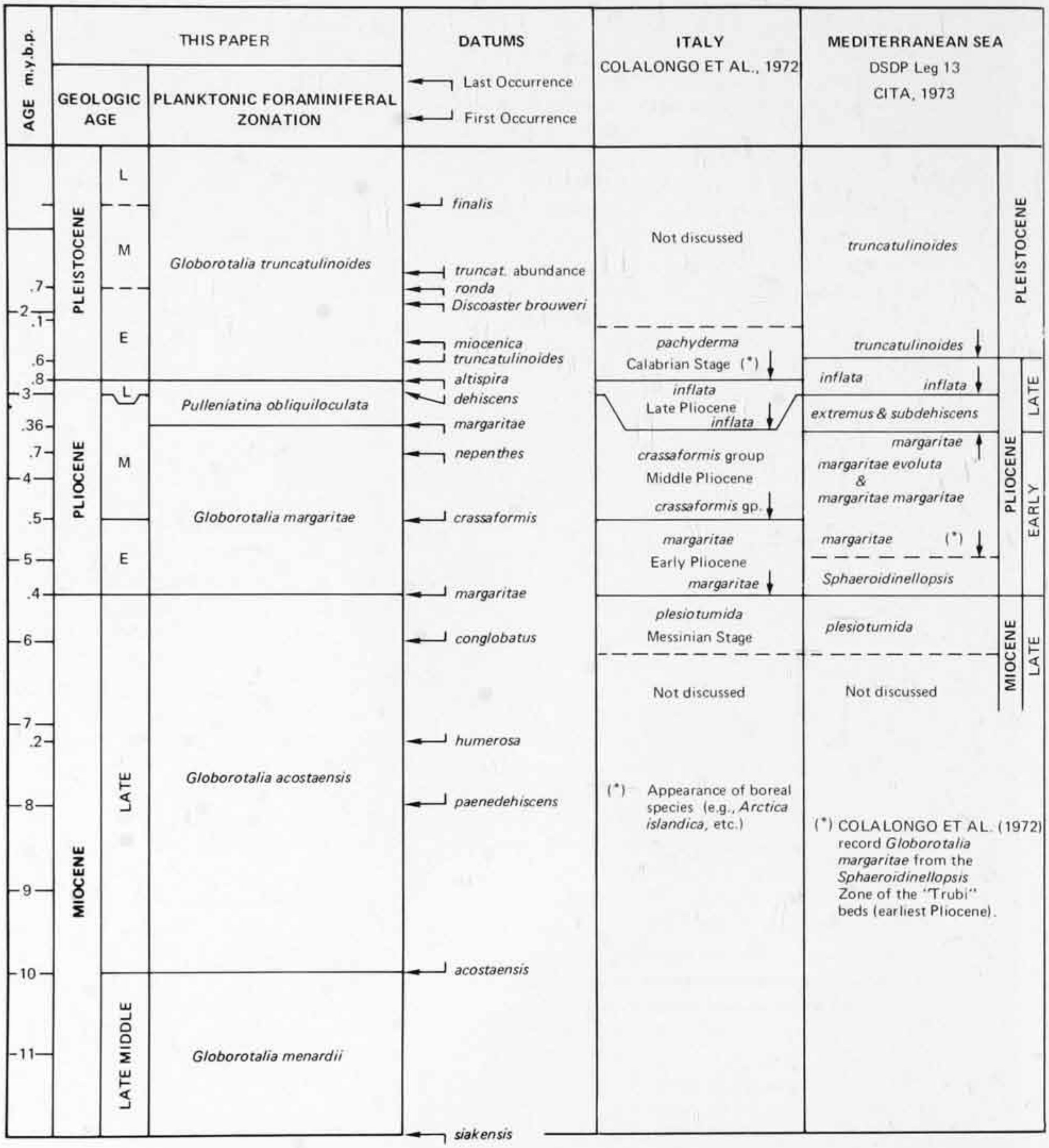
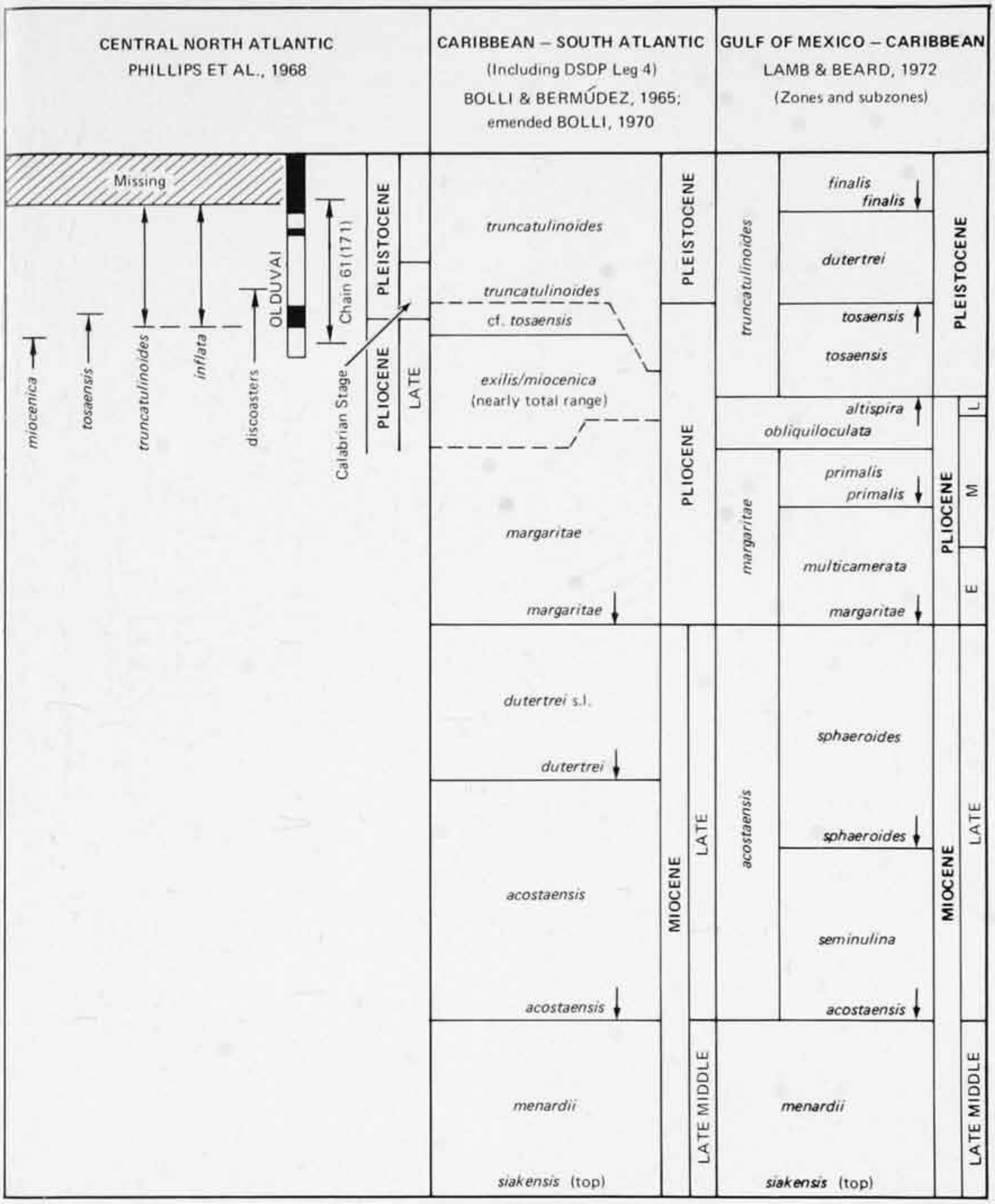


Fig. 17. Planktonic foraminiferal zonation of the present paper for the late Middle Miocene to Holocene compared with some current zonal schemes proposed by different authors for the Mediterranean, Atlantic, Caribbean, and Gulf of Mexico areas.



Zones in these areas are aligned here to conform with biostratigraphic datums. Vertical arrows indicate datums of first occurrences (—┘) and last occurences (—┐) of species used by authors in defining their zones. Offset dashed lines indicate that the zonal definition given by an author differs somewhat from basic data presented by him. (DSDP = Deep Sea Drilling Project.)

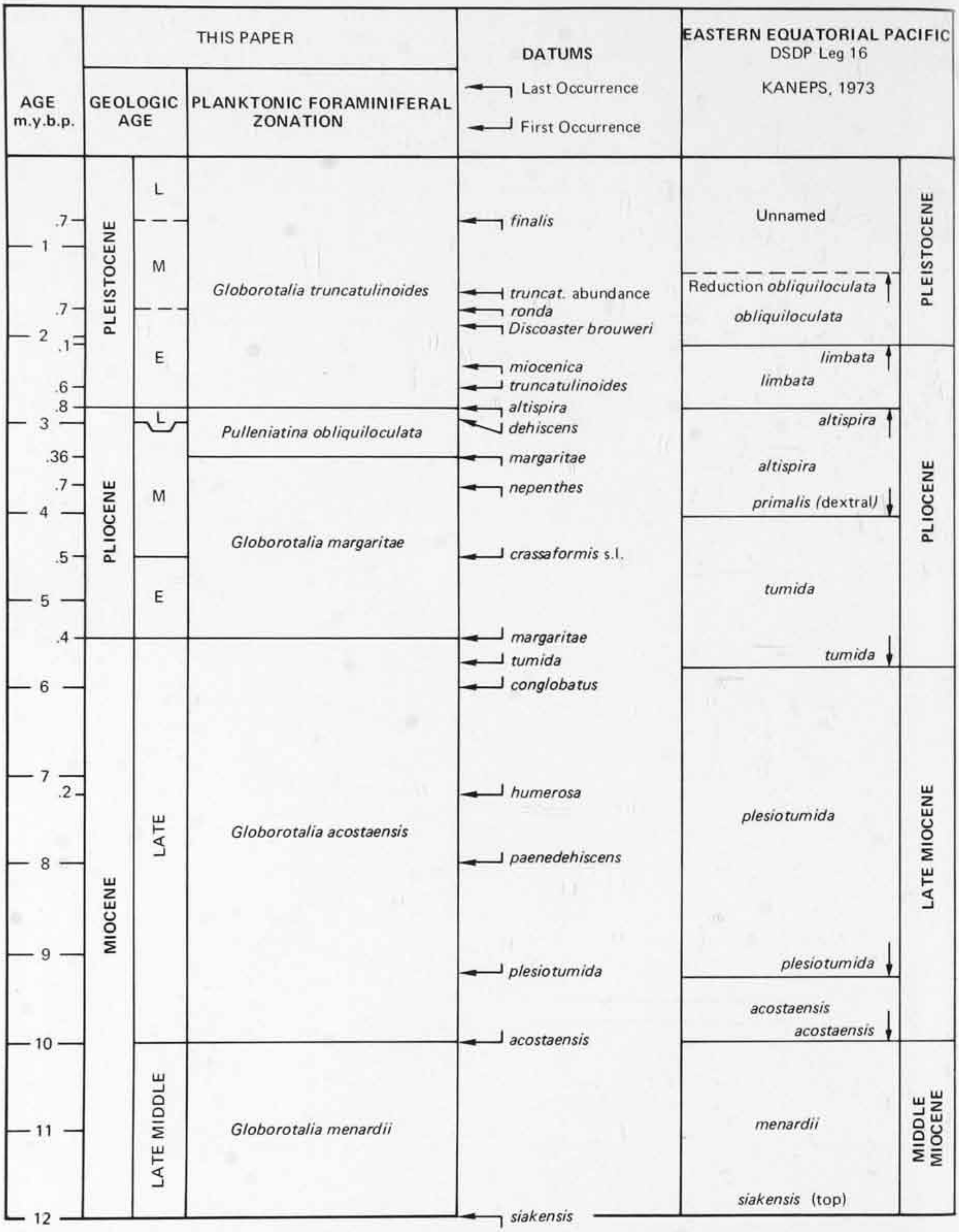
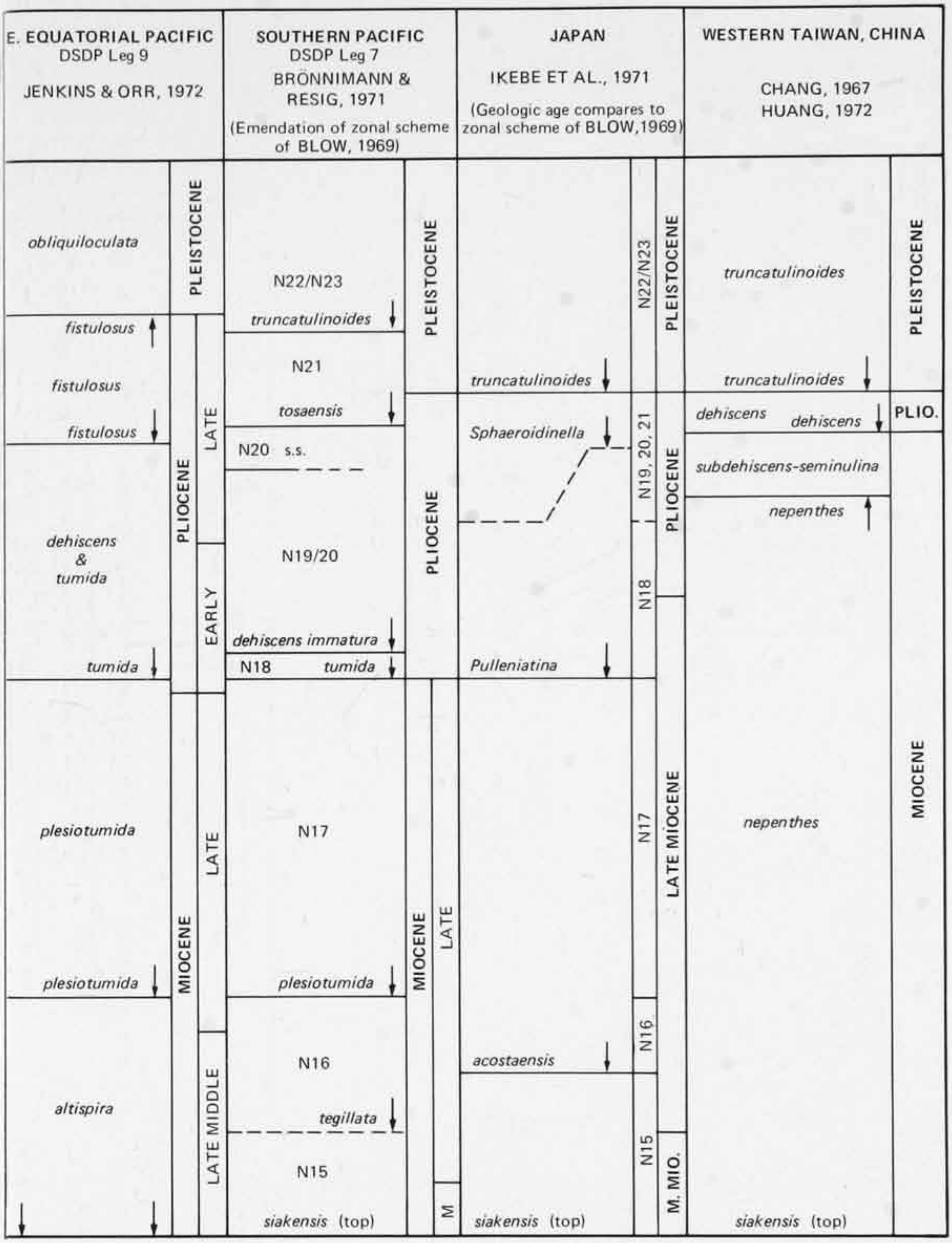


Fig. 18. Planktonic foraminiferal zonation of the present paper for the late Middle Miocene to Holocene compared with some current zonal schemes proposed by different authors for the Pacific Ocean and adjacent areas.



Zones in these areas are aligned here to conform with biostratigraphic datums. Vertical arrows indicate datums of first occurrences (⟵┘) and last occurrences (⟵┐) of species used by authors in defining their zones. Offset dashed lines indicate that the zonal definition given by an author differs somewhat from basic data presented by him. (DSDP = Deep Sea Drilling Project.)

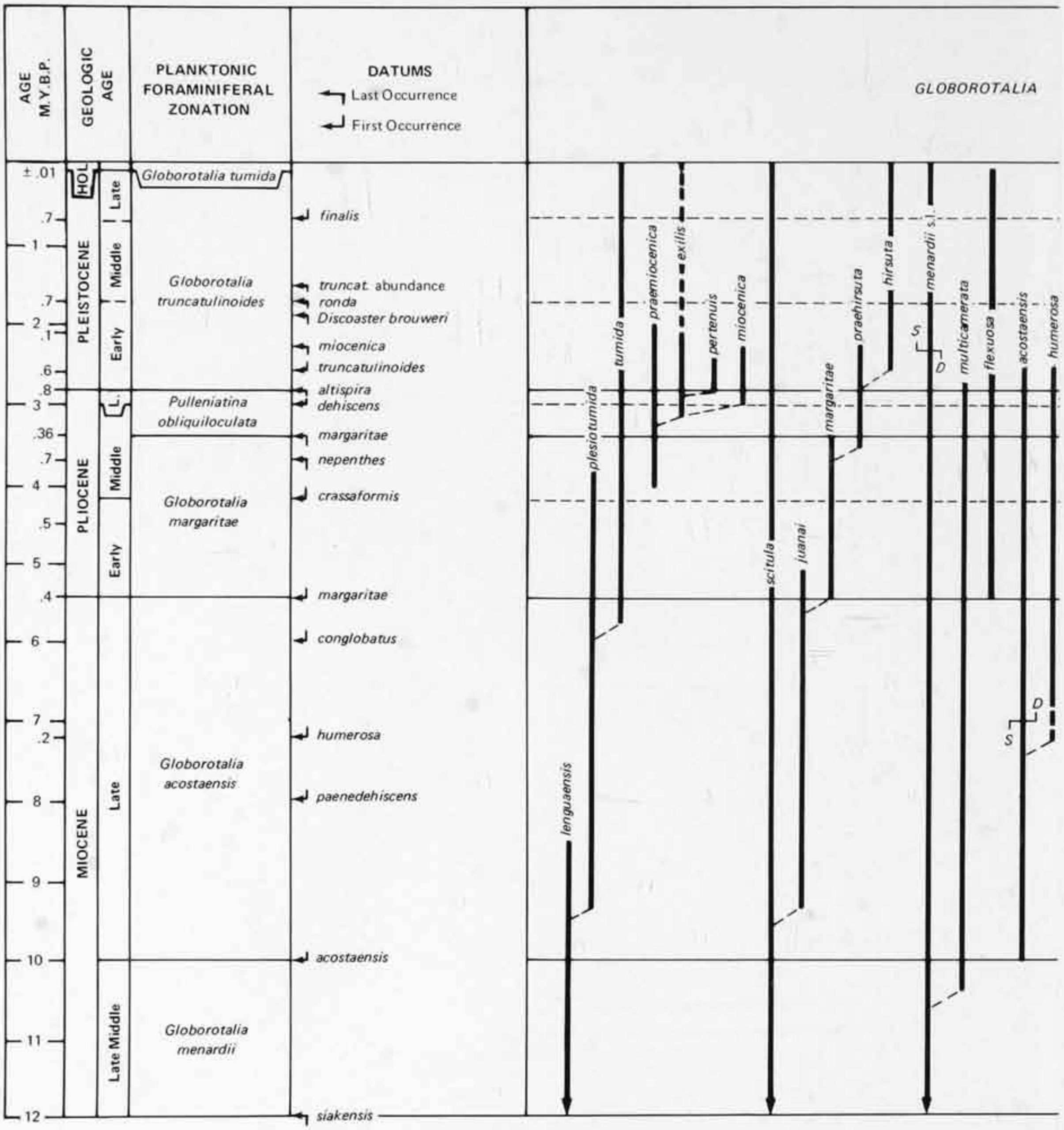
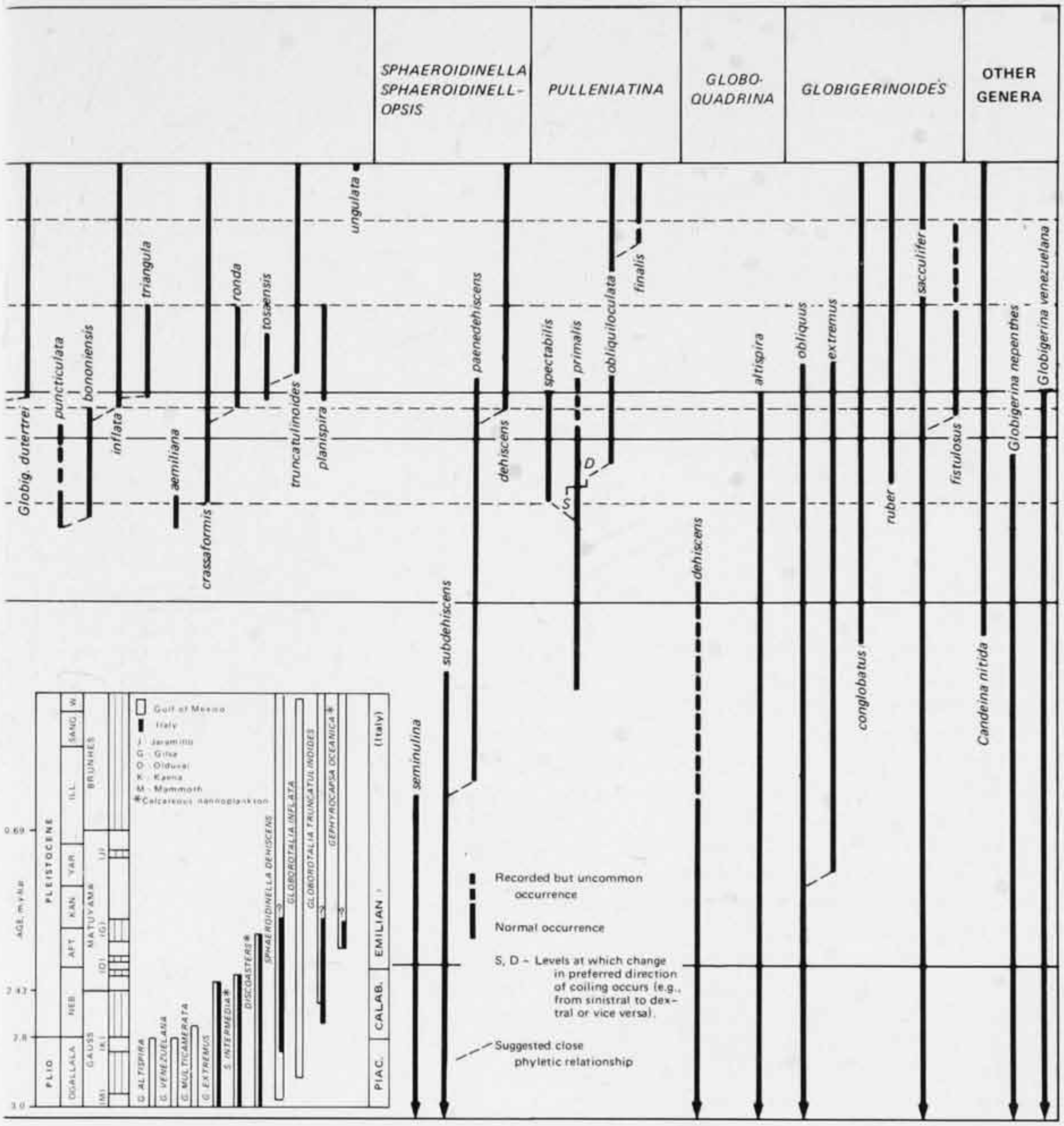


Fig. 19. Planktonic foraminiferal zonation for the Middle Miocene to Holocene with datums and ranges for selected index species.


SPHAEROIDINELLA
SPHAEROIDINELLOPSIS
PULLENIATINA
GLOBOQUADRINA
GLOBIGERINOIDES
OTHER GENERA
Globig. dutertrei
puncticulata
bononiensis
inflata
triangula
aemiliana
crassaformis
ronda
tosaensis
truncatulinoides
planispira
ungulata
paenedehiscens
dehiscens
subdehiscens
seminulina
spectabilis
primalis
obliquiloculata
finalis
S
D
dehiscens
altispira
obliquus
extremus
conglobatus
ruber
sacculifer
fistulosus
Candeina nitida
Globigerina nepenthes
Globigerina venezuelana
Recorded but uncommon occurrence
Normal occurrence
S, D – Levels at which change in preferred direction of coiling occurs (e.g., from sinistral to dextral or vice versa).
Suggested close phyletic relationship
AGE, m.y.B.P.
0.69
2.43
2.8
3.0
PLIO.
PLEISTOCENE
OGALLALA
NEB.
AFT.
KAN.
YAR.
ILL.
SANG.
W.
GAUSS
MATUYAMA
BRUNHES
(M)
(K)
(O)
(G)
(J)
Gulf of Mexico
Italy
J : Jaramillo
G : Gilsa
O : Olduvai
K : Kaena
M : Mammoth
*Calcareous nannoplankton
G. ALTISPIRA
G. VENEZUELANA
G. MULTICAMERATA
G. EXTREMUS
S. INTERMEDIA*
DISCOASTERS*
SPHAEROIDINELLA DEHISCENS
GLOBOROTALIA INFLATA
GLOBOROTALIA TRUNCATULINOIDES
GEPHYROCAPSA OCEANICA*
?
PIAC.
CALAB.
EMILIAN
(Italy)

(1967) and HUANG (1967, 1972) for Taiwan; BANDY (1963) for the Philippines; and BOLLI (1966b, 1972b) for Java. Important biostratigraphic summary papers also are cited by the United Nations Economic Commission for Asia and the Far East (1970).

As for the late Neogene planktonic foraminiferal zonation in warm-water regions of the western hemisphere, the large amount of biostratigraphic information available from the Pacific region precludes serious misunderstandings in correlation and age relationships of planktonic foraminiferal faunas. BRÖNNIMANN & RESIG (1971) claimed that more detailed taxonomic work based on scanning electron-microscope studies will lead to the proliferation of taxa and consequently will result in a more refined zonal system having increased biochronologic resolution. Present knowledge, however, is judged adequate for recognition of late Neogene epochs and several of their internal subdivisions throughout much of the Pacific region. The sequence of planktonic datums (Fig. 17) is essentially the same for the western and eastern hemispheres; thus, these provide a basis for reliable worldwide biostratigraphic correlation irrespective of the zonation scheme applied.

Late Neogene zonations (Fig. 17-18) differ mostly in choice of datums used by authors to define their zones. Warm-water planktonic foraminifers are not represented copiously in all areas (e.g., Mediterranean region and Japan) so that some zonations are essentially provincial. JENKINS & ORR (1972), however, encountered another problem (that of solution of planktonic foraminiferal tests at depths greater than 10,000 feet), and consequently they devised a pragmatic zonation based on the more solution-resistant of the species.

Late Neogene zones proposed for New Zealand by JENKINS (1971) are difficult to correlate precisely with those of warm-water regions owing to the paucity of low-latitude zonal markers at the high latitudes of New Zealand. Late Neogene zones used by BIZON & BIZON (1972) for the Mediterranean region do not differ significantly from those of COLALONGO ET AL. (1972), which are the accepted standard for Italy. Also, zones of POSTUMA (1971) relate closely to the zonation of BOLLI (1966a) except for the *Globoquadrina altispira* Zone of Postuma which is coeval with the *Pulleniatina obliquiloculata* Zone of the present paper.

Presently available data on distinguishing characteristics and stratigraphic ranges of Neogene planktonic foraminifers provide an accurate and precise means for interrelating zones and other biostratigraphic intervals of recent authors (e.g., ALEKSEEV, 1969; UJIIE, 1970; VOLOSHINOVA, KUZNETSOVA, & LEONENKO, 1970; HUANG, 1971; BANDY, 1972).

ZONATION USED IN PRESENT REPORT

A planktonic zonation having worldwide validity and applicability should be based as much as possible on zonal indices whose stratigraphic occurrences are well documented throughout much of the world and also are known in the classical terrains of the Mediterranean region. The terms Miocene, Pliocene, and Pleistocene inescapably imply correlation with Europe.

The late Neogene planktonic zonation proposed here for the interval above the *Globorotalia menardii* Zone of BOLLI (1966a) is based on well-established datums determined by many cited authors, and insofar as possible zonal boundaries conform to epoch boundaries established in Europe (Fig. 17) and to superstage boundaries proposed by DROOGER & MARKS (1971) and CITA ET AL. (1971) (Fig. 20). According to CITA & BLOW (1969) the *Globorotalia menardii* Zone is represented in Italy between the transition interval from Upper Serravallian to Lower Tortonian. Stratigraphic occurrences of planktonic foraminiferal zonal marker species and other important and widely recognized species are plotted against this geologic time framework (Fig. 19).

Criteria for recognizing six late Middle Miocene to Holocene zones are given in the following section of the report. These include zonal markers and characteristic species used to define each zone together with brief clarifying comments. A distribution chart (Fig. 19) summarizes geologic ranges of important and widely recognized species and also stratigraphic positions of datums that may have use locally for dividing zones into smaller biostratigraphic units.

DESCRIPTION OF ZONES

MIOCENE

Globorotalia menardii Zone

Category: Interval zone. **Age**: Late Middle Miocene. **Author**: Name introduced by STAINFORTH

THIS PAPER				DROOGER & MARKS, 1971		CITA ET AL., 1971	
GEOLOGIC AGE			PLANKTONIC FORAMINIFERAL ZONES	STAGE	SUPERSTAGE	STAGE	SUPERSTAGE
PLEISTOCENE		L	*Globorotalia truncatulinoides*			No designation	
	AFT.	M					
	NEB.	E		Calabrian	No designation		
PLIOCENE		L	*Pulleniatina obliquiloculata*	Astian	ARDIAN	No designation	
		M	*Globorotalia margaritae*	Piacenzian			
		E		Tabianian		"Crise de salinité"	
MIOCENE		LATE	*Globorotalia acostaensis*	Messinian Tortonian	CASTELLANIAN	Messinian Tortonian	Base of Trubi PERLETIAN
		LATE MIDDLE	*Globorotalia menardii*	Serravallian ↓ ↓	BUBBIAN ↓ ↓	Serravallian ↓ ↓	CESSOLIAN ↓ ↓

Fig. 20. Planktonic zones of present paper as compared with succession of superstages proposed to supplant existing classical late Neogene. Arrows indicate that units continue into older beds.

(1948a); modified by BRÖNNIMANN (1951b) and BANNER & BLOW (1965b). BRÖNNIMANN (1951b) subdivided STAINFORTH'S zone, which extended above and below current usage, into a lower *Globorotalia mayeri* Zone (currently *Globorotalia siakensis* Zone) and an upper *Globorotalia menardii* Zone with the boundary between the two zones marked by the extinction of *G. siakensis.* BOLLI (1966a) later placed the top of the *Globorotalia menardii* Zone at the level of the first occurrence of *Globorotalia acostaensis,* and BANNER & BLOW (1965b) similarly defined their zone N. 15.

Definition: Interval from the level of extinction of *Globorotalia siakensis* to level of evolutionary appearance of *Globorotalia acostaensis.*

Characteristics: Interval has a decided negative aspect because no marker species originate or terminate within the zone. In a broad sense the zone is a buffer interval between distinctive Middle Miocene and Late Miocene faunas.

Note: Although use of this zonal name is being continued for the present, data obtained very recently indicate that the species identified as *Globorotalia menardii* in the late Middle Miocene of the Caribbean and other warm-water parts of the world is related to *Globorotalia cultrata* (D'ORBIGNY, 1839) and is not *G. menardii* (PARKER, JONES, & BRADY, 1865) as we apply that name.

Globorotalia acostaensis Zone

Category: Interval zone. **Age**: Late Miocene.

Author: Name introduced nearly simultaneously by BOLLI & BERMÚDEZ (1965) as *Globorotalia acostaensis* Zone defined as interval with zonal marker from its first occurrence to first occurrence of *Globorotalia dutertrei* and by BANNER & BLOW (1965b) as *Globorotalia (Turborotalia) acostaensis–G. (G.) merotumida* partial-range Zone defined as that part of range of *G. (T.) acostaensis* which occurs before *G. (G.) merotumida* gives rise to its immediate descendant, *G. (G.) tumida*. The zone was expanded by LAMB & BEARD (1972) to include both the *Globorotalia acostaensis* and *Globorotalia dutertrei* Zones of BOLLI & BERMÚDEZ (1965) and the *Globorotalia (T.) acostaensis-G. (G.) merotumida* partial-range Zone, *Globorotalia (G.) tumida plesiotumida* consecutive-range Zone, and also part of the *Globorotalia (G.) tumida tumida-Sphaeroidinellopsis subdehiscens* partial-range Zone (fide BRÖNNIMANN & RESIG, 1971) of BANNER & BLOW (1965b).

Definition of top: Level of first appearance of *Globorotalia margaritae*.

Characteristics: Within the lower part of this zone the last vestiges of dominant Middle Miocene species essentially disappear with extinction of *Globorotalia lenguaensis* and *Globoquadrina dehiscens* and decrease in dominance of the *Sphaeroidinellopsis seminulina-subdehiscens* group. In the upper part of the zone a rudimentary modern aspect of the fauna is indicated by appearance of species such as *Globorotalia tumida, Globorotalia humerosa, Pulleniatina primalis, Globigerinoides conglobatus,* and *Candeina nitida; Sphaeroidinellopsis paenedehiscens* strongly dominates over the previously dominant *S. seminulina* and *S. subdehiscens. Globorotalia acostaensis* coils mostly to the left in the lower part of the zone but mostly to the right in the upper part, just above the Tortonian-Messinian boundary of SELLI (1960).

Note: LAMB & BEARD (1972) divided the *Globorotalia acostaensis* Zone, as defined herein, into an upper *Sphaeroidinellopsis sphaeroides (=S. paenedehiscens)* Subzone and lower *Sphaeroidinellopsis seminulina* Subzone; these subzones are widely applicable in low latitudes. The zonal subdivisions of BOLLI & BERMÚDEZ (1965) and BOLLI (1966a) may be widely applicable also but are difficult to recognize precisely in some areas because they are based on recognition of several steps in the gradual evolutionary change from *Globorotalia acostaensis* to *Globorotalia humerosa* (=*G. dutertrei* of BOLLI & BERMÚDEZ, 1965). Similarly, the zonal divisions of BANNER & BLOW (1965b) are difficult to recognize because of the close similarity of the subspecies upon which the zonal definitions are based. The sequence of datums, therefore, seems to afford the best criteria for local subdivisions of this zone.

PLIOCENE

Globorotalia margaritae Zone

Category: Range zone. **Age**: Early Pliocene to Middle Pliocene.

Author: Name introduced by BOLLI & BERMÚDEZ (1965) for the range zone of the nominate species.

Definition of top: Level of extinction of *Globorotalia margaritae*.

Characteristics: *Globorotalia margaritae* and *Globorotalia puncticulata* appear first at the base of the zone and *G. crassaformis* (s. l.) prior to extinction of *Globigerina nepenthes*. Within the upper part of the zone both *Globorotalia humerosa* and *Pulleniatina primalis* change preferred direction of coiling from dominantly left to dominantly right.

Note: LAMB & BEARD (1972) divided the *Globorotalia margaritae* Zone into an upper *Pulleniatina primalis* Subzone and lower *Globorotalia multicamerata* Subzone, the common boundary being the first recognized occurrence of *Pulleniatina primalis* in the Caribbean and Gulf of Mexico. These subzones must be considered as only provincial, however, inasmuch as an earlier occurrence of *P. primalis* is recognized in the Pacific region. Because of the endemic nature of some Pliocene species, local subzonation of the *Globorotalia margaritae* Zone may be preferable; the first appearance of *Globorotalia crassaformis* (s. l.) seems to be a widely applicable midpoint datum.

Pulleniatina obliquiloculata Zone

Category: Interval zone. **Age**: Middle Pliocene to Late Pliocene.

Author: Interval proposed as *Globoquadrina altispira* Zone by POSTUMA (1971) as simplification of earlier applications of this marker species to zonation. Same interval independently defined by LAMB & BEARD (1972) as their *Pulleniatina obliquiloculata* Zone.

Definition of top: Level of extinction of *Globoquadrina altispira.*

Characteristics: Despite the short duration of this zone, a host of new species appears first here–characteristic are *Globorotalia miocenica, Globorotalia inflata, Globorotalia tosaensis, Sphaeroidinella dehiscens,* and *Globigerinoides fistulosus. Globoquadrina altispira* and *Globigerina venezuelana* do not persist above the top of the zone, and the genus *Sphaeroidinellopsis* becomes extinct shortly thereafter.

Note: In worldwide terms the extinction level of *Globoquadrina altispira* occurs between levels defined by the first appearances of *Globorotalia tosaensis* and its descendant *Globorotalia truncatulinoides* (Fig. 19). This pattern is obscured locally, however, by paleoclimatic factors. The warm-water species *G. altispira* survives longer in equatorial than in temperate regions, whereas the cool-water lineage of *G. tosaensis – G. truncatulinoides* normally appears later in equatorial than in temperate latitudes. In the intermediate belt (between approximately 10° and 30° Lat.) *G. altispira* became extinct just before the evolutionary appearance of *G. truncatulinoides.* The two datums, therefore, are nearly synchronous.

The upper limit of this zone is defined preferably by extinction of *Globoquadrina altispira* rather than by the appearance of *Globorotalia truncatulinoides* in order to coincide as closely as practicable with the Pliocene-Pleistocene boundary. *Globorotalia truncatulinoides* is first recorded somewhat above the base of the Calabrian Stage (earliest Pleistocene) in southern Italy (BAYLISS, 1969; LAMB & BEARD, 1972; and others). The extinction of *G. altispira* seems to correspond closely to the onset of severe climatic cooling that led to Quaternary continental glaciation in North America. This seems also to be the same climatic event motivating abrupt immigration of cool-water species (e.g., *Hyalina baltica* and *Arctica islandica)* into the Mediterranean area at the beginning of Calabrian time.

The earliest appearance of *Pulleniatina obliquiloculata* is a guide to the base of this zone although the appearance differs somewhat with latitude. This species is preferred as nominative index for the zone, however, simply to avoid confusion with markedly different applications of *Globoquadrina altispira* as a zonal index by several authors (e.g., BOLLI & BERMÚDEZ, 1965; BOLLI, 1966a; BLOW, 1969; POSTUMA, 1971; KANEPS, 1973).

In the emended zonation of BOLLI (1970, 1972a) the zones above his *Globorotalia margaritae* Zone were found to be somewhat inadequate for regional application. His *Globorotalia exilis/Globorotalia miocenica* Zone by definition (i.e., "Interval with *G. exilis* and/or *G. miocenica* between the extinction of *Globorotalia margaritae* and the extinction of the two zonal markers.") leaves an undefined stratigraphic interval between this zone and the underlying *Globorotalia margaritae* Zone because the zonal markers are known to appear somewhat later than the extinction horizon of *G. margaritae.* Also, the *Globorotalia truncatulinoides* cf. *tosaensis* Zone (defined as "the interval with zonal marker from extinction of *G. exilis* and *G. miocenica* to first occurrence of *G. truncatulinoides"*) is untenable because *G. exilis* and *G. miocenica* range concurrently with *G. truncatulinoides* in the Gulf of Mexico region (LAMB & BEARD, 1972), the north Atlantic Ocean (KANEPS, 1970), as well as in BOLLI'S own study area (i.e., his faunal lists for sites 23 and 25 of Deep Sea Drilling Project Leg 4 in BADER ET AL., 1970, p. 17, 59). BOLLI (1966a) defined his *Globorotalia truncatulinoides* Zone as beginning with the first occurrence of the zonal marker which, thereby, makes his current usage of this zone unacceptable by his own standards.

PLEISTOCENE

Globorotalia truncatulinoides Zone

Category: Interval zone. **Age**: Pleistocene.

Author: First use of *Globorotalia truncatulinoides* as a zonal index was by BOLLI & BERMÚDEZ (1965) in two zones designated as *Globoquadrina altispira altispira/Globorotalia truncatulinoides* and *Globorotalia truncatulinoides/Globorotalia inflata* Zones. Subsequently BOLLI (1966a) shortened the names, and the upper unit became his *Globorotalia truncatulinoides* Zone. BLOW (1969) and several others (Fig. 17-19) used *Globorotalia truncatulinoides* as their principal marker for the Pleistocene but differed in placement of zonal limits. Followed here is usage of LAMB & BEARD (1972) in which the *Globorotalia truncatulinoides* Zone is the biostratigraphic equivalent of the entire Pleistocene.

Definition of top: Level of latest faunal change from a cold-water assemblage below to a warm-water assemblage above. Planktonic foraminiferal indicators differ from province to province; in the Gulf of Mexico and Caribbean areas, for example, the change is just subsequent to the appearance of *Globorotalia ungulata* and large specimens of *Globorotalia tumida.* This boundary seems to correspond to the end of the latest glacial interval (about 7,000 to 11,000 years ago) and to the beginning of the Holocene Epoch (BEARD, 1973).

Characteristics: Early Pleistocene is characterized by extinction of many species, including *Globorotalia multicamerata, Globorotalia miocenica, Globorotalia exilis, Globorotalia tosaensis, Globigerinoides extremus,* and *Globigerinoides fistulosus. Globorotalia truncatulinoides,* the most widely recognized marker restricted to the post-Pliocene, first appears just above the base of the zone. Another widely occurring species, *Pulleniatina finalis,* first appears in late Pleistocene.

Note: LAMB & BEARD (1972) divided the Pleistocene of the Gulf of Mexico into three subzones—a lower *Globorotalia tosaensis* Subzone, a middle *Globoquadrina dutertrei* Subzone, and an upper *Pulleniatina finalis* Subzone. These subzones also are widely applicable in low-latitude regions of the Atlantic and Pacific Oceans. Even finer subdivisions of the Pleistocene, however, may be obtained by using both planktonic foraminifers and calcareous nannoplankton. Alternations of warm- and cold-water faunas are used now rather routinely in many areas to distinguish successive glacial and interglacial intervals of the Pleistocene, and in coastal parts of the Gulf of Mexico oil-company paleontologists routinely record and correlate similarly interpreted paleotemperature fluctuations with eustatic cycles (i.e., cool intervals reflect low stands of sea level whereas warm periods reflect high stands).

HOLOCENE

Globorotalia tumida Zone

Category: Interval zone. **Age**: Holocene.

Author: Name introduced by LAMB & BEARD (1972) to include the entire Holocene.

Definition: Definition of the Holocene Epoch depends largely on the method used for defining its boundary with the Pleistocene Epoch. Criteria may be 1) faunal wherein the boundary may have a cold-water fauna below and a warm-water fauna above, 2) lithologic wherein the boundary may be placed above the youngest continental glacial deposit, 3) radiometric wherein the boundary arbitrarily may be placed somewhere between about 7,000 to 11,000 years ago (based on estimates of the end of the latest continental glaciation), or 4) paleoclimatic (e.g., oxygen-isotope measurements, paleobotanical analysis) that may be selected to distinguish postglacial deposits.

Characteristics: In the marine sedimentary record paleoclimatological and faunal methods commonly serve to distinguish the Holocene. Onset of the warm postglacial interval in northern latitudes may be reflected in the faunal record by a change in the direction of coiling of populations of *Globigerina pachyderma* from left to right or in southern latitudes, such as the Gulf of Mexico, by the sudden appearance of large forms of *Globorotalia tumida* and *Globorotalia ungulata.*

PALEOCLIMATIC TRENDS

Studies of living planktonic foraminifers (e.g., WISEMAN & OVEY, 1950; BÉ, 1959, 1960; BÉ & HAMLIN, 1967; BRADSHAW, 1959; PHLEGER, 1960; CIFELLI, 1971; PARKER, 1971; PARKER & BERGER, 1971) show clearly that distribution of these micro-organisms is controlled in part by the temperature of the oceanic water mass in which they live. Similarly, the stratigraphic and geographic distribution of fossil species is affected by worldwide changes in climate; striking examples are marked changes in planktonic foraminiferal faunas at middle latitudes caused by alternations of glacial and interglacial conditions during the Pleistocene. Other less marked changes in world climate during the Tertiary also have been interpreted on the basis of faunal changes, such as abrupt appearance or disappearance of species common to a region or changes in species diversity (e.g., ADDICOTT, 1969, 1970, 1973; BANDY, CASEY, & WRIGHT, 1971; CIFELLI, 1969, 1972; BARASH, 1971; STEINECK, 1971; DEVDARIANI, 1972; HERMAN, 1972; LIDZ, 1972; OBA, 1972; SAVIN & DOUGLAS, 1973). It is well established that latitudinal shifts in faunas through time commonly relate to changes in sea temperatures. Techniques for determining biochronologic datums despite effects of temperature changes have been reviewed earlier in the present report (Fig. 10-11).

Quantitative paleotemperatures seemingly are derived readily and reliably from oxygen-isotope measurements made on fossil shells, and these isotopic analyses of shell carbonate permit deductions about the temperature of the sea at the time the shell was deposited by the living animal (EPSTEIN ET AL., 1951; UREY ET AL., 1951). Results obtained by DEVEREUX (1967) for New Zealand and by DOUGLAS & SAVIN (1971) for low and middle latitudes of the Pacific Ocean seem reasonably compatible (Fig. 21). More detail on temperatures in Pliocene-Pleistocene seas at New Zealand was presented later by DEVEREUX, HENDY, & VELLA (1970).

Biostratigraphers need to understand how changes in world climate affect a planktonic zonation established for low latitudes when this zonation is extended appreciably to the north or south. The present zonation, therefore, was examined in light of the planktonic foraminiferal paleontologic record from the Middle Miocene to early Pleistocene at different latitudes to determine its geographical applicability. This analysis indicated that warm-water low-latitude faunas exhibit marked poleward expansions and contractions several times during the later Neogene; thereby suggesting periodic changes in world sea temperature.

Similarly, changing climatic patterns of the Paleozoic and Mesozoic, as interpreted from past distributions of limestone and dolomite and faunal populations, seem to demonstrate (AGER, 1973) that the present tropical belt is atypically narrow and that wider tropical belts (perhaps even "hyper-tropical" belts having minimum temperatures unknown in modern seas) existed in the past.

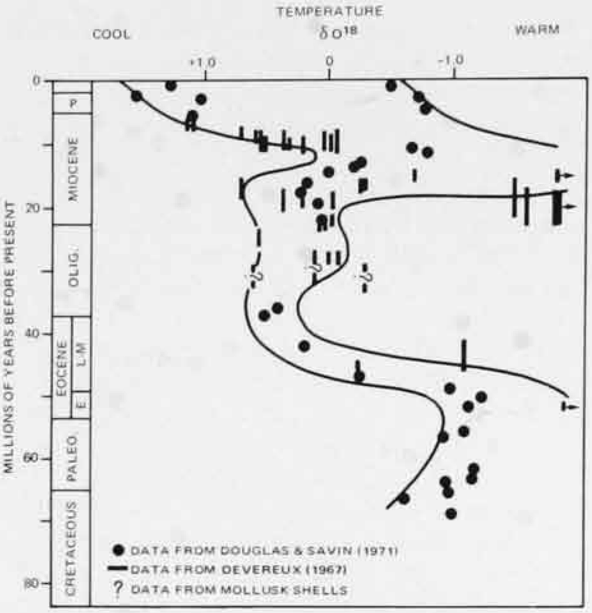


Fig. 21. Oxygen-isotope measurements made on tests of planktonic foraminifers and mollusks (after MOORE, 1972). These data reflect paleotemperatures for the central Pacific Ocean and New Zealand; major climatic optimums were interpreted to have occurred during the Middle Miocene and Early Eocene and a less-pronounced optimum during the late Oligocene. Time scale after BERGGREN (1969d).

A warming trend in late Early Miocene seemingly reached a peak during the early Middle Miocene as is demonstrated by occurrence of tropical species typical of the *Globorotalia fohsi fohsi* Zone at high latitudes, such as New Zealand (JENKINS, 1971), Australia, Japan (SAITO, 1963; ASANO & TAKAYANAGI, 1965, 1969; IKEBE ET AL., 1972), north Atlantic (BERGGREN, 1972b), and Mediterranean region (BLOW, 1957, 1969, EAMES ET AL., 1962; BERGGREN, 1969a).

Worldwide cooling toward the end of the early Middle Miocene (*Globorotalia fohsi lobata-robusta* Zone) caused marked equatorward restriction of tropical faunas. In high-latitude records just mentioned, phyletically advanced carinate subspecies of the *Globorotalia fohsi* lineage (notably *G. f. lobata* and *G. f. robusta*) are lacking and cool-water faunas dominate. Although BLOW (1969) observed this faunal change, evidently he regarded it as only a quirk of evolution and did not consider paleotemperature change as the cause.

CASEY (1970) devised a technique for determining paleotemperatures from marine sediments by comparing ratios of selected radiolarian species deposited in modern sediments, where the average summer sea-surface temperature is known, with those in ancient sediments. CASEY (1971) and CASEY, PRICE, & SWIFT (1972) applied this method to determine paleotemperatures quantitatively for surface sections in southern California and found that sediments in the lower part of the Mohnian Stage were deposited in water 4 to 5°C. cooler than those of the preceding Luisian Stage and of the upper part of the Mohnian Stage. Based on mode of coiling in *Globigerina pachyderma,* BANDY (1968) and BANDY, CASEY, & WRIGHT (1971) reached somewhat similar conclusions. The base of the Mohnian Stage was calibrated radiometrically as having an age of about 12.0 m.y. by TURNER (1968) and was dated paleontologically as late Middle Miocene (basal *Globorotalia siakensis* Zone) by WILCOXON (1969) using nannoplankton. The commonly reproduced Neogene paleoclimate model of BANDY (1968), however, errs seriously in assigning the basal Mohnian to the Late Miocene and in assuming a radiometric age of less than 5 m.y. The model of CASEY (1971) is interpreted more readily because of the conventional biostratigraphic framework.

Micropaleontological and sedimentological studies of Cenozoic deep-sea cores from the Southern Ocean (MARGOLIS & KENNETT, 1971) suggested Antarctic glaciation during the Eocene and Oligocene and a warming trend within the Early to Middle Miocene. ADDICOTT (1969) analyzed distributional patterns of shallow-water molluscan faunas of the middle latitudes in the marginal northeastern Pacific Ocean to show climatic warming from the Oligocene to Middle Miocene, followed by progressive climatic deterioration to the Pliocene.

In an analysis of paleotemperatures derived from Tertiary floras, AXELROD & BAILEY (1969) reviewed the plant record and found insufficient evidence for some proposed pronounced climatic fluctuations. Using more refined methodology, however, they did concede existence of convincing evidence for a general cooling trend in the western United States from Middle Miocene to Quaternary.

The transition from Middle Miocene to Late Miocene was accompanied by moderate temperatures at high latitudes; that is to say, neither as warm as the early Middle Miocene nor as cool as the late Late Miocene. The fauna of the Tortonian Stage of Italy (early Late Miocene) closely approaches a tropical assemblage, and CASEY'S studies in California suggest temperature fluctuations of a few degrees centigrade at this time. In low-latitude regions species diversity gradually decreases as the Pliocene is approached.

Mountain glaciation in Alaska 10 m.y. ago (i.e., late Middle to Late Miocene) was documented by DENTON & ARMSTRONG (1969). In this general region BANDY, CASEY, & WRIGHT (1971) reported left-coiling *Globigerina pachyderma* from the lower part of the Yakataga Formation at Cape Yakataga in beds closely associated with conglomerates which they considered to be marine tillites. A temperature decrease of about 10°C. is suggested for this time. Unclear, however, is why an age of 13 m.y. was inferred for this event when the earliest documented mountain glaciation in the region is 10 m.y.

Latest Miocene time (upper part of the *Globorotalia acostaensis* Zone) was characterized by cool climes at high latitudes and low species diversity at low latitudes. BLOW (1959) recognized an abrupt appearance of the cool-water species *Globigerina bulloides* in the Caribbean region at this time.

In the Mediterranean region the warm Tortonian interval grades upward to what generally is regarded as a cool interval, the Messinian. Studies of plant macrofossils by MARCHETTI (1968) suggest a cool climate during deposition of the Messinian evaporites and a following warm climate for the superjacent Pliocene Epoch. The Messinian evaporites seem to have been deposited during a time of low sea-level stand and desiccation in the Mediterranean basin following its isolation from the Atlantic Ocean (HSÜ & CITA, 1973). Seemingly a low sea level occurred also in the Caribbean region at this time as described by LAMB & BEARD (1972).

DOUGLAS & SAVIN (1971) reported that sea temperature during the Pliocene was comparable with that of the Middle Miocene in the central Pacific region, whereas DEVEREUX (1967) and DEVEREUX, HENDY, & VELLA (1970) claimed that temperature in the Pliocene was lower than that of the Middle Miocene in New Zealand. JENKINS (1971) stated, however, that several distinctly tropical planktonic foraminiferal species made incursions into the Pliocene of North Island.

Tropical planktonic foraminifers occur widely throughout the Pliocene of high latitude regions, such as Japan (IKEBE ET AL., 1972), north Atlantic Ocean (BERGGREN, 1972b), Italy (COLALONGO ET AL., 1972, and citations therein), and the

Mediterranean region in general (BIZON & BIZON, 1972; CITA, 1973). The widespread occurrence of tropical species characteristic of the *Globorotalia margaritae* and *Pulleniatina obliquiloculata* Zones in high-latitude regions during the Pliocene seemingly precludes postulation of Pliocene cold periods (i.e., prior to the Calabrian).

On the basis of studies on cores taken south of the present-day limit of ice rafting in the Southern Ocean KENNETT & BRUNNER (1973) suggested that the Middle Miocene to Late Miocene was an interval of reduced glaciation or deglaciation in Antarctica and that ice-rafted sediments occur first 4 to 5 m.y. ago. In discussing the Antarctic glacial history recorded in sediments of the Southern Ocean, GOODELL ET AL. (1968) concluded that a glacial maximum occurred during the Gauss paleomagnetic epoch (2.35-3.35 m.y. ago) when the zero-degree surface-water isotherm was displaced northward more than five degrees of latitude relative to the present.

A report on radiolarian biostratigraphy and magnetic stratigraphy of seven cores from the Antarctic Ocean (HAYS & OPDYKE, 1967) indicated that the greatest faunal change in these cores is at a level interpreted as about 2.5 m.y. ago and represents transformation from warmer to cooler conditions near this boundary. Additional evidence for climate change in the Southern Ocean at this time is supplied by THEYER (1973a) whose analysis of planktonic foraminifers showed that temperature changed from warm to cool during the Gauss interval.

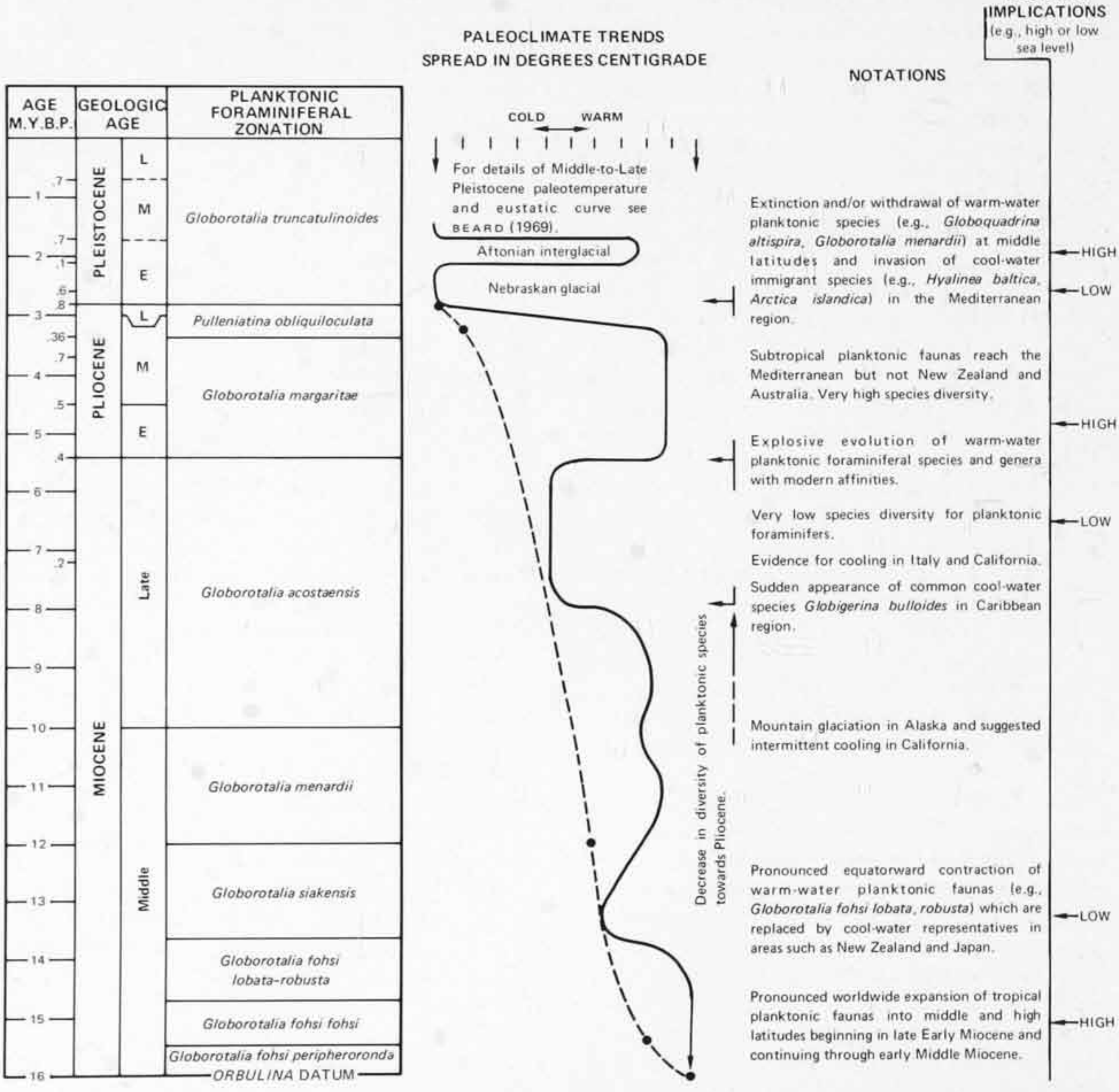
At high latitudes in the north Atlantic tropical planktonic foraminiferal faunas of the Pliocene *Globorotalia margaritae* and *Pulleniatina obliquiloculata* Zones are overlain directly by glacio-marine sediments that DAVIES & LAUGHTON (1972) interpreted as ice-rafted debris from pack ice which they related landward with relics of continental glaciation that covered North America and Europe. BERGGREN (1972b) confirmed this by stating that glaciation began 3 million years ago in the area of the north Atlantic and suggested that this was the time of the first major expansion of Arctic ice sheets over Europe and North America as well as mountain glaciation in the Sierra Nevadas, Rockies, and Alps. He considered the earliest continental glaciation to be Nebraskan. Using essentially the same biostratigraphic method as BERGGREN for the north Atlantic (i.e., paleomagnetically dated planktonic foraminiferal datums), LAMB & BEARD (1972) interpreted the base of the Nebraskan at about 2.8-3.0 million years in the Gulf of Mexico on evidence of marked climatic cooling. Present evidence leaves little if any doubt that this episode of climatic cooling correlates with that of the upper Gauss in southern high latitudes.

Interestingly, ice-rafted detritus appears first in piston cores from the northwestern Pacific Ocean (CONOLLY & EWING, 1970) after the end of the Gauss magnetic epoch about 2.2 million years ago. Such detritus is relatively rare until about 1.5 m.y. ago but is particularly abundant during the past million years.

Oxygen-isotope measurements for New Zealand indicate gradual cooling of sea temperatures on the order of 10°C. from early Middle Miocene to early Pleistocene (although evidence from the central Pacific Ocean indicates amelioration during the Pliocene). Other lines of evidence discussed here, including the stratigraphic and geographic distribution of planktonic foraminifers, suggest wide fluctuations. Climatic records for the southern and northern hemispheres, however, seem to be in harmony.

In conclusion, these and other widely scattered paleoclimatic data are integrated into an empirical worldwide sea-temperature curve (Fig. 22). Although local variations due to causes other than change in world climate are possible and minor fluctuation of the overall curve seems very likely, relative trends are evident. This approximation of temperature-change trends for the later Neogene has especial significance for interpretation of the biostratigraphic position of many planktonic foraminiferal assemblages, particularly in middle to moderately high latitudes, but also provides some basis for dating by using interpreted temperature change in sections where temperature-indicating foraminifers occur without zonal markers. Moreover, marked temperature changes seem related to other worldwide events having stratigraphic significance (e.g., eustatic changes in sea level) so that continued application and refinement of the paleotemperature-trend curve (Fig. 22) should aid importantly in stratigraphic subdivision and interpretation of late Neogene sections.

Although the expression "worldwide temperature change" is applied in the preceding discussion, presently uncertain are several factors generally assumed by this expression. Few data seem available to demonstrate if worldwide changes here described are accompanied by a quantitatively similar decrease or increase in temperature at all latitudes or, for example, by a considerable temperature change at high latitudes but only an incidental change in tropical areas. Incompletely understood also are possible changes in temperature gradient from the poles to the tropics at different times during the geologic past. Moreover, insertion of quantitative values on temperature-trend curves designated for worldwide application (i.e., scale for curves on Fig. 22) obviously is impracticable because of the marked temperature gradient between tropical and polar seas. As noted previously, however, many data have been obtained from middle-latitude regions so that quantitative evaluation of Neogene paleotemperatures may be practicable soon for these latitudes.



For details of Middle-to-Late Pleistocene paleotemperature and eustatic curve see BEARD (1969).

Extinction and/or withdrawal of warm-water planktonic species (e.g., *Globoquadrina altispira, Globorotalia menardii*) at middle latitudes and invasion of cool-water immigrant species (e.g., *Hyalinea baltica, Arctica islandica*) in the Mediterranean region.

Subtropical planktonic faunas reach the Mediterranean but not New Zealand and Australia. Very high species diversity.

Explosive evolution of warm-water planktonic foraminiferal species and genera with modern affinities.

Very low species diversity for planktonic foraminifers.

Evidence for cooling in Italy and California.

Sudden appearance of common cool-water species *Globigerina bulloides* in Caribbean region.

Mountain glaciation in Alaska and suggested intermittent cooling in California.

Pronounced equatorward contraction of warm-water planktonic faunas (e.g., *Globorotalia fohsi lobata, robusta*) which are replaced by cool-water representatives in areas such as New Zealand and Japan.

Pronounced worldwide expansion of tropical planktonic faunas into middle and high latitudes beginning in late Early Miocene and continuing through early Middle Miocene.

Fig. 22. Paleoclimatic trends for the Middle Miocene to Pleistocene. Relative sea-paleotemperature curve (dashed) is from oxygen-isotope analyses of New Zealand Tertiary fossils (after DEVEREUX, 1967, and DEVEREUX, HENDY, & VELLA, 1970). Empirical sea-paleotemperature curve (solid) is based in part on the stratigraphic and geographic occurrences of planktonic foraminifers.

AGES OF ZONES AND DATUMS

The Committee on Mediterranean Neogene Stratigraphy has made commendable progress in standardization of European stage nomenclature and has improved correlations substantially since the first meeting in Paris in 1958. Some nine "working groups" are concerned with specific problems in such fields as sedimentology, stratigraphy, paleontology, and radiometric ages. Of particular interest are activities of the micropaleontology groups which, through sponsorship of studies on planktonic foraminifers, found that these organisms and their horizons of appearance and extinction offer reliable criteria for recognition and correlation of European Neogene stages, which are the basis for a standard stratigraphic time scale. Although many problems involving boundaries and definitions of stages have been resolved, nomenclature still is developing so that a concise standard having widespread approval probably will not be obtained without additional international discussions. Current usage for the late Neogene is summarized in several recent papers by CITA & BLOW (1969), BERGGREN (1971b), CARLONI ET AL. (1971), COLALONGO ET AL. (1972), LAMB & BEARD (1972), and CITA (1973).

A trend toward uniform usage in the chronology and nomenclature of late Neogene stages (Fig. 23-24) seems evident now. Only a few stages remain in international use; many synonyms and local names have been discarded. Studies of planktonic foraminifers, however, have revealed a gap between the Langhian and Tortonian Stages, and this gap is not represented by any stage normally used in western Europe. Thus the little-known Serravallian Stage of northwest Italy (PARETO, 1865) has been revived to provide a name for this interval. Therefore, the Serravallian constitutes the late Middle Miocene, the Tortonian and Messinian the Late Miocene, the Tabianian and Piacenzian (variously spelled Plaisancian and Piacentian) the Early and Late Pliocene, respectively, and the Calabrian the earliest Pleistocene. The partly nonmarine nature of Messinian deposits within the Mediterranean basin prompted PERCONIG (1971), PERCONIG & GRANADOS (1973), and others to propose the Andalusian Stage (type area in southern Spain) as representing a marine succession extending from Tortonian to Pliocene. The Andalusian seems a particularly suitable substitute for the Messinian if Neogene workers prefer a fully marine section

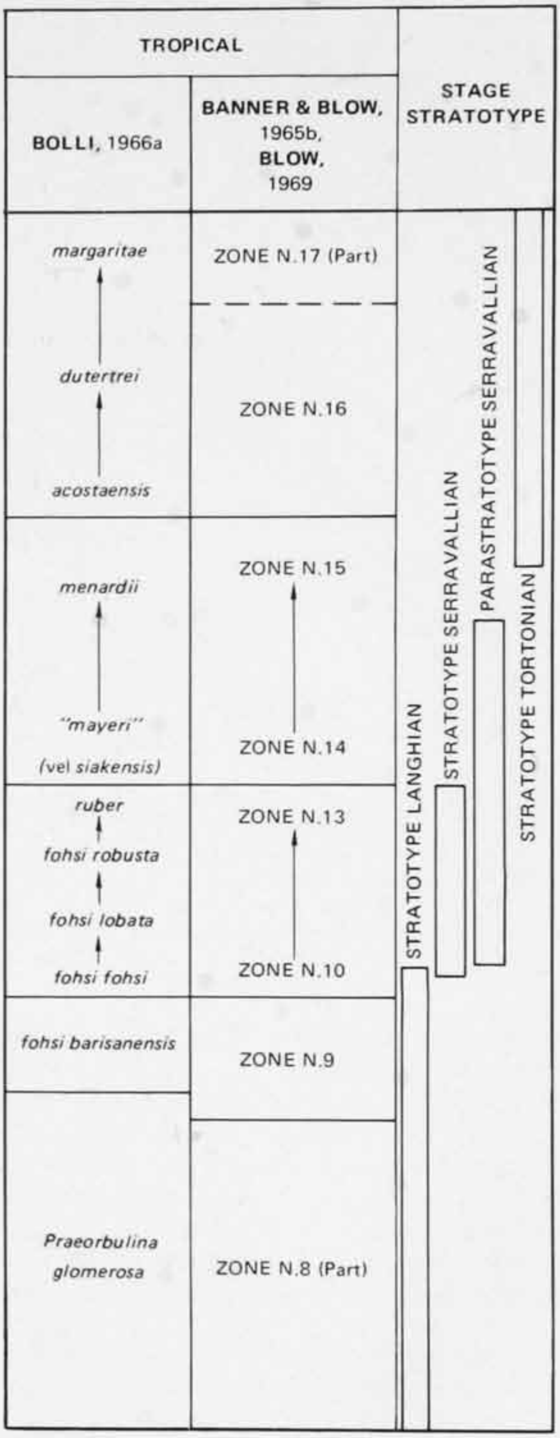


Fig. 23. Correlation of Middle Miocene to Late Miocene stages of Italy with tropical zonations of several authors (from CITA & BLOW, 1969). Placement of the *Globorotalia margaritae* Zone of BOLLI within the Tortonian Stage, however, is not supported by data presently available, and the extinction level of *Globorotalia siakensis* falls between the Serravallian and Tortonian Stages.

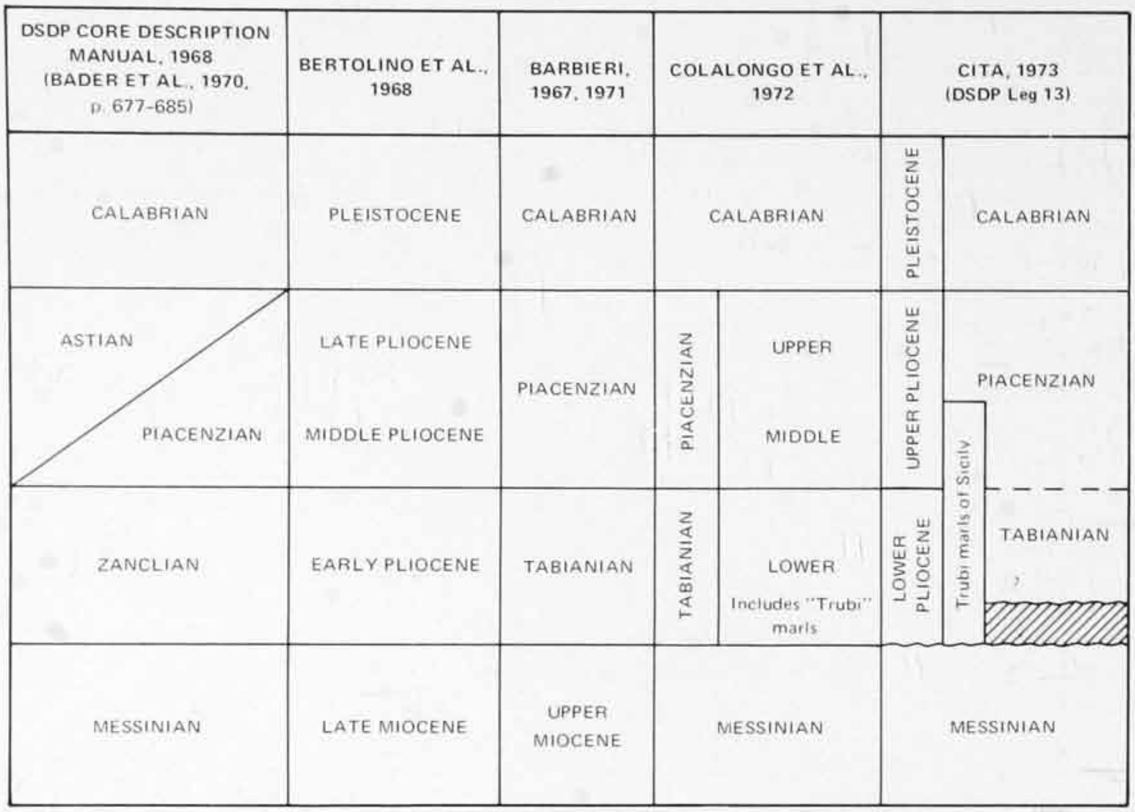


Fig. 24. Current stratigraphic and stage usage by several authors for the Late Miocene to earliest Pleistocene. Pre-Messinian Late Miocene marine intervals are discussed by CITA, PREMOLI SILVA, & ROSSI (1965) (Tortonian Stage); CITA & BLOW (1969) (Tortonian Stage); and TJALSMA & WONDERS (1972) (Sahelian Stage). Correlation with eastern Mediterranean stages characterized by having been deposited in brackish water or continental environments (e.g., Pontian and Sarmatian Stages) is unknown. (DSDP = Deep Sea Drilling Project.)

containing planktonic foraminifers as the representative of a stage.

Except for the nonmarine conditions in the terminal Miocene (i.e., Messinian), the classical stages of Italy provide a nearly complete record of late Neogene intervals with planktonic foraminifers occurring throughout most of the sections. Also, planktonic foraminiferal marker species fortunately occur so as to facilitate extra-Mediterranean dating and correlating. A number of planktonic foraminiferal zones have been proposed to subdivide late Neogene stages in Italy; the more recent are those of CITA, PREMOLI SILVA, & ROSSI (1965), BARBIERI (1967, 1971), BARBIERI & PETRUCCI (1967), FOLLADOR (1967), IACCARINO (1967), BERTOLINO ET AL. (1968), CATI ET AL. (1968), COLALONGO (1968, 1970), D'ONOFRIO (1968), COLALONGO ET AL. (1972), and CITA (1973). Although these zones have application mostly within the Mediterranean region, horizons defined by the first and last occurrence of certain well-documented species can be projected into middle- and low-latitude regions of the world as datums for dating and correlating (Fig. 25).

To avoid ambiguity in procedures applied in worldwide correlation, the *Globorotalia acostaensis* Datum is chosen here as the most appropriate horizon to define the base of the Late Miocene even though this datum occurs about 35 meters above the base of the stratotype Tortonian (CITA & BLOW, 1969). Chronostratigraphic nomenclature for the late part of the Late Miocene is not fully decided because the Messinian evaporite deposits overlying the Tortonian throughout the Mediterranean region represent partially nonmarine sedimentation. Conceivably future consideration may be given to a marine equivalent of the Messinian, such as the Andalusian.

Pliocene correlations in Italy discussed recently by COLALONGO ET AL. (1972) acknowledged that the "Trubi" beds of Sicily (which directly overlie

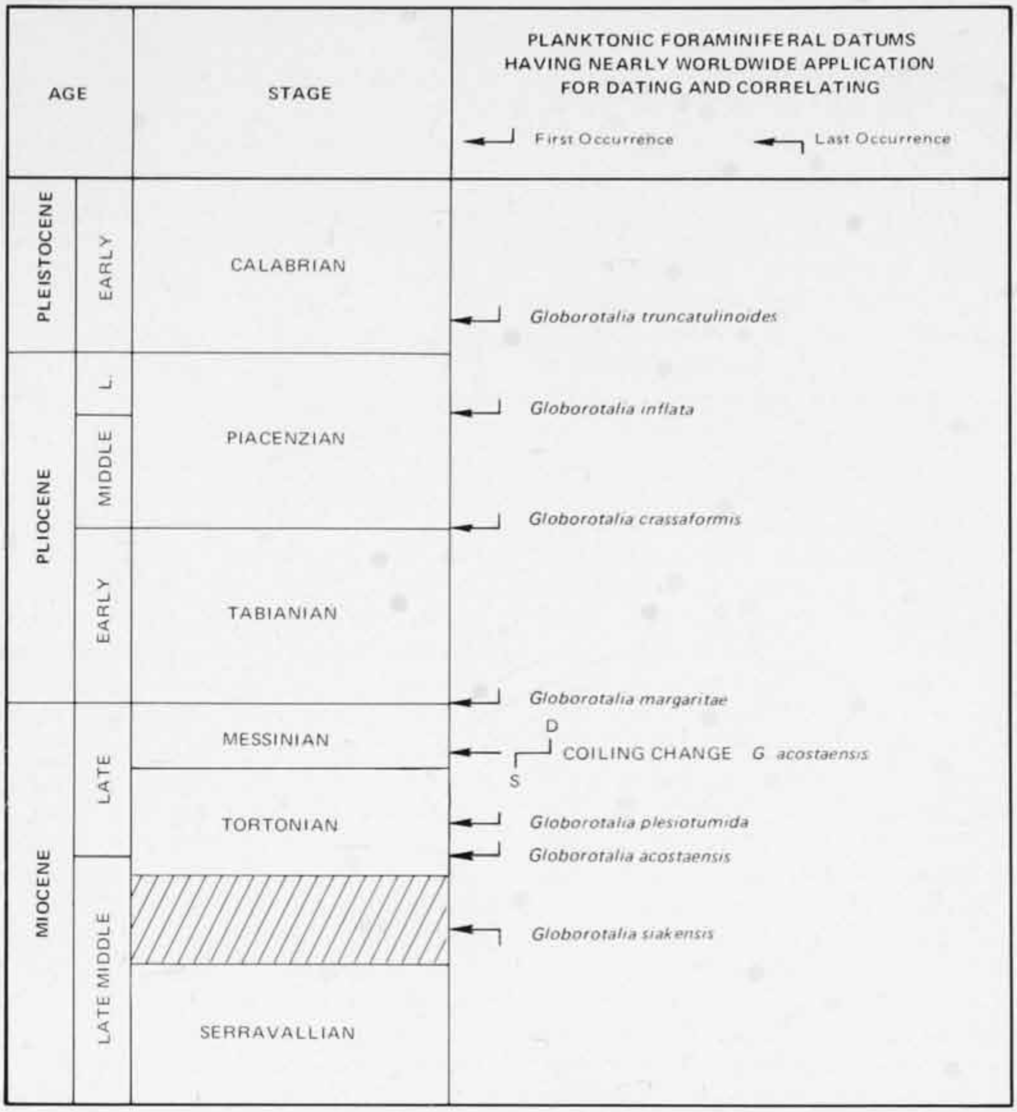


Fig. 25. Commonly accepted succession of late Neogene Mediterranean stages and corresponding planktonic foraminiferal datums. Hachures denote stratigraphic interval not completely represented in stratotype sections.

Messinian evaporites) are slightly older than beds of the stratotype Tabianian which has an unconformity at the base. These "Trubi" beds, however, are considered to be of Tabianian Age, the base of which corresponds to the *Globorotalia margaritae* Datum.

COLALONGO (personal communication) interprets the "Trubi" beds to represent only part of the section occurring in the Zanclian. She noted also that Zanclian beds differ in thickness from place to place and that samples cannot be obtained now from the stratotype. BARBIERI (1971) strongly disapproved use of Zanclean (sic) as a stage in the Early Pliocene inasmuch as the Tabianian has priority and is found in depositional contact with the overlying Piacenzian. Most European workers seemingly favor suppressing the term Zanclian.

The Piacenzian constitutes the Middle and Late Pliocene. BARBIERI (1967) demonstrated the Astian to be a poorly correlatable regressive sandstone lithofacies within the Piacenzian area of outcrop and rejected the term Astian as an unsuitable stage denominator. This usage is followed by most later workers.

Placement of the *Globorotalia crassaformis* Datum in the Italian stratal succession is a point of minor controversy that is discussed by BARBIERI

(1971), COLALONGO ET AL. (1972), and CITA (1973). In brief, the dispute concerns 1) whether *Globorotalia crassaformis* occurs in the stratotype Tabianian and 2) whether the range of *G. crassaformis* overlaps the range of *Globorotalia margaritae*. These are significant issues critical for placement of the Tabianian. BARBIERI & PETRUCCI (1967) and IACCARINO (1967) recorded both *Globorotalia crassaformis* and *Globorotalia puncticulata* from the region of the stratotype Tabianian. On the other hand, DR. MARIA LUISA COLALONGO (personal communication) stated that *G. crassaformis* is lacking in the Tabianian; samples collected by Exxon Production Research Company geologists tend to confirm her conclusion. GRADSTEIN (1972) also maintained that *G. crassaformis* (as the name was applied by BARBIERI & PETRUCCI, 1967, and IACCARINO, 1967) is inseparable from *G. puncticulata*. Lastly, no figured specimens of planktonic foraminifers from either stratotype of Tabianian or "Trubi" beds closely resemble *G. crassaformis*. The species must be assumed to be lacking, therefore, in the Early Pliocene. The joint occurrence of *Globorotalia margaritae* and *Globorotalia puncticulata* with *Globorotalia crassaformis* in Greece (BIZON & MIRKOU, 1969) and in the Mediterranean Sea (CITA, 1973) illustrates that the two first-mentioned species lived longer in southern regions of the Mediterranean than in northern Italy. The same is true for low-latitude regions discussed in the present paper. It is concluded that *G. margaritae* ranges only within the Early Pliocene (Tabianian) in northern Italy but continues into the Middle Pliocene (early Piacenzian) of more southerly regions. This means that the *Globorotalia margaritae* Zone of low latitudes is of Early and early Middle Pliocene age. On this evidence the *Globorotalia crassaformis* Datum is considered the base of the Middle Pliocene (Fig. 25).

Evolutionary development of *Globorotalia inflata* from *Globorotalia bononiensis* in the Upper Piacenzian apparently is accepted by all workers as a datum for the Late Pliocene in the Mediterranean region. Although *G. inflata* appears somewhat later in low-latitude regions, its presence at any latitude denotes an age no older than Late Pliocene.

The Calabrian (earliest Pleistocene) in Italy has been recognized for many years as a time of distinct climatic change that brought boreal immigrant species (e.g., *Hyalinea baltica, Arctica islandica,* and common *Globigerina pachyderma*) into the Mediterranean region for the first time (CATI ET AL., 1968; BERTOLINO ET AL., 1968). Although no definitive planktonic foraminiferal datum corresponds precisely to this climatic event, it definitely occurs subsequent to the first appearance of *Globorotalia inflata* and prior to the first appearance of *Globorotalia truncatulinoides*. *Globorotalia tosaensis* also occurs sporadically first in the Late Pliocene of Italy and more commonly in the southern Mediterranean Sea (CITA, 1973); thus, this datum may be useful also in recognition of the lower Calabrian boundary.

Local records of extinctions and first appearances of species within the Pleistocene tend to diverge from total ranges because of the major paleoclimatic fluctuations. Consequently such paleontologic datums must be applied with caution. *Globorotalia tosaensis* became extinct in the early Pleistocene (Fig. 19). The evolution of *Pulleniatina finalis* from *Pulleniatina obliquiloculata* in the late Pleistocene provides another reliable datum if the transition interval is discernible. *Globorotalia truncatulinoides* is a helpful accessory species for recognizing the early Pleistocene as it appears first just subsequent to the extinction of *G. altispira* (except in low equatorial latitudes where it may appear somewhat later because of environmental conditions).

The Holocene, represented by the *Globorotalia tumida* Zone, is a very short interval characterized by warmer-water faunas than occur in the latest Pleistocene. A change in the gross nature of the fauna is used to distinguish the base more commonly than a particular faunal datum. In our experience, however, the first appearance of *Globorotalia ungulata* coincides approximately with this base.

PLIOCENE-PLEISTOCENE BOUNDARY

SUMMARY

Dramatic developments in analysis of marine Pleistocene deposits have been recorded within very recent years. Cores obtained from all oceans have provided a wealth of material for biostratigraphic study (especially zonation and age correlation using planktonic microfossils). Also changes in paleomagnetic polarity have been related to the radiometric time scale so as to facilitate studies on late Neogene sections. Meanwhile continued development and applications of sedimentology and paleoecology have expanded knowledge of eustatic changes in sea level, and interpretation of isotopic analyses has yielded many data on radiometric ages and on paleotemperatures. Potentially this new information provides a basis for correlating marine sections with long-established Pleistocene stratigraphy and chronology of adjacent continents, and then, by transoceanic correlation, determining firmly relationships from hemisphere to hemisphere. Thus an accurate record of Pleistocene events around the world could be obtained.

Much has been achieved along the lines just mentioned (as is suggested by the many cited references which, however, constitute only a part of the extensive literature now available in this area). Nevertheless, despite harmonious interrelationships of almost all the data, one contentious point remains—the Pliocene-Pleistocene boundary.

Initial studies on deep-sea sections necessarily were dependent on short cores that mostly extended only into the upper part of the Holocene-Pleistocene section. The position of the Pliocene-Pleistocene boundary was assumed on the basis of a change in content of calcium carbonate (ARRHENIUS, 1952) or more or less arbitrarily selected biologic criteria (RIEDEL, 1957; ERICSON, EWING, & WOLLIN, 1963, 1964; RIEDEL, PARKER, & BRAMLETTE, 1963). Early in these oceanographic studies the base of the Pleistocene was asserted to coincide with both extinction of all discoasters and with the Olduvai Normal paleomagnetic event (see ERICSON, EWING, & WOLLIN, 1963; RIEDEL, PARKER, & BRAMLETTE, 1963; HAYS & BERGGREN, 1971). This event was interpreted as occurring 1.8 to 2.0 my ago by correlation with radiometrically dated intervals, and it came to be the age accepted by many of those concerned with deep-sea cores for the base of the Pleistocene. On the other hand, the Nebraskan glacial interval of the North American continent, hitherto regarded as the earliest Pleistocene of that continent, was interpreted as commencing 2.8 to 3.0 million years ago and lasting until the start of the Aftonian interglacial about 2.1 m.y. ago (HIBBARD ET AL., 1965; BEARD, 1969). The automatic postulate follows that the Nebraskan, beginning a million years earlier than the Pleistocene, must be assigned to the Pliocene. To maintain this concept, reasons had to be adduced for a climatic deterioration of continental scale in North America when no such event is apparent in the Pliocene of the type Mediterranean region. One line of argument has been that continental glaciation in northern latitudes would not be accompanied necessarily by indications of cooling in the Mediterranean, mid-Atlantic, and Gulf of Mexico to the south. Also, some authors have cited cool intervals during several parts of the Tertiary as indicating that continental glaciation was not confined to the Pleistocene.

In our considered opinion such reasoning is specious, serving only to preserve a false assumption. We assert that evidence from both the southern and northern hemisphere supports the straightforward interpretation that the bases of the Calabrian and Nebraskan are synchronous. A glacial concept of the Pleistocene probably has as much application in marine as in continental environments. Moreover, it is difficult to imagine an alternative concept for distinguishing the Pliocene-Pleistocene boundary that has comparable practical and wide application with respect to the many different earth-science disciplines.

In the present context emphasis is placed on the major role of planktonic foraminifers in Pliocene-Pleistocene stratigraphy, but some other pertinent aspects are noted. By Pleistocene we mean the epoch or series extending from the base of the Calabrian stratotype up to the Holocene. Other definitions are applied by some current workers (e.g., BIREKELAND, CRANDELL, & RICHMOND, 1970; RUDDIMAN, 1971; COOKE, 1972; GARTNER, 1973). We state here mainly, however, the position previously given (LAMB & BEARD, 1972) and clarify a few interpretations.

PLANKTONIC FORAMINIFERS

Planktonic foraminifers from classical Calabrian localities at Santa Maria di Catanzaro and Le Castella in southern Italy were discussed by BAYLISS (1969), BANDY & WILCOXON (1970), and LAMB & BEARD (1972). *Hyalinea baltica* and common *Globigerina pachyderma* occur at the base of the Calabrian sections at both localities whereas *Globorotalia truncatulinoides* first appears above the base. *Arctica islandica* is recorded only from the Catanzaro section. In these sections, therefore, the Calabrian is well defined by the concept of climatic deterioration (i.e., first appearance of boreal species) so long acknowledged by Italian workers.

The biostratigraphic basis for dating and correlating early Pleistocene in extra-Mediterranean regions is convincing and seemingly lacks serious problems (LAMB & BEARD, 1972). The extinction level of *Globoquadrina altispira* in warm-water regions of the world reflects the onset of climatic deterioration that led to Nebraskan glaciation (Fig. 22, 26). This extinction occurs in the interval between the *Globorotalia tosaensis* and *Globorotalia truncatulinoides* Datums (Fig. 19) so that these widely recognized datums closely bracket the Pliocene-Pleistocene boundary (Fig. 17-18).

CALCAREOUS NANNOPLANKTON

Rich and diverse nannoplankton assemblages from Calabrian strata at Le Castella and Catanzaro discussed by SMITH (1969) surprisingly were dismissed summarily as being redeposited by BANDY & WILCOXON (1970). To correct any possible misunderstanding, samples from another Calabrian interval in the Santerno River section south of Bologna were examined to determine the occurrence of discoasters. This section (described by COLALONGO, 1968) was proposed as an alternate section for the Piacenzian by COLALONGO ET AL. (1972) because of its completeness and conformity with the overlying Calabrian, as indicated by occurrence of *Arctica islandica.* SMITH (personal communication) found rich nannoplankton assemblages (much like those of southern Italy) within this Calabrian interval and observed *Discoaster brouweri* ranging throughout the lower 600 meters.

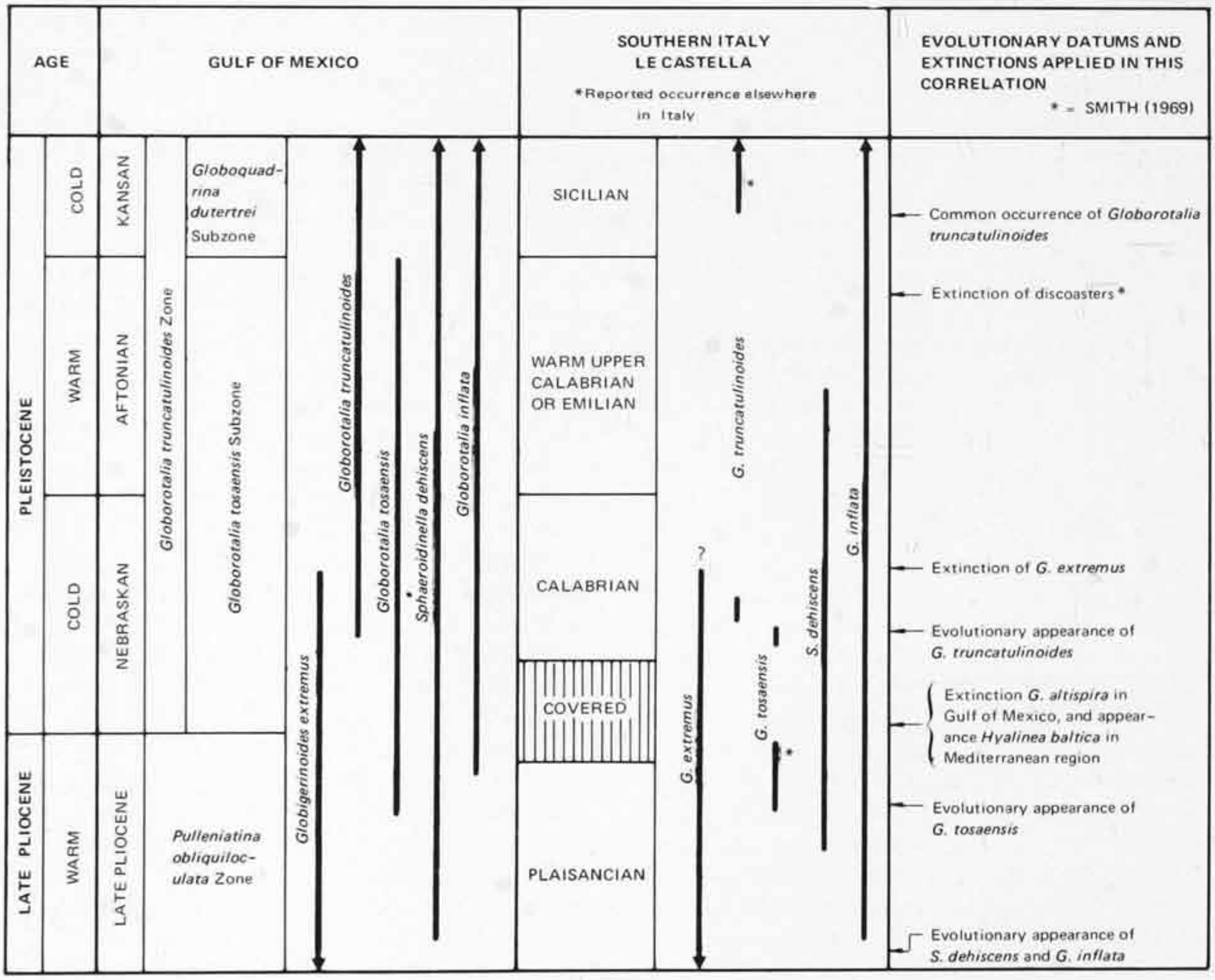


Fig. 26. Correlation of Pliocene-Pleistocene stages of the Gulf of Mexico and Italy based on planktonic foraminifers and climatic implications (after LAMB & BEARD, 1972).

In the southern Mediterranean Sea STRADNER (1973) also records *D. brouweri* ranging through an interval dated as Calabrian by CITA (1973) on the basis of occurrence of *Globorotalia truncatulinoides*. Thus, the assumption that extinction of discoasters corresponds to the base of the Calabrian in Italy is amply refuted. (Repeated mention in publications of the unsubstantiated theory seems to have enhanced the concept so that some workers came to accept it as fact.) *Discoaster brouweri*, therefore, is judged to be a critical key in defining the Calabrian, and BANDY & WILCOXON erred in assuming reworking of all discoasters at Le Castella and Catanzaro. A cardinal point described by SMITH (1969) and SMITH & BEARD (1973) is the reality of the co-occurrence of *Globorotalia truncatulinoides* and *Discoaster brouweri* in the lower and upper Calabrian, and the co-occurrence of *D. brouweri* and *Gephyrocapsa oceanica* in the upper Calabrian. These criteria enhance identification of the early Pleistocene Nebraskan and Aftonian Stages in the marine succession of the Gulf of Mexico as described by LAMB & BEARD (1972).

PALEOCLIMATE

Although the Pleistocene was defined initially on the basis of the proportion of living to extinct species (LYELL, 1839), synonymy of the glacial epoch and the Pleistocene was recognized only slightly later (FORBES, 1846). Geologists, therefore, long have defined and recognized this interval on a climatic basis.

Studies by LAMB & BEARD (1972) and interpretations (using concepts described herein) of data given by many current workers show that the Calabrian is definable climatically as well as biostratigraphically and that climatic fluctuations are recognizable in many regions outside the Mediterranean area (e.g., Gulf of Mexico, Far East) (Fig. 26).

Earliest Pleistocene deposits of northern Italy are preserved in the lower part of the continental sequence at Leffe; these have been assigned to the Donau glacial interval. The vegetational-climatic history of these deposits has been compared with that of other Pleistocene continental sections in Europe as well as with lacustrine and marine Calabrian deposits in northern and central Italy (LONA, 1971; LONA, BERTOLDI, & RICCIARDI, 1971; LONA & BERTOLDI, 1972, 1973). Onset of severe climatic deterioration at the beginning of the Pleistocene was recognized palynologically in both continental and marine sections by the marked changes in the vegetational character from the Late Pliocene to the Early Pleistocene. This level of vegetational change was termed the Tiberian boundary and was demonstrated to correspond with the time of appearance of boreal faunas in the Mediterranean region at the start of the Calabrian Stage. Thus, initiation of the Pleistocene was recognized reliably on physical evidence, such as glacial artifacts, and on biotic evidence indicative of climatic change. TAYLOR (1960, p. 21) also indicated that recognition of the earliest level of marked climatic cooling provides the most practicable and perhaps the most precise basis for correlation of the Pliocene-Pleistocene boundary between the type area of Italy and the midcontinent area of the United States.

Arguments for so-called pre-Pleistocene glaciations or cool periods in the late Cenozoic that conceivably conflict with or refute a climatic definition of the Pleistocene have little substance when such climatic variations are considered in light of their relative intensity and geologic time span (see Fig. 22 and accompanying discussion). For example, the Nebraskan glacial interval, which began with the onset of climatic deterioration about 2.8 to 3.0 million years ago and continued for some 800,000 years, is preceded in the late Neogene by a long interval lacking recognizable cold periods except in the Late Miocene (Messinian). Appreciable evidence (as Fig. 22) indicates that the Late Miocene indeed included a "cold snap" of worldwide importance. Although this is accentuated by the following very warm Pliocene climate, the severity scarcely can be compared to that of the Nebraskan glacial event when nearly one-third of the globe was covered by thick ice sheets. AGER (1973, p. 100) put it very succinctly when he said "The events of the Pleistocene glaciations must never be overlooked in any consideration of the stratigraphical record. Those glaciations were the most obviously catastrophic events in our history and produced in their tills and periglacial deposits some of the most persistent facies of all. In our near-sighted way of looking at the stratigraphical column, we tend to forget that these recent events, if considered on the normal geological time-scale, were virtually instantaneous and certainly catastrophic."

If the base of the Pleistocene is considered to be only as old as about 2.0 million years[1] (e.g., assuming extinction of discoasters is the major criterion for placement of the boundary) then the Nebraskan glacial together with part of the Aftonian interglacial must be assigned arbitrarily to the Late Pliocene. Although this is accepted by some workers concerned with deep-sea cores, adoption by the many geologists studying continental glacial and related deposits seems rather doubtful. Also, other aspects then would be equally confusing, such as considering the Calabrian to be younger than the Nebraskan, which raises the question of why is not the Nebraskan interval of continental glaciation reflected in the Mediterranean Pliocene record. Pliocene planktonic foraminiferal faunas of the Mediterranean, however, are mostly tropical and subtropical in character which precludes existence of a pre-Calabrian glacial interval. The conclusion that the Calabrian and Nebraskan are coeval, therefore, seems unavoidable.

The time-stratigraphic classification for the continental Pleistocene succession of the Central Interior of the United States (WILLMAN & FRYE, 1970; FRYE, 1972; DALRYMPLE, 1972) provides a paleoclimatic model that can be applied very exactly in marine sections (BEARD, 1969). Moreover, biostratigraphic analysis of post-Pliocene marine sections using planktonic foraminiferal events (e.g., extinction levels, appearance levels, joint occurrences, evolutionary development, relative abundance, and changes in preferred coiling direction) provides biostratigraphic and paleoclimatic bases for recognizing and interpreting locally incomplete marine sections and for detailed correlation between them. Radiometric dates from continents and accurate application of the paleomagnetic time scale in marine environments also contribute. The almost exact match for these two models, together with substantial agreement where radiometric age determinations are available, readily permits recognition in marine sections of widely accepted stratigraphic subdivisions of the Pleistocene glacial intervals (e.g., Nebraskan, Kansan, Illinoian, and Wisconsinan) and interglacials (e.g., Aftonian, Yarmouthian, Sangamonian) and, at least locally, even of subdivisions of these glacial and interglacial intervals.

Discussions already given for Paleoclimatic Trends are pertinent here also in evaluating worldwide indications of the temperature change at the position of the Pliocene-Pleistocene boundary.

EUSTASY

A little acknowledged aspect of a glacial concept for the Pleistocene is glacio-eustasy, which was defined by FAIRBRIDGE (1961) as a climatically controlled movement leading to removal or addition of water under conditions of glaciation and deglaciation. Glacioeustatic changes of sea level are important clues in deciphering the Pleistocene history of continental margins and to some extent also in ocean basins. FAIRBRIDGE (1961, 1966) reviewed development of the glacioeustatic theory and showed that glaciation and deglaciation caused significant worldwide changes in sea level. When sea level is lowered by glaciation, fluvial transport of terrigenous clastics to the marine environment tends to increase. Where conditions are favorable at such times, clastics cross the exposed continental shelf, may erode canyons into the shelf margin, and may funnel through these canyons into ocean basins where they are deposited as submarine fans. When sea level is raised by deglaciation, on the other hand, terrestrial clastics tend to be trapped in deltas or other deposits in the nearshore part of broad continental shelves, and biogenic carbonates may be deposited offshore. Thus, the nature and distribution of Pleistocene submarine deposits probably were controlled in no small measure by glacioeustatics.

In studies of deep-sea cores from the north Atlantic, ERICSON & WOLLIN (1964) noted sandstone deposited probably during times of Pleistocene glaciation, and DAVIES & LAUGHTON (1972) also described Pleistocene glaciomarine sediments. LAMB & BEARD (1972) discussed implications of low Pleistocene sea levels in the Gulf of Mexico and Caribbean regions and related low sea level with onset of Nebraskan and later glaciations. More recently SPROVIERI, D'AGOSTINO, & DI STEFANO (1973) described a major regressive-transgressive cycle at the base of the Calabrian at Santa Maria di Catanzaro in southern

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[1] Radiometric ages cited in these discussions are based on those related as exactly as possible to geologic age units (i.e., Fig. 1). Thus, the difference between an age of 2.8 to 3 million years and one of 2.0 million years indicates a different stratigraphic position and not uncertainty or divergent views as to the age of a single boundary.

Italy; this is the first evidence for eustatism in the type region of the Calabrian. BROLSMA & MEULENKAMP (1973) also described sedimentary features (i.e., channel filling, large-scale cross stratification, and coarse, terrigenous clastic material) within the lower Calabrian at Santa Maria. They claimed that these denote a shallowing of the sea at the end of the Pliocene. In an accompanying paper, DROOGER (1973) conjectured that climate-controlled sea-level changes during the Calabrian brought about shoaling. Indeed, a very long list of glacioeustatic applications could be given readily.

PALEOMAGNETIC TIME SCALE

Periodic reversals in polarity of the earth's magnetic field have been related to radiometric dates so as to constitute a paleomagnetic time scale (COX, 1969). This scale is an important aid in correlating and dating marine sections where deposition has been essentially continuous and the magnetic "fingerprint" is identified accurately. The paleomagnetic scale is related to age, however, generally by comparison of models because few deep-sea sections have been dated radiometrically. Moreover, marine sections locally are discontinuous because of submarine erosion, nondeposition, faulting, slumping, and other factors so that stratigraphic interpretation of magnetic "fingerprints" tends to be unreliable unless controlled by biostratigraphic study. Adequate interpretation of magnetic patterns throughout the late Neogene is impeded commonly by spurious events, long intervals lacking data on polarity and age, incomplete resolution of the frequency of very short events, and other difficulties (COX, DOEL, & DALRYMPLE, 1968; COX, 1969).

In spite of these present uncertainties, a very considerable amount of biostratigraphic information has been related to the paleomagnetic time scale. Discoasters became extinct in deep-sea cores about 1.65 to 1.8 m.y. ago at a level that corresponds to the event called Olduvai by some authors but Gilsá by others (e.g., SMITH & BEARD, 1973; GARTNER, 1973). As discoasters occur in the Calabrian (earliest Pleistocene) of southern Italy (SMITH, 1969), it follows that the Olduvai (Gilsá) event falls within rather than at the base of the Pleistocene.

Many deep-sea records support recognition of a major climatic change between the lower and upper parts of the Gauss epoch (i.e., near the Kaena event, about 2.8 m.y. ago). For example OPDYKE ET AL. (1966) correlated the oldest ice-rafted debris in high southern latitudes with the upper Gauss, and THEYER (1973a) recorded planktonic foraminifers in the Southern Ocean indicative of warm water during the lower Gauss and of cool water during the upper Gauss. *Globorotalia truncatulinoides,* which evolved just above the base of the Calabrian in the type area (LAMB & BEARD, 1972), is cited also as beginning in the upper Gauss (LAMB & BEARD, 1972; THEYER, 1973a). A major faunal and floral change (HAYS & OPDYKE, 1967; SMITH & BEARD, 1973) and a major increase in calcium carbonate content (ARRHENIUS, 1952; HAYS ET AL., 1969) are interpreted to have occurred during the upper Gauss. Normal polarity in the Calabrian section at Le Castella, Italy (LAMB & BEARD, 1972, Fig. 10), suggests that the Calabrian of the type area also represents part of the Gauss. Thus the severe climatic deterioration that led to the first Cenozoic continental glaciation of Europe and North America is correlated to within the Gauss interval.

LATE NEOGENE PLANKTONIC FORAMINIFERAL DATUMS

Stratigraphic ranges of planktonic foraminiferal species are shown plotted against a linear time scale which is calibrated with a succession of planktonic foraminiferal datums that have been dated variously by radiometric and paleomagnetic means (Fig. 19). Preceding discussions of the Paleogene and early Neogene closely follow the time scale of BERGGREN (1972a) for reasons stated there. In this late Neogene discussion, however, new data and differences in interpretive procedures (e.g., stage usage and boundary positions) make departure from BERGGREN'S scheme desirable. It is anticipated that increasing scientific interest and logical considerations will lead eventually to better understanding of the problems in the late Neogene.

It is presumptuous to assume that any chronostratigraphic scheme is infallible or to regard all planktonic foraminiferal datums as precisely dated even though their relative positions in time are judged to be established firmly. The procedure followed here was simply to select what are considered to be the most suitable datums (i.e., more widely used and consistently occurring) for a chrono-biostratigraphic framework for interregional dating and correlating

(Fig. 17-18). Datums of unknown or doubtful age then were positioned somewhat arbitrarily at suitable horizons using available stratigraphic evidence. The more significant datums were selected from the following literature:

GLASS ET AL. (1967), HAYS ET AL. (1969)
Globigerinoides fistulosus (top) – 1.85 m.y.
Change in coiling direction of *Globorotalia menardii* complex–2.1 m.y.
Globoquadrina altispira (top)–2.8 m.y.
Sphaeroidinella dehiscens (base)–3.0 m.y.
Globorotalia margaritae (top)–3.36 m.y.
Globigerina nepenthes (top)–3.7 m.y.

SAITO (1972)
Globorotalia crassaformis and related species (base)–between the Nunivak and Cochiti events (about 4.0 m.y.)

CITA (1973), OPDYKE (1972)
Globorotalia margaritae (base)–5.1 to 5.4 m.y.

SAITO (*in* KANEPS, 1970)
Pulleniatina primalis (base)–5.65 m.y.

BERGGREN (1972a)
Globorotalia acostaensis (base)–10.0 m.y.
Globorotalia siakensis (top)–12.0 m.y.

LAMB & BEARD (1972) and THEYER (1973a) reported *Globorotalia truncatulinoides* beginning in the upper Gauss Epoch, which is estimated here to be about 2.6 m.y. ROBINSON & LAMB (1970) recorded *Globorotalia ronda, Globorotalia miocenica, Globorotalia tosaensis,* and *Globorotalia pertenuis* as occurring first in the lower Gauss Epoch.

More details on dating of late Neogene planktonic foraminiferal datums were cited by BERGGREN (1967), GLASS ET AL. (1967), PHILLIPS ET AL. (1968), HAYS ET AL. (1969), KANEPS (1970), ROBINSON & LAMB (1970), BERGGREN (1972c), LAMB & BEARD (1972), and CITA & RYAN (1973).

Apparently conflicting published opinions on the earliest appearance of *Sphaeroidinella dehiscens* (PARKER & JONES, 1865) merit brief explanation. PARKER (1973) placed this datum just subsequent to the first appearance of *Globorotalia margaritae* BOLLI & BERMÚDEZ (1965) and stated (p. 281) that "*S. dehiscens* is separated as soon as a single specimen is seen with a supplementary aperture, rather than when a substantial part of an assemblage is referable to it." On the other hand, SRINIVASAN & SRIVASTAVA (1973), seemingly using a similar identification procedure, recorded the same datum as just prior to the first appearance of *G. margaritae.* Both of these levels are considerably older than that given herein.

Unlike PARKER (1973), we consider the size and character of supplementary aperture or apertures as important criteria in identification of *Sphaeroidinella dehiscens.* We differentiate *S. dehiscens* from its immediate ancestor, *Sphaeroidinellopsis paenedehiscens* BLOW (1969), by the larger size, smooth or crenulate rims (flanges) bordering one or more supplementary apertures, and more egg-shaped outline. Whether small sutural openings noted occasionally on specimens that we refer to *S. paenedehiscens* constitute apertures in the true sense or are merely cortical solution pits is immaterial in our view. LAMB & BEARD (1972) previously expressed their opinion on this subject.

We maintain that our strict concept of *S. dehiscens* is compatible with the type of the species and is stratigraphically dependable. In a number of instances, as just noted, the first appearance of an incipient supplementary aperture is an unreliable basis on which to define a planktonic datum reliably. Furthermore, the cited authors claim that *Sphaeroidinellopsis subdehiscens* is the immediate ancestor of *Sphaeroidinella dehiscens,* with which we do not agree. As they have not recognized *Sphaeroidinellopsis paenedehiscens* as an intermediate stage of evolution between *S. subdehiscens* and *S. dehiscens,* evaluation of their taxonomy is difficult. It would be less confusing if workers listed separately specimens having incipient supplementary apertures but lacking apertural flanges typical of *S. dehiscens* or treated such specimens as possible *formae* of *S. paenedehiscens.* Although not discussed as index species herein, names available for Pliocene sphaeroidinellids having small, incipient supplementary apertures are *Sphaeroidinella immatura* (CUSHMAN, 1919) and *Sphaeroidinella ionica* CITA & CIARANFI (1972).

Recent papers by THEYER (1973a) and BERGGREN (1973) purport to establish additional paleomagnetically-dated planktonic-foraminiferal datums. These are not cited herein, however, because they lack strong supporting biostratigraphic evidence and, as yet, have not received widespread agreement as to their application in dating and correlation.

At the time of this writing a paper appeared discussing the planktonic foraminiferal biostratigraphy of the southwest Pacific region (KENNETT, 1973). This article merits especial comment inasmuch as it presents a late Neogene planktonic succession for a warm-tropical area that compares very favorably with the succession recorded from the Caribbean and Gulf of Mexico regions (LAMB & BEARD, 1972; SMITH & BEARD, 1973) which forms much of the basis for the zonation proposed here. KENNETT determined that extinction of *Globoquadrina altispira* was nearly synchronous with the first appearance of *Globorotalia truncatulinoides* in his study area, and he designated this horizon as the Pliocene-Pleistocene boundary. This is in close agreement with our usage. Also important is the distinct overlap in that area of *G. truncatulinoides* and *Discoaster brouweri* (see also EDWARDS, 1973).

In view of the lack of paleomagnetic data, it is not clear why KENNETT assumed an age of 1.79 m.y.B.P. (base of Gilsá event) for his Pliocene-Pleistocene boundary when the planktonic foraminifers and discoasters clearly suggest Gauss Epoch, or older than 2.43 and younger than 3.0 m.y.B.P. (HAYS ET AL., 1969; THEYER, 1973a). We have accepted conclusions of others who have established radiometric ages of the many planktonic foraminiferal datums cited herein and, therefore, must disagree with the age KENNETT assigned to this horizon.

More recently, PARKER (1973) published a synthesis of late Cenozoic biostratigraphy in DSDP coreholes (Legs 1, 2, and 4) from tropical Atlantic deep-sea sections. Many of her basic data agree closely with our discussion, although her Late Miocene and Early Pliocene biostratigraphy seems to lack integration with previously published works on Caribbean and Gulf of Mexico regions where more expanded sections are encountered. In all, she defined six planktonic foraminiferal zones from the Late Miocene to Holocene. Her Pliocene-Pleistocene boundary corresponds closely to ours and was placed at the first appearance of *Globorotalia truncatulinoides.* Her Zone IV (latest Pliocene) is defined as an interval zone from the first appearance of *Globorotalia tosaensis* to the first appearance of *G. truncatulinoides.* Our boundary (e.g., the extinction horizon of *Globoquadrina altispira*) occurs midway in this zone, whereas her boundary occurs at the top of the zone. Because of the very short time duration of this zone (ca. 200,000 years within the upper Gauss Epoch), the entire zone would suffice for a reasonably accurate regional datum.

Of further interest are PARKER'S (1973) biostratigraphical observations on core Chain 61 (171) from the south-central north Atlantic, which has been cited by BERGGREN ET AL. (1967), BERGGREN (1967), PHILLIPS ET AL. (1968), and others to exemplify an interval illustrating the evolution of *G. truncatulinoides* from its immediate ancestor *G. tosaensis* within the Olduvai Normal Event (ca. 1.85 m.y. B.P.). On this evidence, that horizon was said to correlate with the base of the Calabrian Stage (earliest Pleistocene) in southern Italy. PARKER'S findings are that *G. truncatulinoides* ranges lower in the core than originally proposed and that inadvertently *G. tosaensis* was incorrectly identified (being actually *Globorotalia ronda*), thereby invalidating the horizon of supposed evolutionary development of *G. truncatulinoides* in this core. Interestingly, similar conclusions also were drawn by BOLLI (1970, p. 583).

The occurrence of *Globorotalia miocenica* in the lower disturbed interval of this core (which lacks paleomagnetic definition and is near the appearance of *G. truncatulinoides*) would, in our opinion, be very near or within the Gauss Event. Thus, the same line of reasoning that prompted correlation of the Olduvai with the Calabrian can now be applied to inferring correlation of the Calabrian with a horizon significantly lower in this core, that is to say, below the Olduvai and likely within the Gauss.

DESCRIPTIVE TERMINOLOGY

GENERAL

Planktonic foraminifers selected for zonations of Cenozoic strata reviewed in the present report are all spiral forms. The terminology used to describe their tests is basically the same as for all foraminifers (e.g., CUSHMAN, 1948, p. 14-24) although the planktonic types develop several features (e.g., bullas and cancellate surfaces) not commonly encountered in benthonic foraminifers. Cretaceous planktonics have yet other peculiarities (e.g., portici and tegilla) unknown in Cenozoic genera. Illustrated reviews of morphologic terminology are available in such well-known texts as BOLLI, LOEBLICH, & TAPPAN (1957, p. 9-15), BANNER & BLOW (1959, p. 2-3, 25-26), and BLOW & BANNER (1962, p. 82). So many modern authors provide excellent SEM illustrations of morphologic details that selection of representative examples is invidious; the atlas by MURRAY (1971), however, is outstanding.

The following section briefly reviews terms and their synonyms most commonly applied to taxonomy of planktonic foraminifers supplemented by illustrations drawn mainly from literature already cited (Fig. 27-29).

TERMINOLOGY

COILING PATTERN

1) Corresponding points of successive chambers follow a **spiral** course.

2) Simplest is a **planispire** although usually this is more advanced in a phylogenetic sense.

3) Commonest is a **trochospire** (trochoid, turboid) described as low to high (lofty) depending on degree of divergence from a planispire.

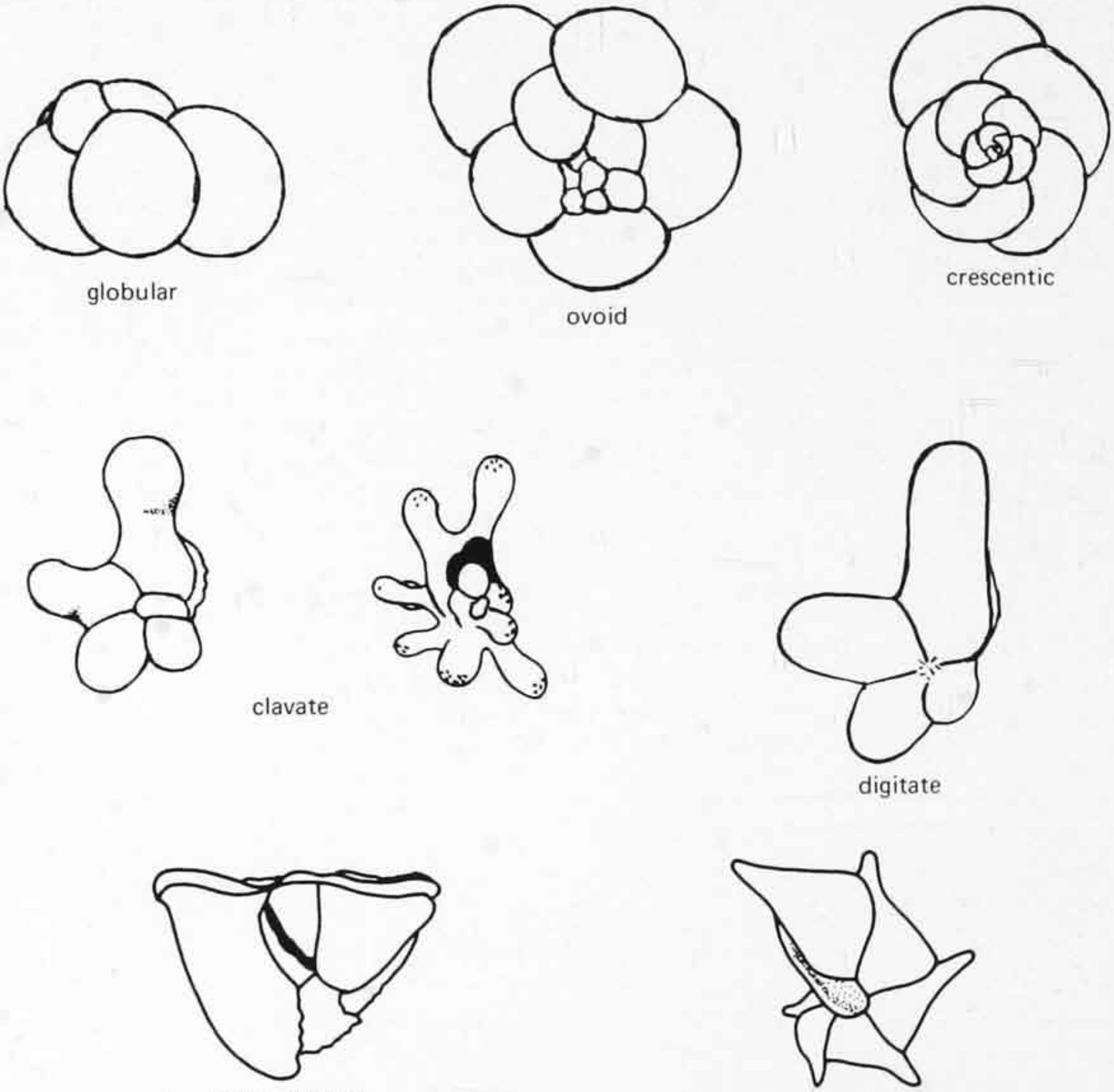


Fig. 27. Shapes of chambers in planktonic foraminifers.

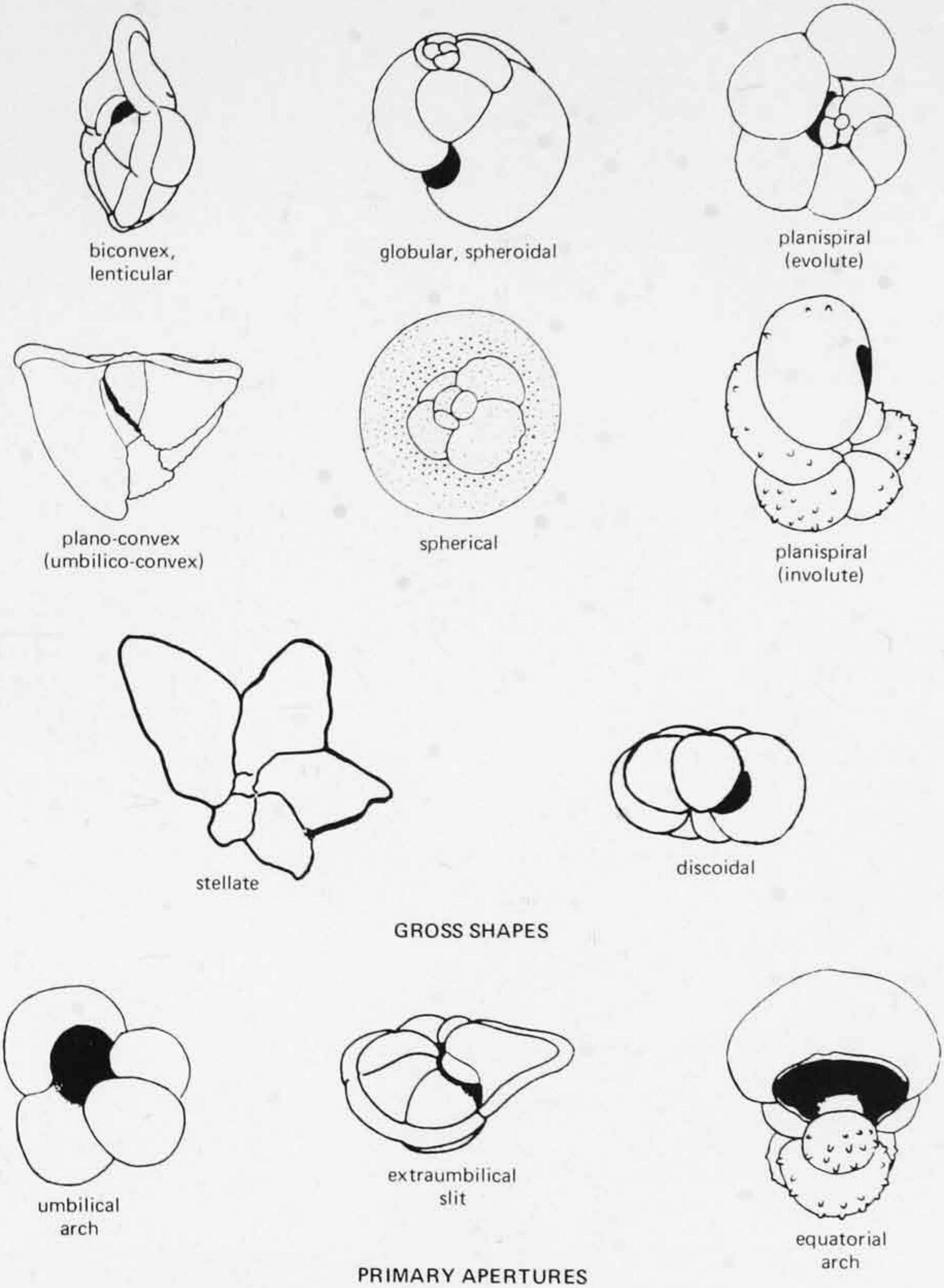
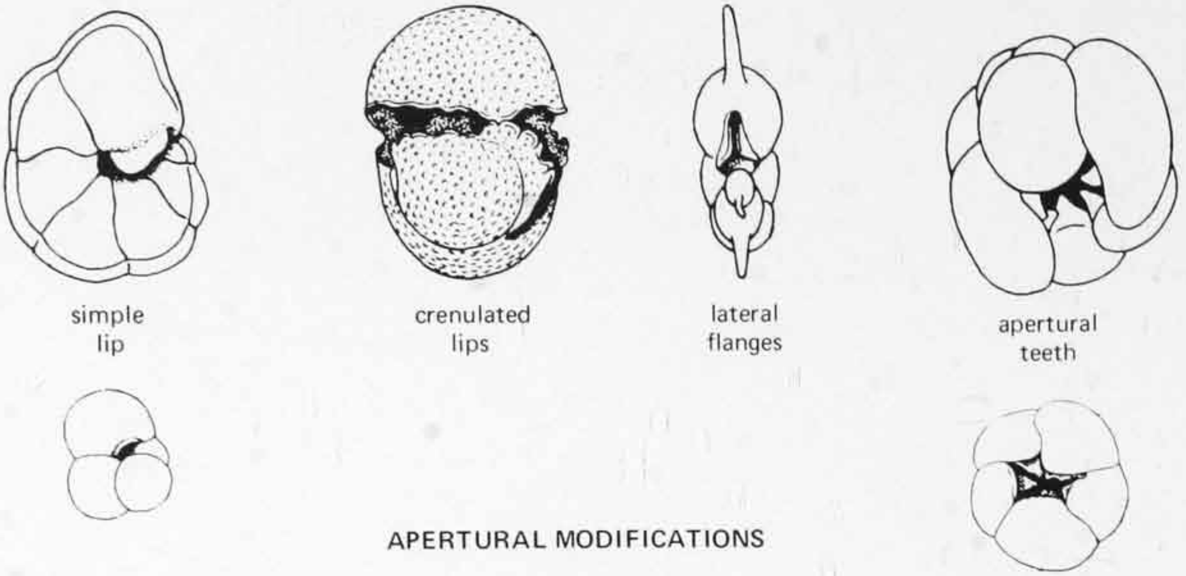
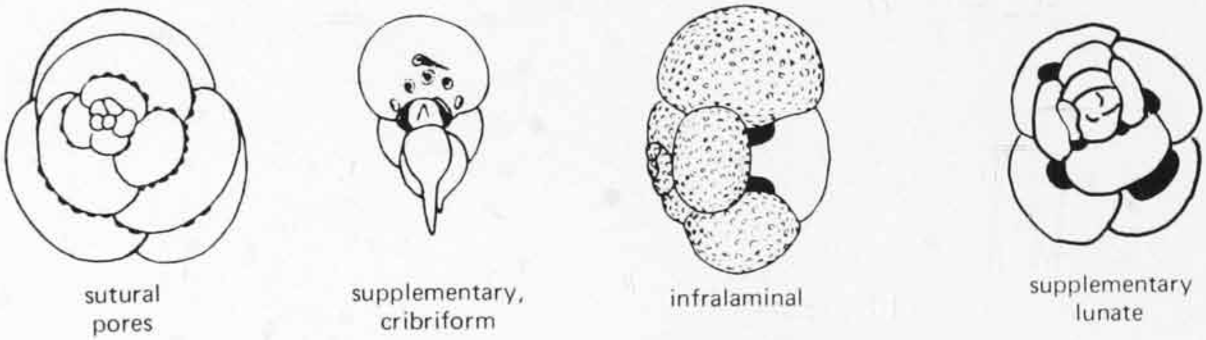


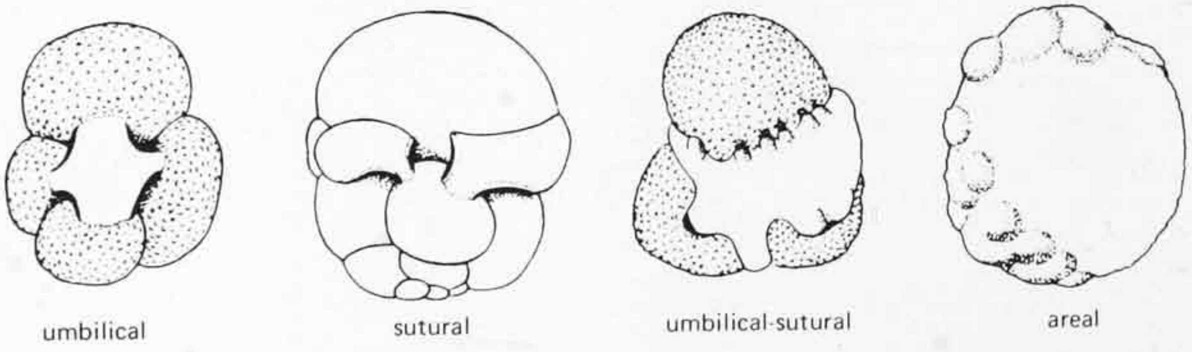
Fig. 28. General shapes of tests and nature of primary apertures in planktonic foraminifers.



APERTURAL MODIFICATIONS



NONPRIMARY APERTURES



BULLAS

Fig. 29. Examples of apertural modifications, nonprimary apertures, and bullas in planktonic foraminifers.

4) Two sides of a trochospire are differentiated as **spiral** or **dorsal** (on which all chambers of spire are visible) and **umbilical** or **ventral** (on which only chambers of last whorl are visible, centered around or radiating from axis of spire).

5) Some forms advance from a **trochospire** to **streptospire** (i.e., plane of coiling changing randomly as in a ball of string).

6) Rare among planktonic foraminifers is a **biserial (cassiduline)** mode of coiling (planispire having successive chambers offset symmetrically from median plane).

7) In forms with **enveloping end chambers**, coiling pattern may be obscure or hidden but can be revealed by dissection.

8) In all coiled forms **anterior** refers to position on spire as measured in direction of growth; **posterior** has opposite meaning.

9) Degree of tightness or laxity of coil is a diagnostic feature, in some cases expressed by **involute** or **evolute**.

SHAPE OF CHAMBERS

1) In globigerinid genera, basic chamber form is **globular** (globose, spheroidal, spherical).

2) Within an individual this basic shape may change progressively to **ovate** by anterior or axial prolongation, to **clavate** and **digitate** by radial prolongation, or to **appressed** by apparent squeezing instead of prolongation.

3) In globorotaliid genera, chamber shape is more variable, with such forms as **wedge shaped**, **rhomboidal**, and **crescentic** occurring commonly; angularity tends to be related to development of **keels (carinas)**.

4) Hantkeninid genera commonly display **apiculate** chambers which may carry apical spines.

SUTURES

1) Sutures commonly provide a means of ready distinction between grossly similar species.

2) They are distinguished by shape (straight, arcuate, sinuous), position (radial, recurved), and character (flush, depressed, incised, limbate, beaded).

INCREMENT OF CHAMBER SIZE

1) Globigerinid forms differ widely in size ratio of successive chambers.

2) Forms with a low ratio of size increase have at least five chambers a whorl and the shape generally remains constant.

3) Forms with a high ratio of size increase have no more than four chambers in each whorl and shape tends to change progressively so as to culminate in embracive spheroidal chambers.

4) Characteristic of forms displaying a high growth ratio is presence of tiny and deformed final chambers; apparently metabolism of the animalcule could not match requirements of its growth pattern; such aborted chambers have no taxonomic significance. The term **kummerform** has been applied to such specimens; their significance is reviewed by OLSSON (1973).

5) Globorotaliid genera mostly have low growth ratios, successive chambers showing only mild ontogenetic changes which follow phylogenetic trend towards sharper and eventually carinate peripheries.

GROSS SHAPE OF TEST

1) Gross shape of test results from a combination of the four growth parameters reviewed above; forms may be identical in three but differences in the fourth may cause complete dissimilarity.

2) For the most part nontechnical terms are applied satisfactorily (e.g., biconvex or lenticular, planoconical, stellate, spheroidal).

UMBILICUS

1) The umbilicus is the **axial area** from which chambers appear to radiate; its character may be diagnostic of both species and genera.

2) In tightly coiled forms umbilicus is either **closed** (apparent only as a point at which ventral sutures meet) or **narrowly deep** (comparable to a pinhole).

3) In loosely coiled forms, a gaping umbilical pit may be present; in such species the umbilicus tends to be partly covered by extra shell material in the form of flaps **(umbilical teeth)** or a lid **(bulla)** (see below).

APERTURE

1) The final chamber generally carries at least one opening through which the living protoplasm could move; earlier chambers commonly carry similar openings which may not be visible without dissection.

2) **Primary aperture** is the term for a single or prominent opening; smaller or **multiple openings** are variously known as secondary, supplementary, or accessory apertures; in some specialized forms enlarged apertural pores replace the more usual apertures.

3) The most usual form of primary aperture is an arch or slit, the character and position of which are highly diagnostic at both specific and generic levels. An umbilical, inturned arch typifies *Globigerina*, whereas an extraumbilical, anteriorly directed slit is normal in *Globorotalia*. In planispiral forms the term **equatorial** applies to an aperture symmetrically embracing the inner whorl.

4) To be distinguished from true supplementary apertures are irregular gaps or holes at intersections of sutures, especially in loosely coiled, spinose forms. SEM photographs reveal that they occur randomly in many spinose species of *Globorotalia;* consequently validity of genera defined by their presence (notably *Truncorotaloides*) is dubious.

5) Apertures tend to be modified by outgrowths of shell material to which nontechnical terms are commonly applied (e.g., lips, flanges, teeth).

6) **Relict apertures** are incompletely resorbed apertures on early chambers, more typical of Cretaceous than of Tertiary genera.

BULLAS

1) A **bulla** (Latin for bubble or blister) is a sheet of shell material additional to the normal coil of chambers; the best known example is the umbilical bulla of *"Globigerina" dissimilis*, formerly described as a supplementary chamber or chamberlet; modern authors apply presence of bullas and their shape and position (umbilical, sutural, areal) to diagnosis of taxa up to the rank of families.

2) **Umbilical bullas** differ greatly between appressed and inflated forms; they may have from one to four arched openings bridging the ventral sutures or multiple tiny openings around the whole bulla; these infralaminal apertures may be simple arches or prolonged into tubules.

3) The function of a bulla is controversial. Self-evidently an umbilical bulla was replaced each time a new chamber was added to the test; this has led to the concept that it served only some temporary purpose, such as a brood pouch, and so should not be applied in taxonomy. Stratigraphers counter, however, with empirical evidence that particular bullate species have sharply defined ranges and are good zonal indices. The problem is reviewed by CATI & BORSETTI (1967).

SHELL TEXTURE AND SURFACE

1) Shell structure varies widely within planktonic foraminifers but authors disagree on its validity as a taxonomic parameter.

2) Descriptive terms commonly applied to the surface include smooth (vitreous, hyaline, porcelaneous), shiny, matte, cancellate (reticulate, pitted, honeycomb), hispid, spinose (spiny), and rugose (rough).

3) Attempts to base classification on microstructure of the shell (granular, radial, lamellar) generally have not survived closer scrutiny made possible by the scanning electron microscope.

4) The SEM also reveals that differential solution may alter the external texture of planktonic foraminiferal tests markedly, a fact to be considered before applying shell differences to taxonomy.

REFERENCES

ADDICOTT, W. O., 1969, *Tertiary climatic change in the marginal northeastern Pacific Ocean:* Science, v. 165, p. 583-586, 3 fig.

———, 1970, *Tertiary paleoclimatic trends in the San Joaquin basin, California:* U.S. Geol. Survey Prof. Paper 644-D, 19 p., 7 fig.

———, 1973, *Giant Neogene pectinids of eastern north Pacific – chronostratigraphic and zoogeographic significance:* Am. Assoc. Petroleum Geologists Bull., v. 57, p. 766.

AGER, D. V., 1973, *The nature of the stratigraphical record:* New York, John Wiley & Sons, 114 p., 28 pl.

A. G. I. P. MINERARIA, 1957, *Foraminiferi Padani (Terziario e Quaternario): Atlante iconografica e distribuzione stratigrafica:* Azienda Generale Italiana Petrole (A.G.I.P.), 4 p., 52 pl.

AKERS, W. H., 1955, *Some planktonic Foraminifera of the American Gulf Coast and suggested correlations with the Caribbean Tertiary:* Jour. Paleontology, v. 29, p. 647-664, 3 fig., pl. 65.

———, 1972, *Planktonic Foraminifera and biostratigraphy of some Neogene formations, northern Florida and Atlantic coastal plain:* Tulane Studies Geology and Paleontology, v. 9, 139 p., 4 fig., 60 pl.

AKERS, W. H., & DORMAN, J. H., 1964, *Pleistocene Foraminifera of the Gulf Coast:* Tulane Studies Geology and Paleontology, v. 3, p. 1-93, 2 fig., 15 pl.

AKERS, W. H., & DROOGER, C. W., 1957, *Miogypsinids, planktonic Foraminifera, and Gulf Coast Oligocene-Miocene correlations:* Am. Assoc. Petroleum Geologists Bull., v. 41, p. 656-678, 2 fig.

ALEKSEEV, M. N., 1969, *Notes on generalized stratigraphic correlation between Cenozoic sedimentary basins in the western Pacific area of the ECAFE region:* U.N. ECAFE Mineral Resources Devel. Ser., no. 30, p. 33-37.

ALIMARINA, V. P., 1963, *Nekotorye osobennosti razvitiya planktonnykh foraminifer v svyazi s zonalnym ras'cheleniem nizhnego paleogena severnogo kavkaza [Some pecularities in the development of planktonic foraminifers in connection with the zonal subdivision of the lower Paleogene in the northern Caucasus]:* Akad. Nauk SSSR Voprosy Mikropaleontologii, no. 7, p. 158-195, 4 fig.

ANDERSEN, H. V., 1971, *Key to Cenozoic foraminiferal families and genera of the Gulf Coastal Plain Province:* Louisiana State Univ. School Geosci., Misc. Pub. 71-2, 34 p.

ANONYMOUS, 1963, *Reshenie postoyannoi stratigraficheskoi komissi mezhved. stratigraf. Komiteta po paleogenu SSSR [Decision of the permanent interdepartmental commission on the Paleogene of the USSR]:* Sovetskaya Geologiya, v. 6, no. 4, p. 145-151.

APPLIN, E. A., ELLISOR, A. E., & KNIKER, H. T., 1925, *Subsurface stratigraphy of the coastal plain of Texas and Louisiana:* Am. Assoc. Petroleum Geologists Bull., v. 9, p. 79-122, 1 fig., pl. 3.

ARRHENIUS, GUSTAF, 1952, *Sediment cores from the east Pacific:* Swedish Deep-Sea Expedition (1947-1948) Repts., v. 5, no. 1, 227 p., illus.

ASANO, KIYOSHI, 1962, *Tertiary globigerinids from Kyushu, Japan:* Tohoku Univ. Sci. Repts., ser. 2, Spec. v. 5, p. 49-65, pl. 19-23

ASANO, KIYOSHI, & TAKAYANAGI, YOKICHI, 1965, *Stratigraphic significance of the planktonic Foraminifera from Japan:* Tohoku Univ. Sci. Rept., ser. 2, v. 37, p. 1-14, 2 fig.

———, 1969, *Stratigraphic significance of the planktonic Foraminifera from Japan:* U.N. ESCAFE Mineral Resources Devel. Ser., no. 30, p. 73-82.

AXELROD, D. I., & BAILEY, H. P., 1969, *Paleotemperature analysis of Tertiary floras:* Palaeogeography, Palaeoclimatology, Palaeoecology, v. 6, p. 163-195, 15 fig.

BADER, R. G., ET AL., 1970, *Initial reports of the Deep Sea Drilling Project:* Washington, D.C., U.S. Government Printing Office, v. 4, 753 p.

BANDY, O. L., 1949, *Eocene and Oligocene Foraminifera from Little Stave Creek, Clarke County, Alabama:* Bulls. Am. Paleontology, v. 32, p. 35-240, 2 fig., pl. 5-32.

———, 1963, *Miocene-Pliocene boundary in the Philippines as related to late Tertiary stratigraphy of deep-sea sediments:* Science, v. 142, p. 1290-1292.

———, 1964a, *The type of* Globorotalia crassata *(Cushman):* Cushman Found. Foram. Research Contr., v. 15, p. 34-35.

———, 1964b, *Cenozoic planktonic foraminiferal zonation:* Micropaleontology, v. 10, p. 1-17, 6 fig.

———, 1964c, *The type of* Globigerina quadrilobata *d'Orbigny:* Cushman Found. Foram. Research Contr., v. 15, p. 36-37.

———, 1966, *Restrictions of the* "Orbulina" *datum:* Micropaleontology, v. 12, p. 79-86, 4 fig., 1 pl.

———, 1968, *Paleoclimatology and Neogene planktonic foraminiferal zonation:* Gior. Geologia, ser. 2, v. 35, pt. 2, p. 277-290, 1 fig.

———, 1972, *Neogene planktonic foraminiferal zones, California, and some geologic implications:* Palaeogeography, Palaeoclimatology, Palaeoecology, v. 12, p. 131-150.

———, 1972a, *Origin and development of* Globorotalia (Turborotalia) pachyderma *(Ehrenberg):* Micropaleontology, v. 18, p. 294-318, 3 fig., 8 pl.

BANDY, O. L., CASEY, R. E., & WRIGHT, R. C., 1971, *Late Neogene planktonic zonation, magnetic reversals, and radiometric dates, Antarctic to the tropics:* Am. Geophys. Union Antarctic Research Ser., v. 15 (Antarctic Oceanology, v. 1), p. 1-26, 15 fig., 4 pl.

BANDY, O. L., FRERICHS, W. E., & VINCENT, EDITH, 1967, *Origin, development, and geologic significance of* Neogloboquadrina *Bandy, Frerichs, and Vincent, gen. nov.:* Cushman Found. Foram. Research Contr., v. 18, p. 152-157, 1 fig., pl. 14.

BANDY, O. L., HORNIBROOK, N. DE B., & SCHOFIELD, J. C., 1970, *Age relationships of the* Globigerinoides trilobus *Zone and the andesite at Muriwai Quarry, New Zealand:* New Zealand Jour. Geology and Geophysics, v. 13, p. 980-995, 5 fig.

BANDY, O. L., & INGLE, J. C., 1970, *Neogene planktonic events and radiometric scale, California;* in Bandy, O. L. (ed.), Radiometric dating and paleontologic zonation: Geol. Soc. America Spec. Paper 124, p. 131-172, 7 fig.

BANDY, O. L., & KOLPACK, R. L., 1963, *Foraminiferal and sedimentological trends in the Tertiary section of Tecolote Tunnel, California:* Micropaleontology, v. 9, p. 117-170, 35 fig.

BANDY, O. L., VINCENT, EDWARD, & WRIGHT, R. C., 1969, *Chronologic relationships of orbulines to the* Globorotalia fohsi *lineage:* Rev. Española Micropaleontología, v. 1, p. 131-145.

BANDY, O. L., & WADE, M. E., 1967, *Miocene-Pliocene-Pleistocene boundaries in deep-water environments:* Progress in Oceanography, v. 8, p. 51-66, 5 fig.

BANDY, O. L., & WILCOXON, J. A., 1970, *The Pliocene-Pleistocene boundary, Italy and California:* Geol. Soc. America Bull., v. 81, p. 2939-2948, 7 fig.

BANNER, F. T., & BLOW, W. H., 1959, *The classification and stratigraphical distribution of the Globigerinaceae:* Palaeontology, v. 2, p. 1-27, 5 fig., pl. 1-3.

———, 1960a, *Some primary types of species belonging to the super-family Globigerinaceae:* Cushman Found. Foram. Research Contr., v. 11, p. 1-41, pl. 1-8.

———, 1960b, *The taxonomy, morphology and affinities of the genera included in the subfamily Hastigerininae:* Micropaleontology, v. 6, p. 19-31, 11 fig.

———, 1965a, Globigerinoides quadrilobatus *(d'Orbigny) and related forms; their taxonomy, nomenclature and stratigraphy:* Cushman Found. Foram. Research Contr., v. 16, p. 105-115, 19 fig., pl. 16.

———, 1965b, *Progress in the planktonic foraminiferal biostratigraphy of the Neogene:* Nature, v. 208, p. 1164-1166.

———, 1965c, *Two new taxa of the Globorotaliinae (Globigerinacea, Foraminifera) assisting determination of the late Miocene/middle Miocene boundary:* Nature, v. 207, p. 1351-1354, 3 fig.

BANNER, F. T., & BLOW, W. H., 1967, *The origin, evolution and taxonomy of the foraminiferal genus* Pulleniatina *Cushman, 1927:* Micropaleontology, v. 13, p. 133-162, 14 fig., 4 pl.

BARASH, M. S., 1971, *Paleoklimaticheskie rekonstrucktsii po planktonnym foraminiferam (chetvertichnye otlozheniya v Atlantike) [Paleoclimatic reconstruction from planktonic foraminifers (Quaternary deposits of the Atlantic)]:* Okeanologiya, v. 11, p. 1049-1055, 3 fig. [transl. in Oceanology, v. 11, p. 868-873, 3 fig.]

BARBIERI, FRANCESCO, 1967, *The Foraminifera in the Pliocene section Vernasca-Castell' Arquato including the "Piacenzian stratotype" (Piacenza Province):* Soc. Italiana Sci. Nat. Milano Mem. 15, p. 147-163, 10 fig., 1 pl.

———, 1969, *Planktonic Foraminifera in western Emily (north Italy):* Internatl. Conf. Planktonic Microfossils, 1st, Geneva 1967, Proc., v. 1, p. 66-80, 3 fig., 1 pl.

———, 1971, *Comments on some Pliocene stages and on the taxonomy of a few species of* Globorotalia: Ateneo Parmense, v. 7, p. 1-24, 18 fig.

BARBIERI, FRANCESCO, & PETRUCCI, FRANCO, 1967, *La serie stratigraphique du Messinien au Calabrien dans vallée du Crostolo (Reggio Emilia–Italie sept.):* Soc. Italiana Sci. Nat. Milano Mem. 15, p. 181-188, 1 fig., 1 pl.

BARKER, R. W., & BROWN, N. K., 1968, *On the type locality of* Globorotalia fohsi *Cushman and Ellisor:* Micropaleontology, v. 14, p. 114-116, 1 fig.

BARKER-WEBB, P., & BERTHELOT, S., 1839, *Foraminiferes;* in Histoire Naturelle des Iles Canaries, v. 2, pt. 2 (Zoology), p. 119-146, pl. 1-3.

BARR, F. T., 1962, *Upper Cretaceous planktonic Foraminifera from the Isle of Wight, England:* Palaeontology, v. 4, p. 552-580, 5 fig., pl. 69-72.

———, 1972, *Cretaceous biostratigraphy and planktonic Foraminifera in Libya:* Micropaleontology, v. 18, p. 1-46, 10 fig., 8 pl.

BATJES, D. A. J., 1958, *Foraminifera of the Oligocene of Belgium:* Belgique Inst. Royal Sci. Nat., Mém. 143, 188 p., illus.

BAUMANN, PAUL, 1970, *Mikropalaeontologische und stratigraphische Untersuchungen der obereozaenen-oligozaenen Scaglia im zentralen Apennin (Italien):* Eclogae Geol. Helvetiae, v. 63, p. 1133-1211, 27 fig., 7 pl.

BAUMANN, PAUL, & ROTH, P. H., 1969, *Zonierung des Obereozaens und Oligozaens des Monte Gagnero (Zentralapennin) mit planktonischen Foraminiferen und Nannoplankton:* Eclogae Geol. Helvetiae, v. 62, p. 303-323, 2 fig.

BAYLISS, D. D., 1969, *The distribution of* Hyalinea balthica *(Schroeter) and* Globorotalia truncatulinoides *(d'Orbigny), Foraminiferida, in the type Calabrian, southern Italy:* Lethaia, v. 2, p. 133-143, 5 fig.

BÉ, A. W. H., 1959, *Ecology of Recent planktonic Foraminifera, pt. 1 – Areal distribution in the western north Atlantic:* Micropaleontology, v. 5, p. 77-100, 52 fig., 2 pl.

———, 1960, *Ecology of Recent planktonic Foraminifera, pt. 2 – Bathymetric and seasonal distributions in the Sargasso Sea off Bermuda:* Micropaleontology, v. 6, p. 373-392, 19 fig.

BÉ, A. W. H., & HAMLIN, W. H., 1967, *Ecology of Recent planktonic Foraminifera; Pt. 3 – Distribution in the North Atlantic during the summer of 1962:* Micropaleontology, v. 13, p. 87-106, 41 fig.

BÉ, A. W. H., & MCINTYRE, ANDREW, 1970, Globorotalia menardii flexuosa *(Koch); an 'extinct' foraminiferal subspecies living in the northern Indian Ocean:* Deep-Sea Research, v. 17, p. 595-601, 3 fig.

BÉ, A. W. H., MCINTYRE, ANDREW, & BREGER, D. L., 1966, *Shell microstructure of a planktonic foraminifer,* Globorotalia menardii *(d'Orbigny):* Eclogae Geol. Helvetiae, v. 59, p. 885-896, 2 fig., 17 pl.

BEARD, J. H., 1969, *Pleistocene paleotemperature record based on planktonic foraminifers, Gulf of Mexico:* Gulf Coast Assoc. Geol. Socs. Trans., v. 19, p. 535-553, 5 fig., 3 pl.

———, 1973, *Pleistocene-Holocene boundary, Wisconsinan substages, Gulf of Mexico:* Geol. Soc. America Mem. 136, p. 277-316, 24 fig.

BEARD, J. H., & LAMB, J. L., 1968, *The lower limit of the Pliocene and Pleistocene in the Caribbean and Gulf of Mexico:* Gulf Coast Assoc. Geol. Socs. Trans., v. 18, p. 174-186, 7 fig.

BECKMANN, J. P., 1953, *Die Foraminiferen der Oceanic Formation (Eocaen-Oligocaen) von Barbados, Kl. Antillen:* Eclogae Geol. Helvetiae, v. 46, p. 301-412, 29 fig., pl. 16-30.

———, 1957, Chiloguembelina *Loeblich and Tappan and related Foraminifera from the lower Tertiary of Trinidad, B.W.I:* U.S. Natl. Museum Bull. 215, p. 83-95, fig. 14-16, pl. 21.

BECKMANN, J. P., ET AL., 1969, *Standard planktonic zones in Egypt:* Internatl. Conf. Planktonic Microfossils, 1st, Geneva 1967, Proc., v. 1, p. 92-103, 1 fig.

BELFORD, D. J., 1962, *Miocene and Pliocene planktonic Foraminifera, Papua-New Guinea:* Australia Bur. Mineral Resources, Geology and Geophysics Bull. 62-1, 35 p., 8 pl.

BELYAEVA, N. V., 1969, *Planktonnye foraminifery v osadkakh Mirovogo okeana [Planktonic foraminifers in sediments of the world's ocean]:* Akad. Nauk SSSR Voprosy Mikropaleontologii, no. 12, p. 168-172, 2 fig.

BERGER, W. H., 1968, *Planktonic Foraminifera; selective solution and paleoclimatic interpretation:* Deep-Sea Research, v. 15, p. 31-43.

———, 1969, *Planktonic Foraminifera; basic morphology and ecologic implications:* Jour. Paleontology, v. 43, p. 1369-1383, 9 fig.

———, 1970, *Planktonic Foraminifera; selective solution and the lysocline:* Marine Geology, v. 8, p. 111-138.

———, 1973, *Cenozoic sedimentation in the eastern tropical Pacific:* Geol. Soc. America Bull., v. 84, p. 1941-1954, 12 fig.

BERGGREN, W. A., 1960a, *Some planktonic Foraminifera from the Lower Eocene (Ypresian) of Denmark and northwestern Germany:* Stockholm Contr. Geology, v. 5, p. 41-108, 12 fig., 13 pl.

———, 1960b, *Paleogene biostratigraphy and planktonic Foraminifera of the southwestern Soviet Union – an analysis of recent Soviet investigations:* Stockholm Contr. Geology, v. 6, p. 64-128, 8 fig.

———, 1963, *Review and discussion [of] F. E. Eames, F. T. Banner, W. H. Blow, and W. J. Clarke; Fundamentals of mid-Tertiary stratigraphical correlation, Cambridge University Press, 1962:* Micropaleontology, v. 9, p. 467-473, 1 fig.

———, 1965a, *Some problems of Paleocene-Lower Eocene planktonic foraminiferal correlations:* Micropaleontology, v. 11, p. 278-300, 12 fig., 1 pl.

———, 1965b, *Paleocene – a micropaleontologist's point of view:* Am. Assoc. Petroleum Geologists Bull., v. 44, p. 1473-1484, 1 fig.

———, 1966, *Problemy taksonomii i filogeneticheskikh otnoshenii nekotorykh tretichnykh planktonnykh foraminifera [Phylogenetic and taxonomic problems of some Tertiary planktonic foraminiferal lineages]:* Akad. Nauk SSSR Voprosy Mikropaleontologii, no. 10, p. 309-332, 3 pl.

———, 1967 [1968], *Micropaleontology and the Pliocene/Pleistocene boundary in a deep-sea core from the south-central north Atlantic:* Gior. Geologia, ser. 2, v. 35, pt. 2, p. 291-312, 6 fig.

———, 1968, *Phylogenetic and taxonomic problems of some Tertiary planktonic foraminiferal lineages:* Tulane Studies Geology and Paleontology, v. 6, p. 1-22, 4 fig.

———, 1969a, *Biostratigraphy and planktonic foraminiferal zonation of the Tertiary System of the Sirte Basin of Libya, north Africa:* Internatl. Conf. Planktonic Microfossils, 1st, Geneva 1967, Proc., v. 1, p. 104-120, 4 fig.

———, 1969b, *Paleogene biostratigraphy and planktonic Foraminifera of northern Europe:* Internatl. Conf. Planktonic Microfossils, 1st, Geneva 1967, Proc., v. 1, p. 121-160, 7 fig., 8 pl.

———, 1969c, *Rates of evolution in some Cenozoic planktonic Foraminifera:* Micropaleontology, v. 15, p. 351-365, 13 fig.

———, 1969d, *Cenozoic chronostratigraphy, planktonic foraminiferal zonation and the radiometric time scale:* Nature, v. 224, p. 1072-1075.

BERGGREN, W. A., 1971a, *Multiple phylogenetic zonations of the Cenozoic based on planktonic Foraminifera:* Internatl. Conf. Planktonic Microfossils, 2nd, Rome 1970, Proc., v. 1, p. 41-56.

———, 1971b, *Tertiary boundaries and correlations;* in Funnell, B. M., & Riedel, W. R., (eds.), Micropaleontology of the Oceans: Cambridge Univ. Press, p. 693-809.

———, 1972a, *A Cenozoic time-scale – some implications for regional geology and paleobiogeography:* Lethaia, v. 5, p. 195-215, 9 fig.

———, 1972b, *Cenozoic biostratigraphy and paleobiogeography of the north Atlantic;* in Laughton, A. S., et al., Initial Repts. Deep Sea Drilling Project, v. 12, p. 965-1001, 6 fig., 13 pl.

———, 1972c, *Late Pliocene-Pleistocene glaciation;* in Laughton, A. S., et al., Initial Repts. Deep Sea Drilling Project, v. 12, p. 953-963.

———, 1973, *The Pliocene time scale; calibration of planktonic foraminiferal and calcareous nannoplankton zones:* Nature, v. 243, p. 391-397, 1 fig.

BERGGREN, W. A., OLSSON, R. K., & REYMENT, R. A., 1967, *Origin and development of the foraminiferal genus* Pseudohastigerina *Banner and Blow, 1959:* Micropaleontology, v. 13, p. 265-288, 12 fig., 1 pl.

BERGGREN, W. A., ET AL., 1967, *Late Pliocene-Pleistocene stratigraphy in deep sea cores from the south-central north Atlantic:* Nature, v. 216, p. 253-254, 2 fig.

BERMÚDEZ, P. J., 1937, *Notas sobre* Hantkenina brevispina *Cushman:* Soc. Cubana Historia Nat. Mem., v. 11, p. 151-152.

———, 1949, *Tertiary smaller Foraminifera of the Dominican Republic:* Cushman Lab. Foram. Research Spec. Pub. 25, 322 p., 6 fig., 26 pl.

———, 1950, *Contribución al estudio del Cenozoico cubano:* Soc. Cubana Historia Nat. Mem., v. 19, p. 205-375.

———, 1952, *Estudio sistemático de los foraminíferos rotaliformes:* Bol. Geología (Venezuela), v. 2, no. 4, p. 7-230, pl. 1-35.

———, 1960, *Contribución al estudio de las Globigerinidea de la región Caribe-Antillana (Paleoceno-Reciente):* Bol. Geología (Venezuela), Spec. Pub. 3 (Cong. Geol. Venezolano, 3d., Caracas 1959, Mem. 3), p. 1119-1393, 20 pl. [Numerous faulty citations as "1961" resulted from date (1961) printed on covers of author's separates.]

———, 1966, *Consideraciones sobre los sedimentos del Mioceno medio al Reciente de las costas central y oriental de Venezuela:* Bol. Geología (Venezuela), v. 7, no. 14, p. 333-411, 10 fig.

BERMÚDEZ, P. J., & BOLLI, H. M., 1969, *Consideraciones sobre los sedimentos del Mioceno Medio al Reciente de las costas central y oriental de Venezuela:* Bol. Geología (Venezuela), v. 10, no. 20, p. 137-223, 6 fig., 18 pl.

BERTOLINO, VERA, ET AL., 1968, *Proposal for a biostratigraphy of the Neogene in Italy based on planktonic Foraminifera:* Gior. Geologia, ser. 2, v. 35, pt. 2, p. 23-30, 1 fig.

BIEDA, FRANCISZEK, 1969, *One hundredth anniversary of the birth of Józef Grzybowski [W stulecie urodzin Józefa Grzybowskiego]:* Polskie Towarz. Geol. Rocznik, v. 39, p. 7-11.

BIELY, ANTON, & SALAJ, JOSEPH, 1971, *L'Oligo-Miocène du Bejaoua oriental (Tunisie septentrionale):* Tunisie Service Geol. Notes, no. 34, p. 71-107, pl. 4-12.

BIREKELAND, P. W., CRANDELL, D. R., & RICHMOND, G. M., 1970, *Status of correlation of Quaternary stratigraphical units in the western conterminous United States:* Quaternary Res., v. 1, p. 208-227.

BIZON, GERMAINE, & BIZON, J. J., 1971, *Observations sur l'évolution de* Globorotalia "menardii" *dans le Miocene moyen et supérieur d'Espagne méridionale:* Internatl. Conf. Planktonic Microfossils, 2nd, Rome 1970, Proc., v. 1, p. 85-93, 3 fig., 5 pl.

———, 1972, *Atlas des principaux foraminifères planctoniques du bassin Méditerranéen – oligocène à quaternaire:* Paris, Editions Technip, 316 p., illus.

BIZON, GERMAINE, & MIRKOU, RHÉA, 1969, *Les foraminifères planctoniques du pliocène de l'île de Zanthe (Crece occidentale):* Internatl. Conf. Planktonic Microfossils, 1st, Geneva 1967, Proc., v. 1, p. 179-189, 4 fig.

BLONDEAU, ALPHONSE, ET AL., 1965, *Stratigraphie du Paléogène du bassin de Paris en relation avec les bassins avoisinants:* Soc. Géol. France Bull., ser. 7, v. 7, p. 200-221.

BLOW, W. H., 1956, *Origin and evolution of the foraminiferal genus* Orbulina: Micropaleontology, v. 2, p. 57-70, 4 fig.

———, 1957, *Transatlantic correlation of Miocene sediments:* Micropaleontology, v. 3, p. 77-79.

———, 1959, *Age, correlation, and biostratigraphy of the upper Tocuyo (San Lorenzo) and Pozón formations, eastern Falcon, Venezuela:* Bulls. Am. Paleontology, v. 39, p. 67-251, pl. 6-19.

———, 1965, Clavatorella, *a new genus of the Globorotaliidae:* Micropaleontology, v. 11, p. 365-368, 5 fig.

———, 1969, *Late middle Eocene to Recent planktonic foraminiferal biostratigraphy:* Internatl. Conf. Planktonic Microfossils, 1st, Geneva 1967, Proc., v. 1, p. 199-422, 43 fig., 54 pl.

———, 1970, *Validity of biostratigraphic correlations based on the Globigerinacea:* Micropaleontology, v. 16, p. 257-268.

BLOW, W. H., & BANNER, F. T., 1962, *The Mid-Tertiary (Upper Eocene to Aquitanian) Globigerinaceae;* in

Eames, F. E., et al., Fundamentals of Mid-Tertiary stratigraphical correlation: Cambridge Univ. Press, p. 61-151, fig. 6-20, pl. 8-17.

———, 1966, *The morphology, taxonomy and biostratigraphy of* Globorotalia barisanensis *LeRoy,* Globorotalia fohsi *Cushman and Ellisor, and related taxa:* Micropaleontology, v. 12, p. 286-302, 4 fig., 2 pl.

BLOW, W. H., & SAITO, TSUNEMASA, 1968, *The morphology and taxonomy of* Globigerina mexicana *Cushman, 1925:* Micropaleontology, v. 14, p. 357-360, 4 fig.

BOLLI, H. M., 1950, *The direction of coiling in the evolution of some Globorotaliidae:* Cushman Found. Foram. Research Contr., v. 1, p. 82-89, 5 fig., pl. 15.

———, 1951, *Notes on the direction of coiling of rotalid Foraminifera:* Cushman Found. Foram. Research Contr., v. 2, p. 139-143.

———, 1954, *Note on* Globigerina concinna *Reuss, 1850:* Cushman Found. Foram. Research Contr., v. 5, p. 1-3, 4 fig.

———, 1957a, *The genera* Globigerina *and* Globorotalia *in the Paleocene-lower Eocene Lizard Springs Formation of Trinidad, B. W. I.:* U.S. Natl. Museum Bull. 215, p. 61-81, fig. 11-13, pl. 15-20.

———, 1957b, *Planktonic Foraminifera from the Oligocene-Miocene Cipero and Lengua Formations of Trinidad, B. W. I.:* U.S. Natl. Museum Bull. 215, p. 97-123, fig. 17-21, pl. 22-29.

———, 1957c, *Planktonic Foraminifera from the Eocene Navet and San Fernando formations of Trinidad, B. W. I.:* U.S. Natl. Museum Bull. 215, p. 155-172, fig. 25-26, pl. 35-39.

———, 1959, *Planktonic Foraminifera as index fossils in Trinidad, West Indies, and their value for worldwide stratigraphic correlations:* Eclogae Geol. Helvetiae, v. 52, p. 627-637.

———, 1962, Globigerinopsis, *a new genus of the foraminiferal family Globigerinidae:* Eclogae Geol. Helvetiae, v. 55, p. 282-284, 1 pl.

———, 1964, *Observations on the stratigraphic distribution of some warm water planktonic Foraminifera in the young Miocene to Recent:* Eclogae Geol. Helvetiae, v. 57, p. 541-552, 1 fig.

———, 1966a, *Zonation of Cretaceous to Pliocene marine sediments based on planktonic Foraminifera:* Asoc. Venezolana Geología, Minería y Petróleo Bol. Inf., v. 9, p. 3-32. [Also unbound correction slip.]

———, 1966b, *The planktonic Foraminifera in well Bodonegore – 1 of Java:* Eclogae Geol. Helvetiae, v. 59, p. 449-465, 1 fig., 1 pl.

———, 1967, *The subspecies of* Globorotalia fohsi *Cushman and Ellisor and the zones based on them:* Micropaleontology, v. 13, p. 502-512, 4 fig.

BOLLI, H. M., 1970, *The Foraminifera of sites 23-31, Leg 4;* in Bader, R. G., et al., Initial Repts. Deep Sea Drilling Project, v. 4, p. 577-643, 22 fig., 9 pl.

———, 1972a, *The genus* Globigerinatheka *Brönnimann:* Jour. Foram. Research, v. 2, p. 109-136, 84 fig., 7 pl.

———, 1972b, *Correlacion de las estáciones Joides 29, 30 y 31 del Caribe con Jamaica, Venezuela y Trinidad:* Cong. Geol. Venezolano, Mem. 4, v. 3, no. 5, p. 1315-1336, 6 fig.

———, 1974, *The role of Trinidad in the study of planktonic Foraminifera:* Naturf. Gesell. Basel Verh., v. 84, p. 222-233, 3 fig.

BOLLI, H. M., & BERMÚDEZ, P. J., 1965, *Zonation based on planktonic Foraminifera of Middle Miocene to Pliocene warm-water sediments:* Asoc. Venezolana Geología, Minería y Petróleo Bol. Inf., v. 8, p. 119-149, 1 pl.

BOLLI, H. M., LOEBLICH, A. R., & TAPPAN, HELEN, 1957, *Planktonic foraminiferal families Hantkeninidae, Orbulinidae, Globorotaliidae, and Globotruncanidae:* U.S. Natl. Museum Bull. 215, p. 3-50, fig. 1-9, pl. 1-11.

BOLTOVSKOY, ESTEBAN, 1971, *Patchiness in the distribution of planktonic Foraminifera:* Internatl. Conf. Planktonic Microfossils, 2nd, Rome 1970, Proc., p. 107-115, 1 fig.

BORGER, H. D., 1952, *Case history of Quiriquire oil field:* Am. Assoc. Petroleum Geologists Bull., v. 36, p. 2291-2230, 22 fig.

BORSETTI, A. M., 1959, *Tre nuovi Foraminiferi planctonici dell'Oligocene Piacentino:* Gior. Geologia, ser. 2, v. 27, p. 205-212, 1 fig., 1 pl.

BRADSHAW, J. S., 1959, *Ecology of living planktonic Foraminifera in the north and equatorial Pacific Ocean:* Cushman Found. Foram. Research Contr., v. 10, p. 25-64, 41 fig., pl. 6-8.

BRADY, H. B., 1877, *Supplementary note on the Foraminifera of the Chalk(?) of the New Britian group:* Geol. Mag., dec. 2, v. 4, p. 534-536.

———, 1879, *Notes on some of the reticularian Rhizopoda of the Challenger Expedition:* Micros. Soc. London Quart. Jour., n. ser., v. 19, p. 20-26, 261-299, pl. 3-5, 8.

———, 1882, *Report on the Foraminifera:* Royal Soc. Edinburgh Proc., v. 11, p. 708-717.

———, 1884, *Report on the Foraminifera dredged by H. M. S. Challenger during the years 1873-1876:* Challenger Exped. 1873-1876, Rept., London, Zoology, v. 9, pt. 22, 814 p., 115 pl. (in Atlas).

BRATU, ELENA, & GHETA, NICOLAE, 1972, *[Zonation of the Paleocene-Eocene facies of Satrile (east Carpathians) by pelagic foraminifers and calcareous nannoplankton]:* Acad. România Studii si Cercetări Geologie, Geofizică, Geografie, ser. Geol., v. 17, p. 323-334, 1 fig., 6 pl.

BROECK, ERNEST, VAN DEN, 1876, *Etude sur les foraminifères de la Barbade (Antilles):* Soc. Belge Microscopie Annals, v. 1, p. 55-152, pl. 2-3.

BROLSMA, M. J., & MEULENKAMP, J. E., 1973, *Lithostratigraphy and sedimentary history of the Calabrian deposits at Santa Maria di Catanzaro:* Newsletters Stratigraphy, v. 3, p. 1-24, 10 fig.

BRÖNNIMANN, PAUL, 1950a, *Occurrence and ontogeny of* Globigerinatella insueta *Cushman and Stainforth from the Oligocene of Trinidad, B. W. I.:* Cushman Found. Foram. Research Contr., v. 1, p. 80-82, pl. 13-14.

———, 1950b, *The genus* Hantkenina *Cushman in Trinidad and Barbados, B. W. I.:* Jour. Paleontology, v. 24, p. 397-420, pl. 55-56.

———, 1950c, *Weitere Beobachtungen an Hantkeninen:* Eclogae Geol. Helvetiae, v. 43, p. 245-251, 3 fig.

———, 1951a, Globigerinita naparimaensis *n. gen., n. sp., from the Miocene of Trinidad, B. W. I.:* Cushman Found. Foram. Research Contr., v. 2, p. 16-18, 14 fig.

———, 1951b, *The genus* Orbulina *d'Orbigny in the Oligo-Miocene of Trinidad, B. W.I.:* Cushman Found. Foram. Research Contr., v. 2, p. 132-138, 5 fig.

———, 1952a, Globigerinoita *and* Globigerinatheka, *new genera from the Tertiary of Trinidad, B. W. I.:* Cushman Found. Foram. Research Contr., v. 3, p. 25-28, 3 fig.

———, 1952b, *Micropaleontologic literature 1941-1951 on Trinidad, Tobago and Barbados, B. W. I.:* The Micropaleontologist [Am. Museum Nat. History], v. 6, p. 23-42.

———, 1952c, *Trinidad Paleocene and lower Eocene Globigerinidae:* Bulls. Am. Paleontology, v. 34, no. 143, 34 p., 3 pl.

———, 1953, *Note on planktonic Foraminifera from Danian localities of Jutland, Denmark:* Eclogae Geol. Helvetiae, v. 45, p. 339-341, 1 fig.

BRÖNNIMANN, PAUL, & BERMÚDEZ, P. J., 1953, Truncorotaloides, *a new foraminiferal genus from the Eocene of Trinidad, B. W. I.:* Jour. Paleontology, v. 27, p. 817-820, pl. 87.

BRÖNNIMANN, PAUL, & RENZ, H. H. (eds.), 1969, *Proceedings of the first international conference on planktonic microfossils:* Leiden, E. J. Brill, v. 1, 422 p.; v. 2, 745 p., illus.

BRÖNNIMANN, PAUL, & RESIG, JOHANNA, 1971, *A Neogene globigerinacean biochronologic time-scale of the south-western Pacific;* in Winterer, E. L., et al., Initial Repts. Deep Sea Drilling Project, v. 7, pt. 2, p. 1235-1469, 25 fig., 51 pl.

BROTZEN, FRITZ, 1936, *Foraminiferen aus dem schwedischen untersten Senon von Eriksdal in Schonen:* Sveriges Geol. Undersökning Arsb., v. 30, no. 3, ser. C, no. 396, 206 p., 69 fig., 14 pl.

BROTZEN, FRITZ, 1942, *Die Foraminiferengattung* Gavelina *nov. gen. und die Systematik der Rotaliiformes:* Sveriges Geol. Undersökning Arsb., v. 36, no. 8, ser. C, no. 451, 60 p., 18 fig., 1 pl.

BROTZEN, FRITZ, & POZARYSKA, KRYSTINA, 1961, *Foraminifères du paléocène et de l'eocène inférieur en Pologne septentrionale; remarques paléogéographiques:* Rev. Micropaléontologie, v. 4, p. 155-166, 1 fig., 4 pl.

BUKRY, DAVID, 1971a, *Coccolith stratigraphy, Leg 6, Deep Sea Drilling Project;* in Fischer, A. G., et al., Initial Repts. Deep Sea Drilling Project, v. 6, p. 965-1004, 8 pl.

———, 1971b, *Cenozoic calcareous nannofossils from the Pacific Ocean:* San Diego Soc. Nat. History Trans., v. 16, p. 303-328, 7 pl.

———, 1973, *Coccolith stratigraphy, eastern equatorial Pacific, Leg 16 Deep Sea Drilling Project;* in van Andel, T. H., et al., Initial Repts. Deep Sea Drilling Project, v. 16, p. 653-711, 4 fig., 5 pl.

———, in press, *New Miocene to Holocene stages in the ocean basins based on calcareous nannoplankton zones;* in Saito, Tsunemasa, & Burckle, L. H. (eds.), Late Neogene epoch boundaries: Am. Museum Nat. History Spec. Pub. 1.

BUTLER, E. A., ET AL., 1968, *Type locality of* Globorotalia fohsi: Caribbean Geol. Conf., 4th, Trinidad 1965, Trans., p. 201-202, 3 fig.

BYKOVA, N. K., ET AL., 1958, *Novye rody i vidy foraminifer [New genera and species of foraminifers]:* Vses. Neft. Nauchno-Issled. Geol.-Razved. Inst. Trudy, no. 115 [Mikrofauna SSSR, pt. 9], p. 5-105, pl. 1-12.

CARALP, MICHELLE, & PUJOL, CLAUDE, 1973, *A propos de l'utilisation des microfaunes de foraminifères planctoniques:* Acad. Sci. [Paris] Comptes Rendus, ser. D, v. 276, p. 2365-2368.

CARALP, MICHELLE, VALETON, SIMON, & VIGNEAUX, MICHEL, 1965 [1966], *Les foraminifères pélagiques du Tertiaire terminal sud-aquitain:* Acad. Sci. [Paris] Comptes Rendus, v. 261, p. 3431-3434. [English translation in Asoc. Venezolana Geología, Minería y Petróleo, Bol. Inf., v. 9, p. 61-64.]

CARLONI, G. C., ET AL., 1971, *Stratotypes of Mediterranean Neogene stages:* Gior. Geologia, ser. 2, v. 37, p. 1-266, 46 fig.

CARPENTER, W. H., 1862, *Introduction to the study of the Foraminifera:* Ray Soc. (London), 319 p., 22 pl.

CASEY, R. E., 1970, *Paleotemperature analyses based on radiolarian ratios;* Geol. Soc. America Abst. Programs, v. 2, p. 736-738, 1 fig.

———, 1971, *Neogene radiolarian biostratigraphy and paleotemperatures; southern California, the Experimental Mohole, Antarctic core E 14-8:* Palaeogeography, Palaeoclimatology, Palaeoecology, v. 12, p. 115-130, 4 fig.

CASEY, R. E., PRICE, A. B., & SWIFT, C. A., 1972, *Radiolarian definition and paleoecology of the Late Miocene to Early Pliocene in southern California;* in Stinemeyer, E. H., & Church, C. C. (eds.), Soc. Economic Paleontologists and Mineralogists Pacific Coast Miocene Biostratigraphic Symposium Proc., p. 226-238, 5 fig.

CATALANO, RAIMONDO, & SPROVIERI, RODOLFO, 1969, *Stratigrafia e micropaleontologia dell' intervallo tripolaceo di torrente Rossi (Enna):* Accad. Gioenia Sci. Nat. Catania Atti, ser. 7, v. 1, suppl. Sc. Geol., p. 513-527, 4 fig., 3 pl.

CATI, FRANCO, & BORSETTI, A. M., 1967 [1968], *The accessory structures in Tertiary planktonic Foraminifera:* Gior. Geologia, ser. 2, v. 35, p. 387-400, 64 fig.

CATI, FRANCO, ET AL., 1968, *Biostratigraphia del Neogene mediterraneo basata sui foraminiferi planctonici:* Soc. Geol. Italiana Boll., v. 87, p. 491-503, 2 fig.

CAUDRI, C. M. B., 1934, *Tertiary deposits of Soemba:* Amsterdam, H. J. Paris, 224 p., 5 pl.

CHANG, LI-SHO, 1967, *Tertiary biostratigraphy of Taiwan and its correlation:* Pacific Sci. Cong., 11th, Tokyo 1966, Symposium 25 (Tertiary correlations and climatic changes in the Pacific), p. 57-65, 1 fig.

CHAPMAN, FREDERICK, PARR, W. J., & COLLINS, A. C., 1934, *Tertiary Foraminifera of Victoria, Australia–The Balcombian deposits of Port Phillip, pt. 3:* Linnean Soc. London Jour., Zoology, v. 38, p. 553-577, pl. 8-11.

CHARLTON DE RIVERO P., FRANCES, & BERMÚDEZ, P. J., 1963, *Micropaleontología general:* Univ. Central Venezuela, 808 p., 147 fig.

CHIERICI, M. A., BUSI, M. T., & CITA, M. B., 1962, *Contribution à une étude écologique des foraminifères dans la mer Adriatique:* Rev. Micropaléontologie, v. 5, p. 123-142, 7 fig., 2 pl.

CICHA, IVAN, & SENEŠ, JAN, 1971, *Problèmes de la relation de la biostratigraphie et de la chronostratigraphie; étages régionaux et interrégionaux du Tertiaire supérieur:* Comm. Mediterranean Neogene Stratigraphy, 5th, Lyon 1971, Proc. (preprint).

CIFELLI, R. J., 1968, *A note on the holotype of* Globorotalia fohsi *Cushman and Ellisor:* Micropaleontology, v. 14, p. 369-370.

———, 1969, *Radiation of Cenozoic planktonic Foraminifera:* Systematic Zoology, v. 18, p. 154-168, 8 fig.

———, 1971 [1972], *On the temperature relationships of planktonic Foraminifera:* Jour. Foram. Research, v. 1, p. 170-177, 3 fig.

———, 1972, *The holotypes of* Pulvinulina crassata *var.* densa *Cushman and* Globigerina spinuloinflata *Bandy:* Jour. Foram. Research, v. 2, p. 157-159, 2 fig.

CIFELLI, RICHARD, & SMITH, R. K., 1970, *Distribution of planktonic Foraminifera in the vicinity of the north Atlantic current:* Smithsonian Contr. Paleobiology 4, 52 p., 22 fig., 6 pl.

CITA, M. B., 1950, *L'Eocene della sponda occidentale del Lago di Garda:* Riv. Italiana Paleontologia e Stratigrafia, v. 56, p. 81-113, pl. 6-9.

———, 1964, *Considérations sur le langhien des Langhe et sur la stratigraphie miocène du bassin Tertiaire du Piémont:* Inst. Geol. "Lucas Mallada" Inv. Geol., Cursillos Conf., no. 9, p. 203-210, illus.

———, 1968, *Report of the Working Group Micropaleontology:* Gior. Geologia, ser. 2, v. 35, pt. 2, p. 1-22, 2 fig.

———, 1969, *Le paléocène et l'eocène de l'Italie du Nord:* [France] Bur. Recherches Géol. et Minières Mém. 69, p. 417-428.

———, 1970, *Observations sur quelques aspects paléoécologiques de sondages subocéaniques effectués dans l'Atlantique nord:* Rev. Micropaléontologie, v. 12, p. 187-201, 2 fig., 4 pl.

———, 1971a, *Paleoenvironmental aspects of DSDP Legs 1-4:* Internatl. Conf. Planktonic Microfossils, 2nd, Rome 1970, Proc., v. 1, p. 251-285, 10 fig., 5 pl.

———, 1971b, *Langhian:* Gior. Geologia, ser. 2, v. 37, pt. 2, p. 107-116, fig. 20-22.

———, 1971c, *Tortonian:* Gior. Geologia, ser. 2, v. 37, pt. 2, p. 199-208, fig. 38-40.

———, 1971d, *Biostratigraphy, chronostratigraphy and paleoenvironment of the Pliocene of Cape Verde (north Atlantic):* Rev. Micropaléontologie, v. 14, p. 17-42, 11 fig.

———, 1973, *Pliocene biostratigraphy and chronostratigraphy;* in Ryan, W. B. F., et al., Initial Repts. Deep Sea Drilling Project, v. 13, p. 1343-1379, 14 fig., 7 pl.

CITA, M. B., & BLOW, W. H., 1969, *The biostratigraphy of the Langhian, Serravallian and Tortonian stages in the type-sections in Italy:* Riv. Italiana Paleontologia e Stratigrafia, v. 75, p. 549-603, 10 fig.

CITA, M. B., & CIARANFI, N., 1972, *Studi sul Pliocene e sugli strati di passaggio dal Miocene al Pliocene; 2, a new species of* Sphaeroidinella *from late Neogene deep-sea Mediterranean sediments (DSDP Leg 13):* Riv. Italiana Paleontologia e Stratigrafia, v. 78, p. 693-710, 1 fig., pl. 74-76.

CITA, M. B., & D'ONOFRIO, SARA, 1967, *Climatic fluctuations in submarine cores from the Adriatic Sea (Mediterranean):* Progress in Oceanography, v. 4, p. 161-178, 3 fig.

CITA, M. B., & GELATI, ROMANO, 1960, Globoquadrina langhiana *n. sp. del Langhiano-tipo:* Riv. Italiana Paleontologia e Stratigrafia, v. 66, p. 241-246, 1 fig., pl. 29.

CITA, M. B., & MAZZOLA, GIULIANO, 1970, Globigerinopsoides *gen. n. from the Miocene of Algeria:* Riv. Italiana Paleontologia e Stratigrafia, v. 76, p. 465-476, pl. 37-38.

CITA, M. B., & PREMOLI SILVA, ISABELLA, 1968, *Evolution of the planktonic foraminiferal assemblages in the stratigraphic interval between the type-Langhian and the type-Tortonian and biozonation of the Miocene of Piedmont:* Gior. Geologia, ser. 2, v. 35, pt. 3, p. 1-39, 4 fig., 2 pl.

CITA, M. B., PREMOLI SILVA, ISABELLA, & ROSSI, R. C., 1965, *Foraminiferi planctonici del Tortoniano-tipo:* Riv. Italiana Paleontologia e Stratigrafia, v. 71, p. 217-308, 9 fig., pl. 18-31.

CITA, M. B., & RYAN, W. B. F., 1973, *Time-scale and general synthesis;* in Ryan, W. B. F., et al., Initial Repts. Deep Sea Drilling Project, v. 13, p. 1405-1415, 4 fig.

CITA, M. B., ET AL., 1971, *Proposal for the definition of superstages for the Middle and Upper Miocene:* Comm. Mediterranean Neogene Stratigraphy, 5th, Lyon 1971, Proc. [preprint.]

———, 1973, *The Quaternary record in the Tyrrhenian and Ionian basins of the Mediterranean Sea;* in Ryan, W. B. F., et al., Initial Repts. Deep Sea Drilling Project, v. 13, p. 1263-1339, 14 fig., 20 pl.

CLOSS, DARCY, 1967, *Miocene planktonic Foraminifera from southern Brazil:* Micropaleontology, v. 13, p. 337-344, 1 pl.

COLALONGO, M. L., 1968, *Cenozone a foraminiferi ed ostracodi nel Pliocene e basso Pleistocene della serie del Santerno e dell'Appennino Romagnolo:* Gior. Geologia, ser. 2, v. 35, pt. 3, p. 29-61, 2 fig.

———, 1970, *Appunti biostratigrafici sul Messiniano:* Gior. Geologia, ser. 2, v. 36, p. 515-542, 1 fig., 2 pl.

COLALONGO, M. L., & SARTONI, SAMUELE, 1967, Globorotalia hirsuta aemiliana *nuova sottospecie cronologica del Pliocene in Italia:* Gior. Geologia, ser. 2, v. 34, p. 255-284, 2 fig., 2 pl.

COLALONGO, M. L., ET AL., 1972, *Biostratigrafia e cronostratigrafia del Pliocene:* Soc. Geol. Italiana Boll., v. 91, p. 489-509, 1 fig.

COLE, W. S., 1927, *A foraminiferal fauna from the Guayabal formation in Mexico:* Bulls. Am. Paleontology, v. 14, no. 51, 46 p., 5 pl.

———, 1928, *A foraminiferal fauna from the Chapapote Formation in Mexico:* Bulls. Am. Paleontology, v. 14, no. 53, p. 1-32, pl. 1-4.

———, 1931, *The Pliocene and Pleistocene Foraminifera of Florida:* Florida Geol. Survey Bull. 6, p. 7-79, pl. 1-7.

COLLEN, J. D., & VELLA, PAUL, 1973, *Pliocene planktonic Foraminifera, southern North Island, New Zealand:* Jour. Foram. Research, v. 3, p. 13-29, 2 fig., 7 pl.

COLOM, GUILLERMO, 1954, *Estudio de las biozonas con foraminíferos del Terciario de Alicante:* España Inst. Geol. y Minero Bol., v. 66, p. 1-279, pl. 1-35.

COLTRO, ROBERTO, 1963, *La facies di polizzi dell'Eocene alloctono della Sicilia centro-settentrionale:* Riv. Italiana Paleontologia e Stratigrafia, v. 69, p. 167-232, 2 fig., pl. 12-16.

COMMITTEE ON MEDITERRANEAN NEOGENE STRATIGRAPHY, 1960, *1ste. Tagung, Wien 1959, Verhandlungen:* Geol. Gesell. Wien Mitt., v. 52, p. 225-243.

———, 1964, *2a Reunión, Sabadell y Madrid 1961, Memoria:* Inst. "Lucas Mallada" Inv. Geol. Cursillos y Conf., no. 9, 318 p., illus.

———, 1966, *Proceedings of the third session in Berne, 8-13 June 1964:* Leiden, E. J. Brill, 345 p., illus.

———, 1967 [1968-1970], *Fourth session, Bologna 1967, proceedings:* Gior. Geolgia, ser. 2, v. 35, pt. 1, 346 p. [1970]; pt. 2, 422 p. [1968]; pt. 3, 448 p. [1968]; pt. 4, 397 p. [1969].

———, 1971, 1972, *6th Congress; Circulaire 1 and Circular 2-4:* Slovak Acad. Sci. Geol. Inst. (mimeographed).

———, 1973, *5th Session, Lyon 1971, proceedings:* [In press.]

CONATO, VITTORIO, 1964, *Alcuni foraminiferi nuovi nel Pliocene nordappenninico:* Geologica Romana, v. 3, p. 279-295, 9 fig., 2 pl.

CONATO, VITTORIO, & FOLLADOR, UMBERTO, 1967, Globorotalia crotonensis *e* Globorotalia crassacrotonensis *nuove species del Pliocene Italiano:* Soc. Geol. Italiana Boll., v. 84, p. 555-563, 6 fig.

CONOLLY, J. R., & EWING, W. M., 1970, *Ice-rafted detritus in northwest Pacific deep-sea sediments:* Geol. Soc. America Mem. 126, p. 219-231, 6 fig.

COOKE, H. B. S., 1972, *Pleistocene chronology; long or short?:* Maritime Sediments, v. 8, p. 1-12.

CORDEY, W. G., 1967, *The development of* Globigerinoides ruber *(d'Orbigny 1839) from the Miocene to Recent:* Palaeontology, v. 10, p. 647-659, 5 fig., pl. 103.

———, 1968a, *A new Eocene* Cassigerinella *from Florida:* Palaeontology, v. 11, p. 368-370, fig. 1.

———, 1968b, *Morphology and phylogeny of* Orbulinoides beckmanni *(Saito 1962):* Palaeontology, v. 11, p. 371-375, 1 fig.

CORDEY, W. G., BERGGREN, W. A., & OLSSON, R. K., 1970, *Phylogenetic trends in the planktonic foraminiferal genus* Pseudohastigerina *Banner and Blow:* Micropaleontology, v. 16, p. 235-242, 5 fig.

CORYELL, H. N., & EMBICH, J. R., 1937, *The Tranquilla shale (Upper Eocene) of Panama and its foraminiferal fauna:* Jour. Paleontology, v. 11, p. 289-305, pl. 41-43.

CORYELL, H. N., & MOSSMAN, R. W., 1942, *Foraminifera from the Charco Azul formation, Pliocene, of Panama:* Jour. Paleontology, v. 16, p. 233-246, pl. 36.

CORYELL, H. N., & RIVERO, F. C., 1940, *A Miocene microfauna from Haiti:* Jour. Paleontology, v. 14, p. 324-344, pl. 41-44.

COX, ALLAN, 1969, *Geomagnetic reversals:* Science, v. 163, p. 237-245, 8 fig.

COX, ALLAN, DOEL, R. R., & DALRYMPLE, G. B., 1968, *Radiometric time-scale for geomagnetic reversals:* Geol. Soc. London Quart. Jour., v. 124, p. 53-66, 1 fig.

CRONEIS, C. G., 1941, *Micropaleontology – past and future:* Am. Assoc. Petroleum Geologists Bull., v. 25, p. 1208-1255, 16 fig.

CURRY, DENNIS, 1967, *Problems of correlation in the Anglo-Paris-Belgian Basin:* Geologists' Assoc. Proc., v. 77, p. 437-467, 5 fig.

CUSHMAN, J. A., 1919, *Fossil Foraminifera from the West Indies:* Carnegie Inst. Washington, Pub. 291, p. 21-71, 8 fig., 15 pl.

______, 1924, *The Foraminifera of the Atlantic Ocean; Pt. 5 – Chilostomellidae and Globigerinidae:* U.S. Natl. Museum Bull. 104, 53 p., 8 pl.

______, 1925a, *A new genus of Eocene Foraminifera:* U.S. Natl. Museum Proc., v. 66, no. 2567, p. 1-4, pl. 1-2.

______, 1925b, *New Foraminifera from the Upper Eocene of Mexico:* Cushman Lab. Foram. Research Contr., v. 1, p. 4-8, pl. 1.

______, 1925c, *Some new Foraminifera from the Velasco Shale of Mexico:* Cushman Lab. Foram. Research Contr., v. 1, p. 18-23, pl. 3.

______, 1925d, *An Eocene fauna from the Moctezuma River, Mexico:* Am. Assoc. Petroleum Geologists Bull., v. 9, p. 298-303, pl. 6-8.

______, 1926, Eouvigerina, *a new genus from the Cretaceous:* Cushman Lab. Foram. Research Contr., v. 2, p. 3-6, pl. 1.

______, 1927a, *An outline of a re-classification of the Foraminifera:* Cushman Lab. Foram. Research Contr., v. 3, p. 1-105, pl. 1-21.

______, 1927b, *New and interesting Foraminifera from Mexico and Texas:* Cushman Lab. Foram. Research Contr., v. 3, p. 111-119, pl. 22-23.

______, 1927c, *The designation of some genotypes in the Foraminifera:* Cushman Lab. Foram. Research Contr., v. 3, p. 188-190.

______, 1928, *Additional Foraminifera from the Upper Eocene of Alabama:* Cushman Lab. Foram. Research Contr., v. 4, p. 73-79, pl. 10.

______, 1930, *Fossil species of* Hastigerinella: Cushman Lab. Foram. Research Contr., v. 6, p. 17-19, pl. 3.

______, 1931a, *The Foraminifera from the Atlantic Ocean, Pt. 8 – Rotaliidae, Amphisteginidae, Calcarinidae, Cymbaloporettidae, Globorotaliidae, Anomalinidae, Planorbulinidae, Rupertiidae and Homotremidae:* U.S. Natl. Museum Bull. 104, pt. 8, 179 p., 26 pl.

______, 1931b, Hastigerinella *and other interesting Foraminifera from the Upper Cretaceous of Texas:* Cushman Lab. Foram. Research Contr., v. 7, p. 83-90, pl. 11.

______, 1932, Rectogümbelina, *a new genus from the Cretaceous:* Cushman Lab. Foram. Research Contr., v. 8, p. 4-7, pl. 1.

______, 1933, *Some new foraminiferal genera:* Cushman Lab. Foram. Research Contr., v. 9, p. 32-38, pl. 3-4.

______, 1934, *Small Foraminifera from Vitileuv, Fiji;* in Ladd, H. S., Geology of Vitileuv, Fiji: Bernice P. Bishop Museum, Bull. 119, p. 102-142, pl. 10-18.

______, 1935, *Upper Eocene Foraminifera of the southeastern United States:* U.S. Geol. Survey Prof. Paper 181, 88 p., 23 pl.

______, 1940, *Midway Foraminifera from Alabama:* Cushman Lab. Foram. Research Contr., v. 16, pt. 3, p. 51-73, pl. 9-12.

______, 1945, *The species of* Globigerina *described by d'Orbigny in 1839 from shore sands of Cuba:* Cushman Lab. Foram. Research Contr., v. 21, p. 74-75, pl. 12 (part).

______, 1946, *The species of* Globigerina *described between 1839 and 1850:* Cushman Lab. Foram. Research Contr., v. 22, p. 15-21, pl. 3-4.

______, 1948, *Foraminifera, their classification and economic use:* Cambridge, Mass., Harvard Univ. Press, 605 p., 9 fig., 86 pl. (ed. 4).

CUSHMAN, J. A., & BERMÚDEZ, P. J., 1936, *Additional new species of Foraminifera and a new genus from the Eocene of Cuba:* Cushman Lab. Foram. Research Contr., v. 12, p. 55-63, pl. 10-11.

______, 1937, *Further new species of Foraminifera from the Eocene of Cuba:* Cushman Lab. Foram. Research Contr., v. 13, p. 1-29, pl. 1-3.

______, 1949, *Some Cuban species of* Globorotalia: Cushman Lab. Foram. Research Contr., v. 25, p. 26-45, pl. 5-8.

CUSHMAN, J. A., & ELLISOR, A. C., 1939, *New species of Foraminifera from the Oligocene and Miocene:* Cushman Lab. Foram. Research Contr., v. 15, p. 1-14, pl. 1-4.

CUSHMAN, J. A., & HENBEST, L. G., 1940, *Geology and biology of north Atlantic deep-sea cores between*

Newfoundland and Ireland; Pt. 2, Foraminifera: U.S. Geol. Survey Prof. Paper 196A, p. 35-50, pl. 8-10.

CUSHMAN, J. A., & JARVIS, P. W., 1929, *New Foraminifera from Trinidad:* Cushman Lab. Foram. Research Contr., v. 5, p. 6-17, pl. 2-3.

______, 1930, *Miocene Foraminifera from Buff Bay, Jamaica:* Jour. Paleontology, v. 4, p. 353-368, pl. 32-34.

______, 1936, *Three new Foraminifera from the Miocene, Bowden marl, of Jamaica:* Cushman Lab. Foram. Research Contr., v. 12, no. 166, p. 3-5, pl. 1.

CUSHMAN, J. A., & PONTON, G. M., 1932a, *The Foraminifera of the Upper, Middle and part of the Lower Miocene of Florida:* Florida Geol. Survey Geol. Bull. 9, p. 7-147, pl. 1-17.

______, 1932b, *An Eocene foraminiferal fauna of Wilcox age from Alabama:* Cushman Lab. Foram. Research Contr., v. 8, p. 51-72, pl. 7-9.

CUSHMAN, J. A., & RENZ, H. H., 1941, *New Oligocene-Miocene Foraminifera from Venezuela:* Cushman Lab. Foram. Research Contr., v. 17, p. 1-27, pl. 1-4.

______, 1942, *Eocene, Midway, Foraminifera from Soldado Rock, Trinidad:* Cushman Lab. Foram. Research Contr., v. 18, p. 1-20, pl. 1-3.

______, 1947, *The foraminiferal fauna of the Oligocene Ste. Croix formation of Trinidad, B. W. I.:* Cushman Lab. Foram. Research Spec. Pub. 22, 46 p., 8 pl.

______, 1948, *Eocene Foraminifera of the Navet and Hospital Hill formations of Trinidad, B. W. I.:* Cushman Lab. Foram. Research Spec. Pub. 24, 42 p., 8 pl.

CUSHMAN, J. A., & STAINFORTH, R. M., 1945, *The Foraminifera of the Cipero Marl Formation of Trinidad, British West Indies:* Cushman Lab. Foram. Research Spec. Pub. 14, 75 p., 16 pl.

______, 1951, *The Tertiary Foraminifera of coastal Ecuador; Pt. 1, Eocene:* Jour. Paleontology, v. 25, p. 129-164, 4 fig., pl. 25-28.

CUSHMAN, J. A., STEWART, R. E., & STEWART, K. C., 1930, *Tertiary Foraminifera from Humboldt County, California; a preliminary survey of the fauna:* San Diego Soc. Nat. History Trans., v. 6, p. 41-94, 8 pl.

CUSHMAN, J. A., & TODD, RUTH, 1945, *Miocene Foraminifera from Buff Bay, Jamaica:* Cushman Found. Foram. Research Spec. Pub. 15, 73 p., 12 pl.

CUSHMAN, J. A., TODD, RUTH, & POST, R. J., 1954, *Recent Foraminifera of the Marshall Islands:* U.S. Geol. Survey Prof. Paper 260-H, p. 319-384, pl. 82-93.

DALRYMPLE, G. B., 1972, *Potassium-argon dating of geomagnetic reversals and North American glaciations;* in Bishop, W. W., and Miller, J. (eds.), Calibration of hominoid evolution: Edinburgh, Scottish Univ. Press, p. 107-134.

DAVIES, T. A., & LAUGHTON, A. S., 1972, *Sedimentary processes in the north Atlantic;* in Laughton, A. S., et al., Initial Repts. Deep Sea Drilling Project, v. 12, p. 905-934, 22 fig.

DENTON, G. H., & ARMSTRONG, R. L., 1969, *Miocene-Pliocene glaciations in southern Alaska:* Am. Jour. Sci., v. 267, p. 1121-1142, 3 fig., 2 pl.

DESHAYES, G. P., 1832, *Encyclopédie méthodique; Histoire naturelle des vers:* Paris, Mme. v. Agasse, v. 2, pt. 2, 594 p.; v. 3, p. 595-1152.

DE STEFANI, TEODOSIO, 1952, *Su alcune manifestazioni di idrocarburi in provincia de Palermo e descrizione di foraminiferi nuovi:* Plinia [Palermo, Italy], v. 3 (1950-51), Nota 4, p. 1-12, 3 pl.

DEVDARIANI, A. S., 1972, *Rekonstruktsiya istorii klimata metodami teorii peredachi informatsii po dannym mikropaleontologicheskikh analizov [Paleoclimatic reconstruction by information-theory methods based on micropaleontologic analyses]:* Okeanologiya, v. 12, p. 252-261, 4 fig. [Transl. in Oceanology, v. 12, p. 214-222, 4 fig.]

DEVEREUX, IAN, 1967, *Oxygen isotope paleotemperature measurements of New Zealand Tertiary fossils:* New Zealand Jour. Sci., v. 10, p. 988-1011, 1 fig.

DEVEREUX, IAN, HENDY, C. H., & VELLA, PAUL, 1970, *Pliocene and early Pleistocene sea temperature fluctuations, Mangaopari Stream, New Zealand:* Earth and Planetary Sci. Letters, v. 8, p. 163-168, 3 fig.

DIENI, IGINIO, & PROTO DECIMA, FRANCA, 1964, Cribrohantkenina *ed altri Hantkeninidae nell'Eocene superiore di Castelnuovo (Colli Euganei):* Riv. Italiana Paleontologia e Stratigrafia, v. 70, p. 555-592, 8 fig., pl. 43-46.

DONDI, L., 1963, *Nota paleontologica-stratigrafica sul Pedeappennino padano:* Soc. Geol. Italiana Boll., v. 81, p. 113-229, fig. 38-62.

D'ONOFRIO, SARA, 1968 [1969], *Biostratigrafia del Pliocene e Pleistocene inferiore nelle Marche:* Gior. Geologia, ser. 2, v. 35, p. 99-114, 3 fig.

D'ORBIGNY, A. D., 1826, *Tableau méthodique de la classe des céphalopodes:* Annales Sci. Nat. Paris, ser. 1, v. 7, p. 95-314, pl. 10-17.

______, 1839, *Foraminifères;* in Ramòn de la Sagra, Histoire physique, politique et naturelle de l'ile de Cuba: Paris, A. Bertrand, 224 p., 12 pl. (Atlas).

______, 1840, *Mémoire sur les foraminifères de la craie blanche du bassin de Paris:* Soc. Géol. France Mém., v. 4, pt. 1, p. 1-51, pl. 1-4.

______, 1846, *Foraminifères fossiles du bassin tertiaire de Vienne (Autriche):* Paris, Gide et Comp., 303 p., 21 pl.

DOUGLAS, R. G., & SAVIN, S. M., 1971, *Isotopic analyses of planktonic Foraminifera from the Cenozoic of the northwest Pacific, Leg 6;* in Fischer, A. G., et al., Initial Repts. Deep Sea Drilling Project, v. 6, p. 1123-1127, 3 fig.

DROOGER, C. W., 1953, *Miocene and Pleistocene Foraminifera from Oranjestad, Aruba (Netherlands Antilles):* Cushman Found. Foram. Research Contr., v. 4, p. 116-147, pl. 19-24.

———, 1954, *The Oligocene-Miocene boundary on both sides of the Atlantic:* Geol. Mag., v. 91, p. 514-518.

———, 1956, *Transatlantic correlation of the Oligo-Miocene by means of Foraminifera:* Micropaleontology, v. 2, p. 183-192, 1 fig., 1 pl.

———, 1973, *Benthonic foraminiferal assemblages from the Calabrian deposits of Santa Maria di Catanzaro:* Newsletters Stratigraphy, v. 3, p. 59-64.

DROOGER, C. W., & MARKS, PETER, 1971, *Proposal of four superstages in the Neogene:* Comm. Mediterranean Neogene Stratigraphy, 5th, Lyon 1971, Proc. [Preprint.]

DUQUE-CARO, HERMANN, 1971, *A reply to "On planktonic foraminiferal zonation in the Tertiary of Colombia":* Micropaleontology, v. 17, p. 365-368.

EAMES, F. E., 1953, *The Miocene-Oligocene boundary and the use of the term Aquitanian:* Geol. Mag., v. 90, p. 388-392.

———, 1954, *The Caribbean "Oligocene":* Geol. Mag., v. 91, p. 326-327.

———, 1955, *The Miocene-Oligocene boundary in the Caribbean region:* Geol. Mag., v. 92, p. 86.

EAMES, F. E., ET AL., 1962, *Fundamentals of mid-Tertiary stratigraphical correlation:* Cambridge, Cambridge Univ. Press, 163 p., 20 fig., 17 pl.

———, 1968, *Some larger Foraminifera from the Tertiary of Central America:* Palaeontology, v. 11, p. 283-305, pl. 49-59.

EDWARDS, A. R., 1973, *Calcareous nannofossils from the southwest Pacific, Deep Sea Drilling Project, leg 21;* in Burns, R. E., et al., Initial Repts. Deep Sea Drilling Project, v. 21, p. 641-691, 3 fig., 15 pl.

EGGER, J. G., 1893, *Foraminiferen aus Meeresgrundproben, gelonthet von 1874 bis 1876 von S. M. Sch. Gazelle:* Bayerische Akad. Wiss., Math.-Physik. Kl. Abh., v. 18, p. 193-458 (1-266), pl. 1-21.

———, 1899, *Foraminiferen und Ostrakoden aus dem Kreidemergeln der Oberbayerischen Alpen:* Kgl. Bayerische Akad. Wiss. [München] Math.-Phys. Kl. Abh., v. 21, p. 1-230, pl. 1-27.

EHRENBERG, C. G., 1843, *Verbreitung und Einfluss des Mikroskopischen Lebens in Süd- und Nord-Amerika:* Akad. Wiss. Berlin Abh. for 1841, p. 291-446, pl. 1-4.

———, 1845, *Ueber das kleinste organische Leben an mehreren bisher nicht untersuchten Erdpunkten, mikroskopische Lebensformen von Portugal und Spanien, Süd-Afrika, Hinter-Indien, Japan und Kurdistan:* Deutsch. Akad. Wiss. Berlin Ber., p. 357-381.

———, 1854, *Mikrogeologie; Das Erden und Felsen schaffende Wirken des unsichtbar kleinen selbstaendigen Lebens auf der Erde:* Leipzig, L. Voss, 374 p. [text], 31 p., 41 pl. [atlas].

———, 1858, *Kurze Characteristik der 9 neuen Genera und der 105 neuen Species des Aegaeischen Meeres und des Tiefgrundes des Mittel-Meeres:* Deutsch. Akad. Wiss. Berlin Monatsber., p. 10-40.

EL-NAGGAR, Z. R., 1969a, *New suggestions for the division and correlation of Paleocene strata by the use of planktonic Foraminifera:* Internatl. Conf. Planktonic Microfossils, 1st, Geneva 1967, Proc., v. 2, p. 182-201.

———, 1969b, *Correlation of the various planktonic foraminiferal zonations of the Paleocene:* Internatl. Conf. Planktonic Microfossils, 1st, Geneva 1967, Proc., v. 2, p. 202-223.

———, 1971, *On the classification, evolution and stratigraphical distribution of the Globigerinacea:* Internatl. Conf. Planktonic Microfossils, 2nd, Rome 1970, Proc., v. 1, p. 421-476.

EL-NAGGAR, Z. R., & AL MEER, A. Y., 1973 [1974], *Position taxonomique du genre* Globanomalina *Haque 1956 et remarques sur les Hantkenininae (foraminifères):* Rev. Micropaléontologie, v. 16, p. 65-72, 2 pl.

EMILIANI, CESARE, 1969, *A new paleontology:* Micropaleontology, v. 15, p. 265-300, 7 fig., 22 pl.

———, 1971, *Isotopic paleotemperatures and shell morphology of* Globigerinoides rubra *in the type section for the Plio-Pleistocene boundary:* Micropaleontology, v. 17, p. 233-238, 3 pl.

EPSTEIN, SAMUEL, ET AL., 1951, *Carbonate-water isotopic temperature scale:* Geol. Soc. America Bull., v. 62, p. 417-426, 5 fig.

ERICSON, D. B., EWING, W. M., & WOLLIN, GOESTA, 1963, *Pliocene-Pleistocene boundary in deep-sea sediments:* Science, v. 139, p. 727-737, 13 fig.

———, 1964, *The Pleistocene epoch in deep-sea sediments:* Science, v. 146, p. 723-732, 5 fig.

ERICSON, D. B., & WOLLIN, GOESTA, 1956, *Correlation of six cores from the equatorial Atlantic and the Caribbean:* Deep-Sea Research, v. 3, p. 104-125, 11 fig.

———, 1964, *The deep and the past:* New York, Alfred A. Knopf, Inc., 292 p., 29 fig., 16 pl.

ERICSON, D. B., WOLLIN, GOESTA, & WOLLIN, JANET, 1954, *Coiling direction of* Globorotalia truncatulinoides *in deep-sea cores:* Deep-Sea Research, v. 2, p. 152-168, 4 fig.

FAIRBRIDGE, R. W., 1961, *Eustatic changes in sea level;* in Physics and chemistry of the earth: New York, Pergamon Press, v. 4, p. 95-185, 15 fig.

———, 1966, *Mean sea level changes, long-term – eustatic and other;* in Fairbridge, R. W. (ed.), The encyclopedia of oceanography – encyclopedia of earth sciences series: New York, Reinhold Publ. Corp., v. 1, p. 479-485, 6 fig.

FARINACCI, ANNA, & MATTEUCCI, R. (eds), 1971, *Proceedings of the II Planktonic Conference Roma 1970:* Rome, Edizions Tecnoscienza, 2 v., 1369 p., illus.

FINLAY, H. J., 1939a, *New Zealand Foraminifera; key species in stratigraphy, No. 1:* Royal Soc. New Zealand Trans., v. 68, p. 504-533, pl. 68-69.

———, 1939b, *New Zealand Foraminifera; the occurrence of* Rzehakina, Hantkenina, Rotaliatina *and* Zeauvigerina: Royal Soc. New Zealand Trans., v. 68, p. 534-543, pl. 69.

———, 1939c, *New Zealand Foraminifera; key species in stratigraphy, No. 2:* Royal Soc. New Zealand Trans., v. 69, p. 89-128, pl. 11-14.

———, 1939d, *New Zealand Foraminifera; key species in stratigraphy, No. 3:* Royal Soc. New Zealand Trans., v. 69, p. 309-329, pl. 27-29.

———, 1940, *New Zealand Foraminifera; key species in stratigraphy, No. 4:* Royal Soc. New Zealand Trans., v. 69, p. 448-472, pl. 62-67.

———, 1947, *New Zealand Foraminifera; key species in stratigraphy, No. 5:* New Zealand Jour. Sci. Tech., sec. B, v. 28, p. 259-292, 9 pl.

FINLAY, H. J., & MARWICK, J., 1940, *The divisions of the Upper Cretaceous and Tertiary in New Zealand:* Royal Soc. New Zealand Trans., v. 70, p. 77-135.

———, 1947, *New divisions of the New Zealand Upper Cretaceous and Tertiary:* New Zealand Jour. Sci. Tech., sec. B, v. 28, p. 228-236.

FLEISHER, R. L., 1974, *Cenozoic planktonic Foraminifera and biostratigraphy, Arabian Sea Deep Sea Drilling Project, Leg 23A;* in Whitmarsh, R. B., et al., Initial Repts. Deep Sea Drilling Project, v. 23, p. 1001-1072, 1 fig., 21 pl.

FOLLADOR, UMBERTO, 1967, *Il Pliocene ed il Pleistocene dell'Italia centro-meridionale, versanta adriatico, biostratigrafia:* Soc. Geol. Italiana Boll., v. 86, p. 565-584, 2 fig.

FORBES, EDWARD, 1846, *On the connexion between the distribution of the existing fauna and flora of the British Isles, and the geological changes which have affected their area, especially during the epoch of the Northern Drift:* Great Britain Geol. Survey Mem., v. 1, p. 336-432.

FORNASINI, CARLO, 1898 [1899], *Le globigerine fossili d'Italia:* Palaeontographica Italica, v. 4, p. 203-216, 5 fig.

———, 1902, *Sinossi metodica, dei foraminiferi sin qui rinvenuti nella sabbia del Lido di Rimini:* Accad. Sci. Ist. Bologna Mem. Sci. Nat., ser. 5, v. 10 (1902-1904), p. 1-68, pl. 1-63.

FOURNIER, GEORGE, 1956, *New methods and techniques in the photography of microfossils:* Micropaleontology, v. 2, p. 37-56, 4 fig., 3 pl.

———, 1957, *Construction of pinhole diaphragms for use in photomicrography:* Micropaleontology, v. 3, p. 85-87, 5 fig.

FRANKLIN, E. S., 1944, *Microfauna from the Carapita Formation of Venezuela:* Jour. Paleontology, v. 18, p. 301-319, pl. 44-48.

FRERICHS, W. E., 1971, *Evolution of planktonic Foraminifera and paleotemperatures:* Jour. Paleontology, v. 45, p. 963-968, 5 fig.

FRYE, J. C., 1972, *The Pleistocene succession of central interior United States:* Am. Quaternary Assoc., 2nd Natl. Conf., Miami, Florida, Abstr., p. 19, 1 fig.

FUENMAYOR, A. N., 1969, *Notas sobre* Globigerina sellii *(Borsetti) y su posición estratigráfica:* Asoc. Venezolana Geología, Minería y Petróleo Bol. Inf., v. 12, p. 355-366, 1 pl.

GALLOWAY, J. J., 1933, *A manual of Foraminifera:* Bloomington, Indiana, Principia Press, 483 p., 42 pl.

GALLOWAY, J. J., & WISSLER, S. G., 1927, *Pleistocene Foraminifera from the Lomita quarry, Palos Verdes Hills, California:* Jour. Paleontology, v. 1, p. 35-87, pl. 7-12.

GARTNER, STEFAN, 1973, *Absolute chronology of the Late Neogene calcareous nannofossil succession in the equatorial Pacific:* Geol. Soc. America Bull., v. 84, p. 2021-2034, 6 fig.

GERMERAAD, J. H., 1946, *Geology of central Seran;* in Rutten, L., & Hotz, W., Geological, petrographical and palaeontological results of explorations carried out from September 1917 till June 1919 in the island of Ceram: Amsterdam, J. H. de Bussy, ser. 3 (Geol.), no. 2, p. 7-135, 12 pl.

GIGNOUX, MAURICE, 1950, *Géologie stratigraphique:* Paris, Masson et Cie., 4th ed., 735 p., illus.

GLAÇON, GEORGETTE, VERGNAUD-GRAZZINI, COLETTE, & SIGAL, M. J., 1971, *Premiers résultats d'une série d'observations saisonnières des foraminifères du plancton méditerranéen:* Internatl. Conf. Planktonic Microfossils, 2nd, Rome 1970, Proc., v. 1, p. 555-581, 5 fig., 7 pl.

GLAESSNER, M. F., 1937a, *Planktonforaminiferen aus der Kreide und dem Eozaen und ihre stratigraphische Bedeutung:* Moscow Univ. Lab. Paleont., Studies Micropaleont., v. 1, pt. 1, p. 27-46, pl. 1-2.

———, 1937b, *Melovye i tretichnye foraminifery Kavkaza. 1.-Foraminifery drevneishikh tretichnykh otloshenii severo-zapadnogo Kavkaza [Studien über Foraminiferen aus der Kreide und dem Tertiär des Kaukasus. 1.–Die Foraminiferen der ältesten Tertiärschichten des*

Nordwest-Kaukasus]: Moskov. Gos. Univ. Problemy Paleontologii, 2-3, p. 349-410, 5 pl.

———, 1945, *Principles of micropaleontology*: New York, Melbourne Univ. Press and John Wiley & Sons, 296 p., 64 fig.

GLASS, BILLY, ET AL., 1967, *Geomagnetic reversals and Pleistocene chronology*: Nature, v. 216, p. 437-442, 6 fig.

GOHRBANDT, K. H. A., 1963, *Zur Gliederung des Paläogen im Helvetikum nördlich Salzburg nach planktonischen Foraminiferen*: Geol. Gesell. Wien Mitt., v. 56, p. 1-116, 7 fig., 11 pl.

GOLL, R. M., 1972, *Leg 9 synthesis, Radiolaria*; in Hays, J. D., et al., Initial Repts. Deep Sea Drilling Project, v. 9, p. 947-1058, 2 fig., 88 pl.

GOODELL, H. G., ET AL., 1968, *The Antarctic glacial history recorded in sediments of the Southern Ocean*: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 5, p. 41-62, 4 fig.

GRADSTEIN, F. M., 1972, *Stratigraphy of Neogene deposits in eastern Crete, with a study of Pliocene* Globorotalia: Utrecht Univ., Ph.D. dissert. (mimeo preprint).

———, 1973, *Pliocene and Pleistocene planktonic Foraminifera from Santa Maria di Catanzaro, southern Italy*: Newsletters Stratigraphy, v. 3, p. 45-58, 1 fig., 1 pl.

GRILL, RUDOLF, 1953, *Der Flysch, die Waschbergzone und das Jungtertiär um Ernstbrunn (Niederösterreich)*: [Austria] Geol. Bundesanst. Jahrb., v. 96, p. 65-116, pl. 3-4.

GRIMSDALE, T. F., 1951, *Correlation, age determination and the Tertiary pelagic Foraminifera*: World Petroleum Cong., 3rd, The Hague 1951, Proc., sec. 1, p. 463-475, 1 fig.

GRZYBOWSKI, JOSEF, 1898, *Mikroskopowe badania namulów wiertniczych z kopaln naftowych. I. Pas potocki i okolice Krosna. II. Uwagi ogólne*: Kosmos, v. 22, p. 393-439, 4 fig. [Partly translated in Polskie. Towarz. Geol. Rocznik, v. 39, p. 13-26.]

GÜMBEL, C. W., 1868 [1870], *Beiträge zur Foraminiferenfauna der nordalpinen, älteren Eocängebilde oder der Kressenberger Nummulitenschichten*: Bayerische Akad. Wiss. Abh., Math.-Physik. Kl., v. 10, pt. 2, p. 579-730, pl. 1-4.

HAGN, HERBERT, 1956, *Geologische und palaeontologische Untersuchungen im Tertiär des Monte Brione und seiner Umgebung (Gardasee, Ober-Italien)*: Palaeontographica, Abt. A, v. 107, p. 67-210, 5 fig., pl. 7-18.

HAGN, HERBERT, & LINDENBERG, H. G., 1966, *Revizija* Globigerina *(Subbotina)* eocaena *Gümbel iz Eocena predgorij Bavarskich Al'p. [Revision of* Globigerina *(Subbotina)* eocaena *Gümbel from the Eocene of the Bavarian Alps]*: Akad. Nauk SSSR Voprosy Mikropaleontologii, no. 10, p. 342-358, 4 fig., 1 pl.

HAGN, HERBERT, & LINDENBERG, H. G., 1969, *Revision der von C. W. Gümbel 1868 aus dem Eozän des bayerischen Alpenvorlandes beschriebenen planktonischen Foraminiferen*: Internatl. Conf. Planktonic Microfossils, 1st, Geneva 1967, Proc., v. 2, p. 229-249, 6 fig., 1 pl.

HANSEN, H. J., 1970, *Biometric studies on the stratigraphic evolution of* Globoconusa daubjergensis *(Brönnimann) from the Danian of Denmark*: Dansk Geol. Foren. Medd., v. 19, p. 341-360, 19 fig., 6 pl.

HAQUE, A. F. M. M., 1956, *The Foraminifera of the Ranikot and the Laki of the Nammal Gorge, Salt Range*: Pakistan Geol. Survey, Paleontologia Pakistanica, v. 1, p. 1-300, pl. 1-34.

———, 1958, Cincoriola, *a new generic name for* Punjabia *Haque, 1956*: Cushman Found. Foram. Research Contr., v. 9, p. 103.

HARPER, C. T. (ed.), 1973, *Geochronology*: Stroudsburg, Pa., Dowden, Hutchinson & Ross, Inc., 488 p., illus.

HARTONO, H. M. S., 1964, *Coiling direction of* Pulleniatina obliquiloculata trochospira *n. var. and* Globorotalia menardii: Indonesia Geol. Survey Bull., v. 1, p. 5-12.

HAY, W. W., & MOHLER, H. P., 1969, *Paleocene-Eocene calcareous nannoplankton and high-resolution biostratigraphy*: Internatl. Conf. Planktonic Microfossils, 1st, Geneva 1967, Proc., v. 2, p. 250-253, 1 fig.

HAYAMI, I., 1973, *An evolutionary interpretation of biostratigraphic zones*: Geol. Soc. Japan Jour., v. 79, p. 219-235.

HAYS, J. D., & BERGGREN, W. A., 1971, *Quaternary boundaries and correlations*; in Funnell, B. M., & Riedel, W. R. (eds.), The micropalaeontology of oceans: Cambridge, Cambridge Univ. Press, p. 669-691, 9 fig.

HAYS, J. D., & OPDYKE, N. D., 1967, *Antarctic Radiolaria, magnetic reversals and climatic change*: Science, v. 158, p. 1001-1011, 10 fig.

HAYS, J. D., ET AL., 1969, *Pliocene-Pleistocene sediments of the equatorial Pacific: their paleomagnetic, biostratigraphic, and climatic record*: Geol. Soc. America Bull., v. 80, p. 1481-1514, 16 fig., 1 pl.

———, 1972, *Introduction*; in Hays, J. D., et al., Initial Repts. Deep Sea Drilling Project, v. 9, p. 3-20A, 5 fig.

HEDBERG, H. D., 1937, *Foraminifera of the middle Tertiary Carapita Formation of northeastern Venezuela*: Jour. Paleontology, v. 11, p. 661-697, pl. 90-92.

———, (ed.), 1971, *Preliminary report on biostratigraphic units*: Internatl. Geol. Cong., Montreal, Canada, Rept. 5 (Internatl. Subcomm. Strat. Classification), 50 p., 4 fig.

HEMMING, FRANCIS (ed.), 1958, *Declaration 40. Determination of the gender to be attributed to generic names having the termination "-ides", "-ites" or "-oides"*: Internatl. Comm. Zool. Nomenclature, Opinions and declarations, v. 19, pt. 14, p. 19-28.

HERMAN, YVONNE, 1971, *Quaternary climatic changes in the eastern Mediterranean as recorded by pteropods and planktonic foraminifers:* Internatl. Conf. Planktonic Microfossils, 2nd, Rome 1970, Proc., p. 611-647, 9 fig., 12 pl.

———, 1972, Globorotalia truncatulinoides; *a palaeo-oceanographic indicator:* Nature, v. 238, p. 394-396, 2 fig.

HIBBARD, C. W., ET AL., 1965, *Quaternary mammals of North America;* in Wright, H. E., Jr. & Frey, D. G. (eds.), The Quaternary of the United States: Princeton, Princeton Univ. Press., p. 509-526.

HILLEBRANDT, AXEL VON, 1962, *Das Paleozän und seine Foraminiferenfauna im Becken von Reichenhall und Salzburg:* Bayerische Akad. Wiss. Abh., Math.-Naturw. Kl., v. 108, 182 p., 15 pl.

———, 1965, *Foraminiferen-Stratigraphie im Alttertiär von Zumaya (Provinz Guipuzcoa, N. W.-Spanien) und ein vergleich mit anderen Tethys-Gebieten:* Bayerische Akad. Wiss. Abh., Math.-Naturw. Kl., v. 123, 62 p.

HINTE, J. E. VAN, 1969, *The nature of biostratigraphic zones:* Internatl. Conf. Planktonic Microfossils, 1st, Geneva 1967, Proc., v. 1, p. 267-272, 4 fig.

———, 1972, *The Cretaceous time scale and planktonic foraminiferal zones:* Koninkl. Nederlandse Akad. Wetensch. Proc., ser. B, no. 1, p. 61-68, 1 fig.

HOFKER, JAN, 1954, *Morphology of* Globigerinatella insueta *Cushman and Stainforth:* Cushman Found. Foram. Research Contr., v. 5, p. 151-152.

———, 1956, *Tertiary Foraminifera of coastal Ecuador; Pt. 2–Additional notes on the Eocene species:* Jour. Paleontology, v. 30, p. 891-958, 101 fig.

———, 1962, *Correlation of the Tuff Chalk of Maestricht (type Maestrichtian) with the Danske Kalk of Denmark (type Danian), the stratigraphic position of the type Montian, and the planktonic foraminiferal break:* Jour. Paleontology, v. 36, p. 1051-1089, 28 fig.

———, 1963a, *Einige planktonische Foraminiferen aus dem borealen europäischen Oligozän:* Neues Jahrb. Geologie u. Palaeontologie Abh., v. 118, p. 197-206, 14 fig.

———, 1963b, Cassigerinella *Pokorný, 1955 and* Islandiella *Nørvang, 1958:* Micropaleontology, v. 9, p. 321-324, 1 pl.

HOFKER, JAN, SR., 1968, *Tertiary Foraminifera of coastal Ecuador; Lower Oligocene and Lower Miocene:* Palaeontographica, Abt. A, v. 130, p. 1-59, 12 fig., pl. 1-25.

———, 1969, *Have the genera* Porticulasphaera, Orbulina (Candorbulina) *and* Biorbulina *a biologic meaning?:* Internatl. Conf. Planktonic Microfossils, 1st., Geneva 1967, Proc., v. 2, p. 279-286, 3 pl.

———, 1972, *The* Sphaeroidinella *gens from Miocene till Recent:* Rev. Española Micropaleontología, v. 4, p. 119-140, 10 pl.

HOOYBERGHS, H. J. F., & MEUTER, F. J. C. DE, 1972, *Biostratigraphy and interregional correlation of the "Miocene" deposits of northern Belgium based on planktonic Foraminifera; the Oligocene-Miocene boundary on the southern edge of the North Sea basin:* Koninkl. Vlaamse Acad. Wetensch. Letteren en Schone Kunsten van Belgie, Mededeel., Kl. Wetensch., v. 34, no. 3, 47 p., 5 fig., 11 pl.

HORNIBROOK, N. DE B., 1958, *New Zealand Upper Cretaceous and Tertiary foraminiferal zones and some overseas correlations:* Micropaleontology, v. 4, p. 25-38, pl. 1.

———, 1961, *Tertiary Foraminifera from the Oamuru district (N. Z.); Pt. 1 – Systematics and distribution:* New Zealand Geol. Survey Paleont. Bull. 34, 192 p., 28 pl.

———, 1965, Globigerina angiporoides *n. sp. from the Upper Eocene and Lower Oligocene of New Zealand and the status of* Globigerina angipora *Stache, 1865:* New Zealand Jour. Geology and Geophysics, v. 8, p. 834-838, 2 fig.

———, 1967, *New Zealand Tertiary microfossil zonation, correlation and climate:* Pacific Sci. Cong., 11th, Tokyo 1966, p. 29-39, 6 fig.

HOTTINGER, LUKAS, LEHMANN, ROGER, & SCHAUB, HANS, 1964, *Données actuelles sur la biostratigraphie du nummulitique méditerranéen:* [France] Bur. Recherches Géol. et Minières Mém. 28, p. 611-652, 6 pl.

HOWE, H. V., 1928, *An observation on the range of the genus* Hantkenina: Jour. Paleontology, v. 2, p. 13-14, 2 fig.

———, 1939, *Louisiana Cook Mountain Eocene Foraminifera:* Louisiana Geol. Survey Geol. Bull. 14, 122 p., 14 pl.

———, 1959, *Fifty years of micropaleontology:* Jour. Paleontology, v. 33, p. 511-517.

HOWE, H. V., & WALLACE, W. E., 1932, *Foraminifera of the Jackson Eocene at Danville Landing on the Ouachita, Catahoula Parish, Louisiana:* Louisiana Dept. Conservation Geol. Bull. 2, p. 18-79, pl. 1-15.

———, 1934, *Apertural characteristics of the genus* Hantkenina, *with description of a new species:* Jour. Paleontology, v. 8, p. 35-37, fig. 13-17, pl. 5.

HSU, K. J., & CITA, M. B., 1973, *The origin of the Mediterranean evaporite;* in Ryan, W. B. F., et al., Initial Repts. Deep Sea Drilling Project, v. 13, p. 1203-1231, 12 fig.

HUANG, TUNYOW, 1967, *Late Tertiary planktonic Foraminifera from southern Taiwan:* Tohoku Univ. Sci. Rept., ser. 2, v. 38, p. 165-192, 6 fig., pl. 15-16.

———, 1971, *Planktonic foraminifers from the Miyozaki Group, Kyushu, Japan:* Oceanogr. Sinica, v. 10, p. 7-23.

———, 1972, *Late Neogene foraminiferal zonation of* *southwestern Taiwan:* Internatl. Geol. Cong., 24th, Canada, Abstr., p. 537.

IACCARINO, SILVIA, 1967, *Les foraminifères du stratotype du Batianien (Pliocene inférieur) de Tabiano Bagni (Parme):* Soc. Italiana Sci. Nat. Milano Mem. 15, p. 165-180, 3 fig., 1 pl.

IKEBE, NOBUO, ET AL., 1972, *Neogene biostratigraphy and radiometric time scale of Japan; an attempt at intercontinental correlation:* Pacific Geology, v. 4, p. 39-78, 8 fig.

INGLE, J. C., JR., 1967, *Foraminiferal biofacies variation and the Miocene-Pliocene boundary in southern California:* Bulls. Am. Paleontology, v. 52, no. 236, p. 209-384, 43 fig., 43 pl.

ISRAELSKY, M. C., 1935, *Tentative foraminiferal zonation of subsurface Claiborne of Texas and Louisiana:* Am. Assoc. Petroleum Geologists Bull., v. 19, p. 689-695, 5 fig.

———, 1949, *Oscillation chart:* Am. Assoc. Petroleum Geologists Bull., v. 33, p. 92-98, 3 fig.

JEDLITSCHKA, HEINRICH, 1934, *Ueber* Candorbulina, *eine neue Foraminiferen-Gattung, und zwei neue* Candeina-*Arten:* Naturforsch. Ver. Brunn Verh., [Brno, Czechoslovakia], v. 65, p. 17-26, 23 fig.

JENKINS, D. G., 1960, *Planktonic Foraminifera from the Lakes Entrance oil shaft, Victoria, Australia:* Micropaleontology, v. 6, p. 345-371, 10 fig., 5 pl.

———, 1964a, *Panama and Trinidad Oligocene rocks:* Jour. Paleontology, v. 38, p. 606.

———, 1964b, *New Zealand Mid-Tertiary stratigraphical correlation:* Nature, v. 203, p. 181-182.

———, 1965a, *Planktonic Foraminifera and Tertiary intercontinental correlations:* Micropaleontology, v. 11, p. 265-277, 2 fig., 2 pl.

———, 1965b, *Planktonic foraminiferal zones and new taxa from the Danian to Lower Miocene of New Zealand:* New Zealand Jour. Geology and Geophysics, v. 8, p. 1088-1126, 16 fig.

———, 1966a, *Standard Cenozoic stratigraphic zonal scheme:* Nature, v. 211, p. 178.

———, 1966b, *Planktonic foraminiferal datum planes in the Pacific and Trinidad Tertiary:* New Zealand Jour. Geology and Geophysics, v. 9, p. 424-427, 2 fig.

———, 1971, *New Zealand Cenozoic planktonic Foraminifera:* New Zealand Geol. Survey Paleont. Bull. 42, 278 p., 2 fig., 23 pl.

JENKINS, D. G., & ORR, W. N., 1972, *Planktonic foraminiferal biostratigraphy of the east equatorial Pacific–DSDP Leg 9;* in Hays, J. D., et al., Initial Repts. Deep Sea Drilling Project, v. 9, p. 1059-1193, 9 fig., 41 pl.

KANE, JULIAN, 1953, *Temperature correlations of planktonic Foraminifera from the north Atlantic Ocean:* The Micropaleontologist, v. 7, no. 3, p. 25-49, 1 fig., 3 pl.

KANEPS, A. G., 1970, *Late Neogene biostratigraphy (planktonic Foraminifera), biogeography, and depositional history:* Columbia Univ., Ph.D. dissert. (University Microfilms).

———, 1973, *Cenozoic planktonic Foraminifera from the eastern equatorial Pacific Ocean;* in van Andel, T. H., et al., Initial Repts. Deep Sea Drilling Project, v. 16, p. 713-745, 6 fig.

KEIJZER, F. G., 1945, *Outline of the geology of the eastern part of the Province of Oriente, Cuba (E. of 76° W.L.), with notes on the geology of other parts of the island:* Utrecht Univ. Geogr. Geol. Meded., Physiogr.-geol. Reeks, ser. 2, no. 6, 238 p., 34 fig., 11 pl.

KENAWY, A. I., 1972, *Planktonic Foraminifera of the lower Tertiary succession in the Taramsa section, Qena, Nile valley, Egypt:* [Hungary] Fragm. Mineral. Paleontol., no. 3, p. 25-100, 20 pl.

KENNETT, J. P., 1966, *The* Globorotalia crassaformis *bioseries in north Westland and Marlborough, New Zealand:* Micropaleontology, v. 12, p. 235-245, 10 fig., 2 pl.

———, 1967, *Recognition and correlation of the Kapitean Stage (Upper Miocene, New Zealand):* New Zealand Jour. Geology and Geophysics, v. 10, p. 1051-1063, 1 fig.

———, 1968a, *Paleo-oceanographic aspects of the foraminiferal zonation in the Upper Miocene-Lower Pliocene of New Zealand:* Gior. Geologia, ser. 2, v. 35, no. 3, p. 143-156, 3 fig.

———, 1968b, Globorotalia truncatulinoides *as a paleo-oceanographic index:* Science, v. 159, p. 1461-1463, 2 fig.

———, 1970, *Pleistocene paleoclimates and foraminiferal biostratigraphy in subantarctic deep-sea cores:* Deep-Sea Research, v. 17, p. 124-140, 8 fig.

———, 1973, *Middle and late Cenozoic planktonic foraminiferal biostratigraphy of the southwest Pacific–DSDP Leg 21;* in Burns, R. E., et al., Initial Repts. Deep Sea Drilling Project, v. 21, p. 575-639, 12 fig., 21 pl.

KENNETT, J. P., & BRUNNER, C. A., 1973, *Antarctic late Cenozoic glaciation; evidence for initiation of ice rafting and inferred increased bottom-water activity:* Geol. Soc. America Bull., v. 84, p. 2043-2052, 5 fig.

KENNETT, J. P., & GEITZENAUER, K. R., 1969, *The Pliocene-Pleistocene boundary in a south Pacific deep-sea cores:* Nature, v. 224, p. 899.

KHALILOV, D. M., 1956, *O pelagicheskoi faune foraminifer paleogenovykh otlozhenii Azerbaydzhana [Pelagic foraminifers of the Paleogene deposits of Azerbaidzhan]:* Akad. Nauk Azerbaydzhan. SSR. Inst. Geol. Trudy, v. 17, p. 234-261, pl. 1-5.

KIERSTEAD, C. H., ET AL., 1969, *Neogene zonation of* *tropical Pacific cores:* Internatl. Conf. Planktonic Microfossils, 1st, Geneva 1967, Proc., v. 2, p. 328-338, 5 fig., 1 pl.

KING, KENNETH, & HARE, P. E., 1972, *Amino acid composition of planktonic Foraminifera; a paleobiochemical approach to evolution:* Science, v. 175, p. 1461-1463, 2 fig.

KLAUS, JEAN, 1961, *La répartition stratigraphique des Globotruncanides au Turonien et au Coniacien:* Eclogae Geol. Helvetiae, v. 53, p. 694-704, 1 fig.

KOCH, R. E., 1923, *Die jung-tertiäre Foraminiferenfauna von Kabu (Res. Surabaja, Java):* Eclogae Geol. Helvetiae, v. 18, p. 342-357, 11 fig.

———, 1926, *Mitteltertiäre Foraminiferen aus Bulongan, Ost-Borneo:* Eclogae Geol. Helvetiae, v. 19, p. 722-751.

———, 1935, *Namensaenderung einiger Tertiaer-Foraminiferen aus Niederlaendisch Ost-Indien:* Eclogae Geol. Helvetiae, v. 28, p. 557-558.

KRASHENINNIKOV, V. A., 1965a, *Zonalnaya stratigrafiya paleogenovykh otlozhenii [Zonal stratigraphy of Paleogene deposits]:* Internatl. Geol. Cong., 21st, Norden 1960, Doklady Soviet Geologists, Problem 16, Problemy stratigrafii Kainozoya [Problems of Cenozoic stratigraphy], Akad. Nauk SSSR Izd., Moscow, p. 37-61.

———1965b, *Zonalnaya stratigrafiya paleogena vostochnogo Sredizemnomoriya [Zonal stratigraphy of the Paleogene in the eastern Mediterranean]:* Akad. Nauk SSSR Geol. Inst. Trudy, no. 133, 76 p., 14 fig.

———, 1969, *Geograficheskoe i stratigraficheskoe raspredelenie planktonnykh foraminifer v otlozheniyakh paleogena tropicheskoi i subtropicheskoi oblastei [Geographical and stratigraphical distribution of planktonic foraminifers in Paleogene deposits of tropical and subtropical areas]:* Akad. Nauk SSSR Geol. Inst. Trudy, no. 202, 190 p.

———, 1971, *Stratigrafiya miotsenovykh otlozheny Sredizemnomorya po foraminiferam [Stratigraphy of the Miocene deposits of the Mediterranean based on foraminifers]:* Akad. Nauk SSSR Geol. Inst. Trudy, no. 220, 236 p., 50 fig.

———, 1973, *Stratigrafia miotsenovykh otlozhenii oblasti Allanticheskogo, Indiiskogo i Tikhogo okeanov po foraminiferam [Stratigraphy of Miocene deposits in the region of the Atlantic, Indian, and Pacific Oceans on the basis of foraminifers]:* Akad. Nauk SSSR Geol. Inst. Trudy, no. 233, 223 p., 38 fig.

KRASHENINNIKOV, V. A., & HOSKINS, R. H., 1973, *Late Cretaceous, Paleogene and Neogene planktonic foraminifers;* in Heezen, B. C., et al., Initial Repts. Deep Sea Drilling Project, v. 20, p. 105-203, pl. 35.

KUGLER, H. G., 1954, *The Miocene-Oligocene boundary in the Caribbean region:* Geol. Mag., v. 91, p. 410-413.

KULP, J. L., 1961, *Geological time scale:* Science, v. 133, p. 1105-1114, 1 fig.

KUNTZ, OTTO, 1895, *Sind Carbon-kohlen autochthon, allochthon oder pelagochthon?:* Geogenetische Beitr. [Leipzig, Gressner und Schramm], p. 42-77, 12 fig.

LALICKER, C. G., 1948, *A new genus of Foraminifera from the Upper Cretaceous:* Jour. Paleontology, v. 22, p. 624, pl. 92.

LAMB, J. L., 1969, *Planktonic foraminiferal datums and late Neogene epoch boundaries in the Mediterranean, Caribbean, and Gulf of Mexico:* Gulf Coast Assoc. Geol. Socs. Trans., v. 19, p. 559-578, 8 fig., 3 pl.

———, 1970, *Demonstration of overturned structure beneath the Quiriquire oil field, Venezuela:* Asoc. Venezolana Geología, Minería y Petróleo Bol. Inf., v. 13, p. 186-198, 8 fig.

LAMB, J. L., & BEARD, J. H., 1972, *Late Neogene planktonic foraminifers in the Caribbean, Gulf of Mexico, and Italian stratotypes:* Kansas Univ. Paleont. Contr., Art. 57 (Protozoa 8), 67 p., 25 fig., 36 pl.

LAMB, J. L., & DE SISTO, JOHN, 1963, *The Morichito Formation of northern Monagas:* Asoc. Venezolana Geología, Minería y Petróleo Bol. Inf., v. 6, p. 269-276, 5 fig.

LAMB, J. L., & SULEK, J. A., 1968 [1969], *Miocene turbidites in the Carapita Formation of eastern Venezuela:* Caribbean Geol. Conf., 4th, Trinidad 1965, Trans., p. 111-119, 9 fig.

LEHMANN, ROGER, 1966, *Les foraminifères pélagiques du Crétacé du Bassin Côtier de Tarfaya:* Maroc Service Géol. Notes et Mém., v. 175, p. 153-176, 2 fig., 2 pl.

LEONOV, G. P., & ALIMARINA, V. P., 1961, *Stratigrafiya i planktonnye foraminifery "perekhodnykh" ot mela k paleogenu sloev tsentralnovo predkavkasya [Stratigraphy and planktonic foraminifers of the "transitional" Cretaceous to Paleogene beds of the central Precaucasus]:* Moskov. Univ. Trudov Geol. Fak. Sbornik (k 21 sessii mezhdunarod. geol. kongr.), Moskov. Univ. Izd., p. 29-53, 5 pl.

LEROY, L. W., 1939, *Some small Foraminifera, Ostracoda and otoliths from the Neogene ("Miocene") of the Rokan-Tapanoeli area, central Sumatra:* Natuurk. Tijdschr. Nederl.-Indië, v. 99, no. 6, p. 215-296, pl. 1-14.

———, 1941, *Small Foraminifera from the late Tertiary of the Nederlands East Indies:* Colorado School Mines Quart., v. 36, no. 1, 132 p., 12 fig., 13 pl.

———, 1944, *Miocene Foraminifera from Sumatra and Java, Netherlands East Indies:* Colorado School Mines Quart., v. 39, no. 3, pt. 1, p. 9-69, pl. 1-8.

———, 1948, *The foraminifer* Orbulina universa *d'Orbigny, a suggested middle Tertiary time indicator:* Jour. Paleontology, v. 22, p. 500-508, 4 fig.

———, 1952, Orbulina universa *d'Orbigny in central Sumatra:* Jour. Paleontology, v. 26, p. 576-584, 4 fig.

LIDZ, BARBARA, 1972, Globorotalia crassaformis *morphotype variations in Atlantic and Caribbean deep-sea* *cores:* Micropaleontology, v. 18, p. 194-211, 7 pl.

LINDENBERG, H. G., 1969, *Statistical notes on the variability of* Globigerina eocaena *Gümbel, 1868, from the Paleogene of the Bavarian Alps:* Internatl. Conf. Planktonic Microfossils, 1st, Geneva 1967, Proc., v. 2, p. 343-365, 11 fig.

LIPPS, J. H., 1964, *Miocene planktonic Foraminifera from Newport Bay, California:* Tulane Studies Geology and Paleontology, v. 2, p. 109-133, 3 pl.

______, 1965, *Oligocene in California?:* Nature, v. 208, p. 885-886.

______, 1966, *Wall structure, systematics and phylogeny of Cenozoic planktonic Foraminifera:* Jour. Paleontology, v. 40, p. 1257-1274.

______, 1967, *Planktonic Foraminifera, intercontinental correlation and age of California mid-Cenozoic microfaunal stages:* Jour. Paleontology, v. 41, p. 994-999.

______, 1969, *Tertiary plankton from the Clipperton Fracture Zone, equatorial east Pacific:* Geol. Soc. America Bull., v. 80, p. 1801-1808.

LIVERSIDGE, A., 1877, *On the occurrence of chalk in the New Britain Group:* Geol. Mag., dec. 2, v. 14, p. 85-91.

LOEBLICH, A. R., JR., 1951, *Coiling in the Heterohelicidae:* Cushman Found. Foram. Research Contr., v. 2, p. 106-110, 2 fig.

LOEBLICH, A. R., JR., & TAPPAN, HELEN, 1956, Chiloguembelina, *a new Tertiary genus of the Heterohelicidae (Foraminifera):* Washington Acad. Sci. Jour., v. 46, p. 340.

______, 1957a, *Planktonic Foraminifera of Paleocene and early Eocene age from the Gulf and Atlantic coastal plains:* U.S. Natl. Museum Bull. 215, p. 173-198, fig. 27-28, pl. 40-64.

______, 1957b, *The new planktonic foraminiferal genus* Tinophodella, *and an emendation of* Globigerinita *Brönnimann:* Washington Acad. Sci. Jour., v. 47, p. 112-116, 1 pl.

______, 1957c, Woodringina, *a new foraminiferal genus (Heterohelicidae) from the Paleocene of Alabama:* Washington Acad. Sci. Jour., v. 47, p. 39-40, 1 fig.

______, 1961, *The genera* Microaulopora *Kuntz, 1895,* and Guembelina *Kuntz, 1895, and the status of* Guembelina *Egger, 1899:* Jour. Paleontology, v. 35, p. 625-627, 1 fig.

______, 1964, *Sarcodina, chiefly "Thecamoebians" and Foraminiferida;* in Moore, R. C. (ed.), Treatise on invertebrate paleontology: Protista 2, pt. C, v. 1, p. C1-C510, fig. 1-399; v. 2, p. C511-C900, fig. 400-653.

LONA, FAUSTO, 1971, *Correlazioni fra alcune sequenze micropaleobotaniche plio-pleistoceniche continentali e marine dell'Italia centro-settentrionale e Europa centro-occidentale, con riferimento al limite Tiberiano:* Acta Naturalia L'Ateneo Parmense, v. 7, p. 145-157, 1 fig.

LONA, FAUSTO, & BERTOLDI, REMO, 1972, *Rinvenimento* di Arctica (Cyprina) islandica *in una serie continua plio-pleistocenica presso Castell' Arquato (Piacenza) in connessione con sequenze pollinologiche:* Acta Naturalia L'Ateneo Parmense, v. 8, p. 35-44, 6 fig.

______, 1973, *La storia del Plio-Pleistocene Italiano in alcune sequenze vegetazionali lacustri e marine:* Accad. Naz. Lincei Atti, Cl. Sci. Fis., Mat. e Nat. Mem., ser. 8, v. 11, p. 1-45, 18 fig., 13 pl.

LONA, FAUSTO, BERTOLDI, REMO, & RICCIARDI, E., 1971, *Synchronization of outstanding stages of some Italian Upper Pliocene and Lower Pleistocene sequences, especially by means of palynological researches:* Cong. Neogene Mediterraneen, 5th., Lyon, 1971, Sec. Paleobotanique [Univ. Parma Inst. Botanico], 9 p., 5 fig.

LUTERBACHER, HANSPETER, 1964, *Studies in some* Globorotalia *from the Paleocene and Lower Eocene of the central Apennines:* Eclogae Geol. Helvetiae, v. 57, p. 631-730, 132 fig.

______, 1966, *K razvitiyu nekotorykh globorotalii v paleotsene tsentralnykh Apennin [Remarks on evolution of some globorotalias in the Paleocene of the central Apennines]:* Akad. Nauk SSSR Voprosy Mikropaleontologii, v. 10, p. 334-341, 4 fig., 3 pl.

______,1969, *Remarques sur la position stratigraphique de la formation d'Ager (Pyrenees meridionales):* [France] Bur. Recherches Geol. et Minieres Mem. 69, p. 225-232.

LUTERBACHER, HANSPETER, & PREMOLI SILVA, ISABELLA, 1964, *Biostratigrafia del limite Cretaceo-Terziario nell'Appennino centrale:* Riv. Italiana Paleontologia e Stratigrafia, v. 70, p. 67-128, 3 fig., 5 pl.

LYELL, CHARLES, 1839, *Nouveaux éléments de géologie:* Paris, Pitois Levrault, 648 p.

MALMGREN, B. A., 1972, *Morphometric studies of* Globorotalia pseudobulloides: Stockholm Contr. Geology, v. 24, p. 33-49, 4 fig.

MARCHETTI, D. B., 1968, *Vegetational features in sediments of Messinian "Formazione gessoso-solifera" in Emilia and Sicily (Italy) and paleoclimatic problems:* Internatl. Geol. Cong., 23rd Czechoslovakia, Abstr., p. 271.

MARGOLIS, S. V., & KENNETT, J. P., 1971, *Cenozoic paleoglacial history of Antarctica recorded in subantarctic deep-sea cores:* Am. Jour. Sci., v. 271, p. 1-36, 9 fig.

MARKS, PETER, 1951, *A revision of the smaller Foraminifera from the Miocene of the Vienna Basin:* Cushman Found. Foram. Research Contr., v. 2, p. 33-73, pl. 5-8.

MARTIN, L. T., 1943, *Eocene Foraminifera from the type Lodo Formation, Fresno County, California:* Stanford Univ. Pubs. Geol. Sci., v. 3, p. 93-125, pl. 5-9.

MARTINI, ERLEND, 1971, *Standard Tertiary and Quaternary calcareous nannoplankton zonation:* Internatl.

Conf. Planktonic Microfossils, 2nd, Rome 1970, Proc., v. 2, p. 739-785, 4 pl.

MCGOWRAN, BRIAN, 1964, *Foraminiferal evidence for the Paleocene age of the King's Park Shale (Perth basin, Western Australia):* Royal Soc. Western Australia Jour., v. 47, p. 81-88, 1 pl.

———, 1968, *Reclassification of Early Tertiary* Globorotalia: Micropaleontology, v. 14, p. 179-198, 3 fig., 4 pl.

MCTAVISH, R. A., 1966, *Planktonic Foraminifera from the Malaiba Group, British Solomon Islands:* Micropaleontology, v. 12, p. 1-36, 6 fig., 7 pl.

MELVILLE, R. V., 1970, *Types in the species-group:* Bull. Zool. Nomenclature, v. 27, p. 194-197.

MENNER, V. V., & KRASHENINNIKOV, V. A., 1970, *Contributions towards a stratigraphic scale for the ECAFE region:* United Nations ECAFE Mineral Resources Devel. Ser. 36, p. 19-25.

MOHAN, MADAN, & SOODAN, K. S., 1967, Inordinatosphaera – *a new genus of Globigerinidae:* Geol. Soc. India Bull., v. 4, p. 22-25, 1 fig.

———, 1970, *Middle Eocene planktonic foraminiferal zonation of Kutch, India:* Micropaleontology, v. 16, p. 37-46, 3 fig., 2 pl.

MONTANARO GALLITELLI, EUGENIA, 1957, *A revision of the foraminiferal family Heterohelicidae;* U.S. Natl. Museum Bull. 215, p. 133-154, pl. 31-34.

MOORE, R. C., & THOMPSON, M. L., 1949, *Main divisions of Pennsylvanian Period and System:* Am. Assoc. Petroleum Geologists Bull., v. 33, p. 275-302, 2 fig.

MOORE, T. C., JR., 1972, *DSDP; Successes, failures, proposals:* Geotimes, v. 17, no. 7, p. 27-31, 9 fig.

MOROZOVA, V. G., 1939, *K stratigrafii verkhnego mela i paleogena Embenskoi oblasti po faune foraminifer [On the stratigraphy of the Upper Cretaceous and Paleogene of the Emba region according to the foraminiferal faunas]:* Moskov. Obshch. Ispytateley Prirody Byull., Otdel. Geol., v. 17, nos. 4-5, p. 59-86, pl. 1-2.

———, 1957, *Nadsemeistvo foraminifer Globigerinidea superfam. nova i nekotorye ego predstaviteli [Foraminiferal superfamily Globigerinidea, superfam. nov., and some of its representatives]:* Akad. Nauk SSSR Doklady, v. 114, p. 1109-1111, 1 fig.

———, 1959, *Stratigrafiya datsko-montskikh otlozhenii Kryma po foraminiferam [Stratigraphy of the Dano-Montian deposits of Crimea according to the foraminifers]:* Akad. Nauk SSSR Doklady, v. 124, p. 1113-1116, 1 fig.

———, 1960, *Zonalnaya stratigrafiya datsko-montskikh otlozhenii SSSR i granitsa mela i paleogenom [Zonal stratigraphy of the Dano-Montian deposits of the USSR and the Cretaceous-Paleogene boundary]:* Internatl. Geol. Cong. 21st., Norden, 1960, Doklady Soviet Geologists, Problem 5, Granitsa melovykh i tretichnykh otlozhenii [The Cretaceous-Tertiary boundary], Akad. Nauk SSSR Izd., Moscow, p. 83-100.

———, 1961, *Datsko-montskie planktonnye foraminifery yugo SSSR. [Planktonic foraminifers from the Danian-Montian of the southern Soviet Union]:* Paleont. Zhur. no. 2, p. 8-19, pl. 1-2.

MURRAY, J. W., 1971 [1972], *An atlas of British Recent foraminiferids:* New York, Am. Elsevier Pub. Co., 244 p., 2 fig., 96 pl.

MYATLIUK, E. V., 1950, *Stratigrafiya flishevykh osadkov severnykh Karpat v cveta dannykh fauny foraminifer [The stratigraphy of the flysch deposits of the northern Carpathian Mountains according to the foraminiferal faunas]:* Vses. Neft. Nauchno-Issled. Geol.-Razved. Inst. Trudy, n. ser., v. 51 [Mikrofauna SSSR, sb. 4], p. 225-287, 4 pl.

NAPOLI ALLIATA, ENRICO DI, 1953, *Microfaune della parte superiore della serie oligocenica del Monte San Vito e del Rio Mazzapiedi-Castellania (Tortona-Alessandria):* Riv. Italiana Paleontologia e Stratigrafia, Mem. 6, p. 25-98, 6 pl.

NICORA, ALDA, 1971, *Biostratigrafia del limite Oligocene-Miocene nelle Langhe (Piemonte):* Riv. Italiana Paleontologia e Stratigrafia, v. 77, p. 157-262, 7 fig., pl. 7-18.

NOGUTI, ISAO, & SANTOS, J. F. DOS, 1972, *Zoneamento preliminar por foraminíferos planctônicos do aptiano ao mioceano na plataforma continental do Brazil:* Bol. Téc. Petrobrás, v. 15, p. 265-283, 9 fig.

NØRVANG, AKSEL [AXEL], 1945, *The zoology of Iceland, Foraminifera:* Copenhagen & Reykjavík, Ejnar Munksgaard, v. 2, pt. 2, 79 p., 14 fig.

———, 1958 [1959], Islandiella *n. g. and* Cassidulina *d'Orbigny:* Dansk Naturhist. Fören. Vidensk. Medd., v. 120, p. 25-41, pl. 6-9.

NUTTALL, W. L. F., 1930, *Eocene Foraminifera from Mexico:* Jour. Paleontology, v. 4, p. 271-293, pl. 23-25.

———, 1932, *Lower Oligocene Foraminifera from Mexico:* Jour. Paleontology, v. 6, p. 3-35, pl. 1-9.

OBA, TADAMICHI, 1972, *$^{18}O/^{16}O$ paleotemperatures:* Tohoku Univ. Inst. Geology Paleontology Prof. Jun-ichi Iwai Mem. v., p. 139-145.

OGNIBEN, LUIGI, 1958, *Stratigrafie e microfaune del Terzierio della zona di Caiazzo (Caserta);6–Descrizione paleontologiche:* Riv. Italiana Paleontologia e Stratigrafia, v. 65, p. 199-286, pl. 8-15.

OLSSON, R. K., 1964, Praeorbulina *Olsson, a new foraminiferal genus:* Jour. Paleontology, v. 38, p. 770-771.

———, 1971, *Pliocene-Pleistocene planktonic foraminiferal biostratigraphy of the northeastern Pacific:* Internatl. Conf. Planktonic Microfossils, 2nd, Rome 1970, Proc., p. 921-928, 2 fig., 2 pl.

OLSSON, R. K., 1972, *Growth changes in the* Globorotalia fohsi *lineage:* Eclogae Geol. Helvetiae, v. 65, p. 165-184, 13 fig.

______, 1973, *What is a kummerform planktonic foraminifer?:* Jour. Paleontology, v. 47, p. 327-329, 2 fig.

OPDYKE, N. D., 1972, *Magnetic stratigraphy and correlation of upper Miocene through the Recent and the age of the Miocene/Pliocene and Pliocene/Pleistocene boundary:* Internatl. Geol. Cong., 24th, Canada, Abstr., p. 539-540.

OPDYKE, N. D., ET AL., 1966, *Paleomagnetic study of Antarctic deep-sea cores:* Science, v. 154, p. 349-357, 7 fig.

PALMER, D. K., 1941, *Foraminifera of the Upper Oligocene Cojimar Formation of Cuba:* Soc. Cubana Historia Nat. Mem., v. 15, p. 281-306, 1 fig., pl. 28-31. [Last of five parts.]

______, 1945, *Notes on the Foraminifera from Bowden, Jamaica:* Bulls. Am. Paleontology, v. 29, no. 115, p. 5-82, 2 pl.

PALMER, D. K., & BERMÚDEZ, P. J., 1936, *An Oligocene foraminiferal fauna from Cuba:* Soc. Cubana Historia Nat. Mem., v. 10, p. 227-316, pl. 13-20.

PARETO, M., 1865, *Note sur les subdivisions que l'on pourrait établir dans les terrains tertiaires de l'Appenin septentrional:* Soc. Géol. France Bull., ser. 2, v. 22, p. 210-277.

PARKER, F. L., 1962, *Planktonic foraminiferal species in Pacific sediments:* Micropaleontology, v. 8, p. 219-254, 10 pl.

______, 1964, *Foraminifera from the experimental Mohole drilling near Guadalupe Island, Mexico:* Jour. Paleontology, v. 38, p. 617-636, pl. 97-102.

______, 1965, *A new planktonic species (Foraminiferida) from the Pliocene of Pacific deep-sea cores:* Cushman Found. Foram. Research Contr., v. 16, p. 151-152, 6 fig.

______, 1967, *Late Tertiary biostratigraphy (planktonic Foraminifera) of tropical Indo-Pacific deep-sea cores:* Bulls. Am. Paleontology, v. 52, no. 235, p. 115-208, 5 fig., pl. 17-32.

______, 1971, *Distribution of planktonic Foraminifera in Recent deep-sea sediments;* in Funnell, B. M., & Riedel, W. R. (eds.), The micropalaeontology of oceans: Cambridge, Cambridge Univ. Press, p. 289-307, 10 fig.

______, 1973, *Late Cenozoic biostratigraphy (planktonic Foraminifera) of tropical Atlantic deep-sea sections:* Rev. Española Micropaleontologiá, v. 5, p. 253-289, 4 fig., 3 pl.

PARKER, F. L., & BERGER, W. H., 1971, *Faunal and solution patterns of planktonic Foraminifera in surface sediments of the south Pacific:* Deep-Sea Research, v. 18, p. 73-107, 16 fig.

PARKER, W. K., & JONES, T. R., 1865, *On some Foraminifera from the North Atlantic and Arctic Oceans, including Davis Straits and Baffin's Bay:* Royal Soc. London Philos. Trans., v. 155, p. 325-441, pl. 12-19.

______, 1872, *On the nomenclature of the Foraminifera, pt. 15; the species figured by Ehrenberg:* Annals & Mag. Nat. History, ser. 4, v. 10, p. 184-200.

PARKER, W. K., JONES, T. R., & BRADY, H. B., 1865, *On the nomenclature of the Foraminifera; pt. 10 (cont.)–The species enumerated by d'Orbigny in the "Annales des Sciences Naturelles":* Annals & Mag. Nat. History, ser. 3, v. 16, no. 91, p. 15-41, pl. 1-3.

PARR, W. J., 1938, *Upper Eocene Foraminifera from the deep borings in King's Park, Perth, Western Australia:* Royal Soc. Western Australia Jour., v. 24, p. 69-101.

______, 1947, *An Australian record of the foraminiferal genus* Hantkenina: Royal Soc. Victoria Proc., n. ser., v. 58, p. 45-47, 7 fig.

PERCONIG, ENRICO, 1968, *Nuove specie di foraminiferi planctonici della sezione di Carmona (Andalusia, Spagna):* Gior. Geologia, v. 35, p. 219-228, 1 fig, pl. 6-7.

______, 1971, *Andalusian;* in Carloni, G. C., et al. (eds.), Stratotypes of Mediterranean Stages: Gior. Geologia, ser. 2, v. 37, pt. 2, p. 13-21, 1 fig.

PERCONIG, ENRICO, & GRANADOS, L. F., 1973, *El estratotipo del Andaluciense:* Guía el XIII Coloquio Europea de Micropaleontología, España, p. 225-246, 10 fig.

PESSAGNO, E. A., 1963, *Planktonic Foraminifera from the Juana Diaz Formation, Puerto Rico:* Micropaleontology, v. 9, p. 53-60, 3 pl.

______, 1969, *Upper Cretaceous stratigraphy of the western Gulf of Mexico area of Mexico, Texas and Arkansas:* Geol. Soc. America Mem. 111, 139 p., 60 fig.

PETERSON, M. N. A., 1966, *Calcite, rates of dissolution in a vertical profile in the central Pacific:* Science, v. 140, p. 1542-1544.

PETRI, SETEMBRINO, 1954, *Foraminíferos fósseis da Bacia do Marajó:* São Paolo Univ. Bol., v. 176 (Geol. no. 11), 173 p., 10 fig., 14 pl.

PEZZANI, FRANCA, 1963, *Studio micropaleontologico di un campione della serie messiniana di Tabiano Bagni (Parma):* Riv. Italiana Paleontologia e Stratigrafia, v. 69, p. 559-662, 4 fig., 10 pl.

PHILLIPS, J. D., ET AL., 1968, *Paleomagnetic stratigraphy and micropaleontology of three deep-sea cores from the central north Atlantic Ocean:* Earth and Planetary Sci. Letters, v. 4, p. 118-130, 5 fig.

PHLEGER, F. B., 1960, *Ecology and distribution of Recent Foraminifera:* Baltimore, Johns Hopkins Press, 297 p., 83 fig., 11 pl.

PHLEGER, F. B., PARKER, F. L., & PEIRSON, J. F., 1953, *North Atlantic Foraminifera:* Swedish Deep-Sea Expedition Repts., v. 7 (Atlantic Ocean), no. 1, p. 3-122, pl. 1-12.

PIJPERS, P. J., 1933, *Geology and paleontology of Bonaire (D. W. I.):* Utrecht Univ. Geog. Geol. Mededeel. Physiog.-Geol. Reeks, no. 8, 103 p., 2 pl.

PLUMMER, H. J., 1926 [1927], *Foraminifera of the Midway formation in Texas:* Texas Univ. Bur. Econ. Geology Bull. 2644, 206 p., 13 fig., 15 pl.

POAG, C. W., 1972a, *Planktonic foraminifers of the Chickasawhay Formation, United States Gulf Coast:* Micropaleontology, v. 18, p. 257-277, 5 fig., 1 pl.

———, 1972b, *Neogene planktonic foraminiferal biostratigraphy of the western north Atlantic, DSDP Leg 11;* in Hollister, C. D., et al., Initial Repts. Deep Sea Drilling Project, v. 11, p. 483-543, 8 fig., 11 pl.

POAG, C. W., & AKERS, W. H., 1967, Globigerina nepenthes *Todd of Pliocene age from the Gulf Coast:* Cushman Found. Foram. Research Contr., v. 18, p. 168-175, 2 pl.

POKORNÝ, VALDIMIŔ, 1955, Cassigerinella boudecensis *n. gen., n. sp. (Foraminifera, Protozoa) from the Oligocene of the Zdanice Flysch:* Ustred. Ustav. Geol. Vestnik, v. 30, p. 136-140, 3 fig.

———, 1958, *Grundzüge der zoologischen Mikropalaeontologie:* Berlin, VEB Deutsch. Verlag. Wiss., v. 1, 582 p., 549 fig.

POMEROL, CHARLES, 1964, *Le Bartonien du bassin de Paris, interprétation stratigraphique et essai de corrélation avec les bassins de Belgique et du Hampshire:* [France] Bur. Recherches Géol. et Minières Mém. 28, p. 153-168, 2 fig.

———, 1969a (ed.), *Colloque sur l'Eocène, Paris, mai 1968:* [France] Bur. Recherches Géol. et Minières Mém. 69, 473 p., illus.

———, 1969b, *Rapport sur la limite Paléocène-Eocène:* [France] Bur. Recherches Géol. et Minières Mém. 69, p. 447-449.

POPESCU, GH. C., 1969, *Some new* Globigerina *(Foraminifera) from the Upper Tortonian of the Transylvanian basin and the Subcarpathians:* Rev. Roumaine Géologie, Géophysique et Géographie, Sér. Géologie, v. 13, p. 103-106, 2 pl.

POSTUMA, J. A., 1971, *Manual of planktonic Foraminifera:* Amsterdam, Elsevier Publishing Co., 420 p., illus.

PREMOLI SILVA, ISABELLA, 1970, *Cretaceous-Ecoene microfaunas of western Badakhshan and Kataghan (north-eastern Afghanistan):* Italian Exped. Karakorum (K^2) and Hindu Kush, Sci. Repts., sec. 4, v. 2, p. 119-160, pl. 17-25.

PROTO DECIMA, FRANCA, & BOLLI, H. M., 1970, *Evolution and variability of* Orbulinoides beckmanni *(Saito):* Eclogae Geol. Helvetiae, v. 63, p. 883-905, 51 fig., 4 pl.

PUJOL, CLAUDE, 1970, *Contribution à l'étude des foraminifères planctoniques néogènes dans le bassin Aquitain:* Inst. Géologie Bassin d'Aquitaine Bull. 9, p. 201-219, 4 fig.

REISS, ZEEV, 1957a, *Stratigraphical distribution of some Mesozoic and Cainozoic Foraminifera from Israel:* Israel Geol. Survey, Notes on Foraminifera from Israel 6, 5 p.

———, 1957b, *Remarks on* Truncorotalia caucasica *(Glaessner):* Israel Research Council Bull. 6B, p. 239-241.

———, 1963, *Reclassification of perforate Foraminifera:* Israel Geol. Survey Bull. 35, 111 p., 8 pl.

REISS, ZEEV, & GVIRTZMAN, G., 1966, *Subsurface Neogene stratigraphy of Israel:* Comm. Mediterranean Neogene Stratigraphy, 3rd Sess., Berne 1964, Proc., p. 310-346, 5 fig., 12 pl.

RENZ, H. H., 1948, *Stratigraphy and fauna of the Agua Salada group, State of Falcon Venezuela:* Geol. Soc. America Mem. 32, 219 p., 12 pl.

———, 1962, *Stratigraphy and paleontology of the type section of the Santa Anita Group and the overlying Merecure Group, Rio Ouerecual, State of Augoátegui, northeastern Venezuela:* Asoc. Venezolana Geología, Minería y Petróleo, Bol. Inf., v. 5, p. 89-108, 2 fig., 1 pl.

RENZ, OTTO, 1936, *Stratigraphische und mikropaläontologische Untersuchung der Scaglia (Ober-Kreide-Tertiär) im zentralen Apennin:* Eclogae Geol. Helvetiae, v. 29, p. 1-149, 14 fig., 15 pl.

REUSS, A. E., 1850, *Neues Foraminiferen aus den Schichten des Osterreichischen Tertiärbeckens:* Akad. Wiss. Wien Denkschr., Math.-Nat. Kl., v. 1, p. 365-390, pl. 46-51.

RHUMBLER, LUDWIG, 1901, *Foraminiferen,* in Brandt, Karl, Nordische Plankton: Kiel, Lipsius und Tischer, Lief. 1, no. 14, 32 p., 33 fig.

———, 1911, *Die Foraminiferen (Thalamophoren) de Plankton-Expedition; Teil I-Die allgemeinen Organisationsverhältnisse der Foraminiferen:* Plankton-Exped. der Humboldt-Stiftung Ergebnisse, v. 3, p. 1-331, fig. 1-110, pl. 1-39. [See also Wetzel, 1949.]

RIEDEL, W. R., 1957, *Radiolaria; a preliminary stratigraphy:* Swedish Deep-Sea Expedition (1947-1948) Rept., v. 7, no. 3, p. 61-94, 4 pl.

———, 1971, *Radiolarians from Atlantic deep-sea drilling:* Internatl. Conf. Planktonic Microfossils, 2nd, Rome 1970, Proc., v. 2, p. 1057-1068, 8 fig.

———, 1973, *Cenozoic planktonic micropaleontology and biostratigraphy:* Annual Rev. Earth and Planetary Sciences, v. 1, p. 241-268.

RIEDEL, W. R., PARKER, F. L., & BRAMLETTE, N. M., 1963, *'Pliocene-Pleistocene' boundary in deep-sea sediments:* Science, v. 140, p. 1238-1240, 1 fig.

ROBINSON, EDWARD, 1969, *Geological field guide to Neogene sections in Jamaica, West Indies:* Gulf Coast

Assoc. Geol. Socs.–Soc. Econ. Mineralogists and Paleontologists, Jamaican field trip (November 1969), 24 p., 5 fig.

ROBINSON, EDWARD, & LAMB, J. L., 1970, *Preliminary palaeomagnetic data from the Plio-Pleistocene of Jamaica:* Nature, v. 227, p. 1236-1237, 2 fig.

ROSENKRANTZ, ALFRED, & BROTZEN, FRITZ (eds.), 1960, *The Cretaceous-Tertiary boundary:* Internatl. Geol. Cong., 21st, Norden 1960, Proc., pt. 5, 215 p., illus.

ROTH, P. H., 1970, *Oligocene calcareous nannoplankton biostratigraphy:* Eclogae Geol. Helvetiae, v. 63, p. 799-881, 17 fig., 14 pl.

RUDDIMAN, W. F., 1971, *Pleistocene sedimentation in the equatorial Atlantic; stratigraphy and faunal paleoclimatology:* Geol. Soc. America Bull., v. 82, p. 283-302, 14 fig.

SAIDOVA, KH. M., 1970, *Planktonnye foraminifery izraiona Kurile-Kamchatckogo Zheloba [Planktonic foraminifers from the Kurile-Kamchatka region]:* Akad. Nauk SSSR Inst. Okeanologii Trudy, v. 86, p. 162-164, 2 fig.

SAITO, TSUNEMASA, 1962, *Eocene planktonic Foraminifera from Hahajima (Hillsborough Island):* Palaeont. Soc. Japan Trans. and Proc., n. ser., no. 45, p. 209-225, pl. 32-34.

———, 1963, *Miocene planktonic Foraminifera from Honshu, Japan:* Tohoku Univ. Sci. Repts., ser. 2, v. 35, p. 123-209, 15 fig., pl. 53-56.

———, 1972, *Late Neogene epoch boundaries in deep-sea sediments:* Internatl. Geol. Cong., 24th, Canada, Abstr., p. 540.

SAITO, TSUNEMASA, & BÉ, A. W. H., 1964, *Planktonic Foraminifera from the American Oligocene:* Science, v. 145, p. 702-705, 2 fig.

SAMANTA, B. K., 1969, *Eocene planktonic Foraminifera from the Garo Hills, Assam, India:* Micropaleontology, v. 15, p. 325-350, 2 fig., 3 pl.

———, 1970, *Middle Eocene planktonic Foraminifera from Lakhpat, Cutch, western India:* Micropaleontology, v. 16, p. 185-215, 3 fig., 3 pl.

SAMUEL, ONDREJ, 1972a, *New species of planktonic foraminifers from the Paleogene in the west Carpathians in Slovakia:* Ceskslovenska Akad. Ved. Zk. Sbornik Geol., no. 17, p. 217-221, 2 pl.

———, 1972b, *Phylogenesis of Paleogene planktonic Foraminifera:* Ceskslovenska Akad. Ved. Zk. Sbornik Geol., no. 17, p. 223-240, 20 pl.

SAMUEL, ONDREJ, & SALAJ, JOSEPH, 1968, *Microbiostratigraphy and Foraminifera of the Slovak Carpathian Paleogene:* Geologiska Ustav, Dionyza Stuza [Bratislava], 232 p., 31 pl.

SARJEANT, W. A. S., 1967, *The stratigraphical distribution of fossil dinoflagellates:* Rev. Palaeobotany and Palynology, v. 1, p. 323-343.

SAUNDERS, J. B., & CORDEY, W. G., 1968, *The biostratigraphy of the Oceanic Formation in the Bath Cliff section, Barbados:* Caribbean Geol. Conf., 4th, Trinidad 1965, Trans., p. 179-181, 2 fig.

SAVIN, S. M., & DOUGLAS, R. G., 1973, *Stable isotope and magnesium geochemistry of Recent planktonic Foraminifera from the south Pacific:* Geol. Soc. America Bull., v. 84, p. 2327-2342, 10 fig.

SCHIMPER, W. P., 1874, *Traité de paléontologie végétale, v. 3:* Paris, 896 p., illus.

SCHUBERT, R. J., 1910, *Über Foraminiferen und einen Fischotolithen aus dem fossilen Globigerinenschlamm von Neu-Guinea:* Geol. Reichsanst. Verh., Vienna, p. 318-328, 2 fig.

SCHWAGER, CONRAD, 1866, *Fossile Foraminiferen von Kar Nikobar:* Novara Exped. 1857-1859, Wien, v. 2, Geol. Theil, p. 187-268, pl. 4-7.

———, 1883, *Die Foraminiferen aus den Eocaen-Ablagerungen der Lybischen Wüste und Ägyptens:* Palaeontographica, v. 30, p. 79-154, pl. 24-29.

SCOTT, G. H., 1966-67, *Description of an experimental class within the Globigerinidae (Foraminifera):* New Zealand Jour. Geology and Geophysics, v. 9, p. 513-540 [1966]; v. 10, p. 55-73, 39 fig. [1967].

———, 1968a, *Comparison of the primary aperture of* Globigerinoides *from the lower Miocene of Trinidad and New Zealand:* New Zealand Jour. Geology and Geophysics, v. 11, p. 356-375, 18 fig.

———, 1968b, Globigerinoides *in the Aquitanian-Burdigalian of S. W. France:* Gior. Geologia, ser. 2, v. 35, p. 271-276, 3 fig.

———, 1968c, *Stratigraphic variation in* Globigerinoides trilobus trilobus *(Reuss) from the lower Miocene of Europe, Trinidad and New Zealand:* New Zealand Jour. Geology and Geophysics, v. 11, p. 391-404, 48 fig.

———, 1969, *Biometric study of lower Miocene* Globigerinoides *from New Zealand, Trinidad and Europe; a review:* Internatl. Conf. Planktonic Microfossils, 1st, Geneva 1967, Proc., v. 2, p. 603-610, 3 fig.

———, 1970, *Basal Miocene correlation;* Globigerinoides *from southern New Zealand:* Micropaleontology, v. 16, p. 385-398, 9 fig., 2 pl.

———, 1971, *Phyletic trees for trans-Atlantic lower Neogene* Globigerinoides: Rev. Española Micropaleontología, v. 3, p. 283-292, 2 fig., 2 pl.

———, 1972a, Globigerinoides *from Escornebéou (France) and the basal Miocene* Globigerinoides *datum:* New Zealand Jour. Geology and Geophysics, v. 15, p. 287-295, 12 fig.

———, 1972b, *The relationship between the Miocene Foraminiferida* Globorotalia miozea miozea *and* G. praemenardii: Micropaleontology, v. 18, p. 81-93, 11 fig., 2 pl.

SCOTT, G. H., 1973, Orbulina; *phylogénie et derniers stades de l'ontogénie:* Rev. Micropaléontologie, v. 16, p. 39-49, 5 fig., 1 pl.

SEIGLIE, G. A., 1973, *Revision of Mid-Tertiary stratigraphy of southwestern Puerto Rico:* Am. Assoc. Petroleum Geologists Bull., v. 57, p. 405-406.

SELLI, RAIMONDO, 1960, *Il messiniano Mayer-Eymar 1867; proposta di un neostratotipo:* Gior. Geologia, v. 28, p. 1-33.

———, 1971, *Messinien:* Gior. Geologia, ser. 2, v. 37, pt. 2, p. 121-133, fig. 23-24.

SENN, ALFRED, 1935, *Die stratigraphische Verbreitung der Tertiaren Orbitoididen:* Eclogae Geol. Helvetiae, v. 28, p. 51-113, 369-373, pl. 8-9.

SEROVA, M. YA., 1969, *Sredneeothenovye planktonnye foraminifery zapadnoi Kamchatki [Middle Eocene planktonic foraminifers of western Kamchatka]:* Akad. Nauk SSSR Voprosy Mikropaleontologii, no. 12, p. 145-167, 2 fig., 4 pl.

SHOKHINA, V. A., 1937, *O rode* Hantkenina *i ego stratigraficheskoe raspredelenie na Severnom Kavkaze [The genus* Hantkenina *and its stratigraphic distribution in the northern Caucasus]:* Moskov. Gos. Univ. Izd., Problemy Paleontologii, v. 2-3, p. 425-452, 2 pl.

SHUTSKAYA, E. K., 1956, *Stratigrafiya nizhnikh gorizontov paleogena tsentral'nogo pred-Kavkaz'ya po foraminiferam [Stratigraphy of the lower horizons of the Paleogene in the central Precaucasus according to the foraminifers]:* Akad. Nauk SSSR Geol. Inst. Trudy, v. 164 (geol. ser.), no. 70, p. 3-114, 4 pl.

———, 1958, *Izmenchivosti nekotorikh nighnepaleogenovikh planktonnikh foraminifer severnogo Kavkaza [Variations of some lower Paleogene planktonic foraminifers of the northern Caucasus]:* Akad. Nauk SSSR Voprosy Mikropaleontologii, v. 2, p. 84-90, pl. 1-3. [Translated to French in Questions de Micropaléontologie, B. R. G. M., Service d'Inf. Géol., 1960, p. 93-103, 1 fig., 3 pl.]

———, 1960a, *Stratigrafiya i fatsii nizhnego paleogena Predkavkazya [Stratigraphy and facies of the lower Paleogene of the Precaucasus]:* Gostoptekhizdat, Moscow, 104 p., 10 fig.

———, 1960b, *Stratigrafiya nizhnego paleogena severnogo Prekavkaza i Kryma [Stratigraphy of the lower Paleogene of the northern Precaucasus and Crimea]*, in Yanshin, A. L., et al. (eds.), Paleogenovye otlozhenii yuga evropeiskoi chasti SSSR [Paleogene of the southern European part of the USSR]: Akad. Nauk SSSR Izd., Moscow, p. 207-229.

———, 1962, *Foraminifery datskogo yarusa i paleotsena fatsii otkrytogo morya Kryma, Predkavkazya i Zakaspiya [Foraminifers of the Danian and Paleocene in open-marine facies of Crimea, the Precaucasus, and the Transcaspian region]:* Moskov. Obshch. Ispytateley Prirody Byull., Otdel. Geol., v. 37, p. 126-127.

SHUTSKAYA, E. K., 1965, *Filogeneticheskie vzaimootnosheniya vidov gruppy* Globorotalia compressa *Plummer v datskom vekhe i paleotzenovoi epokhe [Phylogenetic relations of the species of the* Globorotalia compressa *Plummer group in Danian time and the Paleocene epoch]:* Akad. Nauk SSSR Voprosy Mikropaleontologii, no. 9, p. 173-188, 5 fig., 1 pl.

SIGAL, JACQUES, 1967, *Essai sur l'état actuel d'une zonation stratigraphique à l'aide des principales espèces de rosalines (foraminifères):* Soc. Géol. France Compte Rendu, pt. 2, p. 48.

SINGH, S. N., 1971, *Planktonic Foraminifera in the Eocene stratigraphy of Rajasthan, India:* Internatl. Conf. Planktonic Microfossils, 2nd, Rome 1970, Proc., v. 2, p. 1169-1181, 2 fig., 1 pl.

SINGH, S. N., & KALIA, PRABHA, 1970a, *A new planktonic foraminifer from the Middle Eocene of India:* Micropaleontology, v. 16, p. 76-82, 4 fig., 2 pl.

———, 1970b, *A new planktonic foraminifer from the Laki (Ypresian) of Rajasthan, India:* Current Sci., v. 39, p. 355-356, 3 fig.

———, 1970c, Shastrina – *a new heterohelicid genus and new species of* Pseudogloborotalia *Haque and* Chiloguembelina *Loeblich and Tappan from Kirthars of Rajasthan, India:* Indian Acad. Sci. Proc., ser. B, v. 36, p. 166-174, 2 pl.

SMITH, L. A., 1969, *Pleistocene discoasters from the stratotype of the Calabrian Stage (Santa Maria di Catanzaro) and the section at Le Castella, Italy:* Gulf Coast Assoc. Geol. Socs. Trans., v. 19, p. 579-583, 3 fig.

SMITH, L. A., & BEARD, J. H., 1973, *The late Neogene of the Gulf of Mexico:* in Worzel, J. L., et al., Initial Repts. Deep Sea Drilling Project, v. 10, p. 643-677, 16 fig.

SOEDIONO, H., 1967, *In defense of the* Orbulina *Datum:* Geologie en Mijnbouw, v. 46, p. 363-368.

———, 1969, *Planktonic Foraminifera from the Vélez Rubio region, S. E. Spain; pt. 1–The Ciudad Granada Formation (Oligo-Miocene):* Rev. Española Micropaleontologia, v. 1, p. 335-353, 10 fig., 5 pl.

———, 1970, *Planktonic Foraminifera from the Vélez Rubio region, S. E. Spain; pt. 2–The Espejos Formation:* Rev. Española Micropaleontología, v. 2, p. 215-234, 3 fig., 5 pl.

SPRAUL, G. L., 1963, *Current status of the Upper Eocene foraminiferal guide fossil,* Cribrohantkenina: Jour. Paleontology, v. 37, p. 366-370, pl. 41.

SPROVIERI, RODOLFO, D'AGOSTINO, SALVATORE, & STEFANO, ENRICO DI, 1973, *Giacitura del Calabriano nei dintorni di Catanzaro:* Riv. Italiana Paleontologia e Stratigrafia, v. 79, p. 127-140, 4 fig.

SRINIVASAN, M. S., 1968, *Late Eocene and early Oligocene planktonic Foraminifera from Port Elizabeth and Cape Foulwind, New Zealand:* Cushman Found.

Foram. Research Contr., v. 19, p. 142-159, 6 fig., pl. 13-16.

SRINIVASAN, M. S., KENNETT, J. P., & BÉ, A. W. H., 1974, Globorotalia menardii neoflexuosa *new subspecies from the northern Indian Ocean:* Deep-Sea Research, v. 21, p. 321-324, 1 pl.

SRINIVASAN, M. S., & SRIVASTAVA, S. S., 1974, Sphaeroidinella dehiscens *datum and Miocene-Pliocene boundary:* Am. Assoc. Petroleum Geologists Bull., v. 58, p. 304-323, 11 fig.

STAINFORTH, R. M., 1948a, *Description, correlation and paleoecology of Tertiary Cipero marl formation, Trinidad, B. W. I.:* Am. Assoc. Petroleum Geologists Bull., v. 32, p. 1292-1330, 2 fig.

———, 1948b, *Applied micropaleontology in coastal Ecuador:* Jour. Paleontology, v. 22, p. 113-151, pl. 24-26.

———, 1954, *Comments on the Caribbean Oligocene:* Geol. Mag., v. 91, p. 175.

———, 1960, *Current status of transatlantic Oligo-Miocene correlation by means of planktonic Foraminifera:* Rev. Micropaléontologie, v. 2, p. 219-230.

———, 1971, *La Formación Carapita de Venezuela oriental:* Cong. Geol. Venezolano, 4°, Caracas 1969, Mem., v. 1, p. 433-463, 6 fig.

———, 1974, *Nomenclature of some large Eo-Oligocene Globigerinas:* Naturf. Gesell. Basel Verh., v. 84, p. 256-264, 1 fig., 2 pl.

STEINECK, P. L., 1971, *Middle Eocene refrigeration; new evidence from California planktonic foraminiferal assemblages:* Lethaia, v. 4, p. 125-129.

STOLK, J., 1965, *Contribution à l'étude des correlations microfauniques du Tertiaire inférieur de la Nigeria méridionale:* [France] Bur. Recherches Géol. et Minières Mém. 32, p. 247-275, 4 fig., 3 pl.

STONE, BENTON, 1946, Stichocassidulina, *a new genus of Foraminifera from northwestern Peru:* Jour. Paleontology, v. 20, p. 51-61, 2 fig.

STRADNER, HERBERT, 1973, *Catalogue of calcareous nannoplankton from sediments of Neogene age in the eastern North Atlantic and Mediterranean sea;* in Ryan, W. B. F., et al., Initial Repts. Deep Sea Drilling Project, v. 13, p. 1137-1199, 1 fig.

STUART, ALEXANDER, 1866, *Ueber* Coscinosphaera ciliosa *eine neue Radiolarie:* Zeitschr. Wiss. Zoologie, v. 16, p. 328-345, pl. 18.

SUBBOTINA, N. N., 1947, *Foraminifery datskikh i paleogenovikh otlozhenii severnogo Kavkaza [Foraminifers of the Danian and Paleogene deposits of the northern Caucasus]:* Mikrofauna Kavkaza, Emby i sryednei Azii [Microfauna of the Caucasus, Emba region, and central Asia], Vses. Neft. Nauchno-Issled. Geol.-Razved. Inst. Trudy, p. 39-160, 9 pl.

SUBBOTINA, N. N., 1949, *Mikrofauna melovykh otlozhenii yuzhnogo sklona Kavkaza [Microfauna of Cretaceous deposits of the southern slope of the Caucasus]:* Mikrofauna Neftyanikh Mestorozhdenii SSSR, sb. 2, Vses. Nauchno-Issled. Geol.-Razved. Inst. Trudy, n. ser., v. 34, p. 5-36, 16 fig., 2 pl.

———, 1950, *Mikrofauna i stratigrafiya Elburganskogo Gorizonta Gorizonta Goriatchego Klyutcha [Microfauna and stratigraphy of the Elburgan Horizon and the Horizon of Goriatchii Kliutch]:* Mikrofauna SSSR, sb. 4, Vses. Nauchno-Issled. Geol.-Razved. Inst. Trudy, n. ser., v. 51, p. 5-112, 20 fig., 5 pl.

———, 1953, *Iskopaemye foraminifery SSSR; Globigerinidae, Hantkeninidae i Globorotaliidae [Fossil foraminifers of the USSR; Globigerinidae, Hantkeninidae, and Globorotaliidae]:* Vses. Neft. Nauchno-Issled. Geol.-Razved. Inst. Trudy, n. ser., no. 76, 296 p., 8 fig., 41 pl.

———, 1960, *Pelagicheskie foraminifery paleogenovykh otlozhenii yuga SSSR [Pelagic foraminifers of the Paleogene of southern USSR];* in Yanshin, A. L., et al. (eds.), Paleogenovye otlozhenii yuga evropeiskoi chasti SSSR [The Paleogene of the southern European part of the USSR]: Akad. Nauk SSSR Izd., Moscow, p. 24-36, 4 fig.

———, 1971, *Fossil Foraminifera of the USSR Globigerinidae, Hantkeninidae and Globorotaliidae:* London and Wellingborough, Collet's Ltd., 321 p., 8 fig., 40 pl. [Translated by E. Lees from Russian text of 1953.]

———, 1972, *Ovidakh roda* Globigerapsis *iz eotsenovykh oltozhenii yuva SSSR [On species of the genus* Globigerapsis *in the Eocene deposits of the southern Soviet Union]:* Akad. Nauk SSSR Voprosy Mikropaleontologii, v. 15, p. 118-124, 3 pl.

SUBBOTINA, N. N., GLUSHKO, V. V., & PISHVANOVA, L. S., 1955, *O vozraste nizhney vorotyshchenskoy svity predkarpatskogo kraevogo progiba [On the age of the lower Vorotyshchensky beds of the Carpathian border trough]:* Akad. Nauk. SSSR Doklady, v. 104, p. 605-607.

SULC, JAROSLAV, 1929, *Příspevky k poznání morfologie foraminifer [Contribution to knowledge of foraminifer morphology]:* [Prague] Stát. Geol. Ustavu Ceskosl. Vestnik, v. 5, p. 148-155, pl. 1 (13).

SULEIMANOV, I. S., 1971, *Novyi predstavitel roda* Guembelitriella *Tappan, 1940 iz paleogena srednei Azii [New occurrence of the genus* Guembelitriella *Tappan, 1940 in central Asian Paleogene]:* Akad. Nauk Uzbek. SSR Doklady, Uzbek. SSR Fanlar Akad. Doklady, v. 6, p. 54-55.

TAKAYANAGI, YOKICHI, 1953, *New genus and species of Foraminifera found in the Tonohama Group, Kochi Prefecture, Shikoku, Japan:* Tohoku Univ. Inst. Geology and Paleontology Short Papers, no. 5, p. 25-36, pl. 4.

TAKAYANAGI, YOKICHI, & SAITO, TSUNEMASA, 1962, *Planktonic Foraminifera from the Nobori Formation, Shikoku, Japan:* Tohoku Univ. Sci. Repts., ser. 2 (Geol.), v. 5, p. 67-106, 2 fig., pl. 24-28.

TAPPAN, HELEN, 1940, *Foraminifera from the Grayson Formation of northern Texas:* Jour. Paleontology v. 14, p. 93-126, pl. 14-19.

TAYLOR, D. W., 1960, *Late Cenozoic molluscan faunas from the high plains:* U.S. Geol. Survey Prof. Paper 337, 94 p., 2 fig., 4 pl.

TEN DAM, ABRAHAM, & MAGNÉ, JEAN, 1948, *Les espèces du genre de foraminifères* Globorotalites *Brotzen:* Français Inst. Pétrole et Ann. Combustibles Liquides, v. 3, p. 222-228, 12 fig.

THALMANN, H. E., 1942, *Foraminiferal genus* Hantkenina *and its subgenera:* Am. Jour. Sci., v. 240, p. 809-820, 1 pl.

———, 1950, *New names and homonyms in Foraminifera:* Cushman Found. Foram. Research Contr., v. 1, p. 41-45.

———, 1951, *Mitteilungen ueber Foraminiferen IX.47; validation von* Globorotalia lobata *Bermúdez, 1949:* Eclogae Geol. Helvetiae, v. 43, p. 225.

THEYER, FRITZ, 1972, *Late Neogene paleomagnetic and planktonic zonation, southeast Indian Ocean-Tasman basin:* Univ. Southern California, unpub. Ph.D. dissert., 249 p., 5 pls.

———, 1973a, Globorotalia truncatulinoides *datum plane; evidence for a Gauss (Pliocene) age in subantarctic cores:* Nature, v. 241, p. 142-145, 3 fig.

———, 1973b, Globorotalia inflata triangula, *a new planktonic foraminiferal subspecies:* Jour. Foram. Research, v. 3, p. 199-201, 1 fig., 1 pl.

THOMPSON, P. R., 1973, *Two new late Pleistocene Foraminifera from a core in the southwest Indian Ocean:* Micropaleontology, v. 19, p. 469-474, 1 fig., 2 pl.

THOMSON, WYVILLE, 1876, *Comments;* in Murray, John, Preliminary reports to Professor Wyville Thomson, F.R.S., director of the civilian scientific staff, on work done aboard the "Challenger": Royal Soc. London Proc., v. 24, p. 534, pl. 22-23.

TILTON, G. R., & HART, S. R., 1963, *Geochronology:* Science, v. 140, p. 357-366, 9 fig.

TJALSMA, R. C., & WONDERS, A. A. H., 1972, *Stratigraphic position and planktonic Foraminifera of Brives' classic reference sections of the Sahelian at Carnot, N. Algeria:* Koninkl. Nederlandse Akad. Wetensch Proc., Ser. B, v. 75, p. 69-83, 5 fig., 1 pl.

TODD, RUTH, 1957, *Smaller Foraminifera:* in Geology of Saipan, Mariana Islands, Pt. 3, Paleontology: U.S. Geol. Survey, Prof. Paper 280-H, p. 265-320, pl. 64-93.

———, 1961, *On selection of lectotypes and neotypes:* Cushman Found. Foram. Research Contr., v. 12, p. 121-122.

TODD, RUTH, ET AL., 1954, *Probable occurrence of Oligocene in Saipan:* Am. Jour. Sci., v. 252, p. 673-682, 1 pl.

TOULMIN, L. D., 1941, *Eocene smaller Foraminifera from the Salt Mountain Limestone of Alabama:* Jour. Paleontology, v. 15, p. 567-611, 4 fig., pl. 78-82.

TOUMARKINE, MONIQUE, & BOLLI, H. M., 1970, *Evolution de* Globorotalia cerroazulensis *(Cole) dans l'Eocène moyen et supérieur de Possagno (Italie):* Rev. Micropaléontologie, v. 13, p. 131-145, 17 fig., 2 pl.

TROELSEN, J. C., 1957, *Some planktonic Foraminifera of the type Danian and their stratigraphic importance:* U. S. Natl. Museum Bull. 215, p. 125-131, fig. 22-24, pl. 30.

TURNER, D. L., 1968, *Potassium-argon dates concerning Tertiary foraminiferal time scale and San Andreas fault displacement, California:* Univ. California, Ph.D. dissert.

TURNOVSKY, KURT, 1958, *Eine neue Art von* Globorotalia *Cushman aus dem Eozaen Anatoliens und ihre Zuordnung zu einer neuen Untergattung:* Geol. Soc. Turkey Bull., v. 6, p. 80-85, 1 fig.

UJIIE, HIROSHI, 1970, *Miocene foraminiferal faunas from the Sandakan Formation, north Borneo; contributions to the geology and palaeontology of Southeast Asia, 85:* Geology and Palaeontology Southeast Asia, v. 8, p. 165-185, 4 fig., pl. 33-34.

———, 1971, *Status and problems of the post-Late Miocene planktonic foraminiferal zonation (pt. 1):* Japanese Assoc. Pet. Technol. Jour., v. 36, p. 264-271.

UNITED NATIONS ECONOMIC COMMISSION FOR ASIA AND THE FAR EAST, 1970, *Stratigraphic correlation between sedimentary basins of the ECAFE region (second volume):* ECAFE Mineral Resources Devel. Ser. 36, 154 p.

UREY, H. C., ET AL., 1951, *Measurements of paleotemperatures and temperatures of the Upper Cretaceous of England, Denmark, and the southwestern United States:* Geol. Soc. America Bull., v. 62, p. 399-416, 1 fig., 1 pl.

VOLOSHINOVA, N. A., KUZNETSOVA, V. N., & LEONENKO, L. S., 1970, *Foraminifery neogenovykh otlozhenii Sakhalina [Neogene foraminifers of Sakhalin]:* Vses. Neft. Nauchno-Issled. Geol.-Razved. Inst. Trudy [VNIGRI], v. 284, 303 p., 25 fig., 51 pl.

WADE, M. E., 1964, *Application of the lineage concept to biostratigraphic zoning based on planktonic Foraminifera:* Micropaleontology, v. 10, p. 273-290.

WEINHANDL, RUPERT, 1958, Schackoinella, *eine neue Foraminiferengattung:* [Austria] Geol. Bundesanst. Verh., p. 141-142, 1 fig.

WEINZIERL, L. L., & APPLIN, E. R., 1929, *The Claiborne formation on the coastal domes:* Jour. Paleontology, v. 3, p. 384-410, pl. 42-44.

WEISS, LAWRENCE, 1955, *Planktonic index Foraminifera of northwestern Peru:* Micropaleontology, v. 1, p. 301-319, 3 pl.

WETZEL, OTTO, 1949, *Plate explanations of Rhumbler's "Plankton-Expedition":* The Micropaleontologist [Am. Museum Nat. History], v. 3, p. 33-40.

WHITE, M. P., 1928, *Some index Foraminifera of the Tampico embayment area of Mexico:* Jour. Paleontology, v. 2, p. 177-215, 280-317, 2 fig., pl. 27-29, 38-42.

WILCOXON, J. A., 1969, *Tropical planktonic zones and calcareous nannoplankton correlations in part of the California Miocene:* Nature, v. 221, p. 950-951, 2 fig.

WILES, W. W., 1967, *Pleistocene changes in the pore concentration of a planktonic foraminiferal species from the Pacific Ocean;* in Sears, Mary, (ed.), Progress in Oceanography: v. 4, p. 153-160, 3 fig.

WILLMAN, H. B., & FRYE, J. C., 1970, *Pleistocene stratigraphy of Illinois:* Illinois Geol. Survey Bull. 94, 204 p., 14 fig., 3 pl.

WISEMAN, J. D. H., & OVEY, C. D., 1950, *Recent investigations on the deep-sea floor:* Geologists' Assoc. Proc., v. 61, p. 28-84.

WOODRING, W. P., 1925, *Miocene mollusks from Bowden, Jamaica; pelecypods and scaphopods:* Carnegie Inst. Washington Pub. 366, 222 p., 28 pl.

———, 1928, *Miocene mollusks from Bowden, Jamaica; pt. 2, gastropods and discussion of results:* Carnegie Inst. Washington Pub. 385, 564 p., 3 fig., 40 pl.

WORNARDT, W. W., 1969, *Diatoms, past, present, future:* Internatl. Conf. Planktonic Microfossils, 1st, Geneva 1967, Proc., v. 2, p. 690-714, 28 fig.

———, 1971, *Eocene, Miocene and Pliocene marine diatoms and silicoflagellates studied with the scanning electron microscope:* Internatl. Conf. Planktonic Microfossils, 2nd, Rome 1970, Proc., v. 2, p. 1277-1300, 16 pl.

YANSHIN, A. L., ET AL. (eds.), 1960, *Paleogenovye otlozhenii yuga evropeiskoi chasti SSSR [The Paleogene of the southern European part of the USSR]:* Akad. Nauk SSSR Izd., Moscow, 312 p., illus.

YOCHELSON, E. L., 1973, *Announcement by International Commission on Zoological Nomenclature:* Jour. Paleontology, v. 47, p. 1009-1011.

ZANEWA, P., 1971, *Grenzziehung zwischen dem Mittel–und Obereozän auf Grund der Entwicklung der Gattung* Hantkenina: Magyar Allami Földt. Int. Evi Jelentése, v. 54, p. 331-341.

INDEX TO TAXA

The following alphabetical index lists genera, subgenera, species, and subspecies of planktonic foraminifers described or mentioned in this report with indication of the page for the systematic description (bold number, as **16**) and for other mention of the taxon in text or on illustrations; taxa mentioned but not described and those cited as synonyms also are included. Citation of a taxon in the name of a zone is not noted here.

Names applied to taxa described and illustrated in the present report are given in capital letters (i.e., *AEQUA, GLOBOROTALIA*). Other terms do not necessarily have taxonomic validity.

ADDENDUM

Additional information pertinent to discussions or interpretations of the present report was published or became available to us only after finalization of the typescript. Brief and rather randomly arranged comments on some reports and selected additional references, therefore, are included here.

Menardella BANDY (1972a, p. 297).

Type species: *Globorotalia (Menardella) menardii* (d'Orbigny) [sic] [=*Rotalia menardii* PARKER, JONES, & BRADY (1865) ex D'ORBIGNY]; by original designation.

Discussion: Proposed as a subgenus of *Globorotalia* to include sharp-edged to keeled forms that evolved from turborotaloids along the *Globorotalia (Turborotalia) scitula praescitula-archeomenardii-praemenardii-menardii* series or lineage.

The original designation of the type species as "*Globorotalia (Menardella) menardii* (d'Orbigny)" is unfortunate because both biologic and nomenclatorial uncertainties are introduced. As our discussion of *Globorotalia menardii* (PARKER, JONES, & BRADY) summarizes, BANNER & BLOW (1960a) demonstrated that PARKER, JONES, & BRADY (1865) not D'ORBIGNY (1829) are to be cited as authors of *Globorotalia menardii*. The name of an author does not constitute part of the name of a taxon (ICZN, Art. 51a), however, so that the available species *G. menardii* (PARKER, JONES, & BRADY) ex D'ORBIGNY [=*Rotalia menardii* PARKER, JONES, & BRADY (1865)] is interpreted as the originally designated type species. Further uncertainty exists as to the original concept of the type species. Our studies summarized under discussion of *G. menardii* indicate that *Rotalia menardii* of PARKER, JONES, & BRADY included two morphologically dissimilar forms. One of the included taxa is *Globorotalia menardii* (PARKER, JONES, & BRADY) because it includes the lectotype, is a subjective synonym of *Globorotalia cultrata* (D'ORBIGNY, 1839), and occurs widely in warm-water deposits of late Middle Miocene to Holocene ages. The other presently nameless taxon corresponds to the original illustrations of D'ORBIGNY'S model given by PARKER, JONES, & BRADY (1865) to accompany their *R. menardii*, and to specimens occurring in the Late Miocene of the Mediterranean area. As applied herein under the assumption that our appeal to the International Commission on Zoological Nomenclature will be approved, the name *Globorotalia menardii* is restricted to the Mediterranean form originally named by D'ORBIGNY. Authors, however, have applied the name to specimens of both or either of the taxa just noted.

* * *

The form cited herein (p. 315, 406) as "*Globorotalia subscitula* CONATO (1964)" is that designated as "*Globorotalia scitula* Brady var. *subscitula* n. var." by CONATO (1964, p. 290, 294). A new name proposed explicitly as the name of a "variety" after 1960, however, is unavailable (ICZN Arts. 15, 45e), and authorship and date of priority are determined by the first subsequent author who assigned species-group rank to this name and otherwise validated it.

* * *

LUTERBACHER (in CARO ET AL., in press) recently adopted an additional Eocene zone (*Globorotalia edgari* Zone) corresponding to the lower part of the *Globorotalia subbotinae* Zone of the present report. This unit at the base of the Eocene has been recognized in many areas and seems useful particularly in defining the Paleocene-Eocene boundary locally.

* * *

Madame YOLANDE LE CALVEZ (1974) presented the first part of her detailed revision of foraminifers in the D'ORBIGNY collection from the Canary Islands. Of especial interest are her SEM illustrations of *Globorotalia inflata, Globorotalia truncatulinoides,* and *Globorotalia hirsuta.* She designated especially well-preserved specimens of these species as neotypes, but type specimens have been designated in earlier publications. Additionally, a lectotype was designated and illustrated for *Orbulina universa.*

* * *

SCHMIDT & RAJU (1973) showed by detailed analysis of the structure of *Globorotalia palmerae* that it is a planktonic species and is not related to the genus *Pararotalia.* This species is considered to be the end member of the *planoconica-pseudoscitula-palmerae* lineage.

* * *

CITA & GARTNER (1973) further assessed the Miocene-Pliocene transition in Italy by a discussion of sequences in Sicily and gave cogent reasons for recognition of the Miocene-Pliocene boundary between the Arenazzolo Member of the Gessoso-Solfifera Formation and the unconformably overlying Trubi Formation. Oldest Trubi strata were considered isochronous regionally, and a section exposed at Capo Rossello was designated as stratotype for the Zanclean (sic) Stage, which conforms in its entirety to the Trubi Formation.

Globorotalia margaritae ranges throughout the lower 75 m of the Trubi Formation whereas *Globorotalia crassaformis* occurs first some 120 m above the base. Planktonic foraminiferal zonation of the Trubi Formation was based on CITA (1973). Nannofossil datums (dated paleomagnetically in the Pacific region) were recognized within the Trubi Formation and used to date the base as 4.9 to 5.6 m.y. B.P. Because of the unconformity separating Miocene from Pliocene, it is well to keep in mind that latest Miocene beds must be somewhat older than the earliest Pliocene beds in Sicily. The top of Early Pliocene (i.e., datums of last occurrence of *Globorotalia margaritae* at this latitude) was estimated as between 3.6 and 4.0 m.y. This agrees well with our discussion herein because this species persisted longer in tropical regions than in most parts of Italy. The appearance of *Ceratolithus rugosus* (datum ca. 4.45 m.y. in the Pacific region) was shown to correspond with the first appearance of *Globorotalia puncticulata.*

* * *

In a discussion of Late Miocene-Early Pliocene paleomagnetic stratigraphy, paleoclimatology, and biostratigraphy in New Zealand KENNETT & WATKINS (1974) dated the traditional position of the Miocene-Pliocene boundary (based on the first appearance there of *Globorotalia puncticulata*) as 4.3± 0.1 m.y. Their data now provide a total paleomagnetic polarity sequence for the interval from 5 to 1.7 m.y. B.P. in New Zealand. These authors strongly reject the paleomagnetic stratigraphy given for deep-sea drilling sites (Leg 13) in the Mediterranean near Italy because they consider those data to reflect either a dominant normal polarity overprint due to precipitation of magnetic minerals during the past 0.7 m.y. or a dominant normal polarity brought about by mixing during drilling.

A further appraisal of paleomagnetism in the type Pliocene-Pleistocene boundary section at Santa Maria di Catanzaro, Italy, pointed up problems of postdepositional precipitation of magnetic minerals (WATKINS, KESTER, & KENNETT, 1974). Again a strong normal magnetic polarity overprint was discovered throughout the Calabrian section, which was explained as a geochemical alteration of a magnetic mineral during the past 0.7 m.y. when the earth's magnetic field was normal. These findings seemingly negate the results of NAKAGAWA, NIITSUMA, & HAYASAKA (1969) and presumably the paleomagnetic data offered by LAMB & BEARD (1972) for Late Pliocene and Early Pleistocene strata at Le Castella, Italy, where normal polarities were dominant.

We now lack, therefore, any meaningful polarity stratigraphy from late Cenozoic sedimentary rocks in the Mediterranean region. All age assessments of geologic time in this region, perforce, are indirect and derived mostly from presumed correlation with paleomagnetically dated planktonic foraminiferal and nannofossil datums established mostly in the Pacific Ocean region. Paucity of tropical planktonic foraminiferal and discoaster index fossils in the later Neogene of the Mediterranean area also makes difficult full assessment of the whole stratigraphic column there, even though some authors have attempted this.

* * *

A timely paper by SIEDNER & HOROWITZ (1974) is concerned with radiometric ages of late Cenozoic basalts from northern Israel and the chronostratigraphic implications. Five eruptive phases interbedded with late Cenozoic sediments are distinguished. Of particular interest here are 1) a 4.8 m.y. date within the Tabianian (Early Pliocene), 2) a 1.7 to 2.0 m.y. date for what is termed the end of the preglacial Pleistocene (including Calabrian and Sicilian), and 3) a date of 2.6 to 3.0 m.y. corresponding to the close of the Pliocene. The date for the Pliocene-Pleistocene boundary is based on hard-rock radiometric dating and paleomagnetics and is said to fall within the upper part of the Gauss Normal Epoch. At the present time this is the only unchallenged radiometric date for this boundary in the Mediterranean region.

In a resume of late Cenozoic stratigraphy and paleogeography of Israel HOROWITZ (unpubl.) discussed geological events within the late Neogene. An Early Pliocene (Tabianian) marine transgression is followed by a Middle Pliocene regression and Piacenzian transgression. A Late Pliocene regression is followed by Early Pleistocene transgressions (Calabrian and Sicilian). The Quaternary is subdivided into 1) a preglacial Pleistocene (ca. 2.8 to 1.6 m.y.) which includes both the Calabrian and Sicilian transgressions and 2) a glacial Pleistocene which began approximately 1.6 m.y. ago and encompasses four main pluvial cycles that seem to correlate well with Alpine glacials (e.g., Günz, Mindel, Riss, and Würm) and corresponding interglacials. The "preglacial Pleistocene" is said to include glacial phases (i.e., Biber, Donau, and others); thus the term "preglacial" Pleistocene seems not appropriate. The Calabrian and Sicilian seas were said to have been cooler than the Pliocene sea and to be characterized by a cold north Atlantic fauna and by *Hyalinea baltica*.

* * *

BERGGREN & VAN COUVERING (1974) related biostratigraphy of several microfossil groups with mammalian biochronology for the late Neogene. From the standpoint of planktonic foraminiferal biostratigraphy certain datums for appearances and extinctions applied by these authors can be compared readily with our discussions as these have been treated rather extensively in the literature. Both texts must be read carefully, however, to note discrepancies in placement of certain datums, such as those for *Globorotalia truncatulinoides* and *Sphaeroidinella dehiscens*, and to appraise the significance of these different placements. Authority for their planktonic foraminiferal zonation is that finalized by BLOW (1969), BLOW & BERGGREN (unpublished), and BERGGREN (1973).

A major difference between our treatment and that of BERGGREN & VAN COUVERING is in what constitutes the international geologic time scale, especially with respect to the Pliocene and Pleistocene record in the Mediterranean and tropical regions as exemplified by the fossil record and paleoclimatic indications. In a straightforward manner, we recognize a cool terminal Late Miocene interval (Messinian) followed by a warm Pliocene (Tabianian and Piacenzian) which, in turn, is followed by severe cooling initiating the Pleistocene (marine Calabrian). BERGGREN & VAN COUVERING, however, stated that, in the type section of the Calabrian Stage at Santa Maria di Catanzaro, the base of the calcarenite bed of GIGNOUX (1913, p. 35) (a bed containing the mollusk *Arctica islandica*) is the boundary-stratotype for the base of the Calabrian Stage. The age of the base of the calcarenite bed is assumed to be 1.8 m.y. Acceptance of this proposal would mean that approximately 75 meters of sandstone and siltstone below the calcarenite bed (characterized by a cool-water microfauna including *Hyalinea baltica*, *Globigerina pachyderma*, and *Globorotalia truncatulinoides*) are Late Pliocene and are coeval with the Piacenzian Stage.

We contend that this is not the current concept of the Calabrian for a number of reasons. According to SELLI (1971), GIGNOUX did not indicate a specific lower boundary for the Calabrian although the section at Santa Maria di Catanzaro may be assumed to be a provisional stratotype. GIGNOUX'S description of the Calabrian section says simply that it includes sandstones mixed with clay and a fossiliferous bank of calcarenite (containing *Arctica islandica*) overlying plastic clays of the older Pliocene. His accompanying generalized geological cross section through Monte Santa Maria at a scale of 1:25,000 makes it virtually impossible to select any particular bed as a finite lower or upper boundary. It is not surprising that GIGNOUX failed to designate a particular bed as the base of his Calabrian because the concept of the boundary-stratotype, or Age-Stage classification, was not proposed firmly until about 1935 (see CARTER, 1974).

According to numerous recent papers (SELLI, 1971; SMITH, 1969; BANDY & WILCOXON, 1970; LAMB & BEARD, 1972; SPROVIERI, D'AGOSTINO, & DI STEFANO, 1973; BROLSMA & MEULENKAMP, 1973; SCHMIDT, 1973; and others) the Calabrian Stage, as exposed about 400 meters southwest of the village of Santa Maria di Catanzaro along the western slope of Punta dei Briganti, includes a basal interval of about 70 meters of sandstone and siltstone ("sandy Calabrian" of authors) which is capped by the 5 meter-thick sandy calcarenite bed of GIGNOUX containing *Arctica islandica;* this bed is overlain by about 50 meters of dominantly clay strata ("clayey Calabrian" of authors). The basal sandy interval clearly lies unconformably on Pliocene shales (the "Argiles plastiques" of GIGNOUX).

That *Hyalinea baltica* ranges throughout the section and that *Arctica islandica* seemingly is restricted to the calcarenite bed now is well established. The lowest reported occurrence of *Globorotalia truncatulinoides* in the section (LAMB & BEARD, 1972) is in beds about 42 meters below the calcarenite and within the "sandy Calabrian". The precise stratigraphic position of these beds is given by SMITH (1969, fig. 1; samples IT-807 and IT-809). Only 3 specimens of *G. truncatulinoides* were recovered from sample IT-807, but more than 25 specimens were found in sample IT-809. Location of this section is best described by reference to the detailed map of the area published by BROLSMA & MUELENKAMP (1973, fig. 1). The section begins (lowest sample) at a point corresponding to the apex of the hairpin curve immediately southwest of exposure 4; from here it runs due south to exposure 4 and then follows along the asphalted road in a southwesterly direction to exposure 8 (highest sample). Sandstones occurring in exposure 1 of BROLSMA & MUELENKAMP are considered as stratigraphically below our lowest sample, and, therefore, we lack data on the maximum thickness of the "sandy Calabrian". DR. BROLSMA assisted in recollecting samples from his Catanzaro localities. From his sample locality Exposure 6, within the "sandy Calabrian" and below the calcarenite bed, we recovered numerous specimens of *Globorotalia truncatulinoides.*

At this point we may ask what is to be gained by asserting that the Pleistocene boundary be placed 5 meters below the top of the "sandy Calabrian" and immediately below the calcarenite bed containing *Arctica islandica?* This position does not correspond to a significant lithologic boundary but falls within a broader lithologic unit, the "sandy Calabrian", that has been mapped regionally by SELLI (1971). Furthermore, BAYLISS (1969) maintained that the calcarenite bed is not readily recognizable outside the area of Catanzaro.

From a biostratigraphic standpoint, *Arctica islandica* is only one of many fossils that have been used to recognize the cold-water boreal faunas of the Calabrian. One could assume reasonably that this form would appear somewhat earlier or later depending on when the proper ecologic conditions were attained in a section. Thus, the Calabrian seems recognized best, as it has in the past, by utilizing all elements of the cold-water faunas.

As noted in several recent published discussions, paleomagnetic dating of the Catanzaro section clearly is not feasible at this time, and evidence is lacking for an assumption (BERGGREN & VAN COUVERING, 1974) that 1) the base of the calcarenite represents an age of 1.8 m.y. and 2) falls at the base of the Gilsa event. Our previous discussion points out that this concept, developed in deep-sea sequences, is artificial and unrelated to definition of the Pleistocene boundary.

Evidently, therefore, the calcarenite bed lacks sufficient attributes to qualify as a chronostratigraphic unit or a boundary-stratotype, as discussed by the International Subcommission on Stratigraphic Classification (HEDBERG, 1971). The bed cannot be extended geographically away from the type area by any means into different types of stratigraphic sequences to the extent that time correlation is possible. On the other hand, Early Pleistocene as defined by the base of the "sandy Calabrian" does have sufficient attributes to qualify as a chronostratigraphic unit. This unit can be correlated throughout the Mediterranean region and, in our opinion, essentially worldwide in marine sequences on the basis of climatically induced faunal changes, eustatism, and nearly so (precisely for most practical purposes) with the evolutionary appearance of marker species, such as *Globorotalia truncatulinoides*. In nonmarine sediments this boundary also can be recognized widely by palynological analysis and by interpretation of periglacial deposits. Presumably, also, vertebrate land animals will provide many additional criteria.

In truth, if the "sandy Calabrian" were to be considered Late Pliocene (rather than Pleistocene, as is widely accepted presently), it presumably could then be cited as evidence for severe Late Pliocene cooling and eustatism in the Mediterranean and, thereby, be correlated with the worldwide climatic cooling and glaciation that many workers recognize within the upper Gauss Epoch. Such a procedure would support our position on worldwide stratigraphic correlation of climatic events but would conflict markedly with our placement of the Pleistocene boundary.

We see no need to revise the accepted geologic time scale of the Mediterranean region to preserve the false assumption that continental glaciation in temperate areas began in the Late Pliocene. A rather sobering thought is that commonly used informal lithologic names (e.g., Gessoso-Solfifera and Trubi) not infrequently are elevated in Italy to formational status (see CITA & GARTNER, 1973). Because the "sandy Calabrian" is a well-known mappable lithologic unit, it could reasonably be dignified as the "Sandy-Calabrian Formation"—and then who could be convinced that it should be Piacenzian, Pliocene!

* * *

Choice of a criterion for recognizing the Oligocene-Miocene boundary remains a vexing problem. Use of the earliest appearance of *Globigerinoides quadrilobatus primordius* proves acceptable in some newly studied areas, including the eastern Mediterranean (BAROZ & BIZON, 1974; BIZON ET AL., 1974). In our own continuing studies in the Gulf of Mexico region, however, the range of *G. q. primordius* has been extended back into the Oligocene to near the extinction level of *Globorotalia opima opima*, confirming the anomalous status of the *Globigerinoides* Datum already demonstrated in Puerto Rico (SEIGLIE, 1973). Furthermore, a continuously cored section displays clearly the evolution from sparse, small specimens of the subspecies *primordius* to plentiful, large specimens referable to *triloba, sacculifer,* and other advanced subspecies, just as recorded elsewhere except that here the change is accomplished before the appearance of *Globorotalia kugleri* (treated in its broad sense, inclusive of the primitive forms treated separately as *G. pseudokugleri* and *G. mendacis* by BLOW, 1969). Thus the suggested re-designation of the *Globigerinoides* Datum as the level of earliest proliferation of the genus fails to resolve the problem of defining the Oligocene-Miocene boundary, as locally this event falls within undoubted Oligocene in the Gulf of Mexico region. We are forced to conclude that ecologic factors, as well as genetic forces, influenced both the morphologic change from *Globigerina* to *Globigerinoides* and the biologic success of the innovation. In our experience the earliest appearance of *Globorotalia kugleri* sensu stricto corresponds closely to the Oligocene-Miocene boundary as established by other criteria, but unfortunately this index is scarce or missing except in warm-water provinces.

* * *

A schematic representation of major oscillations of temperature-sensitive planktonic foraminiferal biofacies within the California Current system and related Alaskan Current gyre during the later Miocene through Pleistocene interval is given by INGLE (1973). His figure 4 is highly reminiscent of our empirical paleotemperature curve developed herein (Fig. 22) for the same interval.

* * *

The following remarks are corollary to the section on limitations of planktonic zonation (p. 47-49). Contrary to the general concept of uninterrupted sedimentation in oceanic basins, modern deep-sea research has revealed unexpectedly widespread gaps within time sequences represented by ocean-floor deposits. More or less isolated cases reported earlier were attributed to slumping of beds off topographic highs, the slumped detritus reappearing as downslope turbidites. The siting of many coreholes on geophysically determined high points adds to credibility of this explanation. Nevertheless, some more global mechanism must be invoked to account for recorded lack of Paleocene, Oligocene, or Early Pleistocene sediments within an area approximating one million square miles. Pronounced disconformities or paraconformities of such scope are documented and discussed, for instance, by CARTER & LANDIS (1972), KENNETT ET AL. (1972), LUYENDYK, FORSYTH, & PHILLIPS (1972), WATKINS & KENNETT (1972, 1973), RONA (1973), and SIGAL (1974), who attribute the phenomenon to side effects of plate tectonics and sea-floor spreading. A specific mechanism is the scouring or winnowing effect of rapid currents through a newly opened strait (e.g., between Antarctica and Australia or New Zealand and Australia). Furthermore, the opening of such a seaway or the closing of an intercontinental portal (Panamanian region, eastern Tethys) could affect the pattern of oceanic currents so strongly as to initiate polar glaciation. The resultant eustatic lowering of sea level would induce more rapid flow in constricted areas and thus reduced sedimentation. Pertinence of these concepts in the present context is that they provide an explanation for cases where little physical evidence of disconformity is discernible yet where some planktonic zones of a standard sequence (foraminiferal or other) are missing.

ADDITIONAL REFERENCES

BAROZ, F., & BIZON, GERMAINE, 1974, *Le Néogène de la chaîne du Pentadaktylos et de la partie nord de la Mésaoria (Chypre); étude stratigraphique et micropaléontologique:* Inst. Français Petrole Rev., v. 29, p. 327-359, 7 fig., 5 pl.

BERGGREN, W. A., & VAN COUVERING, J. A., 1974, *The late Neogene:* Palaeogeography, Palaeoclimatology, Palaeoecology, v. 16, p. 1-216, 15 fig.

BIZON, GERMAINE, ET AL., 1974, *Nouvelles précisions stratigraphiques concernant les bassins tertiaires du sud de la Turquie (Antalya, Mut, Adana):* Inst Français Pétrole Rev., v. 29, p. 305-325, 1 fig., 3 pl.

CARO, YVES, ET AL., in press, *Zonations du paleocene supérieur et de l'eocene inférieur à l'aide de microfossiles pelagiques:* Soc. Géol. France Bull.

CARTER, R. M., 1974, *A New Zealand case-study of the need for local time-scales:* Lethaia, v. 7, p. 181-202, 8 fig.

CARTER, R. M., & LANDIS, C. A., 1972, *Correlative Oligocene unconformities in southern Australasia:* Nature Phys. Sci., v. 237, p. 12-13.

CITA, M. B., 1972, *Il significato della trasgressione Pliocenica alla luce delle nuove scoperte nel Mediterraneo:* Riv. Italiana Paleontologia e Stratigrafia, v. 78, p. 527-594, 17 fig., pl. 61-67.

CITA, M. B., & GARTNER, STEFAN, 1973, *Studi sui Pliocene e sugli strati di passaggio dal Miocene al Pliocene; 4, The stratotype Zanclean – foraminiferal and nannofossil biostratigraphy:* Riv. Italiana Paleontologia e Stratigrafia, v. 79, p. 503-558, 21 fig.

GIGNOUX, MAURICE, 1913, *Les formations marines pliocènes et quaternaires de l'Italie du Sud et de la Sicile:* Lyon Univ. Annales, n. ser., v. 35, 693 p., 42 fig., 21 pl.

HEDBERG, H. D., (ed.), 1971, *Preliminary report on chronostratigraphic units:* Internatl. Geol. Congr., Montreal, Canada, Rept. 6 (Internatl. Subcomm. Strat. Classification), 39 p.

HOROWITZ, AHARON, unpubl., *The late Cenozoic stratigraphy and paleogeography of Israel:* Tel Aviv Univ. Inst. Archeology manuscript (1974), 174 p., 12 fig.

INGLE, J. C., JR., 1973, *Summary comments on Neogene biostratigraphy, physical stratigraphy and paleo-oceanography in the marginal northeastern Pacific Ocean;* in Kulm, L. D. et al., Initial Repts. Deep Sea Drilling Project, v. 18, p. 949-960, 5 fig.

JENKINS, D. G., 1974, *Paleogene planktonic Foraminifera of the New Zealand and the Austral region:* Jour. Foram. Research, v. 4, p. 155-170, 4 fig.

KENNETT, J. P., & WATKINS, N. D., 1974, *Late Miocene-Early Pliocene paleomagnetic stratigraphy, paleoclimatology, and biostratigraphy in New Zealand:* Geol. Soc. America Bull., v. 85, p. 1385-1398, 13 fig.

KENNETT, J. P., ET AL., 1972, *Australian-Antarctic continental drift, paleocirculation changes and Oligocene deep-sea erosion:* Nature Phys. Sci., v. 239, p. 51-55, 5 fig.

LE CALVEZ, YOLANDE, 1974, *Révision des foraminifères de la collection d'Orbigny; 1–Foraminifères des Iles Canaries:* Cahiers Micropaléontologie, no. 2, 108 p., 28 pl.

LUYENDYK, B. P., FORSYTH, DONALD, & PHILLIPS, J. D., 1972, *Experimental approach to the paleo-*

circulation of the oceanic surface waters: Geol. Soc. America Bull., v. 83, p. 2649-2664, 6 fig.

NAKAGAWA, HISAO, NIITSUMA, NOBUAKI, & HAYASAKA, ICHIRO, 1969, *Late Cenozoic geomagnetic chronology of the Boso Peninsula:* Geol. Soc. Japan Jour., v. 75, p. 267-280.

POPESCU, G. C., 1971 [1972], *Die Biostratigraphie der oligo-miozaenen Ablagerungen südlich der Preluca, anhand der planktonischen Foraminiferen:* [Romania] Com. Geol. Dari Seama Sed., v. 58, p. 105-127, 1 fig., 5 pl.

RONA, P. A., 1973, *Worldwide unconformities in marine sediments related to eustatic changes of sea level:* Nature Phys. Sci., v. 244, p. 25-26.

SCHMIDT, R. R., 1973, *A calcareous nannoplankton zonation for Upper Miocene-Pliocene deposits from the southern Aegean area, with a comparison to Mediterranean stratotype localities:* Koninkl. Nederlandse Akad. Wetensch. Proc., ser. B, v. 76, p. 287-310, 4 fig.

SCHMIDT, R. R., & RAJU, D. S. S., 1973, Globorotalia palmerae *Cushman and Bermudez and closely related species from the Lower Eocene Cauvery basin, south India:* Koninkl. Nederlandse Akad. Wetensch. Proc., ser. B., v. 76, p. 167-178, 5 fig.

SELLI, RAIMONDO, 1971, *Calabrian:* Gior. Geologia, v. 37, pt. 2, p. 55-64.

SIEDNER, G., & HOROWITZ, AHARON, 1974, *Radiometric ages of late Cainozoic basalts from northern Israel; chronostratigraphic implications:* Nature, v. 250, p. 23-26, 2 fig.

SIGAL, JACQUES, 1974, *Comments on Leg 25 sites in relation to the Cretaceous and Paleogene stratigraphy in the eastern and southeastern African and Madagascar regional setting;* in Simpson, E. S. W., et al., Initial Repts. Deep Sea Drilling Project, v. 25, p. 687-723, 6 fig., 11 pl.

SRINIVASAN, M. S., & SHARMA, VIJAY, 1974, *The age of Car Nicobar Foraminifera described by Schwager in 1866:* Rev. Española Micropaleontologia, v. 6, p. 173-179, 2 fig., 1 pl.

WALKER, D. A., & VILKS, GUSTAVS, 1973, *Spinal ultrastructure of the planktonic foraminifers* Hastigerina *Thomson and* Globigerinella *Cushman:* Jour. Foram. Research, v. 3, p. 196-198, 1 pl.

WATKINS, N. D., & KENNETT, J. P., 1972, *Regional sedimentary disconformities and Upper Cenozoic changes in bottom water velocities between Australasia and Antarctica;* in Hayes, D. E. (ed.), Antarctic oceanology 2; the Australian-New Zealand sector: Am. Geophys. Union Antarctic Res. Ser., v. 19, p. 273-293, 8 fig.

______ 1973, *Response of deep-sea sediments to change in physical oceanography resulting from separation of Australia and Antarctica;* in Tarling, D. H., & Runcorn, S. K. (eds.), Implications of continental drift to the earth sciences: London, Academic Press Inc., v. 2, p. 787-797, 8 fig.

WATKINS, N. D., KESTER, D. R., & KENNETT, J. P., 1974, *Paleomagnetism of the type Pliocene/Pleistocene boundary section at Santa Maria di Catanzaro, Italy, and the problem of post-depositional precipitation of magnetic minerals:* Earth and Planetary Sci. Letters, v. 24, p. 113-119, 4 fig.

THE UNIVERSITY OF KANSAS
PALEONTOLOGICAL CONTRIBUTIONS

ARTICLE 62

CENOZOIC PLANKTONIC FORAMINIFERAL ZONATION AND CHARACTERISTICS OF INDEX FORMS

APPENDIX

R. M. Stainforth, J. L. Lamb, Hanspeter Luterbacher,
J. H. Beard, and R. M. Jeffords
EXXON Production Research Company

The University of Kansas Paleontological Institute

Harold Norman Fisk Memorial Papers
EXXON Company, U. S. A.

The University of Kansas, Lawrence, Kansas
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APPENDIX

ILLUSTRATED REVIEW OF PALEOCENE TO MIDDLE EOCENE INDEX SPECIES

Planktonic foraminiferal species regarded as useful markers for the Paleocene and Early and Middle Eocene are discussed and illustrated (Fig. 30-99) in alphabetical order by species name. These data were collated mainly by HANSPETER LUTERBACHER.

Ranges for these species are recorded in the preceding text and on Figure 13 together with a discussion of the zonation for the interval.

GLOBOROTALIA ACUTA Toulmin, 1941
Plate 1
Late Paleocene

Globorotalia wilcoxensis CUSHMAN & PONTON var. *acuta* TOULMIN, 1941, p. 608, pl. 82, fig. 6-8.
Globorotalia acuta TOULMIN. LOEBLICH & TAPPAN, 1957a, p. 185, pl. 47, fig. 5; pl. 55, fig. 4-5; pl. 58, fig. 5.–LUTERBACHER, 1964, p. 686, fig. 101-104.

Test umbilico-convex with even or only slightly elevated spiral side. Periphery keeled, slightly to distinctly lobate. Angular-conical chambers (4-6) of last whorl increasing fairly rapidly in size, last chamber occupying one-fifth to one-third of whorl. Umbilical shoulders sharp, generally ornamented with thick spines except on last chamber where commonly rounded and smooth. Umbilicus deep, open. Sutures depressed; radial on umbilical side, curved and beaded on spiral side. Surface of test commonly covered partly with small spines; last chamber generally smooth. Aperture a low arch, extraumbilical-umbilical, generally with distinct lip. Diameter to 0.4 mm.

Discussion.–*Globorotalia acuta* is closely related to *Globorotalia velascoensis* and has been included, therefore, with the latter by some authors. Although the two species are linked intimately by transitional forms, separation is justified by the wider stratigraphic and geographic distribution of *G. acuta*. *Globorotalia acuta* differs from *G. velascoensis* mainly in the fewer chambers in the last whorl and the generally less-pronounced ornamentation. It is separated from its probable ancestor, *Globorotalia conicotruncata*, by a strong keel and stronger ornamentation. The two species are linked by intermediate forms which occur mainly in the older part of its range.

Distribution.–Latest Middle Paleocene to earliest Eocene (top of *Globorotalia pusilla pusilla* Zone to within *Globorotalia subbotinae* Zone). The species proliferated during the Late Paleocene (*Globorotalia pseudomenardii* and *Globorotalia velascoensis* Zones). *Globorotalia acuta* was described originally from the Salt Mountain Limestone of southwestern Alabama.

GLOBOROTALIA AEQUA Cushman & Renz, 1942
Figure 31
Late Paleocene to Early Eocene

Globorotalia crassata (CUSHMAN) var. *aequa* CUSHMAN & RENZ, 1942, p. 12, pl. 3, fig. 3.
Globorotalia aequa CUSHMAN & RENZ. BOLLI, 1957a, p. 74-75, pl. 17, fig. 1-3; pl. 18, fig. 13-15.–LUTERBACHER, 1964, p. 670-671, fig. 63-71.–POSTUMA, 1971, p. 168-169.
Pseudogloborotalia aequa (CUSHMAN & RENZ). BERMÚDEZ, 1960, p. 1336, pl. 16, fig. 4.
Globorotalia (Morozovella) aequa aequa CUSHMAN & RENZ. JENKINS, 1971, p. 100, pl. 7, fig. 167-171.

Test umbilico-convex; spiral side almost flat, umbilical side strongly convex. Periphery lobate, often with faint keel. Last whorl with 3½ to 4½ angular-conical chambers which increase rapidly in size, last chamber occupying one-third to one-half of whorl. Sutures on umbilical side radial and depressed, on spiral side curved, depressed or flush; chambers somewhat imbricated. Umbilicus deep, narrow. Aperture extraumbilical-umbilical, a low arch, generally with faint lip. Most of surface spinose but last chamber generally smooth. Diameter to 0.4 mm.

Discussion.–*Globorotalia aequa* differs from *Globorotalia angulata* in being less lobate and more tightly coiled. It is less tightly coiled than *Globorotalia lensiformis*, the intermediate species between *G. aequa* and *Globorotalia aragonensis*.

Distribution.–Late Paleocene to Early Eocene (*Globorotalia pseudomenardii* Zone to within *Globorotalia subbotinae* Zone). This species was

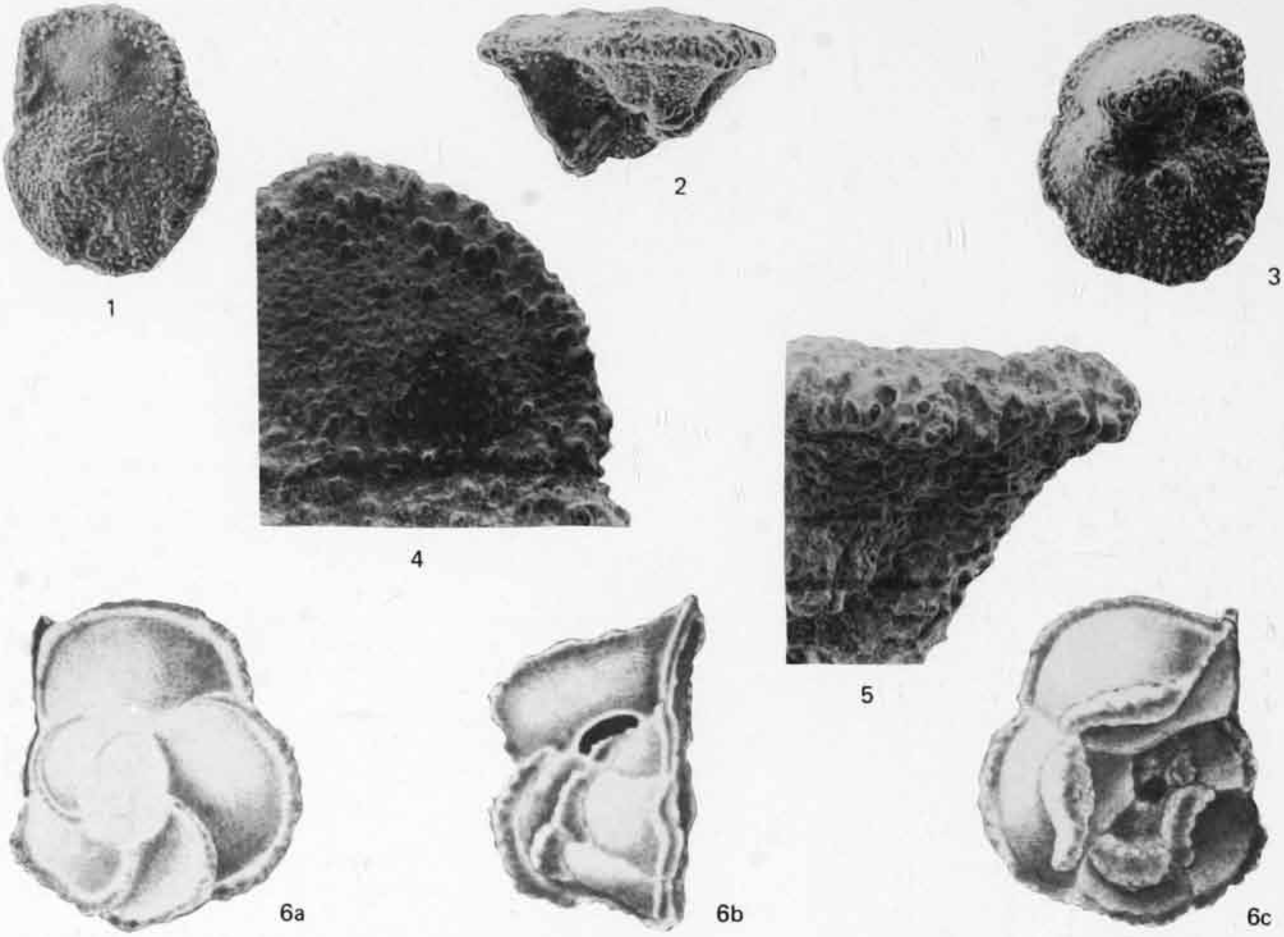


Fig. 30. *Globorotalia acuta* TOULMIN from the Late Paleocene of Mexico and New Jersey.

1-5 Specimens from the *Globorotalia pseudomenardii* Zone of the Velasco Formation of Mexico. **1**–Spiral view, X100; **2**–side view, X100; **3**–umbilical view, X100; **4**–details of last chamber, X250; **5**–keel of last chamber, X250.

6 Specimen from the Vincentown Formation of New Jersey, X110; from LOEBLICH & TAPPAN (1957a, pl. 55, fig. 5). **a**–Spiral view; **b**–side view; **c**–umbilical view.

described originally from the Soldado Formation of Trinidad at a level near the base of the *Globorotalia subbotinae* Zone.

CLAVIGERINELLA AKERSI Bolli, Loeblich, & Tappan, 1957

Figure 32

Middle Eocene

Clavigerinella akersi BOLLI, LOEBLICH, & TAPPAN, 1957, p. 30, pl. 3, fig. 5.–BOLLI, 1957c, p. 161-162, pl. 35, fig. 4.–POSTUMA, 1971, p. 132-133.

Test planispiral, biumbilicate, strongly lobate. Chambers initially spherical, later becoming radially elongate and clavate. Generally 4 chambers in last whorl. Sutures radial, depressed. Aperture equatorial, an elongate slit extending up apertural face, bordered by lateral flanges. Surface of test finely perforate. Diameter typically 0.7 to 0.8 mm, detached chambers 0.2 to 0.4 mm long.

Discussion.–*Clavigerinella akersi* is distinguished readily by the bulbous-tipped clavate chambers of the last whorl. In washed residues broken-off adult chambers are much commoner than specimens retaining the nuclear portion.

Distribution.–Middle Eocene (*Hantkenina aragonensis* and *Globigerinatheka subconglobata* Zones), never plentiful but conspicuous when present. The holotype of this species is from the

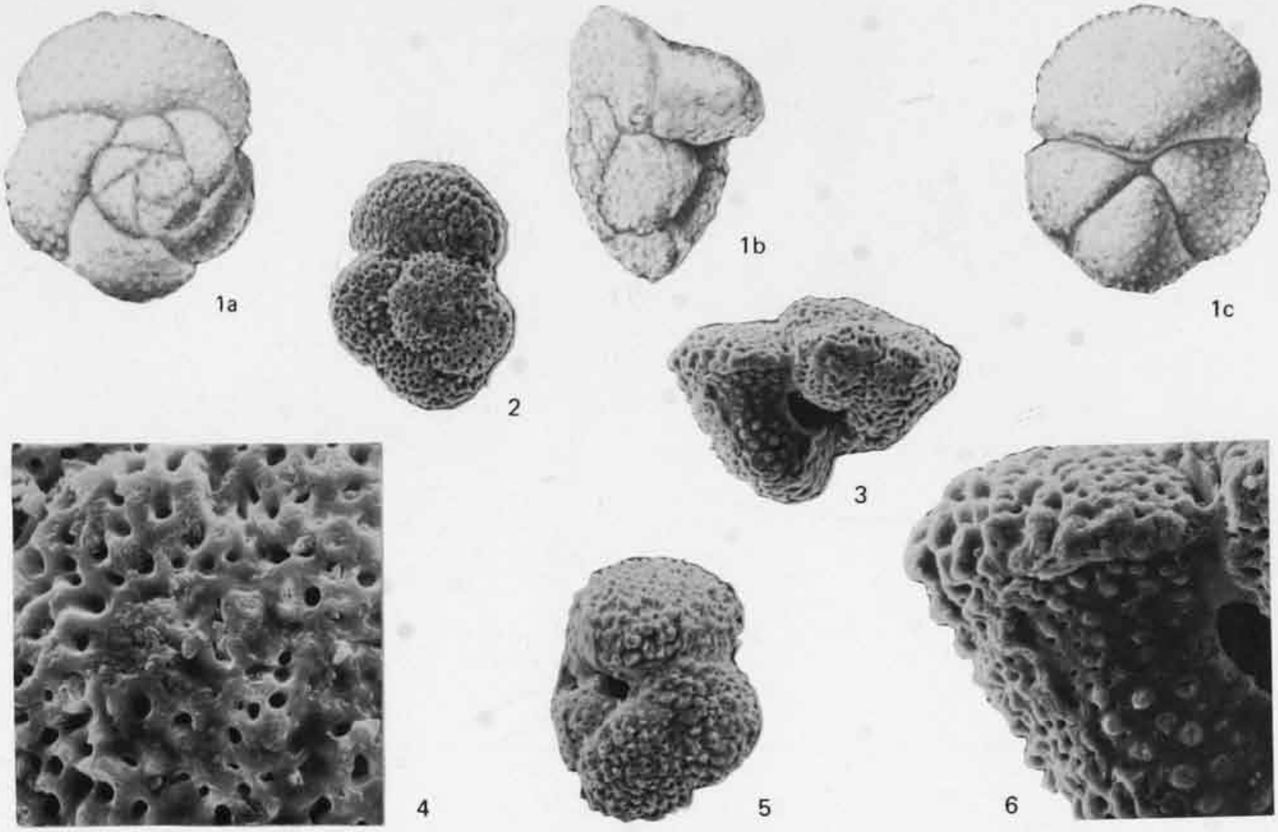


Fig. 31. *Globorotalia aequa* CUSHMAN & RENZ from the Late Paleocene of Trinidad and California.

1 Specimen from the *Globorotalia velascoensis* Zone of the Lizard Springs Formation of Trinidad, X100; from BOLLI (1957a, pl. 17, fig. 1-3). **a**–Spiral view; **b**–side view; **c**–umbilical view.

2-6 Specimens from the Lodo Formation of California. **2**–Spiral view, X100; **3**–side view, X100; **4**–surface of last chamber, X500; **5**–umbilical view, X100; **6**–last chamber showing faint keel, X250.

Hantkenina aragonensis Zone of the Navet Formation of Trinidad.

Species of *Clavigerinella* having tapering to digitate chambers, such as *C. jarvisi* (CUSHMAN, 1930) and *C. eocanica* (NUTTALL, 1930), range higher than *C. akersi* but are nevertheless a useful guide to the later half of the Eocene. An unusual abundance of these forms may be indicative of a cool-water province (STAINFORTH, 1948b, p. 137-139).

HANTKENINA ALABAMENSIS Cushman, 1925

Figure 33

Middle and Late Eocene

Hantkenina alabamensis CUSHMAN, 1925a, p. 3, fig. 1, pl. 1, fig. 1-6; pl. 2, fig. 5.–SUBBOTINA, 1953, p. 133-134, pl. 1, fig. 6-7.–BLOW & BANNER, 1962, p. 126-127, pl. 16, fig. c, d, j, k.–BLOW, 1969, p. 377.–SUBBOTINA, 1971, p. 146-147, pl. 1, fig. 6-7.

Hantkenina brevispina CUSHMAN, 1925a, p. 2, pl. 2, fig. 3.

Hantkenina alabamensis CUSHMAN subsp. *compressa* PARR, 1947, p. 46, fig. 1-7.

Hantkenina (Hantkenina) alabamensis CUSHMAN, BRÖNNIMANN, 1950b, p. 414, pl. 56, fig. 10, 14-16.

Test planispiral, biumbilicate, involute, with subelliptical to subcircular outline. Chambers (4-6) of outer whorl somewhat inflated, increasing rather slowly in size, each carrying slender spine. Spines in anterior position with bases in or close to sutural depressions, projecting clear of test radially or pointing forward in direction of coiling. Sutures depressed, radial to slightly curved. Aperture interiomarginal, equatorial, triradiate, extending halfway up apertural face, bordered by broad apertural flanges which join above in narrow lip.

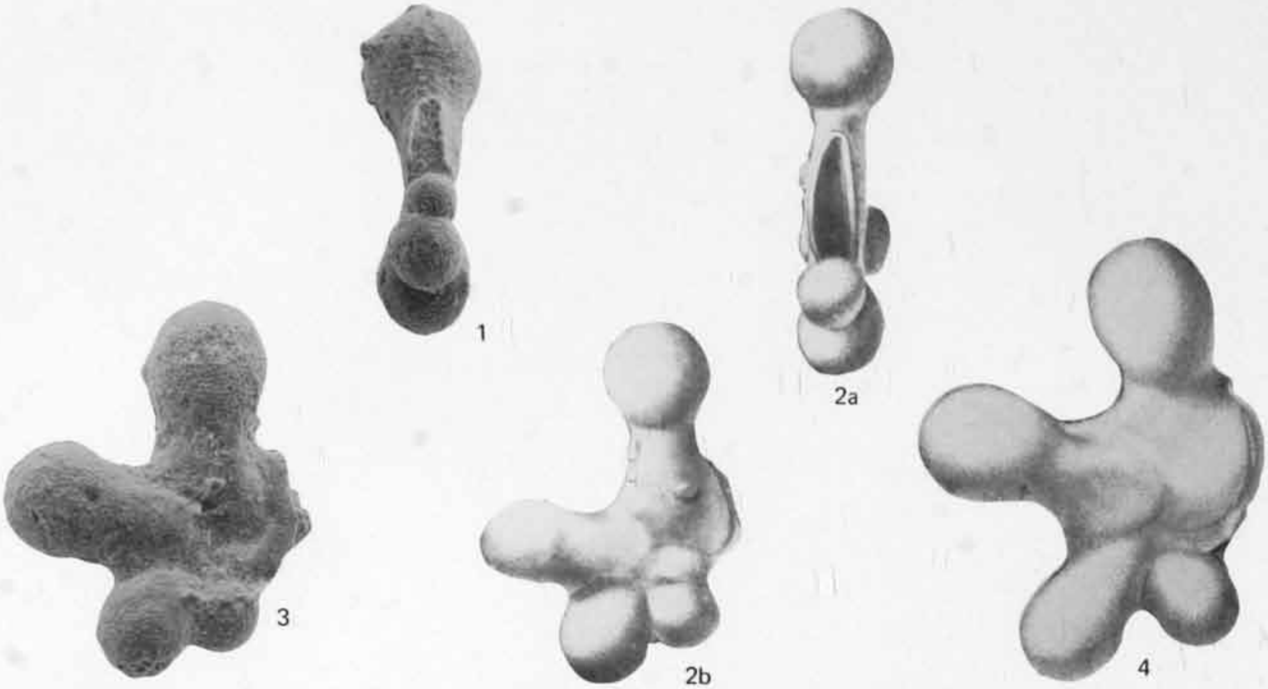


Fig. 32

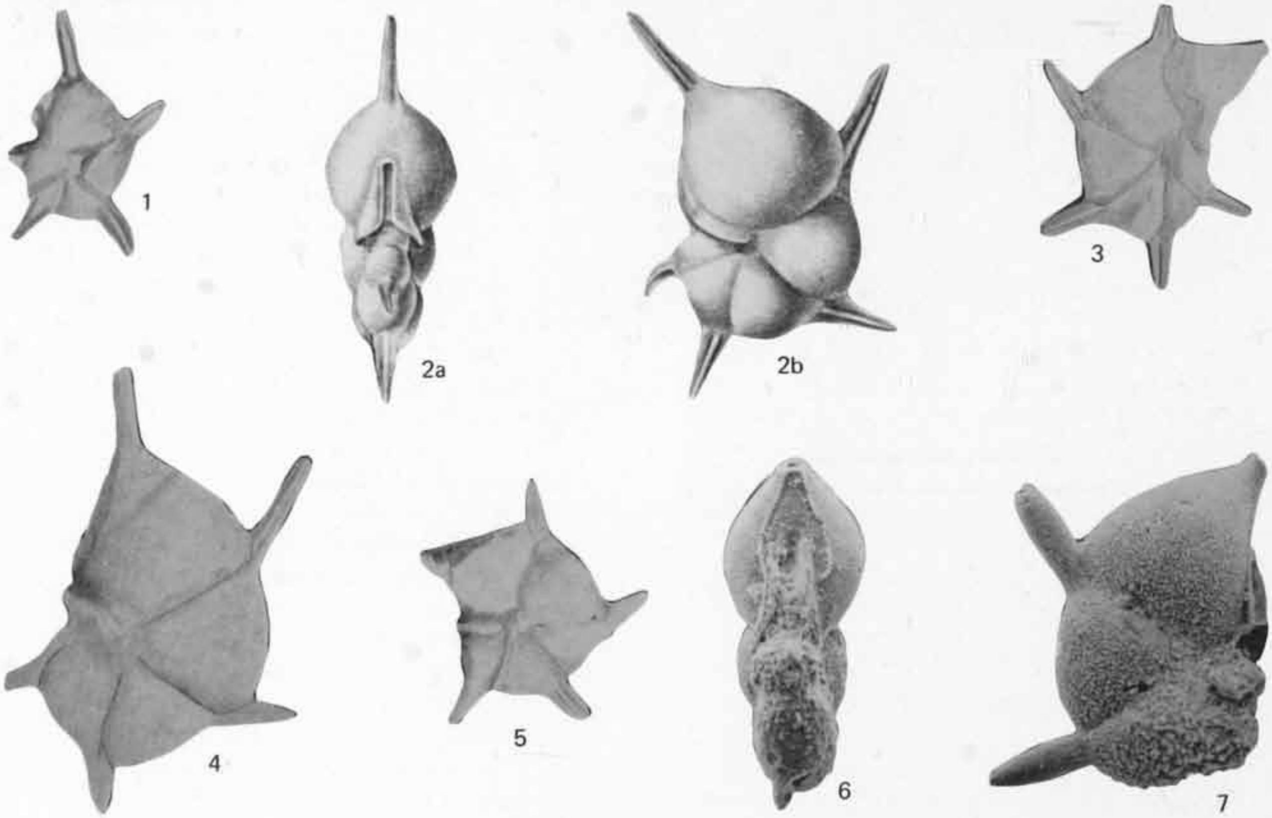


Fig. 33

Fig. 32. *Clavigerinella akersi* BOLLI, LOEBLICH, & TAPPAN from the Middle Eocene part (*Hantkenina aragonensis* Zone) of the Navet Formation of Trinidad.

1,3 Specimens, X100. **1**–Peripheral view showing apertural face; **3**–lateral view.

2 Holotype, X65; from BOLLI, LOEBLICH, & TAPPAN (1957, pl. 3, fig. 5). **a**–Lateral view; **b**–peripheral view showing apertural face.

4 Lateral view of large specimen, X73; from BOLLI (1957c, pl. 35, fig. 4).

Fig. 33. *Hantkenina alabamensis* CUSHMAN from the Eocene of Trinidad, Alabama, Barbados, and Gulf of Mexico.

1 Lateral view of specimen from the Late Eocene Hospital Hill Formation of Trinidad, X50; from BRÖNNIMANN (1950b, pl. 56, fig. 10).

2 Specimen from the Late Eocene Pachuta Formation of Alabama, X35; from BOLLI, LOEBLICH, & TAPPAN (1957, pl. 2, fig. 8). **a**–Peripheral view with apertural face; **b**–lateral view.

3-5 Lateral views of specimens from Late Eocene part of the Oceanic Formation of Barbados, X50; from BRÖNNIMANN (1950b, pl. 56, fig. 14-16).

6-7 Specimens from the Middle Eocene of northeastern Gulf of Mexico, X100. **6**–Peripheral view showing aperture; **7**–lateral view.

Surface finely pitted, inner whorls distinctly hispid. Diameter commonly 0.8 to 1.0 mm exclusive of spines.

Discussion.–*Hantkenina alabamensis* is the type species of the genus *Hantkenina*. It differs from *Hantkenina primitiva* in having more inflated and more rapidly enlarging chambers and in being more tightly coiled. No spines occur in early ontogenetic stages of *H. primitiva*.

Distribution.–Widely recorded in the late Middle and Late Eocene. First described from the Upper Eocene (Jackson) of Alabama.

GLOBOROTALIA ANGULATA (White, 1928)

Figure 34

Middle Paleocene

Globigerina angulata WHITE, 1928, p. 191, pl. 27, fig. 13.

Acarinina conicotruncata (SUBBOTINA) (part). SUBBOTINA, 1953, p. 220-222, pl. 20, fig. 11.–SUBBOTINA, 1971, p. 281, 284-287, pl. 20, fig. 11.

Globorotalia angulata (WHITE). BOLLI, 1957a, p. 74, pl. 17, fig. 10-12 [given as transitional form between *Globorotalia uncinata* and *Globorotalia angulata*].–LOEBLICH & TAPPAN, 1957a, p. 187, pl. 45, fig. 7; pl. 48, fig. 2; pl. 55, fig. 6; pl. 64, fig. 5.–LUTERBACHER, 1964, p. 658-660, fig. 37-39.

Globorotalia (Morozovella) angulata (WHITE). JENKINS, 1971, p. 102, pl. 8, fig. 183-184.

Test umbilico-convex, spiral side flat or only slightly convex. Periphery lobate. Last whorl of 4 to 5 angular-conical chambers which increase rapidly in size. Last chamber approximately one-third of whorl. Umbilicus narrow and deep. Umbilical shoulders rounded, commonly protruding over umbilicus and on last chamber distinctly raised above level of preceding set. Sutures depressed; radial on umbilical side, strongly curved on spiral side, often indistinct on inner whorl. Aperture a low arch with faint lip, extraumbilical-umbilical. Surface covered with fine spines which are concentrated on umbilical shoulders and around periphery but without forming definite keel. Diameter 0.4 to 0.5 mm.

Discussion.–Authors vary between strict and loose definition of *Globorotalia angulata* (see LUTERBACHER, 1964, p. 658-663). BOLLI (1957a) included under *angulata* forms which we separate as *Globorotalia conicotruncata* and *Globorotalia simulatilis*. The concept applied here is that *Globorotalia angulata* evolved from *Globorotalia pseudobulloides* by way of *Globorotalia uncinata* and is distinguishable from other species. It has fewer and, therefore, more rapidly enlarging chambers in the last whorl than *G. conicotruncata*. Conversely, *G. simulatilis* has more chambers in the last whorl than *G. angulata*, as well as a convex spiral side and a less lobate periphery.

Distribution.–Middle Paleocene (*Globorotalia angulata* Zone to within *Globorotalia pseudomenardii* Zone). The oldest representatives of this species are small and closely similar to *G. uncinata* whereas the youngest are transitional towards *Globorotalia aequa*. The level of first appearance of *G. angulata* has been widely used as a zonal datum. The species was first recorded in the Middle Paleocene part of the Velasco Formation of eastern Mexico.

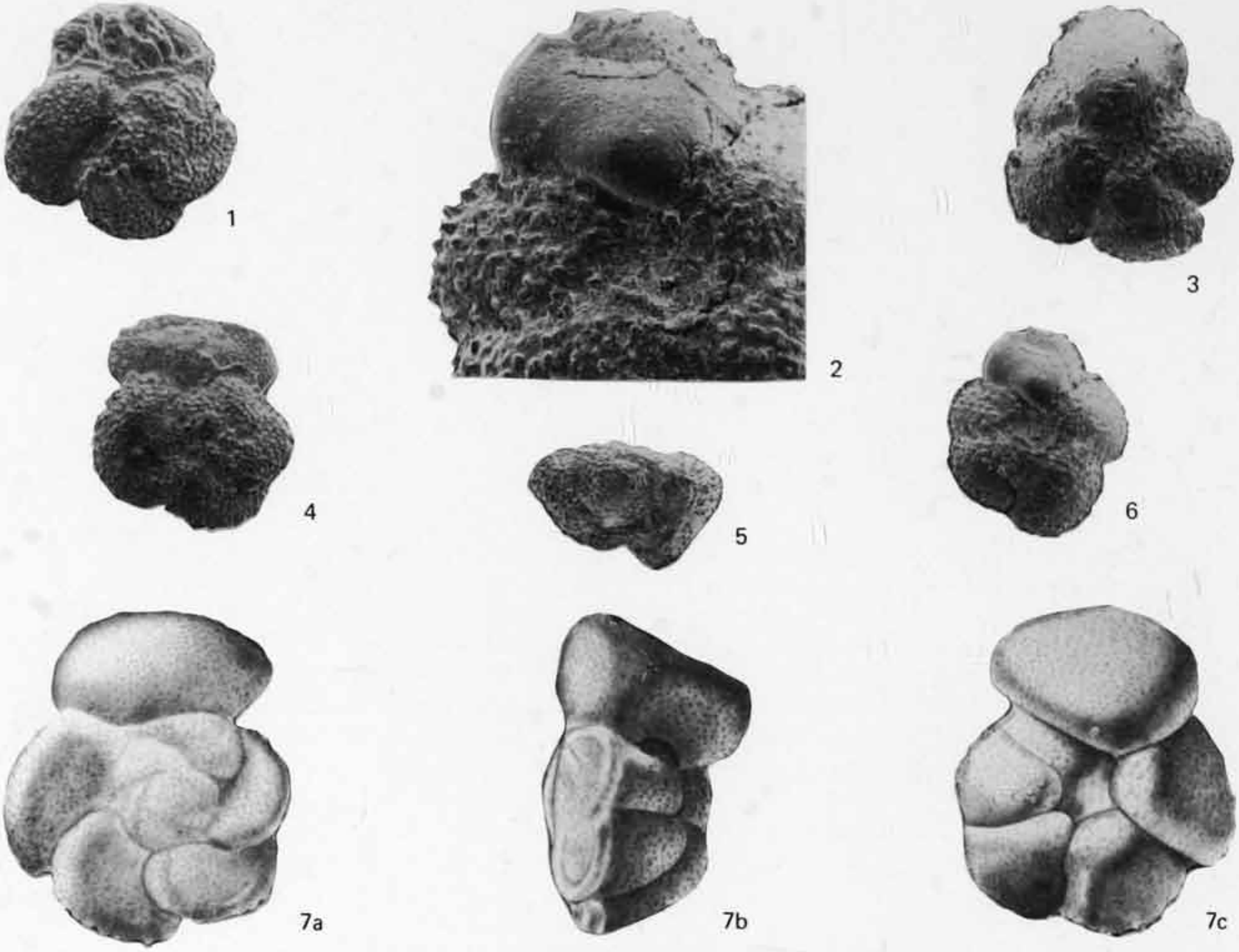


Fig. 34. *Globorotalia angulata* (WHITE) from the Middle Paleocene *Globorotalia pusilla pusilla* Zone of Mexico and Trinidad.

1-6 Specimens from the Velasco Formation of Mexico. **1,4**–Spiral views, X100; **2**–detail of umbilical side, X250; **3,6**–umbilical views, X100; **5**–side view, X100.

7 Specimen from the Lizard Springs Formation of Trinidad, X100; from BOLLI (1957a, pl. 17, fig. 10-12). **a**–Spiral view; **b**–side view; **c**–umbilical view.

GLOBOROTALIA ARAGONENSIS Nuttall, 1930
Figure 35
Early to Middle Eocene

Globorotalia aragonensis NUTTALL, 1930, p. 288, pl. 24, fig. 6-11.–SUBBOTINA, 1953, p. 215-216, pl. 18, fig. 6-7.–BOLLI, 1957a, p. 75, pl. 18, fig. 7-9.–BOLLI, 1957c, p. 167, pl. 38, fig. 1.–LUTERBACHER,1964, p. 696-698, fig. 121-126.–SUBBOTINA, 1971, p. 274-275, pl. 18, fig. 6-7.

Globorotalia (Truncorotalia) aragonensis NUTTALL. CUSHMAN & BERMÚDEZ, 1949, p. 38, pl. 7, fig. 13-15.

Pseudogloborotalia aragonensis (NUTTALL). BERMÚDEZ, 1960, p. 1338-1340, pl. 16, fig. 5.

Test umbilico-convex, spiral side flat or with only slightly convex inner portion. Periphery almost circular, acute, with distinct keel. Last whorl of 5 to 7 angular-conical chambers increasing fairly rapidly in size. Sutures on spiral side flush or slightly raised and beaded, forming distinct angle with periphery; on umbilical side radial, moderately depressed. Umbilical chamber tips rounded, tightly grouped around deep, narrow umbilicus. Aperture a low arch, extraumbilical-umbilical, with distinct lip. Wall generally thick and rugose, especially on umbilical side. Diameter 0.4 to 0.5 mm.

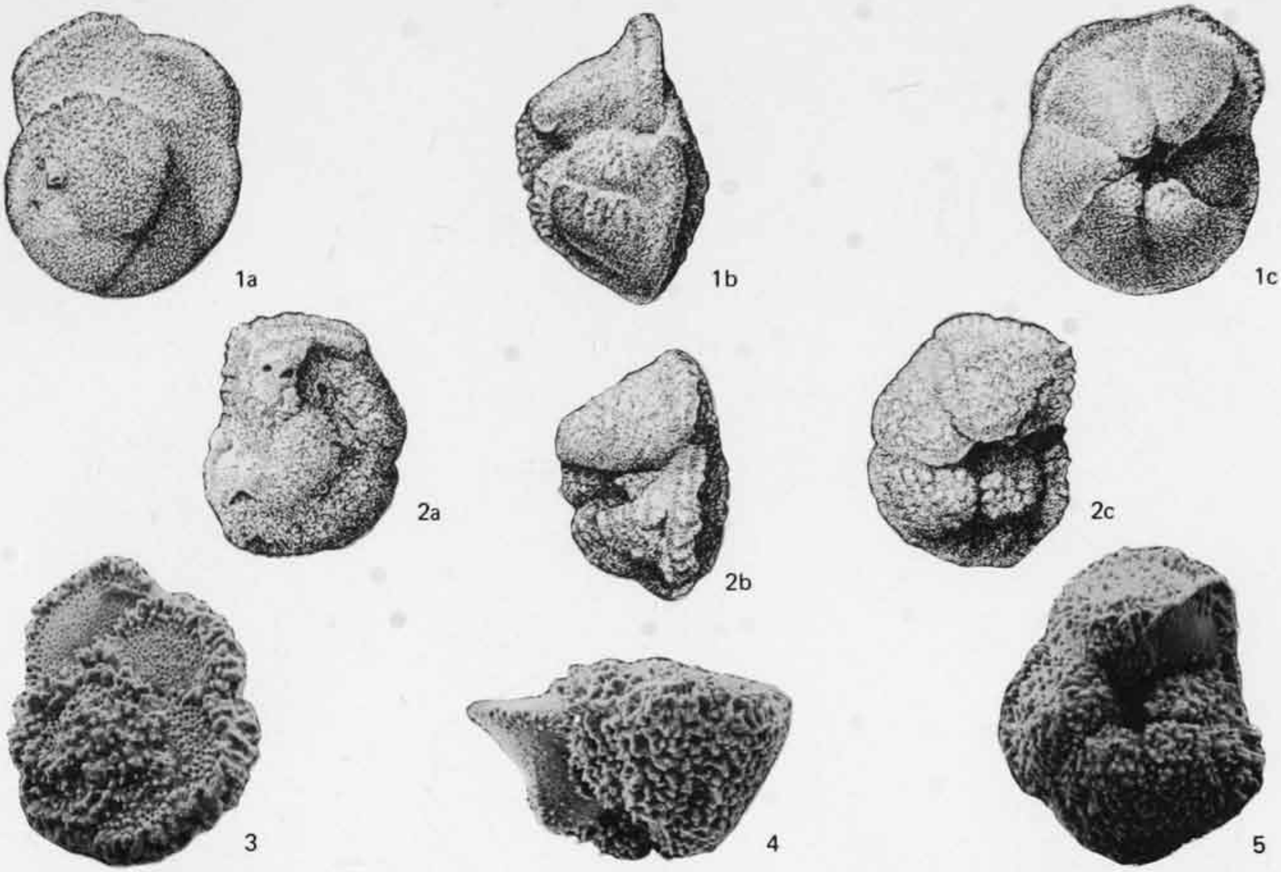


Fig. 35. *Globorotalia aragonensis* NUTTALL from the Lower Eocene of the Soviet Union and France.
1-2 Specimens from the northern Caucasus in the Soviet Union, X72; from SUBBOTINA (1953, pl. 18, fig. 6; pl. 18, fig. 4). **a**–Spiral views; **b**–side views; **c**–umbilical views.
3-5 Specimens from Dozacq in southwestern France, X100. **3**–Spiral view; **4**–side view; **5**–umbilical view.

Discussion.–*Globorotalia aragonensis* is distinguished from its ancestor *Globorotalia lensiformis* by more numerous chambers and compact appearance. The abrupt angle between sutures and keel on the spiral side is very characteristic of this species.

Distribution.–Early and Middle Eocene (*Globorotalia formosa formosa* to *Globigerinatheka subconglobata* Zones). Coiling of *G. aragonensis* is almost exclusively dextral in early assemblages but later becomes predominantly sinistral. The later representatives of the species generally have only five chambers in the last whorl and are less compactly built. This species was first described from the Middle Eocene Aragón Formation of eastern Mexico.

HANTKENINA ARAGONENSIS Nuttall, 1930
Figure 36
Middle Eocene

Hantkenina mexicana CUSHMAN var. *aragonensis* NUTTALL, 1930, p. 284, pl. 24, fig. 1-3.–SHOKHINA, 1937, p. 449, pl. 2, fig. 9-11.
Hantkenina aragonensis NUTTALL. SUBBOTINA, 1953, p. 130-131, pl. 1, fig. 13.–BOLLI, LOEBLICH, & TAPPAN, 1957, pl. 2, fig. 3, 4.–SUBBOTINA, 1971, p. 143, 144, pl. 1, fig. 13.

Test planispiral, involute, biumbilicate, stelliform. Last whorl composed of 5 to 6 rapidly increasing, radially elongate, finger- to pear-shaped chambers which are well individualized, each tapering outwards to stout terminal spine. Sutures depressed, radial to slightly curved. Umbilici shallow with

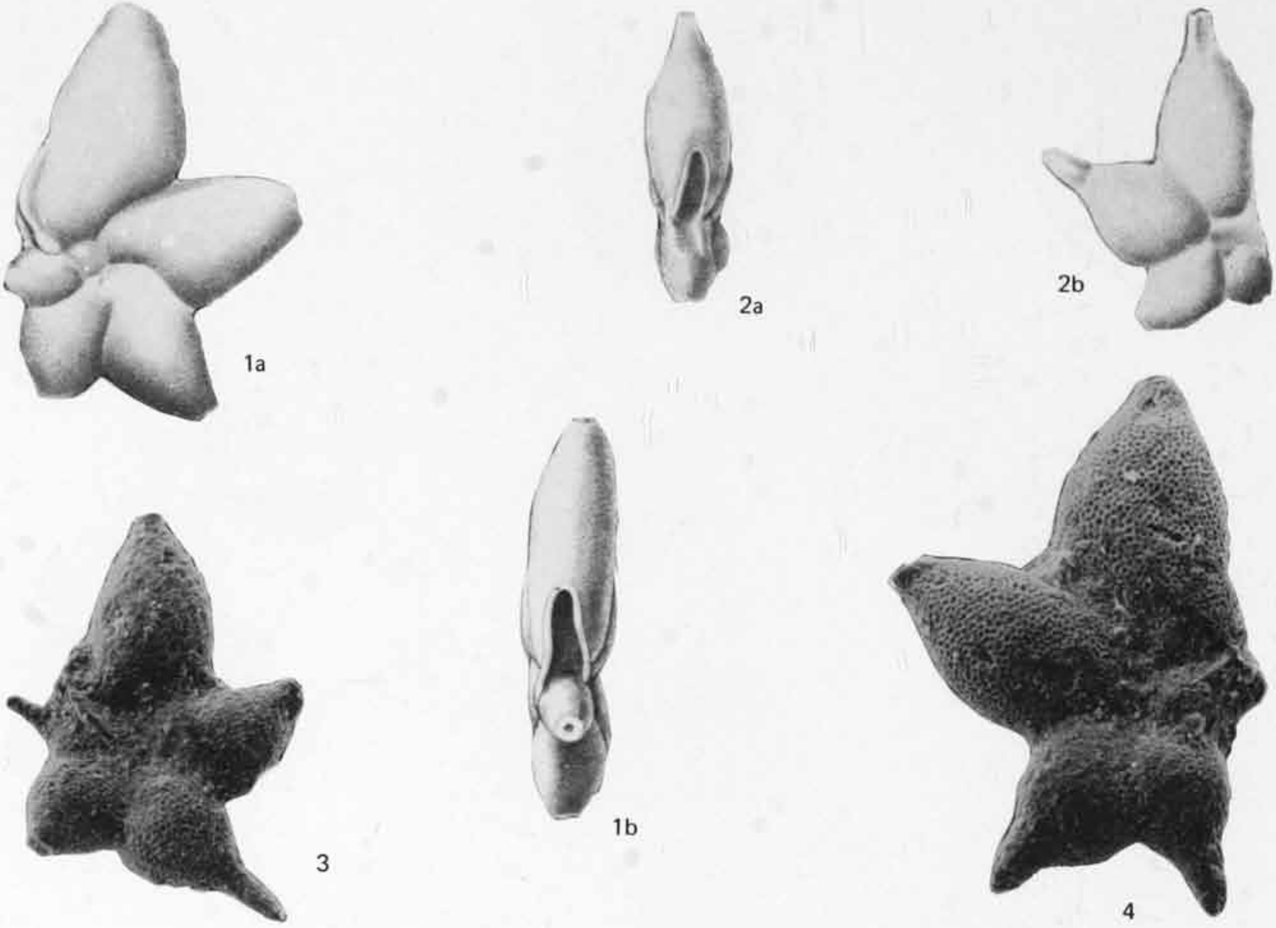


Fig. 36. *Hantkenina aragonensis* NUTTALL from the Middle Eocene of Mexico and the Soviet Union.
1-2 Specimens (**1**=lectotype) from the Aragon Formation of Mexico, X60; from BOLLI, LOEBLICH, & TAPPAN (1957, pl. 2, fig. 3-4). **1a,2b**—Lateral views; **1b,2a**—apertural views.
3-4 Lateral views of specimens from western Turkmenia, Soviet Union, X100.

chambers of earlier whorls often visible. Aperture interiomarginal, equatorial, triradiate, extending about halfway up apertural face, bordered by apertural flanges which join above as narrow lip. Wall finely pitted. Diameter 0.7 to 0.8 mm.

Discussion.—BRÖNNIMANN (1950b) included *Hantkenina aragonensis* in *Hantkenina mexicana*, but the latter species has less elongated and less inflated chambers with generally longer spines. The length of the spines in *H. aragonensis* seldom reaches half the chamber length whereas in *H. mexicana* it equals or exceeds the chamber length.

Distribution.—Middle Eocene (*Hantkenina aragonensis* Zone to approximately *Globorotalia lehneri* Zone). Though used to name a zone, *H. aragonensis* is not an ideal index because of its patchy distribution. It was first described from the Middle Eocene Aragón Formation of Mexico.

GLOBIGERINATHEKA BARRI Brönnimann, 1952
Figure 37
Middle Eocene

Globigerinatheka barri BRÖNNIMANN, 1952a, p. 27-28, fig. 1.—BOLLI, LOEBLICH, & TAPPAN, 1957, p. 38, pl. 7, fig. 12.—BOLLI, 1957c, p. 166, pl. 37, fig. 8-9.
Globigerinatheka mexicana barri BRONNIMANN. BOLLI, 1972a, p. 128, fig. 21-26, pl. 1, fig. 18-21; pl. 2, fig. 8-20; pl. 4, fig. 1-6.

Test subglobular, consisting of trochospiral *Globigerina*-like initial stage and large enveloping final

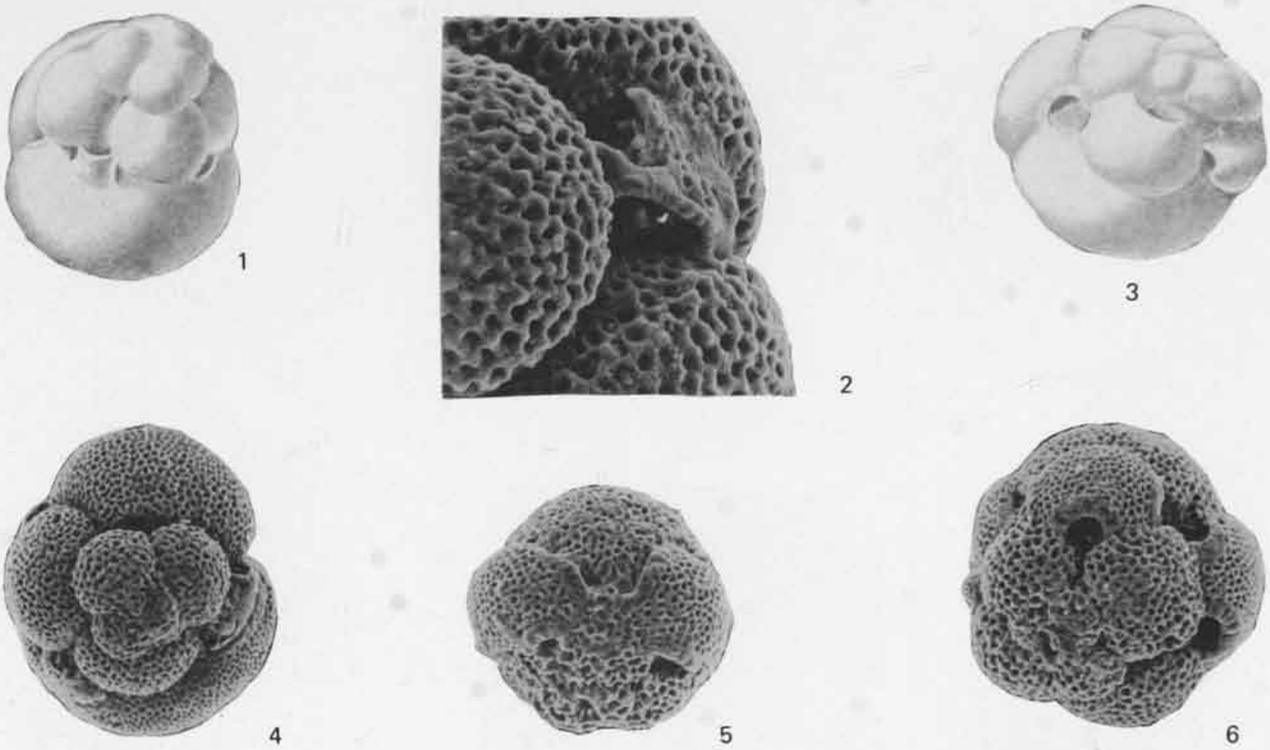


Fig. 37. *Globigerinatheka barri* BRONNIMANN from the Middle Eocene part (*Orbulinoides beckmanni* Zone) of the Navet Formation of Trinidad.

1,3 Oblique side views of specimens, X73; from BOLLI (1957c, pl. 37, fig. 8-9).

2,4-6 Representative specimens. **2**–Detail of secondary aperture, X250; **4**–spiral view, X100; **5**–side view, X100; **6**–oblique spiral view, X100.

chamber covering whole umbilicus. Sutures depressed, radial. Primary aperture as in *Globigerina* but hidden by enveloping final chamber. Multiple well-defined secondary sutural apertures on spiral side, may be covered by small bullas. Diameter 0.4 to 0.5 mm.

Discussion.–*Globigerinatheka barri* is the type species of *Globigerinatheka*, a genus now expanded to include nonbullate specimens formerly placed in *Globigerapsis*. This species differs from *Globigerinatheka kugleri* in having a smaller and more tightly coiled initial spire and less inflated chambers. It is closely related to *Globigerinatheka mexicana* but has slightly more inflated chambers, smaller final chamber, and more delicate over-all aspect. A more detailed discussion of relations among representatives of the genus *Globigerinatheka* was given by BOLLI (1972a).

Distribution.–Middle Eocene (upper part of *Globigerinatheka subconglobata* Zone) to base of Upper Eocene (lower part of *Globigerinatheka semiinvoluta* Zone). The holotype of *G. barri* was described from marl boulders of the Middle Eocene Navet Formation reworked into the Late Eocene Mount Moriah Formation of Trinidad (see PROTO DECIMA & BOLLI, 1970, p. 888-889).

ORBULINOIDES BECKMANNI (Saito, 1962)

Figure 38

Middle Eocene

Globigerinoides mexicana (CUSHMAN). BECKMANN, 1953, p. 393, pl. 25, figs. 17-19. [Not of CUSHMAN, 1925b.]

Porticulasphaera mexicana (CUSHMAN). BOLLI, LOEBLICH, & TAPPAN, 1957, p. 35, pl. 6, fig. 8-9.–BOLLI, 1957c, p. 165, pl. 37, fig. 1.–LOEBLICH & TAPPAN, 1964, p. C676. [Not of CUSHMAN, 1925b.]

Porticulasphaera beckmanni SAITO, 1962, p. 221-222, pl. 34, fig. 1-2.

Orbulinoides beckmanni (SAITO). CORDEY, 1968b (June), p. 371-375, fig. 1.–BLOW & SAITO, 1968 (July), p. 357-360.–BLOW, 1969, p. 331-332, pl. 27, fig. 7.–PROTO DECIMA & BOLLI, 1970, p. 895-899, fig. 16-30, 32-37, 46-47, pl. 1, fig. 12; pl. 2, fig. 1-12; pl. 3, fig. 6-12; pl. 4, fig. 1-9.

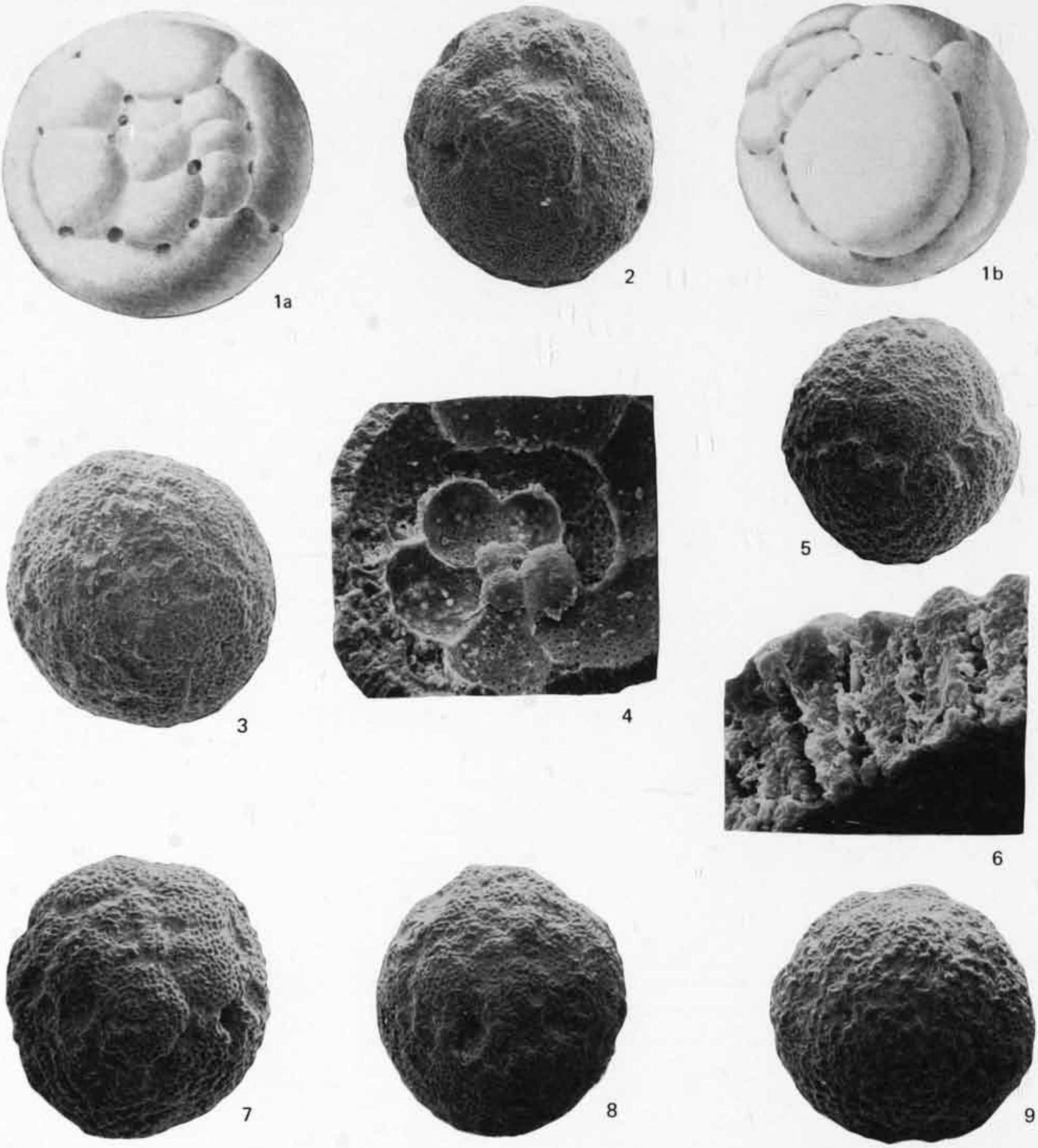


Fig. 38. *Orbulinoides beckmanni* (SAITO) from the Middle Eocene *Orbulinoides beckmanni* Zone of Trinidad and Barbados.

1 Specimen from the Navet Formation of Trinidad, X73; from BOLLI (1957c, pl. 37, fig. 1). **a**–Spiral view; **b**–side view.

2-9 Specimens from the Oceanic Formation of Barbados. **2**–Oblique view, X70; **3,5**–side views, X75, X70; **4**–broken specimen showing early globigerinid coil, X250; **6**–thick wall of last chamber, X1000; **7**–spiral view, X70; **8**–oblique spiral view, X75; **9**–side view of specimen having large final chamber, X75.

Test almost spherical; early part *Globigerina*-like almost enveloped by strongly inflated, globular later portion. Sutures depressed; initially radial, later curved. No primary aperture in adult; multiple sutural openings, especially along suture of final chamber. Wall thick relative to size; coarsely perforate. Diameter to 0.7 mm.

Discussion.–Confusion of this species with *Globigerina mexicana* CUSHMAN led to several nomenclatural difficulties. SAITO (1962) gave it the new trivial name *beckmanni* but retained it in a genus *(Porticulasphaera)* which is actually a junior synonym of the morphologically distinct *Globigerapsis (=Globigerinatheka)*. BLOW & SAITO (1968, July) proposed to resolve the problem by erecting for this form the new monospecific genus *Orbulinoides*. CORDEY (1968b, June) utilized BLOW and SAITO'S manuscript in preparing a detailed morphologic study, however, and is the author of this generic name (International Code of Zoological Nomenclature, Arts. 23, 50) because his paper was published first. CORDEY (1968b) and PROTO DECIMA & BOLLI (1970) gave many details for the test of *Orbulinoides* and on its relationship with *Globigerinatheka*. *Orbulinoides beckmanni* is a very distinctive species, grossly similar to some stages in the *Praeorbulina-Orbulina* lineage but readily distinguished from those Miocene forms.

Distribution.–Restricted to part of the late Middle Eocene; hence, its total range has been used to define a zone which was introduced as the *Porticulasphaera mexicana* Zone by BOLLI (1957c), but renamed the *Orbulinoides beckmanni* Total-range Zone by later authors (e.g., BLOW, 1969, p. 205). The index species has been recognized around the world in tropical to subtropical latitudes but generally not in more temperate regions.

GLOBOROTALIA BROEDERMANNI

Cushman & Bermúdez, 1949

Figure 39

Early to Middle Eocene

Globorotalia (Truncorotalia) broedermanni CUSHMAN & BERMÚDEZ, 1949, p. 40, pl. 7, fig. 22-24.

Globorotalia broedermanni CUSHMAN & BERMÚDEZ. BOLLI, 1957a, p. 80, pl. 19, fig. 13-15.–BOLLI, 1957c, p. 167, pl. 37, fig. 13.

Globorotalia convexa SUBBOTINA, 1953, p. 209-210, pl.

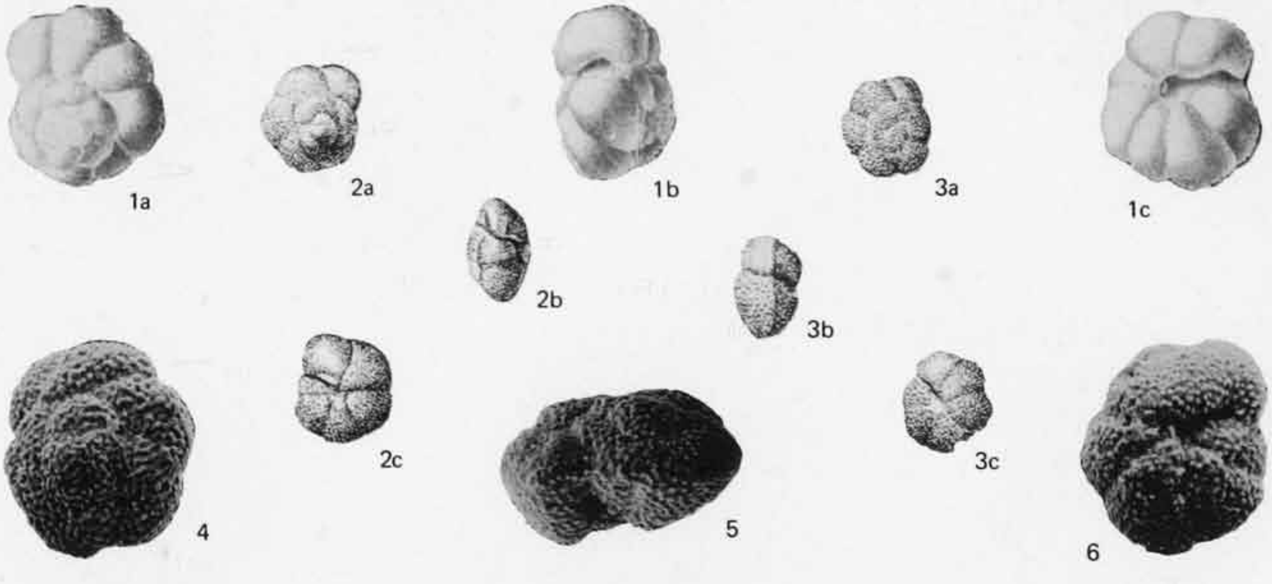


Fig. 39. *Globorotalia broedermanni* CUSHMAN & BERMÚDEZ from the Early Eocene of Trinidad, Soviet Union, and Gulf of Mexico.

1 Specimen from the *Globorotalia pentacamerata* Zone of the Navet Formation of Trinidad, X73; from BOLLI (1957c, pl. 37, fig. 13). **a**–Spiral view; **b**–side view; **c**–umbilical view.

2-3 Specimens from the northern Caucasus in the Soviet Union, X72; from SUBBOTINA (1953, pl. 17, fig. 2-3). **a**–Spiral views; **b**–side views; **c**–umbilical views.

4-6 Specimens from northeastern Gulf of Mexico, X100. **4**–Spiral view; **5**–side view; **6**–umbilical view.

17, fig. 2-3.–SUBBOTINA, 1971, p. 263, pl. 17, fig. 2-3. *Pseudogloborotalia broedermanni* (CUSHMAN & BERMÚDEZ). BERMÚDEZ, 1960, p. 1340, pl. 16, fig. 6.

Test a rather small, low trochospire; biconvex, moderately compressed. Periphery nearly circular, in side view rounded to subangular. Last whorl has 5 to 6 ovate to angular-rhomboid chambers which increase only slowly in size. Umbilicus narrow, open. Sutures slightly depressed; radial on umbilical side, curved on spiral side. Aperture a low arch, extraumbilical-umbilical in position. Surface hispid in well-preserved specimens. Diameter seldom exceeds 0.3 mm.

Discussion.–*Globorotalia convexa* is here placed in synonymy with *Globorotalia broedermanni* as no significant differences are discernible. This species differs from the closely related *Globorotalia pseudoscitula* in being less compressed and lacking the sharpened, faintly keeled margin.

Distribution.–Early to Middle Eocene (*Globorotalia subbotinae* Zone to *Globigerinatheka subconglobata* Zone). *Globorotalia broedermanni* was first described from the Early Eocene Capdevila Formation of Cuba, *G. convexa* from the late Early Eocene of the northern Caucasus.

GLOBOROTALIA BULLBROOKI Bolli, 1957

Figure 40
Middle Eocene

Globorotalia bullbrooki BOLLI, 1957c, p. 167-168, pl. 38, fig. 4-5.

Test umbilico-convex, spiral side flat or slightly convex, umbilical side strongly convex, subconical. Periphery lobate, rounded to subacute in side view

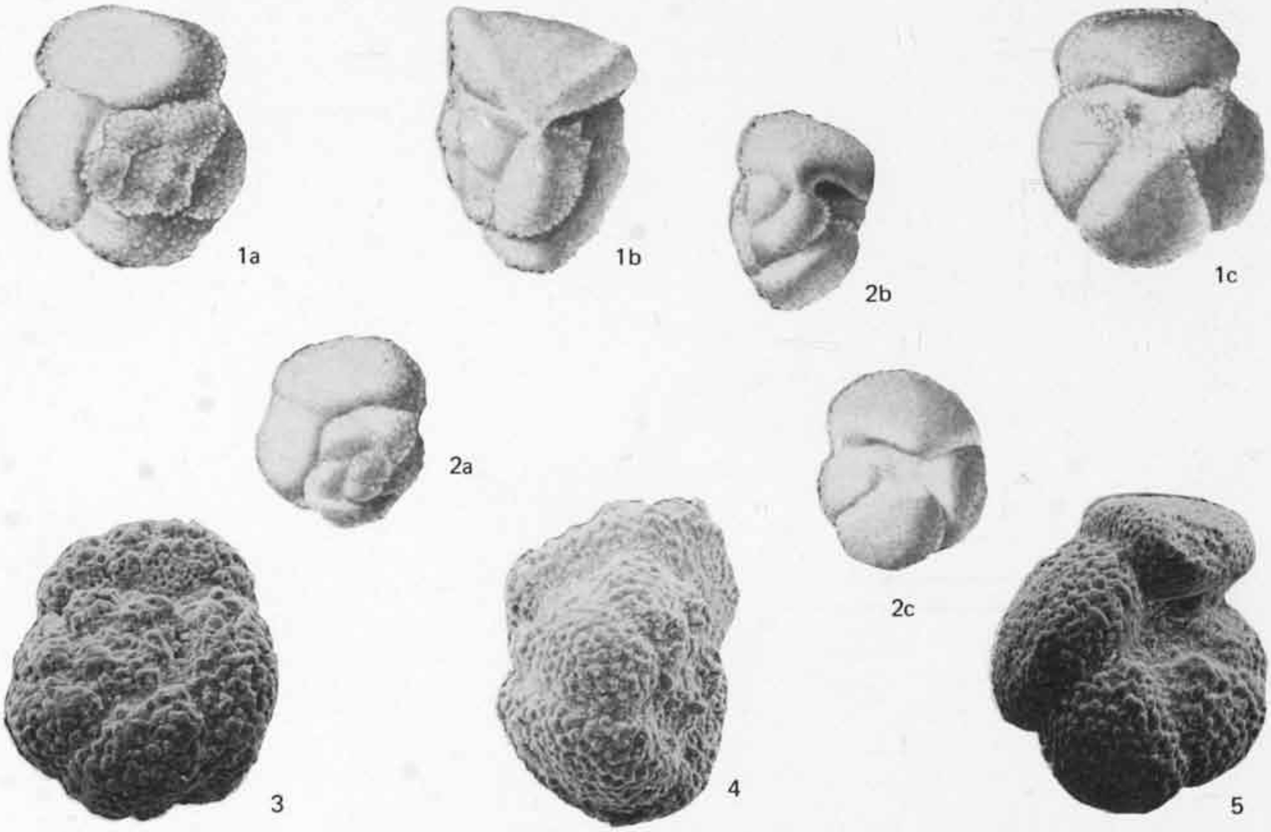


Fig. 40. *Globorotalia bullbrooki* BOLLI from the Middle Eocene part (*Hantkenina aragonensis* Zone) of the Navet Formation of Trinidad.

1-2 Specimens (**1**=holotype), X73; from BOLLI (1957c, pl. 38, fig. 4-5). **a**–Spiral views; **b**–side views; **c**–umbilical views.

3-5 Representative specimens, X100. **3**–Spiral view; **4**–side view; **5**–umbilical view.

but without keel. Last whorl composed of 4 somewhat imbricated, subangular chambers which increase fairly rapidly in size. Umbilicus narrow and deep. Sutures depressed; radial to oblique on spiral side, radial on umbilical side. Aperture a low arch, extraumbilical-umbilical. Surface of test spiny, especially on umbilical side. Diameter 0.4 to 0.5 mm.

Discussion.–Our choice of the name *bullbrooki* is somewhat arbitrary. A group of rather small, spiny species of *Globorotalia* having subangular-conical chambers and no distinct keel commonly occurs abundantly in the Middle Eocene. Modern authors differ in criteria for applying to these such names as *bullbrooki*, *crassata*, *crassula*, *densa*, *rotundimarginata*, and *spinuloinflata*. Careful analysis of the several type specimens is necessary to resolve the taxonomic confusion. Workers tend to prefer the name *Globorotalia spinuloinflata* for this highly variable group, but many base their use of this name on BOLLI'S concept (1957c, p. 168, pl. 38, fig. 8) which differs from *Globorotalia spinuloinflata* as originally described by BANDY (1949, p. 122, pl. 23, fig. 1) in including forms having less inflated chambers. *Acarinina rotundimarginata* (SUBBOTINA, 1953) probably is a junior synonym of BANDY'S species even though BERGGREN (1971b, p. 719) suggested equivalence to BOLLI'S form. To avoid a lengthy subjective discussion we elect to use the name *Globorotalia bullbrooki* strictly as defined by BOLLI and typified by having only four chambers in the final whorl, a subconical aspect, and a narrow umbilicus. It has a shorter upward range than others of the group.

CIFELLI (1972) refigured and redescribed the holotypes of *Globorotalia densa* (CUSHMAN) and of *Globorotalia spinuloinflata* (BANDY). The holotype of *G. densa* differs from *Globorotalia bullbrooki* in having a well developed keel and flush to only slightly depressed sutures on the spiral side. *Globorotalia spinuloinflata* has more inflated chambers and lacks the subconical aspect in side view.

Distribution.–Primarily Middle Eocene (*Hantkenina aragonensis* Zone to approximately *Orbulinoides beckmanni* Zone) although ancestral forms made a sparse appearance late in the Early Eocene. The species proliferated during the early Middle Eocene (*Globorotalia bullbrooki* Zone of some authors). The species was originally described from the Middle Eocene Navet Formation of Trinidad.

GLOBOROTALIA CAUCASICA Glaessner, 1937

Figure 41

Early Eocene

Globorotalia aragonensis NUTTALL var. *caucasica* GLAESSNER, 1937a, p. 31, pl. 1, fig. 6.

Globorotalia caucasica GLAESSNER. LUTERBACHER, 1964, p. 684, fig. 97.

Globorotalia velascoensis (CUSHMAN). SUBBOTINA, 1953, p. 216-219, pl. 19, fig. 1-3.–SUBBOTINA, 1971, p. 275-280, pl. 19, fig. 1-3.

Truncorotalia caucasica (GLAESSNER). REISS, 1957b, p. 239-241.

Globorotalia (Morozovella) crater caucasica GLAESSNER. JENKINS, 1971, p. 103, pl. 8, fig. 189-191.

Globorotalia (Morozovella) crater crater FINLAY. JENKINS, 1971, p. 103-104, pl. 8, fig. 192-197.

Test trochospiral, umbilico-convex with flat spiral side and strongly convex umbilical side. Periphery circular, acute with very distinct, commonly rimlike keel. Last whorl of 5 to 8 angular-conical chambers which increase regularly in size. Sutures on spiral side raised and beaded, oblique, forming a distinct angle with peripheral keel; on umbilical side depressed, radial. In heavily ornamented specimens, sutures on spiral side may be hidden by rugosity of test. Umbilical chamber tips prominent, pointed, carrying bunches of blunt spines; may be turned outwards. Umbilicus wide and deep. Aperture a low arch, extraumbilical-umbilical, with distinct lip. Surface of test rugose. Diameter 0.5 to 0.6 mm.

Discussion.–The late Early Eocene *Globorotalia caucasica* has often been confused with its homeomorph, the Late Paleocene *Globorotalia velascoensis;* single specimens of these two species indeed may be confused very easily. In *G. caucasica,* however, ornamentation generally is heavier than in *G. velascoensis* and the latter normally lacks the abrupt angle between sutures and keel on the spiral side. *Globorotalia caucasica* always occurs together with intermediate forms transitional to the easily distinguishable *Globorotalia aragonensis.* Relationship of *G. caucasica* to *Globorotalia crater* FINLAY (1939c) is not clear. JENKINS (1971) considered *G. caucasica* as a subspecies of *G. crater* (but *G. caucasica* is the prior species) because these forms differ only in number of chambers on the final whorl. Possibly *G. crater* is a highly ornamented member of the *Globorotalia formosa formosa* plexus, and *G. caucasica* is a homeomorph originating from *Globorotalia aragonensis* with which it is linked by transitional forms. The range of *G. crater* is used in

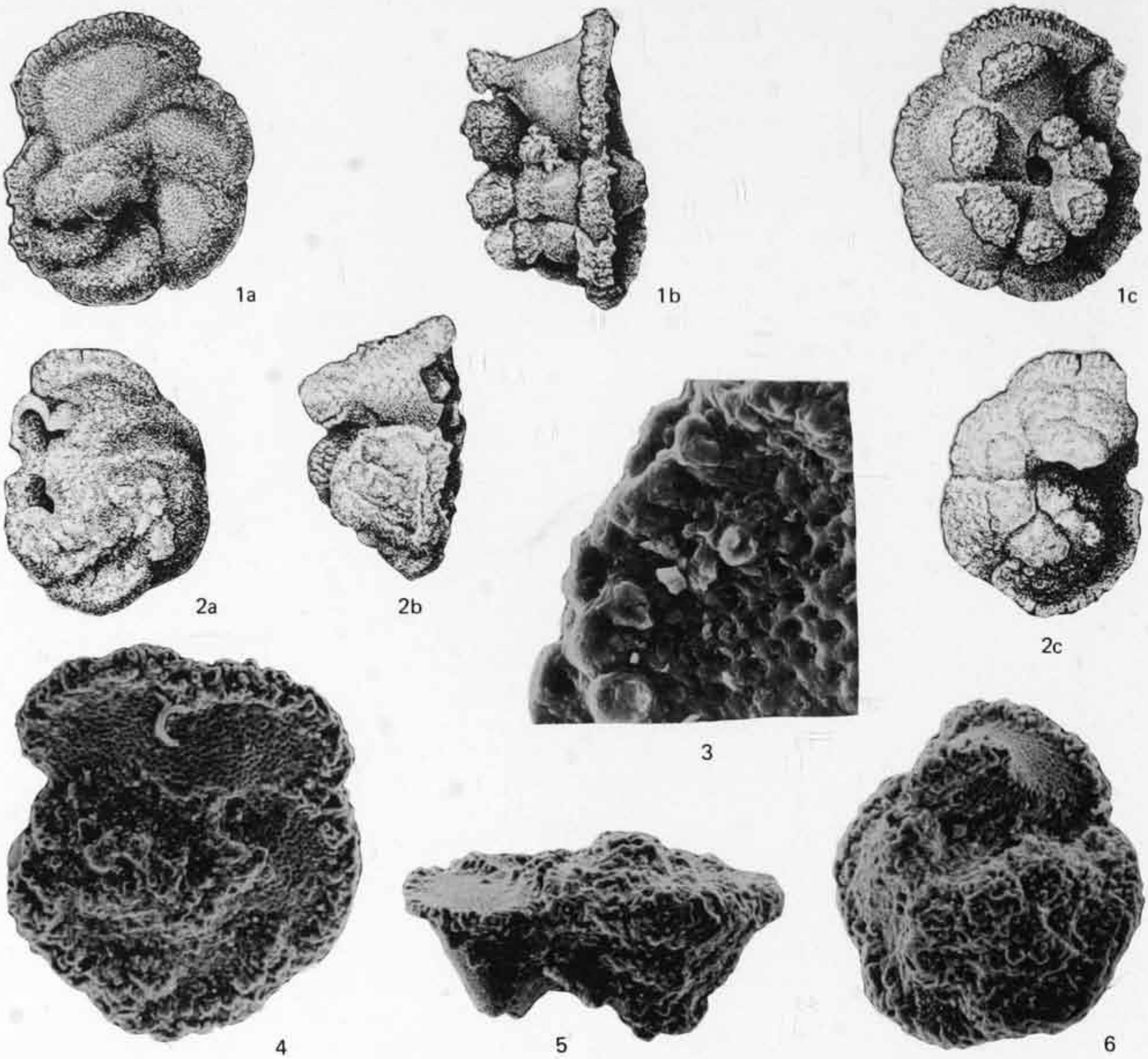


Fig. 41. *Globorotalia caucasica* GLAESSNER from the Lower Eocene of the northern Caucasus, Soviet Union.

1-2 Specimens (**2**=transitional to *Globorotalia aragonensis*), X72; from SUBBOTINA (1953, pl. 19, fig. 1-2). **a**–Spiral views; **b**–side views; **c**–umbilical views.

3-6 Specimens from the *Globorotalia pentacamerata* Zone. **3**–Detail of keel and shell surface, X500; **4**–spiral view, X100; **5**–side view, X100; **6**–umbilical view, X100.

New Zealand to define a zone corresponding (HORNIBROOK, 1967) to the *Globorotalia formosa formosa, Globorotalia aragonensis*, and *Globorotalia pentacamerata* Zones.

Distribution.–Late Early Eocene (from within *Globorotalia aragonensis* Zone to *Globorotalia pentacamerata* Zone) and possibly earliest Middle Eocene (unconfirmed records). *Globorotalia caucasica* is found mainly in temperate latitudes. This species was first described from late Early Eocene deposits of the northern Caucasus.

GLOBOROTALIA CHAPMANI Parr, 1938

Figure 42

Middle Paleocene to Early Eocene

Globorotalia chapmani PARR, 1938, p. 87, pl. 9, fig. 8-9.–MCGOWRAN, 1964, p. 85-86, pl. 1, fig. 1-9.–BERGGREN, OLSSON, & REYMENT, 1967, p. 277-278, fig. 1, 3 (no. 1), 4 (no. 1), pl. 1, fig. 1-6.

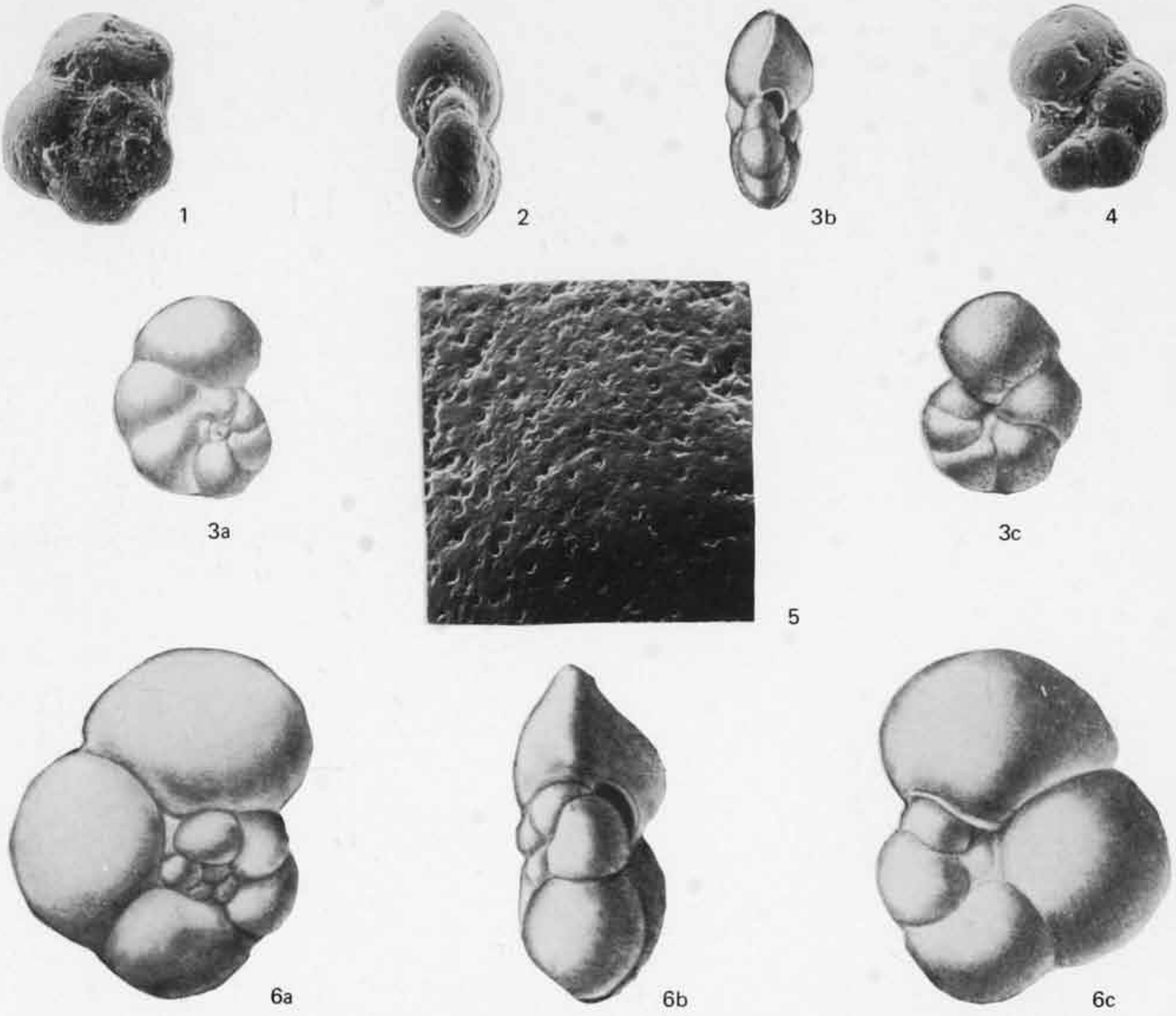


Fig. 42. *Globorotalia chapmani* PARR from the Paleocene of Soviet Union, Trinidad, and Mexico.

1-2,4-5 Specimens from the Middle Paleocene of the northern Caucasus, Soviet Union. **1**–Spiral view, X100; **2**–side view, X100; **4**–umbilical view, X100; **5**–surface of last chamber, X1000.

3 Specimen from the Late Paleocene part (*Globorotalia pseudomenardii* Zone) of the Lizard Springs Formation of Trinidad, X100; from BOLLI (1957a, pl. 20, fig. 11-13). **a**–Spiral view; **b**–side view; **c**–umbilical view.

6 Specimen from the Late Paleocene part (*Globorotalia pseudomenardii* Zone) of the Velasco Formation of Mexico, X145; from LOEBLICH & TAPPAN (1957a, pl. 63, fig. 6). **a**–Spiral view; **b**–side view; **c**–umbilical view.

Globorotalia elongata GLAESSNER. BOLLI, 1957a, p. 77-78, pl. 20, fig. 11-13.–LOEBLICH & TAPPAN, 1957a, p. 189, pl. 45, fig. 5; pl. 46, fig. 5; pl. 48, fig. 5; pl. 49, fig. 7; pl. 54, fig. 1-5; pl. 59, fig. 4; pl. 60, fig. 9; pl. 63, fig. 2.

Globorotalia ehrenbergi BOLLI, 1957a, p. 77, pl. 20, fig. 18-20.

Globorotalia troelseni LOEBLICH & TAPPAN, 1957a, p. 196, pl. 60, fig. 4; pl. 63, fig. 5.

Test very low trochospiral, biconvex, almost equilateral; umbilical side only slightly more convex than spiral side. Last whorl with 4 to 6 angular-rhomboid chambers which increase fairly rapidly in size, last chamber occupying as much as one-third of whorl. Periphery lobate, subacute in axial view. Sutures depressed; curved on spiral side, radial to slightly curved on umbilical side. Umbilicus wide and shallow, matched by depression of inner whorls on spiral side. Aperture a relatively high arch, extraumbilical-umbilical, generally with faint lip. Even in almost planispiral specimens, aperture extends slightly to umbilical side. Surface of test smooth. Diameter 0.3 mm.

Discussion.—According to MCGOWRAN (1964) *Globorotalia chapmani* has an imperforate marginal band which gives the impression of a keel, but the wall is not thickened in this region. This species is intermediate between *Globorotalia compressa* (which lacks the imperforate band) and *Globorotalia pseudomenardii* (which has acquired a true keel). *Globorotalia chapmani* is regarded (BERGGREN, OLSSON, & REYMENT, 1967), as the direct ancestor of *Pseudohastigerina wilcoxensis*.

Distribution.—Middle Paleocene to Early Eocene (*Globorotalia pusilla pusilla* Zone to *Globorotalia subbotinae* Zone). Originally described from beds considered to be Upper Eocene (PARR, 1938) but now placed in the Paleocene *Globorotalia pseudomenardii* Zone (MCGOWRAN, 1964).

GLOBOROTALIA COMPRESSA (Plummer, 1926)

Figure 43

Paleocene

Globigerina compressa PLUMMER, 1926, p. 135, pl. 8, fig. 11.

Globigerina compressa var. *compressa* PLUMMER. SUBBOTINA, 1953, p. 55-56, pl. 2, fig. 4-5.—SUBBOTINA, 1971, p. 63-65, pl. 2, fig. 4-5.

Globorotalia compressa (PLUMMER). BOLLI, 1957a, p. 77, pl. 20, fig. 21-23.—POSTUMA, 1971, p. 186-187.

Test a small low trochospire, biconvex with umbilical side only slightly more convex than spiral side. Periphery lobate, in side view rounded to subacute, without keel or imperforate marginal band. Last whorl of 4 to 5 ovate chambers which increase rather rapidly in size. Last chamber somewhat elongated radially, occupying one-fourth to more than one-third of whorl. Umbilicus wide and shallow. Sutures depressed; on spiral side slightly curved, on umbilical side radial. Aperture a low arch, extraumbilical-umbilical in position, with distinct lip in well-preserved specimens. Surface of test smooth. Diameter 0.2 mm.

Discussion.—*Globorotalia compressa* is the predecessor of *Globorotalia chapmani* and differs in the generally smaller size and ovate instead of angular-rhomboid chambers.

Distribution.—Early to Middle Paleocene (within *Globorotalia pseudobulloides* Zone to approximately *Globorotalia angulata* Zone). Its extinction level is indefinite because juveniles of descendants closely resemble the parent species. This species was first described from the Paleocene Midway Formation of Texas.

GLOBOROTALIA CONICOTRUNCATA Subbotina, 1947

Figure 44

Paleocene

Globorotalia conicotruncata SUBBOTINA, 1947, p. 115-116, pl. 4, fig. 11-13; pl. 9, fig. 9-11.—LUTERBACHER, 1964, p. 660-663, fig. 40-42, 46-51.

Acarinina conicotruncata (SUBBOTINA) (part). SUBBOTINA, 1953, p. 220-222, pl. 20, fig. 6-8, 10.—SUBBOTINA, 1971, p. 281, 284-287, pl. 20, fig. 6-8, 10 [original types refigured].

Globorotalia angulata abundocamerata BOLLI, 1957a, p. 74, pl. 17, fig. 4-6.

Globorotalia apanthesma LOEBLICH & TAPPAN, 1957a, p. 187-188, pl. 48, fig. 1; pl. 55, fig. 1; pl. 58, fig. 4; pl. 59, fig. 1.

Globorotalia hispidocidaris LOEBLICH & TAPPAN, 1957a, p. 190, pl. 58, fig. 1.

Globorotalia abundocamerata BOLLI. POSTUMA, 1971, p. 166-167.

Test umbilico-convex; spiral side flat to slightly convex, umbilical side strongly convex. Periphery slightly lobate to subcircular, in side view acute; may have faint keel. Last whorl contains 5 to 8 angular-conical chambers, closely packed and increasing rather slowly in size. Sutures on spiral side slightly depressed or flush, curved; commonly indistinct on inner whorl; on umbilical side depressed, radial. Aperture a low arch, extraumbilical-umbilical in position, with faint lip. Surface of test covered with fine spines which tend to concentrate on umbilical shoulders and at periphery. Diameter 0.4 to 0.5 mm.

Discussion.—Several authors have included *Globorotalia conicotruncata* in the synonymy of *Globorotalia angulata*, but the former differs in having more chambers in the last whorl and in the more compact shape of its test which resembles a truncated cone.

Distribution.—Middle to Late Paleocene (within *Globorotalia angulata* Zone to within *Globorotalia pseudomenardii* Zone). The main occurrence is in the *Globorotalia pusilla pusilla* Zone (=*Globorotalia conicotruncata* Zone of Soviet authors). The species was first described from the Middle Paleocene of the northern Caucasus.

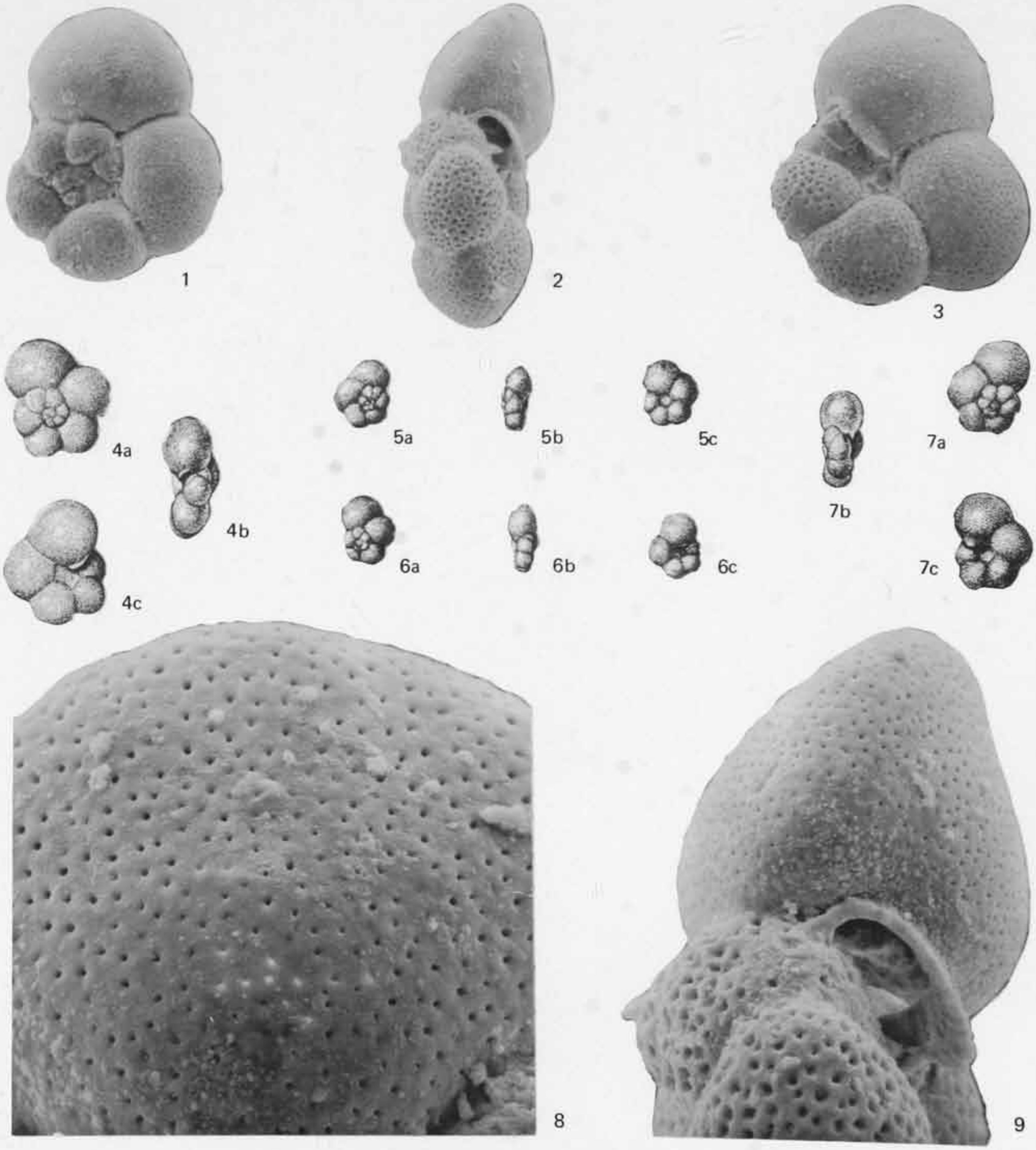


Fig. 43. *Globorotalia compressa* (PLUMMER) from the Paleocene of Texas and Soviet Union.

1-3,8-9 Specimens from the Early Paleocene Midway Formation (*Globorotalia trinidadensis* Zone) of Texas. **1**–Spiral view, X200; **2**–side view, X200; **3**–umbilical view, X200; **8**–surface of last chamber, X750; **9**–last chamber and aperture, X500.

4-7 Specimens from the Lower and Middle Paleocene of the northern Caucasus, Soviet Union, X72; from SUBBOTINA (1953, pl. 2, fig. 2-5). **a**–Spiral views; **b**–side views; **c**–umbilical views.

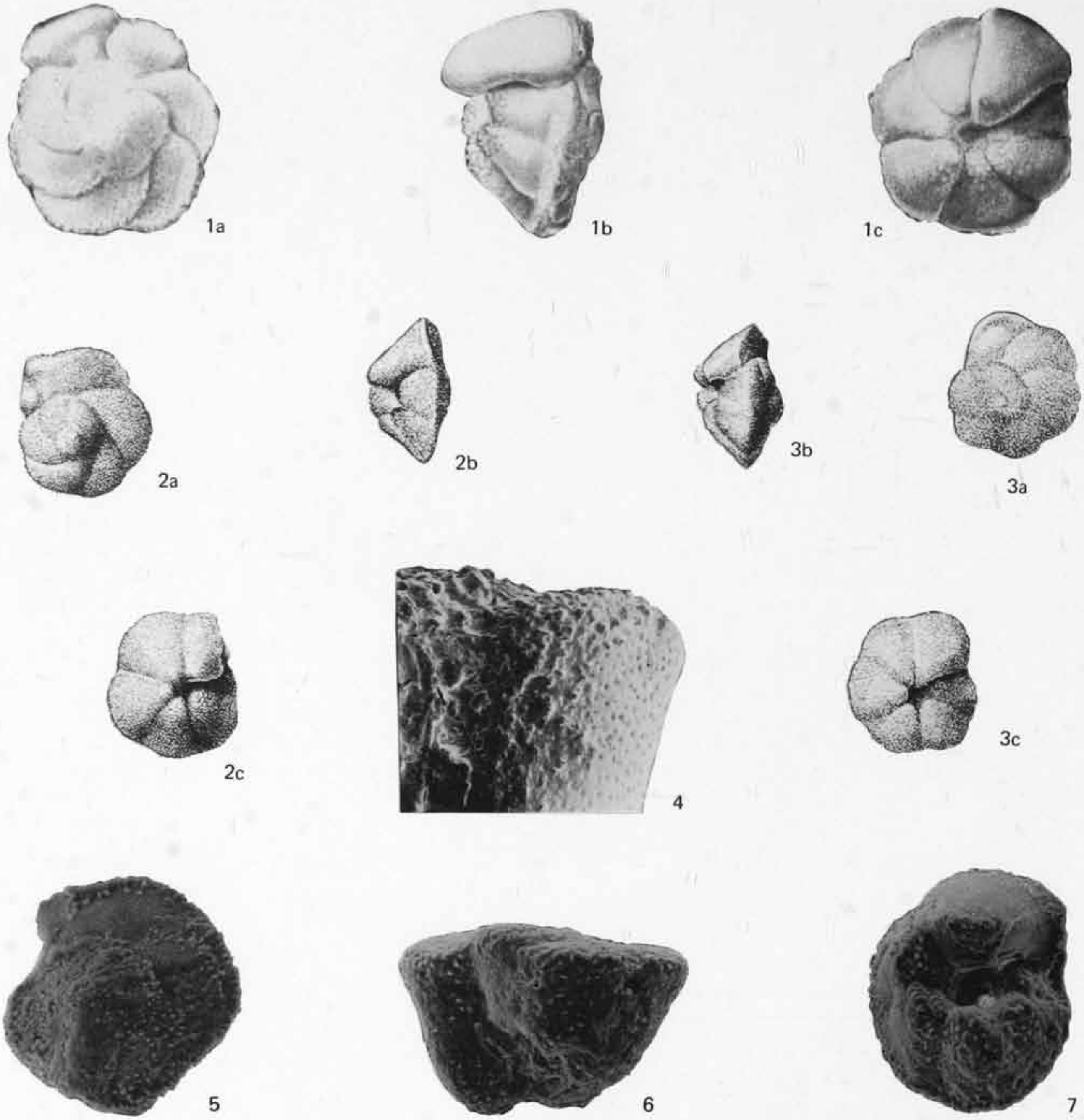


Fig. 44. *Globorotalia conicotruncata* SUBBOTINA from the Middle Paleocene of Trinidad, Soviet Union, and Egypt.

- **1** Specimen (holotype of *Globorotalia angulata abundocamerata* BOLLI) from the *Globorotalia pusilla pusilla* Zone part of the Lizard Springs Formation of Trinidad, X100; from BOLLI (1957a, pl. 17, fig. 4-6). **a**–Spiral view; **b**–side view; **c**–umbilical view.
- **2-3** Specimens from the northern Caucasus, Soviet Union, X72; from SUBBOTINA (1953, pl. 20, fig. 8-10). **a**–Spiral views; **b**–side views; **c**–umbilical views.
- **4-7** Specimens from the Western Desert of Egypt. **4**–Detail of last chamber, X250; **5**–spiral view, X100; **6**–side view, X100; **7**–umbilical view, X100.

GLOBIGERINA DAUBJERGENSIS Bronnimann, 1953
Figure 45
Early Paleocene

Globigerina daubjergensis BRÖNNIMANN, 1953, p. 340, fig. 1.–TROELSEN, 1957, p. 128, pl. 30, fig. 1-2.–HOFKER, 1962, p. 1068, 1070, fig. 22a.–POSTUMA, 1971, p. 148-149.

Globoconusa conusa KHALILOV, 1956, p. 249, pl. 5, fig. 2.

Globigerina kozlowskii BROTZEN & POZARYSKA, 1961, p. 162, pl. 1-3.

Test a small high trochospire having a small and somewhat tapering inner whorl. Last whorl of 3 to 4 spherical to ovate chambers which increase rapidly in size. Periphery lobate. Umbilicus shallow, poorly developed. Sutures depressed and radial on both sides. Aperture a low arch, umbilical to somewhat extraumbilical in position. Surface of test hispid. Diameter 0.15 to 0.25 mm.

Discussion.–Evolution of *Globigerina daubjergensis* was described in detail by HOFKER (1962). Its successive stages are an increase in the height of the spire, acquisition of sutural openings on the spiral side, and finally a bulla covering the umbilicus. *Globigerina conusa* and *Globigerina kozlowskii* represent these later stages and here are included in *G. daubjergensis.* A rather detailed discussion of evolution in this species was given by HANSEN (1970).

Distribution.–Early Paleocene (*Globorotalia pseudobulloides* and *Globorotalia trinidadensis* Zones). First described from the upper Danian of Denmark.

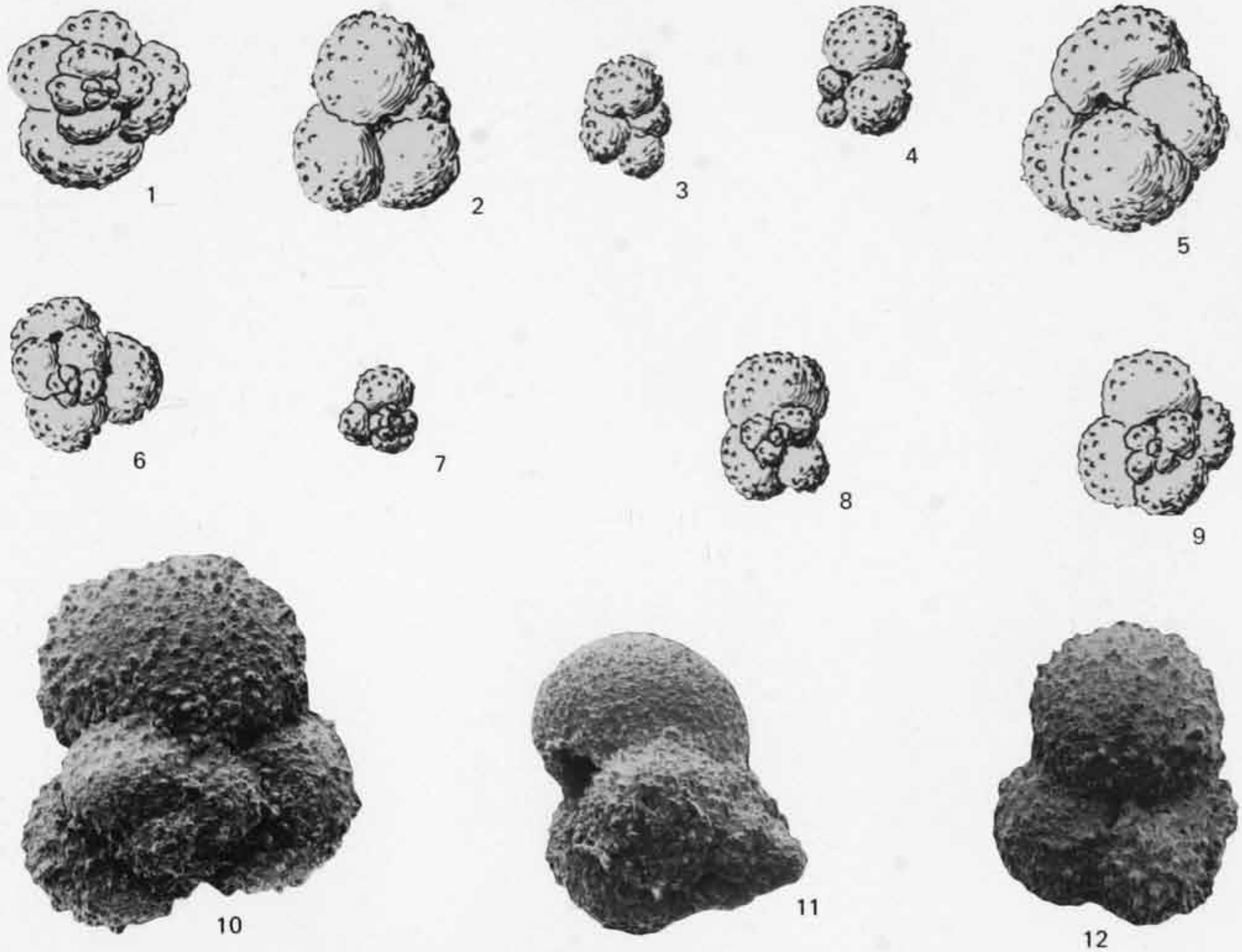


Fig. 45. *Globigerina daubjergensis* BRÖNNIMANN from the basal Paleocene (Danian) of Denmark.
1-9 Representative specimens, X100; from HOFKER (1962, fig. 22a). **1,6-9**–Spiral views; **2-5**–umbilical views.
10-12 Specimens, X250. **10**–Spiral view; **11**–side view; **12**–umbilical view.

CATAPSYDRAX ECHINATUS Bolli, 1957

Figure 46
Middle Eocene

Catapsydrax echinatus BOLLI, 1957c, p. 165-166, pl. 37, fig. 2-5.—JENKINS, 1971, p. 183, pl. 21, fig. 628-631.
Globigerinita echinata (BOLLI). BERMÚDEZ, 1960, p. 1263-1264.—BLOW, 1969, p. 268, 328.

Test a small, low to moderately high trochospire. Periphery lobate. Last whorl generally 4 globular to ovate chambers which increase fairly rapidly in size and may become somewhat elongate radially. Umbilicus rather narrow, covered by bulla. Sutures depressed; radial to oblique on spiral side, radial on umbilical side. Primary aperture umbilical, concealed by bulla of very variable size having one or two small infralaminal apertures above sutures of earlier chambers. Surface of test covered with fine spines. Diameter 0.2 to 0.4 mm.

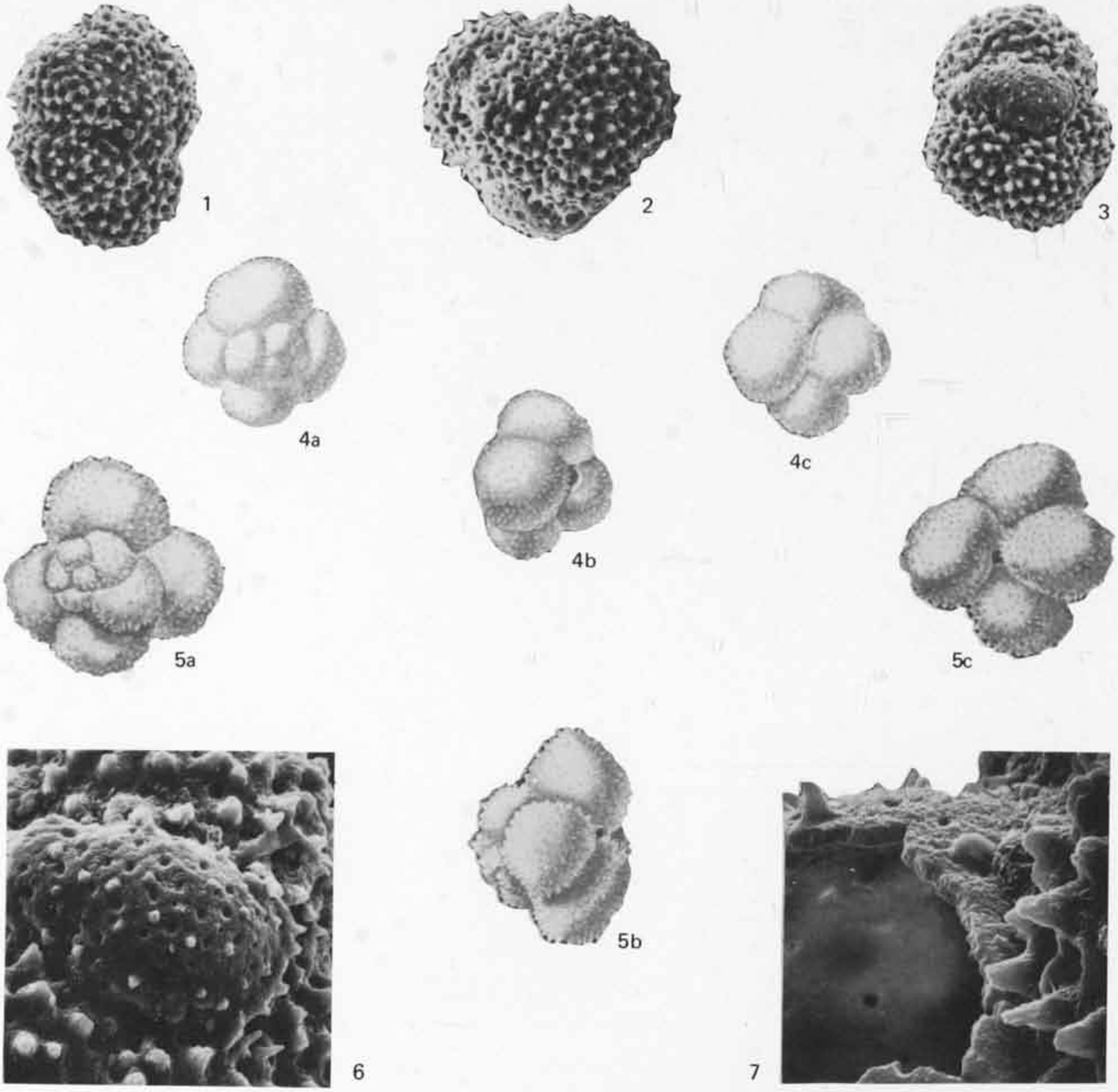


Fig. 46

Discussion.–*Catapsydrax echinatus* differs from all other species of the genus in its spinose test.

Distribution.–Middle Eocene (*Globorotalia lehneri* Zone to *Truncorotaloides rohri* Zone). The species was first described from the *Orbulinoides beckmanni* Zone in the Navet Formation of Trinidad.

GLOBIGERINA EUGUBINA Luterbacher & Premoli Silva, 1964

Figure 47
Earliest Paleocene

Globigerina eugubina LUTERBACHER & PREMOLI SILVA, 1964, p. 105-106, pl. 2, fig. 8.
Globigerina anconitana LUTERBACHER & PREMOLI SILVA, 1964, p. 107-108, pl. 2, fig. 3.

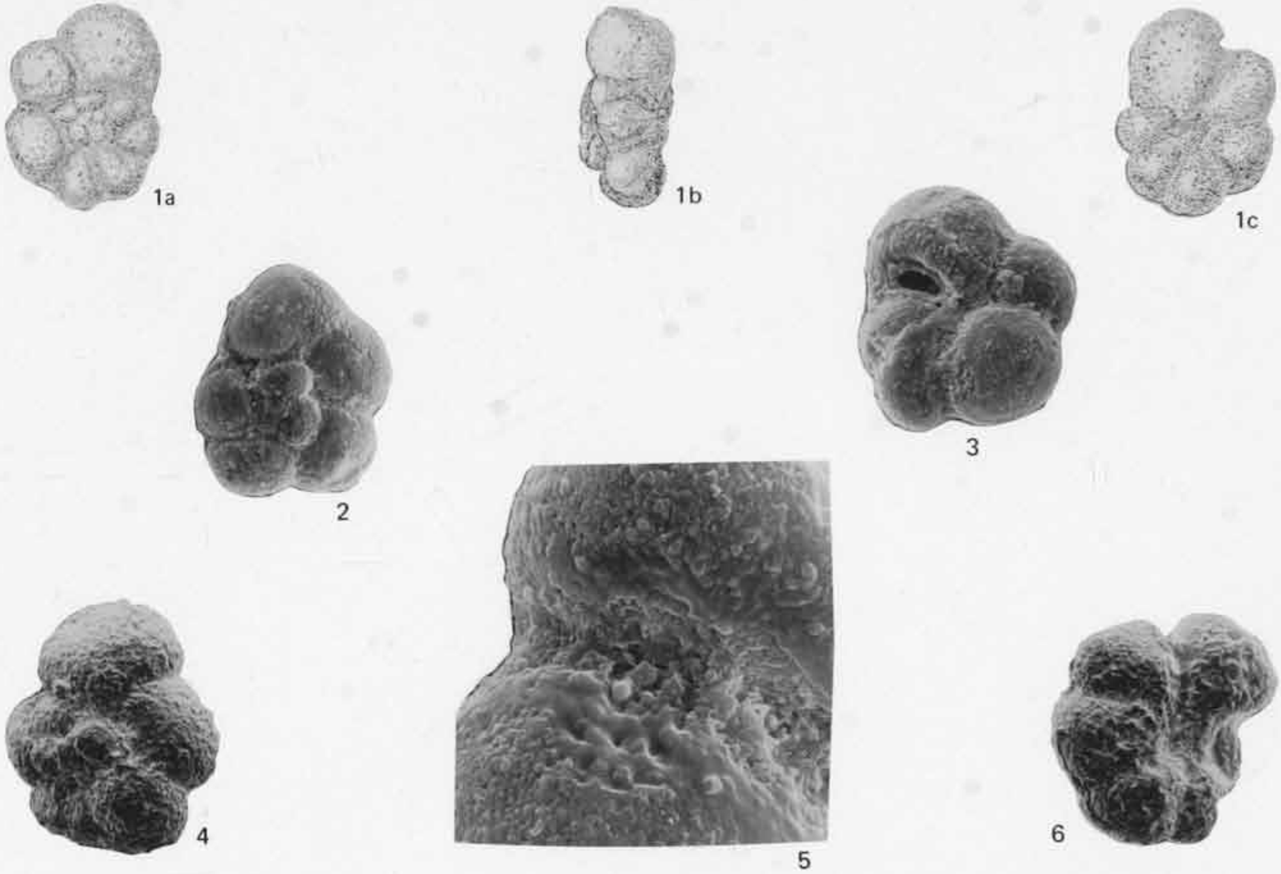


Fig. 47. *Globigerina eugubina* LUTERBACHER & PREMOLI SILVA from the basal Paleocene (*Globigerina eugubina* Zone) of Italy and Caribbean Sea.

1,4,6 Holotype (**1** from LUTERBACHER & PREMOLI SILVA, 1964, pl. 2, fig. 8) and topotypes from the central Apennines of Italy, X250: **1a,4**–Spiral views; **1b**–side view; **1c,6**–umbilical views.

2-3,5 Specimens from the western Caribbean Sea. **2**–Spiral view, X250; **3**–umbilical view, X250; **5**–detail of aperture, X1000.

⇦ Fig. 46. *Catapsydrax echinatus* BOLLI from the Middle Eocene part (*Orbulinoides beckmanni* Zone) of the Navet Formation of Trinidad.

1-3,6-7 Representative specimens. **1**–Oblique spiral view, X200; **2**–side view, X200; **3**–umbilical view, X200; **6**–detail of umbilical side, X500; **7**–detail of broken bulla and surface of adjacent chamber, X1000.

4-5 Specimens (**4**=holotype), X73; from BOLLI (1957c, pl. 37, fig. 2-3). **a**–Spiral views; **b**–side views; **c**–umbilical views.

Globigerina sabina LUTERBACHER & PREMOLI SILVA, 1964, p. 108-109, pl. 2, fig. 1, 6-7.

?*Globigerina globigerinelloides* SUBBOTINA, 1950, p. 103-104, pl. 5, fig. 17-18 [not *Globigerina globigerinelloides* SUBBOTINA, 1949, p. 32-33, pl. 2, fig. 16-18].

?*Globigerinella ultramicra* SUBBOTINA, 1950, p. 106, pl. 5, fig. 16 [not *Globigerinella ultramicra* SUBBOTINA, 1949, p. 33-35, pl. 2, fig. 17-18].

Test very small, low trochospire of 2½ whorls. Initial portion slightly raised above last whorl on spiral side. Last whorl of 5 to 6 globular chambers which increase gradually in size; final chamber generally one-fifth of test. Periphery lobate. Umbilicus distinct but shallow. Sutures depressed; radial on umbilical side, radial to slightly curved on spiral side. Aperture a low arch, umbilical to umbilical-extraumbilical. Surface of test smooth with fine pores. Diameter rarely exceeds 0.1 mm.

Discussion.—*Globigerina eugubina* differs from *Globigerina taurica* in its considerably smaller size and tighter, more regular coiling. *Globigerina anconitana* and *Globigerina sabina* now are included in the range of variability of *G. eugubina*. *Globigerina fringa*, a basal Paleocene species of similar minute size, has generally only four chambers in the last whorl.

Specimens from the basal Paleocene of the northwestern Caucasus figured by SUBBOTINA (1950) as *Globigerinella ultramicra* and *Globigerina globigerinelloides* may correspond to *G. eugubina*. Both species originally were described (SUBBOTINA, 1949) from Aptian to Cenomanian deposits and their type specimens are more than twice the size of the basal Paleocene specimens figured under the same name by SUBBOTINA.

Globigerina eugubina is the marker species for the lowermost zone of the Paleocene which is characterized by globigerinids of very small size (maximum diameters generally less than 0.1 mm). These small globigerinids represent the most primitive phase of the Tertiary globigerinids and a still earlier stage in their evolution than assemblages of the *Globigerina (Eoglobigerina) taurica* or *Globigerina (Eoglobigerina) eobulloides* Zone of Soviet authors. Taxonomic differentiation of the tiny primitive globigerinids of the *Globigerina eugubina* Zone is somewhat problematical. Whereas LUTERBACHER & PREMOLI SILVA (1964) distinguished several species among them (*Globigerina fringa, G. eugubina, G. anconitana, G. sabina, G. minutula*, and *G. umbrica*), we prefer now to recognize only 1) *G. eugubina* which comprises low trochospiral forms having five or more chambers in the last whorl and 2) *G. fringa* for specimens having only three to four chambers.

Distribution.—Basal Paleocene (*Globigerina eugubina* Zone). The species was first described from the lowermost Paleocene of the central Apennines, Italy.

GLOBOROTALIA FORMOSA FORMOSA Bolli, 1957

Figure 48

Early Eocene

Globorotalia formosa formosa BOLLI, 1957a, p. 76, pl. 18, fig. 1-3.—LUTERBACHER, 1964, p. 694-696, fig. 118-120.

Globorotalia formosa BOLLI. POSTUMA, 1971, p. 190-191.

Test umbilico-convex; umbilical side strongly convex, spiral side flat or only very slightly convex. Outline almost circular. Periphery acute with well-developed keel. Last whorl of 6 to 7 (rarely 8) angular-conical chambers which increase regularly in size; last chamber one-fifth to one-sixth of whorl, but commonly smaller than penultimate. Umbilicus well developed, open, and deep. Umbilical shoulders rounded, ranging from smooth to somewhat rougher than remainder of test. Chambers somewhat imbricated on spiral side. Sutures on spiral side raised and beaded, curved, merging smoothly into peripheral keel; on umbilical side depressed and radial. Aperture a low arch, extraumbilical-umbilical in position, with distinct lip. Surface of test spinose. Diameter 0.5 to 0.6 mm.

Discussion.—This form differs from the ancestral *Globorotalia formosa gracilis* in having more chambers in the last whorl and, thus, in being less lobate.

Distribution.—Early Eocene (from within *Globorotalia subbotinae* Zone to within *Globorotalia aragonensis* Zone). The species was first described from the Lizard Springs Formation of Trinidad.

GLOBOROTALIA FORMOSA GRACILIS Bolli, 1957

Figure 49

Early Eocene

Globorotalia formosa gracilis BOLLI, 1957a, p. 75, pl. 18, fig. 4-6.—LUTERBACHER, 1964, p. 692-694, fig. 115, 117.

Pseudogloborotalia formosa BOLLI [sic] var. *gracilis* (BOLLI). BERMÚDEZ, 1960, p. 1344.

Globorotalia (Morozovella) gracilis BOLLI. JENKINS, 1971, p. 105, pl. 9, fig. 202-204.

Globorotalia gracilis BOLLI. POSTUMA, 1971, p. 192-193.

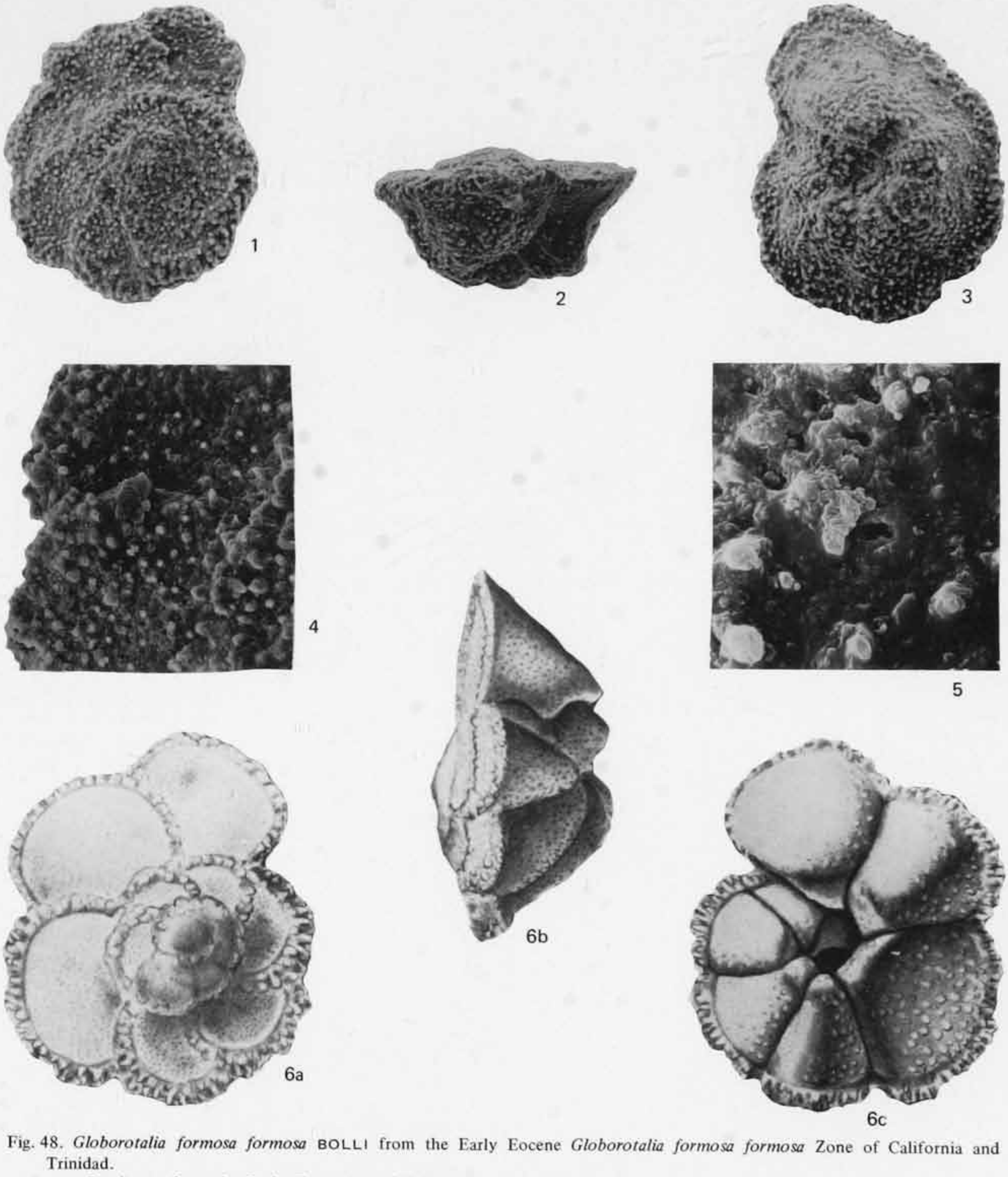


Fig. 48. *Globorotalia formosa formosa* BOLLI from the Early Eocene *Globorotalia formosa formosa* Zone of California and Trinidad.

1-5 Specimens from the Lodo Formation of California. **1**–Spiral view, X100; **2**–side view, X100; **3**–umbilical view, X100; **4**–surface of spiral side, X500; **5**–detail of surface of last chamber, X1000.

6 Holotype from the Lizard Springs Formation of Trinidad, X100; from BOLLI (1957a, pl. 18, fig. 1-3). **a**–Spiral view; **b**–side view; **c**–umbilical view.

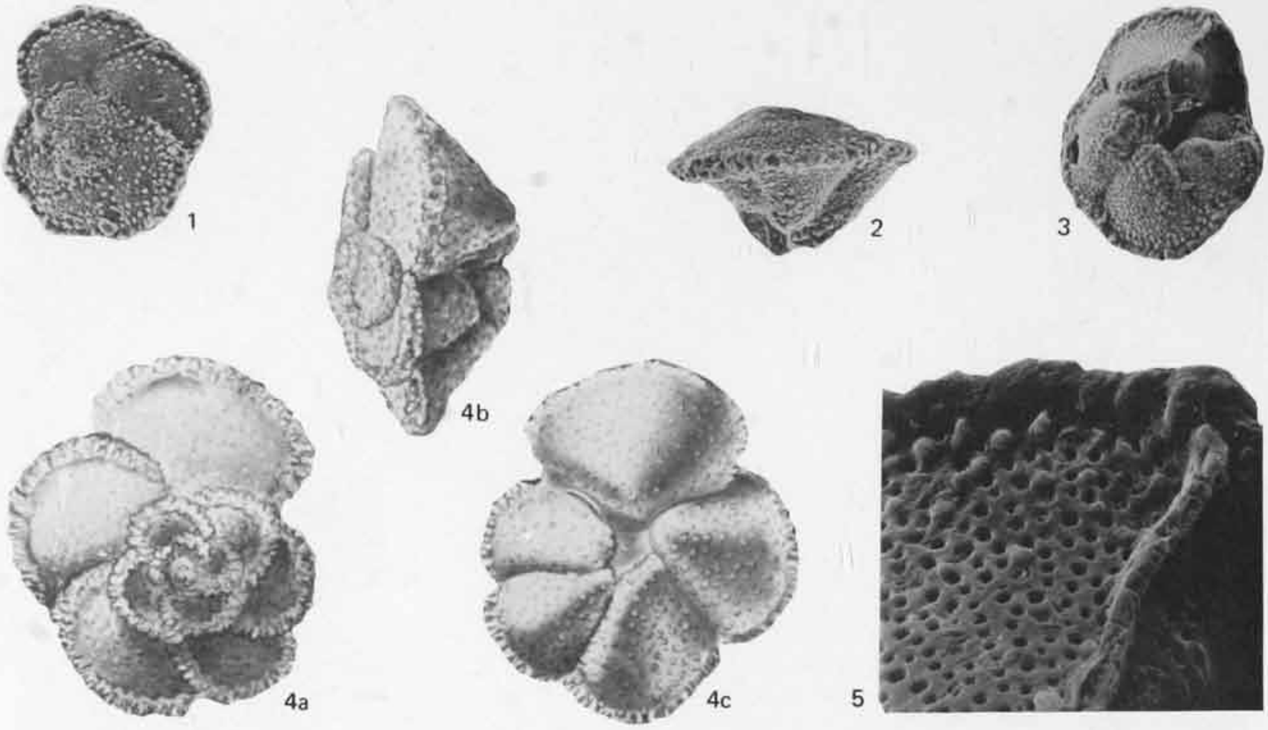


Fig. 49. *Globorotalia formosa gracilis* BOLLI from the Early Eocene *Globorotalia subbotinae* Zone of California and Trinidad.

1-3,5 Specimens from the Lodo Formation of California. **1**–Spiral view, X100; **2**–side view, X100; **3**– umbilical view, X100; **5**–surface of last chamber, X500.

4 Holotype from the Lizard Springs Formation of Trinidad, X100; from BOLLI (1957a, pl. 18, fig. 4-6). **a**–Spiral view; **b**–side view; **c**–umbilical view.

Test a trochospire with spiral side slightly and umbilical side strongly convex. Periphery acute with beaded keel; strongly lobate. Last whorl of 5 to 6 angular-conical chambers which increase rapidly in size, last one-third to one-fifth of whorl. Umbilical shoulders rounded with no distinct ornament. Umbilicus medium sized, deep. Sutures on spiral side curved, depressed or flush; chambers somewhat imbricated; on umbilical side sutures depressed, radial. Aperture a low arch, extraumbilical in position, generally without or with only faint lip. Surface of test spinose. Diameter 0.35 to 0.50 mm.

Discussion.–*Globorotalia formosa gracilis* differs from *Globorotalia acuta* by a narrower umbilicus and simple, unornamented umbilical shoulders. *Globorotalia aequa* has only a weak keel or no keel at all and fewer chambers in the last whorl. *Globorotalia marginodentata* has a broad and heavy keel and a more lenticular test.

Distribution.–Earliest Eocene (*Globorotalia subbotinae* and *Globorotalia formosa formosa* Zones). The species was first described from the *Globorotalia subbotinae* Zone in the Lizard Springs Formation of Trinidad.

GLOBIGERINA FRINGA Subbotina, 1950

Figure 50

Early Paleocene

Globigerina fringa SUBBOTINA, 1950, p. 104, pl. 5, fig. 19-21.–SUBBOTINA, 1953, p. 62-63, pl. 3, fig. 3-4.–SUBBOTINA, 1971, p. 73-74, pl. 3, fig. 3-4 [original types refigured].

Globigerina (Eoglobigerina) eobulloides MOROZOVA, 1959, p. 1113, fig. 1.

Globigerina minutula LUTERBACHER & PREMOLI SILVA, 1964, p. 109-110, pl. 2, fig. 5.

Test a very small, low trochospire of 2 tightly coiled whorls. Last whorl with 4 spherical to ovate chambers which increase rapidly in size. Periphery slightly lobate in outline, bluntly rounded in side view. Umbilicus small and shallow. Sutures depressed,

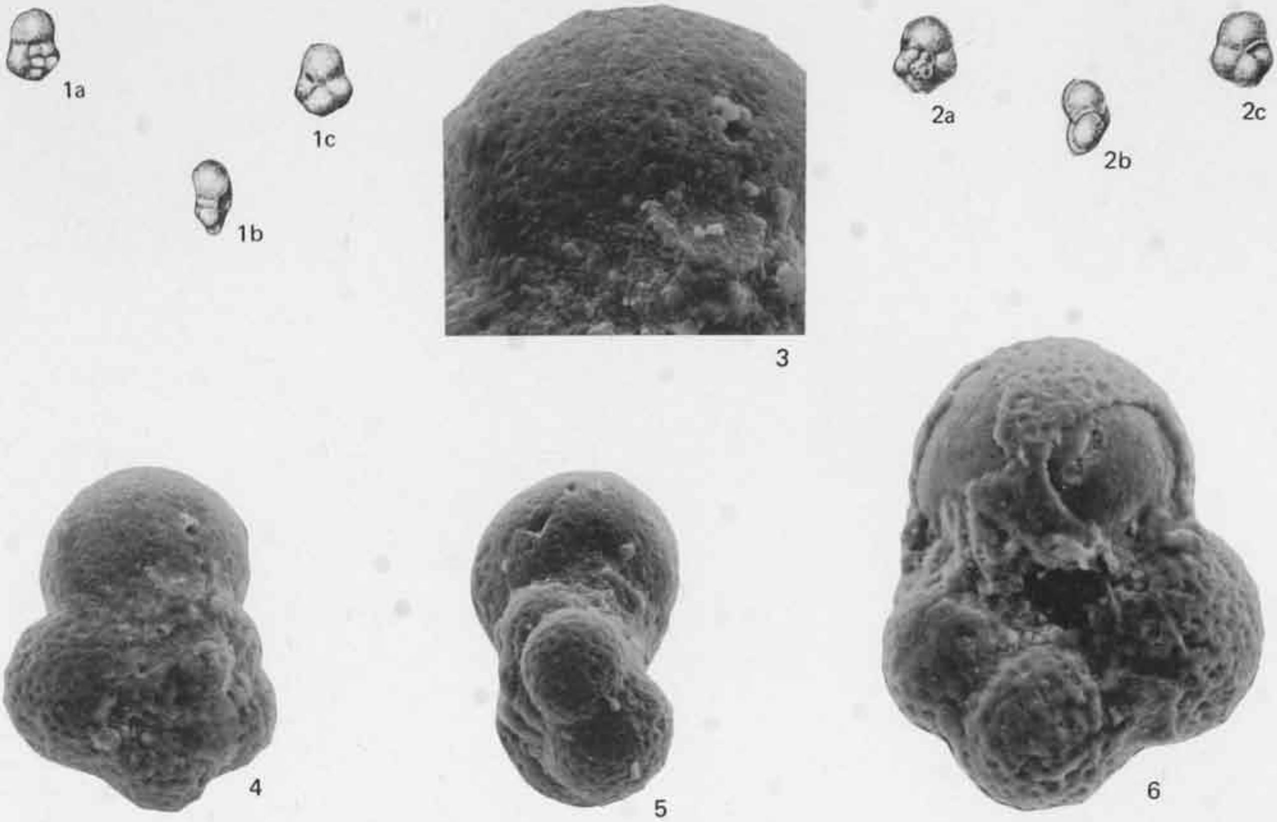


Fig. 50. *Globigerina fringa* SUBBOTINA from the basal Paleocene of the Soviet Union.

1-2 Specimens (**1**=holotype) from the northwestern Caucasus, X102; from SUBBOTINA (1953, pl. 3, fig. 3-4). **a**–Spiral views; **b**–side views; **c**–umbilical views.

3-6 Specimens from northwestern Crimea. **3**–Surface of last chamber, X500; **4**–spiral view, X250; **5**–side view, X250; **6**–umbilical view; X250.

radial; on umbilical side forming oblique cross. Aperture small, umbilical with extraumbilical tendency. Surface of test smooth or finely pitted. Diameter rarely exceeds 0.2 mm.

Discussion.–*Globigerina fringa* differs from *Globorotalia pseudobulloides* by its tighter coiling, smaller dimensions, and smoother and more fragile test. Small specimens of *G. fringa* may occur in assemblages of the basal Paleocene *Globigerina eugubina* Zone (see, for instance, SUBBOTINA, 1953; 1971, pl. 2, fig. 7). They differ from *Globigerina eugubina* by having fewer chambers in the last whorl. *Globigerina eobulloides* is included here within the range of variability of *G. fringa*.

Distribution.–Earliest Paleocene (*Globigerina eugubina* and *Globorotalia pseudobulloides* Zones). *Globigerina fringa* was first described from the basal Paleocene of the northwestern Caucasus.

GLOBIGERINA FRONTOSA Subbotina, 1953

Figure 51

Early to Middle Eocene

Globigerina frontosa SUBBOTINA, 1953, p. 84, pl. 12, fig. 3-7.–SUBBOTINA, 1971, p. 113, 116, pl. 12, fig. 3-7.

Globigerina boweri BOLLI, 1957c, p. 163, pl. 36, fig. 1-2.–POSTUMA, 1971, p. 144-145.

Globorotalia cerroazulensis frontosa (SUBBOTINA). TOUMARKINE & BOLLI, 1970, p. 139, pl. 1, fig. 1-3.

Globigerina (Globigerina) boweri BOLLI. JENKINS, 1971, p. 138, pl. 15, fig. 428-430.

Test trochospiral, of 2 tightly coiled whorls. Spiral side somewhat flattened; inner whorl indistinct, at same level as last whorl or even slightly depressed. Last whorl with 3 to 3½ inflated chambers which increase in size rapidly but evenly, each roughly twice as broad as that preceding, final chamber nearly one-half test. Periphery trilobate in outline, broadly rounded in side view. Sutures only moderately depressed; slightly curved on spiral side,

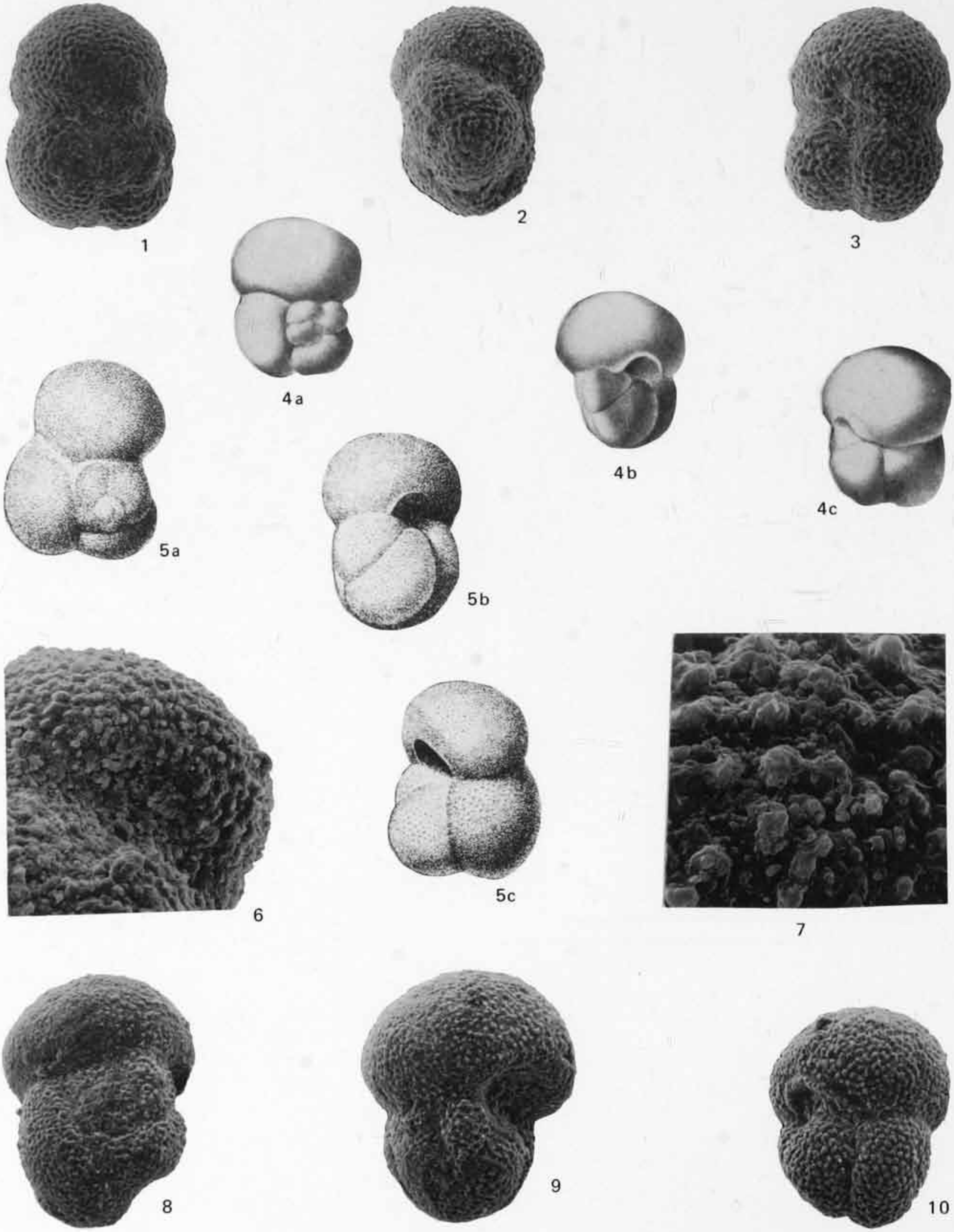


Fig. 51

radial on umbilical side. Umbilicus small, commonly concealed. Aperture a large, gaping arch, generally slightly extraumbilical-umbilical. Test finely cancellate in early portion, becoming smoother. Diameter 0.4 to 0.5 mm.

Discussion.–*Globigerina boweri* is regarded as a junior synonym of *Globigerina frontosa. Globigerina linaperta* has a smaller and strictly umbilical aperture. Some authors suggest that *G. frontosa* is ancestral to the *Globorotalia cerroazulensis* lineage.

Distribution.–Early to Middle Eocene (*Globorotalia pentacamerata* Zone to *Globorotalia lehneri* Zone). *Globigerina frontosa* originally was described from the basal Middle Eocene of the northern Caucasus; *G. boweri* from the *Hantkenina aragonensis* Zone in the Navet Formation of Trinidad.

GLOBIGERINA HIGGINSI (Bolli, 1957)

Figure 52
Early to Middle Eocene

"Globigerinoides" higginsi BOLLI, 1957c, p. 164, pl. 36, fig. 11-13.
Globigerapsis higginsi (BOLLI). BERMÚDEZ, 1960, p. 1250, pl. 8, fig. 5.
Globigerina (Globigerina) higginsi (BOLLI). JENKINS, 1971, p. 149, pl. 16, fig. 469-470.

Test very high trochospiral, of 2½ or 3 rather loosely coiled whorls, each with 4 to 5 chambers. Last whorl generally has 4 spherical chambers which increase only moderately in size; last typically smaller than penultimate. Equatorial and side profiles both strongly lobate. Umbilicus narrow, deep. Sutures strongly depressed, almost radial. Aperture umbilical, a high arch. Sutural apertures occasionally visible on spiral side of well-preserved specimens. Surface of test finely pitted. Diameter (and height) 0.4 to 0.5 mm.

Discussion.–*Globigerina higginsi* is a very conspicuous form which differs from all other Paleogene species by its high and loosely coiled spire. The secondary sutural apertures observed in well-preserved specimens are not considered to be of generic importance. This species certainly does not belong in the Eocene genus *Globigerinatheka* (including *Globigerapsis*) nor in the Miocene genus *Globigerinoides;* it is the type species of *Guembelitrioides* EL-NAGGAR (1971).

Distribution.–Early to Middle Eocene (*Globorotalia pentacamerata* Zone to *Globigerinatheka subconglobata* Zone). The holotype was described from an Eocene core in the northwestern Atlantic Ocean.

CATAPSYDRAX HOWEI (Blow & Banner, 1962)

Figure 53
Middle to Late Eocene

Globigerinita howei BLOW & BANNER, 1962, p. 109, fig. 11, x-xiv, pl. 14, fig. p-r.–BLOW, 1969, p. 328.

Test low trochospiral, of approximately 3 whorls, each with 3½ to 4 globular, slightly embracing chambers which increase rapidly in size. Periphery distinctly lobate. Sutures depressed, radial to slightly curved. Umbilical area concealed by very large and strongly inflated bulla, covering more than one-half of umbilical side; 2 or 3 arched infralaminal apertures. In specimens with broken bulla, umbilicus is rather small and deep and primary aperture a low arch, umbilical. Surface of test finely cancellate. Diameter 0.3 to 0.4 mm.

Discussion.–This species here is transferred from *Globigerinita* to *Catapsydrax* because of the distinctly cancellate shell. *Catapsydrax howei* has an exceptionally large bulla which distinguishes it from all other species. It is characterized further by the strongly depressed sutures in the last whorl.

Distribution.–Middle to Late Eocene (*Truncorotaloides rohri* Zone to within *Globorotalia cerroazulensis* Zone). The species was first described from the *Globigerinatheka semiinvoluta* Zone in Tanzania.

Fig. 51. *Globigerina frontosa* SUBBOTINA from the Middle Eocene of the Soviet Union, Trinidad, and Italy.

1-3,6-7 Specimens from western Turkmenia in the Soviet Union. **1**–Spiral view, X100; **2**–side view, X100; **3**–umbilical view, X100; **6**–aperture and last chamber, X250; **7**–detail of surface of last chamber, X1000.

4 Specimen (holotype of *Globigerina boweri* BOLLI) from the *Hantkenina aragonensis* Zone part of the Navet Formation of Trinidad, X73; from BOLLI (1957c, pl. 36, fig. 1). **a**–Spiral view; **b**–side view; **c**–umbilical view.

5 Holotype from the northern Caucasus, Soviet Union, X72; from SUBBOTINA (1953, pl. 12, fig. 3). **a**–Spiral view; **b**–side view; **c**–umbilical view.

8-10 Specimens from the "scaglia cinerea" of northern Italy, X100. **8**–Spiral view; **9**–side view; **10**–umbilical view.

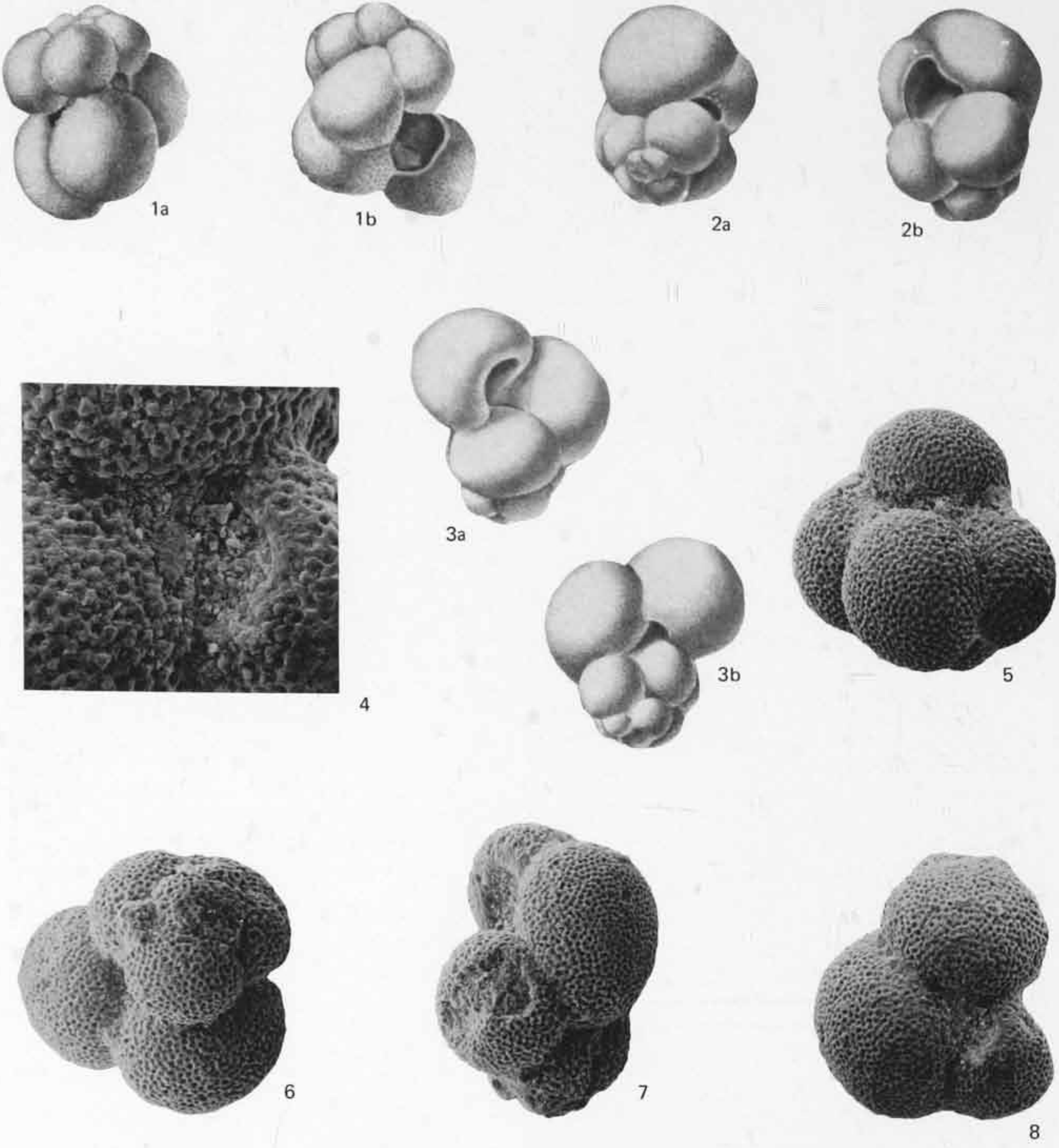


Fig. 52. *Globigerina higginsi* (BOLLI) from the Middle Eocene of the north Atlantic and Trinidad.

1 Side views of holotype from early Middle Eocene deposits of the western north Atlantic, X73; from BOLLI (1957c, pl. 36, fig. 11).

2-3 Specimens from the *Hantkenina aragonensis* Zone part of the Navet Formation of Trinidad, X73; from BOLLI (1957c, pl. 36, fig. 11-13). **2a,3b**–Side views; **2b,3a**–umbilical views.

4-8 Specimens from the *Hantkenina aragonensis* Zone part of the Navet Formation of Trinidad. **4**–Aperture, X250; **5**; oblique side view, X100; **6**–spiral view, X100; **7**–side view, X100; **8**–umbilical view, X100.

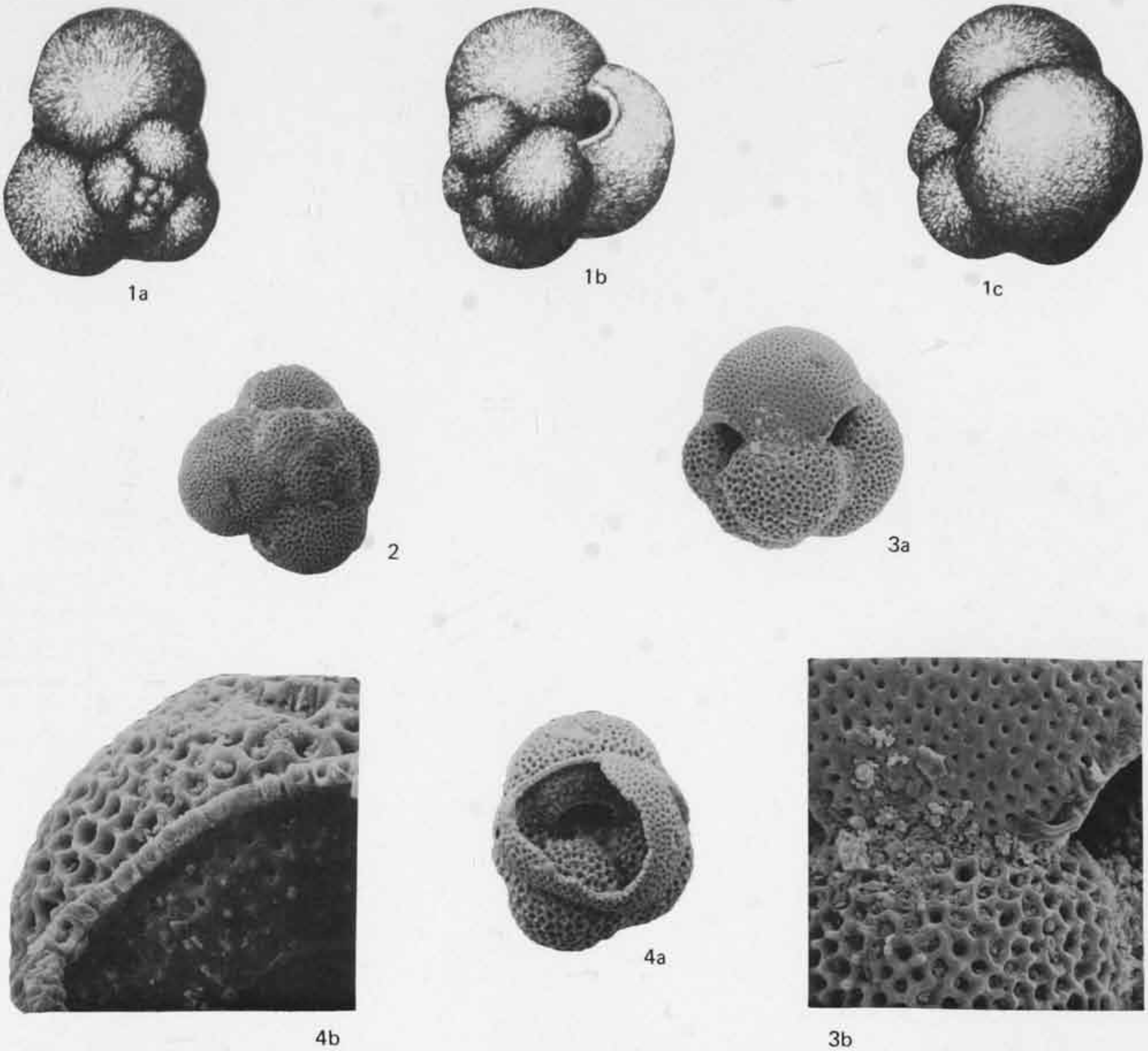


Fig. 53. *Catapsydrax howei* (BLOW & BANNER) from the Eocene of Tanzania and Gulf of Mexico.

1 Spiral, umbilical, and side views of holotype from the Late Eocene *Globigerinatheka semiinvoluta* Zone of Tanzania, X100; from BLOW & BANNER (1962, pl. 14, fig. P-R).

2-4 Specimens from the Middle Eocene of northeastern Gulf of Mexico. **2**–Spiral view, X100; **3a**–side view, X100; **3b**–surface of bulla (above) and adjacent chamber, X300; **4a**–umbilical view with primary aperture visible through broken bulla, X100; **4b**–surface of last chamber and transverse section of bulla, X400.

GLOBIGERINA INAEQUISPIRA Subbotina, 1953

Figure 54

Early to Middle Eocene

Globigerina inaequispira SUBBOTINA, 1953, p. 69, pl. 6, fig. 1-4.–SUBBOTINA, 1971, p. 84-85, pl. 6, fig. 1-4.

Test low trochospiral, composed of 2 whorls. Spiral side flattened, inner whorl generally somewhat depressed. Periphery strongly lobate. Inner whorl compact and considerably smaller than outer whorl, which has generally 4 globular chambers. Chambers of last whorl increasing rapidly in size and becoming loosely attached to one another. Umbilicus wide shallow. Sutures depressed, radial. Aperture rather small, a low arch with distinct lip, umbilical. Surface of test finely cancellate, may be hispid. Diameter 0.4 to 0.5 mm.

Discussion.—*Globigerina inaequispira* is superficially similar to *Globigerina linaperta* but differs in being more loosely coiled and in the change of character between its initial and final whorls. LOEBLICH & TAPPAN (1957a) applied this name erroneously to a more compact, more hispid Paleocene species.

Distribution.—Early to Middle Eocene (*Globorotalia aragonensis* Zone to *Globorotalia lehneri* Zone). The species was first described from the upper part of the Lower Eocene in the northern Caucasus.

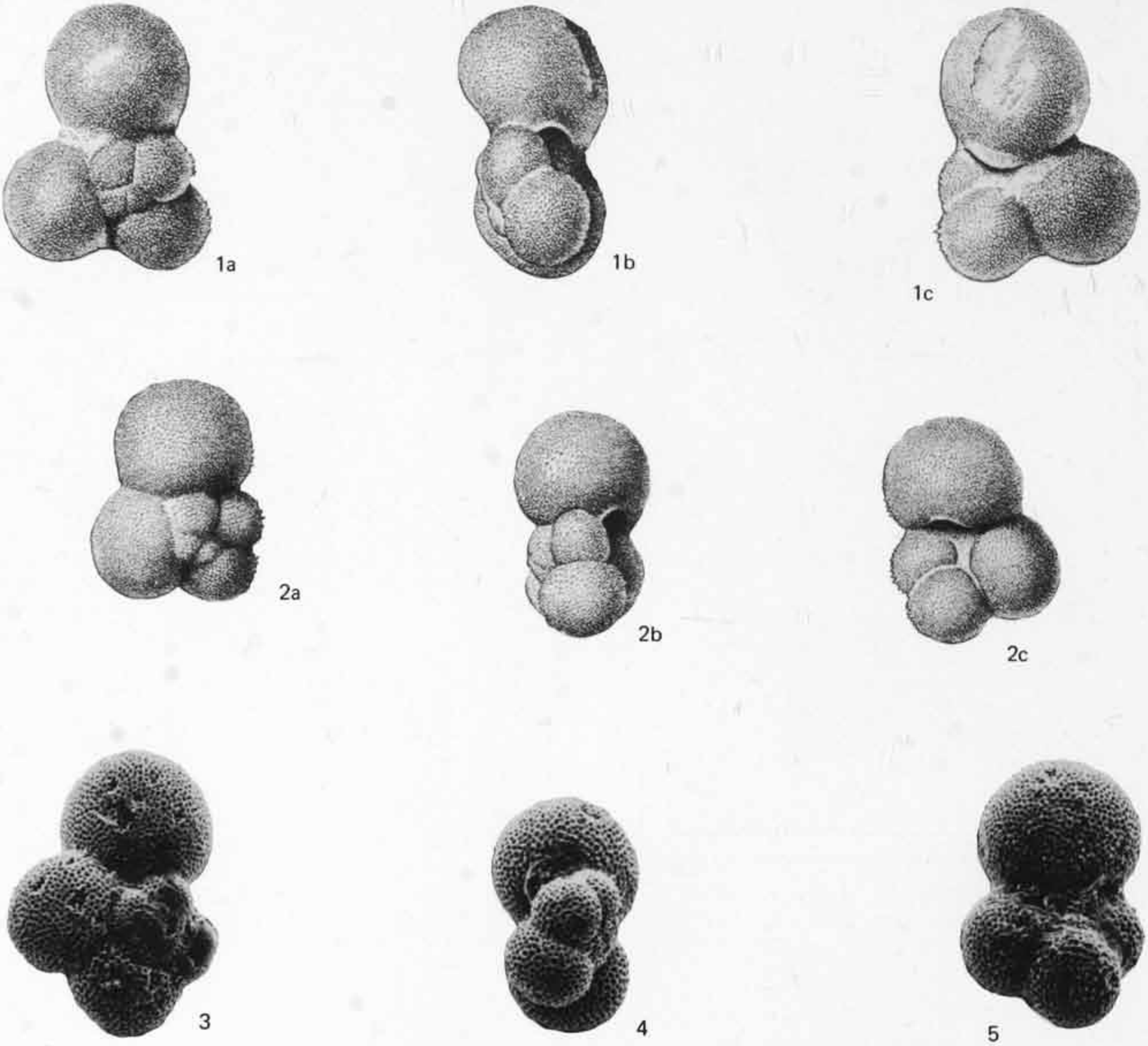


Fig. 54. *Globigerina inaequispira* SUBBOTINA from the Eocene of the northern Caucasus, Soviet Union.

1-2 Specimens (**2**=holotype) from the Lower Eocene, X72; from SUBBOTINA (1953, pl. 6, fig. 1, 4). **a**—Spiral views; **b**—side views; **c**—umbilical views.

3-5 Specimens from the Middle Eocene, X100. **3**—Spiral view; **4**—side view; **5**—umbilical view.

GLOBOROTALIA INCONSTANS (Subbotina, 1953)
Figure 55
Early Paleocene

Globigerina inconstans SUBBOTINA, 1953, p. 58, pl. 3, fig. 1-2.–SUBBOTINA, 1971, p. 66, pl. 3, fig. 1-2.
Globorotalia inconstans (SUBBOTINA). LUTERBACHER, 1964, p. 650-651, fig. 19-23.

Test low trochospiral. Spiral side flattened, inner whorls depressed, often indistinct; umbilical side inflated. Outline slightly lobate, periphery smoothly rounded. Last whorl with 5 to 6 globular to ovate chambers which increase gradually in size, last one tending to be considerably larger than penultimate. Sutures depressed; radial on umbilical side, radial to slightly curved on spiral side. Umbilicus wide and shallow. Aperture a low arch, extraumbilical-umbilical in position. Surface of test rather coarsely perforate, almost smooth. Diameter 0.3 to 0.4 mm.

Discussion.–*Globorotalia inconstans* differs from *Globorotalia trinidadensis* in having fewer chambers in the last whorl and in its smoother surface.

Distribution.–Early into Middle Paleocene (from within *Globorotalia pseudobulloides* Zone through *Globorotalia uncinata* Zone). The species was first described from the Lower Paleocene of the northern Caucasus where it is used as a subzonal index.

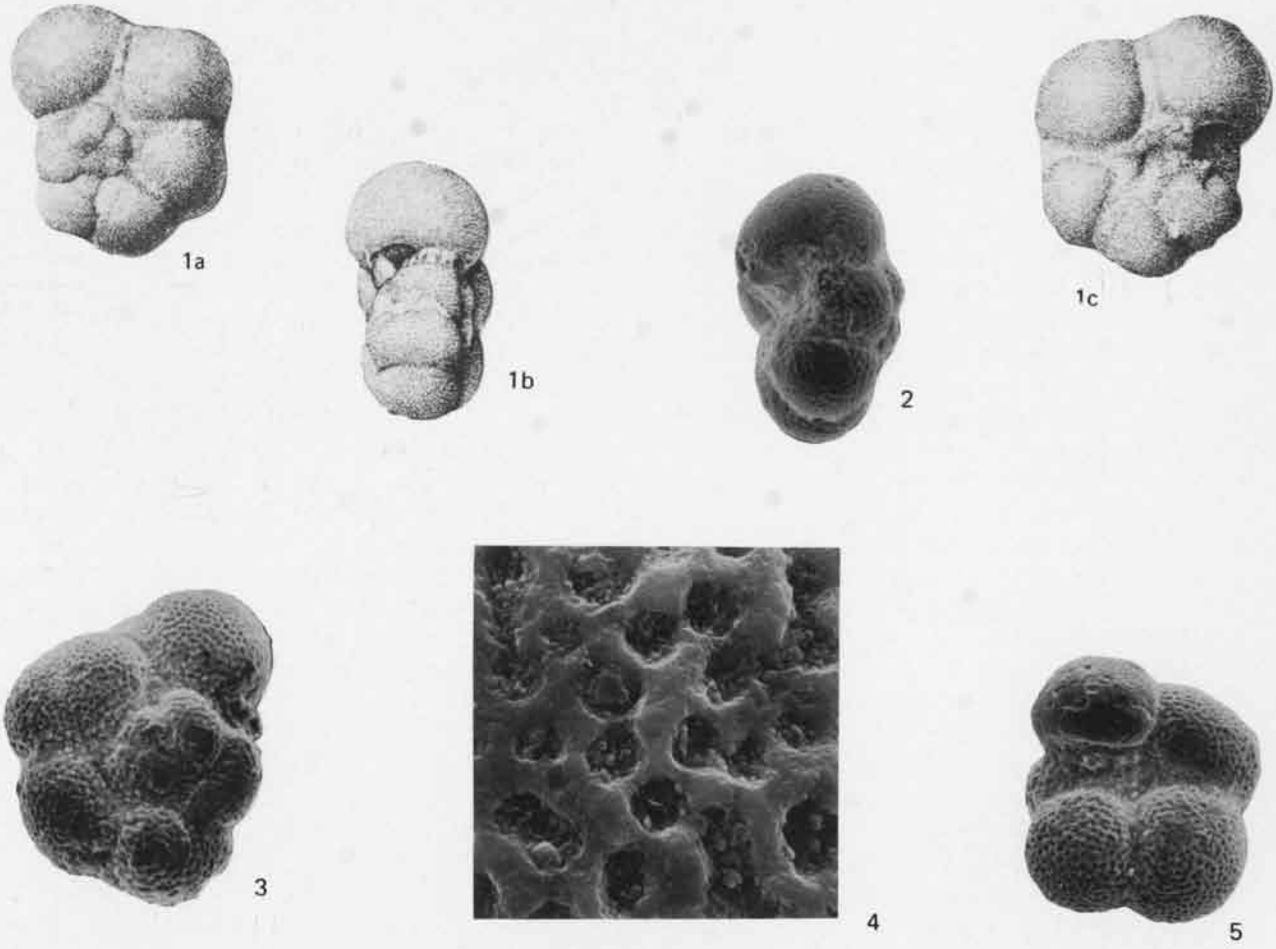


Fig. 55. *Globorotalia inconstans* (SUBBOTINA) from the Paleocene of the northern Caucasus, Soviet Union.

1 Holotype from the Lower to Middle Paleocene, X72; from SUBBOTINA (1953, pl. 3, fig. 1). **a**–Spiral view; **b**–side view; **c**–umbilical view.

2-5 Specimens from the Lower Paleocene. **2**–Side view, X150; **3**–spiral view, X150; **4**–detail of surface of last chamber, X1000; **5**–umbilical view, X150.

GLOBIGERINATHEKA INDEX (Finlay, 1939)

Figure 56

Middle to Late Eocene

Globigerinoides index FINLAY, 1939c, p. 125, pl. 14, fig. 85-88.—HORNIBROOK, 1958, p. 35, pl. 1, fig. 11-14 [original types refigured].

Globigerinoides macrostoma HAGN, 1956, p. 173, pl. 16, fig. 11.

Globigerapsis index (FINLAY). BLOW & BANNER, 1962, p. 124-125, pl. 15, fig. g-h.—BLOW, 1969, p. 330, pl. 27, fig. 1-2.—SUBBOTINA, 1972, p. 120-121 (part), pl. 1, fig. 1 (not pl. 1, fig. 2-5).

Globigerinatheka (Globigerapsis) index index (FINLAY). JENKINS, 1971, p. 187-188, pl. 22, fig. 641-645 [original types refigured].

Globigerinatheka index index (FINLAY). BOLLI, 1972a, p. 124, fig. 51-57, 63-64, pl. 1, fig. 1-4, 6-7.

Test almost globular, consisting of 3 whorls, initial 2 whorls forming a low, *Globigerina*-like trochospire. Last whorl of 3 chambers considerably larger than previous ones, embracing earlier whorls, and increasing rapidly in size so that final chamber envelops most of umbilical side of test. Sutures deeply incised, cleftlike. Adult test has large gaping primary aperture and 2 or 3 arched secondary apertures on final chamber where it overlaps earlier sutures. Test thick, very rugose. Diameter to 0.5 mm.

Discussion.—Although *Globigerinatheka index* differs from *Globigerinatheka tropicalis* in having a thicker wall, distinctively rugose surface, and more deeply incised sutures, the two species are intimately linked by intermediate forms. Reference is made to the detailed discussion of representatives of the genus *Globigerinatheka* by BOLLI (1972a).

Distribution.—According to BOLLI (1972a) *G. index* ranges from within the *Globigerinatheka subconglobata* Zone (Middle Eocene) to within the *Globigerinatheka semiinvoluta* Zone (Late Eocene). BLOW (1969) referred to its possible extension into the earliest Oligocene. It is found only rarely in tropical assemblages. BOLLI (1972a) suggested that its upper limit is within the Middle Eocene of the tropics, low in the Upper Eocene of middle latitudes (e.g., northern Italy), and near the top of the Eocene in still higher latitudes (North Sea, New Zealand). *Globigerinatheka index* was first described from the Middle Eocene of New Zealand.

CRIBROHANTKENINA INFLATA (Howe, 1928)

Figure 57

Late Eocene

Hantkenina inflata HOWE, 1928, p. 14, pl. 14, fig. 2.

Hantkenina danvillensis HOWE & WALLACE, 1934, p. 37, pl. 5, fig. 14, 17.

Hantkenina (Cribrohantkenina) bermudezi THALMANN, 1942, p. 812, pl. 1, fig. 6.—BRÖNNIMANN, 1950b, p. 417-418, pl. 56, fig. 6-9, 24-25.

Cribrohantkenina danvillensis (HOWE & WALLACE). BLOW & BANNER, 1962, p. 128, 129, pl. 15, fig. 19 (i-vii), pl. 15, fig. g-h.

Cribrohantkenina inflata (HOWE). BLOW, 1969, p. 377, pl. 52, fig. 1-3.

Cribrohantkenina bermudezi THALMANN. POSTUMA, 1971, p. 134-135.

Test planispiral, biumbilicate. Last whorl with 4 to 6 strongly inflated chambers, increasing fairly rapidly in size, and carrying stout spines attached at distal tips and aligned with sutures. Outline lobate to stellate. Sutures depressed, radial to slightly curved. Umbilici small and deep, may be covered by apertural flanges. Primary aperture trilobate, median, with variable extension up apertural face; with distal lip which fuses into lateral flanges. Accessory apertures in form of tuberculate holes within apertural face, number variable. Surface of test finely perforate, almost smooth. Diameter 0.5 to 0.6 mm exclusive of spines.

Discussion.—Accessory apertures, whose origin is reviewed by BLOW & BANNER (1962), readily identify this species. The genus *Cribrohantkenina* was reviewed by SPRAUL (1963) and DIENI & PROTO DECIMA (1964) among others.

Distribution.—Late Eocene (*Globorotalia cerroazulensis* Zone). BLOW (1969) used the range of *Cribrohantkenina inflata* to define a new zone overlapping parts of the *Globigerinatheka semiinvoluta* and *Globorotalia cerroazulensis* Zones of BOLLI. Most other authors claim that *Globorotalia cerroazulensis* subspecies and *Cribrohantkenina* became extinct at virtually the same time; this zonal level is accepted widely as defining the Eocene-Oligocene boundary. The species was described first from the Vicksburg Formation of southern Alabama but this occurrence in the early Oligocene is attributed to reworking (THALMANN, 1942).

GLOBOROTALIA KOLCHIDICA Morozova, 1961

Figure 58

Middle to Late Paleocene

Globorotalia kolchidica MOROZOVA, 1961, p. 17, pl. 2, fig. 2.

Test umbilico-convex, spiral side flattened with inner whorls slightly raised above level of last whorl, umbilical side strongly convex resembling a low

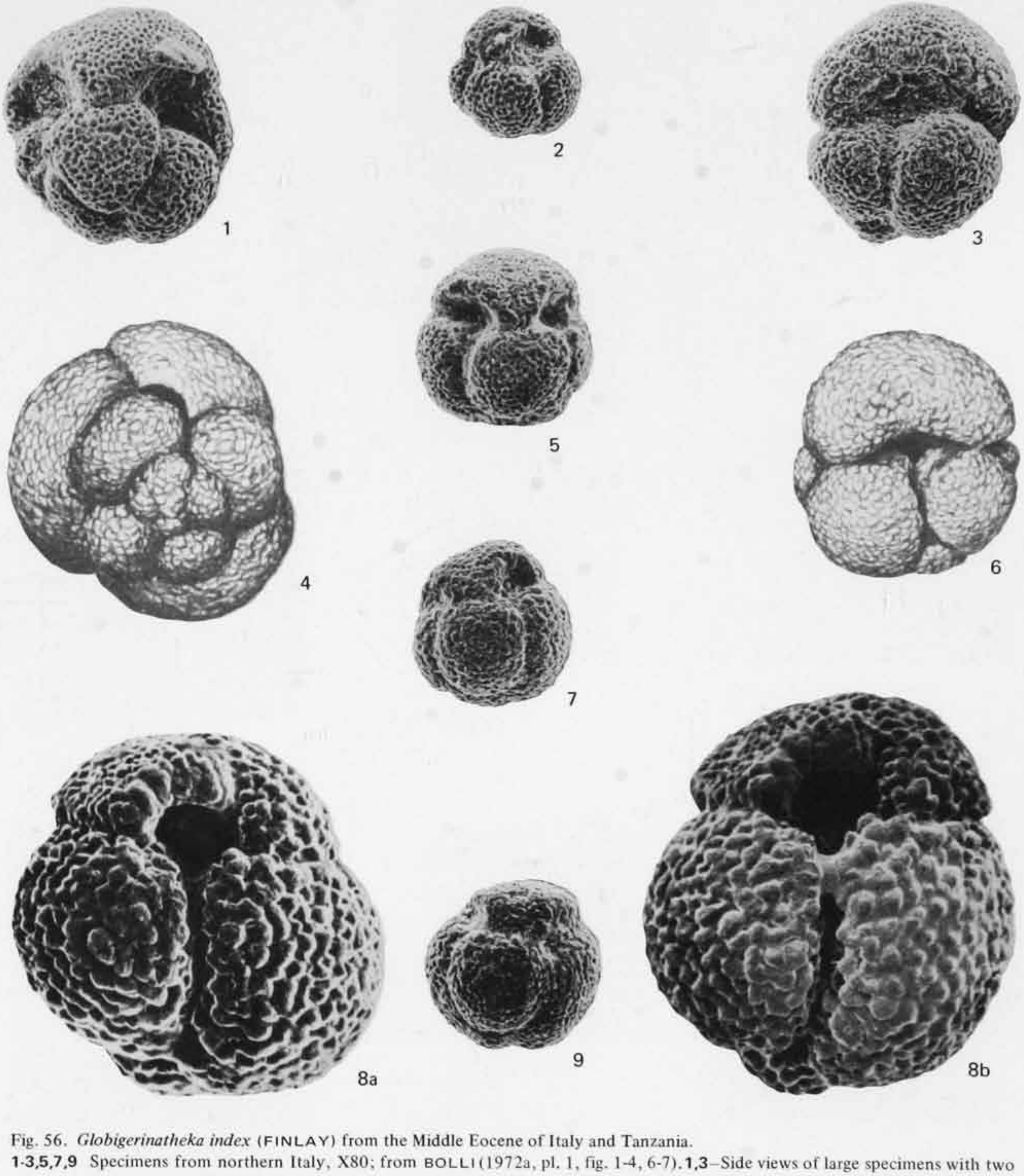


Fig. 56. *Globigerinatheka index* (FINLAY) from the Middle Eocene of Italy and Tanzania.

1-3,5,7,9 Specimens from northern Italy, X80; from BOLLI (1972a, pl. 1, fig. 1-4, 6-7). **1,3**–Side views of large specimens with two apertures; **2**–side view of small specimen with two apertures; **5**–side view of medium-sized specimen with two apertures; **7,9**–side views of specimens with last chamber smaller than penultimate, both with two apertures.

4,6 Specimens from Tanzania, X100; from BLOW & BANNER (1962, pl. 15, fig. G-H). **4**–Spiral view; **6**–umbilical view of immature specimen.

8 Side views of specimen from Tanzania, X130; from BLOW (1969, pl. 27, fig. 1-2).

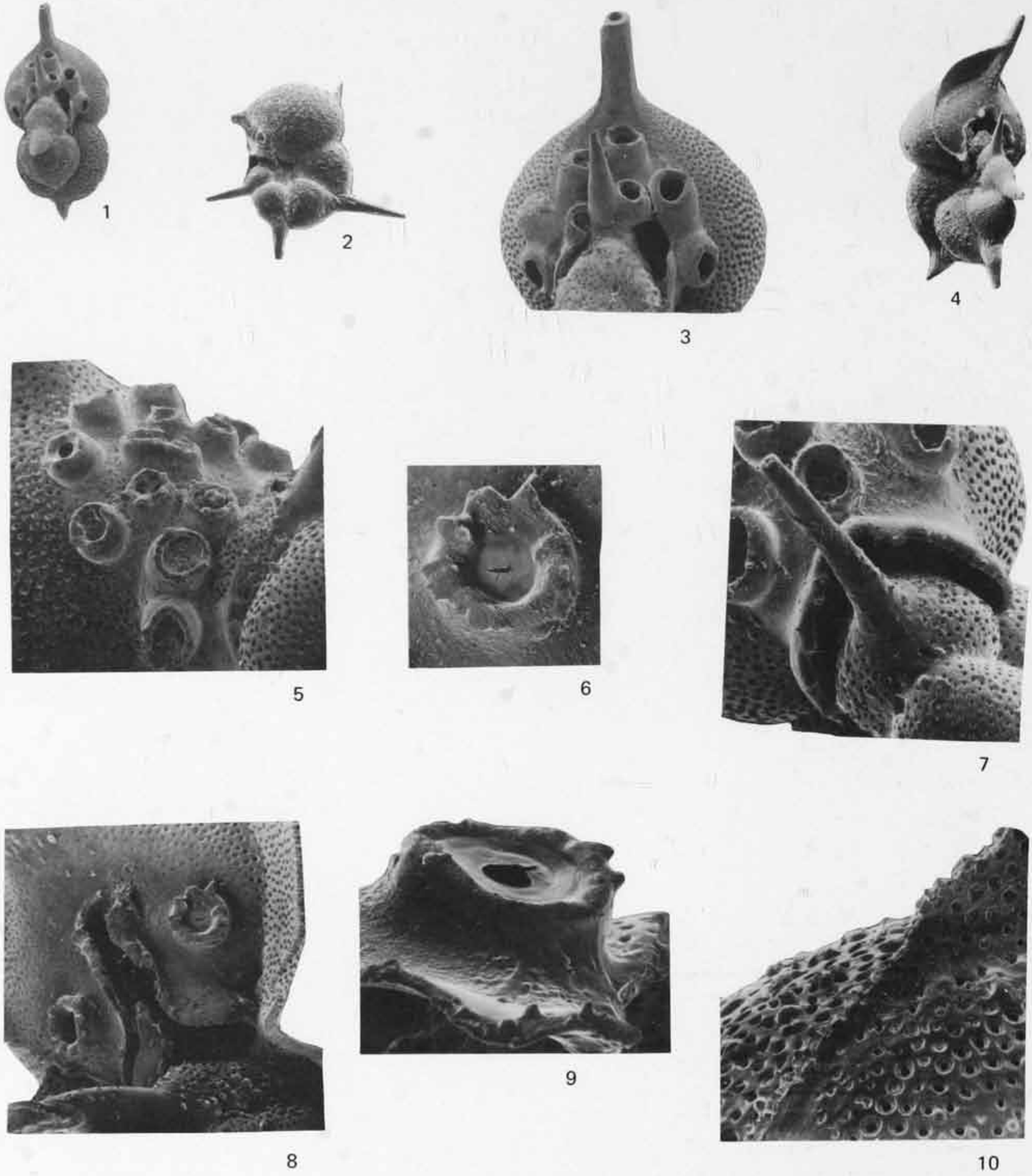


Fig. 57. *Cribrohantkenina inflata* (HOWE) from the Late Eocene (*Globorotalia cerroazulensis* Zone) in the Shubuta Member of the Yazoo Formation of Mississippi.

1-10 Representative specimens. **1**–Apertural face, X50; **2**–lateral view, X50; **3,5,7**–details of aperture, X125, X200, X250; **4**–oblique view of specimen having broken last chamber, X50; **6,9**–detail of supplementary aperture, X500, X700; **8**–aperture of penultimate chamber, X200; **10**–surface of test, X500.

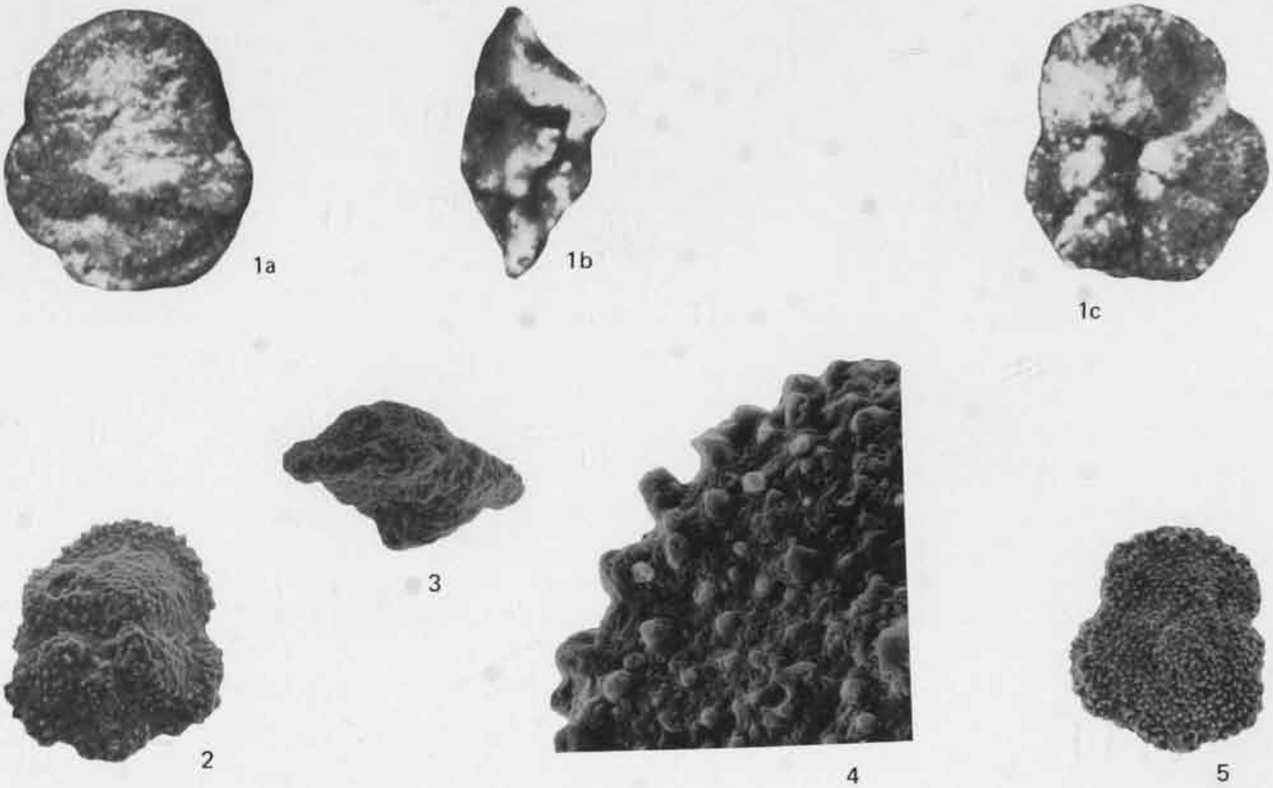


Fig. 58. *Globorotalia kolchidica* MOROZOVA from the Paleocene of the northern Caucasus, Soviet Union.

1 Holotype from the Middle Paleocene, X75; from MOROZOVA (1961, pl. 2, fig. 2). **a**–Spiral view; **b**–side view; **c**–umbilical view.

2-5 Specimens from the Upper Paleocene. **2**–Umbilical view, X100; **3**–side view, X100; **4**–surface and keel of last chamber, X500; **5**–spiral view, X100.

obtuse cone. Last whorl with 4 to 6 angular-conical chambers which increase rapidly in size. Outline lobate, periphery acute, with keel which tends to be ragged. Sutures on spiral side curved, slightly depressed or flush; on umbilical side depressed and radial. Umbilicus deep and narrow with some thickening on shoulders. Aperture a low arch, extraumbilical-umbilical, generally with distinct lip. Test spinose, especially on umbilical side. Diameter 0.3 to 0.5 mm.

Discussion.–*Globorotalia kolchidica* differs from *Globorotalia simulatilis* mainly by the distinct keel but also by its more rapid increase in chamber size and flatter spiral side. *Globorotalia kolchidica* is the first Paleocene *Globorotalia* having a distinct keel.

Distribution.–Middle to Late Paleocene (*Globorotalia angulata* Zone to within *Globorotalia pseudomenardii* Zone). The species was first described from the Middle Paleocene of the southern Soviet Union.

GLOBIGERINATHEKA KUGLERI (Bolli, Loeblich, & Tappan, 1957)

Figure 59
Middle Eocene

Globigerapsis kugleri BOLLI, LOEBLICH, & TAPPAN, 1957, p. 34, pl. 6, fig. 6.

Globigerinatheka mexicana kugleri (BOLLI, LOEBLICH, & TAPPAN). BOLLI, 1972a, p. 128, fig. 12-17, pl. 2, fig. 6-7.

[not] *Globigerapsis kugleri* BOLLI, LOEBLICH, & TAPPAN. BOLLI, 1957c, pl. 36, fig. 21 (=*Globigerinatheka curryi* PROTO DECIMA & BOLLI, 1970, p. 889).

Test almost globular, initial portion trochospiral, each whorl with approximately 4 globular chambers which increase rapidly in size. Final chamber considerably larger than preceding and somewhat embracive, covering umbilical portion of older chambers. Sutures deeply depressed, commonly almost incised, radial to slightly curved. Aperture in early part of test umbilical, but in adult test covered by final embracing chamber, which has 2 to 4 arched

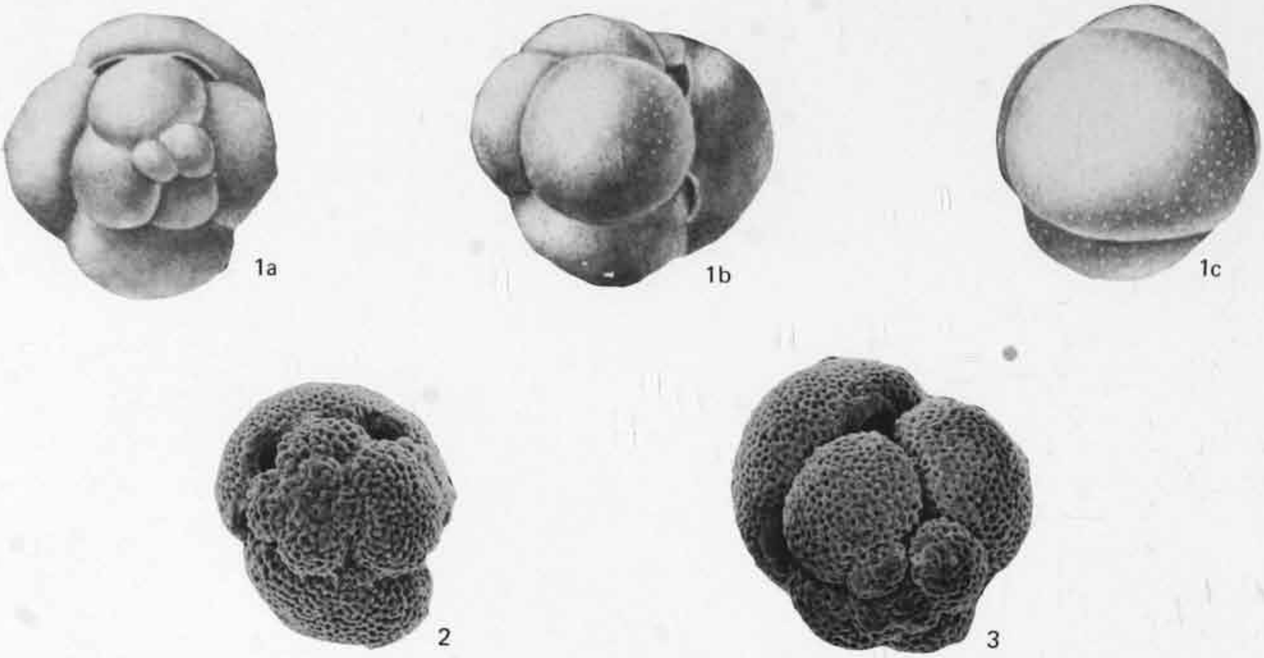


Fig. 59. *Globigerinatheka kugleri* (BOLLI, LOEBLICH, & TAPPAN) from the Middle Eocene part (*Orbulinoides beckmanni* Zone) of the Navet Formation of Trinidad.

1-3 Holotype (**1** from BOLLI, LOEBLICH, & TAPPAN, 1957, pl. 6, fig. 6) and other specimens. **1**–Spiral, side, and umbilical views, X95; **2-3**–spiral and oblique views, X100.

sutural apertures along basal suture, each bordered by slight lip. Surface of test coarsely perforate, finely hispid. Diameter close to 0.4 mm.

Discussion.–This is the type species of *Globigerapsis* BOLLI, LOEBLICH, & TAPPAN (1957, p. 33-34, pl. 6, fig. 6-7), but that genus was put in synonymy with *Globigerinatheka* by PROTODECIMA & BOLLI (1970, p. 884, 888).

Globigerinatheka kugleri differs from *Globigerinatheka semiinvoluta* in having more deeply depressed sutures, a better individualized initial whorl, and smaller secondary apertures. *Globigerinatheka index* is grossly similar but has a very typical thick and rugose wall. *Globigerinatheka kugleri* is closely related to *Globigerinatheka mexicana* but has a larger and more loosely coiled initial spire, more globular chambers, and consequently a less compact aspect. It differs from *Globigerinatheka barri* mainly by lack of bullas. For a more thorough discussion of the relationships among representatives of the genus *Globigerinatheka*, reference is made to BOLLI (1972a).

Distribution.–Middle Eocene (top of *Globigerinatheka subconglobata* Zone to top of *Orbulinoides beckmanni* Zone). The species is rare in the *Globorotalia lehneri* Zone and frequent in the *Orbulinoides beckmanni* Zone. The holotype of *G. kugleri* is from the *Orbulinoides beckmanni* Zone in the Navet Formation of Trinidad.

GLOBOROTALIA LEHNERI Cushman & Jarvis, 1929

Figure 60

Middle Eocene

Globorotalia lehneri CUSHMAN & JARVIS, 1929, p. 17, pl. 3, fig. 16.–BOLLI, 1957c, p. 169, pl. 38, fig. 9-13.–BLOW, 1969, p. 363, pl. 50, fig. 1.–POSTUMA, 1971, p. 198-199.

Test compressed, umbilico-convex to almost lenticular. Periphery strongly lobate, serrated, and frilled; with faint keel. Last whorl with 5 to 7 radially elongate chambers which increase regularly in size. Umbilicus open, shallow. Umbilical shoulders rounded, commonly ornamented with blunt spines.

Aperture a low arch, extraumbilical-umbilical. Surface in part spinose, especially on umbilical side and at periphery. Diameter 0.4 to 0.6 mm.

Discussion.–*Globorotalia lehneri* is linked with *Globorotalia spinulosa* by intermediate forms but is distinguished by the radial elongation of its chambers.

Distribution.–Middle Eocene (*Globigerinatheka subconglobata* Zone to *Truncorotaloides rohri* Zone). *Globorotalia lehneri* was first described from the Middle Eocene of Trinidad.

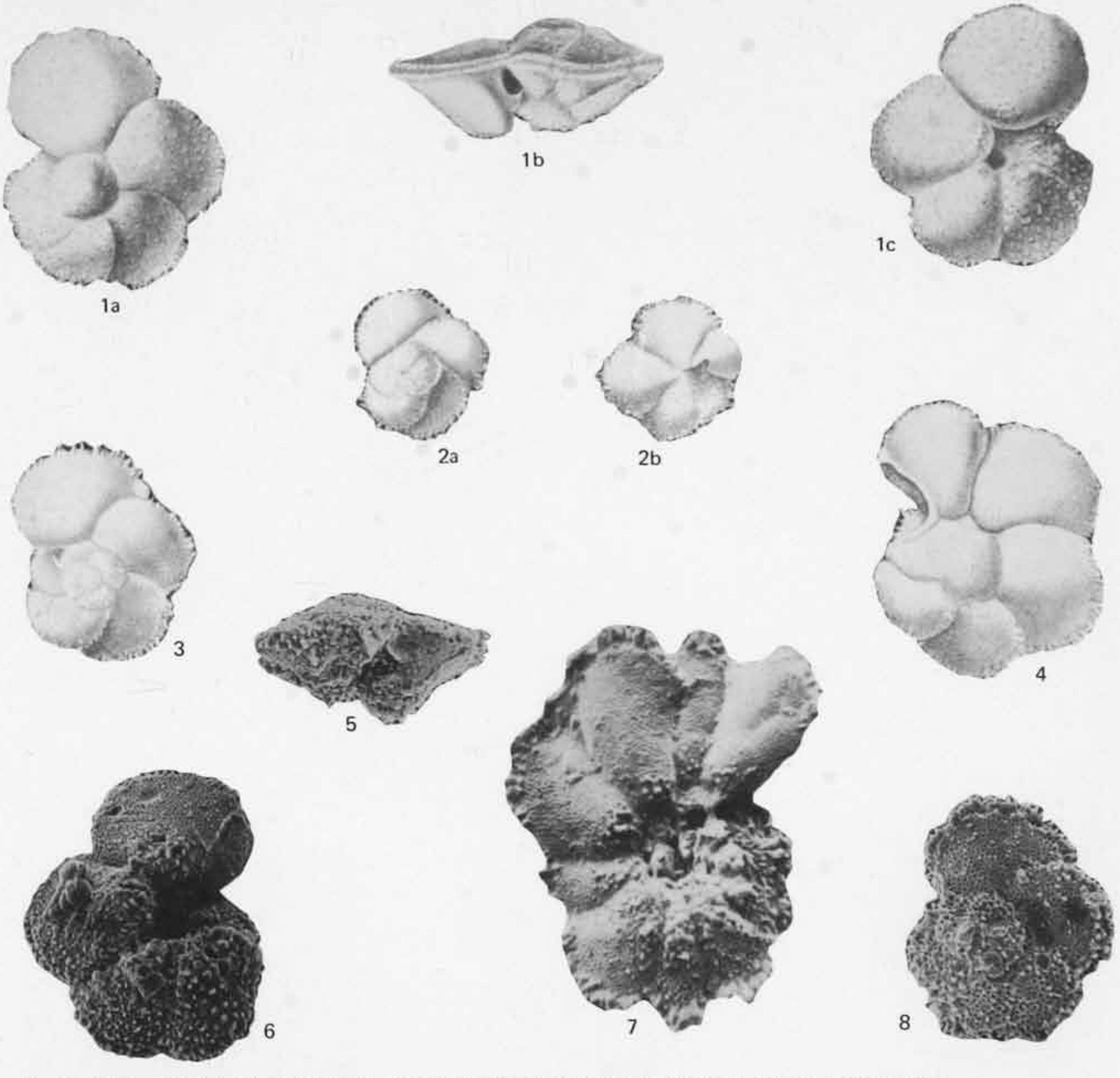


Fig. 60. *Globorotalia lehneri* CUSHMAN & JARVIS from the Middle Eocene of Trinidad, Mexico, and east Africa.

1-4 Specimens (**1**=holotype) from the *Orbulinoides beckmanni* Zone in the Navet Formation of Trinidad, X73; from BOLLI (1957c, pl. 38, fig. 9-10, 12-13). **1a,2a,3-4**–Spiral views; **1b**–side view; **1c,2b**–umbilical views.

5-6,8 Specimens from the Guayabal Formation of Mexico, X100. **5**–Side view; **6**–umbilical view; **8**–spiral view.

7 Umbilical view of specimen from Zanzibar, east Africa, X130; from BLOW (1969, pl. 50, fig. 1).

GLOBOROTALIA LENSIFORMIS Subbotina, 1953

Figure 61

Early Eocene

Globorotalia lensiformis SUBBOTINA, 1953, p. 214, pl. 18, fig. 4-5.–SUBBOTINA, 1971, p. 272-273, pl. 18, fig. 4-5.

Globorotalia nartanensis SHUTSKAYA, 1956, p. 96-98, pl. 4, fig. 2.

Test umbilico-convex, spiral side almost flat, umbilical side strongly convex, subconical. Last whorl rather tightly coiled with 4 to 5 angular-conical chambers which increase rapidly in size with last occupying at least one-third of entire whorl. Sutures on spiral side curved, slightly depressed or flush; on umbilical side depressed, radial. Umbilicus narrow but

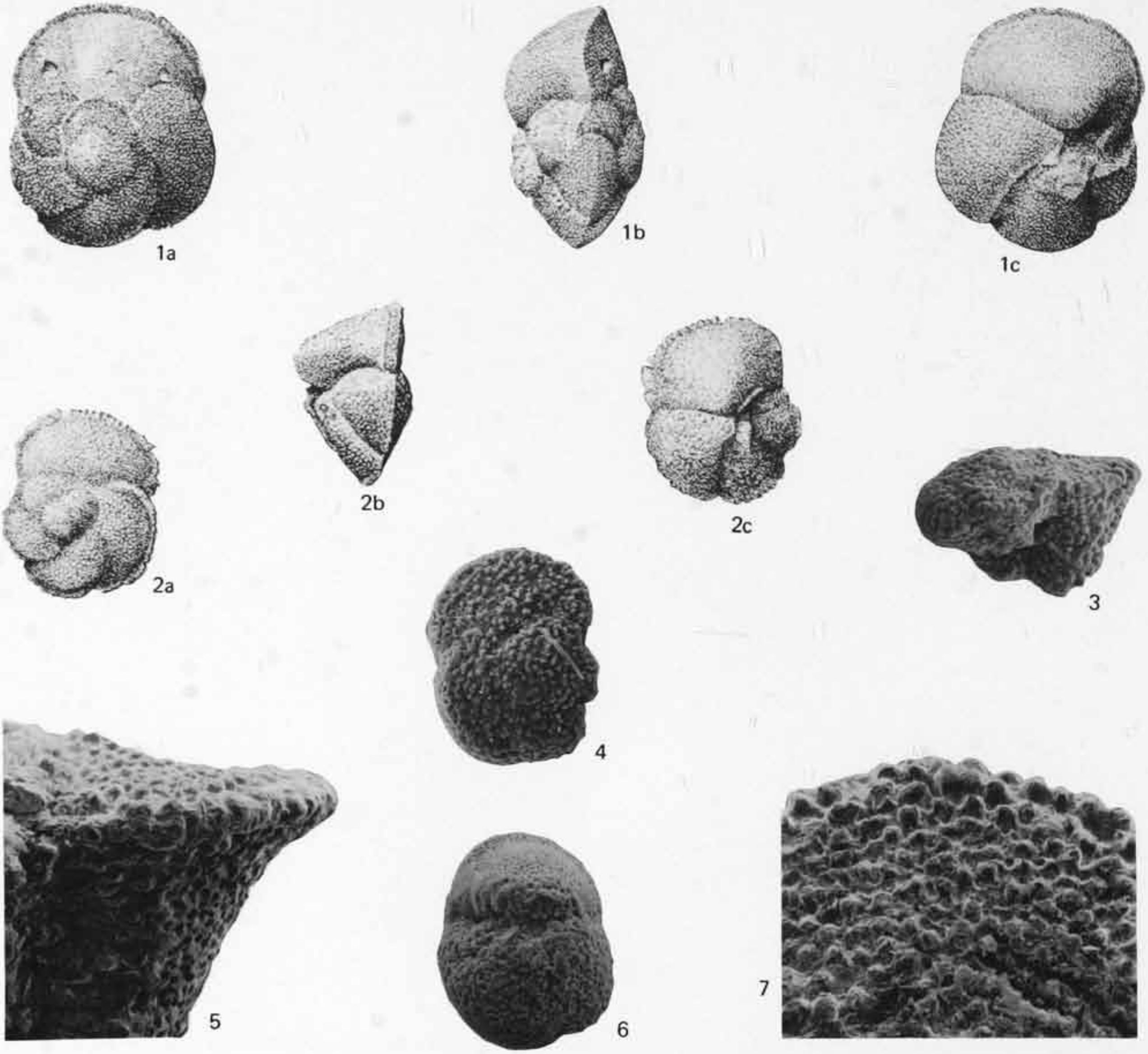


Fig. 61. *Globorotalia lensiformis* SUBBOTINA from the Lower Eocene of the Soviet Union and California.

1-2 Specimens (**1**=holotype) from the northern Caucasus, Soviet Union, X72; from SUBBOTINA (1953, pl. 18, fig. 4-5). **a**–Spiral views; **b**–side views; **c**–umbilical views.

3-7 Specimens from the *Globorotalia formosa formosa* Zone in the Lodo Formation of California. **3**–Side view, X100; **4**–spiral view, X100; **5**–keel of last chamber, X250; **6**–umbilical view, X100; **7**–surface of last chamber, X250.

deep. Aperture a low arch, extraumbilical-umbilical, with faint lip. Surface of test rugose. Diameter 0.40 to 0.55 mm.

Discussion.–*Globorotalia lensiformis* is the predecessor of *Globorotalia aragonensis* from which it differs mainly in fewer chambers in the last whorl. *Globorotalia naussi* MARTIN (1943, p. 116, pl. 8, fig. 3) also has generally more chambers in the last whorl than *G. lensiformis.*

Distribution.–Early Eocene (from within *Globorotalia subbotinae* Zone through *Globorotalia formosa formosa* Zone). The species was first described from the Lower Eocene of the northern Caucasus.

HANTKENINA LIEBUSI Shokhina, 1937

Figure 62

Middle Eocene

Hantkenina liebusi SHOKHINA, 1937, p. 444, 446, pl. 2, fig. 2-3.–SUBBOTINA, 1953, p. 132-133, pl. 1, fig. 11.–SUBBOTINA, 1971, p. 145-146, pl. 1, fig. 11.

?Hantkenina (Applinella) liebusi SHOKHINA. BRONNIMANN, 1950b, p. 410-411, pl. 56, fig. 1, 18-19, 23.

?Hantkenina (Hantkenina) liebusi SHOKHINA. BRONNIMANN, 1950c, p. 248-251, fig. B.

Test planispiral, biumbilicate, involute, strongly compressed laterally, tightly coiled. Last whorl with 5 to 6 apiculate chambers which actually increase regularly in size although, because of their imbrication, last may appear abnormally large. Chambers radially elongate, tapering without break into slender spines which arise from their distal tips. Outline oval, made stellate by spines. Sutures distinctly depressed, sigmoid. Aperture trilobate, median lobe reaching about halfway up apertural face, with distinct lip and apertural flanges. Surface of test distinctly perforate, smooth. Diameter to 1 mm.

Discussion.–*Hantkenina liebusi* differs from *Hantkenina aragonensis* and *Hantkenina mexicana* by its less lobate periphery, large final chamber, and more slender spines.

Distribution.–According to SUBBOTINA (1953, 1971) *H. liebusi* is restricted to Middle Eocene beds ranging approximately from the *Globigerinatheka subconglobata* Zone to the *Truncorotaloides rohri* Zone, but other authors record it in the Upper Eocene.

GLOBIGERINA LINAPERTA Finlay, 1939

Figure 63

Late Paleocene to Late Eocene

Globigerina linaperta FINLAY, 1939c, p. 125, pl. 13, fig. 54-56.–BOLLI, 1957c, p. 163, pl. 36, fig. 5.–HORNIBROOK, 1958, p. 33, pl. 1, fig. 19-21 [holotype refigured].–BERMÚDEZ, 1960, p. 1188, pl. 4, fig. 5; pl. 5, fig. 1.–BLOW, 1969, p. 320.

Globigerina (Subbotina) linaperta FINLAY. JENKINS, 1971, p. 162-163, pl. 18, fig. 551-554 [holotype refigured, fig. 551-553].

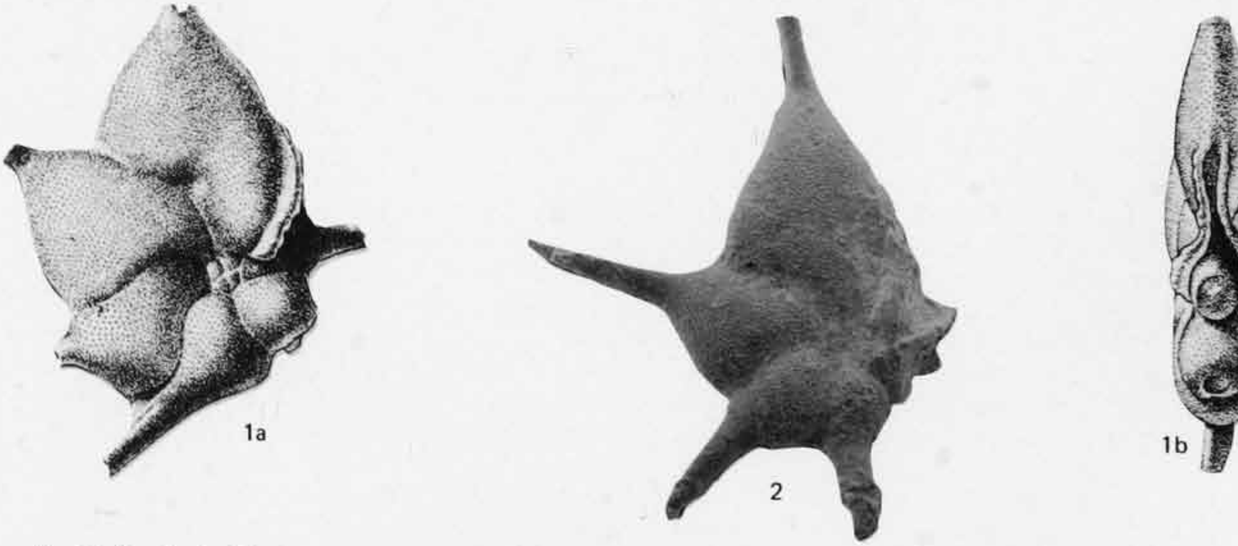


Fig. 62. *Hantkenina liebusi* SHOKHINA from the Middle Eocene of the Soviet Union.

1 Specimen from the northern Caucasus, X72; from SUBBOTINA (1953, pl. 1, fig. 11). **a**–Lateral view; **b**–apertural face.

2 Lateral view of specimen from western Turkmenia, X100.

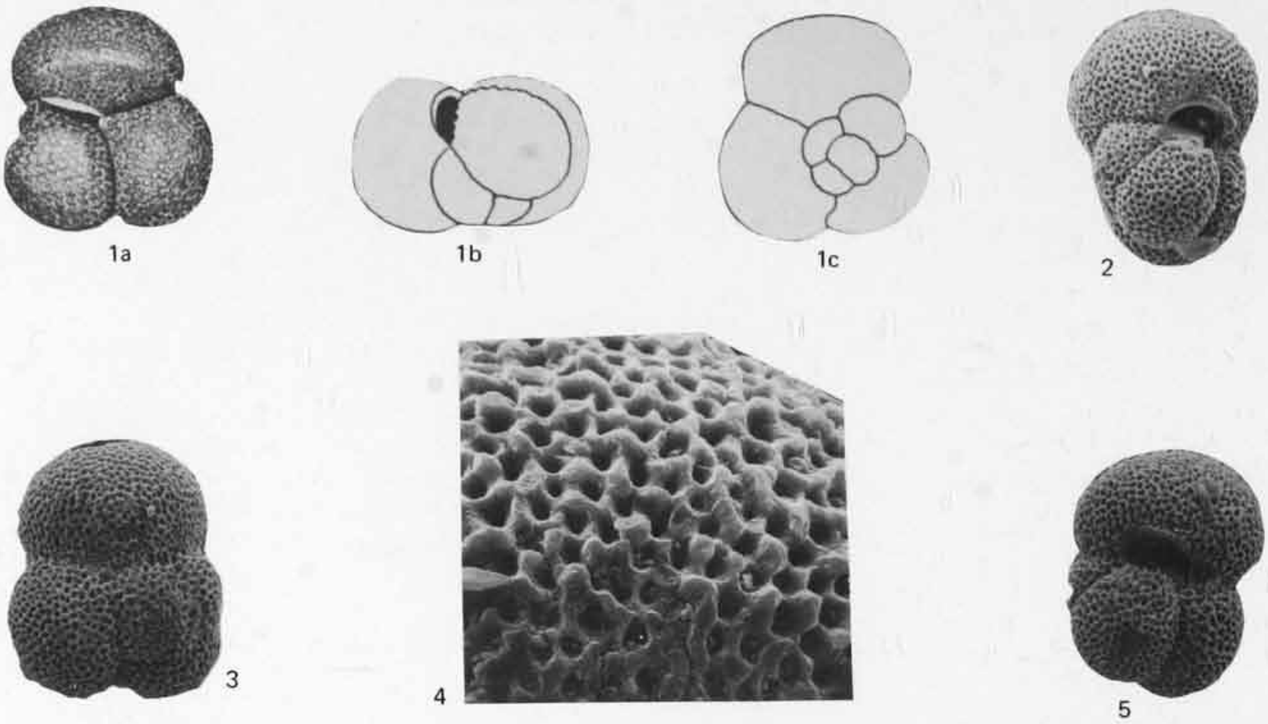


Fig. 63. *Globigerina linaperta* FINLAY from the Eocene of New Zealand and California.

1 Holotype from the Middle Eocene of New Zealand, X70; from HORNIBROOK (1958, pl. 1, fig. 19-21). **a**–Umbilical view; **b**–side view; **c**–spiral view.

2-5 Specimens from the Early Eocene part (*Globorotalia formosa formosa* Zone) of the Lodo Formation of California. **2**–Side view, X100; **3**–spiral view, X100; **4**–surface of last chamber, X500; **5**–umbilical view, X100.

Test a compact trochospire, spiral and umbilical sides both slightly flattened, thickness about two-thirds diameter. Last whorl generally composed of 3½ subglobular chambers which increase rapidly in size, last occupying close to half of whorl. Outline trilobate, margin broadly rounded. Sutures depressed, radial. Umbilicus shallow. Aperture large but very low, somewhat extraumbilical-umbilical in position, with distinct lip. Surface of test coarsely perforate, distinctly cancellate. Diameter 0.3 to 0.4 mm.

Discussion.–Elsewhere in this paper *Globigerina linaperta* is designated the central form of a closeknit plexus which displays great variability of coiling parameters. The usually smaller *Globigerina triloculinoides* is considered ancestral to the group. *Globigerina angiporoides* is closely related but has a tighter, more compact coil.

Distribution.–Late Paleocene to Late Eocene (*Globorotalia velascoensis* Zone to *Globorotalia cerroazulensis* Zone). The species was originally described from the Middle Eocene of New Zealand.

HANTKENINA LONGISPINA Cushman, 1925
Figure 64
Middle to Late Eocene

Hantkenina longispina CUSHMAN, 1925a, p. 2, pl. 2, fig. 4.–SUBBOTINA, 1953, p. 134-135, pl. 1, fig. 8-10.–SUBBOTINA, 1971, p. 148, pl. 1, fig. 8-10.

Hantkenina (Applinella) longispina CUSHMAN. BRÖNNIMANN, 1950b, p. 411-413, pl. 55, fig. 11, 13, 15.

Test planispiral, biumbilicate, involute. Outline stellate. Last whorl with 4 to 5 somewhat lobate chambers which increase gradually in size, each carrying a tapering spine. Spines conspicuous, straight, radial. In early portion spines are centrally placed extensions of apiculate chambers but migrate distally so that adult spines are adjacent to sutures. Length of spines generally exceeds length of chambers. Umbilici very small and shallow. Aperture trilobate, median lobe reaching about halfway up apertural face. Apertural flanges only weakly developed. Surface of test finely pitted, smooth, except on earlier part where may be granular. Diameter 0.4 to 0.5 mm exclusive of spines.

Fig. 64. *Hantkenina longispina* CUSHMAN from the Middle Eocene of the Soviet Union, Trinidad, and Gulf of Mexico.

1-2 Specimens from the upper part of the Middle Eocene of the northern Caucasus, Soviet Union, X72; from SUBBOTINA (1953, pl. 1, fig. 8-9). **1**–Lateral views; **2**–apertural face.

3,5 Lateral views of specimens from the Navet Formation of Trinidad, X50; from BRÖNNIMANN (1950b, pl. 55, fig. 12, 15).

4,6 Lateral views of specimens from the northeastern Gulf of Mexico, X100.

Discussion.–*Hantkenina longispina* differs from *Hantkenina aragonensis* and *Hantkenina mexicana* in being less lobate and from *Hantkenina alabamensis* by the generally longer spines and their apical position on early chambers.

Distribution.–Middle to Late Eocene (approximately *Orbulinoides beckmanni* Zone to *Globorotalia cerroazulensis* Zone). The species was first described from the Late Eocene Alazan Formation of Mexico.

GLOBOROTALIA MARGINODENTATA Subbotina, 1953

Figure 65

Late Paleocene to Early Eocene

Globorotalia marginodentata SUBBOTINA, 1953, p. 212-213, pl. 17, fig. 14-16; pl. 18, fig. 1-3.–SUBBOTINA, 1971, p. 268-269, 272, pl. 17, fig. 14-16; pl. 18, fig. 1-3.

Test trochospiral, umbilico-convex to lenticular, inner coil raised above flattened last whorl on spiral side, umbilical side variably convex. Periphery lobate, acute, with broad frilled keel. Last whorl with 4 to 5 chambers which increase rapidly in size. Sutures on spiral side curved, varying from raised to flush; on umbilical side radial and depressed. Umbilicus very narrow to closed. Umbilical shoulders vary from rounded and smooth to sharp and ornamented. Aperture a low arch, extraumbilical-umbilical in position. Test rugose, especially on umbilical side. Diameter 0.4 to 0.5 mm.

Discussion.–*Globorotalia marginodentata* is characterized by broad keel which gives the periphery a distinctive pinched appearance.

Distribution.–Late Paleocene to Early Eocene (from within the *Globorotalia velascoensis* Zone to within the *Globorotalia formosa formosa* Zone). The species was first described from the Lower Eocene of the northern Caucasus.

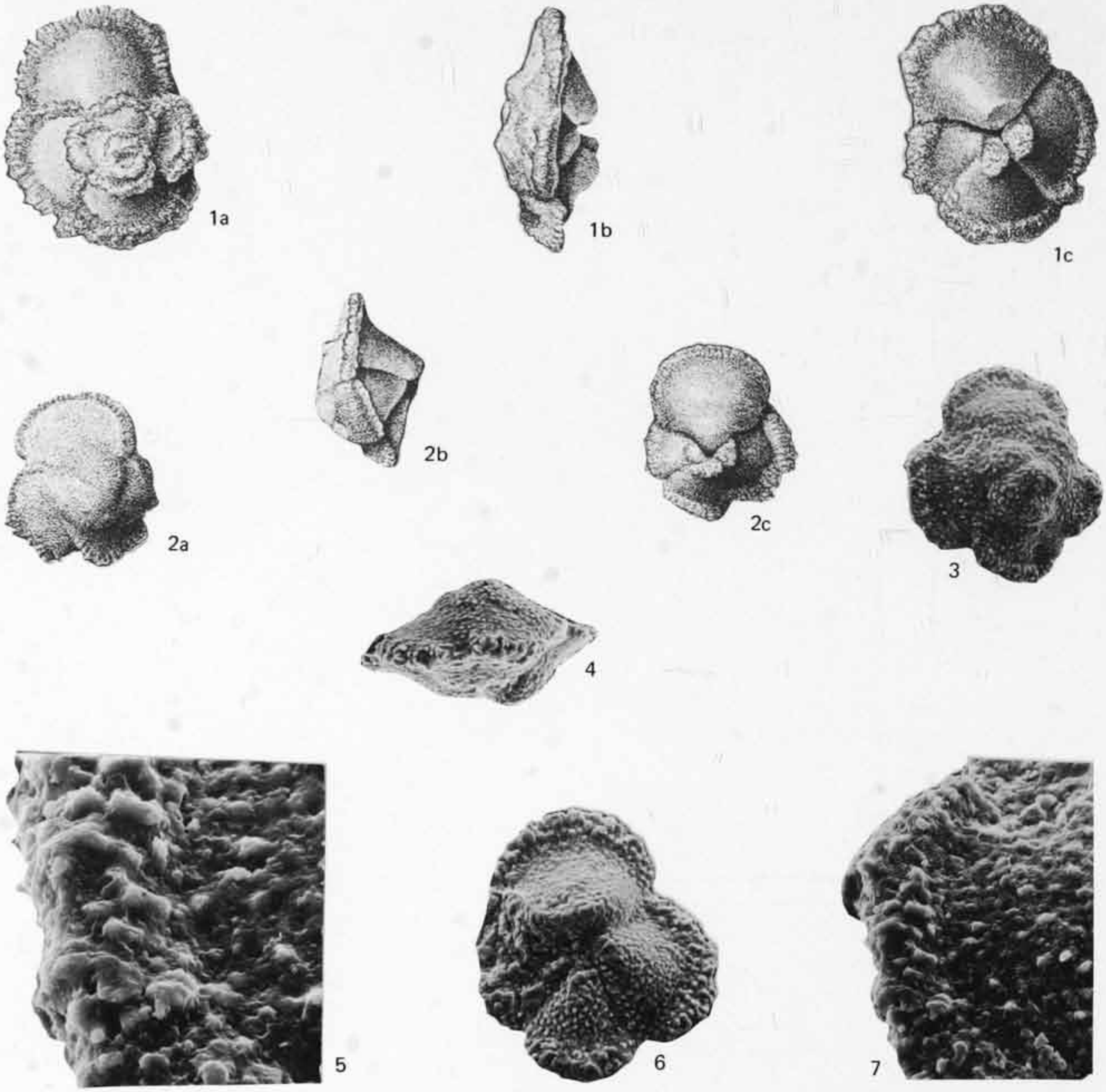


Fig. 65. *Globorotalia marginodentata* SUBBOTINA from the Lower Eocene (*Globorotalia subbotinae* Zone) of the northern Caucasus, Soviet Union (**1-2** from SUBBOTINA, 1953, pl. 17, fig. 15-16).

1-7 Holotype (**1**) and other specimens. **1a,2a,3**–Spiral views, X72, X72, X100; **1b,2b,4**–side views, X72, X72, X100; **1c,2c,6**–umbilical views, X72, X72, X100; **5,7**–keel of penultimate chamber, X500, X250.

GLOBIGERINA MCKANNAI White, 1928

Figure 66

Middle to Late Paleocene

Globigerina mckannai WHITE, 1928, p. 194, pl. 27, fig. 16.–LOEBLICH & TAPPAN, 1957a, p. 181-182, pl. 47, fig. 7; pl. 53, fig. 1-2; pl. 57, fig. 8; pl. 62, fig. 5-7.–PREMOLI SILVA, 1970, p. 140-141, pl. 25, fig. 3.

Globigerina subsphaerica SUBBOTINA, 1947, p. 108-109, pl. 5, fig. 23-28.

Acarinina subsphaerica (SUBBOTINA). SHUTSKAYA, 1956, p. 89-90, pl. 2, fig. 6-14; pl. 3, fig. 1-21.

Globorotalia mckannai (WHITE). BOLLI, 1957a, p. 79, pl. 19, fig. 16-18.–POSTUMA, 1971, p. 200-201.

Test a compact trochospire consisting of 3 to 3½ whorls; thickness about three-quarters of diameter. Inner whorls disproportionately smaller than last whorl and raised above it so that gross form of test approaches subglobular. Last whorl has 5 to 7 subspherical chambers which increase only gradually in size and are somewhat axially elongate, crowded around narrow but deep, star-shaped umbilicus. Periphery subcircular, only very slightly lobate. Sutures depressed; on spiral side oblique, on umbilical side radial. Aperture a low arch, umbilical to extraumbilical-umbilical in position. Test hispid. Diameter 0.3 mm.

Discussion.–*Globigerina subsphaerica* is treated here as a junior synonym of *Globigerina mckannai* as series of topotypes of the two species show the same range of variability. *Globigerina nitida* has fewer chambers in the last whorl. The species is intermediate between the genera *Globigerina* and *Globorotalia.*

Distribution. –Middle to Late Paleocene (*Globorotalia pusilla pusilla* Zone to *Globorotalia velascoensis* Zone). *Globigerina mckannai* is an important marker species for the Late Paleocene in higher latitudes where keeled *Globorotalia* species are lacking. It was first described from the Paleocene Velasco Formation of eastern Mexico.

GLOBIGERINATHEKA MEXICANA (Cushman, 1925)

Figure 67

Middle Eocene

Globigerina mexicana CUSHMAN, 1925b, p. 6, pl. 1, fig. 8.

Globigerapsis mexicana (CUSHMAN). SAITO, 1962, p. 219, pl. 34, fig. 6 [not 7].–BLOW & SAITO, 1968, p. 357-360, fig. 1-4 [holotype redrawn].

Globigerinatheka mexicana mexicana (CUSHMAN). BOLLI, 1972a, p. 129, fig. 1-11, pl. 2, fig. 1-5.

[not] *Porticulasphaera mexicana* (CUSHMAN). BOLLI, LOEBLICH, & TAPPAN, 1957, p. 34, pl. 6, fig. 8-9.–BOLLI, 1957c, p. 165, pl. 37, fig. 1 [=*Orbulinoides beckmanni* (SAITO)].

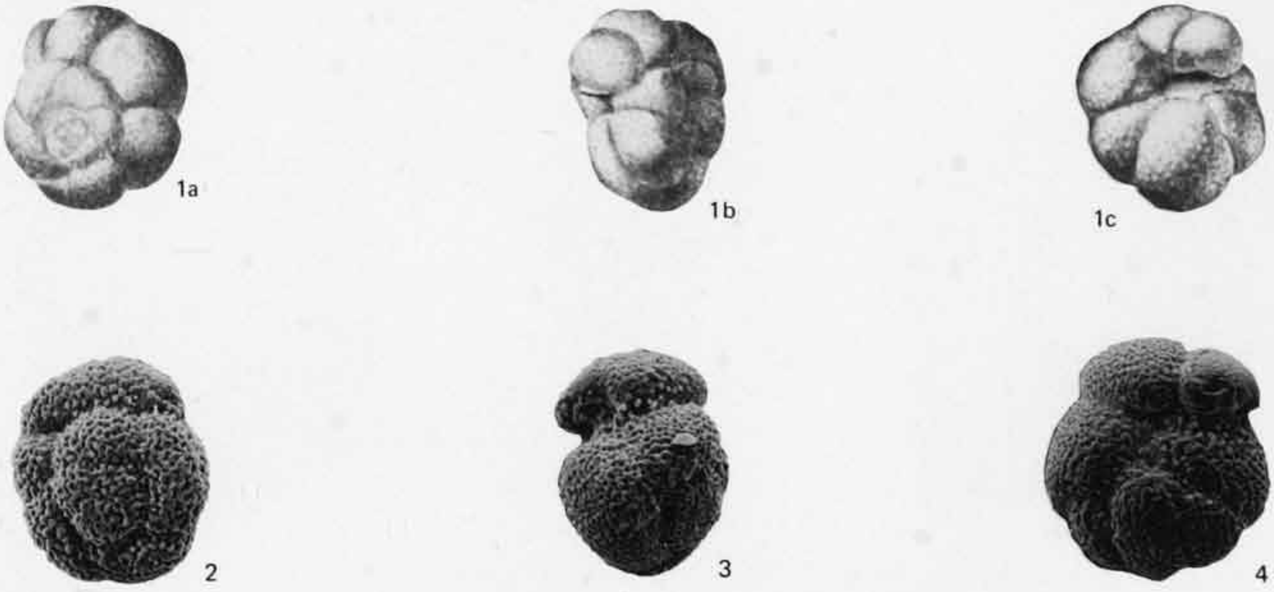


Fig. 66. *Globigerina mckannai* WHITE from the Late Paleocene *Globorotalia pseudomenardii* Zone of Trinidad and Egypt, X100.

1 Specimen from the Lizard Springs Formation of Trinidad; from BOLLI (1957a, pl. 19, fig. 16-18). **a**–Spiral view; **b**–side view; **c**–umbilical view.

2-4 Specimens from the Western Desert of Egypt. **2**–Spiral view; **3**–side view; **4**–umbilical view.

Test small for the genus, more or less globular. Earlier chambers moderately inflated and domelike, embracing one-third to two-fifths of earlier part of test and covering umbilicus. Sutures shallow, distinctly depressed. Sutural apertures typical for genus, relatively small, with distinct rims. Surface coarsely perforate, last chamber generally smoother than others. Diameter 0.3 to 0.4 mm.

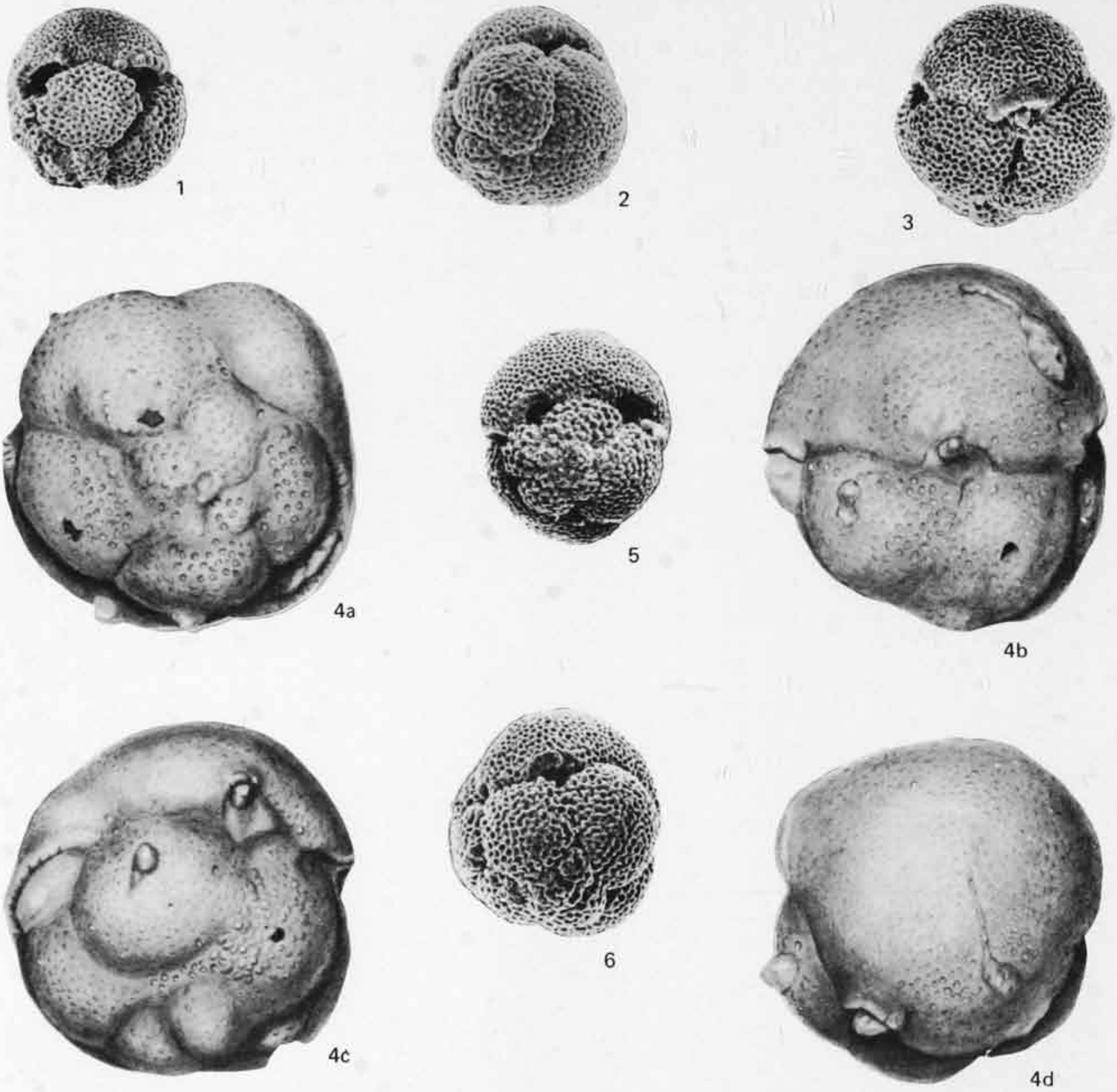


Fig. 67. *Globigerinatheka mexicana* (CUSHMAN) from the Middle Eocene of Trinidad and Mexico.

1-3,5-6 Specimens from the *Orbulinoides beckmanni* Zone of the Navet Formation in Trinidad, X100. **1,6**–Specimens with three apertures (two visible); **2-3**–specimens with two apertures (both visible); **5**–specimen with three apertures (all visible).

4 Holotype from Mexico, X174; from BLOW & SAITO (1968, fig. 1-4). **a**–Spiral view; **b-c**–oblique side views; **d**–umbilical view.

Discussion.–"*Globigerina*" *mexicana* was redescribed and its holotype refigured by BLOW & SAITO (1968). It had been misidentified by BOLLI, LOEBLICH, & TAPPAN (1957), who selected it as type species for the invalid genus *Porticulasphaera*. For more detailed discussions see, in particular, BLOW & SAITO (1968) and BOLLI (1972a).

Other species of *Globigerinatheka* differ from *G. mexicana* in the following respects. *Globigerinatheka semiinvoluta* generally is larger with mostly flush and indistinct sutures, generally has more prominent and circular sutural apertures, and in particular has a more embracing and hemispherical final chamber which accounts for half or more of the test volume. *Globigerinatheka kugleri* has a larger initial spire and more globular chambers, resulting in a less compact aspect of the test. *Globigerinatheka barri* is closely related to *G. mexicana* and differs mainly in the presence of bullas.

Distribution.–Middle Eocene (*Globigerinatheka subconglobata* Zone to base of *Globigerinatheka semiinvoluta* Zone). *Globigerinatheka mexicana* is frequent in the *Globorotalia lehneri* and *Orbulinoides beckmanni* Zones but becomes scarce to absent in the *Truncorotaloides rohri* Zone. The species was first described from Middle Eocene deposits of eastern Mexico; for discussion of the age of its type level see BLOW & SAITO (1968) and BOLLI (1972a).

PSEUDOHASTIGERINA MICRA (Cole, 1927)

Figure 68

Middle Eocene to early Oligocene

Nonion micrus COLE, 1927, p. 22, pl. 5, fig. 12.

Nonion danvillensis HOWE & WALLACE, 1932, p. 51, pl. 9, fig. 3.

Nonion iota FINLAY, 1940, p. 456, pl. 65, fig. 108-110.

Globigerinella micra (COLE). SUBBOTINA, 1953, p. 88-89, pl. 13, fig. 16-17.–SUBBOTINA, 1971, p. 122-124, pl. 13, fig. 16-17.–BERMÚDEZ, 1960, p. 1213-1214, pl. 7, fig. 2.

Hastigerina micra (COLE). BOLLI, 1957c, p. 161, pl. 35, fig. 1-2.

Pseudohastigerina micra (COLE). BANNER & BLOW, 1959, p. 19-20, fig. 4 (g-i),–BLOW, 1969, p. 275, 376, pl. 53, fig. 1, 4-6.–CORDEY, BERGGREN, & OLSSON, 1970, p. 235-242, fig. 1-5.

Globanomalina micra (COLE). JENKINS, 1971, p. 78-79, pl. 2, fig. 50-54.

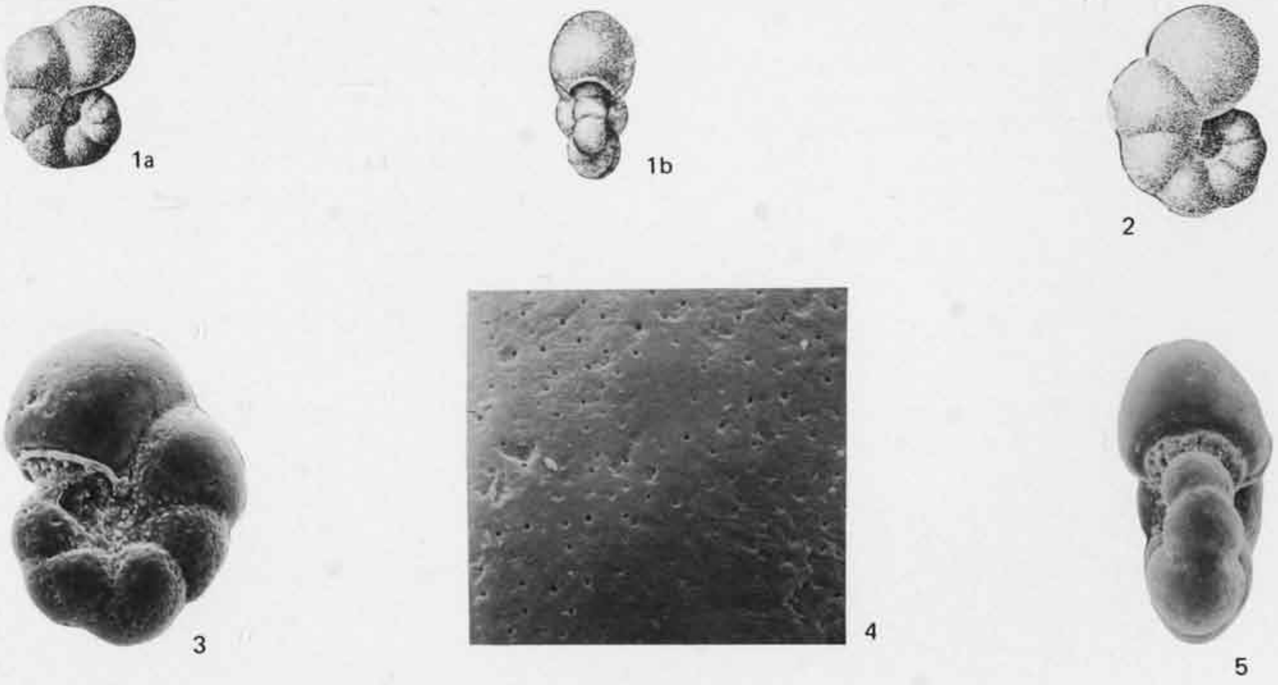


Fig. 68. *Pseudohastigerina micra* (COLE) from the Eocene of the Soviet Union.

- 1 Specimen from the upper Middle Eocene of the northern Caucasus, X72; from SUBBOTINA (1953, pl. 13, fig. 16). **a**–Side view; **b**–apertural view.
- 2 Side view of specimen from the Upper Eocene of the Ukraine, X72; from SUBBOTINA (1953, pl. 13, fig. 17).
- 3-5 Specimens from the upper Middle Eocene of the northern Caucasus. **3**–Side view, X200; **4**–detail of surface of last chamber, X1000; **5**–apertural view, X200.

Test small, planispiral, of 2 to 3 whorls of slowly enlarging, partially embracing chambers, 6 to 7 in each whorl. Equatorial outline only weakly lobate. Axial profile suboval, chambers appearing ovate. Periphery rounded, tending towards subacute in youngest chambers of large specimens. Sutures depressed, initially almost radial, becoming increasingly curved in younger part of test. Biumbilicate with part of initial coil visible in shallow umbilici. Aperture a low interiomarginal-equatorial arch extending along base of apertural face and embracing earlier whorl, with lip and partial flanges. Relict parts of earlier apertures may be visible in umbilici. Surface smooth except weakly hispid on early chambers. Diameter 0.2 to 0.4 mm.

Discussion.—Most modern authors accept *Pseudohastigerina* as the valid generic name for this species. A proposal to substitute *Globanomalina* was made by LOEBLICH & TAPPAN (1964, p. C665) but refuted by BERGGREN, OLSSON, & REYMENT (1967). *Pseudohastigerina micra* differs from *Pseudohastigerina wilcoxensis* in being more laterally compressed and generally smaller, but the two species are linked by intermediate forms in the early Middle Eocene.

Distribution.—Middle Eocene to earliest Oligocene (*Globigerinatheka subconglobata* Zone to *Cassigerinella chipolensis-Pseudohastigerina micra* Zone). Its short-lived co-occurrence with *Cassigerinella chipolensis* is useful in defining the oldest zone in the Oligocene. The species was first described from the Middle Eocene of eastern Mexico.

Pseudohastigerina micra is relatively rare in Middle and Late Eocene assemblages of tropical and subtropical areas where the species diversity is high. In contrast, however, it may be a dominant form in assemblages of the Eocene of higher latitudes and the Oligocene of both higher and lower latitudes where fewer species are present. As an example, the top of the Middle Eocene is marked in eastern Europe and central Asia by impoverished and dwarfed assemblages of planktonic foraminifers which tend to be dominated by *P. micra.*

GLOBIGERINA NITIDA Martin, 1943

Figure 69

Late Paleocene and Early Eocene

Globigerina nitida MARTIN, 1943, p. 115, pl. 7, fig. 1.

Acarinina acarinata SUBBOTINA, 1953, p. 229-230, pl. 22, fig. 4-10.—SUBBOTINA, 1971, p. 298-299, pl. 22, fig. 4-10.

Test a compact trochospire consisting of 2½ whorls with initial portion generally distinctly raised above level of last whorl, umbilical side strongly inflated. Outline subcircular, only slightly lobate; in side view subovate, thickness at least two-thirds width. Last whorl with 4 to 5 globular, axially elongate chambers which increase rapidly in size, last projecting somewhat over narrow umbilicus. Sutures depressed; radial to slightly curved on spiral side, radial on umbilical side. Aperture a low arch, umbilical to extraumbilical-umbilical. Surface of test very hispid, especially on umbilical side. Diameter 0.3 to 0.4 mm.

Discussion.—*Globigerina nitida* differs from *Globigerina mckannai* in having fewer chambers in the last whorl and a somewhat less convex spiral side. It differs from *Globigerina primitiva* by its more rounded aspect in side view. *Globigerina acarinata* (= type species of the genus *Acarinina*) is considered a junior synonym of *G. nitida.* The generic position of the species is not well defined since the position of its aperture varies from umbilical *(Globigerina)* to extraumbilical-umbilical *(Globorotalia).*

Closely related forms having a more open umbilicus and a lower spire are separated as *Globigerina collactea* (FINLAY, 1939d, p. 327, pl. 29, fig. 164-165) (see also BRÖNNIMANN, 1952c, p. 13-14, pl. 1, fig. 13-15, and BOLLI, 1957a, p. 72, pl. 15, fig. 21-23; 1957c, p. 162, pl. 35, fig. 18). BOLLI gave the range of *G. collactea* as Early Eocene (*Globorotalia subbotinae* Zone to within *Globorotalia pentacamerata* Zone).

Distribution.—Late Paleocene and Early Eocene (*Globorotalia velascoensis* Zone to within *Globorotalia formosa formosa* Zone). The species was first described from the Early Eocene part of the Lodo Formation in southern California. *Globigerina nitida* is an important marker for the Paleocene-Eocene transition beds in higher latitudes where keeled species of *Globorotalia* are lacking. Under the name *Acarinina acarinata,* this species is used by Soviet authors as the index of a zone which corresponds to part of the *Globorotalia velascoensis* Zone.

GLOBOROTALIA OCCLUSA Loeblich & Tappan, 1957

Figure 70

Late Paleocene

Globorotalia occlusa LOEBLICH & TAPPAN, 1957a, p. 191, pl. 55, fig. 3; pl. 64, fig. 3.—LUTERBACHER, 1964, p. 690-692.

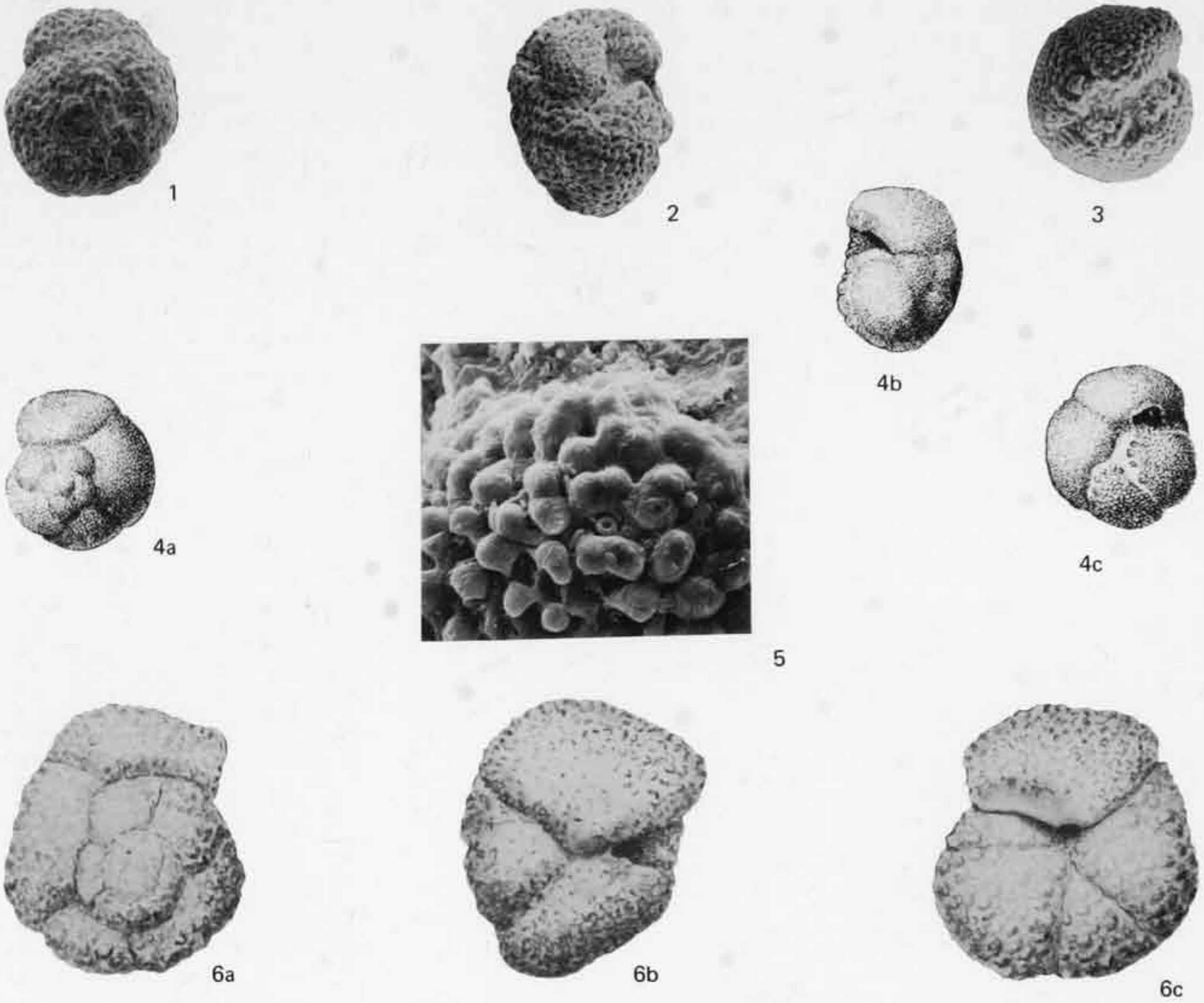


Fig. 69. *Globigerina nitida* MARTIN from the Paleogene of California and the Soviet Union.

1-3,5-6 Specimens (**6**=holotype from MARTIN, 1943, pl. 7, fig. 1) from the Early Eocene part (*Globorotalia subbotinae* Zone) of the Lodo Formation of California. **1,6a**–Spiral views, X100, X136; **2,6b**–side views, X100, X136; **3,6c**–umbilical views, X100, X136; **5**–detail of surface of last chamber, X500.

4 Specimen (holotype of *Acarinina acarinata* SUBBOTINA, 1953) from the Lower Eocene or Upper Paleocene of the northern Caucasus in the Soviet Union, X72; from SUBBOTINA (1953, pl. 22, fig. 4). **a**–Spiral view; **b**–side view; **c**–umbilical view.

Test trochospiral, biconvex, almost lenticular; umbilical side only slightly more convex than spiral side. Last whorl with 5 to 8 angular-rhomboid chambers which increase slowly in size, last chamber commonly smaller than previous. Periphery circular and acute with pustulose keel. Sutures on umbilical side depressed, radial; on spiral side flush or raised and beaded, curved. Umbilicus deep, varying from almost closed to fairly wide. Aperture a low arch, extraumbilical-umbilical, usually with distinct lip. Surface rugose in early part of test, becoming smoother in later chambers. Diameter 0.2 to 0.4 mm.

Discussion.–*Globorotalia occlusa* is often included in the range of variability of *Globorotalia velascoensis* with which it is linked by intermediate forms. Typical representatives of *G. occlusa* have smaller dimensions, weaker ornamentation, and more tightly arranged umbilical shoulders which are not separated by deep clefts as in *G. velascoensis. Globorotalia simulatilis* has the same lenticular aspect as *G. occlusa* but lacks the distinct keel.

Distribution.–Late Paleocene (*Globorotalia pseudomenardii* and *Globorotalia velascoensis* Zones). The species was described originally from the *Globorotalia pseudomenardii* Zone of the Velasco Formation in eastern Mexico.

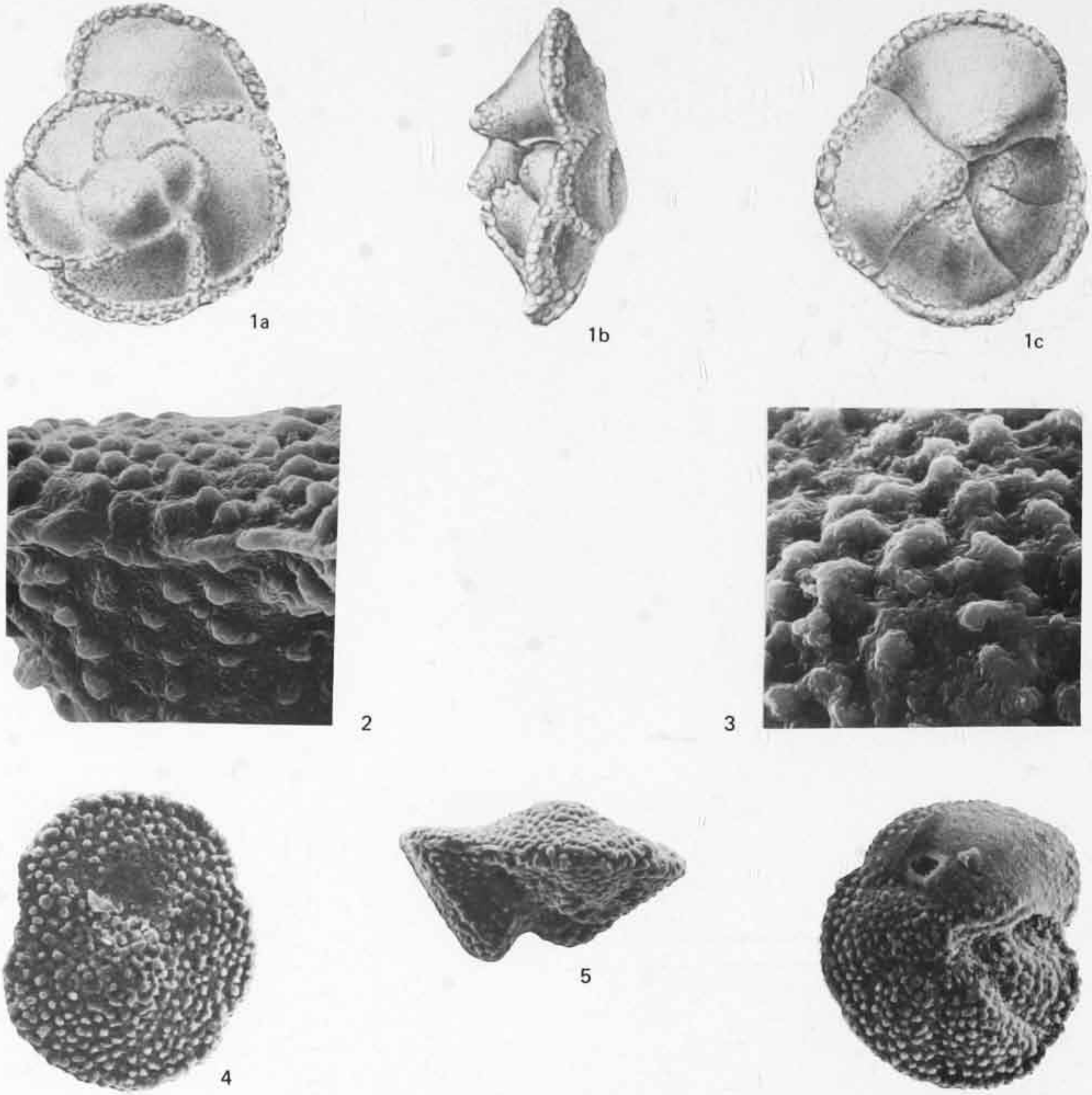


Fig. 70. *Globorotalia occlusa* LOEBLICH & TAPPAN from the Late Paleocene part (*Globorotalia pseudomenardii* Zone) of the Velasco Formation of Mexico.

1-6 Specimens (**1**=holotype from LOEBLICH & TAPPAN, 1957a, pl. 64, fig. 3). **1a,4**–Spiral views, X110, X200; **1b,5**–side views, X110, X200; **1c,6**–umbilical views, X110, X200; **2**–detail of keel on last chamber, X1000; **3**–detail of surface of last chamber, X1000.

GLOBIGERINA OFFICINALIS Subbotina, 1953

Figure 71

Middle Eocene to Oligocene

Globigerina officinalis SUBBOTINA, 1953, p. 78, pl. 11, fig. 1-7.–BLOW & BANNER, 1962, p. 88, fig. 16, pl. 9, fig. A-C.–BLOW, 1969, p. 320, pl. 1, fig. 1-3.–SUBBOTINA, 1971, p. 105, 108, pl. 11, fig. 1-7.

Globigerina parva BOLLI, 1957b, p. 108, pl. 22, fig. 14.

Test a small, low trochospire composed of 3 rather tightly coiled whorls. Last whorl with 3½ to 4 chambers which increase rapidly in size, last occupying up to half of whorl. Sutures depressed, radial to slightly curved. Umbilicus small and shallow. Aperture a low arch, umbilical, with distinct lip. Test fragile, almost smooth, finely perforate and cancellate. Diameter barely exceeds 0.2 mm.

Discussion.–*Globigerina officinalis* differs from *Globigerina ouachitaensis* HOWE & WALLACE in lacking a broad open umbilicus and in being more tightly coiled (BLOW & BANNER, 1962, p. 88, 90).

Distribution.–Late Middle Eocene to Oligocene (*Truncorotaloides rohri* Zone to approximately *Globigerina ampliapertura* Zone). The species was first described from Upper Eocene deposits of the northern Caucasus.

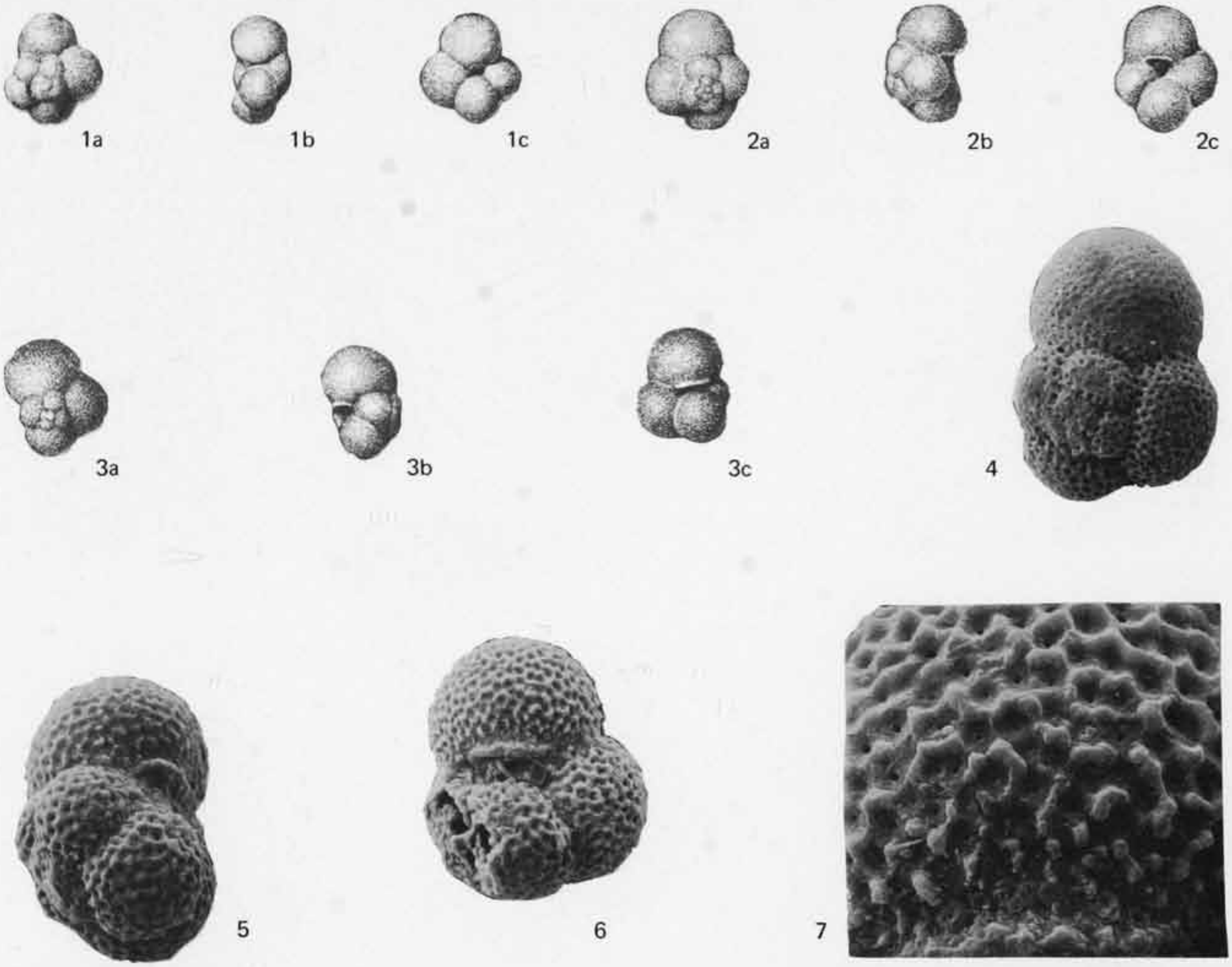


Fig. 71. *Globigerina officinalis* SUBBOTINA from the Upper Eocene of the northern Caucasus, Soviet Union (**1-3** from SUBBOTINA, 1953, pl. 11, fig. 1, 3, 5).

1-7 Holotype (**1**) and other specimens. **a,4**–Spiral views, X72, X72, X72, X200; **b,5**–side views, X72, X72, X72, X200; **c,6**–umbilical views, X72, X72, X72, X200; **7**–surface of last chamber, X500.

GLOBOROTALIA PALMERAE Cushman & Bermúdez, 1937

Figure 72

Early Eocene

Globorotalia palmerae CUSHMAN & BERMÚDEZ, 1937, p. 26, pl. 2, fig. 51-53.–BOLLI, 1957c, p. 166, pl. 38, fig. 2.

Test compressed-lenticular, spiral and umbilical sides equally flattened. Last whorl with 5 to 7 chambers which increase in size evenly at a rate proportionate to their number. Later chambers radially elongate, becoming apiculate and prolonged into fragile spines. Periphery polygonal to stellate with a faint keel. Umbilicus open, shallow. Sutures depressed, radial to slightly curved. Aperture a low arch, extraumbilical-umbilical. Surface of test rather smooth, coarsely perforate. Diameter to 0.4 mm.

Discussion.–*Globorotalia palmerae* differs from all other Paleogene species of *Globorotalia* in its tubulospinate chambers. In fact placement among planktonic foraminifers was disputed by several authors (e.g., BERGGREN, 1966, p. 313; 1968, p. 5-6) and the species is considered by them to belong to a benthonic genus, such as *Rotalia* or *Pararotalia*. Nevertheless, whether planktonic or not, the stratigraphic usefulness of the species justifies its inclusion here.

Distribution.–Late Early Eocene (*Globorotalia pentacamerata* Zone = *Globorotalia palmerae* Zone of authors). The distribution of this species is very patchy; it is quite often lacking in assemblages representing the *G. palmerae* range zone of BOLLI so that we prefer to follow KRASHENINNIKOV in using *G. pentacamerata* as the name species of this zone. *Globorotalia palmerae* was first described from the Eocene Capdevila Formation of Cuba.

GLOBOROTALIA PENTACAMERATA Subbotina, 1947

Figure 73

Early to Middle Eocene

Globorotalia pentacamerata SUBBOTINA, 1947, p. 128-129, pl. 7, fig. 12-17; pl. 9, fig. 24-26.

Acarinina pentacamerata (SUBBOTINA). SUBBOTINA, 1953, p. 233-234, pl. 23, fig. 8; pl. 24, fig. 1-9.–SUBBOTINA, 1971, p. 305, 308, pl. 23, fig. 8; pl. 24, fig. 1-9 [cotypes refigured].

Globigerina aspensis COLOM, 1954, p. 151-154, pl. 3, fig. 1-5; pl. 4, fig. 1-3.

Globorotalia aspensis (COLOM). BOLLI, 1957c, p. 166-167, pl. 37, fig. 18.–POSTUMA, 1971, p. 174-175.

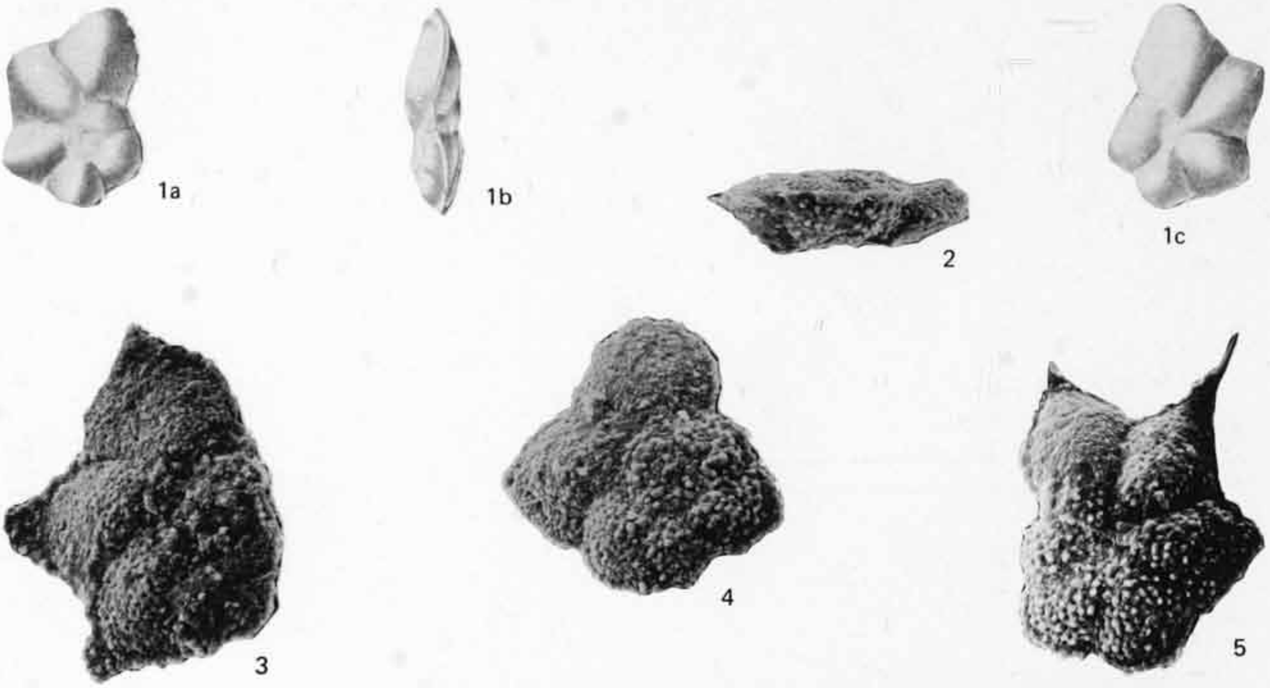


Fig. 72. *Globorotalia palmerae* CUSHMAN & BERMÚDEZ from the Lower Eocene of Trinidad and Cuba.

1 Specimen from the *Globorotalia pentacamerata* Zone in the Navet Formation of Trinidad, X73; from BOLLI (1957c, pl. 38, fig. 2). **a**–Spiral view; **b**–side view; **c**–umbilical view.

2-5 Specimens from Cuba, X200. **2**–Side view; **3-4**–spiral views; **5**–umbilical view.

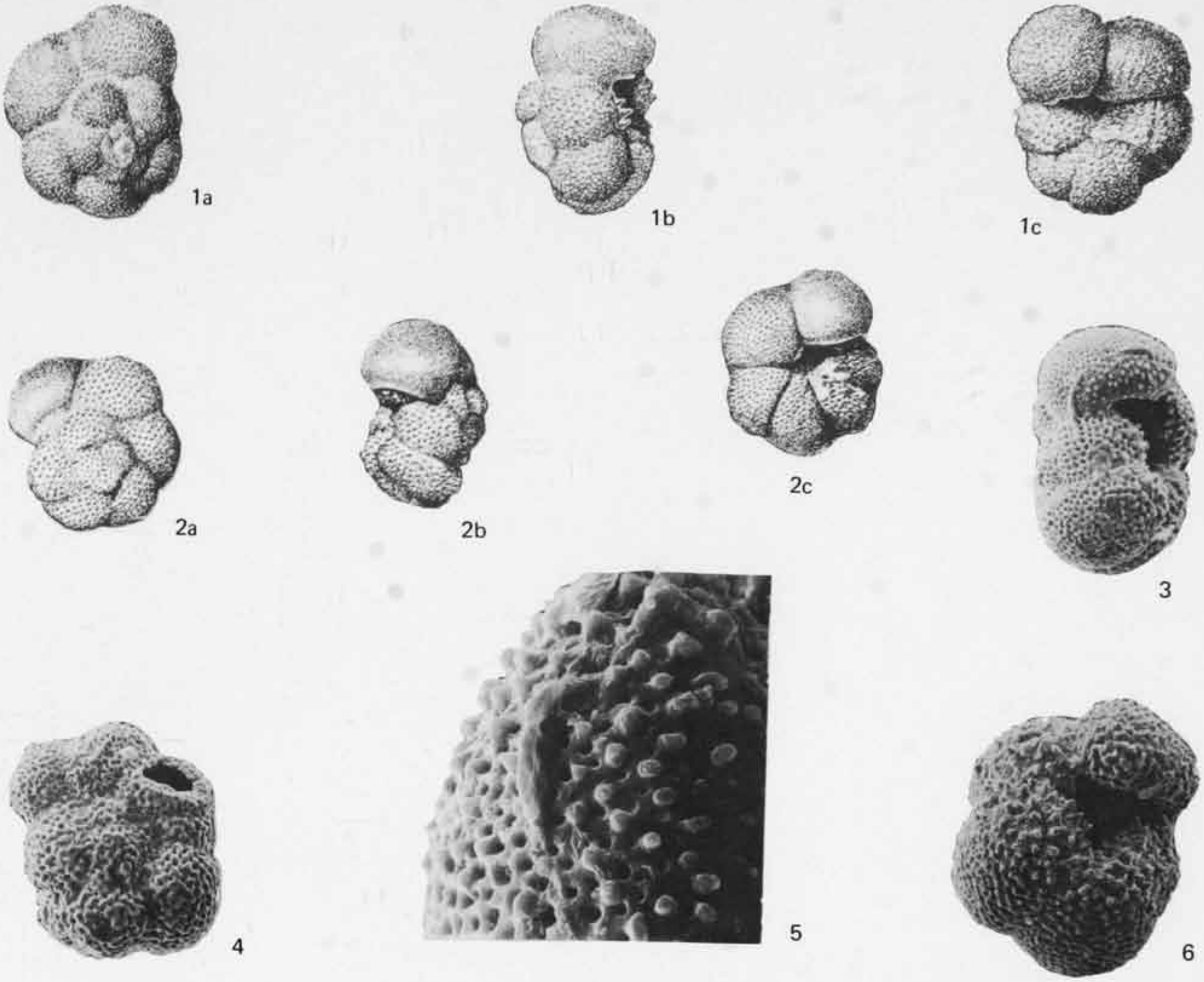


Fig. 73. *Globorotalia pentacamerata* SUBBOTINA from the Lower Eocene of the northern Caucasus, Soviet Union (**1-2** from SUBBOTINA, 1953, pl. 24, fig. 1, 3).

1-6 Representative specimens. **a,4**–Spiral views, X72, X72, X100; **b,3**–side views, X72, X72, X100; **c,6**–umbilical views, X72, X72, X100; **5**–surface of last chamber, X500.

Test a low trochospire consisting of 2 to 3 whorls, spiral side more or less flattened, umbilical side inflated. Last whorl with 5 to 8 globular, axially elongate chambers which increase slowly in size and may become subequal. Periphery bluntly rounded, faintly lobate. Sutures depressed; curved on spiral side, radial on umbilical side. Umbilicus generally wide and deep. Aperture a low arch, umbilical to extraumbilical. Surface of test spinose, especially on umbilical side. Diameter 0.3 to 0.4 mm.

Discussion.–The generic position of *Globorotalia pentacamerata* is not well defined because the position of its aperture varies. It differs from *Globigerina soldadoensis* in having more rounded chambers and a less lobate periphery; *Globigerina mckannai* has a more closed umbilicus and a higher, distinctly convex spiral side.

Distribution.–Early to Middle Eocene (*Globorotalia aragonensis* Zone to *Globorotalia lehneri* Zone). *Globorotalia pentacamerata* is very characteristic of the upper part of the Lower Eocene where it may constitute almost monospecific assemblages in middle latitudes and, therefore, has been used as a zonal index. The species was first described from this level in the northern Caucasus.

GLOBOROTALIA PRAECURSORIA (Morozova, 1957)

Figure 74

Middle Paleocene

Acarinina praecursoria MOROZOVA, 1957, p. 1111, fig. 1.
Globorotalia praecursoria (MOROZOVA). LUTERBACHER, 1964, p. 652-654, fig. 25.

Test low trochospiral, with flattened spiral side and inflated umbilical side. Last whorl with 5 to 8 chambers which increase gradually in size. First 2 or 3 chambers of last whorl somewhat imbricated, distinctly angular-conical, but younger chambers globular to ovate. Periphery slightly lobate, initially subacute but becoming broadly rounded. Sutures depressed; on umbilical side radial, on spiral side strongly recurved in initial part of last whorl, later radial. Umbilicus wide and open. Aperture a low arch, extraumbilical-umbilical, with faint lip. Surface of test spinose on inner coil and initial chambers of last whorl, but last few chambers almost smooth. Ornamentation concentrated on umbilical shoulders and peripheral margin. Diameter to 0.8 mm but generally less.

Discussion.–*Globorotalia praecursoria* differs from *Globorotalia uncinata* in having more chambers in the last whorl, a wider umbilicus, and a globular-to-ovate instead of ovate-to-subangular last chamber. It is separated from *Globorotalia trinidadensis* by the distinctly angulate initial chambers of the last whorl. The species appears to be intermediate between *G. trinidadensis* and the subconical, subcarinate *Globorotalia conicotruncata.*

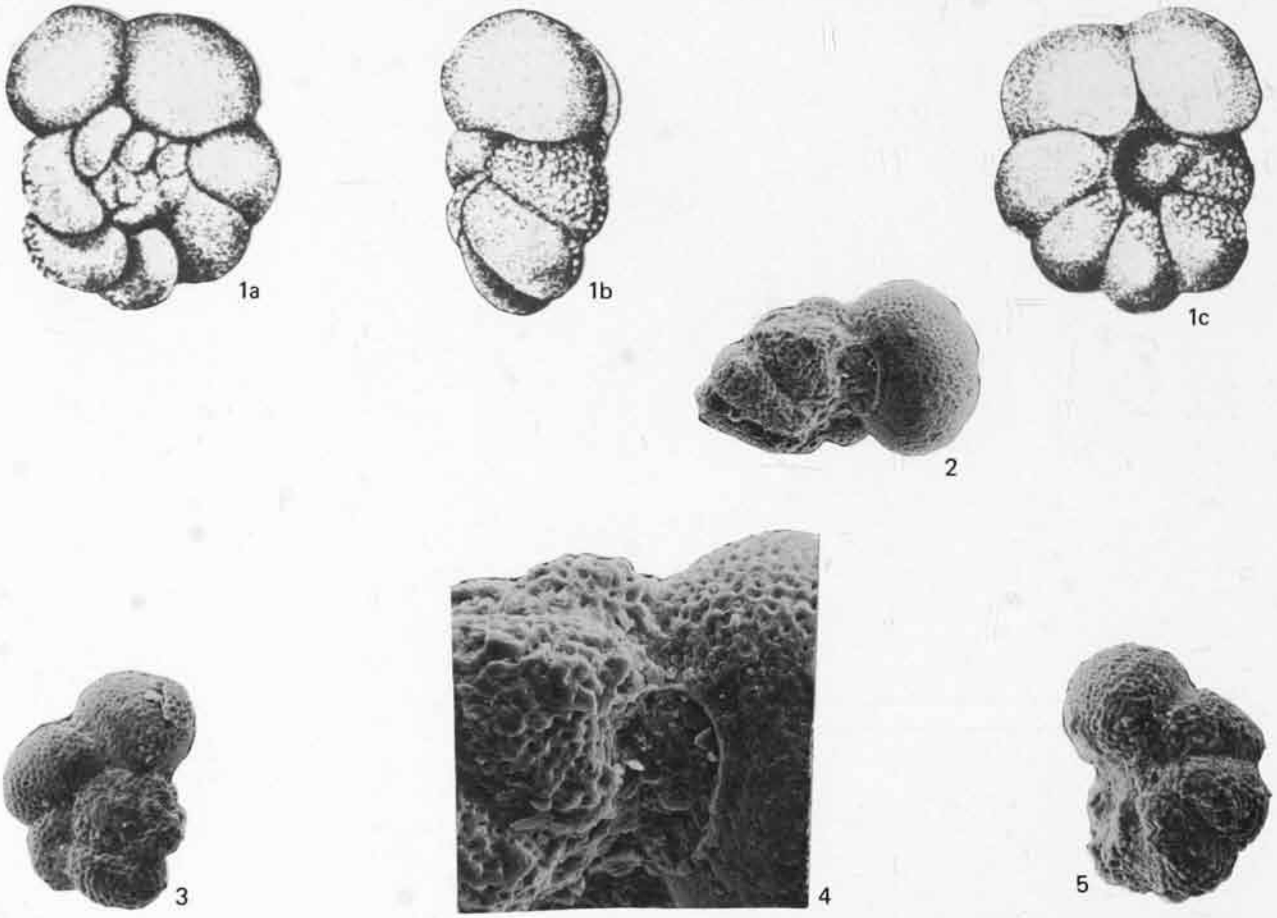


Fig. 74. *Globorotalia praecursoria* (MOROZOVA) from the Lower Paleocene of the Soviet Union.

1 Holotype from the northern Caucasus, X50; from MOROZOVA (1957, fig. 1). **a**–Spiral view; **b**–side view; **c**–umbilical view.

2-5 Specimens from the Crimea. **2**–Side view, X100; **3**–spiral view, X100; **4**–aperture, X250; **5**–umbilical view, X100.

Distribution.–Middle Paleocene (*Globorotalia uncinata* Zone to within *Globorotalia angulata* Zone). This short-ranging species was first described from the Middle Paleocene of northwestern Crimea.

GLOBIGERINA PRIMITIVA (Finlay, 1947)

Figure 75

Late Paleocene to Middle Eocene

Globoquadrina primitiva FINLAY, 1947, p. 291, pl. 8, fig. 129-134.

Globigerina primitiva FINLAY [sic]. BOLLI, 1957a, p. 71, pl. 15, fig. 6-8.

Pseudogloboquadrina primitiva (FINLAY). JENKINS, 1965b, p. 1124-1125, fig. 9 (nos. 81-86).–JENKINS, 1971, p. 170, pl. 18, fig. 555-561 [original types refigured, fig. 555-560].

Test a compact, tightly coiled trochospire with somewhat flattened spiral side and tumid umbilical side. Last whorl with 3 to 4 compressed chambers, longer than broad on spiral side, somewhat elongated towards umbilicus, increasing regularly in size. Profile approaches quadrate, viewed at any angle. Sutures depressed; radial on umbilical side, curved on spiral side. Umbilicus small, open and deep. Aperture a low arch, umbilical to extraumbilical-umbilical, with distinct lip. Wall coarsely perforate, rugose and pustulose. Diameter to 0.35 mm.

Discussion.–*Globigerina primitiva* is grossly similar to *Globigerina velascoensis* but has a much more rugose, partly pustulose surface. This species was assigned originally to *Globoquadrina* because the

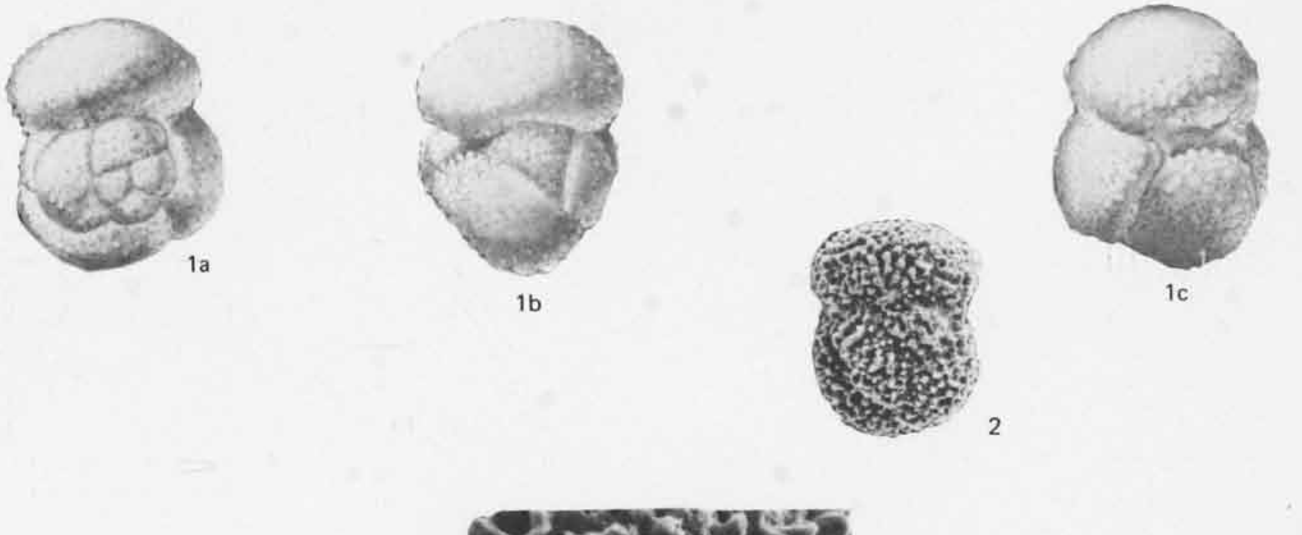


Fig. 75. *Globigerina primitiva* (FINLAY) from the Early Eocene of Trinidad and California.

1 Specimen from the *Globorotalia subbotinae* Zone in the Lizard Springs Formation of Trinidad, X100; from BOLLI (1957a, pl. 15, fig. 6-8). **a**–Spiral view, **b**–side view; **c**–umbilical view.

2-5 Specimens from the *Globorotalia formosa formosa* Zone in the Lodo Formation of California. **2**–Side view, X100; **3**–spiral view, X100; **4**–aperture, X250; **5**–umbilical view, X100.

gross form is definitely reminiscent of the Miocene *Globoquadrina dehiscens* group. Because of this similarity, it has been treated as the type species of the monospecific *Pseudogloboquadrina*, a genus here included in *Globigerina*.

Distribution.–Though primitive forms occurred earlier, the normal range of *Globigerina primitiva* was Late Paleocene through Middle Eocene (*Globorotalia velascoensis* Zone to approximately *Orbulinoides beckmanni* Zone). The *Pseudogloboquadrina primitiva* Zone in New Zealand (JENKINS, 1965b, 1971) corresponds to the early part of the Middle Eocene. This species was first described from the Middle Eocene of New Zealand.

GLOBOROTALIA PSEUDOBULLOIDES (Plummer, 1926)

Figure 76

Early to Middle Paleocene

Globigerina pseudobulloides PLUMMER, 1926, p. 33, pl. 8, fig. 9.

Globigerina compressa var. *pseudobulloides* PLUMMER. SUBBOTINA, 1953, p. 55-57, pl. 2, fig. 7, 11-14.–SUBBOTINA, 1971, p. 63-66, pl. 2, fig. 7, 11-14.

Globorotalia pseudobulloides (PLUMMER). BOLLI, 1957a, p. 73, pl. 17, fig. 19-21.

Test low trochospiral, spiral side only slightly more compressed than umbilical side. Last whorl with generally 5 spherical to ovate chambers which increase rapidly in size. Periphery rounded, lobate.

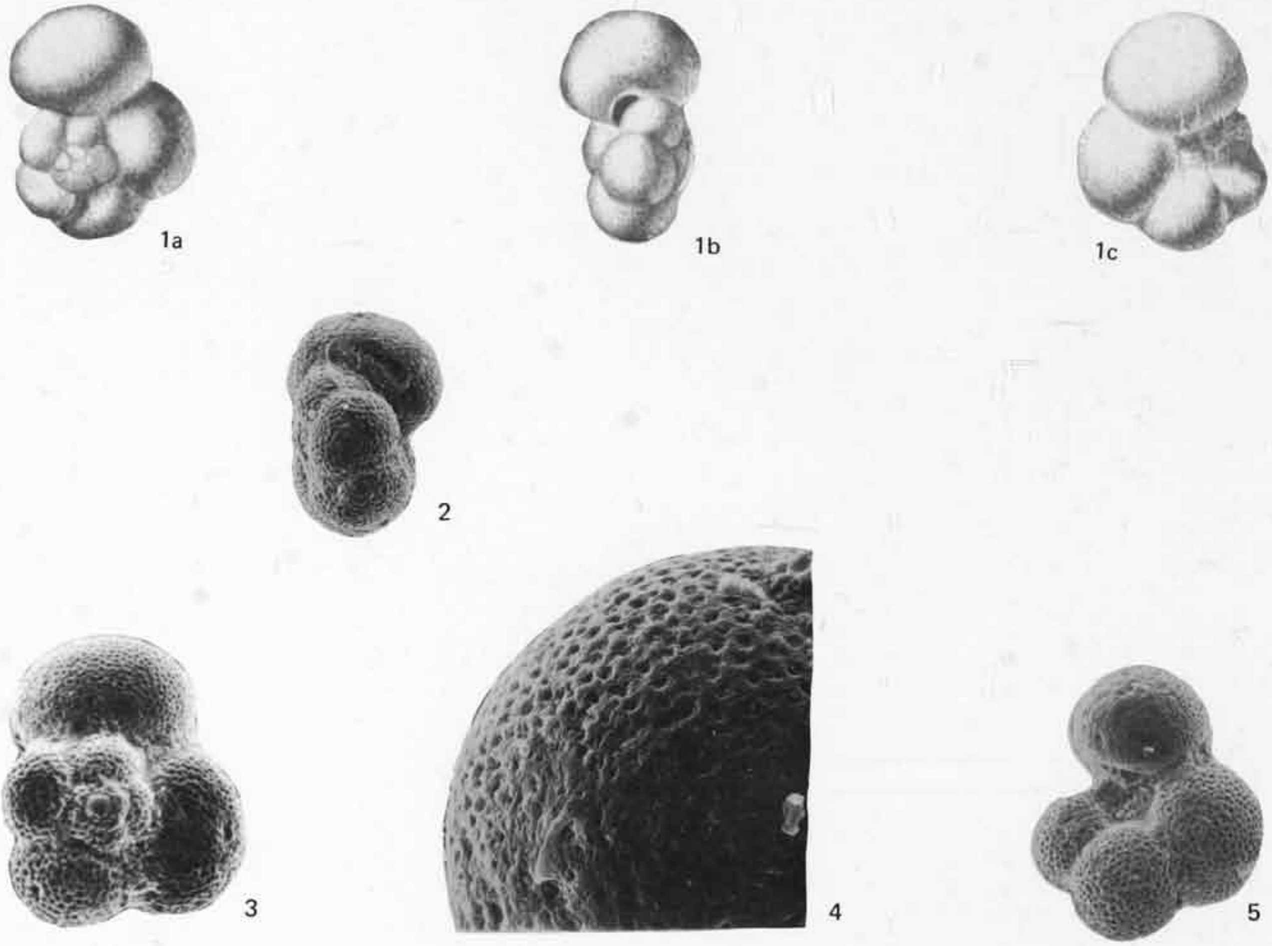


Fig. 76. *Globorotalia pseudobulloides* (PLUMMER) from the Paleocene of Trinidad and the Soviet Union.

1 Specimen from the Middle Paleocene part (*Globorotalia pusilla pusilla* Zone) of the Lizard Springs Formation of Trinidad, X100; from BOLLI (1957a, pl. 17, fig. 19-21). **a**–Spiral view; **b**–side view; **c**–umbilical view.

2-5 Specimens from the Lower Paleocene of the northern Caucasus, Soviet Union. **2**–Side view, X100; **3**–spiral view, X100; **4**–surface of last chamber, X400; **5**–umbilical view, X100.

Sutures depressed; radial on umbilical side, radial to slightly curved on spiral side. Umbilicus moderately narrow but open. Aperture a low arch, extraumbilical-umbilical in position, with faint lip. Surface finely perforate; in early part of test hispid to rugose, in later part almost smooth. Maximum diameter 0.4 mm.

Discussion.–*Globorotalia pseudobulloides* differs from *Globorotalia uncinata* in having spherical instead of subangular chambers in the early part of the last whorl. *Globigerina fringa* is smaller and more tightly coiled. (Note also MALMGREN, 1972.)

Distribution.–This species has a wide geographic spread and is an accepted zonal index for the Early and Middle Paleocene (*Globorotalia pseudobulloides* Zone to approximately *Globorotalia angulata* Zone). *Globorotalia pseudobulloides* was first described from the Paleocene Midway Formation of Texas.

GLOBOROTALIA PSEUDOMENARDII Bolli, 1957

Figure 77

Late Paleocene

Globorotalia pseudomenardii BOLLI, 1957a, p. 77, pl. 20, fig. 14-17.–LOEBLICH & TAPPAN, 1957a, p. 193, pl. 47, fig. 4; pl. 63, fig. 1.

Test a lenticular trochospire. Periphery acute with distinct keel; outline lobate, strongly so in large specimens. Generally 5 chambers in last whorl. On spiral side chambers mostly crescentic, closely packed, increasing evenly and rather slowly in size, but in larger specimens last 2 or 3 chambers may be abnormally large, loosely attached, approaching scallop-shape. Similarly in umbilical aspect chambers usually appear as evenly arranged, acute-angled segments of test, but in large specimens late chambers may subtend right to obtuse angles and project above compact initial coil. Depending on tightness of coiling, specimens may have a shallow, open umbilicus or be nonumbilicate. Sutures depressed; radial on umbilical side, recurved on spiral side. Aperture a low arch with distinct lip, extraumbilical-umbilical. Surface smooth, finely perforate. Diameter to 0.7 mm with large, loosely attached chambers typical of specimens larger than 0.35 mm.

Discussion.–*Globorotalia pseudomenardii* differs from *Globorotalia chapmani* in the distinct imperforate keel. References by early authors to *Globorotalia membranacea* in Paleocene beds may be to either of these two species (for a partial list of such references, see BERMÚDEZ, 1960, p. 1298-1300).

Distribution.–Late Paleocene, where its range defines the *Globorotalia pseudomenardii* Zone. First described from the Paleocene portion of the Lizard Springs Formation of Trinidad.

GLOBOROTALIA PSEUDOTOPILENSIS (Subbotina, 1953)

Figure 78

Late Paleocene and Early Eocene

Acarinina pseudotopilensis SUBBOTINA, 1953, p. 227-228, pl. 21, fig. 8-9; pl. 22, fig. 1-3.–SUBBOTINA, 1971, p. 294-295, 298, pl. 21, fig. 8-9; pl. 22, fig. 1-3.

Test a distinctly quadrate trochospire with flattened spiral side and strongly inflated umbilical side. Last whorl with 4 to 5 chambers which increase rapidly in size. Chambers longer than broad, prolonged axially. Margin rounded, equatorial outline subquadrangular, lobate. Sutures depressed; radial on umbilical side, oblique on spiral side. Umbilicus deep, varying from narrow to fairly wide. Aperture a low arch with faint lip, extraumbilical-umbilical in position. Surface of test very spinose, especially on umbilical side. Diameter 0.3 to 0.4 mm.

Discussion.–*Globorotalia pseudotopilensis* differs from *Globorotalia wilcoxensis* in having a more broadly rounded axial periphery and from *Globigerina primitiva* in being more loosely coiled.

Distribution.–Late Paleocene to Early Eocene (approximately *Globorotalia pseudomenardii* Zone to *Globorotalia aragonensis* Zone). The species was first described from the Lower Eocene of the northern Caucasus and has received widespread recognition as a zonal index (e.g., LOEBLICH & TAPPAN, 1957a; BANDY, 1964b; JENKINS, 1971).

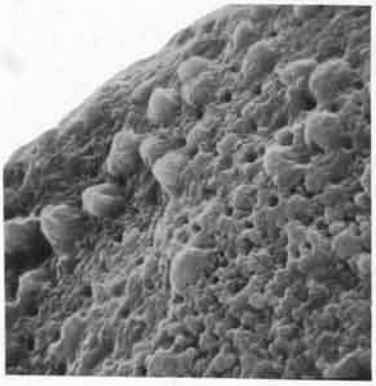
GLOBOROTALIA PUSILLA PUSILLA
Bolli, 1957

Figure 79

Middle to Late Paleocene

Globorotalia pusilla pusilla BOLLI, 1957a, p. 78, pl. 20, figs. 8-10.

Test small, trochospiral, biconvex, compressed and tightly coiled. Last whorl with 5 to 6 crescentic chambers which increase slowly in size. Equatorial peripheral outline circular, slightly lobate; axial periphery subacute to acute. Sutures on spiral side slightly depressed, strongly curved backwards; on



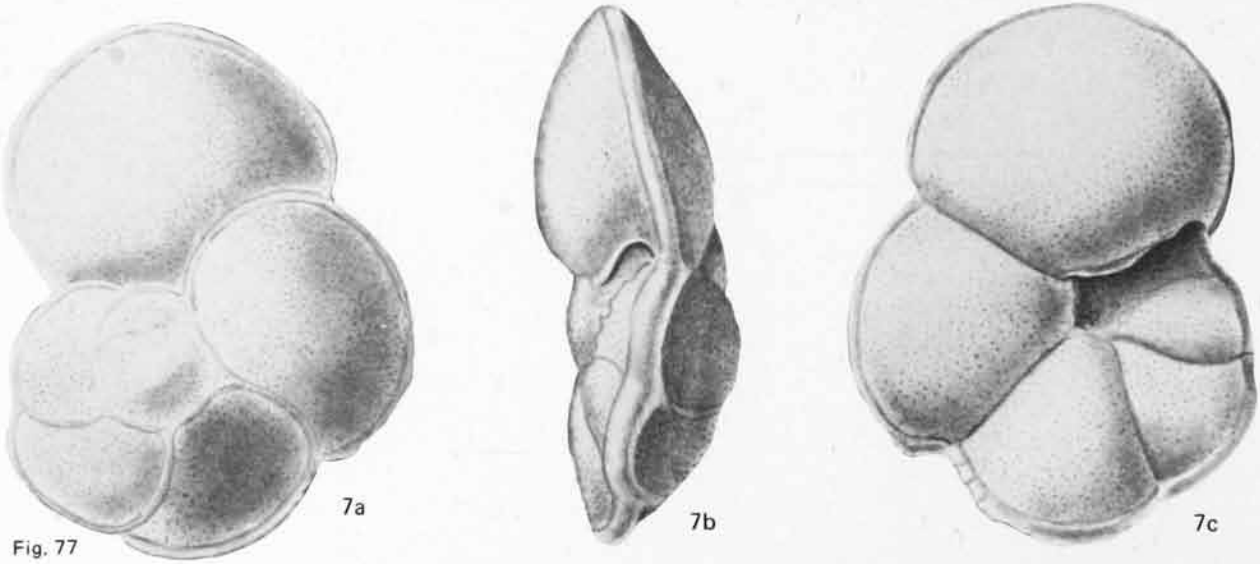


Fig. 77

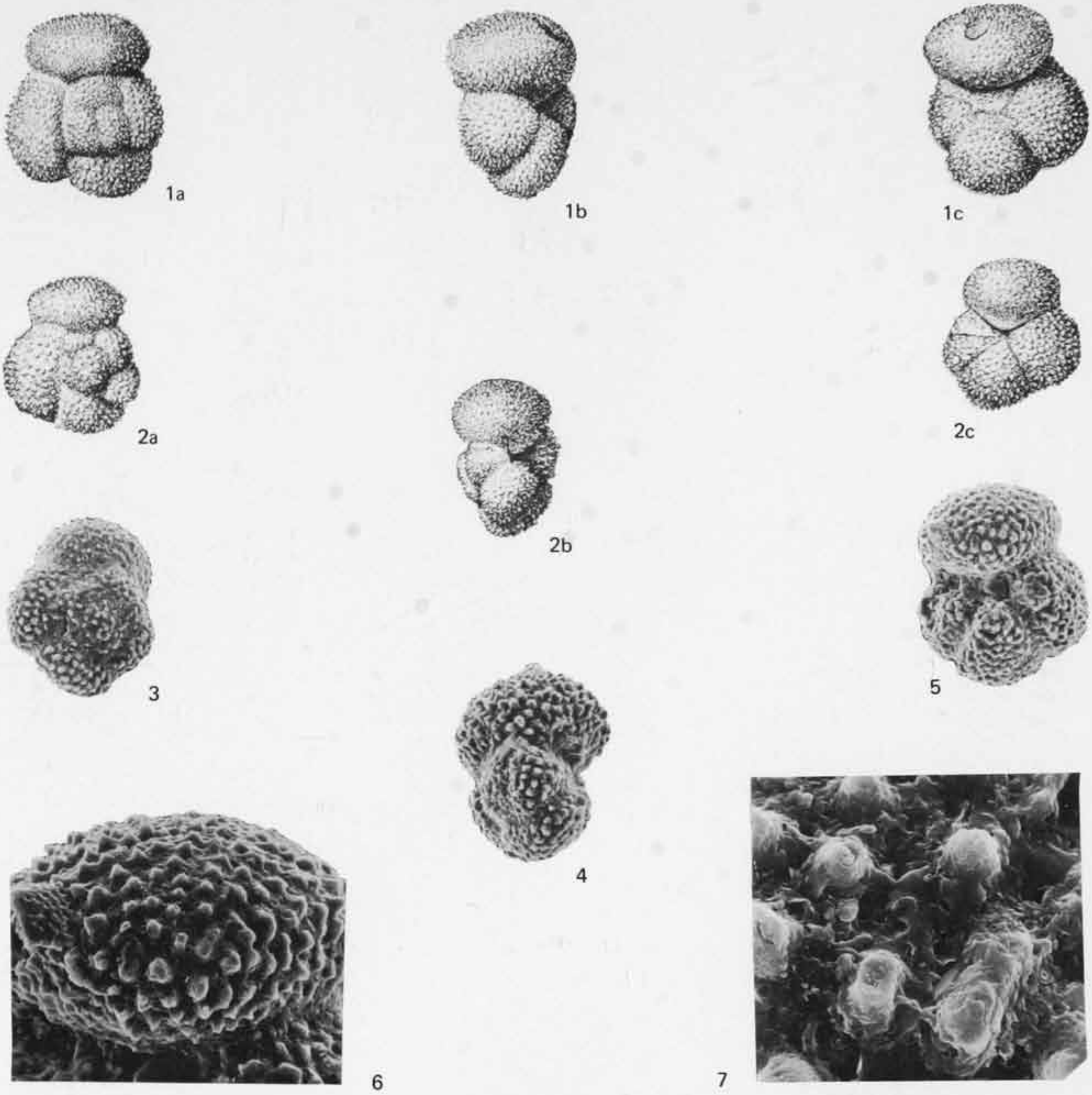


Fig. 78. *Globorotalia pseudotopilensis* (SUBBOTINA) from the Lower Eocene of the northern Caucasus, Soviet Union.

1-7 Holotype **(1)** and other specimens **(1-2** from SUBBOTINA, 1953, pl. 21, fig. 8-9). **a,3**–Spiral views, X72, X72, X100; **b,4**–side views, X72, X72, X100; **c,5**–umbilical views, X72, X72, X100; **6**–last chamber, X250; **7**–surface of last chamber, X1000.

⇦ Fig. 77. *Globorotalia pseudomenardii* BOLLI from the Late Paleocene *Globorotalia pseudomenardii* Zone of Mexico and Trinidad.

1-3,5-7 Specimens from the Velasco Formation of Mexico (**7** from LOEBLICH & TAPPAN, 1957a, pl. 63, fig. 1). **1,7a**–Spiral views, X100, X145; **2,7b**–side views, X100, X145; **3,7c**–umbilical views, X100, X145; **5**–surface of last chamber, X1000; **6**–detail of aperture, X250.

4 Holotype from the Lizard Springs Formation of Trinidad, X100; from BOLLI (1957a, pl. 20, fig. 14-17). **a**–Spiral view; **b**–side view; **c**–umbilical view.

umbilical side depressed, radial. Umbilicus narrow, open. Aperture a low arch, extraumbilical-umbilical in position. Surface of test rough, very coarsely perforate. Maximum diameter 0.25 mm.

Discussion.–*Globorotalia pusilla pusilla* differs in its slightly lobate and less acute periphery from its descendant, *Globorotalia pusilla laevigata* BOLLI (1957a). The wall of this species was described originally as finely perforate and smooth, but excellently preserved specimens obtained during the Deep Sea Drilling Project are very coarsely perforate.

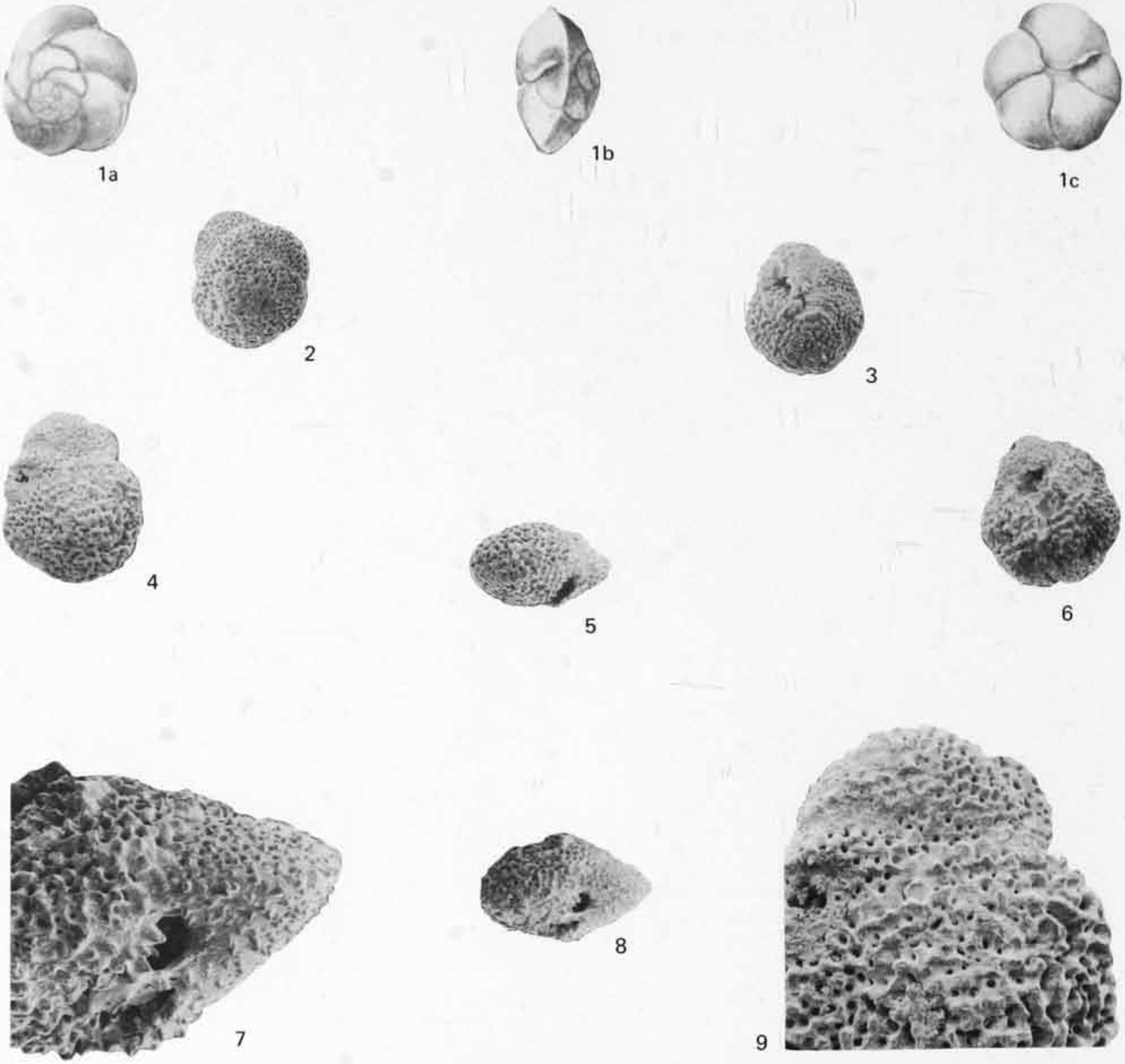


Fig. 79. *Globorotalia pusilla pusilla* BOLLI from the Middle Paleocene *Globorotalia pusilla pusilla* zone of Trinidad and the south Atlantic.

1 Holotype from the Lizard Springs Formation of Trinidad, X100; from BOLLI (1957a, pl. 20, fig. 8-10). **a**–Spiral view, **b**–side view; **c**–umbilical view.

2-9 Specimens from the northwestern south Atlantic. **2,4**–Spiral views, X100; **3,6**–umbilical views, X100; **5,8**–side views, X100; **7**–detail of spiral side, X250; **9**–detail of side view, X250.

Distribution.—Middle to Late Paleocene (*Globorotalia pusilla pusilla* Zone to *Globorotalia pseudomenardii* Zone). The species was first described from the Paleocene portion of the Lizard Springs Formation in Trinidad.

GLOBOROTALIA QUETRA Bolli, 1957

Figure 80
Early Eocene

Globorotalia quetra BOLLI, 1957a, p. 79-80, pl. 19, fig. 1-6.

Test fairly large, trochospiral, spiral side flat to slightly concave, umbilical side strongly convex. Last whorl with 4 to 5 angular-conical to subangular chambers which increase steadily in size. Chambers longer than broad, attached to each other rather loosely at almost right angles. Equatorial peripheral outline scalloped to strongly lobate, axial periphery subacute to acute; spiny keel may occur on early chambers of last whorl, becoming subacute to rounded on younger chambers. Sutures depressed; on spiral side oblique to curved, on umbilical side radial. Umbilicus rather narrow, deep, open. Aperture a low arch, extraumbilical-umbilical. Wall distinctly perforate, strongly spinose. Diameter typically 0.5 to 0.6 mm.

Discussion.—*Globorotalia quetra* differs from *Globorotalia wilcoxensis* by its more angular periphery which commonly is accentuated by a spiny keel. Its general aspect is somewhat similar to *Truncorotaloides rohri* and *Truncorotaloides topilensis* of the Middle Eocene.

Distribution.—Early Eocene (from within *Globorotalia subbotinae* Zone to within *Globorotalia pentacamerata* Zone). The species was first described from the Early Eocene portion of the Lizard Springs Formation of Trinidad.

GLOBOROTALIA RENZI Bolli, 1957

Figure 81
Early to Middle Eocene

Globorotalia renzi BOLLI, 1957c, p. 168, pl. 38, fig. 3.
Globorotalia (Planorotalites) renzi BOLLI. JENKINS, 1971, p. 110, pl. 9, fig. 224-226.

Test a small, low trochospire, biconvex, lenticular. Last whorl with generally 6 crescentic chambers which increase regularly in size. Equatorial periphery circular, only faintly lobate; axial periphery angular with a faint keel. Sutures flush to slightly depressed; on spiral side recurved, on umbilical side radial and slightly recurved. Umbilicus very narrow and shallow. Aperture a low arch, extraumbilical-umbilical, often with distinct lip. Wall finely perforate, smooth. Diameter barely exceeds 0.2 mm.

Discussion.—*Globorotalia renzi* differs from *Globorotalia pseudoscitula* GLAESSNER in its smooth instead of hispid surface.

Distribution.—Early to Middle Eocene (approximately *Globorotalia aragonensis* Zone to *Truncorotaloides rohri* Zone). *Globorotalia renzi* was first described from an exotic block of the Middle Eocene Navet Formation in Trinidad.

TRUNCOROTALOIDES ROHRI
Bronnimann & Bermúdez, 1953

Figure 82
Middle Eocene

Truncorotaloides rohri BRÖNNIMANN & BERMÚDEZ, 1953, p. 818-819, pl. 87, fig. 7-9.—BOLLI, LOEBLICH, & TAPPAN, 1957, p. 42, pl. 10, fig. 5.—BOLLI, 1957c, p. 170, pl. 39, fig. 8-12.—BLOW & BANNER, 1962, p. 121-122.—BLOW, 1969, p. 372, pl. 50, fig. 6-8.

Test a low trochospire with flattened spiral side and slightly inflated umbilical side. Generally 5 (4-6) chambers in last whorl, initially subspherical but may develop angulosity. Rate of increase of chamber size varies widely between individuals. Equatorial periphery subcircular, moderately to strongly lobate; axial periphery varying from broadly rounded to subacute. Sutures depressed to incised; radial to curved on spiral side, radial on umbilical side. Umbilicus rather wide, open. Main aperture a low arch, extraumbilical-umbilical, with distinct lip. Secondary sutural apertures on spiral side in 2 or 3 youngest chambers. Surface strongly spinose, especially on umbilical shoulders and around margin. Diameter 0.3 to 0.4 mm.

Discussion.—*Truncorotaloides rohri* is a variable species within which BRÖNNIMANN & BERMÚDEZ (1953) distinguished several named varieties based on shape of the chambers and margin. It is linked with *Truncorotaloides topilensis* by intermediate forms. These two species conventionally are separated from comparable forms of *Globorotalia* by their supplementary apertures. Nevertheless, sutural openings on the spiral side have been observed in exceptionally well-preserved specimens of several species of *Globorotalia* from the Paleocene and Early

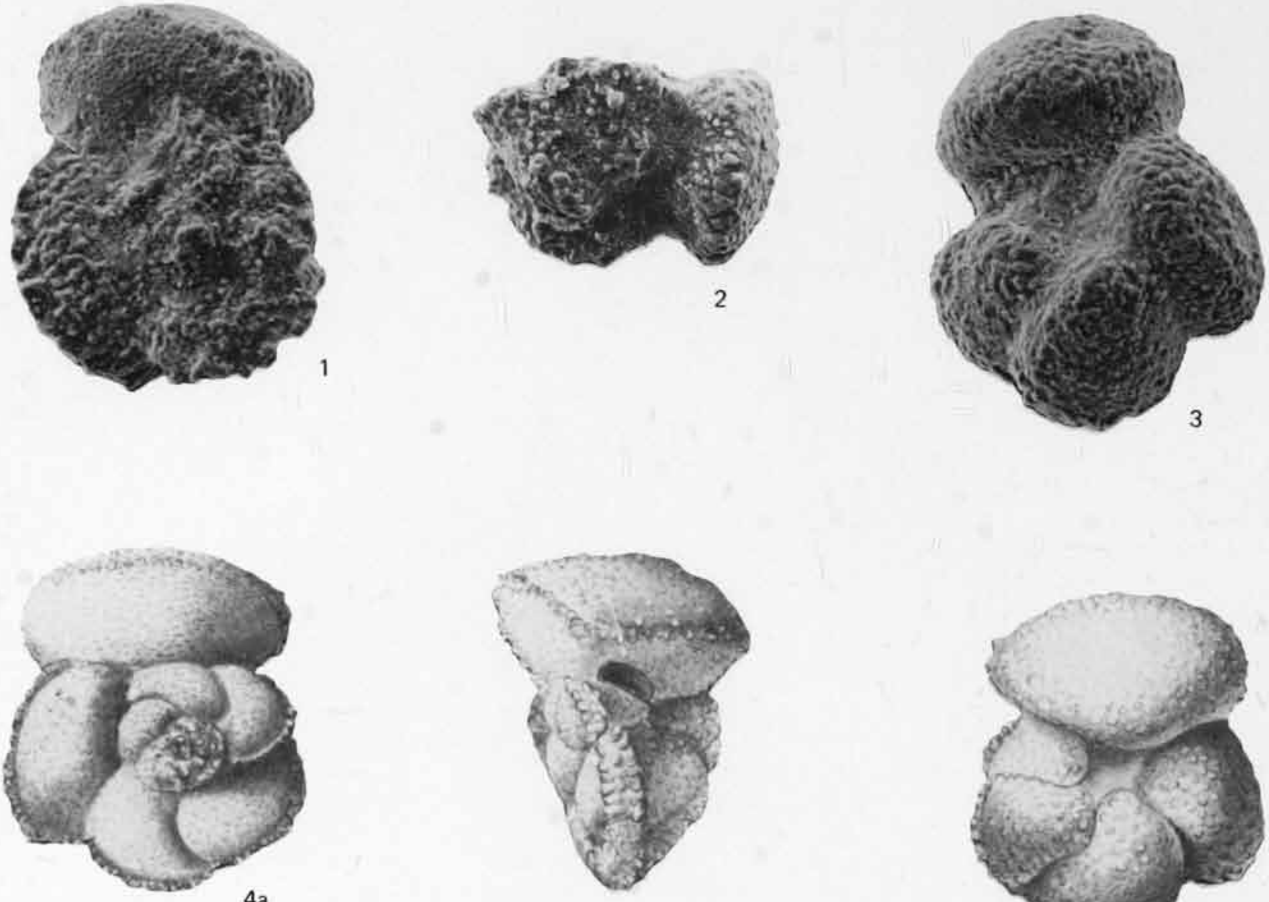


Fig. 80. *Globorotalia quetra* BOLLI from the Early Eocene part (*Globorotalia formosa formosa* Zone) of the Lizard Springs Formation of Trinidad (**4-5** from BOLLI, 1957a, pl. 19, fig. 1-6).

1-5 Holotype **(5)** and other specimens, X100. **a,1**–spiral views; **b,2**–side views; **c,3**–umbilical views.

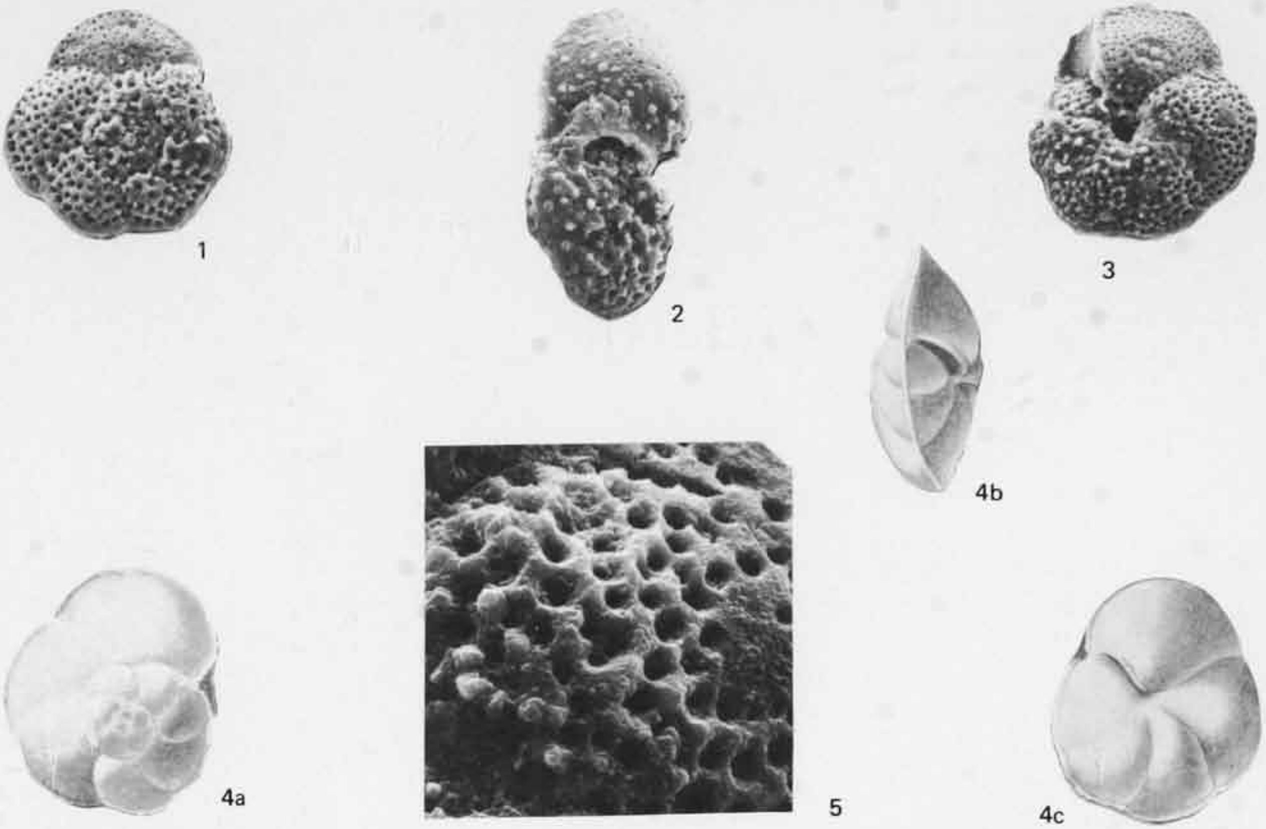


Fig. 81. *Globorotalia renzi* BOLLI from the Middle Eocene part (*Orbulinoides beckmanni* Zone) of the Navet Formation of Trinidad.

1-5 Holotype (**4** from BOLLI, 1957c, pl. 38, fig. 3) and other specimens. **1,4a**–Spiral views, X200, X144; **2,4c**–side views, X200, X144, **3,4b**–umbilical views, X200, X144; **5**–surface of last chamber, X1000.

Eocene. The generic value of this character in Paleogene planktonic foraminifers, therefore, is doubtful.

The relation between *T. rohri* and *Globigerinoides pseudodubia* BANDY (1949, p. 123, pl. 24, fig. 4) needs to be investigated, as possibly BANDY'S species is identical and has priority (see, for instance, BANDY, 1964b; BECKMANN ET AL., 1969, p. 99; BERGGREN, 1971b, p. 719).

Distribution.–Middle Eocene (*Hantkenina aragonensis* Zone to *Truncorotaloides rohri* Zone). Small spiny forms similar to *T. rohri* have been reported from the later Eocene and early Oligocene of northern Europe, but their status needs further investigation. This species was first recorded from a heterogeneous (reworked) assemblage in Trinidad, but later records limit it to the Middle Eocene. It is the name fossil for a zone defined by that portion of its range which extends above the extinction level of *Orbulinoides beckmanni*.

GLOBIGERINATHEKA SEMIINVOLUTA (Keijzer, 1945)

Figure 83

Late Eocene

Globigerinoides semiinvolutus KEIJZER, 1945, p. 206, pl. 4, fig. 58.

Globigerapsis semiinvoluta (KEIJZER). BOLLI, LOEBLICH, & TAPPAN, 1957, p. 34, pl. 6, fig. 7.–BOLLI, 1957c, p. 165, pl. 36, fig. 19-20.–BLOW & BANNER, 1962, p. 125, pl. 15, fig. J-L.

Globigerapsis mexicana (CUSHMAN). BLOW & SAITO, 1968, p. 357-360.–BLOW, 1969, p. 330-331, pl. 27, fig. 3-4.

Globigerinatheka semiinvoluta (KEIJZER). BOLLI, 1972a, p. 131, fig. 72-79, pl. 5, fig. 1-27; pl. 6, fig. 1-17 [line drawings of holotype, traced from original figures of KEIJZER, fig. 72-76].

Test subglobular to globular. Initial portion 2 to 2½ whorls of a regular trochospire with 4 to 6 moderately inflated chambers per whorl. Rate of increase of chamber size accelerates so that final whorl contains only 3 chambers, of which last is

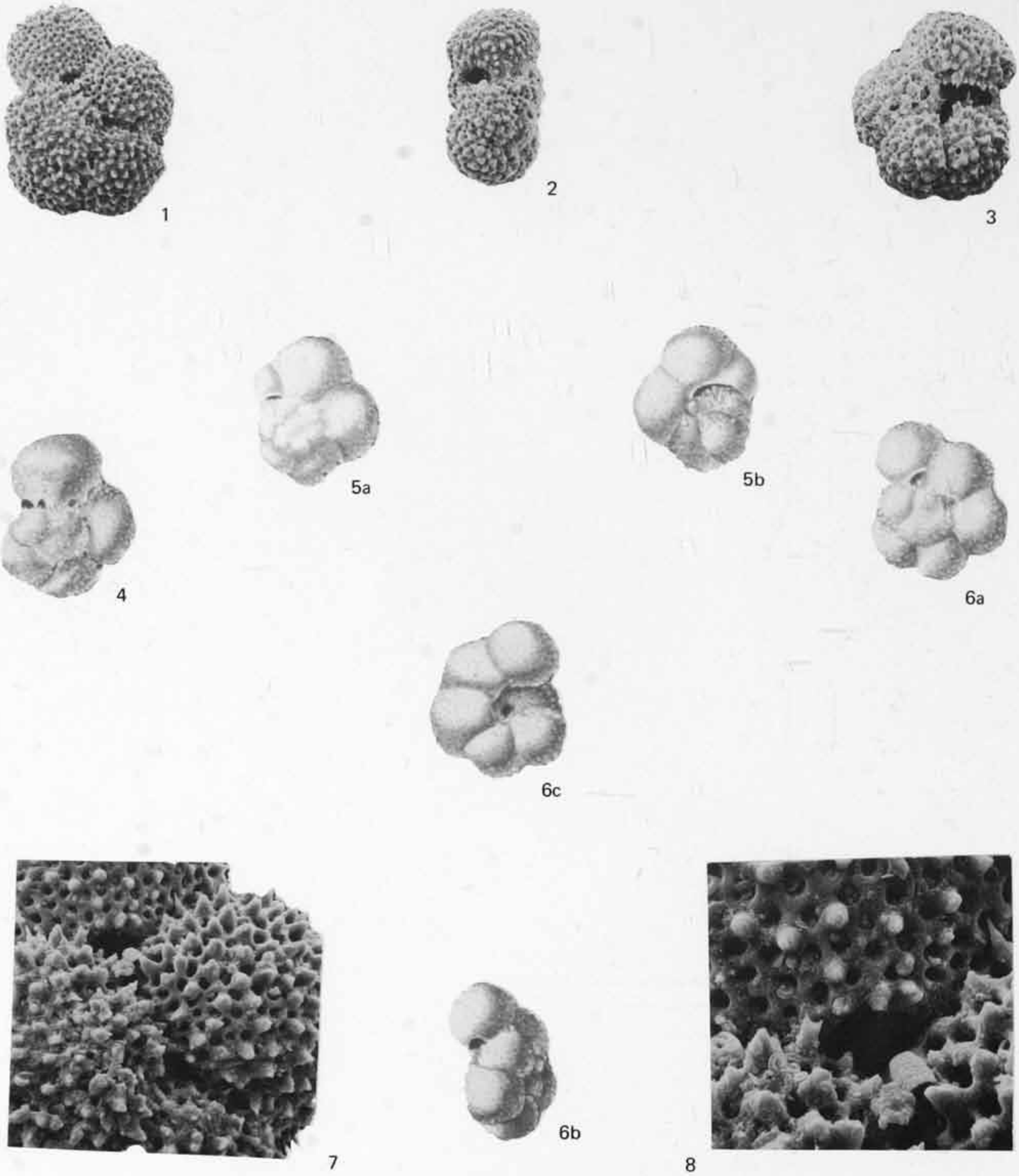


Fig. 82. *Truncorotaloides rohri* BRÖNNIMANN & BERMÚDEZ from the Eocene part (*Orbulinoides beckmanni* Zone) of the Navet Formation of Trinidad (**4-6** from BOLLI, 1957c, pl. 39, fig. 10-12).

1-8 Representative specimens. **1,4,5a,6a**–Spiral views, X100, X73, X73, X73; **2,6b**–side views, X100, X73; **3,5b,6c**–umbilical views, X100, X73, X73; **7**–secondary apertures, X250; **8**–secondary apertures, X500.

dome-shaped and embraces two-thirds or half of earlier test, completely covering its umbilical region. Sutures shallow, radial to oblique; basal suture of last chamber sinuous. Apertures 2 to 4 openings on last chamber, along spiral suture at intersections with intercameral sutures, prominent, high-arched to circular, with distinct rims, occasionally bullate. Wall rather coarsely perforate, cancellate. Diameter to 0.55 mm.

Discussion.–*Globigerinatheka semiinvoluta* differs from *Globigerinatheka tropicalis* by its much larger, more embracing, and more inflated final chamber and its shallower, often indistinct, sutures. *Globigerinatheka kugleri* has more inflated, almost spherical early chambers, incised sutures, a somewhat less embracing final chamber, and lower-arched apertures. BLOW & SAITO (1968) considered *G. semiinvoluta* to be a junior synonym of *"Globigerina" mexicana* CUSHMAN, but BOLLI (1972a) presented reasons for maintaining the two species as morphologically distinct, with different stratigraphic ranges. One obvious difference is the small, low openings on *G. mexicana* in comparison with the large, sculptured apertures of *G. semiinvoluta.*

Distribution.–Late Eocene, where its life range defines the *Globigerinatheka semiinvoluta* Zone. The species was first described from the Upper Eocene of Cuba. *Globigerinatheka semiinvoluta* is widespread in tropical regions but grades into smaller, less distinct forms towards higher latitudes.

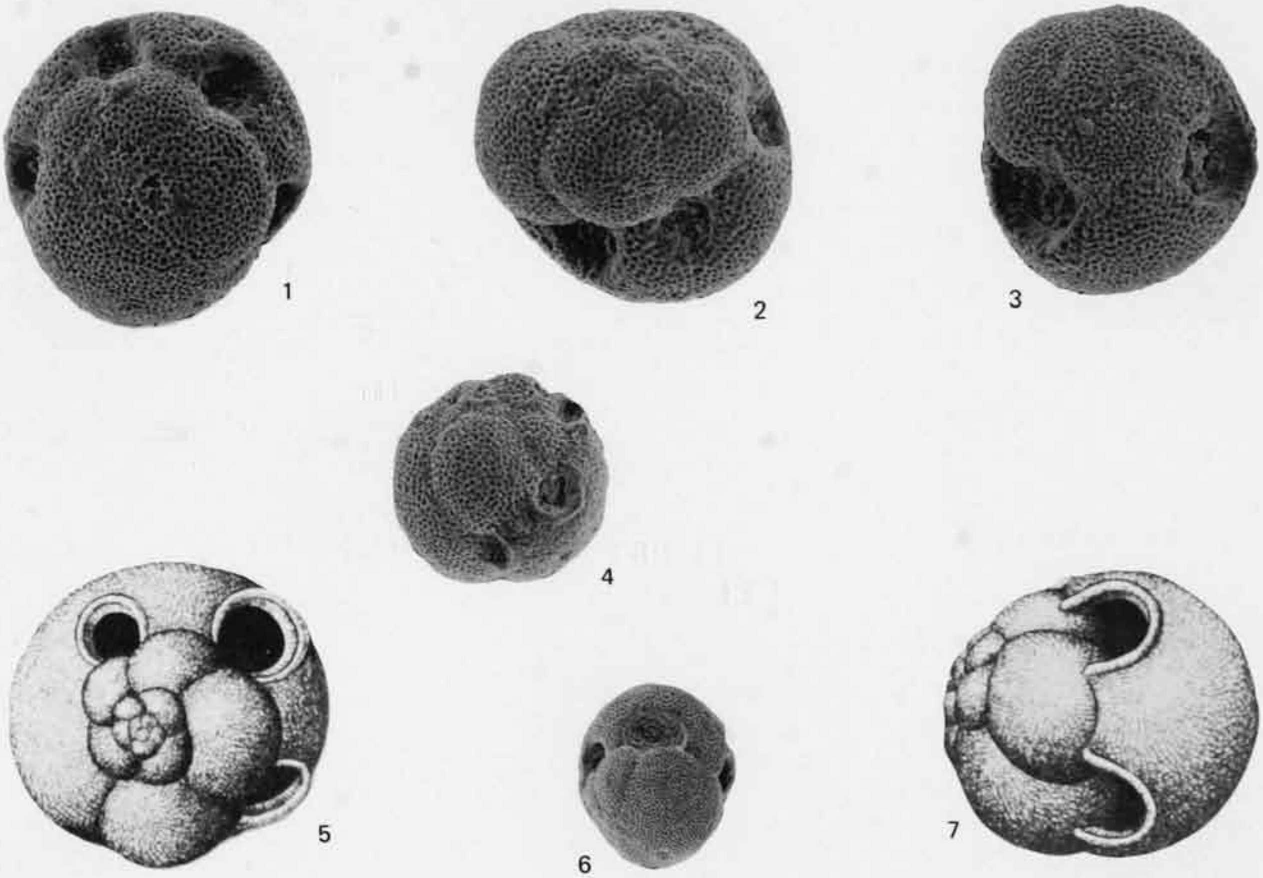


Fig. 83. *Globigerinatheka semiinvoluta* (KEIJZER) from the Late Eocene *Globigerinatheka semiinvoluta* Zone of Trinidad and Tanzania.

1-4,6 Specimens from the Navet Formation of Trinidad, X100. **1,6**–Spiral views; **2-4**–side views.

5,7 Specimens from Tanzania, X100; from BLOW & BANNER (1962, pl. 15, fig. j-k). **5**–Spiral view; **7**–side view.

GLOBIGERINA SENNI (Beckmann, 1953)

Figure 84

Early to Middle Eocene

Sphaeroidinella senni BECKMANN, 1953, p. 394-395, fig. 20, pl. 26, fig. 2-4.

Globigerina senni (BECKMANN). BOLLI, 1957c, p. 163, pl. 35, fig. 10-12.–POSTUMA, 1971, p. 156-157.

Test a lofty trochospire, tightly coiled, subspherical. Last whorl with 3 to 4 slightly embracing chambers which increase rapidly in size. Axial periphery rounded, equatorial outline circular, only very slightly lobate. Sutures flush and indistinct on spiral side, incised at umbilical margin. Umbilicus small and deep with somewhat serrated margins. Aperture tends to be hidden, a low arch, umbilical. Wall robust, finely perforate, smooth except at umbilical extremities where granulated to pustulose. Diameter or height to 0.4 mm.

Discussion.–*Globigerina senni* differs from all other Paleogene species of *Globigerina* by the granulation around the umbilicus and the serrated umbilical margin.

Distribution.–Early and Middle Eocene (from within *Globorotalia aragonensis* Zone through *Truncorotaloides rohri* Zone). The species was first described from the Middle Eocene of Barbados.

GLOBOROTALIA SIMULATILIS (Schwager, 1883)

Figure 85

Middle to Late Paleocene

Discorbina simulatilis SCHWAGER, 1883, p. 120, pl. 29, fig. 15.

Globorotalia simulatilis (SCHWAGER). LUTERBACHER, 1964, p. 665-668, fig. 53-58.

Test trochospiral, biconvex, umbilical side only slightly more convex than spiral side. Last whorl with 5 to 6 angular-rhomboid chambers which increase regularly in size. Axial periphery acute but not distinctly keeled, equatorial outline circular, only

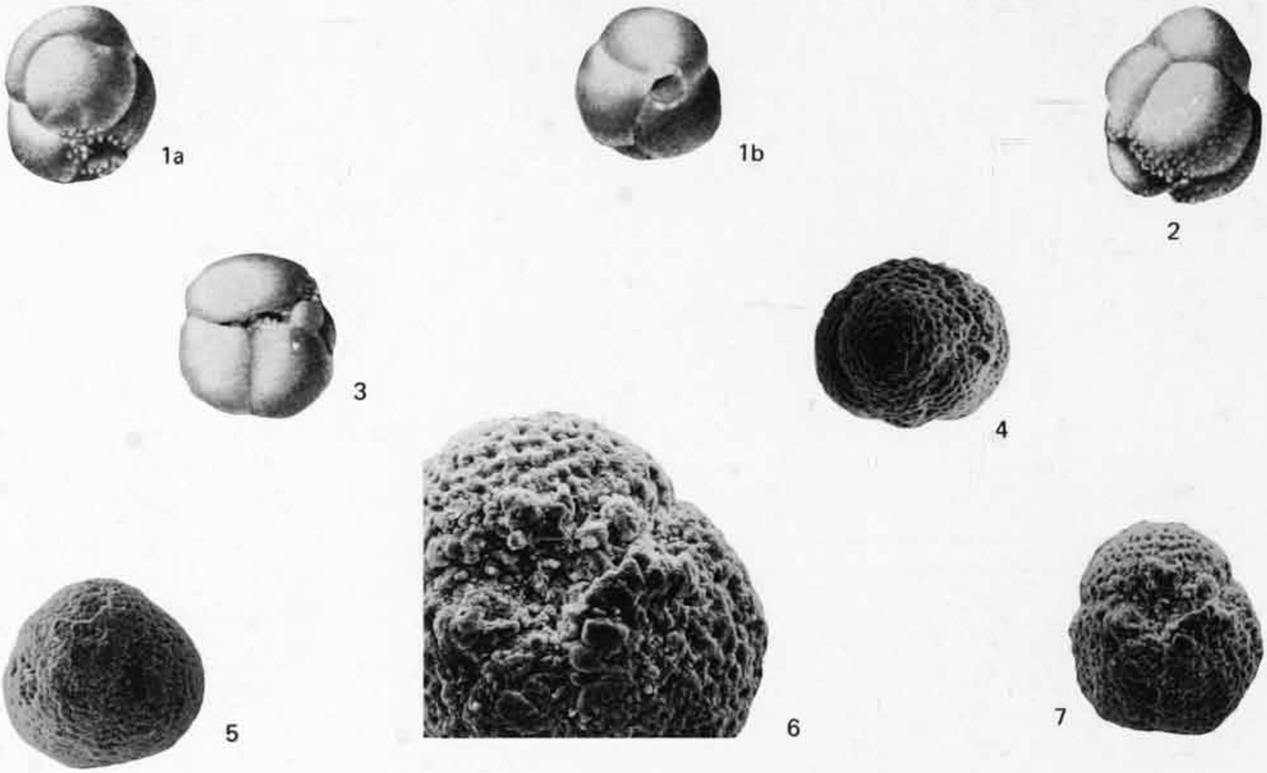


Fig. 84. *Globigerina senni* (BECKMANN) from the Middle Eocene of Trinidad and Barbados.

1-3 Specimens from the *Orbulinoides beckmanni* Zone in the Navet Formation of Trinidad, X73; from BOLLI (1957c, pl. 35, fig. 10-12). **1a,2**–Side views; **1b,3**–umbilical views.

4-7 Specimens from Barbados. **4**–Side view, X100; **5**–spiral view, X100; **6**–aperture, X250; **7**–umbilical view, X100.

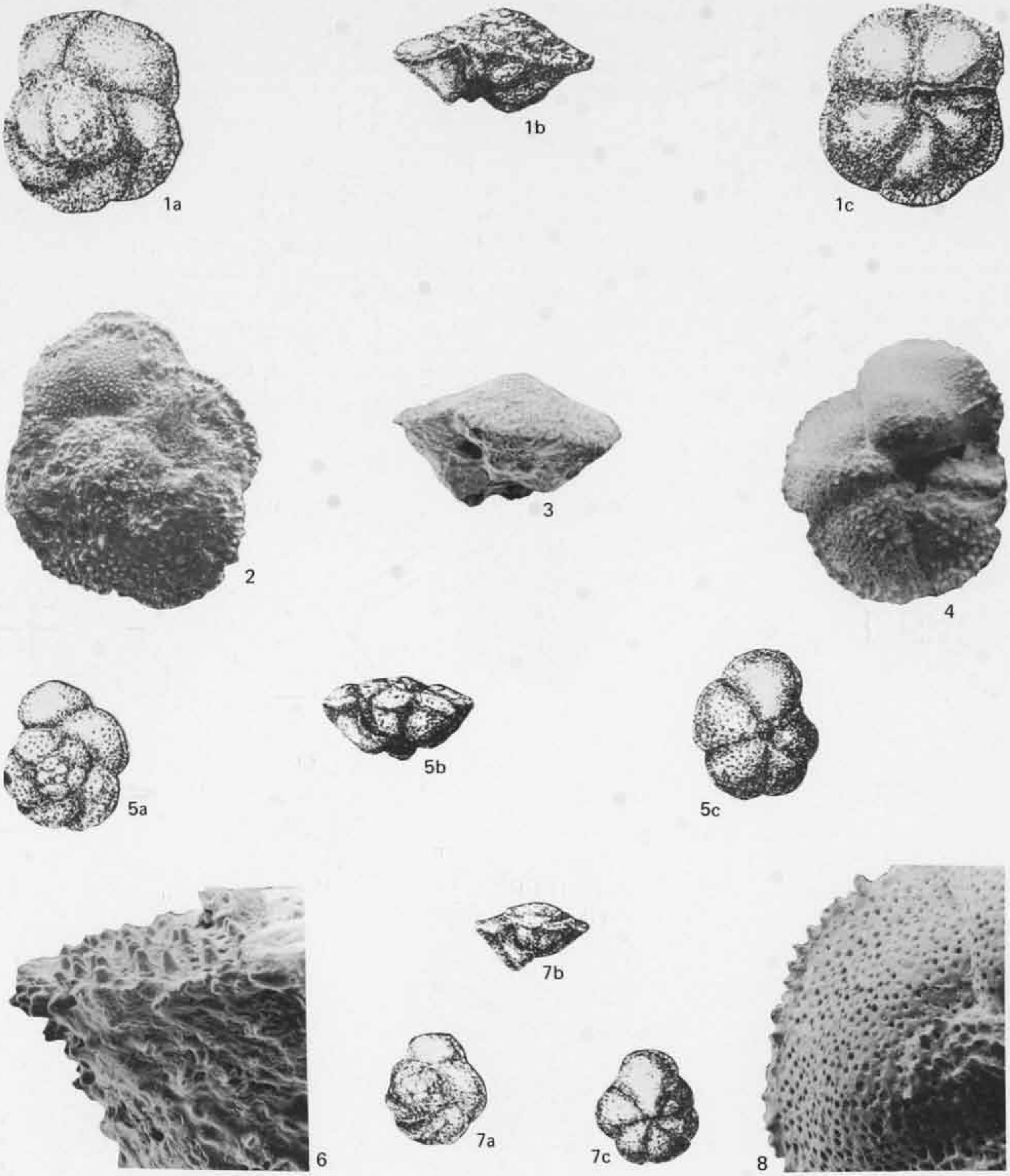


Fig. 85. *Globorotalia simulatilis* (SCHWAGER) from the Upper Paleocene (*Globorotalia pseudomenardii* Zone) of the Western Desert of Egypt (**1,5,7** from LUTERBACHER, 1964, p. 667, fig. 53-55.)

1-8 Representative specimens. **a**,**2**–Spiral views, X73, X100, X73, X75; **b**,**3**–side views, X73, X100, X75, X75; **c**,**4**–umbilical views, X75, X100, X75, X75; **6**–detail of side, X500; **8**–detail of umbilical surface, X250.

moderately lobate. Sutures depressed; curved on spiral side, radial on umbilical side. Umbilicus narrow but deep. Umbilical chamber tips rounded, tightly adherent to one another. Aperture a low arch with faint lip, extraumbilical-umbilical. Surface of test covered with fine spines, tending to be concentrated at peripheral margin and on umbilical side. Diameter 0.25 to 0.4 mm.

Discussion.–*Globorotalia simulatilis* differs from both *Globorotalia conicotruncata* and *Globorotalia angulata* by the biconvex, lenticular shape of its test.

Distribution.–Middle to Late Paleocene (*Globorotalia pusilla pusilla* Zone to *Globorotalia velascoensis* Zone). This species was first described from the Western Desert of Egypt from beds now referred to the *Globorotalia pseudomenardii* Zone.

GLOBIGERINA SOLDADOENSIS ANGULOSA

Bolli, 1957
Figure 86
Early Eocene

Globigerina soldadoensis angulosa BOLLI, 1957a, p. 71, pl. 16, fig. 4-6.–BOLLI, 1957c, p. 162, pl. 35, fig. 8.

Test trochospiral, spiral side flattened, umbilical side strongly inflated. Coiling initially compact but becoming looser. Last whorl with 4½ to 5 axially elongate chambers which increase fairly rapidly in size, each projecting backwards over preceding one so that test acquires angulate aspect. Axial periphery broadly rounded, equatorial outline strongly lobate. Sutures depressed; oblique on spiral side, radial on umbilical side. Umbilicus moderately wide, open.

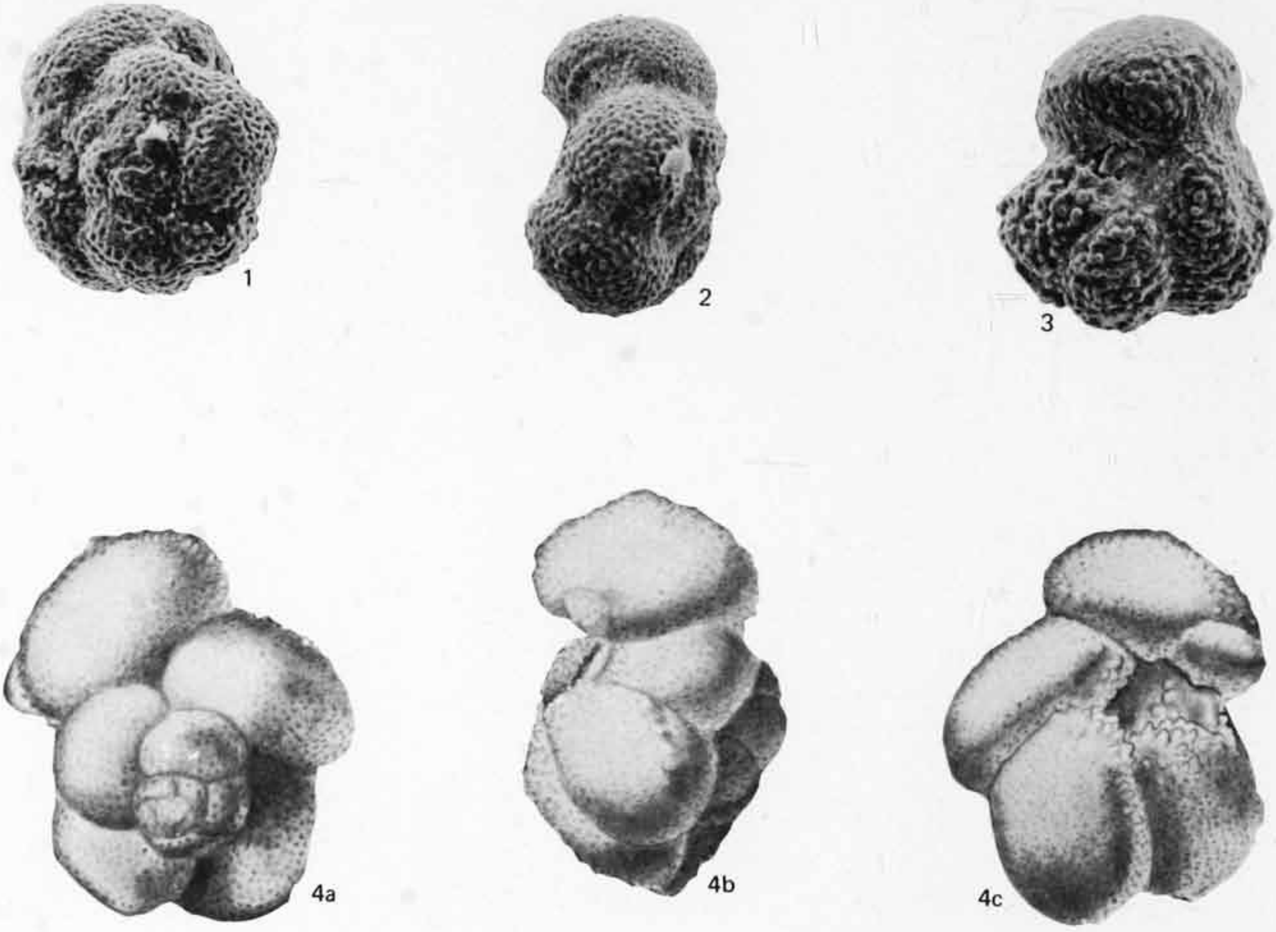


Fig. 86. *Globigerina soldadoensis angulosa* BOLLI from the Early Eocene part (*Globorotalia formosa formosa* Zone) of the Lizard Springs Formation of Trinidad.

1-4 Holotype (**4** from BOLLI, 1957a, pl. 16, fig. 4-6) and other specimens, X100. **1,4a**–Spiral views; **2,4b**–side views; **3,4c**–umbilical views.

Aperture a low arch, umbilical to extraumbilical-umbilical. Surface of test spinose, especially on umbilical side. Diameter 0.4 to 0.6 mm.

Discussion.–The subspecies *Globigerina soldadoensis angulosa* differs from the nominate subspecies by its very lobate equatorial outline. The form described here differs from *Globorotalia quetra* by its rounded axial periphery.

Distribution.–Early Eocene (*Globorotalia formosa formosa* Zone to *Globorotalia pentacamerata* Zone). The species was first described from the type locality of the *Globorotalia formosa formosa* Zone in the Lizard Springs Formation of Trinidad.

GLOBIGERINA SOLDADOENSIS SOLDADOENSIS

Brönnimann, 1952

Figure 87

Latest Paleocene and Early Eocene

Globigerina soldadoensis BRÖNNIMANN, 1952c, p. 7, 9, pl. 1, fig. 1-9.

Globigerina soldadoensis soldadoensis BRÖNNIMANN. BOLLI, 1957a, p. 71, pl. 16, fig. 7-12.–BOLLI, 1957c, p. 162, pl. 35, fig. 9.

Test a compact trochospire; spiral side flattened, umbilical side inflated. Last whorl with 4 to 5 ovate chambers, somewhat prolonged axially and increasing regularly in size. Arrangement of chambers somewhat

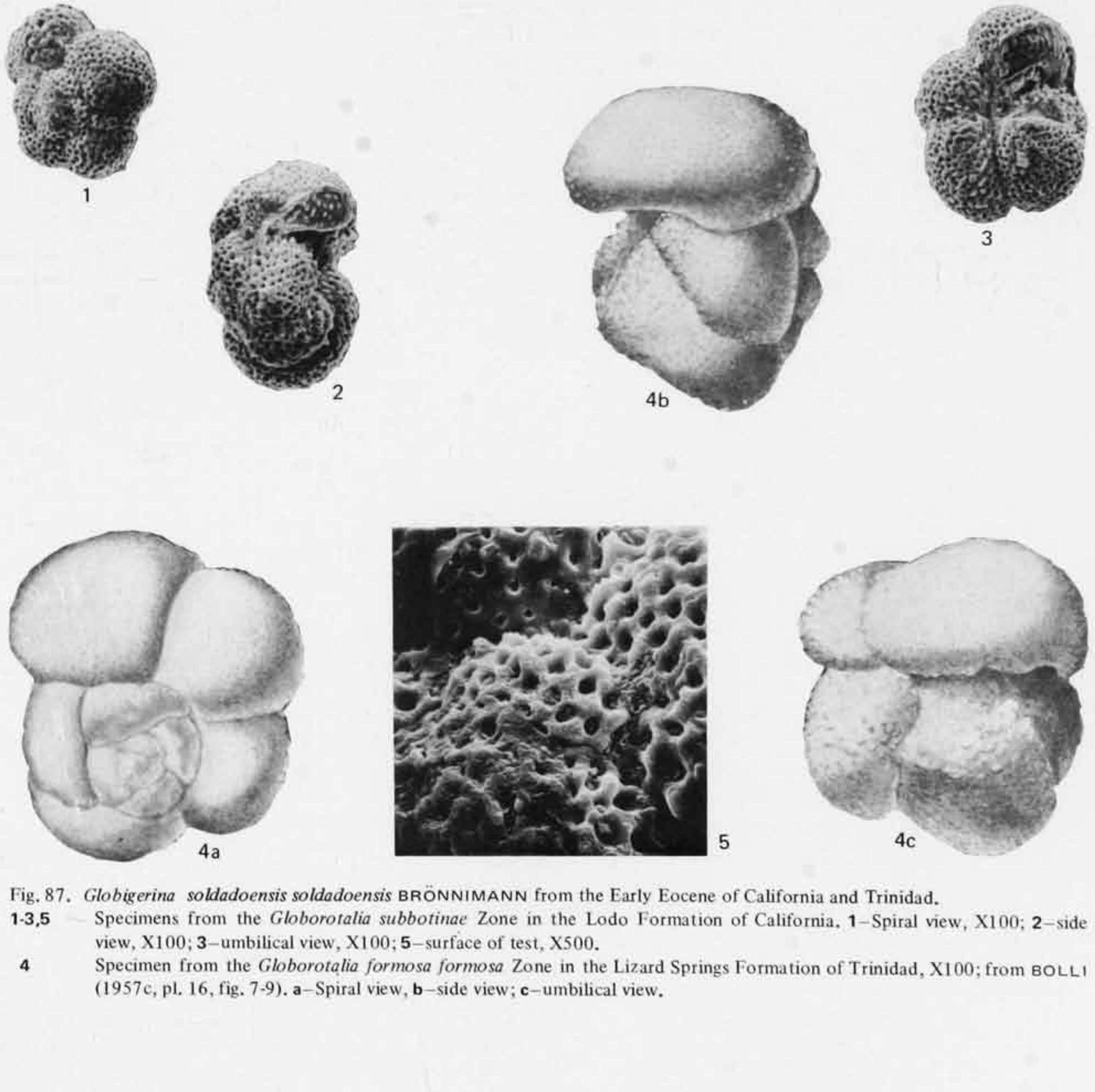


Fig. 87. *Globigerina soldadoensis soldadoensis* BRÖNNIMANN from the Early Eocene of California and Trinidad.

1-3,5 Specimens from the *Globorotalia subbotinae* Zone in the Lodo Formation of California. **1**–Spiral view, X100; **2**–side view, X100; **3**–umbilical view, X100; **5**–surface of test, X500.

4 Specimen from the *Globorotalia formosa formosa* Zone in the Lizard Springs Formation of Trinidad, X100; from BOLLI (1957c, pl. 16, fig. 7-9). **a**–Spiral view, **b**–side view; **c**–umbilical view.

imbricated, last one often aborted in specimens with 5 in the final whorl. Axial periphery usually broadly rounded, equatorial outline subcircular, lobate. Sutures depressed to incised; oblique to curved on spiral side, radial on umbilical side. Umbilicus wide and deep. Aperture a low arch, umbilical to somewhat extraumbilical, with distinct lip. Surface of test covered with spines which are more prominent in early part and on umbilical side. Diameter 0.3 to 0.5 mm.

Discussion.—The position of the aperture of this species is intermediate between that of *Globorotalia* and *Globigerina.* It has a more compact test than the shorter-ranging subspecies *Globigerina soldadoensis angulosa. Globigerina gravelli* BRÖNNIMANN (1952c, p. 12-13, pl. 1, fig. 16-18) (also BOLLI, 1957a, p. 72, pl. 16, fig. 1-3) differs from *G. soldadoensis soldadoensis* by its larger size, more numerous chambers and higher spire, but the two are linked by intermediate forms (BOLLI, 1957a, pl. 16, fig. 10-12). *Globigerina gravelli* is reported from the *Globorotalia subbotinae* Zone to the *Globorotalia aragonensis* Zone.

Distribution.—Latest Paleocene and Early Eocene (from within *Globorotalia velascoensis* Zone through *Globorotalia pentacamerata* Zone). The holotype of this species originates from the *Globorotalia velascoensis* Zone in Trinidad.

GLOBOROTALIA SPINULOSA Cushman, 1927
Figure 88
Early and Middle Eocene

Globorotalia spinulosa CUSHMAN, 1927b, p. 114, pl. 23, fig. 4.—BOLLI, 1957c, p. 168, pl. 38, fig. 6-7.—BLOW, 1969, p. 370, pl. 50, fig. 2-5.

Test trochospiral; spiral side almost flat, umbilical side strongly inflated, subconical. Last whorl with 4 to 5 crescentic to angular-rhomboid chambers which increase steadily in size. Axial periphery acute with spinose keel, equatorial outline scalloped. Sutures on spiral side curved, often beaded; on umbilical side depressed, radial. Umbilicus varying from narrow to fairly wide, open. Aperture a low arch, extraumbilical-umbilical. Surface of test covered with fine spines which may coalesce to form pustules. Diameter 0.35 to 0.65 mm.

Discussion.—*Globorotalia spinulosa* differs from *Globorotalia aragonensis* in being more loosely coiled and from *Globorotalia lehneri* in lacking radial elongation of chambers. The name *G. spinulosa* is retained pending further clarification of its status; either *Globorotalia densa* (CUSHMAN, 1925d) or *Globorotalia crassata* (CUSHMAN, 1925d) may be a senior synonym (BLOW, 1969, p. 373; CIFELLI, 1972).

Distribution.—Late Early Eocene and Middle Eocene (approximately *Globorotalia aragonensis* Zone through *Truncorotaloides rohri* Zone). *Globorotalia spinulosa* was first described from the Middle Eocene of eastern Mexico.

GLOBOROTALIA SUBBOTINAE Morozova, 1939
Figure 89
Early Eocene

Globorotalia subbotinae MOROZOVA, 1939, p. 80-81, pl. 2, fig. 16.—LUTERBACHER, 1964, p. 676-679, fig. 85-90.
Globorotalia rex MARTIN, 1943, p. 117, pl. 8, fig. 2.
[not] *Globorotalia rex* of BOLLI, 1957a, pl. 18, fig. 10-12.

Test trochospiral; spiral side flat to slightly convex, umbilical side low conical to inflated. Last whorl with 4 to 5 (rarely 6) crescentic to rhomboidal chambers which increase rapidly in size, last chamber generally occupying one-third to one-fourth of whorl. Axial periphery acute, often pinched, with light spinose keel; equatorial outline lobate. Sutures on spiral side recurved, varying from slightly raised and beaded to distinctly depressed, on umbilical side radial and depressed. Umbilicus generally narrow but deep. Aperture a low arch, extraumbilical-umbilical. Wall covered with fine spines, especially near periphery. Typical diameter 0.4 mm.

Discussion.—*Globorotalia subbotinae* differs from *Globorotalia aequa* in the distinct keel and in being less tightly coiled. *Globorotalia marginodentata* is more lenticular and has a thick, broad keel.

Distribution.—Latest Paleocene and Early Eocene (within *Globorotalia velascoensis* Zone to within *Globorotalia aragonensis* Zone). The short overlap in the ranges of *G. subbotinae* and *Globorotalia velascoensis* is a useful guide to the Paleocene-Eocene boundary (see, for instance, BERGGREN, 1971b, p. 712-715).

GLOBIGERINATHEKA SUBCONGLOBATA
(Shutskaya, 1958)
Figure 90
Middle Eocene

Globigerinoides subconglobatus CHALILOV var. *subconglobata* CHALILOV in SHUTSKAYA, 1958, p. 86-87, pl. 1, fig. 4-11 [cotypes; fig. 8 subsequently designated as lectotype by BOLLI, 1972a].

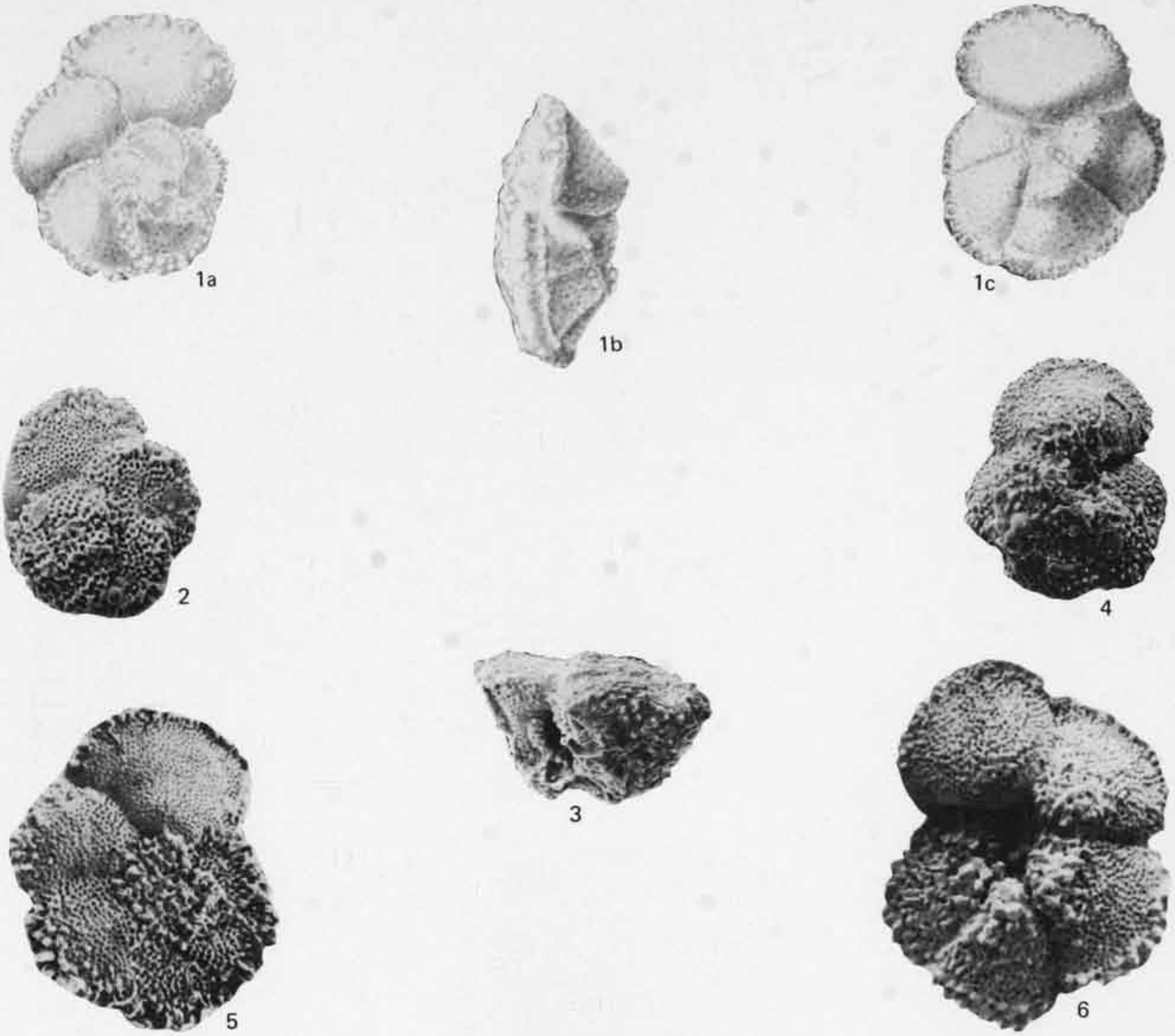


Fig. 88. *Globorotalia spinulosa* CUSHMAN from the Middle Eocene of Trinidad, Gulf of Mexico, and Tanzania.

1 Specimen from the *Hantkenina aragonensis* Zone in the Navet Formation of Trinidad, X73; from BOLLI (1957c, pl. 38, fig. 6). **a**–Spiral view; **b**–side view; **c**–umbilical view.

2-4 Specimens from the northeastern Gulf of Mexico, X100. **2**–Spiral view; **3**–side view; **4**–umbilical view.

5-6 Specimens from Tanzania, X80; from BLOW (1969, pl. 50, fig. 2-3). **5**–Spiral view; **6**–umbilical view.

Globigerinatheka subconglobata subconglobata (SHUTSKAYA). BOLLI, 1972a, p. 134, fig. 43-46, pl. 1, fig. 8-10, 15-16 [line drawings traced from original type figures, fig. 43-46].

Globigerapsis index (FINLAY). SUBBOTINA, 1972, p. 120-121 (part), pl. 1, fig. 2-5 (not pl. 1, fig. 1).

Test rather large, almost spherical, composed of 3 whorls of which inner 2 form only an insignificant part. Last whorl with 3 globular chambers which embrace umbilical part of earlier coil. Last chamber

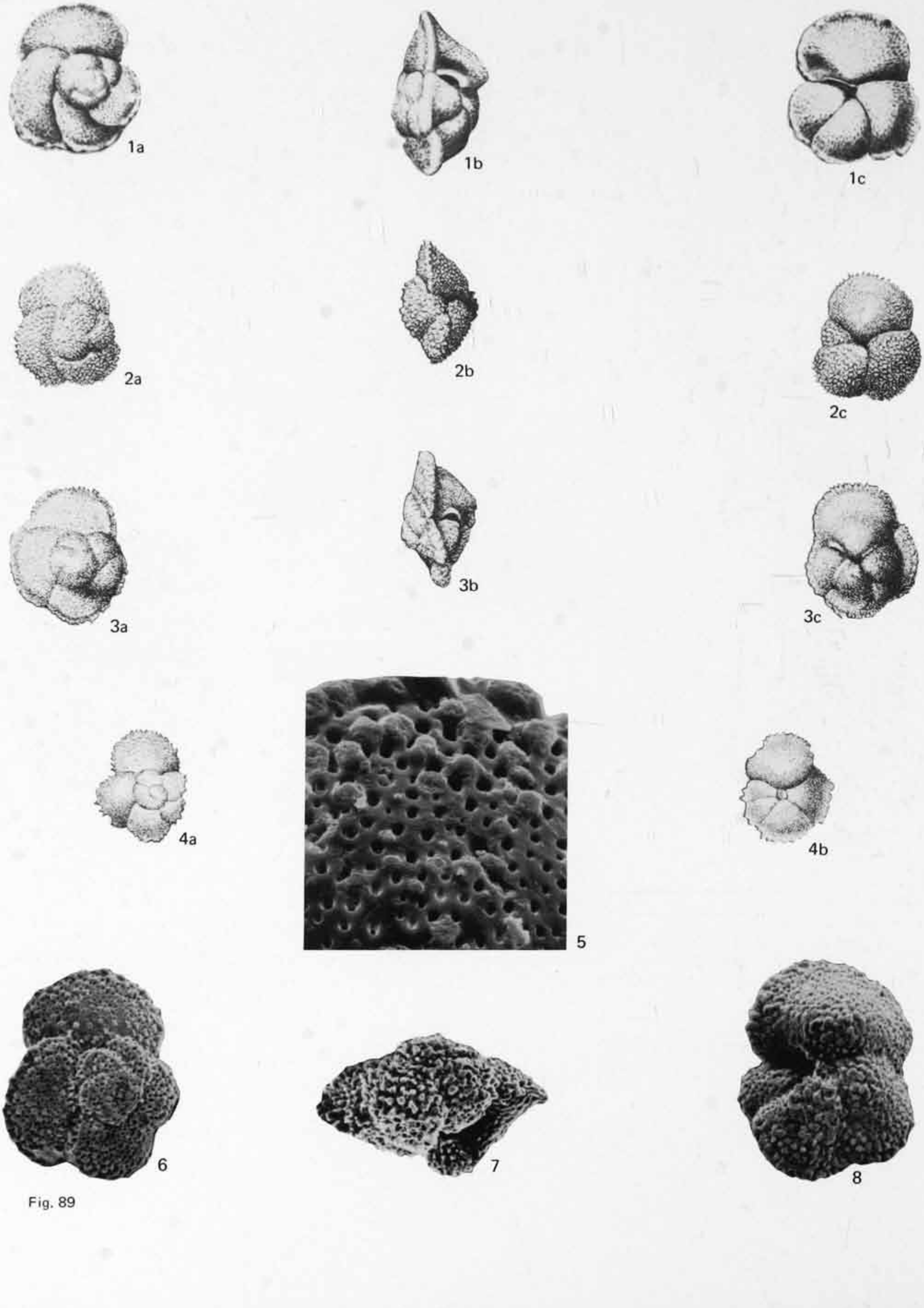


Fig. 89

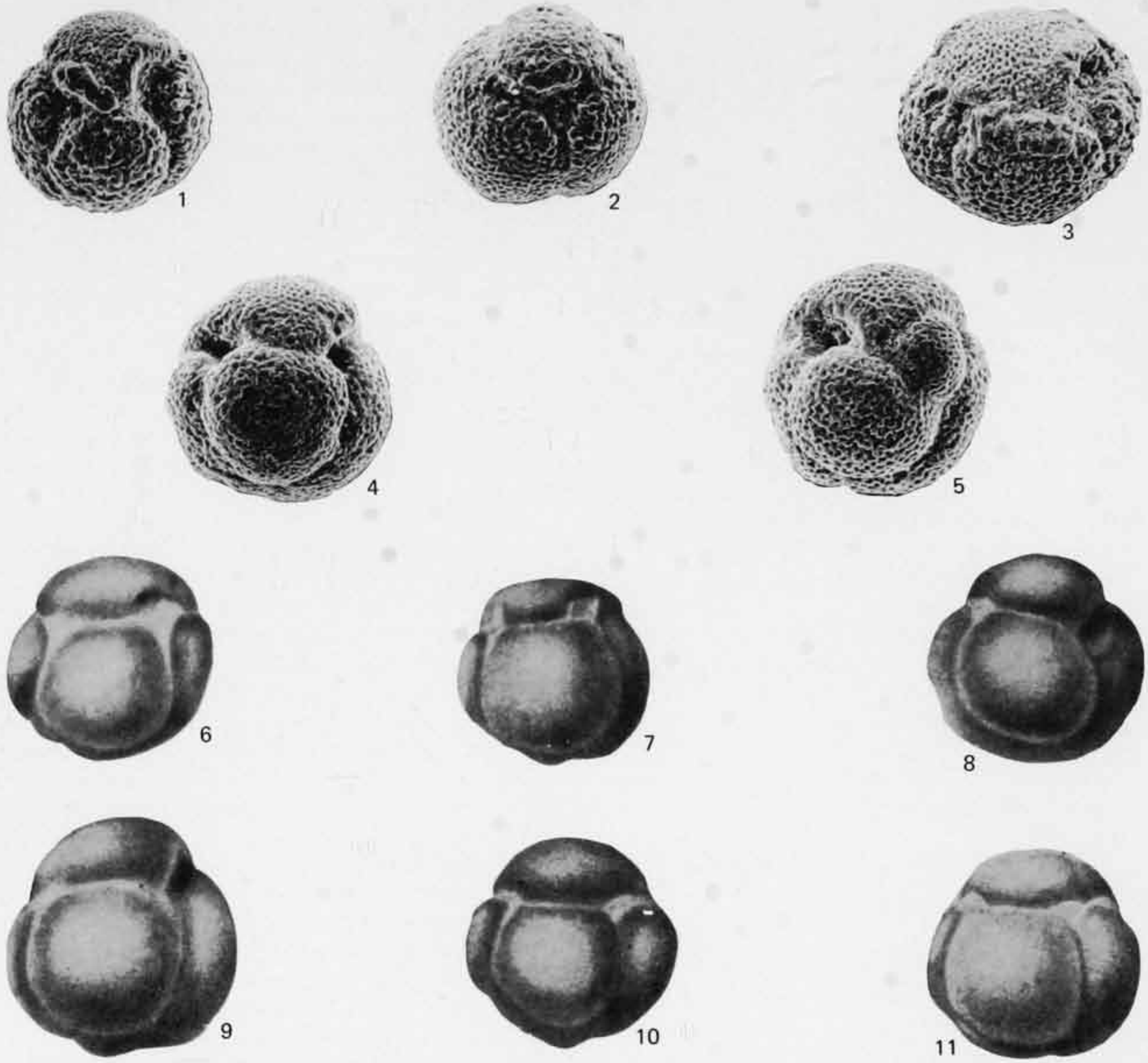


Fig. 90. *Globigerinatheka subconglobata* (SHUTSKAYA) from the Middle Eocene of Italy and the Soviet Union.

1-5 Specimens from the early Middle Eocene (*Globigerinatheka subconglobata* Zone) of northern Italy, X80; from BOLLI (1972a, pl. 1, fig. 8-10, 15-16). **1-2**–Small specimens with last chamber smaller than penultimate, both with two apertures having thick rims; **3**–specimen with flat last chamber and three apertures (two visible); **4**–specimen with two apertures; **5**–specimen with two apertures (one covered by a bulla).

6-11 Lateral views of lectotype **(11)** and other specimens from the northern Caucasus, Soviet Union, X60; from SHUTSKAYA (1958, pl. 1, fig. 4-5, 7-9, 11).

◁ Fig. 89. *Globorotalia subbotinae* MOROZOVA from the Eocene of California and the Soviet Union.

1,5-8 Specimens (**1**=holotype of *Globorotalia rex* MARTIN from MARTIN, 1943, pl. 8, fig. 2) from the Early Eocene part (*Globorotalia subbotinae* Zone) of the Lodo Formation of California. **1a,6**–Spiral views, X60, X100; **1b,7**–side views, X60, X100; **1c,8**– umbilical views, X60, X100; **5**–surface of last chamber, X500.

2-3 Specimens from the Lower Eocene of northwestern Crimea, X72; from SUBBOTINA (1953, pl. 17, fig. 11,13). **a**–Spiral views; **b**–side views; **c**–umbilical views.

4 Holotype from the Lower Eocene of the Emba region of the Soviet Union, X55; from SUBBOTINA (1953, pl. 17, fig. 7). **a**–Spiral view; **b**–umbilical view.

often smaller than preceding. Sutures depressed, distinct. Apertures sutural, as typical for genus, generally small and low, not bullate. Wall thick, robust, coarsely perforate. Diameter to 0.6 mm.

Discussion.—In accordance with Article 50 of the International Code of Zoological Nomenclature authorship of this name is attributed to SHUTSKAYA who first published a valid description of the species. Reference is made to the detailed discussion of the representatives of the genus *Globigerinatheka* by BOLLI (1972a). *Globigerinatheka subconglobata* differs from *Globigerinatheka index* in having a more compact test, a less rugose surface, and shallower sutures. SUBBOTINA (1972) placed *G. subconglobata* in synonymy with *G. index.* She used a very broad species concept, however, and we prefer to follow BOLLI'S (1972a) subdivision for species of the genus *Globigerinatheka*. *Globigerinatheka mexicana* is smaller and its growth pattern is less regular. *Globigerinatheka kugleri* has better individualized chambers and, therefore, a less compact test.

Distribution.—Middle Eocene (mainly from within *Hantkenina aragonensis* Zone to within *Orbulinoides beckmanni* Zone, very rare above). *Globigerinatheka subconglobata* was first described from the Middle Eocene of the northern Caucasus. According to BOLLI (1972a) this species occurs mainly in temperate regions.

TRUNCOROTALOIDES TOPILENSIS (Cushman, 1925)

Figure 91

Middle Eocene

Globigerina topilensis CUSHMAN, 1925b, p. 7, pl. 1, fig. 9. *Truncorotaloides topilensis* (CUSHMAN). BOLLI, 1957c, p. 170, pl. 39, fig. 13-16.—BLOW, 1969, p. 373, pl. 51, fig. 1-3.

Test trochospiral, initially compact but becoming loosely coiled. Last whorl consistently has 4 chambers at right angles to one another, increasing rapidly in size. Shape of younger chambers highly distinctive, as if flattened radially against test but projecting in all other directions to form a subcircular rim which tends to be accentuated by spines and pustules. Profile appears angulate or sculptured from all aspects. Sutures in last whorl deeply incised; oblique on spiral side, radial on umbilical side. Umbilicus deep and narrow. Aperture a well-formed arch, umbilical to extraumbilical. Secondary sutural apertures on spiral side between youngest chambers (but may be difficult to discern except in excellently preserved specimens). Wall coarsely perforate, spinose, especially around periphery of each chamber.

Discussion.—*Truncorotaloides topilensis* differs from all other Paleogene planktonic foraminifers by the bizarre shape of its youngest chambers. It is linked by intermediate forms to the less distinctive and almost coeval *Truncorotaloides rohri.*

Distribution.—Middle Eocene (whole interval except topmost part of *Truncorotaloides rohri* Zone). The species was originally described from the Middle Eocene of eastern Mexico.

GLOBIGERINA TRILOCULINOIDES Plummer, 1926

Figure 92

Paleocene

Globigerina triloculinoides PLUMMER, 1926, p. 134, pl. 8, fig. 10.—BOLLI, 1957a, p. 70, pl. 15, fig. 18-20.

Test rather small, low trochospiral, tightly coiled, inner whorl very small; spiral side slightly flattened, umbilical side inflated. Last whorl with 3 to 3½ globular chambers which increase rapidly in size, last occupying one-third to half of whorl. Axial periphery broadly rounded, equatorial outline trilobate. Sutures depressed, radial to oblique. Umbilicus shallow. Aperture umbilical or even slightly extraumbilical-umbilical, with distinct lip. Surface of test rather coarsely perforate, reticulate. Diameter rarely exceeds 0.4 mm.

Discussion.—We prefer to restrict the name *triloculinoides* to rather small trilobate forms with a distinct honeycomb pattern as described by PLUMMER despite the loose usage of later authors (for a representative list see BERMÚDEZ, 1960, p. 1204-1206). In this strict sense *G. triloculinoides* is confined to the Paleocene and is considered ancestral to larger and more variable species within the *Globigerina linaperta-Globigerina eocaena* lineage of the Eocene. *Globigerina velascoensis* is superficially similar, but its chambers are more appressed and prolonged so as to enclose the umbilicus. *Globigerina triloculinoides* was selected by BROTZEN & POZARYSKA (1961) as type species of their poorly defined subgenus *Subbotina* (see also LOEBLICH & TAPPAN, 1964, p. C673).

Distribution.—Paleocene (*Globorotalia pseudobulloides* Zone to approximately *Globorotalia pseudomenardii* Zone). The species was first described from the Midway Formation of Texas.

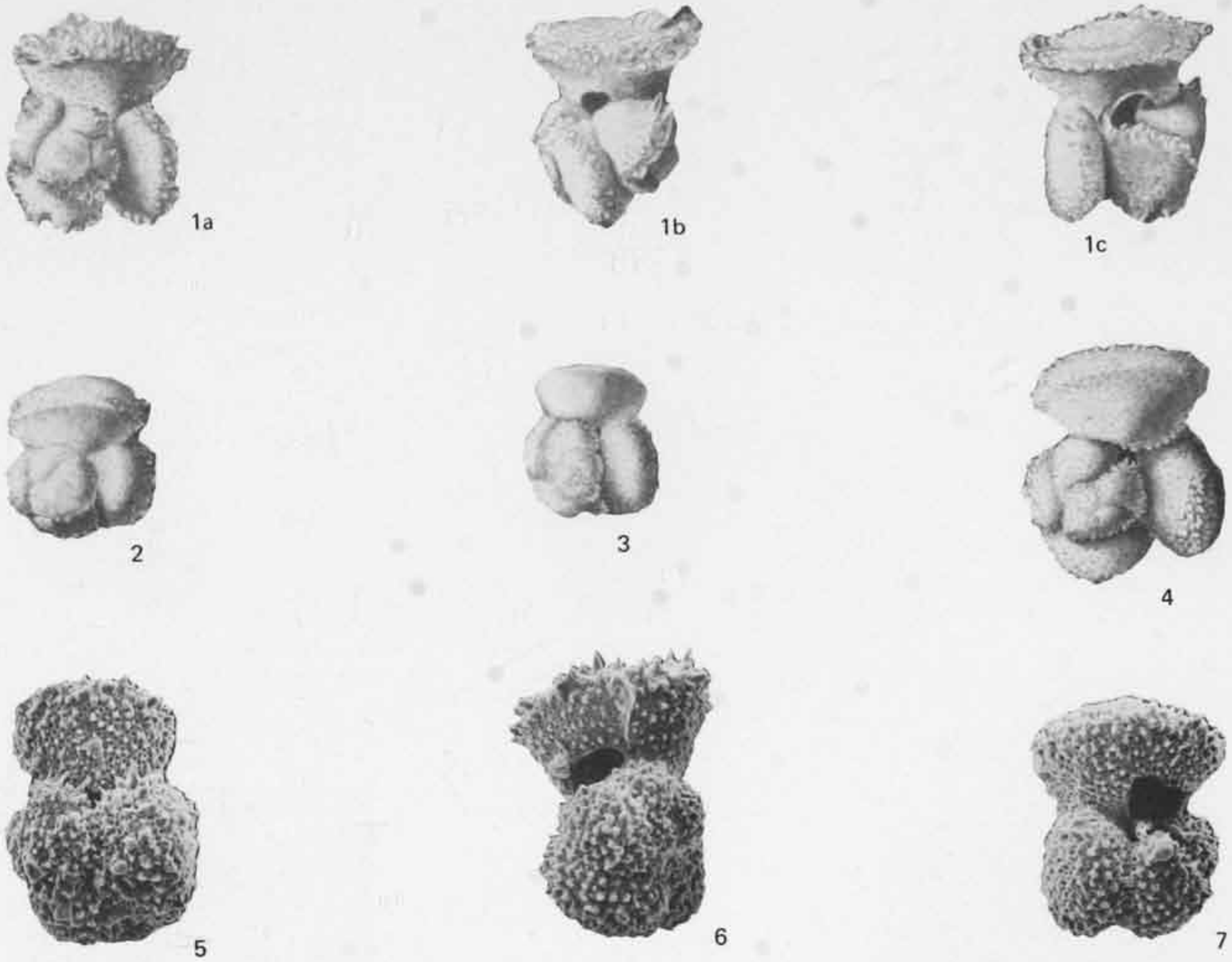


Fig. 91. *Truncorotaloides topilensis* (CUSHMAN) from the Middle Eocene part (*Orbulinoides beckmanni* Zone) of the Navet Formation of Trinidad.

1-7 Representative specimens (**1-4** from BOLLI, 1957c, pl. 39, fig. 13-16). **1a,2-5**–Spiral views, X73, X73, X73, X73, X100; **1b,6**–side views, X73, X100; **1c,7**–umbilical views, X73, X100.

GLOBOROTALIA TRINIDADENSIS Bolli, 1957

Figure 93
Paleocene

Globorotalia trinidadensis BOLLI, 1957a, p. 73, pl. 16, fig. 19-23.–LUTERBACHER, 1964, p. 651-652, fig. 26-29.

Test very low trochospiral. Inner whorls often depressed on spiral side, umbilical side inflated. Last whorl with 5 to 8 (mostly 6) globular to pear-shaped chambers which increase slowly in size. Last chamber often somewhat detached. Axial periphery broadly rounded; equatorial outline almost circular, lightly notched. Sutures depressed; radial to slightly curved on spiral side, radial on umbilical side. Umbilicus wide. Aperture a low arch, extraumbilical-umbilical, with faint lip. Surface of test rugose to spinose, especially inner whorls and initial chambers of last whorl. Diameter about 0.4 mm.

Discussion.–*Globorotalia trinidadensis* differs from *Globorotalia inconstans* in having more chambers in the last whorl, a flatter–even depressed–spiral side, and a rougher surface. *Globorotalia praecursoria* also is grossly similar but its chambers strongly tend to become angulate, foreshadowing the conical species of *Globorotalia* of the Middle Paleocene and younger levels.

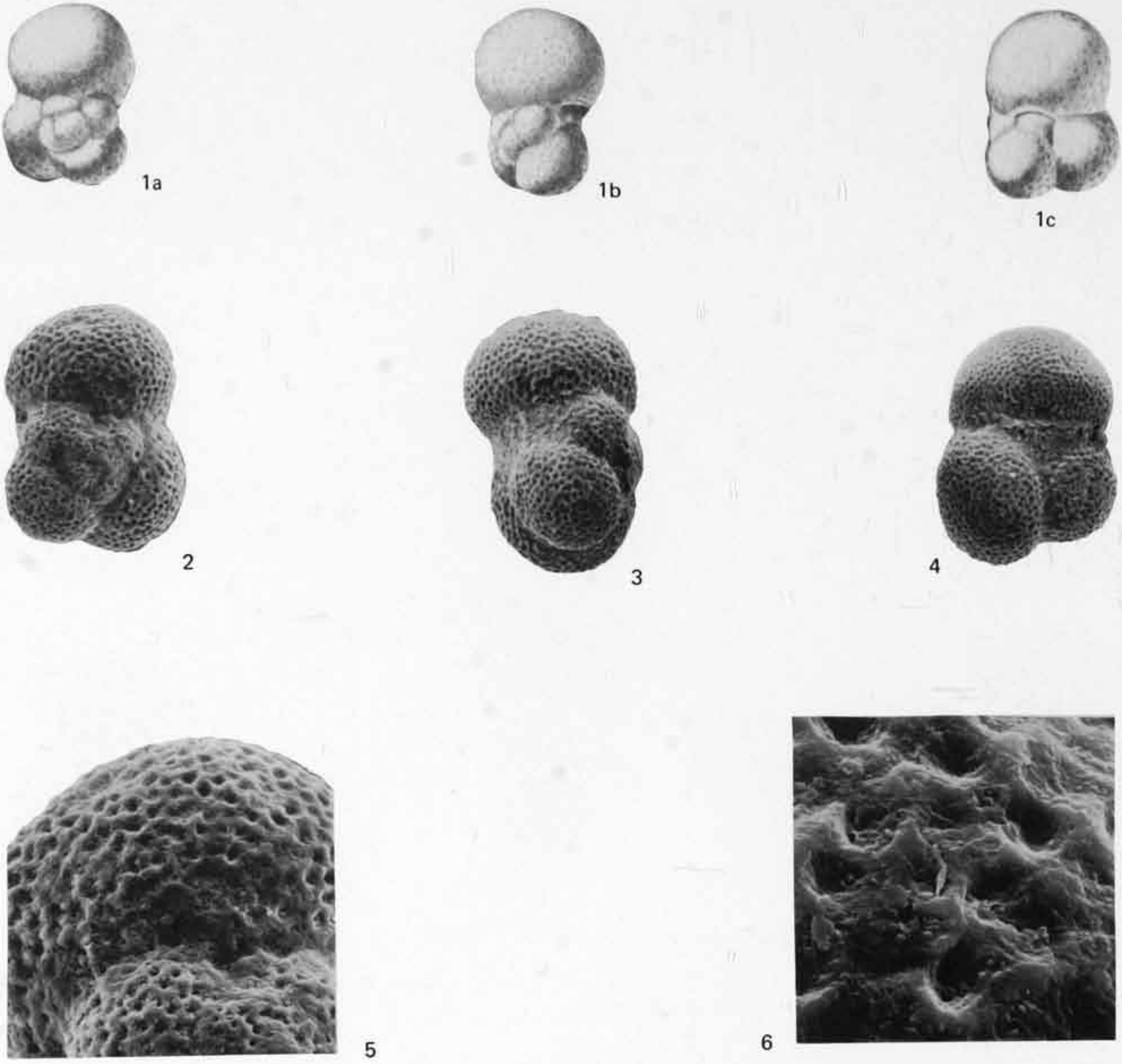


Fig. 92. *Globigerina triloculinoides* PLUMMER from the Paleocene of Trinidad and France.

1 Specimen from the Middle Paleocene part (*Globorotalia pusilla pusilla* Zone) of the Lizard Springs Formation of Trinidad, X100; from BOLLI (1957a, pl. 15, fig.18-20). **a**–Spiral view; **b**–side view; **c**–umbilical view.

2-6 Specimens from the Lower Paleocene of southwestern France. **2**–Spiral view, X100; **3**–side view, X100; **4**–umbilical view, X100; **5**–last chamber, X250; **6**–surface of last chamber, X1000.

Fig. 93. *Globorotalia trinidadensis* BOLLI from the Early Paleocene of Trinidad and the Soviet Union.

1 Holotype from the *Globorotalia trinidadensis* Zone in the Lizard Springs Formation of Trinidad, X100; from BOLLI (1957a, pl. 16, fig. 19-21). **a**–Spiral view; **b**–side view; **c**–umbilical view.

▷

2-6 Specimens from northwestern Crimea. **2**–Spiral view, X100; **3**–side view, X100; **4**–umbilical view, X100; **5**–first chamber of outer whorl, X500; **6**–surface of test, X1000.

Distribution.–Paleocene. Most of its short range defines the youngest part (*Globorotalia trinidadensis* Zone) of the Early Paleocene and the rest falls within the *Globorotalia uncinata* Zone of the Middle Paleocene, where both the name species occur together. *Globorotalia trinidadensis* was first described from the Paleocene Lizard Springs Formation of Trinidad.

GLOBIGERINATHEKA TROPICALIS
(Blow & Banner, 1962)
Figure 94
Middle and Late Eocene

Globigerinoides conglobatus (BRADY). SUBBOTINA, 1953, p. 94, 95, pl. 14, fig. 2-5.–SHUTSKAYA, 1958, pl. 2, fig. 1-5.–SUBBOTINA, 1971, p. 128-129, pl. 14, fig. 2-5.

Globigerapsis index (FINLAY). BOLLI, 1957c, p. 165, pl. 36, fig. 14-16.

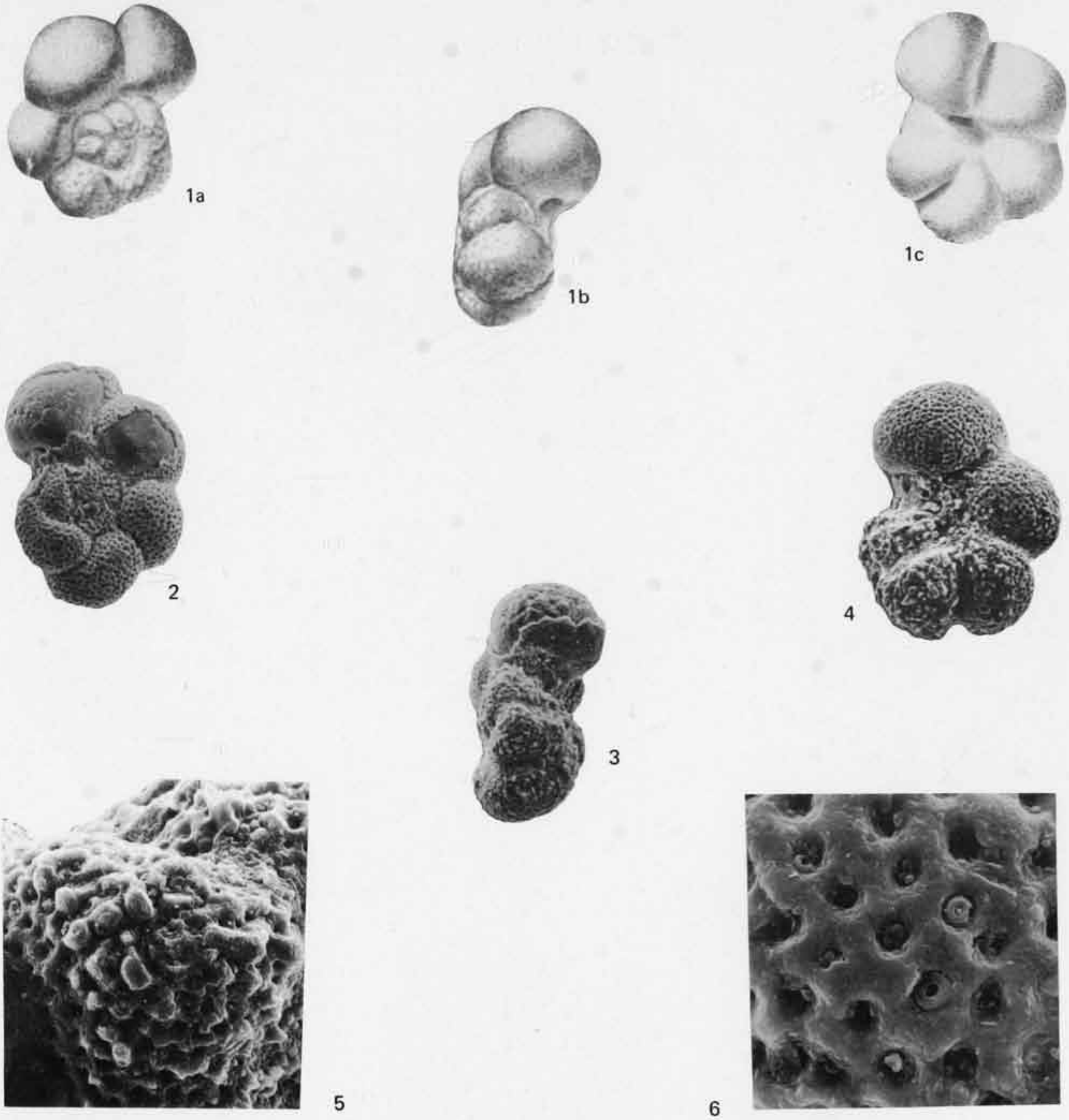


Fig. 93

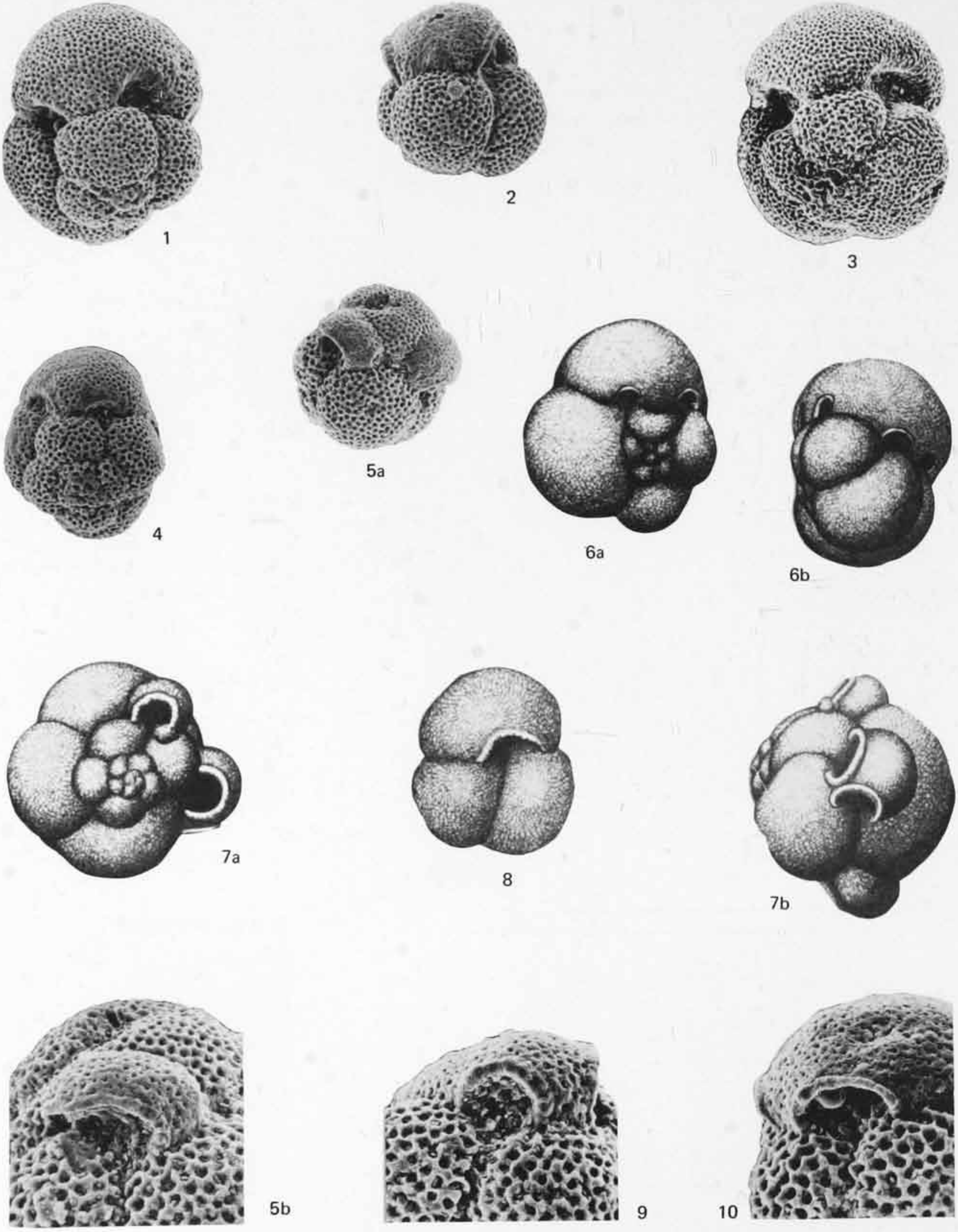


Fig. 94

Globigerapsis tropicalis BLOW & BANNER, 1962, p. 124-125, pl. 15, fig. D-F.–BLOW, 1969, p. 331, pl. 27, fig. 5-6.
Globigerinatheka lindiensis BLOW & BANNER, 1962, p. 125-126, pl. 15, fig. O-P.
Globigerinatheka index tropicalis (BLOW & BANNER). BOLLI, 1972a, p. 127, fig. 58-60, pl. 3, fig. 1-24; pl. 4, fig. 7-12.

Test subspherical. Inner whorls a simple low trochospire of slowly enlarging chambers. In outer whorl rate of growth accelerates abruptly and its 4 globose chambers embrace successively more of early umbilical region, final one usually covering it completely. Sutures depressed, radial to slightly curved. Adult test has 3 or 4 arched semicircular apertures situated along basal suture of last chamber at its intersection with earlier intercameral sutures, apertures bordered by thickened rims, occasionally bullate. Wall finely and uniformly cancellate, may appear smooth. Diameter about 0.4 mm.

Discussion.–*Globigerinatheka index* differs from *Globigerinatheka tropicalis* by its very thick, rugose wall and deeply incised sutures. *Globigerinatheka semiinvoluta* is distinguished by its less individualized chambers and especially its more globular, more embracive final chamber. *Globigerinatheka lindiensis* here is placed in synonymy with *G. tropicalis* because it differs only in the consistent presence of bullas (BOLLI, 1972a).

Distribution.–Middle to Late Eocene (mainly *Globigerinatheka semiinvoluta* Zone with short extension above and below). The species was first described from the Upper Eocene (*Globigerinatheka semiinvoluta* Zone) of Tanzania and is widespread in tropical and temperate regions.

GLOBOROTALIA UNCINATA Bolli, 1957

Figure 95

Middle Paleocene

Globorotalia uncinata BOLLI, 1957a, p. 74, pl. 17, fig. 13-15.–LUTERBACHER, 1964, p. 655-656, fig. 30-31.

Test low trochospiral; flat or only slightly convex spiral side, inflated umbilical side. Last whorl with 5 to 6 chambers which increase rather rapidly in size, shape subangular-conical except last, which is more globular. Equatorial outline slightly lobate, axial periphery subangular to angular in early part of last whorl, later becoming rounded. Sutures depressed; strongly curved backwards on spiral side, radial on umbilical side. Umbilicus narrow but deep. Aperture a low arch, extraumbilical-umbilical. Surface of test spinose, especially on umbilical side and at periphery. Diameter about 0.3 mm.

Discussion.–*Globorotalia uncinata* is intermediate between *Globorotalia pseudobulloides* and *Globorotalia angulata*. It differs from the former by the strong backward curvature of sutures on the spiral side and its partly subangular periphery, from the latter by the broadly rounded profile of its younger chambers. The forms which BOLLI (1957a, pl. 17, fig. 16-18) considered intermediate between *G. pseudobulloides* and *G. uncinata* are here included in the latter species.

Distribution.–Middle Paleocene, lower part (*Globorotalia uncinata* Zone to within *Globorotalia angulata* Zone). Its level of first appearance is an accepted zonal datum. The species was first described from the Paleocene of Trinidad.

GLOBIGERINA VELASCOENSIS Cushman, 1925

Figure 96

Middle Paleocene to Early Eocene

Globigerina velascoensis CUSHMAN, 1925c, p. 19, pl. 3, fig. 6.–BOLLI, 1957a, p. 71, pl. 15, fig. 9-11.–BERMÚDEZ, 1960, p. 1206-1207, pl. 6, fig. 2.

Test a compact trochospire; spiral side flattened to even slightly concave, umbilical side strongly inflated. Last whorl with 4 chambers which increase rapidly in size, last occupying close to one-half of whorl. Chambers inflated, slightly appressed.

◁ Fig. 94. *Globigerinatheka tropicalis* (BLOW & BANNER) from the Late Eocene of Trinidad and Tanzania.

1-5,9-10 Specimens from the *Globigerinatheka semiinvoluta* Zone in the Navet Formation of Trinidad; from BOLLI (1972a, pl. 3, fig. 5, 14-15, 19-20; pl. 4, fig. 7-9). **1,3**–Oblique views of large specimens with three apertures, X100; **2**–side view of specimen with bulla-like final chamber, X100; **4**–spiral view of medium-sized specimen, X100; **5a**–oblique view of specimen with delicate bullas, X100; **5b**–detail of delicate bulla, X200; **9**–detail of small bulla-like final chamber, X200; **10**–detail of aperture with delicate bulla, X200.

6-8 Specimens from Tanzania (**6**=holotype of *Globigerinatheka tropicalis*; **7**=holotype of *Globigerinatheka lindiensis*), X100; from BLOW & BANNER (1962, pl. 15, fig. D-F, O-P). **6a**–Spiral view; **6b,7b**–side views; **7a**–spiral view of specimen with bullas; **8**–umbilical view.

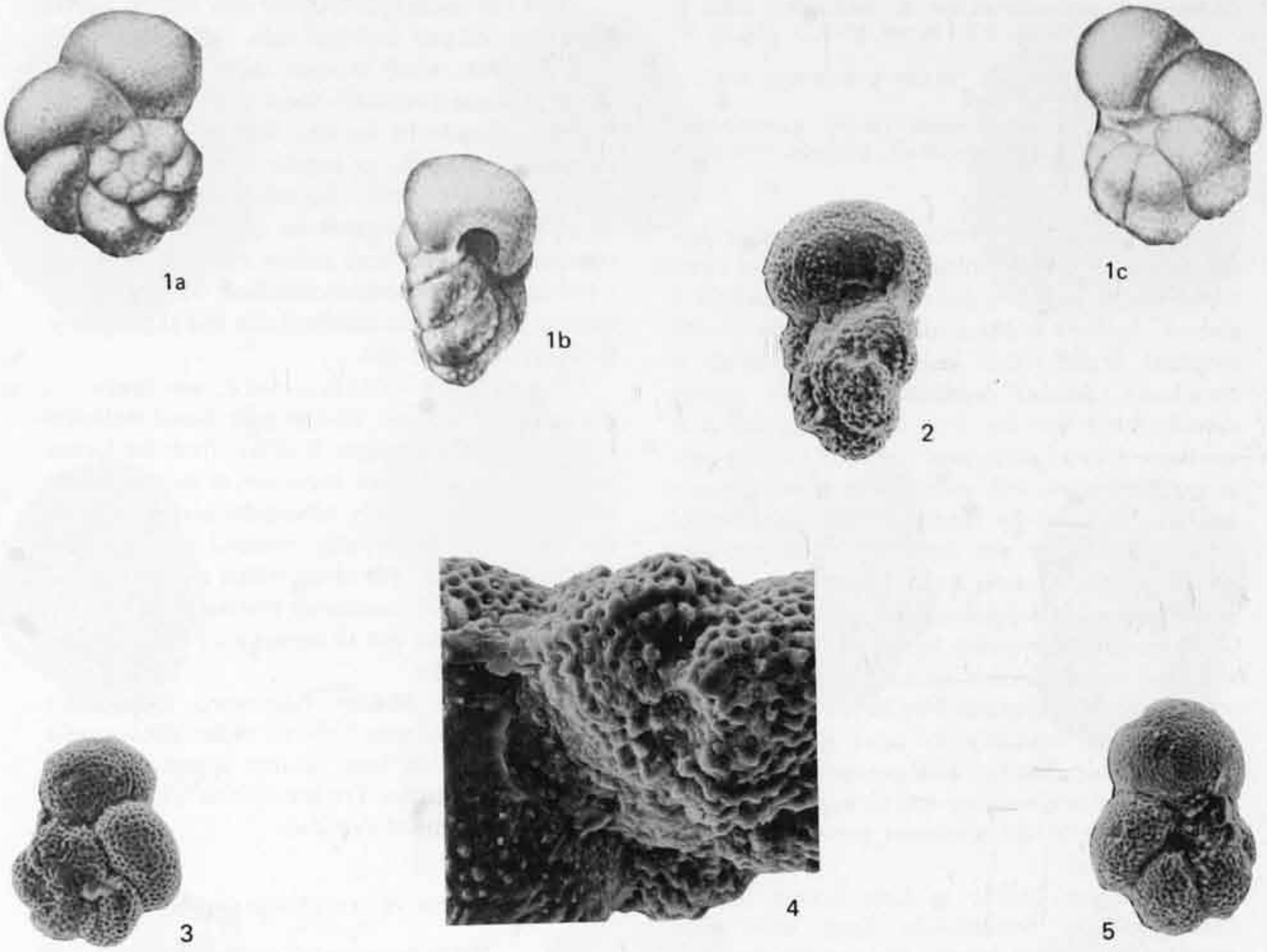


Fig. 95. *Globorotalia uncinata* BOLLI from the Paleocene in Trinidad and the Soviet Union.

1 Holotype from the Middle Paleocene part (*Globorotalia uncinata* Zone) of the Lizard Springs Formation of Trinidad, X100; from BOLLI (1957a, pl. 17, fig. 13-15). **a**–Spiral view; **b**–side view; **c**–umbilical view.

2-5 Specimens from low in the Paleocene of northwestern Crimea. **2**–Side view, X100; **3**–spiral view, X100; **4**–acute periphery of first chamber of outer whorl, X250; **5**–umbilical view, X100.

Equatorial outline lobate, axial periphery broadly rounded. Sutures depressed; on spiral side oblique, meeting at right angles, on umbilical side radial. Umbilicus deep and narrow. Aperture a low arch, umbilical to slightly extraumbilical-umbilical, with distinct broad lip. Wall rather coarsely perforate, almost smooth. Diameter 0.30 to 0.35 mm.

Discussion.–*Globigerina velascoensis* differs from *Globigerina triloculinoides* by its laterally compressed chambers and rather smooth instead of cancellate surface. The grossly similar *Globigerina primitiva* has a spinose surface and well-developed pustules on the umbilical side.

Distribution.–Middle Paleocene to Early Eocene (*Globorotalia pusilla pusilla* Zone to *Globorotalia subbotinae* Zone). The species was first described from the Paleocene Velasco Formation of eastern Mexico.

GLOBOROTALIA VELASCOENSIS (Cushman, 1925)

Figure 97

Late Paleocene

Pulvinulina velascoensis CUSHMAN, 1925c, p. 19, pl. 3, fig. 5.

Globorotalia velascoensis (CUSHMAN). BOLLI, 1957a, p. 76, pl. 20, fig. 1-3.–LOEBLICH & TAPPAN, 1957a, p. 196, pl. 64, fig. 1-2.–LUTERBACHER, 1964, p. 681-686, fig. 92-94, 98-99.–POSTUMA, 1971, p. 218-219.

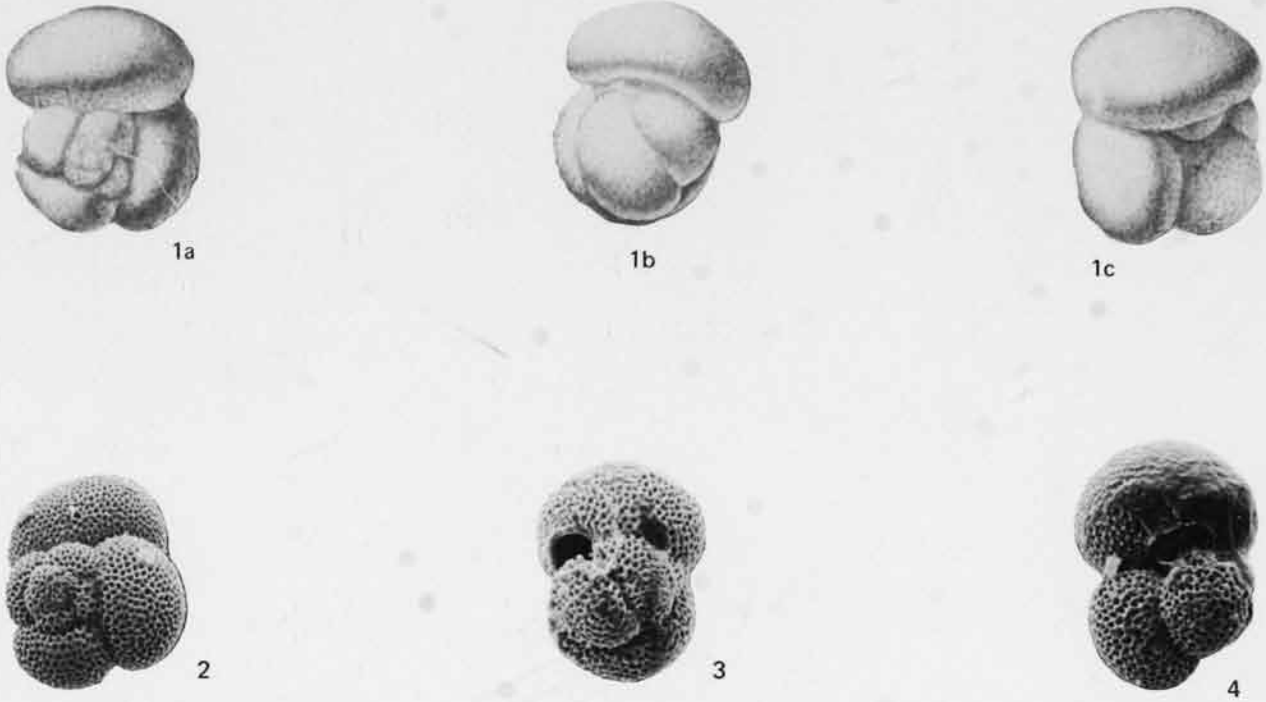


Fig. 96. *Globigerina velascoensis* CUSHMAN from the Late Paleocene of Trinidad and Egypt.

1 Specimen from the *Globorotalia pseudomenardii* Zone in the Lizard Springs Formation of Trinidad, X100; from BOLLI (1957a, pl. 15, fig. 9-11). **a**–Spiral view; **b**–side view; **c**–umbilical view.

2-4 Specimens from the Western Desert of Egypt, X100. **2**–Spiral view; **3**–side view; **4**–umbilical view.

Test trochospiral; spiral side varying from slightly convex to slightly concave, umbilical side strongly convex, bluntly conical, with very prominent chamber tips. Last whorl with 5 to 8 angular-conical chambers which increase regularly in size, though last may be abnormally small. Axial periphery acute with well-developed pustulose keel, equatorial outline almost circular, only faintly lobate. Spiral suture prominent, raised and beaded. Intercameral sutures on umbilical side depressed, radial; on spiral side curved, raised and beaded except between younger chambers where may be flush. Umbilicus wide and open. Umbilical chamber tips well individualized, sharp, with bunches of blunt spines which on earlier chambers may fuse into thick cushions. Surface of test rather coarsely perforate, rugose, ornamented by blunt spines on sutures of spiral side, peripheral margin, and umbilical chamber tips. Diameter to 0.5 mm.

Discussion.–Typical *Globorotalia velascoensis* differs from *Globorotalia acuta* by having more chambers in the last whorl and more heavily ornamented umbilical shoulders, but the two species are linked by intermediate forms. The geographic distribution of *G. acuta* seems to be wider. It may be virtually impossible to distinguish single specimens of the Paleocene *G. velascoensis* from its Eocene homeomorph *Globorotalia caucasica*. The two species can be distinguished readily, however, by attention to the associated planktonic foraminifers, especially the transitional forms between *G. caucasica* and *Globorotalia aragonensis* which always occur in the same interval as *G. caucasica*. *Globorotalia velascoensis* was chosen by MCGOWRAN (1968, p. 190) as a type species of the subgenus *Morozovella* (see also LUTERBACHER, 1964, p. 641; JENKINS, 1971, p. 99-107).

Distribution.–Late Paleocene (*Globorotalia pseudomenardii* and *Globorotalia velascoensis* Zones). *Globorotalia velascoensis* originally was described from the Paleocene Velasco Formation of eastern Mexico and it has subsequently received worldwide application as a conspicuous, short-lived zonal index.

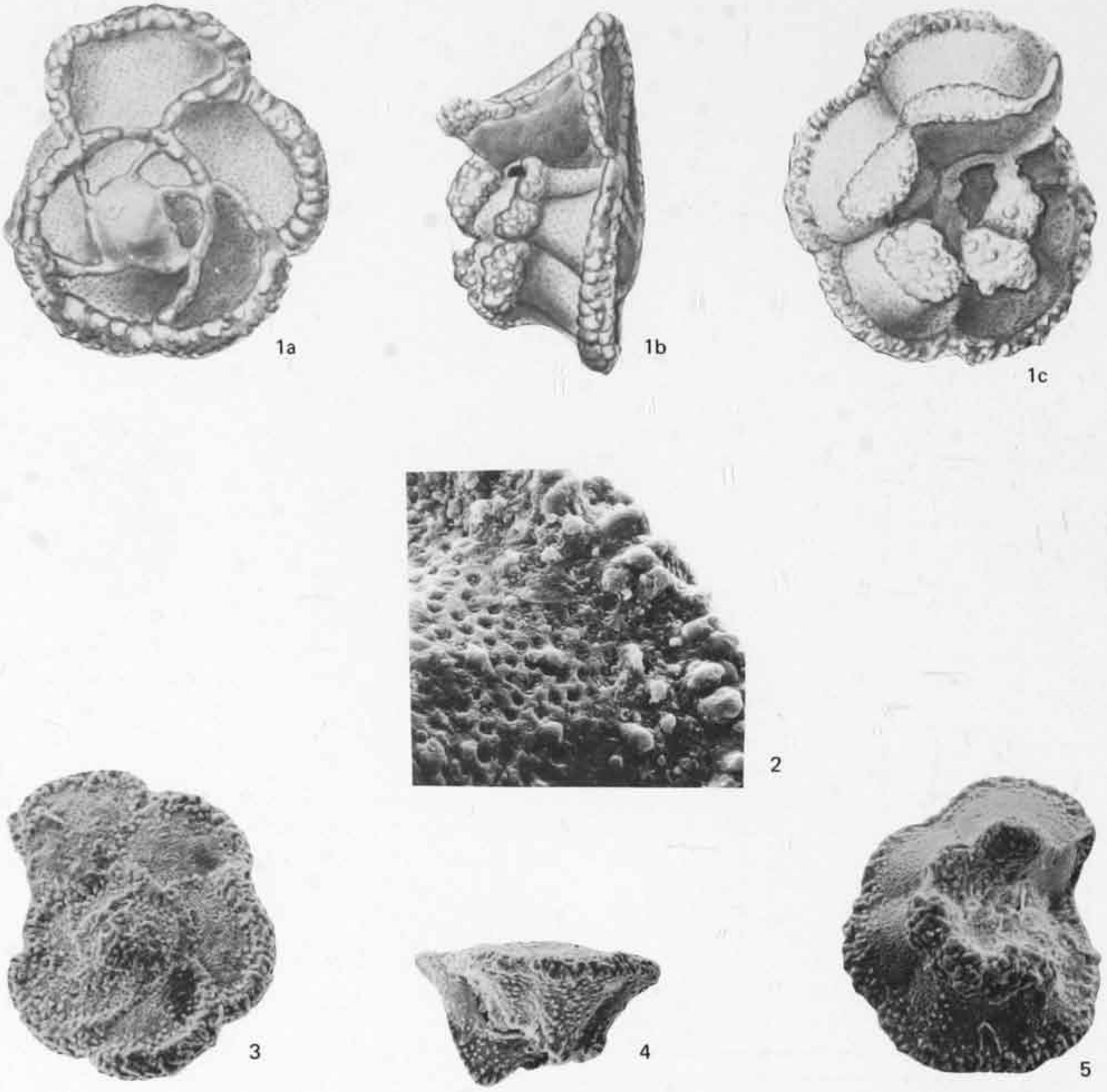


Fig. 97. *Globorotalia velascoensis* (CUSHMAN) from the Late Paleocene part (*Globorotalia pseudomenardii* Zone) of the Velasco Formation of Mexico (**1** from LOEBLICH & TAPPAN, 1957a, pl. 64, fig. 2).

1-5 Representative specimens. **1a**,**3**–Spiral views, X110, X100; **1b**,**4**–side views, X110, X100; **1c**,**5**–umbilical views, X110, X100; **2**–surface of chamber and keel, X500.

Fig. 98. *Globorotalia wilcoxensis* CUSHMAN & PONTON from the Early Eocene of Trinidad and California.

1 Specimen from the *Globorotalia subbotinae* Zone in the Lizard Springs Formation of Trinidad, X100; from BOLLI (1957a, pl. 19, fig. 7-9). **a**–Spiral view; **b**–side view; **c**–umbilical view.

2-5 Specimens from the *Globorotalia formosa formosa* Zone in the Lodo Formation of California. **2**–Spiral view, X100; **3**–periphery in early part of last whorl, X500; **4**–side view, X100; **5**–umbilical view, X100.

GLOBOROTALIA WILCOXENSIS
Cushman & Ponton, 1932
Figure 98
Late Paleocene to Early Eocene

Globorotalia wilcoxensis CUSHMAN & PONTON, 1932b, p. 71, pl. 9, fig. 10.–BOLLI, 1957a, p. 79, pl. 19, fig. 7-9.

Test trochospiral; spiral side flat or even slightly concave, umbilical side strongly convex. Last whorl with generally 4 chambers which increase rapidly in size. Chambers subangular-conical, longer than broad on spiral side, somewhat imbricated. Axial periphery rounded to subacute, equatorial outline strongly lobate. Sutures depressed; radial on umbilical side, oblique on spiral side. Umbilicus narrow and deep. Aperture a low arch, extraumbilical-umbilical, without or with only a faint lip. Wall rather coarsely perforate, spinose. Diameter 0.35 to 0.45 mm.

Discussion.–*Globorotalia quetra* differs from *Globorotalia wilcoxensis* by the more angular shape of its test. *Globorotalia aequa* is more tightly coiled and has a more acute margin.

Distribution.–Late Paleocene and earliest Eocene (*Globorotalia velascoensis* Zone to *Globorotalia formosa formosa* Zone). *Globorotalia wilcoxensis* was first described from the Wilcox Formation of southeastern Alabama.

PSEUDOHASTIGERINA WILCOXENSIS
(Cushman & Ponton, 1932)
Figure 99
Late Paleocene to Middle Eocene

Nonion wilcoxensis CUSHMAN & PONTON, 1932b, p. 64, pl. 8, fig. 11.
Hastigerina eocenica BERGGREN, 1960a, p. 85-91, pl. 5, fig. 1-2; pl. 10, fig. 2.
Pseudohastigerina wilcoxensis (CUSHMAN & PONTON). BERGGREN, OLSSON, & REYMENT, 1967, p. 278-280, fig. 2-6.

Test of small size, planispiral or nearly so, evolute. Last whorl with 5 to 7 moderately inflated chambers which increase fairly regularly in size. Periphery rounded, moderately lobate. Ratio of diameter to thickness (hence degree of apparent lateral compression) variable. Biumbilicate, parts of earlier whorls visible from both sides except in asymmetrical specimens. Sutures depressed, radial to slightly curved. Aperture a low median arch at base of apertural face of last chamber, with a faint lip, very rarely bipartite. Wall finely perforate, smooth. Diameter 0.2 to 0.3 mm.

Discussion.–*Pseudohastigerina micra* differs from *Pseudohastigerina wilcoxensis* in being generally smaller and less inflated, but the two species are linked by intermediate forms. Generic assignment to

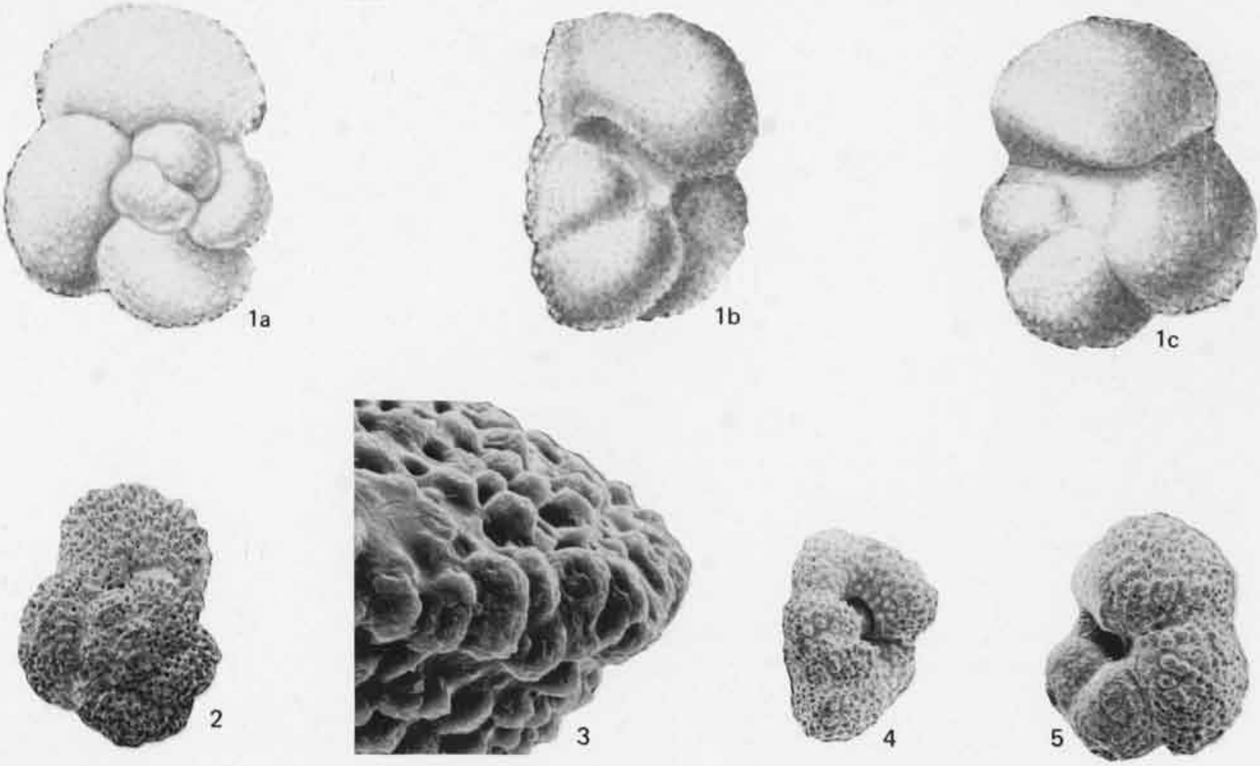


Fig. 98

Pseudohastigerina is retained following BERGGREN, OLSSON, & REYMENT who refuted the proposed substitution of *Globanomalina* by LOEBLICH & TAPPAN (1964, p. C665).

Distribution.–Late Paleocene into Middle Eocene (approximately *Globorotalia pseudomenardii* Zone to *Globorotalia lehneri* Zone; not sharply defined owing to gradual evolution of this form from *Globorotalia chapmani* into *Pseudohastigerina micra*). The species was first described from the Wilcox Formation of southeastern Alabama.

According to BERGGREN (1960a, 1971b) the first occurrence of planispiral plankton (i.e., *Pseudohastigerina wilcoxensis*) is within the *Globorotalia subbotinae* Zone, and this level ("*Pseudohastigerina* datum") defines the base of the Eocene. In the eastern Mediterranean, however, specimens indistinguishable from *Pseudohastigerina wilcoxensis* have been observed well down in the Paleocene within the *Globorotalia pseudomenardii* Zone.

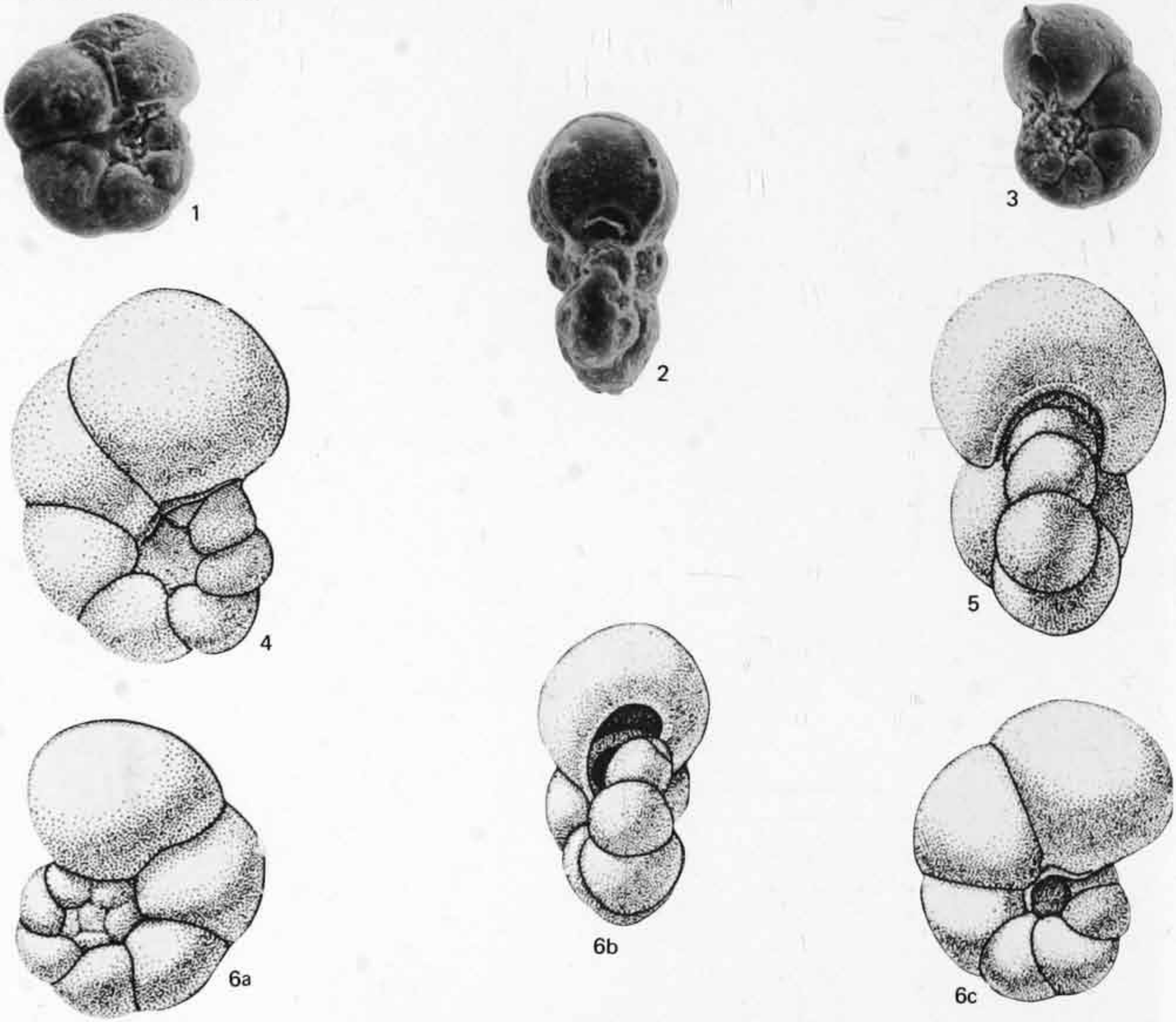


Fig. 99. *Pseudohastigerina wilcoxensis* (CUSHMAN & PONTON) from the Early Eocene of California and Alabama.

1-3 Specimens from the *Globorotalia subbotinae* Zone in the Lodo Formation of California. **1,3**–lateral views, X150; **2**–apertural face, X200.

4-6 Specimens (**6**=transitional to *Globorotalia chapmani*) from the Bashi Formation of Alabama, X150 ca.; from BERGGREN, OLSSON, & REYMENT (1967, fig. p-r, u-v). **4,6c**–Lateral views showing umbilical depression; **5,6b**–peripheral views showing aperture; **6a**–lateral view showing early coil.

ILLUSTRATED REVIEW OF LATE EOCENE TO MIDDLE MIOCENE INDEX SPECIES

Planktonic foraminiferal species regarded as useful markers for the Late Eocene, Oligocene, and Early and Middle Miocene are discussed and illustrated (Fig. 100-151) in alphabetical order by species name. These data were collated mainly by R.M. STAINFORTH.

Ranges for these species are recorded in the preceding text and on Figure 16 together with a discussion of the zonation for the interval.

GLOBOQUADRINA ALTISPIRA ALTISPIRA
(Cushman & Jarvis, 1936)
Figure 100
Early Miocene to Late Pliocene

Globigerina altispira CUSHMAN & JARVIS, 1936, p. 5, pl. 1, fig. 13-14.–CORYELL & RIVERO, 1940, p. 339, pl. 42, fig. 31.

Globoquadrina altispira (CUSHMAN & JARVIS). FINLAY, 1947, p. 290.–GRIMSDALE, 1951, p. 466.–BERMÚDEZ, 1960, p. 1307-1308, pl. 12, fig. 7.–LAMB & BEARD, 1972, p. 49, pl. 9, fig. 1-5.

Globoquadrina altispira altispira (CUSHMAN & JARVIS). BOLLI, 1957b, p. 111, pl. 24, fig. 7-8.–BLOW, 1959, p. 183, pl. 8, fig. 51.–BLOW, 1969, p. 339.

Test a large, lofty trochospire, height and diameter subequal. Commonly 4, but may be as many as 6, chambers in final whorl. Chambers compactly arranged, initially globose and rapidly enlarging, later appressed; prolonged toward umbilicus and maintaining subequal size. Spiral profile subcircular, slightly indented at sutures; side profile ovate to subtriangular. Sutures distinct, depressed. Aperture umbilical, concealed by a triangular flap (tooth) of imperforate shell material. Umbilicus gaping and deep, with apertural teeth of earlier chambers visible within. Shell finely cancellate. Diameter and height typically 0.45 to 0.75 mm.

Discussion.–*Globoquadrina altispira altispira* evolved from the subspecies *globosa* by developing more appressed, axially prolonged chambers and a loftier spire. A Late Miocene form with an even loftier, somewhat tiered spire has been separated by BRÖNNIMANN & RESIG (1971) as *Globoquadrina altispira conica*.

Distribution.–*Globoquadrina altispira altispira* first appeared in the Early Miocene (approximately *Catapsydrax stainforthi* Zone) and persisted through the Neogene. It has a worldwide distribution but was commoner in warmer than in cooler regions. It was first recorded in Jamaica in beds currently regarded as Pliocene (ROBINSON, 1969).

GLOBOQUADRINA ALTISPIRA GLOBOSA Bolli, 1957
Figure 101
Latest Oligocene to Pliocene

Globoquadrina altispira globosa BOLLI, 1957b, p. 111, pl. 24, fig. 9-10.–BLOW, 1959, p. 183, pl. 11, fig. 52.–CITA, PREMOLI SILVA, & ROSSI, 1965, p. 255, pl. 26, fig. 6.–BLOW, 1969, p. 339.

Globoquadrina pozonensis BLOW, 1959, p. 184, pl. 10, fig. 54-56 (fide BLOW, 1969, p. 339).

Globoquadrina altispira (CUSHMAN & JARVIS) var. *globosa* BOLLI. BERMÚDEZ, 1960, p. 1308, pl. 12, fig. 8-9.

Globoquadrina altispira (CUSHMAN & JARVIS) (part). PARKER, 1967, p. 165.

Test a large somewhat elevated trochospire of globular chambers which increase in size regularly and rather slowly. Usually 5 chambers in final whorl; holotype has 6. Spiral profile lobulate, side aspect pyramidal. Sutures distinct, depressed. Aperture intraumbilical, concealed by a triangular flap of shell material; these projections usually visible on earlier chambers within wide and deep umbilicus. Shell surface finely cancellate, may be slightly spinose in well-preserved specimens. Diameter to 0.8 mm.

Discussion.–The subspecies *Globoquadrina altispira globosa* is consistent in the features mentioned but is variable in the laxity and vertical angle of its spire. The earlier subspecies *globularis* differs in its more globose test and in having only 4 chambers in the last whorl (BERMÚDEZ, 1960, p. 1311, pl. 13, fig. 4-6; BLOW, 1969, p. 339-340). The almost coeval subspecies *altispira* s.s. differs in its more elevated spire and appressed, axially prolonged chambers. Small, juvenile specimens of the three subspecies lack the distinctive features of large

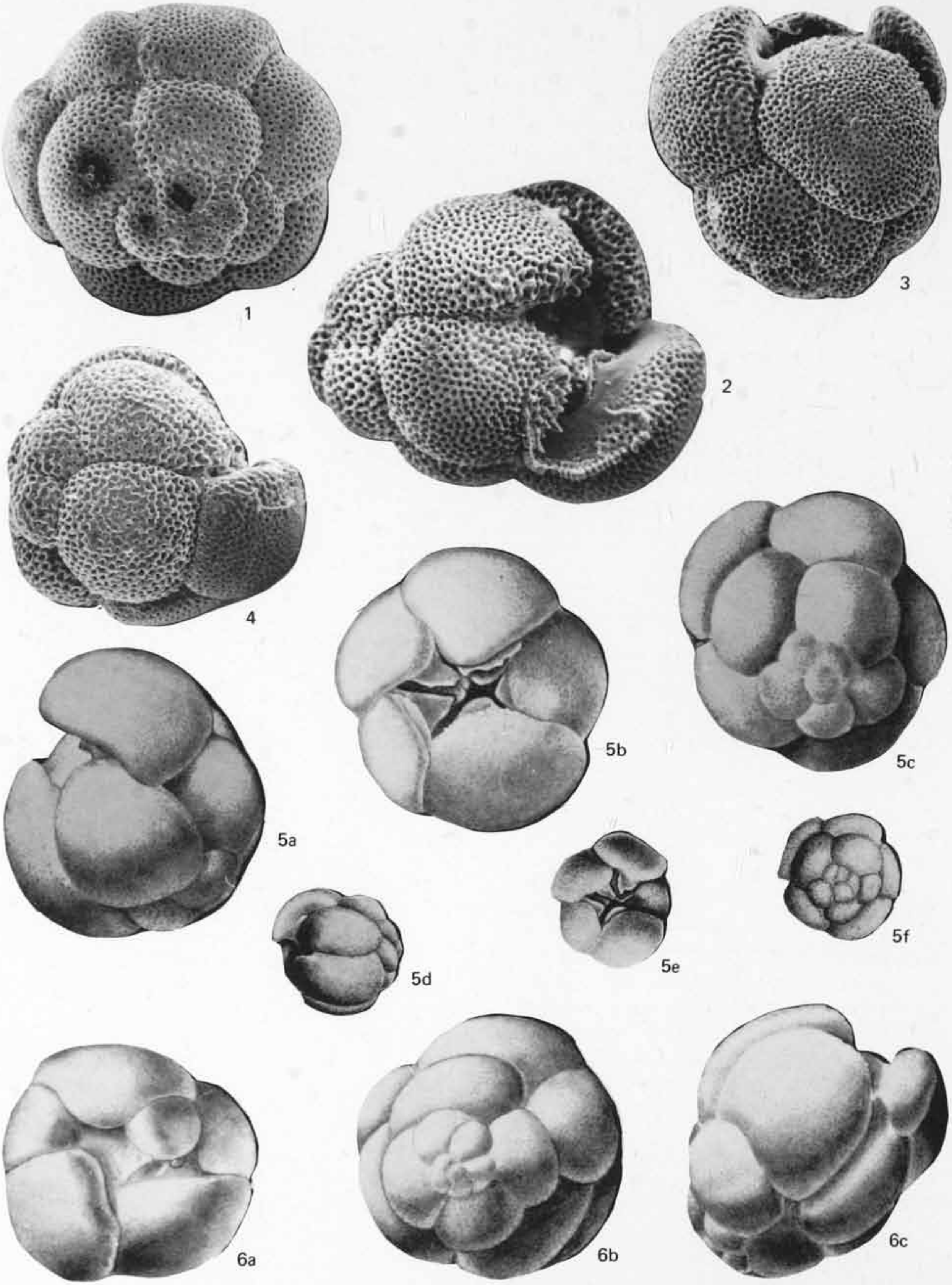


Fig. 100

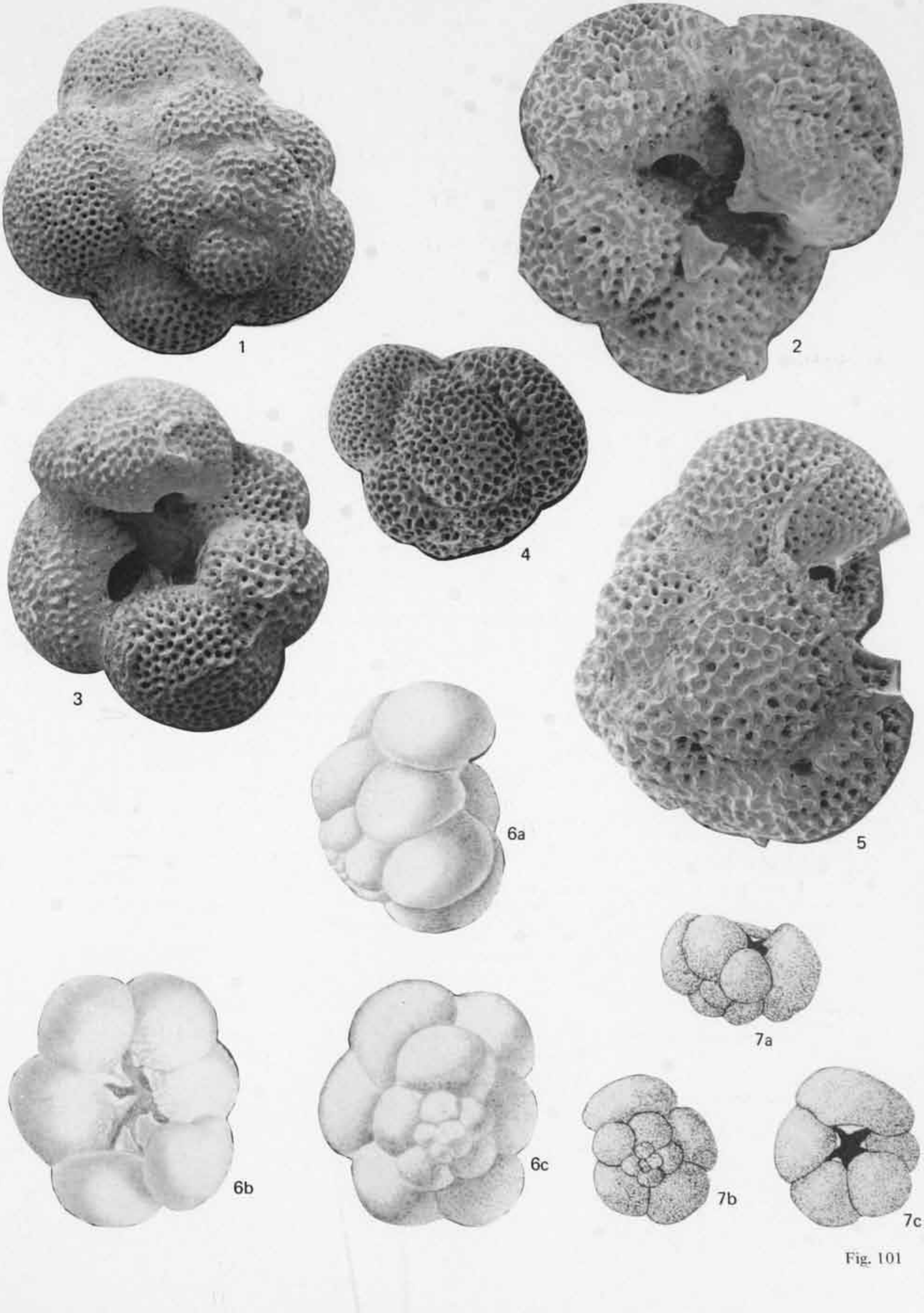


Fig. 101

Fig. 100. *Globoquadrina altispira altispira* (CUSHMAN & JARVIS) from the Pliocene of the Gulf of Mexico and Jamaica and the Middle Miocene of the Gulf of Mexico and Trinidad. [p. 246]

1-4 Specimens from the Pliocene (**1,3-4**; X90) and Middle Miocene (**2**; X105) of the Gulf of Mexico; from LAMB & BEARD (1972, pl. 9, fig. 2-5). **1**–Spiral view; **2-4**–side views.

5 Holotype from the Pliocene of Jamaica; **a-c** from BOLLI, LOEBLICH, & TAPPAN (1957, pl. 5, fig. 4), **d-f** from CUSHMAN & JARVIS (1936, pl. 1, fig. 13). **a,d**–Side views, X70, X32; **b,e**–umbilical views, X70, X32; **c,f**–spiral views, X70, X32.

6 Specimen from the Middle Miocene part of the Cipero Formation of Trinidad, X68; from BOLLI (1957b, pl. 24, fig. 7). **a**–Umbilical view; **b**–spiral view; **c**–side view.

Fig. 101. *Globoquadrina altispira globosa* BOLLI from the Miocene of Trinidad and Venezuela. [p. 247]

1-6 Specimens (**6**= holotype from BOLLI, 1957b, pl. 24, fig. 9) from the Early Miocene part (*Catapsydrax dissimilis* Zone) of the Cipero Formation of Trinidad. **1,6c**–Spiral views, X115, X68; **2,3,6b**–umbilical views, X160, X115, X68; **4,5,6a**–side views, X115, X160, X68.

7 Specimen from the late Middle Miocene part of the Pozón Formation of Venezuela, X75; from BLOW (1959, pl. 11, fig. 52). **a**–Side view; **b**–spiral view; **c**–umbilical view.

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adults. The *Globoquadrina altispira* lineage appears to have evolved from loosely coiled forms within the *Globigerina linaperta* plexus by enlargement of the umbilicus.

Distribution.–Earliest occurrence of *Globoquadrina altispira globosa* is a good guide to proximity of the base of the Miocene, from which level it persists through the Neogene. It has a wide geographic spread. The types of this subspecies were collected in the Lower Miocene *Catapsydrax dissimilis* Zone in the Cipero Formation of Trinidad.

GLOBIGERINA AMPLIAPERTURA Bolli, 1957

Figure 102

Late Eocene to early Oligocene

Globigerina apertura CUSHMAN. BRÖNNIMANN, 1950a, p. 80.

Globigerina ampliapertura BOLLI, 1957b, p. 108, pl. 22, fig. 4-7.–BERMÚDEZ, 1960, p. 1155, pl. 3, fig. 8.–HOFKER, 1968, p. 17, pl. 7, fig. 2.–BLOW, 1969, p. 315, 349, 382, pl. 12, fig. 6, 9-10.

Globigerina ampliapertura ampliapertura BOLLI. BLOW & BANNER, 1962, p. 83, 130-133, pl. 11, fig. A-D; pl. 17, fig. C, H.–CARALP, VALETON, & VIGNEAUX, 1965, p. 3431-3434.

Globigerina (Globigerina) ampliapertura BOLLI. JENKINS, 1971, p. 137, pl. 15, fig. 423-425.

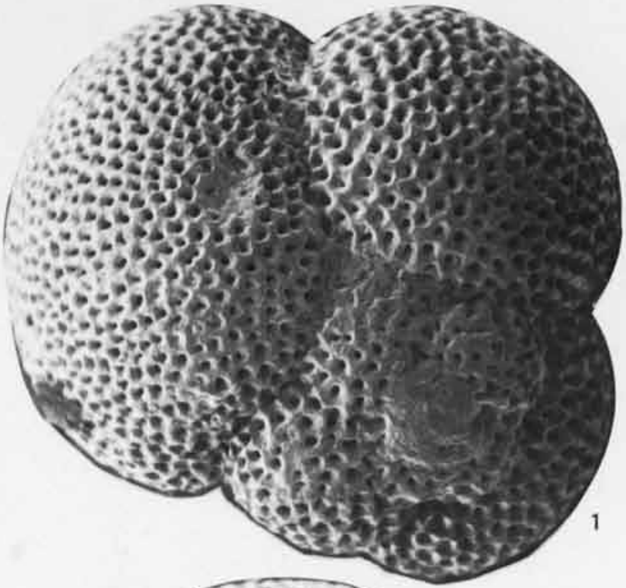
Test a regular trochospire of inflated chambers which maintain their shape while increasing rapidly in size. Consistently 4 chambers in last whorl. Spiral outline subquadrate to subcircular; overall shape globose, spiral side flattened. Sutures distinct, depressed to incised; on umbilical side radial, on spiral side tangential to spire and giving it a rectangular aspect. Aperture a smooth-rimmed arch aligned obliquely across umbilical region, usually conspicuous though somewhat concealed by projecting anterior margin of last chamber, embracing three penultimate chambers. Essentially nonumbilicate, as chambers reach axis of coiling on umbilical side. Surface finely cancellate to granulose. Diameter to 0.6 mm.

Discussion.–*Globigerina ampliapertura* is consistent in its gross morphology and the only variability noted in topotype material is in the height and shape of the aperture. It closely resembles and intergrades with *Globorotalia increbescens*, which differs in its forward-pointing aperture and generally more compressed test. Early forms of *Globorotalia cerroazulensis (=Globorotalia centralis* of authors) are also grossly similar but differ from *G. ampliapertura* in shell texture and other details. Our study of Gulf Coast material supports the concept that *G. ampliapertura* evolved gradually from *G. increbescens*

Fig. 102. *Globigerina ampliapertura* BOLLI from the Oligocene of Trinidad and Tanzania.

1-5 Specimens (**5**=holotype from BOLLI, 1957b, pl. 22, fig. 6) from the *Globigerina ampliapertura* Zone in the Cipero Formation of Trinidad. **1,5c**–Spiral views, X200, X68; **2,4,5b**–two oblique and one normal umbilical views, X200, X200, X68; **3,5a**–side views, X200, X68.

6-7 Specimens from Tanzania, X100; from BLOW & BANNER (1962, pl. 11, fig. A-D). **6,7c**–Oblique and normal umbilical views; **7a**–side view; **7b**–spiral view.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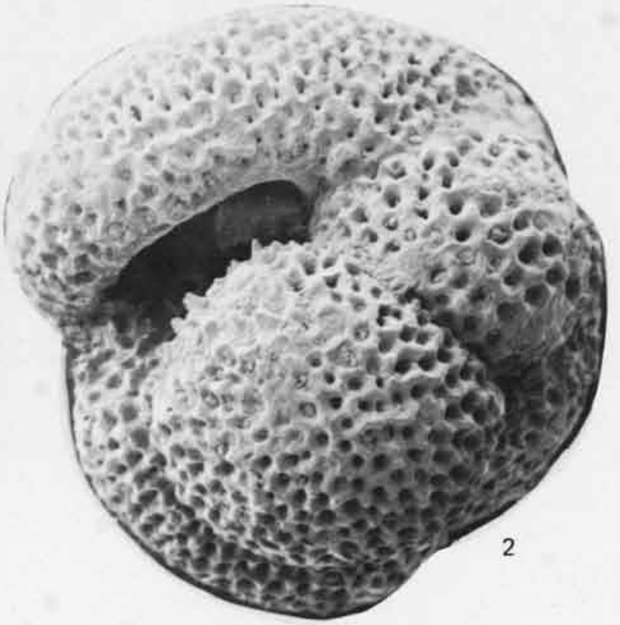
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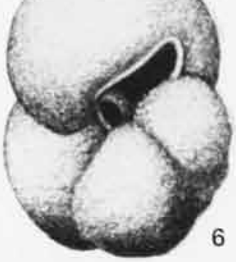
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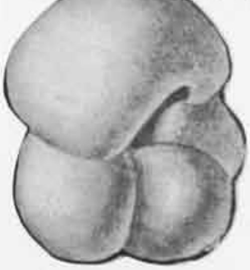
7a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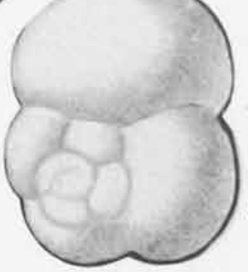
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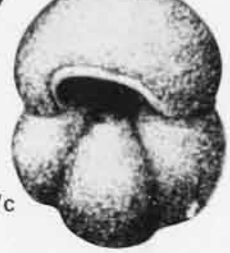
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Fig. 102

by swivelling of the gaping aperture so as to embrace the umbilical area (see BLOW & BANNER, 1962, fig. 12-b). On other aspects of proposed Eocene-Oligocene *Globorotalia-Globigerina* lineages we prefer to reserve judgment until leading authors have reached agreement. *Globigerina ampliapertura euapertura* of BLOW & BANNER (1962) (not *Globigerina euapertura* JENKINS, 1960) was renamed *Globigerina prasaepis* by BLOW (1969) but we consider this to be simply a low-apertured variant. It has virtually the same recorded range as *G. ampliapertura*, as does also the form separated as *Globigerina pseudoampliapertura* by BLOW & BANNER (1962) and BLOW (1969), whether or not it is truly distinct from *G. ampliapertura*. PESSAGNO (1963) introduced the subspecies *Globigerina ampliapertura cancellata*, but BLOW (1969, p. 340) and JENKINS (1971, p. 189) asserted that it is unrelated to *G. ampliapertura* BOLLI.

Distribution.–*Globigerina ampliapertura* is a valuable index fossil, being distinctive, widely distributed, usually plentiful where present, and limited in range to the Late Eocene and early Oligocene (high in *Globorotalia cerroazulensis* Zone to top of *Globigerina ampliapertura* Zone).

GLOBIGERINA ANGIPOROIDES Hornibrook, 1965

Figure 103

Late Eocene to Oligocene

Globigerina angipora STACHE. HORNIBROOK, 1961, p. 145, fig. 3.

Globigerina linaperta linaperta FINLAY. BLOW & BANNER, 1962, p. 85, pl. 11, fig. H [fide BLOW, 1969, p. 315].

Globigerina angiporoides HORNIBROOK, 1965, p. 834-838, fig. 1-2.–BLOW, 1969, p. 315, pl. 12, fig. 3-5, 7.–BRÖNNIMANN & RESIG, 1971, p. 1291, pl. 8, fig. 4-5.

Globigerina (Subbotina) angiporoides angiporoides HORNIBROOK. JENKINS, 1971, p. 160-162, pl. 20, fig. 588-594 [original types refigured, fig. 588-590].

Test a rather small, compact trochospire. Inner whorls obscure, outer whorl with usually 3½ hemispherical chambers. Chambers increase in size regularly and rapidly but last is commonly disproportionately small or large (embracive). Spiral profile slightly lobate, side profile ovate. Sutures of outer whorl distinct, slightly depressed. Umbilicus usually concealed by apertural portions of adult chambers. Aperture a low arch or slit with a thick lip, umbilical to slightly extraumbilical, aligned diametrically in umbilical aspect. Surface of test distinctly to coarsely cancellate. Diameter 0.25 to 0.35 mm.

Discussion.–The name *Globigerina angiporoides* was introduced for forms previously identified as *Globigerina angipora* STACHE, which is a nomen dubium. It is very variable in size, compactness of coiling, and details of its aperture on which a small bulla is occasionally developed. This species is similar to and may have developed from *Globigerina linaperta* but its chambers are more embracive and its profile less lobate. JENKINS (1965b, 1971) distinguished a smaller, smoother ancestral form as the subspecies *Globigerina angiporoides minima*.

Distribution.–Late Eocene and early Oligocene (*Globigerinatheka semiinvoluta* Zone to within *Globigerina ampliapertura* Zone). Peak development was in the latest Eocene and earliest Oligocene, including the *Globigerina angiporoides* Zone of some authors. It seems to be more typical of subtropical and temperate latitudes than the tropics. This species was first described from the lower Oligocene of southern New Zealand.

GLOBIGERINA ANGULISUTURALIS Bolli, 1957

Figure 104

Late Oligocene to earliest Miocene

Globigerina ciperoensis angulisuturalis BOLLI, 1957b, p. 109, pl. 22, fig. 11.–BERMÚDEZ, 1960, p. 1165.

Globigerina angulisuturalis BOLLI. BLOW & BANNER, 1962, p. 84, pl. 9, fig. Aa-Cc.–BLOW, 1969, p. 219, 316, 379, pl. 1, fig. 4-6; pl. 12, fig. 1-2.

Globigerina concinna angulisuturalis BOLLI. BANDY, 1964b, p. 8, 12.

Globigerina (Globigerina) ciperoensis angulisuturalis BOLLI. JENKINS, 1971, p. 143, pl. 15, fig. 448-450.

Test a small low trochospire of subglobular chambers increasing regularly and generally slowly in size. Consistently 5 chambers in final whorl. Spiral outline a pentagonal rosette. Sutures occupy conspicuous U-shaped depressions in periphery. Aperture a simple arch facing into open umbilicus. Shell surface smooth, finely pitted. Topotype material contains numerous specimens with an accelerated increase in chamber size, otherwise as above. Diameter 0.15 to 0.20 mm.

Discussion.–*Globigerina angulisuturalis* closely resembles *Globigerina ciperoensis* in all respects except the conspicuous U-shaped depressions between adult chambers. Originally the two forms were regarded as subspecies (BOLLI, 1957b) or at least directly related species (BLOW & BANNER,

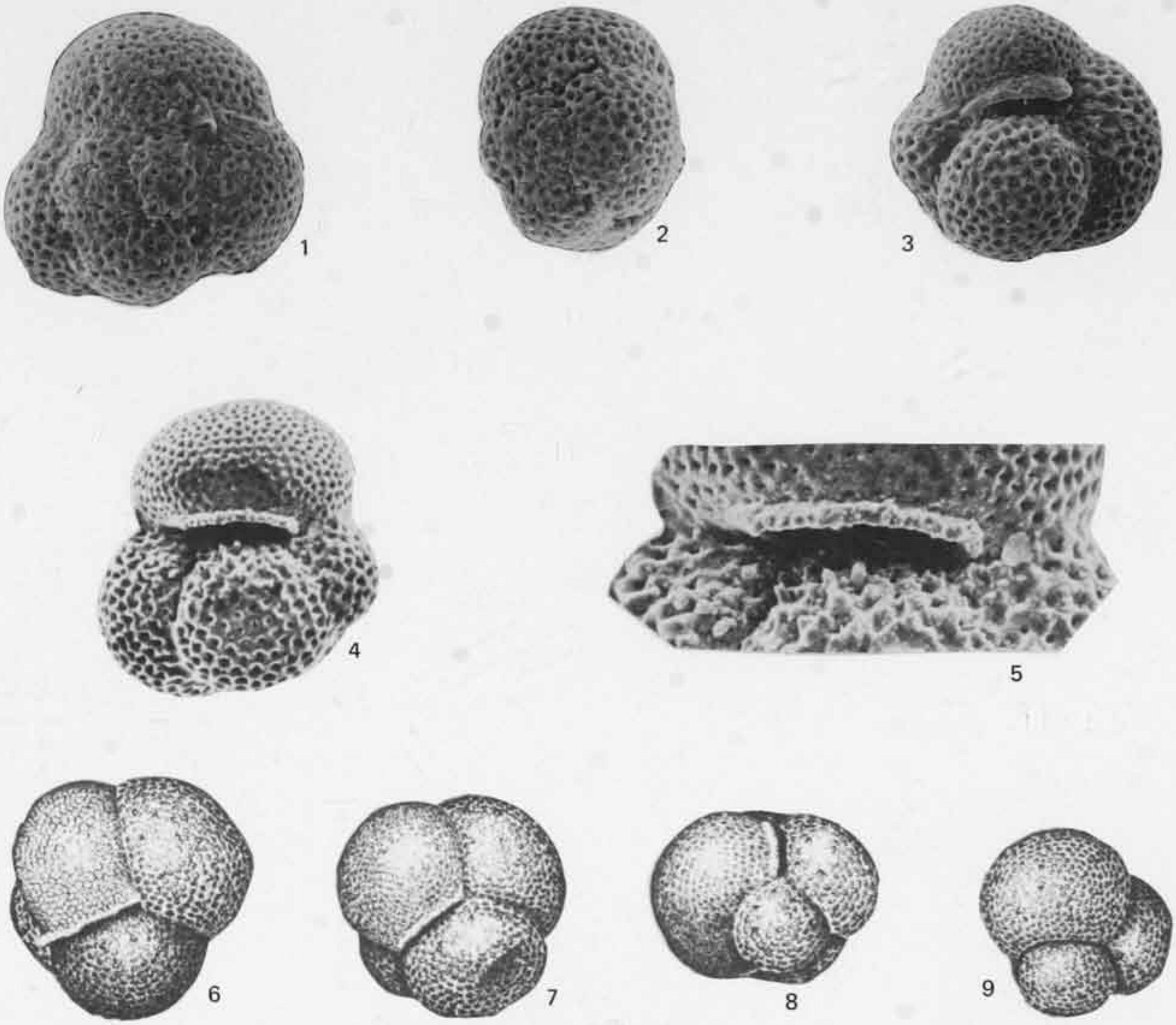


Fig. 103. *Globigerina angiporoides* HORNIBROOK from the Middle Eocene of the Gulf of Mexico and the Oligocene of Tanzania and New Zealand.

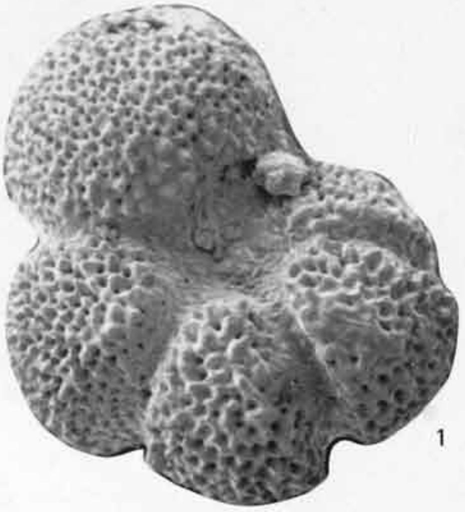
1-3 Specimens from the Middle Eocene of northeastern Gulf of Mexico, X200. **1**–Spiral view; **2**–side view; **3**–umbilical view.

4-5 Specimens from the Oligocene of Tanzania; from BLOW (1969, pl. 12, fig. 4-5). **4**–Umbilical view, X120; **5**–aperture, X235.

6-9 Specimens (**7**=holotype) from the Oligocene of New Zealand, X100; from HORNIBROOK (1961, fig. 3). **6-7,9**–Umbilical views; **8**–side view.

1962). Later, however, BLOW (1969) asserted that *G. angulisuturalis* evolved from *Globigerina officinalis* and he introduced a new species, *G. anguliofficinalis*, which is morphologically transitional between these two.

Distribution.–The distinctive form and short range of *G. angulisuturalis* make it a useful marker restricted to the later Oligocene and earliest Miocene (*Globorotalia opima opima* Zone to within *Globorotalia kugleri* Zone). It occurs in such extratropical areas as Sicily as well as in the tropics. The somewhat similar ancestral species *Globigerina anguliofficinalis* first appeared in the Late Eocene. First described from the Oligocene *Globorotalia opima opima* Zone in the Cipero Formation of Trinidad.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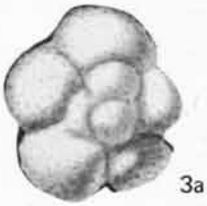
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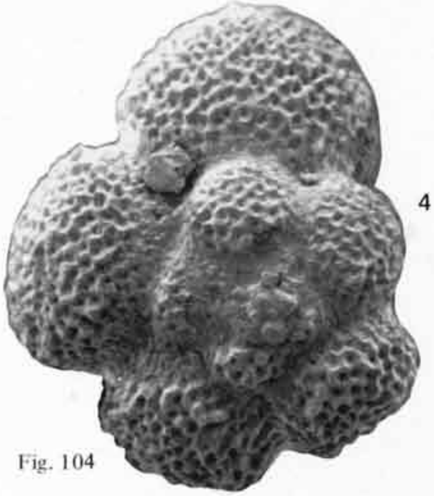
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6

Fig. 104

Fig. 104. *Globigerina angulisuturalis* BOLLI from the Oligocene part (*Globorotalia opima opima* Zone) of the Cipero Formation of Trinidad.

1-6 Specimens (**3**=holotype from BOLLI, 1957b, pl. 22, fig. 11) with **1** and **6** representing forms having an accelerated growth rate. **1-2,3c**–Umbilical views, X250, X250, X150; **3a,4-6**–spiral views, X150, X250, X250, X250; **3b**–side view, X150.

GLOBIGERINA ANGUSTIUMBILICATA Bolli, 1957

Figure 105

Late Eocene to Pleistocene or Holocene

Globigerina ciperoensis angustiumbilicata BOLLI, 1957b, p. 109, pl. 22, fig. 12-13.–BOLLI, 1957c, p. 164, pl. 36, fig. 6.–BERMÚDEZ, 1960, p. 1166.

Globigerina angustiumbilicata BOLLI. BLOW, 1959, p. 172, pl. 7, fig. 33-34.–BLOW & BANNER, 1962, p. 85, pl. 9, fig. X-Z.

Globigerina (Globigerina) ciperoensis angustiumbilicata BOLLI. JENKINS, 1971, p. 144, pl. 15, fig. 451-453.

Test a small low spire of subglobular chambers which increase slowly in size as added. Uniformly 5 chambers in final whorl. Sutures distinct. Umbilicus very small or closed. Aperture generally not visible, a simple opening into umbilicus. Surface finely rugose. Diameter to 0.3 mm.

Discussion.–*Globigerina angustiumbilicata* is grossly similar to *Globigerina ciperoensis* but differs in having more appressed chambers and a small to closed umbilicus. BOLLI (1957b) gave reasons for regarding the two forms as subspecific variants, but we find it expedient to follow BLOW (1959) and BLOW & BANNER (1962) in treating *G. angustiumbilicata* as a recognizable species.

Distribution.–This species has a long range from Late Eocene to Pleistocene or Holocene and care must be taken not to misidentify it as the shorter-ranging zonal index, *Globigerina ciperoensis.*

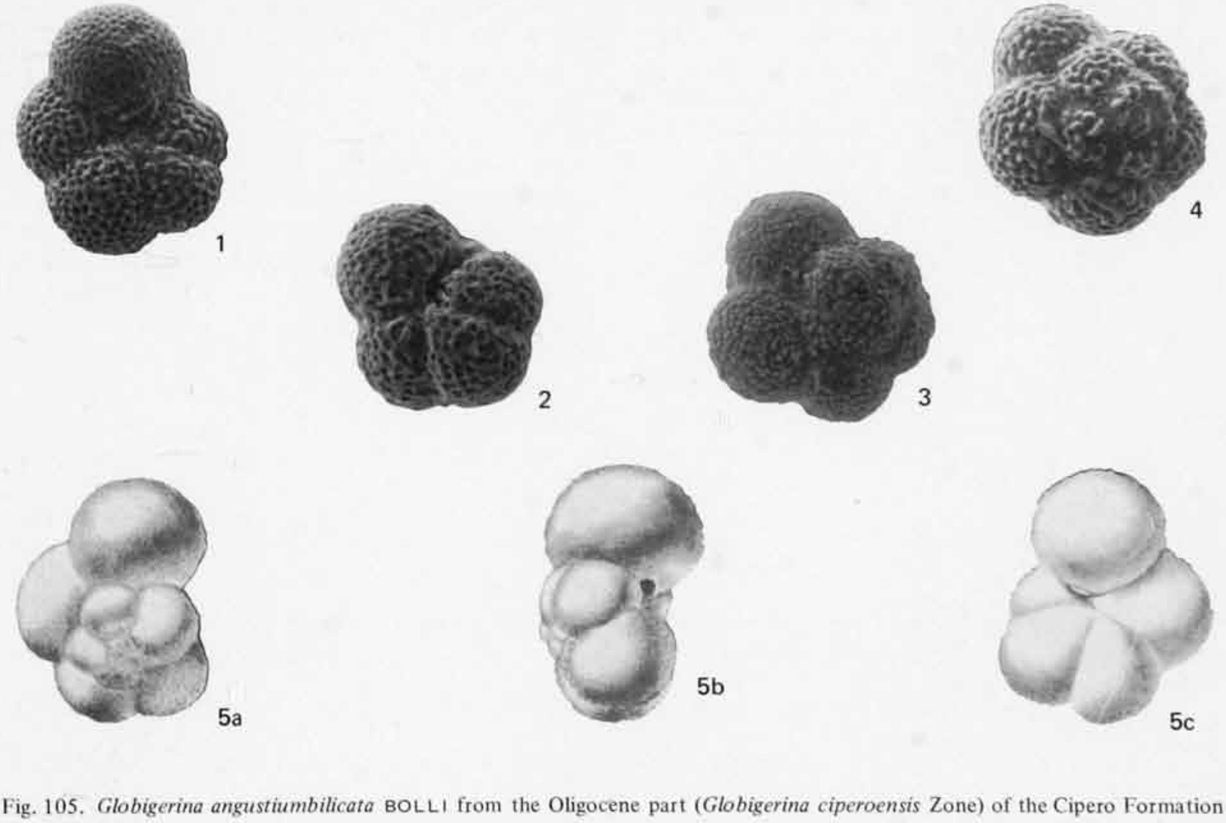

Fig. 105. *Globigerina angustiumbilicata* BOLLI from the Oligocene part (*Globigerina ciperoensis* Zone) of the Cipero Formation of Trinidad.

1-4 Representative specimens, X150. **1**–Umbilical view; **2**–oblique umbilical view; **3-4**–spiral views.

5 Holotype, X150; from BOLLI (1957b, pl. 22, fig. 13). **a**–Spiral view; **b**–side view; **c**–umbilical view.

GLOBIGERINA BINAIENSIS Koch, 1935

Figure 106

Late Oligocene to ?Early Miocene

Globigerina? aspera KOCH, 1926, p. 737, 746, fig. 22-23 [not *G. aspera* of EHRENBERG].
Globigerina binaiensis KOCH, 1935, p. 558.–BLOW, 1969, p. 216, 222, 316, pl. 13, fig. 1-2.–POSTUMA, 1971, p. 262-263.

Test a trochospire of closely appressed chambers which increase rapidly in both size and axial prolongation so that final whorl contains only 3 chambers. Spiral profile characterized by acute angle between periphery and apertural face of final chamber; side view dominated by flat, roughly semicircular apertural face occupying more than half of visible area. Adult sutures distinct, incised. Aperture a low arch embracing 2 penultimate chambers. Surface mostly finely cancellate but rim of last chamber carries band of coarse pores. Usual diameter 0.4 to 0.5 mm.

Discussion.–The remarkably flattened apertural face, a unique feature among globigerinids, distinguishes *Globigerina binaiensis* from its forerunner *Globigerina sellii*, which is similar in all other respects. BERMÚDEZ (1960, p. 1309) obviously is mistaken in suggesting synonymy with *Globoquadrina dehiscens.*

Distribution.–This distinctive species is a useful zonal marker but appears to be confined to the tropical portion of the Indo-Pacific province. It is found mainly in late Oligocene beds (*Globigerina ciperoensis ciperoensis* Zone).

GLOBOROTALIA CERROAZULENSIS

(Cole, 1928) sensu lato

Figures 7, 107-109

Middle and Late Eocene

Highly typical of Middle through Late Eocene microfaunas is a group of *Globorotalia* species characterized by large, robust tests and smooth, densely perforate shell which commonly has a polished look at normal magnifications. In some early references they were recorded as *Globigerina inflata* (e.g., COLE, 1927; NUTTALL, 1930), but in modern literature they appear mostly under the two names of *Globorotalia cerroazulensis* (for shouldered to angulate forms) and *Globorotalia centralis* (for forms with an evenly rounded periphery). Also the trivial name *cocoaensis* formerly was used extensively but this came to be accepted as a synonym slightly junior to *cerroazulensis.*

Despite general use of only two names, there has been wide but poorly documented recognition that an orderly morphologic evolution exists within this group, offering possibilities of providing subspecific zonal indices as in the case of the Miocene *Globorotalia fohsi* sensu lato. BLOW & BANNER (1962) illustrated the succession from inflated to angulate forms but did not modify the nomenclature. Not until 1970 did TOUMARKINE & BOLLI formally propose a division into evolutionary subspecies and a zonation based on their ranges.

TOUMARKINE & BOLLI (1970) made the logical proposal that the name *cerroazulensis* be applied to the lineage on grounds of both priority and being a morphologically central form. This decision was followed by a discussion of the names available for subspecies and of the status of their types leading to a rather startling development concerning *Globorotalia centralis.* J. P. BECKMANN tried to examine its holotype in Washington in the spring of 1970, but found it missing; no comment is made on the fact that BLOW (1969, p. 346) had studied it in recent years. The correct procedure in such a case is for a subsequent author to select a neotype from among the original author's paratypes, picking a specimen which matches as closely as possible the holotype as first figured and described. In the case of *G. centralis*, however, this was impracticable because

Fig. 106. *Globigerina binaiensis* KOCH from the Oligocene of Sabah (northern Borneo) and late Oligocene or Early Miocene of Sarawak (eastern Borneo).

1-3 Specimens from the Oligocene of Sabah (northern Borneo). **1**–Side view showing apertural face, X140; **2**–oblique spiral view, X140; **3**–umbilical view, X160.

4-5 Abraded specimens from the late Oligocene or Early Miocene of Sarawak (eastern Borneo); from BLOW (1969, pl. 13, fig. 1-2). **4**–Spiral view, X115; **5**–side view showing apertural face, X127.

6-7 Cotypes from the late Oligocene to Early Miocene of Sarawak (eastern Borneo), X36 ca; from KOCH (1926, p. 737, fig. 22-23). [Dr. H. M. BOLLI informed us that one of the two cotypes at Basel has disintegrated. Thus, the remaining one (e.g., that illustrated by KOCH as Figure 23a-c and reproduced here as **7a-c**) is the lectotype.] **6a**–Spiral view; **6b-c,7a-b**–side to umbilical views showing apertural face and peripheral angle; **7c**–oblique spiral view.

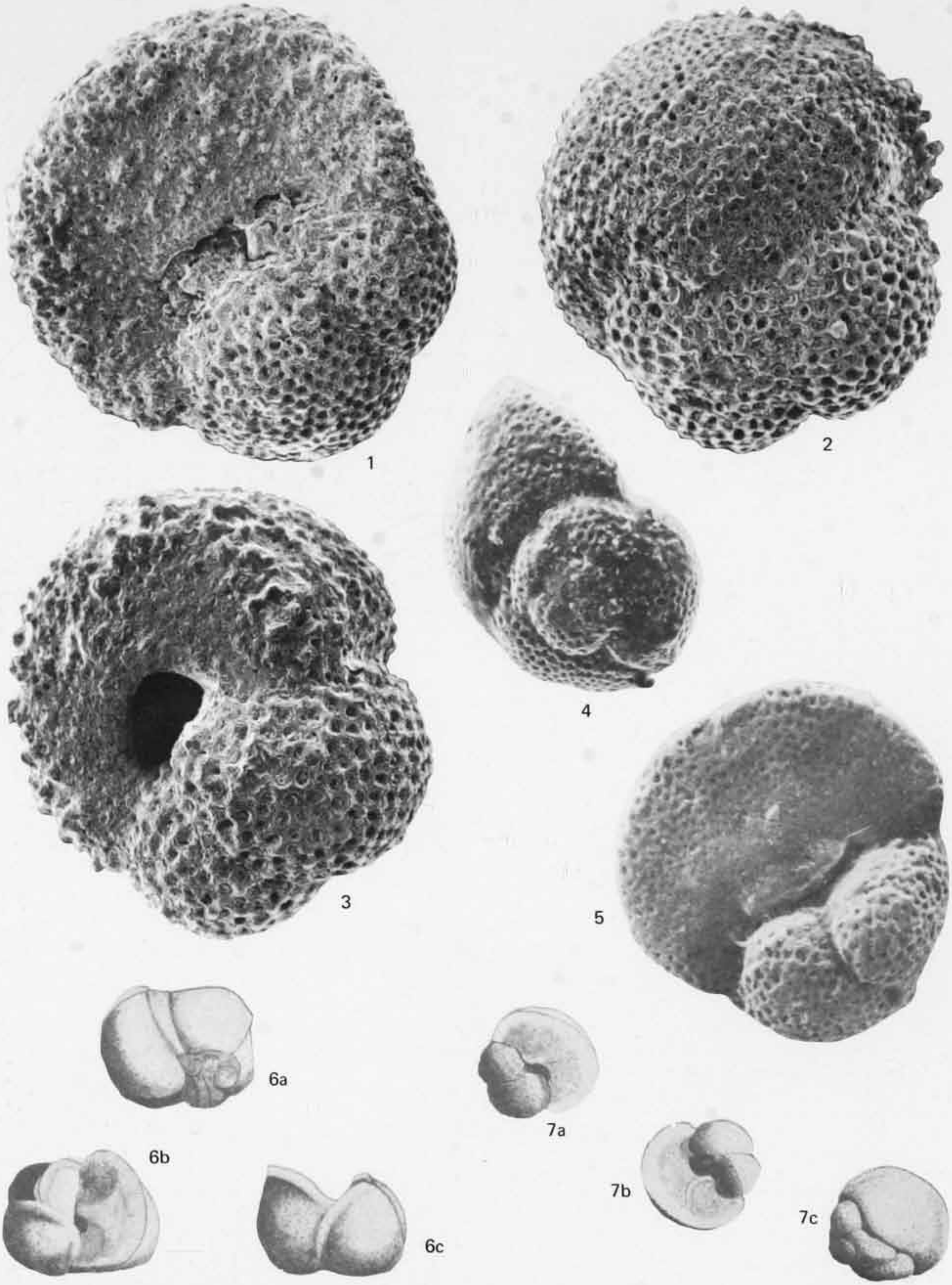

Fig. 106

all three existing paratypes are morphologically inseparable from the holotype of *G. cerroazulensis.* This is yet another in a series of nomenclatural problems arising basically from the latitude applied in definition of planktonic species by earlier authors in contrast with the fine splitting applied today.

TOUMARKINE & BOLLI (1970) followed SAMUEL & SALAJ (1968) in postulating that the lineage starts with *Globigerina frontosa* SUBBOTINA (=*G. boweri* BOLLI), which they reallocated to become a subspecies of *Globorotalia cerroazulensis.* This form (Fig. 51) has a globigerine test but its arched aperture tends to be extraumbilical as in *Globorotalia.* Its descendants belong more definitely to the latter genus, with the aperture withdrawn into a slit from umbilicus to periphery and more numerous chambers (4 to 5) in the final whorl. The early subspecies are biconvex, more strongly inflated on the umbilical side, with an evenly rounded periphery. TOUMARKINE & BOLLI introduced the names *Globorotalia cerroazulensis possagnoensis* and *G. c. pomeroli,* which evidently correspond (especially *pomeroli*) to the discarded name *Globorotalia centralis* as used extensively in the literature. The next evolutionary step is a distinct flattening of the spiral surface, resulting in a shouldered periphery (Fig. 7). This form is *G. cerroazulensis* sensu stricto, which in turn passes by further compression into *G. c. cocoaensis,* a lenticular form with an acute periphery less perforate than the rest of the test. The end form, separated by TOUMARKINE & BOLLI as *G. c. cunialensis,* is distinguished by a light imperforate keel. The three advanced forms show distinct homeomorphy with the much younger lineage of *Globorotalia scitula praescitula, G. scitula* s.s., and *G. praemenardii.*

TOUMARKINE & BOLLI presented data from Italy, Barbados, and Trinidad in support of their proposed set of zones based mainly on ranges of the successive subspecies of *Globorotalia cerroazulensis.* This scheme is potentially applicable where other zonal indices (notably *Orbulinoides beckmanni*) are absent for climatic or other reasons.

The subspecies *cerroazulensis* s.s., *cocoaensis,* and *pomeroli* are discussed in more detail next.

GLOBOROTALIA CERROAZULENSIS CERROAZULENSIS
(Cole, 1928)
Figures 7, 107
Late Eocene

Globigerina cerro-azulensis COLE, 1928, p. 17, pl. 1, fig. 11-13.

[The following appear to refer to *Globorotalia cerroazulensis* s.s., but in numerous other references this name has been applied sensu lato and to the form now separated as the subspecies *Globorotalia cerroazulensis cocoaensis.*]

Eponides cerro-azulensis (COLE). NUTTALL, 1930, p. 274.

Globorotalia bonairensis PIJPERS, 1933, p. 71, fig. 107-110.

Globorotalia cerro-azulensis (COLE). BERMÚDEZ, 1949, p. 285, pl. 22, fig. 27-29.

[and also the special case of]

Globorotalia centralis CUSHMAN & BERMÚDEZ, 1937, as emended by TOUMARKINE & BOLLI (1970, p. 132, 144). [Their emendation applies only to the types as now extant, the holotype being lost. It does not apply to pre-1970 records of *G. centralis* in the literature, of which the majority would today be placed in *G. cerroazulensis pomeroli.*]

Test large for the genus, a regular trochospire approaching planoconvex with 4 to 5½ chambers in last whorl. Spiral profile subcircular, flattened at sutures; side profile shows distinct but bluntly rounded shoulder between flattened spiral and inflated umbilical faces. Sutures distinct; on umbilical side radial, on spiral side recurved, defining

Fig. 107. *Globorotalia cerroazulensis cerroazulensis* (COLE) from the Late Eocene of Italy, Trinidad, and Mexico and the Middle Eocene of Trinidad.

1-5 Specimens from the Late Eocene (*Globorotalia cerroazulensis* s.l. Zone) of northern Italy; from TOUMARKINE & BOLLI (1970, pl. 1, fig. 21-23; pl. 2, fig. 3-4; partly from original SEM prints). **1,4-5.** Side views, X100, X100, X90; **2**–spiral view, X100; **3**–umbilical view, X100.

6 Side view of specimen from Late Eocene part (*Globorotalia cerroazulensis* s.l. Zone) of the San Fernando Formation of Trinidad, X73; from BOLLI (1957c, pl. 39, fig. 4).

7 Holotype from the Late Eocene Chapapote Formation of Mexico, X25; from COLE (1928, pl. 1, fig. 11-13). **a**–Spiral view; **b**–side view; **c**–umbilical view.

8,10-11 Specimens from the Late Eocene part (*Globigerinatheka semiinvoluta* Zone) of the Navet Formation of Trinidad, X50; from TOUMARKINE & BOLLI (1970, pl. 2, fig. 23-25). **8**–Umbilical view; **10**–spiral view; **11**–side view.

9,12-13 Specimens from the Middle Eocene part (*Truncorotaloides rohri* Zone) of the Navet Formation of Trinidad, X50; from TOUMARKINE & BOLLI (1970, pl. 2, fig. 20-22). **9**–Umbilical view; **12**–side view; **13**–spiral view.

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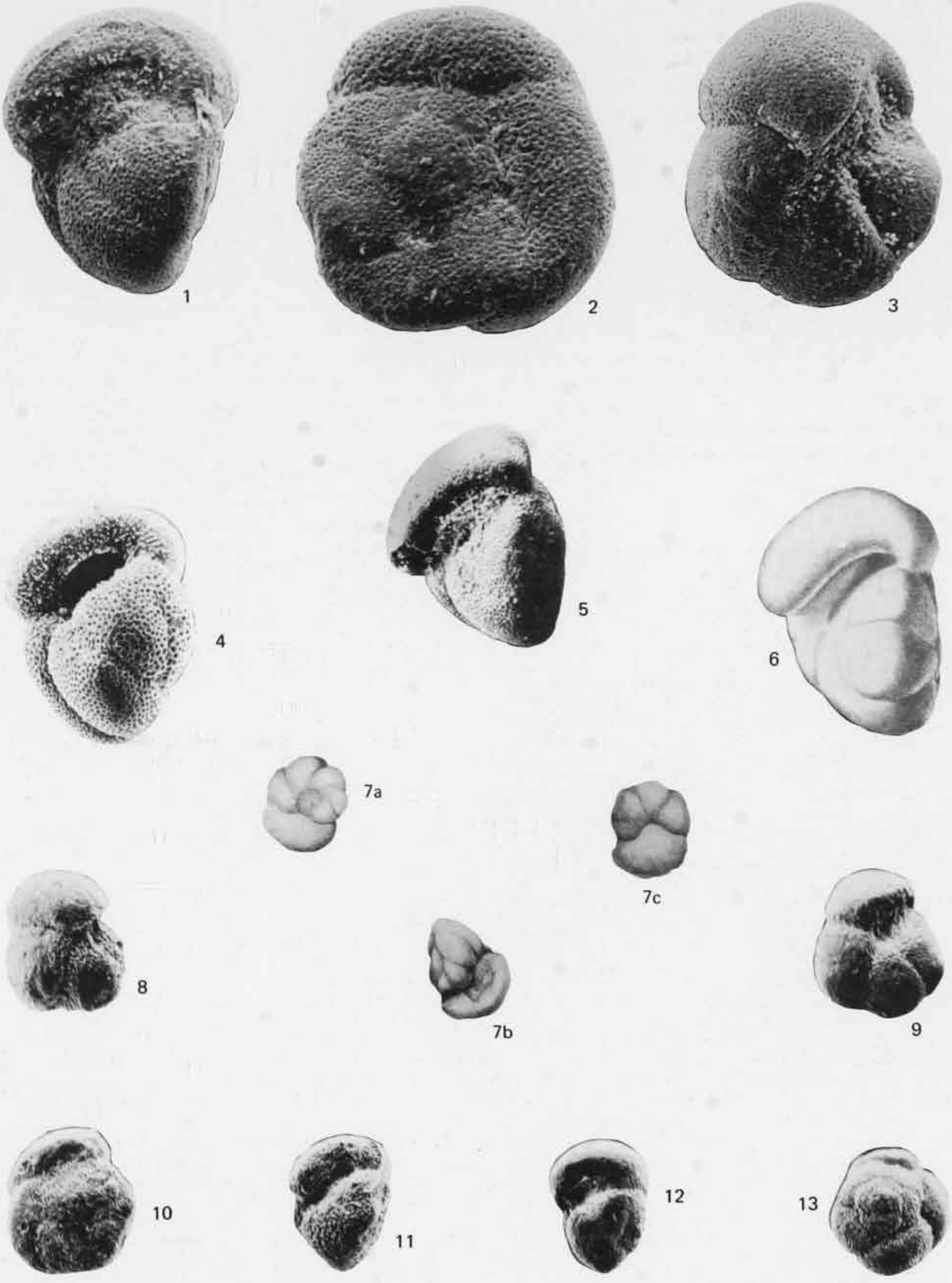

Fig. 107

lozenge- to crescent-shaped chambers. Aperture a curved slit or low arch from umbilicus to periphery. Shell surface smooth, finely perforate, commonly glossy, but may be rugose in umbilical area.

Discussion.—The side profile of this subspecies distinguishes it from the preceding *pomeroli* (evenly rounded, no shoulder) and the ensuing *cocoaensis* (angulate shoulder to acute margin). There is also an evolutionary tendency towards more precisely formed and sharply defined chambers, with *G. cerroazulensis cerroazulensis* in mid-position (Fig. 7). Transitional forms exist.

Distribution.—The subspecies *G. c. cerroazulensis* is an outstandingly useful index fossil, being a distinctive and widely distributed form whose life range coincides almost exactly with the Late Eocene Epoch (*Globigerinatheka semiinvoluta* and *Globorotalia cerroazulensis* s.l. Zones). It was first recorded in the Upper Eocene Chapapote Formation of Mexico.

GLOBOROTALIA CERROAZULENSIS COCOAENSIS

Cushman, 1928
Figures 7, 108
Late Eocene

Globorotalia cocoaensis CUSHMAN, 1928, p. 75, pl. 10, fig. 3.

[The following appear to refer to the subspecies *cocoaensis* as currently recognized, distinct from *cerroazulensis* s.s. In much of the pre-1970 literature the two names were used indiscriminately for either or both of the forms which they now designate.]

Globorotalia cocoaensis CUSHMAN. BANDY, 1949, p. 79, pl. 12, fig. 1.—BOLLI, 1957c, p. 169, pl. 39, fig. 5-7.

Globorotalia (Turborotalia) cerro-azulensis (COLE). BLOW & BANNER, 1962, p. 118, fig. 12d-e, pl. 12, fig. D-F.

Globorotalia (Turborotalia) cerroazulensis (COLE). BLOW, 1969, p. 347, pl. 36, fig. 3-4.

Globorotalia cerroazulensis cocoaensis CUSHMAN. TOUMARKINE & BOLLI, 1970, p. 144, pl. 1, fig. 28-33; pl. 2, fig. 6-8, 27.

Test trochospiral, biconvex approaching lenticular, with 4 to 5 chambers in last whorl. Spiral profile subcircular, indented at sutures; side profile shows acute-angled, blunt-tipped margin all around, marginal angle 50-60° in figures of TOUMARKINE & BOLLI (1970). Sutures distinct, sharply incised, radial to slightly recurved on umbilical side, strongly recurved on spiral side. In umbilical aspect final chamber commonly projects above earlier ones. Aperture a semicircular arch between umbilicus and periphery. Shell surface smooth, finely perforate, commonly glossy, but may be rugose in umbilical area. Marginal belt less densely perforate than rest of test. Diameter reaches 0.6 mm.

Discussion.—The subspecies *G. c. cocoaensis* is distinguished by its acute margin from its predecessor *G. c. cerroazulensis* (Fig. 7). It gives rise to forms with an even sharper margin (40-50°) and a light keel, which were designated *G. c. cunialensis* by TOUMARKINE & BOLLI (1970). There is a close homeomorphy with the younger *Globorotalia scitula-G. praemenardii* lineage.

Distribution.—*G. c. cocoaensis* is an excellent guide fossil for the Late Eocene (*Globorotalia cerroazulensis* s.l. Zone). Its carinate offshoots only appear in the latest Eocene. This form was first described from the Cocoa Member of the Upper Eocene Jackson Formation in Alabama.

GLOBOROTALIA CERROAZULENSIS POMEROLI

Toumarkine & Bolli, 1970
Figure 109
Middle and Late Eocene

Globorotalia centralis of many authors but not CUSHMAN & BERMÚDEZ, 1937, as emended by TOUMARKINE & BOLLI, 1970. [On discovery in 1970 that the holotype of *Globorotalia centralis* was lost, the normal procedure would have been to select a neotype from among the paratypes of the original authors. Unfortunately, however, these three specimens were found to be

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Fig. 108. *Globorotalia cerroazulensis cocoaensis* CUSHMAN from the Late Eocene of Italy and Alabama.

1-3 Specimens from the *Globorotalia cerroazulensis* (s.l.) Zone of northern Italy, X100; from original SEM illustrations of TOUMARKINE & BOLLI (1970, pl. 1, fig. 28-30). **1**—Spiral view; **2**—side view; **3**—umbilical view.

4-7 Specimens from the *Globorotalia cerroazulensis* (s.l.) Zone in the Yazoo Formation of Alabama. **4**—Spiral view, X120; **5**—umbilical view, X110; **6-7**—side views, X150, X110.

8 Edge view of specimen having advanced form with acute, carinate periphery (=subspecies *cunialensis* of TOUMARKINE & BOLLI, 1970) from the latest Eocene of northern Italy, X225; from TOUMARKINE & BOLLI (1970, pl. 2, fig. 10).

9 Holotype from the Cocoa sand of Alabama, X90; from CUSHMAN (1928, pl. 10, fig. 3). **a**—Spiral view; **b**—umbilical view; **c**—side view.

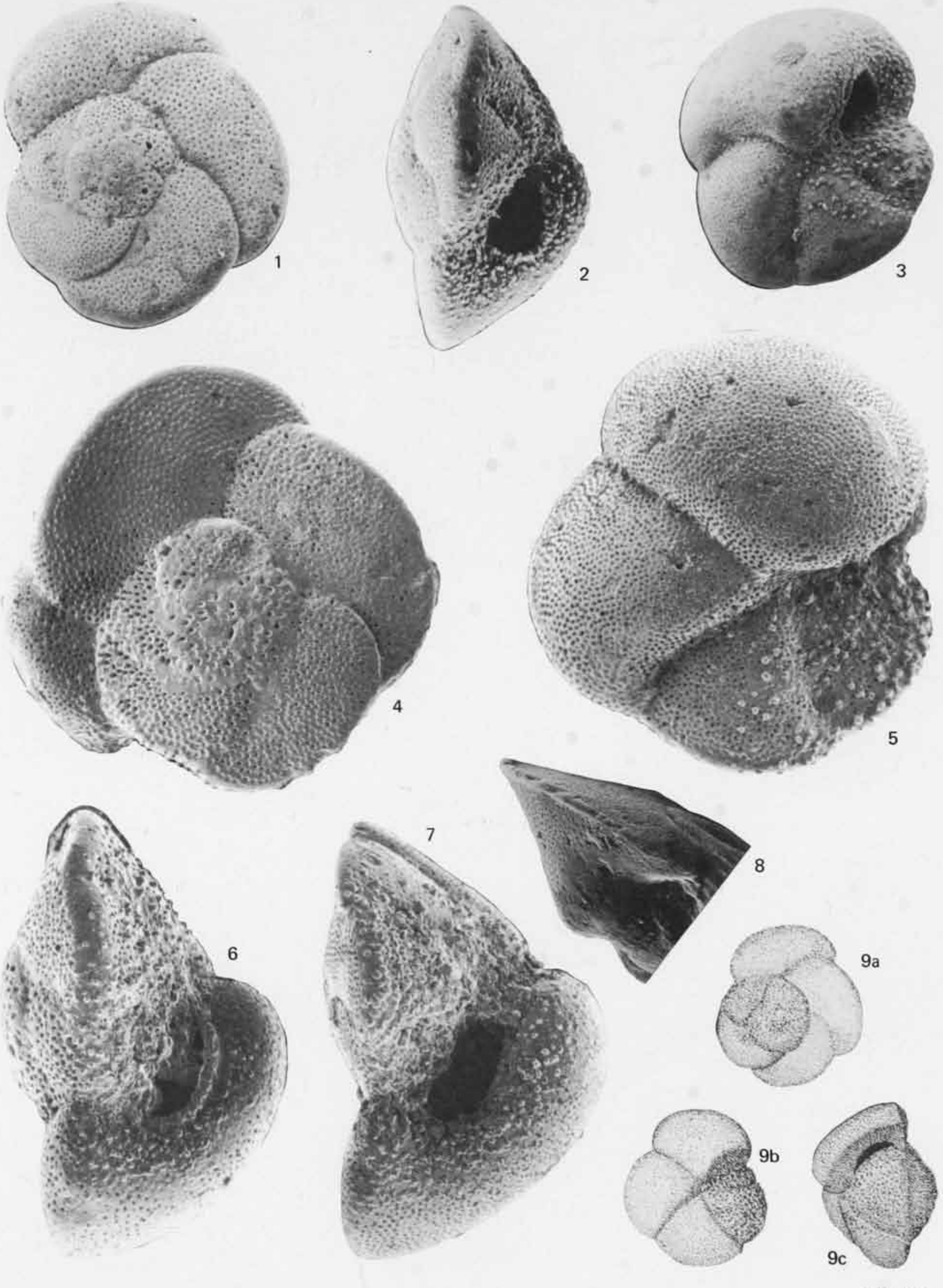

Fig. 108

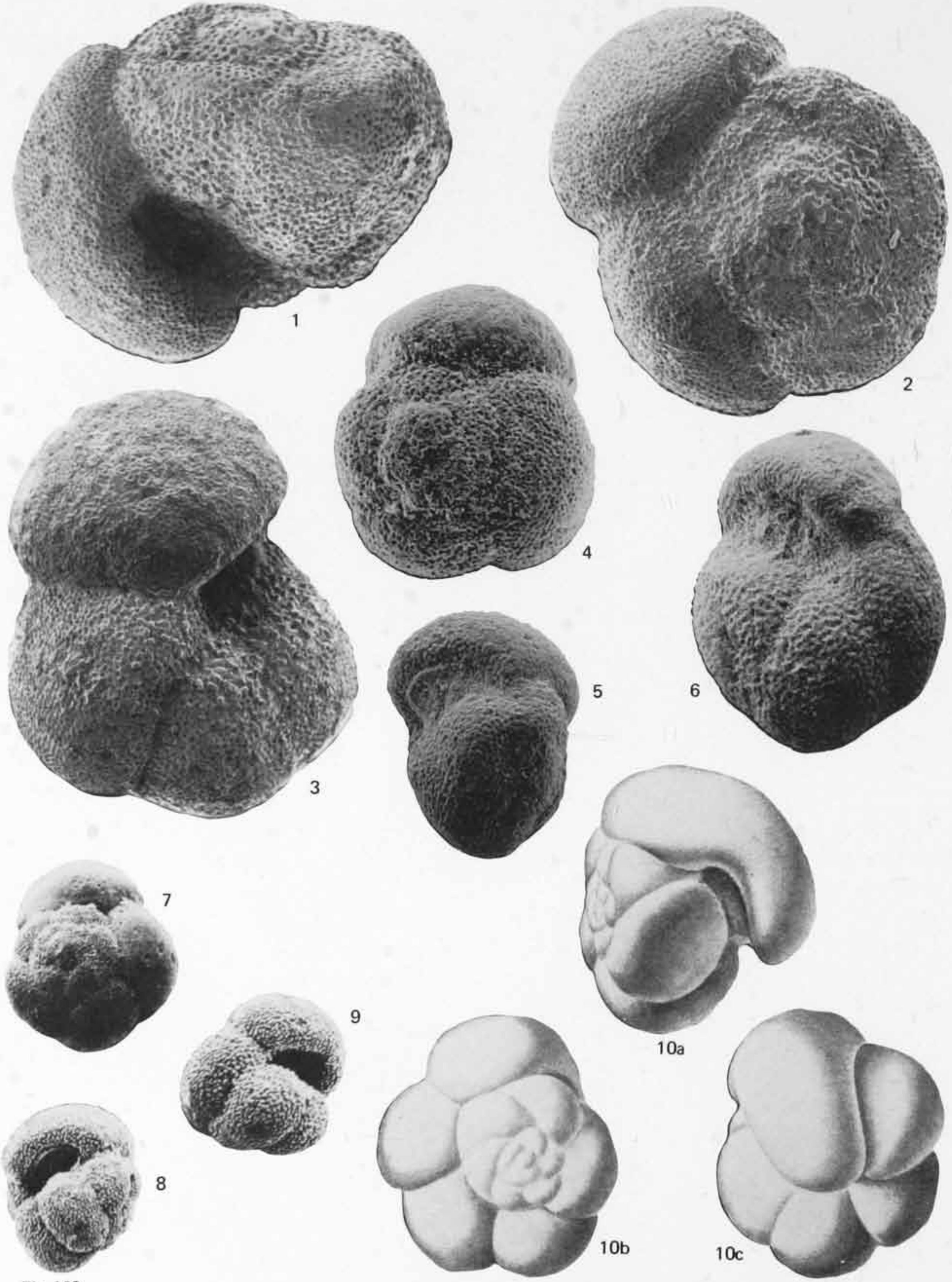

Fig. 109

Fig. 109. *Globorotalia cerroazulensis pomeroli* TOUMARKINE & BOLLI from the Late Eocene of Trinidad and Middle Eocene of Italy and Trinidad.

1-3 Specimens from the Late Eocene (*Globigerinatheka semiinvoluta* Zone) in the Hospital Hill Formation of Trinidad, X110. **1**–Side view; **2**–spiral view; **3**–umbilical view.

4-6 Holotype **(4)** and paratypes **(5-6)** from the Middle Eocene (*Orbulinoides beckmanni* Zone) of northern Italy, X100; from original SEM illustrations used by TOUMARKINE & BOLLI (1970, pl. 1, fig. 13-15). **4**–Spiral view, **5**–side view; **6**–umbilical view.

7-10 Specimens from the Middle Eocene part (*Orbulinoides beckmanni* Zone) of the Navet Formation of Trinidad; **7-9** from TOUMARKINE & BOLLI (1970, pl. 2, fig. 17-19) and **10** from BOLLI (1957c, pl. 39, fig. 1). **7,10b**–Spiral views, X50, X73. **8,10a**–side views, X50, X73; **9-10c**–umbilical views, X50, X73.

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indistinguishable from *Globorotalia cerroazulensis* (COLE, 1928), so that the name *centralis* became invalid as a junior synonym. Although not specifically stated by them, it seems clear that TOUMARKINE & BOLLI (1970) intended their new subspecific name *pomeroli* to replace *centralis* in the sense of its wide usage for over thirty years. A lengthy list of such references, 1937-1957, is given by BERMÚDEZ (1960, p. 1317-1319) and some later ones are cited by BLOW (1969, p. 346), who also comments on the now-missing holotype.]

Globorotalia cerroazulensis pomeroli TOUMARKINE & BOLLI, 1970, p. 140, pl. 1, fig. 10-18; pl. 2, fig. 1-2, 11-19.

Test a rather large, regular, globose trochospire with 4 to 5 chambers in last whorl. Spiral profile rounded, almost flush in early portion but becoming lobulate; side profile ovate, with umbilical portion boldly inflated, spire mildly convex, no break or shoulder in peripheral curve. Sutures distinct except in initial portion, may be incised. Aperture extraumbilical, a low arched opening, commonly recessed behind an anterior projection of final chamber. Shell surface smooth to glossy, very finely perforate. Diameter typically 0.5 to 0.7 mm.

Discussion.–*Globorotalia cerroazulensis pomeroli* is distinguished from its predecessor *G. c. possagnoensis* by having more chambers, a tighter coil and a more inflated test. The succeeding subspecies *G. cerroazulensis* s.s. has a flatter spiral face and hence a shouldered to bluntly subangular periphery. Transitional forms exist. Authors have recorded a lofty form which BERMÚDEZ (1960) separated as *Turborotalia altispiroides* but which is now included in *G. c. pomeroli* (see comments of BLOW, 1969, p. 346).

Distribution.–*Globorotalia cerroazulensis pomeroli* is widely distributed and often plentiful in microfaunas of Middle and Late Eocene age (*Globigerinatheka subconglobata* Zone to within *Globorotalia cerroazulensis* s.l. Zone). Under this name it was first described from the Middle Eocene, approximately *Orbulinoides beckmanni* Zone, of northern Italy.

CASSIGERINELLA CHIPOLENSIS
(Cushman & Ponton, 1932)
Figure 110
Basal Oligocene to Middle Miocene

Cassidulina chipolensis CUSHMAN & PONTON, 1932a, p. 98, pl. 15, fig. 2.–CUSHMAN & STAINFORTH, 1945, p. 64, pl. 11, fig. 7.

Cassigerinella boudecensis POKORNÝ, 1955, p. 136-140, fig. 1-3 [fide BLOW & BANNER, 1962, p. 83, and HOFKER, 1963b, p. 321-324].

Cassigerinella chipolensis (CUSHMAN & PONTON). BOLLI, 1957b, p. 108, pl. 22, fig. 3.–BLOW, 1959, p. 169, pl. 7, fig. 30.–BLOW & BANNER, 1962, p. 81, 83, pl. 15, fig. M-N.–CORDEY, 1968a, p. 368-370, fig. 1, f-m.–BLOW, 1969, p. 377, pl. 51, fig. 5.

Cassigerinella globolocula IVANOVA, in BYKOVA ET AL., 1958, p. 57, pl. 11, fig. 1-3 [fide BLOW & BANNER, 1962, p. 83].

Test a tiny biserial (cassiduline) coil; 8 to 10 chambers visible, enlarging gradually, and becoming more inflated as added. Surface smooth, hyaline, very finely perforate. Sutures distinct, incised. Aperture a U-shaped arch centrally placed on inward-facing portion of final chamber. Diameter seldom exceeds 0.2 mm.

Discussion.–*Cassigerinella eocaenica* CORDEY (1968a) (see also BLOW, 1969) is even smaller than *C. chipolensis*, has a narrower periphery and more inflated chambers, and typically reveals a planispirally coiled nucleus preceding the biserially coiled portion.

Distribution.–*Cassigerinella chipolensis* first appeared in the earliest Oligocene and its overlap with *Pseudohastigerina micra* is diagnostic of the oldest post-Eocene zone, of which these two species are the joint name fossils. Care must be taken to distinguish it from *C. eocaenica*, currently recorded from the Late Eocene in a single submarine core. The types of *C. chipolensis* were described from the Miocene of Florida and of its synonyms from the Oligo-Miocene of central Europe. Its extinction level appears to be near the end of the Middle Miocene.

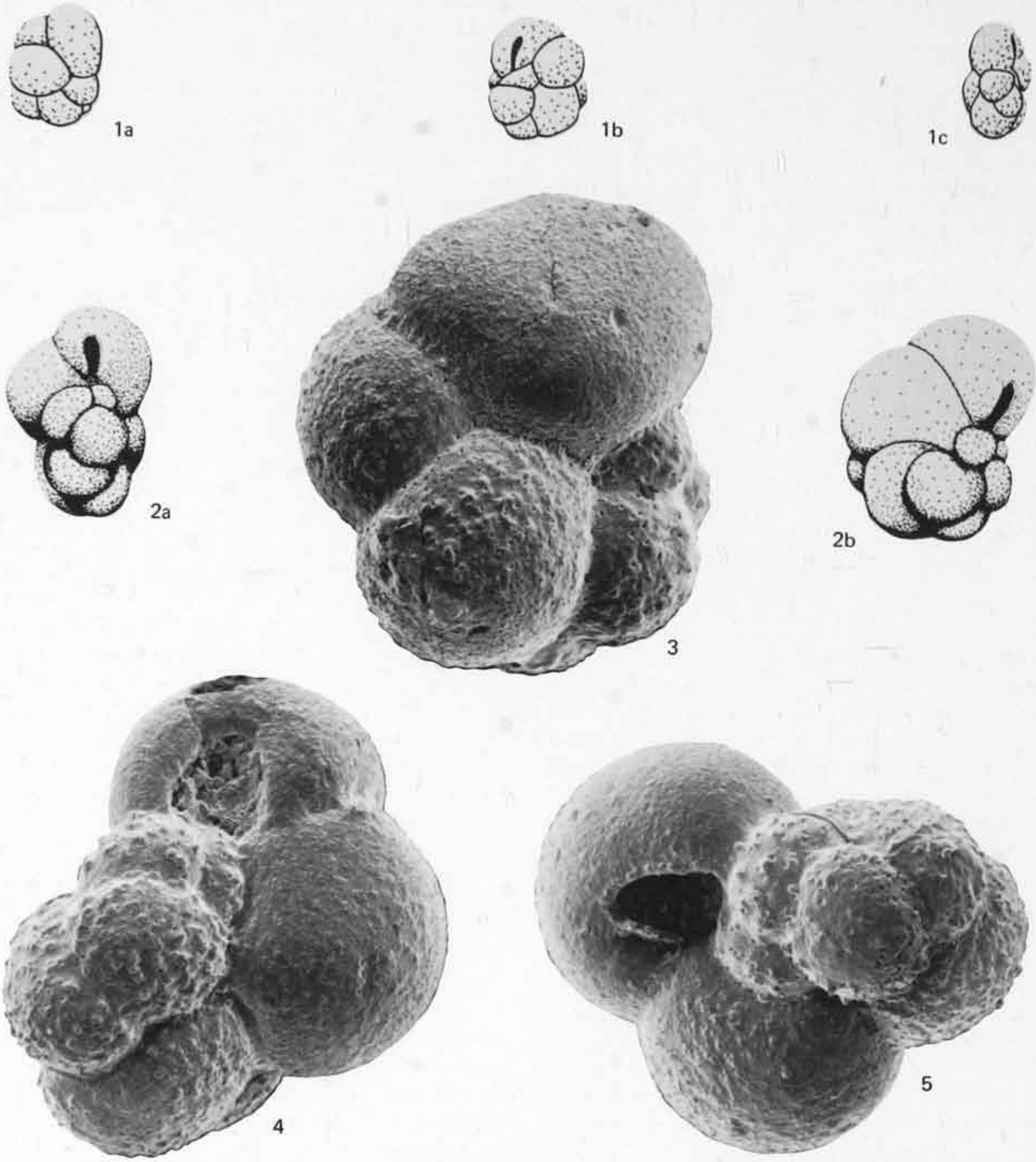


Fig. 110. *Cassigerinella chipolensis* (CUSHMAN & PONTON) from the Oligocene of Trinidad and Miocene of Florida.

1 Holotype from the Miocene of Florida, X150; from CORDEY (1968a, p. 369, fig. i-k; after CUSHMAN & PONTON). **a,b**–Side views; **c**–peripheral view.

2 Specimen from the Oligocene part (*Globigerina ampliapertura* Zone) of the Cipero Formation of Trinidad, X275; from CORDEY (1968a, p. 369, fig. 1-m). **a**–Peripheral view; **b**–side view.

3-5 Specimens from the Oligocene part (*Globorotalia opima opima* Zone) of the Cipero Formation of Trinidad. **3**–Side view, X310; **4**–oblique peripheral view, X290; **5**–peripheral view, X310.

GLOBIGERINA CIPEROENSIS Bolli, 1954

Figure 111

Oligocene and Earliest Miocene

Globigerina concinna REUSS. NUTTALL, 1932, p. 29, pl. 6, fig. 9-11.–FRANKLIN, 1944, p. 317, pl. 48, fig. 5.

Globigerina cf. *concinna* REUSS. CUSHMAN & STAINFORTH, 1945, p. 67, pl. 13, fig. 1. [This specimen was later designated the holotype of *G. ciperoensis* BOLLI].–STAINFORTH, 1948b, p. 118, pl. 25, fig. 19-21.–BECKMANN, 1953, p. 390, pl. 25, fig. 5.

Globigerina ciperoensis BOLLI, 1954, p. 1-3, fig. 3-4. [These type figures are simply line drawings traced from the illustrations of CUSHMAN & STAINFORTH, 1945, as above].–HOFKER, 1968, p. 14-16, pl. 6, fig. 7, h-k.–LIPPS, 1969, p. 1806, fig. 4.

Globigerina ciperoensis ciperoensis BOLLI. BOLLI, 1957b, p. 108, pl. 22, fig. 10.

Glogiberina ouachitensis ciperoensis (BOLLI). BLOW & BANNER, 1962, p. 90-91, fig. 9, i-iii, pl. 9, fig. E-G.–BLOW, 1969, p. 320, pl. 1, fig. 4-6; pl. 17, fig. 7, 10-11.–BERGGREN, 1969a, p. 111.

Globigerina concinna ciperoensis BOLLI. BANDY, 1964b, p. 8, 12, fig. 5.

Globigerina (Globigerina) ciperoensis ciperoensis BOLLI. JENKINS, 1971, p. 145, pl. 14, fig. 411-413.

Test a small low-angled spire of subspherical chambers which increase slowly and regularly in size as added. Consistently 5 chambers in final whorl. Equatorial profile lobate, tending to pentagonal; side aspect reveals nuclear coil projecting only slightly above spiral surface of outer whorl. Sutures distinct, mostly incised. Umbilicus open and conspicuous, width approximating one-quarter to one-third of test diameter. Aperture a circular opening directed into umbilicus. Surface finely perforate, hispid in well preserved specimens. Diameter may reach 0.35 mm.

Discussion.–*Globigerina ciperoensis* is consistent in size and morphology. Somewhat similar species are *Globigerina angulisuturalis* which has conspicuous U-shaped channels between its chambers and *G. angustiumbilicata* which has a small or closed umbilicus. BOLLI (1957b) treated all three as subspecies of *G. ciperoensis* but later authors placed them in different lineages, partly as full species. Consequently we have reverted to BOLLI'S original name of *Globigerina ciperoensis*, undivided, for the species in question. *Globigerina concinna* is superficially similar but is generally larger and shows more rapid increase in chamber size (see BOLLI, 1954).

Distribution.–Its short range and distinctive form make *Globigerina ciperoensis* a valuable index fossil. When present in its usual abundance, it is a reliable guide to Oligocene age even though records exist of its occurrence in Early Miocene beds. This species has the distinction of being one of the first Tertiary planktonic foraminifers to be applied to regional and interregional correlations and is the accepted name fossil for the highest of the four Oligocene zones. Its type locality is in the *Globorotalia opima opima* Zone within the Cipero Formation of Trinidad.

GLOBIGERINA CORPULENTA Subbotina, 1953

Figure 112

Late Middle and Late Eocene

Globigerina corpulenta SUBBOTINA, 1953, p. 76, pl. 9, fig. 5-7; pl. 10, fig. 1-4.–SUBBOTINA, 1971, p. 101, 104-105, pl. 9, fig. 5-7; pl. 10, fig. 1-4.

Test a fairly large, robust trochospire of globose, rather loosely attached chambers. Specimens display wide individual variability. Early chambers increase rapidly in size, almost doubling as added, but rate slows and late chambers approach subequal. Usually 4 chambers in last whorl. Final chamber may be abnormally small and misplaced towards umbilicus. Equatorial profile more or less quadrilateral, varying from mildly to strongly lobate; side profile shows early coil projecting upwards as a low turret or obtuse-angled spire. Sutures depressed, radial. Umbilicus usually open and deep. Aperture a variable arched opening into umbilicus, commonly with faint lip. Diameter 0.4 to 0.6 mm.

Discussion.–The plexus of large Eocene-Oligocene species is reviewed under *Globigerina linaperta* group. It is concluded that from a central trilobate form there radiates a web of intimately linked variants which lead to certain morphologic extremes. Among the latter are *Globigerina eocaena* (=*yeguaensis*), distinguished by a relatively slow rate of increase in the size of its adult chambers and by an almost flat spire, and *Globigerina gortanii* (=*turritilina*), whose coil is closely similar in plan view but in side view reveals a distinctly elevated, commonly lofty, spire.

Globigerina corpulenta was clearly described by SUBBOTINA (1953, 1971), who supplied 20 illustrations of 7 specimens and noted its close relationship to *Globigerina eocaena*. It differs, however, in having a raised, though not lofty, spire which links it closely to *Globigerina gortanii*. Because of the difficulty of setting objective limits between such intergradational forms, we preferred in other cases to recognize only the morphologic extremes. In the present case, however, an exception is made because *G. corpulenta* is formally used as a zonal

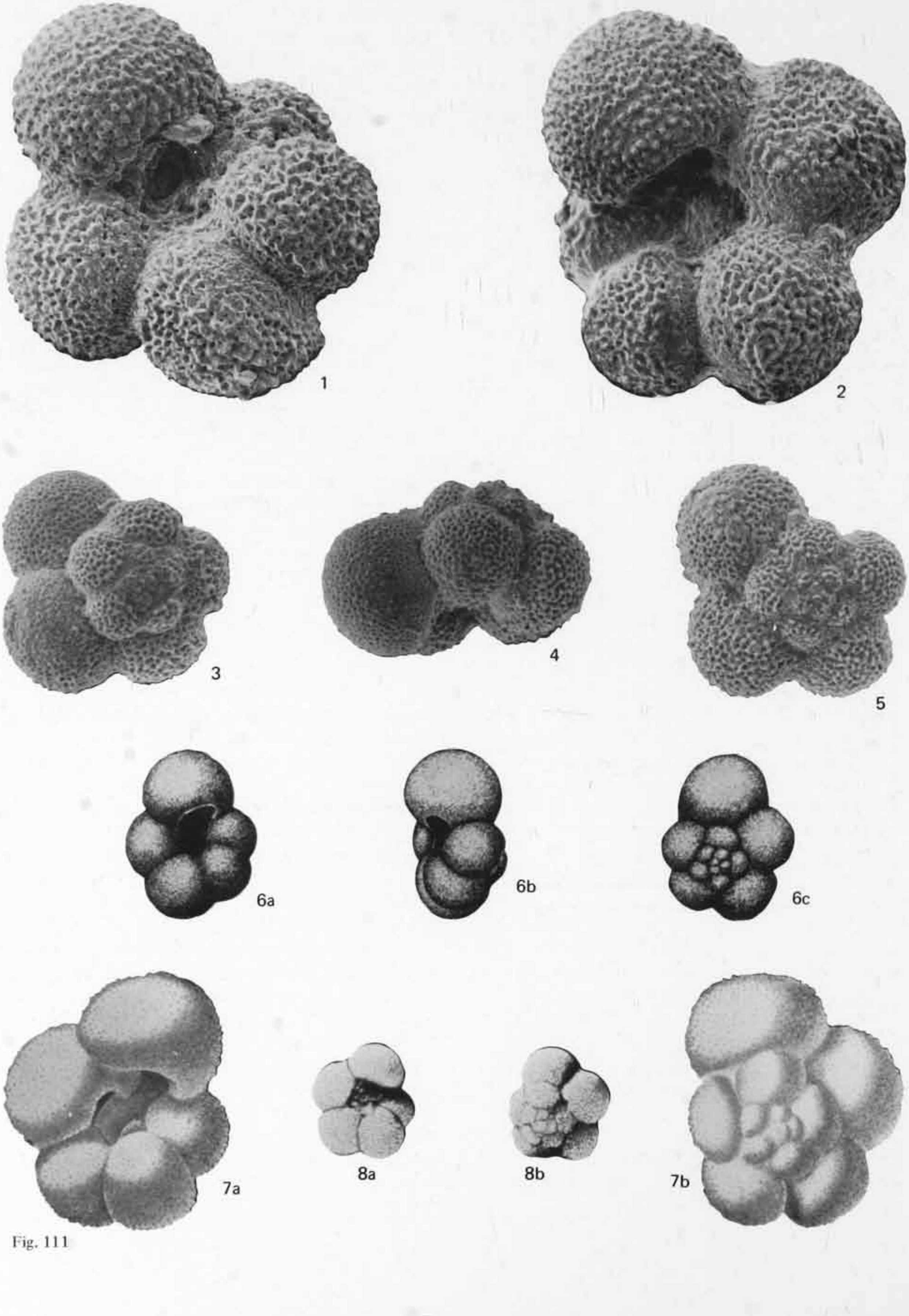


Fig. 111

Fig. 111. *Globigerina ciperoensis* BOLLI from the Oligocene of Trinidad and Tanzania.

1-5,8 Specimens (**8**=holotype from CUSHMAN & STAINFORTH, 1945, pl. 13, fig. 1) from the *Globorotalia opima opima* Zone in the Cipero Formation of Trinidad. **1-2,8a**–Umbilical views, X220, X220, X55; **3,5,8b**–spiral views, X150, X150, X55; **4**–side view, X150.

6 Specimen from the early Oligocene part of the Lukuledi Formation of Tanzania, X100; from BLOW & BANNER (1962, pl. 9, fig. E-G). **a**–Umbilical view; **b**–side view; **c**–spiral view.

7 Paratype from the *Globigerina ciperoensis* Zone in the Cipero Formation of Trinidad, X150; BOLLI (1957b, pl. 22, fig. 10). **a**–Umbilical view; **b**–spiral view.

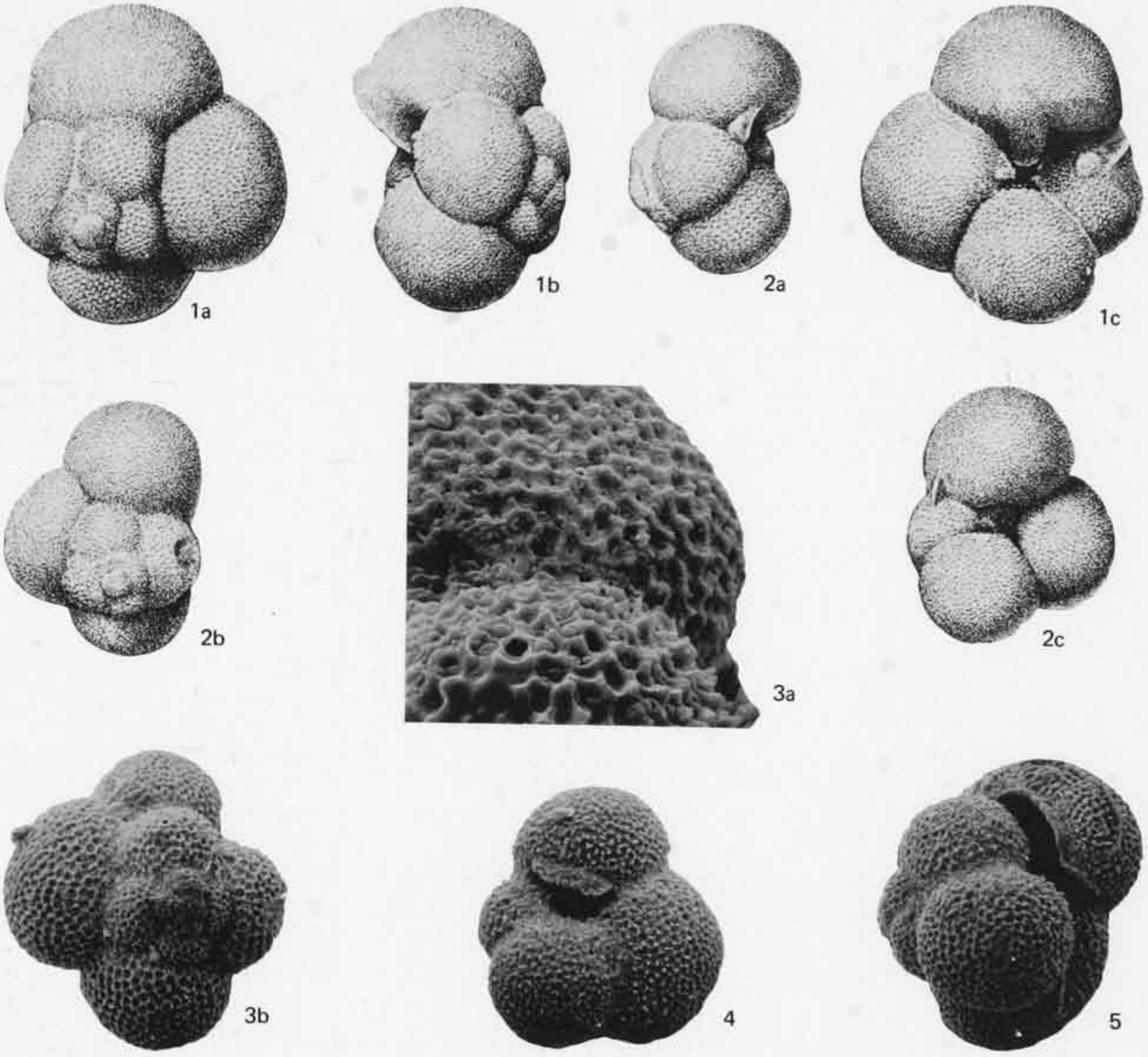


Fig. 112. *Globigerina corpulenta* SUBBOTINA from the Late Eocene of the northern Caucasus, Soviet Union.

1-5 Representative specimens (**2**=holotype); **1-2** from SUBBOTINA (1953, pl. 9, fig. 5, 7). **1a,2b,3b**–Spiral views, X72, X72, X100; **1b,2a,5**–side views, X72, X72, X100; **1c,2c,4**–umbilical views, X72, X72, X400; **3a**–shell surface, X400.

index by Soviet stratigraphers (e.g., KRASHENINNIKOV, 1965a,b) in a region where the strikingly lofty forms of *G. gortanii* are apparently unknown.

Distribution.—Latest Middle and Late Eocene (approximately *Truncorotaloides rohri* Zone to *Globorotalia cerroazulensis* Zone). *Globigerina corpulenta* was first described from the Upper Eocene "White Series" in the northern Caucasus.

GLOBOQUADRINA DEHISCENS Group

Figure 113

Miocene

[The following list is by no means exhaustive but gives a lead to attempted subdivisions of the genus in the literature. Failure of leading authorities to reach agreement gives support to our broad treatment of this group. As one clear example, almost simultaneously BLOW (1969) referred to *Globoquadrina langhiana* as "either fully synonymous with, or only subspecially distinct from, *G. baroemoensis*" while CITA & BLOW (1969) designated it *Globoquadrina larmeui langhiana*. Pertinent comments on the intergradation of *Globoquadrina* species are offered by BRÖNNIMANN & RESIG (1971, p. 1276)].

(1) *Globorotalia dehiscens* CHAPMAN, PARR, & COLLINS, 1934, p. 569, pl. 11, fig. 6.
  Globoquadrina dehiscens (CHAPMAN, PARR & COLLINS). FINLAY, 1947, p. 290.—BOLLI, 1957b, p. 111, pl. 24, fig. 3-4.—JENKINS, 1971, p. 165-166, pl. 20, fig. 595-597 [holotype refigured].
  Globoquadrina dehiscens dehiscens (CHAPMAN, PARR, & COLLINS). BLOW, 1959, p. 181-182, pl. 8, fig. 49.—BLOW, 1969, p. 341, pl. 29, fig. 1.

(2) *Globoquadrina quadraria advena* BERMÚDEZ, 1949, p. 287, pl. 22, fig. 36-38.—PETRI, 1954, p. 131, pl. 14, fig. 1.
  Globoquadrina dehiscens advena BERMÚDEZ. BLOW, 1959, p. 182, pl. 8, fig. 50.—BLOW, 1969, p. 341, pl. 29, fig. 2.

(3) *Globigerina baroemoensis* LEROY, 1939, p. 263, pl. 6, fig. 1-2.
  Globoquadrina baroemoensis (LEROY). BLOW, 1969, p. 340-341, pl. 28, fig. 4, 8.

(4) *Globoquadrina langhiana* CITA & GELATI, 1960, p. 241-246, pl. 29, fig. 1.—CITA, 1964, p. 203-210.—BLOW, 1969, p. 341.
  Globoquadrina larmeui langhiana CITA & GELATI. CITA & BLOW, 1969, p. 549-603.

(5) *Globoquadrina larmeui* AKERS, 1955, p. 661, pl. 65, fig. 4.—BLOW, 1959, p. 183, 184, pl. 11, fig. 53.—BERMÚDEZ, 1960, p. 1311, pl. 13, fig. 7.
  Globoquadrina larmeui larmeui AKERS. BLOW, 1969, p. 341, pl. 28, fig. 5-6.

(6) *Globoquadrina obesa* AKERS, 1955, p. 661, pl. 65, fig. 5.—BERMÚDEZ, 1960, p. 1312, pl. 13, fig. 8.
  Globoquadrina larmeui obesa AKERS. BLOW, 1969, p. 342, pl. 28, fig. 7, 9.

(7) *Globorotalia quadraria* CUSHMAN & ELLISOR, 1939, p. 11, pl. 2, fig. 5.
  Globoquadrina quadraria (CUSHMAN & ELLISOR). FINLAY, 1947, p. 291.—AKERS, 1955, p. 661.

(8) *Globorotalia dehiscens* FINLAY (not CHAPMAN, PARR, & COLLINS), in FINLAY & MARWICK, 1940, p. 114, 123.
  Globoquadrina subdehiscens FINLAY, 1947, p. 291.

Test of medium size, a regular quadrate coil. Consistently 4 chambers in last whorl, commonly but not exclusively cuneate, flattened on spiral side and prolonged beyond umbilicus; increasing in size rather rapidly but maintaining constant shape. Spiral outline square to subcircular; axial outline flattened at spire, strongly convex at umbilicus, commonly with final chamber projecting beyond earlier chambers. Sutures almost flush in prismatic forms, lightly incised in inflated forms, approximately radial. In loosely coiled forms aperture a slit at base of very smooth, flattened to concave apertural face, which commonly carries a toothlike projection filling space between earlier chambers; in tightly coiled forms aperture concealed within an umbilical slot. Surface variable, often rough or pustulose around umbilicus. Diameter typically 0.5 mm.

Discussion.—The extreme forms of the *Globoquadrina dehiscens* lineage are so distinct from both *Globorotalia* and *Globigerina* that FINLAY'S erection of a separate genus appears well justified. Nevertheless, in normal assemblages loosely and tightly coiled forms seemingly intergrade completely with flattened, prismatic and inflated, globose forms. Numerous specific and subspecific names have been applied to variants within this plexus, as listed in the foregoing synonymy. The trivial name *dehiscens* has priority by its date of publication (1934).

The *Globoquadrina dehiscens* group differs in obvious respects from *Globoquadrina altispira* subspecies, to the extent that BLOW (1969)

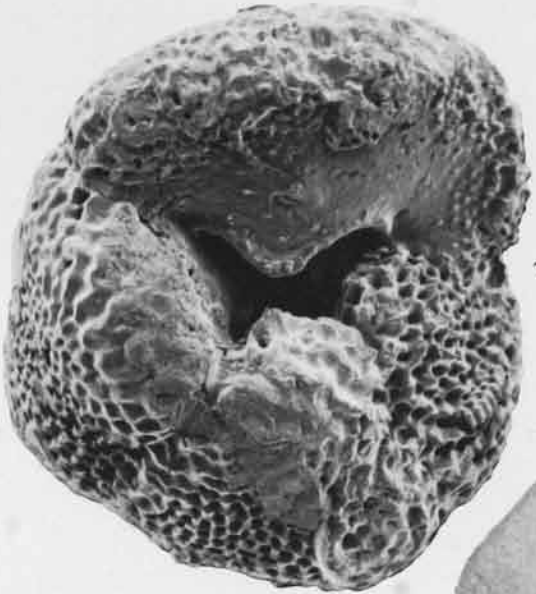
Fig. 113. *Globoquadrina dehiscens* group from the Miocene of Trinidad, Australia, and Italy.

⇨

1-3 Umbilical views of specimens from the Middle Miocene part of the Cipero Formation of Trinidad showing normal range of variation from appressed to inflated chambers, X150.

4 Specimen of *Globoquadrina dehiscens* (s.s.) from the Lower Miocene (Balcombian) of Australia, X140; from BOLLI, LOEBLICH, & TAPPAN (1957, pl. 5, fig. 5). **a**—Spiral view; **b**—side view; **c**—umbilical view.

5-6 Topotypes of *Globoquadrina langhiana* from the Middle Miocene (Langhian) of Italy. **5**—Side view, X130; **6**—spiral view, X150.



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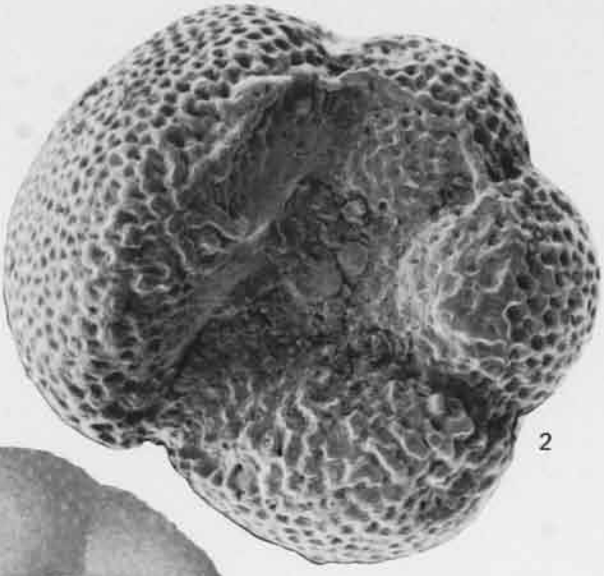

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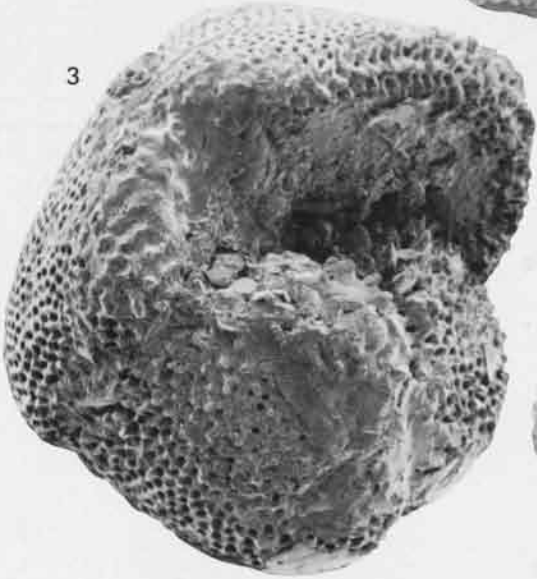

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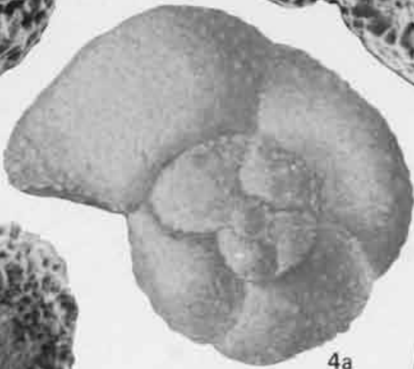

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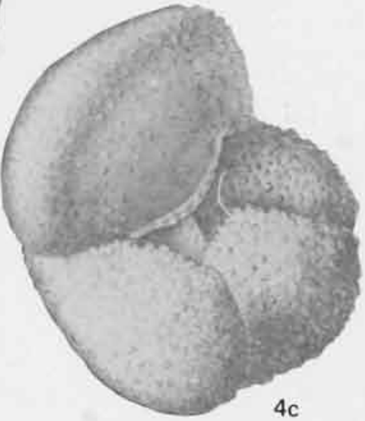

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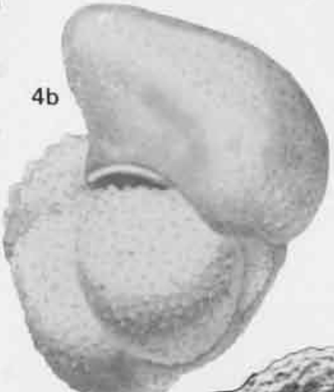

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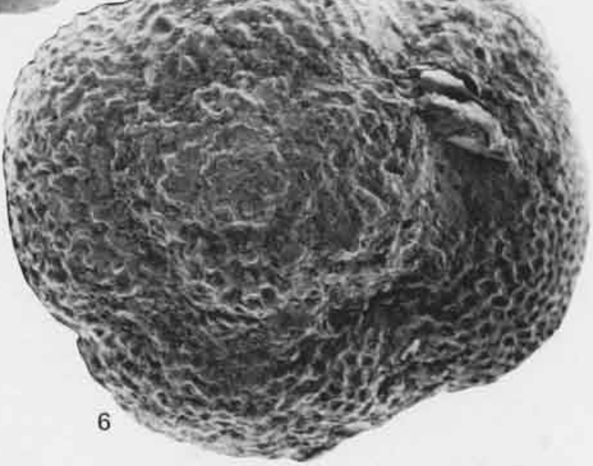

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Fig. 113

suggested the two lineages should be regarded as generically distinct. *Globorotalia crassaformis* subspecies are grossly similar to some forms included under *Globoquadrina dehiscens*, but their apertures are distinct.

Distribution.—Under the broad definition accepted here, the *Globoquadrina dehiscens* group is largely confined to the Miocene. The more narrowly defined species of various authors may have local value in zonation.

CATAPSYDRAX DISSIMILIS (Cushman & Bermúdez, 1937)

Figure 114

Middle Eocene to Early Miocene

Globigerina dissimilis CUSHMAN & BERMÚDEZ, 1937, p. 25, pl. 3, fig. 4-6.—CUSHMAN & STAINFORTH, 1945, p. 68, pl. 13, fig. 2.—STAINFORTH, 1948b, p. 119, pl. 25, fig. 29-31.—NAPOLI ALLIATA, 1953, p. 78, pl. 2, fig. 2.—BECKMANN, 1953, p. 391, pl. 25, fig. 10.—HOFKER, 1968, p. 17, pl. 7, fig. 5.

Globigerina ("Dissimiloglobigerina") dissimilis REISS, 1957a, p. 4.

Catapsydrax dissimilis (CUSHMAN & BERMÚDEZ). BOLLI, LOEBLICH, & TAPPAN, 1957, p. 36, pl. 7, fig. 6-8.—BLOW, 1959, p. 203, pl. 12, fig. 88-90.—SOEDIONO, 1969, p. 347, 348, pl. 4, fig. 1-3.—JENKINS, 1971, p. 182-183, pl. 21, fig. 625-627.

Globigerinita dissimilis (CUSHMAN & BERMÚDEZ). BERMÚDEZ, 1960, p. 1262, 1263, pl. 7, fig. 4-5.—[emended] BLOW & BANNER, 1962, p. 106-108, pl. 14, fig. A-D.—BLOW, 1969, p. 327-328.

Globigerina (Globigerinita) dissimilis CUSHMAN & BERMÚDEZ. MCTAVISH, 1966, p. 1-36, pl. 2, fig. 15-17, 27-28, 30.

Catapsydrax dissimilis dissimilis (CUSHMAN & BERMÚDEZ). FUENMAYOR, 1969, p. 355-366.

Test medium sized, a compact lobate-ovate coil. On spiral side a flat embryonic coil is surrounded by, and usually projects above, a low spire of ellipsoidal chambers which increase in size slowly as added. Consistently 4 chambers in final whorl. On umbilical side final chambers surround a rectangular umbilicus bridged by a bulla. Sutures radial, initially faint, flush but later distinct, lightly incised. Spiral profile somewhat lobate; side profile ovate, height about two-thirds of diameter. Bulla variable but generally subrectangular and not highly inflated. Only visible apertures at least 2 and up to 4 simple arches between bulla and sutural depressions. Surface distinctly and commonly coarsely cancellate. Diameter to 0.6 mm.

Discussion.—For stratigraphic purposes we find it satisfactory to use *Catapsydrax dissimilis* as an inclusive name for forms with a simple bulla having at least two openings into the umbilicus. BLOW & BANNER (1962) used minor variations of the bulla to define (under *Globigerinita*) several new species and subspecies, mostly given shorter ranges than *C. dissimilis*, but in the present compilation we did not confirm their validity (see also SOEDIONO, 1969). An exception is *Catapsydrax howei*, distinguished by a large strongly inflated bulla and apparently restricted to the Late Eocene.

Distribution.—Although long ranging, *Catapsydrax dissimilis* is distinctive, widespread, and tolerant of facies variation, so it has been used in several zonal schemes. It ranges from Middle Eocene to Early Miocene (within *Orbulinoides beckmanni* Zone to top of *Catapsydrax stainforthi* Zone) and may serve as a guide to Oligocene age in the absence of index species of either Eocene or Miocene.

GLOBIGERINA EOCAENA Gümbel, 1868, emended Hagn & Lindenberg, 1966

Figure 115

Eocene and early Oligocene

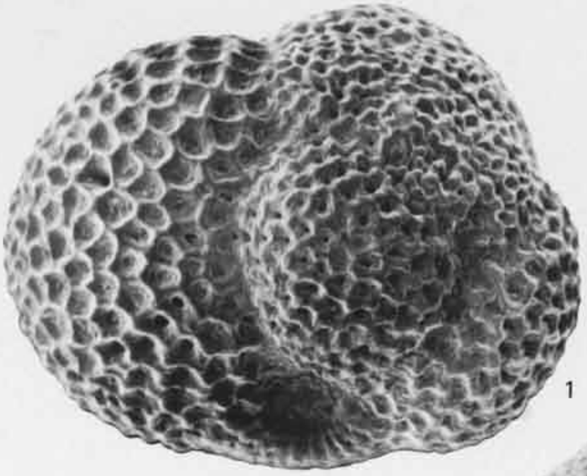
Globigerina eocaena GÜMBEL, 1868, p. 662, pl. 2, fig. 109.—COLE, 1928, p. 17, pl. 1, fig. 20.—CITA, 1950, p. 94, pl. 8, fig. 1.—BERMÚDEZ, 1960, p. 1178, pl. 3, fig. 4.—LINDENBERG, 1969, p. 343-365, fig. 2-11.

Globigerina (Subbotina) eocaena GÜMBEL. HAGN & LINDENBERG, 1966, p. 342-358, fig. 1-4, pl. 1.—HAGN & LINDENBERG, 1969, p. 236-245, pl. 1, fig. 1 [neotype refigured], 2-6.

Globigerina yeguaensis WEINZIERL & APPLIN, 1929, p. 408, pl. 43, fig. 1.—BOLLI, 1957c, p. 163, pl. 35, fig. 14-?15.—BERMÚDEZ, 1960, p. 1208-1209, pl. 6, fig.

Fig. 114. *Catapsydrax dissimilis* (CUSHMAN & BERMÚDEZ) from the Miocene of Trinidad, Oligocene of Panama, Eocene of Cuba, and Oligocene-Miocene of Trinidad.

1,3-4	Specimens from the Early Miocene part (*Catapsydrax dissimilis* Zone) of the Cipero Formation of Trinidad. **1**—Oblique side view, X140; **3**—umbilical view, X120; **4**—spiral view, X140.
2,8	Unusually large specimens from the Oligocene (*Globorotalia opima opima* Zone) of Panama. **2**—Side view, X120; **8**—umbilical view, X110.
5-6	Holotype **(5)** and paratype **(6)** from the Upper Eocene of Cuba; **5a-b,6**—from CUSHMAN & BERMÚDEZ (1937, pl. 3, fig. 4-6), **5c-e** from BOLLI, LOEBLICH, & TAPPAN (1957, pl. 7, fig. 6). **5a,5c,6**—Umbilical views, X33, X60, X33; **5b,5e**—spiral views, X33, X60; **5d**—side view, X60.
7	Specimen from the Oligocene-Miocene Cipero Formation of Trinidad, X60; from BOLLI, LOEBLICH, & TAPPAN (1957, pl. 7, fig. 8). **a**—Spiral view; **b**—side view; **c**—umbilical view.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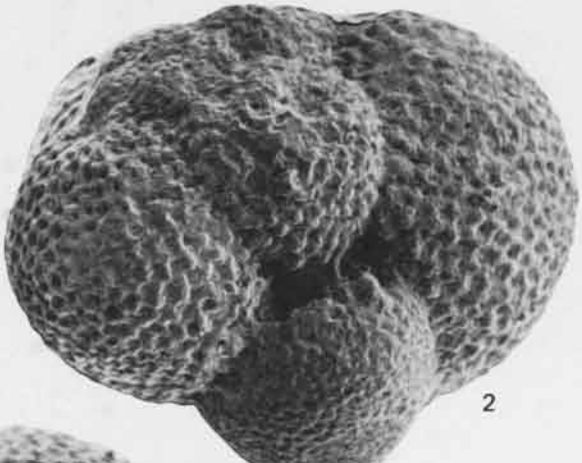
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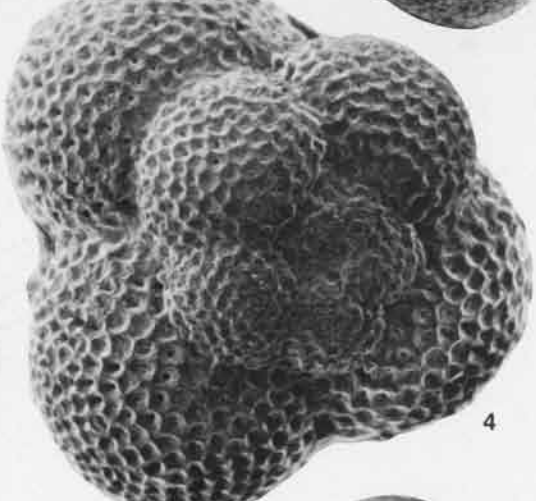
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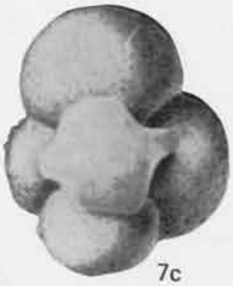
5b


7a


7b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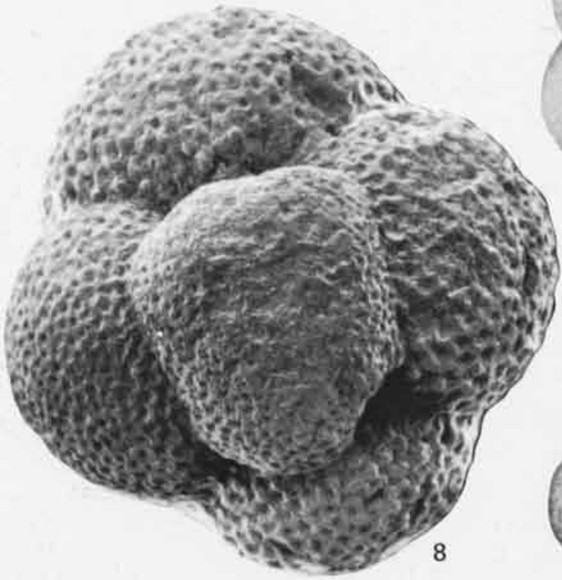
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5c


5e

Fig. 114

5.–BLOW, 1969, p. 319, pl. 3, fig. 12-14 [holotype refigured].–SAMANTA, 1969, p. 332, pl. 3, fig. 7.–SAMANTA, 1970, p. 192, pl. 1, fig. 15-17.

Globigerina yeguaensis yeguaensis WEINZIERL & APPLIN. BLOW & BANNER, 1962, p. 99, 141-144, pl. 13, fig. H-M.

Subbotina yeguaensis (WEINZIERL & APPLIN). SRINIVASAN, 1968, p. 149, pl. 16, fig. 1-3.

Test usually large, a thickset low-spired coil of inflated, ovate to subglobular chambers which increase in size regularly and rather slowly. Final whorl of 3½ to 4 chambers. Shell surface distinctly cancellate. Spiral profile distinctly lobate, side profile nondescript. Sutures clear, deep-set. Umbilicus small and deep. Aperture a low arch with a delicate lip or tooth, usually umbilical but tending to become extraumbilical. Coiling parameters subject to much individual variation. Last chamber often abnormally small and displaced or deformed. Diameter to 0.7 mm, thickness exceeds one-half diameter.

Discussion.–Although referred to by many European authors, the status of this species became dubious because GÜMBEL'S type figures are useless and his types were destroyed. Latterly a neotype was designated by HAGN & LINDENBERG (1966) and the preceding description mainly follows their later figures and text (HAGN & LINDENBERG, 1969). They recognized that it is a difficult form to handle rigidly because it grades morphologically into other named species. For instance, they cited very different opinions expressed about a single specimen by COLE and EMILIANI and, referring to SUBBOTINA'S principal work, they rejected her *Globigerina eocaena* as misidentified but regarded her "new" *G. pseudoeocaena* as a junior synonym of this species.

Our solution is to treat *G. eocaena* as one of the standard forms within the intergradational plexus of the *Globigerina linaperta* group (discussed separately). *Globigerina eocaena* is mainly distinguished by the slow enlargement of its chambers (relative to *G. linaperta* s.s.), the lowness of its spire (relative to *G. corpulenta* and *G. gortanii*), and the shape of its adult chambers, which do not become noticeably appressed or axially prolonged (relative to *G. venezuelana*). Under this scheme the distinction between *G. eocaena* and *G. yeguaensis* becomes too tenuous to maintain, so that the latter is regarded as a subjective junior synonym. This decision appears justified by reference to the holotype of *G. yeguaensis*, conveniently refigured by BLOW (1969), as well as the broad limits given to this species in modern American literature. BERMÚDEZ (1960) introduced two species which, though upheld by BLOW (1969), seem too close to *eocaena* to be separated with confidence, namely *Globigerina galavisi* (approaching the *venezuelana* branch) and *Globigerina winkleri* (approaching the *corpulenta-gortanii* lineage).

Distribution.–*Globigerina eocaena* ranges throughout the Eocene and into the early Oligocene and has a cosmopolitan distribution. Its peak of abundance is in late Middle and Late Eocene faunas. The morphologic lineages alluded to above were coexistent through the later Eocene, hence the variability of *G. eocaena* is only related in a very broad way to zonal levels (see LINDENBERG, 1969).

GLOBOROTALIA FOHSI Cushman & Ellisor, 1939, sensu lato

Figures 116-120
Middle Miocene

(Detailed synonymy is given with following subspecies.)

Evolutionary lineage.–The form originally designated *Globorotalia fohsi* now is recognized as central in a well-defined evolutionary sequence (Fig. 116). Consequently most authors apply a subspecific terminology, in essence following the

Fig. 115. *Globigerina eocaena* GÜMBEL from the Eocene of Texas, Trinidad, Bavaria, and Alabama.

1 Specimen (=holotype of *Globigerina yeguaensis*) from the Middle Eocene Claiborne Formation of Texas, X67; from BLOW (1969, pl. 3, fig. 12-14). **a**–Spiral view; **b**–side view; **c**–umbilical view.

2 Specimen from the Late Eocene part (*Globigerinatheka semiinvoluta* Zone) of the Navet Formation of Trinidad, X73; from BOLLI (1957c, pl. 35, fig. 15). **a**–Side view; **b**–spiral view; **c**–umbilical view.

3 Specimen from the Middle Eocene part (*Orbulinoides beckmanni* Zone) of the Navet Formation of Trinidad, X73; from BOLLI (1957c, pl. 35, fig. 14). **a**–Side view; **b**–spiral view; **c**–umbilical view.

4 Neotype from the Upper Eocene of Bavaria, X77; from HAGN & LINDENBERG (1969, pl. 1, fig. 1). **a**–Umbilical view; **b**–spiral view; **c**–side view.

5-7 Specimens from the Late Eocene Pachuta Member of the Yazoo Formation of Alabama. **5**–Side view of specimen lacking final chamber, X130; **6**–umbilical view, X100; **7**–spiral view, X120.

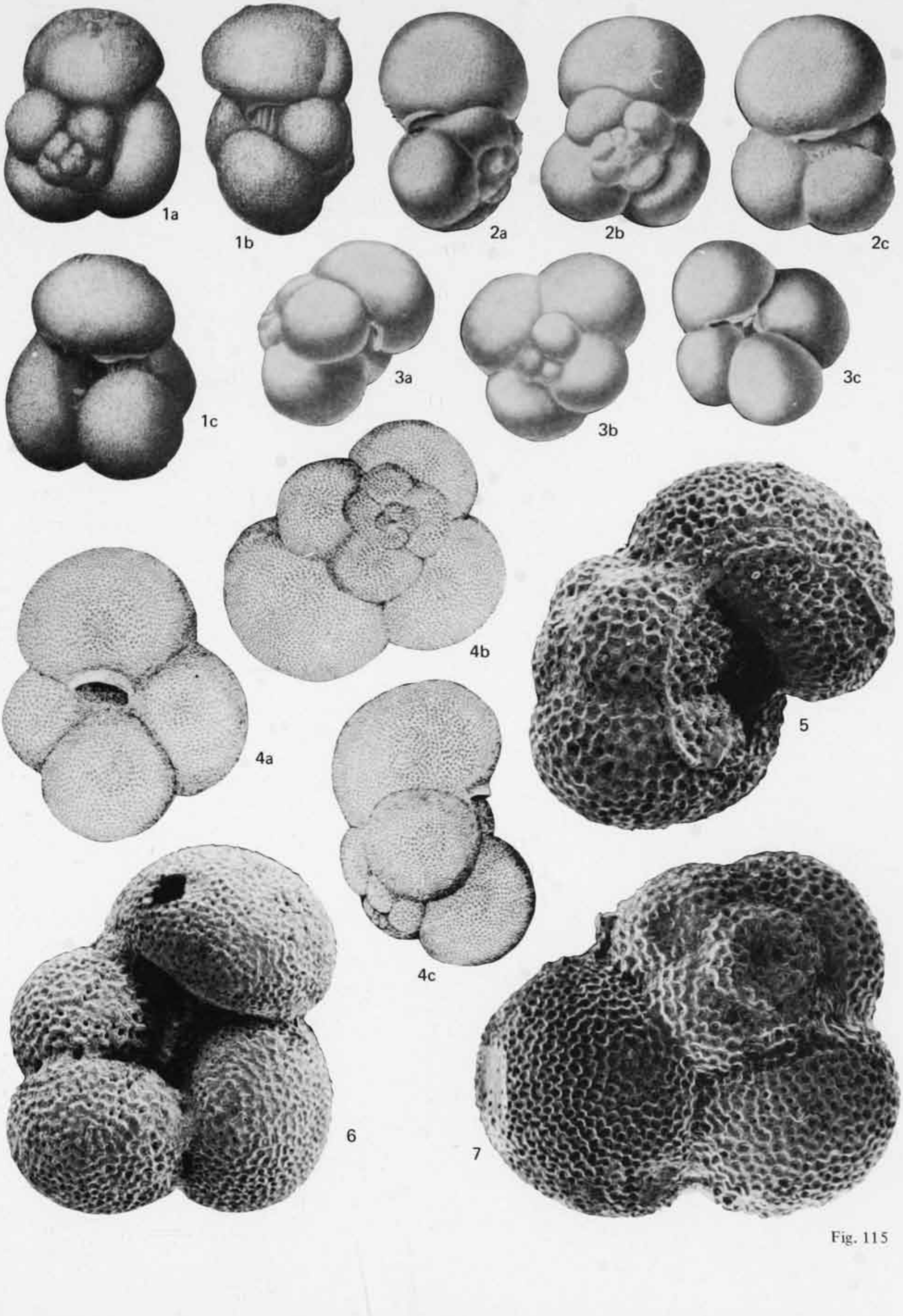

Fig. 115

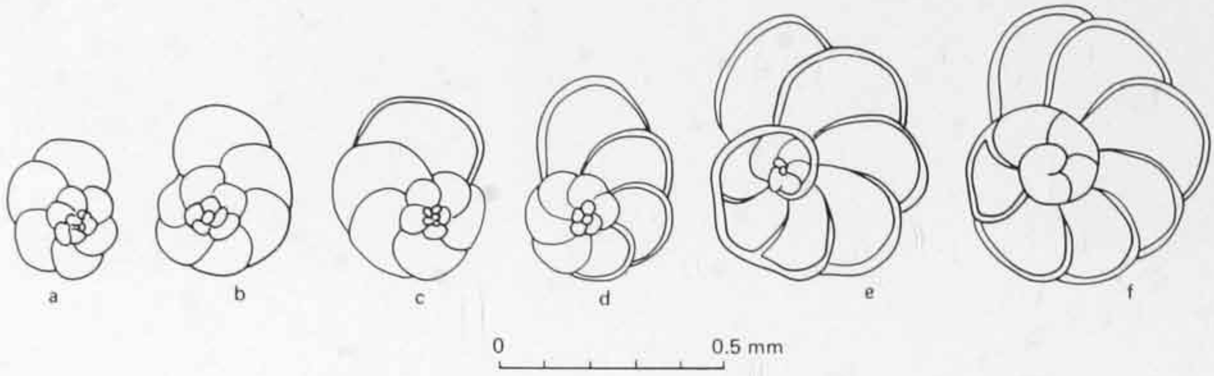

Fig. 116. Evolutionary stages of *Globorotalia fohsi* CUSHMAN & ELLISOR. Line drawings from published figures adjusted to a uniform magnification. Arranged from left to right in order of stratigraphic appearance. **a**–*Globorotalia fohsi peripheroronda* (=*barisanensis* of authors); **b-d**–*Globorotalia fohsi fohsi* (sensu BOLLI) including the successive stages *peripheroacuta, praefohsi,* and *fohsi* (sensu BLOW & BANNER); **e**–*Globorotalia fohsi lobata;* **f**–*Globorotalia fohsi robusta.* (After BOLLI, 1967, fig. 2.)

recommendations of BOLLI (1950, 1957b) who observed the following stages of evolution:

1. Small, compact, subcircular, 5- to 6-chambered *Globorotalia,* periphery shouldered but bluntly rounded *(barisanensis).*
2. Slightly larger, 6- to 7-chambered form, chambers lengthening radially to produce ovate outline, periphery acute (*fohsi* s.s.).
3. Distinctly larger, 7- to 8-chambered form, adult chambers strongly lobate (cristate), periphery acute and commonly keeled *(lobata).*
4. Similar in size but not lobulate, main characteristic a blunt keel around entire periphery and tendency for sutures to be limbate *(robusta).*

In 1966[1] BLOW & BANNER expressed criticism of BOLLI'S scheme because his demarcation between subspecies was indefinite, hence zonation based on their first appearances was imprecise. They proposed to use the stages of evolutionary development of a keel as the main basis for subdivision, thus:

1. Bluntly rounded periphery *(peripheroronda).*
2. Acute periphery, no keel whatever *(peripheroacuta).*
3. Acute periphery, becoming keeled on later chambers *(praefohsi).*
4. Outer whorl completely keeled (*fohsi,* emended).

BLOW & BANNER further contended that the two end forms in BOLLI'S scheme *(lobata* and *robusta)* are mere morphologic variants of the fully carinate stage. BOLLI (1967) responded to BLOW & BANNER'S critique, accepting some of their points but rejecting others, and BLOW (1969) made further reference to the problems.

Nomenclature.–Published discussions of appropriate nomenclature for the *Globorotalia fohsi* lineage are lengthy and involved; crucial points are as follows:

a) The primitive form appears identical with *Globorotalia barisanensis* as figured and described by LeROY (1939) so that name

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[1] The new names appeared as nomina nuda in BANNER & BLOW (1965b) but were not available as a part of zoologic nomenclature until properly proposed in 1966.

was applied with subspecific rank for many years. Eventually, however, BLOW & BANNER (1966) checked LEROY'S holotype and found it to be a completely different, fully carinate form. To resolve the difficulty they introduced the new trivial name *peripheroronda* for the subspecies hitherto known as *barisanensis*.

b) Whereas BOLLI (1950, 1957b) included a broad range of lenticular forms in the nominate subspecies, *Globorotalia fohsi fohsi*, BLOW & BANNER (1966) restricted the undivided species *Globorotalia fohsi* to fully carinate specimens. The reason given was that re-examination of the holotype showed it to be carinate. BOLLI (1967) challenged this assertion on the basis of the original figures of CUSHMAN & ELLISOR (1939) as well as BLOW & BANNER'S new illustrations, but CIFELLI (1968) confirmed presence of a complete keel.

c) BLOW & BANNER introduced the names *Globorotalia peripheroacuta* and *Globorotalia praefohsi* for the unkeeled and partly keeled forms, respectively, included in *Globorotalia fohsi fohsi* by BOLLI.

d) BOLLI (1967) pointed out that an abrupt increase in average size is a diagnostic feature of the later forms (subspecies *lobata* and *robusta*). This useful criterion (Fig. 116) was not utilized by BLOW & BANNER. OLSSON (1972) suggested that it might signalize the worldwide onset of a warm episode during the Middle Miocene.

e) BLOW & BANNER (1966) dropped subspecific nomenclature and gave full specific rank to *Globorotalia peripheroronda*, *G. peripheroacuta*, *G. praefohsi*, and *G. fohsi* (emended); the latter including the formae *lobata* and *robusta*. Futhermore, they placed the first two (noncarinate) species in the subgenus *Turborotalia* and the second two in the subgenus *Globorotalia* s.s.. This revision destroyed the sense of evolutionary continuity conveyed by treating all the forms as subspecies of *Globorotalia fohsi* and thus was criticized sharply by JENKINS (1966a), BOLLI (1967), BECKMANN ET AL. (1969), and others.

f) BOLLI (1967) expressed willingness to accept the new names of BLOW & BANNER (1966) as subspecies of *Globorotalia fohsi*. In particular he recognized *Globorotalia fohsi peripheroacuta* and *G. f. praefohsi* as indices whose levels of first appearance are serviceable in defining subzones. On the other hand, BOLLI rejected relegation of the more advanced forms *Globorotalia fohsi lobata* and *G. f. robusta* to mere formae of *Globorotalia fohsi* (forma typica) as proposed by BLOW & BANNER. Regarding this point, BOLLI commented with justice that BLOW & BANNER were inconsistent in picking on minor distinctions to define two new species at the same time as lumping the distinctive *lobata* and *robusta* together with fully carinate *Globorotalia fohsi*.

g) BOLLI'S discussion (1967) leaves uncertain his criteria for separating the nominate subspecies, *Globorotalia fohsi fohsi*, from the other named forms. His remarks seem to imply that, if the holotype of *Globorotalia fohsi* CUSHMAN & ELLISOR is fully keeled (as subsequently verified by CIFELLI, 1968), the nominate subspecies should be restricted to such forms. His recognition of the subspecies *peripheroacuta* and *praefohsi* is further evidence of such intent. On the other hand BOLLI retained the name of the *Globorotalia fohsi fohsi* Zone in its original sense for an interval which terminates well below the first appearance of fully keeled specimens.

In our opinion the main cause of confusion is that, being based on independent sets of objective criteria (shape and size versus degree of development of a keel), the nomenclatures of BOLLI and of BLOW & BANNER are incompatible and paleontologists must choose one or the other. The priority of BOLLI'S zonation deserves respect which is not offset by any demonstrable superiority of the new scheme. We, therefore, prefer to recognize only four subspecies named (from more primitive to more advanced forms) *Globorotalia fohsi peripheroronda*, *Globorotalia fohsi fohsi*, *Globorotalia fohsi lobata*, and *Globorotalia fohsi robusta*. Presence or absence of a keel is not a diagnostic feature of the nominate subspecies, therefore we treat the names *peripheroacuta* and *praefohsi* as infrasubspecific.

Occurrence.—Presence of any element of the *Globorotalia fohsi* lineage is a useful guide to mid-Miocene age. In warm-water tropical faunas the presence of *G. f. peripheroronda* without more advanced forms defines the late Early to early Middle Miocene and the successive advent of the later forms is applicable to division of the mid-Middle Miocene. The interval between incipience of *G. f. fohsi* and extinction of *G. f. robusta* has been termed the *Globorotalia fohsi* Zone (s.l.).

Caution is needed, however, in faunas of cooler waters, where the more advanced forms may not appear. This can happen even in tropical latitudes under the influence of cool currents (e.g., Ecuador; see STAINFORTH, 1948b). There is also some evidence that the local distribution of *G. f. lobata* and *G. f. robusta* is subject to ecologic control and that their sequential appearance in Trinidad (BOLLI, 1950, 1957b) is not a general rule. It has been suggested that in cooler waters the normal offshoots of *G. f. peripheroronda* were unkeeled forms such as *Globorotalia mayeri* or *Globorotalia miotumida* (see JENKINS, 1960, 1971; WADE, 1964; BLOW, 1969).

In early references some confusion may be encountered, as the type level of *Globorotalia fohsi* in Louisiana was recorded as Miocene, whereas subsequent reports of it around the Caribbean region were from levels then regarded as Oligocene. The discrepancy has been eliminated by more recent interregional studies, and ages of the species and its subspecies are now generally accepted as given here. The original holotype-locality data were queried by BUTLER ET AL. (1968), but their doubts have been dispelled by BARKER & BROWN (1968).

GLOBOROTALIA FOHSI FOHSI Cushman & Ellisor, 1939

Figure 117

Middle Miocene

Globorotalia fohsi CUSHMAN & ELLISOR, 1939, p. 12, pl. 2, fig. 6.—PALMER, 1941, p. 291, pl. 29, fig. 3.—CUSHMAN & STAINFORTH, 1945, p. 70, pl. 13, fig. 13.—RENZ, 1948, p. 137, pl. 11, fig. 2.—BERMÚDEZ, 1949, p. 285, pl. 22, fig. 18-20.

Globorotalia barissanensis [sic] LEROY. LEROY, 1944, p. 41, pl. 2, fig. 43-45.—CUSHMAN & STAINFORTH, 1945, p. 70, pl. 13, fig. 15.

Globorotalia fohsi fohsi CUSHMAN & ELLISOR. BOLLI, 1950, p. 88, pl. 15, fig. 4.—BOLLI, 1957b, p. 119, pl. 28, fig. 9-10.—BLOW, 1959, p. 212, pl. 17, fig. 112.—BOLLI, 1967, p. 508, fig. 2.—BECKMANN ET AL., 1969, p. 101.

Globorotalia (Turborotalia) fohsi fohsi CUSHMAN & ELLISOR. BANNER & BLOW, 1959, p. 22, pl. 1, fig. 2.—EAMES ET AL., 1962, p. 161.

* *Globorotalia (Globorotalia) fohsi* CUSHMAN & ELLISOR. BLOW & BANNER, 1966, p. 290-292, pl. 1, fig. 5-7 [holotype redrawn]; pl. 2, fig. 8-9, 12.—JENKINS, 1971, p. 88, pl. 4, fig. 108-110.—BIELY & SALAJ, 1971, p. 86, 88, 90.

* *Globorotalia (Turborotalia) peripheroacuta* BLOW & BANNER, 1966, p. 294-295, pl. 1, fig. 2; pl. 2, fig. 4-5, 13.—BLOW, 1969, p. 232-238, 353.

* *Globorotalia (Globorotalia) praefohsi* BLOW & BANNER, 1966, p. 295-296, pl. 1, fig. 3-4; pl. 2, fig. 6-7, 10-11.—BLOW, 1969, p. 231-238, 358.—BIELY & SALAJ, 1971, p. 83-90.

* *Globorotalia fohsi peripheroacuta* BLOW & BANNER. BOLLI, 1967, p. 508, fig. 2.—BECKMANN ET AL., 1969, p. 101.

* *Globorotalia fohsi praefohsi* BLOW & BANNER. BOLLI, 1967, p. 505-508, fig. 2.

Globigerina fohsi foshi CUSHMAN & ELLISOR [sic]. HOFKER, 1968, p. 50.

* *Turborotalia peripheroacuta* BLOW & BANNER. LIPPS, 1969, p. 1806, fig. 4.

* *Turborotalia (Turborotalia) peripheroacuta* BLOW & BANNER. BIELY & SALAJ, 1971, p. 83, 90.

*Names that are partial synonyms of *Globorotalia fohsi fohsi* as accepted here, sensu BOLLI.

Test a discoidal to lenticular trochospire, umbilical side slightly more convex than spiral; 5 to 7 chambers in final whorl. In side profile periphery forms an acute angle with rounded tip. Sutures distinct, lightly incised, recurved on spiral surface, almost radial on umbilical surface. Aperture a slit from closed umbilicus to periphery, bordered by a thin, flange-like lip. Surface smooth, densely perforated by fine pores. This subspecies shows evolutionary traits, with more advanced forms tending 1) to display more rapid increase in size of successive chambers, especially their radial length, resulting in a change from subcircular to ovate or ear-shaped outline, and 2) to develop an imperforate

Fig. 117. *Globorotalia fohsi fohsi* CUSHMAN & ELLISOR from the Middle Miocene part of the Cipero Formation of Trinidad.

1-9 Specimens selected to show evolutionary development, X150. **1,4,6**—Side views showing increasing size and increasingly acute (eventually carinate) periphery; **2,5,8**—spiral views showing increasing size and also change from subcircular to earshaped outline which is associated with radial lengthening of chambers; **3,7,9**—umbilical views showing the same features as **2,5,** and **8.**

⇨

Fig. 117

keel on later chambers and occasionally around entire final whorl. Diameter to 0.5 mm.

Discussion.—The early forms of this subspecies are distinguished from the ancestral *peripheroronda* by their more angular peripheral profile. The later forms further differ from *peripheroronda* in their longer final chambers and tendency to become keeled, and from the more advanced subspecies *lobata* and *robusta* in their smaller size, but also in their usual lack of limbate sutures. Small specimens with lobulate peripheries are, for stratigraphic use, better treated as variants within *Globorotalia fohsi fohsi* than as diminutive *G. f. lobata.*

This treatment follows BOLLI (1950, 1957b) and not BLOW & BANNER (1966), who emended the name *fohsi* to apply only to fully carinate forms. As recognized here, *Globorotalia fohsi fohsi* sensu BOLLI includes *G. peripheroacuta, G. praefohsi,* and part of *G. fohsi* (emended) of BLOW & BANNER. In practice the distinction between partly and wholly keeled specimens is by no means easy (see BLOW, 1970, p. 259-260), hence the scheme proposed by BLOW & BANNER offers little, if any, advantage over the long-established scheme of BOLLI.

Distribution.—Mid-Middle Miocene, where its short range and evolutionary status render it a valuable zonal index in warm-water regions.

GLOBOROTALIA FOHSI LOBATA Bermúdez, 1949

Figure 118

Middle Miocene

Globorotalia lobata BERMÚDEZ, 1949, p. 286, pl. 22, fig. 15-17.—BERMÚDEZ, 1950, p. 342.

Globorotalia dominicana BERMÚDEZ, in THALMANN, 1950, p. 42; suppressed in THALMANN, 1951, p. 225.

Globorotalia fohsi lobata BERMÚDEZ. BOLLI, 1950, p. 88, pl. 15, fig. 7-8.—BOLLI, 1957b, p. 119, pl. 28, fig. 13-14.—BLOW, 1959, p. 213, pl. 16, fig. 113.—BOLLI, 1967, p. 508, fig. 2.

Globorotalia (Globorotalia) lobata lobata BERMÚDEZ. BANNER & BLOW, 1959, p. 22, pl. 1, fig. 3.

Globorotalia (Globorotalia) fohsi forma *lobata* BERMÚDEZ. BLOW & BANNER, 1966, p. 293, fig. 4 [original types redrawn].—BLOW, 1969, p. 239-241, 362.

Globorotalia lobata lobata BERMÚDEZ. LIPPS, 1967, p. 995-997.—BERGGREN, 1968, p. 1-22, fig. 3.

Test a lenticular trochospire with a lobate to cristate periphery. Final whorl contains 6 to 8 chambers, of which irregular radial prolongations give rise to distinctive cockscomb outline. Sutures on spiral side recurved, limbate, coalescing into a keel of clear shell material; on umbilical side incised, radial. Umbilicus slightly open. Aperture a slit from umbilicus to margin, with a small flange-like lip. Surface mostly smooth, finely perforate, but umbilical area often pustulose. Diameter typically 0.6 to 0.7 mm.

Discussion.—Specimens of the subspecies *lobata* are distinctly larger than those of *fohsi* s.s. and also consistently have limbate dorsal sutures and a well-developed keel and limbate sutures on the spiral side. The markedly lobate outline distinguishes *lobata* from the almost circular *robusta.*

Largely on the basis of the pattern of distribution in the Cipero Formation of Trinidad, BOLLI (1950-1967) has consistently postulated that the subspecies *lobata* is a normal element within the *Globorotalia fohsi* lineage. Nevertheless, it appears odd that, in a linear evolution, this form with a lobate to cristate outline should intervene between ovate to circular subspecies, namely *fohsi* s.s. and *robusta.* While picking specimens from Trinidad for the present study, it was noticed that many specimens of *lobata* contain twisted and deformed chambers, suggestive of an inimical environment and giving some support to suggestions (BLOW & BANNER, 1966; BLOW, 1969) that *lobata* and *robusta* may be ecologic variants of a single form.

Distribution.—Middle Miocene. For the reason indicated above, some doubt is felt as to reliability of *Globorotalia fohsi lobata* as the index of a range zone. On the other hand the joint range of *G. f. lobata* and *G. f. robusta* is diagnostic of a short interval in the late Middle Miocene.

GLOBOROTALIA FOHSI PERIPHEROACUTA Blow & Banner, 1966

Middle Miocene

Globorotalia (Turborotalia) peripheroacuta BLOW & BANNER, 1966, p. 294, pl. 1, fig. 2; pl. 2, fig. 4-5, 13.—BLOW, 1969, p. 232-238, 353.

Globorotalia fohsi peripheroacuta BLOW & BANNER. BOLLI, 1967, p. 508, fig. 2.—BECKMANN ET AL., 1969, p. 101.

Turborotalia peripheroacuta BLOW & BANNER. LIPPS, 1969, p. 1806, fig. 4.

Turborotalia (Turborotalia) peripheroacuta BLOW & BANNER. BIELY & SALAJ, 1971, p. 83, 90.

For those who choose to follow BLOW & BANNER (1966) in classifying the *Globorotalia fohsi* lineage on degree of development of a keel, this is the second stage of evolution, characterized by a more acute periphery than the primitive subspecies *peripheroronda* but lacking any sign of a keel. For those who retain BOLLI'S classification based on shape and size, it is an infrasubspecific variant of *Globorotalia fohsi fohsi.* Additional details are given under discussion of nomenclature for *G. fohsi.*

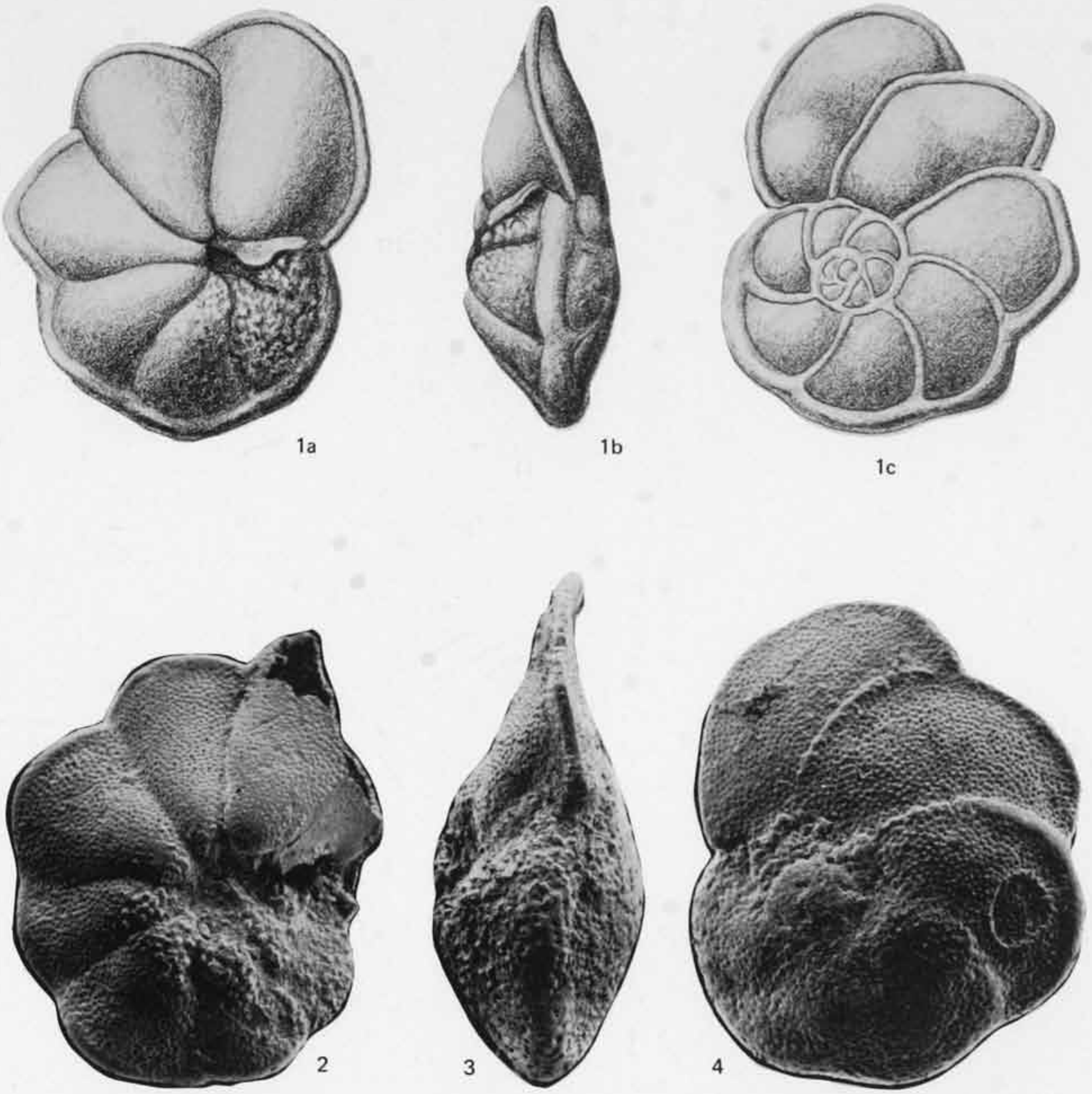

Fig. 118. *Globorotalia fohsi lobata* BERMÚDEZ from the Middle Miocene of Dominican Republic and Trinidad.

1 Holotype from the Trinchera Formation of the Dominican Republic, X100; from BLOW & BANNER (1966, fig. 4, no. 1). **a**–Umbilical view; **b**–side view; **c**–spiral view.

2-4 Specimens from the *Globorotalia fohsi lobata-robusta* Zone in the Cipero Formation of Trinidad. **2**–Umbilical view (last chamber broken), X90; **3**–edge view, X110; **4**–spiral view, X100.

GLOBOROTALIA FOHSI PERIPHERORONDA

Blow & Banner, 1966
Figure 119
Early and Middle Miocene

Globorotalia barisanensis LEROY, 1939, p. 265, pl. 1, fig. 8-10 [figures only, not holotype; see BLOW & BANNER, 1966].–STAINFORTH, 1948b, p. 120, pl. 26, fig. 24-26.–WEISS, 1955, p. 310, pl. 3, fig. 4-6.

Globorotalia fohsi barisanensis LEROY. BOLLI, 1950, p. 88, pl. 15, fig. 5-6.–BOLLI, 1957b, p. 119, pl. 28, fig. 8.–BLOW, 1959, p. 212, pl. 17, fig. 110-111.

Globorotalia (Turborotalia) fohsi barisanensis (LEROY). BANNER & BLOW, 1959, p. 22, pl. 1, fig. 1.

Globorotalia (Turborotalia) peripheroronda BLOW & BANNER, 1966, p. 294, pl. 1, fig. 1; pl. 2, fig. 1-3.–BLOW, 1969, p. 230-233, 354.

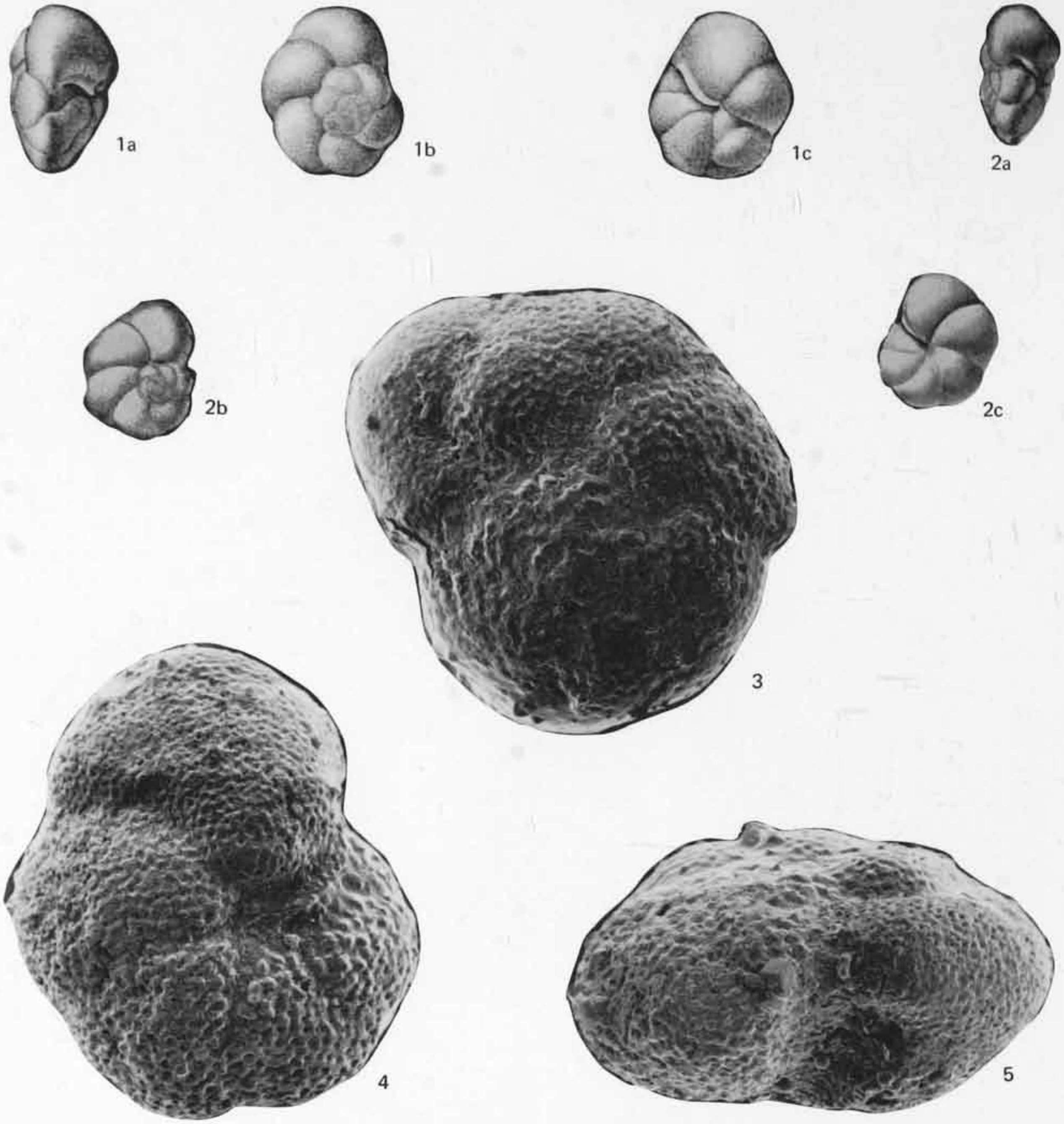

Fig. 119. *Globorotalia fohsi peripheroronda* BLOW & BANNER from the Miocene of Venezuela and Trinidad.

1 Holotype from the Middle Miocene part of the Pozón Formation of Venezuela, X87; from BLOW & BANNER (1966, pl. 1, fig. 1). **a**–Side view; **b**–spiral view; **c**–umbilical view.

2 Specimen from the Middle Miocene part (*Globorotalia fohsi peripheroronda* Zone) of the Cipero Formation of Trinidad, X68; from BOLLI (1957b, pl. 28, fig. 8). **a**–Side view; **b**–spiral view; **c**–umbilical view.

3-5 Specimens from the Early Miocene part (*Globigerinatella insueta* Zone) of the Cipero Formation of Trinidad, X150. **3**–Spiral view; **4**–umbilical view; **5**–side view.

Turborotalia peripheroronda BLOW & BANNER. LIPPS, 1967, p. 996.–LIPPS, 1969, p. 1805, fig. 4.
Globorotalia fohsi peripheroronda BLOW & BANNER. BOLLI, 1967, p. 505-508, fig. 2.–BECKMANN ET AL., 1969, p. 101.
Globigerina barisanensis LEROY [sic]. HOFKER, 1968, p. 49-50, pl. 24, fig. 4-5.
Globorotalia peripheroronda. PUJOL, 1970, p. 201-219.
Turborotalia fohsi peripheroronda (BLOW & BANNER). SOEDIONO, 1970, p. 217, pl. 1, fig. 1.
Globorotalia (Turborotalia) mayeri barisanensis LEROY. JENKINS, 1971, p. 119, pl. 11, fig. 288-293.
Turborotalia (Turborotalia) peripheroronda BLOW & BANNER. BIELY & SALAJ, 1971, p. 76-89.

Test a discoidal trochospire, umbilical side more convex than spiral; 5 to 6 chambers in final whorl. Spiral profile subcircular, tending to become slightly lobulate; side profile shows a definite, though bluntly rounded, shoulder. In umbilical aspect sutures distinct, lightly incised, initially radial but becoming curved; in spiral aspect sutures indistinct on initial portion, later distinct and commonly incised, recurved, defining comma-shaped to crescentic chambers. Aperture a slit from umbilicus to periphery, bordered by a thin, flange-like lip. Diameter 0.3 to 0.35 mm.

Discussion.–This subspecies formerly was widely recorded under the name *barisanensis* based on the **type figure** of *Globorotalia barisanensis* LEROY. In 1966, however, BLOW & BANNER demonstrated that LEROY'S holotype is a distinctly different (carinate) form and they introduced the descriptive name *peripheroronda* to rectify the nomenclature. Later authors have accepted this revision, but vary between ranking the blunt-edged form as a distinct species or as a subspecies of *Globorotalia fohsi*. We prefer the latter course, so that the nomenclature reflects the close interlinkage within this stratigraphically important group of planktonic foraminifers.

Globorotalia fohsi peripheroronda is the most primitive element of the *G. fohsi* lineage. (Morphologically and stratigraphically, *Globorotalia kugleri* could be its direct ancestor, but the literature contains little comment on this possibility.) To avoid any confusion with immature specimens of more advanced forms, the stereoscan photographs herewith show specimens from the *Globigerinatella insueta* Zone of Trinidad below the level of first appearance of *G. fohsi fohsi*, from which *G. f. peripheroronda* is distinguished by its blunt periphery.

Distribution.–Early to Middle Miocene (approximately *Catapsydrax dissimilis* Zone to within *Globorotalia fohsi lobata/robusta* Zone). LEROY first figured this form from the Miocene of Sumatra and its holotype is from the Miocene Pozón Formation of north-central Venezuela.

GLOBOROTALIA FOHSI PRAEFOHSI Blow & Banner, 1966

Figure 116c
Middle Miocene

Globorotalia (Globorotalia) praefohsi BLOW & BANNER, 1966, p. 295, pl. 1, fig. 3-4; pl. 2, fig. 6-7, 10-11.–BLOW, 1969, p. 231-238, 353.–BIELY & SALAJ, 1971, p. 83-90.
Globorotalia fohsi praefohsi BLOW & BANNER. BOLLI, 1967, p. 505-508, fig. 2.

For those who choose to follow BLOW & BANNER (1966) in classifying the *Globorotalia fohsi* lineage on degree of development of a keel, this is a partly keeled form intermediate between the unkeeled subspecies *peripheroacuta* and the fully carinate nominate subspecies, *fohsi* s.s.. For those who retain BOLLI'S classification based on shape and size, it is an infrasubspecific variant of *Globorotalia fohsi fohsi*. Additional details are given under discussion of nomenclature for *G. fohsi*.

GLOBOROTALIA FOHSI ROBUSTA Bolli, 1950

Figure 120
Middle Miocene

Globorotalia fohsi robusta BOLLI, 1950, p. 89, pl. 15, fig. 3.–BOLLI, 1957b, p. 119, pl. 28, fig. 16.–BLOW, 1959, p. 213, pl. 16, fig. 114.–BOLLI, 1967, p. 508, fig. 2.
Globorotalia (Globorotalia) lobata robusta (BOLLI). BANNER & BLOW, 1959, p. 22, pl. 1, fig. 4.
Globorotalia (Globorotalia) fohsi forma *robusta* BOLLI. BLOW & BANNER, 1966, p. 293, pl. 2, fig. 9.–BLOW, 1969, p. 239-242, 363.
Globorotalia fohsi CUSHMAN & ELLISOR. POSTUMA, 1971, p. 322-323.

Test a discoidal trochospire, spiral side slightly convex, umbilical side inflated, tending to be subconical; 6 to 8 chambers in final whorl. Spiral profile a smooth circular curve, seldom indented between chambers; side profile reveals blunt keel. Sutures on spiral side limbate, merging into thick rounded keel; on umbilical side flush to incised, radial, straight to wavy. Umbilicus slightly open, often pustulose. Aperture an open slit from umbilicus to keel, with slight lip. Surface initially smooth, finely perforate, but commonly sheathed by secondary shell material, pustulose or coarsely perforate. Diameter typically 0.6 to 0.8 mm.

Discussion.–The subspecies *robusta* is the largest in the *Globorotalia fohsi* lineage. It differs from *fohsi* s.s. in its more circular outline and prominent limbate keel and from *lobata* mainly in its nonlobate outline but also in its more convex, subconical umbilical side.

Distribution.–Late Middle Miocene. *Globorotalia fohsi robusta* was the short-lived end form of an evolving lineage, hence it is a valuable zonal index. From existing records, however, it appears to have been strictly a tropical form.

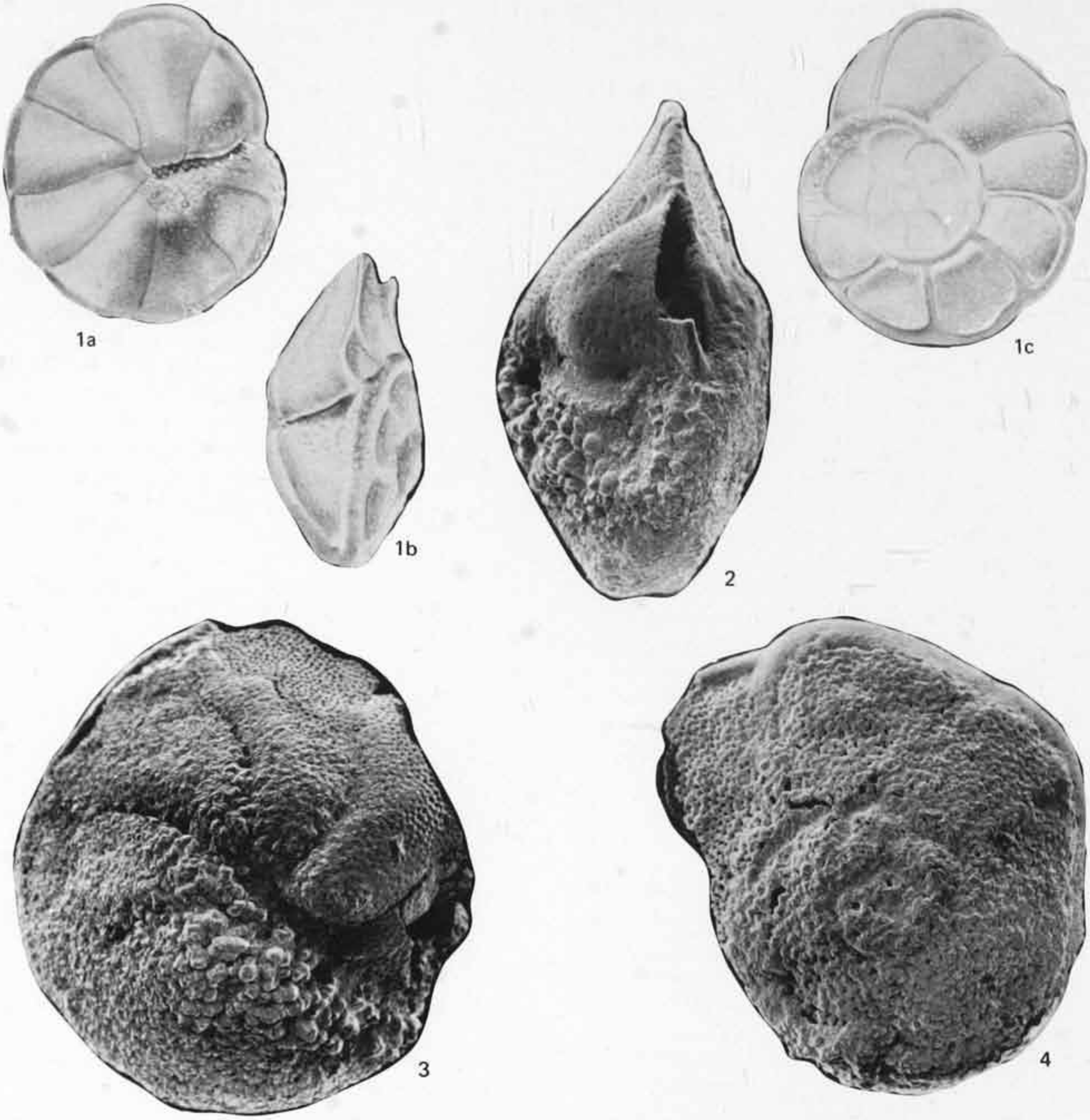

Fig. 120. *Globorotalia fohsi robusta* BOLLI from the Middle Miocene part (*Globorotalia fohsi lobata-robusta* Zone) of the Cipero Formation of Trinidad.

1 Paratype, X68; from BOLLI (1957b, pl. 28, fig. 16). **a**–Umbilical view, **b**–side view; **c**–spiral view.

2-4 Slightly damaged topotypes. **2**–Side view, X110; **3**–umbilical view, X110; **4**–spiral view, X120.

PRAEORBULINA GLOMEROSA (Blow, 1956)

Figure 121

Late Early Miocene to early Middle Miocene

Globigerinoides glomerosa BLOW, 1956, p. 64-65, fig. 1-2.

Porticulasphaera glomerosa (BLOW). BOLLI, 1957b, p. 115, pl. 27, fig. 2, 7, 8.–BLOW, 1959, p. 202, pl. 14, fig. 85-86.

Globigerinoides glomerosus BLOW. BERMÚDEZ, 1960, p. 1229-1231, pl. 11, fig. 7-11.

Praeorbulina glomerosa (BLOW). OLSSON, 1964, p. 770-771.–BLOW, 1969, p. 333.–JENKINS, 1971, p. 196-198, pl. 23, fig. 665-668.

Candorbulina universa JEDLITSCHKA. LIPPS, 1964, p. 120.

[Most of these references include mention of the subspecies *glomerosa* s.s., *curva*, and *circularis*.]

Test spherical, mostly a single chamber which envelops one-half to three-fourths of initial globigerine portion. Apertures a set of evenly spaced openings confined to suture of final chamber, varying from short slits to large circular pores. Surface finely to coarsely cancellate. Diameter 0.5 to 0.7 mm.

Discussion.–BLOW (1956) postulated the evolutionary lineage *Globigerinoides triloba–G. bisphericus–G. glomerosa* subspp.–*Orbulina suturalis–O. universa*. The morphologic trend was a gradual compaction into spherical form, with the final chamber enveloping progressively more (and eventually all) of the earlier portion, and a concomitant shrinking of the apertures into sutural slits and pores and finally large pores scattered over the test. Later authors have accepted BLOW'S concept, but there have been some changes of name. In particular *Globigerinoides bisphericus* TODD has been replaced by its senior synonym *Globigerinoides sicanus* DE STEFANI; the late pre-*Orbulina* forms were temporarily placed in *Porticulasphaera* (by BOLLI, 1957b, and others) and then became types of the genus *Praeorbulina* proposed by OLSSON in 1964.

BLOW (1956, 1969) recognized three subspecies *curva*, *glomerosa* s.s., and *circularis* within the species *Praeorbulina glomerosa*, distinguished on rather fine differences in their sutural apertures and degree of envelopment. Only slight differences are postulated in their overlapping ranges and we follow POSTUMA (1971), therefore, in considering only *P. glomerosa* sensu lato for stratigraphic purposes. Its immediate ancestor *Globigerinoides sicanus* differs in being less completely enveloped by the final chamber and in having long crescentic-slit apertures. Its immediate descendant *Orbulina suturalis* differs in having large apertural pores scattered around the final spherical chamber as well as along the final suture. The fineness of the distinctions has led some authors to suggest different treatment of the lineage, one example being that LIPPS (1964-1969) equated *Praeorbulina* OLSSON with *Candorbulina* JEDLITSCHKA, a genus which most authors abandoned as a supposed synonym of *Orbulina*.

Distribution.–The presence of *Praeorbulina* is generally thought to typify a short Miocene interval just below the important *Orbulina* Datum and to be valuable in confirming that local first appearances of *Orbulina* do represent this worldwide datum and are not reflecting an ecologic change of later date. *Praeorbulina glomerosa* is the name fossil for this late Early Miocene zone. Nevertheless, some dissent has been expressed by authors who conceive the orbulines as polyphyletic end forms (see, for instance, BANDY, 1966; BANDY, VINCENT, & WRIGHT, 1969; and reply by SOEDIONO, 1967).

GLOBIGERINA GORTANII (Borsetti, 1959)

Figure 122

Oligocene

Globigerina dutertrei D'ORBIGNY. BANDY, 1949, p. 120, pl. 22, fig. 4 [fide BANDY, 1964b, p. 7].

Catapsydrax gortanii BORSETTI, 1959, p. 205-212, pl. 1, fig. 1.

Globigerina turritilina BLOW & BANNER, 1962, p. 98-99, pl. 13, fig. A-G.

Globigerina gortanii (BORSETTI). BLOW & BANNER, 1962, p. 146 [postscript].–SAITO & BÉ, 1964, p. 702-705.–JENKINS, 1964a, p. 606.–SAUNDERS & CORDEY, 1968, p. 179, 181.–BLOW, 1969, p. 208-214, 320, pl. 17, fig. 1-2.–BERGGREN, 1969a, p. 114.–BERGGREN, 1969b, p. 125-127.

Test a helicoid spire of inflated chambers, initially subglobular but becoming ellipsoidal by

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Fig. 121. *Praeorbulina glomerosa* (BLOW) from the late Early Miocene (*Praeorbulina glomerosa* Zone) of Venezuela and Italy. [p. 282]

1-3 Paratypes (**1-3**) from the Pozón Formation of Venezuela showing minor apertural differences on which BLOW based the subspecies *Praeorbulina glomerosa glomerosa* (**1**), *P.g. circularis* (**2**), and *P.g. curva* (**3**), X60 ca.; from BLOW (1956, fig. 1,10-11; fig. 2, 1-4).

4 Specimen from northern Italy, X110.

5-6 Topotypes from the same locality as **1-3** showing sutural apertures, X130.

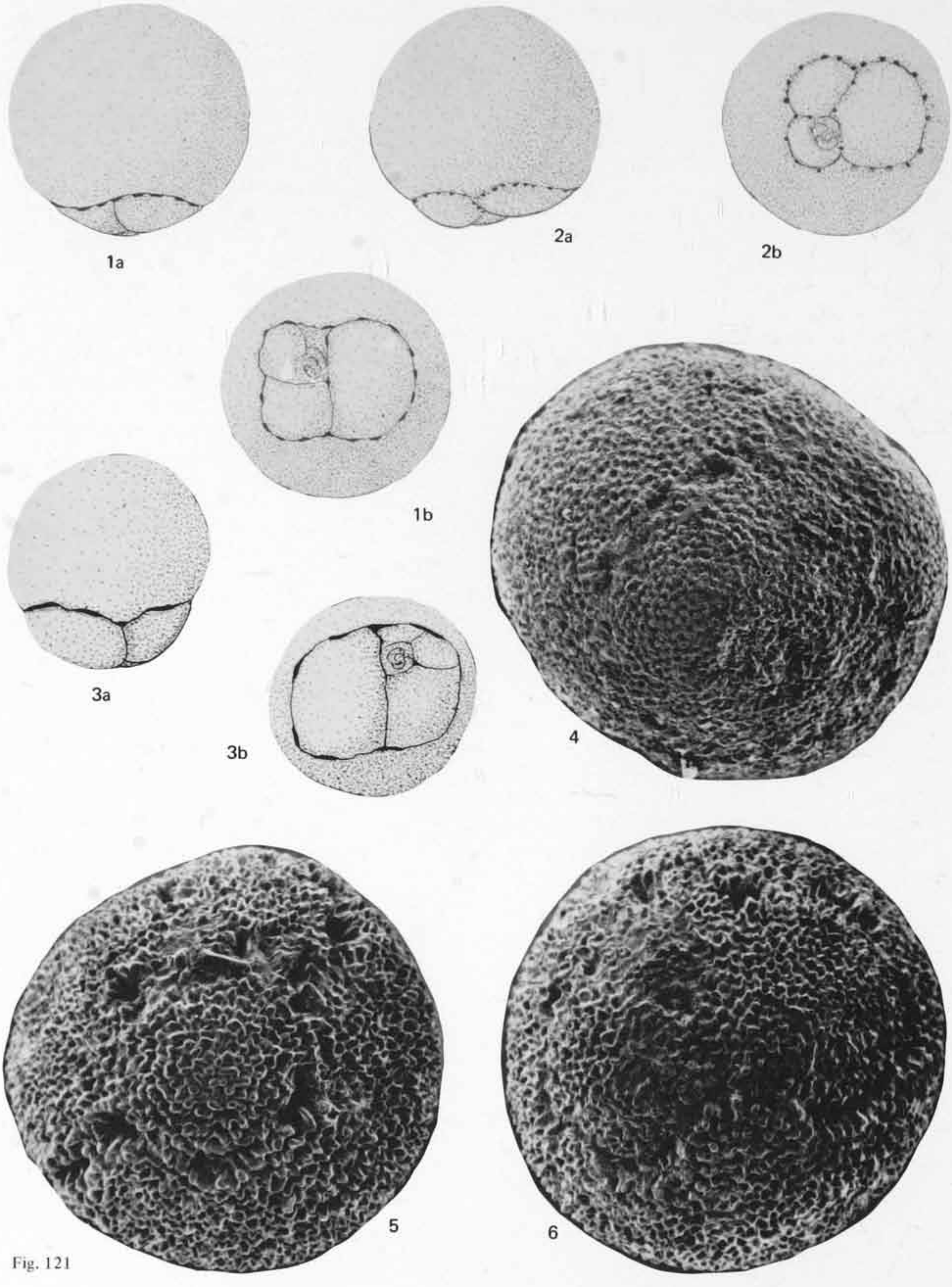

Fig. 121

axial prolongation. Elevation of spire variable but in most specimens unusually lofty for the genus; 4 chambers in final whorl. Spiral profile subquadrate, lobulate, 4 final chambers tending to appear subequal; side profile approximates egg-shape, with early spire conforming to narrower portion, inward curve of successively taller final chambers conforming to broader base of egg. Intercameral sutures subradial, spiral suture lobulate; all distinct. Aperture a simple opening into deep rectangular umbilicus, often concealed but a centrally-thickened lip may be discernible. Final chamber may be aborted, resembling a bulla. Surface medium to coarsely cancellate, developing hispidity around umbilicus. Diameter to 0.7 mm, may be exceeded by height.

Discussion.–The loftiness of its spire distinguishes *Globigerina gortanii* from other species, but this feature was accentuated during growth by axial migration and elongation of successive chambers, so that identification is best based on large, mature specimens. *Globoquadrina altispira* s.l. may be superficially similar but differs in generally larger umbilicus and triangular apertural teeth visible within umbilicus.

Both BORSETTI (1959) and BLOW & BANNER (1962, as *G. turritilina*) illustrated type specimens with a chamberlet across the umbilicus. BORSETTI treated this as a bulla and placed the species in *Catapsydrax*. BLOW & BANNER regarded it as an aborted final chamber, with which we agree. These authors (also BLOW, 1969) recognized a subspecies *(praeturritilina)* which we have not found advantageous to differentiate. Additional comments on the affinities of *G. gortanii* are included in the discussion of the *Globigerina linaperta* group.

Distribution.–The distinctive form and short range of this species make it a useful zonal index. *Globigerina gortanii* s.s. is confined to the Oligocene (though the slightly different subspecies *praeturritilina* is recorded from the Late Eocene). EAMES ET AL. (1962) used absence of *G. gortanii* in American faunas as supporting evidence for their thesis that the Oligocene is widely absent in that region, but the species has subsequently been reported from Alabama, Barbados, Cuba, and elsewhere in America.

GLOBOROTALIA INCREBESCENS (Bandy, 1949)
Figure 123
Late Eocene and early Oligocene

Globigerina increbescens BANDY, 1949, p. 120, pl. 23, fig. 3.–COLTRO, 1963, p. 202, pl. 14, fig. 5.–HOFKER, 1968, p. 18, pl. 8, fig. 1.

Globorotalia (Turborotalia) increbescens (BANDY). BLOW & BANNER, 1962, p. 118, pl. 13, fig. T-V.–LIPPS, 1965, p. 885-886.–BLOW, 1969, p. 349-350, pl. 36, fig. 5-6.–JENKINS, 1971, p. 115, pl. 111, fig. 276-281.

Turborotalia increbescens (BANDY). BERMÚDEZ, 1960, p. 1322, pl. 18, fig. 3-4.

Globorotalia increbescens increbescens (BANDY). BANDY, 1964b, p. 8, 13, fig. 5.

Globorotalia increbescens (BANDY). NICORA, 1971, p. 184, pl. 7, fig. 6.

Test a rather small, compact trochospire. Spiral side shows coil of subelliptical chambers increasing regularly in size, initially 5 but reducing to 4 per whorl. Umbilical side shows 4 inflated chambers whose sutures form a right-angled cross. Spiral outline squarish with rounded corners, indented at sutures; side profile bluntly ovate, thickness about two-thirds of maximum diameter. All sutures distinct, depressed.

Fig. 122. *Globigerina gortanii* (BORSETTI) from the Oligocene of Cuba, Tanzania, and Italy. [p. 284]

1-4 Specimens from the Tinguaro Formation of Cuba, **1**–Spiral view, X130; **2-3**–umbilical views of unusually large and normal specimens, X95, X140; **4**–side view of unusually large specimen, X95.

5 Specimen (=holotype of *Globigerina turritilina*) from Tanzania, X71; from BLOW & BANNER (1962, pl. 13, fig. E-G). **a**–Side view; **b**–spiral view; **c**–umbilical view.

6 Holotype from northern Italy, X70 ca; from BORSETTI (1959, fig. 1). **a**–Umbilical view; **b**–spiral view; **c**–side view.

Fig. 123. *Globorotalia increbescens* (BANDY) from the Late Eocene of Alabama and Tanzania. [p. 285]

1-4,6 Specimens from the Pachuta Member of the Yazoo Formation of Alabama. **1-2**–Spiral view of specimen having damaged final chamber and normal specimen, X140, X130; **3,6**–umbilical views, X120, X140; **4**–side view, X120.

5 Holotype from the top of the Yazoo Formation of Alabama, X50; from BANDY (1949, pl. 23, fig. 3). **a**–Umbilical view; **b**–side view, **c**–spiral view.

7 Specimen from Tanzania, X100; from BLOW & BANNER (1962, pl. 13, fig. T-V). **a**–Spiral view; **b**–side view; **c**–umbilical view.

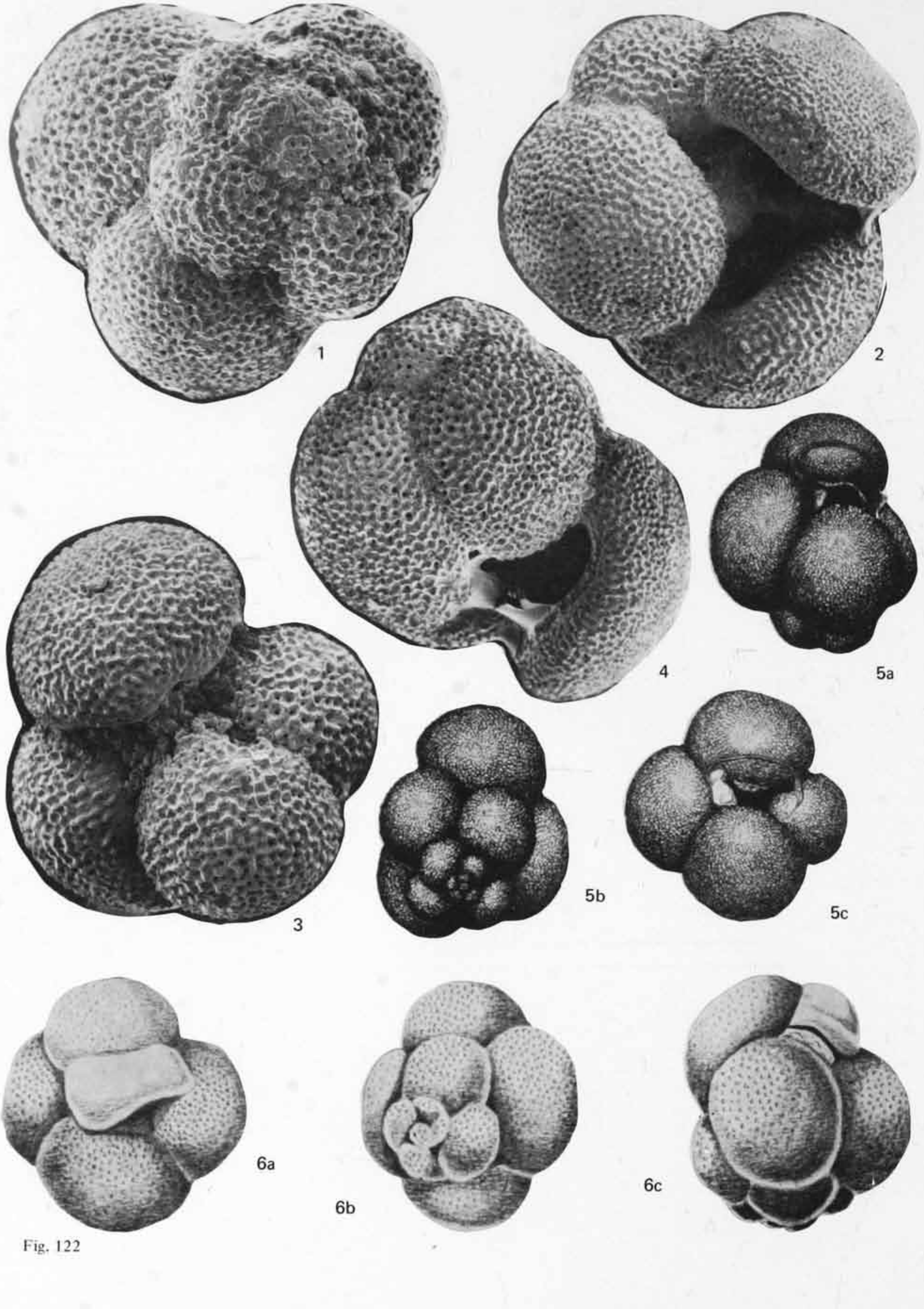

Fig. 122

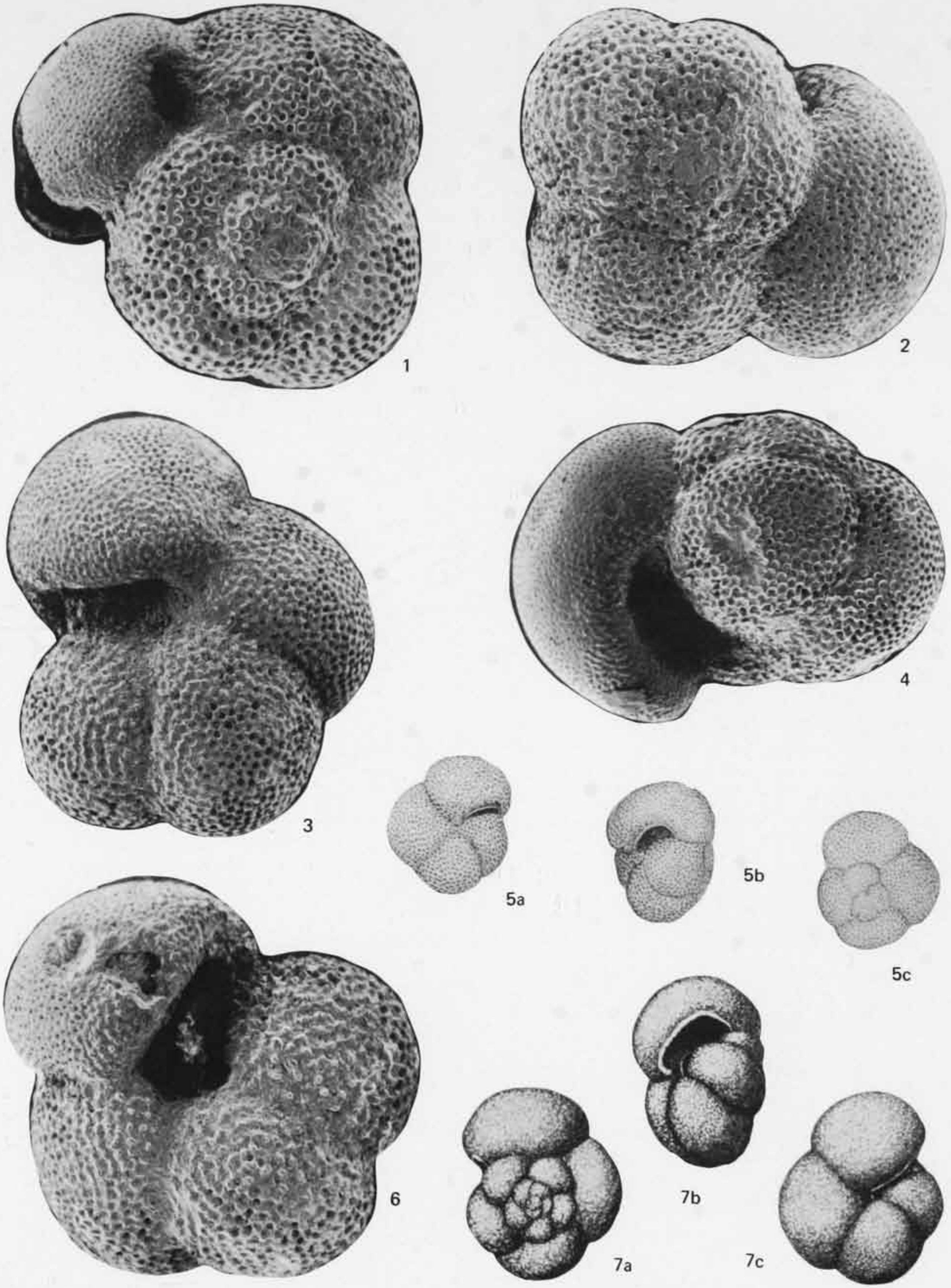

Fig. 123

Aperture a conspicuous arch from axis almost to periphery, directed straight forward along curve of coiling. Surface distinctly and often coarsely cancellate on initial chambers, but becoming progressively less so to extent that final chamber may be smooth and shiny. Diameter 0.3 to 0.4 mm.

Discussion.–*Globorotalia increbescens* undoubtedly evolved gradually into *Globigerina ampliapertura* by swivelling of the apertural arch inwards to bridge the umbilical area and by concomitant enlargement of chambers to produce a more globose test. *Globorotalia increbescens* may itself have branched off from the similar *Globorotalia opima nana* as suggested by BLOW & BANNER (1962), but we consider their apertural differences an adequate basis for maintaining both species (contrary to BERMÚDEZ, 1960).

Attention is drawn to the change of shell texture within individual specimens of *G. increbescens.* It was observed in American material reviewed during this study and is clearly apparent in an African specimen illustrated by BLOW (1969). We feel that this evidence weakens the assertion that shell texture provides a major criterion for distinguishing between some Eocene-Oligocene lineages. In particular it makes the separation of homeomorphic *G. ampliapertura* and *Globigerina pseudoampliapertura* appear dubious.

Distribution.–This species is a reliable guide to Late Eocene or early Oligocene age. The numerical ratio of *Globorotalia increbescens* to its descendant *Globigerina ampliapertura* decreases up-section and may be applied locally to zonation. First recorded from the Upper Eocene Jackson Formation of Alabama.

GLOBIGERINITA INCRUSTA Akers, 1955

Figure 124

Neogene

Globigerinita incrusta AKERS, 1955, p. 655, pl. 65, fig. 2.–(part) BERMÚDEZ, 1960, p. 1264, pl. 7, fig. 3.–BLOW & BANNER, 1962, p. 102, 104.–BLOW, 1969, p. 328, 383, pl. 24, fig. 3.–JENKINS, 1971, p. 184-185, pl. 19, fig. 585-587.

Globigerinita naparimaensis incrusta (AKERS) [sic]. BLOW, 1959, p. 206, pl. 15, fig. 100-101.

Test small, a slightly elevated spire of subglobular chambers which increase regularly in size. Typically 4 chambers in last whorl. Profile variable but usually lobulate in all aspects. Sutures distinct. Umbilical area covered by a bulla, usually mildly inflated, similar in texture to rest of test. Apertures infralaminal, 4 small semicircular openings in bulla at tips of its prolongations along ventral sutures. Shell surface smooth or matte, very finely perforate. Diameter 0.15 to 0.25 mm.

Discussion.–*Globigerinita incrusta* and *Catapsydrax stainforthi* have bullas of similar shape but are distinct in other features, especially their shell texture, respectively smooth and cancellate. *Globigerinita incrusta* appears to be a primitive form from which, by developing variability of the bulla, arose the group of forms here placed under *Globigerinita naparimaensis* (inclusive of *G. glutinata* and *G. ambitacrena* of authors).

Distribution.–*Globigerinita incrusta* first appeared in the basal Miocene (*Globorotalia kugleri* Zone) and is a reliable guide to post-Oligocene age but has no precise zonal significance.

GLOBIGERINATELLA INSUETA Cushman & Stainforth, 1945

Figure 125

Early Miocene

Globigerinatella insueta CUSHMAN & STAINFORTH, 1945, p. 69, pl. 13, fig. 7-9.–BRÖNNIMANN, 1950a, p. 80-82, pl. 13-14.–TODD ET AL., 1954, p. 673-682, pl. 1, fig. 2-3.–BOLLI, LOEBLICH, & TAPPAN, 1957, p. 38, pl. 8, fig. 4-7.–BERMÚDEZ, 1960, p. 1268, pl. 6, fig. 6-7.–MCTAVISH, 1966, p. 1-36, pl. 2, fig. 24.–HOFKER, 1968, p. 40, pl. 19, fig. 2.–BLOW, 1969, p. 226-229, 330, pl. 26, fig. 1-7.–SOEDIONO, 1970, p. 228, pl. 5, fig. 4.–JENKINS, 1971, p. 195, pl. 23, fig. 661.–POSTUMA, 1971, p. 280-281.

Test orbiform to oviform, somewhat irregular. Initial coil of globigerine chambers usually discernible but obscure, almost flush with surface of test. Later chambers subglobular, successively enveloping most of earlier portion. Sutures faint, slightly depressed. Apertures multiple, consisting of lipped circular openings scattered around final chamber, but normally only visible on broken or dissected specimens as they are covered by bullas. Bullas appressed, variously covering large areas of test, or following sutural lineaments, or confined to small circular patches, their development varying greatly from one specimen to another. All three types of bulla carry tiny, evenly spaced infralaminal apertures along their margins. Surface smooth to finely granulose. Usual diameter 0.4 to 0.5 mm.

Discussion.–The bullas of this monospecific genus are unique, hence it has been identified uniformly by all authors who mention it. Members of

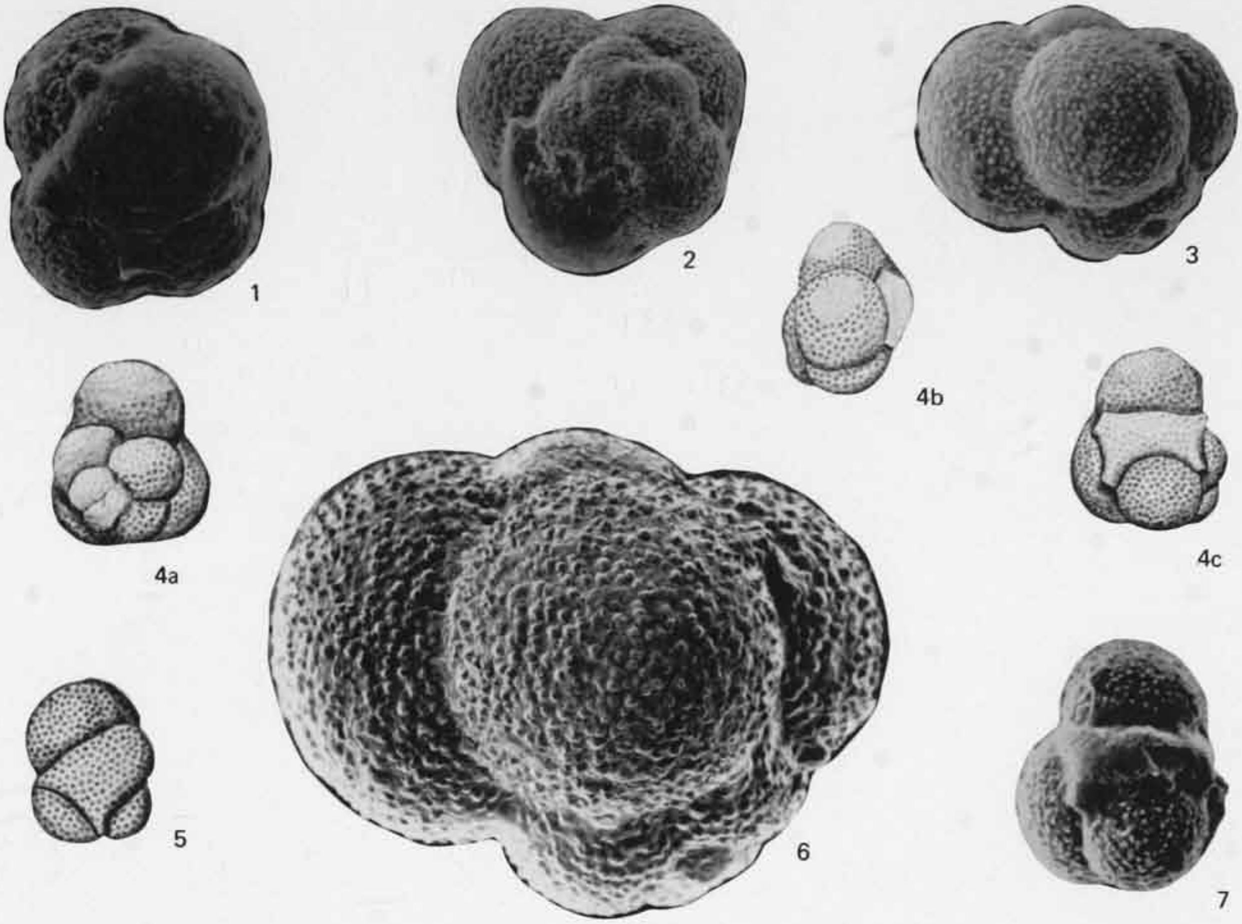

Fig. 124. *Globigerinita incrusta* AKERS from the Miocene of Louisiana and Venezuela.

1-3,6 Specimens from the Middle Miocene (*Globorotalia fohsi peripheroronda* Zone) in the subsurface of Louisiana. **1**–Umbilical view showing bulla, X200; **2**–spiral view, X200; **3**–side view with bulla at top, X200; **6**–view of noncancellate surface, X350.

4-5 Holotype **(4)** and paratype **(5)** from the Louisiana subsurface, X143; from AKERS (1955, pl. 65, fig. 2A-D). AKERS described the surface as finely perforate. **4a**–Spiral view; **4b**–side view; **4c,5**–umbilical views.

7 Umbilical view of specimen from the late Early Miocene part of the Pozón Formation of Venezuela, X125; from BLOW (1969, pl. 24, fig. 3).

the *Praeorbulina-Orbulina* lineage may resemble *Globigerinatella* superficially, but they differ appreciably in detail and are generally more precisely spherical.

The origin of *G. insueta* is debatable, as it appears abruptly with no clear evolutionary development from an earlier form. BRÖNNIMANN (1950a) discussed its ontogeny in detail and suggested that it arose from a small trochoid *Globigerina* with a large semicircular aperture. BLOW (1969) opined that *Globigerinita ambitacrena* may be the ancestral form. HOFKER (1954) moved *Globigerinatella* from the Globigerinidae to the Chilostomellidae, but this treatment was refuted by BOLLI, LOEBLICH, & TAPPAN (1957).

Distribution.–Distinctive form and short range make *Globigerinatella insueta* an excellent marker fossil used by numerous authors as a zonal index of mid-Early Miocene age. The drawback is that it only occurs commonly in tropical localities, such as the Caribbean region, northern Africa, and some deep-sea cores. It was originally described from the Lower Miocene portion of the Cipero Formation of Trinidad.

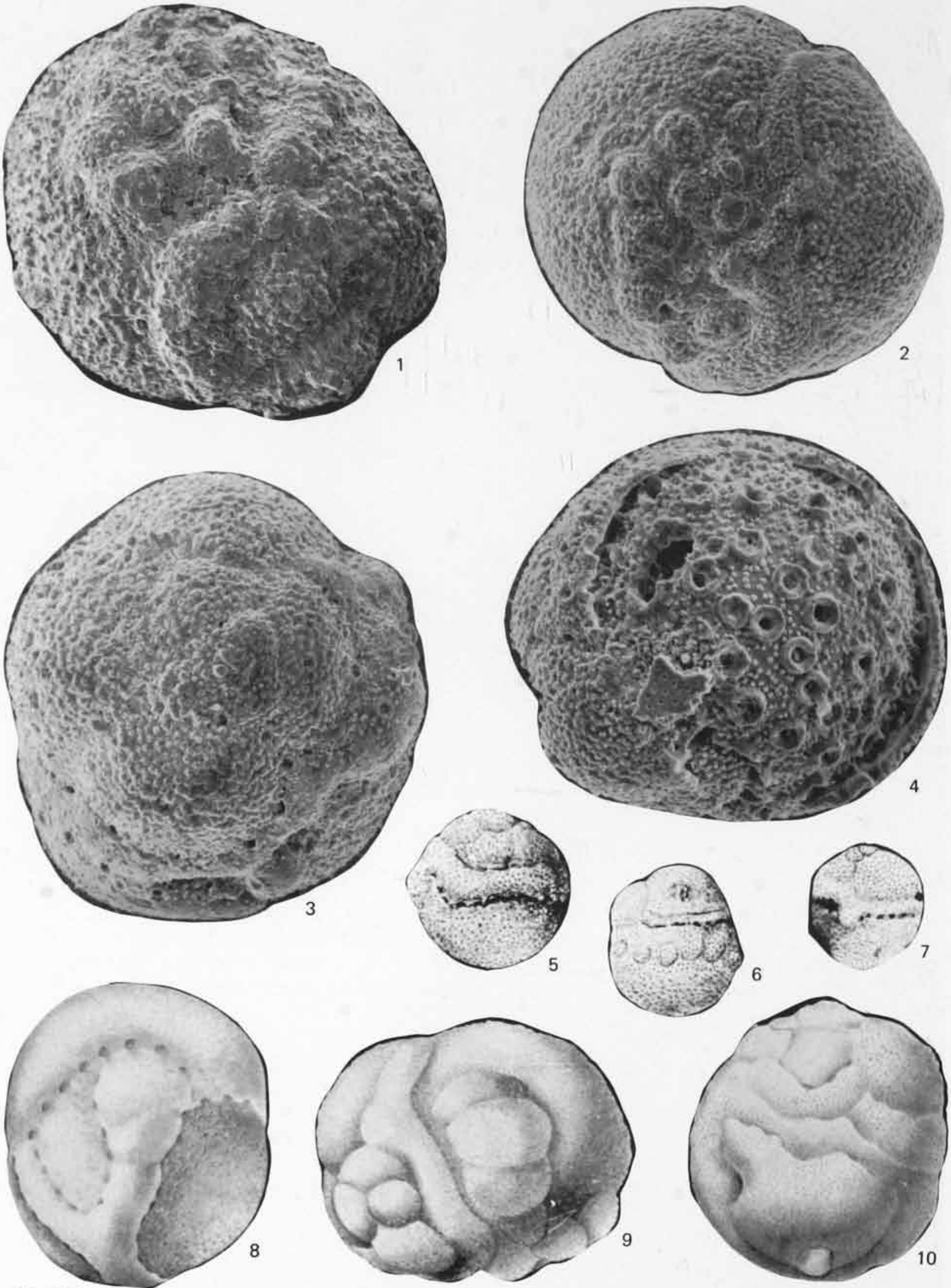

Fig. 125

Fig. 125. *Globigerinatella insueta* CUSHMAN & STAINFORTH from the Early Miocene of Trinidad and Barbados.

1,5-10 Random views of holotype **(5)**, paratypes **(6-7,9-10)**, and topotypes **(1,8)** from the *Globigerinatella insueta* Zone in the Cipero Formation of Trinidad. **1**–Specimen, X160; **5-7**–from CUSHMAN & STAINFORTH (1945, pl. 13, fig. 7-9), X65; **8-10**–from BOLLI, LOEBLICH, & TAPPAN (1957, pl. 8, fig. 5b, 6, 7c), X105-110.

2-4 Specimens from the Bissex Hill Formation of Barbados. **2-3**–Random views, X130; **4**–areal apertures on broken specimen, X160.

GLOBOROTALIA KUGLERI Bolli, 1957

Figure 126

Latest Oligocene to Earliest Miocene

Globorotalia kugleri BOLLI, 1957b, p. 118, pl. 28, fig. 5-6.–BLOW, 1959, p. 90-95.–BERMÚDEZ, 1960, p. 1292.–MCTAVISH, 1966, p. 1-36, pl. 5, fig. 1-5.

Globorotalia (Turborotalia) kugleri BOLLI. BLOW, 1969, p. 350-351, 390, 391, pl. 10, fig. 1-3; pl. 38, fig. 1-4.–JENKINS, 1971, p. 118, pl. 12, fig. 315-317.–BRÖNNIMANN & RESIG, 1971, p. 1313-1314, pl. 39, fig. 1, 3-5.

Turborotalia kugleri (BOLLI). LIPPS, 1967, p. 996, fig. 2.–LIPPS, 1969, p. 1803.

Test a small discoidal trochospire; 6 to 8 chambers in last whorl. Spiral profile mildly lobate; side profile flattish on spiral side, margin smoothly rounded, changing during growth from symmetrical to asymmetrical with subangular tendency. Sutures distinct, lightly incised; on spiral side sloping back, initially straight but becoming recurved or hooked; on umbilical side radial, straight (though last one may be recurved). Umbilical pit small but conspicuous. Aperture a well formed arch from umbilicus to near periphery, often with delicate lip. Surface densely perforate, smooth to rugose. Diameter 0.30 to 0.35 mm.

Discussion.–*Globorotalia kugleri* and *G. fohsi peripheroronda* are similar in size and gross shape, but the growth rates of their chambers differ and typically they have 7 and 5 chambers, respectively, in the outer whorl.

With no textual comment, BOLLI (1957b) figured as *Globorotalia* cf. *kugleri* a specimen with sutures almost radial on the spiral side and periphery remaining symmetrically rounded. BLOW (1969), in view of the stratigraphic importance attached to *G. kugleri*, proposed a rigid definition for it, separating BOLLI'S variant under the name *G. pseudokugleri* and also an intermediate form which he named *G. mendacis*.

Distribution.–*Globorotalia kugleri* is recognized on almost a worldwide scale as a short-ranging index species diagnostic of levels close to the Oligocene-Miocene boundary. This is true even if it is treated in a broad sense, inclusive of BLOW'S two species, so that his subdivision appears unnecessary for normal purposes. This species was first described from the Cipero Formation of Trinidad.

GLOBOROTALIA LENGUAENSIS Bolli, 1957

Figure 127

Middle to Late Miocene

Globorotalia lenguaensis BOLLI, 1957b, p. 120-121, pl. 29, fig. 5.–BLOW, 1959, p. 213-214, pl. 17, fig. 115.–LAMB & BEARD, 1972, p. 53, pl. 19, fig. 1-3.

Globorotalia (Turborotalia) lenguaensis BOLLI. BANNER, & BLOW, 1965c, p. 1351-1354.–BLOW, 1969, p. 351, pl. 34, fig. 10-11.

Test a small lenticular trochospire. Chambers crescentic to comma-shaped on spiral side, radial segments on umbilical side, closely packed, increasing in size slowly and evenly, commonly 6 to 7 in last whorl. Shell smooth, mostly densely perforate but margin may become imperforate. Spiral profile close to circular, side profile compressed ovate. Sutures strongly recurved on spiral side, radial and faintly sinuous on umbilical side, all tending to be flush and indistinct. Aperture a low arch between umbilicus and periphery, commonly with a slight lip. Umbilicus virtually closed. Diameter seldom exceeds 0.3 mm.

Discussion.–*Globorotalia lenguaensis* appears to be intermediate between *Globorotalia minima* AKERS (1955) and *Globorotalia merotumida* BLOW & BANNER (BANNER & BLOW, 1965c). The former has a more convex umbilical side, more rapid increase of chamber size, and an ovate rather than circular periphery; the latter differs in possessing limbate sutures and a complete imperforate keel. BLOW (1969) described as *Globorotalia (Globorotalia) paralenguaensis* forms which might more simply be treated as a phylogenetically advanced stage of *Globorotalia lenguaensis*.

Distribution.–*Globorotalia lenguaensis* is confined to the late Middle and Late Miocene. It was first recorded in the Miocene Lengua Formation of Trinidad.

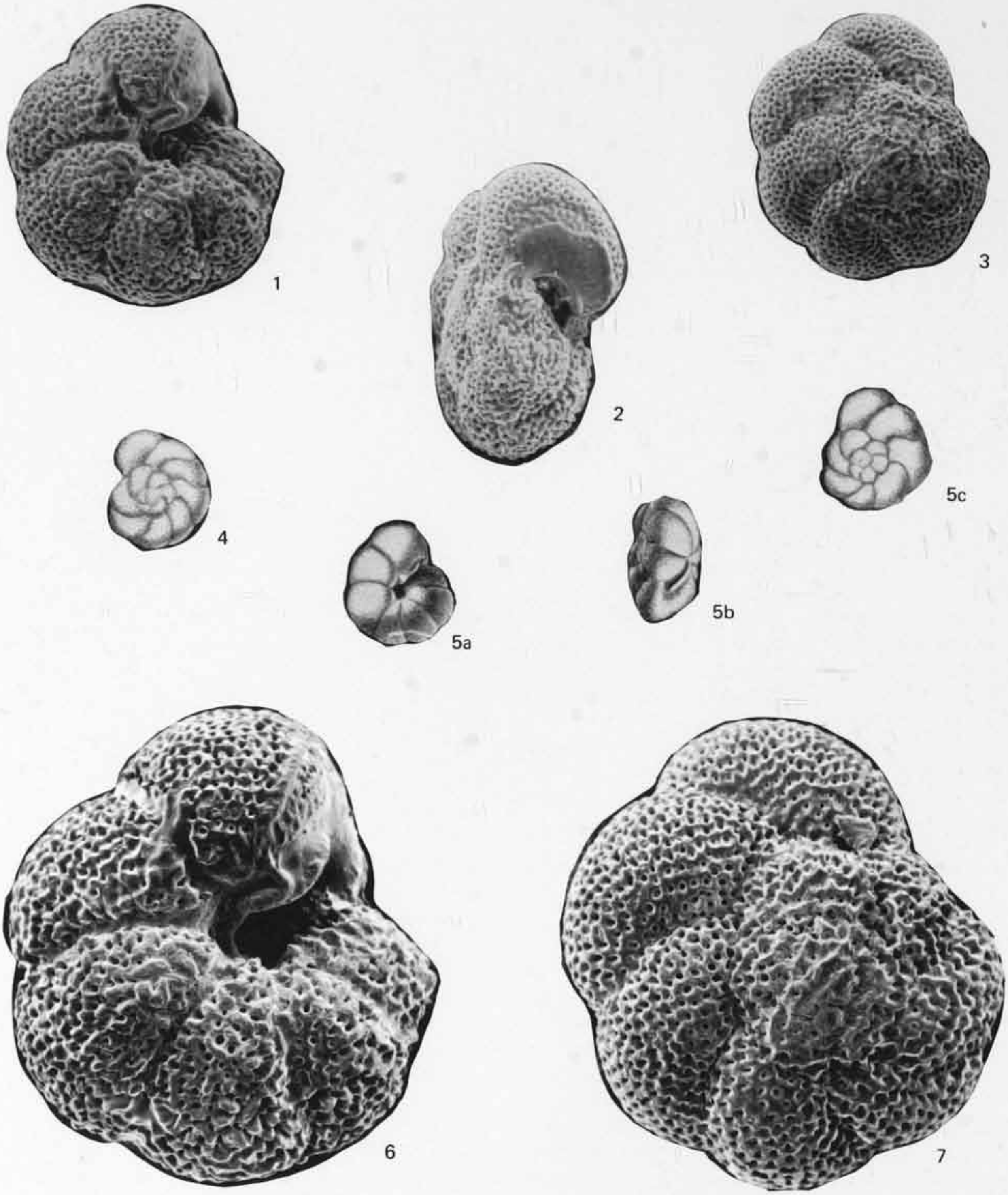

Fig. 126. *Globorotalia kugleri* BOLLI from the earliest Miocene part (*Globorotalia kugleri* Zone) of the Cipero Formation of Trinidad.

1-3,6-7 Topotypes. **1,6**–Umbilical views, X150, X230; **2**–side view, X150; **3,7**–spiral views, X150, X250.

4-5 Paratype **(4)** and holotype **(5)**, X68; from BOLLI (1957b, pl. 28, fig. 5-6). **4,5c**–Spiral views; **5a**–umbilical view; **5b**–side view.

Fig. 127. *Globorotalia lenguaensis* BOLLI from the Miocene of Venezuela, Trinidad, and Gulf of Mexico.

1 Specimen from the Middle Miocene part of the Pozón Formation of Venezuela, X100; from BLOW (1959, pl. 17, fig. 115). **a**–Spiral view; **b**–side view; **c**–umbilical view.

2 Holotype from the Late Miocene Lengua Formation of Trinidad, X68; from BOLLI (1957b, pl. 29, fig. 5). **a**–Umbilical view; **b**–side view; **c**–spiral view.

3-5 Specimens from the Late Miocene in a submarine core from the Gulf of Mexico, X230. **3**–Umbilical view; **4**–side view; **5**–spiral view.

GLOBIGERINA LINAPERTA Group

Figure 128

Microfaunas of the later Eocene and Oligocene commonly are dominated by large, simple species of *Globigerina* which outnumber more distinctive planktonic indices habitually used in zonation. Nomenclature of these large globigerinas is extremely difficult and no two authors handle it alike. The problem has two aspects, one natural and one artificial. The natural problem is that specimens form a plexus within which extremes are sharply distinct yet linked by every conceivable shade of intergradational form. Statistical treatment of part of the plexus by LINDENBERG (1969) demonstrated this infinite variability (Fig. 128). The explosive development of this group in the later Eocene illustrates the strange biological developments in mutations and gerontism within hitherto stable lines.

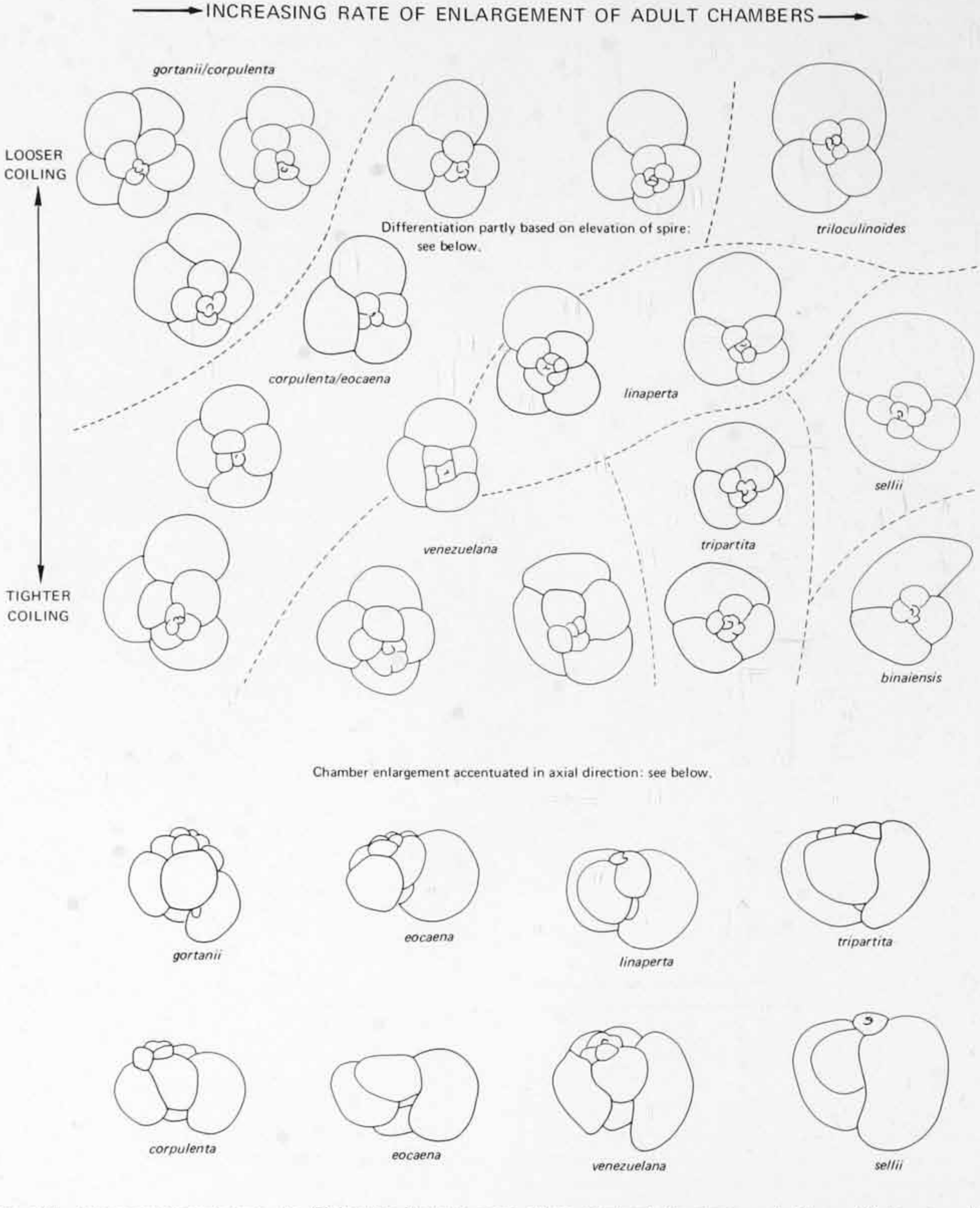

Fig. 128. Representative variants in the *Globigerina linaperta* group. These spiral and side views are slightly modified tracings of published figures shown, for ready comparison, as if all were dextrally coiled. Diameters typically range from 0.5 to 0.7 mm; magnification here is not uniform. Dashed lines indicate rather arbitrary transitional limits between named species.

By Oligocene time certain strains of this *Globigerina* tribe had proved viable so that they persisted conjointly without intermediate forms.

The artificial problem arises because many of these large planktonic foraminifers were observed and named by early micropaleontologists when standards were much less strict for delimiting species, selecting and preserving types, and checking for synonymy. As a result several venerable species names remain in use (*trilocularis, eocaenica, eocaena, globularis,* and others) although their basic distinction and their degree of synonymy with newer names are difficult to establish. We were informed recently by MME. LE CALVEZ that she found the type of *Globigerina eocaenica* TERQUEM to be a benthonic form despite unquestioned acceptance of its original generic assignment since 1882 (as, for example, by SUBBOTINA, 1953, 1971, and BERMÚDEZ, 1960).

Biostratigraphic utility of the plexus is insufficient to justify delving deeply into details of nomenclature so, for present purposes, we offer the following pragmatic scheme. As all the forms mentioned belong to *Globigerina,* the generic name is omitted to avoid constant repetition.

1. The central form of the plexus is conceived as a species having a quadrate coil in which each successive chamber is approximately equal in size to the whole preceding test; the outer whorl comprises 3½ chambers; its gross aspect is neither compressed nor elevated and chambers are neither strongly appressed nor loosely attached. The species *linaperta* of FINLAY (1939c) matches this concept (e.g., BOLLI, 1957a,c; HORNIBROOK, 1958); thus this modern name is chosen arbitrarily for the plexus.

2. Most planktonic foraminiferal species are stable in the sense that, at any given stratigraphic level, individuals differ only slightly from an average form. It is as if they inherited rather rigid growth parameters which changed only slowly as species evolved. In contrast, the *linaperta* group of the later Eocene displays multiple variability, as if its growth parameters had become unstable. Specifically, the helix followed by its chambers varies from depressed to elevated as seen from the side and from a tight to a lax spiral as seen from above; the rate of growth of successive chambers varies from quite slow to very rapid; and the shape of chambers may remain subglobular or may change progressively to reniform or appressed. If just five stages are visualized from one extreme to the other in each of the four variables mentioned, the 5^4 (=625) morphologic variants possible give some measure of nomenclatural complexity within the group. Variability is enhanced by the large average size of individuals; nuclear portions in all are like a miniature *linaperta* with differentiation becoming marked only in the last 3 or 4 adult chambers.

3. The described variability concerns solely the gross form of the test. In addition to this, authors tried to apply other criteria to subdivisions of the group by directing attention to the umbilicus, aperture, apertural lips and teeth, shell surface, and dwarfed final chambers (interpreted as bullas by some). In our opinion most of these are not independent characteristics but rather are intimately related to gross variations of the test. Empirical evidence supported by concepts of geometric growth suggests that a slit aperture tends to develop a flange or lip; size of umbilicus is governed jointly by compactness of spire and rate of increase of chamber size; a gaping umbilicus tends to be lined by apertural teeth; certain growth formulas lead to geometric or biologic impossibilities resulting in the common dwarfing and aborting of final chambers; and comparable relationships. Regardless of this somewhat subjective argument, introduction of umbilical characters as a second basis for classification multiplies the already great difficulties in applying conventional nomenclature.

4. From the foregoing we conclude that a practical way to handle this group is to apply formal names only to the central form *(linaperta)* and to the extremes of obvious growth lines which radiate from it. Individuals not referable to one of these few named species then can be cited as "intermediate between X and Y" and perhaps qualified as "closer to Y."

Specifically we recognize the end forms of the four morphologic lines cited next; others (e.g., the *inaequispira* lineage) may deserve consideration.

eocaena: Differing from *linaperta* in appreciably lower rate of increase of chamber size; tending as a result to have a more open umbilicus around which last 4 chambers are fully visible; prior name for this form appears to be *eocaena* based on neotype designated by HAGN & LINDENBERG (1966, as cited in 1969, p. 237); within the broad limits here applied, the widely used name *yeguaensis* regrettably appears to be a junior synonym.

gortanii: Similar in all respects to *eocaena* except that spire becomes elevated to present a right- or acute-angled apex; gross form pyramidal; *gortanii* of BORSETTI is a senior synonym of *turritilina* of BLOW & BANNER.

venezuelana: Coil quadrate as in *linaperta* but chambers show progressive axial prolongation, with extremities curving in to define a rectangular umbilicus around which 3½ chambers are visible typically; gross form spheroidal to cuboidal; *venezuelana* of HEDBERG here includes the Eocene form later split off as *pseudovenezuelana* by BLOW & BANNER.

tripartita: Grossly similar to *venezuelana* but rate of chamber growth accelerated and adult coil trigonal; small umbilicus is triangular with 2½ to 3 chambers visible around it; gross form spheroidal; BOLLI'S *rohri* is a junior synonym.

5. The foregoing treatment seems unequivocal and satisfactory for most stratigraphic purposes. As finer splitting may be justified locally by stratigraphic utility, however, additional available names include the following [those marked with an asterisk (*) are treated individually in the present report]:

**angiporoides:* In temperate latitudes variability of the plexus is less extreme, and the name *angiporoides* is applied habitually to the common form in both northern and southern hemispheres.

**binaiensis:* Discussed under *sellii.*

**corpulenta:* Halfway between *eocaena* and *gortanii* (see HAGN & LINDENBERG, 1969, p. 244); used as a zonal index by Soviet paleontologists.

galavisi: Contrary to BLOW (1969) we see no significant difference between *yeguaensis* and *galavisi* and regard both as junior synonyms of *eocaena.*

praebulloides: BLOW & BANNER (1962) and BLOW (1969) seem to lump a strange mixture of large and small Globigerinas in the four subspecies of *praebulloides;* they include some which we would include in the *linaperta* group and others which we would exclude.

praeturritilina: A subspecific variant of *gortanii;* see BLOW & BANNER (1962) and BLOW (1969).

pseudovenezuelana: Introduced by BLOW & BANNER (1962) as a subspecies of *yeguaensis* yet regarded by them as unrelated to *venezuelana;* they mention *quadripartita* KOCH and *rotundata jacksonensis* BANDY as possible synonyms but consider those as inadequately known because of defective types.

**sellii:* The *tripartita* lineage had an offshoot with even more accelerated chamber growth, resulting in forms having a hemispherical final chamber which stands out from the rest of the test; *sellii* (senior synonym of *oligocaenica*) is the typical form of this line; *binaiensis* is even more distinct in having a large, flat apertural face forming an acute angle with the outer spire; these Oligocene forms evolved so far out of the *linaperta* plexus that they merit individual treatment.

tapuriensis: Defined by BLOW & BANNER (1962) as a short-lived form intermediate between *tripartita* and *sellii,* later applied to formal zonation by BLOW (1969); it has received only occasional mention by other authors.

(cf). *trilocularis:* BOLLI (1957b,c) revived this old name for forms between *linaperta* and *eocaena* but BLOW & BANNER (1962, p. 94) point out difficulties in accepting it.

winkleri: Despite BLOW'S support (1969) for BERMÚDEZ' name, we regard this as an indefinite variant within the plexus not far removed from *corpulenta.*

GLOBIGERINITA NAPARIMAENSIS Brönnimann, 1951
Figure 129
Middle Miocene to Holocene

Globigerina glutinata RHUMBLER, 1911, pl. 29, fig. 14-26; pl. 33, fig. 20; pl. 34, fig. 1 [see WETZEL, 1949] [? not *Globigerina glutinata* EGGER, 1893, p. 371, pl. 13, fig. 19-21].

Globigerinita naparimaensis BRÖNNIMANN, 1951a, p. 16-18, fig. 1-14.–BOLLI, LOEBLICH, & TAPPAN, 1957, p. 37, pl. 8, fig. 1-2.–[restricted] LOEBLICH & TAPPAN, 1957b, p. 112.–BERMÚDEZ, 1960, p. 1265, pl. 7, fig. 6,–BLOW, 1969, p. 328-329.

Globigerina (Globigerinita) naparimaensis (BRÖNNIMANN). DROOGER, 1953, p. 142, pl. 24, fig. 20.

Globigerinita glutinata (EGGER). PHLEGER, PARKER, & PEIRSON, 1953, p. 16, pl. 2, fig. 15.–PARKER, 1962, p. 246-249, pl. 9, fig. 1-16.–BÉ & HAMLIN, 1967, p. 102, fig. 24.–BERMÚDEZ & BOLLI, 1969, p. 157, pl. 5, fig. 1-6 [subheading misprinted as *Globigerina glutinata*].–LAMB & BEARD, 1972, p. 48, pl. 5, fig. 1-4.

Tinophodella ambitacrena LOEBLICH & TAPPAN, 1957b, p. 114-115, fig. 2-3.–LOEBLICH & TAPPAN, 1964, p. C678, fig. 543,6.

Globigerinita naparimaensis naparimaensis BRÖNNIMANN. BLOW, 1959, p. 206, pl. 15, fig. 99.

Globigerinita glutinata glutinata (EGGER). PARKER, 1964, p. 618, 630.

Globigerinita glutinata naparimaensis BRÖNNIMANN. PARKER, 1964, p. 618, 630.

Globigerinita ambitacrena (LOEBLICH & TAPPAN). BLOW, 1969, p. 327.

[The cited references variously refer to one or to both of the forms distinguished below as typical and ambitacrene.]

Test small, lobulate-ovate. A slightly elevated coil of inflated but appressed chambers which approximately double in size as added; 3 to 4 chambers in final whorl. Sutures faint. Umbilicus entirely covered by bulla. Bulla variable, ranging from inflated chamberlet with 1 or 2 small openings into umbilicus to appressed sheet spreading along sutures on umbilical and bordered by numerous tiny arched or tubulose openings. Surface smooth or finely hispid, finely perforate, appearing matte at low magnifications. Diameter to 0.35 mm.

Discussion.–Nomenclature of forms included here is difficult as authorities express divergent views. BRÖNNIMANN (1951a) included both extremes in his original description of *Globigerinita naparimaensis* as did BOLLI, LOEBLICH, & TAPPAN (1957). Yet almost simultaneously LOEBLICH & TAPPAN (1957b) split BRÖNNIMANN'S species, restricted its name to the form of his holotype (which has an inflated bulla with few openings), and introduced the name *Tinophodella ambitacrena,* n. gen., n. sp., for specimens with appressed bulla and multiple infralaminal openings. PARKER (1962) demonstrated in a Recent population of *Globigerinita glutinata* that all transitional stages are present between the two extreme types of bulla. She, therefore, rejected *Tinophodella* as an artificial genus and suggested that the Miocene species *naparimaensis* may well be synonymous with the living *glutinata.* PARKER (1964) and BLOW (1969) commented further on the tentative, arbitrary basis for recognizing two distinct species.

The trivial name *glutinata* is derived from RHUMBLER'S usage (1911) of *Globigerina glutinata* EGGER (1893) and is evidently a nomen dubium. LOEBLICH & TAPPAN (1957b) and JENKINS (1971) asserted that EGGER'S original species appears to be a true, nonbullate *Globigerina,* but PARKER (1962) adduced that RHUMBLER had seen EGGER'S material before adopting his name for the bullate form. BERMÚDEZ (1960) sided with LOEBLICH & TAPPAN in rejecting *glutinata* but BERMÚDEZ & BOLLI (1969) followed PARKER'S acceptance of this name. BLOW (1969) discussed *Globigerinita naparimaensis* and *G. ambitacrena* but did not mention *G. glutinata.*

To resolve the confusion, we suggest that the name *Globigerinita naparimaensis* be used in the original embracive sense of BRÖNNIMANN. Should informal distinction be required, forms with a simple inflated bulla may be referred to as typical and those with a flatter, multiapertured bulla as ambitacrene. A form with infralaminal apertures only where the ventral sutures meet the bulla is separated as *Globigerinita incrusta* and considered ancestral to the others (see separate discussion of this species).

Distribution.–Stratigraphic value of *G. naparimaensis* is small, but the species (or plexus) is diagnostic of post-Oligocene age. The ambitacrene form appeared early enough to be the possible ancestor of *Globigerinatella insueta* (see BLOW, 1969, p. 330). The typical form is not recorded below the Middle Miocene near the extinction level of subspecies of *Globorotalia fohsi.*

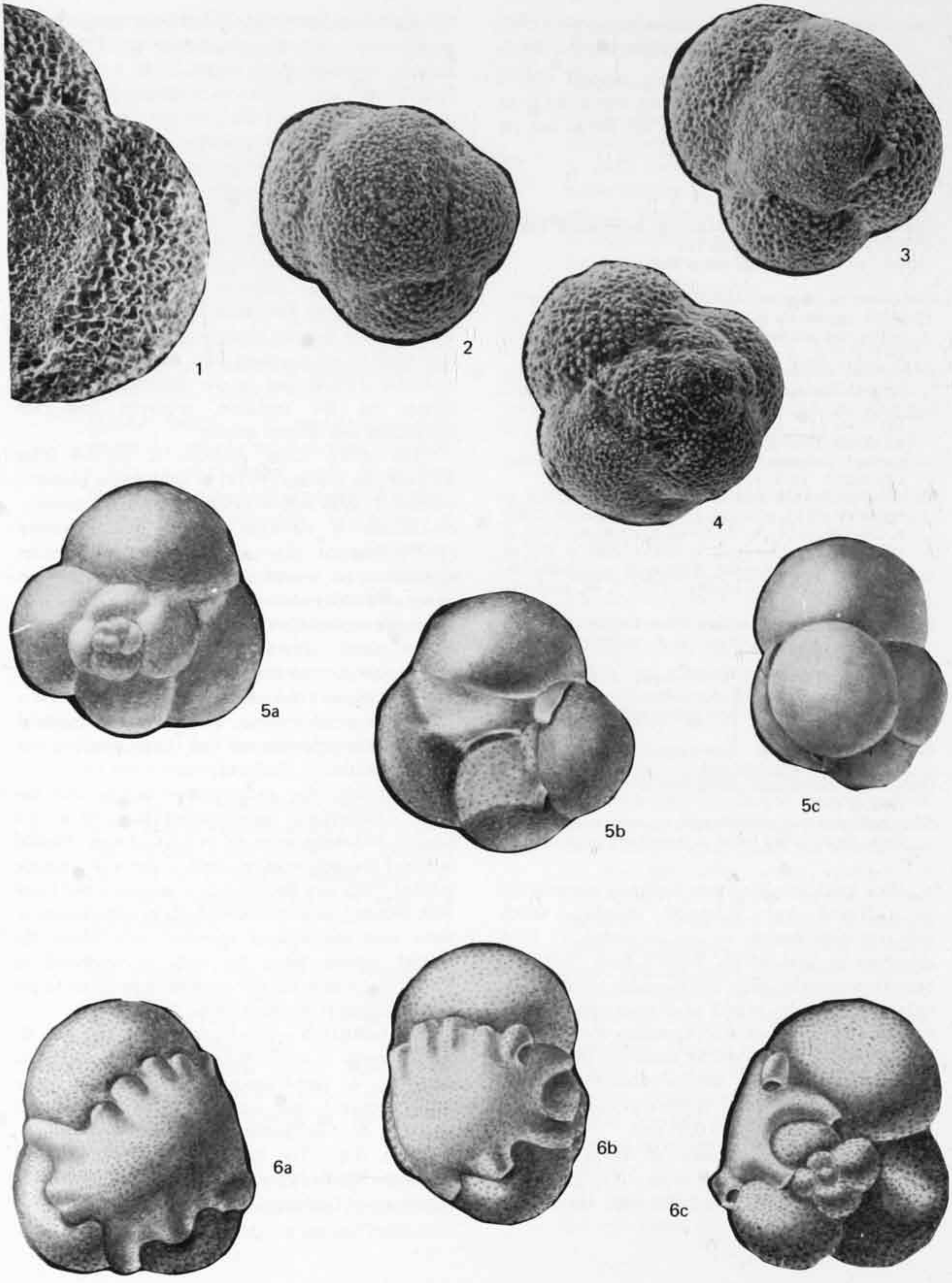

Fig. 129

Fig. 129. *Globigerinita naparimaensis* BRONNIMANN from the Miocene of Trinidad and Holocene off Brazil.

1-4 Specimens (typical forms) from the Early Miocene part (*Catapsydrax dissimilis* Zone) of the Cipero Formation of Trinidad. **1**–Noncancellate surface, X210; **2-3**–umbilical views, X150; **4**–spiral view, X150.

5 Holotype (typical form) from the Miocene Lengua Formation of Trinidad, X190; from BOLLI, LOEBLICH, & TAPPAN (1957, pl. 8, fig. 1). **a**–Spiral view; **b**–umbilical view; **c**–side view.

6 Specimen (*ambitacrena* form) from Holocene deposits off Brazil. This is the holotype of *Tinophodella ambitacrena*, X145; from LOEBLICH & TAPPAN (1957b, fig. 3). **a**–Umbilical view; **b**–side view; **c**–spiral view.

GLOBOROTALIA OBESA Bolli, 1957

Figure 130

Late Oligocene to Holocene

Globorotalia obesa BOLLI, 1957b, p. 119, pl. 29, fig. 2-3.–BLOW, 1959, p. 218, pl. 19, fig. 124.–JENKINS, 1960, p. 364, pl. 5, fig. 2.–PUJOL, 1970, p. 210-214.–NICORA, 1971, p. 185, pl. 8, fig. 3.

Globorotalia (Turborotalia) obesa BOLLI. BLOW & BANNER, 1962, p. 29.–BLOW, 1969, p. 352, 409.–JENKINS, 1971, p. 127, pl. 13, fig. 348-350.–BRÖNNIMANN & RESIG, 1971, p. 1314, pl. 50, fig. 7-8.

Globigerina obesa (BOLLI). PARKER, 1964, p. 629.–BERGGREN, 1971b, p. 739.

Turborotalia obesa (BOLLI). SOEDIONO, 1970, p. 217, pl. 1, fig. 4.

Test small, a very low quadrate trochospire. Chambers increasing in size regularly and fairly rapidly, maintaining globose shape. Spiral profile mildly lobate, side profile discoidal, periphery smoothly and symmetrically rounded. Sutures faint on initial portion, distinct, depressed on outer whorl. Aperture a simple arch from small umbilical pit to periphery, opening forward in direction of coiling. Surface finely rugose, finely perforate. Diameter typically 0.4 to 0.5 mm.

Discussion.–*Globorotalia obesa* is not one of the more distinctive species but can be separated by its simple, forward-pointing aperture from small species and juveniles which normally accompany it. This species is considered ancestral to the planispiral *Hastigerina siphonifera* (see BLOW, 1969; JENKINS, 1971).

Distribution.–Recorded in the interval from later Oligocene to Holocene on both sides of the Atlantic and also in the Pacific region.

GLOBOROTALIA OPIMA NANA Bolli, 1957

Figure 131

Late Eocene and Oligocene

Globigerina wilsoni COLE(?). STAINFORTH, 1948b, p. 117, pl. 26, fig. 1-3.

Globorotalia opima nana BOLLI, 1957b, p. 118, pl. 28, fig. 3.–BOLLI, 1957c, p. 169.–PESSAGNO, 1963, p. 53, pl. 2, fig. 1-2.

Turborotalia increbescens (BANDY). BERMÚDEZ, 1960, p. 1322.

Globorotalia (Turborotalia) opima nana BOLLI. BLOW & BANNER, 1962, p. 119.–BLOW, 1969, p. 215-219, 352-353, pl. 39, fig. 1.

Globigerina opima nana (BOLLI). HOFKER, 1963a, p. 199-200, fig. 1-3.–HOFKER, 1968, p. 15, pl. 6, fig. 5.

Turborotalia nana (BOLLI). LIPPS, 1967, p. 995, fig. 2.

Turborotalia opima nana (BOLLI). SOEDIONO, 1970, p. 217, pl. 1, fig. 5.

Globorotalia (Turborotalia) nana nana BOLLI. JENKINS, 1971, p. 123, pl. 11, fig. 303-308.

Globorotalia nana BOLLI, JENKINS & ORR, 1972, p. 1101, pl. 28, fig. 7-9.

Test a small, tightly coiled, almost planispiral trochospire; 4 chambers in final whorl. Spiral outline almost a square with rounded corners; in side view thickness almost equals diameter. Sutures clear but only slightly depressed, typically forming a right-angled cross on umbilical side. Aperture a curved slit around periphery on umbilical side, commonly carrying a slight rim or lip. Surface smooth, finely pitted. Maximum diameter 0.3 mm.

Discussion.–The smaller size of *Globorotalia opima nana* is supposedly its main distinction from *G. opima opima*, but in topotype material we could distinguish it also by its smoother test; initial chambers of *G. opima opima* are appreciably pustulose. The Miocene *Globorotalia continuosa* is grossly similar to *G. opima nana* but is more loosely coiled and has a larger, comma-shaped aperture.

Distribution.–*Globorotalia opima nana* ranges through the Late Eocene and most of the Oligocene and has a wide geographic distribution. BLOW (1969) observed that similar but distinguishable forms range into the Miocene, and these may account for post-Oligocene records, such as that of BANDY, HORNIBROOK, & SCHOFIELD (1970). BLOW (1969, p. 352-353) discussed possible ecologic control of distribution of the two subspecies *opima* s.s. and *nana*. Some support for his contention is found in Ecuador where *nana* is unusually abundant in a cool-water fauna and *opima* s.s. is not yet recorded. Their differences of shell texture also may have ecologic rather than genetic significance.

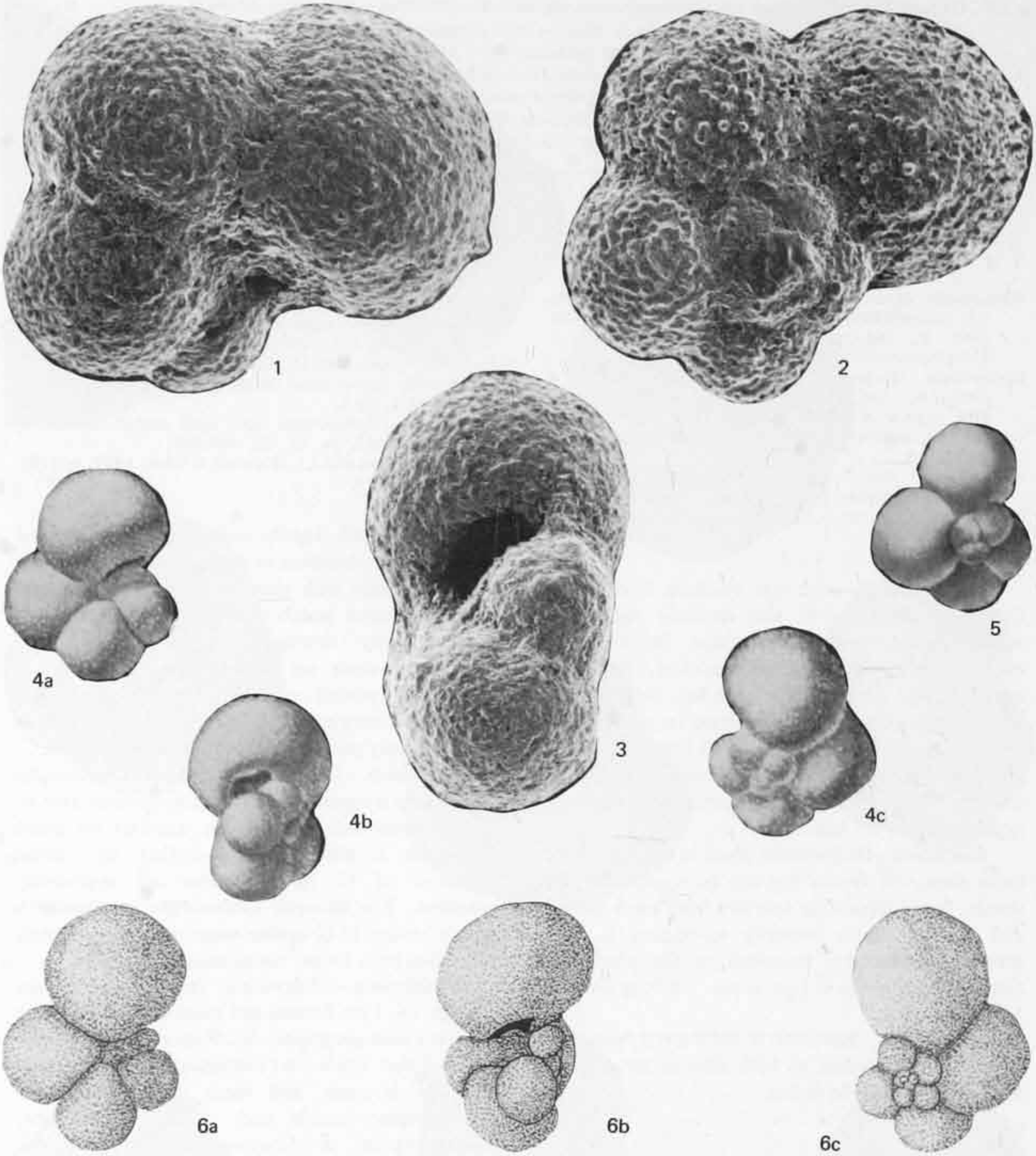

Fig. 130. *Globorotalia obesa* BOLLI from the Miocene of Trinidad and Venezuela.

1-3 Specimens from the Early Miocene part (*Globigerinatella insueta* Zone) of the Cipero Formation of Trinidad. **1**–Umbilical view, X200; **2**–spiral view, X210; **3**–side view, X180.

4-5 Holotype **(4)** and paratype **(5)** from the Middle Miocene part (*Globorotalia fohsi lobata-robusta* Zone) of the Cipero Formation of Trinidad, X68; from BOLLI (1957b, pl. 29, fig. 2-3). **4a**–Umbilical view; **4b**–side view; **4c**,**5**–spiral views.

6 Specimen from the Middle Miocene part (*Globorotalia fohsi lobata-robusta* Zone) of the Pozón Formation of Venezuela, X110; from BLOW (1959, pl. 19, fig. 124). **a**–Umbilical view; **b**–side view; **c**–spiral view.

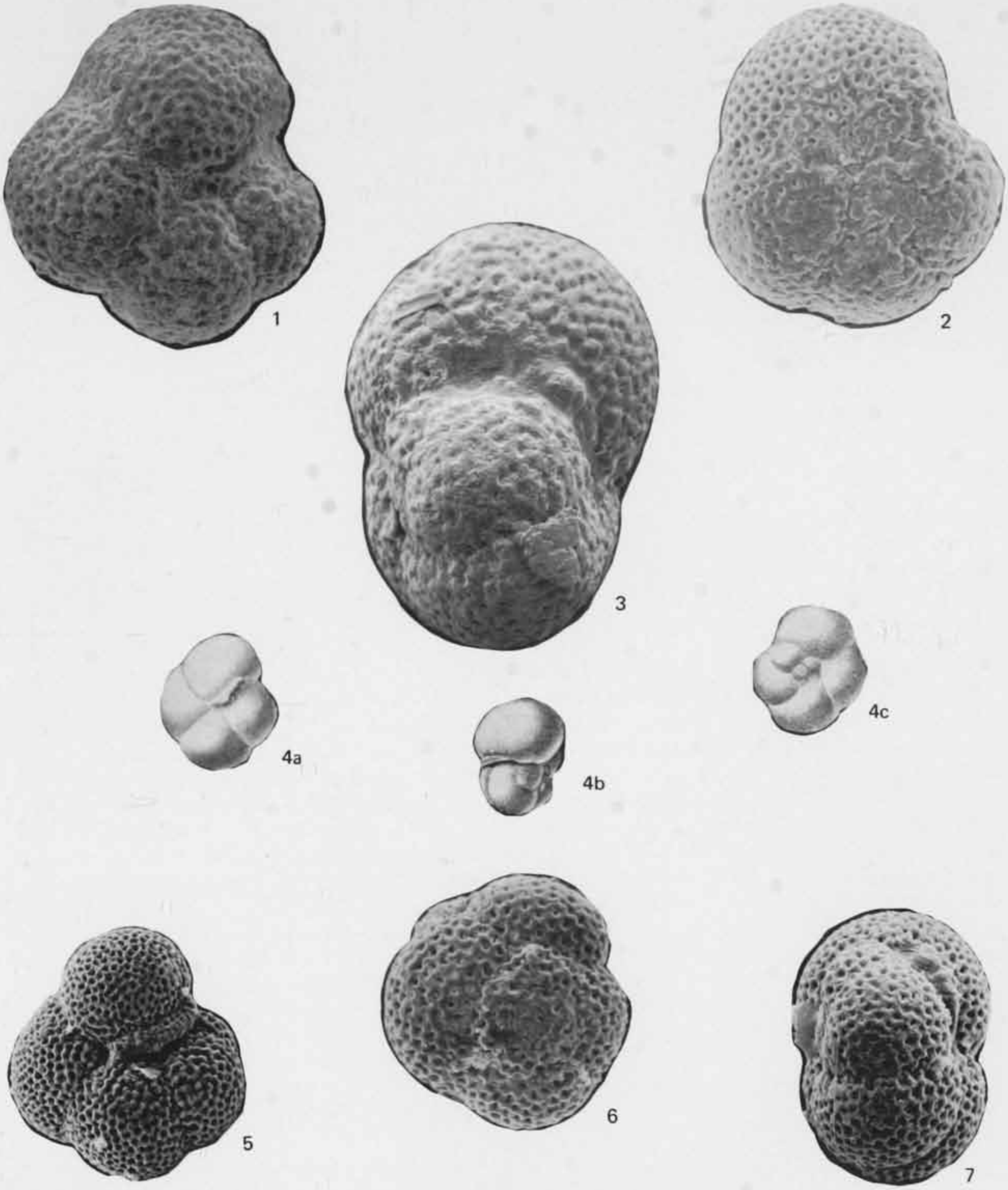

Fig. 131. *Globorotalia opima nana* BOLLI from the Oligocene of the Cipero Formation in Trinidad.

1-3,5-7 Specimens from the *Globigerina ampliapertura* Zone below appearance of *Globorotalia opima opima*. **1,5**–Umbilical views, X180, X150; **2,6**–spiral views, X180; **3,7**–side views, X245, X200.

4 Holotype from the *Globorotalia opima opima* Zone, X68; from BOLLI (1957b, pl. 28, fig. 3). **a**–Umbilical view; **b**–side view; **c**–spiral view.

GLOBOROTALIA OPIMA OPIMA Bolli, 1957

Figure 132

Oligocene

Globorotalia opima opima BOLLI, 1957b, p. 117, pl. 28, fig. 1-2.–BLOW, 1959, p. 92-95.–PESSAGNO, 1963, p. 53, pl. 1, fig. 4-6.

Globorotalia (Turborotalia) opima opima BOLLI. BLOW & BANNER, 1962, p. 119.–BLOW, 1969, p. 215-219, 352-353, pl. 39, fig. 2-3.

Turborotalia increbescens (BANDY). BERMÚDEZ, 1960, p. 1322, pl. 18, fig. 3-?4.–LIPPS, 1967, p. 996.

Globorotalia increbescens opima BOLLI. BANDY, 1964b, p. 7-8, 13, fig. 5.

Globorotalia (Turborotalia) opima BOLLI. JENKINS, 1971, p. 128, pl. 13, fig. 354-357.

Globorotalia opima BOLLI. JENKINS & ORR, 1972, p. 1101-1102, pl. 28, fig. 10-12.

Test a depressed trochospire of bulbous chambers, initial portion almost planispiral, spiral surface flat to concave; 4 to 5 chambers in last whorl. Spiral profile subcircular with indentations at sutures; side profile chunky, ovate. Early sutures obscure, later ones distinct, approximately radial, slightly incised. Aperture a low arched slit extending from spiral suture to umbilical axis, occasionally with slight rim or lip. Surface commonly pustulose to rugose on early chambers, smoother on later ones. Diameter to 0.6 mm.

Discussion.–By definition *Globorotalia opima opima* differs from *G. opima nana* mainly in its larger size; *nana* also appears to have a consistently smoother test than immature *opima* s.s.. *Globorotalia siakensis* (= *G. mayeri* of many authors) is grossly similar but differs in numerous details such as having 5 to 6 chambers in the final whorl, oblique sutures, and aperture restricted to umbilical side. The post-Miocene species *Globorotalia acostaensis pseudopima* of BLOW (1969, p. 387-388, pl. 35, fig. 1-7) is virtually homeomorphic with *G. opima opima* and differentiation depends on associated plankton.

Synonymy or relationship of *Globorotalia opima* with *G. increbescens* has been claimed (BERMÚDEZ, 1960; BANDY, 1964b; LIPPS, 1967), but we consider the latter species quite distinct in its more inflated chambers, more shouldered profile, and gaping aperture.

Distribution.–*Globorotalia opima opima* is a valuable zonal index, being recorded only from the Oligocene within the interval between extinction of *Pseudohastigerina* and first appearance of *Globorotalia kugleri.* BLOW (1969) noted minor differences in local levels of appearance and extinction and suggested that ecologic factors had some effect on its distribution and development from the smaller *G. opima nana.*

GLOBOROTALIA POSTCRETACEA (Myatliuk, 1950)

Figure 133

Late Eocene to Oligocene

Globigerina postcretacea MYATLIUK, 1950, p. 280, pl. 4, fig. 3.–SUBBOTINA, 1953, p. 60-61, pl. 2, fig. 16-20.–SUBBOTINA, 1971, p. 70-71, pl. 2, fig. 16-20 [paratypes refigured].

Globorotalia (Turborotalia) postcretacea (MYATLIUK). BLOW & BANNER, 1962, p. 120-121, pl 12, fig. G-J.

Globorotalia postcretacea (MYATLIUK). SAITO & BÉ, 1964, p. 704, fig. 2.

Globorotalia gemma JENKINS, 1965b, p. 1115, fig. 11, no. 97-103.

Globorotalia (Turborotalia) gemma JENKINS. BLOW, 1969, p. 348-349, pl. 34, fig. 9.–JENKINS, 1971, p. 115, pl. 10, fig. 263-269.

Test a very small, compressed trochospire, close to planispiral, tending to be concave on spiral as well as umbilical side. Last whorl with 5 (rarely 6) globular chambers which increase regularly in size. Periphery broadly rounded in side view, lobate in spiral profile. Sutures depressed, radial to slightly curved. Umbilicus shallow, varying from narrow to fairly wide. Aperture an arched slit from umbilicus to periphery or slightly on to spiral side, with faint lip. Test fragile, finely spinose.

Discussion.–SUBBOTINA (1953) commented on the great variability of this species so that JENKINS (1965b) seems unjustified in separating the more planispiral forms under a different name *(gemma).* The small *Globorotalia minutissima* is morphologically similar but has been recorded only in a post-Miocene interval (BOLLI, 1957b; PARKER, 1964; JENKINS, 1971).

Fig. 132. *Globorotalia opima opima* BOLLI from the Oligocene part (*Globorotalia opima opima* Zone) of the Cipero Formation in Trinidad.

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- **1-7** Topotypes. **1-2,7**–Side views, X200, X200, X100; **3-4**–umbilical views, X180, X100; **5-6**–spiral views, X180, X100.
- **8** Holotype, X68; from BOLLI (1957b, pl. 28, fig. 1). **a**–Umbilical view; **b**–side view; **c**–spiral view.


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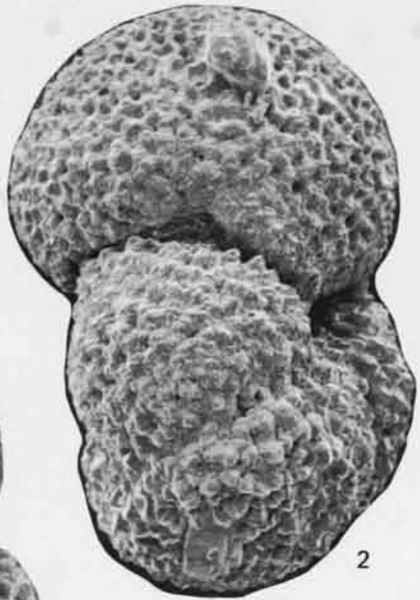
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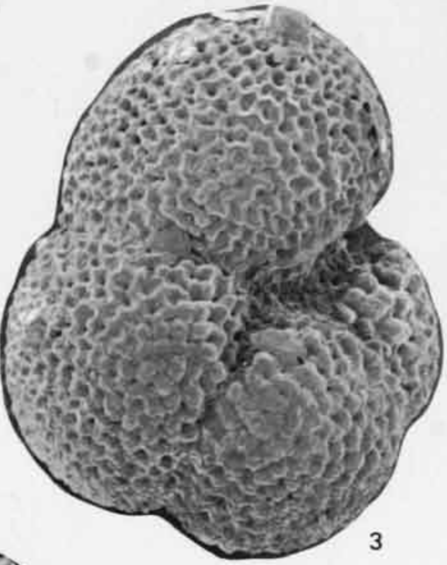
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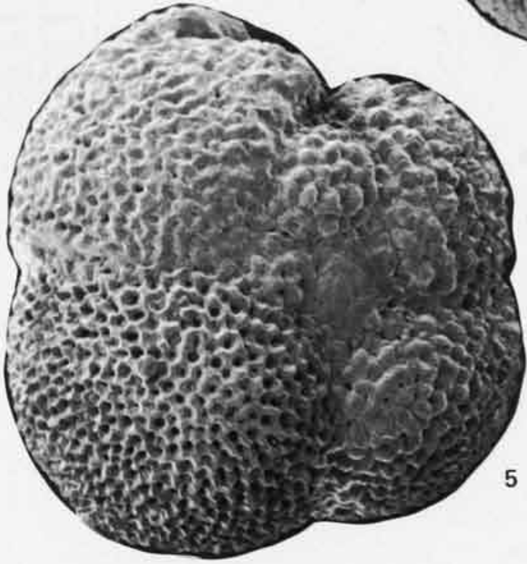
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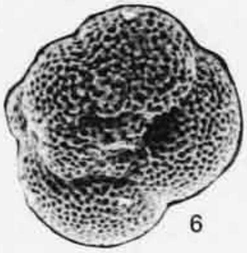
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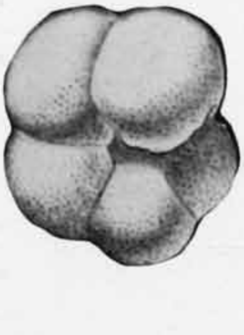
8a


8b


8c

Fig. 132

Distribution.–Late Eocene and Oligocene (*Globorotalia cerroazulensis* Zone to approximately *Globorotalia opima opima* Zone). It is typical of early Oligocene assemblages outside the tropics, hence name fossil for the *Globorotalia postcretacea* Zone of East European authors. This species was first described from the Oligocene of the eastern Carpathian Mountains.

GLOBOROTALIA PRAEMENARDII Cushman & Stainforth, 1945
Figure 134
Middle Miocene

Globorotalia praemenardii CUSHMAN & STAINFORTH, 1945, p. 70, pl. 13, fig. 14.–STAINFORTH, 1948b, p. 121, pl. 26, fig. 34-35.–CUSHMAN & BERMÚDEZ, 1949, p. 31, pl. 5, fig. 17-19.–BOLLI, 1957b, p. 120, pl. 29, fig. 4.–HOFKER, 1968, p. 51, pl. 25, fig. 3.
Globorotalia menardii praemenardii (CUSHMAN &

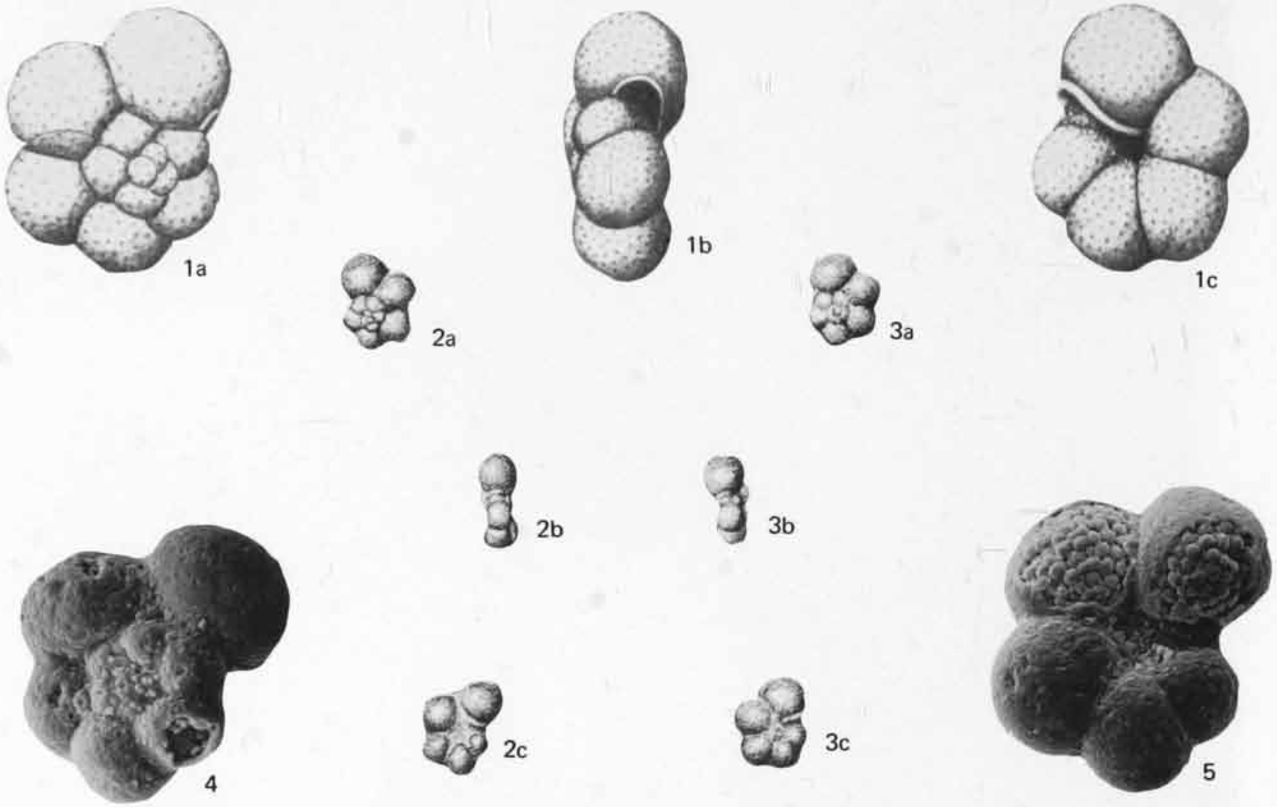

Fig. 133. *Globorotalia postcretacea* (MYATLIUK) from the Oligocene of Tanzania and Eocene of the Caucasus in the Soviet Union.
1 Specimen from the Oligocene of Tanzania, X300; from BLOW & BANNER (1962, pl. 12, fig. G-J). **a**–Spiral view; **b**–side view; **c**–umbilical view.
2-3 Specimens from the topmost Eocene to lower Oligocene of the northern Caucasus, X72; from SUBBOTINA (1953, pl. 2, fig. 16-17). **a**–Spiral views; **b**–side views; **c**–umbilical views.
4-5 Specimens from the topmost Eocene of the northern Caucasus, X250. **4**–Spiral view; **5**–umbilical view.

Fig. 134. *Globorotalia praemenardii* CUSHMAN & STAINFORTH from the Middle Miocene of Trinidad and Barbados.
1-2,6,8 Large topotypes (**1-2,8**) and holotype (**6** from BLOW, 1969, pl. 6, fig. 1-3) from the *Globorotalia fohsi lobata-robusta* Zone in the Cipero Formation of Trinidad. **1,6b**–Umbilical views, X110, X67; **2,6c**–spiral views, X110, X67; **6a,8**–side views, X67, X110.
3-4,7 Specimens from the Consett Formation of Barbados, X110. **3**–Umbilical view; **4**–spiral view; **7**–side view.
5 Specimen from the *Globorotalia fohsi fohsi* Zone in the Cipero Formation of Trinidad, X68; from BOLLI (1957b, pl. 29, fig. 4). **a**–Side view; **b**–umbilical view; **c**–spiral view.

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6a


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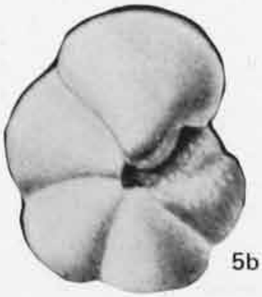
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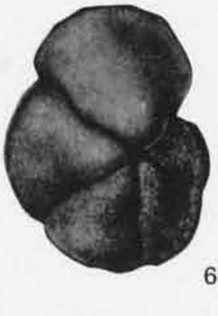
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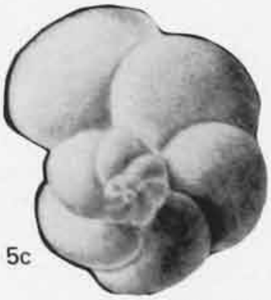
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Fig. 134

STAINFORTH) [sic]. BLOW, 1959, p. 215, pl. 18, fig. 118.–BANDY, 1964b, p. 9, 13, fig. 6.–BERGGREN, 1968, p. 1-22, fig. 3.

Globorotalia (Globorotalia) praemenardii praemenardii CUSHMAN & STAINFORTH. BLOW, 1969, p. 368-370, pl. 6, fig. 1-3 [holotype redrawn].

Globorotalia (Globorotalia) praemenardii CUSHMAN & STAINFORTH. JENKINS, 1971, p. 97, pl. 6, fig. 155-157.

Test an evenly formed discoidal trochospire of chambers which increase regularly in size as added and maintain constant shape. Final whorl of 4½ to 6 chambers. Equatorial profile slightly lobate, pentagonal in smaller specimens, becoming ear-shaped in larger by radial elongation of chambers; profile in side view sharply acute, usually with delicate imperforate keel on later chambers. Sutures on spiral side strongly recurved, resulting in elongate crescentic to comma-shaped chambers; on umbilical side nearly straight, radial, becoming deeply incised between later chambers. Umbilicus variable but larger specimens tend to show distinct pit. Aperture a low arch from umbilicus to near periphery, carrying a delicate lip. Surface smooth, finely perforate, may be rugose near aperture. Diameter 0.5 to 0.7 mm.

Discussion.–*Globorotalia praemenardii* appears to evolve from *G. scitula* by developing an acute, lightly carinate periphery and to give rise to the *G. menardii* tribe of species distinguished by a complete limbate keel and limbate sutures on the spiral side. BOLLI (1957b) separated an earlier-appearing, less lobate, more tumid form as *Globorotalia archeomenardii*, but BLOW (1959, 1969) treated this as a subspecies of *G. praemenardii*. BLOW regarded the nonlimbate sutures of *G. praemenardii* as a better criterion than strength of keel in its separation from the *G. menardii (G. cultrata)* plexus.

Distribution.–In tropical faunas the limited range of *G. praemenardii* makes it a useful guide to Middle Miocene age, approximating the *Globorotalia fohsi* Zone sensu lato of some authors. In temperate regions, however, this species is generally too scarce for use in zonation.

GLOBIGERINOIDES QUADRILOBATUS
(d'Orbigny, 1846) sensu lato
Figures 135-138

The genus *Globigerinoides* first appeared inconspicuously in the later Oligocene; then in Early Miocene proliferated strikingly both in its numerical contribution to worldwide planktonic faunas and in morphologic diversity. Many of the forms which appeared in the Early Miocene persist into Holocene faunas. Consequently the prime stratigraphic value of species of *Globigerinoides* lies in their level of explosive appearance–often called the *Globigerinoides* Datum, which is virtually coincident with the beginning of the Miocene. A complex nomenclature has been applied to the intergrading morphologic variants, but only a few are both distinctive and short-ranging so we make no attempt to treat the group fully here. For more detailed discussion reference is made to BANNER & BLOW (1965a).

The genus *Globigerinoides* evolved from a simple quadrate *Globigerina* (possibly *Globigerina [praebulloides] occlusa* BLOW & BANNER, 1962) by the development of supplementary dorsal apertures along the spiral suture. Conceptually the most primitive form had only one such aperture *(Globigerinoides quadrilobatus primordius)* and was followed by a form, still close to the globigerine ancestor, with two or more (*Globigerinoides quadrilobatus* sensu stricto). Authors concerned with the south Pacific region differ on details of the incipience of the genus (see, in particular, SCOTT, 1966-1971, and JENKINS, 1971). From this root stock divergent strains developed, in particular:

1. More rapid increase in size of chambers resulting in the trilobate *Globigerinoides quadrilobatus triloba*.
2. As subspecies *triloba* but chambers becoming irregularly thumb- or sack-shaped *(Globigerinoides quadrilobatus sacculifer)* and in the Late Tertiary developing additional prolongations *(G. q. hystricosus, G. q. fistulosus)*.
3. Involute coiling and inflation of chambers leading to *Globigerinoides sicanus* and on to the orbuline genera.
4. Elevation of the spire producing the lineage of *Globigerinoides quadrilobatus altiapertura - Globigerinoides ruber/ subquadratus-Globigerinoides mitra.*

Within each lineage occurs much intragradational variation in rate of enlargement of successive chambers, degree of appression of chambers, and size and lunateness of both primary and secondary apertures. It is this variability which led to the complex nomenclature of the group among systematists, but we pay it scant attention here because of its negligible stratigraphic significance.

Until fairly recently authors tended to follow BOLLI and others in treating all but the extreme variants as subspecies of *Globigerinoides triloba* (REUSS). Actually, however, *Globigerinoides quadrilobatus* (D'ORBIGNY) has priority over REUSS' species (1846 against 1850) and is genetically more primitive, so this has become the preferred group name. The subspecific nomenclature has been applied to forms in which ontogenetic development from a *quadrilobatus*-like nucleus is evident, but full specific treatment is given to more advanced forms, such as *G. ruber* and *G. sicanus*.

Some nomenclatural confusion arose because many specific (trivial) names were introduced in the feminine form following widely accepted interpretation of *Globigerinoides* as feminine. The genus *Globigerinoides*, however, subsequently was pronounced to be masculine (HEMMING, 1958; International Code of Zoological Nomenclature, Article 30ii). Acceptance of this ruling is obligatory, and expressions of disagreement (e.g., BANDY, 1964c, p. 36; EMILIANI, 1969, p. 273) lack standing. Most adjectival names could be rectified simply by changing the *-a* ending to *-us*, as in *quadrilobatus* and *immaturus*, but the masculine forms *sacculifer* and *ruber* are exceptions. Other names are nouns in apposition and must remain constant regardless of gender. Best known of these is *triloba* (three-lobed thing) which should not be changed to *trilobus* even though many authors have erroneously done so. Another example is *mitra*, and seemingly yet another is *altiapertura*, which we assume to be noninflectional, contrary to the usage of most authors but in accord with WADE (1964) and CLOSS (1967). Note also recently revised ICZN Art. 30i (YOCHELSON, 1973).

GLOBIGERINOIDES QUADRILOBATUS ALTIAPERTURA Bolli, 1957

Figure 135

Early Miocene

Globigerinoides triloba altiapertura BOLLI, 1957b, p. 113, pl. 25, fig. 7-8.–BLOW, 1959, p. 187, pl. 10, fig. 61.

Globigerinoides trilobus (REUSS) var. *altiaperturus* BOLLI. BERMÚDEZ, 1960, p. 1246.

Globigerinoides quadrilobatus altiapertura BOLLI. BLOW & BANNER, 1962, p. 137.–WADE, 1964, p. 273-290.–CLOSS, 1967, p. 340, pl. 1, fig. 14.

Globigerinoides quadrilobatus altiaperturus BOLLI. BANNER & BLOW, 1965a, p. 111, fig. 9.–CORDEY, 1967, p. 651-653, fig. 2.–BLOW, 1969, p. 325.

Globigerina triloba forma *altiapertura* BOLLI. HOFKER, 1968, p. 43, pl. 20, fig. 3, j-l.

Globigerinoides altiaperturus BOLLI. JENKINS, 1971, p. 174-175, pl. 20, fig. 604-606.

[We regard the name *altiapertura* as a nominal form which should not be modified to *altiaperturus* even though many authors have made this change.]

Test ovoid with gaping apertures, a low-spired quadrate coil of appressed globular chambers, each approximately double size of preceding chamber. Final whorl consistently of 4 chambers in spiral aspect, 3½ in umbilical aspect. Periphery in both vertical and side aspects ovate, lightly waisted at final suture. Sutures initially faint, later depressed. Primary aperture a large circular arch facing outward along prolongation of spire, extending from last to antepenultimate chamber, completely embracing umbilical part of penultimate chamber. Final (and occasionally penultimate) chamber also carries large lunate aperture contiguous with spiral suture on spiral side. Viewing specimens at random, some usually have primary and supplementary apertures aligned so that one sees right through them. Surface coarsely cancellate, hispid. Diameter to 0.55 mm.

Discussion.–*Globigerinoides quadrilobatus altiapertura* is best recognized by its strikingly large primary aperture. It develops transitionally into *Globigerinoides ruber* (the *subquadratus* form) which is distinguished by its aperture extending over only 2 (not 3) chambers (see CORDEY, 1967) and by its more elevated spire. The subspecies *triloba* differs in numerous details but particularly in that the primary aperture turns inward not outward.

Distribution.–*Globigerinoides quadrilobatus altiapertura* appeared early in the explosive evolution of its tribe but quickly gave place to *Globigerinoides ruber* and is, therefore, a useful index of Early Miocene age (mainly the *Catapsydrax dissimilis* and *Catapsydrax stainforthi* Zones). SCOTT (1966-1971) and JENKINS (1971) contended that this subspecies is the most primitive of the whole plexus. It was first recorded from the Lower Miocene (*Catapsydrax dissimilis* Zone) in the Cipero Formation of Trinidad.

GLOBIGERINOIDES QUADRILOBATUS PRIMORDIUS Blow & Banner, 1962

Figure 136

Earliest Miocene

Globigerinoides quadrilobatus primordius BLOW &


1


2


3a


3b


3c


4

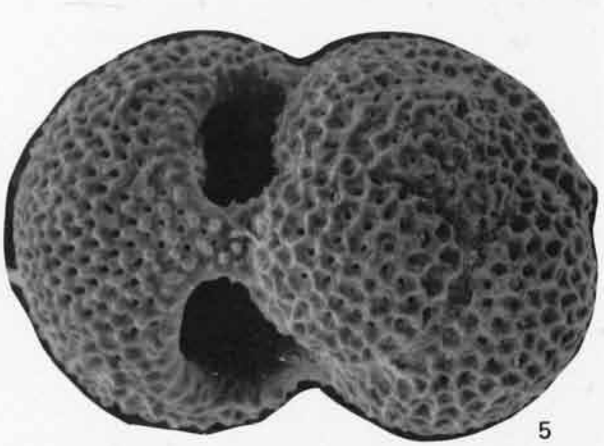
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Fig. 135. *Globigerinoides quadrilobatus altiapertura* BOLLI from the Early Miocene part (*Catapsydrax dissimilis* Zone) of the Cipero Formation of Trinidad.

1-5 Topotypes (**1-2,4-5**) and holotype (**3** from BOLLI, 1957b, pl. 25, fig. 7). **1,3c**–Spiral views, X140; X68; **2,3b**–umbilical views, X180, X68; **3a,5**–side views, X68, X150; **4**–oblique spiral view, X180.

BANNER, 1962, p. 115, pl. 9, fig. Dd-Ff.–BANNER & BLOW, 1965a, p. 10, fig. 10.–BLOW, 1969, p. 325, pl. 20, fig. 1, 5-6.

Globigerinoides altiaperturus BOLLI, JENKINS, 1971, p. 174.

Test a low quadrate coil of appressed hemispherical chambers, approximately doubling in size as added. Final whorl of 4 chambers in both spiral and umbilical aspects. Periphery ovate, lightly indented at sutures. Final chamber protrudes slightly from umbilical surface, forming a simple, low, arched primary aperture opening into umbilical area. Spiral surface carries a single small supplementary aperture, usually a triangular pit where sutures intersect, but may be slightly lunate. Surface cancellate. Diameter about 0.4 mm.

Discussion.–*Globigerinoides quadrilobatus primordius* differs from its immediate ancestor (*Globigerina praebulloides* subsp. or *Globigerina woodi* subsp. of authors) by the primitive aperture on the spiral side. It is included because of its reputation as a zonal index, but we are dubious that it can be distinguished with confidence from juveniles of more advanced subspecies.

Distribution.–Reputedly restricted to earliest Miocene (mainly *Globorotalia kugleri* Zone), the level at which it was first recorded in the Cipero Formation of Trinidad, but undoubtedly occurs also in the late Oligocene, as previously noted in discussion of the *Globigerinoides* Datum.

GLOBIGERINOIDES QUADRILOBATUS SACCULIFER (Brady, 1877)

Figure 137

Miocene to Holocene

Globigerina sacculifera BRADY, 1877, p. 535; based on figure of *Globigerina helicina* CARPENTER (not D'ORBIGNY), 1862, pl. 12, fig. 11.–CUSHMAN, 1924, p. 21, pl. 4, fig. 1-6.–BANNER & BLOW, 1960a, p. 21-24, pl. 4, fig. 1-2 [lectotype, fig. 1].

Globigerinoides sacculifera (BRADY). CUSHMAN & JARVIS, 1930, p. 366, pl. 34, fig. 4.–CORYELL & MOSSMAN, 1942, p. 238, pl. 36, fig. 28.

Globigerinoides triloba forma *sacculifera* (BRADY). COLOM, 1954, p. 215, pl. 18, fig. 49-54.

Globigerinoides sacculifer (BRADY). AKERS, 1955, p. 656.–BERMÚDEZ, 1960, p. 1236, pl. 11, fig. 4-6.–JENKINS, 1971, p. 178, pl. 21, fig. 619-621.

Globigerinoides triloba sacculifera (BRADY). BOLLI, 1957b, p. 113, pl. 25, fig. 5-6.–BLOW, 1959, p. 188, pl. 11, fig. 63.

Globigerinoides quadrilobatus sacculifer (BRADY). BLOW & BANNER, 1962, p. 137, fig. 13.–BANNER & BLOW, 1960a, p. 17 [pl. explanation].–BANNER & BLOW, 1965a, p. 111, fig. 3.

[For more extensive reference lists see CUSHMAN (1924) and BERMÚDEZ (1960) cited here.]

Test a low trochospire of inflated chambers, initially appressed and globular, later becoming loose and asymmetrical, prolonged into thumb- and almond-shaped forms, with conspicuous supplementary apertures on the spiral side.

Discussion.–Except for its distinctive adult chambers, *Globigerinoides quadrilobatus sacculifer* is morphologically the same as *G. q. triloba; G. q. immaturus* LEROY (1939) is intermediate between them.

Distribution.–Widespread in post-Oligocene assemblages. Original description was based on modern specimens.

Fig. 136. *Globigerinoides quadrilobatus primordius* BLOW & BANNER from the Early Miocene off Florida, in Texas, and in Trinidad. [p. 308]

1-2	Specimens from a submarine core from off Florida, X110; **1**–Spiral view; **2**–umbilical view.
3-4,6	Specimens from earliest Miocene beds in the subsurface of Texas; X170. **3-4**–Spiral views; **6**–umbilical view.
5	Holotype from the earliest Miocene part (*Globorotalia kugleri* Zone) of the Cipero Formation of Trinidad, X100; from BLOW & BANNER (1962, pl. 9, fig. Dd-Ff). **a**–Spiral view; **b**–side view; **c**–umbilical view.

Fig. 137. *Globigerinoides quadrilobatus sacculifer* (BRADY) from the Neogene of Trinidad, Gulf of Mexico, north Pacific Ocean, and New Guinea area. [p. 309]

1	Umbilical view of specimen from the Middle Miocene part (*Globorotalia fohsi fohsi* Zone) of the Cipero Formation of Trinidad, X100.
2-4	Specimens from Pleistocene sediments in a submarine corehole in the Gulf of Mexico; from original SEM illustrations of LAMB & BEARD (1972, pl. 31, fig. 2-3,5). **2**–Oblique umbilical view, X100; **3**–oblique spiral view, X85; **4**–spiral view, X85.
5	Ideotype from Holocene sediments in the north Pacific, X50; from BANNER & BLOW (1960a, pl. 4, fig. 2). **a**–Spiral view; **b**–umbilical view.
6	Lectotype from later Neogene beds of New Ireland in the New Guinea area, X100; from BANNER & BLOW (1960a, pl. 4, fig. 1). **a**–Spiral view; **b**–umbilical view.

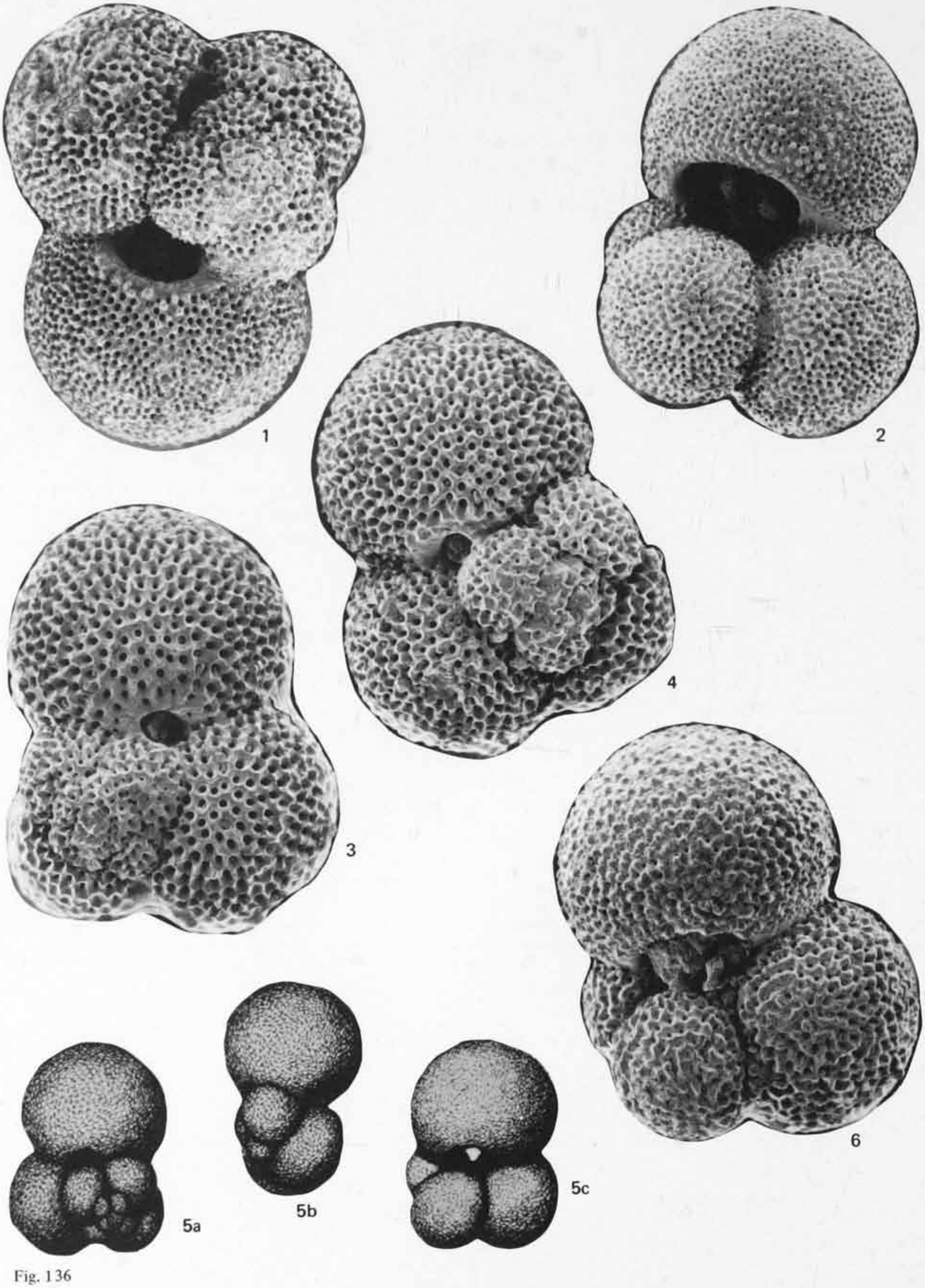

Fig. 136

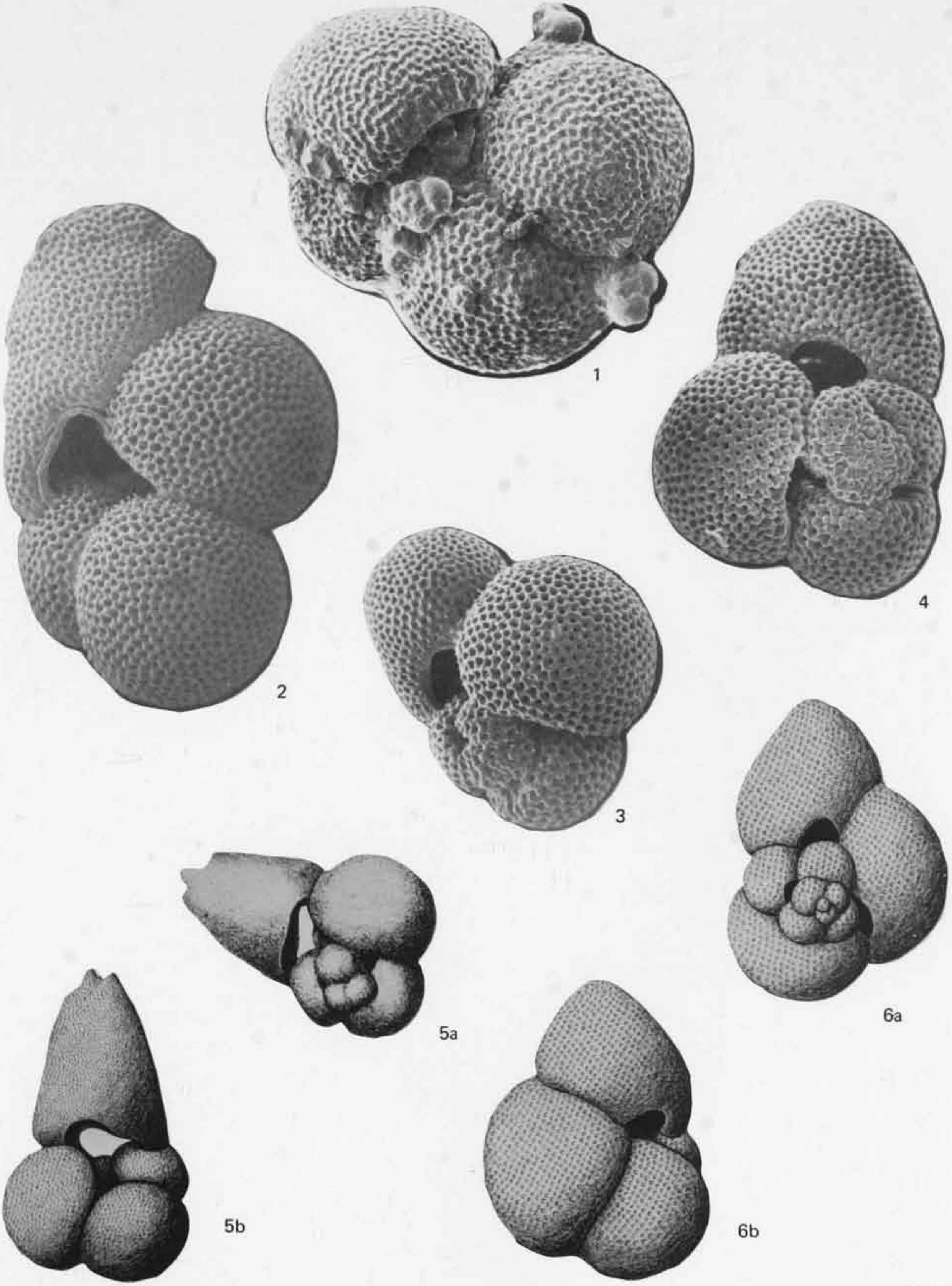

Fig. 137

GLOBIGERINOIDES QUADRILOBATUS TRILOBA (Reuss, 1850)

Figure 138

Miocene to Holocene

Globigerina triloba REUSS, 1850, p. 347, pl. 47, fig. 11.–COLE, 1931, p. 55, pl. 7, fig. 10-11.–PALMER, 1945, p. 68.–BANNER & BLOW, 1965a, p. 108, fig. 2 [line drawing of cotype, after REUSS, 1850].
Globigerinoides triloba (REUSS). CORYELL & RIVERO, 1940, p. 340.–CORYELL & MOSSMAN, 1942, p. 238, pl. 36, fig. 29-30.–CUSHMAN, 1946, p. 20, pl. 3, fig. 8; pl. 4, fig. 16-18.
Globigerinoides trilobus (REUSS). GRIMSDALE, 1951, p. 446.–DROOGER, 1953, p. 142.–BERMÚDEZ, 1960, p. 1244, pl. 12, fig. 6.–LIPPS, 1964, p. 120, pl. 2, fig. 3.
Globigerinoides triloba triloba (REUSS). BOLLI, 1957b, p. 112, pl. 25, fig. 2.–BLOW, 1959, p. 187, pl. 11, fig. 60.
Globigerinoides quadrilobatus trilobus (REUSS). BLOW & BANNER, 1962, p. 137.–BANNER & BLOW, 1965a, p. 105-112, pl. 16, fig. 4.–BLOW, 1969, p. 326.

[For more extensive reference lists see CUSHMAN (1946) and BERMÚDEZ (1960) cited here. The trivial name *triloba* is a noun used in apposition and should not be modified to *trilobus* even though a majority of modern authors erroneously do so.]

Test consists of two unequal subspherical portions separated by a conspicuous incised suture. One portion is initial quadrate coil of appressed chambers, other is final chamber. On umbilical side only 3 chambers visible. Periphery in most aspects ovate with incised median line. Primary aperture a simple arch turned inward to embrace earlier portion of test. Supplementary apertures along spiral suture, mainly irregular slits but becoming lunate in adult portion. Surface coarsely cancellate, often hispid. Greatest dimension varies in different assemblages, reaching maximum of 0.8 mm.

Discussion.–*Globigerinoides quadrilobatus triloba* is based on a species of which the types are lost, and the name has been applied to a broad range of forms having basic characteristics noted above. It is distinguished from *G. quadrilobatus* s.s. by showing only 3, not 4, chambers on the umbilical side. The *G. q. altiapertura-G. ruber* lineage differs in having large, lunate, supplementary apertures and outwardly directed primary apertures. The subspecies *sacculifer* is identical with *triloba* in early stages but differs in developing bizarre adult chambers.

Distribution.–*Globigerinoides quadrilobatus triloba* is the central form of a plexus which developed explosively in Early Miocene time. This group had a worldwide distribution and was apparently more tolerant than most planktonic foraminifers of varying ecologic factors. Consequently the *Globigerinoides* Datum is highly important for the separation of Neogene from Paleogene. *G. q. triloba* persists to the present day. It was first described from Miocene beds near Krakow (then in Austria but now in southern Poland).

GLOBIGERINOIDES RUBER (d'Orbigny, 1839) sensu lato

Figure 139

Miocene to Holocene

Globigerina rubra D'ORBIGNY, 1839, p. 82, 83, pl. 4, fig. 12-14.–BANNER & BLOW, 1960a, p. 19-21, pl. 3, fig. 8 [lectotype].–HOFKER, 1968, p. 44, pl. 21, fig. 2.
Globigerinoides rubra (D'ORBIGNY). PALMER & BERMÚDEZ, 1936, p. 240.–CORYELL & RIVERO, 1940, p. 340.–CUSHMAN, 1945, p. 75, pl. 12, fig. 9.–BOLLI, 1957b, p. 113, pl. 25, fig. 12-13.
Globigerinoides ruber (D'ORBIGNY). DROOGER, 1953, p. 142.–KANE, 1953, p. 35, pl. 2, fig. 16.–WEISS, 1955, p. 312, pl. 3, fig. 18.–BERMÚDEZ, 1960, p. 1233, pl. 11, fig. 1.–CORDEY, 1967, p. 647-659, fig. 1, 3, pl. 103, fig. 7-15.–BLOW, 1969, p. 326, pl. 21, fig. 4, 7.–LAMB & BEARD, 1972, p. 49, pl. 33, fig. 1-3, 5.
Globigerinoides subquadrata BRÖNNIMANN, in TODD ET AL., 1954, p. 680, pl. 1, fig. 5, 8.
Globigerinoides subquadratus BRÖNNIMANN. BERMÚDEZ, 1960, p. 1244, pl. 12, fig. 4.–CORDEY, 1967, p. 650, fig. 1-2, pl. 103, fig. 1-4.–BLOW, 1969, p. 326-327, pl. 21, fig. 5-6.

[For more extensive reference lists see CUSHMAN (1945) and BERMÚDEZ (1960) as cited here.]

Test an elevated trochospire of subglobular chambers, initially appressed but in adult portion loosely attached and only lightly embracing. Generally 3½ chambers in final whorl. Periphery lobate in umbilical aspect, a blunt-topped pyramid in side view, indented at spiral suture. Sutures depressed to incised. Primary aperture large, almost circular, directed outward along prolongation of spire, embracing suture between penultimate and

Fig. 138. *Globigerinoides quadrilobatus triloba* (REUSS) from the Miocene of Trinidad and Poland.

1-4 Specimens from Early Miocene levels in the Cipero Formation of Trinidad. **1**–Spiral view, X110; **2-4**–umbilical views, X150, X110, X150.

5 Approximate topotype from Middle Miocene beds near Krakov in Poland (formerly Austria), X140; from BANNER & BLOW (1965a, pl. 16, fig. 4). **a**–Umbilical view; **b**–spiral view.

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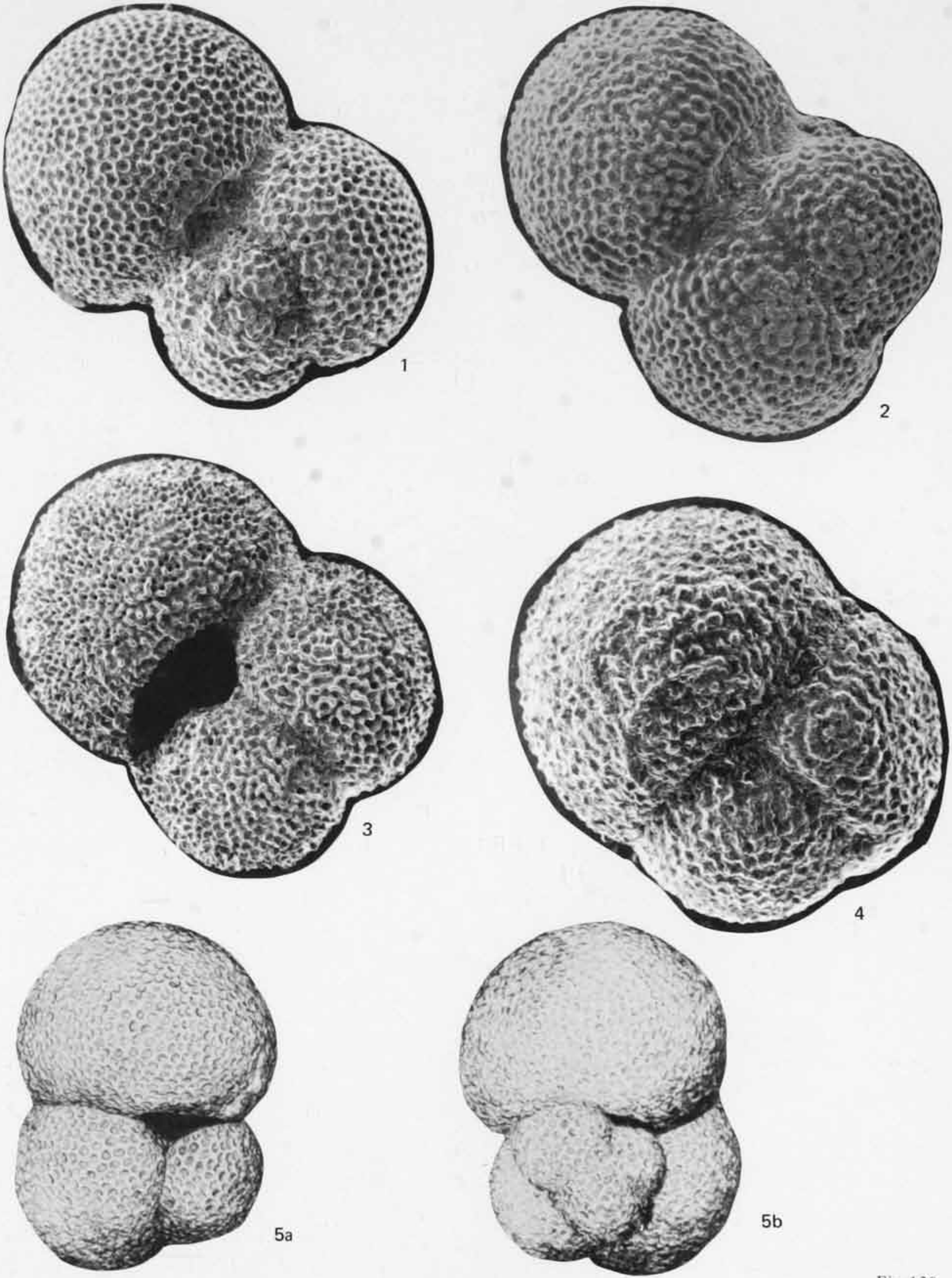
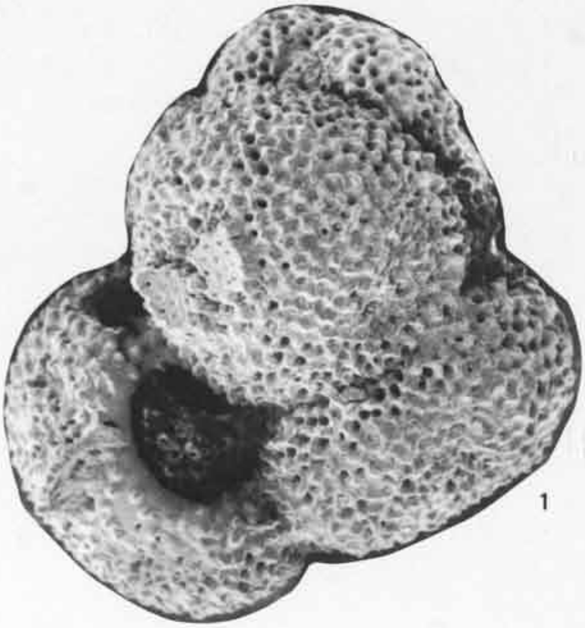


Fig. 138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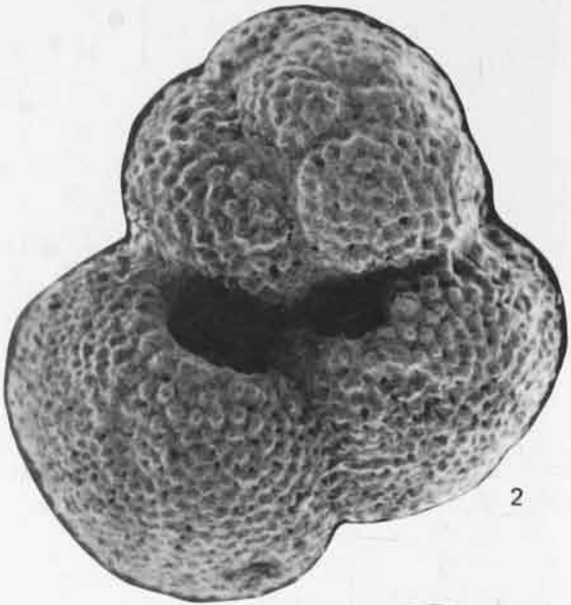
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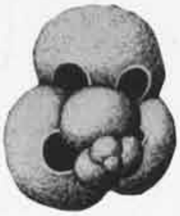
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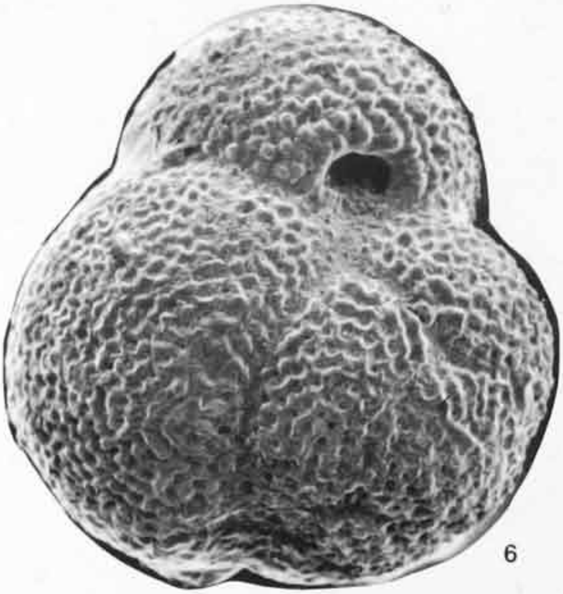
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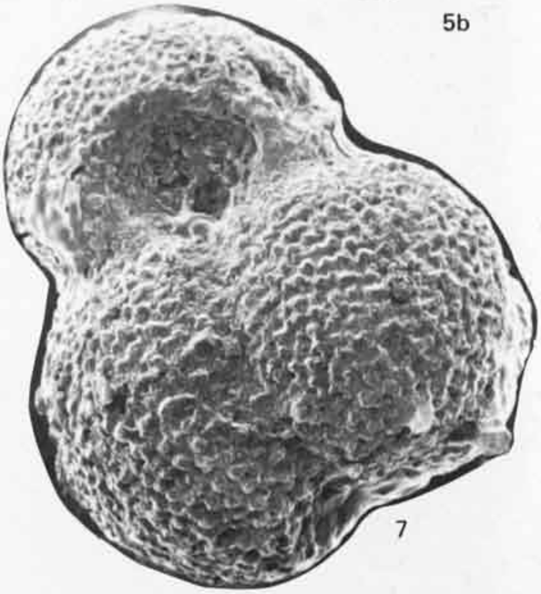
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Fig. 139

Fig. 139. *Globigerinoides ruber* (D'ORBIGNY) (s.l.) from the Neogene of Barbados, Gulf of Mexico, Niger Delta, Cuba, and Trinidad.

1-2 Side views of lofty-spired specimens from the Early Miocene Bissex Hill Formation of Barbados, X140, X130.

3 Spiral view of specimen from Pleistocene sediments in the Gulf of Mexico, X100; from LAMB & BEARD (1972, pl. 33, fig. 1).

4 Spiral view of specimen from a submarine core in the Niger Delta, X130; from BLOW (1969, pl. 21, fig. 4).

5 Lectotype from Holocene deposits of Cuba, X50; from BANNER & BLOW (1960a, pl. 3, fig. 8). **a**–Umbilical view; **b**–spiral view.

6-7 Low-spired specimens from the Middle Miocene part (*Globorotalia fohsi fohsi* Zone) of the Cipero Formation of Trinidad, X140. **6**–Spiral view; **7**–umbilical view.

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antepenultimate chambers. Later chambers carry conspicuous supplementary apertures contiguous with spiral suture on spiral side, usually two per chamber in larger specimens. Surface rather coarsely cancellate. Largest dimension (which may be height of spire) variable, can exceed 1 mm.

Discussion.–Until recently authors treated all forms with this morphology as *Globigerinoides ruber.* BOLLI (1957b) noted that in Trinidad it seemed to disappear within a mid-Miocene interval and suggested that environmental conditions might be responsible. CORDEY (1967) studied the matter further and demonstrated that there are, in fact, two closely homeomorphic species which he separated as *Globigerinoides subquadratus* BRÖNNIMANN (the older form derived from *G. quadrilobatus altiapertura*) and *Globigerinoides ruber* (D'ORBIGNY) (the younger form derived from *G. obliquus*). The differences are slight, partly depending on dissection for demonstration, and CORDEY proposed to refer to the two forms jointly as *Globigerinoides ruber* sensu lato. We adopt his treatment here.

Globigerinoides quadrilobatus altiapertura evolved transitionally into *G. ruber* but is generally smaller and less elevated. CORDEY restricted the name *altiapertura* to specimens in which the apertural arch completely embraces the antepenultimate chamber. Exceptionally lofty forms of *G. ruber* may be referred to the variety *pyramidalis* of VAN DEN BROECK (1876, p. 127, pl. 3, fig. 9-10), of which the still larger and somewhat aberrant *G. mitra* of TODD (1957, p. 302, pl. 78, fig. 3, 6) may be a variant. EMILIANI (1971) demonstrated that morphologic variation within the species is directly related to Pliocene-Pleistocene temperature fluctuations determined from oxygen-isotope analyses of the tests.

Distribution.–*Globigerinoides ruber* (the *subquadratus* form) first appeared in the *Catapsydrax stainforthi* Zone of Early Miocene age and became extinct coincidentally with the *Globorotalia fohsi* group in the late Middle Miocene. *Globigerinoides ruber* s.s. appeared during the Late Miocene and persists into present-day faunas. The two forms were initially described, respectively, from the Lower Miocene of Saipan (Mariana Islands) and from beach sand of Cuba.

GLOBOROTALIA SCITULA (Brady, 1882)
(including subspecies)

Figure 140
Miocene to Holocene

Pulvinulina scitula BRADY, 1882, p. 716.–BANNER & BLOW, 1960a, p. 27, pl. 5, fig. 5 [lectotype].

Pulvinulina patagonica BRADY, 1884, p. 693, pl. 103, fig. 7 (not *Rotalina patagonica* D'ORBIGNY, 1839).

Globorotalia scitula (BRADY). CUSHMAN, 1931a, p. 100, pl. 17, fig. 5.–CUSHMAN & HENBEST, 1940, p. 36, pl. 8, fig. 5.–BOLLI, 1957b, p. 120, pl. 29, fig. 11-12.–PARKER, 1962, p. 238-239, pl. 6, fig. 4-6.–PEZZANI, 1963, p. 576-577, pl. 33, fig. 8.

Globorotalia canariensis CUSHMAN & STAINFORTH, 1945, p. 70, pl. 13, fig. 12.–RENZ, 1948, p. 139, pl. 11, fig. 3 [not *Rotalina canariensis* D'ORBIGNY, 1839].

Globorotalia scitula ventriosa OGNIBEN, 1958, p. 246-249, pl. 11, fig. 3-4; pl. 15, fig. 4-5.

Globorotalia scitula scitula (BRADY). BLOW, 1959, p. 219, pl. 16, fig. 126.

Globorotalia scitula gigantea BLOW, 1959, p. 220, pl. 16, fig. 127.

Globorotalia scitula praescitula BLOW, 1959, p. 221, pl. 19, fig. 128.–JENKINS, 1960, p. 366, pl. 5, fig. 6.

Turborotalia scitula (BRADY). LIPPS, 1967, p. 995, fig. 2.

Turborotalia praescitula (BLOW). LIPPS, 1967, p. 995, fig. 2.

Globorotalia (Turborotalia) scitula (BRADY) subspp. BLOW, 1969, p. 354-356, pl. 4, fig. 21-23 [holotype of *praescitula* redrawn]; pl. 39, fig. 4, 7, 10.

Globorotalia (Turborotalia) praescitula BLOW. JENKINS, 1971, p. 129-130, pl. 14, fig. 392-394.

Globorotalia (Turborotalia) scitula (BRADY). JENKINS, 1971, p. 131-132, pl. 13, fig. 371-373.

Globorotalia praescitula BLOW. NICORA, 1971, pl. 7, fig. 7; pl. 8, fig. 1-2; pl. 17, fig. 1.

Test a discoidal trochospire of chambers which increase regularly in size and maintain constant shape.

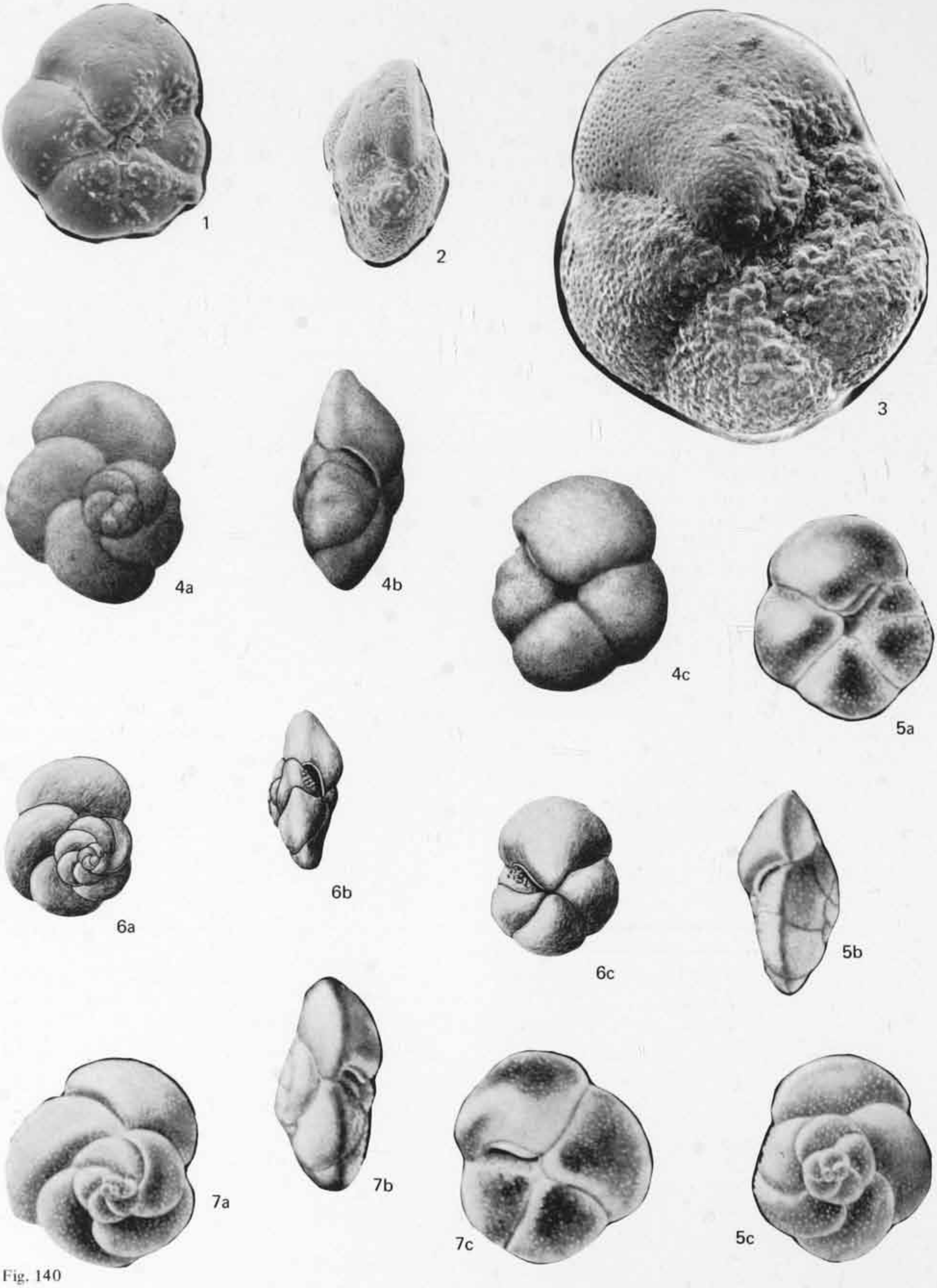


Fig. 140

Fig. 140. *Globorotalia scitula* (BRADY) from the Miocene of Trinidad and Venezuela and Holocene of the Atlantic Ocean.

1-3 Specimens from the Middle Miocene part (*Globorotalia fohsi fohsi* Zone) of the Cipero Formation of Trinidad. **1**–Umbilical view, X110; **2**–side view, X110; **3**–umbilical view of giant form (*G. scitula gigantea* of BLOW), X100.

4 Specimen (=holotype of *G. scitula praescitula* BLOW) from the Early Miocene part (*Globigerinatella insueta* Zone) of the San Lorenzo Formation of Venezuela, X135, from BLOW (1969, pl. 4, fig. 21-23). **a**–Spiral view; **b**–side view; **c**–umbilical view.

5 Specimen from the Middle Miocene part (*Globorotalia fohsi lobata-robusta* Zone) of the Cipero Formation of Trinidad, X68; from BOLLI (1957b, pl. 29, fig. 11). **a**–Umbilical view; **b**–side view; **c**–spiral view.

6 Lectotype from Holocene sediments in the northeasternmost Atlantic Ocean, X100; from BANNER & BLOW (1960a, pl. 5, fig. 5). **a**–Spiral view; **b**–side view; **c**–umbilical view.

7 Specimen from the Middle Miocene part of the Lengua Formation of Trinidad, X68; from BOLLI (1957b, pl. 29, fig. 12). **a**–Spiral view; **b**–side view; **c**–umbilical view.

Final whorl of 4 to 5 chambers. Profile in vertical aspect subcircular to pentagonal, may be slightly lobate; in side profile spiral and umbilical faces form an acute angle but periphery is bluntly rounded. Sutures on spiral side very strongly recurved, resulting in elongate crescentic chambers; sutures on umbilical side almost straight, radial. Umbilicus closed or narrow and deep. Surface smooth, finely perforate, but may be pustulose near aperture. Diameter usually 0.3 to 0.4 mm but may reach 0.6 mm.

Discussion.–As indicated in the preceding synonymy, modern authors tend to apply subspecific nomenclature to *Globorotalia scitula* based mainly on degree of inflation of the umbilical side (subspp. *ventriosa*, *praescitula*, and *scitula* s.s.) or exceptionally large size *(gigantea)*. As a group these forms are similar in gross form and are presumed to be ancestral to several later-appearing species of *Globorotalia* *(miozea, archeomenardii-praemenardii, margaritae)* which are all readily distinguished by their distinct keels. A late Tertiary homeomorph is *Globorotalia subscitula* CONATO (1964, p. 290, pl. 2, fig. 16) which differs mainly in a lower length-to-breadth ratio of its chambers on the spiral side.

Distribution.–Presence of any member of the *Globorotalia scitula* group is a reliable guide to post-Oligocene age, and ventrally tumid subspecies are widely accepted as indicative of Early Miocene age. This is a cosmopolitan species first recorded in living plankton from the north Atlantic.

GLOBIGERINA SELLII (Borsetti, 1959)

Figure 141

Oligocene

Globigerina conglomerata (part) BECKMANN, 1953, p. 391, pl. 25, fig. 8-9 [not 6-7] [not *Globigerina conglomerata* SCHWAGER, fide FUENMAYOR, 1969].

Globoquadrina sellii BORSETTI, 1959, p. 209, pl. 1, fig. 3.

Globigerina clarae BERMÚDEZ, 1960, p. 1166, pl. 2, fig. 4 [fide BLOW, 1969; FUENMAYOR, 1969].–HOFKER, 1968, p. 18, pl. 8, fig. 2.

Globigerina oligocaenica BLOW & BANNER, 1962, p. 88-89, pl. 10, fig. G, L-N.–BANDY, 1964b, p. 7.

Globigerina sellii (BORSETTI). BLOW & BANNER, 1962, p. 146 [postscript].–BERGGREN, 1963, p. 471-472.–REISS & GVIRTZMAN, 1966, p. 314, fig. 84.–SAUNDERS & CORDEY, 1968, p. 179, 181.–BLOW, 1969, p. 213-222, 322, pl. 19, fig. 4-6.–FUENMAYOR, 1969, p. 356-367, pl. 1, fig. 1-5.–SOEDIONO, 1969, p. 343, pl. 2, fig. 1.–POSTUMA, 1971, p. 272-273.–DUQUE-CARO, 1971, p. 366.

Globigerina selli (sic) (BORSETTI). JENKINS & ORR, 1972, p. 1090, pl. 11, fig. 4-6.

Test medium size to large, a globose trigonal coil. Bulk of test formed by 3 chambers of last whorl, more than doubling in size as added so that final chamber forms fully one-half test. Spiral and side profiles both subcircular to ovate with indentations at sutures; if slightly tilted, flattening of apertural face breaks smooth curve of profile. Sutures distinct, variably depressed. Umbilicus small to nonexistent. Aperture a slit or low arch, bordered by delicate flange, at base of last chamber; apertural face appreciably flattened and, in immediate area of aperture, recessed. Shell surface usually hispid to spinose, but apertural face smoother. Diameter to 0.75 mm but generally less.

Discussion.–*Globigerina sellii* is readily distinguished from *G. tripartita* by its more rapidly enlarging chambers and by its projecting, partly flattened apertural face. *Globigerina binaiensis* is closely similar in gross form to *G. sellii* but differs in its completely flattened apertural face which forms an acute angle with the peripheral margin. *Globigerina tapuriensis* BLOW & BANNER (1962, p. 97) is an intermediate form which we prefer to ignore for stratigraphic purposes.

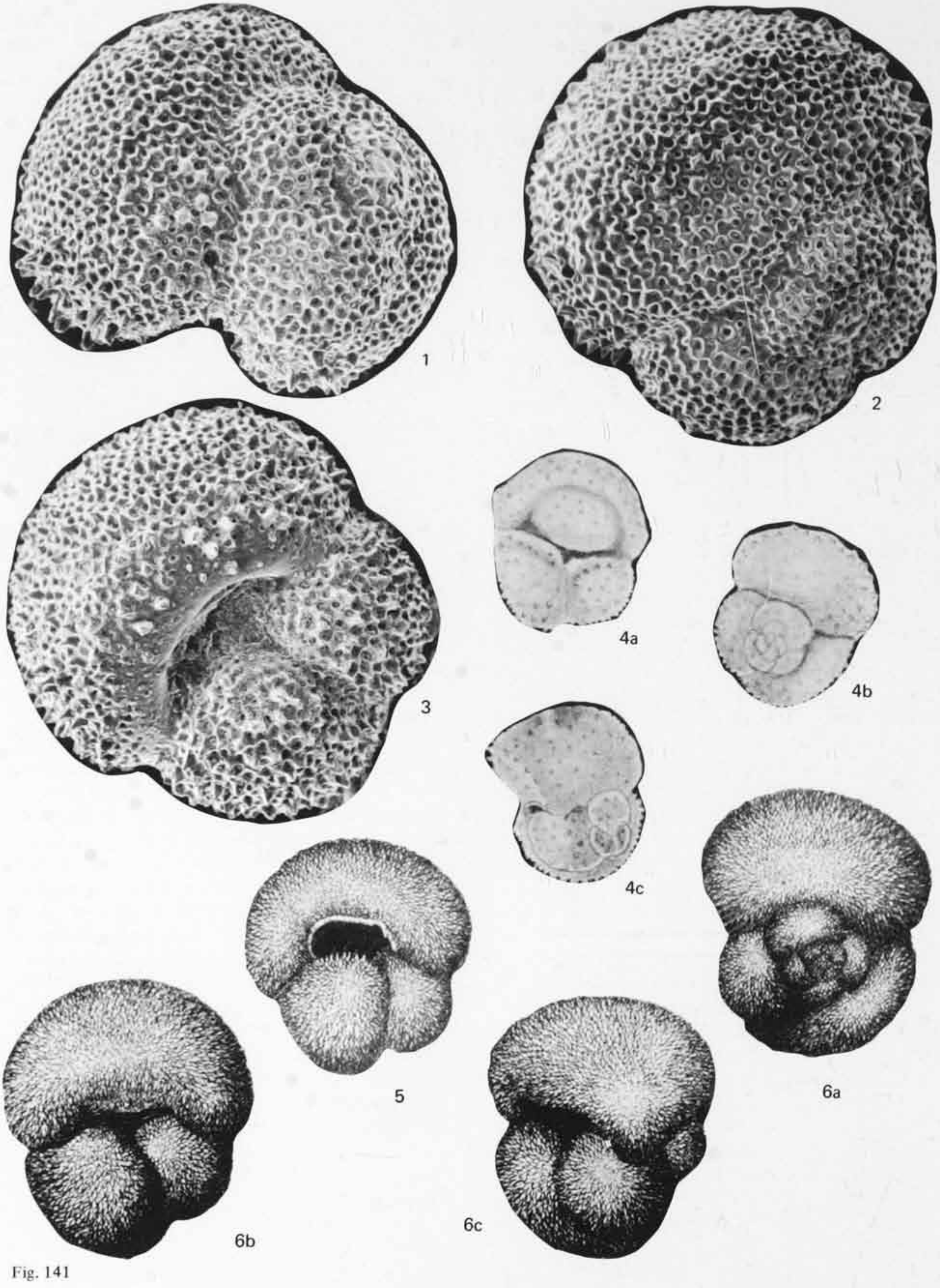


Fig. 141

Fig. 141. *Globigerina sellii* (BORSETTI) from the Oligocene of Mexico, Italy, and Tanzania.

1-3 Specimens from the Alazan Formation of Mexico. **1**–Oblique side view, X140; **2**–oblique spiral view, X140; **3**–umbilical view, X120.

4 Holotype from northern Italy, X60 ca; from FUENMAYOR (1969, pl. 1, fig. 1). **a**–Umbilical view; **b**–side view; **c**–spiral view.

5-6 Specimens (**5**=paratype and **6**=holotype of *Globigerina oligocaenica*) from the Lukuledi Formation of Tanzania, X75; from BLOW & BANNER (1962, pl. 10, fig. G, L-N). **5,6b**–Umbilical views; **6a**–spiral view; **6c**–side view.

Distribution.–It is rather odd that, after being overlooked in early planktonic studies, this distinctive species was recognized at almost the same time and named independently by BORSETTI (1959), BERMÚDEZ (1960), and BLOW & BANNER (1962) in widely scattered Oligocene faunas. EAMES ET AL. (1962) applied its apparent absence in the Americas to support the thesis that Oligocene sediments are largely absent in that region, but subsequent search has revealed its presence in many American faunas, though seldom in abundance. Apparently some climatic factor kept *Globigerina sellii*, and even more so its near relative *G. binaiensis*, largely confined to the Indo-Pacific region. The species is a reliable guide to Oligocene age; first described from northern Italy.

SPHAEROIDINELLOPSIS SEMINULINA
(Schwager, 1866)
Figure 142
Miocene

Globigerina seminulina SCHWAGER, 1866, p. 256, pl. 7, fig. 112.–LEROY, 1941, p. 44, pl. 3, fig. 108.–BANNER & BLOW, 1960a, p. 241, pl. 7, fig. 2 [neotype].–POSTUMA, 1971, p. 274-275.

Sphaeroidinella seminulina (SCHWAGER). AGIP MINERARIA, 1957, pl. 47, fig. 6.–PARKER, 1967, p. 161, pl. 23, fig. 1-5.–JENKINS & ORR, 1972, p. 1109, pl. 40, fig. 9-11.

Sphaeroidinella seminulina seminulina (SCHWAGER). BLOW, 1959, p. 197, pl. 12, fig. 74-77.

Sphaeroidinellopsis seminulina (SCHWAGER). BANNER & BLOW, 1959, p. 15.–BANNER & BLOW, 1960a, p. 40.–LAMB & BEARD, 1972, p. 59, pl. 1, fig. 7-8; pl. 36, fig. 4-9.

Sphaeroidinellopsis seminulina seminulina (SCHWAGER). BLOW, 1969, p. 337-338, pl. 30, fig. 7.–BRÖNNIMANN & RESIG, 1971, p. 1323, pl. 15, fig. 7-8.

Test a compressed trochospire, individuals varying considerably in details. Early chambers obscure, compacted, enlarging rapidly. Later chambers subequal, tending to become loosely attached, 3 to 5 in last whorl. Individual chambers ovate to somewhat digitate, oriented erratically. Equatorial profile highly variable, side profile smoothly rounded. Umbilicus prominent, triangular to diamond-shaped. Aperture a low arch or simple opening into umbilicus. Final aperture usually carries a smoothly thickened lip but earlier ones have commonly accumulated crenulated or frilly borders of clear shell material. Shell distinctive, with an inner layer densely perforated by large pores, almost latticelike, and an outer cortex of vitreous aspect. Usual diameter 0.5 to 0.6 mm, occasionally larger.

Discussion.–The variability of this species, aggravated by strong changes of appearance arising from susceptibility of the vitreous cortex to solution and mineralization, led to taxonomic difficulties. Forms described under the names *disjuncta, grimsdalei, kochi, multiloba,* and *rutschi* have been regarded as fully synonymous (PARKER, 1967; POSTUMA, 1971) or as closely related subspecies (BLOW, 1959).

Sphaeroidinellopsis seminulina gave rise gradationally to *Sphaeroidinellopsis subdehiscens,* which typically has only three outer chambers compacted into an egg-shaped test with a rectangular umbilical slit reminiscent of a letter box. A later descendant was *Sphaeroidinellopsis paenedehiscens* BLOW (1969) [=*S. sphaeroides* LAMB, 1969], distinguished by flange-like lips surrounding aperture and projecting slightly to produce a puckered appearance and by broadly ovate to spheroidal shape.

Distribution.–*Sphaeroidinellopsis seminulina* is a reliable guide to post-Oligocene age and is usually scarce below the Middle Miocene. Authors have recorded it up into the Pliocene but actually, if distinguished from *S. sphaeroides,* it ranges only part way into the Upper Miocene (see LAMB & BEARD, 1972, p. 33-45). The holotype, now lost, and neotype were collected at an undetermined Neogene level on the island of Kar Nicobar in the Indian Ocean.

GLOBOROTALIA SIAKENSIS LeRoy, 1939
Figure 143
Late Oligocene to Middle Miocene

Globorotalia siakensis LEROY, 1939, p. 39-40, pl. 3, fig. 30-31.–POSTUMA, 1971, p. 359-360.

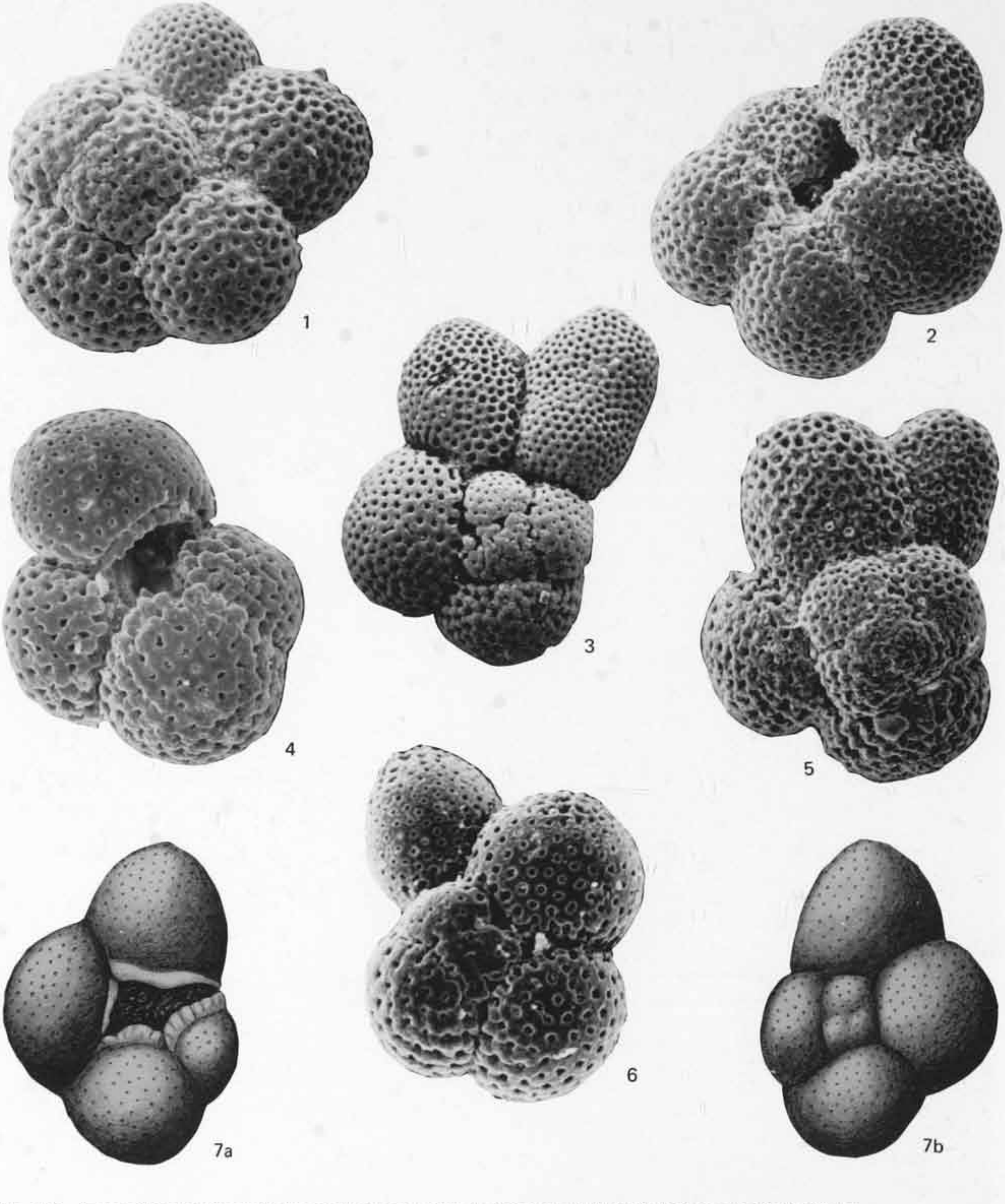


Fig. 142. *Sphaeroidinellopsis seminulina* (SCHWAGER) from the Neogene of the Gulf of Mexico and Indian Ocean.

1-6 Specimens from Middle and Upper Miocene sediments in submarine cores in the Gulf of Mexico; from original SEM illustrations of LAMB & BEARD (1972, pl. 35, fig. 4-9). **1,3,5-6**–Spiral views, X100, X86, X100, X112; **2,4**–umbilical views, X100, X125.

7 Neotype from indefinite Neogene level at Kar Nicobar in the Indian Ocean, X100; from BANNER & BLOW (1960a, pl. 7, fig. 2). **a**–Umbilical view; **b**–spiral view.

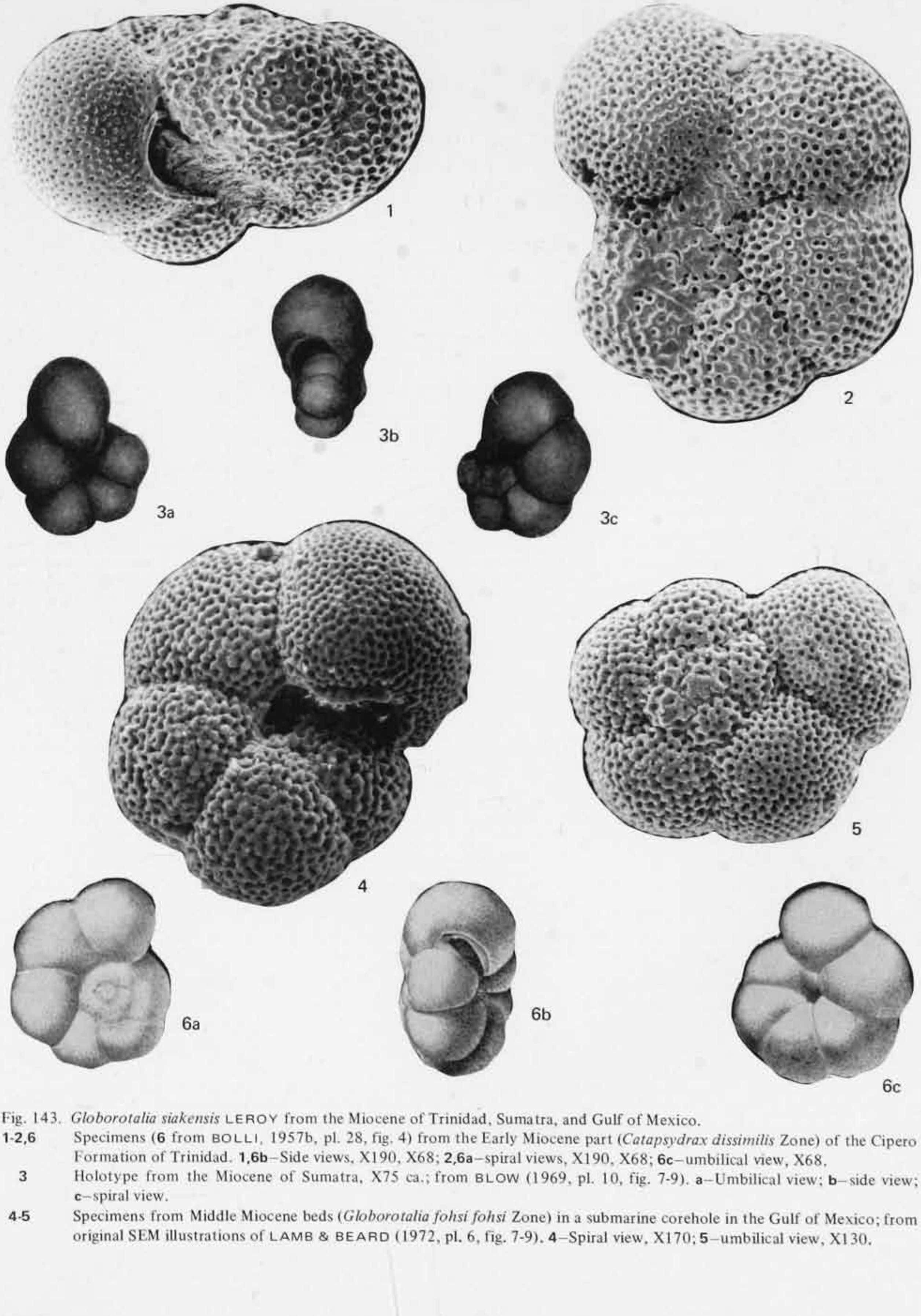


Fig. 143. *Globorotalia siakensis* LEROY from the Miocene of Trinidad, Sumatra, and Gulf of Mexico.

1-2,6 Specimens (**6** from BOLLI, 1957b, pl. 28, fig. 4) from the Early Miocene part (*Catapsydrax dissimilis* Zone) of the Cipero Formation of Trinidad. **1,6b**–Side views, X190, X68; **2,6a**–spiral views, X190, X68; **6c**–umbilical view, X68.

3 Holotype from the Miocene of Sumatra, X75 ca.; from BLOW (1969, pl. 10, fig. 7-9). **a**–Umbilical view; **b**–side view; **c**–spiral view.

4-5 Specimens from Middle Miocene beds (*Globorotalia fohsi fohsi* Zone) in a submarine corehole in the Gulf of Mexico; from original SEM illustrations of LAMB & BEARD (1972, pl. 6, fig. 7-9). **4**–Spiral view, X170; **5**–umbilical view, X130.

Globorotalia mayeri CUSHMAN & ELLISOR, 1939, p. 11, pl. 2, fig. 4.–BERMÚDEZ, 1949, p. 286, pl. 22, fig. 24-26.–BOLLI, 1957b, p. 118, pl. 28, fig. 4.–BLOW, 1959, p. 214, pl. 18, fig. 116.–POSTUMA, 1971, p. 332-333.

Globorotalia (Turborotalia) mayeri CUSHMAN & ELLISOR. CUSHMAN & BERMÚDEZ, 1949, p. 44, pl. 8, fig. 16-18.–CUSHMAN & STAINFORTH, 1951, p. 162.–BLOW & BANNER, 1962, p. 131, 133.–BLOW, 1969, pl. 3, fig. 7-9 [holotype refigured].

Globigerina mayeri (CUSHMAN & ELLISOR). DROOGER, 1956, p. 183-192.–HOFKER, 1968, p. 50, pl. 25, fig. 1.

Turborotalia mayeri (CUSHMAN & ELLISOR). BERMÚDEZ, 1960, p. 1325, pl. 18, fig. 7.–LIPPS, 1964, p. 124-125, pl. 3, fig. 4-5.

Globorotalia (Turborotalia) siakensis LEROY. BERGGREN, 1963, p. 471.–BLOW, 1969, p. 351, 356, pl. 10, fig. 7-9 [holotype refigured]; pl. 34, fig. 4-5.–BRÖNNIMANN & RESIG, 1971, p. 1315-1317, pl. 34, fig. 1-2, 4; pl. 35, fig. 1-8.

Globorotalia (Turborotalia) mayeri mayeri CUSHMAN & ELLISOR. JENKINS, 1971, p. 119-126, pl. 11, fig. 297-302.

Turborotalia (Turborotalia) mayeri (CUSHMAN & ELLISOR). BIELY & SALAJ, 1971, p. 76, 83, 88.

Test discoidal, a depressed trochospire. Typically 5 to 6 chambers in outer whorl. Equatorial profile most commonly rounded pentagonal; side profile shows bluntly rounded periphery, only slightly asymmetrical, thickness at least half diameter. Sutures of last whorl distinct, depressed to lightly incised, on earlier portion less clear. Umbilical pit deep, narrow. Aperture a crescentic to comma-shaped opening between umbilicus and periphery, with inconspicuous rim or lip. Surface smooth, densely perforate. Diameter to 0.6 mm.

Discussion.–Modern authors, following a lead by BERGGREN (1963), claim that *Globorotalia siakensis* and *Globorotalia mayeri* are almost homeomorphic, yet distinguishable, species belonging to separate lineages (e.g., BLOW, 1969; POSTUMA, 1971; and BRÖNNIMANN & RESIG, 1971). For pragmatic stratigraphic purposes, however, we see little merit in documenting such subtle distinctions. Both names were published in 1939 but *siakensis* is said to have slight priority.

Distribution.–*Globorotalia siakensis* is widely distributed and was apparently more tolerant of environmental change than most planktonic foraminifers. It serves as an index for mid-Tertiary age, ranging from late Oligocene to late Middle Miocene. *Globorotalia siakensis* was described originally from the Miocene of Sumatra and *G. mayeri* from the Miocene of Louisiana.

GLOBIGERINOIDES SICANUS de Stefani, 1952

Figure 144

Miocene

Globigerinoides conglobata CUSHMAN & STAINFORTH, 1945, p. 68, pl. 13, fig. 6.–STAINFORTH, 1948b, p. 121, pl. 26, fig. 4.–WEISS, 1955, p. 311, pl. 3, fig. 17 [not *Globigerina conglobata* BRADY, 1879].

Globigerinoides sicana DE STEFANI, 1952, p. 9, note 4 [type figure designated as CUSHMAN & STAINFORTH, 1945, pl. 13, fig. 6].

Globigerinoides bispherica TODD, *in* TODD ET AL., 1954, p. 681, pl. 1, fig. 1-4.–BLOW, 1956, p. 62, fig. 1-3.–BOLLI, 1957b, p. 114, pl. 27, fig. 1.–BLOW, 1959, p. 189, pl. 11, fig. 64.–JENKINS & ORR, 1972, p. 1091, pl. 12, fig. 6-8. [The masculine form *bisphericus* has been used also, and some European authors changed the *e* to *ae*.]

Globigerinoides sicanus DE STEFANI. BERMÚDEZ, 1960, p. 1240, pl. 11, fig. 12; pl. 12, fig. 1.–BLOW, 1969, p. 326-327, pl. 3, fig. 10-11 [holotype refigured].–POSTUMA, 1971, p. 304-305.

Globigerinoides sicanicus (no attribution). PUJOL, 1970, p. 201-219.

Globigerinoides trilobus bisphericus TODD. JENKINS, 1966b, p. 424-427.–JENKINS, 1971, p. 179-180, pl. 21, fig. 622-624.

Test ovoid to spherical; divided unequally by circumferential depression, smaller portion being initial coil of rapidly enlarging and appressed chambers, larger portion hemispherical final chamber. Main aperture a crescentic slit, on umbilical side; supplementary apertures one or more triangular to slit openings on spiral side. Surface finely cancellate. Usual diameter 0.4 to 0.6 mm.

Discussion.–*Globigerinoides sicanus* is intermediate between *Globigerinoides quadrilobatus triloba* and the genus *Praeorbulina*, evolution marked by increasing sphericity of test and diminution of apertures. Every stage of transition exists, hence *G. sicanus* shows much individual variation in the amount of test occupied by the final chamber and in the width of apertural slits. By the definition of BLOW (1956, as *Globigerinoides bispherica*), *G. sicanus* includes forms in which the final chamber

Fig. 144. *Globigerinoides sicanus* DE STEFANI from the Early Miocene *Globigerinatella insueta* Zone of Barbados and Trinidad.

1-3 Random views of specimens from the Bissex Hill Formation of Barbados, X110, X115, X130.

4-6 Holotype (**4** from BLOW, 1969, pl. 3, fig. 10-11) and approximate topotypes (**5** from BOLLI, 1957b, pl. 27, fig. 1) from the Cipero Formation of Trinidad. **4a,5a**–Side views, X67, X68; **4b**–spiral view, X67; **5b,6**–umbilical views, X68, X110.

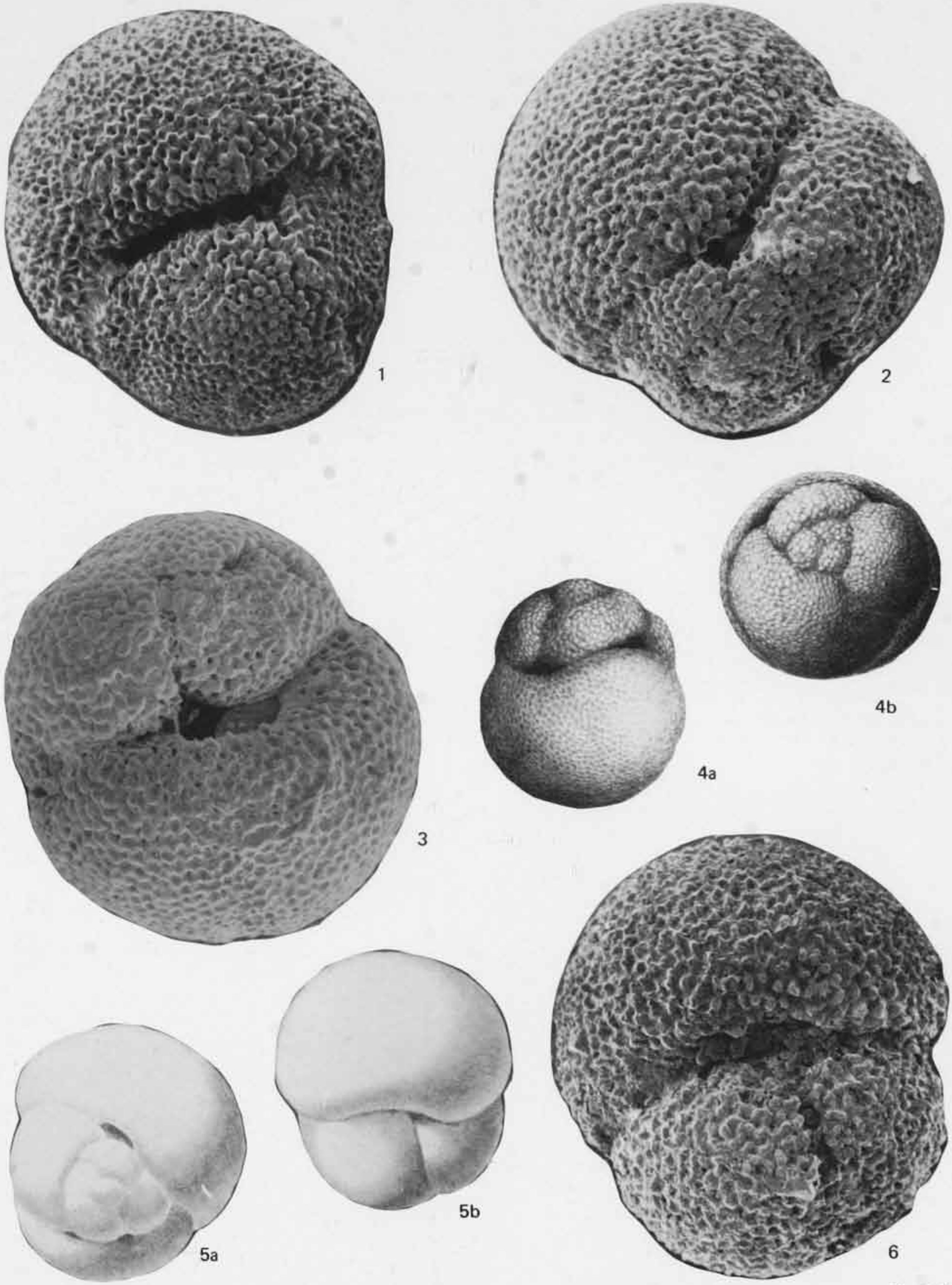


Fig. 144

embraces about 30 percent of the earlier test; evolution has reached the stage of *Praeorbulina glomerosa* subspp. when the percentage rises above 40 and long apertures are replaced by a series of short slits or apertural pores.

The holotype of *Globigerinoides sicanus* was designated by DE STEFANI as the specimen figured by CUSHMAN & STAINFORTH (1945) under the incorrect name of *Globigerinoides conglobata*. The original type figure is of indifferent quality but BLOW (1969) has re-illustrated the holotype. Many authors referred to this species as *G. bisphericus* TODD, but the priority of DE STEFANI'S name now is generally recognized.

Distribution.–*Globigerinoides sicanus* made a worldwide appearance near the end of the Early Miocene and is, therefore, an important index fossil. It has the reputation of ranging only a little way into the Middle Miocene (e.g., BOLLI, 1957b; BLOW, 1969; JENKINS, 1971) but in preparing the present compilation we encountered seemingly identical forms at higher levels. The holotype is from the Lower Miocene portion of the Cipero Formation of Trinidad.

CATAPSYDRAX STAINFORTHI Bolli, Loeblich, & Tappan, 1957

Figure 145

Early Miocene

Catapsydrax stainforthi BOLLI, LOEBLICH, & TAPPAN, 1957, p. 37, pl. 7, fig. 11.–BLOW, 1959, p. 204, pl. 14, fig. 91, 93.–SOEDIONO, 1970, p. 228, pl. 5, fig. 2.–POSTUMA, 1971, p. 238-239.

Globigerina stainforthi (BOLLI, LOEBLICH, & TAPPAN). BANDY, 1964b, p. 8, fig. 5 [not *Globigerina stainforthi* HOFKER, 1956, p. 955, fig. 96-97] [not *Globigerina stainforthi* BOLLI, LOEBLICH, & TAPPAN (sic). HOFKER, 1968, p. 41, pl. 19, fig. 3].

Globorotaloides stainforthi (BOLLI, LOEBLICH, & TAPPAN). LIPPS, 1966, p. 1268.–LIPPS, 1967, p. 996, fig. 2.–LIPPS, 1969, p. 1803.–JENKINS & ORR, 1972, p. 1105-1106, pl. 35, fig. 7-9.

Globigerinita stainforthi stainforthi (BOLLI, LOEBLICH, & TAPPAN). BLOW, 1969, p. 329, 383, pl. 25, fig. 8-10.

Test small, quadrate-discoidal. On spiral side a flat embryonic coil, almost flush with surface, is followed by a very low spire of ellipsoidal chambers which increase slightly in size as added. Usually 4 chambers in final whorl (5 in holotype). Spiral profile mildly lobate, side profile bluntly ovate. Sutures initially obscure, later distinct and lightly incised; spiral suture lobate, intercameral sutures radial. On umbilical side final chambers surround an umbilicus completely covered by a bulla. Primary aperture concealed by bulla. Infralaminal apertures in form of small arched openings on bulla above each intercameral suture, may be at end of tubule aligned with suture, or may have delicate flaring lip. Surface distinctly cancellate. Diameter 0.25 to 0.45 mm.

Discussion.–*Catapsydrax stainforthi* and *Catapsydrax unicavus* are closely similar except for their distinctive bullas. The bullas of *C. stainforthi* and *Globigerinita incrusta* are closely similar, but these forms differ in shell texture and test morphology. BLOW (1969) claimed to describe a subspecies under the name *praestainforthi*, but on the basis of its noncancellate surface we assign this form to the genus *Globigerinita* not far removed from *G. incrusta*.

Distribution.–*Catapsydrax stainforthi* is a useful index for the latter part of the Early Miocene, becoming extinct near the earliest appearance of *Globigerinoides sicanus*. It was first recorded at this level in the Cipero Formation of Trinidad and is the name fossil for the zone defined by joint occurrence of *Catapsydrax dissimilis* and *Globigerinatella insueta*.

GLOBOROTALOIDES SUTERI Bolli, 1957

Figure 146

Middle Eocene to Early Miocene

Globorotaloides suteri BOLLI, 1957b, p. 117, pl. 27, fig. 9-13.–BOLLI, 1957c, p. 166, pl. 37, fig. 10-12.–BLOW & BANNER, 1962, p. 122, pl. 13, fig. N-P.–BLOW, 1969, p. 374.–BERGGREN, 1969b, p. 130-131.–SOEDIONO, 1969, p. 344, pl. 3, fig. 4.–JENKINS, 1971, p. 189-190, pl. 22, fig. 646-648.

Globigerina globularis BATJES [?not ROEMER], 1958, p. 161-162, pl. 11, fig. 3, 5.

Globorotaloides hexagona (NATLAND). LIPPS, 1964, p. 128.–LIPPS, 1966, p. 1268.

Globoquadrina hexagona (NATLAND). PARKER, 1967, p. 169, pl. 25, fig. 9-10.

Test starts with a diminutive plano-convex coil like a tiny *Globorotalia*, followed by a low trochospire of inflated chambers of *Globigerina* type. Generally 4 chambers in final whorl. Spiral outline differs with growth stage but is roughly ovate in larger specimens; side profile compressed. Sutures distinct, mostly depressed. Aperture varies with growth stage, initially an extraumbilical slit, later an intraumbilical opening, and finally bullate. Individual specimens vary greatly, and small ones may have bullas whereas large ones may retain slit apertures. Surface cancellate. Diameter to 0.4 mm.

Discussion.–The status of this species is not firmly established in the literature. BOLLI (1957b) considered it ancestral to *Globorotaloides variabilis* and BLOW (1969) agreed in principle although he treated BOLLI'S *G. variabilis* as a subspecies of *G. hexagona* (NATLAND). In contrast, LIPPS (1964, 1966) and PARKER (1967) asserted that *G. suteri* is identical with *G. hexagona*. Furthermore the type descriptions of *G. suteri* and *Catapsydrax unicavus*, both in the same publication, fail to make a clear-cut distinction between them. BOLLI specified in the type description that *G. suteri* has a finely cancellate surface, yet BLOW & BANNER (1962), BLOW (1969), and SOEDIONO (1969) all stressed an unusually coarsely reticulate surface as characteristic of this species.

Distribution.–Perhaps fortunately, in view of the discrepant opinions on its status, *G. suteri* has a long stratigraphic range from mid-Eocene through Early Miocene and so is not an important index in zonation. It was first described from the Oligocene portion of the Cipero Formation of Trinidad.

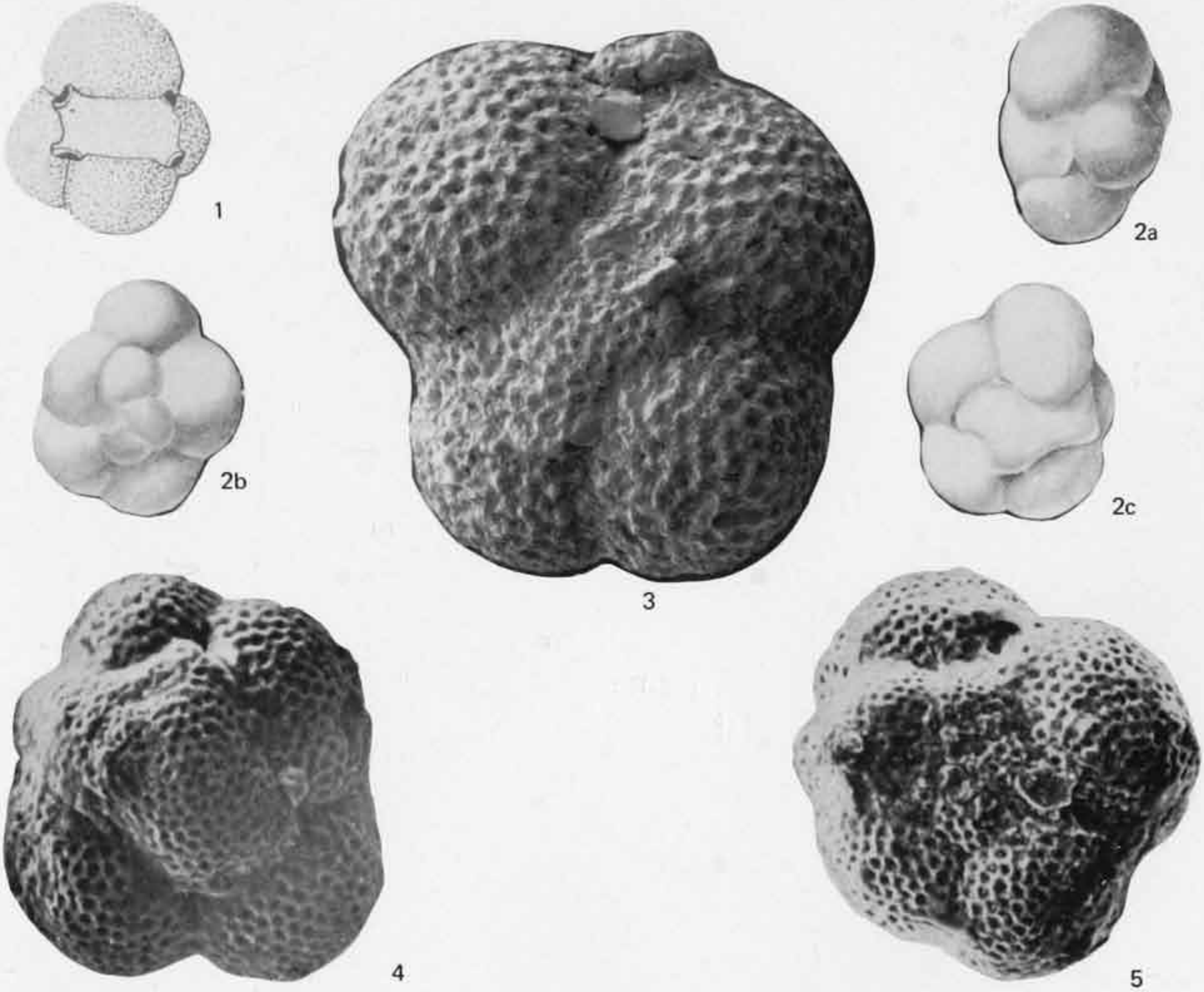


Fig. 145. *Catapsydrax stainforthi* BOLLI, LOEBLICH, & TAPPAN from the Early Miocene of Venezuela and Trinidad.

1 Umbilical view of specimen from the *Globigerinatella insueta* Zone in the San Lorenzo Formation of Venezuela, X100; from BLOW (1959, pl. 14, fig. 91).

2-3 Holotype (**2** from BOLLI, LOEBLICH, & TAPPAN, 1957, pl. 7, fig. 11) and topotype (**3**) from the *Catapsydrax stainforthi* Zone in the Cipero Formation of Trinidad. **2a**–Side view, X95; **2b**–spiral view, X95; **2c**–umbilical view, X95; **3**–umbilical view of leached specimen with cancellate surface still evident, X220.

4-5 Specimens from the *Catapsydrax stainforthi* Zone in the San Lorenzo Formation of Venezuela, X167; from BLOW (1969, pl. 25, fig. 9-10). **4**–Umbilical view; **5**–spiral view.

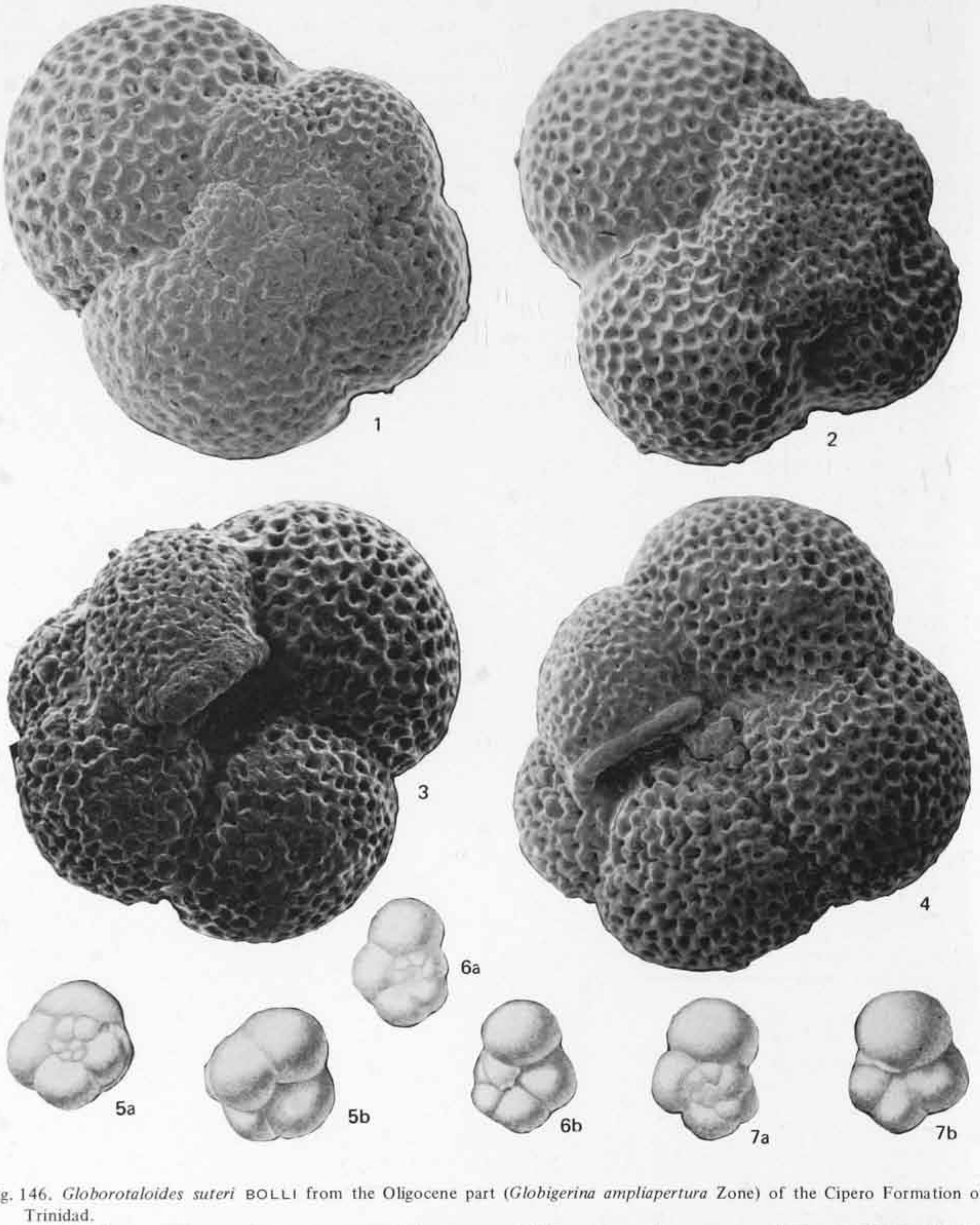


Fig. 146. *Globorotaloides suteri* BOLLI from the Oligocene part (*Globigerina ampliapertura* Zone) of the Cipero Formation of Trinidad.

1-7 Specimens (**1-4**=approximate topotypes; **5**=holotype and **6-7**=paratypes from BOLLI, 1957b, pl. 27, fig. 11-13). **1-2,5a,6a,7a**–Spiral views, X195, X205, X68, X68, X68; **3-4,5b,6b,7b**–umbilical views (**3-4** of bullate form), X200, X195, X68, X68, X68.

ORBULINA SUTURALIS Bronnimann, 1951
Figure 147
Middle Miocene to Holocene

Candorbulina universa JEDLITSCHKA, 1934, p. 21, fig. 1-7, 19, 21-23.–CUSHMAN & STAINFORTH, 1945, p. 69, pl. 13, fig. 10.–BERMÚDEZ, 1960, p. 1247, pl. 7, fig. 11.–LIPPS, 1964, p. 120-122, pl. 2, fig. 5-7.

Orbulina suturalis BRONNIMANN, 1951b, p. 135, fig. 2-4.–BLOW, 1956, p. 66, fig. 2, no. 5-7.–BOLLI, 1957b, p. 115, pl. 27, fig. 4.–POSTUMA, 1971, p. 372-373.

Test consists mostly of a single spherical chamber with a discernible nuclear coil of globigerine chambers flush with or slightly protruding from the sphere. No primary aperture, but enlarged pores outlining nucleus and scattered over test presumably served an apertural purpose. Surface cancellate, may be finely hispid. Specimens may be encountered consisting of a segment as described loosely embraced by a second spherical chamber [=*Praeorbulina transitoria* (BLOW) of authors]. Diameter variable, to 0.8 mm.

Discussion.–This species was described as *Candorbulina universa* by JEDLITSCHKA (1934). BRONNIMANN (1951b) considered it too close to *Orbulina* to warrant generic separation and named it *Orbulina suturalis* (since *universa* was preoccupied by D'ORBIGNY'S species). BRÖNNIMANN'S treatment of the two forms has become widely accepted, though a few authors still maintain the validity of *Candorbulina*.

We differentiate *Orbulina suturalis* and *O. universa*, respectively, by partial exposure or complete concealment of the nuclear chambers. Other authors, notably BLOW (1956), use presence or absence of sutural pores.

Distribution.–For stratigraphic purposes choice of criterion for separating *O. suturalis* and *O. universa* is immaterial as the two species made an almost simultaneous worldwide appearance at the beginning of the Middle Miocene (the important *Orbulina* Datum of authors). Recognition of the *Orbulina* Datum in the Vienna basin (MARKS, 1951; GRILL, 1953; DROOGER, 1956), for example, was a key step towards major revisions of European Neogene stratigraphy accomplished in the past decade.

GLOBIGERINA TRIPARTITA Koch, 1926
Figure 148
Latest Eocene to Earliest Miocene

Globigerina bulloides D'ORBIGNY var. *tripartita* KOCH, 1926, p. 746, fig. 21a-b.

Globigerina venezuelana HEDBERG (part). CUSHMAN & STAINFORTH, 1945, p. 67.–BECKMANN, 1953, p. 392, pl. 25, fig. 12-13.

Globigerina rohri BOLLI, 1957b, p. 109, pl. 23, fig. 1-4.–BOLLI, 1957c, p. 164, pl. 36, fig. 4.–BERMÚDEZ, 1960, p. 1196, pl. 4, fig. 8.

(?)*Globoquadrina rohri* (BOLLI). BLOW, 1959, p. 185, pl. 11, fig. 57.

Globigerina tripartita tripartita KOCH. BLOW & BANNER, 1962, p. 96-97, 141-144, pl. 10, fig. A-F [redrawn holotype, fig. A-C].–REISS & GVIRTZMAN, 1966, p. 314, fig. 84, pl. 90, fig. 1-4.

Fig. 147. *Orbulina suturalis* BRÖNNIMANN from the Miocene of Austria, Florida, and Trinidad. [p. 326]

1-2 Initial coil in specimens from the Miocene of Austria and Florida, X95; from BOLLI, LOEBLICH, & TAPPAN (1957, pl. 7, fig. 2,5). These illustrate differing treatment of the orbuline lineage; specimens assigned to *Orbulina universa* by BOLLI, LOEBLICH, & TAPPAN (1957) are (by BRÖNNIMANN'S criteria) no more advanced than *O. suturalis* and may be referred (especially **1**) even to *Praeorbulina glomerosa.*

3 Side view of specimen from the Middle Miocene part (*Globorotalia fohsi fohsi* Zone) of the Cipero Formation of Trinidad, X120.

4-10 External and internal views showing normal variation in specimens from the Middle Miocene part of the Cipero Formation of Trinidad, X80 ca.

Fig. 148. *Globigerina tripartita* KOCH from the Paleogene of Trinidad, Panama, and Borneo. [p. 327]

1,6 Specimens from the Late Eocene part (*Globigerinatheka semiinvoluta* Zone) of the Navet Formation of Trinidad. **1**–Spiral view, X110; **6**–umbilical view, X120.

2,4 Specimens from the Oligocene (*Globorotalia opima opima* Zone)of Panama, X120. **2**–Spiral view; **4**–umbilical view.

3 Holotype (a slightly deformed specimen) from the later Paleogene of Borneo, X75; from BLOW & BANNER (1962, pl. 10, fig. A-C). **a**–Umbilical view; **b**–side view; **c**–spiral view.

5,7-8 Specimens (**7-8**=paratype and holotype, respectively, of *Globigerina rohri;* from BOLLI, 1957b, pl. 23, fig. 1a, 2b) from the Oligocene part (*Globorotalia opima opima* Zone) of the Cipero Formation of Trinidad. **5**–Spiral view of juvenile, X100; **7**–oblique umbilical view, X68; **8**–spiral view, X68.

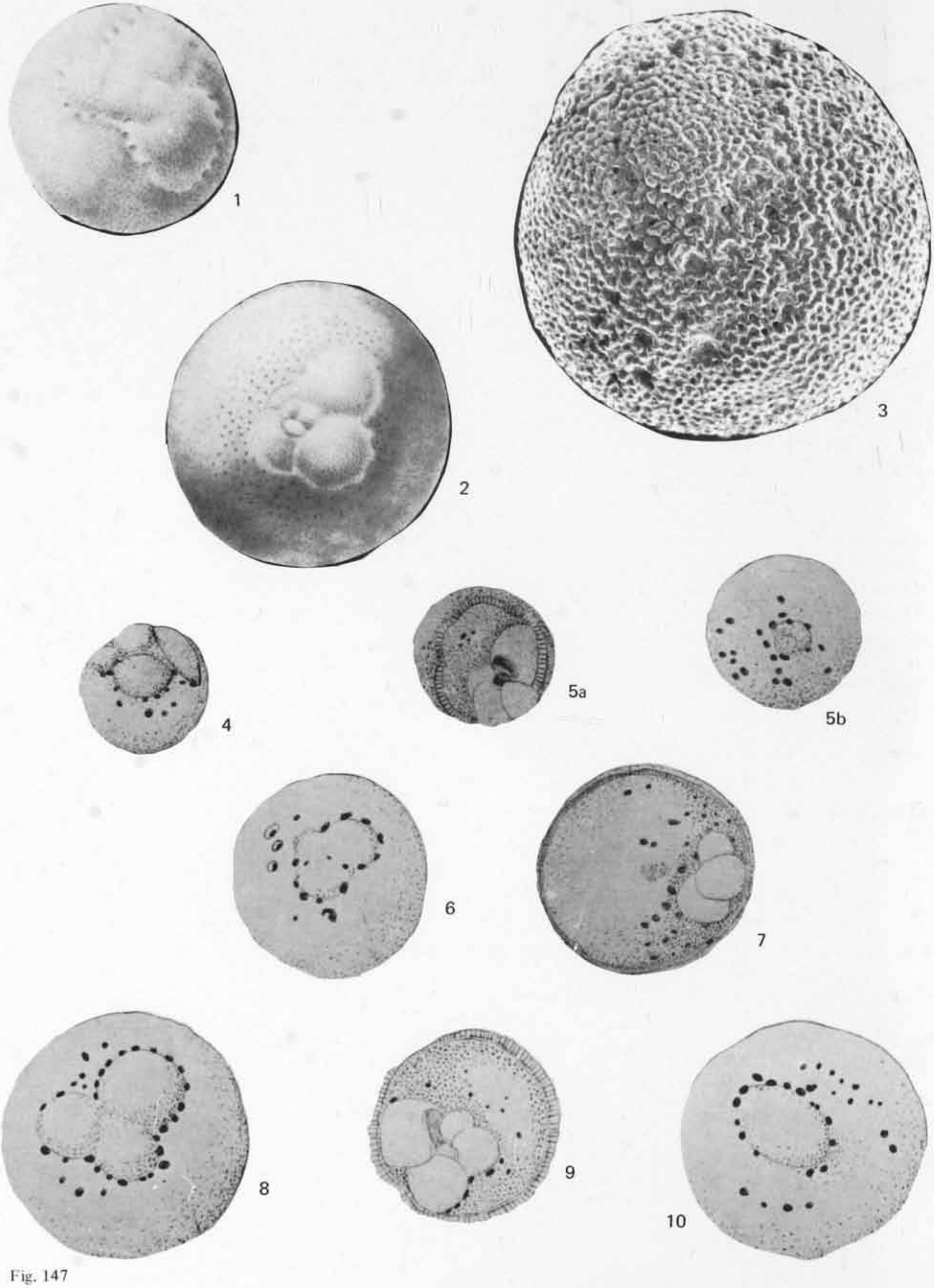


Fig. 147

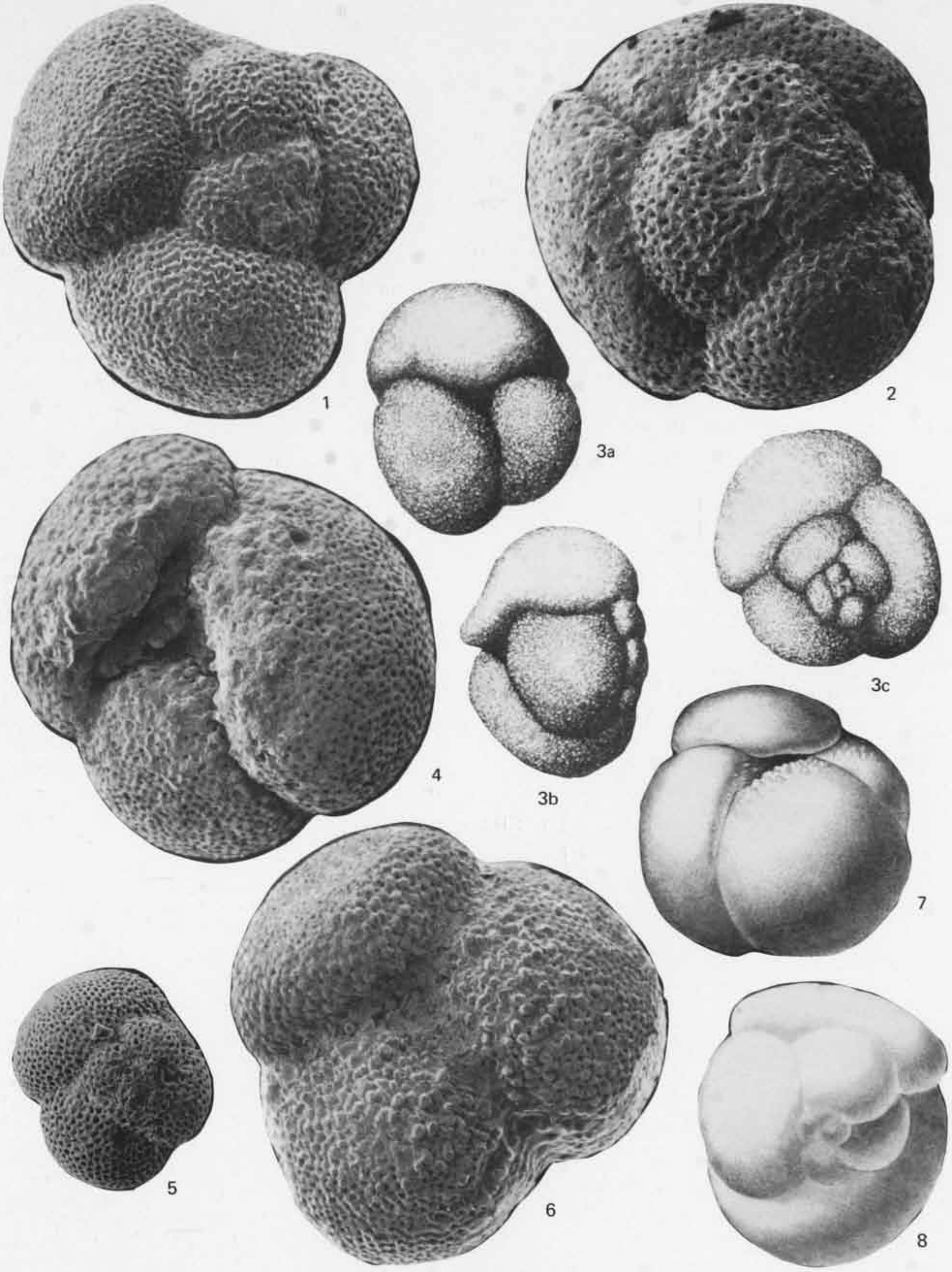


Fig. 148

Globoquadrina tripartita tripartita (KOCH). BANDY, 1964b, p. 7-8, 13, fig. 5.
Globoquadrina tripartita rohri (BOLLI). BANDY, 1964b, p. 7-8, 13, fig. 5.
Globigerina tripartita KOCH. HOFKER, 1968, p. 18, pl. 8, fig. 3.–BLOW, 1969, p. 322.–SOEDIONO, 1969, p. 343, pl. 2, fig. 2-3.

Test large, globose. In spiral view initial portion quadrate (as *Globigerina linaperta*) but adult chambers lengthen rapidly so that only 3 comprise final whorl. Adult chambers also extend axially, curving in to define small triangular umbilicus between extremities. Coiling regular except that final chamber may be aborted (small and irregular). Spiral profile subcircular, commonly indented at sutures in Eocene forms but almost flush in Oligocene; side profile ovate, flatter on spiral than umbilical side. Sutures distinct. Aperture intraumbilical, concealed. Shell surface smooth, finely perforate, with umbilical area sometimes rugose or hispid. Diameter to 0.8 mm.

Discussion.–*Globigerina tripartita* differs from *G. venezuelana* in having 3 instead of 4 chambers in final whorl and triangular rather than rectangular umbilicus. Intermediate specimens are not rare. The *G. venezuelana-G. tripartita* lineage evolves into species distinguished by even more rapid increase in chamber size (*G. sellii, G. binaiensis*). Three-chambered forms of *G. venezuelana* noted by early authors were named *Globigerina rohri* by BOLLI (1957b,c), but BLOW & BANNER (1962) demonstrated that *Globigerina tripartita* KOCH (1926) is a prior synonym and at the same time defined the species more restrictively. They also gave names to some transitional variants, but these have received only limited acceptance (e.g., *Globigerina tapuriensis, Globoquadrina dehiscens praedehiscens*).

Distribution.–*Globigerina tripartita* occurs regularly in the Late Eocene and Oligocene and is recognized also in the Early Miocene if not defined too rigidly. Its transitional relationship with longer-ranging forms reduces its value in zonation, but an abundance of *G. tripartita* is suggestive of the Oligocene if more reliable markers are missing. First described from an unspecified mid-Tertiary level in Borneo and later (as *G. rohri*) from the Oligocene of Trinidad.

CATAPSYDRAX UNICAVUS Bolli, Loeblich, & Tappan, 1957

Figure 149

Late Middle Eocene to Early Miocene

Catapsydrax unicavus BOLLI, LOEBLICH, & TAPPAN, 1957, p. 37, pl. 7, fig. 9.–BOLLI, 1957b, p. 116.–BOLLI, 1957c, p. 166, pl. 37, fig. 7.–BLOW, 1959, p. 204, pl. 15, fig. 94.–NICORA, 1971, p. 210, pl. 12, fig. 4-5.
Globigerinita unicava (BOLLI, LOEBLICH, & TAPPAN). BERMÚDEZ, 1960, p. 1267.–[emended] BLOW & BANNER, 1962, p. 113-115, pl. 14, fig. J-N.–BLOW, 1969, p. 330, pl. 24, fig. 8-9; pl. 25, fig. 1-2.–SAMANTA, 1969, p. 332, pl. 1, fig. 4.
Globigerina isahayensis ASANO, 1962, p. 55, pl. 21, fig. 9.
Globigerina (Globigerinita) unicava BOLLI, LOEBLICH, & TAPPAN [sic]. MCTAVISH, 1966, p. 1-36, pl. 2, fig. 19, 22-23.

Test small, quadrate-discoidal. On spiral side a flat embryonic coil, almost flush with surface, is followed by very low coil of ellipsoidal chambers which increase in size regularly and rather slowly as added. Commonly 4 chambers in final whorl. On umbilical side chambers surround umbilicus covered by rectangular bulla attached at 3 sides. Spiral profile slightly lobate; side profile ovate, height about one-half width. Spiral suture faint; intercameral sutures obscure in early portion, radial and lightly incised on outer whorl. Only visible aperture a low arch between bulla and umbilicus, embracing penultimate chamber or last intercameral suture. Surface, usually including bulla, distinctly cancellate. Diameter 0.3 to 0.45 mm.

Discussion.–*Catapsydrax unicavus* is distinguished by having only a single opening between bulla and umbilicus. It can resemble closely certain forms of the variable *Globorotaloides suteri*, and, in fact, published discussions leave their differentiation indefinite. BLOW & BANNER (1962) erected two subspecies (see also BLOW, 1969).

Distribution.–Late Middle Eocene to within Early Miocene (*Truncorotaloides rohri* Zone to *Catapsydrax stainforthi* Zone). The extinction of *C. unicavus* and *C. dissimilis* at virtually the same level provides a useful zonal datum. First described from the Oligocene of Trinidad.

ORBULINA UNIVERSA d'Orbigny, 1839

Figure 150

Middle Miocene to Holocene

Orbulina universa D'ORBIGNY, 1839, p. 2, pl. 1, fig. 1.–BRÖNNIMANN, 1951b, p. 134, fig. 3-4.–BOLLI, LOEBLICH, & TAPPAN, 1957, p. 35-36, pl. 7, fig. 1-5.–BERMÚDEZ, 1960, p. 1257-1261, pl. 7, fig. 10.
Biorbulina bilobata (D'ORBIGNY). BLOW, 1956, p. 69, fig. 2-3.–BERMÚDEZ, 1960, p. 1255-1257, pl. 7, fig. 8-9.

[These selected references contain extensive bibliographies and synonymies for *Orbulina universa*.]

Test, as viewed externally, a single spherical chamber. Surface cancellate, often finely hispid, with scattered large pores assumed to serve as apertures. Broken or dissected individuals reveal a globigerine nucleus within the spherical chamber. Bilobate specimens comprising two tightly embracing orbuline chambers occur commonly. Diameter variable, exceptionally as large as 1 mm.

Discussion.–*Orbulina universa* differs from all other spheroidal forms in having no portion of any earlier chamber visible on the external surface of its final chamber. For stratigraphic purposes we consider it expedient to include the bilobate form within *O. universa*, but some authors treat it as distinct at the species level *(O. bilobata)* and even at the generic level *(Biorbulina)*.

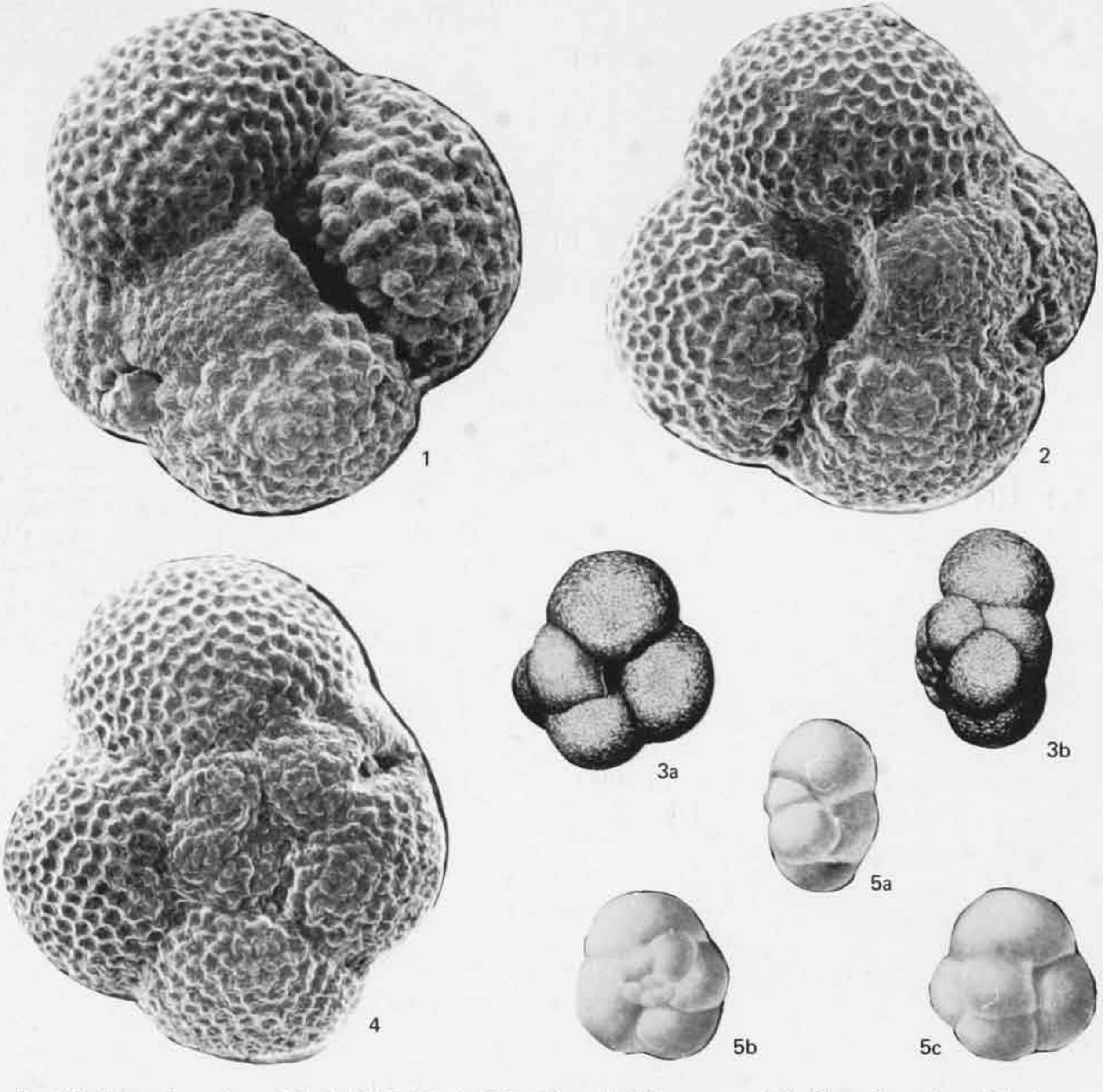


Fig. 149. *Catapsydrax unicavus* BOLLI, LOEBLICH, & TAPPAN from the Oligocene part of the Cipero Formation of Trinidad.

1-2,4-5 Approximate topotypes and holotype (**5** from BOLLI, LOEBLICH, & TAPPAN, 1957, pl. 7, fig. 9) from the *Globigerina ciperoensis* Zone. **1-2,5c**–Umbilical views, X180, X150, X95; **4,5b**–spiral views, X150, X95; **5a**–spiral view, X95.

3 Specimen from the *Globigerina ampliapertura* Zone, X92; from BLOW & BANNER (1962, pl. 14, fig. M-N). **a**–Umbilical view; **b**–side view.

Distribution.—Authors agree that, within certain limits, the first appearance of species of *Orbulina* defines a worldwide datum which approximately coincides with the beginning of the Middle Miocene. Many postulate a rapid one-time evolution of the lineage *Globigerinoides sicanus* ⟶ *Praeorbulina* spp. ⟶ *Orbulina suturalis* to the end form *Orbulina universa*, but others assert that a variety of globigerine forms could develop the spherical final chamber, which perhaps is a specialized form of bulla. These authors deny the precise synchroneity of the *Orbulina* Datum around the world (e.g., PARKER, 1962; BANDY, 1966; HOFKER, 1968, 1969; BANDY, VINCENT, & WRIGHT, 1969).

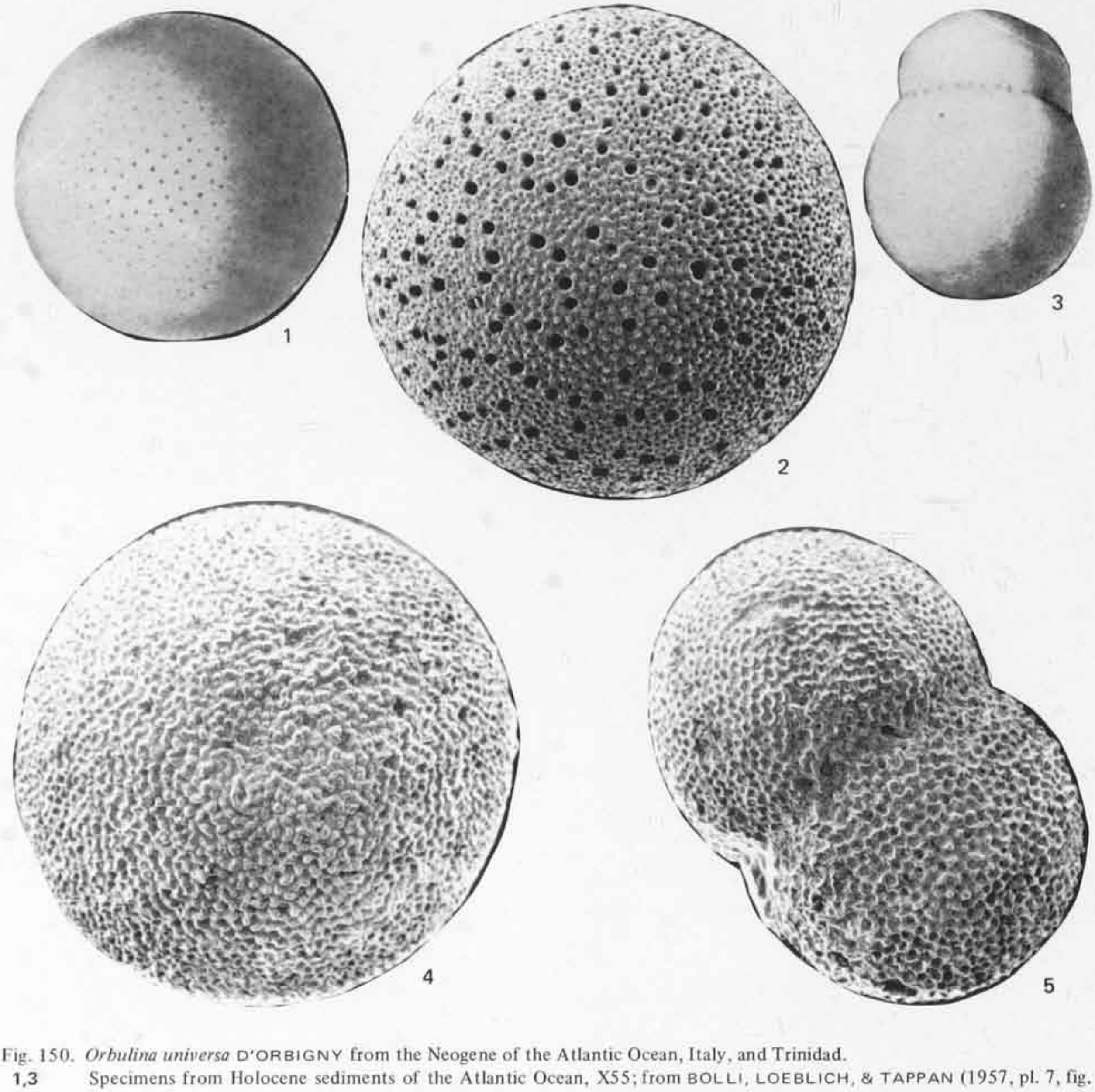


Fig. 150. *Orbulina universa* D'ORBIGNY from the Neogene of the Atlantic Ocean, Italy, and Trinidad.

1,3 Specimens from Holocene sediments of the Atlantic Ocean, X55; from BOLLI, LOEBLICH, & TAPPAN (1957, pl. 7, fig. 3-4). **1**—Normal monocular form; **3**—scarcer bilocular form.

2 Specimen from the Late Pliocene of southern Italy showing large apertural pores, X100.

4-5 Specimens from the Middle Miocene part (*Globorotalia fohsi fohsi* Zone) of the Cipero Formation of Trinidad. **4**—Monocular form, X110; **5**—bilocular form, X120.

GLOBIGERINA VENEZUELANA Hedberg, 1937

Figure 151
Middle Eocene through Miocene

Globigerina venezuelana HEDBERG, 1937, p. 681, pl. 92, fig. 7.–BERMÚDEZ, 1949, p. 280, pl. 21, fig. 39-40.–NAPOLI ALLIATA, 1953, p. 78, pl. 4, fig. 2.–BOLLI, 1957b, p. 110, pl. 23, fig. 6-8.–BOLLI, 1957c, p. 164, pl. 35, fig. 16-17.–BLOW, 1969, p. 322-323.

Globigerina haitiensis CORYELL & RIVERO, 1940, p. 339, pl. 42, fig. 29, 30 [fide BERMÚDEZ, 1960].

Globoquadrina venezuelana (HEDBERG). FINLAY, 1947, p. 290.–BLOW, 1959, p. 186, pl. 11, fig. 58-59.–BERMÚDEZ, 1960, p. 1313, pl. 13, fig. 9.

Globigerina yeguaensis pseudovenezuelana BLOW & BANNER, 1962, p. 100, pl. 11, fig. J-L, N-O.

Globigerina pseudovenezuelana BLOW & BANNER. BLOW, 1969, p. 321, pl. 19, fig. 1-2.

Globigerina (Globigerina) venezuelana HEDBERG. JENKINS, 1971, p. 156, pl. 16, fig. 498-501.

Test large, an inflated quadrate coil. Initial portion like a small *Globigerina linaperta* but growth of later chambers directed axially more than radially. Chambers increasing in size regularly; final chamber commonly aborted (small and irregular). Spiral profile somewhat lobate, side profile ovate. Sutures distinct, usually depressed. Axial prolongations of chambers incurved to define roughly rectangular umbilicus of variable size. Aperture intraumbilical, commonly invisible but occasionally marked by delicate, bluntly triangular lip. Shell surface clearly but rather finely cancellate, umbilical area may be hispid to rugose. Diameter to 0.8 mm.

Discussion.–In Miocene assemblages *Globigerina venezuelana* is unmistakable even though specimens vary appreciably in details of umbilicus and inflation of chambers. Traced back into the Eocene-Oligocene, however, it merges into a closely knit plexus of intergrading species so that separation from *Globigerina eocaena* (=*G. yeguaensis* of authors; chambers not prolonged axially) and *Globigerina tripartita* (chambers enlarging more rapidly, only 3 in last whorl) becomes arbitrary. The Eocene form designated *Globigerina pseudovenezuelana* appears to fall within the natural variability of *G. venezuelana.* Homeomorphs occur within the post-Miocene plexus of *G. conglomerata* (e.g., PARKER, 1967) although this species typically has more inflated chambers and a larger umbilicus.

Distribution.–*Globigerina venezuelana* is a long-ranging species known from Middle Eocene to Pliocene levels. It is, therefore, not an important zonal index although levels of local abundance may be useful for correlation. First described from the Oligocene-Miocene Carapita Formation of eastern Venezuela.

Fig. 151. *Globigerina venezuelana* HEDBERG from the Late Eocene and Early Miocene of Trinidad. [p. 332]

1-2 Specimens from the Late Eocene part (*Globigerinatheka semiinvoluta* Zone) of the Navet Formation. **1**–Side view, X110; **2**–umbilical view, X120.

3-6 Specimens from the Early Miocene part (*Catapsydrax stainforthi* Zone) of the Cipero Formation. **3**–Spiral view, X90; **4**–umbilical view showing deformed final chamber, X100; **5-6**–side views, X110.

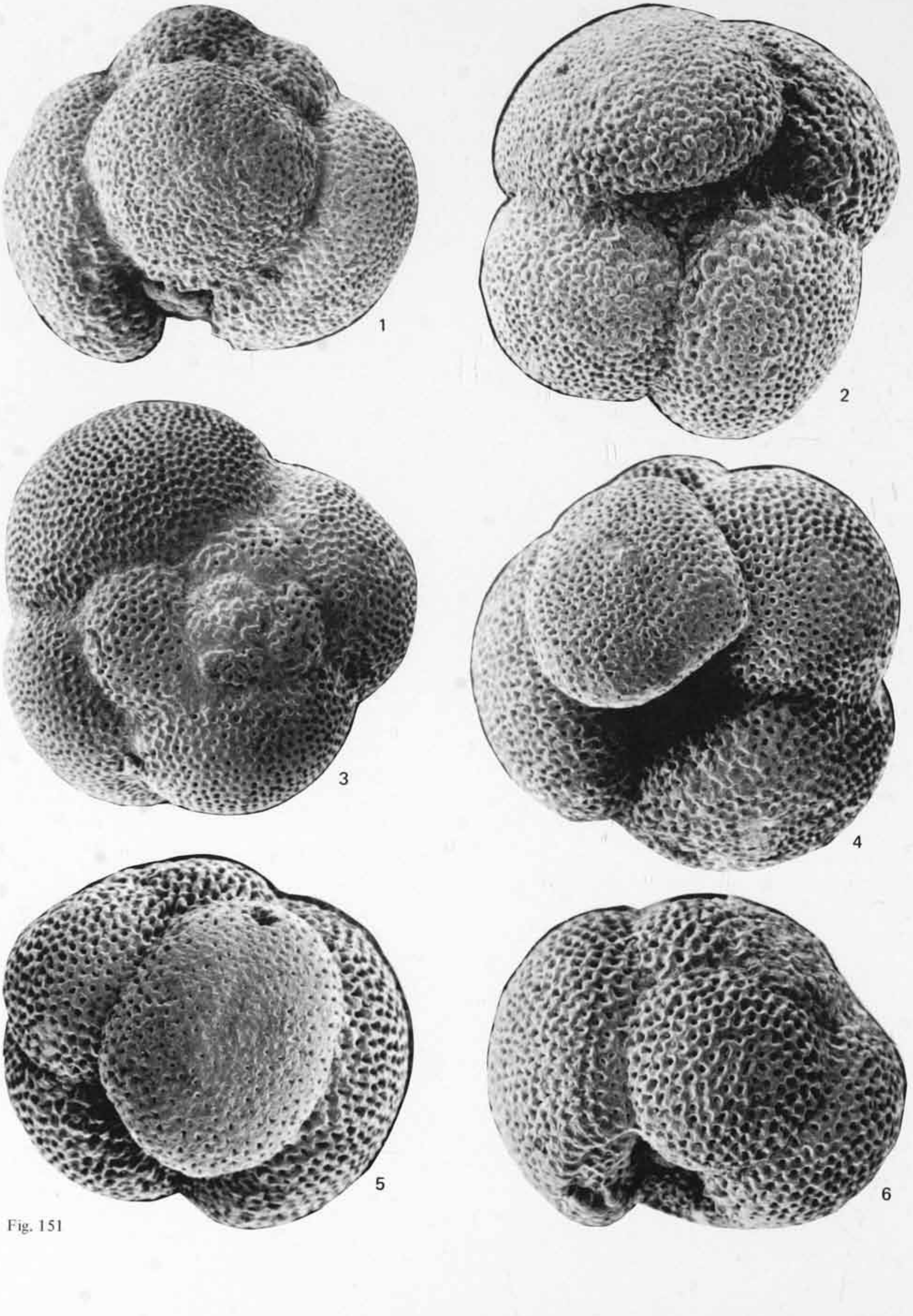


Fig. 151

ILLUSTRATED REVIEW OF LATE MIDDLE MIOCENE TO HOLOCENE INDEX SPECIES

Planktonic foraminiferal species regarded as useful markers for the late Middle Miocene to Holocene are discussed and illustrated (Fig. 152-213) in alphabetical order by species name. These data were collated mainly by J. L. LAMB with assistance from R. M. STAINFORTH and J. H. BEARD.

Ranges for these species are recorded in the preceding text and on Figure 19 together with a discussion of the zonation for the interval.

GLOBOROTALIA ACOSTAENSIS Blow, 1959

Figures 152-153

Late Miocene to Early Pleistocene

Globorotalia acostaensis BLOW, 1959, p. 208, pl. 17, fig. 106.–CITA, PREMOLI SILVA, & ROSSI, 1965, p. 225-226, fig. 5, pl. 18, fig. 6.–POAG & AKERS, 1967, p. 171, pl. 16, fig. 22-24.–LAMB & BEARD, 1972, p. 51, pl. 7, fig. 1-11.

Globorotalia (Turborotalia) acostaensis BLOW. BANNER & BLOW, 1967, p. 153, pl. 3, fig. 1 [holotype refigured].

Globoquadrina acostaensis (BLOW). PARKER, 1967, p. 164-165, pl. 24, fig. 3-9.

Globoquadrina continuosa (BLOW). PARKER, 1967, p. 166, pl. 24, fig. 1-2.

Globorotalia (Turborotalia) acostaensis acostaensis BLOW. BLOW, 1969, p. 344-345, pl. 9, fig. 13-15 [holotype refigured]; pl. 33, fig. 1-2.–BRÖNNIMANN & RESIG, 1971, p. 1277, 1312, fig. 18, pl. 33, fig. 2, 4.

Globorotalia (Turborotalia) acostaensis tegillata BRÖNNIMANN & RESIG, 1971, p. 1277-1278, pl. 33, fig. 3, 6-7, 10.

Test a thick discoidal trochospire; 4½ to 6 chambers in last whorl, ovate to subspherical, increasing regularly in size. Spiral outline subcircular, strongly lobate; side profile parallel-sided with bluntly rounded periphery, thickness more than half diameter. Sutures straight, radial, more distinct on umbilical than on spiral side. Umbilicus inconspicuous but deep. Aperture a low arch between umbilicus and periphery, generally bordered by distinct rim or lip; exceptionally lip extends into flap concealing the umbilicus, reminiscent of tegilla in certain Cretaceous genera (BOLLI, LOEBLICH, & TAPPAN, 1957, p. 13, fig. 4). Surface distinctly perforate, pustulose around umbilicus. Diameter 0.3 to 0.35 mm.

Discussion.–*Globorotalia acostaensis* is regarded as intermediate between *Globorotalia continuosa* BLOW (1969) (more compact, quadrate form) and *Globorotalia humerosa* TAKAYANAGI & SAITO (1962) (larger, looser coil, more distinct umbilicus). It is grossly similar to *Globorotalia siakensis* LEROY (1939) but has more inflated chambers, a more concealed aperture, and a more rapidly opening spire. Separation of *Globorotalia tegillata* from *G. acostaensis* by means of a standard light microscope comes close to straining the limits of human ability.

Within the lower part of the *Globorotalia acostaensis* Zone this species coils almost exclusively to the left, whereas in the upper part of the zone dominantly right and random coiling predominates. This horizon of coiling change has been observed in the South China Sea, in the Caribbean and Gulf of Mexico regions, and in Italy within the lower part of the Messinian stratotype of SELLI (1971), a few feet above the base of his Unit 2 within "paper shales" of the Tripoli beds that lie below the evaporite sequence. The datum, therefore, approximates closely the base of the Messinian Stage.

Distribution.–Late Miocene to Early Pleistocene (*Globorotalia acostaensis* Zone to within *Globorotalia truncatulinoides* Zone). First described from the Pozón Formation of Venezuela, its recorded distribution is nearly worldwide.

GLOBOROTALIA AEMILIANA Colalongo & Sartoni, 1967

Figures 154-155

Middle Pliocene

Globorotalia hirsuta aemiliana COLALONGO & SARTONI, 1967, p. 267-274, pl. 30, fig. 1.

Globorotalia crotonensis CONATO & FOLLADOR, 1967, p. 556-557, fig. 1, fig. 4, 1-2.

Globorotalia aemiliana COLALONGO & SARTONI. LAMB & BEARD, 1972, p. 51-52, pl. 18, fig. 7-8; pl. 20, fig. 1-2.

Test trochospiral; spiral side nearly flat, umbilical side a low convex profile. Periphery lobulate, imperforate but not distinctly keeled. Last whorl with 3½ to 4 chambers which increase gradually in size. Sutures on spiral side curved and flush, on umbilical side curved and depressed. Aperture extraumbilical-umbilical without noticeable lip. Diameter about 0.4 to 0.5 mm.

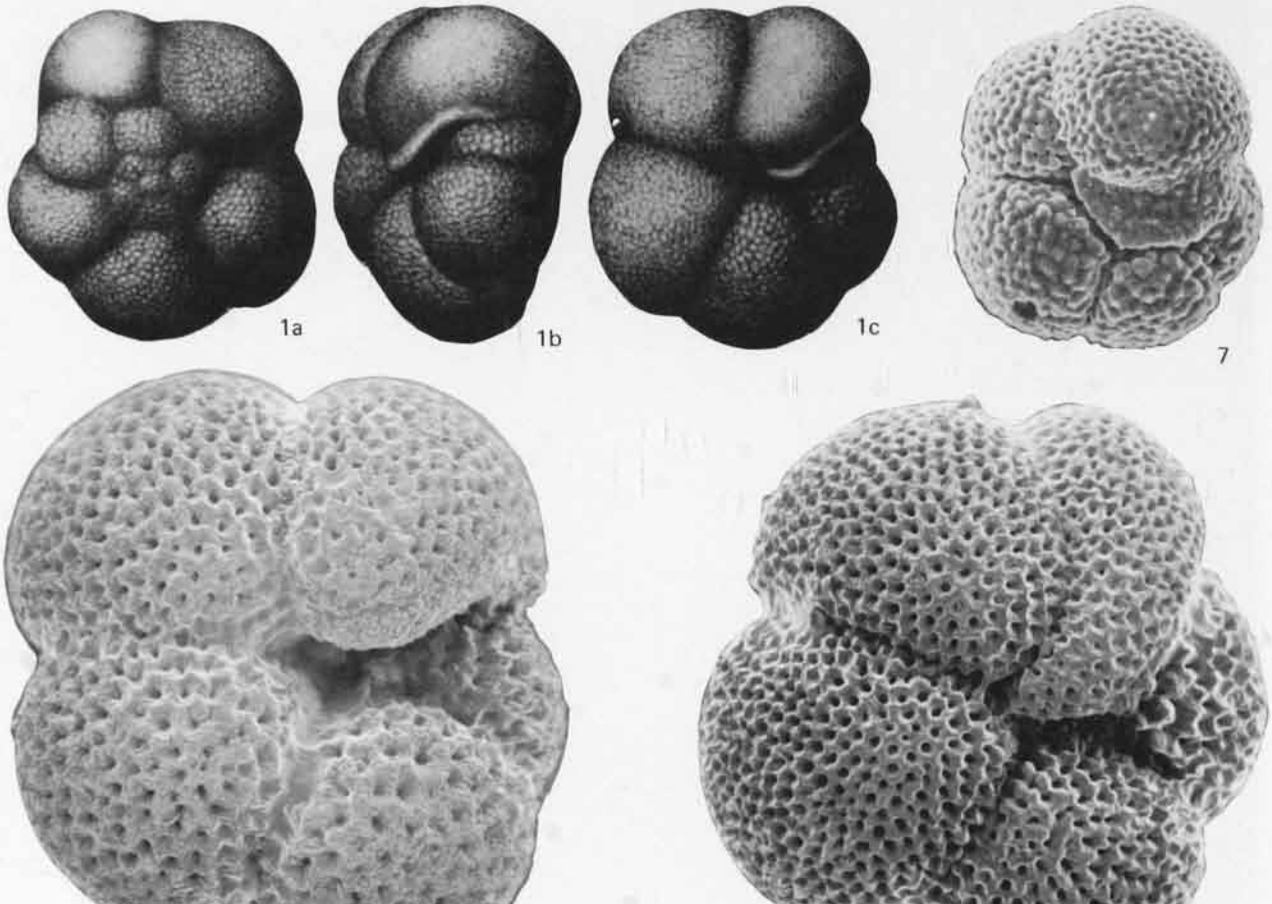


Fig. 152

Fig. 152. *Globorotalia acostaensis* BLOW from the Late Miocene of the Caribbean and Gulf of Mexico regions.
1 Holotype, X130; from BLOW (1969, pl. 9, fig. 13-15). **a**–Spiral view; **b**–side view; **c**–umbilical view.
2-4 Topotypes from the Pozón Formation, Venezuela (BLOW'S sample number R.M. 19,808), X220. **2-3**–Umbilical views; **4**–spiral view.
5-7 Specimens from the Late Miocene, *Globorotalia acostaensis* Zone, Gulf of Mexico. From original SEM illustrations of LAMB & BEARD (1972, pl. 7, fig. 3, 8, 10). **5**–Spiral view, X170; **6**–side view, X215; **7**–umbilical view, X170.

Discussion.–*Globorotalia aemiliana* appears to be an evolutionary development intermediate between *Globorotalia juanai* BERMÚDEZ & BOLLI (1969) [in part = *Globorotalia hirsuta* of Italian authors] and *Globorotalia crassaformis* GALLOWAY & WISSLER (1927) with which it may be associated (COLALONGO & SARTONI, 1967). Though used extensively as a zonal index in Italy (e.g., BERTOLINO ET AL., 1968), this species is generally too scarce for biostratigraphic use.

Distribution.–The species was described from Middle Pliocene of northern Italy and has since been recorded from many other Mediterranean localities as well as the Gulf of Mexico region.

GLOBOROTALIA BONONIENSIS Dondi, 1963
Figures 156-157
Early to Middle Pliocene

Globorotalia bononiensis DONDI, 1963, p. 162, fig. 41, 1.

Test a low trochospire. Chambers globose with 4 to 5 in final whorl increasing in size regularly. Sutures depressed and straight. Equatorial profile only slightly lobulate; axial profile rounded. Umbilicus deep. Aperture a simple arch from umbilicus to near periphery with raised rim. Surface rugose, coarsely perforate. Diameter 0.5 mm.

Discussion.–This species is recognized widely as having evolved from *Globorotalia puncticulata*

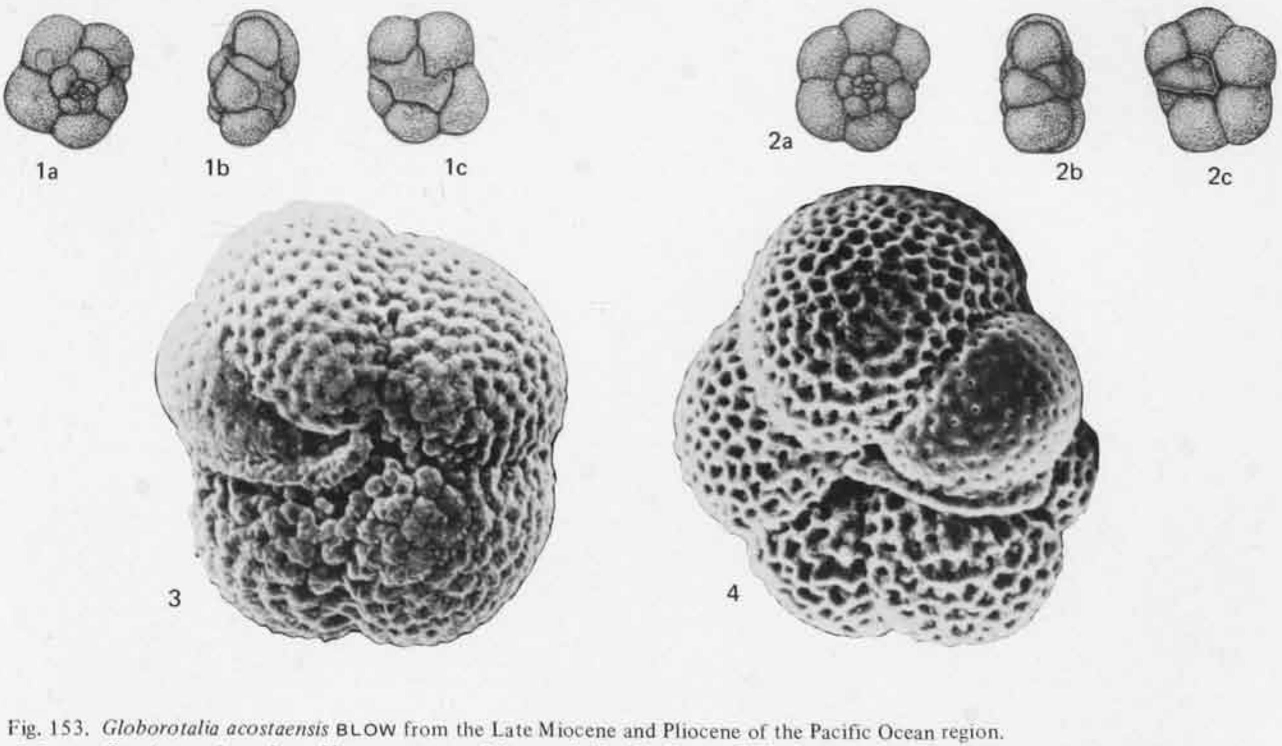


Fig. 153. *Globorotalia acostaensis* BLOW from the Late Miocene and Pliocene of the Pacific Ocean region.
1-2 Specimens from Late Miocene strata of the south Pacific Ocean, X52; from PARKER (1967, pl. 24, fig. 5-6). **a**–Spiral views; **b**–side views, **c**–umbilical views.
3-4 Specimens from Pliocene and Late Miocene strata, respectively, of the southwestern Pacific Ocean; from BRÖNNIMANN & RESIG (1971, pl. 33, fig. 2, 5). **3**–Umbilical view, X260; **4**–umbilical view, X218.

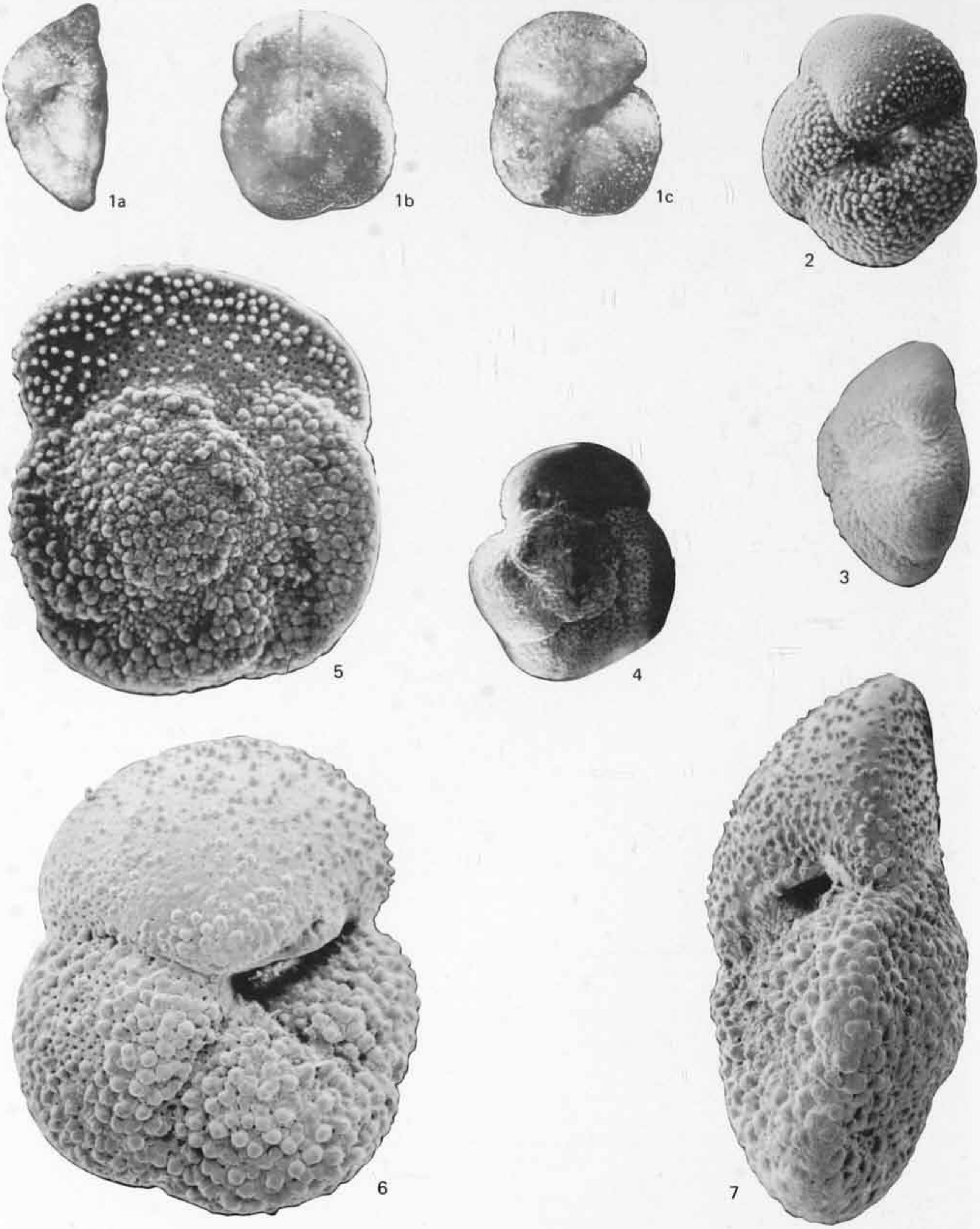


Fig. 154

Fig. 154. *Globorotalia aemiliana* COLALONGO & SARTONI from the Middle Pliocene of Italy and the Gulf of Mexico.

1 Holotype from Italy, X70; from COLALONGO & SARTONI (1967, pl. 30, fig. 1). **a**–Side view; **b**–spiral view; **c**–umbilical view.

2-4 Specimens from the Middle Pliocene, upper part of the *Globorotalia margaritae* Zone, Gulf of Mexico. From original SEM illustrations of LAMB & BEARD (1972, pl. 20, fig. 1-2), X110. **2**–Umbilical view; **3**–side view; **4**–spiral view.

5-7 Ideotypes contributed by DR. M. L. COLALONGO from her Middle Pliocene Catanzaro [Italy] locality 228. **5**–Spiral view, X170; **6**–umbilical view, X175; **7**–side view, X180.

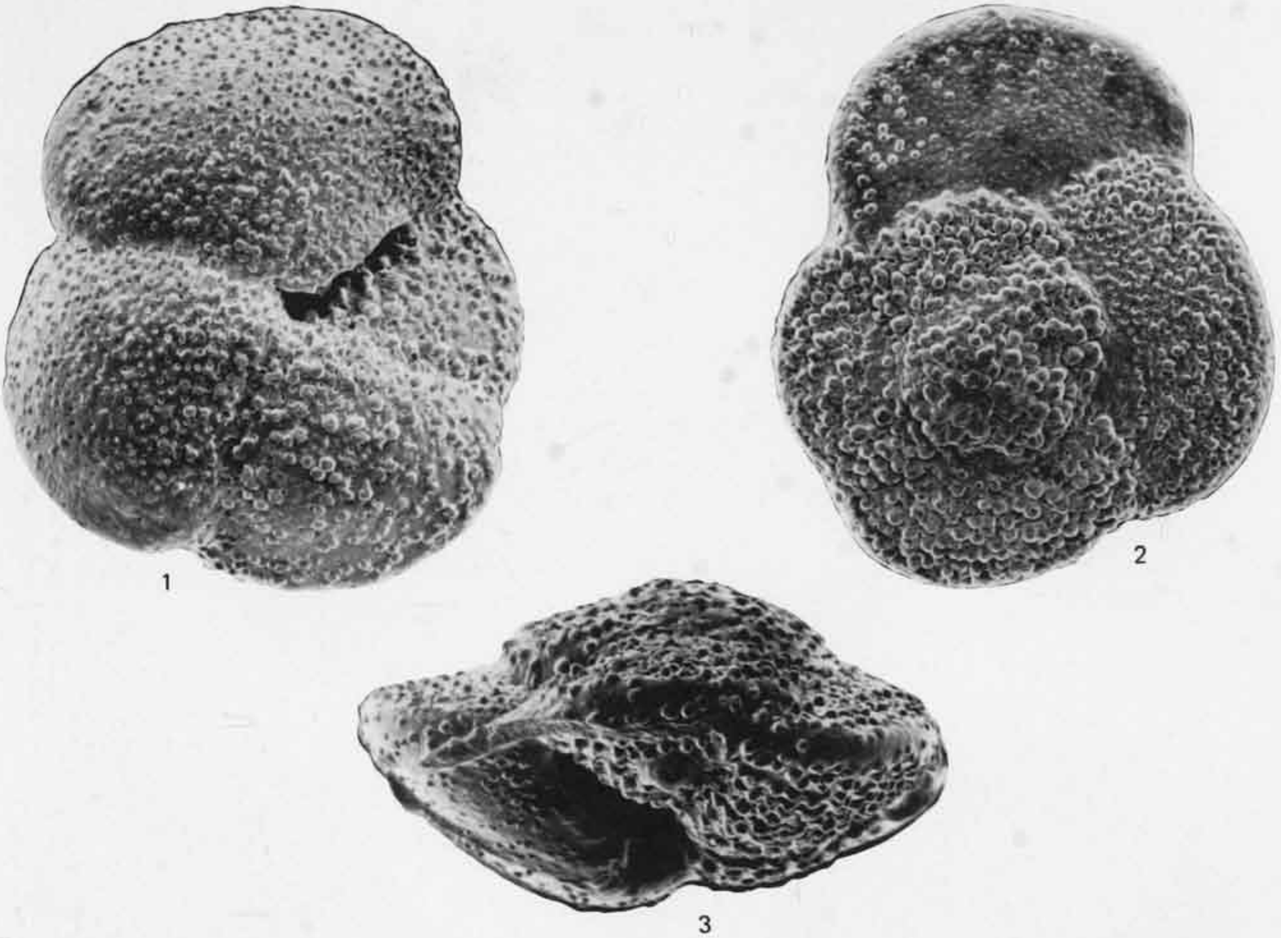
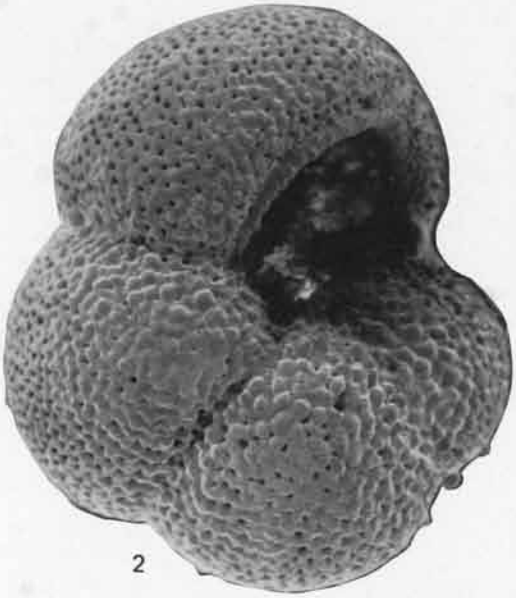


Fig. 155. *Globorotalia aemiliana* COLALONGO & SARTONI from the Middle Pliocene of central Italy. Ideotypes of *Globorotalia crotonensis* CONATO & FOLLADOR (=*G. aemiliana* COLALONGO & SARTONI) contributed by DR. UMBERTO FOLLADOR. **1**–Umbilical view, X140; **2**–spiral view, X140; **3**–side view, X140.

Fig. 156. *Globorotalia bononiensis* DONDI from the Middle Pliocene of Italy. [p. 338]

1 Holotype, X80; from DONDI (1963, fig. 41, no. 1). **a**–Umbilical view; **b**–side view; **c**–spiral view.

2-5 Specimens from Middle Pliocene beds at Le Castella, southern Italy, X150; locality IT-780 of LAMB & BEARD (1972, fig. 8-10). **2,5**–Umbilical views; **3**–side view; **4**–spiral view.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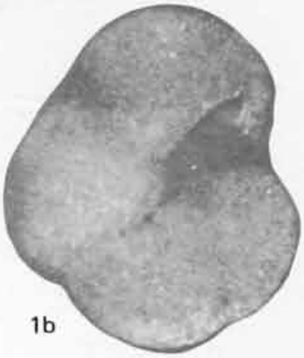
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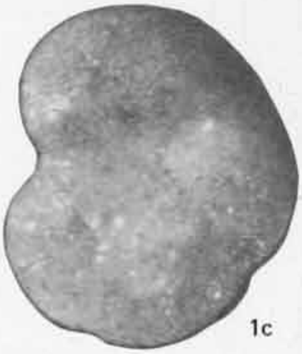
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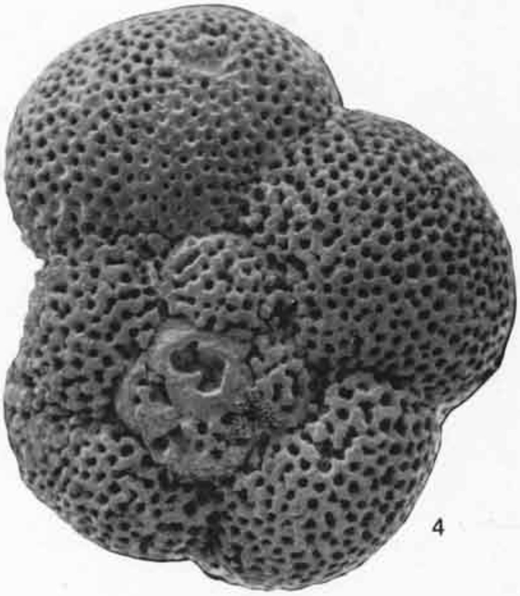
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Fig. 156

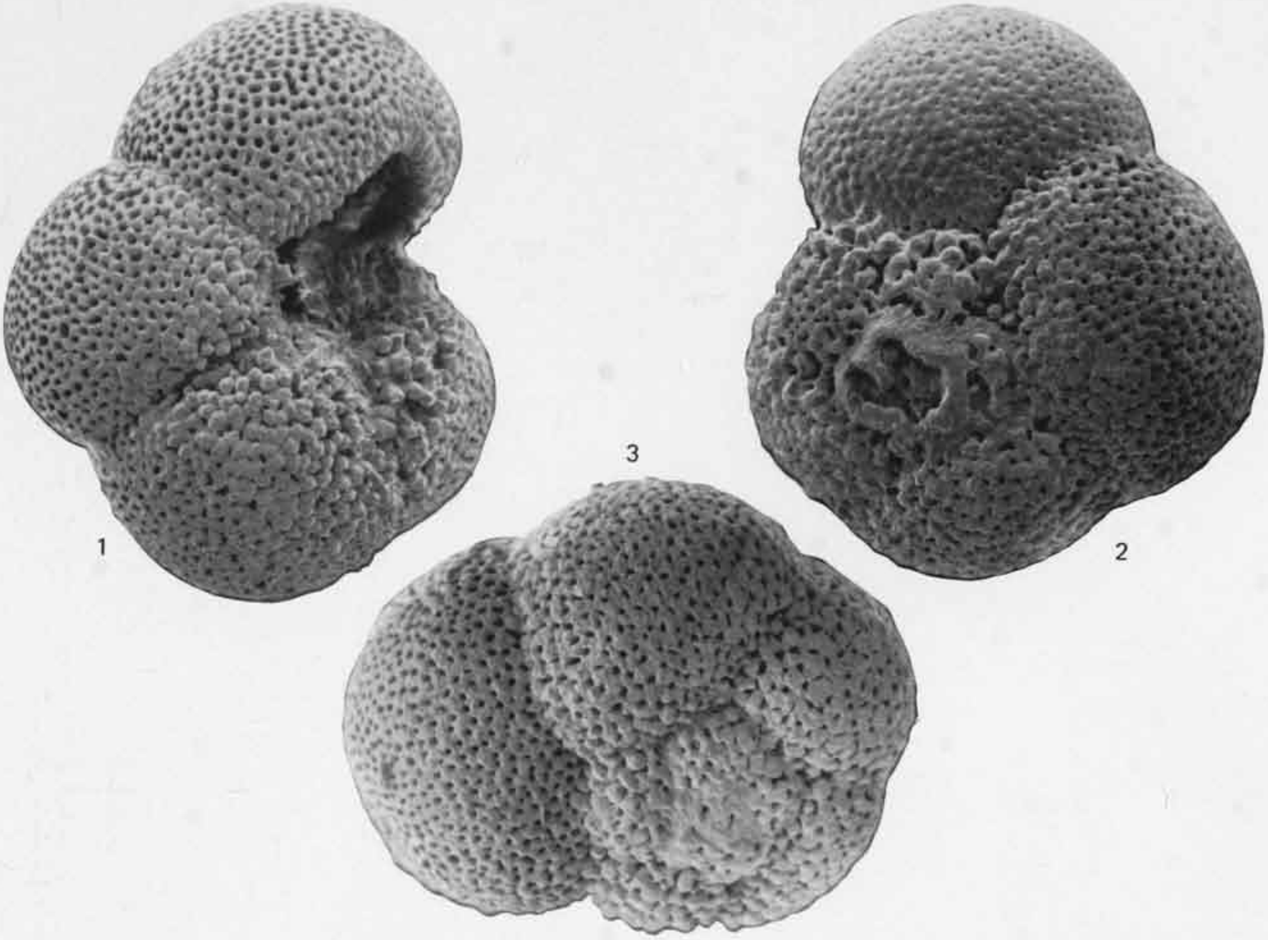

Fig. 157. *Globorotalia bononiensis* DONDI from Middle Pliocene beds at Le Castella, southern Italy; X150. **1**–Umbilical view; **2-3**–spiral views.

(DESHAYES, 1832) from which it differs in more globose chambers, more depressed sutures, and higher arched aperture. It also is the evolutionary antecedent of *Globorotalia inflata* (D'ORBIGNY, in BARKER-WEBB & BERTHELOT, 1839) from which it differs in more incised sutures, more globose chambers, and a more coarsely perforate test. Although this species frequently is mentioned by Italian authors (e.g., BERTOLINO ET AL., 1968; CITA, 1973), rarely is it illustrated.

Distribution.–Described from the Middle Pliocene of northern Italy and presently recorded only from the Mediterranean region, where it is a useful index species for Early and Middle Pliocene.

GLOBIGERINOIDES CONGLOBATUS (Brady, 1879)

Figure 158
Late Miocene to Holocene

Globigerina conglobata BRADY, 1879, p. 286.–BRADY, 1884, p. 603, pl. 80, fig. 1-5; pl. 82, fig. 5.–BANNER & BLOW, 1960a, p. 6, pl. 4, fig. 4 [lectotype].

Globigerinoides conglobatus (BRADY). PARKER, 1967, p. 154, pl. 20, fig. 3-4.–POSTUMA, 1971, p. 286-287.–LAMB & BEARD, 1972, pl. 33, fig. 4, 6-7.

Globigerinoides conglobatus conglobatus (BRADY). BLOW, 1969, p. 324.

Test a large subglobular to subquadrate trochospire of appressed, moderately inflated, kidney-shaped chambers, with 3 to 4 in the last

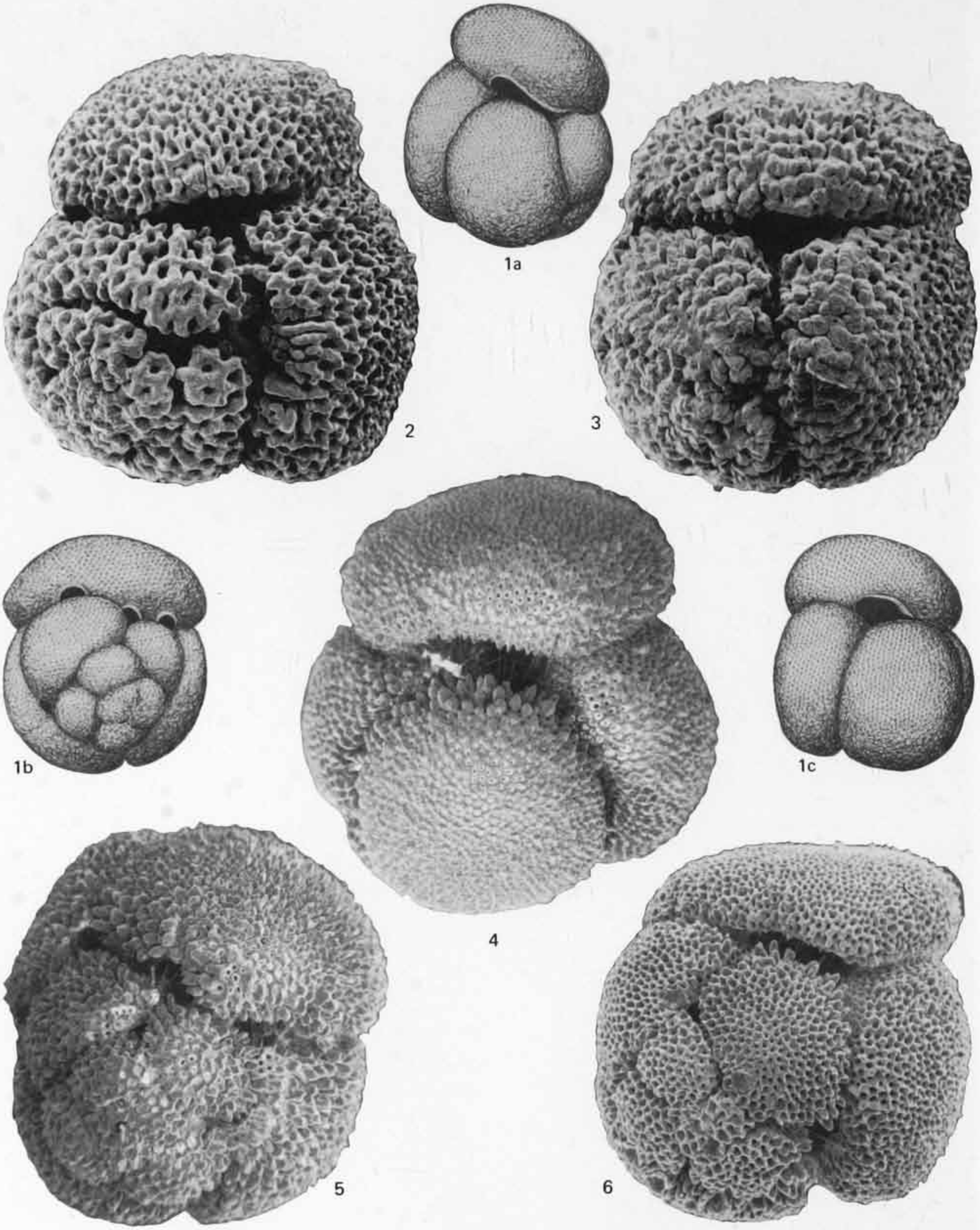

Fig. 158

Fig. 158. *Globigerinoides conglobatus* (BRADY) from the Pleistocene and Holocene of the Mediterranean, Atlantic, and Gulf of Mexico.

- **1** Lectotype from Recent [Holocene] deposits of the north Atlantic, X50; from BANNER & BLOW (1960a, pl. 4, fig. 4). **a**–Umbilical view; **b**–spiral view; **c**–oblique umbilical view.
- **2-3** Specimens from Early Pleistocene (Calabrian Stage) beds at Le Castella, southern Italy, showing how pustules have coalesced to form coarse, blunt ridges around pores; locality IT-908A of LAMB & BEARD (1972, fig. 8-10). **2**–Spiral view, X90; **3**–umbilical view, X105.
- **4-6** Specimens from Late Pleistocene deposits of the Gulf of Mexico showing rough, pustulose surface of test; X90; from LAMB & BEARD (1972, pl. 33, fig. 4, 6-7). **4**–Umbilical view; **5-6**–spiral views.

whorl. Wall spinose and coarsely perforate. Primary aperture umbilical, almost closed but deep; secondary sutural apertures large and slit-like. Diameter to 1.0 mm.

Discussion.–Typical forms of this species occur as early as Late Miocene and Early Pliocene, but specimens are smaller than in the Pleistocene and Holocene. BLOW (1969) derived this species from *Globigerinoides conglobatus canimarensis* BERMÚDEZ (1960) but we follow PARKER (1973) in not differentiating the two. PARKER (1962) recorded rare modern specimens having bulla-like chambers.

Distribution.–Late Miocene to Holocene (*Globorotalia acostaensis* Zone to *Globorotalia tumida* Zone). Described from the Recent of the north Atlantic?, the species is ubiquitous.

GLOBOROTALIA CRASSAFORMIS

(Galloway & Wissler, 1927)

Figures 159-160

Middle Pliocene to Holocene

Globigerina crassaformis GALLOWAY & WISSLER, 1927, p. 41, pl. 7, fig. 12.

Globorotalia crassaformis (GALLOWAY & WISSLER), PARKER, 1962, p. 235, pl. 4, fig. 17-18, 20-21.–INGLE, 1967, p. 357, pl. 38, fig. 3-5. BLOW, 1969, p. 347-348, pl. 37, fig. 1-4.–LAMB & BEARD, 1972, p. 52, pl. 2, fig. 1-9; pl. 21, fig. 1-8.–GRADSTEIN, 1973, p. 51, pl. 1, fig. 6.

Globorotalia crassacrotonensis CONATO & FOLLADOR, 1967, p. 36-37, fig. 4, 3.–LAMB & BEARD, 1972, p. 52, pl. 2, fig. 10-12; pl. 20, fig. 3-7.

Test a regular trochospire, flattish to depressed on spiral side, moderately to strongly convex on umbilical side; rather large for genus. Last whorl of 4 to 4½ chambers, slowly increasing in size as added but maintaining same shape. Equatorial profile lobulate, approaching quadrate in large specimens; axial profile approximately planoconvex, shoulders rounded to sharply angled or keeled, convexity proportional to vaulting of chambers. Sutures on spiral side distinct, depressed, limbate in carinate specimens, recurved to define posterior tip of each chamber; on umbilical side depressed, sinuously radial. Umbilicus small, surrounded by blunt tips of last 3 to 4 chambers. Aperture a low arched slit from umbilicus to near periphery. Wall finely perforate, evenly pustulose except that last chamber has sparser pustules. Diameter 0.5 to (exceptionally) 1.0 mm.

Fig. 159. *Globorotalia crassaformis* (GALLOWAY & WISSLER) from the Late Pliocene and Pleistocene of California and the Gulf of Mexico. [p. 342]

- **1** Holotype from California, X50; from GALLOWAY & WISSLER (1927, pl. 7, fig. 12). **a**–Umbilical view; **b**–side view; **c**–spiral view.
- **2-5** Specimens from Middle Pleistocene deposits, Gulf of Mexico; after LAMB & BEARD (1972, pl. 21, fig. 4-5, 7-8). **2**–Side view, X100; **3**–umbilical view, X120; **4**–side view, X120; **5**–spiral view, X120.
- **6** Specimen from the Late Pliocene (*Pulleniatina obliquiloculata* Zone) of the Gulf of Mexico, X120; from LAMB & BEARD (1972, pl. 2, fig. 7; corehole A, core no. 8).

Fig. 160. *Globorotalia crassaformis* (GALLOWAY & WISSLER) from the Late Pliocene of the Gulf of Mexico and the Middle Pliocene of central Italy. [p. 343]

- **1-2** Specimens from the Late Pliocene (*Pulleniatina obliquiloculata* Zone) of the Gulf of Mexico (core no. 8, corehole A of LAMB & BEARD, 1972), X110. **1**–Side view; **2**–spiral view.
- **3-5** Ideotypes of *Globorotalia crassacrotonensis* CONATO & FOLLADOR [=*Globorotalia crassaformis*] from the Middle Pliocene of central Italy (courtesy of DR. UMBERTO FOLLADOR). **3**–Spiral view, X160; **4**–umbilical view, X130; **5**–side view, X150. Notice the well-developed keeled periphery.

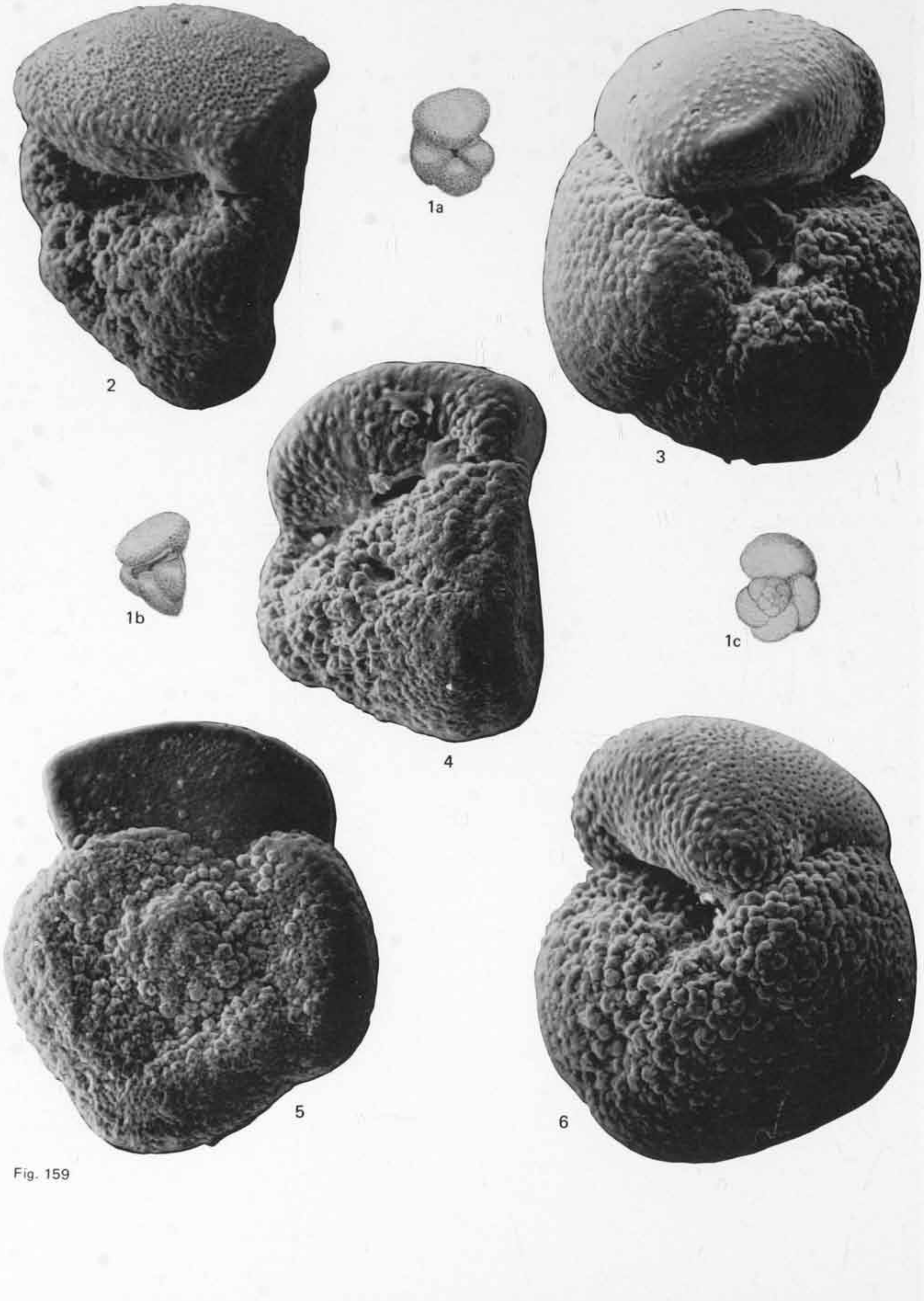

Fig. 159

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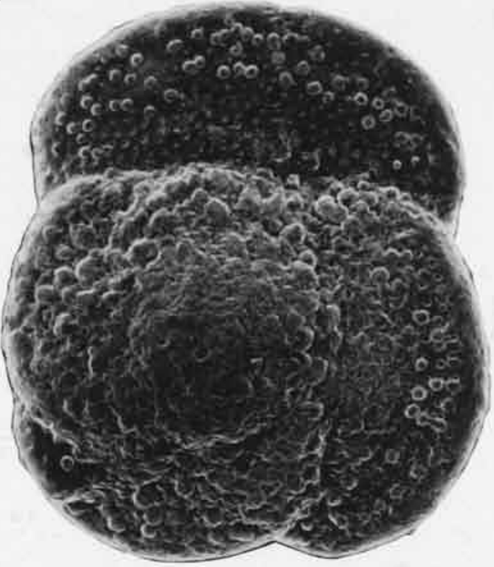

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Fig. 160

Discussion.—This species varies greatly in size, chamber height on umbilical side, and appression of peripheral margin; thus selection of an easily recognizable central form is difficult. Subspecific nomenclature has been applied by some authors, e.g., *Globorotalia crassaformis oceanica* [=*G. (Turborotalia) oceanica* CUSHMAN & BERMÚDEZ, 1949], *G. crassaformis ronda* BLOW (1969), *G. crassaformis viola* [= *G. (G.) crassula viola* BLOW, 1969], and the subspecies designated informally as A, Aa, and B by BOLLI (1970), in addition to *G. crassaformis crassaformis.* Subcarinate to fully keeled forms are separated by some authors as *Globorotalia crassula* CUSHMAN, STEWART, & STEWART (1930), and subspecific variants have been recognized [e.g., *G. crassula conomiozea* (=*G. conomiozea* KENNETT, 1966) and *G. crassula viola,* as above, in addition to *G. crassula crassula*]. Distinctions between adjacent forms are tenuous and arbitrary and not expressible in objective terms. Our preference is to separate *Globorotalia aemiliana* COLALONGO & SARTONI (1967) and *Globorotalia ronda* as recognizably more primitive and more advanced forms, respectively, than the plexus assigned to *G. crassaformis.*

This eurythermal species is recorded commonly and almost equally for cool- and warm-water regions. Attempts were made in several widespread areas to recognize a morphogenetic sequence applicable to worldwide biostratigraphy, for instance in New Zealand (KENNETT, 1966), Italy (COLALONGO & SARTONI, 1967; CONATO & FOLLADOR, 1967), Mediterranean region (CATI ET AL., 1968), and Caribbean-Gulf of Mexico region (LAMB & BEARD, 1972). Conclusions of the several authors seemed conflicting until variability of *G. crassaformis* was shown to correspond as much to effects of latitude and paleoclimatic change as to a linear evolutionary pattern. PARKER (1962) hinted at latitudinal variability, and the theme of temperature control was developed by BLOW (1969, p. 361; 1970), LIDZ (1972), and others.

In a biometric analysis of Pliocene globorotaliids GRADSTEIN (1972) found little confirmation of evolutionary trends proposed by earlier authors. In particular he observed no chronologic significance in flatness of the spiral side, degree of equatorial lobation, or sharpness of periphery. GRADSTEIN did, however, confirm that chambers became progressively more highly vaulted on the umbilical side. Contrary to earlier expressed views (LAMB & BEARD, 1972) we now tend to agree with GRADSTEIN (1972) that locally observed morphologic trends within *Globorotalia crassaformis* are not necessarily indicative of evolutionary trends applicable in worldwide biostratigraphy. In particular, development of an imperforate carinate margin appears to be a reiterative rather than a palingenetic character.

Distribution.—Middle Pliocene to Holocene (*Globorotalia margaritae* Zone to *Globorotalia tumida* Zone). The species was described from Pleistocene beds in California. It is one of the most widely distributed late Neogene planktonic species and is found nearly worldwide.

SPHAEROIDINELLA DEHISCENS (Parker & Jones, 1865)
Figures 161-162
Late Pliocene to Holocene

Sphaeroidina bulloides dehiscens PARKER & JONES, 1865, p. 369, pl. 19, fig. 5.—BANNER & BLOW, 1960a, p. 35, pl. 7, fig. 3 [subsequent description of lectotype designated by BOLLI, LOEBLICH, & TAPPAN, 1957, p. 33].

Sphaeroidinella dehiscens (PARKER & JONES). BOLLI, LOEBLICH, & TAPPAN, 1957, p. 32, 33, pl. 6, fig. 1-3, 5,?4 [lectotype designated but not described].—PARKER, 1962, p. 234, pl. 5, fig. 1.—PARKER, 1967 [part], p. 160, pl. 23, fig. 9 [not 8].—LAMB & BEARD, 1972, p. 59, pl. 1, fig. 1-2; pl. 34, fig. 1-2.

Sphaeroidinella dehiscens excavata BANNER & BLOW, 1965b, p. 1164-1165 [paratype designated as pl. 84, fig.

Fig. 161. *Sphaeroidinella dehiscens* (PARKER & JONES) from the Quaternary of the Atlantic and Pacific Oceans and the Gulf of Mexico.

1 Lectotype from the Holocene of the Atlantic Ocean, X50; after BANNER & BLOW (1960a, pl. 7, fig. 3). a—Spiral view; b—umbilical view.

2 *Sphaeroidinella dehiscens* (PARKER & JONES) *excavata* BANNER & BLOW, holotype from Holocene sediments of the south Pacific Ocean, X50; after BANNER & BLOW (1967, pl. 4, fig. 5).

3,6 Specimens from the Early Pleistocene of the Gulf of Mexico, X85; after LAMB (1969, pl. 1, fig. 6, 8).

4,7 Specimens from the Gulf of Mexico; after LAMB & BEARD (1972, pl. 34, fig. 1-2). 4—Oblique view of specimen from the Early Pleistocene, X80; 7—side view of specimen from the Holocene (*Globorotalia tumida* Zone), X85.

5 Specimen from the Pleistocene of the southwestern Pacific Ocean, X66; after BRÖNNIMANN & RESIG (1971, pl. 15, fig. 1).

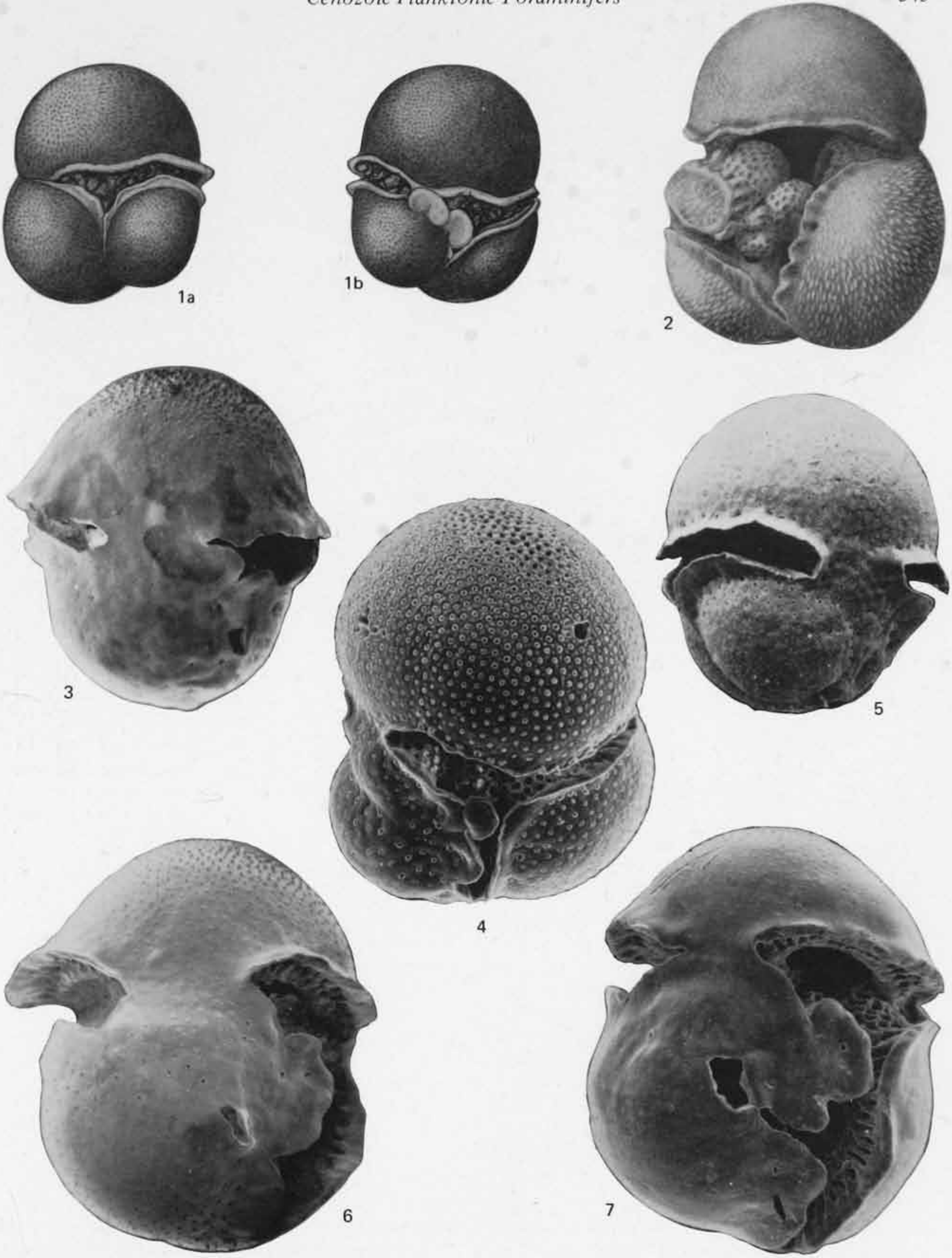


Fig. 161

Fig. 162. *Sphaeroidinella dehiscens* (PARKER & JONES) from Late Pliocene beds at Le Castella, Italy [locality IT-906A of LAMB & BEARD, 1972, fig. 8-10). **a**–Side view, X90; **b**–apertural view, X100; **c**–spiral view, X100.

8 of BRADY (1884)].–BANNER & BLOW, 1967, p. 153, pl. 4, fig. 5 [holotype].–BLOW, 1969, p. 336, pl. 29, fig. 6-8.

Sphaeroidinella dehiscens dehiscens (PARKER & JONES). BLOW, 1969, p. 336, pl. 29, fig. 9.

Gross form egg-shaped, gashed by apertural slits. Only last 3 chambers visible externally; their relative sizes variable and trochoid pattern not obvious. Sutures depressed to flush where not modified by apertures. Umbilicus a deep irregular pit. Primary aperture umbilical, extended by reentrants along intercameral sutures; supplementary apertures of similar aspect also on spiral side, at least in adults; all apertures with lips varying from smooth or crenulate rims to projecting flanges. Surface typically smooth and vitreous owing to secondary covering, but abrasion or solution may reveal coarsely perforate, almost latticelike primary shell. Diameter commonly to 1.0 mm.

Discussion.–*Sphaeroidinella* developed from *Sphaeroidinellopsis* in the late Pliocene by addition of supplementary apertures coincident with gradual increase in size and disappearance of the large abberant end-chambers typical of *Sphaeroidinellopsis*. In our opinion *Sphaeroidinella* is a monospecific genus. A subspecific variant of the type species was introduced as *Sphaeroidinellopsis dehiscens excavata* BANNER & BLOW (1965b), but its stated distinctions (less embracing chambers, wider apertures) are too tenuous for biostratigraphic application.

Seen only occasionally in the Pliocene are sphaeroidinellids exhibiting what may be small incipient supplementary apertures; these have been described as *Sphaeroidinella dehiscens immatura*

(CUSHMAN, 1919) and *Sphaeroidinella ionica ionica* CITA & CIARANFI (1972). The supplementary apertures of these forms, however, lack the projecting crenulate lips so characteristic of *Sphaeroidinella dehiscens* sensu stricto.

Distribution.–Late Pliocene to Holocene (*Pulleniatina obliquiloculata* Zone to *Globorotalia tumida* Zone). Described from the Recent of the tropical Atlantic Ocean and recorded worldwide from warm-water regions.

GLOBIGERINA DUTERTREI d'Orbigny, 1839

Figure 163

Early Pleistocene to Holocene

Globigerina dutertrei D'ORBIGNY, 1839, p. 84, pl. 4, fig. 19-21.–BANNER & BLOW, 1960a, p. 11, pl. 2, fig. 1 [lectotype].

Globoquadrina dutertrei (D'ORBIGNY). PARKER, 1962, p. 242, pl. 7, fig. 1-13; pl. 8, fig. 1-4.–PARKER, 1967, p. 168, pl. 25, fig. 7.–LAMB & BEARD, 1972, p. 50, pl. 8, fig. 7-9.–AKERS, 1972, p. 94, 96, pl. 60, fig. 2.

Neogloboquadrina dutertrei (D'ORBIGNY). BANDY, FRERICHS, & VINCENT, 1967, p. 152-153, pl. 14, fig. 3-12.

Globorotalia dutertrei (D'ORBIGNY). JENKINS & ORR, 1972, p. 1097-1098, pl. 22, fig. 1-6.

Test a regular, loosely coiled trochospire, varying from low to high; 5 to 6 chambers in final whorl, last commonly aberrant. Chambers inflated, ovate, elongated parallel to axis of spire. Equatorial profile subcircular, indented at sutures; side profile nondescript. Sutures depressed. Umbilicus polygonal, open or partly concealed by apertural teeth. Aperture in young stages a low arch from near periphery to umbilicus, becoming more umbilical in adults. Wall fairly coarsely perforate. Maximum diameter about 0.5 mm.

Discussion.–Our diagnosis is in conformity with the lectotype designated by BANNER & BLOW (1960a), who selected the sole remaining undamaged cotype [syntype] even though it differs somewhat from the originally figured specimen. Modern authors agree that this is the end form of the bioseries *Globorotalia acostaensis–Globorotalia humerosa–Globigerina dutertrei* (sensu stricto). Separation of the intermediate form *G. humerosa* TAKAYANAGI & SAITO (1962) did not become general, however, until PARKER (1967) commented on its relationships. Meanwhile the name *G. dutertrei* (sensu lato) was applied regularly in biostratigraphic studies to all the post-*acostaensis* forms of the bioseries. This broader usage persists to some degree and accounts for use of *G. dutertrei* as the nominate index of pre-Pleistocene zones (e.g., BERMÚDEZ & BOLLI, 1969; BOLLI, 1970; POSTUMA, 1971).

Variability of coiling and especially of umbilical-apertural characteristics led to difficulty in generic assignment within the bioseries, as seen in accompanying synonymies. For *G. dutertrei*, the open umbilicus typifies *Globigerina* rather than *Globorotalia*, and the adult aperture is never completely extraumbilical; apertural teeth are of dubious genetic significance (e.g., BLOW, 1969, p. 339; BRÖNNIMANN & RESIG, 1971). Thus, assignment to *Globoquadrina* or the homeomorphic *Neogloboquadrina* appears undesirable, and we retain the species in *Globigerina*. Possible junior synonyms of *G. dutertrei* are *Globigerina eggeri* RHUMBLER (1901) and *Globigerina globorotaloidea* COLOM (1954).

This species has greater development of apertural teeth in warm-water than in cool-water regions and generally is higher spired in the Western Hemisphere than in the Eastern. WILES (1967) reported that tests from warm-water regions have more pores per unit area than those from cool-water regions.

Distribution.–Pleistocene and Holocene (*Globorotalia truncatulinoides* Zone to *Globorotalia tumida* Zone). Described originally from beach sands in the West Indies, this species is known to have worldwide distribution.

GLOBOROTALIA EXILIS Blow, 1969

Figure 164

Middle Pliocene to Early Pleistocene

Globorotalia (Globorotalia) cultrata exilis BLOW, 1969, p. 396-397, pl. 7, fig. 1-3.

Fig. 163. *Globigerina dutertrei* D'ORBIGNY from the Late Pleistocene and Holocene of the Caribbean and Gulf of Mexico regions. [p. 348]

1 Lectotype from Recent [Holocene] beach sands of Cuba, X100; from BANNER & BLOW (1960a, pl. 2, fig. 1). **a**–Spiral view; **b**–side view; **c**–umbilical view.

2-4 Specimens from the Late Pleistocene of the Gulf of Mexico, X85; from LAMB & BEARD (1972, pl. 8, fig. 7-9). **2**–Detail of umbilical side showing deep umbilicus; **3**–side view showing lofty trochospire; **4**–spiral view.

5-6 Virtual topotype specimens from Holocene sediments off the coast of Cuba (Atlantis Expedition station 2967; courtesy DR. P. J. BERMÚDEZ); X110. **5**–Spiral view; **6**–umbilical view showing an abortive final chamber.

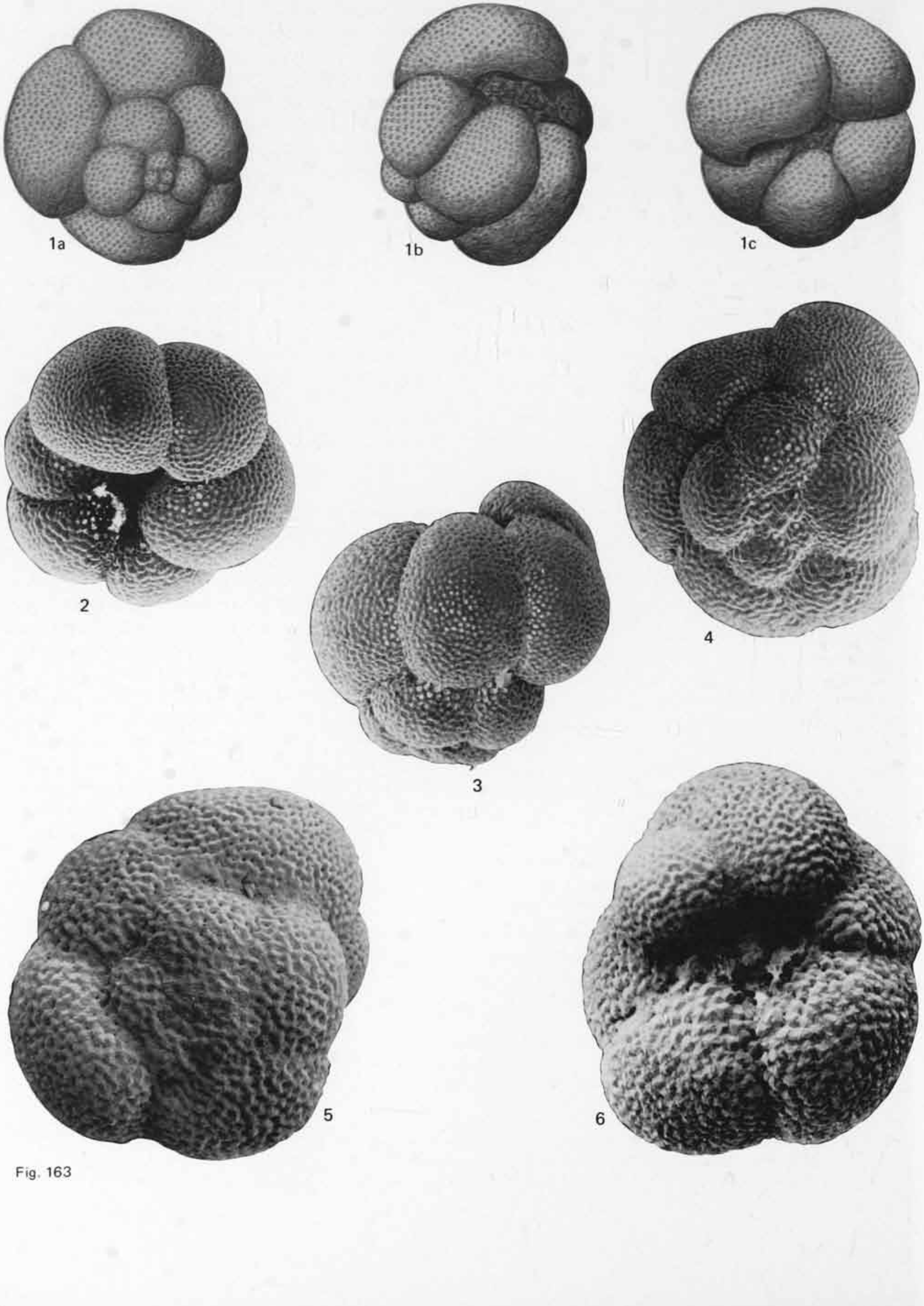


Fig. 163

Globorotalia exilis BLOW [part]. BOLLI, 1970, p. 581, pl. 7, fig. 9-12.

Test a compressed lenticular trochospire. Last whorl with 5 to 7 chambers which are scallop-shaped, each having limbate keel. Equatorial profile lobate, notched between chambers; axial profile reveals acute, pinched margin and low (to concave) spiral surface. Sutures on spiral side recurved, limbate, merging into keel, but limbate portion commonly concealed by posterior overlap of adjacent chamber; on umbilical side depressed, incised, sinuously radial. Umbilicus narrow, deep. Aperture a low arched slit extending from umbilicus to near periphery, generally with distinct flangelike lip. Wall thin and finely perforate. Diameter 0.65 to 0.75 mm.

Discussion.–*Globorotalia exilis* is one of a complex of related globorotaliid species that developed within the Middle to Late Pliocene (probably from *Globorotalia menardii* stock) and continued into the Early Pleistocene. In order of appearance this complex includes *Globorotalia praemiocenica* LAMB & BEARD (1972), *G. exilis*, *Globorotalia miocenica* PALMER (1945), and *Globorotalia pertenuis* BEARD (1969), all of which coil dominantly to the right. Beginning with *G. praemiocenica*, overall morphologic differentiation of species from older to younger levels tends toward flattening of the test and thinning of the wall (beginning with *G. exilis*), increasing lobation of the peripheral margin (except for *G. miocenica* which develops a nearly circular outline), and increase in size (largest species being *G. pertenuis*). A curious morphological character of species of this lineage is that limbate intercameral sutures on the spiral side commonly are "buried" or overlapped by succeeding chambers, a feature that caused BLOW to remark erroneously that they were weakly or nonlimbate. It should be evident that spiral and associated intercameral sutures at one time occupied the peripheral margin; thus, if a species has a carinate peripheral margin, it must follow that it has limbate sutures even though they may be "buried" by succeeding chambers.

Of this lineage, BLOW (1969) cited *G. exilis*, *G. miocenica*, and *G. limbata (=G. praemiocenica)* as occurring in the same stratigraphic order as given herein, but he evidently construed *G. pertenuis* as a normal variant of his *G. exilis* because he did not mention this large lobate form. KANEPS (1970) also observed essentially this same globorotaliid evolutionary progression from the Blake Plateau area of the western Atlantic.

We are in essential agreement with KANEPS that members of this lineage are endemic to the Atlantic-Caribbean-Gulf of Mexico regions and that they are not present in the Indo-Pacific region owing to closing of the Isthmus of Panama prior to their development. Nevertheless, records of species similar to *Globorotalia praemiocenica* exist in the Pacific Ocean region (e.g., JENKINS & ORR, 1972; BRÖNNIMANN & RESIG, 1971) and need further evaluation.

Globorotalia exilis differs from *Globorotalia praemiocenica*, its immediate ancestor, in having a more compressed, less biconvex, test and a thinner, more delicate wall, whereas the test in *Globorotalia miocenica* is essentially planoconvex with a flat spiral side and a rounded outline; *Globorotalia pertenuis* is distinctly more lobate, has a more compressed test, and reaches a larger diameter.

Distribution.–Middle Pliocene to Early Pleistocene (*Pulleniatina obliquiloculata* Zone to within lower part of the *Globorotalia truncatulinoides* Zone). Described from the upper part of the Bowden Formation of Jamaica and more recently reported from the western Atlantic Ocean, eastern equatorial Pacific Ocean, and southwestern Pacific Ocean. It is apparent from the literature, however, that some authors include both *Globorotalia praemiocenica* and *Globorotalia pertenuis* in their concept of this species, thus casting some doubt on stated occurrences of *Globorotalia exilis* in the Pacific region.

Fig. 164. *Globorotalia exilis* BLOW from the Late Pliocene and Early Pleistocene of the Caribbean and Gulf of Mexico regions. [p. 350]

1 Holotype from Late Pliocene beds within the Bowden Formation of Jamaica; X67; from BLOW (1969, pl. 7, fig. 1-3). **a**–Spiral view illustrating partially buried intercameral sutures and the lobulate periphery; **b**–side view of the flattened test; **c**–umbilical view showing sinuous sutures and thin apertural lip.

2-4 Specimens from Late Pliocene strata of the Caribbean Sea, X48; from BOLLI (1970, pl. 7, fig. 10-12). **2**–Umbilical view; **3**–spiral view; **4**–side view.

5-7 Specimens from Early Pleistocene sediments of the Sigsbee knolls, Gulf of Mexico; **5-6** from LAMB (1969, pl. 2, fig. 4-5). **5**–Spiral view, X85; **6a**–umbilical view, X85; **6b**–enlarged view of spiral side showing perforations of chamber wall and imperforate suture, X493; **7**–specimen photographed using light microscope to show translucent nature of wall in some well-preserved specimens, X70 ca.

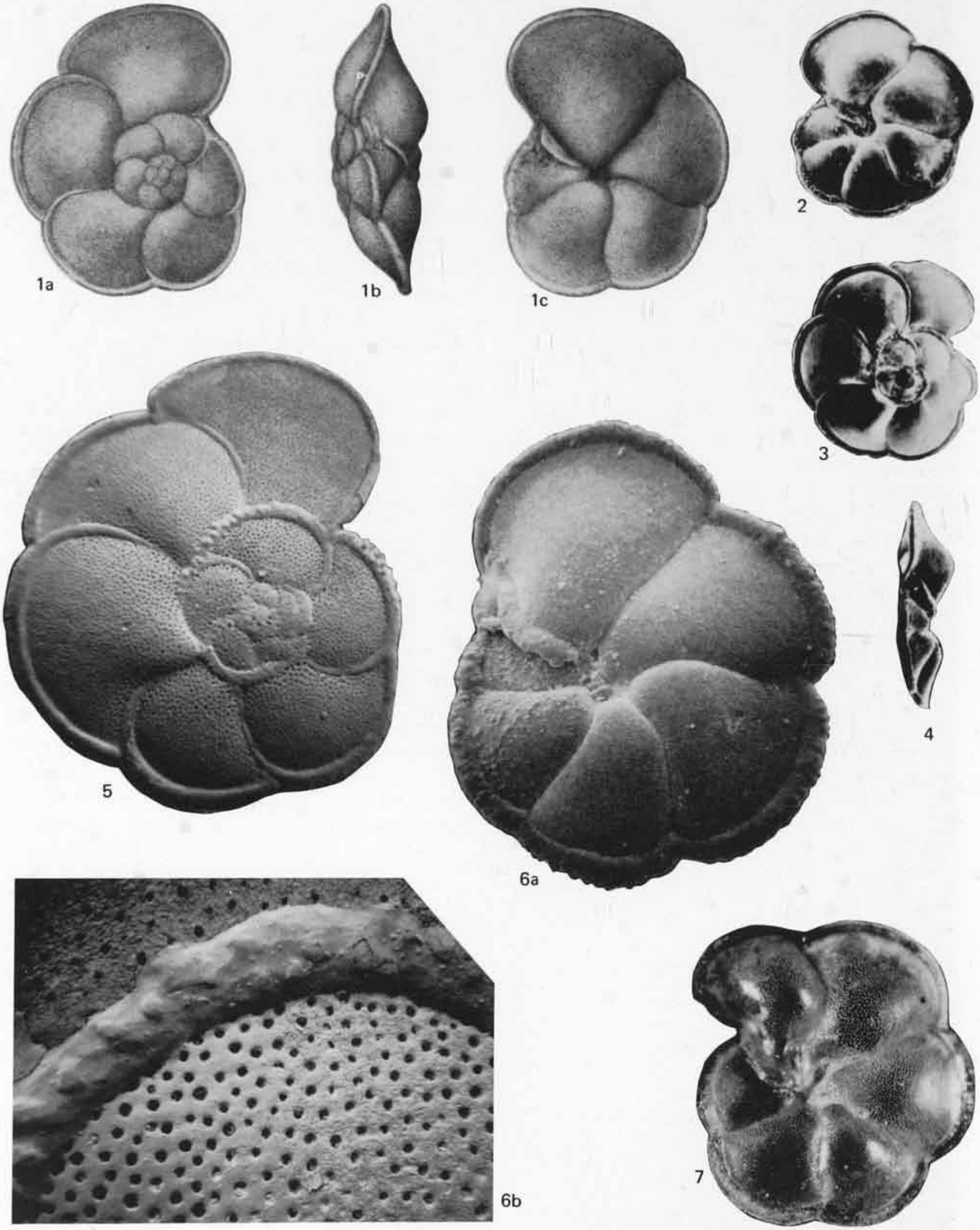


Fig. 164

GLOBIGERINOIDES EXTREMUS

Bolli & Bermúdez, 1965

Figure 165

Late Miocene to Early Pleistocene

Globigerinoides obliquus extremus BOLLI & BERMÚDEZ, 1965, p. 139, pl. 1, fig. 10-12.–BLOW, 1969, p. 324, pl. 21, fig. 2-3.

Globigerinoides obliquus BOLLI. PARKER, 1967, p. 155, pl. 20, fig. 5-6.–POAG & AKERS, 1967, p. 171, pl. 16, fig. 16-18.

Globigerinoides obliquus extrema BOLLI & BERMÚDEZ. BERMÚDEZ & BOLLI, 1969, p. 162, pl. 7, fig. 4-6.

Globigerinoides extremus BOLLI & BERMÚDEZ. LAMB & BEARD, 1972, p. 48, pl. 32, fig. 1-6.

Test a high trochospire. Chambers (3 to 4) of last whorl progressively more compressed in lateral, oblique manner; final chamber mitriform. Equatorial profile distinctly lobate; axial profile reveals bluntly elevated initial spire and somewhat looser adult chambers. All intercameral sutures somewhat oblique, incised. Umbilicus lacking. Primary aperture a distinct arch of medium height, interiomarginal to umbilical. Small supplementary aperture at spiral suture of final chamber and commonly earlier chambers. Wall rather thick, coarsely perforate, and pitted to pustulose. Diameter 0.3 to 0.4 mm.

Discussion.–This species evolved transitionally from *Globigerinoides obliquus* BOLLI (1957) by earlier appearance of obliquely appressed chambers and by development of a lopsided, mitriform final chamber.

Distribution.–Late Miocene to Early Pleistocene (*Globorotalia acostaensis* Zone to within lower part of the *Globorotalia truncatulinoides* Zone). This species was first described from the Early Pliocene of the Cubagua Formation of Venezuela and since has been recorded nearly worldwide.

PULLENIATINA FINALIS Banner & Blow, 1967

Figures 166-167

Late Pleistocene and Holocene

Pulleniatina obliqueloculata [sic] (PARKER & JONES) [part]. BOLLI, LOEBLICH, & TAPPAN, 1957, p. 33, pl. 4, fig. 4.

Pulleniatina obliquiloculata finalis BANNER & BLOW, 1967, p. 140-142, pl. 2, fig. 4-10; pl. 3, fig. 5; pl. 4, fig. 10.–BRÖNNIMANN & RESIG, 1971, p. 1320, pl. 19, fig. 1-3.

Pulleniatina obliquiloculata (PARKER & JONES) [part]. PARKER, 1967, p. 172.

Pulleniatina finalis BANNER & BLOW. LAMB & BEARD, 1972, p. 57-58, pl. 29, fig. 5-7; pl. 30, fig. 1.

Test tumid, initially trochospiral, becoming strongly streptospiral in adult. Last whorl of 4 to 5 chambers appears planispiral, enveloping most of earlier portion. Spiral profile smoothly curved, nautiloid; axial profile an obtuse oval, flattened at axis. Sutures indistinct; lightly depressed or flush. Original umbilicus hidden; umbilical area occupied by blunt tip of final chamber. Aperture a high arch embracing entire inner coil, strongly oblique to initial axis of coiling. Wall thick, smooth to shiny, finely perforate, granular around aperture; abrasion or solution may reveal very coarsely perforate inner wall. Diameter 0.6 to 0.8 mm.

Discussion.–*Pulleniatina finalis* differs from *Pulleniatina obliquiloculata* (PARKER & JONES,

Fig. 165. *Globigerinoides extremus* BOLLI & BERMÚDEZ from the Late Miocene and Pliocene of the Caribbean and Gulf of Mexico regions and the south of Italy. [p. 352]

1 Holotype from the Pliocene portion of the Cubagua Formation (*Globorotalia margaritae* Zone) of Venezuela, X96; from BOLLI & BERMÚDEZ (1965, pl. 1, fig. 10-12). **a**–Spiral view; **b**–side view; **c**–umbilical view showing mitered last chamber.

2-3 Specimens from the Pliocene (*Globorotalia margaritae* Zone) of the Gulf of Mexico, X180; after LAMB & BEARD (1972, pl. 32, fig. 1-2). **2**–Oblique umbilical view; **3**–spiral view.

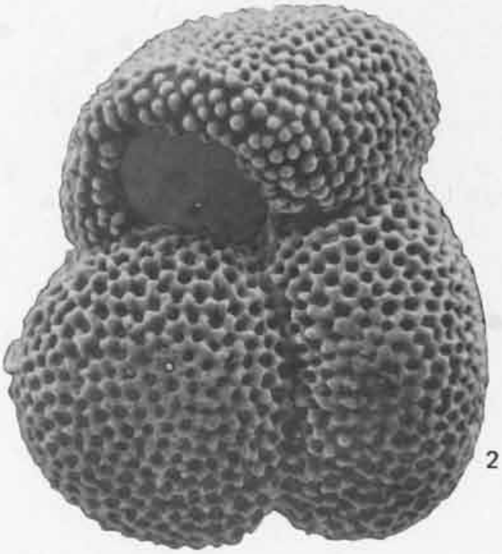
4 Ideotype from the Late Miocene of the Caribbean region, X125; contributed by DR. P. J. BERMÚDEZ.

5-6 Specimens from Middle Pliocene beds at Le Castella, Italy, locality IT-783 of LAMB & BEARD (1972, fig. 8-10). **5**–Spiral view, X140; **6**–apertural view, X125.

Fig. 166. *Pulleniatina finalis* BANNER & BLOW from the Late Pleistocene and Holocene of the south Atlantic Ocean and the Gulf of Mexico. [p. 353]

1 Holotype from Recent [Holocene] sediments of the south Atlantic Ocean, X100; from BANNER & BLOW (1967, pl. 3, fig. 5). **a**–Side view; **b**–apertural view.

2-3 Specimens from the Late Pleistocene of the Gulf of Mexico; after LAMB & BEARD (1972, pl. 29, fig. 5, 7; pl. 30, fig. 1d). **2a**–Oblique side view, X75; **2b**–enlarged view of decortexed portion of wall showing coarsely perforate inner wall, X850; **3**–apertural view, X75.



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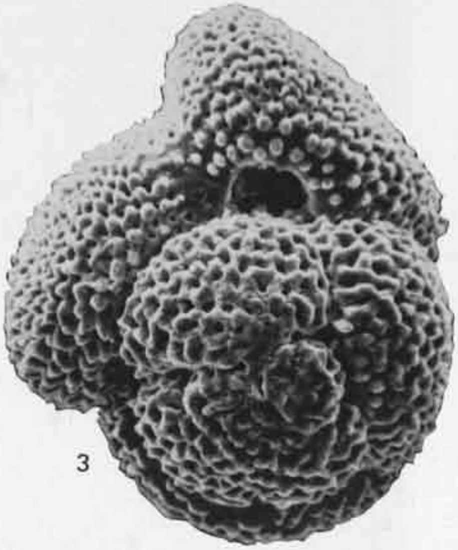

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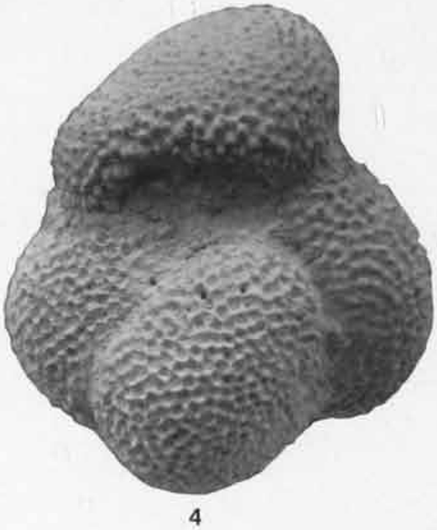

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Fig. 165

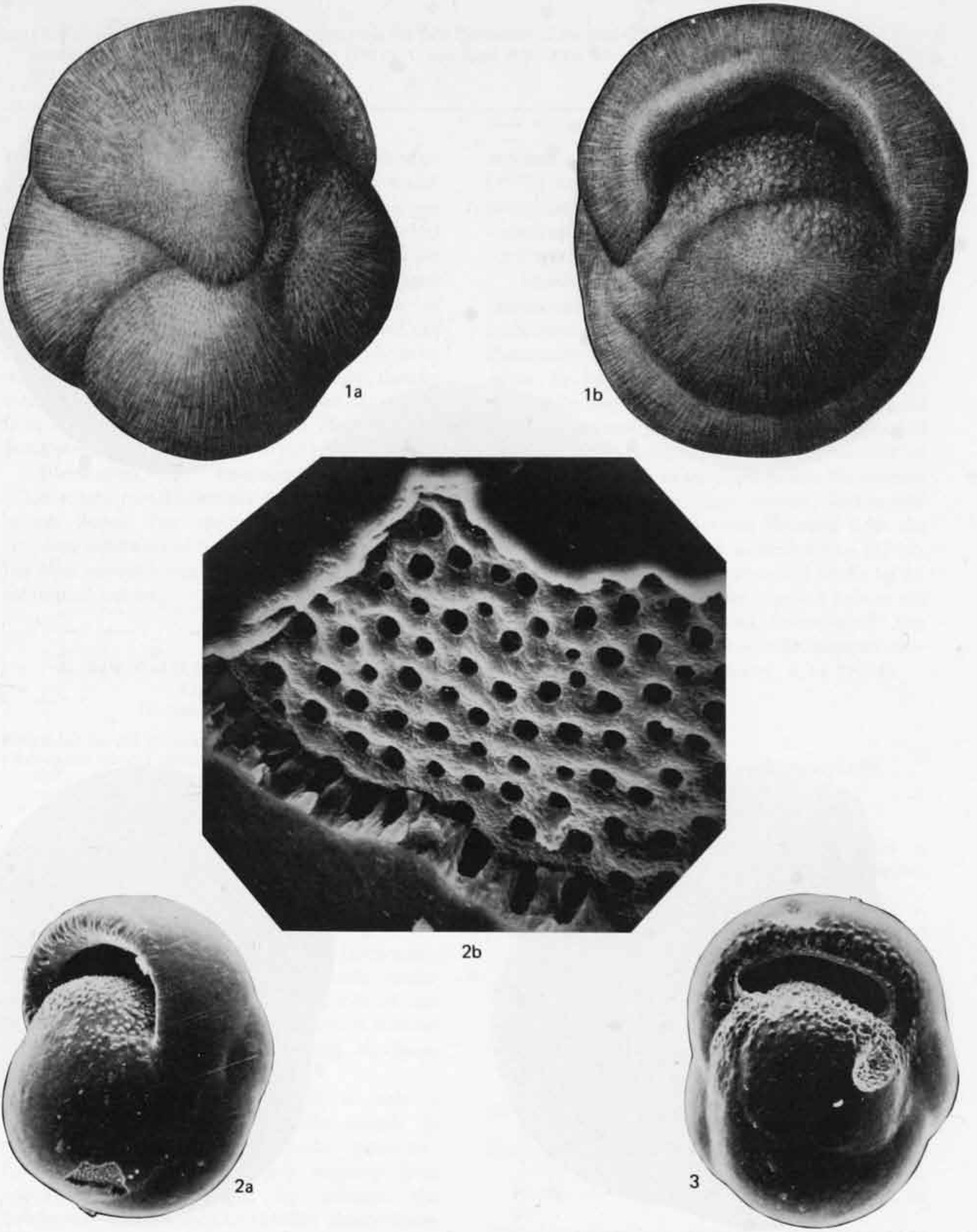

Fig. 166


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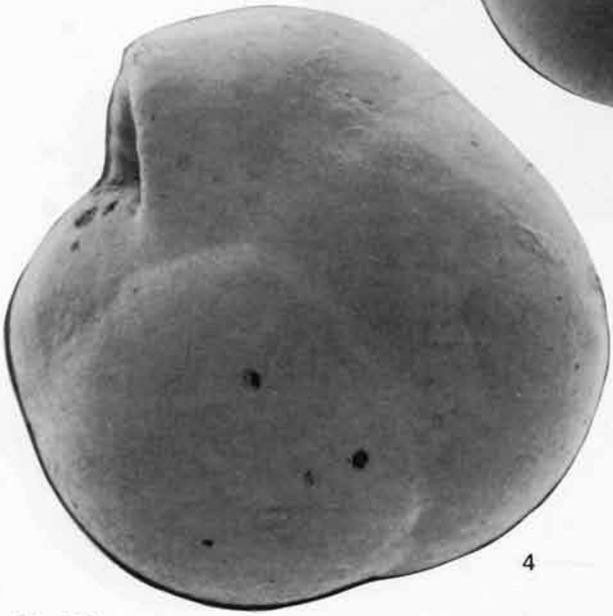
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Fig. 167

Fig. 167. *Pulleniatina finalis* BANNER & BLOW from the Late Pleistocene of the Gulf of Mexico. Specimens from corehole D, core number 1 discussed by LAMB & BEARD (1972). **1**–Apertural view, X95; **2-3**–apertural views, X105, X110; **4**–side view, X110; **5**–oblique side view, X90.

1865) principally in the test which is strongly dorsally evolute throughout all of the last whorl. Generally a much higher and broader final aperture and a reduced number of chambers in the last whorl are common and characteristic features. As with the other pulleniatines (see under *P. obliquiloculata* group) we closely follow species diagnoses of BANNER & BLOW (1967). Some workers have not restricted their concept of this species to forms wholly, or almost wholly, involute dorsally, thereby confusing the stratigraphic range. This species evolved from *P. obliquiloculata* in the later Pleistocene by developing a greater involution of the test.

Distribution.–Late Pleistocene to Holocene (*Globorotalia truncatulinoides* Zone to *Globorotalia tumida* Zone). This species was described from Holocene sediments of the south Atlantic Ocean and has been recorded nearly worldwide in tropical and subtropical regions.

GLOBOROTALIA FLEXUOSA (Koch, 1923)

Figure 168
Pliocene to Pleistocene

Pulvinulina tumida flexuosa KOCH, 1923, p. 357, fig. 9-10.

Globorotalia tumida flexuosa (KOCH). BOLLI, 1966b, p. 459, 462.–BOLLI, 1970, p. 583, pl. 6, fig. 10-12.–LAMB & BEARD, 1972, p. 52, pl. 12, fig. 6-8.–JENKINS & ORR, 1972, p. 1104-1105, pl. 31, fig. 6-8.

Globorotalia tumida (BRADY) (part). PARKER, 1967, p. 182, pl. 32, fig. 7 [**not** fig. 5-6].

Globorotalia (Globorotalia) tumida flexuosa (KOCH). BLOW, 1969, p. 371.

Test a large, heavily keeled, biconvex trochospire. Identical in all respects with *Globorotalia tumida* (BRADY, 1877) except that anterior rim of last chamber is bent sharply toward umbilicus, in extreme cases perpendicular to plane of coiling. Maximum diameter 0.8 to 1.3 mm.

Discussion.–Probably this form is only a morphologic variant of *Globorotalia tumida* as maintained by authors cited in the synonymy. Possibly it is a teratoid form resulting from paleotemperature changes; for instance, the distribution chart of BOLLI (1966b) clearly shows coincidence of its first appearance with abrupt reversals of coiling direction, and LAMB & BEARD (1972) note coincidence of its appearance with interglacial intervals. Regardless of such subjective considerations, *Globorotalia flexuosa* is a conspicuous form well suited to biostratigraphic use.

Distribution.–Pliocene to Pleistocene (within *Globorotalia margaritae* Zone to within *Globorotalia truncatulinoides* Zone). Almost unknown before Pleistocene in Caribbean-Atlantic region but recorded earlier in Pacific province. First described from "young Tertiary" beds in Java that now are assigned to the Pleistocene. LAMB & BEARD (1972) showed that this species occurs within the Caribbean-Gulf of Mexico region as late as the warm middle Wisconsinan glacial stage. A living form termed *Globorotalia menardii flexuosa* (KOCH) was recorded from the Indian Ocean recently by BÉ & MCINTYRE (1970). The specimens illustrated and described briefly by BÉ & MCINTYRE, however, are interpreted here as not typical of *Globorotalia flexuosa*. Subsequently, this form was redescribed as *Globorotalia menardii neoflexuosa* SRINIVASAN, KENNETT, & BÉ (1974).

GLOBOROTALIA HIRSUTA (d'Orbigny, 1839)

Figure 169
Early Pleistocene to Holocene

Rotalina hirsuta D'ORBIGNY, *in* BARKER-WEBB & BERTHELOT, 1839, p. 131, pl. 1, fig. 37-39.–BLOW, 1969, p. 398-400, pl. 8, fig. 1-3 [neotype].

Pulvinulina canariensis (D'ORBIGNY). BRADY, 1884, p. 692, pl. 103, fig. 8-10 [fide CUSHMAN (1931a), BLOW (1969)] [**not** *Rotalina canariensis* D'ORBIGNY, *in* BARKER-WEBB & BERTHELOT, 1839].

Globorotalia hirsuta (D'ORBIGNY). CUSHMAN, 1931a, p. 99-100, pl. 17, fig. 6.–PARKER, 1962, p. 236-237, pl. 5, fig. 10-12, 14 [**not** 13, 15 = *G. crassula* (fide PARKER, 1967)]; pl. 6, fig. 1.–PARKER, 1967, p. 178, pl. 32, fig. 3.–CIFELLI & SMITH, 1970, p. 39-40, pl. 6, fig. 2.

Globorotalia (Globorotalia) hirsuta (D'ORBIGNY). BANNER & BLOW, 1967, p. 153, fig. 14.

Globorotalia (Globorotalia) hirsuta hirsuta (D'ORBIGNY). BLOW, 1969, p. 398-400, pl. 8, fig. 1-3 [neotype]; pl. 43, fig. 1-2.–COLLEN & VELLA, 1973, p. 25, pl. 7, fig. 6-8.

[**not**] *Globigerina hirsuta* D'ORBIGNY, *in* BARKER-WEBB & BERTHELOT, 1839.

Fig. 168

Fig. 168. *Globorotalia flexuosa* (KOCH) from the Pleistocene of Indonesia, Caribbean Sea, and Gulf of Mexico.

1-3 Specimens from the Caribbean Sea, X52; from BOLLI (1970, pl. 6, fig. 10-12). **1**–Side view; **2**–apertural view; **3**–spiral view.

4 Holotype from Java, X35; from KOCH (1923, p. 357, fig. 10). **a**–Umbilical view; **b**–spiral view.

5-7 Specimens from the Late Pleistocene of the Gulf of Mexico, X85. **5**–Umbilical view; **6**–side view; **7**–apertural view.

Test a large discoidal trochospire. Last whorl of 4 to (uncommonly) 5 chambers; on spiral side scallop-shaped, oblique to the spire, becoming progressively more loosely attached, bordered by a conspicuous narrow keel. Equatorial profile ovate to subpentagonal, more or less lobate; axial profile biconvex, domed to tumid on spiral side. Sutures on spiral side strongly recurved, depressed, and limbate (although limbation may be concealed by chamber overlap); on umbilical side sinuously radial, sharply defined. Umbilicus a deep, narrow pit, generally conspicuous. Aperture a low slit from within umbilicus to near periphery, bordered by thin, narrow lip. Surface smooth, finely perforate, commonly dappled with calcite pustules. Diameter 0.7 to 1.1 mm.

Discussion.–*Globorotalia hirsuta* evolved from *Globorotalia margaritae* BOLLI & BERMÚDEZ (1965) via *Globorotalia praehirsuta* BLOW (1969). It differs from the ancestral forms in larger size, distinct umbilical pit, and more inflated aspect. Intraspecific variability is considerable, as illustrated by PARKER (1962, 1967). *Globorotalia tumida* (BRADY, 1877) is comparable in size but differs in a much heavier keel, more rapidly opening spire, and other details.

Distribution.–Pleistocene to Holocene (lower part of *Globorotalia truncatulinoides* Zone to *Globorotalia tumida* Zone). The species was described from "Recent or Subrecent" deposits off the Canary Islands and has a worldwide distribution.

GLOBOROTALIA HUMEROSA Takayanagi & Saito, 1962

Figure 170

Latest Miocene to Early Pleistocene

Globorotalia humerosa TAKAYANAGI & SAITO, 1962, p. 78, pl. 28, fig. 1-2.

Globoquadrina humerosa (TAKAYANAGI & SAITO). PARKER, 1967, p. 169, pl. 24, fig. 10-11; pl. 25, fig. 1-6.–LAMB & BEARD, 1972, p. 50-51, pl. 3, fig. 4-9; pl. 8, fig. 1-6.

Globorotalia (Turborotalia) acostaensis humerosa TAKAYANAGI & SAITO. BLOW, 1969, p. 345-346, pl. 33, fig. 4-7 (?not 8-9); pl. 34, fig. 1-3.

Globorotalia dutertrei humerosa TAKAYANAGI & SAITO. BOLLI, 1970, p. 580, pl. 2, fig. 4-6.

Globorotalia (Turborotalia) dutertrei (D'ORBIGNY). JENKINS, 1971, p. 114.

Fig. 169. *Globorotalia hirsuta* (D'ORBIGNY) from the Pleistocene and Holocene of the north Atlantic and Indian Oceans and the Tasman Sea. [p. 358]

1 Neotype from Recent [Holocene] sediments off the Canary Islands, X67; after BLOW (1969, pl. 8, fig. 1-3). **a**–Spiral view; **b**–side view; **c**–umbilical view.

2 Specimen from plankton sample collected in the vicinity of the north Atlantic current, X70; from CIFELLI & SMITH (1970, pl. 6, fig. 2). **a**–Spiral view; **b**–side view showing distinctive convexity of spiral side of this group; **c**–umbilical view.

3 Specimen from Early Pleistocene sediments of the Indian Ocean, X52; from PARKER (1967, pl. 32, fig. 3). **a**–Spiral view; **b**–side view; **c**–umbilical view.

4-5 Recent [Holocene] specimens from the Tasman Sea; from COLLEN & VELLA (1973, pl. 7, fig. 6-8). **4a**–Spiral view, X80; **4b**–detail of final chamber showing fine pores, X674; **5**–umbilical view, X90.

Fig. 170. *Globorotalia humerosa* TAKAYANAGI & SAITO from the Pliocene of Japan and Gulf of Mexico. [p. 359]

1 Holotype from Pliocene beds of the Nobori Formation, Japan, X67; from TAKAYANAGI & SAITO (1962, pl. 28, fig. 1). **a**–Spiral view; **b**–umbilical view; **c**–side view.

2-4 Virtual topotypes collected from near the base of the Nobori Formation (courtesy DR. J. C. INGLE), X120. **2**–Umbilical view showing deep umbilicus; **3**–side view; **4**–spiral view.

5-6 Specimens from the Pliocene of the Gulf of Mexico; from LAMB & BEARD (1972, pl. 8, fig. 1,6). **5**–Umbilical view, X169; **6**–spiral view, X177.

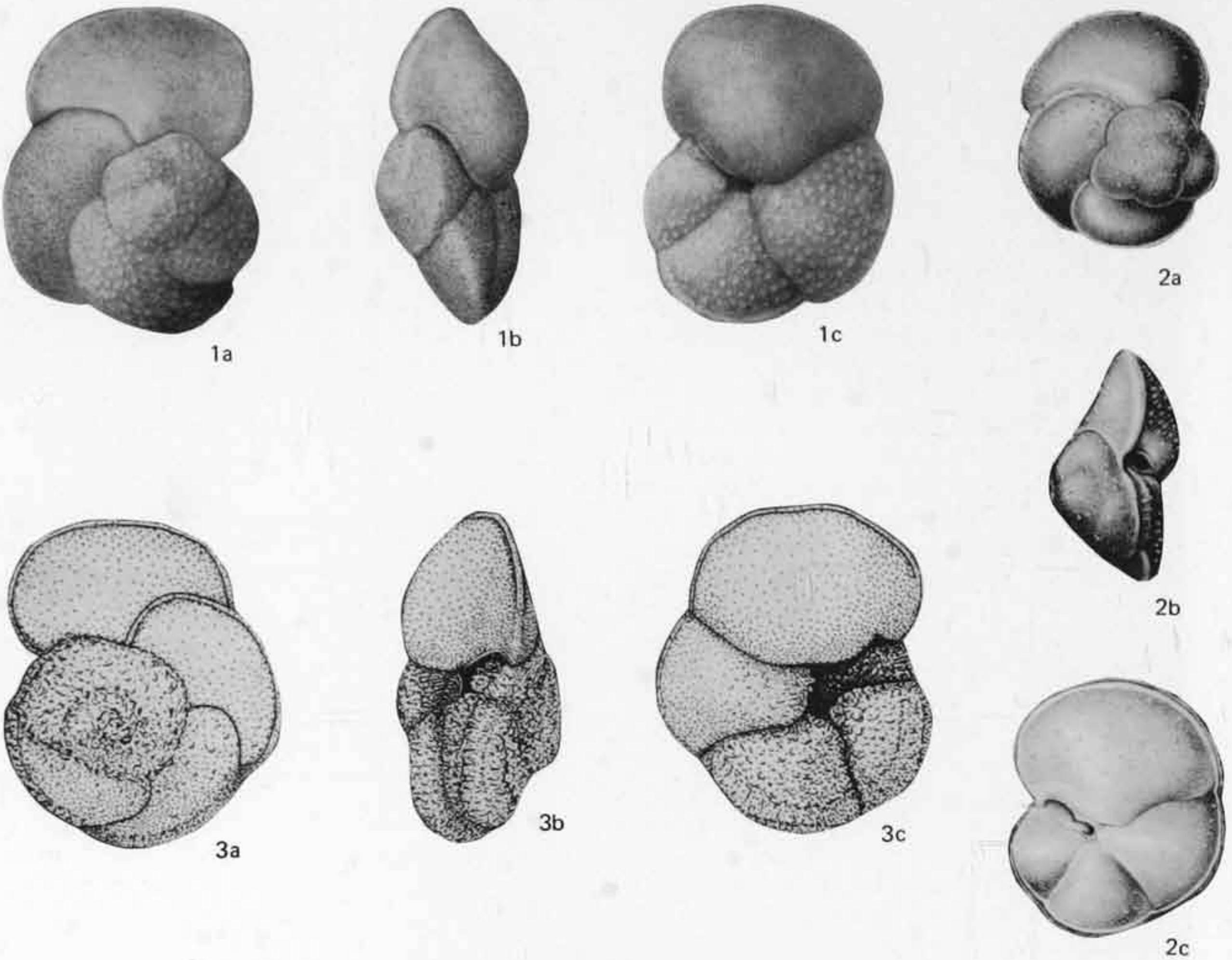
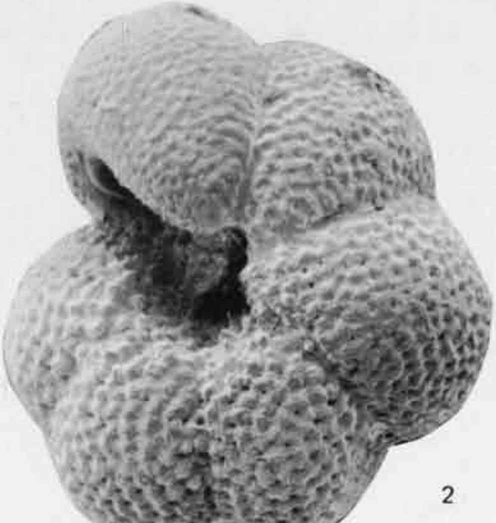


Fig. 169



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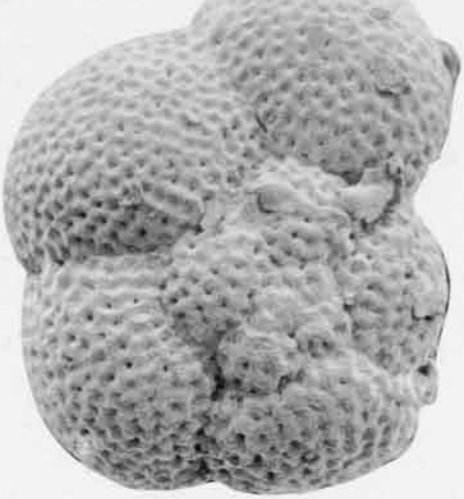

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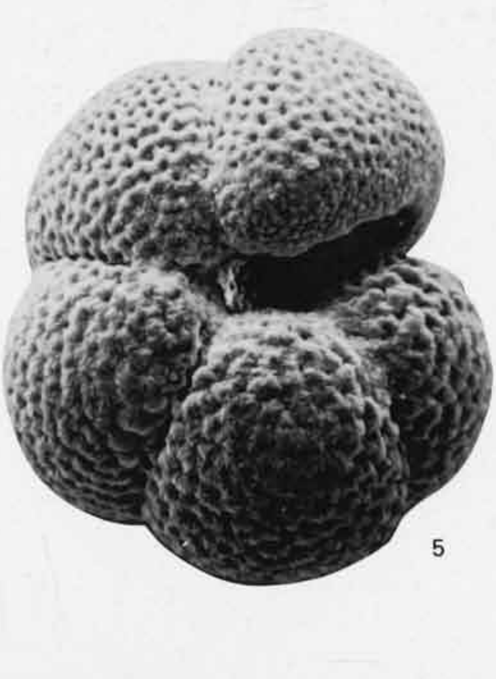

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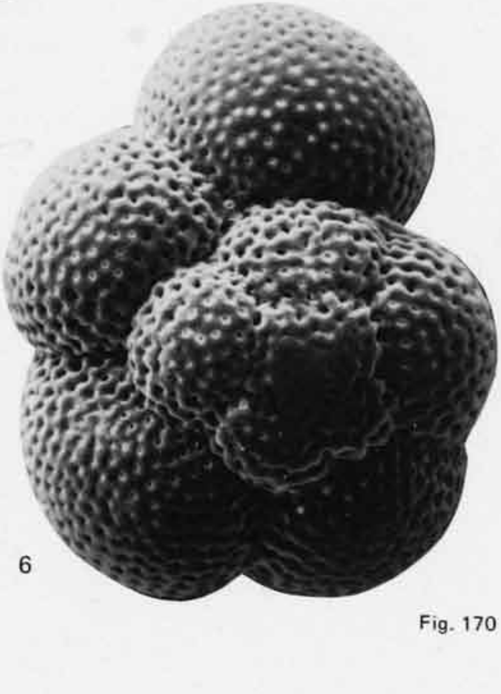

6

Fig. 170

Turborotalia humerosa (TAKAYANAGI & SAITO). POAG, 1972b, p. 512, pl. 2, fig. 9-10.

Test a low, regular trochospire, spiral side almost flat; 5 to 7 mildly inflated chambers in last whorl, becoming subequal, occasionally aberrant. Equatorial profile subpolygonal, slightly lobate; axial profile reveals bluntly rounded periphery. Sutures depressed. Umbilicus small but clearly defined by inturned tips of chambers. Aperture a low umbilical-extraumbilical arch, commonly carrying delicate lip but rarely with apertural teeth. Surface granular, coarsely perforate. Normal diameter 0.4 to 0.5 mm.

Discussion.—Modern authors accept *Globorotalia humerosa* as an intermediate form between *Globorotalia acostaensis* BLOW (1969) and *Globigerina dutertrei* D'ORBIGNY (1839). From *G. acostaensis* it differs in larger size, looser coiling, development of a distinct umbilicus, and lack of tegillate apertural teeth; from *G. dutertrei* it differs in tighter coiling and a lower spire, hence a smaller and simple umbilicus. Although changes within the bioseries are subtle and are guided by environmental as well as chronologic factors, levels of first appearance of *G. humerosa* and *G. dutertrei* (sensu stricto) are useful stratigraphic datums. Some authors evidently included *G. humerosa* within their broad usage of *G. dutertrei*.

Distribution.—Latest Miocene to early Pleistocene. Originally described from the Pleistocene? Nobori Formation of Japan and subsequently recorded widely in the Pacific, Caribbean, and north Atlantic regions, especially in deep-sea cores.

GLOBOROTALIA INFLATA (d'Orbigny, 1839)

Figures 171-172

Late Pliocene to Holocene

Globigerina inflata D'ORBIGNY, *in* BARKER-WEBB & BERTHELOT, 1839, p. 134, pl. 2, fig. 7-9.—AKERS & DORMAN, 1964, p. 16, pl. 13, fig. 17-19.

Globorotalia sp. 1 PHLEGER, PARKER, & PEIRSON, 1953, p. 23, pl. 4, fig. 19-21.

Globorotalia inflata (D'ORBIGNY). PARKER, 1962, p. 236, pl. 5, fig. 6-9.—PARKER, 1967, p. 179, pl. 29, fig. 1-3.—INGLE, 1967, p. 357, pl. 39, fig. 4-5; pl. 40, fig. 1.—LAMB & BEARD, 1972, p. 52-53, pl. 27, fig. 8-11; pl. 28, fig. 1-4, 6.—CITA ET AL., 1973, p. 1280, pl. 10, fig. 1-6; pl. 11, fig. 1-5.

Globorotalia (Turborotalia) inflata (D'ORBIGNY). BANNER & BLOW, 1967, p. 144-146, pl. 4, fig. 1 [neotype], 11.—JENKINS, 1971, p. 116-117, pl. 11, fig. 282-287.

Test a low, tumid trochospire. Last whorl of 4 to 5 inflated chambers. Equatorial profile weakly lobulate; axial profile broadly rounded, slightly flattened on spiral side. Intercameral sutures on spiral side curved, depressed; on umbilical side subradial, depressed. Umbilicus narrow, deep. Aperture a broad, high arch from umbilicus to near periphery, without distinct lip. Wall thick, perforations uniform but obscured by granularity; wall of last-formed chamber smooth except on rimlike apertural face. Diameter about 0.5 mm.

Discussion.—Italian workers derive *Globorotalia inflata* from the *Globorotalia puncticulata – Globorotalia bononiensis* lineage recognized in the Early and Middle Pliocene of Italy whereas workers in the Australasian region tend to emphasize *G. puncticulata* (DESHAYES, 1832) as the immediate ancestor to *G. inflata* because *G. bononiensis* DONDI (1963) is not recorded from that area. In a biometrical study of globorotaliid assemblages by GRADSTEIN (1972), morphological transition from *G. puncticulata* to *G. bononiensis* was not observed, but an evolutionary link between *G. bononiensis* and *G. inflata* was deemed possible. GRADSTEIN also pointed out that no direct relationship is apparent between *G. puncticulata* and *G. inflata*. Our observations, especially with respect to the Middle and Late Pliocene planktonic succession at Le Castella, Italy, suggest that *G. bononiensis* is the likely ancestor of *G. inflata* and that *G. puncticulata* is lacking in the very late Middle and Late Pliocene.

Globorotalia inflata differs from *G. puncticulata* in its generally larger size and in having a more rounded axial periphery and less coarsely perforate last chambers. It differs from *G. bononiensis* in having a more flattened spiral side, less coarse wall perforations, and a more broadly rounded last chamber. Early forms of *Pulleniatina* are grossly similar to *G. inflata* (see under *Pulleniatina obliquiloculata* group).

Distribution.—Late Pliocene to Holocene (*Pulleniatina obliquiloculata* Zone to *Globorotalia tumida* Zone). The neotype of this species was described from a sample dredged off the Canary Islands. Although a cool-water species having a nearly worldwide distribution, it advanced well into present warm-water regions during onset of Pleistocene cooling and during later glacial intervals.

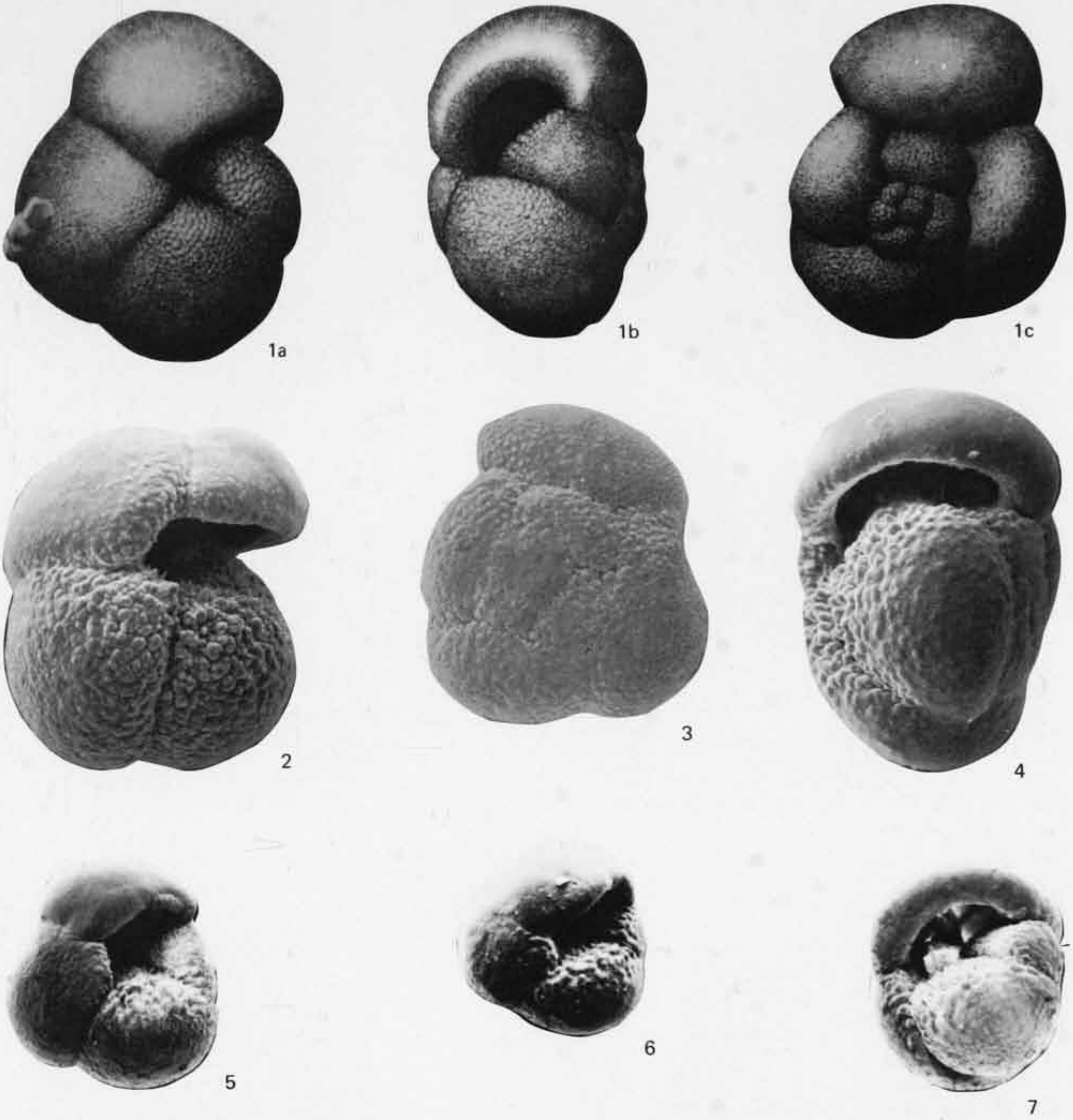

Fig. 171. *Globorotalia inflata* (D'ORBIGNY) from the Late Pleistocene and Holocene of the north Atlantic Ocean and Gulf of Mexico.

1 Neotype from Recent [Holocene] sea-floor sediments off the Canary Islands, X100; from BANNER & BLOW (1967, pl. 4, fig. 1). **a**–Apertural view; **b**–side view showing high-arched aperture; **c**–spiral view.

2-4 Specimens from the Late Pleistocene of the Gulf of Mexico, X100; from LAMB & BEARD (1972, pl. 28, fig. 1-3). **2**–Apertural view; **3**–spiral view; **4**–side view.

5-7 Specimens from the Late Pleistocene of the subantarctic; from KENNETT (1970, fig. 1, no. 10-12). **5**–Umbilical view, X75; **6**–umbilical view, X78; **7**–side view, X70.

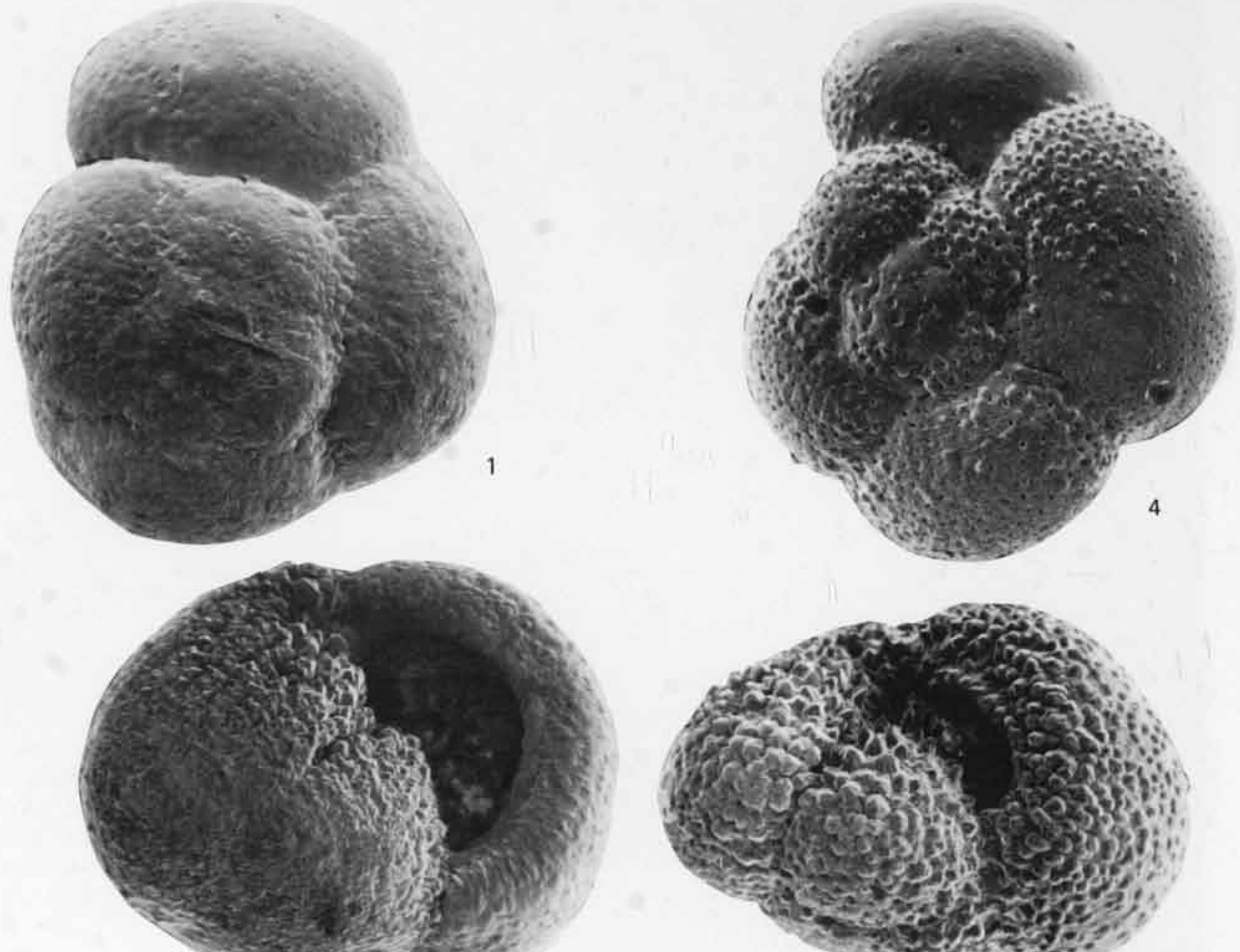

Fig. 172

Fig. 172. *Globorotalia inflata* (D'ORBIGNY) from the Late Pliocene and Early Pleistocene of southern Italy.

1-3 Specimens from the Early Pleistocene (Calabrian) at Le Castella, Italy; locality IT-907A of LAMB & BEARD (1972, fig. 8-10). **1**–Spiral view, X130; **2**–side view, X110; **3**–apertural view, X120.

4-6 Specimens from basal Late Pliocene (*Globorotalia inflata* Zone of Italian authors) at Le Castella, Italy; locality IT-784 of LAMB & BEARD (1972, fig. 8-10). This is the earliest evolutionary form of this species in Italy, being somewhat transitional from *Globorotalia bononiensis* in that the cortex still shows fairly large pores. **4**–Spiral view, X180; **5**–side view, X175; **6**–apertural view, X210.

GLOBOROTALIA JUANAI Bermúdez & Bolli, 1969

Figures 173-174

Late Miocene to Early Pliocene

Globorotalia hirsuta (D'ORBIGNY). COLALONGO & SARTONI, 1967, p. 267, pl. 31, fig. 5.

Globorotalia (Turborotalia) cf. *scitula scitula* (BRADY). BLOW, 1969, p. 356, pl. 39, fig. 4, 10.

Globorotalia juanai BERMÚDEZ & BOLLI, 1969, p. 171-172, pl. 14, fig. 1-6.–BOLLI, 1970, p. 581, pl. 8, fig. 22-24.

Globorotalia praemargaritae CATALANO & SPROVIERI, 1969, p. 523-524, pl. 1, fig. 5.

Globorotalia margaritae primitiva CITA, 1973, p. 1352, pl. 2, fig. 1-3.

Test small, a low, compressed trochospire. Chambers (4 to 4½) in last whorl somewhat protrusive radially. Equatorial profile rounded-quadrate, indented at sutures; axial profile flattish on both sides except for umbonate initial chambers, bluntly rounded to subacute at periphery. Sutures depressed, incised; recurved to oblique on spiral side; radial, roughly at right angles on umbilical side. Umbilicus closed, in shallow depression. Aperture a low arch or slit from umbilicus to near periphery, generally with thin lip. Surface finely perforate, smooth except for granularity around umbilicus. Diameter 0.25 to 0.30 mm, seldom larger.

Discussion.–We regard this species as an offshoot of *Globorotalia scitula* (BRADY, 1882), initiating the bioseries *Globorotalia juanai* – *Globorotalia margaritae* BOLLI & BERMÚDEZ (1965) – *Globorotalia praehirsuta* BLOW (1969) – *Globorotalia hirsuta* (D'ORBIGNY, *in* BARKER-WEBB & BERTHELOT, 1839). To some extent this lineage reiterates the earlier bioseries of *Globorotalia praemenardii* CUSHMAN & STAINFORTH (1945) and ensuing menardiform species, but it differs in maintaining the tight, quadrate coil of *G. scitula* and thus the long crescentic shape of the chambers on the spiral side. The more compressed test and umbonate early chambers distinguish *G. juanai* from *G. scitula* and lack of any keel distinguishes it from *G. margaritae.* Italian authors formerly applied the name *G. hirsuta* to a broad range of forms with and without keeled peripheries, including most elements of the *G. juanai-G. hirsuta* lineage, thereby obscuring the biostratigraphic utility of the individual species; see, for instance, CITA (1968, p. 9, 15). CITA (1973) helped put some of these inconsistencies in order by designating the more primitive nonkeeled member of this plexus as *Globorotalia margaritae primitiva,* not realizing that this previously had been described and named by BERMÚDEZ & BOLLI (1969). She commented that it is phylogenetically related to *G. margaritae margaritae* and that these two subspecies occur together in the Lower Pliocene.

Distribution.–Late Miocene to Early Pliocene (*Globorotalia acostaensis* Zone to *Globorotalia margaritae* Zone). The species was described from the Carenero Formation of Venezuela, a unit earlier ascribed (BERMÚDEZ, 1966) to the Middle Miocene *Globorotalia menardii* Zone. Our studies of material from the P. J. BERMÚDEZ collection support the contention of BOLLI (1972b, p. 1324) that the type level is in the Late Miocene *Globorotalia acostaensis* Zone. Though not yet widely recognized and in part identified under other names, this species is potentially a useful guide to the Miocene-Pliocene boundary.

GLOBOROTALIA MARGARITAE Bolli & Bermúdez, 1965

Figures 175-176

Early to Middle Pliocene

Globorotalia hirsuta (D'ORBIGNY). AGIP MINERARIA, 1957, pl. 48, fig. 4.

Globorotalia margaritae BOLLI & BERMÚDEZ, 1965, p. 139-140, pl. 1, fig. 16-18 [holotype; now lost, fide BLOW, 1969].–BERMÚDEZ & BOLLI, 1969, p. 174, pl. 13, fig. 7-9 [metatype].–BOLLI, 1970, p. 581, pl. 8, fig. 1-7.–POSTUMA, 1971, p. 330-331.–POAG, 1972b, p. 509, pl. 5, fig. 5-6.–BIZON & BIZON, 1972, p. 67-74, 30 fig.–KRASHENINNIKOV & HOSKINS, 1973, p. 130, pl. 24, fig. 1-4.

Globorotalia (Globorotalia) margaritae BOLLI &

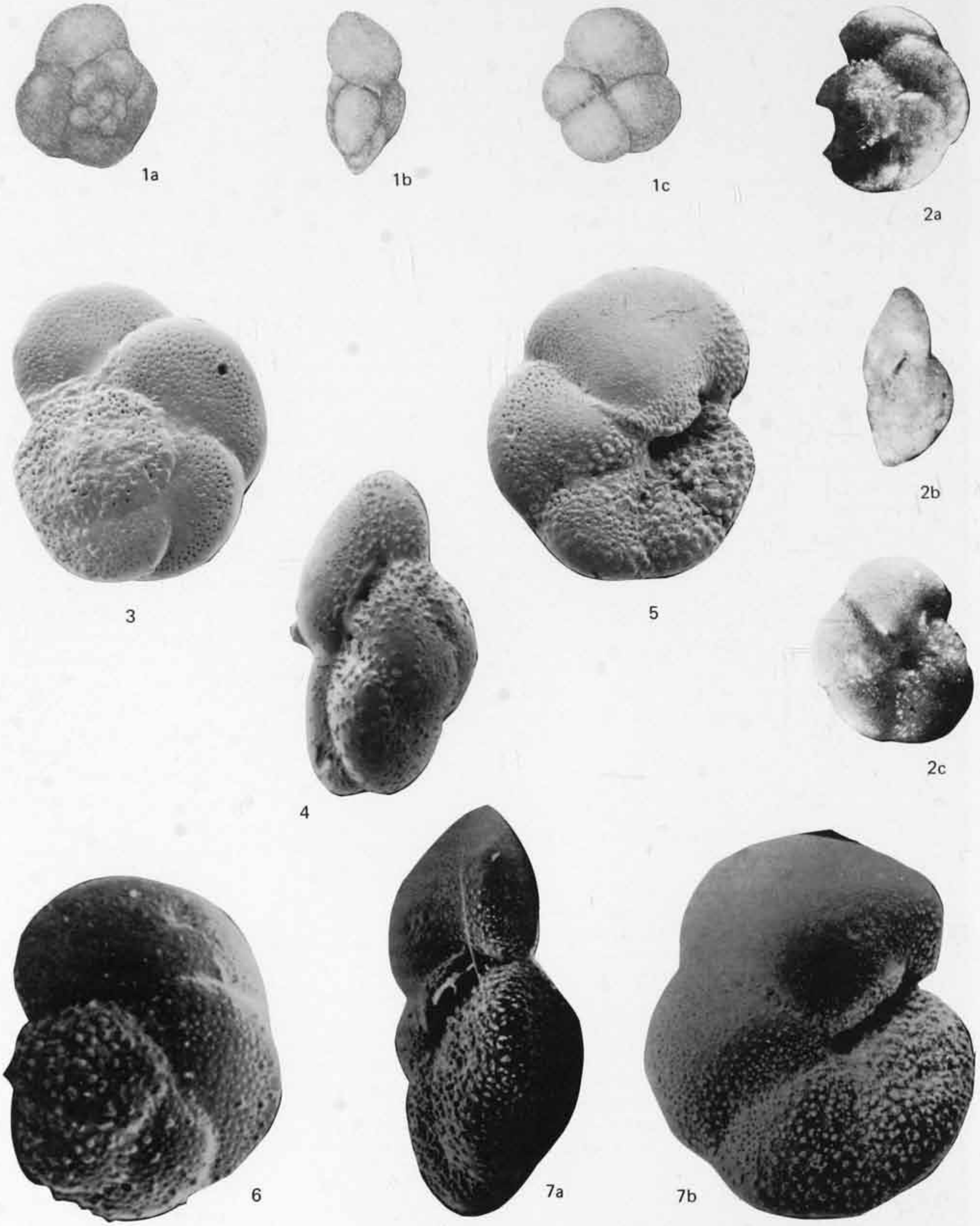

Fig. 173

Fig. 173. *Globorotalia juanai* BERMÚDEZ & BOLLI from the Late Miocene and Early Pliocene of the Caribbean and Mediterranean regions.

1 Holotype from the Late Miocene Carenero Formation of Venezuela, X82; from BERMÚDEZ & BOLLI (1969, pl. 14, fig. 4-6). **a**–Spiral view; **b**–side view; **c**–umbilical view.

2 Specimen from the Early Pliocene of northern Italy, identified as *Globorotalia hirsuta* (D'ORBIGNY) by COLALONGO & SARTONI (1967, pl. 31, fig. 5), X70. **a**–Spiral view; **b**–side view; **c**–umbilical view.

3-5 Specimens from the type section of the Tabianian Stage (Early Pliocene) of northern Italy ("New Church" locality). **3**–Spiral view, X120; **4**–side view, X125; **5**–umbilical view, X120.

6-7 Specimens described as *Globorotalia margaritae primitiva* by CITA (1973, pl. 2, fig. 1-3) from Early Pliocene sediments of the Tyrrhenian basin. **6**–Spiral view, X160; **7a,b**–side and umbilical views of holotype, X160, X157.

BERMÚDEZ [part]. BLOW, 1969, p. 363-364, pl. 45, fig. 1-3, 5-6 [metatypes]; pl. 44, fig. 4-5.

cf. *Globorotalia (Globorotalia) miozea cibaoensis* BERMÚDEZ [part]. BLOW, 1969, pl. 8, fig. 7-9 [fide PARKER, 1973].

Test a lightly keeled, lenticular trochospire. Last whorl contains 4½ to 5 chambers, increasing slowly in size as added, maintaining same shape but becoming slightly more loosely attached; shape in spiral view crescentic, length along spire at least double radial width; in umbilical view triangular, compacted except for last chamber which projects above others and typically occupies 1/3 visible area. Equatorial profile ovate, slightly lobate; axial profile moderately convex on spiral side, accentuated by umbonate initial spire; less convex on umbilical side and, in specimens with

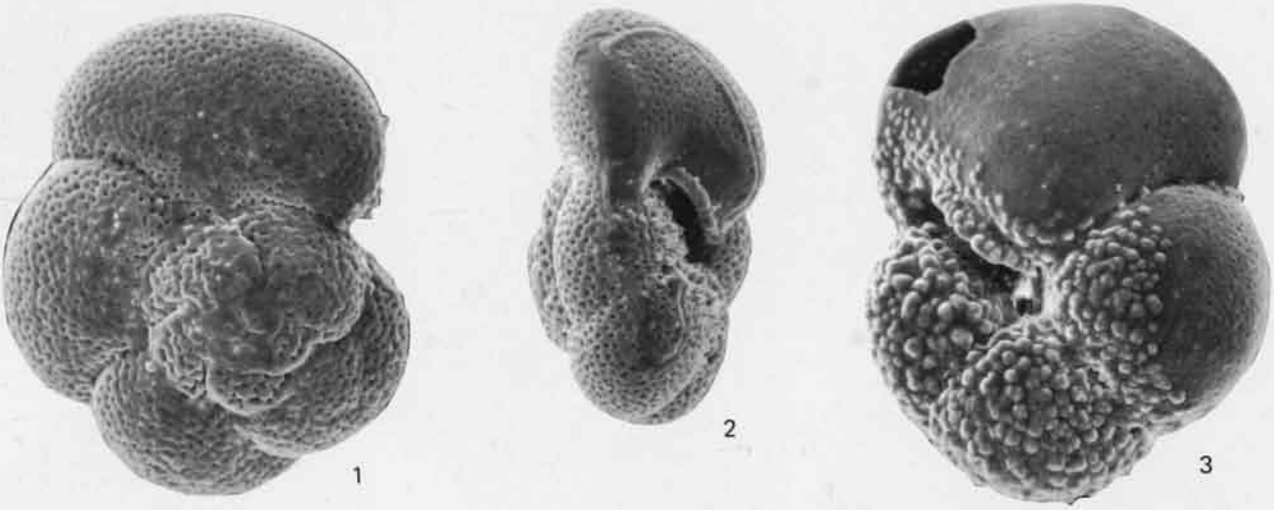

Fig. 174. *Globorotalia juanai* BERMÚDEZ & BOLLI from the Late Miocene (*Globorotalia acostaensis* Zone) of the Gulf of Mexico; from corehole A, core no. 14, discussed in LAMB & BEARD (1972, fig. 12). Late Miocene forms of this species coil mostly to the right whereas Pliocene forms coil mostly to the left. **1**–Spiral view, X160; **2**–side view, X150; **3**–umbilical view, X170.

Fig. 175. *Globorotalia margaritae* BOLLI & BERMÚDEZ from the Pliocene (*Globorotalia margaritae* Zone) of the Caribbean, Pacific, Atlantic, and Mediterranean regions. [p. 366]

1 Holotype from Margarita Island, Venezuela, X130; from BOLLI & BERMÚDEZ (1965, pl. 1, fig. 16-18). **a**–Umbilical view; **b**–side view; **c**–spiral view.

2-4 Specimens from the south Pacific Ocean; from KRASHENINNIKOV & HOSKINS (1973, pl. 24, fig. 1, 3-4). **2**–Spiral view, X85; **3**–umbilical view, X140; **4**–side view, X97.

5-6 Specimens from the western north Atlantic Ocean, X90; from POAG (1972b, pl. 5, fig. 5-6). **5**–Umbilical view; **6**–side view.

7-9 Specimens from the Mediterranean Sea; from CITA (1973, pl. 2, fig. 1-3). **7**–Umbilical view, X157; **8-9**–spiral views, X157, X165.

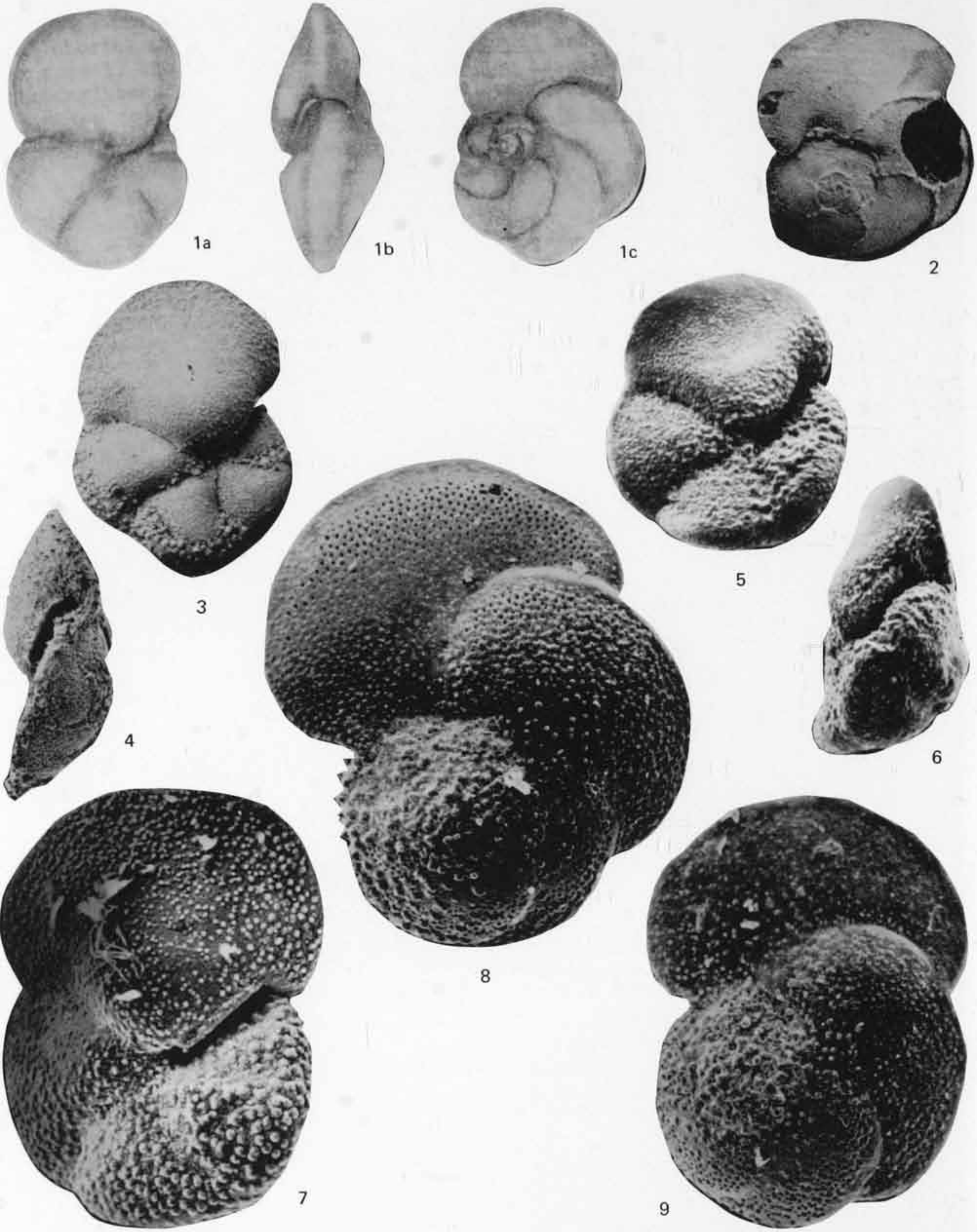

Fig. 175

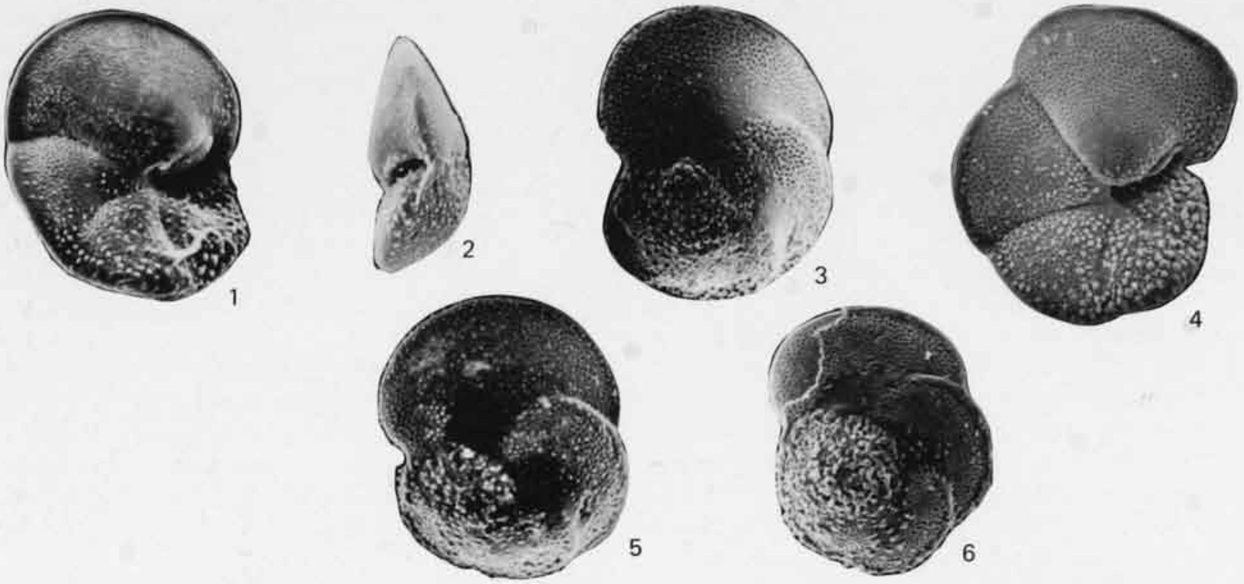

Fig. 176. *Globorotalia margaritae* BOLLI & BERMÚDEZ from the Pliocene (*Globorotalia margaritae* Zone) of the Gulf of Mexico; after LAMB & BEARD (1972, pl. 18, fig. 1-6). **1,4**–Umbilical views, X100, X90; **2**–side view, X100; **3,5-6**–spiral views, X100, X100, X85.

compressed chambers and wide umbilical depression, may be flat to concave; periphery subacute to acute, with light imperforate keel. Sutures on spiral side strongly recurved, limbate, merging into keel; on umbilical side radial, almost straight, obscure on early portion, later depressed to incised. Umbilicus virtually closed. Aperture a low arched slit from umbilicus to periphery, bordered by light rim. Surface finely perforate, smooth except for granulosity around umbilicus. Direction of coiling dominantly sinistral. Diameter 0.35 to 0.65 mm, but large specimens are exceptional.

Discussion.–*Globorotalia margaritae* is regarded as a direct descendant of *Globorotalia scitula* (BRADY, 1882), with *G. juanai* BERMÚDEZ & BOLLI (1969) intermediate between them. The ancestral forms are distinguished by complete lack of an imperforate keel. Further development of the bioseries leads via *Globorotalia praehirsuta* BLOW (1969) to *Globorotalia hirsuta* (D'ORBIGNY, *in* BARKER-WEBB & BERTHELOT, 1839), forms having a more open spire composed of chambers broader than in *G. margaritae* and scallop- to comma-shaped rather than crescentic. Objective demarcation of the interrelated species is difficult and requires further study. PARKER (1973), for instance, proposed revision of the nomenclature employed by other authors. Apparently related to *G. margaritae* is the partially keeled species *Globorotalia cibaoensis* BERMÚDEZ (1949) (fide PARKER, 1973).

Distribution.–Early to Middle Pliocene (*Globorotalia margaritae* Zone). First recorded in the Miocene to Pliocene Cubagua Formation of Venezuela. In the Atlantic province, including the Caribbean-Gulf of Mexico region, the well-defined range of this species delimits a useful zone. It is recorded also in the Mediterranean and Pacific regions but its biostratigraphic utility there is not established clearly.

MENARDIFORM GLOBOROTALIAS

Figures 177-179

Late Neogene assemblages of planktonic foraminifers, especially those of warm-water regions, are characterized by a group of globorotalias having many features in common yet differing widely in other aspects. "Menardiform" is a convenient eponym for the group because *Globorotalia menardii* (PARKER, JONES, & BRADY, 1865) ex D'ORBIGNY is firmly established as the central form regardless of taxonomic complexities discussed elsewhere.

Morphologic features common in typical menardiform globorotalias include:

Gross form – Regular, more or less lenticular trochospire with blunt, generally carinate rim.

Chambers in last whorl – Generally 5 to 6, rarely more or less.

Chamber shape – Lunate, crescentic, or rhomboid on spiral side; on umbilical side radial segments with tendency for each to extend back over adjacent so that last-formed chamber may appear disproportionately large.

Sutures – Strongly curved or hooked backwards on spiral side, commonly limbate; on umbilical side radial, straight or sinuous, somewhat incised.

Surface – Smooth and densely perforate except for secondary pustulosity and encrustation.

Morphological features that differ and thus lead to distinguishable and individually named morphotypes include:

Convexity – Biconvex forms vary from appressed (diameter 4 to 5 times axial thickness) to tumid (thickness exceeding half diameter); planoconvexity may result from flatness of either spiral or umbilical side.

Keel – Ranges from mere thickening of periphery to massive, cordlike rim around test.

Sutures – On spiral side may be nonlimbate in primitive forms or limbation may be hidden by posterior overlap of successive chambers.

Spiral – Shape of trochospire governed by a logarithmic spiral which may be relatively tight (approaching equiangular) or open (flaring, evolute). Evoluteness of spire is limited, however, so that beyond this limit successive chambers are constrained to rapid radial lengthening not typical of the menardiform group [a key difference between *Globorotalia fohsi* CUSHMAN & ELLISOR (1939) s.l. and *Globorotalia menardii* s.l. is the more flaring spire of the former]; parameters of the spire may be quantified conveniently as ratio of widths of successive whorls.

Number of chambers – Maximum of 7 normally but to 12 in some short-lived forms.

Peculiarities – A few forms have striking features [e.g., bent final chamber in *Globorotalia flexuosa* (KOCH, 1923) and abortive bullas in *Globorotalia pertenuis* BEARD, 1969].

Much investigation is required to clarify the evolution and internal relationships of the menardiform group. Types, for example, are poorly defined for some forms so that problems regarding species proposed by pioneer authors remain unsolved despite laudable efforts to designate lectotypes and neotypes (e.g., BANNER & BLOW, 1960a).

Globorotalias of menardiform aspect (but deemed neither representative of nor related to the menardiform group) appeared in the Paleogene; *Globorotalia pseudomenardii* BOLLI (1957a) in Late Paleocene and advanced subspecies of the *Globorotalia cerroazulensis* lineage (i.e., *Globorotalia cerroazulensis cocoaensis* CUSHMAN, 1928, and *Globorotalia cerroazulensis cunialensis* TOUMARKINE & BOLLI, 1970) in Late Eocene. Menardiform tests apparently were well adapted for planktonic existence and appeared as the endform of several unconnected lineages. The *Globorotalia scitula* group is regarded as the rootstock from which the earliest Neogene menardiform line (*archeomenardii-praemenardii-menardii*) developed in the later

Fig. 177. Representatives of the menardiform group from the Holocene of the Gulf of Mexico and Irish Sea and the Middle Miocene of Trinidad. The lobulate periphery and flattened test of these specimens indicates affinity with *Globorotalia cultrata* (D'ORBIGNY).

1-2,4 Specimens from Holocene deposits of the Gulf of Mexico identified as *Globorotalia menardii* (D'ORBIGNY) [sic] by LAMB & BEARD (1972, pl. 14, fig. 1-3). **1**–Spiral view, X40; **2**–umbilical view, X65; **4**–side view, X50.

3 Lectotype of *Globorotalia menardii* (PARKER, JONES, & BRADY) ex D'ORBIGNY [=*G. cultrata*] from Holocene deposits in the Irish Sea; X75. From BANNER & BLOW (1960a, pl. 6, fig. 2). **a**–Spiral view; **b**–umbilical view; **c**–side view.

5-6 Small (**5**) and large (**6**) specimens identified as *Globorotalia menardii* (D'ORBIGNY) [sic] from the *Globorotalia menardii* Zone of the Lengua Formation of Trinidad, X68, by BOLLI (1957b, pl. 29, fig. 6, 8). **a**–Spiral views; **b**–side views; **c**–umbilical views.

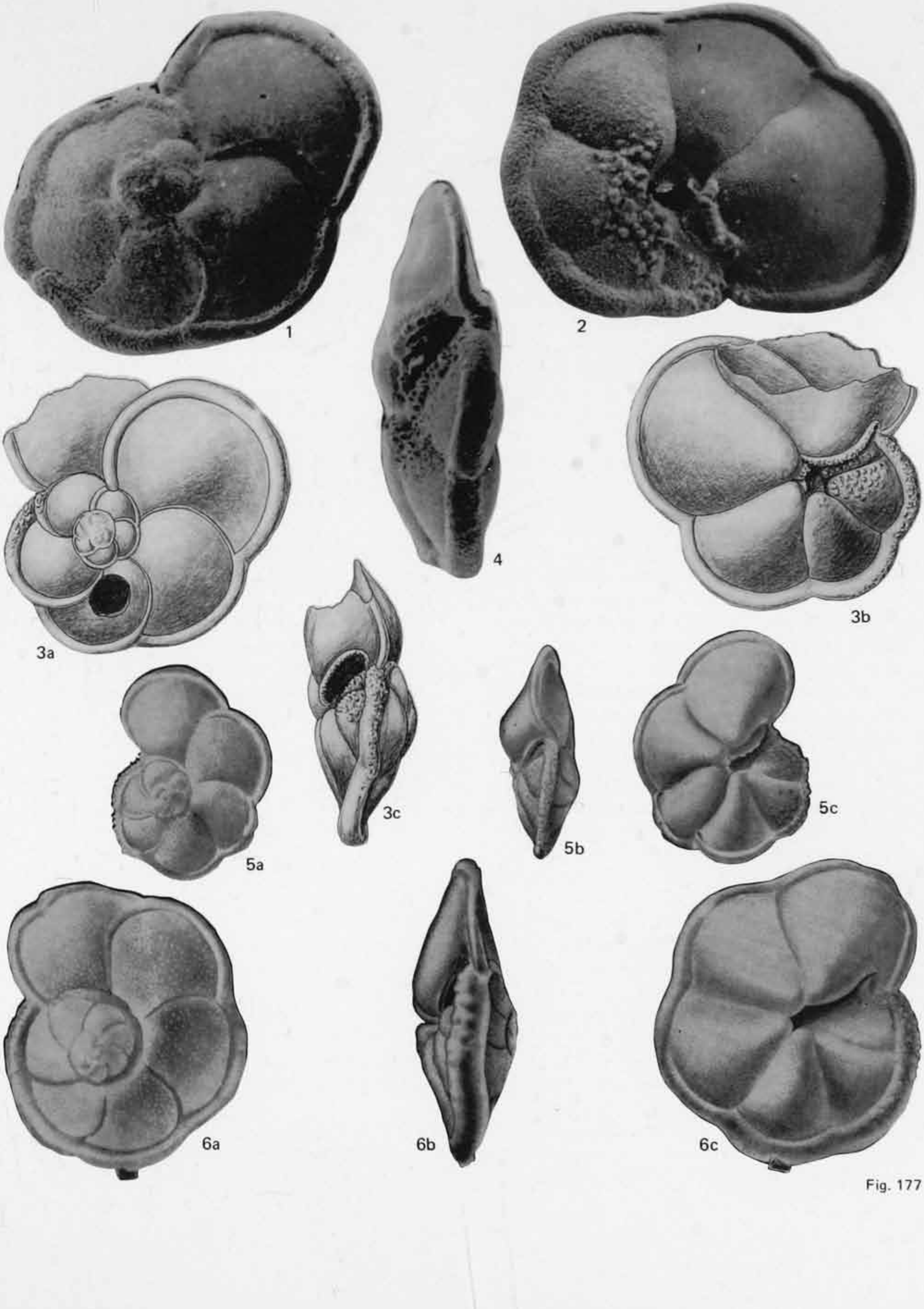

Fig. 177

Miocene and a second line (*juanai-margaritae-praehirsuta-hirsuta*) in the Pliocene. The morphologically comparable Middle Miocene to Pliocene-Pleistocene line of *Globorotalia lenguaensis-paralenguaensis-merotumida-plesiotumida-tumida*, however, appears to be derived from a different unkeeled form (possibly the small *Globorotalia minima* AKERS, 1955). These three examples demonstrate that concepts of chronologic as well as morphologic differentiation of taxa must be applied to taxonomy of this group. For instance, individual specimens of *G. praemenardii* and *G. plesiotumida* may appear morphologically identical, but chronologically they represent disconnected time intervals in the Middle and Late Miocene, respectively. Identification of a menardiform taxon should be based, therefore, on its position within an evolving line and/or its association with reliable zonal indices of other groups.

A further problem in taxonomy of menardiform globorotalias is variability induced by environmental differences. Strength of keel and degree of limbation of sutures increase as water temperature rises so that evolutionary stages may be duplicated in different ages by coeval forms from different water masses. BÉ, MCINTYRE, & BREGER (1966) showed that differences in shell structure reflect differences in depth habitat and that shell structure may differ even in different parts of an individual.

Morphotypes within the group, whether adjacent in evolutionary sequences or in alignments across temperature gradients, are intimately linked by transitional forms. Consequently, recognition of species limits within the group is highly subjective. Some authors reduced this difficulty by recognizing several principal species [e.g., *Globorotalia menardii* (PARKER, JONES, & BRADY, 1865) ex D'ORBIGNY, *Globorotalia tumida* (BRADY, 1877), *Globorotalia cultrata* (D.ORBIGNY, 1839), *Globorotalia miotumida* JENKINS (1960), and *Globorotalia miozea* FINLAY (1939d)] and assigning subspecific rank to other forms (e.g., *Globorotalia tumida plesiotumida* BLOW & BANNER, *in* BANNER & BLOW, 1965c). We recognize merit in this procedure but tend here to classify most forms as species for the pragmatic reason of brevity.

The menardiform group first appeared in later Miocene; thus presence of any of its elements is a guide to the younger Neogene. Historically, the approximately coincident extinction of *Globorotalia fohsi* CUSHMAN & ELLISOR (1939) s.l. and incipience of *Globorotalia cultrata* [= *Globorotalia menardii* of authors] defined one of the earliest datums recognized in planktonic foraminiferal biostratigraphy (e.g., STAINFORTH, 1948b). In the Caribbean region this level was regarded as the Oligocene-Miocene boundary until improved trans-Atlantic correlations forced a revision.

Individual species (or subspecies) are applicable to zonation and correlation subject to caution for reasons already noted. The limited ranges of certain forms (e.g., *Globorotalia margaritae* BOLLI & BERMÚDEZ, 1965) define zonal intervals on a circumglobal scale.

Because of the group's preference for the warmer environments and persistence through the Pliocene-Pleistocene interval of marked temperature changes, its members are valuable as paleoclimatic indices. Alternating presence and absence in a sequence of beds facilitates recognition of climatic changes, such as glacial-interglacial cycles, and, furthermore, reversals of coiling direction in such forms are said by some to be symptomatic of sharp temperature changes.

The following 15 menardiform species of the Neogene are described individually herein.

Globorotalia exilis BLOW (1969)
Globorotalia flexuosa (KOCH, 1923)
Globorotalia hirsuta (D'ORBIGNY, 1839)
Globorotalia lenguaensis BOLLI (1957b)
Globorotalia margaritae BOLLI & BERMÚDEZ (1965)
Globorotalia menardii (PARKER, JONES, & BRADY, 1865) ex D'ORBIGNY
Globorotalia miocenica PALMER (1945)
Globorotalia multicamerata CUSHMAN & JARVIS (1930)
Globorotalia pertenuis BEARD (1969)
Globorotalia plesiotumida BLOW & BANNER (in BANNER & BLOW, 1965c)
Globorotalia praehirsuta BLOW (1969)
Globorotalia praemenardii CUSHMAN & STAINFORTH (1945)
Globorotalia praemiocenica LAMB & BEARD (1972)
Globorotalia tumida (BRADY, 1877)
Globorotalia ungulata BERMÚDEZ (1960).

Other menardiform taxa mentioned in modern literature on Neogene biostratigraphy but not utilized here because of their limitations as warm-water index species include:

- *Globorotalia archeomenardii* BOLLI (1957b)
- *Globorotalia cibaoensis* BERMÚDEZ (1949)
- *Globorotalia cultrata* (D'ORBIGNY, 1839)
- *Globorotalia dalii* PERCONIG (1968)
- *Globorotalia fimbriata* (BRADY, 1884)
- *Globorotalia hemisphaerica* BIZON & BIZON (1971)
- *Globorotalia limbata* (FORNASINI, 1902) ex D'ORBIGNY
- *Globorotalia martinezi* PERCONIG (1968)
- *Globorotalia menardii neoflexuosa* SRINIVASAN, KENNETT, & BÉ (1974)
- *Globorotalia merotumida* BLOW & BANNER *(in* BANNER & BLOW, 1965c)
- *Globorotalia miotumida* JENKINS, 1960 [with subspecies]
- *Globorotalia miozea* FINLAY, 1939d [with subspecies]
- *Globorotalia miroensis* PERCONIG (1968)
- *Globorotalia paralenguaensis* BLOW, 1969
- *Globorotalia pseudomiocenica* BOLLI & BERMÚDEZ, 1965

GLOBOROTALIA MENARDII (Parker, Jones, & Brady, 1865) ex d'Orbigny

Figures 178, **6-10**, 179
Miocene to ?Holocene

Rotalia (Rotalie) *menardii* D'ORBIGNY, 1826, p. 273 [nomen nudum].

Rotalia menardii PARKER, JONES, & BRADY, 1865, p. 20, pl. 3, fig. 81 [part].

Globorotalia menardii (D'ORBIGNY) [sic] [part] of authors [e.g., CITA, PREMOLI SILVA, & ROSSI, 1965, p. 231, pl. 20, fig. 1; pl. 31, fig. 12.–CITA & PREMOLI SILVA, 1968, p. 4-20, pl. 2, fig. 1.–BIZON & BIZON, 1972, p. 86-87, fig. 1-9].

Globorotalia menardii (PARKER, JONES, & BRADY) [part] of authors.

Test a medium lenticular trochospire rimmed by a blunt keel. Chambers in last whorl (5 to 6) increase steadily in size and maintain constant shape as added; lunate to crescentic on spiral side, radial segments on umbilical side where posterior overlap makes final chamber more prominent than preceding. Equatorial profile subcircular to rounded-polygonal, not lobate; axial profile unequally biconvex, chambers of umbilical side more highly vaulted and inflated than those of spiral side. Sutures on spiral side recurved,

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Fig. 178. Representatives of the menardiform group from the Miocene of Jamaica and Italy. [p. 372] ⇨

1-5 Specimens from the Middle Miocene (*Globorotalia siakensis* Zone) in the lower part of the Buff Bay Formation; from sample collected by STAINFORTH at Buff Bay, Jamaica, no. 119609A. This is approximately the oldest level containing this form [generally identified as *Globorotalia menardii* but seems closer to the lectotype of *Globorotalia cultrata*] in the Caribbean and Gulf of Mexico regions. **1,4**–Umbilical views showing lobulate periphery, X70, X65; **2**–side view illustrating typical flattened, equally biconvex test, X60; **3,5**–spiral views showing narrow, raised and limbate, smoothly hemicircular intercameral sutures, X65.

6-10 Virtual topotypes of redeposited Miocene specimens of *Globorotalia menardii* (PARKER, JONES, & BRADY) from recent beach deposits at Lido Cervia, Ravenna, Italy. **6,8**–Umbilical views showing rounded periphery, X100, X85; **7,10**–spiral views showing unequal thickened intercameral sutures that are not distinctly hemicircular but rather show a break in their curvature so as to approach a "hockey-stick" shape (an apt description used by BLOW, 1969), X120, X130; **9**–side view showing unequally biconvex test with highly vaulted chambers of umbilical side, X110.

Fig. 179. Representatives of the menardiform group from the Miocene of the Mediterranean region. These specimens are interpreted to represent *Globorotalia menardii* (PARKER, JONES, & BRADY) [ICZN appeal pending]. The rounded periphery, highly vaulted chambers of umbilical side, and "hockey-stick" shape of intercameral sutures on spiral side are distinguishing characteristics of *Globorotalia menardii* as interpreted herein. [p. 373] ⇨

1 Illustration of D'ORBIGNY'S plaster model of *Globorotalia menardii.* The model presumably represents the concept used as a basis for *G. menardii* (PARKER, JONES, & BRADY) [=unavailable *G. menardii* (D'ORBIGNY)] prior to subsequent designation of lectotype. From PARKER, JONES, & BRADY (1865, pl. 3, fig. 81) **a**–Spiral view; **b**–side view; **c**–umbilical view.

2 Specimen identified as *Globorotalia menardii* (D'ORBIGNY) [sic] from the early Late Miocene (type Tortonian Stage) of Italy, X100. From CITA, PREMOLI SILVA, & ROSSI (1965, pl. 20, fig. 1). **a**–Umbilical view; **b**–spiral view; **c**–side view.

3-5 Specimens identified as belonging to the *Globorotalia menardii* (D'ORBIGNY) [sic] group from the early Late Miocene of Spain, X100. From BIZON & BIZON (1972, p. 87, fig. 6-8). **3**–Spiral view; **4**–side view; **5**–umbilical view.

6-8 Specimens identified as belonging to the *Globorotalia menardii* (D'ORBIGNY) [sic] group from the early Late Miocene of Greece, X100. From BIZON & BIZON (1972, p. 86, fig. 1-3). **6**–Umbilical view; **7**–side view; **8**–spiral view.

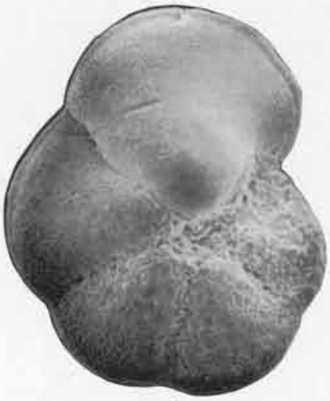
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Fig. 178

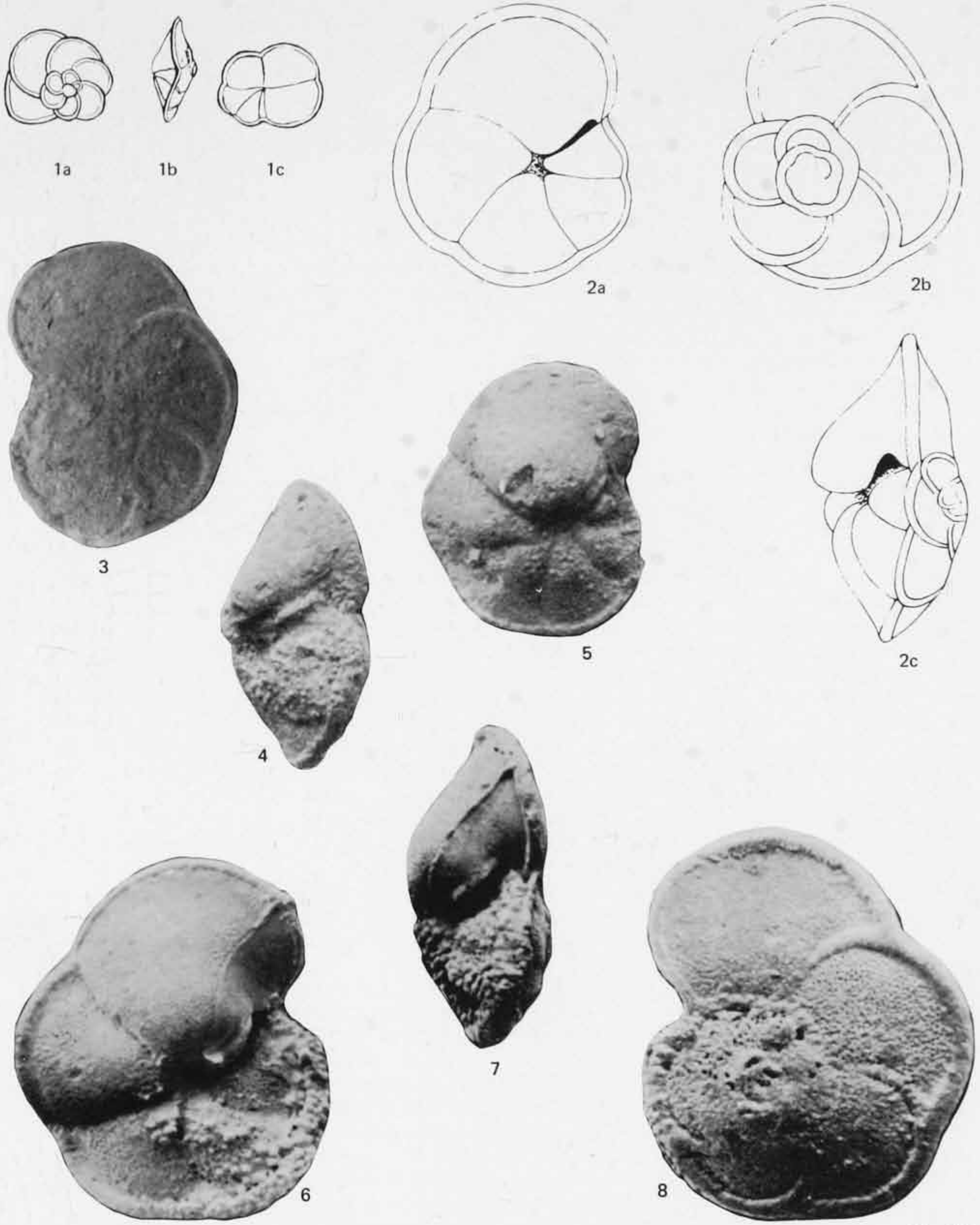

Fig. 179

limbate, more thickened where merging into keel to give "hockey-stick" appearance; on umbilical side lightly incised, sinuously radial. Umbilicus a narrow stellate pit between slightly swollen chamber tips. Aperture a low arched slit from umbilicus to near periphery, may have light lip. Surface mostly smooth, densely perforate; somewhat pustulose around umbilicus. Observed diameters 0.4 to 0.6 mm.

Discussion.–The synonymy and description just given characterize *Globorotalia menardii* (PARKER, JONES, & BRADY) ex D'ORBIGNY as this name is applied in the later Miocene interval of the Mediterranean region and as the International Commission on Zoological Nomenclature is to be requested to declare valid. More lobulate, generally larger and flattened biconvex forms of the menardiform group predominate in the Miocene to Holocene interval within the tropical regions of the world and are differentiated readily on a morphologic basis. These forms comprise *Globorotalia cultrata* (D'ORBIGNY) and other members of a *cultrata* lineage. *Globorotalia menardii*, as recognized herein, is distinguished by a rounded periphery, highly vaulted chambers on the umbilical side, and "hockey-stick" shape of intercameral sutures on the spiral side. More adequate knowledge of geographic and chronologic occurrences of these distinct morphotypes seems necessary, however, to explain better the phyletic and stratigraphic relationships worldwide.

Globorotalia menardii (PARKER, JONES, & BRADY, 1865) is retained here as the name for the Miocene (and younger) menardiform species commonly recorded under this name in the Mediterranean area although authorship has been assigned either to D'ORBIGNY (1826) or to PARKER, JONES, & BRADY (1865). In preparation is an appeal to the International Commission on Zoological Nomenclature for validation of this name under plenary powers because of the need to preserve a well-established and much used name having notable biologic and biostratigraphic significance.

BANNER & BLOW (1960a) reviewed in some detail the taxonomic status of *Globorotalia menardii*, which had been assumed to have been validated as *Rotalia* (Rotalie) *menardii* by D'ORBIGNY in 1826 for specimens from beach sands at Rimini, Italy. Their review, however, demonstrated that D'ORBIGNY failed to make the name available because no description or illustration was given in the 1826 report and distribution of the model representing the species did not constitute the published indication required to validate the name. Earliest valid use of the name then was by PARKER, JONES, & BRADY in 1865 who there credited it to D'ORBIGNY, used a picture of D'ORBIGNY'S model as the only illustration (Fig. 179,**1**), cited the locality previously recorded by D'ORBIGNY, and applied the name to specimens dredged from off the Isle of Man. In seeking a type specimen for the taxon, BANNER & BLOW checked first and unsuccessfully in the D'ORBIGNY collection at Paris. Next they turned to the BRADY collection in London where they found a slide labeled "*Pulvin. menardii*" from off the Isle of Man, the locality mentioned by PARKER, JONES, & BRADY. The three specimens on this slide were accepted by BANNER & BLOW as the only available syntypes of *Rotalia menardii* PARKER, JONES, & BRADY, and the best preserved of these was designated, described, and figured as the lectotype (Fig. 177,**3**).

The procedure followed by BANNER & BLOW ostensibly was correct and efficient in providing an objective basis for evaluating this species and accords with methods used by other workers for many forms inadequately treated by pioneer authors. Further, however, BANNER & BLOW concluded that *Globorotalia cultrata* [= *Rotalina cultrata* D'ORBIGNY, 1839] is a senior synonym of *Globorotalia menardii* (PARKER, JONES, & BRADY, 1865) as the latter is recognized on the basis of the lectotype. They noted "As much as we would have liked to invoke plenary powers of the I.C.Z.N. to suppress the little used name *Rotalina cultrata* in favour of *Rotalia menardii* D'ORBIGNY, this cannot be done as the latter name has never possessed taxonomic availability."

Not recognized at that time, however, was the fact that the shore sands at Rimini, Italy, contain abundant and excellently preserved Miocene and other Neogene material reworked from nearby highlands (LAMB & BEARD, 1972, p. 54). Many foraminiferal species described from these Rimini sands as "Recent" [Holocene] have not been encountered in living faunas, as documented by CHIERICI, BUSI, & CITA (1962, p. 136), CITA, PREMOLI SILVA, & ROSSI (1965, p. 231), and others. Moreover, the form designated by D'ORBIGNY as *Rotalia menardii* has come to be regarded as a typical Miocene form. CITA & D'ONOFRIO (1967, p. 173), for example, stated ". . . *Globorotalia menardii* has never been recorded from recent or Pleistocene deposits in the Adriatic area. This species is, however, present in Tertiary sediments especially of Tortonian age outcropping in the hills surrounding the Rimini coast. We believe that the species, often recorded from the Rimini beach, is in fact fossil." (Note also BIZON & BIZON, 1971, p. 85.)

We contend, therefore, that the taxon *Rotalia menardii* PARKER, JONES, & BRADY (1865) contained originally two somewhat similar but morphologically and chronologically distinct forms (cf. Fig. 178,**6-10** vs. 177,**3**). One is a Miocene form recognized from beach sands at Rimini by D'ORBIGNY (1826), used as a basis for D'ORBIGNY'S model to which he attributed the name, and illustrated by PARKER, JONES, & BRADY (1865). The other is a modern (Holocene) form that was included with the Miocene form by PARKER, JONES, & BRADY. Paleontologists generally accepted and applied the name *Globorotalia menardii* (=*Rotalia menardii* D'ORBIGNY, 1826) to the Miocene form and, to a lesser extent, to Miocene and younger forms whose differentiating characteristics were not recognized by early workers. Wide distribution of the D'ORBIGNY model based on the Rimini material was a major factor in facilitating recognition of the species.

TODD (1961), with subsequent support from BÉ, MCINTYRE, & BREGER (1966) and JENKINS (1971), argued subjectively that the neotype of *Rotalina cultrata* designated by BANNER & BLOW (1960a) differs from the specimens originally described by D'ORBIGNY and that validation of the long-neglected name *R. cultrata* as a senior synonym of *Rotalia menardii* was contrary to basic principles of ICZN. No mention was made by these authors about the possible change in species concept for *R. menardii* when interpreted on the modern lectotype rather than on Miocene specimens from Rimini.

According to ICZN (Art. 72b), however, specimens eligible for designation as lectotype are "all the specimens on which an author bases the species . . .". Although uncertainty exists in some cases as to exactly the limitation on which specimens an author "based" a species (MELVILLE, 1970, p. 195), the Isle of Man specimens seem clearly to constitute available syntypic material for *R. menardii* PARKER, JONES, & BRADY (1865) and to have been designated validly by BANNER & BLOW (1960a). Similarly, *R. cultrata* D'ORBIGNY (1839) was reported originally from modern marine sands of Cuba, Martinique, Guadeloupe, and Jamaica. The neotype designated from topotypic material (i.e., modern sand off Cape Cruz, Cuba) was regarded by BANNER & BLOW as "clearly conspecific with D'ORBIGNY'S form." These designations of type specimens for *R. menardii* PARKER, JONES, & BRADY (1865) and *R. cultrata* D'ORBIGNY (1839) are objectively valid.

We agree with BANNER & BLOW (1960a), PARKER (1962), and others that *Globorotalia menardii* (PARKER, JONES, & BRADY, 1865) (which must be interpreted at present on the basis of the lectotype from modern sediments near the Isle of Man) is a junior subjective synonym of *Globorotalia cultrata* (D'ORBIGNY, 1839) (which must be interpreted on the basis of its neotype from modern sediments off Cuba). TODD (1961) and others seem to accept the synonymy of these forms but to dispute mainly the desirability of replacing a well-known name by the little-used *cultrata*. On the other hand, we accept *cultrata* as the valid and available name for the modern and older form but recognize also a presently nameless species-group taxon that accords with the species-group concept originally proposed invalidly by D'ORBIGNY (1826) and widely applied subsequently by paleontologists.

The considerable recent advances in understanding the biostratigraphic significance of Neogene menardiform taxa and accompanying detailed differentiation of species-group taxa on the basis of morphologic features largely ignored by earlier workers necessitates, in our considered judgment, legal resolution of the present situation. Accordingly, we have in preparation an appeal to the International Commission on Zoological Nomenclature for use of its plenary powers to 1) revoke the designation of lectotype by BANNER & BLOW (1960a) for *Rotalia menardii* PARKER, JONES, & BRADY (1865), 2) accept for the same species-group taxon a neotype designation for a Rimini specimen (i.e., type locality of D'ORBIGNY, 1826), and 3) validate *R. menardii* PARKER, JONES, & BRADY (1865) ex D'ORBIGNY (1826) as an available name for the mainly Miocene taxon long recognized by paleontologists. *Globorotalia cultrata* (D'ORBIGNY 1839) is accepted on the basis of the modern neotype and is interpreted as a prominent but different member of a Neogene menardiform lineage. Illustrations and descriptions included herein indicate our bases for differentiating the taxon termed *Globorotalia menardii*.

It is noted that some modern workers similarly have recognized several species-group taxa among this menardiform lineage (or lineages) (e.g., CITA, PREMOLI SILVA, & ROSSI, 1965). Other workers, however, tended to accept the synonymy of *G.*

menardii and *G. cultrata* and to identify their forms (commonly in extra-Mediterranean areas what we deem representative of a *cultrata* lineage) as either *G. cultrata* (e.g., PARKER, 1962, 1967, 1973; JENKINS & ORR, 1972; POAG, 1972b) or as *G. menardii* (e.g., TODD, 1961; BÉ, MCINTYRE, & BREGER, 1966; JENKINS, 1971). BLOW (1969, p. 359, pl. 6, fig. 9-11) (and followed by CITA & BLOW, 1969, p. 576; and AKERS, 1972, p. 100) distinguished *G. cultrata cultrata* (D'ORBIGNY) from *G. cultrata menardii* (PARKER, JONES, & BRADY) on the same morphologic basis as is done herein for *G. cultrata* and *G. menardii*. Unfortunately, however, the earlier subsequent designation of the lectotype by BANNER & BLOW (1960a) for *G. menardii* (PARKER, JONES, & BRADY) had restricted the name *menardii* to the *cultrata*-like component of the two taxa originally included by PARKER, JONES, & BRADY in *G. menardii*. Thus, an ICZN declaration is necessary before the nomenclature used by BLOW in 1969 can be applied validly.

The most reliable previously published figures of *Globorotalia menardii*, as interpreted herein, seem to be those by CITA, PREMOLI SILVA, & ROSSI (1965) and CITA & PREMOLI SILVA (1968) of specimens from the Tortonian stratotype section where exposed sediments are similar in age and nature to those around Rimini about 200 miles to the east. CITA, PREMOLI SILVA, & ROSSI (1965) treated *G. menardii* as an evolutionary stage linking *Globorotalia praemenardii* CUSHMAN & STAINFORTH (1945) with *Globorotalia miocenica* PALMER (1945) and stressed as distinctive features its larger size, stronger keel, nonlobate margin, and equally biconvex sides. There is reasonable doubt now, however, that the *G. praemenardii* of European authors is the same as that of tropical regions. Furthermore, *G. miocenica* of Italian authors has been designated an endemic form and now is referred to *Globorotalia miocenica mediterranea* CATALANO & SPROVIERI (1969). Thus, clear evidence currently is lacking to support unmodified application of the "*menardii*" lineage concept of tropical regions in the Mediterranean area or to regard the first appearance of *G. menardii* in the Mediterranean area as the same useful biostratigraphic datum as that recognized in tropical regions (e.g., BOLLI, 1959; STAINFORTH, 1960).

Recently BANDY (1972, p. 297) proposed *Menardella* as a subgenus of *Globorotalia* (CUSHMAN, 1927a) and designated *Globorotalia (Menardella) menardii* (D'ORBIGNY) [sic] as the type species (see Addendum herein).

Distribution.—Presently available data support recognition of this species (as restricted herein) only in the Late Miocene of the Mediterranean region. Many forms identified under this name in the Caribbean and other parts of the world seem more closely related to the *Globorotalia cultrata* (D'ORBIGNY, 1839) lineage. Presumably, however, re-examination of menardiform globorotalias in the Miocene and younger beds of several parts of the world may well demonstrate a wider occurrence for *G. menardii* than is recognized here.

GLOBOROTALIA MIOCENICA Palmer, 1945

Figure 180

Late Pliocene to Early Pleistocene

Globorotalia menardii miocenica PALMER, 1945, p. 70-71, pl. 1, fig. 10.—AKERS & DORMAN, 1964, p. 18, pl. 14, fig. 1-5, 19-21.

Globorotalia miocenica PALMER, BERMÚDEZ, 1960, p. 1295-1296, pl. 15, fig. 5.—BOLLI, 1970, p. 582, pl. 7, fig. 4-8.—LAMB & BEARD, 1972, p. 54, pl. 16, fig. 1-4.—POAG, 1972b, p. 510, pl. 3, fig. 3-4.

Globorotalia (Globorotalia) miocenica PALMER, BLOW, 1969, p. 365-366, pl. 42, fig. 4, 8.

Test a regular dextral trochospire, umbilical side strongly convex, spiral side flat or very slightly convex. Last whorl carinate, composed of 5 to 7 chambers, increasing in size very slowly. Equatorial profile a smooth subcircular curve; axial profile displays planoconvex form, strongly carinate margin, and tendency of peripheral angle to become blunter during growth. Sutures on spiral side strongly curved, limbate, fusing with keel; on umbilical side depressed, sinuously radial. Umbilicus a small but distinct pit, accentuated by surrounding bulbous chamber tips. Aperture a low-arched slit extending from umbilicus to near periphery, with thin lip. Diameter 0.4 to 0.6 mm.

Discussion.—This species is characterized by a flat spiral side, thin-walled test, high chambers, and circular outline (see also discussion under *Globorotalia exilis*).

Distribution.—Late Pliocene to Early Pleistocene (from within the *Pulleniatina obliquiloculata* Zone to within lower part of the *Globorotalia truncatulinoides* Zone). Originally recorded from the Bowden Formation of Jamaica and regarded as probably Miocene, but the type locality is now established as Pleistocene in age (e.g., LAMB, 1969; LAMB & BEARD, 1972).

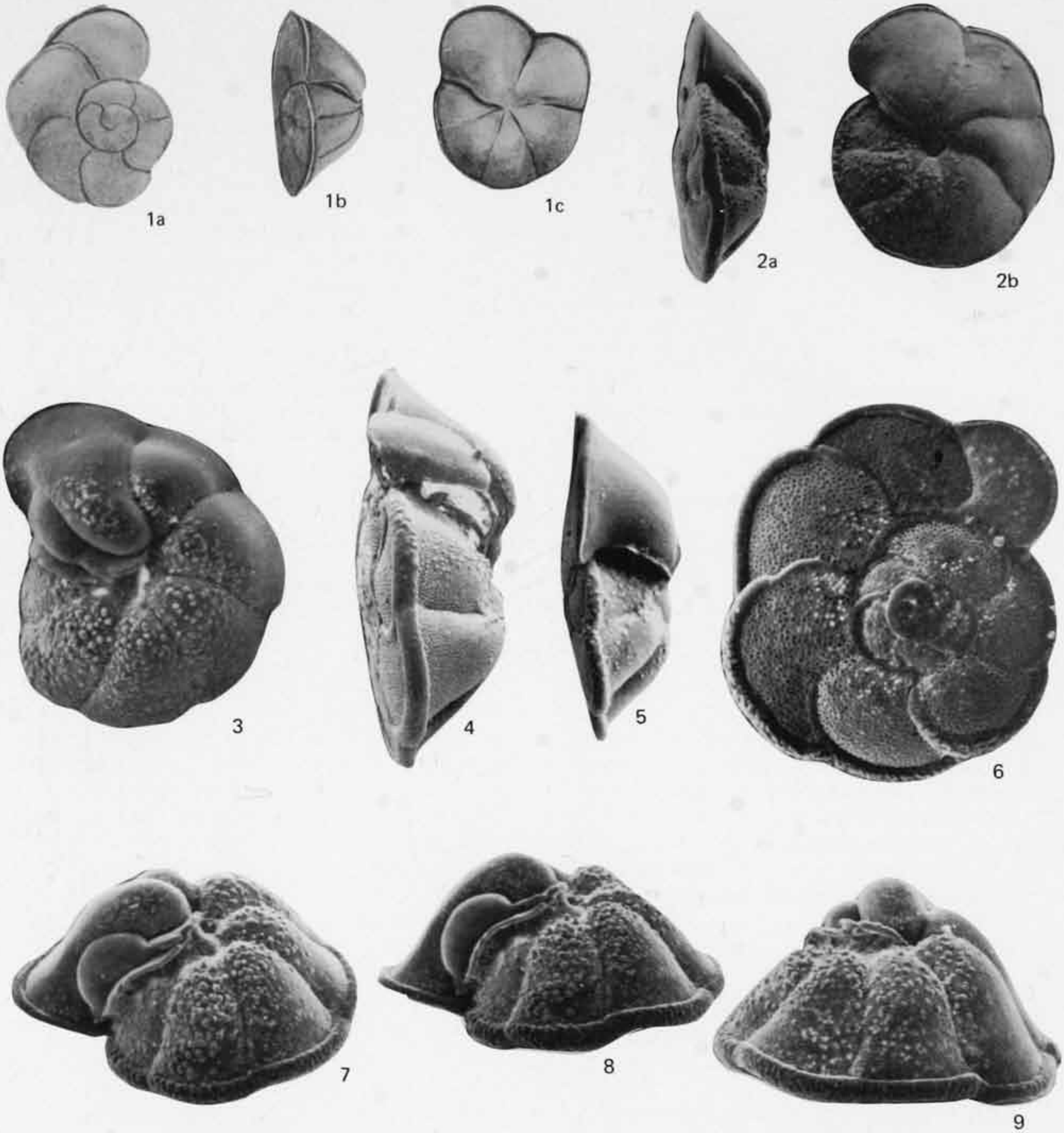

Fig. 180. *Globorotalia miocenica* PALMER from the Early Pleistocene of the Caribbean, north Atlantic, and Gulf of Mexico regions.

1 Holotype from a Pleistocene interval within the Bowden Formation of Jamaica, X50; from PALMER (1945, pl. 1, fig. 10). **a**–Spiral view; **b**–side view; **c**–umbilical view.

2 Specimen from Early Pleistocene beds of the western north Atlantic, X90; from POAG (1972b, pl. 3, fig. 3-4). **a**–side view; **b**–umbilical view.

3-9 Specimens from the Early Pleistocene of the Gulf of Mexico, X90; from LAMB & BEARD (1972, pl. 16, fig. 1-4). **3**–Umbilical view; **4-5,7-9**–side views showing planoconvex shape of test; **6**–spiral view.

GLOBOROTALIA MULTICAMERATA

Cushman & Jarvis, 1930

Figures 181-182

Pliocene and Early Pleistocene

Globorotalia menardii multicamerata CUSHMAN & JARVIS, 1930, p. 367, pl. 34, fig. 8.–CUSHMAN & BERMÚDEZ, 1949, p. 30, pl. 5, fig. 8-13.

Globorotalia menardii fijiensis CUSHMAN, 1934, p. 136, pl. 17, fig. 5.–STAINFORTH, 1948b, p. 125, pl. 26, fig. 38-39.

Globorotalia multicamerata CUSHMAN & JARVIS. BERMÚDEZ, 1960, p. 1296-1297.–PARKER, 1967, p. 180, pl. 31, fig. 5-6.–POAG & AKERS, 1967, p. 171, pl. 17, fig. 4-6.–BOLLI, 1970, p. 582, pl. 7, fig. 17-20.–POSTUMA, 1971, p. 338-339.–POAG, 1972b, p. 510, pl. 4, fig. 3-4.–LAMB & BEARD, 1972, p. 54-55, pl. 11, fig. 4-6; pl. 12, fig. 4-5; pl. 13, fig. 6-8; pl. 14, fig. 5-8.–JENKINS & ORR, 1972, p. 1101, pl. 28, fig. 4-6.

Globorotalia (Globorotalia) multicamerata CUSHMAN & JARVIS. BLOW, 1969, p. 367-368, pl. 7, fig. 7-9; pl. 42, fig. 7.

Test a large lenticlular trochospire rimmed by prominent cordlike keel. At least 7 (commonly 8 to 10, exceptionally 11 to 12) chambers in last whorl; subequal in size, arrangement somewhat irregular; rhomboid to lunate on spiral side, radial segments on umbilical side. Equatorial profile subcircular to ovate, somewhat lobate; axial profile biconvex, spiral side generally but not invariably more tumid, maximum thickness appreciably less than half diameter. Sutures on spiral side strongly limbate, curving or hooking backward to merge into peripheral keel; on umbilical side incised, sinuously radial. Umbilicus a prominent circular pit. Aperture a low arched slit from umbilicus to keel, central portion with arcuate flap. Surface mostly smooth and densely perforate; pustulose to rugose near umbilicus and to some degree elsewhere, especially around keel and on apertural flap. Diameter 0.8 to 1.0 mm.

Discussion.–Excepting BLOW (1969) and PARKER (1973), most authors distinguish *Globorotalia multicamerata* from other menardiform species on the basis of its large number of chambers, at least 7 in the final whorl. The only species comparable in this respect is *Globorotalia pertenuis* BEARD (1969) which is more compressed and only lightly keeled.

Distribution.–Pliocene and earliest Pleistocene (*Globorotalia margaritae* Zone to base of *Globorotalia truncatulinoides* Zone). First recorded in the Buff Bay Formation of Jamaica at a level formerly regarded as Miocene but now interpreted as Pliocene. This species is a useful although not rigid guide to Pliocene age but is recorded only in warm water, mainly tropical areas.

GLOBIGERINA NEPENTHES Todd, 1957

Figures 183-184

Middle Miocene to Middle Pliocene

Globigerina nepenthes TODD, 1957, p. 301, pl. 78, fig. 7.–BLOW, 1959, p. 178-179, pl. 8, fig. 44-45.–BLOW, 1969, p. 320, pl. 14, fig. 5.–POSTUMA, 1971, p. 266-267.–LAMB & BEARD, 1972, p. 47, pl. 4, fig. 1-8.–AKERS, 1972, p. 52, 54, pl. 14, fig. 1.–POAG, 1972b, p. 506, pl. 6, fig. 5-8.

Globigerina druryi nepenthes TODD, BANDY & INGLE, 1970, p. 152, pl. 1, fig. 5.

Test trochospiral, compact, spire ranging from low to high. Chambers (4 to 5) in final whorl slightly inflated and subequal except last which typically protrudes obliquely, resembling a fingertip. Profiles variable, nondescript. Sutures mostly indistinct, on last whorl indented, approximately radial on both sides. Umbilicus narrow, formed by blunt, inturned tips of 3 penultimate chambers. Aperture a broad arch in umbilical portion of protruding last chamber, bordered by thickened rim. Surface coarsely perforate, pitted. Intraspecific variability characterizes this species. Diameter 0.4 to 0.6 mm.

Discussion.–We conceive this species as a central form having its chambers arranged in a low to

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Fig. 181. *Globorotalia multicamerata* CUSHMAN & JARVIS from the Pliocene and Pleistocene of the Caribbean, Gulf of Mexico, and western Pacific Ocean.

1 Holotype from Pliocene beds of the Buff Bay Formation, Jamaica, X35; from CUSHMAN & JARVIS (1930, pl. 34, fig. 8). **a**–Spiral view; **b**–side view; **c**–umbilical view.

2-4 Specimens from the Pliocene (*Globorotalia margaritae* Zone) of the western Pacific Ocean; from KRASHENINNIKOV & HOSKINS (1973, pl. 25, fig. 7-9). **2**–Side view, X82; **3**–spiral view, X78; **4**–umbilical view, X72.

5-6 Specimens from the Pliocene (*Globorotalia margaritae* Zone) of the Caribbean Sea; from BOLLI (1970, pl. 7, fig. 17, 20). **5**–Umbilical view, X44; **6**–spiral view, X60.

7-9 Specimens from the Pliocene (*Pulleniatina obliquiloculata* Zone) of the Gulf of Mexico, X85; from LAMB & BEARD (1972, pl. 14, fig. 6-8). **7**–Umbilical view; **8**–side view; **9**–spiral view.

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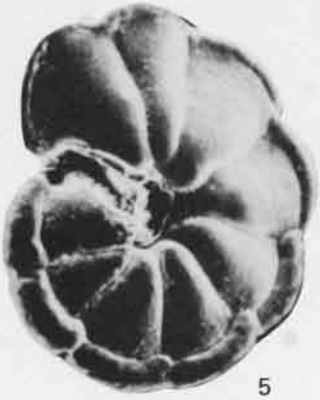

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Fig. 181

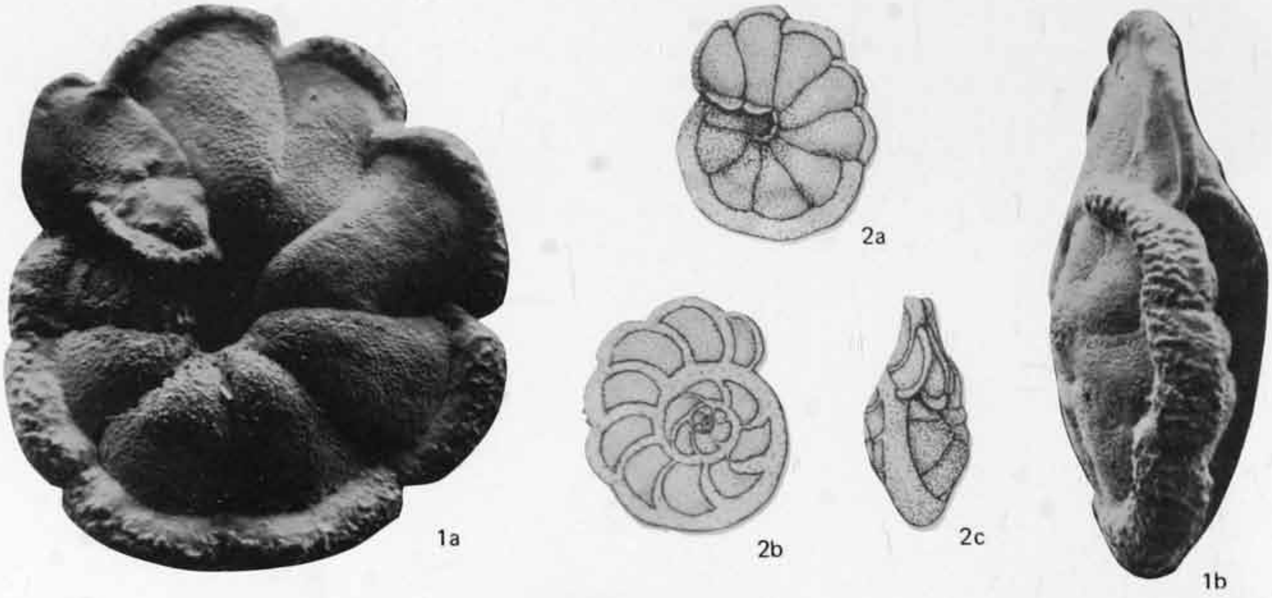

Fig. 182. *Globorotalia multicamerata* CUSHMAN & JARVIS from the Pliocene of the western north Atlantic and south Pacific Oceans.

1 Specimen from the Pliocene (*Pulleniatina obliquiloculata* Zone) of the western north Atlantic, X73; from POAG (1972b, pl. 4, fig. 3-4). **a**–Umbilical view; **b**–side view.

2 Specimen from the Pliocene (*Globorotalia margaritae* Zone) of the south Pacific Ocean, X34; from PARKER (1967, pl. 31, fig. 5). **a**–Umbilical view; **b**–spiral view; **c**–side view.

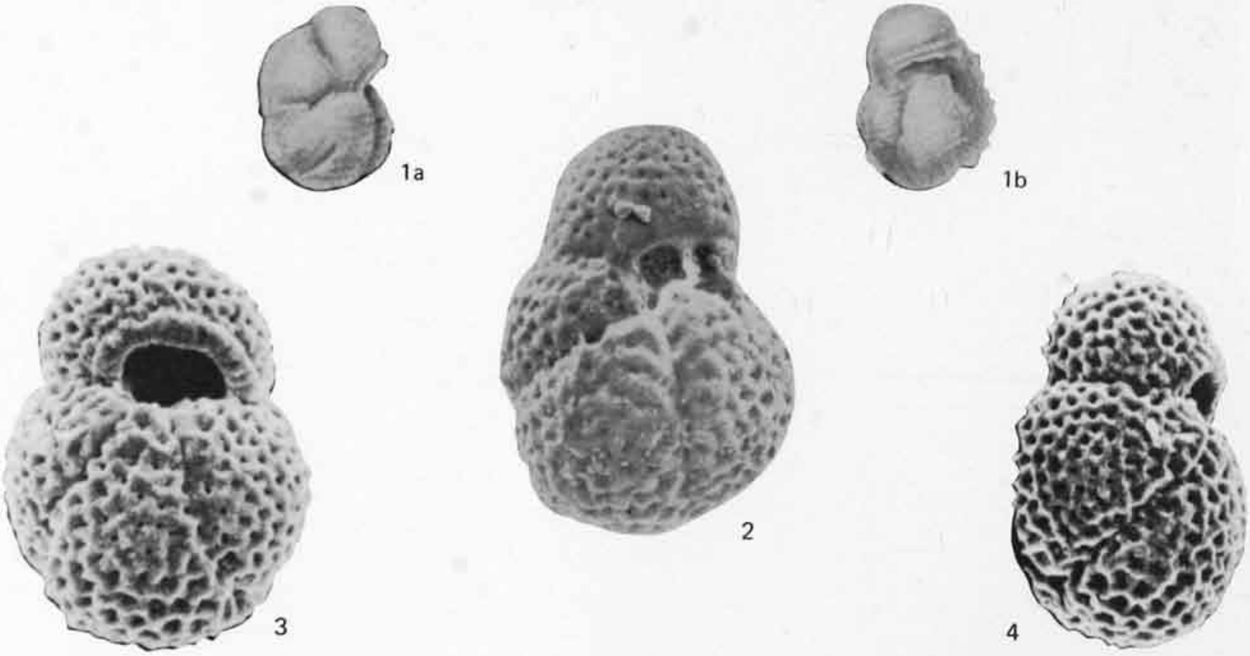

Fig. 183. *Globigerina nepenthes* TODD from the Pliocene of the south Pacific region.

1-2 Holotype (**1**) and metatype (**2**) from Saipan; **1** from TODD (1957, pl. 78, fig. 7), **2** from BLOW (1969, pl. 14, fig. 5). **1a**–Side view, X55; **1b,2**–apertural views, X55, X120.

3-4 Specimens from the southwestern Pacific Ocean; from BRÖNNIMANN & RESIG (1971, pl. 1, fig. 4,6). **3**–Apertural view, X404; **4**–side view, X250.

moderately high trochospire with a protruding final chamber. Variations in the height of spire, lobation of chambers, and size and shape of final chamber (which not infrequently is conical) prompted some observers (e.g., PERCONIG, 1968; BRÖNNIMANN & RESIG, 1971) to propose new species and subspecies to account for these variations. Irrespective of the systematic grounds for naming such seemingly distinct morphotypes, we judge that little biostratigraphic advantage is gained by such procedures and, therefore, favor a rather broad concept in identification of *Globigerina nepenthes.* Several authors suggested close relationship to *Globigerina druryi* AKERS (1955).

Distribution.–Middle Miocene to Middle Pliocene (*Globorotalia siakensis* Zone to within the *Globorotalia margaritae* Zone). Originally described from Miocene strata of Saipan, this species has a nearly worldwide distribution. In well-bore samples, it is a useful species for recognizing the upper limits of the *Globorotalia margaritae* Zone.

CANDEINA NITIDA d'Orbigny, 1839

Figure 185

Late Miocene to Holocene

Candeina nitida D'ORBIGNY, 1839, p. 108, pl. 2, fig. 27-28.–BOLLI, LOEBLICH, & TAPPAN, 1957, p. 35, pl. 6, fig. 10-11.–CITA, 1971, p. 40, pl. 2, fig. 6.–LAMB & BEARD, 1972, p. 47, pl. 5, fig. 5.

Candeina nitida nitida D'ORBIGNY. BLOW, 1969, p. 335, 384-386, pl. 23, fig. 1-4.

Test a lofty, tightly coiled, symmetrically formed trochospire. Chambers inflated, subglobular, rapidly enlarging in early portion, later subequal, 3 in whorl. Equatorial profile trilobate; axial profile ovate, indented at spiral suture. Sutures deeply depressed, accentuated by apertural pores, outlining neat arrangement of chambers. Umbilicus completely closed. Primary aperture not visible in adult. Large apertural pores, individually rimmed, aligned evenly along sutures at spacing of 6 to 10 in a sutural segment. Maximum dimension (which may be height) typically 0.5 to 0.6 mm, occasionally larger.

Discussion.–Ontogeny of *Candeina nitida* indicates derivation from *Globigerinoides* CUSHMAN (1927a) by elimination of the primary aperture and breakdown of secondary apertures into sutural pores. BLOW (1969) identified the ancestral form as *Globigerinoides parkerae* BERMÚDEZ (1960).

Distribution.–Late Miocene to Holocene (*Globorotalia acostaensis* Zone to *Globorotalia tumida* Zone). This species was described from Recent sediments off Cuba and has been recorded nearly worldwide. In the Caribbean, Gulf of Mexico, and Atlantic regions it seemingly does not occur below the Pliocene.

PULLENIATINA OBLIQUILOCULATA Group

Figures 186-187

The genus *Pulleniatina* CUSHMAN (1927a) was long treated as monospecific, containing the type

Fig. 184. *Globigerina nepenthes* TODD from the Late Miocene and Pliocene of the Gulf of Mexico. [p. 382]

1,4-8 Specimens from the Late Miocene; from LAMB & BEARD (1972, pl. 4, fig. 1,4-8). **1,4**–Side views, X160, X175; **5-8**–apertural views, X170.

2-3 Specimens from the Pliocene; from LAMB & BEARD (1972, pl. 4, fig. 2-3). **2**–Side view, X95; **3**–spiral view, X200.

Fig. 185. *Candeina nitida* D'ORBIGNY from the Pliocene, Pleistocene, and Holocene of the Atlantic and Pacific Oceans, Gulf of Mexico, and Caribbean Sea. [p. 383]

1 Holotype from Recent [Holocene] sediments off Cuba, X48; from D'ORBIGNY (1839, pl. 2, fig. 27-28). **a**–Side view; **b**–spiral view.

2-3 Specimens from Recent [Holocene] sediments of the Pacific region, X64; from PARKER (1962, pl. 8, fig. 29-30). **2a**–Spiral view; **2b**–umbilical view; **3**–view showing supplementary umbilical aperture found in some specimens.

4 Specimens from Pliocene sediments of the Atlantic Ocean; from BLOW (1969, pl. 23, fig. 1-2). **a**–Oblique umbilical view showing primary aperture of the penultimate whorl of chambers after dissection, X120; **b**–spiral view of specimen lacking sutural apertures in early whorls and interpreted as phylogenetically primitive, X115 ca.

5 Side view of specimen from the Late Pleistocene of the Gulf of Mexico, X85; from LAMB & BEARD (1972, pl. 5, fig. 5).

6-8 Specimens from the Pliocene of the eastern equatorial Pacific region, X97; from JENKINS & ORR (1972, pl. 1, fig. 1-3). **6**–Side view; **7-8**–spiral views.


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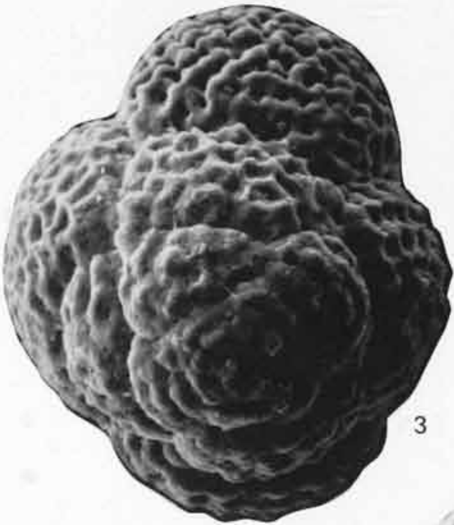
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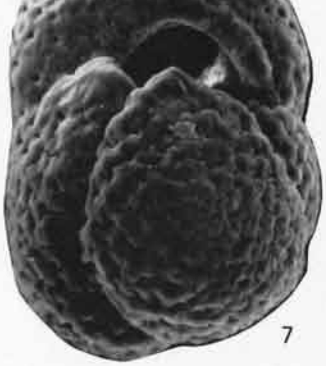
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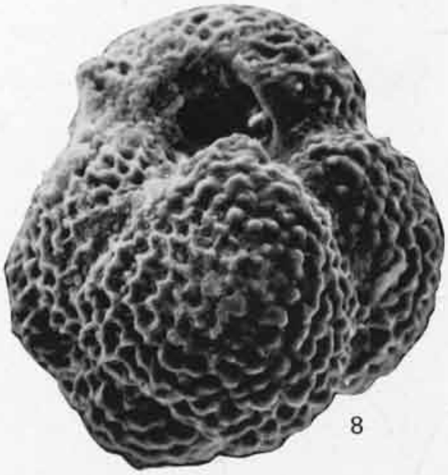
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Fig. 184

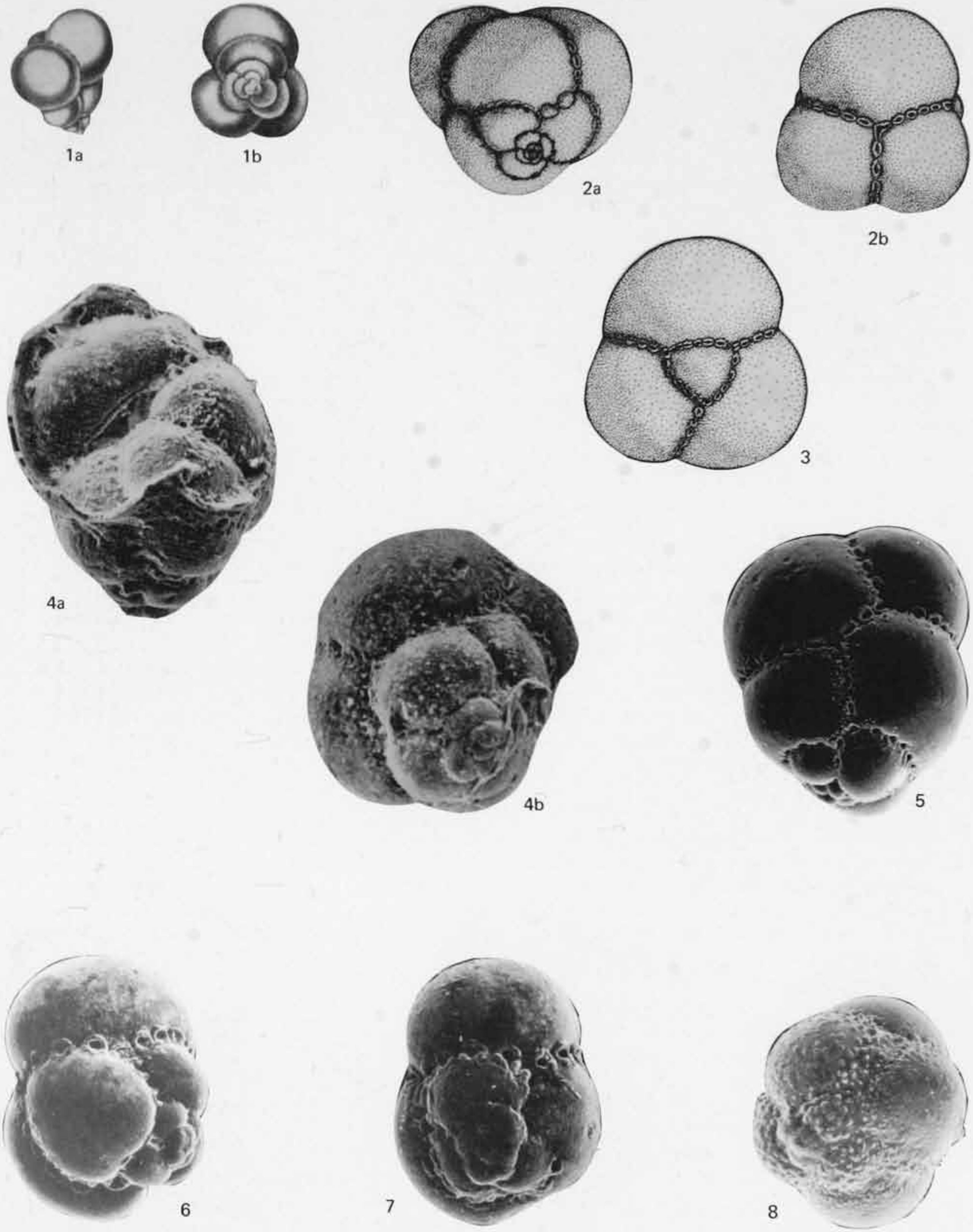

Fig. 185

species *Pulleniatina obliquiloculata* (PARKER & JONES, 1865). In fact, the only exceptions to this statement were proposal of *?Pulleniatina semiinvoluta* GERMERAAD (1946) and *Pulleniatina spectabilis* PARKER (1965); the former subsequently was removed from *Pulleniatina* and designated as the type species of the distinct genus *Rotaliatinopsis* BANNER & BLOW (1967). Eventually however, BANNER & BLOW (1967) reviewed the genus in detail and recognized an evolutionary sequence of forms for which they introduced new names for species and subspecies. A condensation of their exhaustive discussion follows here, plus comments derived from later authors; separate items also are included herein for *Pulleniatina finalis, P. obliquiloculata* s. s., *P. primalis,* and *P. spectabilis.*

Specimens of *Pulleniatina* initially are trochospiral with early stages as in *Globigerina* (open umbilicus) followed by a *Globorotalia* stage (closed umbilicus, extraumbilical aperture) distinguished by conversion to mildly streptospiral coiling so that original umbilicus is concealed by later chambers. All species are more or less tumid and have 4 to 5 chambers in each whorl. A typical (though not diagnostic) feature is a sheath of smooth shell material covering the coarsely perforate inner wall.

Streptospiral specimens referable to *Pulleniatina* began to appear in the Late Miocene, evidently derived from the *Globorotalia humerosa* – *Globorotalia acostaensis* lineage. Evolution proceeded during the Pliocene and the most advanced forms appeared during the Pleistocene. Stages in the bioseries are as follows:

1. Streptospirality slight, revealed by oblique encroachment of successive chambers. Intercameral sutures meet at point on umbilical side.
    a. Similar to ancestral globorotalias but chambers lengthened axially and skewed toward spiral side. [*Pulleniatina praepulleniatina* BRÖNNIMANN & RESIG, 1971.]
    b. Umbilical tips of chambers prolonged, overlapping successively. Aperture a slit or low arch, not reaching periphery of inner coil.
        (1) Periphery rounded. [*Pulleniatina primalis* BANNER & BLOW, 1967.]
        (2) Periphery strongly shouldered, angled, commonly pseudocarinate. [*Pulleniatina spectabilis* PARKER, 1965 (divided into two subspecies by BRÖNNIMANN & RESIG, 1971).]
    c. Chambers encroaching over both spiral side and umbilical region. Aperture longer, reaching to periphery of inner coil. [*Pulleniatina praecursor* BANNER & BLOW, 1967 (as *P. obliquiloculata praecursor*).]
2. Streptospirality more advanced so that umbilical tips of final and opposing chambers are separated by short suture instead of meeting at point.
    a. Involute tendency evident but early chambers visible. Aperture reaches periphery and generally extends to the spiral surface. [*Pulleniatina obliquiloculata* (PARKER & JONES, 1865) emended BANNER & BLOW, 1967.]
    b. Markedly involute. External aspect a tumid planispire coiled around an axis oblique to that of initial trochospire. Aperture a wide arch embracing periphery of inner whorl. [*Pulleniatina finalis* BANNER & BLOW, 1967 (as *P. obliquiloculata finalis*).]

The changes are gradual and transitional so that intermediate forms, difficult to name, are plentiful. Nevertheless, current literature indicates a general acceptance of this bioseries and its applicability to biostratigraphy (e.g., PARKER, 1967; BERMÚDEZ & BOLLI, 1969; BRÖNNIMANN & RESIG, 1971; LAMB & BEARD, 1972). The holotype of the subspecies *P. obliquiloculata trochospira* HARTONO (1964) is considered to be inseparable from *P. obliquiloculata* sensu stricto, although other specimens mentioned by HARTONO are closer to *P. praecursor.* Likewise *Globigerina antillensis* BERMÚDEZ (1960) [renamed *Pulleniatina obliqueloculata* (sic) *antillensis* (BERMÚDEZ) *in* BERMÚDEZ & BOLLI (1969)] is considered as inseparable from *P. obliquiloculata* s.s., its holotype being a small, immature individual. Subspecific nomenclature certainly is justified within such a closely linked bioseries, but in the interest of brevity we give specific rank to the stratigraphically successive named forms.

Mention must be made in this context of *Globorotalia inflata* (D'ORBIGNY, *in* BARKER-WEBB & BERTHELOT, 1839), a species which not only shows gross homeomorphy with the *Pulleniatina obliquiloculata* group but also occurs in close association with it. BANNER & BLOW (1967, p. 145) inferred that D'ORBIGNY included the whole range of forms within his *"Globigerina inflata"* and that BRADY (1884) was the first to make a clear separation. *Globorotalia inflata* is distinguished primarily by maintaining regular trochospiral growth with no sign of streptospirality and is, in fact, closely homeomorphic with the Eocene form *Globorotalia cerroazulensis pomeroli* TOUMARKINE & BOLLI (1970) [= *G. centralis* of authors].

Pulleniatina is a temperature-sensitive genus, most typical of warm-water assemblages. Cases are recorded of its disappearance from an area during a phase of climatic cooling (e.g., BOLLI & BERMÚDEZ, 1965). Its absence from the Mediterranean region, presumably due to paleoclimatic factors, reduces its value as a worldwide biostratigraphic index.

PULLENIATINA OBLIQUILOCULATA

(Parker & Jones, 1865)

Figures 186-187

Middle Pliocene to Holocene

Pullenia obliquiloculata PARKER & JONES, *in* CARPENTER, 1862, p. 183 [nomen nudum].

Pullenia sphaeroides obliquiloculata PARKER & JONES, 1865, p. 365, 368, pl. 19, fig. 4.–BANNER & BLOW, 1960a, p. 25, pl. 7, fig. 4 [lectotype designated by BOLLI, LOEBLICH, & TAPPAN, 1957].

Pulleniatina obliqueloculata [sic] (PARKER & JONES). CUSHMAN, 1927a, p. 90.–GALLOWAY, 1933, p. 332.–BOLLI, LOEBLICH, & TAPPAN, 1957, p. 33.–LOEBLICH & TAPPAN, 1964, p. C671-C672.–BLOW, 1969, p. 376.

Pulleniatina obliquiloculata (PARKER & JONES). BERMÚDEZ, 1960, p. 1329-1331.–PARKER, 1962, p. 234, pl. 4, fig. 13-16, 19, 22.–PARKER, 1967, p. 172, pl. 28, fig. 1.–LAMB & BEARD, 1972, p. 58, pl. 29, fig. 1-4.

Globigerina antillensis BERMÚDEZ, 1960, p. 1156, pl. 1, fig. 1.

Pulleniatina obliquiloculata trochospira HARTONO, 1964, p. 10, fig. a-c.

Pulleniatina obliquiloculata obliquiloculata (PARKER & JONES). BANNER & BLOW, 1967, p. 137, pl. 3, fig. 4 [lectotype refigured]; pl. 4, fig. 9.–BRÖNNIMANN & RESIG, 1971, p. 1318-1321, pl. 16, fig. 1-11; pl. 17, fig. 1-4, 5?; pl. 18, fig. 1-7; pl. 19, fig. 6.

Pulleniatina obliqueloculata [sic] *antillensis* (BERMÚDEZ). BERMÚDEZ & BOLLI, 1969, p. 183, pl. 16, fig. 7-9.

Test tumid, initially trochospiral, becoming streptospiral in adult. Last whorl of 4 to 5 broadly rounded chambers, enlarging regularly, oriented progressively more obliquely to original axis. Profiles smoothly curved, nondescript. Sutures distinct; lightly depressed to flush. Umbilicus of initial trochospire concealed by overlapping tips of successive chambers; the umbilical area of adult characterized by short suture between final and penultimate (or preceding) chambers. Aperture a low arch extending from umbilical area to periphery and generally to spiral surface, directed obliquely toward initial spire, bordered by rimlike apertural face. Wall thick, smooth to shiny, variably pustulose, especially in apertural region. Diameter 0.2 to 0.6 mm.

Discussion.–In early forms of *Pulleniatina* umbilical chamber tips meet at point, but, as streptospirality increases, their contact changes to a short suture. This feature distinguishes *P. obliquiloculata* s.s. from the *Pulleniatina primalis-Pulleniatina praecursor* forms [see also under *Pulleniatina obliquiloculata* group].

The species name originally was spelled *"obliquiloculata,"* as kindly verified by A. N. DUSENBURY, JR. (personal communication, February 1974). As recorded here in the synonymy, some authors have used the spelling *"obliqueloculata"* without clear indication of whether this modified spelling was an inadvertent lapse, an intentional emendation, or a reliance on a prior author. The form *"obliquiloculata"* must be accepted as the correct original spelling (ICZN, Art. 32a, ii).

Distribution.–Middle Pliocene to Holocene (*Globorotalia margaritae* Zone to *Globorotalia tumida* Zone). This species was described from a dredge haul from the Atlantic Ocean off the coast of Brazil and occurs nearly worldwide in tropical and subtropical regions.

GLOBIGERINOIDES OBLIQUUS Bolli, 1957

Figure 188

Early Miocene to Early Pleistocene

Globigerinoides obliqua BOLLI, 1957b, p. 113, fig. 21-5, pl. 25, fig. 9-10.

Globigerinoides obliquus obliquus BOLLI. BOLLI & BERMÚDEZ, 1965, p. 139.–BLOW, 1969, p. 324.–BRÖNNIMANN & RESIG, 1971, p. 1310, pl. 11, fig. 4.

Globigerinoides obliquus BOLLI. JENKINS, 1971, p. 177, pl. 21, fig. 613-615.–POSTUMA, 1971, p. 296-297, 4 fig.

Test a compact trochospire with 3 to 4 spherical chambers per whorl. Chambers of last whorl increase rapidly in size and develop obliquely appressed shape. Equatorial periphery distinctly lobate; axial profile reveals bluntly elevated spire. Sutures on spiral side

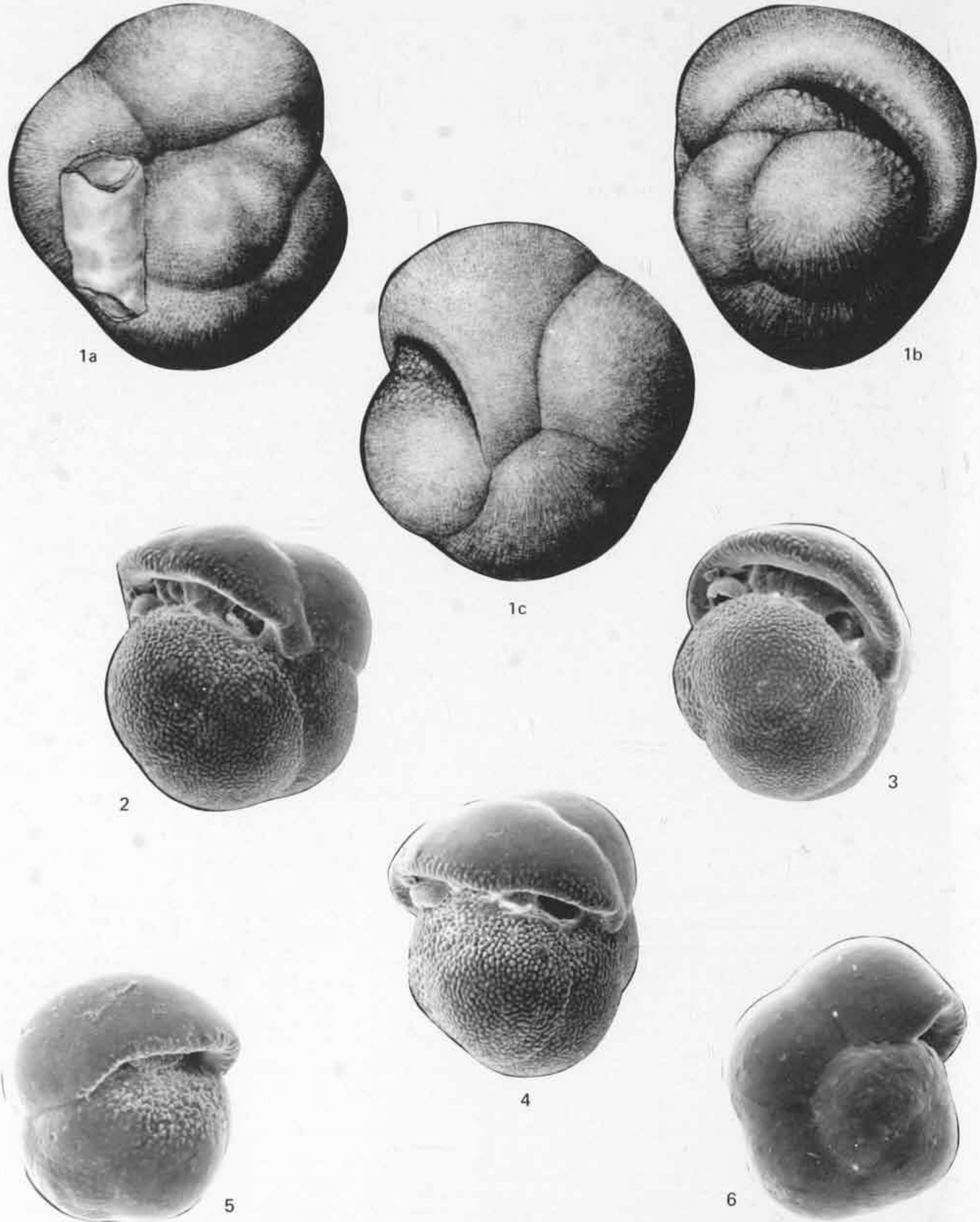

Fig. 186

Fig. 186. *Pulleniatina obliquiloculata* (PARKER & JONES) from the Early Pleistocene and Holocene of the south Atlantic Ocean and Gulf of Mexico.

1 Lectotype from the Holocene of the south Atlantic Ocean, X100; from BANNER & BLOW (1967, pl. 3, fig. 4). **a**–Spiral view; **b**–side view; **c**–umbilical view.

2-6 Specimens from the Early Pleistocene of the Gulf of Mexico, X85; from LAMB & BEARD (1972, pl. 29, fig. 1-3). **2-4**–Oblique side views; **5**–umbilical view; **6**–spiral view.

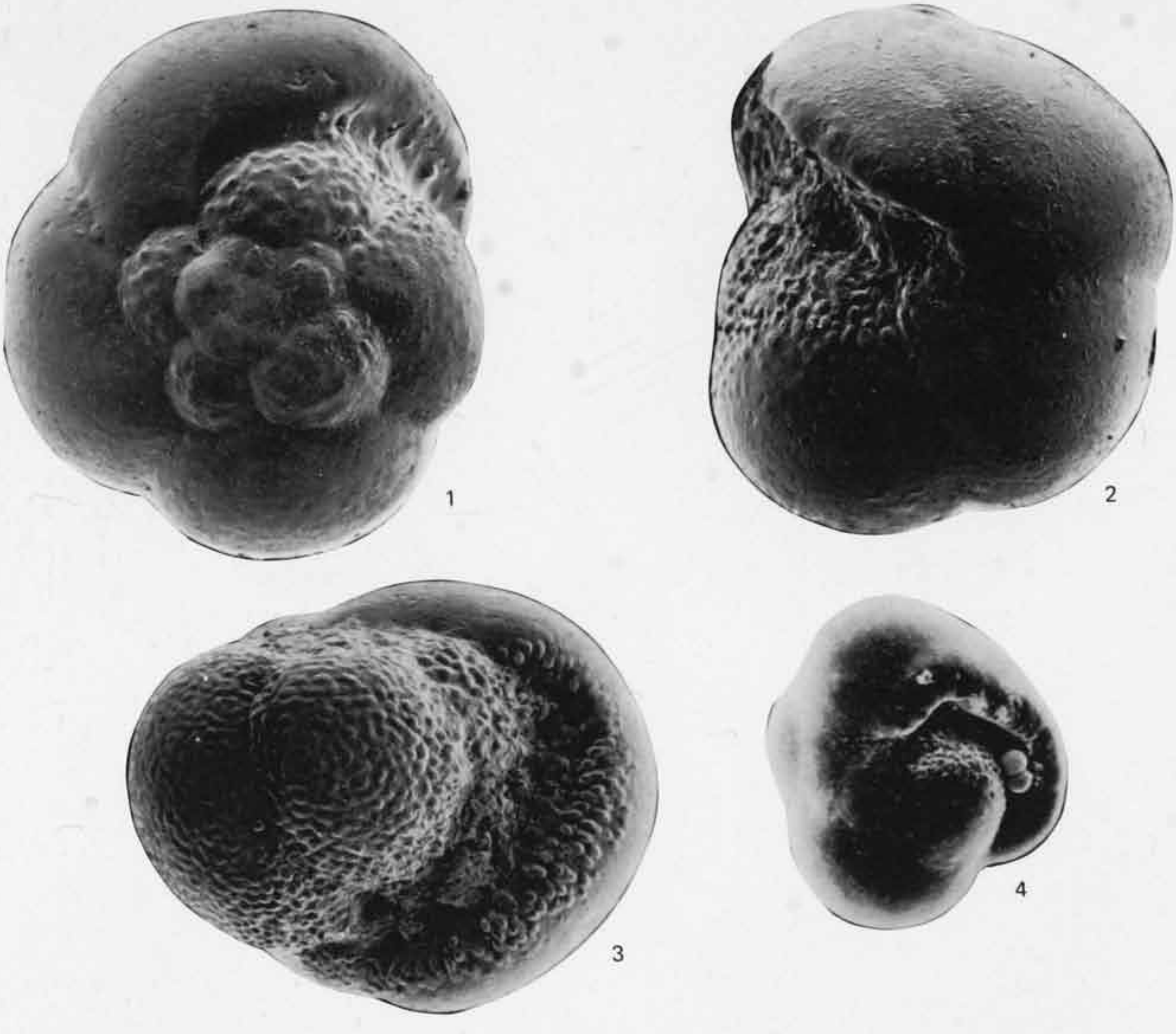

Fig. 187. *Pulleniatina obliquiloculata* (PARKER & JONES) from the Late Pliocene and Holocene of Ecuador and the south Pacific Ocean.

1-3 Topotypes from a Late Pliocene level within the Borbón Formation of Ecuador described as *Pulleniatina obliquiloculata praecursor* BANNER & BLOW (1967). **1**–Spiral view, X180; **2**–umbilical view, X140; **3**–side view, X140.

4 Side view of specimen from the Holocene of the southwestern Pacific Ocean, X60; from BRÖNNIMANN & RESIG (1971, pl. 19, fig. 6).

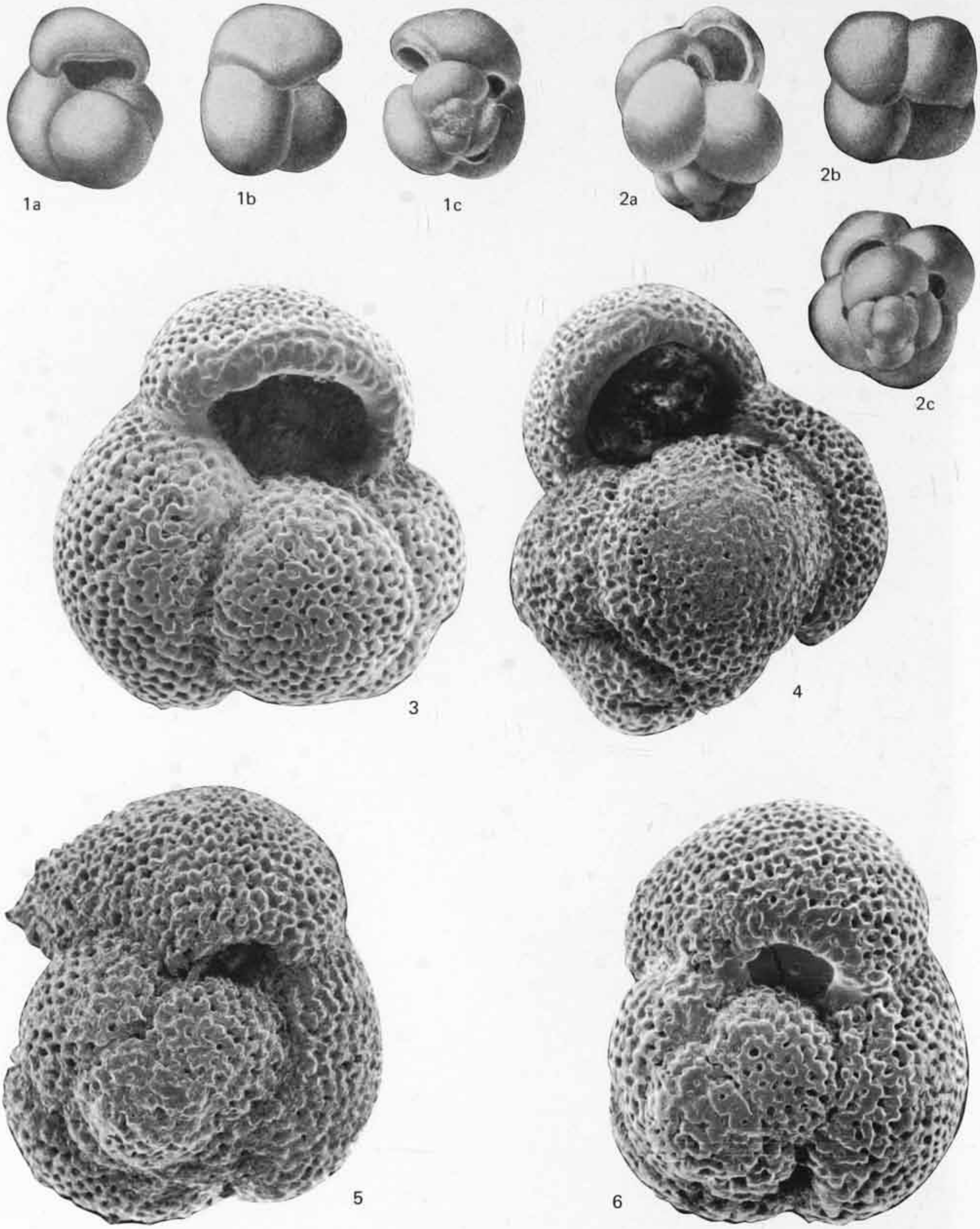

Fig. 188

Fig. 188. *Globigerinoides obliquus* BOLLI from the late Middle Miocene (*Globorotalia siakensis* Zone) of the Caribbean region.

1-2 Holotype (**1**) and paratype (**2**) from Trinidad, X68; from BOLLI (1957b, pl. 25, fig. 9-10). **1a,2b**–Umbilical views; **1b,2a**–side views; **1c,2c**–spiral views.

3-6 Specimens from the lower Buff Bay Formation of Jamaica. **3-4**–Umbilical views, X145, X130; **5-6**–spiral views, X170, X160.

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radial to oblique, depressed; on umbilical side radial, depressed. Umbilicus lacking. Primary aperture a distinct arch, generally moderately high, interiomarginal to umbilical. Later chambers have lunate supplementary apertures, generally one each (seldom two), along spiral suture. Wall perforate, surface finely pitted. Normal diameter 0.5 mm.

Discussion.–This species is distinguished from others of the genus by its obliquely appressed later chambers; also its spire is more compact and elevated than in subspecies of *Globigerinoides quadrilobatus* (D'ORBIGNY, 1846). In its offshoot *Globigerinoides extremus* (=*Globigerinoides obliquus extremus* BOLLI & BERMÚDEZ, 1965) the appression is accentuated and the final chamber is mitriform.

Distribution.–Early Miocene to Early Pleistocene (*Catapsydrax dissimilis* Zone to within lower part of the *Globorotalia truncatulinoides* Zone). This species was first described from the type locality of the *Globorotalia mayeri* Zone in Trinidad and has a nearly worldwide distribution.

SPHAEROIDINELLOPSIS PAENEDEHISCENS Blow, 1969

Figures 189-190

Late Miocene to Early Pleistocene

Sphaeroidinella seminulina (SCHWAGER). PARKER, 1967, p. 161-162, pl. 23, fig. 1-4.

Sphaeroidinellopsis seminulina (SCHWAGER). POAG & AKERS, 1967, p. 172, pl. 17, fig. 18-20.–BERMÚDEZ, 1960, p. 1279, pl. 9, fig. 7.–INGLE, 1967, p. 357, pl. 43, fig. 7.

Sphaeroidinella subdehiscens BLOW. PARKER, 1967, p. 162, pl. 23, fig. 6-7.–JENKINS & ORR, 1972, p. 1109-1110, pl. 41, fig. 1-2.–POAG, 1972b, p. 516, pl. 5, fig. 4.

Sphaeroidinella dehiscens (PARKER & JONES) [part]. PARKER, 1967, p. 160, pl. 23, fig. 8.

Sphaeroidinellopsis subdehiscens paenedehiscens BLOW, 1969, p. 336, 338, 386-387, 417-418, pl. 30, fig. 4-5, 9.–BRÖNNIMANN & RESIG, 1971, p. 1323, pl. 15, fig. 2.

Sphaeroidinellopsis sphaeroides LAMB, 1969, p. 571, 578, pl. 1, fig. 1-5; pl. 2, fig. 1-3.–LAMB & BEARD, 1972, p. 60, pl. 1, fig. 3-4; pl. 34, fig. 3-8; pl. 35, fig. 1-7.

Fig. 189. *Sphaeroidinellopsis paenedehiscens* BLOW from the Late Miocene and Pliocene of the Caribbean, Gulf of Mexico, and Pacific regions. [p. 390]

1-2 Specimens from a Pliocene (*Pulleniatina obliquiloculata* Zone) level within the Drivers River Formation of Jamaica; from BLOW (1969, pl. 30, fig. 4-5). **1**–Oblique spiral view of holotype, X65; **2**–oblique side view of paratype, X60.

3-5 Specimens from the Pliocene (*Pulleniatina obliquiloculata* Zone) of the Gulf of Mexico described as *Sphaeroidinellopsis sphaeroides* LAMB; from LAMB (1969, pl. 1, fig. 1-2, 4; pl. 2, fig. 1). **3a**–Umbilical view of holotype showing flangelike lips, X106; **3b**–close-up showing aperture enclosed by flangelike lips, X212; **4**–spiral view of paratype showing smooth, unbroken cortex covering chambers and sutures, X106; **5**–umbilical view of paratype, X106.

6 Specimen from the Pliocene of the South Pacific Ocean identified as *Sphaeroidinella subdehiscens* BLOW, X40; from PARKER (1967, pl. 23, fig. 7). **a**–Umbilical view; **b**–spiral view.

7-8 Specimens from the Late Miocene (*Globorotalia acostaensis* Zone) of the eastern equatorial Pacific Ocean identified as *Sphaeroidinella subdehiscens* BLOW; from JENKINS & ORR (1972, pl. 41, fig. 1-2). **7**–Umbilical view, X75; **8**–spiral view, X79.

Fig. 190. *Sphaeroidinellopsis paenedehiscens* BLOW from the Pliocene of the Atlantic and Pacific Oceans and the Gulf of Mexico. Variants of this species with 4 (rarely 5) chambers in the last whorl instead of the usual 3 are encountered not infrequently in Pliocene sediments. These seem to be gerontic individuals that lack a primary globigerine chamber beneath the cortex of the ultimate chamber. As in the normal 3-chambered form, the aperture is entirely enclosed by flangelike lips unlike the species *Sphaeroidinellopsis seminulina* and *Sphaeroidinellopsis subdehiscens*. [p. 391]

1-2 Specimens identified as *Sphaeroidinella seminulina* (SCHWAGER) from the Pliocene of the south Pacific Ocean, X40; from PARKER (1967, pl. 23, fig. 1-2). **1a**–Spiral view; **1b,2**–umbilical views.

3 Umbilical view of specimen identified as *Sphaeroidinellopsis seminulina* (SCHWAGER) from the Pliocene of the western north Atlantic Ocean, X90; from POAG (1972b, pl. 5, fig. 3).

4-9 Specimens identified as *Sphaeroidinellopsis sphaeroides* LAMB from the Pliocene (*Globorotalia margaritae* Zone) of the Gulf of Mexico; from LAMB & BEARD (1972, pl. 35, fig. 1-6). **4-5**–Side views, X130, X115; **6-7**–spiral views, X102, X115; **8-9**–umbilical views, X80.

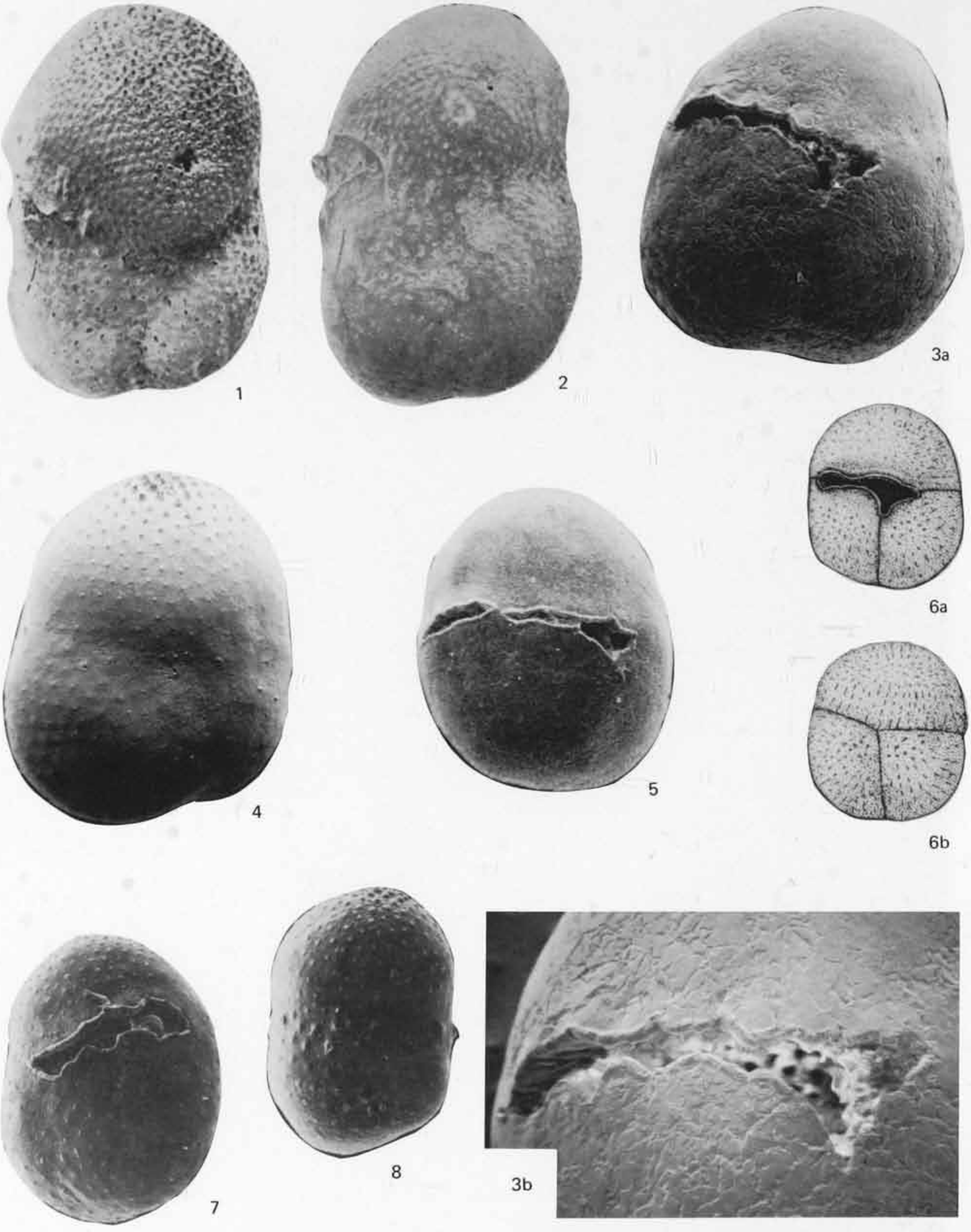

Fig. 189

Fig. 190

Test an ovoid to spheroidal sheath concealing trochospire inside. Final whorl of 3 to 4 chambers, generally fitting into smooth external contours but, where present, 4th commonly is aberrant and protrusive. Profiles variable but in all aspects smoothly rounded, as in potatoes. Sutures obscured by cortex, only faintly discernible as shallow troughs. Umbilicus coincides with aperture, which is prominent slit bordered by slightly projecting, puckered to crenulate lips composed of cortex. Primary surface reticulate and pitted with deep pores, later covered by thick, smooth layer (cortex) which gives test a shiny, finely perforate appearance; aberrant chambers composed of cortex only, lacking primary wall. Diameter to 0.7 mm, generally smaller.

Discussion.—The description of *S. paenedehiscens* BLOW (1969) was published when definition of *Sphaeroidinellopsis sphaeroides* LAMB (1969) was already in press and too late for more than passing reference in LAMB & BEARD (1972). These authors independently conceived and observed an evolutionary stage intermediate between *Sphaeroidinellopsis subdehiscens* (BLOW, 1959) and *Sphaeroidinella dehiscens* (PARKER & JONES, 1865) so that their two species are synonymous. Slight differences in the original diagnoses represent normal intraspecific variability.

This species differs from its immediate ancestor, *Sphaeroidinellopsis subdehiscens,* in having a more inflated ovoid to spheroidal exterior (obscuring sutures and chamber arrangement) and distinctly projecting apertural lips. It differs from its descendant, *Sphaeroidinella dehiscens,* in having only a single aperture. Nevertheless, determinations should be based on suites of specimens because immature individuals of *Sphaeroidinella* may lack supplementary apertures and so be mistaken for *Sphaeroidinellopsis;* moreover, solution pits along sutures of the latter may give a false impression of *Sphaeroidinella.*

Distribution.—Late Miocene to Early Pleistocene (*Globorotalia acostaensis* Zone to *Globorotalia truncatulinoides* Zone). The holotype of *S. paenedehiscens* came from the Pliocene San San Clay of Jamaica and that of *S. sphaeroides* from a Late Pliocene submarine core in the Gulf of Mexico. The species has been found nearly worldwide and, like its modern descendant *Sphaeroidinella dehiscens,* preferred a warm-water habitat.

GLOBOROTALIA PERTENUIS Beard, 1969

Figures 191-192

Late Pliocene to Early Pleistocene

Globorotalia pertenuis BEARD, 1969, p. 552-553, pl. 1, fig. 1-6; pl. 2, fig. 5-6. LAMB & BEARD, 1972, p. 55, pl. 16, fig. 5-6; pl. 17, fig. 5, 7.—POAG, 1972b, p. 510, pl. 4, fig. 1-2.

Test a very low trochospire, biconvex, strongly compressed. Chambers (6 to 11) in final whorl increase in size slowly and somewhat irregularly. Equatorial profile subcircular to ovate, variably lobate; axial profile reveals acutely keeled margin and exceptionally compressed coil, height approximately one-fourth of diameter. Sutures on spiral side limbate and curved, passing into keel; on umbilical side subradial, slightly sinuous. Umbilicus shallow, poorly defined. Aperture a low arch, extraumbilical-umbilical with flaring apertural lip extending into umbilical area; successive flaps becoming imbricate in mature specimens. Diameter to 1.0 mm.

Discussion.—The thin lenslike test, lobate periphery, and large size differentiate this species from both *Globorotalia miocenica* PALMER (1945) and *Globorotalia exilis* BLOW (1969) (see also discussion under *Globorotalia exilis*). *Globorotalia multicamerata* CUSHMAN & JARVIS (1930) has a much thicker wall and keel.

Distribution.—Late Pliocene to Early Pleistocene (*Pulleniatina obliquiloculata* Zone to within lower part of the *Globorotalia truncatulinoides* Zone). Recorded from the western north Atlantic, Gulf of Mexico, and Caribbean regions. The highest development of this species, in terms of size and lobation of periphery, is in the early Pleistocene (Nebraskan glacial interval).

Fig. 191. *Globorotalia pertenuis* BEARD from the Early Pleistocene of Sigsbee knolls, Gulf of Mexico; from BEARD (1969, pl. 1, fig. 1-6). **1**—Umbilical view of holotype, X50; **2**—side view of paratype, X80; **3,5,6a**—umbilical views of paratypes, X80; **4**—spiral view of paratype, X80; **6b**—apertural view, X160.

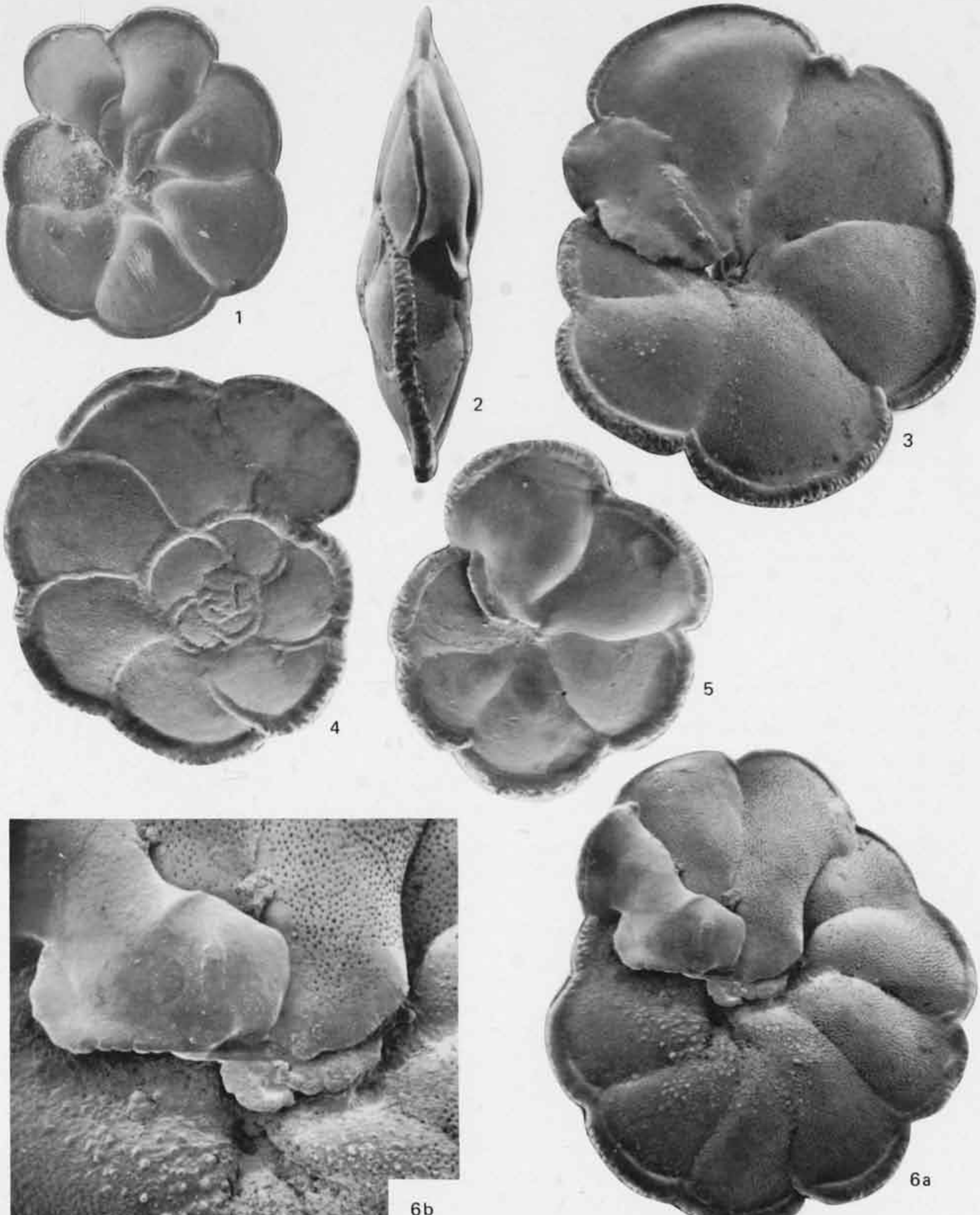

Fig. 191

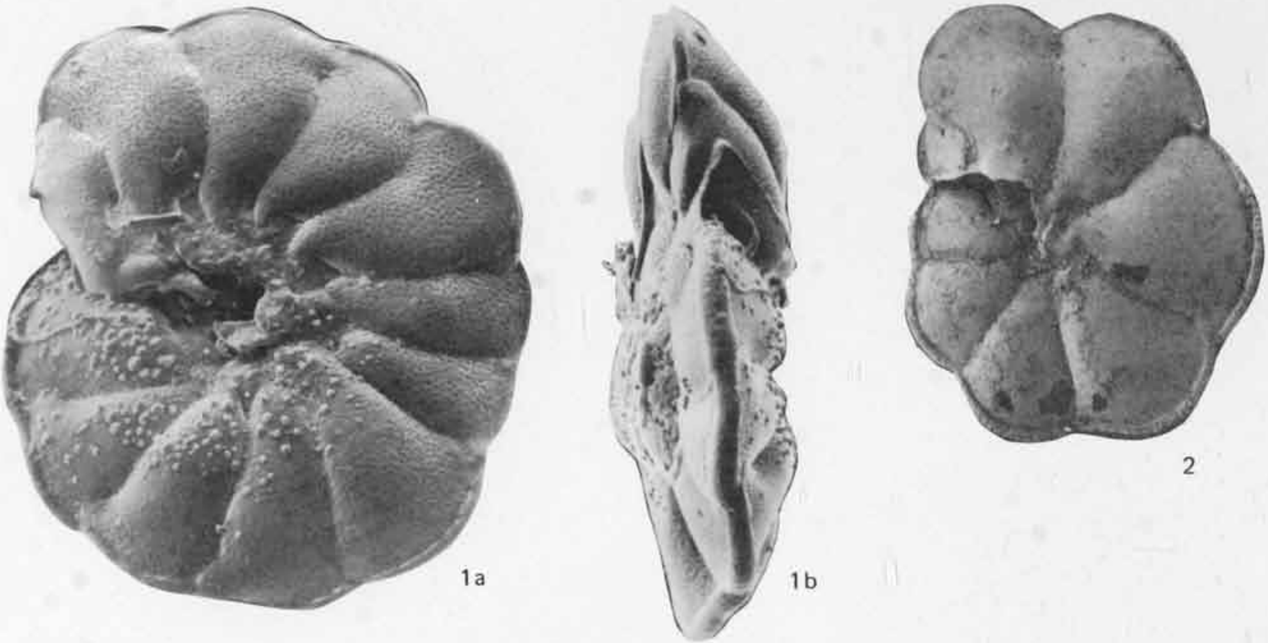

Fig. 192. *Globorotalia pertenuis* BEARD from the Early Pleistocene of the north Atlantic region.

1 Specimen from the western north Atlantic, X90; from POAG (1972b, pl. 4, fig. 1-2). **a**–Umbilical view; **b**–side view.

2 Umbilical view of specimen identified as *Globorotalia exilis* BLOW from the eastern north Atlantic, X50; from CITA (1971a, pl. 1, fig. 7).

GLOBOROTALIA PLANISPIRA Brönnimann & Resig, 1971

Figure 193

Late Pliocene to Early Pleistocene

Globorotalia (Turborotalia) planispira BRÖNNIMANN & RESIG, 1971, p. 1282, pl. 36, fig. 4, 6; pl. 44, fig. 1-2, 4-5, 7-8.

Test a very small, compact, planoconvex trochospire. Tiny initial coil slightly depressed, dwarfed by surrounding adult chambers. Chambers (5) in final whorl maintain same reniform shape and increase in size gradually as added except last, which is smaller than penultimate and slightly displaced toward umbilical side. Axial profile flat on spiral side, evenly rounded at periphery except for offset last chamber. Sutures incised, set in depressions or grooves; oblique to radial on spiral side, radial on umbilical side. Umbilicus narrow, deep. Aperture a low slit from umbilicus to periphery, covered by granulose flap or broad lip. Surface evenly perforate, generally pustulose. Coiling typically dextral. Diameter seldom exceeds 0.2 mm [holotype diameter given in text as 0.24 mm but plate data indicate 0.18 mm; metatypes figured by BRÖNNIMANN & RESIG (1971) are 0.13 to 0.22 mm].

Discussion.–Foraminiferal zonation of the Late Pliocene-Early Pleistocene interval presents difficulties because paleoclimate controlled distribution of the more conspicuous planktonic species. BRÖNNIMANN & RESIG (1971) first recorded the persistent presence of *Globorotalia planispira* within a limited range at the general level given here, and our studies reveal comparable occurrences elsewhere. Despite its small size, therefore, this species may prove to be a useful biostratigraphic index.

Globorotalia planispira is distinguished by its flat spiral side, small size and offset position of final

Fig. 193. *Globorotalia planispira* BRÖNNIMANN & RESIG from the Early Pleistocene of the Pacific Ocean and the Gulf of Mexico.

⇨

1-3 Specimens from the southwestern Pacific Ocean; from BRÖNNIMANN & RESIG (1971, pl. 44, fig. 2, 4-5). **1**–Umbilical view of holotype, X497; **2**–spiral view of paratype, X356; **3**–side view of paratype, X396.

4-6 Specimens from the Gulf of Mexico, X270; from core hole B, core 16, of LAMB & BEARD (1972, fig. 12, 19). **4**–Side view; **5**–umbilical view; **6**–spiral view.

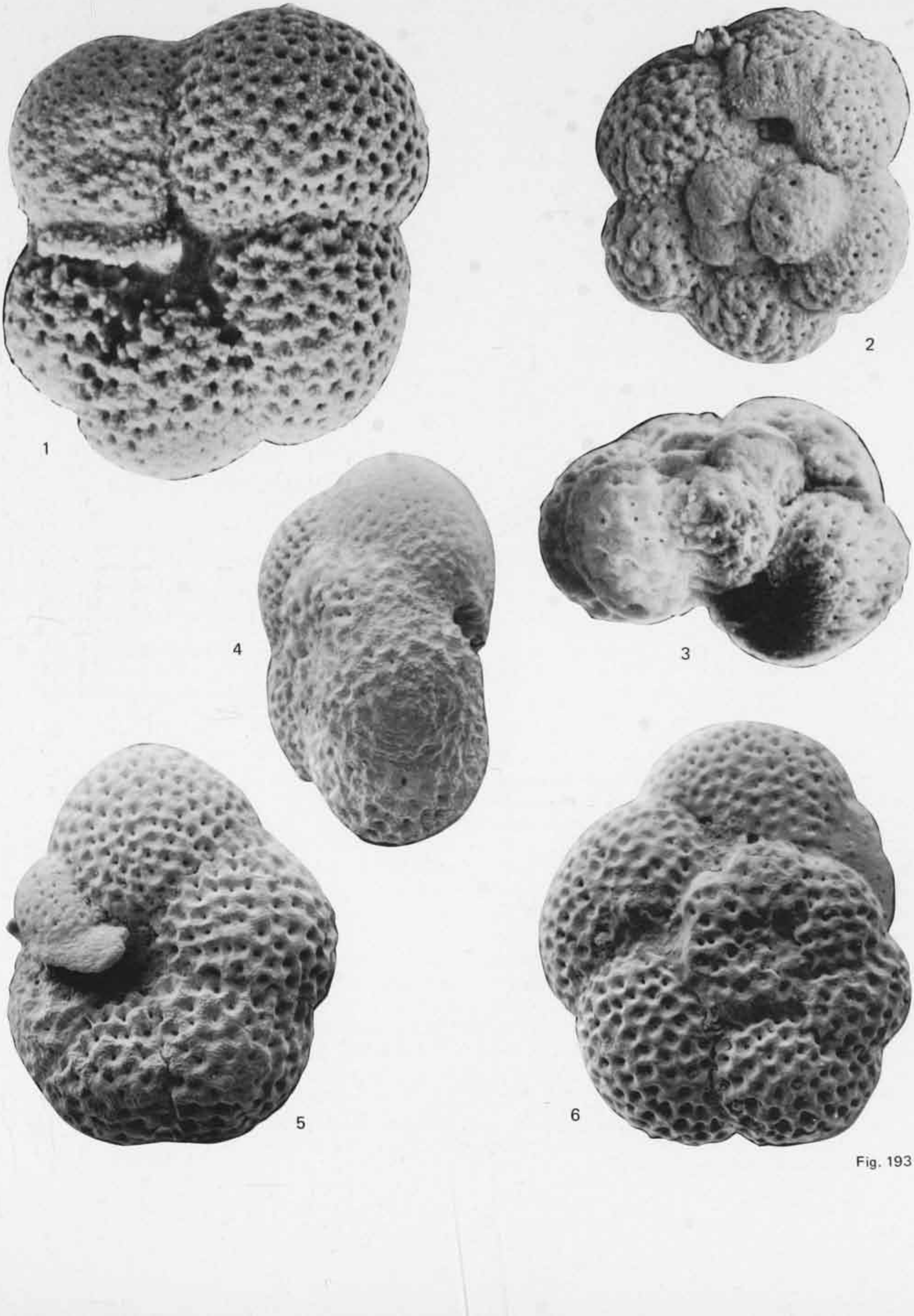

Fig. 193

chamber, and platelike rim of its aperture. In other respects it resembles, and may be related to, the less distinctive *Globorotalia pseudopumilio* BRÖNNIMANN & RESIG (1971); these authors (pl. 44, fig. 3; pl. 48, fig. 8) figure specimens not firmly assigned to either species.

Distribution.—Late Pliocene to Early Pleistocene (*Pulleniatina obliquiloculata* Zone to lower part of *Globorotalia truncatulinoides* Zone). This small species was described from Pleistocene sediments of the south Pacific region, and we have recorded it in the Gulf of Mexico and south China Sea regions.

GLOBOROTALIA PLESIOTUMIDA Blow & Banner, 1965

Figure 194

Late Miocene to Middle Pliocene

Globorotalia (Globorotalia) tumida plesiotumida BLOW & BANNER, *in* BANNER & BLOW, 1965c, p. 1353, fig. 2.—PARKER, 1967, p. 182.—BANNER & BLOW, 1967, p. 152, fig. 14, pl. 4, fig. 3 [holotype reproduced].—BLOW, 1969, p. 371, pl. 9, fig. 7-9 [type figures reproduced, enlarged]; pl. 47, fig. 6-8.

Globorotalia tumida plesiotumida BLOW & BANNER. BOLLI, 1966b, p. 455-462.—BOLLI, 1970, p. 583-586, 597-598.

Globorotalia plesiotumida BLOW & BANNER. BERMÚDEZ & BOLLI, 1969, p. 176, pl. 12, ?fig. 4-6 [transposition is suspected for figures designated as *G. plesiotumida* and *G. merotumida*].—POSTUMA, 1971, p. 350-351.—JENKINS & ORR, 1972, p. 1102-1103, pl. 30, fig. 1-3.—POAG, 1972b, p. 510, pl. 6, fig. 9-10.—PARKER, 1973, p. 279, pl. 3, fig. 18-20.—KRASHENINNIKOV & HOSKINS, 1973, p. 129, pl. 26, fig. 10-12.

Test a lenticular trochospire rimmed by blunt keel. Generally 6 chambers in last whorl, increasing somewhat irregularly in size as added, especially in radial length. Equatorial profile ear-shaped, slightly lobate, last chamber projecting noticeably; axial profile biconvex, slightly more inflated on umbilical than on spiral side. Sutures on spiral side limbate, initially flush, later depressed to sunken, oblique to recurved, coalescing into keel; on umbilical side incised, radial, almost straight. Umbilicus almost closed, umbilical shoulders developed only on last 3 chambers. Aperture a low arch from umbilicus almost to keel, carrying narrow lip along whole length. Wall smooth, densely and uniformly perforate except for granular area adjacent to the umbilicus. Maximum diameter 0.5 to 0.7 mm.

Discussion.—BANNER & BLOW (1965b-c), with modification by BLOW (1969), postulated a bioseries of globorotalias in which successive species were *G. lenguaensis* BOLLI (1957b), *G. paralenguaensis* BLOW (1969), *G. merotumida* BLOW & BANNER (*in* BANNER & BLOW 1965c), *G. plesiotumida*, and *G. tumida* (BRADY, 1877). *Globorotalia plesiotumida* differs from the ancestral group by its more rapidly opening spire (heights of successive whorls in ratio 1:4:8). In its descendant *G. tumida* these ratios increase to 1:4:12 and the test becomes larger, more tumid, and more heavily keeled.

Distribution.—Late Miocene to Pliocene (*Globorotalia acostaensis* Zone to within *Globorotalia margaritae* Zone). Described from the Pliocene part of the Cubagua Formation of Venezuela and recorded from many localities in the Caribbean, Atlantic, Pacific, and Mediterranean provinces, generally in warm-water sediments.

GLOBOROTALIA PRAEHIRSUTA Blow, 1969

Figure 195

Middle Pliocene to Early Pleistocene

Globorotalia (Globorotalia) hirsuta praehirsuta BLOW, 1969, p. 400-402, pl. 43, fig. 3-7 [4-5 = holotype].—BRÖNNIMANN & RESIG, 1971, p. 1424, pl. 49, fig. 1-2.—COLLEN & VELLA, 1973, p. 25, pl. 7, fig. 9.

Globorotalia praehirsuta BLOW. LAMB & BEARD, 1972, p. 55, pl. 18, fig. 9-12.

Globorotalia crassula CUSHMAN & STEWART [sic]. POAG, 1972b, p. 508, pl. 3, fig. 11-12.

Test a lenticular trochospire. Chambers (4) in last whorl comma- to scallop-shaped on spiral side, lightly keeled. Equatorial profile ovate, initially smooth curve, becoming lobate as attachment of later chambers becomes looser; axial profile biconvex, approximately symmetrical, axial thickness almost 1/2 diameter. Sutures on spiral side strongly recurved, depressed, not visibly limbate; on umbilical side obscure, position indicated by radial grooves. Umbilicus closed. Aperture a low arched slit from near umbilicus to near periphery. Wall smooth, finely perforate, commonly dappled with calcite pustules. Diameter about 0.6 mm.

Discussion.—The concept maintained here is of a form intermediate between *Globorotalia margaritae* BOLLI & BERMÚDEZ (1965) and *Globorotalia hirsuta* (BRADY, 1882), but some aspects of the

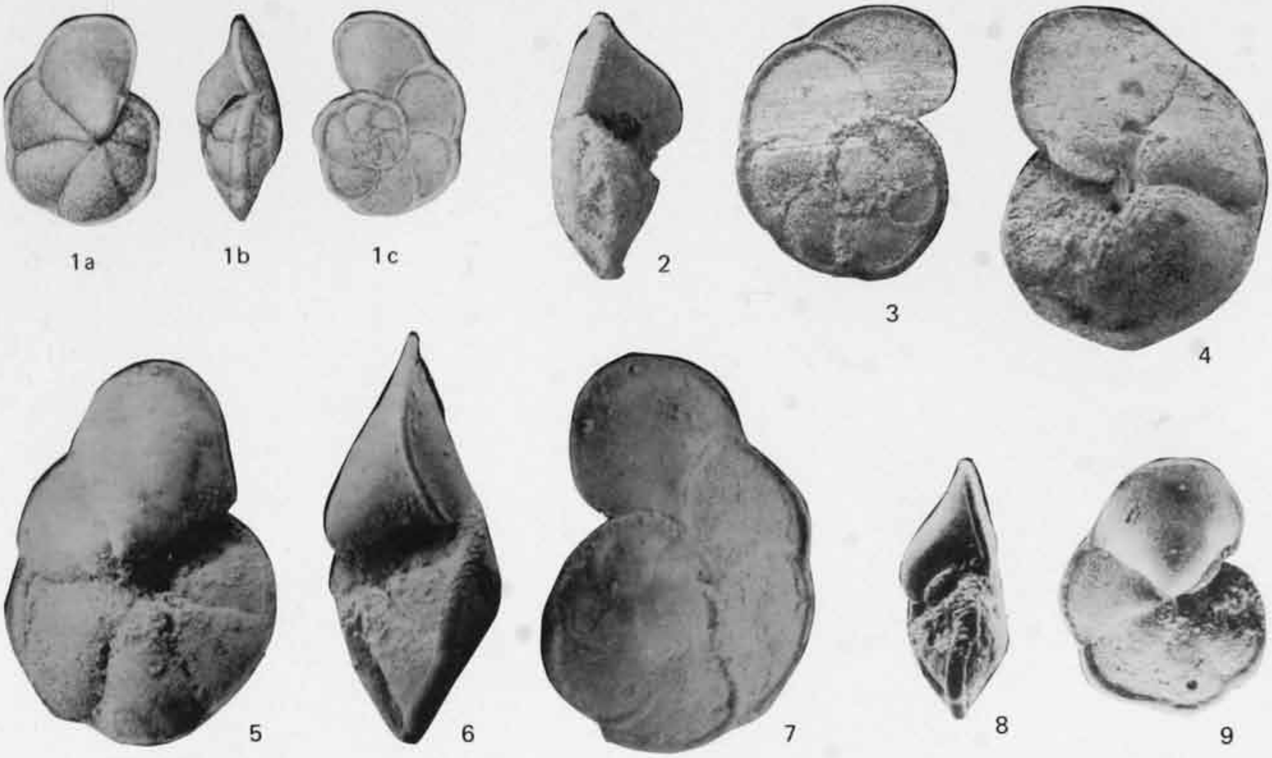

Fig. 194. *Globorotalia plesiotumida* BLOW & BANNER from the Late Miocene and Pliocene of the Atlantic and Pacific Oceans and Venezuela.

1 Holotype from a Pliocene level (*Globorotalia margaritae* Zone) within the Cubagua Formation of Venezuela, X50; from BANNER & BLOW (1967, pl. 4, fig. 3). **a**–Umbilical view; **b**–side view; **c**–spiral view.

2-4 Specimens from the Pliocene (*Globorotalia margaritae* Zone) of the tropical Atlantic Ocean, X80; from PARKER (1973, pl. 3, fig. 1-3). **2**–Side view; **3**–spiral view; **4**–umbilical view.

5-7 Specimens from the Late Miocene (*Globorotalia acostaensis* Zone) of the western Pacific Ocean; from KRASHENINNIKOV & HOSKINS (1973, pl. 26, fig. 10-12). **5**–Umbilical view, X70; **6**–side view, X72; **7**–spiral view, X70.

8-9 Specimens from the Late Miocene (*Globorotalia acostaensis* Zone) of the western north Atlantic Ocean, X90; from POAG (1972b, pl. 6, fig. 9-10). **8**–Side view; **9**–umbilical view.

original diagnosis of *G. praehirsuta* are emended. In particular, BLOW described it as planoconvex but did not illustrate the axial profile; in our studies, specimens assigned to the transitional category were consistently biconvex.

This species differs from *Globorotalia margaritae* in having only four chambers in the last whorl, generally larger size, greater inflation of chambers around the umbilicus, and radially broader, differently shaped chambers on the spiral side. From *G. hirsuta*, on the other hand, it differs in being smaller and less convex and in lacking an umbilical pit and incision of adjacent sutures.

Distribution.–Mid-Pliocene to Early Pleistocene (upper part of *Globorotalia margaritae* Zone to lower part of *Globorotalia truncatulinoides* Zone). The species was described from Pliocene rocks at Anzio, Italy, and has been reported nearly worldwide. The unillustrated species listed as *Globorotalia praehirsuta* from the Tabianian Stage of Italy by COLALONGO ET AL. (1972) is suspected to be *Globorotalia juanai* BERMÚDEZ & BOLLI (1969). BRÖNNIMANN & RESIG (1971), without text comment, plotted the range of *G. praehirsuta* as mainly preceding the first appearance of *G. margaritae* in the southwestern Pacific.

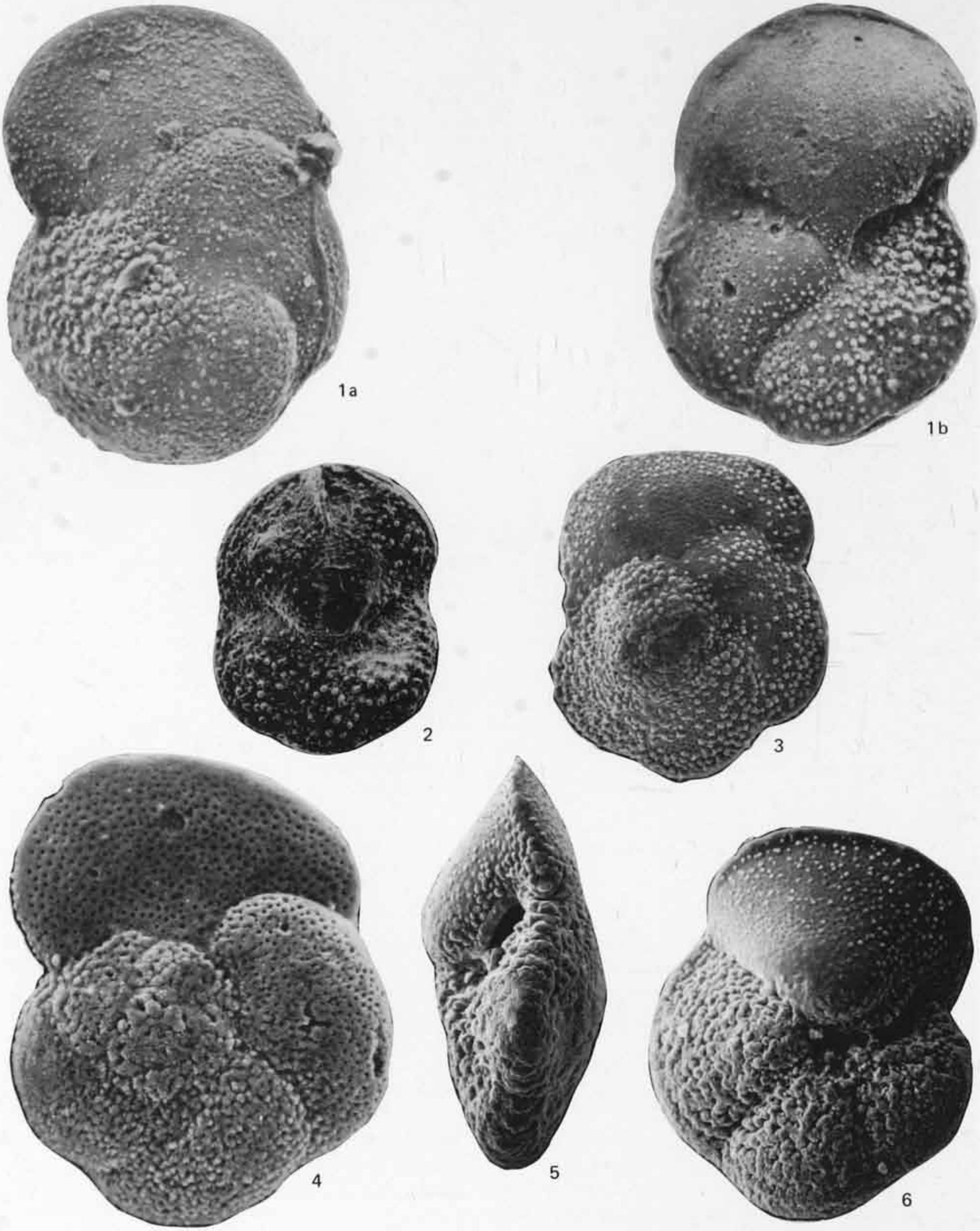

Fig. 195

Fig. 195. *Globorotalia praehirsuta* BLOW from the Pliocene of Italy, Gulf of Mexico, and New Zealand.

1 Holotype from the Pliocene of Anzio, Italy; from BLOW (1969, pl. 43, fig. 4-5). **a**–Spiral view, X122; **b**–umbilical view, X120.

2 Umbilical view of specimen transitional to *Globorotalia margaritae* BOLLI & BERMÚDEZ from the Pliocene of North Island, New Zealand, X156?; from COLLEN & VELLA (1973, pl. 7, fig. 9).

3-6 Specimens from the Pliocene (*Pulleniatina obliquiloculata* Zone) of the Gulf of Mexico, X110; after LAMB & BEARD (1972, pl. 18, fig. 9-12). **3-4**–Spiral views; **5**–side view; **6**–umbilical view.

GLOBOROTALIA PRAEMIOCENICA Lamb & Beard, 1972

Figure 196

Middle Pliocene? to Early Pleistocene

Globorotalia (Globorotalia) cultrata limbata (FORNASINI, 1902) [part]. BLOW, 1969 [**not** FORNASINI], p. 359, pl. 42, fig. 2-3 [**not** pl. 7, fig. 4-6].

Globorotalia pseudomiocenica BOLLI & BERMÚDEZ. BOLLI, 1970, pl. 7, fig. 1-3 [**not** BOLLI & BERMÚDEZ, 1965].

Globorotalia praemiocenica LAMB & BEARD, 1972, p. 55, pl. 17, fig. 1-3, 6.

Test a lenticular trochospire of average size for the genus. Chambers (5 to 7) in last whorl increase in size gradually and slightly irregularly, each carrying a conspicuously blunt keel. Equatorial profile subpolygonal in early portion, becoming lobate on last 2 to 3 chambers. Axial profile reveals tumid umbilical region and distinctly convex spiral side, thickness approximately half diameter. Sutures on spiral side strongly limbate, strongly recurved, in early portion fusing into a continuous keel; on umbilical side depressed, radial, faintly sinuous. Umbilicus small, shallow. Aperture a low opening from umbilicus to margin, with thin lip. Wall thin, finely perforate. Diameter 0.5 to 0.6 mm.

Discussion.–This is the first of a line of thin-walled, dextrally coiled, menardiform globorotalias that developed during the Pliocene, as already discussed under *Globorotalia exilis* BLOW (1969). Its presumed forerunners in the Late Miocene were generally sinistral (e.g., *Globorotalia pseudomiocenica* BOLLI & BERMÚDEZ, 1965), more compressed, and thicker shelled.

Distribution.–Middle Pliocene to Early Pleistocene in the Caribbean and Gulf of Mexico regions (*Globorotalia margaritae* Zone to within lower part of the *Globorotalia truncatulinoides* Zone). Very similar forms seemingly occur in the Late Miocene of the Pacific region.

PULLENIATINA PRIMALIS Banner & Blow, 1967

Figures 197-198

Late Miocene to Early Pleistocene

Pulleniatina semiinvoluta GERMERAAD. PARKER, 1965, p. 151, fig. 5-6.

Fig. 196. *Globorotalia praemiocenica* LAMB & BEARD from the Pliocene of the western Atlantic Ocean, Virginia, Gulf of Mexico, and Papua. [p. 400]

1-3 Specimens from the Pliocene (*Pulleniatina obliquiloculata* Zone) of the Gulf of Mexico, X125; from LAMB & BEARD (1972, pl. 17, fig. 1-3). **1**–Umbilical view of holotype; **2**–side view of paratype; **3**–spiral view of paratype.

4-5 Specimens identified as *Globorotalia exilis* BLOW? from the Pliocene (*Pulleniatina obliquiloculata* Zone) of the western north Atlantic, X90; from POAG (1972b, pl. 3, fig. 7-8). **4**–Umbilical view; **5**–side view.

6-8 Specimens identified as a subspecies of *Globorotalia cultrata* (D'ORBIGNY) from the Pliocene Yorktown Formation of Virginia; from AKERS (1972, pl. 51, fig. 2). **6**–Side view, X78; **7**–umbilical view, X80; **8**–spiral view, X79.

9-10 Specimens identified as *Globorotalia cultrata limbata* (FORNASINI) from probable Pliocene strata of Papau, X130; from BLOW (1969, pl. 42, fig. 2-3). **9**–Side view; **10**–spiral view.

Fig. 197. *Pulleniatina primalis* BANNER & BLOW from the Pliocene (*Globorotalia margaritae* Zone) of Jamaica and western north Atlantic Ocean. [p. 401]

1-4 Holotype (1 from BANNER & BLOW, 1967, pl. 3, fig. 2) and topotypes (from a split of BLOW'S sample WHB 181.B = locality RMS 119608) from the Bowden Formation of Jamaica. Right coiling of the holotype indicates that it came from a level above the coiling change for this species which occurs within the upper part of the *Globorotalia margaritae* Zone. A list of associated planktonic species in this sample was given by LAMB & BEARD (1972, fig. 14). **1a,2**–Spiral views, X100, X190; **1b,4**–umbilical views, X100, X190; **1c,3**–side views, X100, X210.

5-6 Specimens from the western north Atlantic, X90; from POAG (1972b, pl. 4, fig. 5-6). **5**–Side view; **6**–umbilical view.

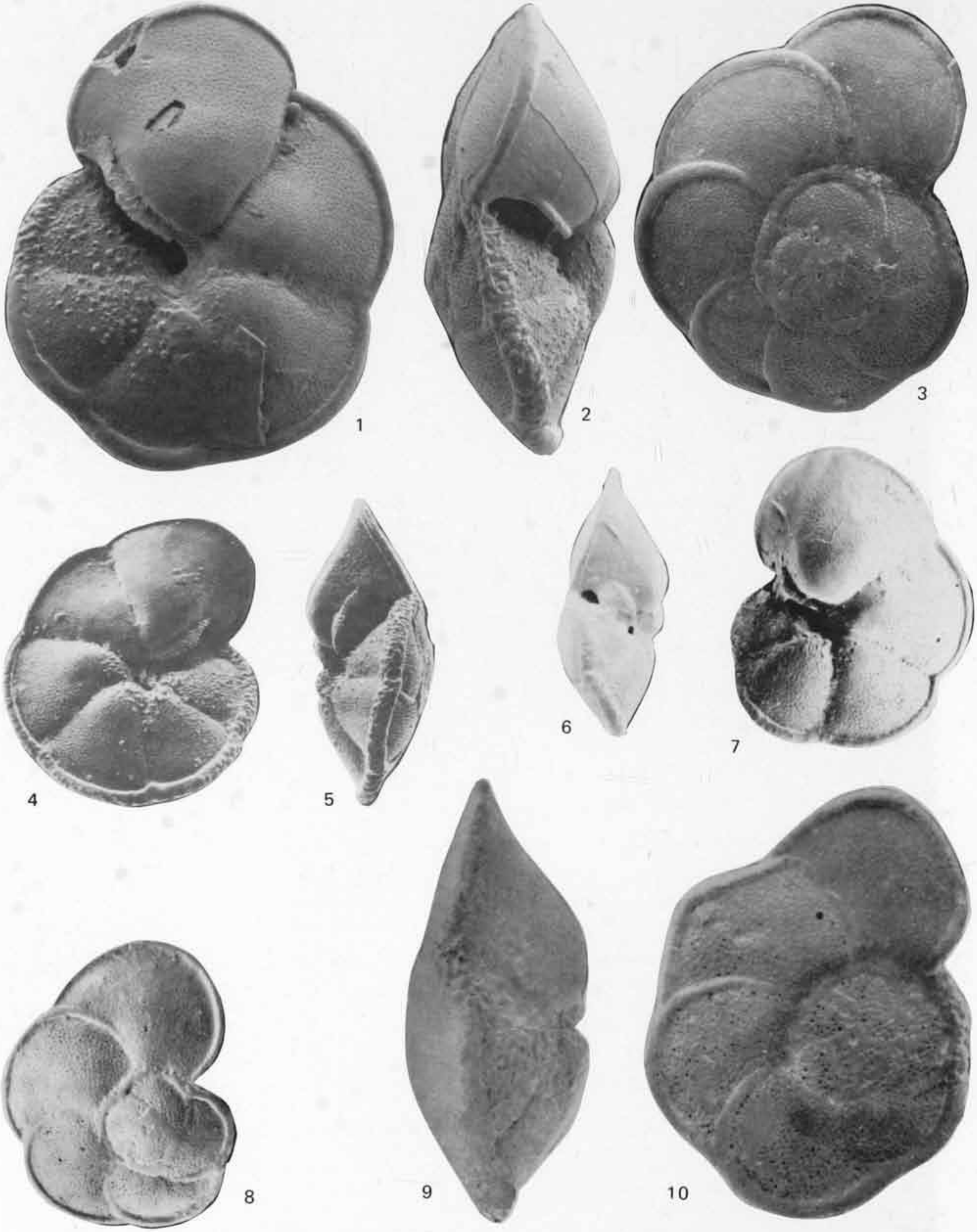

Fig. 196

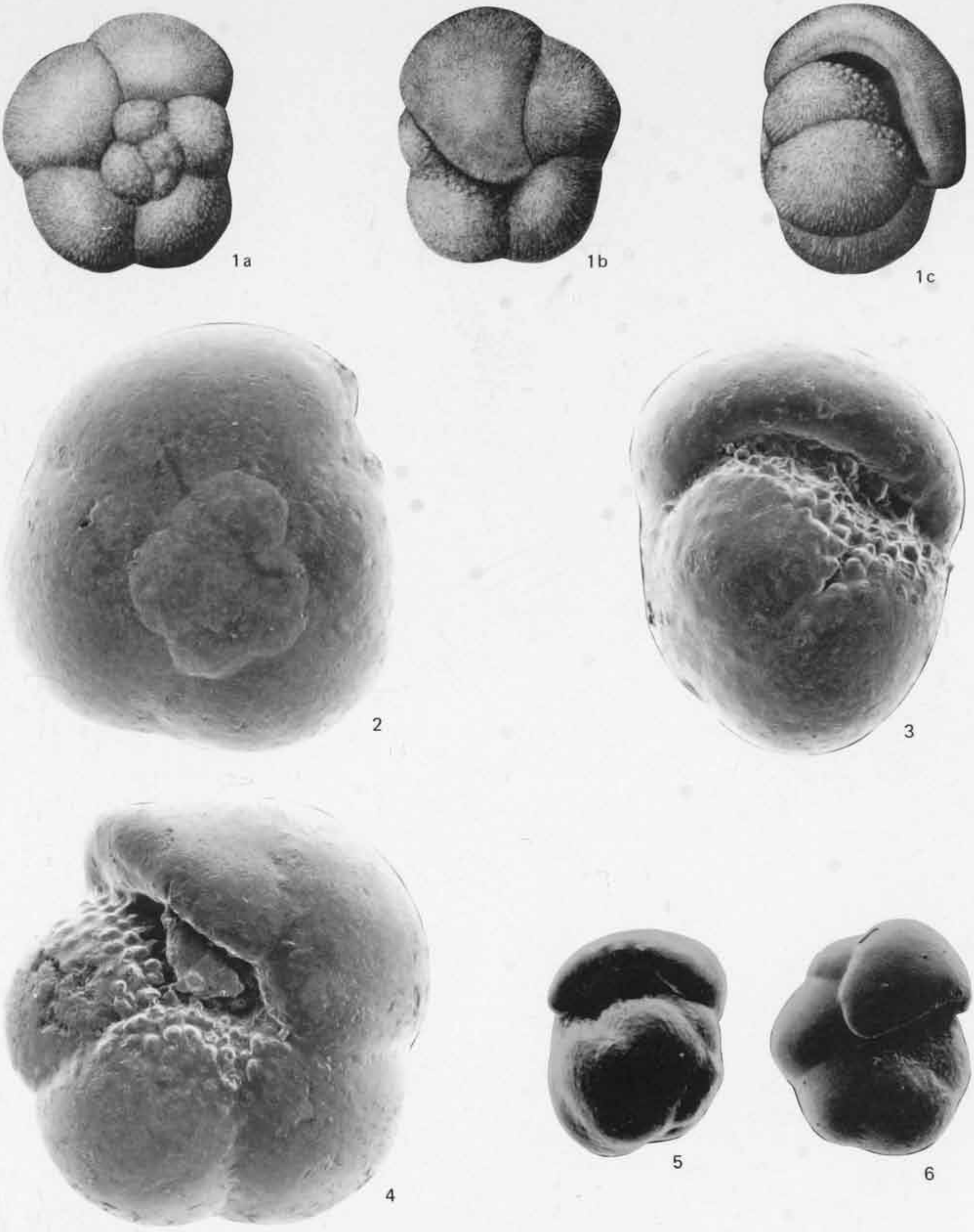

Fig. 197

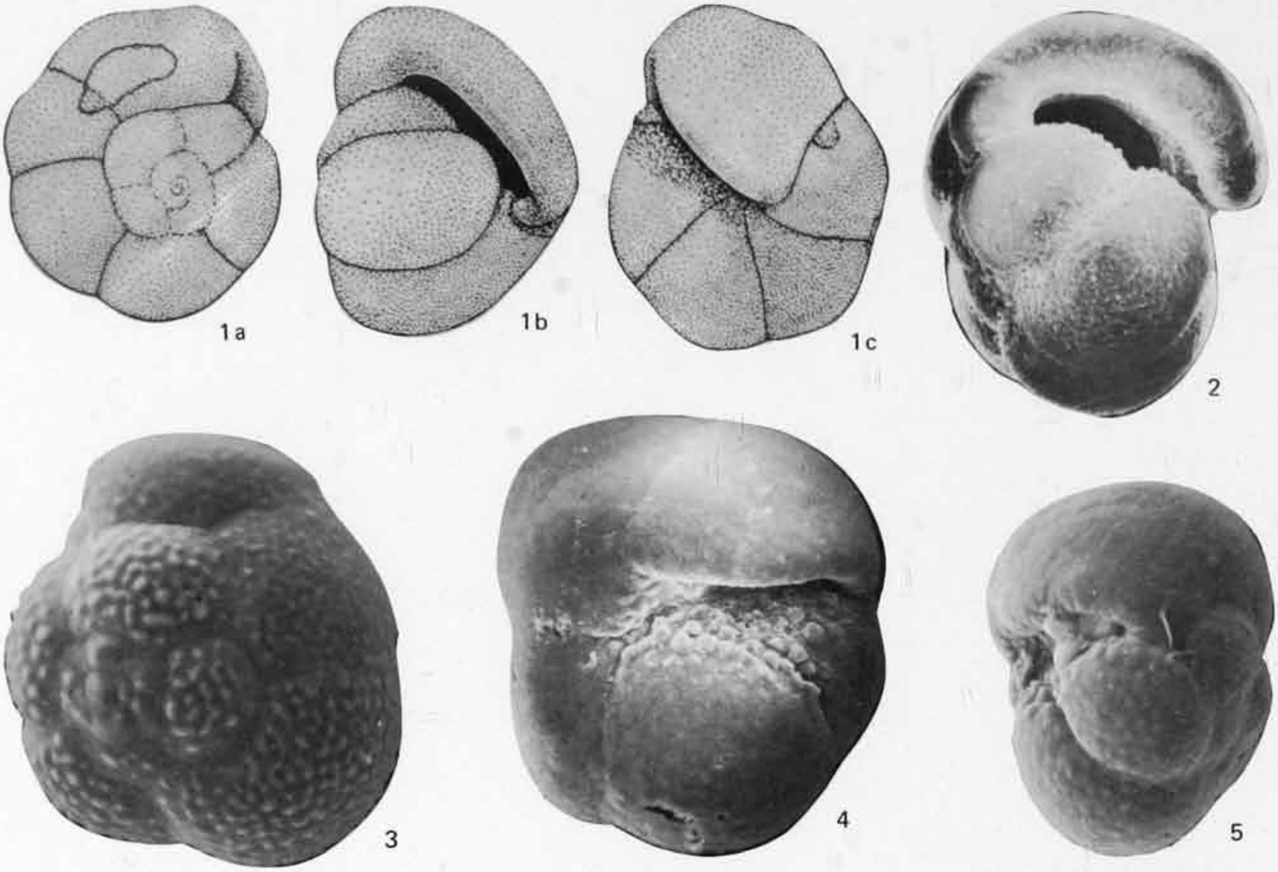

Fig. 198. *Pulleniatina primalis* BANNER & BLOW from the Pliocene (*Globorotalia margaritae* Zone) of the south Pacific Ocean and Gulf of Mexico regions.

1 Specimens from the south Pacific Ocean, X72; from PARKER (1967, pl. 27, fig. 5). **a**–Spiral view; **b**–side view; **c**–umbilical view.

2 Side view of specimen from the southwestern Pacific Ocean, X132; from BRÖNNIMANN & RESIG (1971, pl. 20, fig. 7).

3-5 Specimens from the Gulf of Mexico, X90; from LAMB & BEARD (1972, pl. 28, fig. 7-9). **3**–Spiral view; **4**–umbilical view; **5**–side view.

Pulleniatina primalis BANNER & BLOW, 1967, p. 142, pl. 1, fig. 3-8; pl. 3, fig. 2.–PARKER, 1967, p. 173, pl. 27, fig. 6 [**not** 5].–JENKINS & ORR, 1972, p. 1108, pl. 39, fig. 3-10.–BRÖNNIMANN & RESIG, 1971, p. 1286, fig. 24, pl. 20, fig. 7.–LAMB & BEARD, 1972, p. 58, pl. 28, fig. 5, 7-9.

Test tumid, seemingly a regular trochospire. Last whorl of 4 to 5 broadly rounded chambers increasing rather slowly in size. Equatorial periphery subcircular to subpentagonal; axial profile ovate, somewhat flattened on spiral side. Sutures distinct, depressed, radial, slightly curved to sinuous. Umbilicus initially shallow, later hidden by overlapping tips of adult chambers. Aperture a low arch from umbilical area to near periphery, bordered by rimlike apertural face. Wall perforate, smooth; generally pustulose in umbilical region, less commonly over much of test. Overlap of umbilical-chamber tips is symptom of developing streptospirality typical of *Pulleniatina*. Diameter 0.20 to 0.65 mm; holotype 0.43 mm.

Discussion.–*Pulleniatina primalis* evidently developed from the lineage of *Globorotalia acostaensis* BLOW (1959) and an intermediate form was described as *Pulleniatina praepulleniatina* BRÖNNIMANN & RESIG (1971). In turn *P. primalis* gave rise to the more obviously streptospiral forms typical of *P. obliquiloculata* s.s. Specimens transitional between these two species were designated as *P. obliquiloculata praecursor* BANNER & BLOW (1967). We consider *P. praecursor* a recognizable species, contrary to some authors (e.g., PARKER, 1967), but unimportant as a zonal index; its range falls within the concurrent range of *P. primalis* and *P. obliquiloculata* s.s. The lineage is reviewed further under discussion of the *Pulleniatina obliquiloculata* group.

Distribution.—Late Miocene to Early Pleistocene (*Globorotalia acostaensis* Zone to within basal part of *Globorotalia truncatulinoides* Zone). This species was described from the Pliocene part of the Bowden Formation of Jamaica and is recorded nearly worldwide. Although it first appears in the Late Miocene of the Pacific region, it is not encountered below the Pliocene (*Globorotalia margaritae* Zone) in the Gulf of Mexico, Caribbean, and Atlantic regions.

GLOBOROTALIA PUNCTICULATA (Deshayes, 1832)

Figures 199-200

Pliocene

Globigerina punctulata D'ORBIGNY, 1826, p. 277 [nomen nudum].

Globigerina puncticulata "D'ORBIGNY", nobis, DESHAYES, 1832, p. 170.—BANNER & BLOW, 1960a, p. 15-17, pl. 5, fig. 7 [lectotype designated].

Globigerina punctulata D'ORBIGNY [sic]. FORNASINI, 1898 [1899], p. 210, fig. 5 [unpublished figure of D'ORBIGNY].—BANNER & BLOW, 1960a, p. 15-17, pl. 5, fig. 7 [lectotype designated].

Globorotalia punctulata (D'ORBIGNY) of authors [nomen nudum].

Globorotalia puncticulata (D'ORBIGNY) [sic] of authors.

Globorotalia (Turborotalia) puncticulata (DESHAYES). BANNER & BLOW, 1960a, p. 17, pl. 5, fig. 7.—BLOW, 1969, p. 354.

Globorotalia puncticulata (DESHAYES). BARBIERI, 1969, p. 73, pl. 1, fig. 9.—BARBIERI, 1971, p. 10-12, fig. 3-6.

Test a compact, biconvex trochospire, umbilical side slightly more convex than spiral side. Chambers (4) in last whorl increasing in size slowly and somewhat irregularly as added; elongate crescents on spiral side, radial segments on umbilical side. Equatorial profile mildly lobate, subcircular; axial profile typified by bluntly rounded, faintly shouldered periphery. Sutures distinct, on adult portion incised; on spiral side strongly recurved, conforming with lunate shape of individual chambers, on umbilical side almost straight, radial. Umbilicus closed. Aperture a prominent arch in slightly recessed apertural face, extending from umbilicus about halfway to periphery. Surface smooth and finely perforate except where covered by dense to sparse pustules. Diameter to 0.5 mm. [Description based on lectotype which was designated by BANNER & BLOW (1960a) for both *Globigerina puncticulata* DESHAYES and *Globigerina punctulata* FORNASINI.]

Discussion.—This species is mentioned frequently in modern literature on the Neogene of the Mediterranean region. Unfortunately its biostratigraphic utility has been dissipated by taxonomic complexities and imprecise application of the name. BANNER & BLOW (1960a) explained the reasons for accepting DESHAYES' name and described a lectotype. BARBIERI (1971), however, challenged their choice of lectotype and further reviewed the confused state of the species. The authors cited (also JENKINS, 1971) indicated that the name *Globorotalia puncticulata* was applied erroneously to specimens of *Globorotalia crassaformis* (GALLOWAY & WISSLER, 1927), *Globorotalia crassula* CUSHMAN, STEWART, &

Fig. 199. *Globorotalia puncticulata* (DESHAYES) from the Early Pliocene of Italy. [p. 404]

1 Lectotype from redeposited Neogene sediments near Rimini, Italy, X100; from BANNER & BLOW (1960a, pl. 5, fig. 7). **a**—Umbilical view; **b**—side view; **c**—spiral view.

2-7 Specimens from the type section of the Tabianian Stage (Early Pliocene) of northern Italy ("New Church" locality). **2**—Side view showing high-arched aperture with rim, X125; **3-4**—spiral views, X120, X125; **5-7**—umbilical views, X125.

Fig. 200. *Globorotalia puncticulata* (DESHAYES) from the Pliocene of the Mediterranean Sea and New Zealand. [p. 405]

1-2 Specimens from the Pliocene of North Island, New Zealand; from COLLEN & VELLA (1973, pl. 5, fig. 8-9). **1**—Side view, X148; **2**—spiral view, X143.

3-5 Specimens from the Early Pliocene (*Globorotalia margaritae* Zone) of the Tyrrhenian basin; from CITA (1973, pl. 3, fig. 1, 3-4). **3**—Oblique side view, X185; **4**—spiral view, X153; **5**—umbilical view, X165.

6-8 Virtual topotypes from Lido Cervia, Ravenna, Italy; intertidal zone in front of the Kursaal. **6**—Spiral view, X120; **7**—side view, X125; **8**—umbilical view, X120.

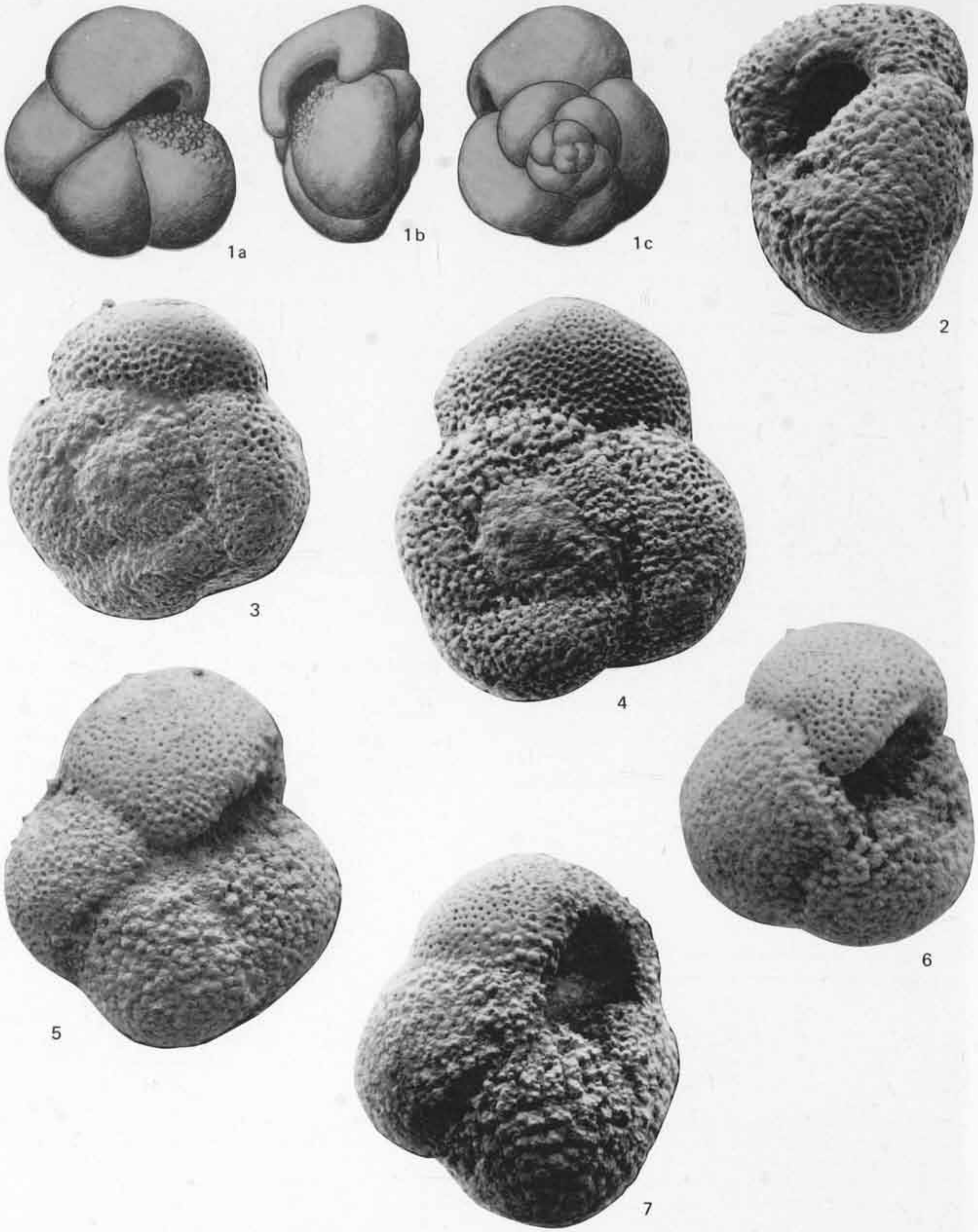

Fig. 199

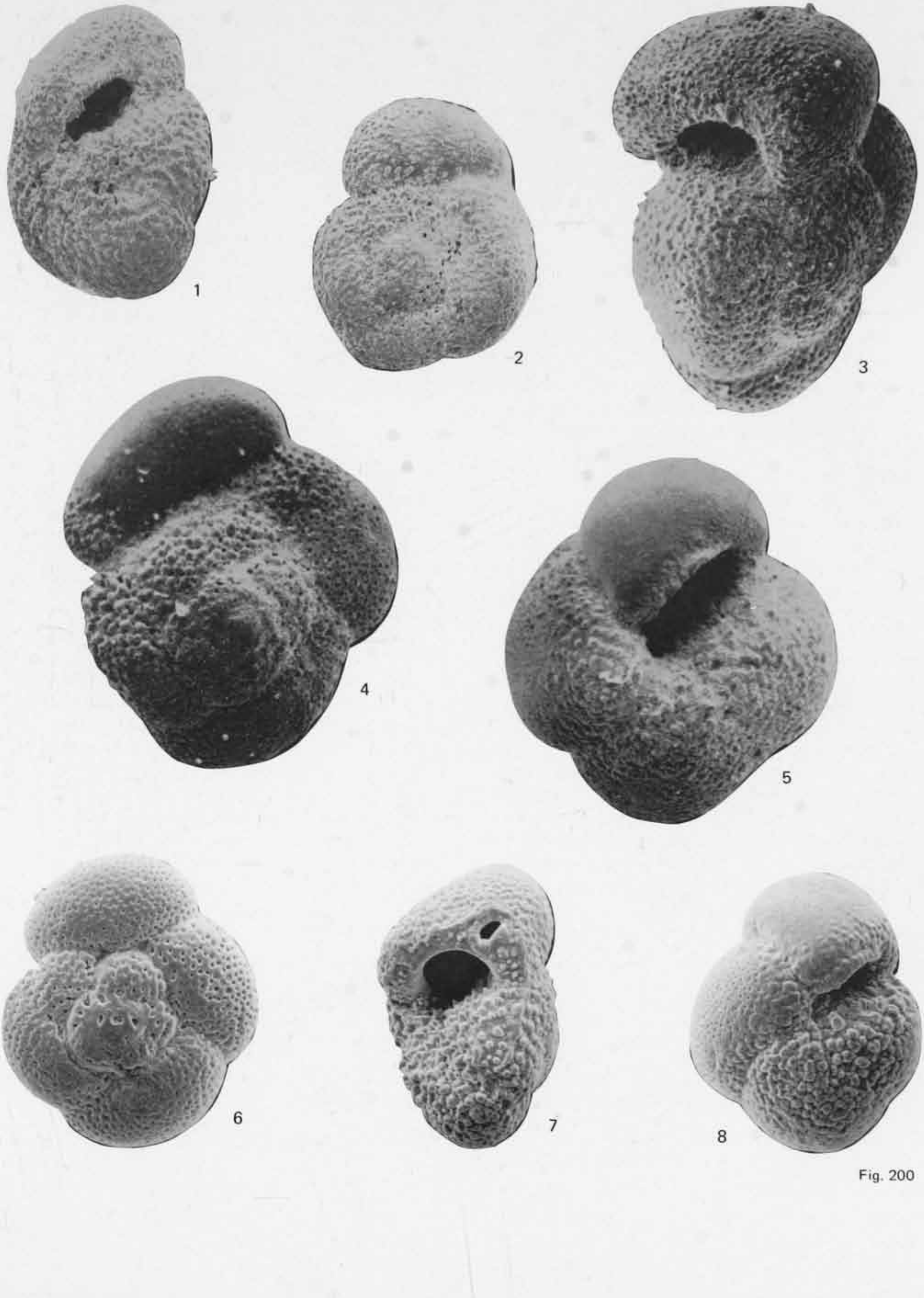

Fig. 200

STEWART (1930), *Globorotalia inflata* (D'ORBIGNY, *in* BARKER-WEBB & BERTHELOT, 1839), and *Globorotalia ronda* BLOW (1969). In the Mediterranean region *G. puncticulata* is used widely as the nominal index of a Pliocene zone (CATI ET AL., 1968), but authors evidently apply differing criteria to its identification.

In our opinion the form lectotypified by BANNER & BLOW (1960a) is morphologically distinct enough for biostratigraphic use whether it is a true species or an ecologically produced variant (as suggested by BARBIERI). To reduce confusion, we provide illustrations of comparable specimens from the stratotype Tabianian (Early Pliocene) of northern Italy, where this species has been recorded by many workers. *Globorotalia puncticulata* may well be a descendant of *Globorotalia subscitula* CONATO (1964) and represent a lineage homeomorphic with, but younger than, the forerunners of *Globorotalia scitula* (BRADY, 1882). We distinguish it from *G. crassaformis* mainly by its axial profile in which the umbilical side is only mildly inflated and never subconical to hemispherical; the periphery is bluntly rounded, not subacute or pinched; and the spiral side is definitely convex, never flattened or dished. Though DESHAYES described the chambers as "... tous chagrinés et couverts de ponctuations ...," the roughness and pustulosity differ greatly among individuals, possibly reflecting ecologic more than genetic factors.

Distribution.—Early to Middle Pliocene (*Globorotalia margaritae* Zone to within *Pulleniatina obliquiloculata* Zone). Described from modern beach sands at Rimini, northeast Italy, but regarded as a reworked Neogene fossil there (e.g., CITA & D'ONOFRIO, 1967). Many nominal records exist for Pliocene and Holocene assemblages, including that of BANNER & BLOW (1960a) accompanying the description of the lectotype, but our studies fail to confirm undoubted *Globorotalia puncticulata* at post-Pliocene levels. BLOW (1969) asserted that this species is virtually confined to cool-water areas and does not occur in tropical assemblages.

GLOBIGERINOIDES QUADRILOBATUS FISTULOSUS (Schubert, 1910)

Figure 201

Middle Pliocene to Early Pleistocene

Globigerina fistulosa SCHUBERT, 1910, p. 323-324, fig. 2.

Globigerinoides sacculifera fistulosa (SCHUBERT). CUSHMAN, TODD, & POST, 1954, p. 369, pl. 91, fig. 13.

Globigerinoides quadrilobatus fistulosus (SCHUBERT). BELFORD, 1962, p. 16, pl. 4, fig. 7-10.—BANNER & BLOW, 1965a, p. 112.

Globigerinoides fistulosus (SCHUBERT). PARKER, 1967, p. 154-155, pl. 21, fig. 3, 5-6.—POSTUMA, 1971, p. 292-293, 4 fig.—LAMB & BEARD, 1972, p. 48, pl. 31, fig. 4, 7-8.

Globigerinoides trilobus fistulosus (SCHUBERT). BOLLI, 1970, p. 579, pl. 1, fig. 8-11.

Test a low trochospire, closely similar to *Globigerinoides quadrilobatus sacculifer* (BRADY, 1877) in all respects except that wall of final and (commonly) penultimate chamber is prolonged into 1 to 5 slender, digitate extensions. Diameter 0.35 to 0.50 mm.

Discussion.—This subspecies seemingly developed directly from *Globigerinoides quadrilobatus sacculifer;* several of the cited authors illustrate transitional forms. The subspecies *G. q. hystricosus* BELFORD (1962) differs only slightly, having fewer digitate extensions that partly merge into apiculate spines. BOLLI (1970) illustrated more complexly fistulose forms under the name *Globigerinoides trilobus A.* Strongly digitate specimens appear to be good indicators of tropical environments.

Distribution.—Middle Pliocene to Early Pleistocene (*Pulleniatina obliquiloculata* Zone to within

Fig. 201. *Globigerinoides quadrilobatus fistulosus* (SCHUBERT) from the Pliocene and Pleistocene of the Pacific and Caribbean regions. ▷

1 Spiral view of holotype (magnification unknown) from SCHUBERT (1910, fig. 2) from *Globigerina* marls of indefinite Neogene age in New Guinea.

2 Specimen from probable Pliocene sediments of the south Pacific Ocean, X36; from PARKER (1967, pl. 21, fig. 6). **a**—Spiral view; **b**—umbilical view.

3-5 Specimens from the Pleistocene of the Caribbean Sea, from BOLLI (1970, pl. 1, fig. 6, 16-17). **3-4**—Broken-off final chambers of extreme variants showing the proliferation and irregular arrangement of the fistules, X56; **5**—oblique spiral view, X88.

6-7 Specimens from the Pliocene-Pleistocene of the eastern equatorial Pacific Ocean; from JENKINS & ORR (1972, pl. 13, fig. 1, 3). **6**—Umbilical view, X70; **7**—spiral view, X110.

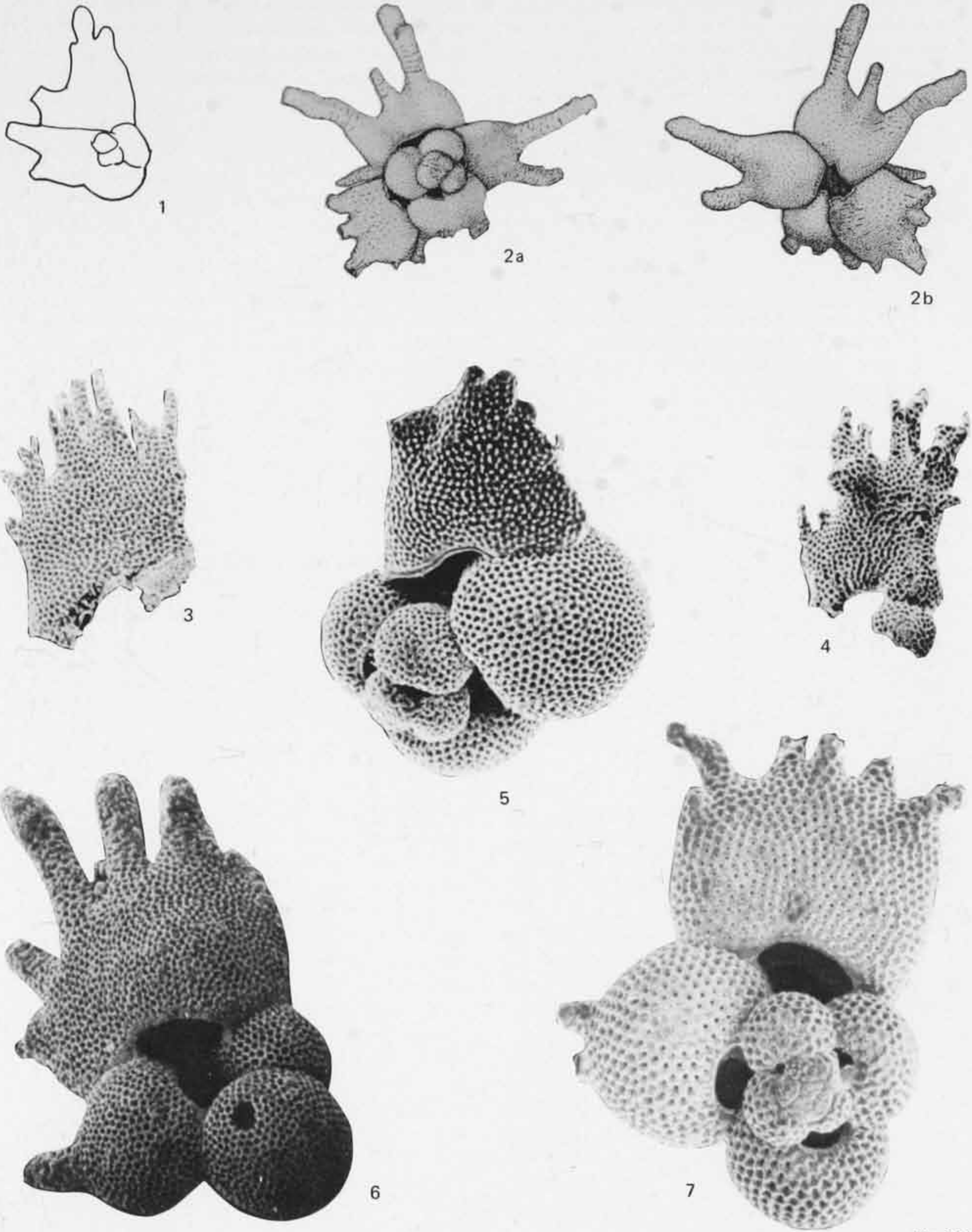

Fig. 201

lower part of *Globorotalia truncatulinoides* Zone). Described originally from *Globigerina* marl of indefinite Neogene age in New Guinea, this subspecies since has been recorded almost worldwide.

GLOBOROTALIA RONDA Blow, 1969

Figures 202-203
Late Pliocene to Early Pleistocene

Globorotalia (Turborotalia) crassaformis ronda BLOW, 1969, p. 388-389, 393-394, pl. 4, fig. 4-6; pl. 37, fig. 6-9.–BRÖNNIMANN & RESIG, 1971, p. 1380, 1443, 1449, 1455, 1461, 1467, pl. 27, fig. 8.

Globorotalia tosaensis TAKAYANAGI & SAITO. PHILLIPS ET AL., 1968, p. 122-123, fig. 4 (fide PARKER, 1973).–KENNETT & GEITZENAUER, 1969, p. 2, fig. 1 [middle row].–LAMB & BEARD, 1972, p. 56, pl. 22, fig. 1-7 [not pl. 23, fig. 1-2].

?*Globorotalia truncatulinoides* cf. *ronda* BLOW. BOLLI, 1970, p. 583, pl. 3, fig. 13-15.

Globorotalia truncatulinoides cf. *tosaensis* TAKAYANAGI & SAITO. BOLLI, 1970, p. 583, pl. 3, fig. 16-18.

Globorotalia crassaformis GALLOWAY & WISSLER X *G. tosaensis* TAKAYANAGI & SAITO. KENNETT, 1973, p. 626, pl. 15, fig. 1-4.

Test moderately large, a regular trochospire approximating planoconvex, umbilical side tumid. Chambers (4, rarely 4½) in last whorl increase in size slowly as added, maintaining same shape. Equatorial profile slightly lobulate to (more commonly) unindented, subcircular; axial profile on umbilical side approximately semicircular, on spiral side slightly depressed between axial convexity and peripheral rim formed by bluntly rounded shoulders of chambers of last whorl. Sutures on spiral side incised, very slightly curved to almost straight; on umbilical side incised, radial to slightly sinuous. Umbilicus small, open, deep. Aperture a low arched slit from umbilicus to near periphery, may have thin lip. Diameter 0.5 to 0.6 mm.

Discussion.–*Globorotalia ronda* differs from its immediate ancestor *Globorotalia crassaformis* (GALLOWAY & WISSLER, 1927) in its more rounded general shape (contributing to which is the rounded shoulder of its final whorl), hemispherical umbilical side, and generally unindented periphery. It is regarded as the direct ancestor of *Globorotalia tosaensis* TAKAYANAGI & SAITO (1962) (e.g., BLOW, 1969; BOLLI, 1970), a form of more planoconical shape and differing also in its less pustulose wall, deeper umbilicus, and 5- rather than 4-chambered last whorl. Almost imperceptible gradation from *G. ronda* into *G. tosaensis* was observed in the upper part of the Pleistocene Bowden Formation of Jamaica in samples discussed by ROBINSON & LAMB (1970). In studies completed before BLOW (1969) separated this transitional species, several authors applied the name *G. tosaensis* to specimens of *G. ronda*.

Distribution.–Late Pliocene to Early Pleistocene (*Pulleniatina obliquiloculata* Zone to within lower part of the *Globorotalia truncatulinoides* Zone). This species locally is quite common in the Aftonian interglacial interval of the Gulf of Mexico region, where it has been mistaken for *G. tosaensis*. Similar morphotypes mentioned by LIDZ (1972) from the late Quaternary and Holocene of the Caribbean Sea and Atlantic Ocean seemingly are more lobulate than typical *G. ronda*. This species was described from the Early Pleistocene Bowden Formation of Jamaica and has been recorded from the Atlantic, Caribbean and Gulf of Mexico, and equatorial Pacific Ocean regions.

PULLENIATINA SPECTABILIS Parker, 1965

Figure 204
Middle to Late Pliocene

Pulleniatina spectabilis PARKER, 1965, p. 151-152, fig. 1-4.–PARKER, 1967, p. 174, pl. 28, fig. 2.–BANNER & BLOW, 1967, p. 143-144, pl. 2, fig. 2-3.–BRÖNNIMANN & RESIG, 1971, p. 1320, fig. 25, pl. 19, fig. 5.

Pulleniatina spectabilis spectabilis PARKER. BRÖNNIMANN & RESIG, 1971, p. 1287.

Test tumid, initially trochospiral, becoming slightly streptospiral in adult. Early chambers globose and very little embracing; later chambers progressively less inflated and more embracing, developing subacute and ultimately pinched, pseudocarinate periphery. Chambers (4½ to 6) in last whorl of subequal size in adult specimens. Axial profile planoconvex except for slightly protruding initial coil; equatorial profile lobulate, rounded. Sutures obscure on umbilical side, sinuously radial distinct on spiral side, recurved to subradial, nearly flush. Umbilicus concealed by blunt tips of final chambers. Aperture a narrow slit to low arch, wholly extraumbilical, without lip or rim. Wall layered, in adult smooth and somewhat polished, finely perforate. Diameter commonly 0.6 to 0.7 mm but may exceed 0.8 mm.

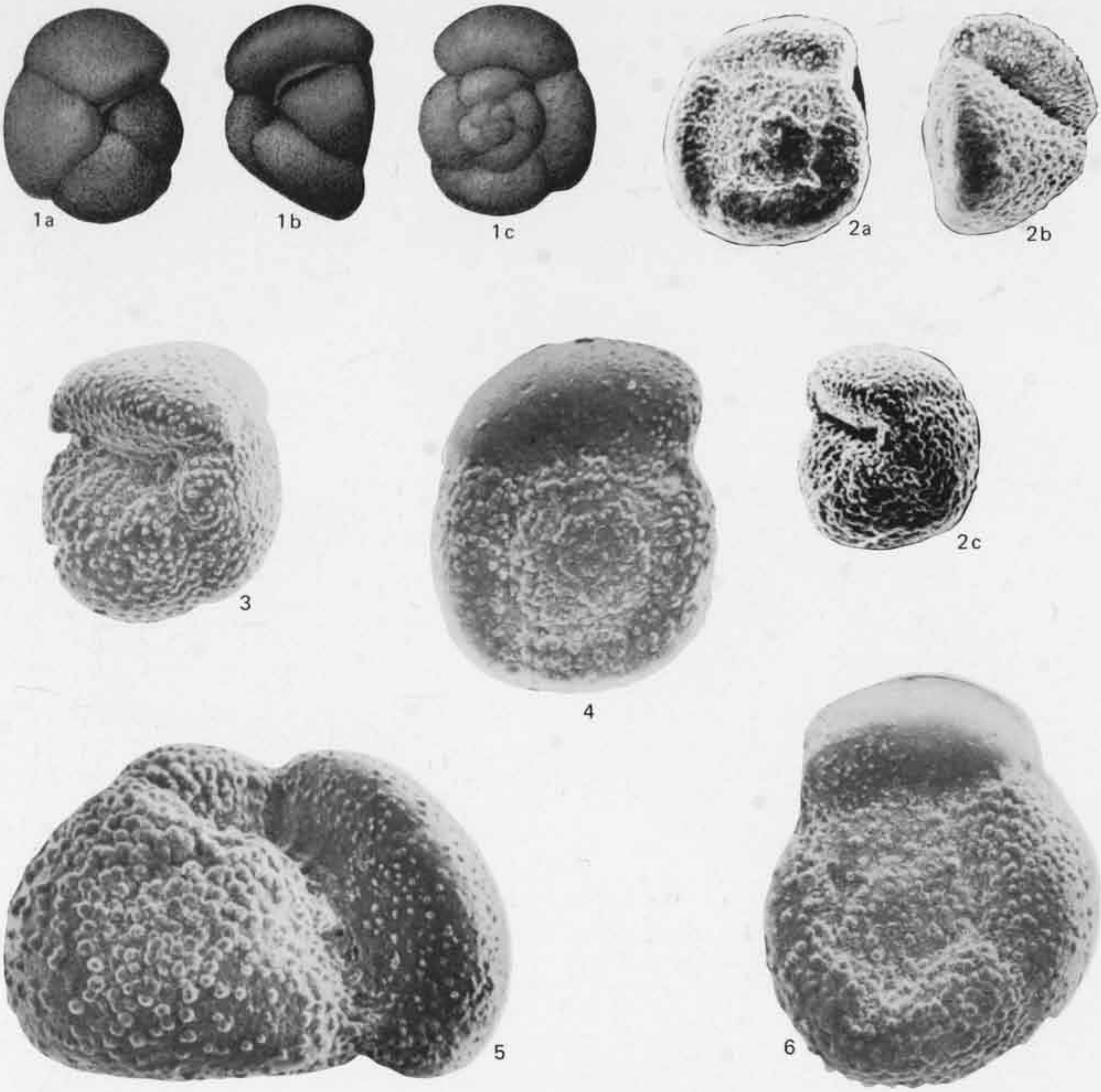

Fig. 202. *Globorotalia ronda* BLOW from the Pliocene and Early Pleistocene of the Atlantic Ocean and Jamaica.

1 Holotype from a Pliocene level within the Buff Bay Formation of Jamaica, X67; from BLOW (1969, pl. 4, fig. 4-6). **a**–Umbilical view; **b**–side view; **c**–spiral view.

2 Specimen from the Early Pleistocene of the southcentral north Atlantic Ocean identified as *Globorotalia truncatulinoides* cf. *tosaensis* TAKAYANAGI & SAITO, X65; from BOLLI (1970, pl. 3, fig. 16-18). BERGGREN (1967, fig. 4) identified this species as *Globorotalia tosaensis* TAKAYANAGI & SAITO. **a**–Spiral view; **b**–side view; **c**–umbilical view.

3-6 Paratypes from a Pliocene level (*Pulleniatina obliquiloculata* Zone) within the Drivers River Formation of Jamaica; from BLOW (1969, pl. 37, fig. 6-9). LAMB & BEARD (1972, fig. 16) gave a list of associated species from this sample (ER. 195). **3**–Umbilical view, X95; **4,6**–spiral views, X120, X95. **5**–side view, X120.

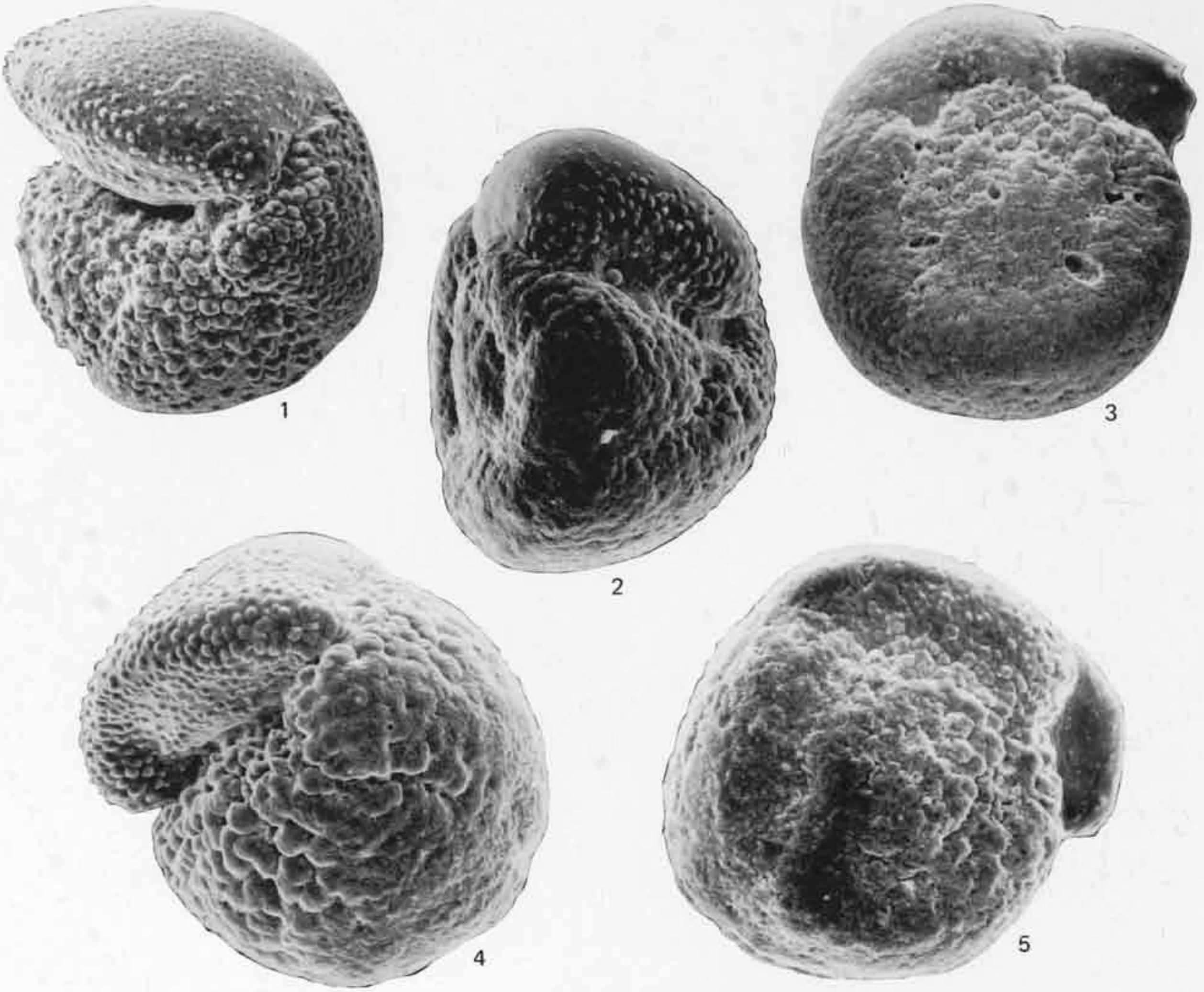

Fig. 203. *Globorotalia ronda* BLOW from the Early Pleistocene of the Gulf of Mexico. Specimens identified as *Globorotalia tosaensis* TAKAYANAGI & SAITO, X120; from LAMB & BEARD (1972, pl. 22, fig. 1-5). **1**–Umbilical view of specimen transitional to *Globorotalia tosaensis;* **2**–side view; **3,5**–spiral views; **4**–umbilical view.

Discussion.–The planoconvex test and sharply angled periphery distinguish this species from other pulleniatines. BANNER & BLOW (1967) considered this species to be derived from *Pulleniatina primalis* BANNER & BLOW (1967) by lateral compression of the later chambers along the peripheral margin. BRÖNNIMANN & RESIG (1971) expressed a similar opinion and gave the subspecific name *praespectabilis* to transitional forms.

Distribution.–Middle to Late Pliocene (*Globorotalia margaritae* Zone to *Pulleniatina obliquiloculata* Zone). This species was described from Pliocene sediments of the south Pacific Ocean and so far is recorded only within this narrow tropical belt, not in the Atlantic region.

SPHAEROIDINELLOPSIS SUBDEHISCENS (Blow, 1959)

Figure 205
Middle to Late Miocene

Sphaeroidinella rutschi CUSHMAN & RENZ, 1941 [part], p. 25, pl. 4, fig. 5c [**not** fig. 5a-b = holotype].–RENZ,

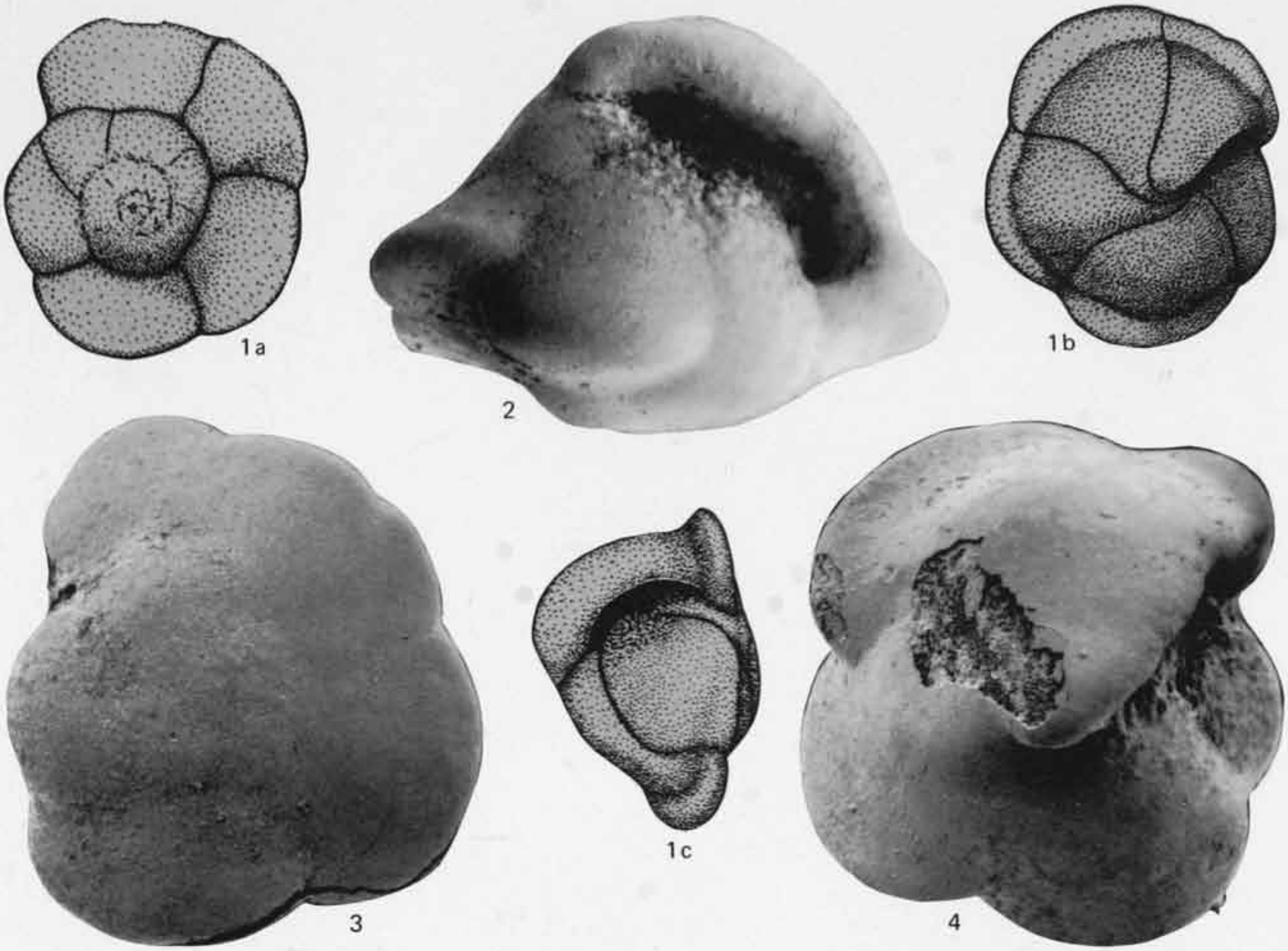

Fig. 204. *Pulleniatina spectabilis* PARKER from the Pliocene (*Globorotalia margaritae* Zone) of the south Pacific Ocean.

1 Ideotype, X52; from PARKER (1967, pl. 28, fig. 2). **a**–Spiral view; **b**–umbilical view; **c**–side view.

2-4 Topotypes from core LSDH 78P (120-122 cm) identified and contributed by MISS FRANCES L. PARKER. **2**–Side view, X105; **3**–spiral view, X100; **4**–umbilical view, X110.

1948 [part], p. 167, pl. 10, fig. 1c [refigured paratype] [**not** fig. 1a-b = holotype refigured].–BOLLI, 1957b, p. 115, pl. 26, fig. 6-7.

Sphaeroidinella dehiscens (PARKER & JONES). STAINFORTH, 1948b, p. 124, pl. 26, fig. 20.–WEISS, 1955, p. 313, pl. 3, fig. 28-29.

Sphaeroidinella dehiscens subdehiscens BLOW, 1959, p. 195, pl. 12, fig. 71 [holotype]–72.

Sphaeroidinellopsis subdehiscens (BLOW). BANNER & BLOW, 1959, p. 15, fig. 5 [holotype, original figure reproduced].–LAMB & BEARD, 1972, p. 60-61, pl. 35, fig. 8-9; pl. 36, fig. 1-3.

Sphaeroidinellopsis subdehiscens subdehiscens (BLOW). BLOW, 1969, p. 338, pl. 30, fig. 1-3, 6.

Sphaeroidinella subdehiscens BLOW. POSTUMA, 1971, p. 388-389.

Test a low trochospire compacted into ovoid form. Subglobular chambers (3) in last whorl subequal or reducing in size as added. Equatorial profile ovate, slightly indented between chambers; axial periphery rounded. Sutures of last whorl distinct although almost flush; earlier sutures obscured by cortex. Umbilicus open, irregular. Aperture an elongate umbilical slit, bordered by thickened and crenulate margins of penultimate and antepenultimate chambers and low arch of thickened shell material at base of last chamber. Primary globigerine wall coarsely perforate, covered with secondary layers of shell material

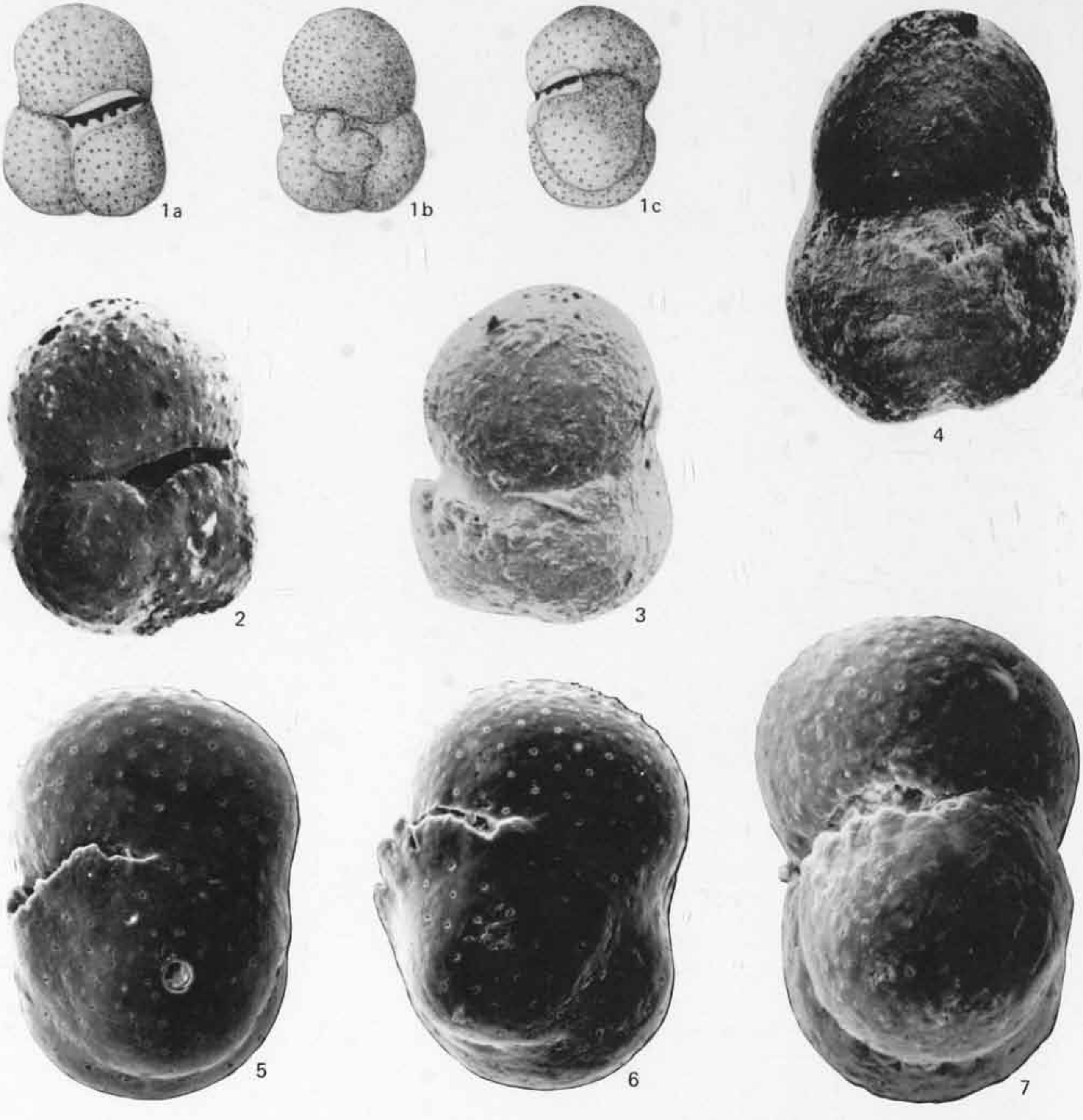

Fig. 205. *Sphaeroidinellopsis subdehiscens* (BLOW) from the Middle and Late Miocene of Venezuela, Trinidad, and Gulf of Mexico.

1 Holotype from the late Middle Miocene (*Globorotalia siakensis* Zone) of the Pozón Formation of Venezuela, X50; from BLOW (1959, pl. 12, fig. 71). **a**–Umbilical view; **b**–spiral view; **c**–side view.

2-4 Ideotype specimens from the Late Middle Miocene (*Globorotalia menardii* Zone) of the Lengua Formation of Trinidad and the late Middle Miocene (*Globorotalia siakensis* Zone) of the Pozón Formation of Venezuela; from BLOW (1969, pl. 30, fig. 1-2, 6). **2**–Umbilical view showing protruding flangelike apertural lips of early chambers and depressed low, smooth apertural arch of last chamber, X105; **3**–oblique umbilical view showing typical strong underbite of profile, X130; **4**–spiral view showing lack of any supplementary aperture, X90.

5-7 Specimens from the Late Miocene (lower part of the *Globorotalia acostaensis* Zone) of the Gulf of Mexico (side views, X150, X150, X170); from LAMB & BEARD (1972, pl. 35, fig. 8-9; pl. 36, fig. 3).

(cortex) restricting pore openings and giving smooth, glassy appearance to test. Diameter 0.3 to 0.5 mm.

Discussion.—This species differs from *Sphaeroidinellopsis seminulina* (SCHWAGER, 1866) primarily in having 3 (rather than 4 or more) chambers in the last whorl and in the heavier cortex. It differs from *Sphaeroidinellopsis paenedehiscens* BLOW (1969) mainly in lacking a completely crenulate umbilical aperture and in being less smoothly ovate.

Distribution.—Middle Miocene to Late Miocene (*Globorotalia fohsi lobata-robusta* Zone to *Globorotalia acostaensis* Zone). This species was described from Late Miocene strata of eastern Falcón, Venezuela, and has a wide distribution.

GLOBOROTALIA TOSAENSIS

Takayanagi & Saito, 1962

Figures 206-207

Late Pliocene to Early Pleistocene

Globorotalia tosaensis TAKAYANAGI & SAITO, 1962, p. 81-82, pl. 28, fig. 11-12.—PARKER, 1967, p. 181, pl. 30, fig. 4-7.—LAMB & BEARD, 1972, p. 56, pl. 23, fig. 1-2 [**not** pl. 22, fig. 1-7 = *G. ronda* BLOW, 1969].

Globorotalia (Turborotalia) tosaensis tosaensis TAKAYANAGI & SAITO. BLOW, 1969, p. 357, 393-394, pl. 4, fig. 10-12; ?pl. 40, fig. 4-7.

Globorotalia (Turborotalia) tosaensis tenuitheca BLOW, 1969, p. 394-396, pl. 4, fig. 13-17, pl. 40, fig. 1-3.—BRÖNNIMANN & RESIG, 1971, p. 1248.

Globorotalia truncatulinoides tosaensis TAKAYANAGI & SAITO. BOLLI, 1970, p. 583, pl. 3, fig. 19-21.

Globorotalia (Turborotalia) tosaensis TAKAYANAGI & SAITO. BRÖNNIMANN & RESIG, 1971, p. 1248, pl. 27, fig. 3, 5.

Test a moderately tumid, planoconvex trochospire. Four (in holotype) or more commonly 5 chambers in final whorl, increasing slowly in size as added, maintaining constant shape; periphery subacute, not keeled. Equatorial profile a smooth subcircular curve; axial profile bluntly triangular, defined by almost flat spiral side and subconical umbilical side. Sutures generally obscure, somewhat oblique on spiral side, sinuously radial on umbilical side. Umbilicus a deep, narrow pit flanked by blunt tips of later chambers. Aperture an inconspicuous low arch at base of flattish apertural face, bordered by narrow lip. Surface strongly pustulose around umbilicus, elsewhere granular to smooth. Diameter typically 0.35 to 0.40 mm, exceptionally to 0.60 mm.

Discussion.—*Globorotalia tosaensis* is intermediate between *Globorotalia ronda* BLOW (1969) (typified by more inflated, less conical test and tighter umbilicus) and *Globorotalia truncatulinoides* (D'ORBIGNY, 1839) (a keeled species with wide umbilicus). Identification of marginal forms within the close-knit bioseries is arbitrary. BLOW (1969) discussed the possibly genetic significance of peculiar thickening observed in the tests of these species. The level of earliest evolution of *G. truncatulinoides* from *G. tosaensis* was emphasized in some zonation schemes and worldwide correlation (e.g., BANNER & BLOW, 1965b; BERGGREN, 1967; PARKER, 1967) and assumed to coincide closely with the Pliocene-Pleistocene boundary. Subsequent studies have shown anomalies, however, suggesting that acquisition of a keel was influenced by environmental factors as well

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Fig. 206. *Globorotalia tosaensis* TAKAYANAGI & SAITO from the Late Pliocene and Early Pleistocene of Japan, Italy, Caribbean Sea, and Gulf of Mexico. [p. 414]

- **1** Holotype from a Late Pliocene or Early Pleistocene level within the Nobori Formation of Japan, X65; from TAKAYANAGI & SAITO (1962, pl. 28, fig. 11). **a**—Spiral view; **b**—side view; **c**—umbilical view.
- **2** Specimen from earliest Pleistocene (Calabrian Stage) at Le Castella, Italy, X140; from LAMB & BEARD (1972, fig. 8-10, locality 907-A). **a**—Side view; **b**—umbilical view.
- **3** Specimen from probable Pliocene strata of the Caribbean Sea, X60; from BOLLI (1970, pl. 3, fig. 19-21). **a**—Spiral view; **b**—side view; **c**—umbilical view.
- **4-5** Specimens from the Late Pliocene (*Pulleniatina obliquiloculata* Zone) of the Gulf of Mexico, X120; from LAMB & BEARD (1972, pl. 22, fig. 6-7). **4**—Umbilical view; **5**—spiral view.

Fig. 207. *Globorotalia tosaensis* TAKAYANAGI & SAITO from the Indian Ocean. Ideotypes identified and contributed by DR. TSEUNEMASA SAITO. [p. 415] **1a,2b**—Umbilical views, X200; **1b**—side view, X200; **2a**—spiral view, X200; **2c,d**—enlarged views showing nonperforate and encrusted margin of early chambers, X2000.

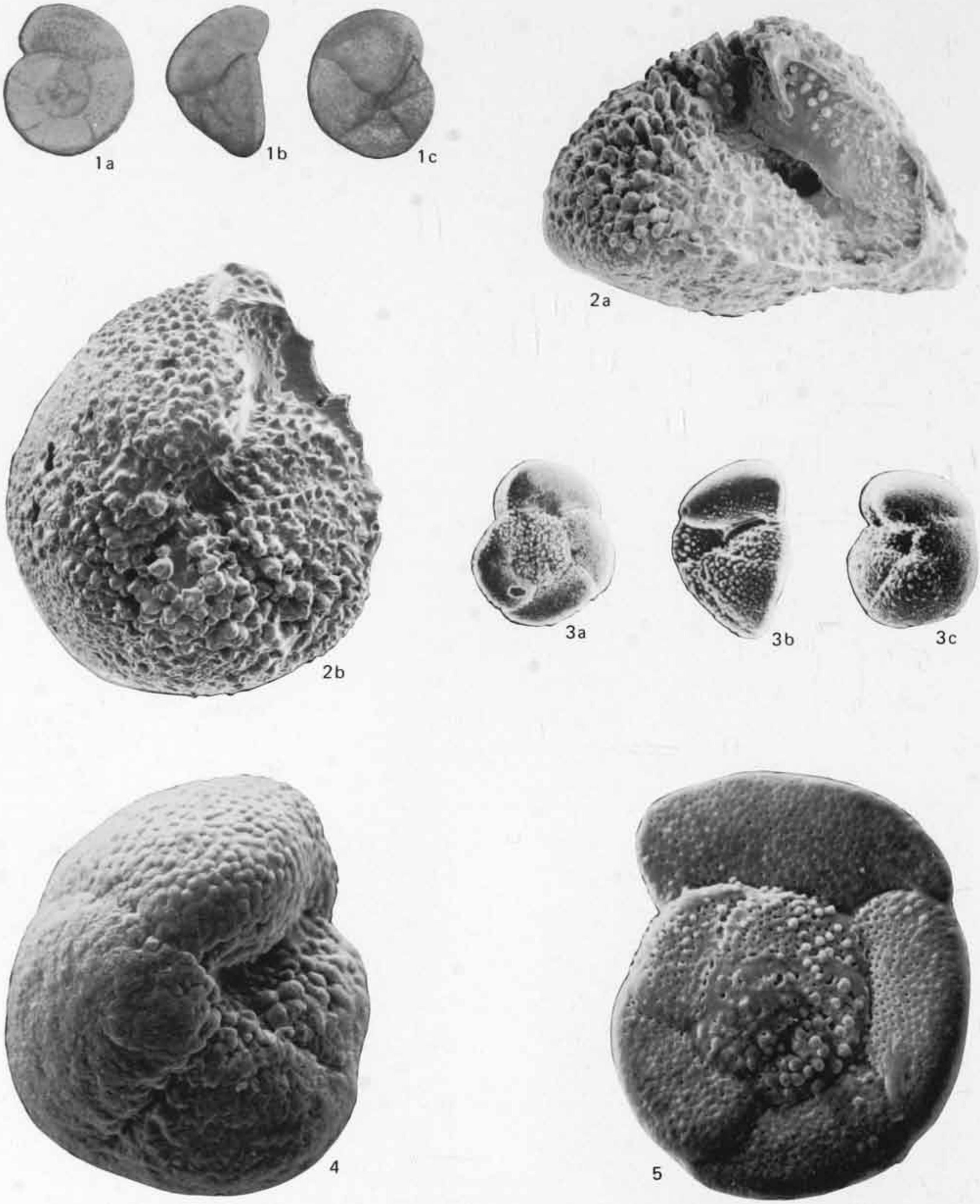


Fig. 206

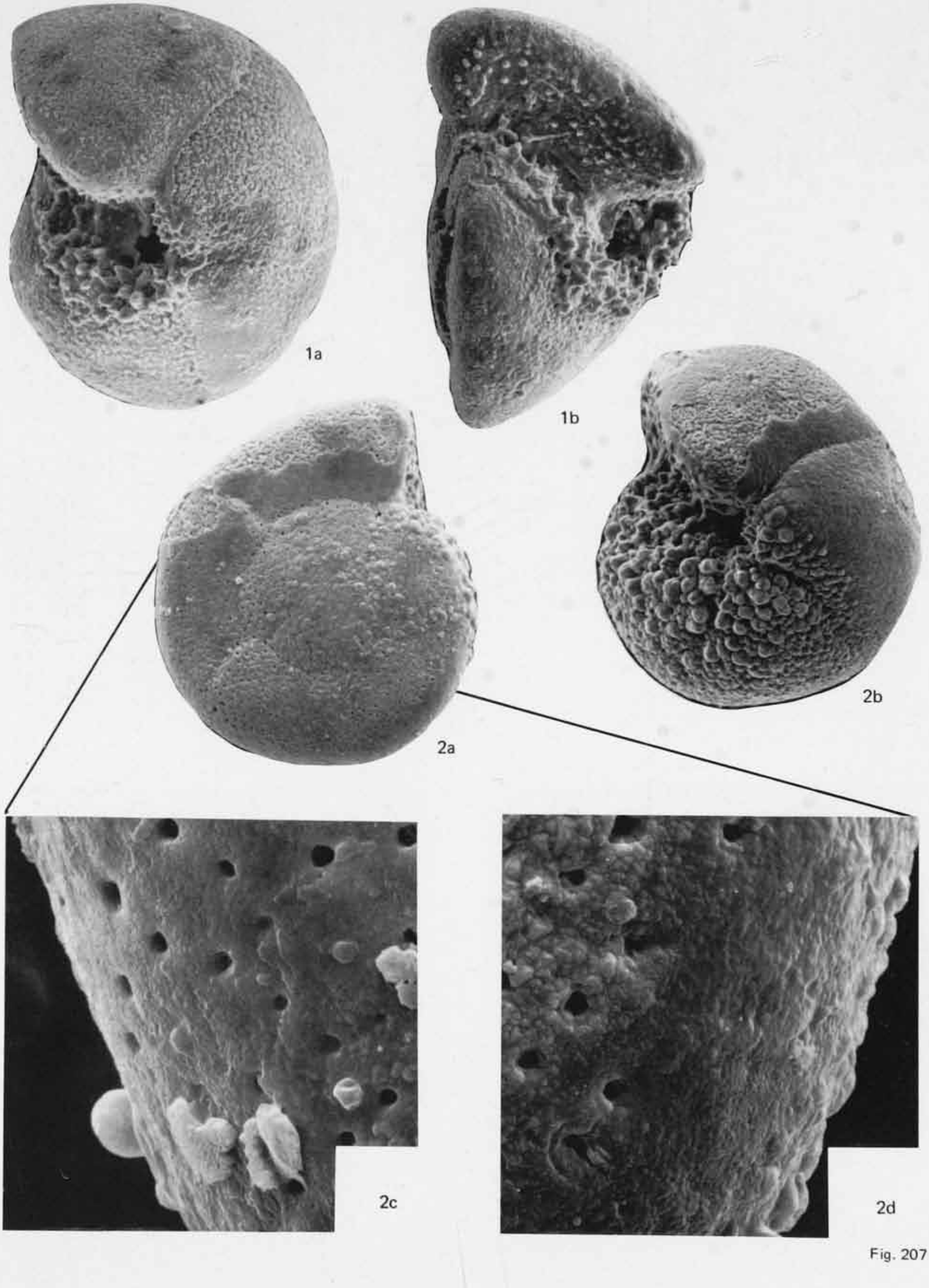


Fig. 207

as linear evolution (e.g., KENNETT, 1968b; BEARD & LAMB, 1968; KENNETT & GEITZENAUER, 1969).

Distribution.—Late Pliocene to Early Pleistocene (upper part of *Pulleniatina obliquiloculata* Zone and lower part of *Globorotalia truncatulinoides* Zone). First described from the Neogene Nobori Formation of Japan and subsequently recorded around the world, especially in submarine core samples.

GLOBOROTALIA TRIANGULA Theyer, 1973

Figure 208

Late Pliocene to Early Pleistocene

?*Globorotalia inflata* (D'ORBIGNY). [variant] PARKER, 1967, p. 179, pl. 29, fig. 3.

Globorotalia inflata (variant) LAMB & BEARD, 1972, p. 53, pl. 27, fig. 1-7.

Globorotalia inflata triangula THEYER, 1973b, p. 200-201, pl. 1, fig. 1-7.

Test rather small, planoconvex trochospire; spiral side almost flat, umbilical side strongly convex, approaching conical. Chambers (3 to 3½) on both spiral and umbilical sides of last whorl increase rapidly in size as added; each overlapping anterior margin of preceding chamber, having form of slender rectangles on spiral side. Equatorial profile rounded, faintly triangular; axial profile subtriangular or ogival curve, notched at umbilicus. Sutures barely discernible on spiral side, tangential to inner coil; distinct on umbilical side, flush to slightly depressed, radial to moderately curved. Umbilicus closed, generally concealed by inturned chamber tip. Aperture a narrow, almost straight slit with no lip, extending from umbilicus to near peripheral shoulder. Surface smooth, shiny, very finely perforate; secondary encrustation of initial coil common; umbilical area generally covered with pustules, which may spread sparsely over remainder of test. Diameter 0.25 to 0.40 mm.

Discussion.—This species is distinguished from *Globorotalia inflata* (D'ORBIGNY, *in* BARKER-WEBB & BERTHELOT, 1839) by the highly vaulted chambers, flat spiral side, narrow slit-like aperture, subtriangular axial view, and generally three nonglobose subtriangular chambers in the last whorl. On the average, it is also smaller. Although PARKER'S (1967) figured specimen of this species is more lobate than typical, her discussion suggests that it should be in our synonymy. Through possibly an oversight, THEYER (1973b) did not include all specimens figured by LAMB & BEARD (1972) in his synonymy and made no mention of this in his text.

Distribution.—Late Pliocene to Early Pleistocene (*Pulleniatina obliquiloculata* Zone to within lower part of *Globorotalia truncatulinoides* Zone). This species was described from the Tasman basin and also has been recorded from the Gulf of Mexico and Atlantic regions.

GLOBOROTALIA TRUNCATULINOIDES (d'Orbigny, 1839)

Figures 209-211

Early Pleistocene to Holocene

?*Rotalina truncatulinoides* D'ORBIGNY, 1839, p. 132, pl. 2, fig. 25-27.

Globorotalia truncatulinoides (D'ORBIGNY). CUSHMAN, 1931a, p. 97-99, pl. 17, fig. 14.—PARKER, 1967, p. 181, pl. 31, fig. 1.—BOLLI, LOEBLICH, & TAPPAN, 1957, p. 247, pl. 10, fig. 3.—BAYLISS, 1969, p. 133-134, fig. 5.—LAMB & BEARD, 1972, p. 56, pl. 24, fig. 1-4; pl. 25, fig. 1-7; pl. 26, fig. 1-3.—CITA ET AL., 1973, p. 1283, pl. 16, fig. 1-6.

Globorotalia (Truncorotalia) truncatulinoides (D'ORBIGNY). CUSHMAN & BERMÚDEZ, 1949, p. 35, pl. 6, fig. 22-24.

Globorotalia (Globorotalia) truncatulinoides truncatulinoides (D'ORBIGNY). BLOW, 1969, p. 403-405, 418, pl. 5, fig. 10-12 [neotype]; pl. 49, fig. 6.

Globorotalia (Globorotalia) truncatulinoides pachytheca BLOW, 1969, p. 405-408, pl. 5, fig. 13-15; pl. 48, fig. 1-5.

Globorotalia truncatulinoides truncatulinoides (D'ORBIGNY). BOLLI, 1970, p. 583, pl. 3, fig. 22-24.

Globorotalia (Globorotalia) truncatulinoides (D'ORBIGNY). BRÖNNIMANN & RESIG, 1971, p. 1248, pl. 27, fig. 1-2, 4; pl. 28, fig. 1-6.

Test a tall, planoconical trochospire. Last whorl of 5, rarely 6, cuneate chambers, subequal or increasing only slowly in size as added; mostly carrying limbate keels which coalesce to form complete or partial rim around test. Equatorial profile subcircular to polygonal, seldom indented at sutures; axial profile flat to concave on spiral side, mitriform on umbilical side. Sutures on spiral side mostly flush, indistinct, subradial; on umbilical side slightly depressed, sinuously radial. Umbilicus deep, rather wide; accentuated by projecting tips of late chambers, partly separated by sutural clefts. Wall finely perforate, commonly pustulose to granular; keel commonly canaliculate. Aperture a slit or low

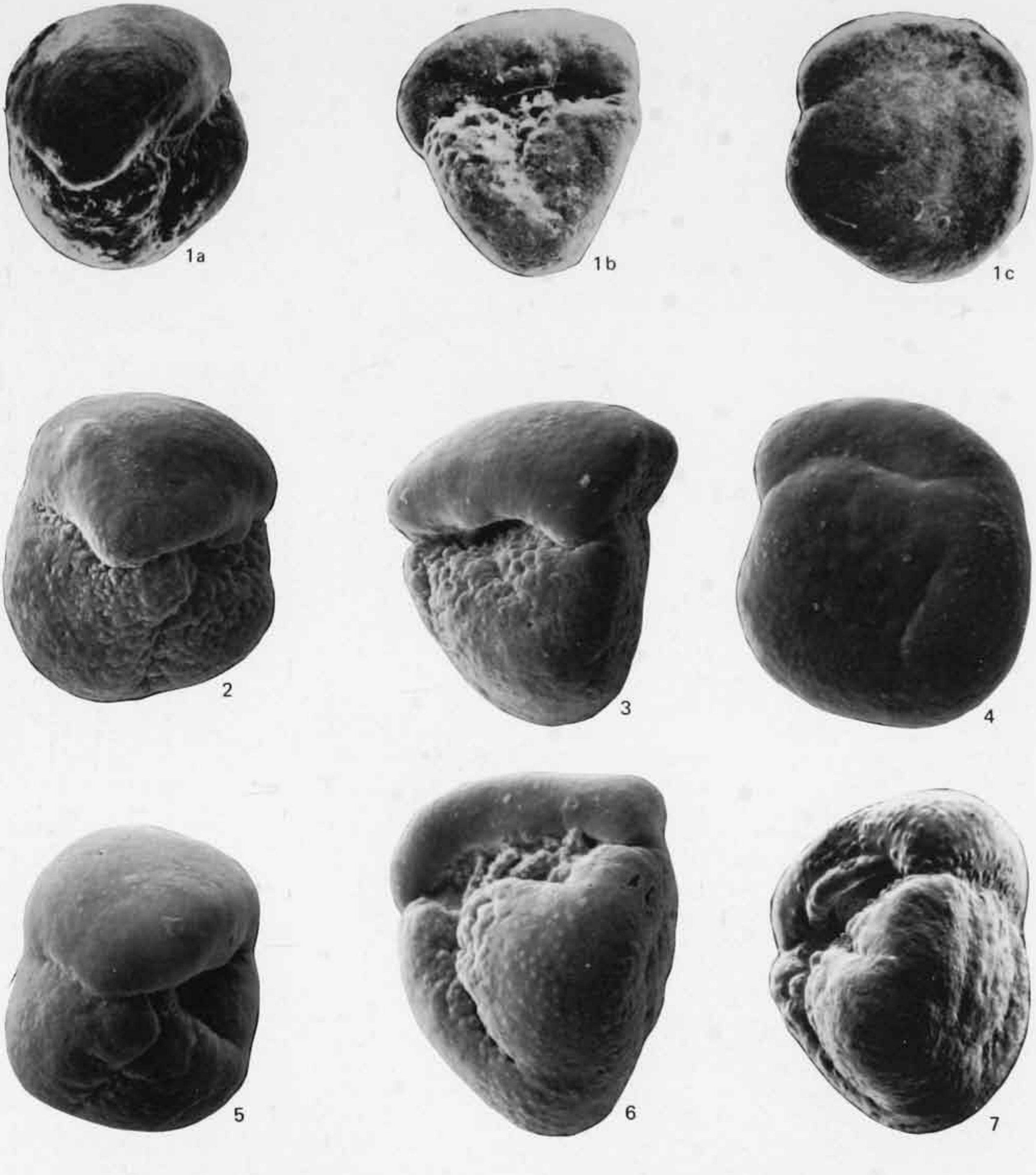


Fig. 208. *Globorotalia triangula* THEYER from the Early Pleistocene of the Tasman Sea and Gulf of Mexico.

1 Holotype from the Tasman Sea, X140; from THEYER (1973b, pl. 1, fig. 1). **a**–Umbilical view showing subtriangular chambers of last whorl; **b**–side view showing highly vaulted and conical profile; **c**–spiral view showing early chambers obscured by thick cortex.

2-7 Specimens from the Gulf of Mexico identified as *Globorotalia inflata* variant, X80 except **6** which is X95; from LAMB & BEARD (1972, pl. 27, fig. 2-7). **2,5**–Umbilical views; **3,6-7**–side views; **4**–spiral view.

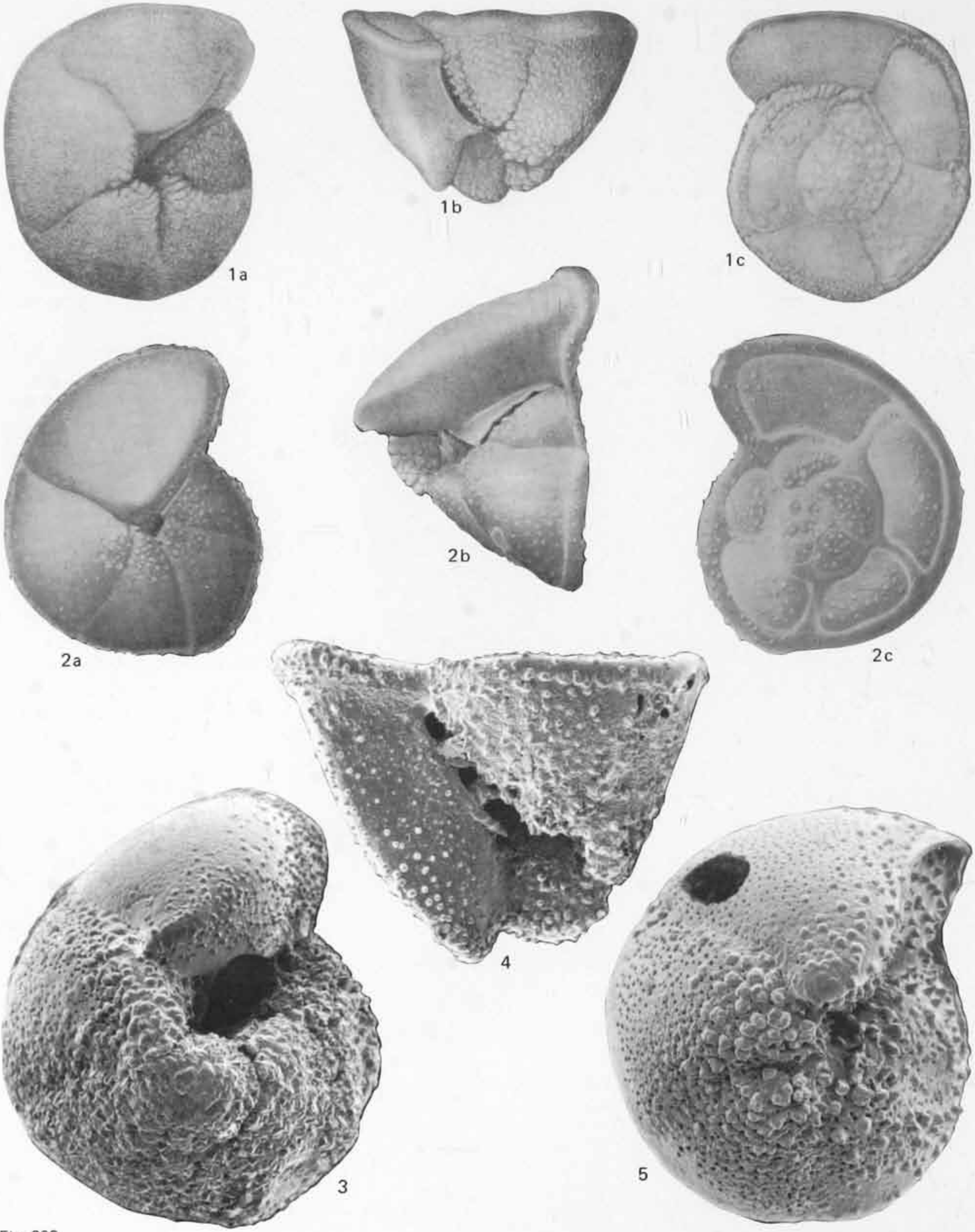


Fig. 209

Fig. 209. *Globorotalia truncatulinoides* (D'ORBIGNY) from the Early Pleistocene of Italy and Holocene of the north Atlantic Ocean.

1 Neotype from Holocene sediments off the Canary Islands, X67; from BLOW (1969, pl. 5, fig. 10-12). **a**–Umbilical view showing deep umbilicus; **b**–side view showing prominent keel; **c**–spiral view showing keeled margin and radial intercameral sutures.

2 Topotype from Holocene sediments off the Canary Islands, X95; from BOLLI, LOEBLICH, & TAPPAN (1957, pl. 10, fig. 3). **a**–Umbilical view; **b**–side view; **c**–spiral view.

3-4 Specimens from the Calabrian Stage exposed at Santa Maria di Catanzaro, Italy. Identified and contributed by the late DR. ORVILLE L. BANDY; locality 35 of BANDY & WILCOXON (1970). **3**–Umbilical view, X130; **4**–side view, X100.

5 Umbilical view of specimen from the Calabrian Stage exposed at Le Castella, Italy, X160; from locality 910-A of LAMB & BEARD (1972). Note shallow umbilicus.

arch from umbilicus to near periphery, at base of flattish apertural face. Diameter of Pleistocene specimens 0.4 to 0.5 mm, of Holocene examples to 0.9 mm.

Discussion.–The status of *Globorotalia truncatulinoides* became dubious largely because the syntypes were lost. The description and figures of D'ORBIGNY (1839) are inadequate so that the modern concept of the species derives mainly from BRADY'S (1884) description of *Pulvinulina micheliana* [sic] (D'ORBIGNY), based on *Rotalina micheliniana* D'ORBIGNY (1840), which he considered synonymous. On grounds that *R. micheliniana* was described as a Cretaceous form, CUSHMAN (1931a) reinstated the name *truncatulinoides* for the modern species and also reassigned it to the genus *Globorotalia*. BLOW (1969) regularized the situation by selecting and describing a neotype approximately topotypic with D'ORBIGNY'S taxon. This is the type species of the subgenus *Truncorotalia* CUSHMAN & BERMÚDEZ (1949) occasionally given generic rank, as by BERMÚDEZ (1960).

TAKAYANAGI & SAITO (1962) suggested that their *Globorotalia tosaensis* was the forerunner of *G. truncatulinoides*, and many later authors have verified this proposal. Development of a partial or complete keel is the prime distinguishing feature of *G. truncatulinoides* but also its coil became progressively looser so that the umbilicus became wider and deeper.

Within the genus *Globorotalia*, appearance of keeled forms is partly a function of paleotemperatures and, in the case of *G. truncatulinoides*, evidence exists that it appeared earlier in warm rather than in subpolar regions (e.g., KENNETT, 1968, 1970). Nevertheless, at least in broad terms the level of first evolutionary appearance of this species is a reliable guide to the Pliocene-Pleistocene boundary, appearing just subsequent to worldwide cooling.

The coiling direction of several species of *Glo-*

Fig. 210. *Globorotalia truncatulinoides* (D'ORBIGNY) from the Pleistocene of the Gulf of Mexico; from LAMB & BEARD (1972, pl. 24, fig. 1-4). [p. 420]

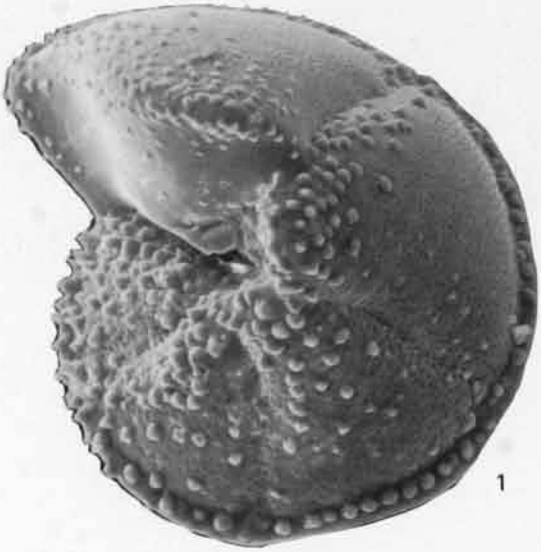
1 Umbilical view of a rather small specimen with a shallow umbilicus from the Early Pleistocene *Globorotalia tosaensis* Subzone of LAMB & BEARD (1972), X190.

2-4 Specimens from the Late Pleistocene *Pulleniatina finalis* Subzone of LAMB & BEARD (1972). **2**–Umbilical view, X90; **3a**–spiral view, X90; **3b**–enlarged view showing encrusted overgrowth on early keeled chamber, X450; **3c**–enlarged view showing keeled margin of last chamber, X450; **4**–side view showing highly vaulted chambers of last whorl, X90.

Fig. 211. *Globorotalia truncatulinoides* (D'ORBIGNY) from the Pleistocene and Holocene of the Gulf of Mexico; from LAMB & BEARD (1972, pl. 25, fig. 1-7). [p. 421]

1-4 Specimens from the Early Pleistocene *Globorotalia tosaensis* Subzone of LAMB & BEARD (1972). **1,3**–Umbilical views of tightly coiled primitive forms with a shallow umbilicus, X166, X170; **2**–side view of somewhat asymmetric specimen showing imperforate margin, X157; **4a**–spiral view illustrating radial intercameral sutures, X160; **4b**–enlarged view of last chamber showing the well-developed canaliculate keel, X800.

5-7 Specimens from the Holocene *Globorotalia tumida* Zone, X90. **5**–Umbilical view of loosely coiled specimen with a deep umbilicus; **6**–side view showing thick-keeled margin; **7**–spiral view showing radial intercameral sutures.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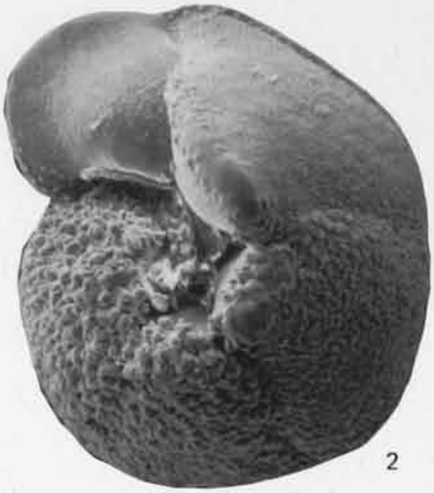
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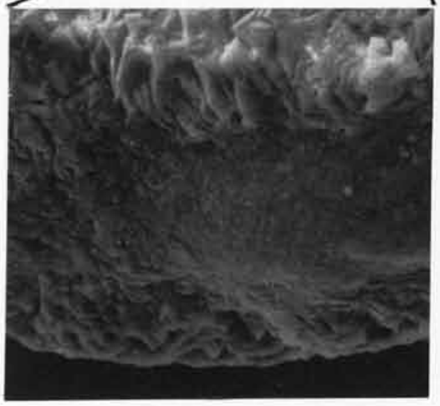
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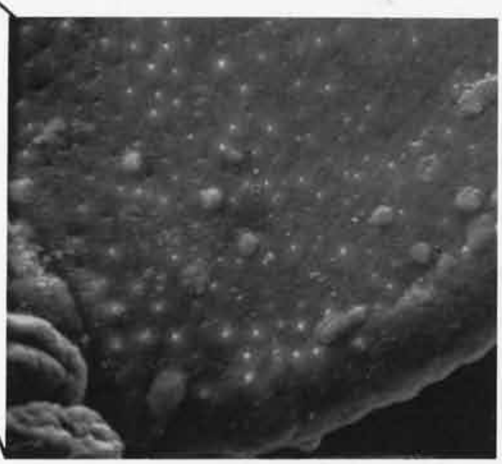
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Fig. 210

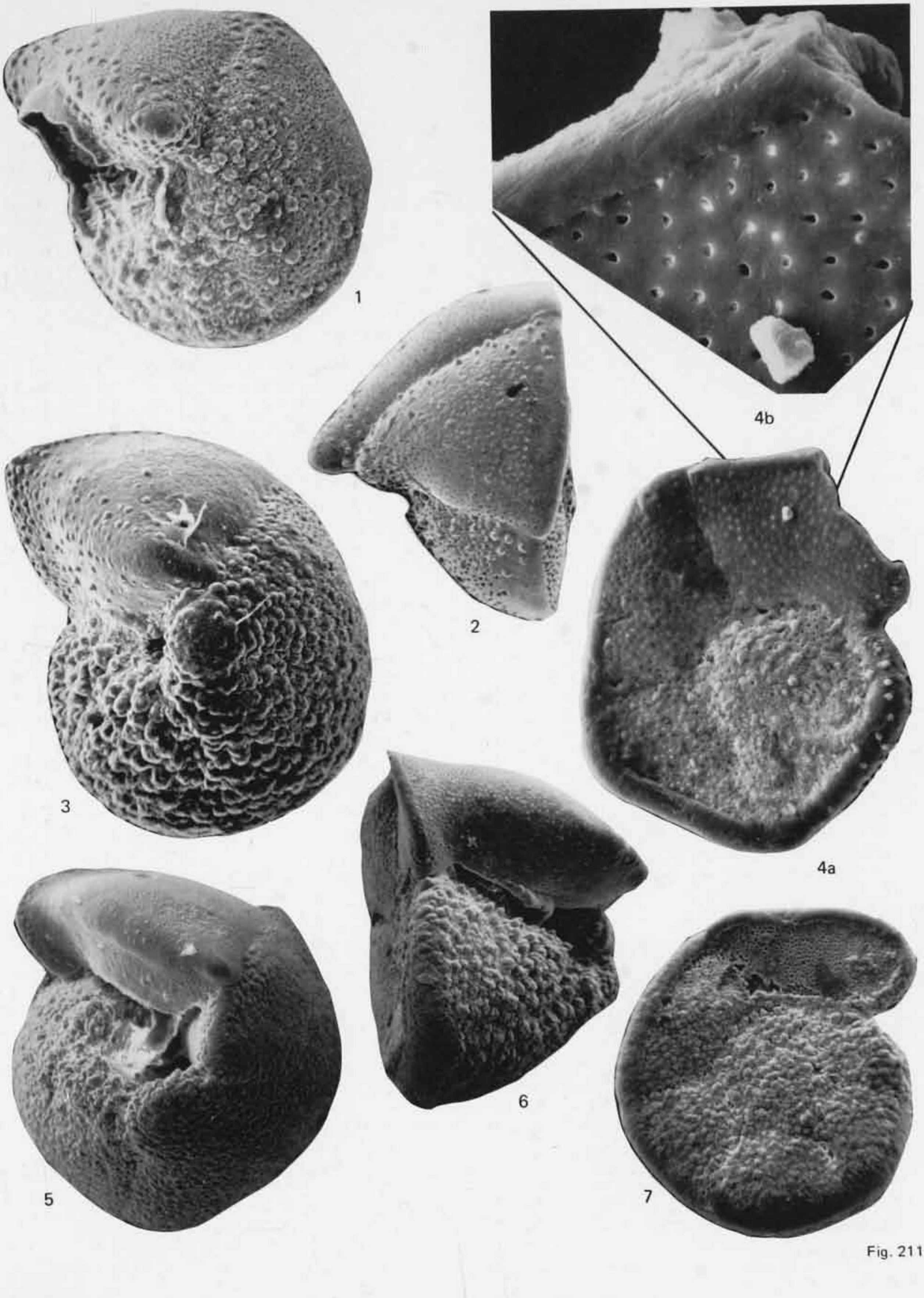

Fig. 211

borotalia is strongly influenced by temperature so that abrupt changes in their coiling directions are applicable to correlation and paleoclimatic interpretation of sediments. Although *G. truncatulinoides* is not the most reliable of these temperature-sensitive species, it was one of the first used in such studies of the Pleistocene (e.g., ERICSON, WOLLIN, & WOLLIN, 1954; ERICSON & WOLLIN, 1956).

Distribution.—Pleistocene and Holocene (*Globorotalia truncatulinoides* and *Globorotalia tumida* Zones). The species was described from modern sediments off the Canary Islands and is an absolute indicator of post-Pliocene. The Holocene neotype is more advanced (deep umbilical pit) than the phylogenetically primitive forms (tighter coil, smaller umbilicus) typical of the Early Pleistocene, e.g., Nebraskan Stage. Initial appearance is nearly synchronous with extinction of *Globoquadrina altispira* (CUSHMAN & JARVIS, 1936) except in equatorial regions where it appears much later, about at the onset of the second glacial period. This species has been recorded from nearly all oceans.

GLOBOROTALIA TUMIDA (Brady, 1877)

Figure 212

Pliocene to Holocene

Pulvinulina menardii tumida BRADY, 1877, p. 535.—BANNER & BLOW, 1960a, p. 26, pl. 5, fig. 1 [lectotype].

Pulvinulina tumida BRADY. BRADY, 1884, p. 692, pl. 103, fig. 4-6.

Globorotalia tumida (BRADY). CUSHMAN, 1927a, p. 91, pl. 19, fig. 12 [syntype, after BRADY].—CUSHMAN, 1931a, p. 95-96, pl. 17, fig. 3.—LEROY, 1941, p. 45, pl. 3, fig. 101-103.—BOLLI, LOEBLICH, & TAPPAN, 1957, pl. 10, fig. 2 [syntype].—BERMÚDEZ, 1960, p. 1303-1304, pl. 15, fig. 1.—BELFORD, 1962, p. 25, pl. 7, fig. 1-5.—PARKER, 1967, p. 182-183, pl. 32, fig. 5-6 [**not** fig. 7].—LAMB & BEARD, 1972, p. 57, pl. 12, fig. 1-3.

Globorotalia (Globorotalia) tumida tumida (BRADY). BANNER & BLOW, 1965c, p. 1353, fig. 3.—BLOW, 1969, p. 371-372.

Globorotalia tumida tumida (BRADY). BOLLI, 1970, p. 583, pl. 6, fig. 4-6.—JENKINS & ORR, 1972, p. 1105, pl. 34, fig. 1-3.

Test a large, biconvex, axially tumid trochospire rimmed by heavy, blunt keel. Chambers (5 to 6) in last whorl increase irregularly in size as added, especially in radial length. Equatorial profile ear-shaped, slightly lobate; axial profile rhomboid to dropshaped. Sutures on spiral side limbate, curved to hooked obliquely backwards, coalescing into thick keel; on umbilical side sinuously radial. Umbilicus narrow, deep. Aperture a slit or low arch between umbilicus and keel, generally bordered by rim or flap. Wall finely perforate, smooth except for pustulose area centered on umbilicus. Maximum diameter generally 0.7 to 1.0 mm.

Discussion.—This type species of the genus *Globorotalia* has the same gross morphology as many other Late Neogene species (i.e., the menardiform group). Distinguishing features are its large size, exceptionally heavy keel, biconvex tumidity, and rapidly opening spire. BANNER & BLOW (1965b-c), BLOW (1969), and JENKINS & ORR (1972) postulated evolution from the similar but smaller *Globorotalia plesiotumida* [=*G. tumida plesiotumida* BANNER & BLOW, 1965c] and used the level of change as a zonal datum. Along with other cited authors, we agree with the postulated evolutionary trend but find objective recognition of *G. tumida* too tenuous to be reliable in zonation. *Globorotalia flexuosa* [=*G. tumida flexuosa* KOCH, 1923] is identical with *G. tumida* except for a strongly bent final chamber. *Globorotalia ungulata* BERMÚDEZ (1960) resembles *G. tumida* in size and proportions but has a thinner shell and lighter keel.

Globorotalia tumida is a warm-water species. Abrupt and abundant appearance of large specimens coincided with the end of the latest glacial interval so this species is a natural zonal index for sediments of Holocene age (LAMB & BEARD, 1972). The

Fig. 212. *Globorotalia tumida* (BRADY) from the Pliocene and Holocene of the Pacific Ocean and Gulf of Mexico.

1 Lectotype from an exotic block of Late Miocene or Pliocene age at New Ireland, X50; from BANNER & BLOW (1960a, pl. 5, fig. 1). **a**—Umbilical view; **b**—side view; **c**—spiral view.

2 Syntype from New Ireland, X60; from BOLLI, LOEBLICH, & TAPPAN (1957, pl. 10, fig. 2). **a**—Umbilical view; **b**—side view; **c**—spiral view.

3-5 Specimens from the Pliocene of the eastern equatorial Pacific Ocean, X35; from JENKINS & ORR (1972, pl. 34, fig. 1-3). **3**—Umbilical view; **4**—side view; **5**—spiral view.

6-8 Specimens from the Holocene of the Gulf of Mexico, X80; from LAMB & BEARD (1972, pl. 12, fig. 1-3). **6**—Umbilical view; **7**—side view; **8**—spiral view.

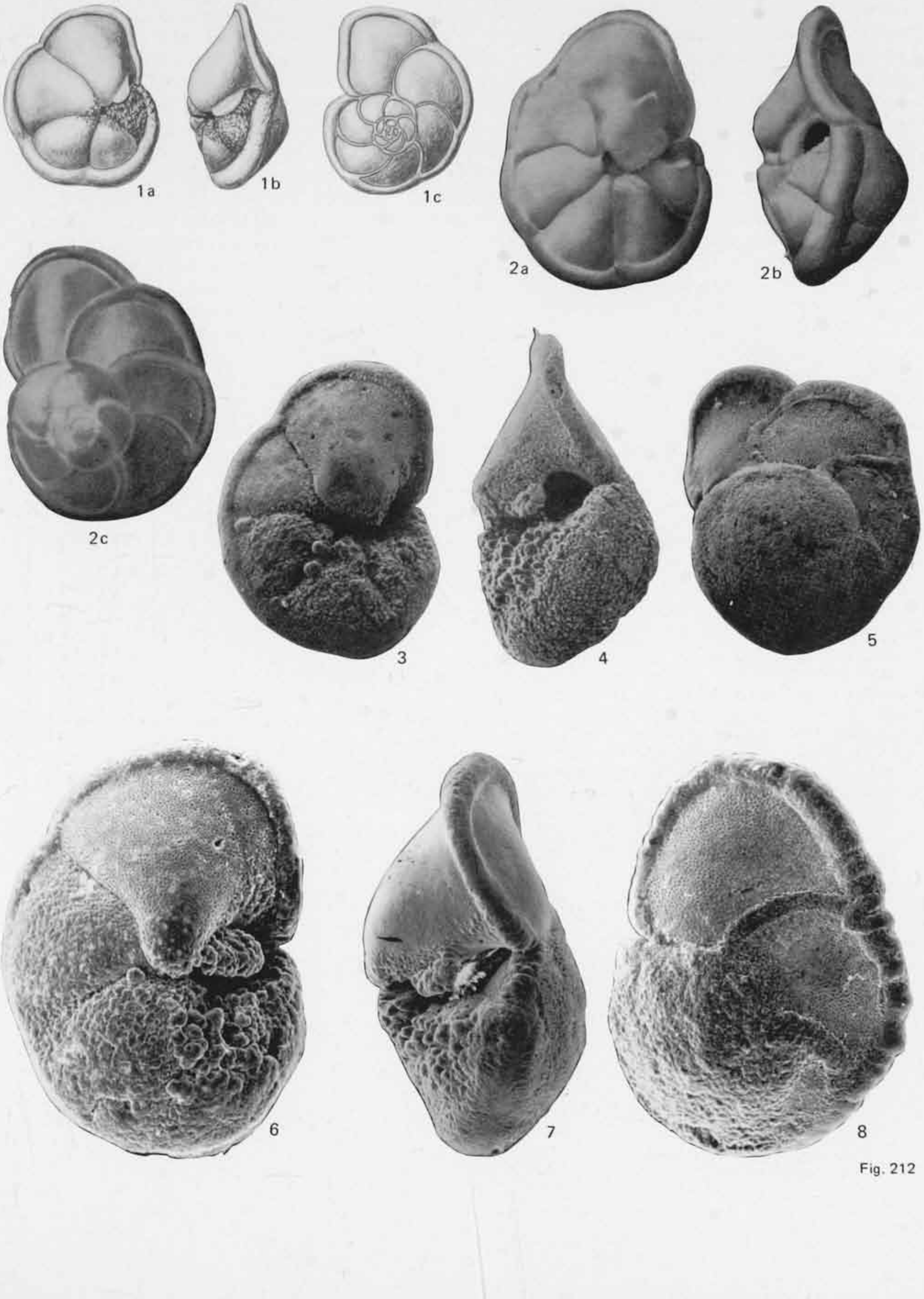

Fig. 212

"*Globorotalia tumida* Zone" of JENKINS & ORR (1972) is a different unit broadly equivalent to the *Globorotalia margaritae* Zone of other authors.

Distribution.–Pliocene to Holocene (*Globorotalia margaritae* Zone to *Globorotalia tumida* Zone). First described from a chalk artifact of unknown origin in New Ireland (west-central Pacific), determined as Pliocene by BLOW (1969). The species is now recorded around the world, mainly in warm-water sediments. Records of occurrences in Miocene beds were not confirmed by our studies.

GLOBOROTALIA UNGULATA Bermúdez, 1960

Figure 213

Mainly Holocene

Globorotalia ungulata BERMÚDEZ, 1960, p. 1304, pl. 15, fig. 6.–BERMÚDEZ & BOLLI, 1969, p. 180, pl. 12, fig. 10-12.–LAMB & BEARD, 1972, p. 57, pl. 11, fig. 7-9.–JENKINS & ORR, 1972, p. 1105, pl. 35, fig. 1-6.

Globorotalia (Globorotalia) ungulata BERMÚDEZ. BANNER & BLOW, 1965c, p. 1353.–BLOW, 1969, p. 257, 372, pl. 8, fig. 13-15.

Test a large, biconvex trochospire, umbilical side more tumid than spiral, rimmed by blunt keel. Last whorl with 4½ to 5½ chambers; scallop-shaped on spiral side, cuneate on umbilical side. Spiral profile ear-shaped, slightly lobate; axial profile biconvex, revealing increasing convexity of chambers on umbilical side. Sutures on spiral side limbate, smoothly recurved, coalescing with keel; on umbilical side subradial, straight or slightly curved. Umbilicus narrow, deep. Aperture a low arch or slit at base of smooth apertural face, bordered by rim or projecting flap. Wall thin, densely perforate, smooth except for pustulosity on early chambers near umbilicus. Maximum diameter 0.7 to 1.0 mm.

Discussion.–*Globorotalia ungulata* resembles *Globorotalia tumida* (BRADY, 1877) in size and shape but is more delicately constructed (i.e., thinner wall and lighter keel). Possibly these two generally differentiated species are growth forms of a single species, perhaps modified for life at different water depths (LAMB & BEARD, 1972).

Distribution.–Mainly Holocene (*Globorotalia tumida* Zone), earlier range not yet firmly established. Described originally from seafloor sediments dredged in the vicinity of Cuba and so far only recorded from the Holocene of the type region. In the Pacific province JENKINS & ORR (1972) gave locality data for sparse records in the Pleistocene and, in one core hole only, the Late Pliocene. BLOW (1969) mentioned Pliocene occurrences but supplied no details.

Fig. 213. *Globorotalia ungulata* BERMÚDEZ from the Late Pleistocene and Holocene of the Pacific Ocean, Caribbean Sea, and Gulf of Mexico.

1-2	Holotype (**1** from BERMÚDEZ, 1960, pl. 15, fig. 6) and metatype (**2** from BLOW, 1969, pl. 8, fig. 13-15) from the Holocene of the Caribbean Sea. **1a,2a**–Umbilical views, X40ca, X67; **1b,2b**–side views, X40ca, X67; **2c**–spiral view, X67.
3-5	Specimens from the Late Pleistocene of the eastern equatorial Pacific Ocean, X48; from JENKINS & ORR (1972, pl. 35, fig. 4-6). **3**–Umbilical view; **4**–side view; **5**–spiral view.
6-8	Specimens from the Holocene of the Gulf of Mexico; from LAMB & BEARD (1972, pl. 11, fig. 7-9). **6**–Umbilical view, X85; **7**–side view, X100; **8**–spiral view, X100.

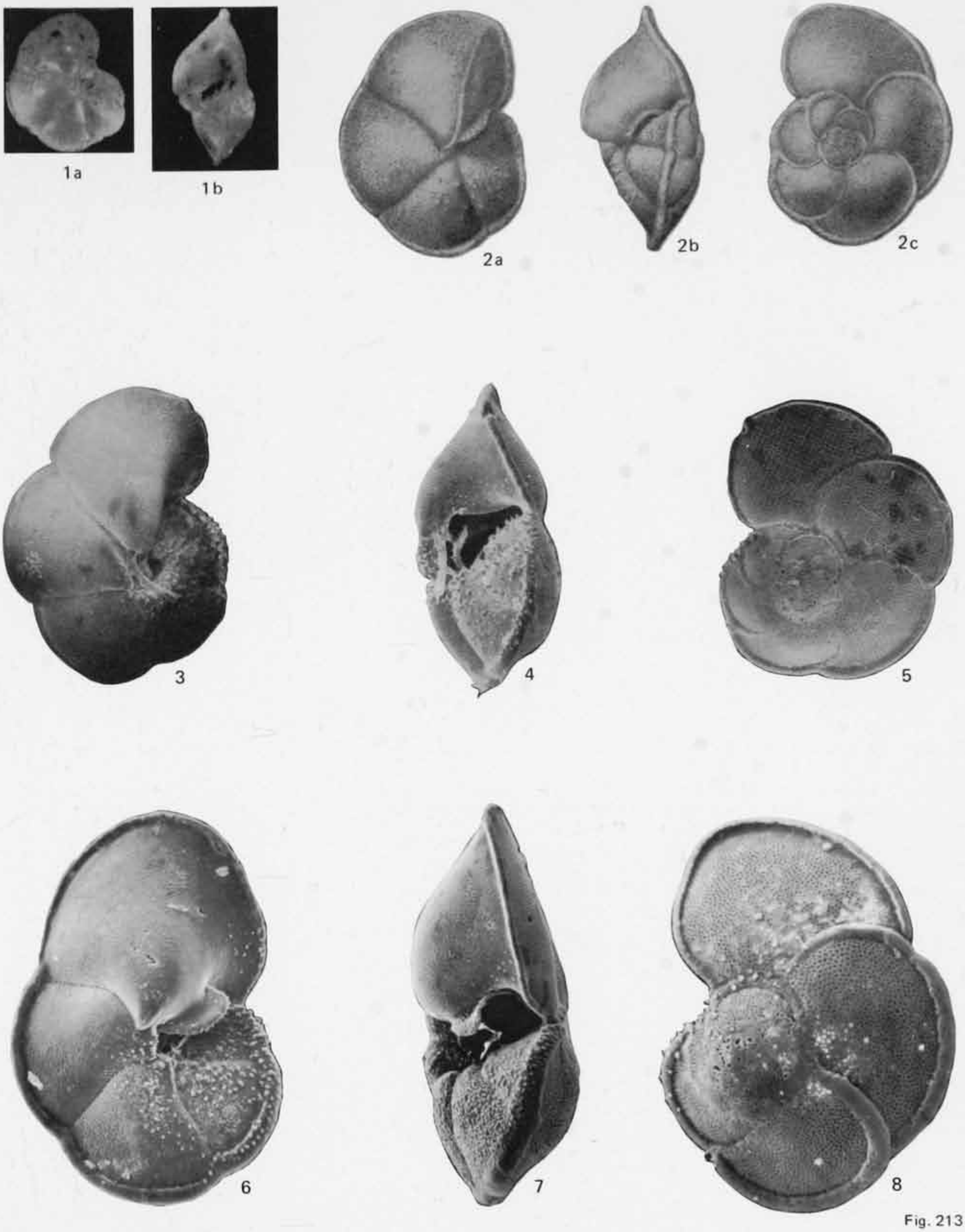

Fig. 213