Planktonic Foraminifera

Allan W. H. Bé

INTRODUCTION

There are about 30 species of planktonic Foraminifera, as contrasted with the more than 4200 benthic species in the oceans of the world. Most of the planktonic species belong to the families Globigerinidae and Globorotaliidae. Of the 30 species, 9 occur in Antarctic and Subantarctic waters; however, none of these cold-water species are restricted to the Southern Ocean,

Uchio (1960) described the planktonic Foraminifera in two plankton tows and eleven bottom samples from the southern Indian Ocean. Belyaeva (1964) has made an extensive comparison of the distribution of living and dead assemblages of planktonic Foraminifera in 400 plankton and 286 bottom samples in the Indian Ocean. Her observations on the fossil distributions covered the entire Indian Ocean to Antarctica, but her study of living species was limited to the region north of 40°S latitude.

The dead assemblages of planktonic Foraminifera in South Pacific sediments have been studied by Parker (1962), whose definitive taxonomic survey of 34 species included their gross geographic distributions. Blackman (1966) also investigated planktonic foraminiferal assemblages in bottom samples from the southeastern Pacific, including the Albatross Cordillera. Kustanowich (1963) recorded the distributions of 26 species in sediments from the New Zealand region between 18°S and 54°S latitude. Blair's (1965) and Kennett's (1968) investigations of planktonic foraminiferal assemblages in sediments of the Scotia Sea and the South Pacific are particularly pertinent, and correlatable to our study, because their core samples and our plankton tows were obtained on the same expeditions (Eltanin Cruses 3 to 15).

Uchio's (1960) study is the most extensive comparison of the distribution of living planktonic Foraminifera in the Antarctic region, and it is the most extensive comparison of the distribution of living planktonic Foraminifera in the Indian Ocean. Belyaeva's (1964) study is the most extensive comparison of the distribution of living planktonic Foraminifera in the Indian Ocean. Her observations on the fossil distributions covered the entire Indian Ocean to Antarctica, but her study of living species was limited to the region north of 40°S latitude.

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Distribution in the Upper 300 M (Plates 1 and 2)

Maps 2 and 3: Globigerina quinqueloba Natland

This species occurs commonly along both sides of the Antarctic Convergence but is perhaps more abundant south of it. The typical form has a final chamber that extends as a lobe over the umbilicus and constricts the aperture. Unfortunately, this prominent feature is lacking in the earlier stages, and they are then difficult to distinguish from juvenile Globigerina pachyderma. Since the latter species lacks spines in the adult stages and probably also in earlier ontogeny, we consider the possession of spines by G. quinqueloba and the absence thereof on G. pachyderma as the major distinguishing criterion. This is not always as obvious as it seems because the very delicate spines of G. quinqueloba can be readily rubbed off by abrasion while in the plankton net or sample jar or dissolved by inadequately buffered preservative.

The regions and seasons of maximum abundance of Globigerina quinqueloba coincide with those of Globigerina pachyderma (Maps 4 and 5), but the former decreases toward the pole and is absent in the southernmost stations (Maps 2 and 3). It occurs less abundantly in Subantarctic waters and has a northern limit in the Southern Hemisphere at approximately 40°S latitude.

Blair (1965) noted that G. quinqueloba constitutes less than 10% of the total planktonic Foraminifera in Recent sediments in the Drake Passage and the South Pacific and that it appeared in larger numbers and at more stations north of the Antarctic Convergence than south of it. Kustanowich (1963) found it a rare but widespread species in the surface sediments around New Zealand and south of it.

Globigerina quinqueloba occurs predominantly in waters colder than 12°C, and in the Antarctic region it is most frequently found in water temperatures between 1°C and 6°C.

Maps 4, 5, and 6: Globigerina pachyderma (Ehrenberg)

This species, particularly the left-coiling variety, is the most cold-tolerant of the planktonic Foraminifera and is abundant in Antarctic and Subantarctic as well as in Arctic and Subarctic waters. In Subantarctic waters it is especially common over the Argentine continental shelf. The species is very rare, or absent, in subtropical waters.

Juveniles of G. pachyderma have 4.5 to 5 hemispherical chambers per whorl, a large aperture, an open umbilicus, and a thin-walled test that looks considerably different from the compact, thick-walled adult test.
whorl, a large aperture, an open umbilicus, and a thin-walled test that looks considerably different from the compact, thick-walled adult test with 4 coalescing chambers per whorl, a reduced final chamber, and a constricted aperture. The typical adult form of *G. pachyderma* is attained by crystalline thickening (Bé, 1960b).

The young forms of *Globigerina pachyderma* are difficult to separate from *G. quinqueloba* Natland, as we have discussed previously. Spinosity may or may not prove to be a real distinguishing characteristic, since it has not yet been established whether *G. pachyderma* truly lacks spines in its earlier stages.

There are several regions where either the right-coiling or the left-coiling variety is predominant (Map 6). One area where right-coiling specimens predominate is located over the Argentine continental shelf north of the Falkland Islands, where concentrations of *G. pachyderma* are exceptionally high for a region so far north of the Antarctic Convergence. Our plankton collections and those of Boltovskoy (1966a) both indicate a sharply defined boundary between predominantly left-coiling and right-coiling populations north of the Falkland Islands. Another region of mostly right-coiling forms is east and west of New Zealand (Jenkins, 1967). Because of the generally rapid decrease of *G. pachyderma* northwards and the lack of sample coverage in certain parts of the ocean, the actual extent of these regions cannot be readily ascertained. It should be noted, however, that the water is warmer in these areas than in regions inhabited by left-coiling forms. It may well be that dextral populations of *G. pachyderma* are distributed in a continuous belt north of their sinistral relatives in a manner reciprocal to that observed by Ericson (1959) in the North Atlantic. It is also possible that a gradual and nearly continuous genetic gradient exists from left-coiling to right-coiling populations of *G. pachyderma* and that the latter, in turn, grade into *Globoquadrina dutertrei*. Cifelli (1961), Parker (1962) and Zobel (1968) have noted strong morphological similarities between the two species.

The left-coiling variety occurs preponderantly in the colder Subantarctic and Antarctic waters. The percentage of sinistral forms increases southward as water temperature decreases. Ninety percent or more of *G. pachyderma* tests are sinistral south of the Antarctic Convergence. This agrees closely with Blair’s (1965) and Kennett’s (1968) observations of coiling ratios of *G. pachyderma* in Antarctic Recent bottom sediments. The 90% left-coiling isopleth of both investigators is based on fossil populations and runs north of the Antarctic Convergence, while our relative abundances of 90% for living forms generally follow the Antarctic Convergence or are located to the south of it. We believe this indicates that a southward shift of predominantly sinistral populations has taken place in the recent past.

### TABLE 1. Species Composition of World Distributional Zones Shown in Figure 1.

<table>
<thead>
<tr>
<th>Zone</th>
<th>Species</th>
</tr>
</thead>
<tbody>
<tr>
<td>NORTHERN AND SOUTHERN COLD-WATER REGIONS</td>
<td></td>
</tr>
<tr>
<td>Arctic and Antarctic zones</td>
<td><em>Globigerina pachyderma</em> (left-coiling variety)</td>
</tr>
<tr>
<td>Subarctic and Subantarctic zones</td>
<td><em>Globigerina pachyderma</em> (right-coiling variety)</td>
</tr>
<tr>
<td></td>
<td><em>Globigerina quinqueloba</em></td>
</tr>
<tr>
<td></td>
<td><em>Globigerina bulloides</em></td>
</tr>
<tr>
<td></td>
<td><em>Globigerina uvula</em></td>
</tr>
<tr>
<td></td>
<td><em>Globoquadrina scitula</em></td>
</tr>
<tr>
<td></td>
<td><em>Globoquadrina cavernal</em></td>
</tr>
<tr>
<td>TRANSITION ZONES</td>
<td></td>
</tr>
<tr>
<td>Northern and southern zones</td>
<td><em>Globoquadrina inflata</em></td>
</tr>
<tr>
<td>of transition between cold-water and warm-water regions</td>
<td>Also, mixed occurrences of subpolar and tropical–subtropical species</td>
</tr>
<tr>
<td>WARM-WATER REGIONS</td>
<td></td>
</tr>
<tr>
<td>Northern and southern subtropical zones</td>
<td><em>Globoquadrina ruber</em> (pink variety in Atlantic Ocean only)</td>
</tr>
<tr>
<td></td>
<td><em>Globoquadrina congobatus</em> (fall species)</td>
</tr>
<tr>
<td></td>
<td><em>Hastigerina pelagica</em></td>
</tr>
<tr>
<td></td>
<td><em>Globoquadrina glutinata</em></td>
</tr>
<tr>
<td></td>
<td><em>Globoquadrina truncatulinoides</em> (winter species)</td>
</tr>
<tr>
<td></td>
<td><em>Globoquadrina hirsuta</em> (winter species)</td>
</tr>
<tr>
<td></td>
<td><em>Globoquadrina rubescens</em></td>
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<td></td>
<td><em>Globoquadrina falconensis</em></td>
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<tr>
<td></td>
<td><em>Globoquadrina aequilateralis</em></td>
</tr>
<tr>
<td></td>
<td><em>Orbulina universa</em></td>
</tr>
<tr>
<td></td>
<td><em>Globoquadrina dutertrei</em></td>
</tr>
<tr>
<td></td>
<td><em>Globoquadrina crassaforma</em></td>
</tr>
<tr>
<td>Tropical zones</td>
<td><em>Globoquadrina saccularifer</em> [incl. <em>Sphaerooidinella dehiscens</em> (Parker and Jones)]</td>
</tr>
<tr>
<td></td>
<td><em>Globoquadrina menardii</em></td>
</tr>
<tr>
<td></td>
<td><em>Globoquadrina tumida</em></td>
</tr>
<tr>
<td></td>
<td><em>Pulvinatina obliquiloculata</em></td>
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<td></td>
<td><em>Candeina nitida</em></td>
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<td></td>
<td><em>Hastigerina digitata</em></td>
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<tr>
<td></td>
<td><em>Globoquadrina congolomolaria</em></td>
</tr>
<tr>
<td></td>
<td><em>Globoquadrina adamsi</em></td>
</tr>
<tr>
<td></td>
<td><em>Globoquadrina hexagona</em></td>
</tr>
</tbody>
</table>

Most species from subtropical zones are also common in tropical zones.

1Species are listed under the zone where their highest concentrations are observed, but they are not necessarily limited to these areas.
2Prefers outer margins of subtropical central water masses and fringes of the Transitional Zone.
3Restricted to the Indo-Pacific.
4Restricted to the Subantarctic.
**TABLE 2. Plankton Collections Used in This Study**

<table>
<thead>
<tr>
<th>Ship and Cruise Number</th>
<th>Date of Collection</th>
<th>Number of Samples</th>
<th>Number of Stations</th>
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<tbody>
<tr>
<td>Eilat 8</td>
<td>April 14–June 12, '63</td>
<td>66</td>
<td>21</td>
</tr>
<tr>
<td></td>
<td>Aug. 12–Sept. 13, '63</td>
<td>66</td>
<td>21</td>
</tr>
<tr>
<td></td>
<td>Oct. 15–Nov. 29, '63</td>
<td>101</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td>Dec. 28, Feb. 6, '64</td>
<td>117</td>
<td>29</td>
</tr>
<tr>
<td></td>
<td>Mar. 13–April 18, '64</td>
<td>96</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>May 19–June 20, '64</td>
<td>127</td>
<td>16</td>
</tr>
<tr>
<td></td>
<td>Aug. 2–Sept. 5, '64</td>
<td>152</td>
<td>19</td>
</tr>
<tr>
<td></td>
<td>Oct. 11–Nov. 21, '64</td>
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<td>24</td>
</tr>
<tr>
<td></td>
<td>Feb. 4–Feb. 18, '65</td>
<td>45</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>Mar. 25–April 30, '65</td>
<td>204</td>
<td>23</td>
</tr>
<tr>
<td></td>
<td>May 5–10, '65</td>
<td>26</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>July 13–Aug. 24, '65</td>
<td>147</td>
<td>19</td>
</tr>
<tr>
<td>Vema 14</td>
<td>Jan. 8–April 5, '64</td>
<td>21</td>
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<td></td>
<td>Feb. 24, '65</td>
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<td></td>
<td>Mar. 20–April 16, '65</td>
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<tr>
<td></td>
<td>Feb. 28–May 15, '62</td>
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<td>29</td>
</tr>
<tr>
<td></td>
<td>July 29–Aug. 7, '62</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Conrad 8</td>
<td>Feb. 18–April 1, '64</td>
<td>19</td>
<td>19</td>
</tr>
<tr>
<td></td>
<td>Mar. 8–April 14, '65</td>
<td>15</td>
<td>15</td>
</tr>
</tbody>
</table>

**Globigerina pachyderma** occurs most abundantly during spring, summer, and early fall (early October to late April); this coincides with the period of high phytoplankton production. The region of highest abundance, where *G. pachyderma* exceeds 10 specimens/m³, lies between 60°W and 155°W and south of the Antarctic Convergence; a secondary area of high concentration is located off the Argentine shelf (Map 4). Low concentrations of *G. pachyderma* prevail during late fall and winter (May to September). The left-coiling populations are encountered at water temperatures between −1°C to 8°C, and reach highest concentrations at temperatures below 2°C. Dextral populations are found primarily between 9°C and 15°C.

**MAPS 7 AND 8: Globigerina bulloides**

This is the most abundant species in Subantarctic waters, often reaching 80% to 90% of the total planktonic foraminiferan populations. It is next in importance to *G. pachyderma* as a cold-water indicator. The species occurs in a broad belt roughly between 40°S latitude and the Antarctic Convergence. Highest concentrations are generally observed during spring and summer, while sparse populations are usual in winter. *G. bulloides* is found to about 4800 km south of the Antarctic Convergence, but the main decrease in numbers occurs within the first 160 km or so south of the Convergence. In addition, seasonal fluctuations of *G. bulloides* are responsible for southward invasions beyond the Convergence during summer and spring and northward retreats during late fall and winter.

The northern limit of abundant *G. bulloides* in the Southern Hemisphere is at approximately 40°S latitude coinciding roughly with the 18°C surface isotherm. *Globigerina bulloides* grades morphologically and zoogeographically into *G. falconensis* Blow. The latter inhabits the cooler edges of subtropical regions and differs from *G. bulloides* in having a smaller test, a more constricted low-arched aperture with a lip, and more elongate chambers (Bé, 1967a). We believe that the two forms belong to a cline.

Blair (1965) found that the 20% isopleth of fossil *G. bulloides* in recent bottom sediments of the South Pacific is situated north of the Antarctic Convergence, whereas relative abundances of 20% for living *G. bulloides* are located about 160 km south of the Convergence. As is true in the comparison of fossil with living *G. pachyderma* populations, we infer that the present-day extension of *G. bulloides* south of the Convergence is due to a warming trend of waters in the recent geologic past.

Blackman (1966) observed that *G. bulloides* constituted from 39% to 73% of the total planktonic Foraminifera in Recent sediments of the Albatross Cordillera south of 40°S latitude. Kustanowich (1963) also observed the dominance of *G. bulloides* in Subantarctic sediments south of New Zealand. The species made up more than 40% of the total planktonic Foraminifera south of 40°S latitude.

**Globigerina bulloides** is encountered primarily in near-surface waters and decreases in number with depth. Its optimum temperature range lies between 2°C and 10°C.

**MAPS 9 AND 10: Globorotalia truncatulinoides**

This species flourishes in Subantarctic waters during late fall and winter (May to October), but is rare during the remaining months of the year (Figure 2). The seasonal factor explains why this species is sparsely distributed during summer and early fall. If in late fall and winter samples are considered, the high densities found in the Subantarctic region may well be part of an extensive bloom of *G. truncatulinoides* over the middle latitudes of the southeastern Pacific. The northern extent of such a fall–winter bloom cannot be ascertained because of the paucity of samples in the southeastern Pacific.

Park (1960) did not report any *G. truncatulinoides* south of 40°S latitude. However, on the Albatross Cordillera between 25°S and 45°S latitude, in Recent sediments, it is one of the dominant species, constituting more than 20% of the planktonic foraminiferal assemblages (Blackman, 1966). The absence of *G. truncatulinoides* in Parker's southern stations may be due to its very low concentration between October and February and is a further indication that it is a mid-latitude species which occurs most abundantly in late fall and winter in subtropical, transitional, and Subantarctic waters of the South Pacific.

In the North and South Atlantic *G. truncatulinoides* is also a winter species, occurring primarily between December and April in the Sargasso Sea and in July and August in the central South Atlantic (Bé, 1960a, and unpublished data). However, while it is restricted to subtropical waters in the Northern Hemisphere (Bradshaw, 1959; Bé, and Hamlin, 1967), *G. truncatulinoides* appears to have a wider temperature tolerance in the Southern Hemisphere, where it flourishes in Subantarctic as well as subtropical waters. In the Northern Hemisphere it does not occur in regions with surface temperatures below 14°C, but in the Southern Hemisphere this species is common in Subantarctic waters with temperatures as low as 4°C.

Blair (1965) reported that in bottom sediments the relative abundance of *G. truncatulinoides* tests are about 1% and 2% along the Antarctic Convergence in the South Pacific and about 1% to 5% in the Scotia Sea north of the Convergence. Although this seems considerably lower than the high percentages of living *G. truncatulinoides* along or north of the Convergence (Map 10), the lower frequencies in the sediments may reflect either the averaging effect of the strongly seasonal productivity of this species or the recession of the incursion of greater concentrations of *G. truncatulinoides* in the Subantarctic region.

Left-coiling tests of *G. truncatulinoides* greatly outnumber the right-coiling ones in Subantarctic waters.

**MAPS 11 AND 12: Globorotalia inflata**

This is a good indicator species of transitional waters between the subtropical and Subantarctic regions in the South Atlantic, but in the South Pacific highest frequencies are found mainly in Subantarctic waters (Map 12). Whereas in the Atlantic highest relative abundances are encountered in regions where surface isotherms are between 13°C and 19°C, in the Pacific it is one of the dominant species of Subantarctic waters having surface temperatures between 2°C and 6°C.

**Globorotalia inflata** occurs predominantly during winter and spring (early August to early January) reaching a climax in October and November, when relative abundances up to 70% of the total population and absolute abundances of 10 specimens/m³ or more are recorded. The seasonal distribution of *G. inflata* (Figure 2) shows its spring preference even more distinctly if Conrad Cruises 8 and 9 are disregarded, because they are mostly north of 50°S latitude. The high concentrations in the New Zealand region contrast with the relatively low densities to the south near the Antarctic Convergence; this difference can probably be attributed to the seasonal factor.
G. inflata is not common over the Argentine continental shelf, although the temperature-salinity conditions appear favorable for its development. Here right-coiling Globigerina pachyderma and G. bulboides are predominant among the planktonic Foraminifera. Whether G. inflata is also abundant in the southeastern Pacific to the north of our present area of study is a matter of conjecture. Parker (1965) reported low relative abundance (<10%) in 2 out of 11 stations in this area, but her plankton samples were collected with coarse-meshed nets (0.65 mm mesh aperture) which in all likelihood allowed the escape of many Foraminifera. Blackman (1966) observed that G. inflata constituted more than 20% of the planktonic foraminiferal thanatoocoenosis in the sediments south of 45°S latitude of this same area.

Blair (1965) reported relative abundances of G. inflata as high as 30% in the southeastern Pacific floor and up to 20% in the Drake Passage sediments north of the Antarctic Convergence. His 10° isoloph is also located north of the Convergence, whereas equivalent relative abundances for living G. inflata are generally south of the Convergence. This is interpreted as the result of a southward migration during the warming trend of the recent geological past. Blair’s high relative abundances in the Scotia Sea are also reflected in the living populations which are transported eastward from the Pacific into the Scotia Sea.

MAPS 13 AND 14: Globigerinita glutinata (Egger)

This is a ubiquitous species that is found commonly in small numbers in Subantarctic waters. Its frequency is usually less than 5% of the total planktonic Foraminifera, although it sporadically increases to as high as 20% in the equatorial Pacific. Its frequency is usually less than 5% of the total planktonic foraminiferal thanatoocoenosis in the sediments south of 45°S latitude of this same area.

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Planktonic Foraminifera

Sheet 1

Map 1
Station Map
- Eltanin cruises
- Vema cruises
- Conrad cruises
- Yelcho cruises

MAP 4
Globigerina pachyderma
Absolute abundance

<table>
<thead>
<tr>
<th>Season</th>
<th>Fall</th>
<th>Winter</th>
<th>Spring</th>
</tr>
</thead>
<tbody>
<tr>
<td>Absent</td>
<td>1-99</td>
<td>100-999</td>
<td>10,000 and greater</td>
</tr>
</tbody>
</table>

Austral seasons are indicated

Compiled by A. W. H. Be
Globigerina pachyderma
Relative abundance
(percentage of total population)
- Absent
- 0.1-4.9
- 5.0-9.9
- 10.0-19.9
- 20.0 and greater

Globigerina quinqueloba
Absolute abundance
(no. of specimens per 1000 m³)
- Absent
- 1-99
- 100-999
- 1000-9999
- 10,000 and greater

Globigerina pachyderma
Coiling percentage
(percentage of total population)
- Absent
- 0-9
- 10-49
- 50-89
- 90-100

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PLANKTONIC FORAMINIFERA

MAP 7
Globigerina bulloides
Absolute abundance
- (no. of specimens per 1000m³)
- Absent
- 1-99
- 100-999
- 1000-9999
- 10,000 and greater

MAP 11
Globorotalia inflata
Absolute abundance
- (no. of specimens per 1000m³)
- Absent
- 1-99
- 100-999
- 1000-9999
- 10,000 and greater

MAP 8
Globigerina bulloides
Relative abundance
(percentage of total population)
- Absent
- 0.1-4.9
- 5.0-9.9
- 10.0-19.9
- 20.0 and greater

MAP 12
Globorotalia inflata
Relative abundance
(percentage of total population)
- Absent
- 0.1-4.9
- 5.0-9.9
- 10.0-19.9
- 20.0 and greater

Austral seasons are indicated

COMPiled by A. W. H. Be
Globigerina bulloides

Relative abundance (percent of total population)

- Absent
- 0.1-4.9
- 5.0-9.9
- 10.0-19.9
- 20.0 and greater

Globorotalia truncatulinoides

Absolute abundance (no. of specimens per 1000 m³)

- Absent
- 1-99
- 100-999
- 1000-9999
- 10,000 and greater

Globigerinita glutinata

Relative abundance (percent of total population)

- Absent
- 0.1-4.9
- 5.0-9.9
- 10.0-19.9
- 20.0 and greater

American Geographical Society—1969