

11. A SEDIMENTOLOGICAL, FAUNAL, AND ISOTOPIC RECORD OF THE MIDDLE-TO-LATE PLIOCENE TRANSITION IN THE NORTHEASTERN ATLANTIC, DEEP SEA DRILLING PROJECT SITE 548¹

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ABSTRACT

Hydraulic piston coring at DSDP Site 548, on the upper continental slope southwest of Ireland, recovered a nearly complete Pliocene section spanning 103 m of sediment. The sediments are greenish gray carbonate-rich hemipelagites containing abundant nannofossils and foraminifers. Grain-size analysis demonstrates that the texture of the section is fairly constant, with most of the variation occurring in 63- to 32- μm and <2- μm fractions. Previous research has shown that the middle-to-late Pliocene transition in the North Atlantic was marked by the appearance of the planktonic foraminiferal species *Globorotalia inflata* and by the first occurrence of significant quantities of ice-rafted sediment grains in deep-sea sediments. The latter is taken to represent the first important development of Northern Hemisphere glaciation. The first appearance of *G. inflata* is carefully documented for Site 548 and is demonstrated to be an evolutionary datum at this site, rather than an ecologically controlled first appearance. Surface ocean conditions represented in the sediment section spanning the appearance of *G. inflata* were strongly cyclic, resulting in large periodic changes in the abundances of *Globorotalia puncticulata* and *N. acostaensis*. The benthic foraminiferal population was studied in detail over the middle-to-upper Pliocene transition to establish the nature and behavior of the intermediate-depth water mass in the northeastern Atlantic at the time of ice-sheet growth in the Northern Hemisphere. This water mass is presently warm and saline, having its source in the Mediterranean Sea. The benthic data show that the intermediate-depth water mass was undergoing a series of progressive changes over the interval including the first appearance of *G. inflata*. These changes are particularly reflected in the relative abundances of *Globocassidulina subglobosa* (Brady), *Uvigerina*, and *Ehrenbergina*. Also, the mean size of individuals in the *G. subglobosa* populations shows systematic variation, indicating changing intermediate-depth water properties. Oxygen-isotope analyses show that the intermediate-depth water mass was cold during the middle-to-late Pliocene transition. This interpretation is supported by the relative abundances of benthic foraminiferal species. Hence, the intermediate-depth northeastern Atlantic water mass of the middle to late Pliocene was considerably different from the intermediate-depth water mass of the present.

INTRODUCTION

The purpose of this chapter is to establish the characteristics of the Pliocene sediments at DSDP Site 548 and to examine the paleoceanic record preserved in these sediments. We present first a sedimentological description of the nearly complete Pliocene section recovered on Leg 80 at Site 548, and then offer a detailed examination of the first appearance of the planktonic foraminifer *Globorotalia inflata* (d'Orbigny). We also present a detailed examination of the variation in planktonic and benthic foraminiferal taxic abundance over the interval where *G. inflata* appears in the sediment record of Site 548. These data are accompanied, finally, by benthic oxygen-isotope analyses, which help establish bottom-water properties for the site.

The *G. inflata* datum is important because Poore (1981) and Berggren (1972b) have shown that it is associated with the first occurrence of significant quantities of ice-rafted sand in deep-sea sediments from all parts of the North Atlantic. Hence, the species appearance can be tied to a period of significant expansion of Northern Hemisphere polar ice. Our purpose is to establish that the Pliocene section at Site 548 is suitable for paleoceanic studies and to establish the nature of

surface and bottom waters at the time of the middle-to-late Pliocene transition when the ice sheets first expanded. Following Stainforth et al. (1975), we define the middle/upper Pliocene boundary as marked by the first occurrence of *G. inflata*.

SEDIMENTOLOGICAL DESCRIPTION OF THE PLIOCENE SECTION

Site 548 is southwest of Ireland and directly west of Brittany, France, in 1251 m of water. The drilling location is an extension of the Western Approaches Basin and the English Channel (see Fig. 1 and the site chapter). The Plio-Pleistocene boundary occurs at about 108 m sub-bottom, and a nearly complete Pliocene section extending down to 211 m was recovered using the variable-length hydraulic piston corer. Sediments recovered are dominantly light greenish-gray nannofossil oozes (5G6/1, 5G8/1, and 5B7/1).

Figure 2 summarizes the lithostratigraphy of the Site 548 Pliocene. From 108 to 131 m sub-bottom, the section contains frequent evidence of deposition by bottom gravity flows. The evidence consists of sandy horizons, often normally graded, and frequent dark, very muddy intervals with low carbonate content (20%).

From 131 to 211 m the section is dominantly hemipelagic ooze containing abundant carbonate (generally 50-70%). There is evidence for occasional current winnowing, or gravity-flow deposition, in the form of thin (1-2 mm) silty partings or burrows partly filled with fine-

¹ Graciansky, P. C. de, Poag, C. W., et al., *Init. Repts. DSDP*, 80: Washington (U.S. Govt. Printing Office).

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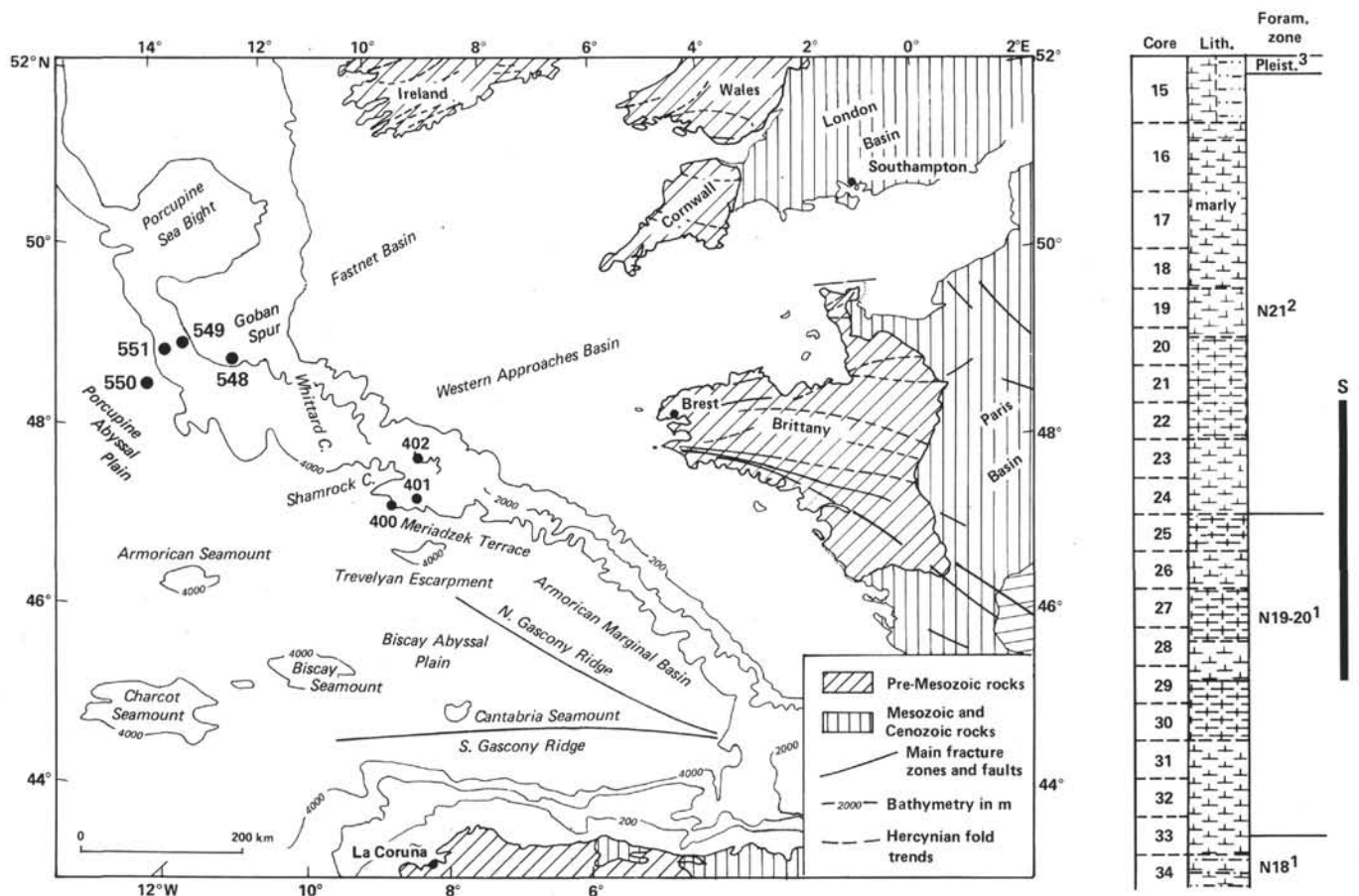


Figure 1. Location of Site 548, southwest of Ireland, on the upper continental slope of the northeastern Atlantic. Also shown is a stratigraphic column of the Pliocene at Site 548. S = interval studied in this paper. Planktonic foraminiferal zone determinations are as follows: (1) Snyder and Waters, this vol.; (2) after Poore (1979), based on the occurrence of *G. inflata* as reported in this paper; (3) shipboard scientists. Symbols for lithology as defined in Explanatory Notes (this vol.).

grained sand or silt. These are not common, and comprise only a very small fraction of the Pliocene section (see Fig. 2).

More important in the section are intervals where the ooze coarsens somewhat (see Fig. 2). These intervals are unusual in that they are not marked by any color changes or sedimentary structures, and the boundaries between coarser and finer horizons are nearly all completely gradational. The coarsening is not dramatic, but is quite noticeable when the sediment is rubbed on a sampling spatula. Coarser horizons are most common between 175 and 194 m, but they occur throughout the section. Between 134 and 141 m a different sediment lithology is recorded in the form of several horizons of greenish gray ooze, which are conspicuously darker than the surrounding sediment and have a noticeably higher clay content (Fig. 2).

PARTICLE-SIZE ANALYSIS

Twenty-one particle-size analyses (locations on Fig. 2) were used to define the textural variation that occurs in the previously described hemipelagite. These are presented in Table 1. The measurements were performed following the procedures of Royce (1970). Four samples were reanalyzed to establish repeatability of analysis; the

results indicate a precision of about 2%. The data in Table 1 show that the sediment is fairly uniform in texture, but that there is significant variation in the 63- to 32- μm and <2- μm fractions. The coarser intervals in the section are enriched in the 63- to 32- μm fraction, and contain correspondingly less material in the <2- μm fraction. Microscopic examination of the 63- to 32- μm fraction shows that it is composed largely of subangular quartz and carbonate grains. The coarser intervals in the hemipelagite therefore probably represent brief influxes of terrigenous silt to a hemipelagic setting. There is no evidence for transport of this material by traction or density current, so the "shelf spillover" mechanism of Doyle et al. (1979) is the mostly likely depositional agent.

The foregoing data show that most of the Pliocene section at Site 548 was deposited by pelagic settling of grains and microfossils. The influence of density currents was minimal. Significant textural variation occurs at grain sizes smaller than is often used for paleoceanic research based on foraminifers (>150 μm). Hence, the foraminiferal population should be largely "autochthonous." For the samples examined in this chapter, the >150- μm fraction is composed almost entirely of foraminifers.

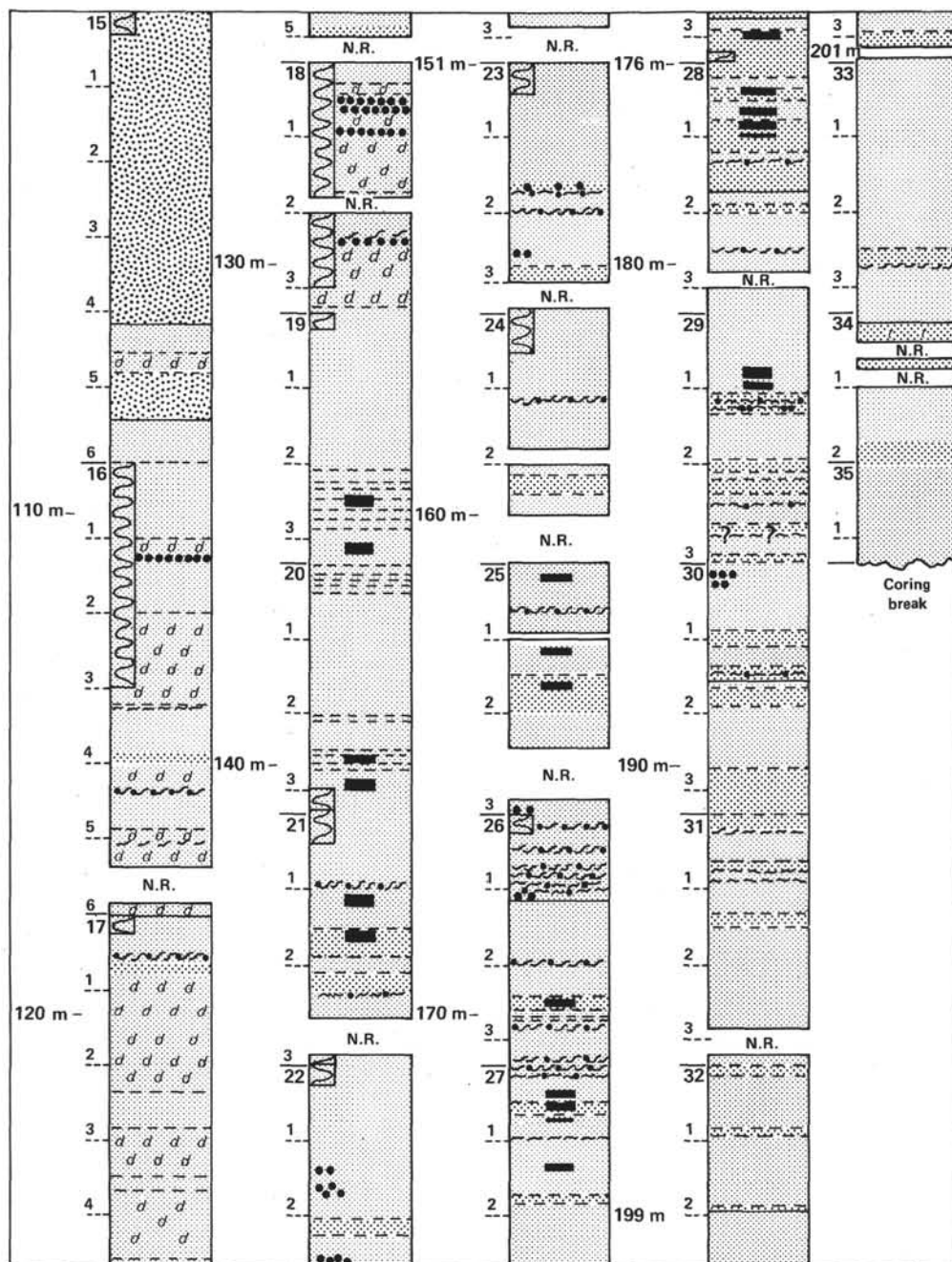


Figure 2. Lithostratigraphy of the Pliocene at Site 548. Largest numbers indicate sub-bottom depth; next largest numbers are core numbers, and smallest numbers designate sections. Fine stipple = dominant green-gray calcareous hemipelagite. Intermediate stipple = horizons of somewhat coarser hemipelagite. Heavy stipple = alternating sandy graded beds and beds of silt and mud. d = dark brown olive mud. Dashed pattern = horizons where gray-green hemipelagite has a higher clay content and a somewhat darker color. Dots = silty partings and/or silt-filled burrows. t = apparently higher terrigenous content. Black rectangles = sampling locations for grain size. The vertical sinuous line in $\frac{1}{4}$ of the core section = sediment deformed by piston coring. N.R. = no recovery.

THE FIRST APPEARANCE OF *GLOBOROTALIA INFLATA*

In the North Atlantic, *G. inflata* is presented as evolving from and gradually replacing *Globorotalia puncticulata* (Deshayes) (Poore, 1979, 1981). Illustrations of both species are presented by Poore (1979). Photomicrographs of upper Pliocene and lower to upper Pleistocene

specimens of *G. inflata* from Sites 548 and 549 (which is adjacent to Site 548) are given in Plate 1. *G. inflata* was distinguished from *G. puncticulata* on the basis of four characters. These are the shape of the dorso-peripheral shoulder, the aperture location and shape, the number of chambers in the final whorl as seen from the spiral side, and the texture. The ideal specimen of *G. puncticulata* (as figured by Poore, 1979, plate 5, figs. 4-6, and

Table 1. Hole 548 Pliocene particle-size distributions (wt. %).

Core-Section (level in cm)	Particle size (μm)							
	>149	149-63	63-32	32-15	15-8	8-3	3-2	<2
19-3, 80	0.44	0.41	4.27	14.73	15.84	14.05	7.42	42.83
19-4, 25	2.90	3.16	17.57	16.52	14.10	8.18	7.38	30.18
20-3, 94	2.26	2.82	12.62	14.61	13.58	7.92	6.38	39.81
	(2.18) ^a	(2.72)	(12.89)	(15.26)	(13.89)	(7.71)	(7.02)	(38.24)
20-3, 141	2.31	4.41	27.21	15.52	10.95	5.86	5.26	28.46
	(2.12)	(4.04)	(31.86)	(15.18)	(9.05)	(6.01)	(4.23)	(27.52)
21-2, 20	2.32	4.31	22.38	14.02	9.79	10.54	3.96	32.66
21-2, 96	4.00	10.95	32.65	14.01	5.66	6.83	4.66	21.24
25-1, 21	1.52	3.61	26.40	13.38	9.79	10.27	6.58	28.50
25-2, 26	2.64	4.88	31.15	13.01	8.13	9.12	5.89	25.17
25-2, 97	1.72	4.63	35.90	13.30	7.54	7.66	5.25	24.00
26-3, 75	3.44	6.44	31.76	14.12	7.50	6.89	4.28	25.58
27-1, 65	1.10	5.28	20.46	12.77	8.71	10.76	8.00	32.92
27-1, 85	1.32	5.15	31.26	15.24	9.14	8.93	7.16	21.80
27-1, 100	1.30	3.40	18.20	12.79	12.52	10.06	7.43	34.29
27-2, 53	0.54	1.59	16.67	14.70	13.73	11.21	7.24	34.40
27-3, 149	1.34	5.45	30.10	8.60	10.31	8.79	7.11	28.40
28-1, 51	1.38	5.78	40.70	14.19	7.54	6.61	5.40	18.39
	(1.27)	(5.32)	(42.36)	(14.31)	(6.80)	(5.62)	(5.22)	(19.10)
28-1, 104	1.30	3.86	25.52	12.38	8.40	7.03	8.86	32.65
28-1, 124	2.27	7.33	26.32	12.47	7.00	9.36	4.64	30.61
28-1, 145	2.69	7.51	35.93	12.77	10.38	6.03	5.91	18.77
29-1, 128	2.31	3.02	12.35	8.21	12.77	11.53	9.93	39.91
	—	—	(12.77)	(8.61)	(14.69)	(12.19)	(7.94)	(38.45)
29-1, 147	1.66	3.46	10.50	9.99	12.44	12.03	9.00	40.91
\bar{X}	1.94	4.64	24.28	13.21	10.28	9.03	6.56	30.07
S.d.	0.90	2.25	9.59	2.10	2.76	2.18	1.63	7.17

^a Parentheses enclose values for the second run of the sample.

Stainforth et al., 1975, figs. 199 and 200) would have a high, angled shoulder, an interio-marginal-peripheral highly arched aperture, four chambers in the last whorl, and a punctulate texture. The ideal *G. inflata* (Poore, 1979, plate 5, figs. 1-3; Plate 1) would have a low, rounded shoulder, a large umbilical to extra-umbilical aperture, about 3½ chambers in the final whorl, and a smooth to clear crystalline texture. As can be seen in Plate 1, the Pliocene and lower Pleistocene specimens from Site 548 have a crystalline texture, whereas upper Pleistocene specimens have a smooth test.

At Site 548, *G. inflata* appears over the span of Cores 548-25 and 548-24. *G. puncticulata* is abundant in these cores, and a considerable number of intergrades between the two species are also present.

To document the appearance of *G. inflata* and also to determine whether the appearance was evolutionary or controlled by a change in paleoceanic conditions (ecologic first appearance), samples were taken about every 50 cm through Cores 548-27 to 548-24, and relative abundances of planktonic species were determined for the >150- μm fraction. The counting techniques used are described in Loubere (1982), and have been demonstrated to provide good reproducibility. In all cases more than 300 individuals were counted (average of 387). Also, the relative abundances of *G. inflata*, *G. puncticulata*, and their intergrades were determined. The relative-abundance data are presented in Table 2 and Figure 3. In Table 3 the types of *G. inflata* and *G. puncticulata* forms are quantified according to the criteria already listed; for this table about thirty well-formed individuals were carefully examined in a random transect across a counting slide. The table has the ideal *G. inflata* and *G. puncticulata* as end-members and a gradation of mor-

photypes in between; from it one can form an impression of the degree and type of variability present in the populations examined. Following Stainforth et al. (1975), we gave primary consideration to the dorso-peripheral shoulder, which reflects overall test shape.

Table 4 presents the relative abundances of the dominant species from Cores 548-27 to 548-24 and the ratio of *G. inflata* and the intergrade forms to the sum of all the *G. inflata* and *G. puncticulata* morphotypes. It is evident from Tables 2 and 4 and Figure 3 that planktonic species abundances fluctuate regularly through Cores 548-26 to 548-24. Over this interval there are no indications of major unidirectional changes in surface ocean conditions, but instead there is recorded a regular oscillation between two conditions: one reflected in an assemblage of which the *G. puncticulata*-*G. inflata* group accounts for more than 20% of the specimens, and one reflected in an assemblage of which that group accounts for less than about 15% of the specimens. The ratio of *G. inflata* + intergrades to the sum of the *G. puncticulata*-*G. inflata* group remains uniformly low through Cores 548-26 and 548-25. The ratio shows no relationship to the fluctuating abundance of the *G. puncticulata*-*G. inflata* group within the planktonic assemblage.

As shown in Table 3, Core 548-26 contains only *G. puncticulata* and intergrade forms close to the *G. puncticulata* morphotype. No individuals that could be called *G. inflata* were observed. In Core 548-25 the degree of morphotype variability increases considerably, and individuals that could be called *Globorotalia cf. inflata* were occasionally observed. Within Core 548-24 *G. inflata* forms become common to dominant. As seen in the planktonic-assemblage data (Table 2), there is no environmental change indicated that will explain this trend

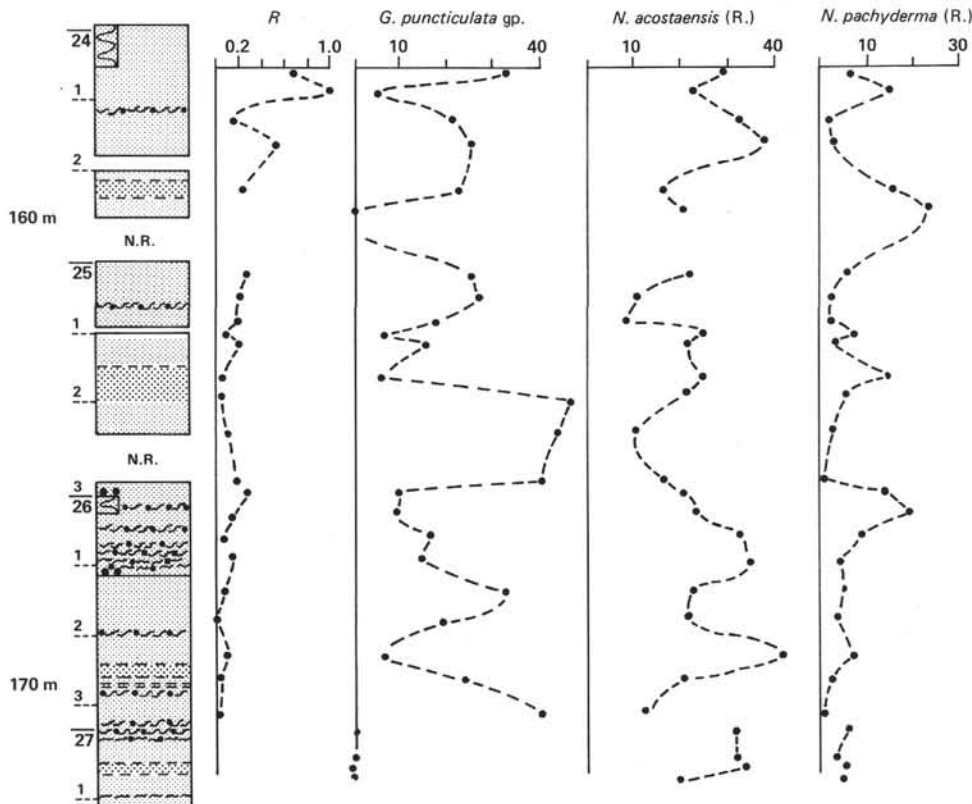


Figure 3. Relative abundances of planktonic foraminiferal species over the interval of the first occurrence of *G. inflata*. *R* = abundance ratio of *G. inflata* and *G. inflata*-*G. puncticulata* intergrade to the sum of *G. inflata*, the intergrade, and *G. puncticulata*. *G. puncticulata* gp. = percent of *G. inflata*, the intergrade, and *G. puncticulata* in the planktonic assemblage. *N. acostaensis* (*R.*) = percent of right-coiling *N. acostaensis* (Blow). *N. pachyderma* (*R.*) = percent of right-coiling *N. pachyderma* (Ehrenberg). Stratigraphic column as in Figure 2.

in *G. puncticulata*-*G. inflata* morphotypes, so the record must represent an evolutionary sequence.

The exact age of this evolutionary event is in dispute. Berggren and Van Couvering (1974) place it at about 3 m.y. ago. Backman (1979) has disputed this on the basis of nannofossil correlations among DSDP sites in the higher-latitude North Atlantic. He would have the first appearance of *G. inflata* as late as 2.4 m.y. ago. At Site 548 the record of this event occurs near the base of a long interval of normally magnetized sediments (Cores 548-19-548-26, Townsend, this vol.), which must be of the Gauss paleomagnetic epoch (2.5-3.4 m.y. ago, Ness et al., 1980). These data support the age proposed by Berggren and Van Couvering (1974). Further, an age of 2.4 m.y. for the *G. inflata* datum would give the upper Pliocene at Site 548 (about 159.5-108 m sub-bottom on Fig. 2; shipboard scientists place the Plio-Pleistocene boundary at 108 m sub-bottom) a sediment accumulation rate of about 10 cm/1000 yrs. This is nearly twice the estimated Pleistocene accumulation rate of 5.7 cm/1000 yrs. If the Pliocene estimate were correct, it would require the Pliocene planktonic-microfossil-rich hemipelagite to have accumulated much faster than the Pleistocene section, which contains abundant evidence of frequent deposition by density currents and turbidity currents. This is not likely, given our current understanding of the rates of deep-sea sedimentation. Again,

these data support the age date of Berggren and Van Couvering (1974).

CHARACTERIZING BOTTOM WATERS: BENTHIC FORAMINIFERS

Site 548 was drilled at relatively shallow depths, so its benthic fauna represents the intermediate-depth water mass of the North Atlantic. Presently, this water mass is formed in the Mediterranean, and the sea-bottom around Site 548 is bathed by warm, saline water (Reid, 1978). Caralp (this vol.) shows that the Mediterranean water mass at Site 548 is identified by a benthic foraminiferal assemblage containing abundant *Sigmoilopsis*, *Uvigerina peregrina* (Cushman), *Bulimina*, and *Melonis*. To examine the benthic foraminiferal record over the middle-to-late Pliocene transition, calcareous specimens in the >150- μ m fraction of 51 samples from Cores 548-29 to 548-22 were counted and apportioned to genera as defined by Loeblich and Tappan (1964) (see Fig. 4). In identifying specimens, reference was also made to Schnitker (1979b), Berggren (1972a), Pujos-Lamy (1973), and Murray (1971). In all samples save one (548-24-1, 100 cm; 88 individuals), at least 150 individuals were counted (average count was 387 individuals). In nearly all cases the entire population of benthic specimens was counted without sample splitting. The counts are presented in Figure 4, along with a record of average

Table 2. Planktonic species abundances in samples spanning the F.A.D. of *G. inflata*, Hole 548.

Species	Core-Section (level in cm)													
	23-3, 125	24-1, 100	24-1, 146	24-2, 50	24-2, 102	24-3, 45	24-3, 97	25-1, 21	25-1, 75	25-1, 125	25-2, 0	25-2, 26	25-2, 97	25-2, 148
<i>Neogloboquadrina acostaensis</i> R.	10.3	29.4	22.6	32.9	38.0	16.62	20.8	21.3	10.6	8.6	25.6	21.8	24.7	21.0
L.	—	—	0.62	0.43	0.43	0.54	0.47	0.83	0.26	0.89	0.66	—	1.06	0.47
<i>Neogloboquadrina atlantica</i> R.	6.9	2.36	13.7	6.9	6.0	1.34	3.07	5.3	3.7	1.2	3.9	2.2	3.45	2.3
L.	4.9	0.67	0.93	1.7	1.5	1.34	0.71	2.2	9.5	29.2	17.0	4.9	3.45	2.8
<i>Neogloboquadrina pachyderma</i> R.	5.9	6.42	14.5	2.2	2.6	15.0	23.4	6.1	2.9	2.4	7.2	3.9	14.6	5.6
L.	—	—	0.15	—	0.43	0.27	0.24	—	—	0.30	0.33	—	0.27	—
<i>Neogloboquadrina</i> sp. 1 ^a	1.0	1.69	0.93	0.43	0.21	0.80	—	1.7	7.9	10.4	6.2	1.72	1.33	—
<i>Globigerina woodii</i>	2.9	—	2.95	0.86	1.50	3.75	6.9	6.1	2.9	3.0	3.6	1.47	2.13	—
<i>Globigerina bulloides</i> ^a	4.0	4.73	11.0	8.67	1.9	3.22	5.4	6.6	4.2	0.90	1.6	1.96	6.38	0.47
Quadrate bulloides ^a	2.3	1.02	4.4	2.2	1.1	1.88	1.89	3.6	7.7	3.87	3.3	2.45	3.46	2.8
Inflated bulloides ^a	0.33	—	1.6	0.87	—	0.54	0.24	—	0.79	0.60	1.6	0.25	0.27	—
<i>Globigerina falconensis</i>	2.3	0.34	5.6	4.33	1.9	4.02	1.89	3.6	5.5	2.7	3.0	1.23	1.33	1.4
<i>Globigerina calida</i>	—	0.34	0.16	0.43	—	—	—	0.28	—	—	—	0.25	1.06	—
<i>Globigerinella aequilateralis</i>	2.3	0.67	0.62	1.73	0.43	0.80	0.71	0.28	—	0.30	0.33	—	1.60	0.93
<i>Globorotalia inflata</i>	11.6	5.07	3.3	—	1.9	0.80	—	—	—	—	—	—	—	—
<i>Globorotalia bononiensis</i> ^a	2.0	3.72	—	1.73	2.1	2.15	—	0.55	0.79	0.60	0.33	0.98	—	1.9
<i>Globorotalia inflata-Globorotalia puncticulata</i> (intergrades)	11.6	16.89	2.0	4.3	11.9	5.09	—	8.0	5.3	4.2	0.98	3.92	0.53	2.8
<i>Globorotalia puncticulata</i>	11.6	10.8	—	17.3	11.8	16.89	—	17.5	22.4	13.9	5.9	11.52	5.32	44.4
<i>Globigerinita naparimaensis</i>	4.0	1.69	0.16	1.3	3.0	2.14	3.3	2.5	0.53	0.30	0.66	0.49	1.33	0.47
<i>Globigerinita glutinata</i>	7.9	4.05	5.9	3.0	4.3	7.24	6.62	7.5	5.3	3.6	5.6	8.08	6.65	6.5
<i>Globigerina quinqueloba</i>	3.6	6.42	1.6	1.3	1.1	2.14	8.03	0.55	1.0	4.5	3.9	8.08	3.46	—
<i>Globorotalia scitula</i>	0.33	0.68	3.7	0.43	1.7	1.88	0.95	0.83	2.64	1.5	1.6	1.23	1.86	0.93
<i>Globorotalia crassaformis</i>	1.3	—	0.62	1.73	2.6	11.26	13.2	-3.3	3.2	1.8	0.66	6.86	8.78	1.87
<i>Globorotalia praeirsuta</i>	—	—	—	—	—	—	0.24	—	—	3.87	2.6	12.0	2.39	—
<i>Orbulina universa</i>	1.7	1.01	1.9	2.6	2.6	0.27	1.42	—	1.1	0.30	0.33	3.68	3.46	3.3
<i>Globigerina venezuelana</i>	0.33	1.35	0.3	2.2	—	—	—	—	1.1	0.60	1.3	0.49	0.79	—
<i>Globigerina apertura</i>	—	—	—	—	—	—	—	—	—	—	—	—	—	—

^a These forms are discussed in the Appendix.

specimen length in the populations of *Globocassidulina subglobosa*. All specimens of *G. subglobosa* in the samples were measured along their longest axis for this statistic.

The genera presented in Figure 4 account for between 80 and 95% of the benthic assemblages. The most abundant genera are *Globocassidulina*, *Cibicidoides*, *Melonis*, and *Bulimina*. Contamination by shallower-water species appears to be minimal, since the forms indicating shelf and nearshore environments in the Bay of Biscay (Schnitker, 1969; Pujos-Lamy, 1973; Caralp, this vol.; Murray, 1971) are scarce in our samples. Also, abraded and damaged specimens of both benthic and planktonic foraminifers are infrequent. Hence, the large majority of the specimens in our samples appear to be more or less *in situ* for the upper slope in the northeastern Atlantic.

Numerous authors (Streeter, 1973; Schnitker, 1980; Lohman, 1978; Corliss, 1979a) have interpreted deep-sea benthic foraminiferal taxic variations in terms of hydrologic parameters. Since the lithology in Cores 548-29 to 548-22 is a fairly uniform muddy calcareous ooze, the variations in taxic abundances presented in Figure 4 should represent changes in hydrology for the middle-to-late Pliocene transition in the intermediate depths of the northeastern Atlantic.

The benthic foraminiferal data in Figure 4 show a series of distinct events that can be interpreted as five stages in the evolution of intermediate-depth water properties over the middle-to-late Pliocene transition. These stages are described as follows:

1. Cores 548-29 and 548-28 contain abundant *G. subglobosa*, *Cibicidoides*, and *Bulimina*. Within Core 548-29 there is a peak in the abundance of *Ehrenbergina*, ac-

companied by a small peak in abundance for *Uvigerina* (dominantly *U. peregrina*). Within Core 548-28 there is a peak in the abundance of *Pullenia*.

2. In Core 548-27 the assemblage changes as the abundances of *Cibicidoides* and *Bulimina* decrease greatly and *Cibicides*, *Melonis*, and *Pleurostomella* become more abundant. Also in Core 548-27, the average size of the *G. subglobosa* populations becomes much more variable. There is probably a short break in the record at the boundary between Cores 548-27 and 548-26. At this point the gamma-ray intensity recorded in the downhole logs changes sharply (see Poag and Low, this vol.). Along with this change, the species composition of the planktonic foraminifers also changes sharply. Core 548-27 contains few *G. puncticulata*, but the species is abundant in Core 548-26. Finally, the boundary between Cores 548-27 and 548-26 is a "nick" point on many of the abundance curves for benthic taxa. All these changes coinciding indicates that at least some brief part of the record must be missing, even though no sedimentologic evidence was recovered indicating a hiatus.

3. In Cores 548-26 and 548-25, the abundance of *G. subglobosa* becomes quite variable and then decreases considerably from average values greater than 20% to values less than 10%. Accompanying this pattern is a large drop in the average size of the *G. subglobosa* population, from values around 400 μm to values less than 250 μm . Corresponding to these events, the abundance of *Melonis*, *Bulimina*, and *Cibicidoides* increase considerably. Abundances of *Gyroidinoides* and *Ehrenbergina* also increase somewhat over this interval. As shown in Figure 4, a progressive series of taxic abundance peaks occurs through Cores 548-26 and 548-25. The decrease

Table 2. (Continued).

Core-Section (level in cm)																	
25-3, 70	25-3, 139	25-4, 17	26-1, 40	26-1, 96	26-1, 148	26-2, 60	26-2, 125	26-3, 50	26-3, 100	26-4, 18	27-1, 4	27-1, 65	27-1, 85	27-1, 100	28-1, 24	28-1, 51	28-1, 104
10.2	16.3	21.06	23.6	33.3	35.0	22.9	21.86	41.8	20.86	11.6	32.3	31.9	34.1	19.2	17.8	11.9	12.9
—	0.47	1.19	—	0.23	1.1	0.52	0.77	0.71	0.71	0.24	0.33	—	0.5	0.2	—	0.31	—
3.2	1.41	5.04	2.33	3.8	3.2	3.1	2.64	2.48	2.49	4.7	13.8	24.1	17.5	19.5	3.1	3.7	2.3
2.5	2.13	10.38	8.91	1.79	1.3	3.9	5.12	0.53	2.14	12.5	1.98	1.3	0.2	0.2	0.3	5.3	—
3.2	0.95	13.9	18.99	9.2	4.7	5.2	4.03	6.91	4.18	1.4	6.6	3.7	5.8	5.6	4.8	1.25	4.2
0.32	—	0.89	0.39	—	0.42	—	0.15	0.35	0.18	0.24	—	0.5	0.2	—	0.9	0.31	—
1.9	0.24	7.72	11.24	—	0.85	3.91	8.68	2.84	6.24	4.5	0.99	5.8	0.9	1.8	1.4	13.1	6.1
5.7	2.13	1.48	1.16	3.58	1.27	1.83	1.70	1.06	2.49	0.71	3.96	2.1	3.7	4.9	14.1	15.0	10.9
2.5	4.02	2.97	4.65	4.70	7.6	3.65	8.06	7.27	6.77	6.6	11.9	6.8	7.4	15.2	4.5	7.8	6.1
1.3	0.95	2.37	3.1	3.13	5.3	2.34	3.88	2.13	5.17	2.6	1.32	3.4	5.8	5.6	6.8	3.4	9.7
—	0.24	—	0.39	0.45	1.3	—	1.39	1.42	1.6	0.24	0.33	1.6	1.8	1.1	1.4	0.63	1.9
2.2	0.71	1.78	3.1	2.23	5.1	1.82	1.39	1.95	4.28	3.1	1.98	3.7	2.7	2.0	5.5	2.8	7.4
—	0.95	0.29	1.2	0.22	—	1.3	—	0.35	—	—	—	1.8	0.5	3.1	1.1	—	1.9
0.63	1.18	1.18	0.77	0.89	—	0.26	0.31	3.19	0.53	0.24	0.99	1.6	1.2	1.8	0.6	—	2.2
—	—	—	—	—	—	—	—	—	—	—	0.99	—	—	—	—	—	—
2.2	3.1	1.19	—	0.22	0.64	0.78	0.31	0.71	0.71	0.24	—	—	—	—	—	—	—
5.7	9.2	2.97	1.55	1.57	2.3	3.13	0.31	0.89	1.78	1.2	—	—	—	—	—	—	—
38.1	31.0	6.82	8.14	14.7	11.7	29.9	19.38	5.85	22.28	39.5	0.33	—	—	0.2	—	—	—
0.63	0.95	0.29	—	1.1	1.9	1.56	—	—	—	0.24	1.65	5.3	5.3	6.5	7.6	6.6	9.7
6.9	8.3	2.97	1.55	9.4	7.6	5.9	6.98	4.43	—	—	—	—	—	—	—	—	—
—	1.18	0.89	1.16	3.58	1.27	2.86	1.70	7.65	4.1	3.3	4.62	1.1	0.5	0.5	2.6	0.63	2.6
0.95	0.47	1.48	0.39	2.46	1.27	0.78	1.70	2.13	1.79	—	1.98	—	0.5	0.4	0.5	1.9	0.6
9.2	11.6	4.74	3.1	2.01	3.4	0.78	6.51	2.66	4.1	—	0.66	1.6	—	0.2	—	—	—
0.32	1.65	—	0.39	0.45	0.43	0.26	0.15	—	—	—	1.32	0.5	3.7	7.6	0.5	—	—
1.9	0.95	3.26	1.16	1.34	1.7	0.78	0.46	1.77	3.92	5.2	12.54	—	—	—	—	—	—
—	—	2.97	1.55	—	—	0.52	2.02	2.30	0.18	0.48	0.33	—	—	0.2	11.8	7.8	15.1
—	—	—	—	—	—	—	—	—	2.85	—	—	0.5	1.6	1.6	3.1	1.9	2.6

Table 3. Description of *Globorotalia puncticulata*, *Globorotalia inflata*, and their intergrades for Cores 548-26 to 548-23.

Core-Section (level in cm)	Texture	Shape of dorso-peripheral shoulder												Elevated and angled							
		Rounded				Elevated but rounded				Aperture location ^a				Low umb. arch	Umb. to periphery	High, round periph. arch	Low umb. arch	Umb. to periphery	High, round periph. arch		
		Low umb. arch		Umb. to periphery		High, round periph. arch		Low umb. arch		Umb. to periphery		High, round periph. arch									
		Number of chambers in final chamber set ^b												3	4	3	4	3	4	3	4
		3	4	3	4	3	4	3	4	3	4	3	4								
				<i>Globorotalia inflata</i> and <i>G. cf. inflata</i>				<i>Globorotalia inflata</i> - <i>G. puncticulata</i> intergrades				<i>Globorotalia puncticulata</i>				<i>Globorotalia bononiensis</i>					
		Number of specimens																			
23-3 (125)	Puncticulate	3		2		1		2		3		1		5		1					
24-1 (146)	Crystalline	1	4	6	1		2		2		3		1		1		1				
24-2 (50)	Puncticulate	14	12	1		1		14		2		1		5		5					
24-2 (102)	Crystalline	1	2		2		2		3		2		1		6		6				
24-3 (28)	Puncticulate	2		2		2		2		1		5		14		4					
25-1 (21)	Crystalline	2		2		2		4		1		3		5		4					
25-1 (75)	Puncticulate	6		1		1		3		4		1		5		13					
25-1 (97)	Crystalline	1		1		4		2		1		1		1		8					
25-1 (125)	Puncticulate	1		1		4		3		1		4		2		3					
25-2 (148)	Crystalline	1		1		1		1		1		1		3		3					
25-4 (17)	Puncticulate	1		2		1		1		1		2		1		4					
26-1 (96)	Crystalline	1		1		1		1		1		1		5		17					
26-2 (60)	Puncticulate	1		1		1		1		1		1		10		12					
26-3 (50)	Crystalline	2		2		2		2		2		1		1		2					
26-4 (18)	Puncticulate	1		1		1		1		1		2		4		5					
	Crystalline	1		1		1		1		1		2		4		16					

^a Low umbilical arch; extending from umbilicus to periphery; high, round peripheral arch.

^b As seen from spiral side, 3 = 3 to 3.75, 4 = 4 to 4.5.

Table 4. Morphologic variability in the *Globorotalia puncticulata* group and abundances of dominant species (%), Hole 548.

Core-Section (level in cm)	(<i>G. inflata</i> + int.)/ <i>G. puncticulata</i> gp. ^a	<i>G. puncticulata</i> gp.	% <i>N. acostaensis</i> (R.)	% <i>N. pachyderma</i> (R.)
23-3, 125	0.67	34.8	10.3	5.9
24-1, 100	0.67	32.8	29.4	6.4
24-1, 146	1.00	5.3	22.6	14.5
24-2, 50	0.20	21.6	32.9	2.2
24-2, 102	0.54	25.6	38.0	2.6
24-3, 45	0.26	22.8	16.62	15.0
24-3, 97	—	0.0	20.8	23.4
25-1, 21	0.31	25.5	21.3	6.1
25-1, 75	0.24	27.7	10.6	2.9
25-1, 125	0.23	18.1	8.6	2.4
25-2, 0	0.14	6.88	25.6	7.2
25-2, 26	0.25	15.44	21.8	3.9
25-2, 97	0.10	5.85	24.7	14.6
25-2, 148	0.06	47.2	21.0	5.6
25-3, 70	0.13	43.8	10.2	3.2
25-3, 139	0.23	40.2	16.3	0.95
25-4, 17	0.30	9.79	21.06	13.9
26-1, 40	0.16	9.69	23.6	18.99
26-1, 96	0.10	16.27	33.3	9.2
26-1, 148	0.16	14.0	35.0	4.7
26-2, 60	0.09	33.0	22.9	5.2
26-2, 125	0.02	19.69	21.86	4.0
26-3, 50	0.13	6.7	41.8	6.9
26-3, 100	0.07	24.06	20.86	4.2
26-4, 18	0.03	40.7	11.6	1.4
27-1, 4	0.0	0.3	32.3	6.6
27-1, 65	—	0.0	31.9	3.7
27-1, 85	—	0.0	34.1	5.8
27-1, 100	0.0	0.2	19.2	5.6

^a This column gives the ratio of *G. inflata* + the intergrade forms to the sum of *G. inflata* + *G. puncticulata* + *G. inflata*-*G. puncticulata* intergrade forms.

in the size and abundance of *G. subglobosa* is accompanied initially by abundance peaks for *Melonis* and *Bulimina*. This is followed sequentially by peaks for *Cibicidoides*, *Ehrenbergina*, and finally *Uvigerina*. Clearly the mid-depth water-mass characteristics were evolving progressively over the interval represented by Cores 548-26 and 548-25.

4. In Core 548-24, corresponding to the first common occurrence of *G. inflata*, *G. subglobosa* once again becomes abundant, and average population size becomes large. Also, there is a peak in the abundances of *Ehrenbergina* and *Uvigerina peregrina*.

5. In Cores 548-23 and 548-22, *U. peregrina* is replaced by other *Uvigerina* species, chiefly *U. auberiana* d'Orbigny. *Ehrenbergina* disappears completely from the record. This interval is marked by abundant, large *G. subglobosa* and common *Uvigerina*. In addition, the abundances of *Melonis*, *Bulimina*, and *Cibicidoides* are quite variable, and the abundance of *Pullenia* is cyclic.

The ecology of most deep-sea benthic foraminiferal species is not well understood, so exact interpretation of the variations in abundance just described is not easy. The size variation in *G. subglobosa* is also hard to interpret, though it must represent changes in some aspect of the benthic environment, since the size measurements show very clear trends. Corliss (1979b) examined *G. subglobosa* sizes in specimens from the Indian Ocean, and found size trends to be related to water depth in some fashion. He was unable, however, to determine exactly what variable was affecting individual size in the

G. subglobosa population. He hypothesized that calcite dissolution could be an important factor, but this is not likely to be true for the Site 548 Pliocene, which has a very well preserved calcareous-sediment record. The variations in benthic taxa detailed in the foregoing may indicate changes in both water temperature and chemistry. To establish which of these factors was most important, we analyzed a subset of our samples for stable isotopes.

ISOTOPE RESULTS: BENTHIC FORAMINIFERS

To help evaluate the hydrology of the bottom waters at Site 548 during the middle-to-late Pliocene transition, we analyzed the stable isotopes of benthic foraminifera from 20 samples taken in Cores 548-28 to 548-24. These analyses used 20 to 80 individuals of either *Globocassidulina subglobosa* or *Cibicidoides* sp. The samples were prepared in the standard manner (Keigwin, 1979). They were reacted at 50°C with 100% orthophosphoric acid, and the stable isotopes of the carbon dioxide gas trapped from this were measured using a Varian Mat 250 mass spectrometer and the standard NBS-20. All measurements were converted to the PDB standard using the equation of Garlick (1978). As part of the analysis, routine small aliquots of the standards were run along with our samples through our preparation line to ensure consistency of results. Repeated experiments with NBS-20 and our laboratory standard Phi-1, which has been calibrated to PDB by the National Bureau of Standards, give a measurement precision to within $\pm 0.1\%$ for $\delta^{18}\text{O}$ and within $\pm 0.05\%$ for $\delta^{13}\text{C}$. The isotope measure-

ments are presented in Table 5. The $\delta^{18}\text{O}$ measurements show a periodic oscillation of about 0.5‰ and a mean value of 2.97‰.

These data cannot be converted directly to a temperature estimate, since the isotopic composition of northeastern Atlantic waters during the Pliocene is not known. Our data can be compared with other work from the deep Pacific and Atlantic, however, and a general statement about bottom-water temperatures at Site 548 can be made. The average oxygen-isotope value from Table 5 can be directly compared to the average value in the late Pliocene for the deep equatorial Pacific, as reported by Shackleton and Opdyke (1977). Their study is based on *G. subglobosa*, the same species as used in this report. The data from Table 5 may also be compared to the data of Keigwin (1982b) for the Pliocene of the Colombian Basin in the low-latitude North Atlantic (Site 502). It should be noted immediately that the values of the data for Site 548 are only 0.7‰ lighter than those for the deep Pacific, and they are nearly the same as the values obtained for the late Pliocene of the deep Atlantic. Thus, during the middle-to-late Pliocene transition, a site at about 1200 m depth in the northeastern Atlantic had nearly the same range of isotopic values as sites

in the deep Pacific and Atlantic oceans. This is unusual, since the upper-slope region around Site 548 is today bathed by waters generated in the western Mediterranean (Sverdrup, Johnson, and Fleming, 1942) and having temperatures ranging between 6 and 9°C (*U.S. Naval Oceanographic Atlas for the North Atlantic*, 1967). This contrasts with a temperature of about 1°C for the deep Pacific in the region of the core studied by Shackleton and Opdyke (Defant, 1961). In Table 6, an average isotopic difference between Site 548 and the Pacific site, for modern oceanic conditions, is calculated using standard procedures. The difference is about 1.6‰, or twice as large as the difference recorded for the period of the middle-to-late Pliocene transition. The Pacific isotopic record shows only a moderate, gradual increase in average value through the late Pliocene and Pleistocene. The increase can be associated with development of North Polar ice, and it seems likely that deep-Pacific water temperature in the Pliocene was not much different from the present one. Thus, it seems probable that the water flowing over Site 548 during the middle to late Pliocene was much colder than the western Mediterranean water now bathing the region. In the Colombian Basin (Site 502), ^{18}O values for *C. wuellerstorfi* average 2.07‰ over the interval from about 3.1 m.y. ago to the Plio-Pleistocene boundary (12 samples averaged from Keigwin, 1982b). This value can be compared to the average for Site 548 by adding about 0.5‰ to the *C. wuellerstorfi* analyses to get a *G. subglobosa* equivalent (Graham et al., 1981). When this is done, given the limitations of the averaging process, the average for Site 548 is similar to the value for Site 502. The deep Atlantic Ocean was undoubtedly cold during the late Pliocene (Keigwin, 1982a), so the data cited here indicate that the waters flowing over Site 548 during the interval represented by our samples were cold. Hence, during the middle-to-late Pliocene transition, warm, saline Mediterranean water was not flowing through the northeastern Atlantic.

This conclusion is supported by the benthic foraminiferal populations described earlier. The samples contain abundant *G. subglobosa* and *Cibicidoides kullenbergi* (Parker). Both these species are associated with colder waters (Schnitker, 1974, 1979a). Neither is present in the Holocene samples from Site 548 (Caralp, this vol.), which represent warm water.

CONCLUSIONS

1. The Pliocene section at Site 548 is a hemipelagite in which the greatest variation in grain size occurs in the

Table 5. Isotopic measurements for the middle-to-late Pliocene transition (Hole 548), referred to PDB standard.

Core-Section (level in cm)	Taxon	$\delta^{18}\text{O}$	$\delta^{13}\text{C}$
24-1, 100	<i>Globocassidulina subglobosa</i>	3.40	-0.08
24-2, 50	<i>G. subglobosa</i>	3.17	-0.20
24-3, 45	<i>G. subglobosa</i>	2.87	0.19
25-1, 95	<i>G. subglobosa</i>	3.29	-0.52
	<i>Cibicidoides</i> sp.	2.63	0.68
25-2, 0	<i>Cibicidoides</i> sp.	2.48	0.41
25-2, 26	<i>Cibicidoides</i> sp.	1.8	0.49
25-3, 70	<i>Cibicidoides</i> sp.	1.88	0.64
26-1, 96	<i>Cibicidoides</i> sp.	1.95	0.59
26-2, 25	<i>G. subglobosa</i>	2.77	-0.01
26-2, 71	<i>G. subglobosa</i>	3.07	0.20
26-2, 160	<i>G. subglobosa</i>	3.19	0.24
26-3, 0	<i>G. subglobosa</i>	3.31	0.24
27-1, 65	<i>G. subglobosa</i>	3.28	0.07
27-1, 85	<i>G. subglobosa</i>	2.98	-0.21
27-1, 100	<i>G. subglobosa</i>	3.04	-0.14
27-2, 126	<i>G. subglobosa</i>	3.26	0.03
27-3, 20	<i>G. subglobosa</i>	3.13	0.05
	<i>Cibicidoides</i> sp.	2.19	0.58
	<i>Cibicidoides</i> sp.	2.17	0.52
27-3, 75	<i>G. subglobosa</i>	3.46	-0.03
28-1, 24	<i>G. subglobosa</i>	2.77	0.13
28-3, 24	<i>G. subglobosa</i>	2.82	0.24
		$\bar{X} = 2.97^a$	0.24

^a *Cibicidoides* values converted to a *G. subglobosa* equivalent by adding 0.5‰ (after Graham et al., 1981).

Table 6. Calculation of oxygen isotopic difference (‰) between the deep Pacific and Site 548 at the present day.

(a) Site	Water temperature (°C) ^a	Salinity ^a	w^a	Calculated Δ_{calcite}	Recent Δ	mid-Plio. Δ
548	7.0	35.4	-0.3	2.33	1.57	0.72
Equatorial Pacific ^b	1.0	34.7	-0.5	3.90		

^a Temperatures and salinities from *U.S. Naval Oceanographic Atlas for the North Atlantic* (1967) and Defant (1961). Associated ^{18}O values for the water from Epstein et al. (1951).

^b Location 4°37'N, 139°36'W (Shackleton and Opdyke, 1977). Mean ^{18}O from Gauss upper boundary to 3.2 m.y. = 3.69‰.

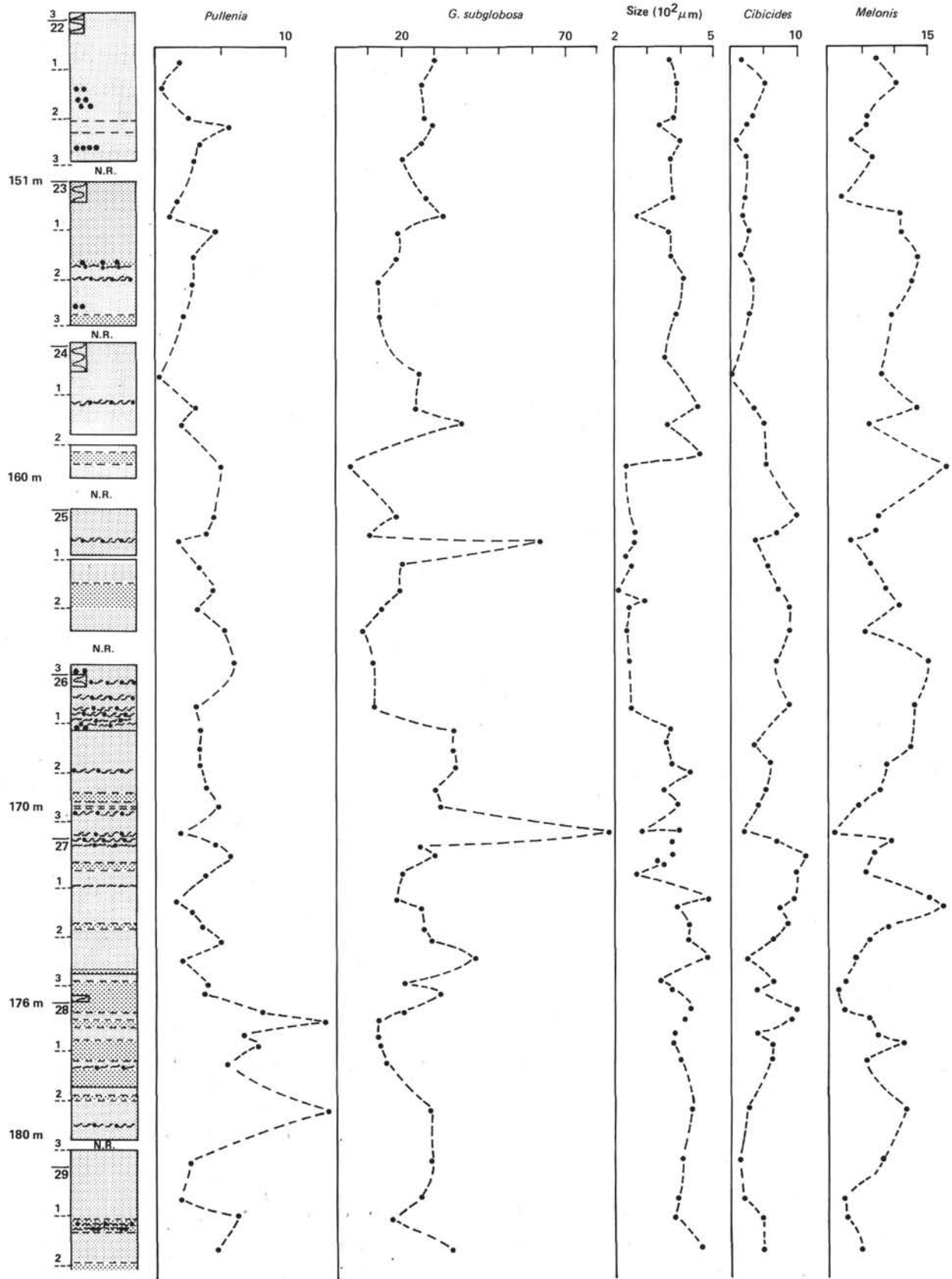


Figure 4. Relative abundances of benthic foraminiferal genera and species over the interval spanning the first occurrence of *G. inflata*. Size = mean test size of *G. subglobosa* population. Shaded area = abundance of *U. peregrina*. Numbers at far left as in Figure 2.

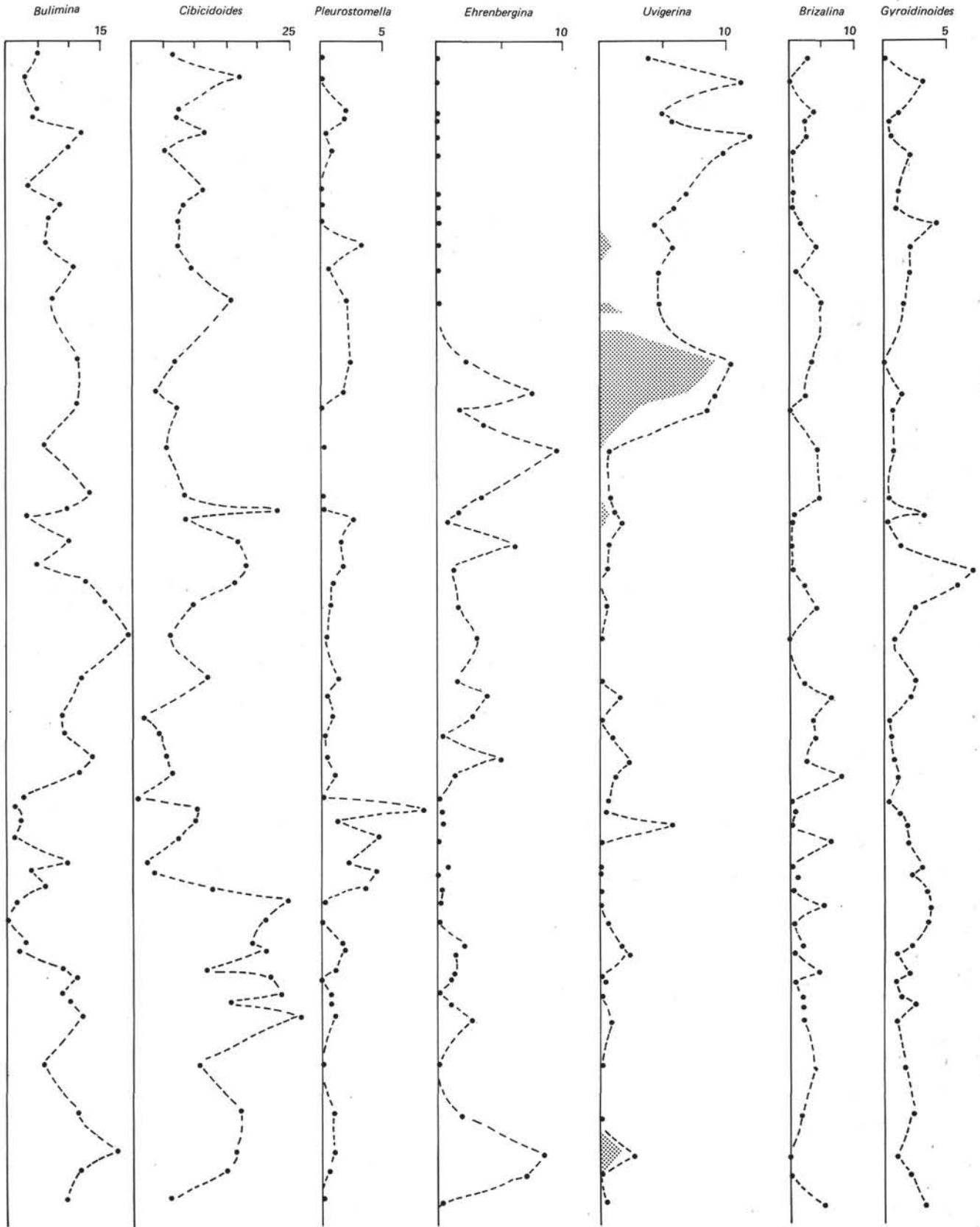


Figure 4. (Continued).

63- to 32- μm and <2- μm fractions. This variation results from fluctuations in the input of terrigenous quartz and calcite to the 63- to 32- μm fraction of the sediments. Since this input is not related to any sedimentary structures, it must have been accomplished by a pelagic settling process.

2. The evolutionary appearance of *Globorotalia inflata* is recorded at Site 548 within Cores 548-25 and 548-24. Over this interval, species abundances in the planktonic assemblages fluctuate periodically indicating significant oscillatory, lateral displacements of surface water masses in the northeastern Atlantic Ocean.

3. During the mid- to late Pliocene the intermediate-depth water mass was undergoing a series of progressive changes represented by changes in the benthic foraminiferal assemblages. These changes particularly affected *Globocassidulina subglobosa*, *Uvigerina*, and *Ehrenbergina*. The appearance of *G. inflata* was marked by a peak in abundance of both *Ehrenbergina* and *Uvigerina peregrina*. These taxa are associated with waters of lower oxygen content and with sediments richer in organic carbon (Lohman, 1978; Miller and Lohmann, 1982). So it seems possible that there was a reduction in the oxygen content of intermediate waters of the northeastern Atlantic during the middle-to-late Pliocene transition. After this event, *Ehrenbergina* disappears from the record, and *Uvigerina* species become common in benthic assemblages.

4. Oxygen-isotope data and benthic foraminiferal species abundances show that the water bathing Site 548 during the middle-to-late Pliocene transition was cold. This contrasts markedly with the present-day situation, in which warm, saline Mediterranean water flows over Site 548. Hence, during the middle to late Pliocene, the thermal structure of the North Atlantic Ocean was different from that of the present. The foregoing observations support, in part, Benson's (1972) study of the Pliocene Mediterranean. On the basis of ostracode assemblages, he shows that the deep Mediterranean was cold during the Pliocene. Benson's model of Pliocene temperatures in the western Mediterranean would make it an unlikely source for warm, saline waters that could invade the intermediate-depth Atlantic. However, in that model (1972, fig. 7), the eastern Mediterranean would have been a possible source for warm, saline water, since this region was apparently a warm, sill-protected, deep basin. Our data indicate that eastern Mediterranean water was not present at intermediate depths in the northeastern Atlantic over the Pliocene time interval we have studied. Thus, the intermediate-depth water in the northeastern Atlantic during the middle to late Pliocene probably had its source in the Atlantic or Arctic basin.

5. The isotopically estimated bottom-water temperature for Site 548 did not change very much over the time spanning the first appearance of *G. inflata* (variation of about 0.5‰). So the changes in abundances of benthic taxa observed over this interval can be interpreted as indicating that the intermediate-depth water mass underwent progressive chemical, rather than thermal, evolution.

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APPENDIX Planktonic Foraminiferal Taxonomy

The taxonomy used in Table 2 is that of Poore (1979) and of standard references on Recent planktonic foraminifers (e.g., Bé, 1977). Several varieties have also been recognized, since we encountered several forms that could not be assigned to established species, or which seemed likely to be paleoecologically useful. Photographs of these forms are presented in Plate 2. The forms are described here in order of appearance in Table 2, where they are identified by superscript a:

Neogloboquadrina sp. 1. This form is superficially similar to *Globigerina bulloides*, but it has a neogloboquadrinid texture. Also, its chambers and their arrangement are more quadrate than globular. The forms seen to date are dominantly left-coiling, and have a distinct lip along the aperture.

Globigerina bulloides, quadrate form. This form is similar to *Globigerina bulloides* in chamber arrangement and texture, but it has a distinctly quadrate chamber arrangement. Chambers appear more rectangular than round; sutures, on the umbilical side especially, are often deeply incised. The final chamber is not much larger than the penultimate chamber. This form has been called *Globigerina incisa* (Brönnimann and Resig) (C. W. Poag, pers. comm.).

Globigernia bulloides, inflated form. This form resembles *Globigerina bulloides* in chamber arrangement and texture, but its chambers are laterally inflated, so that the chamber length is greater than its height. These form are generally rare.

Globorotalia bononiensis Dondi. This species resembles *Globorotalia puncticulata* in general morphology, and is discussed in Stainforth et al. (1975, p. 335).

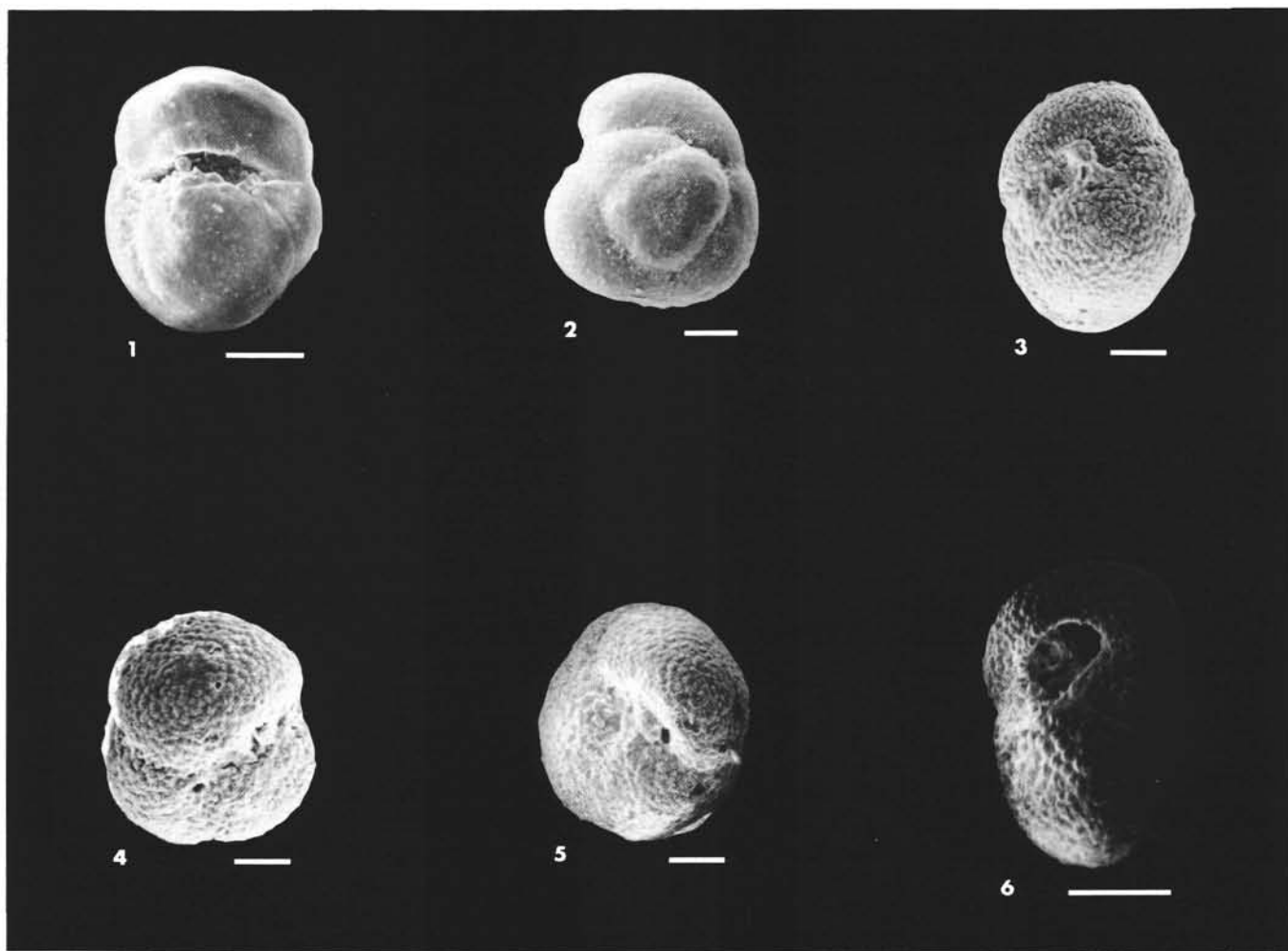


Plate 1. Pliocene-Pleistocene specimens of *Globorotalia inflata* and *Globorotalia puncticulata*. (All scale bars = 100 μ m.) 1-5. *G. inflata*, (1-2) upper Pleistocene, Hole 549A (adjacent to Site 548), Sample 549A-2-6, 116 cm (1, view showing umbilical aperture; 2, view showing spiral side coiling with $3\frac{1}{2}$ chambers in the final whorl), (3-4) lower Pleistocene, with crystalline texture, Sample 548-15-4, 128 cm; (5) upper Pliocene, Sample 548-24-1, 146 cm. 6. *G. puncticulata* exhibiting arched interio-marginal aperture, Sample 548-26-4, 18 cm.

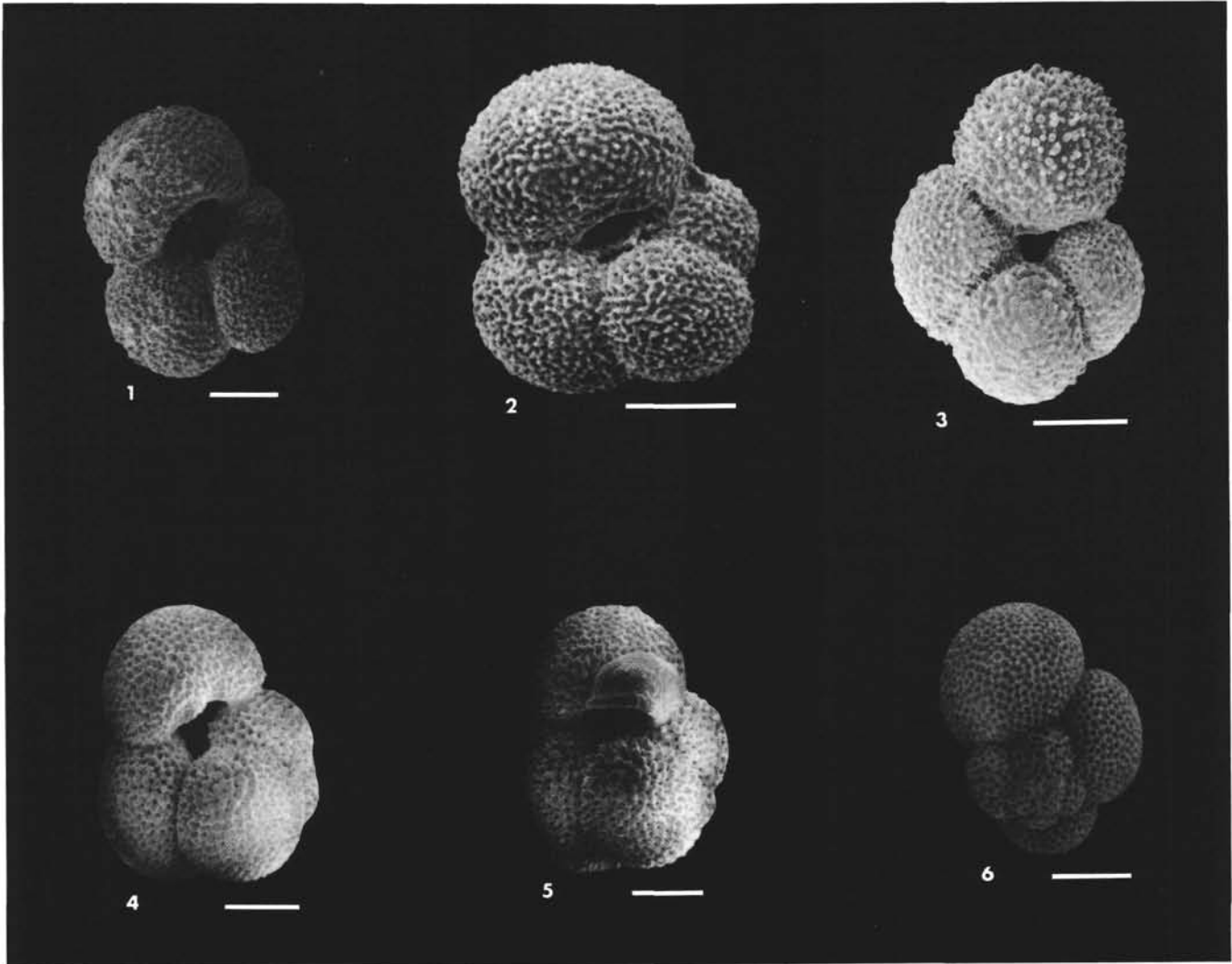


Plate 2. Selected planktonic upper Pliocene foraminifera at Site 548 (some forms are discussed in Appendix); all specimens taken from Sample 548-21-2, 20 cm. (All scale bars = 100 μm .) 1, 10. *Globigerina bulloides*, (10) closeup of penultimate chamber of Fig. 1, showing texture. 2. *G. bulloides* inflated form. 3. *G. bulloides*, quadrate form. 4, 6-7, 12. *Globoquadrina* sp. 1, (7) higher magnification to show texture, (12) closeup of final chamber of Fig. 6, showing texture. 5. Kummerform *Globoquadrina* sp. 1. 8-9, 11. *Globoquadrina venezuelana*, (11) closeup of texture, penultimate chamber of Fig. 9.

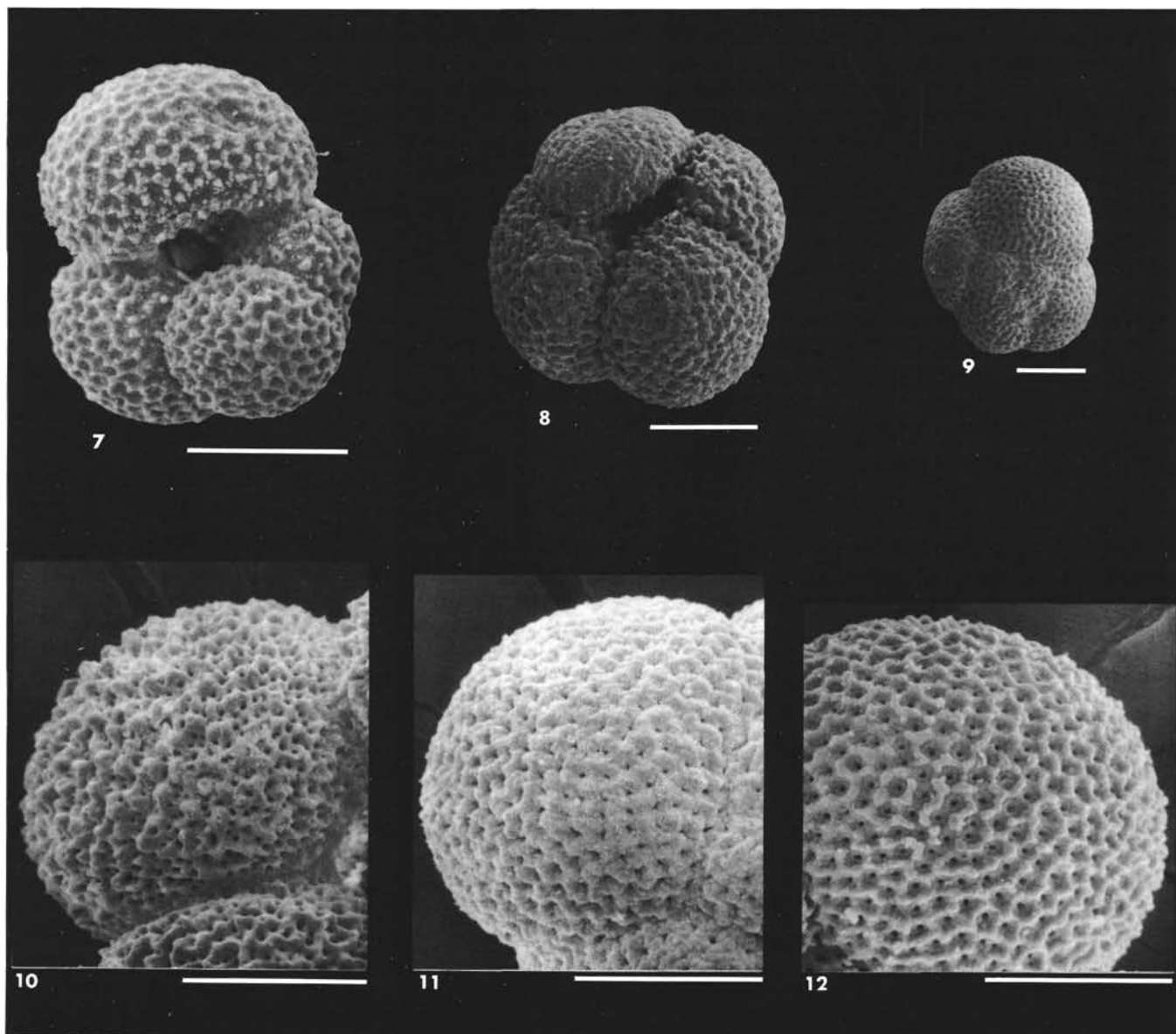


Plate 2. (Continued).