Distribution patterns of benthic foraminifera on the floor of the Mediterranean sea

Benthic
Foraminifera
Mediterranean
Bathymetry
Ecology
Benthique
Foraminifères
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Bathymétrie
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ABSTRACT

Fifty three tops of gravity cores and one of piston core from the Alboran, Balearic, Tyrrhenian, Ionian and Levantine Basins of the Mediterranean have been investigated quantitatively and qualitatively in their content in benthic foraminifera. Partly allochthonous thanatocoenoses were recorded in 17 core samples, which were subsequently discarded. In the remaining 37 cores (12 from the Levantine Basin, 16 from the Ionian Basin, 8 from the Balearic Basin and only 1 from the Tyrrhenian) the B foraminiferal number here defined as the number of benthic foraminifera/gram of sediment, the number of species and the diversity index (calculated following van Straaten, 1960, as the number of specimens/number of species) were calculated.

The Eastern Mediterranean bioprovince is characterized by a benthic fauna very restricted both in terms of density and of diversity. Foraminifera with arenaceous test and a pseudochitinous base are always dominant at depths in excess of 1 800 m. They are apparently the only benthic forms recorded where the clay minerals consist essentially of kaolinite.

A tentative bathymetric zonation is proposed for depths beyond the epibathyal zone (200-1 000 m). It includes an upper mesobathyal zone (1 000-1 800 m), a middle mesobathyal zone (1 800-2 500 m) and a lower mesobathyal zone (2 500-4 000 m).

The zones, as above defined, are further subdivided into a Western Mediterranean bioprovince and an Eastern Mediterranean bioprovince. They can be recognized essentially on the basis of the B foraminiferal number and of the number of species present. They are also recognizable for their (qualitative) faunal assemblages.

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RÉSUMÉ

La distribution des foraminifères benthiques dans les sédiments superficiels de la Mer Méditerranée

Les foraminifères benthiques ont été étudiés quantitativement et qualitativement dans 53 sommets de carottes prélevées au carottier à gravité et à 1 piston dans les bassins méditerranéens d'Alboran, des Baléares, Tyrrhénien, Ionien et Levantin.

Des thanatocoenoses en partie allochtones ont été rencontrées dans 17 carottes qui ont été, de ce fait, écartées. Dans les 37 autres carottes (12 provenant du bassin Levantin, 16 du bassin Ionien, 8 du bassin Baléarique et 1 du bassin Tyrrhénien) on a calculé le « Nombre de foraminifères B » (défini dans le présent travail comme le nombre de foraminifères benthiques par gramme de sédiment), le nombre d'espèces et l'index de diversité (calculé selon van Straaten, 1960, comme le nombre de spécimens/nombre d'espèces).

La province biologique de Méditerranée orientale est caractérisée par une faune benthique très réduite tant en densité qu'en diversité. Les foraminifères à test arénacé et à base pseudochitineuse sont toujours dominants aux profondeurs supérieures à 1 800 m. Ce sont apparemment les seules faunes benthiques signalées lorsque la fraction argileuse comprend une quantité notable de kaolinite.
Un essai de zonation bathymétrique est proposé pour les profondeurs supérieures à l'épibathyal (200 à 1 000 m). On distingue une zone mésobathyale supérieure (1 000 à 1 800 m), une zone mésobathyale moyenne (1 800 à 2 500 m) et une zone mésobathyale inférieure (2 500 à 4 000 m).
Les zones ainsi définies sont ensuite subdivisées en province biologique occidentale et orientale. Celles-ci peuvent être distinguées essentiellement d'après le « nombre de foraminifères B » et d'après le nombre d'espèces présentes. On peut aussi les reconnaître par la composition qualitative de leurs assemblages faunistiques.

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INTRODUCTION

Benthic foraminifera are commonly used as a tool to evaluate the depth of deposition of fossil sediments: the method is founded on the observation of their present day distribution (see Phleger, Parker, Peirson, 1953; Bandy, 1953; Parker, 1958; Bandy, Arnal, 1960; Phleger, 1960 *inter alia*), and is quite successful for the shallower parts of the continental margins, a distinction of three or four depth zones being in most cases easy and immediate. Much more difficult is to subdivide the column beyond the outer limit of the continental shelf. In other words, while it is easy to say *how shallow* is a sediment on the basis of its fossil content, by far more difficult is to say *how deep* it is. As an example, much debate has recently arisen in the scientific community on the depth of deposition of the sediments laid down in the deepest parts of the Mediterranean basins immediately above the Messinian evaporites, or immediately after the end of the "crisis of salinity" (see "Messinian events in the Mediterranean", Amsterdam, 1973, especially Nesteroff, 1973, p. 72; Cita, 1973; Bandy, 1973; Drooger, 1973, p. 266).

The present investigation is motivated by the insufficient data available on the distribution of the benthic fauna in the deeper parts of the Mediterranean sea; it tries to fill a gap existing in our knowledge and also to interpret the faunal assemblages recorded as a function of the peculiar conditions existing in the Mediterranean in terms of distribution pattern of temperature, of salinity, of dissolved oxygen, of nutrients at depth and also as related to the nature of the pelitic sediments.

The depth zones recognized by the various authors are comparable, but not identical. Phleger (1960) bases his zones on the occurrence of characteristic assemblages. Parker (1958) takes into account both the characteristic assemblages and the upper and respectively lower depth limits of individual taxa as does Pujos-Lamy (1971); Bandy (many papers) essentially works on the upper depth limits recorded for individual taxa. All these methods are qualitative. A further complication recorded in the Mediterranean depends on the present distribution of temperature at depth (never colder than 13°C). In fact the upper depth limit of a number of species have been found to be different with reference to the Mediterranean and to California (Bandy, Chierici, 1966).

In order to quantify our observations, and to try a different and independent approach to the problem of how to evaluate the depth of deposition of a basinal deposit in the Mediterranean, we oriented our investigations—always starting from the foraminiferal assemblages—towards the *faunal abundance* and *faunal diversity*.

SAMPLES AND PROCEDURES

The samples investigated are 54 overall (see Table 1). They consist of tops of gravity (trigger) cores taken during the Cruise n. 14 of the "Vema" (V-14) and Cruise n.9 of the "Conrad" (RC-9) oceanographic ships of Lamont-Doherty Geological Observatory of the Columbia University. Table 1 shows their location and water

Table 1
Location of the gravity cores considered in this study.

Cores	Latitude	Longitude	Water depth
RC 9-174	32°57.7'N	32°25.1'E	1 397 m
RC 9-175	35°50.7'N	32°16.4'E	2 639
RC 9-176	36°01.1'N	31°27.7'E	2 465
RC 9-177	33°41.9'N	30°05.3'E	2 820
RC 9-178	33°44.3'N	27°55.3'E	2 628
RC 9-179	34°16.3'N	27°10.9'E	2 604
RC 9-180	34°05.8'N	25°40.8'E	2 653
RC 9-181	33°24.4'N	25°00.5'E	2 286
RC 9-182	33°48.2'N	23°35.8'E	1 794
RC 9-183	34°29.8'N	23°25.4'E	2 684
RC 9-184	35°42.1'N	22°26.2'E	4 609
RC 9-185	34°27.1'N	20°06.9'E	2 858
RC 9-186	33°58.3'N	19°18.9'E	3 888
RC 9-187	35°42.9'N	19°23.9'E	3 303
RC 9-188	36°11.3'N	19°29.9'E	3 290
RC 9-189	36°58.7'N	19°41.0'E	3 378
RC 9-190	38°39.3'N	19°13.7'E	1 712
RC 9-191	38°11.6'N	18°02.0'E	2 345
RC 9-192	39°18.4'N	14°06.3'E	3 435
RC 9-194	40°19.5'N	12°32.9'E	3 581
RC 9-195	40°45.2'N	11°05.6'E	2 338
RC 9-196	41°33.0'N	08°01.6'E	2 694
RC 9-197	41°57.7'N	06°57.8'E	2 703
RC 9-199	39°14.2'N	04°37.6'E	2 318
RC 9-200	38°27.9'N	03°59.3'E	2 657
RC 9-201	37°11.6'N	01°58.3'E	2 776
RC 9-202	37°44.6'N	00°44.6'E	2 701
RC 9-203	36°08.3'N	01°57.7'W	1 287
RC 9-204	35°55.6'N	04°02.4'W	1 371
V 14-128	32°27'N	29°45'E	1 931
V 14-129	31°47'N	29°55'E	576
V 14-130	32°12'N	28°15'E	2 909
V 14-131	33°12'N	26°00'E	2 436
V 14-132	35°46.5'N	23°24.5'E	2 750
V 14-133	36°03'N	23°42.5'E	779
V 14-134	36°03'N	23°43'E	841
V 14-135	35°42'N	18°40'E	4 021
V 14-136	35°44'N	16°31.5'E	3 864
V 14-137	36°17'N	15°35'E	1 580
V 14-138	36°19'N	14°48'E	124
V 14-139	36°28'N	13°31'E	1 703
V 14-140	37°10.5'N	11°47.5'E	166
V 14-141	39°38.5'N	11°49'E	3 450
V 14-142	38°45'N	07°00'E	2 845
V 14-143	41°39'N	05°00'E	2 439
V 14-144	40°58'N	01°49'E	1 311
V 14-145	36°01'N	02°14'W	1 867
V 14-146	36°17'N	02°09'W	1 329
V 14-147	36°13'N	04°47'W	878
KR 05	37°18'N	16°49.3'E	2 580
KR 06	36°35.9'N	17°52.9'E	3 482
KR 07	35°59.2'N	18°31.5'E	3 975
KS 09	35°09.7'N	20°09.9'E	2 880
KR 09	35°52.7'N	22°19.7'E	4 625

depth. The last five samples considered (KR 05, KR 06, KR 07, KS 09, KR 09) were taken during the Cruise Polymède 2 of the "Jean Charcot" oceanographic ship in April, 1972. KR is for gravity (Reineck) cores, KS for piston cores.

Tops of gravity cores ideally represent the sediment/water interface. However, since no particular treatement was done to fix the protoplasm, we have no clear evidence that the benthic foraminifera were actually living on the sea floor.

The distribution of the samples in the various Mediterranean basins is quite uneven: we investigated 2 samples from the Alboran Basin, 12 from the Balearic Basin, 5 from the Tyrrhenian, 24 from the Ionian and 12 from the Levantine Basin, the distinction between the last 2 being taken arbitrarily in correspondence with the 25°E meridian. With 24 core samples examined, the best coverage is for the Ionian Basin.

Also the vertical distribution of our samples is quite uneven. In fact we only examined 2 samples from the neritic zone (shallower than 200 m), which is the best known from previous investigations (see above). Four samples are from depths deeper than 200 m but shallower than 1 000 (epibathyal). Five more samples are from the part of the mesobathyal zone shallower than 1 500 m. Six are from depths comprised in between 1 500 and 2 000 m. The greatest part of the samples investigated (38, or 69 %) are from depths in excess of 2 000 m, which was the most interesting depth range for the purpose of the present study. In fact, *our main objective was to prove or disprove that in the present Mediterranean – on the basis of qualitative and quantitative investigations – there is a real possibility to evaluate the depth of deposition of a sediment, starting from its benthic fauna, for depths in excess of those corresponding to the epibathyal zone.*

Finally, 2 samples (4 609 and 4 625 m respectively) are from the Hellenic Trough, where the Mediterranean reaches its greatest depth.

In order to obtain strictly quantitative data on the distribution of benthic foraminifera, we used the following procedures:

The sediment was dried and weighted (see column C in Tables 2-4), then washed using a sieve with mesh of 63 μm dried again and weighted (see column D in Tables 2-4).

The ratio between the sediment fraction greater than 63 μm or sand-size fraction, and the total sediment was then calculated (column E). This fraction is essentially organogenic, consisting of tests of planktonic foraminifera and of pteropods, with minor amounts of benthic foraminifera; the ratio as above indicated can be used to evaluate the productivity in calcareous microplankton, with the exception of turbiditic sediments.

The plankton/benthos ratio was not calculated since in the greatest part of the core samples examined it is so high (always in excess of 95%, sometimes as high as 100%) that eventual variations recorded would be of no use for the purpose of our study.

At this point, all the benthic foraminifera were isolated, identified and counted. The total number of benthic foraminifera (individual specimens) recorded is indicated in column F of Tables 2-4; then the "B *foraminiferal number*" was calculated dividing the total number of specimens recorded for the weight of the sediment treated (F/C, see column G in Tables 2-4). The term "foraminiferal number" was introduced by Schott (1955), who referred to the number of foraminifera/gram of sediment (see also Ingle, 1967). Since we refer to benthic foraminifera, the letter B (for benthic) is used. *This parameter is used to express the faunal abundance, with reference to the benthic fauna.*

The number of species identified is indicated in column H. This variable may be used as representing the *faunal diversity*. We also calculated in a very simple way, following van Straaten (1960) a diversity index, dividing the number of specimens recorded/the number of species.

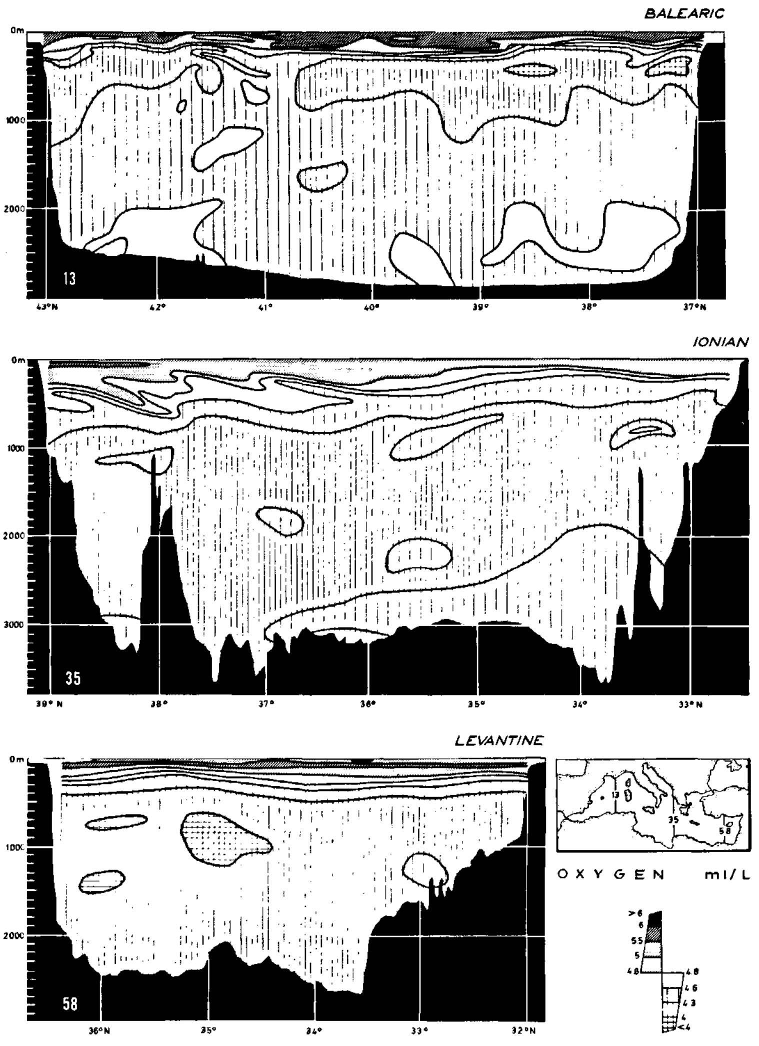

Figure 1
Distribution of oxygen along three profiles crossing the Mediterranean from N to S in the Balearic, Ionian and Levantine Basins (after Miller et al., 1970, *simplified).*

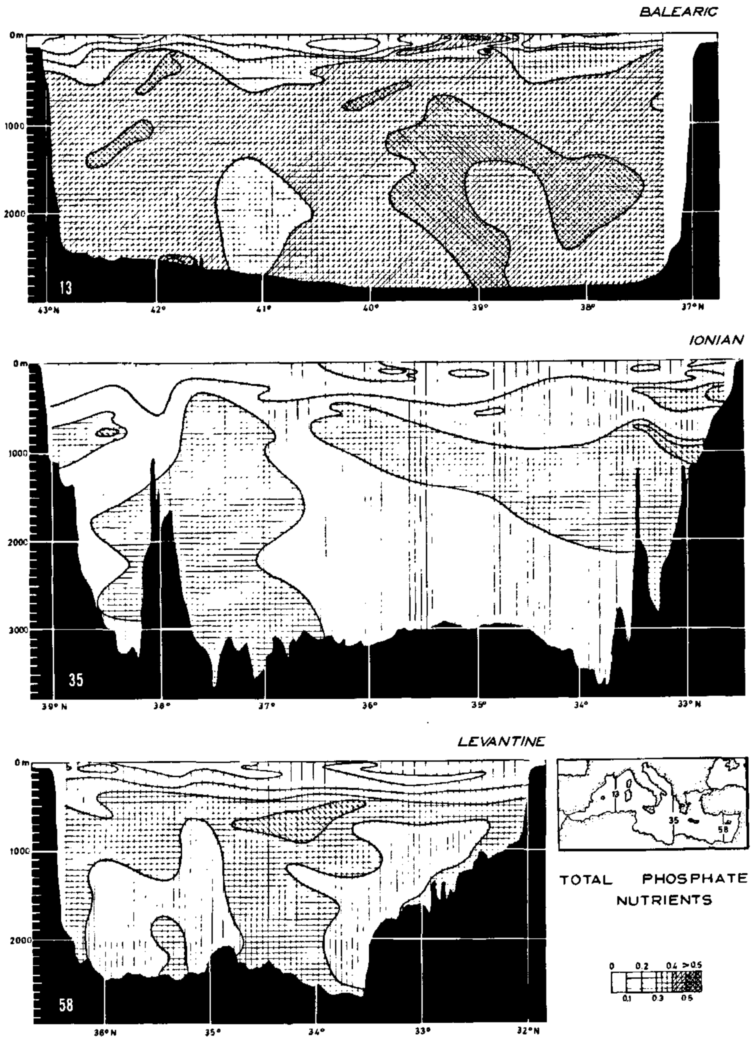

Figure 2
Distribution of nutrients (total phosphate) along three profiles crossing the Mediterranean from N to S in the Balearic, Ionian and Levantine Basins (after McGill, 1970, *simplified).*

The variables F and H were measured and the parameters G and I were calculated only for the samples yielding foraminiferal assemblages which could be safely interpreted as autochthonous thanatocoenoses. In all the cases when we found evidence of displaced taxa (allochthonous thanatocoenoses, mostly related to turbiditic sediments), we discarded the sample. In fact, the discrimination of the taxa supposedly displaced from shallower slopes into the deeper parts of the basins versus the autochthonous species appeared as arbitrary and scientifically questionable. So, we lost 17 samples, representing over 30% of our collection, including most of the Tyrrhenian Basin samples, of clear turbiditic origin, and also occasional samples from the Balearic and Ionian Basins.

Besides observations on the sedimentary characters, the strictly paleontological criteria followed to distinguish the displaced faunas was the finding-at depth in excess of 300 m—of one or more taxa known to be limited to the neritic zone of the continental shelf, with special reference to the Mediterranean (see Parker, 1958; Chierici, Busi, Cita, 1962; Blanc-Vernet, 1969). As characteristic species we considered *Astrononion stelligerum, Nonion granosum, Elphidium complanatum, E. crispum Ammonia beccarii and Planorbulina mediterranensis.*

A secondary criterion was the occurrence—at depth in excess of 1 000 m—of one or more of the following taxa, which according to Parker (*op. cit.*) do not occur deeper than 500-700 m in the Eastern Mediterranean: *Bolivina catanensis, Textularia conica, T. sagittula.*

SAND-SIZE SEDIMENT FRACTION

The sand-size fraction of the sediment, or the sediment fraction greater than 63 µm, shows a considerable variation in the 45 samples investigated (see Tables 2-4). The lowest values recorded (0.0 to 0.1%) are from the Messina abyssal plain, which is the deepest abyssal plain of the Mediterranean, with very poor ventilation and nutrient content, as shown by figures 1 and 2. The sediment is a fine olive-grey mud yielding sparse foraminifera or barren of microfossils. The two highest values recorded (50.1 and 18.1 respectively) are from very shallow settings from the Tyrrhenian Basin and from the Sicily channel respectively: in both cases the sand-size fraction of the sediment is *not* entirely organogenic.

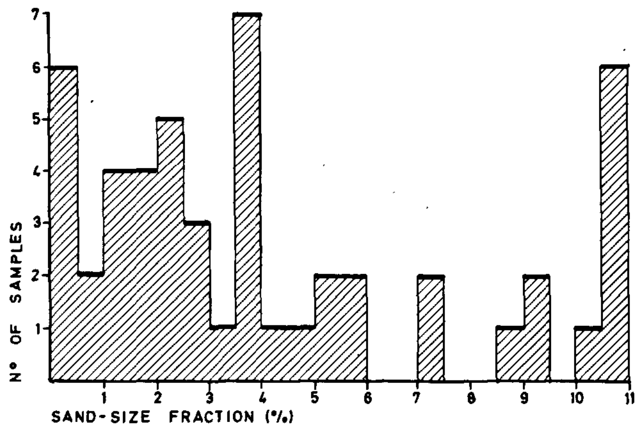

Figure 3

Histogram showing the distribution of the sand-size sediment fraction in the 54 cores investigated (tops). In most cases the sediment fraction essentially consists of shells of pteropods and of tests of planktonic foraminifers.

The highest values recorded in sediments recovered from water depths in excess of 1 000 m are: (*a*) a 13.7% from 1397 m in the Levantine Basin; (*b*) a 16.9% from 2 580 m in the Ionian Basin and (*c*) a 10.7% from 2657 m in the Balearic Basin. In (*b*) and (*c*) the sediment was turbiditic, and yielded displaced foraminiferal faunas.

Figure 3 shows a histogram with the distribution of the sand-size fraction (percentage) in the 54 samples examined. Both the lowest values (less than 1%) and the highest ones (in excess of 10%) are usually recorded in samples yielding allochthonous thanatocoenoses. The most frequently recorded percentages are between 2% and 4%. Since the sediments are essentially pelagic, and since the sand-size fraction consists of foraminiferal tests, the greatest part being planktonic, and of pteropod shells, it results from the above that the productivity in calcareous plankton is very low in the Mediterranean. This observation is consistent with other lines of evidence (see Figs.1, 2 4 and 5) and has already been noticed in Pleistocene sections investigated quantitatively (Cita, D'Onofrio, Zocchi, 1974).

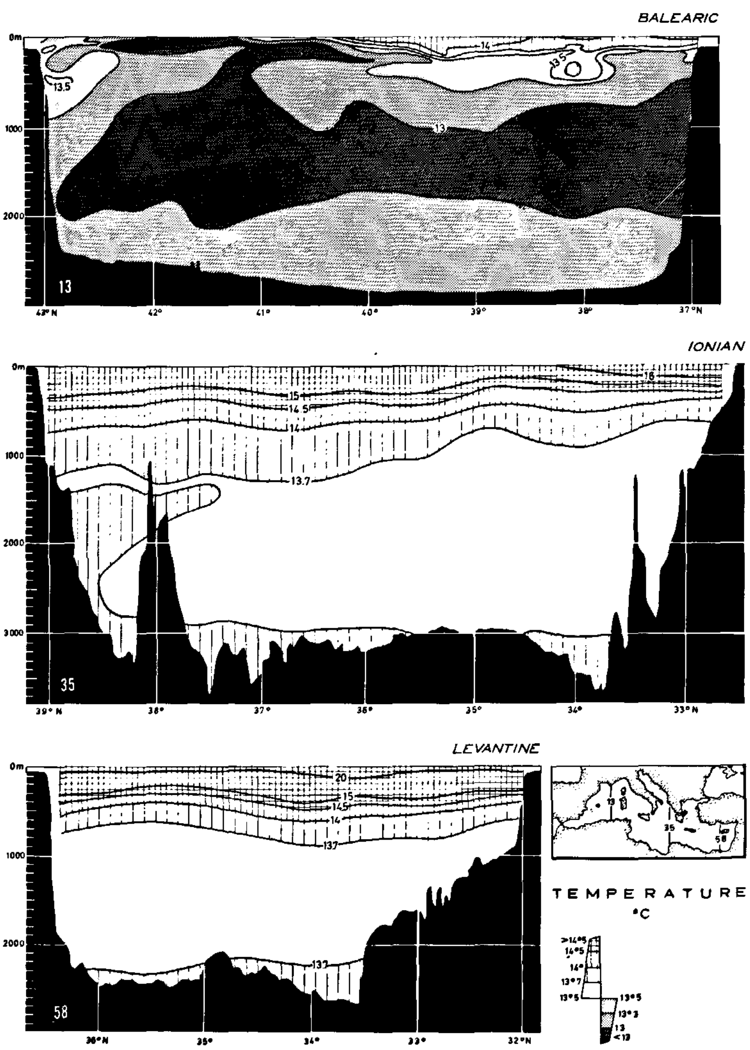

Figure 4

Distribution of temperature along three profiles crossing the Mediterranean from N to S in the Balearic, Ionian and Levantine Basins (after Miller et al., 1970, *simplified).*

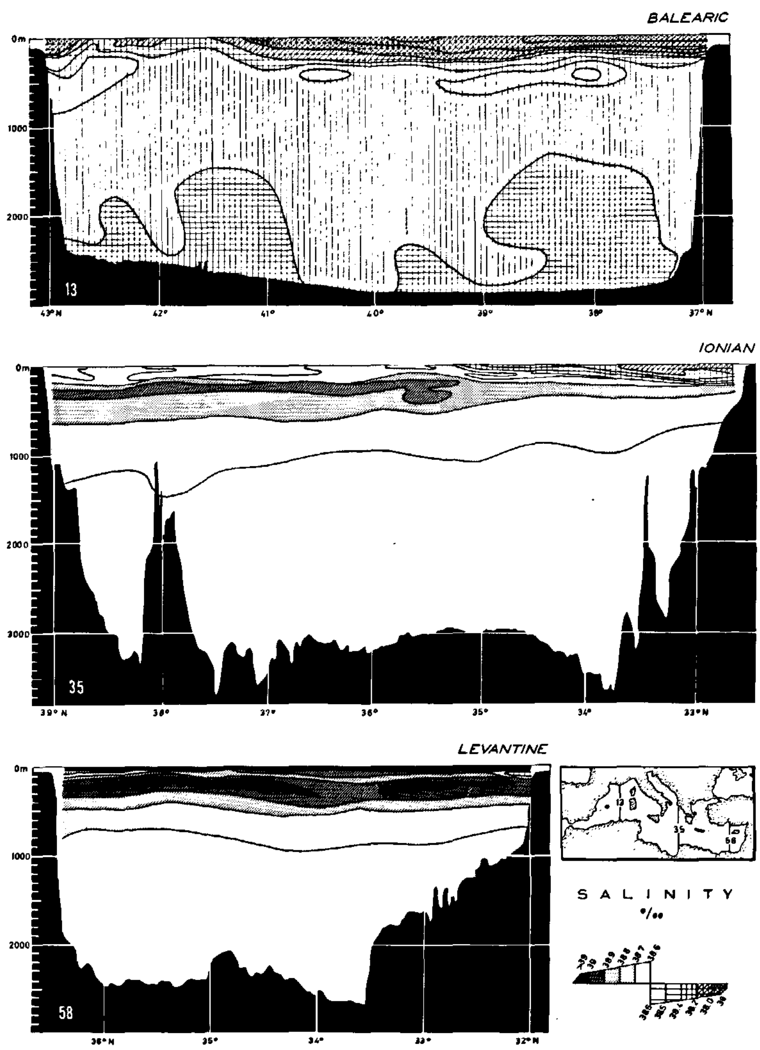

Figure 5

Distribution of salinity along three profiles crossing the Mediterranean from N to S in the Balearic, Ionian and Levantine Basins (after Miller et al., 1970, *simplified).*

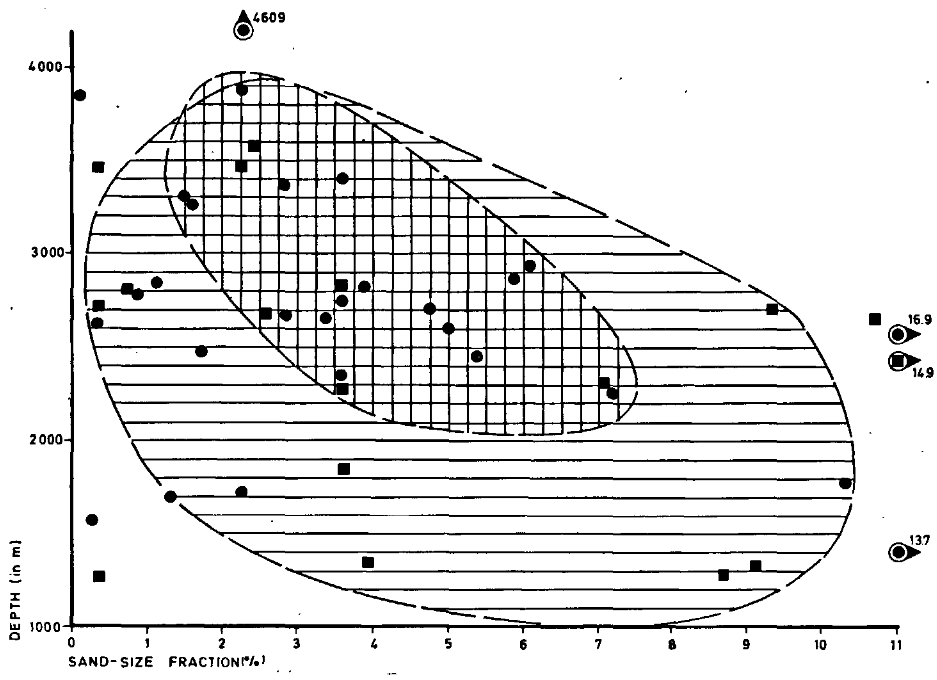

Figure 6
Scatter diagram showing the distribution of the sand-size sediment fraction versus depth in 46 *samples investigated from the meso-bathyal zone (deeper than* 1 000 *m). Solid circles indicate the Eastern Mediterranean cores; solid squares the Western Mediterranean cores. Further explanations on the distribution patterns are found in the text.*

Figure 6 is a scatter diagram where the percentage of the sand-size sediment fraction is plotted against depth. Only the samples from depths in excess of 1 000 m are considered here, to avoid interactions with other disturbing factors. Out of the 46 samples considered, 22 fall in a well delimited area (shadowed); 11 more samples fall in a wider area, however fairly well delimited. Practically all the samples falling outside these 2 areas yield allochthonous thanatocoenoses: those falling on the left side of the scatter diagram are characterized by very low percentages of the sand-size fraction, and mostly consist of fine-grained distal turbidites; those falling on the right side of the scatter diagram are characterized by very high percentages of the sand-size fraction and mostly consist of sandy turbidites.

FAUNAL DENSITY AND FAUNAL DIVERSITY

Investigations on the faunal density and faunal diversity carried on benthic foraminifera, as related to the depth of deposition, are just beginning. Eicher *et al.* (1974) considered the benthic assemblages of four Cenomanian sections from various parts of the Alps, trying to find evidence of the Cenomanian transgression. Sen Gupta and Kilbourne (1974) studied the diversity of benthic foraminifera on the Georgia continental shelf and found diversity values rising from the shoreline to water depth of about 15 m, while from 15 m to the edge the values remain steady.

Our observations though fairly limited in number for the time being, clearly show that the Western Mediterranean and the Eastern Mediterranean behave in quite a different way, so that they can be considered as distinct bioprovinces.

The faunal diversity is treated here in a very simple way, viz. as number of species recorded (column H in Tables 2-4) and as diversity index sensu van Straaten (1960) (column I in Tables 2-4).

The number of species recorded in core samples deeper than 1 000 m ranges from 92 (Balearic Basin, water depth 1 311 m) to 0 (Messina abyssal plain, water depth 3 973 m). We consistently recorded a lesser faunal diversity in the Eastern Mediterranean than in the Balearic Basin, the Tyrrhenian Basin being intermediate between the two.

The diversity index, as here calculated, has a fairly restricted range in the Balearic Basin, 8.1 being the highest recorded value, 3.8 the lowest, the general trend is a decrease as a function of depth, with some irregularities.

The values recorded in the Eastern Mediterranean are by far more irregular, especially from depth in excess of 2 000 m, where the oceanographic conditions leading to provincialism strongly affect the benthic faunas. In the Ionian basin the recorded values range from 75 to 1. The index 75 was calculated for a sample from the Gulf of Taranto (water depth 2 345 m) where only 2 species were represented by 150 specimens.

B FORAMINIFERAL NUMBER

The B foraminiferal number is obtained, by dividing the total number of individual specimens recorded in a given sample (sediment fraction > 63 μm) for the weight of the sediment treated. This number needs some comments, in terms of its reliability. In fact we found some difficulties in how to treat the foraminifera, especially the most primitive forms with a pseudochitinous cement, which are quite common in the deep sea Mediterranean sediments, often giving rise to exclusive faunas. We consistently followed these procedures:

Ammolagena clavata was recorded, however not counted: so, it results as a species, however not as specimens, since we found no way of how to treat the small fragments attached to the pteropod shells. *A. clavata* is the only sexile form recorded in our investigations.

Bathysiphon filiforme: the taxon is never recorded in its entirety: the fragments of the cylindrical chamber (in many instances only hemicylindrical) were recorded and counted as single specimens.

Psammophaera fusca: both entire specimens (sphaerical) and fragmented ones were considered as individual, and recorded as such.

Rhabdammina abyssorum: the record of entire specimens is quite exceptional. The cement being pseudochitinous, the test breaks quite easily into pieces: when recognizable, these have been treated as single individuals.

Ammobaculites agglutinans: as for *Rhabdammina abyssorum,* entire tests are quite rare, while fragmented tests devoid of the last, uncoiled ontogenetic stage are quite common. The latter have been considered as individual specimens, when recognized.

Generally speaking, the B foraminiferal number decreases as a function of depth. This is clearly shown by the observational data recorded in the Balearic Basin (see Fig. 9) and also in the Ionian and Levantine basins, where it is much lower, especially at depth. Reference is made to the final part of this paper for a discussion on the trends shown by this parameter and on its utility in the bathymetric interpretation of fossil assemblages.

DISCUSSION

The present study on the faunal abundance and faunal diversity as recorded in 37 cores selected from the 54 investigated, as well as on the bathymetric range of the assemblages and of individual taxa, demonstrates that the Eastern Mediterranean behaves in a different way with respect to the Western Mediterranean, both on a quantitative and on a qualitative basis. It also demonstrates that this holds true especially for the deeper parts of the basin, with depths in excess of 2 000 m. Indeed, the existence of a number of shallow thresholds across the Mediterranean results in the lack of a deep thermo-haline circulation giving rise to a distribution of temperature, salinity, oxygen and also of nutrients at depth, strongly different from those recorded in the open ocean.

The oceanographic data gathered by the Woods Hole Oceanographic Institution in the Mediterranean (Cruises "Atlantis" and "Chain", see Miller *et al.*, 1970) are very important in this respect; Figures 5 and 6, here reproduced from that highly informative atlas, clearly visualize how depleted in oxygen and in nutrients is the Eastern Mediterranean versus the Balearic Basin.

In order to evaluate these profiles, the following precisions are provided:

1) Profile 13, crossing the Balearic Basin in N-S direction, has been constructed with the data collected during the Cruise "Atlantis 263": this cruise took place from February 4 to March 10, 1961.

2) Profile 35 across the Ionian Basin has been constructed with the data collected during the Cruise "Atlantis 375" (February 1 to March 10, 1962).

3) Profile 57 across the Levantine Basin has been constructed with the data collected during the Cruise "Chain 21" (October 18 to November 11, 1961).

Due to the strongly different oceanographic situation, it would be meaningless to treat all our faunal data together. Consequently, the discussion will be separated for the three major basins, starting from the Levantine Basin, which is the more restricted and provincial one due to its distal setting, through the Ionian Basin where a number of different situations are found, to the Balearic Basin which is definitely less restricted and provincial, owing to its proximal position with respect to the open ocean.

Levantine Basin

Quantitative data

Figure 7 shows the B foraminiferal number, the number

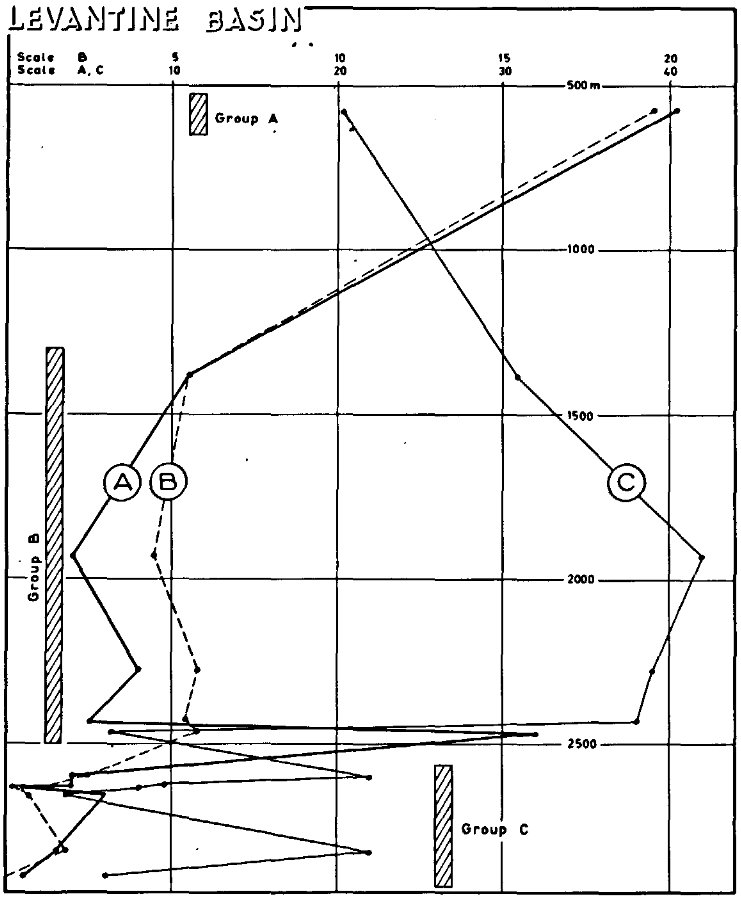

Figure 7

Distribution of the B foraminiferal number (B), of the number of species recorded (A) and of the diversity index (C) versus depth in 12 cores investigated from the Levantine Basin. For the significance of groups A, B and C, see text.

of species and the diversity index plotted against depth. The 12 cores considered can be easily distinguished in three groups, clearly depth-controlled:

- the first group (*a*) includes only 1 core (V 14-129, water depth 576 m, from the Nile cone area) where the number of species and the B foraminiferal number are highest (41 and 19.5 respectively);
- the second group (*b*) includes 5 cores from different locations, showing low values of the B foraminiferal number (ranging from 4.4 to 5.8) and number of species ranging from 4 to 11, with the only exception of sample RC 9-176 (water depth 2 465 m) from the Antalya Gulf, yielding 32 species. The faunal assemblage of the top of this core is partly reworked, however it has been not discarded since it was very interesting: besides the autochthonous assemblage dominated by *Glomospira charoides*, it yielded a foraminiferal fauna reworked from the Pleistocene, deposited in a shallower environment; the reworked benthic foraminifera include taxa as *Discorbis* sp., *Bolivina alata, Cibicides pseudoungerianus, Valvulineria bradyana, Elphidium,* never recorded by us in the Levantine Basin from depth in excess of 2 000 m. The reworking from the Pleistocene is strongly supported by the composition of the planktonic fauna; in fact besides the present warm-water fauna including Pteropods, *Globigerinoides ruber* with pink tests, *Globigerina digitata, Hastigerina* spp., etc., it yields abundant cold water forms with *Globigerina pachyderma, Globorotalia inflata* and *G. scitula.*

All the cores referred to this group yield the *Glomospira charoides-Gyroidina* fauna (see below);

- the third group (*c*) includes the remaining 6 cores, from depth in excess of 2 500 m. Their B foraminiferal number is extremely low, ranging from 2.5 to 0.1; the number of species present is also very low, ranging from 1 to 6. All the *Glomospira charoides* s. s. assemblages (see below) are recorded from this third group of cores. The diversity index has a trend which is opposite to the trends shown by both the B foraminiferal number and by the number of species for groups (*a*) and (*b*), while for the third group of cores it has a very irregular

Table 2

Numerical date recorded in 12 cores from the Levantine Basin.

A	B	C	D	E (%)	F	G	H	I
V 14-129	576	21.19	0.26	1.23	415	19.5	41	10.1
RC 9-174	1 397	30.64	4.22	13.7	170	5.5	11	15.4
V 14-128.	1 931	19.10	1.05	5.52	84	4.4	4	21
RC 9-181	2 286	26.69	1.92	7.21	156	5.8	8	19.5
V 14-131	2 436	17.93	0.95	5.32	95	5.4	5	19
RC 9-176	2 465	17.0	0.30	1.77	100	5.8	32	3.1 partly displaced fauna
RC 9-179	2 604	17.47	0.87	5.01	44	2.5	4	11
RC 9-178	2 628	13.7	0.47	3.43	19	1.38	4	4.75
RC 9-175	2 639	22.48	0.07	0.31	4	0.17	1	4.
RC 9-180	2 653	12.84	0.61	4.77	11	0.85	6	1.83
RC 9-177	2 820	17.14	0.66	3.9	33	1.9	3	11
V 14-130	2 909	28.35	0.21	0.75	3	0.1	1	3

A, core number; B, water depth; C, weight of the dry sediment (g); D, weight of the sediment fraction greater than 63 μm (g); E, D/C %; F, number of benthic foraminifera (total); G, B foraminiferal number (number of specimens of benthic foraminifera/gram of dry sediment); H, number of species identified (benthic foraminifera); I, diversity index (F/H).

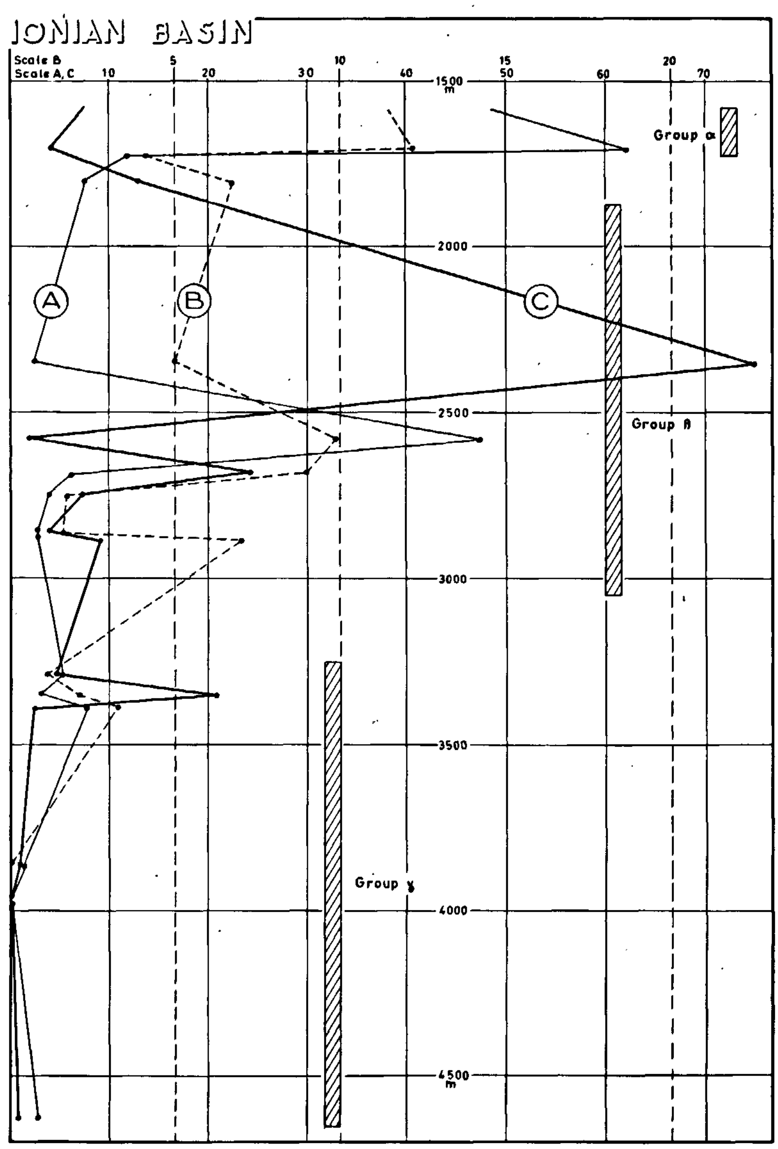

Figure 8
Distribution of the B foraminiferal number (B), of the number of species present (A) and of the diversity index (C) versus depth in 16 cores investigated from the Ionian Basin. For the significance of groups alfa, beta and gamma, see text.

behaviour which is not entirely understood. Generally speaking, the diversity index as here calculated does not appear as very significant in its bathymetric relationship.

Faunal assemblages

All the samples investigated from depth in excess of 1 900 m are characterized by what we call the *Glomospira charoides* assemblage. Besides the index taxon, which dominates the assemblages, the fauna consists of occasional tests of *Glomospira gordialis, Saccammina* sp., *Psammosphaera fusca, Hyperammina abyssorum, Ammolagena clavata,* all of them with arenaceous test with a chitinous base. Foraminifera with calcitic test belong to either the genus *Gyroidina* (with the species *G. altiformis, G. neosoldanii, G. laevigata* and *Gyroidina* sp.) or to *Articulina tubulosa.* No Uvigerinids are recorded.

A further distinction within the *Glomospira charoides* assemblage can be made, as follows:

(*a*) *Glomospira charoides* s.s. assemblage, without calcitic tests and

(*b*) *Glomospira charoides-Gyroidina* assemblage, also including a very limited number of foraminiferal species with calcareous test, as above indicated.

The *Glomospira charoides-Gyroidina* assemblage has been recorded in the Nile Cone area and in the Mediterranean Sea South of Crete. The *Glomospira charoides* s.s. assemblage is apparently restricted to a belt striking SW-NE in the Eastern Mediterranean, from the Egyptian coast to the Gulf of Antalya, where Venkatarathnam and Ryan (1971) found clay mineral assemblages characteristic of the Nile derived sediments relatively rich in kaolinite, a clay mineral consistenly associated with low pH. The acidic environment would prevent the development of benthic foraminifera with calcitic test.

Ionian Basin

Quantitative data

Of the 24 cores investigated from the Ionian Basin, only 17 were studies quantitatively, all from depth in excess of 1 500 m. The shallower cores analyzed have been judged unsuitable for a quantitative treatement. However, 2 cores (indicated with an asterisk in Figure 8) have been considered, though yielding partly displaced faunas, since they have been judged interesting for the understanding of the problem.

The B foraminiferal number, number of species and diversity index are plotted against depth (see Fig. 8).

The 17 cores from the Ionian Basin can be grouped in three depth-controlled groups, as follows:

- the first group *(alfa)* includes 2 cores from the Sicily Channel (depth 1 580 and 1 703 m respectively): their B foraminiferal number is comparable (11.5 and 12.2 respectively) as well as the number of species (48 and 64). The faunal assemblages yielded by these cores is of the costate *Uvigerina-Bulimina* type (see below);
- the second group *(beta)* includes 8 cores from the Gulf of Taranto from the northern slopes of the Mediterranean Ridge and from the crestal area of the ridge, ranging in depth from 1 712 to 2 880 m. 2 cores from this group yield partly displaced assemblages, which indeed show up in the graph with numerical values strongly different from those of the adjoining cores. If we discard these anomalous values, the B foraminiferal number ranges from 1.6 to 7.1. The lowest value is recorded in the Messina cone, where extremely poor foraminiferal faunas are recorded. Relatively high B foraminiferal numbers are found from the crestal part of the Mediterranean Ridge (KS 09 and RC 9-183, with 7.1 and 9 individual foraminifers/gramme of sediment respectively). This is accounted to the better deep circulation on a physiographic high, also recorded in the oxygen content (see Fig. 1);
- the third group *(gamma)* includes 7 cores, all of them from the Messina abyssal plain and surrounding slopes, plus one from the Hellenic Trough (other cores from the Hellenic Trough were discarded because found to yield largely displaced faunas).

The B foraminiferal number is always extremely low (max. value 3.3, 4 values out of 7 less than 1) as well as the number of species. The sediments from the floor of the Messina abyssal plain are in most cases devoid of foraminifera.

The diversity index shows a trend opposite to that of the B foraminiferal number and of the number of species, as recorded also in the Levantine Basin. Some irregularities in behaviour at water depths comprised between 2 500 and 3 000 m are noticed, however not as marked as in the Levantine Basin.

Table 3
Numerical data recorded in 16 cores from the Ionian Basin (selected samples).

A	B	C	D	E (%)	F	G	H	I
V 14-137	1 580	27.80	0.06	0.23	322	11.5	48	6.7
V 14-139	1 703	24.46	0.31	1.27	294	12.2	64	4.6
RC 9-190	1 712	18.65	0.41	2.24	73	3.9	12	6 partly displaced fauna
RC 9-182	1 794	16.28	1.68	10.3	113	6.7	8	14.1
RC 9-191	2 345	29.58	1.04	3.52	150	5	2	75
KR 05	2 580	12.16	2.05	16.9	119	9.9	47	2.5 partly displaced fauna
RC 9-183	2 684	16.08	0.46	2.88	144	9	6	24
V 14-132	2 750	18.13	0.74	4.09	31	1.7	4	7.7
RC 9-185	2 858	21.02	0.24	1.16	13	1.6	3	4.3
KS 09	2 880	3.91	0.22	5.82	28	7.1	3	9.3
RC 9-188	3 290	20.48	0.31	1.53	24	1.1	5	4.8
RC 9-189	3 378	19.68	0.54	2.77	63	3.3	3	21
KR 06	3 356	9.12	0.32	3.64	20	2.1	8	2.5
V 14-136	3 864	25.14	0.02	0.10	2	0.08	2	1
KR 07	3 945	7.10	0.00	0	0	0	0	0
KR 08	3 970	6.88	0	0	0	0	0	0
KR 09	4 625	11.86	0.22	1.81	3	0.25	3	1

A, core number; B, water depth; C, weight of the dry sediment (g); D, weight of the sediment fraction greater than 63 μm (g); E, D/C %; F, number of benthic foraminifera (total); G, B foraminiferal number (= number of benthic foraminifera/gram of dry sediment); H, number of species identified (benthic foraminifera); I, diversity index (F/H).

Faunal assemblages

The benthic foraminiferal faunas of the Ionian Basin appear much more restricted than those of the Balearic Basin, and in some aspects even more provincial than those of the Levantine Basin. The following faunal assemblages may be distinguished:

- costate *Uvigerina-Bulimina* assemblage, recorded in the cores from the Sicily Channel. The assemblage is dominated by four taxa, all of them showing characteristic ornamentations consisting of costae and/or spines. They include *Uvigerina peregrina, U. mediterranea, Bulimina costata* and *B. marginata* which, taken together, represent the bulk of the fauna. Also present are *Gyroidina neosoldanii, G. complanata, G. altiformis, Gyroidina* sp., *Glomospira charoides* and the taxa recorded from the deeper assemblages. We consider as characteristic elements of this assemblage *Robertina translucens, Sigmoilina tenuis, Bolivina pseudoplicata, Biloculinella* sp. *Pulvinulinella* sp. This characteristic assemblage, with minor variations, is also found in the Western Mediterranean, where it characterizes the Balearic abyssal plain, but it is definetly not present in the Eastern Mediterranean from depth in excess of 1 712 m.

It results from the above that—on the basis of the available data—a bathymetric limit well recognizable in the benthic assemblages can be traced between 1 703 and 1 713 m. Further data are required to control the areal extent of this distinct boundary.

If we discard Core KR 05 (Messina Cone), which yields a partly displaced fauna, we never recorded more than 8 individual taxa from depths in excess of 2 000 m;

- a distinction between a *Glomospira charoides-Gyroidina* assemblage and a *Glomospira charoides* s.s. assemblage, as practiced for the Levantine Basin, is not easy: in other words, all the cores examined, from depths in excess of 1 710 m, excluding those from the deepest parts of the Mediterranean, which are practically barren, can be referred to the former assemblage. We only found 1 core (RC 9-191) from the Gulf of Taranto, water depth 2 345 m., which yielded a typical *Glomospira charoides* s.s. assemblage, viz. devoid of foraminifera with calcitic test. This cannot be accounted to water depth, indeed, since down to the greatest depth, in excess of 4 000 m, we found in the Ionian Basin the *Glomospira charoides-Gyroidina* assemblages. An hypothesis to be tested in that this faunal assemblage is in some way related to the composition of the clay minerals. Indeed, Ventakarathnam and Ryan (1971) found in the Gulf of Taranto sediments rich in kaolinite, as in the

Table 4
Numerical data recorded in 8 cores from the Balearic Basin (selected samples).

A	B	C	D	E %	F	G	H	I
V 14-144	1 311	21.17	0.08	0.38	620	29.2	92	6.7
V 14-146	1 329	29.74	2.73	9.20	643	21.6	79	8.1
V 14-145	1 867	19.34	0.70	3.64	479	24.7	65	7.3
RC 9-199	2 318	28.31	2.0	7.06	627	22.1	54	11.6
V 14-143	2 439	17.31	2.58	14.9	352	20.3	46	7.6
RC 9-196	2 694	28.54	0.77	2.72	271	9.5	71	3.8
RC 9-202	2 701	15.91	1.47	9.29	210	13.2	39	5.3
RC 9-197	2 703	27.58	0.10	0.36	73	2.6	19	3.8

A, core number; B, water depth; C, weight of the dry sediment (g); D, weight of the sand-size fraction of the sediment; E, D/C %; F, number of benthic foraminifera (total); G, B foraminiferal number (=number of benthic foraminifera/gram of sediment); H, species present; I, diversity index (F/H).

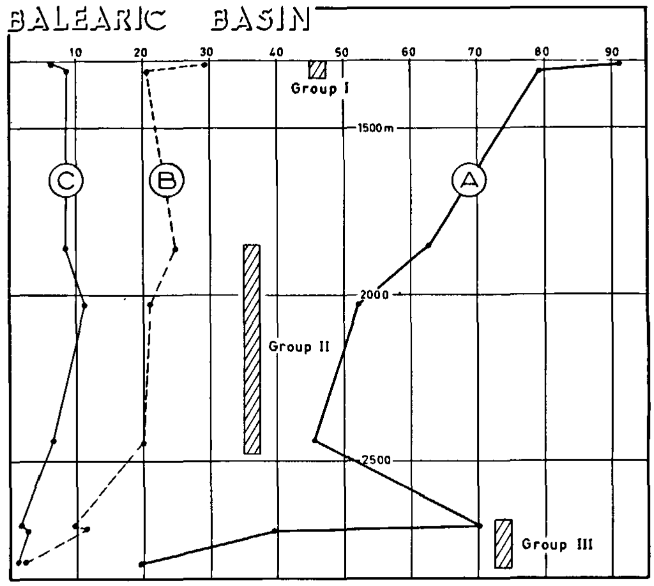

Figure 9
Distribution of the B foraminiferal number (B), of the number of species recorded (A) and of the diversity index (C) in 8 cores investigated from the Balearic Basin. For the significance of groups I, II and III, see text.

belt SW-NE striking in the Levantine Basin, where we found the *Glomospira charoides* s.s. assemblage.

Balearic Basin

Quantitative data

Of the 12 cores investigated from the Balearic Basin, only 8 were studied quantitatively, all of them from depths in excess of 1 300 m. Core V 14-142 was discarded because yielding Pleistocene sediments; cores RC 9-203, RC 9-200 and RC 9-201 because the faunal assemblages were partly displaced. Evidence of minor faunal displacement were also found in cores RC 9-199 and RC 9-202, which however have been treated quantitatively.

The numerical data recorded are plotted in Table 4; generally speaking, they are much more regular than the data recorded in the other basins previously considered, and the trends are clearly related to the actual depth of deposition.

Figure 9 shows the B foraminiferal number, the number of species and the diversity index plotted against depth. 3 groups can be distinguished also in the Balearic Basin on the basis of the analytical data, as follows:

• the first group (I) includes 2 cores from 1 311 and 1 329 m respectively: their B foraminiferal number is comprised between 21.6 and 29.2 and is much higher than the values recorded at similar depth in the Ionian Basin (11-12) and in the Levantine Basin (5.5). The number of species present is comparable in the 2 cores under discussion (92 and 79 respectively) and again is much higher than the values recorded at similar depth in both the Sicily Channel (48-64) and especially in the Levantine Basin (11);

• the second group (II) includes 3 cores ranging in depth from 1 867 to 2 439 m. A regular and slow decrease of the B foraminiferal number is recorded, as a function of depth (24.7 at 1 867 m; 22.1 at 2 318 m; 20.3 at 2 439 m), along with a more pronounced decrease in the number of species present (65, 54 and 46 respectively). This group II corresponds to group C of the Levantine Basin and to (part of) group beta of the Ionian Basin, which is very heterogeneous, as mentioned before.

• the third group (III) includes 3 cores from the Balearic abyssal plain with the lowest values of the B foraminiferal number recorded in the Western Mediterranean (ranging from 13.2 to 2.6) and a number of species which is 5 to 10 times greater than those recorded in the Eastern Mediterranean at similar depths (compare Tables 2, 3 and 4). The high diversification recorded in Core RC 9-196 deserves some comments. In fact 71 taxa recorded at a depth of 2 694 m is an unusual finding also in the Western Mediterranean. This core is located west of the straits of Bonifacio and, though not showing clear indications of displacement from upslope, is possibly affected in part by weak bottom currents in the vicinity of the straits.

Group (III) as here discussed corresponds to group (C) of the Levantine Basin and to the lower part of group (beta) in the Ionian Basin.

As a general comment, the Balearic Basin is the one where we recorded the highest number of species, and where the diversity index shows lower and more regular values (never in excess of 10, with one exception in Core RC 9-199 located south of Maiorca, where a slight displacement is noticed). In other words, the Balearic Basin clearly appears on the basis of this quantitative study as the less provincial and restricted of the Mediterranean, which conclusion is in complete agreement with the oceanographic data (see Figs. 1, 2, 4 and 5).

Faunal assemblages

The faunal assemblages of the Balearic Basin appear much more diversified and less affected by unfavourable life conditions at the sediment/water interface such as oxygen depletion, shortage of nutrients, etc. than those recorded from the Eastern Mediterranean.

We never recorded in any of the samples investigated the *Glomospira charoides* s. str. assemblage and also the *Glomospira charoides-Gyroidina* assemblage is atypical,

Table 5

B *foraminiferal number, number of species and diversity index as recorded in 6 tops of cores from similar water depth in the Balearic, Tyrrhenian, Ionian and Levantine Basins.*

	water depth	B foram. number	species present	div. index
RC 9-199 (Balearic Basin)	2 318	22.1	54	11.6
V 14-143 (Balearic Basin)	2 439	20.3	46	7.6
RC 9-195 (Tyrrhenian Basin)	2 338	10.4	24	8.4
RC 9-191 (Ionian Basin)	2 345	5	2	75
RC 9-181 (Levantine Basin)	2 286	5.8	8	19.5
V 14-131 (Levantine Basin)	2 436	5.4	5	19

because the nominal taxa, although present, are never really dominating.

The characteristic foraminiferal assemblage of the Balearic abyssal plain—which is known to be the largest of the entire Mediterranean, very flat and regular—ranging in depth from 2 650 to 2 900 m—includes foraminifera with calcitic, aragonitic and arenaceous tests. Both perforate and imperforate taxa are recorded from the deepest parts of the Western Mediterranean. Reference is made to page 457 for comments on *Robertina translucens*, a taxon whose deepest record in the Balearic Basin is from 2 703 m. Characteristic constituents of this assemblage are: *Glomospira charoides, Gyroidina altiformis, Gyroidina neosoldanii, Gyroidina laevigata, Robertina translucens, Articulina tubulosa, Biloculinella* sp. 1, *Pyrgo* spp., *Sigmoilina tenuis.*

The deepest record of *Cibicides pseudoungerianus* and of *Cibicides wuellerstorfii* is from 2 701 m. The deepest record of *Bulimina costata, B. marginata, Uvigerina peregrina* and *U. mediterranea* is from 2 694 m. All these species are very rare in sediments from the Balearic abyssal plain, and are by far better represented at shallower depth, where they represent the most conspicuous constituent of the faunal assemblage of group II (see Fig. 9). Also occasionally recorded in sediments from the Balearic abyssal plain are small and rare specimens of *Cassidulina subglobosa* and *C. laevigata.* These small-sized forms which—unlike *Robertina translucens*—have solid and resistent tests, might possibly be displaced from shallower slopes, however no firm statement is made on this point, pending information on the living forms. Large Cassidulinids are apparently restricted to shallower habitats (epibathyal) where they occur in abundance, however the lower depth limit of 1 000-1 300 m indicated by Parker (1958) for the eastern Mediterranean for *Cassidulina crassa* and *C. subglobosa* should possibly not be extrapolated to the Western Mediterranean bioprovince.

The foraminiferal assemblages from depth comprised between 2 500 and 1 800 m are characterized by *Uvigerina peregrina* and *U. mediterranea* (see Plate 2, 2-7), which in the Levantine Basin are not recorded from comparable depths, but only from the epibathyal zone: the restricted bathymetric range in the Eastern Mediterranean bioprovince being related to poor ventilation at depth. Generally speaking, the assemblages appear well diversified and none of the taxa recorded is really dominant. The forms with calcareous perforate test prevail numerically on the imperforate ones. *Hoeglundina elegans* is well represented along with *Gyroidina* which occur with the same species recorded in the Eastern Mediterranean bioprovince.

A core from this depth range (water depth 2 439 m) which needs a special comment is V 14-143: it yields in abundance foraminifera with arenaceous tests which are rare or absent in the cores investigated from the Balearic Basin. *Glomospira charoides*, with 71 specimens out of 352 is the dominant taxon. Also very abundant is *Ammobaculites agglutinans*, with some 56 specimens, while representatives of the genera *Bulimina, Uvigerina, Bolivina* are less common than in the other cores from the same depth range. Though we had no data available on the clay mineral composition from this station, a relationship with the nature of the sediment accumulating on the sea floor appears as obvious, since the core is from the distal part of the Rhone fan, where clastic sediments are expected to accumulate.

Other basins

Both Cores V 14-147 and RC 9-204 from the Alboran Basin yielded foraminiferal faunas indicating a considerable amount of displacement, thus being unsuitable for a quantitative study and were discarded.

On the 5 cores available from the Tyrrhenian Basin (V 14-140; RC 9-195; RC 9-192; V 14-141; RC 9-194), only one was studied on a quantitative basis, the remaining four indicating a turbiditic sedimentation, with displaced foraminiferal faunas. The numerical data recorded in Core RC 9-195 are as follows:

water depth 2 338 m;
weight of the (dry) sediment treated 18.67 g;
weight of the sand-size sediment fraction 0.68 g;
percentage of the sand-size fraction 3.65%;
total number of benthic foraminifera 195;
B foraminiferal number 10.4;
species recorded 24;
diversity index 8.4.

Though single, this core provides valuable information on the composition of the benthic fauna of the Tyrrhenian in comparison with that recorded in the Balearic Basin and in the Eastern Mediterranean respectively. In comparing the same variables as recorded from similar water depths in the Balearic Basin, and in the Eastern Mediterranean, we find that the Tyrrhenian is intermediate between the two, as shown by Table 5.

The B foraminiferal number in the Tyrrhenian core is about one half the one recorded at similar bathymetries in the Western Mediterranean, but it is twice as much as the value found for the Eastern Mediterranean.

Also the number of species indentified is about one half in the Tyrrhenian than in the Balearic, but much higher than in the Ionian and Levantine Basin. In other words, the provincialism of the benthic fauna of the Tyrrhenian is not so apparent as in the Eastern Mediterranean, however there is some evidence of restricted circulation at depth, unlike in the Balearic Basin.

With 24 species present, the foraminiferal assemblage under discussion recorded in Core RC 9-195 can be defined as moderately diversified.

The dominant species is *Glomospira charoides* (94 specimens over 195), which makes the Tyrrhenian fauna under discussion similar to the Eastern Mediterranean mesobathyal assemblages, which are always dominated by the named taxon. Other species recorded, listed in order of decreasing abundance, are *Nummuloculina* (?) sp. with 19 specimens, *Robertina translucens* with 14, *Gyroidina altiformis* with 10 and *G. neosoldanii* with 9. Also recorded in this core are *Articulina tubulosa, Biloculinella* sp., *Melonis pompilioides, Ammolagena clavata* along with other 15 taxa.

The occurrence of *Robertina translucens* deserves a brief comment. This species (see Plate 2, 8, 11) has a very thin and transparent test, which is composed of aragonite as all the tests of the *Robertinidae;* this test can very unlikely be displaced without major damage; therefore, if present, *R. translucens* has to be considered as autochthonous. We found this taxon as a characteristic constituent of the benthic fauna from the Balearic abyssal plain. *Robertina translucens* was occasionally recorded by Parker (1958) in the Eastern Mediterranean from depth shallower than 1 300 m, with the only exception of station 4 710 in the Ionian Basin (water depth 3 241 m). In our samples from the Eastern Mediterranean, *Robertina translucens* was seldom recorded.

Tentative bathymetric zonation of the mesobathyal zone

As a conclusion of the present study, we are here proposing a tentative bathymetric zonation of the Mediterranean. Though aware that the observational data are fairly limited in number, we consider the results of our quantitative study so consistent and interesting as to motivate a zonation, which we qualify as "tentative", hoping to improve it in the near future.

Following Hedgepeth's terminology (modified), we are not dealing here with the neritic zone (0-200 m) and with the epibathyal zone (200-1 000 m) either, which zones have already been subdivided on the basis of their foraminiferal assemblages (qualitative) in the Mediterranean by numerous authors, including Parker (1958), Chierici, Busi and Cita (1962), Blanc-Vernet (1969), etc.

Our interest is for the mesobathyal zone extending beyond the isobath of 1 000 m. According to the recent investigations of Ciabatti and Marabini (1973) on the hypsography of the Mediterranean, inclusive of the Black Sea, 2,280,000 km² or the 77% of the Mediterranean is deeper than 200 m, and 1,720,000 km² or 58.1% is deeper than 1 000 m, the average depth of the Mediterranean and Black Sea being 1 485.6 m. The mesobathyal zone as here defined, viz. extending from 1 000 to 4 000 m, is the more extended large bathymetric zone of the Mediterranean: the areas deeper than 4 000 m indeed are only 17,780 km² wide (0.6%). The average depth of the Mediterranean falls within this zone, as well as all the so-called "Abyssal plains", as the Balearic a. p., the Tyrrhenian a. p., the Messina a. p., the Herodotus a. p., etc.

The mesobathyal zone has been subdivided as follows:

Upper mesobathyal (1 000-1 800 m):

- Western Mediterranean bioprovince:

In this zone the highest B foraminiferal number is recorded (21 to 29 in the Balearic Basin) and the highest number of species (65 to 92).

Group I of the Balearic Basin belongs here (see Fig. 9).

- Eastern Mediterranean bioprovince:

In the Eastern Mediterranean the B foraminiferal number is much lower than in the western (3.9 to 12.2); the number of species recorded ranges from 11 to 64.

Group B of the Levantine Basin (upper part) and Group gamma of the Ionian Basin (Sicily Channel) belong here (see Figs. 7 and 8).

Middle mesobathyal (1 800-2 500 m):

- Western Mediterranean bioprovince:

B foraminiferal number 20 to 25.

Species present 46 to 65.

Uvigerina mediterranea, U. peregrina assemblage, with abundance of costate Uvigerinids.

Group II of the Balearic Basin belongs here (see Fig. 9).

- Eastern Mediterranean bioprovince:

B foraminiferal number 5 to 10.

Species present 4 to 8.

Glomospira charoides s. str. or *Glomospira charoides-Gyroidina* assemblages.

Group beta (upper part) of the Ionian Basin and Group B of the Levantine Basin belong here (see Figs. 7 and 8).

Lower mesobathyal (2 500-4 000 m)

- Western Mediterranean bioprovince:

B foraminiferal number no more than 13.

Species present 20 to 40 (assemblage characteristic of the Balearic abyssal plain, including *Glomospira charoides, Gyroidina, Robertina translucens, Sigmoilina tenuis*), etc.

Group III of the Balearic Basin belongs here (see Fig. 9).

- Eastern Mediterranean bioprovince:

B foraminiferal number 0 to 10, often less than 2.

Species present no more than 8, usually less than 5.

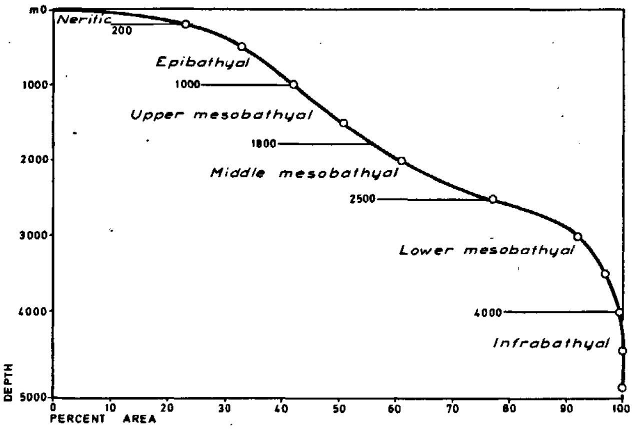

Figure 10

Tentative bathymetric zonation of the Mediterranean. The hypsographic curve is after Ciabatti and Marabini (1973), *slightly modified for the upper* 500 *m. This curve has been calculated for the Mediterranean and Black Sea. The distinction between the upper, middle and lower mesobathyal zones is discussed in the text.*

Glomospira charoides-Gyroidina assemblage.

Group beta (lower part) of the Ionian Basin and Group C of the Levantine Basin belong here (see Figs. 7 and 8).

The upper, middle and lower mesobathyal zones, as above defined, are plotted in Figure 10 against the hypsographic curve of the Mediterranean calculated by Ciabatti and Marabini (1973). Their curve has been modified in its upper part on the basis of the numerical data given by the same authors, in such a way that the continental shelf is now apparent, thus permitting an easy distinction between the neritic and bathyal zones.

The possibility of distinguishing an upper, middle and lower mesobathyal zone on the basis of numerical data such as B foraminiferal number, number of species present, diversity index, is quite rewarding. In fact the application of such a method to late Neogene fossil assemblage permits to evaluate their depth of deposition with reference to the present day distribution patterns in the Mediterranean (see Cita, 1974). A combination of this quantitative method and of the classical one, based on the occurrence of characteristic faunal assemblages and on the recognition of upper and lower depth limits of individual taxa, gives the best results.

Acknowledgements

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Note

The present paper was written for a memorial book dedicated to the late professor Orville L. Bandy, who pioneered the study of benthic foraminifera, and delivered for publication in June, 1974.

It has been re-submitted for publication in April, 1978, to *Oceanologica Acta.* No changes have been introduced in the text. The tentative bathymetric zonation here proposed has been followed by Ramil Wright in his study of benthic foraminifera from Dsdp Leg 42A. Investigations on faunal density and faunal diversity are still active at the Micropaleontological Laboratory of the University of Milano, following the same procedures outlined in the present study (Elisabetta Parisi and Isabella Vignali, in preparation). A study which summarizes the data presented here for the Eastern Mediterranean and investigates with the same techniques tops of trigger cores from Cruise Vema n° 10 has been presented at the International Symposium on Benthonic Foraminifera of Continental Margins (Halifax, 1975) and published in 1976 (see Massiotta P., Cita M. B., Mancuso M., 1976. Benthonic Foraminifers from Bathyal Depths in the Eastern Mediterranean. Maritime Sediments Spec. Publ. n° 1, pp. 251-262).

Plate 1

1 *and* 2 : Bolivina alata *Seguenza* (×90). *Core V* 14-129, *Levantine Basin, water depth* 576 *m.*
3 : Lagenonodosaria scalaris *(Batsch)* (×90). *Core V* 14-129, *Levantine Basin, water depth* 576 *m.*
4 : Bulimina marginata *d'Orbigny* (×90). *Core V* 14-129, *Levantine Basin, water depth* 576 *m.*
5 : Loxostomum karrerianum *(Brady)* (×90). *Core V* 14-129, *Levantine Basin, water depth* 576 *m.*
6 : Bulimina costata *d'Orbigny* (×90). *Core V* 14-129, *Levantine Basin, water depth* 576 *m.*
7 : Valvulineria bradyiana *d'Orbigny* (×90), *spiral view. Core V* 14-129, *Levantine Basin, water depth* 576 *m.*
8 : Hyalinea baltica *(Schroeter)* (×90). *Core V* 14-129, *Levantine Basin, water depth* 576 *m.*
9 : Pyrgo oblonga *(d'Orbigny)* (×70). *Core V* 14-129, *Levantine Basin, water depth* 576 *m.*
10 : Valvulineria bradyiana *d'Orbigny* (×90). *Core V* 14-129, *Levantine Basin, water depth* 576 *m.*

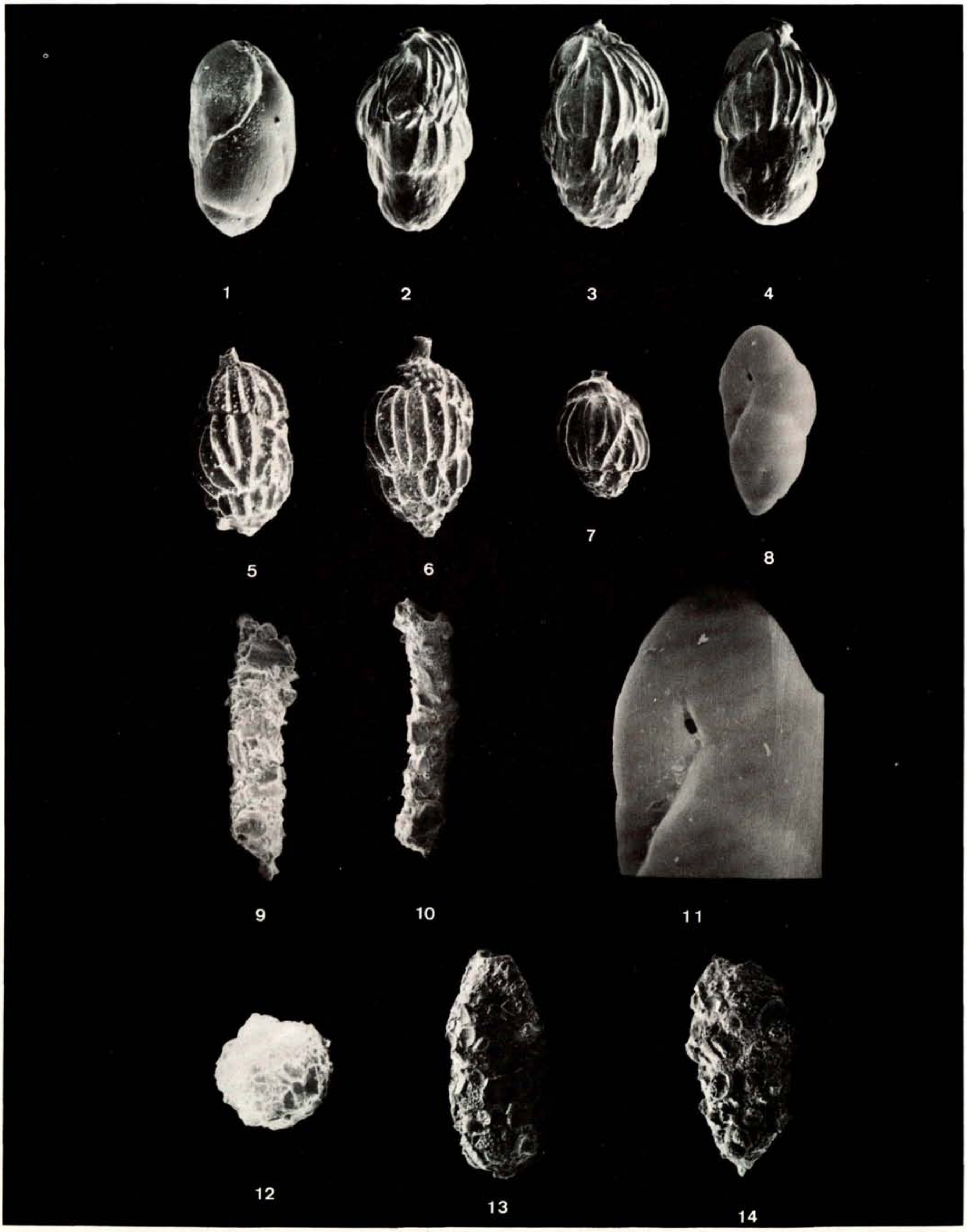

Plate 2

1 : Globobulimina affinis *(d'Orbigny)* (×45). *Core V* 14-129, *Levantine Basin, water depth* 576 *m.*
2, 3, 4 : Uvigerina mediterranea *Hofker* (×45). *Core V* 14-129, *Levantine Basin, water depth* 576 *m.*
5, 6, 7 : Uvigerina peregrina *Cushman* (×75). *Core V* 14-129, *Levantine Basin, water depth* 576 *m.*
8 : Robertina translucens *Cushman and Parker* (×90). *Core RC* 9-202, *Balearic Basin, water depth* 2 701 *m.*
9, 10 : Rhabdammina abyssorum *Sars* (×45). *Core V* 14-139, *Ionian Basin, water depth* 1 703 *m.*
11 : *Detail of the aperture of* Robertina translucens (×225). *Core RC* 9-202, *Balearic Basin, water depth* 2 701 *m.*
12 : Psammosphaera fusca *Schultze* (×70). *Core V* 14-139, *Ionian Basin, water depth* 1 703 *m.*
13, 14 : Bigenerina nodosaria *(d'Orbigny)* (×45). *Core RC* 9-203, *Balearic Basin, water depth* 1 287 *m.*

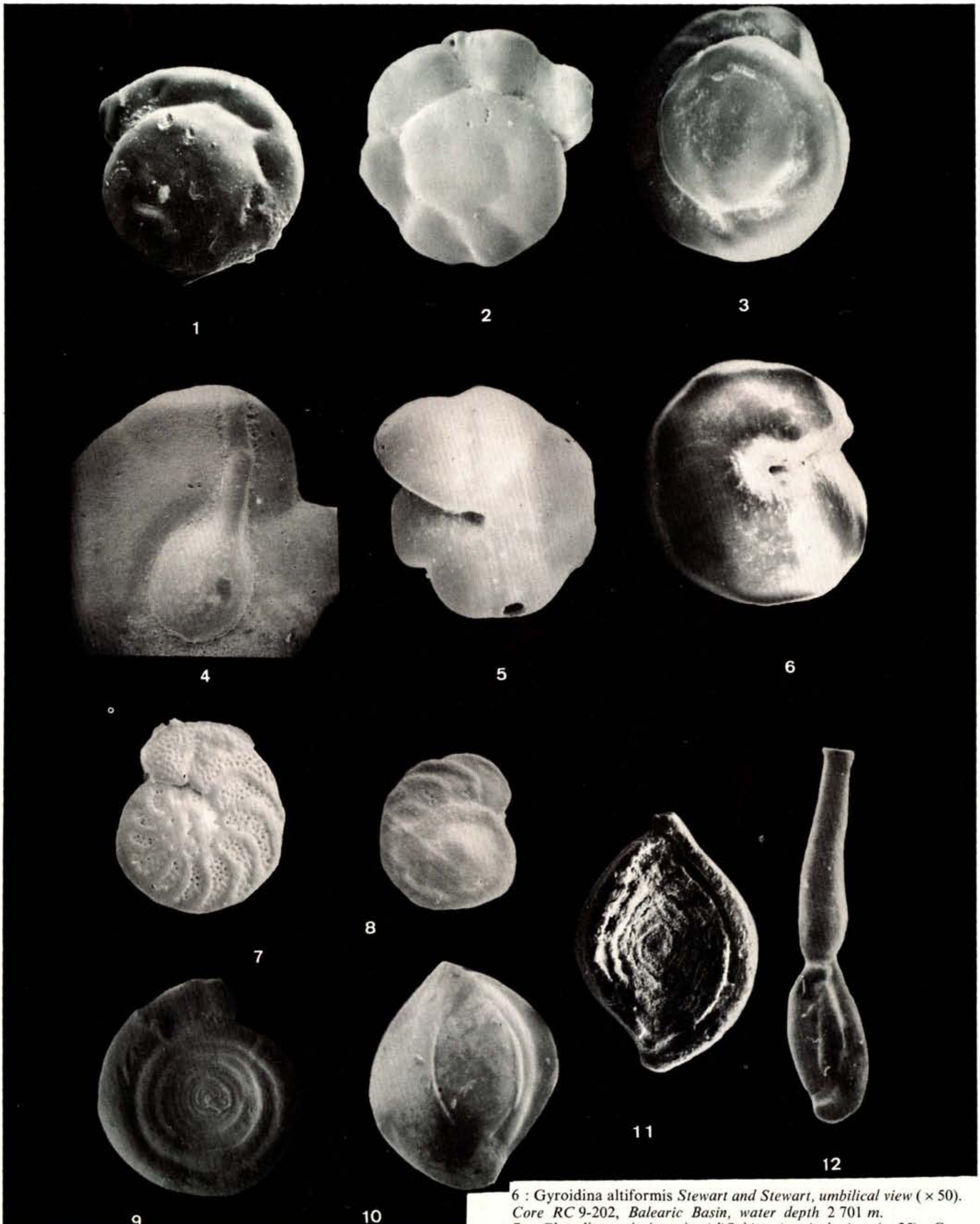

Plate 3

1 : Gyroidina laevigata *d'Orbigny, spiral view* (× 80). *Core RC* 9-202, *Balearic Basin, water depth* 2 701 *m.*
2 : Gyroidina *sp. l, spiral view* (× 50). *Core RC* 9-202, *Balearic Basin, water depth* 2 701 *m.*
3 : Gyroidina altiformis *Stewart and Stewart, spiral view* (× 55). *Core RC* 9-202, *Balearic Basin, water depth* 2 701 *m.*
4 : Ammolagena clavata *(Parker and Jones) on an otolith* (× 105). *Core V* 14-131, *Levantine Basin, water depth* 2 436 *m.*
5 : Gyroidina laevigata *d'Orbigny, umbilical view* (× 80). *Core RC* 9-202, *Balearic Basin, water depth* 2 701 *m.*
6 : Gyroidina altiformis *Stewart and Stewart, umbilical view* (× 50). *Core RC* 9-202, *Balearic Basin, water depth* 2 701 *m.*
7 : Planulina ariminensis *(d'Orbigny) spiral view* (× 35). *Core V* 14-129, *Levantine Basin, water depth* 576 *m.*
8 : Planulina ariminensis *(d'Orbigny) umbilical view* (× 30). *Core V* 14-129, *Levantine Basin, water depth* 576 *m.*
9 : Cornuspira involvens *(Reuss)* (× 70). *Core RC* 9-199, *Balearic Basin, water depth* 2 318 *m.*
10 : Quinqueloculina lamarckiana *d'Orbigny* (× 45). *Core V* 14-129, *Levantine Basin, water depth* 576 *m.*
11 : Spiroloculina canaliculata *d'Orbigny* (× 75). *Core V* 14-129, *Levantine Basin, water depth* 576 *m.*
12 : Articulina tubulosa *(Seguenza)* (× 45). *Core V* 14-143, *Balearic Basin, water depth* 2 439 *m.*

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