

Distribution of planktonic Foraminifera in some Mediterranean sediments*

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Summary—The planktonic foraminiferal populations of the Mediterranean Sea may be differentiated from those of the adjacent Atlantic Ocean.

Three distinct populations are found located in the western and eastern Mediterranean and the Aegean Sea, and additional discrete populations may occur in the unsampled areas.

Populations probably are derived from the Atlantic and from indigenous ancestral stock.

The direction of coiling of *Globorotalia truncatulinoides* shows a shift to left coiling dominance within the Mediterranean. Additional statistical analysis may give further evidence concerning derivation of species in the area.

INTRODUCTION

THE PLANKTONIC Foraminifera in sediment-surface samples from forty-six stations throughout the Mediterranean Sea have been studied and compared with planktonic assemblages in the adjacent Atlantic. These populations show some regional variation and the Mediterranean faunas as a whole differ from those of the Atlantic. The samples were collected, in 1947-48, by members of the Woods Hole Oceanographic Institution on R/V *Atlantis* Cruise 151. This study was supported by the Office of Naval Research (Project NR 081-050, Contract Nonr-233 Task 1). The drafting was done by Miss J. F. PEIRSON and R. R. LANKFORD.

Much has been published on the description and taxonomy of Mediterranean faunas but few quantitative studies have been made. PHLEGER (1947) gives quantitative lists of planktonic species in top samples of three long cores from the Tyrrhenian Sea, but suggests that at least one of these does not represent the modern fauna. MURAOUR (1954 A, B) gives quantitative data for two stations near Algiers. DI NAPOLI-ALLIATA (1952) gives a very useful résumé of the literature on Mediterranean planktonic faunas.

The stations (Fig. 1, Table I) are scattered throughout most of the area south of North Latitude 38° 51' with the exception of four in the northern part of the Aegean Sea. No samples were obtained from the Adriatic Sea, where many of the previous studies have been made, nor from the northern part of the western Mediterranean. The samples were collected with a gravity corer or with a coring tube attached to a camera and are believed to contain material from the surface of the sediment. Three hundred to five hundred planktonic specimens larger than 0.149 mm were counted from each and the relative abundances of the species calculated. Samples having fewer specimens are omitted; the majority contain many more.

SURFACE TEMPERATURE AND SALINITY DISTRIBUTION

For convenience in the later discussion of the planktonic populations, the area may be divided into three parts: western Mediterranean, eastern Mediterranean, and the

* Contribution No. 20, Marine Foraminifera Laboratory; Contribution No. 803, Scripps Institution of Oceanography.

Aegean Sea. The depth of the surface-water layer in the Mediterranean is approximately 200 m or less. Although planktonic Foraminifera have been found living at greater depths it is probable that they are most abundant in the upper layers (PHLEGER, 1954) and it is assumed here that the characteristics of the surface layer are those to which they are adapted.

The eastern and western basins of the Mediterranean are separated by a sill, between Sicily and Tunis, having a maximum depth of about 400 m. The western basin (Tyrrhenian Sea and Algiers-Provençal Basin) is separated from the Atlantic by a sill depth of 320 m. Water enters the Mediterranean from the Atlantic and passes from the western basin to the eastern basin by surface currents. In both cases water flows westward at intermediate depths. A study of numerous sources of information shows that the surface temperature variation in the western area is approximately 13° C to 24° C, the warmest season being in July-August and the coldest in February-March. Greater extremes are found at various near-shore areas, especially along the coast of France. The temperature of the surface water just east of Gibraltar in August, 1938, was 19.5° C rising to 24° C farther east (ROUCH, 1940). Surface salinities vary from 36‰ at Gibraltar to 38‰ near Sicily. Variable salinities are often found at near-shore localities. In 1949-50 at Monaco there was a winter variation from 36.8‰ to 38.5‰ and at Algiers 34.5‰ to 37.6‰ (KRUGER, 1950). The eastern basin (Ionian Sea and Levantine Basin) apparently contains surface water derived chiefly from the west via the surface current through the Sicily-Tunis gap. The deep water, according to POLLAK (1951), is all derived from the Adriatic Sea. Little is known at present about the influence of the Suez Canal, but it is probable that any water derived from this source would quickly lose its identity. Surface temperatures in this area vary from 16° C to 24° C in the western part and 16° C to 28° C in the extreme east. Surface salinities vary from 38‰ in the west to approximately 39.5‰ in the east but here again local variations may occur near shore. An example of this is the comparatively low salinity of 30‰ found off Gaza, Israel, in September, 1947, due probably to the Nile flood (OREN, 1952). Surface currents enter the Aegean Sea from the southeast and from the Black Sea. Surface temperatures vary from 13° C to 25° C and surface salinities from approximately 30‰ near the Dardanelles to 39‰ just north of Crete. Due to the counter-clockwise surface circulation, salinities on the eastern side are higher than those on the western.

These data show that there are lower winter temperatures and somewhat lower salinities in the western than in the eastern Mediterranean. In the Aegean there are lower winter temperatures than in the eastern area and a complex salinity pattern with comparatively low salinities in the northern part.

Conditions in the Atlantic immediately west of Gibraltar are also of interest. Here the surface temperature variation is somewhat less than in the Mediterranean, 16° C to 22° C. The surface salinity is somewhat less than that obtaining at Gibraltar.

DISCUSSION OF PLANKTONIC POPULATIONS

The identifications of the planktonic species are in most cases the same as those given by PHLEGER, PARKER and PEIRSON (1954) in their study of Atlantic deep-sea cores. Some species groups, as defined here, contain forms recognized as species or varieties by some authors. Their omission does not necessarily indicate that they are believed to be invalid. *Globigerinoides rubra* probably includes, or in some cases is

Table 1. Percentage distribution of planktonic Foraminifera in the Mediterranean Sea and adjacent Atlantic Ocean.

| | | MEDITERRANEAN | | | | | | | | | | ATL. |
|---|--|---------------|------|--------|--------|--|--|--|--|--|--|------|
| STATION | | | | | | | | | | | | |
| DEPTH IN METERS | | | | | | | | | | | | |
| N. LATITUDE | | | | | | | | | | | | |
| LONGITUDE | | | | | | | | | | | | |
| Globigerina bulloides d'Orbigny | | 4665 | 1587 | 40°15' | 25°18' | | | | | | | |
| G. digitata H.B. Brady | | 4650 | 859 | 40°14' | 24°42' | | | | | | | |
| G. eggeri Rhumbler | | 4649 | 1265 | 39°35' | 23°53' | | | | | | | |
| G. inflata d'Orbigny | | 4654 | 746 | 39°04' | 24°54' | | | | | | | |
| G. pachyderma (Ehrenberg) | | 4655 | 1102 | 37°50' | 26°25' | | | | | | | |
| G. quinqueloba Natland | | 4656 | 680 | 37°59' | 25°31' | | | | | | | |
| Globigerinella aeguliferalis (H.B. Brady) | | 4647 | 366 | 37°09' | 23°38' | | | | | | | |
| Globigerinita glutinata (Egger) | | 4675 | 1064 | 35°21' | 26°40' | | | | | | | |
| Globigerinoides conglobata (H.B. Brady) | | 4673 | 1844 | 35°55' | 25°16' | | | | | | | |
| G. rubra (d'Orbigny) | | 4671 | 1016 | 36°16' | 24°18' | | | | | | | |
| G. sacculifera (H.B. Brady) | | 4670 | 996 | 35°49' | 23°27' | | | | | | | |
| Glabrotalia hirsuta (d'Orbigny) & var. | | 4694 | 567 | 36°02' | 35°03' | | | | | | | |
| G. punctulata (d'Orbigny) | | 4693 | 1073 | 35°08' | 34°56' | | | | | | | |
| G. scitula (H.B. Brady) | | 4691 | 1331 | 33°17' | 34°59' | | | | | | | |
| G. truncatulinoides (d'Orbigny) | | 4687 | 631 | 31°49' | 33°29' | | | | | | | |
| Hastigerina pelagica (d'Orbigny) | | 4688 | 1312 | 32°42' | 32°43' | | | | | | | |
| Orbulina universa d'Orbigny | | 4689 | 2442 | 33°32' | 32°09' | | | | | | | |
| Pulleniatina obliquiloculata (Parker & Jones) | | 4686 | 799 | 32°06' | 32°05' | | | | | | | |
| | | 4685 | 647 | 32°06' | 30°41' | | | | | | | |
| | | 4683 | 2358 | 32°59' | 30°28' | | | | | | | |
| | | 4681 | 2852 | 34°03' | 30°12' | | | | | | | |
| | | 4698 | 2738 | 34°24' | 29°34' | | | | | | | |
| | | 4678 | 1862 | 35°34' | 29°49' | | | | | | | |
| | | 4676 | 3974 | 35°46' | 28°28' | | | | | | | |
| | | 4701 | 2760 | 32°33' | 26°03' | | | | | | | |
| | | 4702 | 799 | 32°05' | 25°16' | | | | | | | |
| | | 4703 | 552 | 32°48' | 23°13' | | | | | | | |
| | | 4705 | 1788 | 33°44' | 23°18' | | | | | | | |
| | | 4708 | 3499 | 36°01' | 21°37' | | | | | | | |
| | | 4710 | 3241 | 37°49' | 19°19' | | | | | | | |
| | | 4711 | 3309 | 34°58' | 19°24' | | | | | | | |
| | | 4713 | 684 | 31°37' | 17°32' | | | | | | | |
| | | 4714 | 665 | 32°30' | 15°49' | | | | | | | |
| | | 4716 | 1378 | 33°52' | 15°47' | | | | | | | |
| | | 4718 | 541 | 35°06' | 15°44' | | | | | | | |
| | | 4721A | 179 | 36°49' | 12°54' | | | | | | | |
| | | 4723 | 567 | 37°12' | 11°34' | | | | | | | |
| | | 4724A | 380 | 38°22' | 11°22' | | | | | | | |
| | | 4643 | 1609 | 38°17' | 09°31' | | | | | | | |
| | | 4726 | 2775 | 37°26' | 07°02' | | | | | | | |
| | | 4642 | 2870 | 38°26' | 05°33' | | | | | | | |
| | | 4729 | 2481 | 38°51' | 03°27' | | | | | | | |
| | | 4730 | 2766 | 37°15' | 01°30' | | | | | | | |
| | | 4732 | 2471 | 35°59' | 00°53' | | | | | | | |
| | | 4733 | 1919 | 36°08' | 02°21' | | | | | | | |
| | | 4734 | 1340 | 36°01' | 03°58' | | | | | | | |
| | | 4735 | 1292 | 35°17' | 07°25' | | | | | | | |
| | | 4736 | 4420 | 34°10' | 10°30' | | | | | | | |
| | | 4637 | 4182 | 35°22' | 10°23' | | | | | | | |

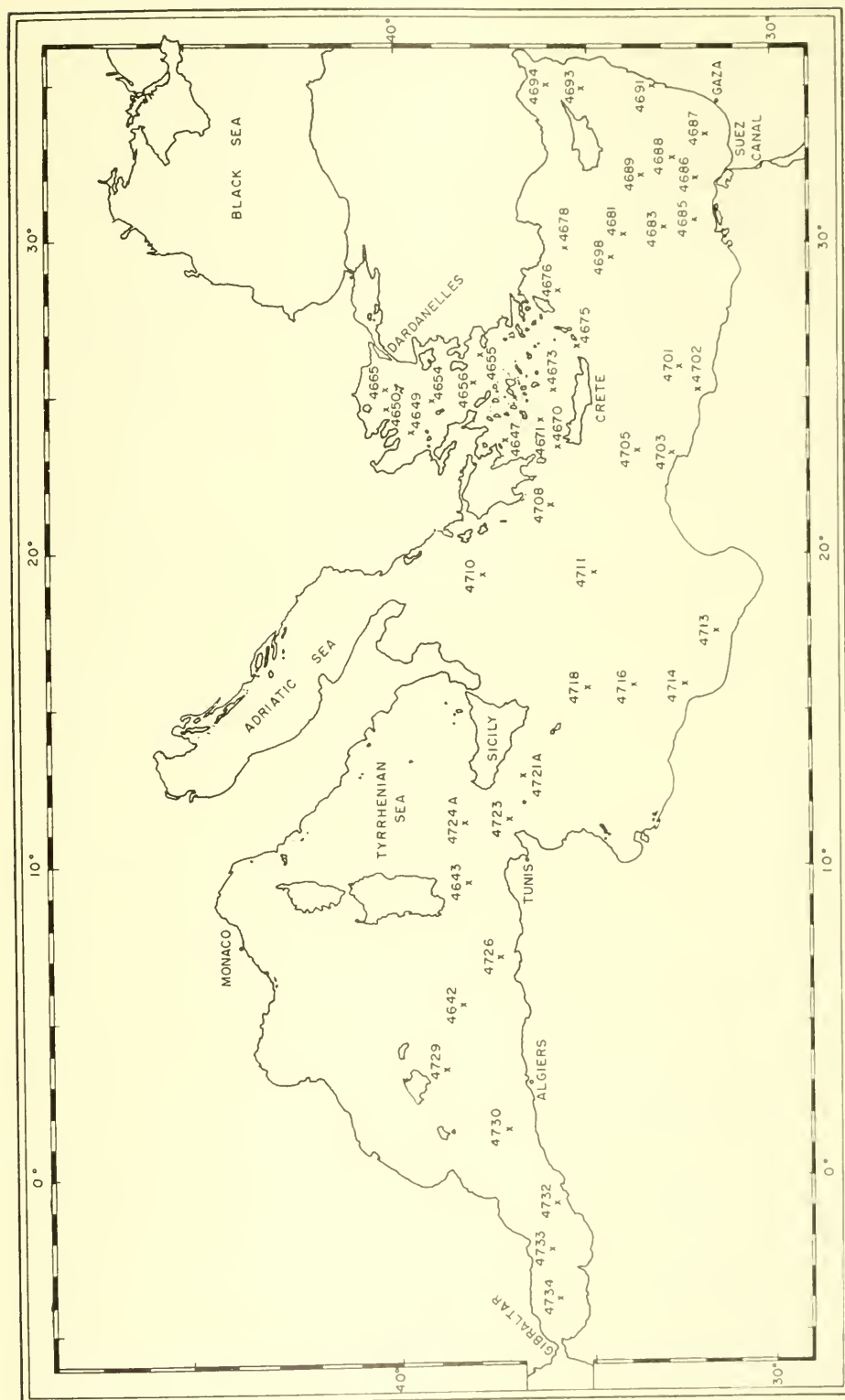


Fig. 1. Mediterranean Sea showing locations of stations.

synonymous with, *G. elongata* (d'Orbigny) and *G. helicina* (d'Orbigny), reported by D'ORBIGNY from Rimini, Italy, *G. adriatica* (Fornasini), and *G. rubra* var. *pyramidalis* (vanden Broeck). *G. sacculifera* includes a form listed by various authors as *G. triloba* (Reuss) and described by REUSS from the Miocene of the Vienna Basin. Specimens of *Globigerina eggeri* are small but otherwise typical except for Aegean specimens which frequently have a final whorl consisting of $3\frac{1}{2}$ chambers. The latter are similar to *G. bulloides* and further study may modify the ratios of the two species in Aegean Sea samples. *Hastigerina pelagica*, not reported from the Atlantic in significant numbers, is found in low frequencies chiefly in the eastern Mediterranean.

The relative percentages of the planktonic species are listed in Table I. Included in this table, for comparative purposes, are data for three stations from the Atlantic in the general vicinity of Gibraltar. The data for stations 4637 and 4736 are taken from PHLEGER, PARKER and PEARSON (1954). The following discussion deals only with occurrences as they appear in this table. Species with frequencies of less than 0.2%, therefore, are not included although they may occur. The sampling is sparse for such a large area but the percentage data show clearly that there are three distinctive populations. The first of these is that of the western Mediterranean which extends east to include station 4721A. This assemblage differs from that of the adjacent mid-latitude Atlantic in the following ways:

| | Atlantic (mid-latitude) | Western Mediterranean |
|-------------------------------------|-------------------------|--------------------------------------|
| <i>Globigerina digitata</i> | absent | present |
| <i>G. inflata</i> | 8-13% | 14-30% (usually more than 20%) |
| <i>G. quinqueloba</i> | absent | present |
| <i>Globigerinoides conglobata</i> | present | absent |
| <i>G. sacculifera</i> | 9-10% | less than 1-5% |
| <i>Globorotalia hirsuta</i> | present | first 2 stas. east of Gibraltar only |
| <i>G. punctulata</i> | present | absent |
| <i>G. scitula</i> | 2% | less than 1% (scattered) |
| <i>Hastigerina pelagica</i> | absent | present (1 sta.) |
| <i>Pulleniatina obliquiloculata</i> | present | absent |

The second assemblage is found in the eastern Mediterranean. It differs from that of the western area in the following ways:

| | Western Mediterranean | Eastern Mediterranean |
|--------------------------------------|-----------------------|------------------------|
| <i>Globigerina bulloides</i> | 20-56% | 8-18% |
| <i>G. inflata</i> | 14-38% | 0-6% |
| <i>Globigerinoides rubra</i> | 1-25% | 41-77% |
| <i>G. sacculifera</i> | 1-5% | 3-14% (except 4 stas.) |
| <i>Globorotalia truncatulinoides</i> | less than 1-14% | 0-2% (scattered) |
| <i>Hastigerina pelagica</i> | at 1 sta. | consistent occurrence |

The third assemblage is found in the Aegean Sea. It differs from that of the eastern Mediterranean in the following ways:

| | Eastern Mediterranean | Aegean Sea |
|------------------------------------|--------------------------------------|---------------------------------|
| <i>Globigerina eggeri</i> | 2–13% (except 2 stas. off Israel) | 3–28% (mostly more than 20%) |
| <i>G. pachyderma</i> | | slight consistent increase |
| <i>Globigerinoides sacculifera</i> | 3–14% | 0–3% |

In the western Mediterranean the population must be adapted to a wider temperature range than that found in the adjacent Atlantic. The winter temperatures are more nearly analogous to those found on the western Atlantic continental slope in mid-latitudes. In some respects the western Mediterranean population reflects this and shows a resemblance to the populations in that area (PARKER, 1948; PHLEGER, 1939, 1942) as shown by the high frequencies of *Globigerina bulloides* and *G. inflata* and the low frequency of *Globigerinoides sacculifera* as well as in lesser respects. The fauna occurring at the three stations (4732–4734) just east of Gibraltar is of interest. Two of these stations lie within the low temperature area reported by ROUCH (1940). Here exceptionally high frequencies of *Globigerina bulloides* and low frequencies of *Globigerinoides rubra* and *Globorotalia truncatulinoides* are found. Whether or not these changes are due to a lowered mean temperature maximum is a matter of speculation. The presence of *G. hirsuta* in significant frequencies in this area may be due to transport by the entering Atlantic current. The faunas reported by MURAOUR (1954 A, B) from the vicinity of Algiers show a much lower percentage of *Globigerinoides rubra*. The populations reported by PHLEGER (1947) from the Tyrrhenian Sea are analogous to those found in the present study.

The increase in the mean minimum temperature in the eastern area from 13° C to 16° C may account for some or all of the shifts in population found there, as similar trends occur when passing from mid to low latitudes in the Atlantic. In general there is a decrease in such species as *Globigerina bulloides* and *G. inflata*, which occur in high frequencies in mid-latitudes, and an increase in *Globigerinoides sacculifera* which is found in increasingly high frequencies in low latitudes.

In the Aegean Sea the mean minimum temperature is 13° C, as it is in the western Mediterranean, which may account for the more consistent occurrence of *Globigerina pachyderma* and the decrease in *Globigerinoides sacculifera* as compared to eastern area occurrences. Lower salinities in the northern part and/or changes in the chemistry of the surface water resulting from the inflow of water from the Black Sea may also account for these changes. This may be especially true in the case of the high frequencies of *Globigerina eggeri* and the fact that many of the specimens are atypical.

The populations at several stations, besides those noted previously, show unusual features but two are especially noteworthy. Station 4724A contains what appears to be a "colder water" fauna. There are higher frequencies of *Globigerina eggeri*, *G. pachyderma*, and *G. quinqueloba* and lower frequencies of *Globigerinella aequilateralis* and *Globigerinoides rubra*. *Globigerina eggeri* is the only species of the group which does not fit this pattern, since that species is found in higher frequencies in low latitudes. Further study may reveal whether or not this fauna is pre-modern. The sample from station 4718 contains a large percentage of weathered, discoloured

specimens, some of which are filled with glauconite. This suggests that little deposition has taken place in this area for a long time, since at most stations the planktonic specimens appear to be fresh and well-preserved, showing recent deposition. It is possible that there is a strong current in this area which removes the specimens as they are deposited, leaving the older, filled tests.

The planktonic populations in the Mediterranean probably are derived in two ways: from material brought in by the Atlantic current and from ancestral stock indigenous to the area, a so-called "relict" fauna. A third possible source may be transport through the Suez Canal, but too little is known about this at the present time to evaluate its importance. A study of Table I and of the specimens themselves leads to some interesting speculations on this point. PHLEGER (1947) believes that occasional specimens of *Globorotalia scitula* are introduced from the Atlantic, but that the species is not found living here. The present findings point to the same source, but it is probable that there is some survival as there is a scattered occurrence of the species throughout the area. *Globigerinoides conglobata* and *Globorotalia hirsuta*, which occur rarely at many stations, may have a similar origin. On the other hand *Globigerina digitata* and *Hastigerina pelagica*, which are rare in modern Atlantic sediments, may be species indigenous to the Mediterranean. The atypical form of *Globigerina eggeri* found in the Aegean Sea is probably an indigenous form.

A recent study of the coiling direction of *Globorotalia truncatulinoides* by ERICSON, WOLLIN and WOLLIN (1954), shows that the North Atlantic may be divided into provinces in which there occur "races" showing a dominance of left or right coiling. According to their interpretation the area immediately west of Gibraltar should contain a population showing equi-directional coiling. Samples from *Atlantis* stations 4637, 4735 and 4736 were examined and this was found to be the case. East of Gibraltar at station 4734 the ratio shifts to 79% left coiling (based on 62 specimens) and increases rapidly to the east until at station 4730, just east of 0° Long., a dominance of 99% left coiling is found. High ratios of 88% or more are maintained eastward to station 4711, just west of 20° E. Long., which shows 62% left coiling. Farther east there are too few individuals to give significant results. Where possible, 400 specimens were counted and such samples served to check neighbouring stations containing fewer specimens. These results also suggest that at least part of the Mediterranean populations are indigenous and not directly derived from the Atlantic. A study of other species by statistical analysis of measurements or other characteristics and a comparison with Atlantic specimens would give additional data on this point.

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