Abstract

Study of DSDP sites and piston cores from the Northern Atlantic Ocean provided new knowledge of the range and distribution of the *Globorotalia crassaformis* plexus. The following subspecies are differentiated: *Globorotalia crassaformis crassaformis*, *G. crassaformis ronda*, *G. crassaformis hessi*, *G. crassaformis viola*, and *G. crassaformis imbricata* and are described and illustrated. A similar sequence of FADs and LADs of the plexus was recorded in different climatic realms. *G. crassaformis crassaformis* appeared at 5.06 Ma in the subtropical region and at 4.62 Ma in the boreal realm. It was then followed by other subspecies in a specific succession. At all sites *G. puncticulata* appeared slightly later than the earliest members of *G. crassaformis ss*. Its first occurrence data range from 4.88 to 4.54 Ma in different realms. The stratigraphic significance of the plexus is considerably greater than has formerly been recognized and it may be recommended for wider use in the Pliocene–Quaternary zonations.

Keywords: planktonic foraminifera, *Globorotalia crassaformis*, Atlantic Ocean, biostratigraphy, zonations, FADs and LADs.

1. Introduction

The species *Globorotalia crassaformis*, first described by Galloway and Wissler (1927), is widespread throughout the World Ocean and, along with *Globorotalia punticulata* and *G. inflata*, commonly defines the specific character of Pliocene and Quaternary planktonic foraminiferal assemblages. Subsequently the following subspecies of *Globorotalia crassaformis* were described: *G. crassaformis oceanica* (Cushman and Bermudez, 1949),
2. Methods

The samples were washed through a 100-µm sieve and the residues were studied under a light microscope and SEM. The complete residues of each sample (an average of several thousand specimens) were looked through in order to trace all rare species that can be overlooked on cursory examination.

The DSDP holes and piston cores with the available paleomagnetic record (von Rad et al., 1979) were most thoroughly investigated. An important aim was to estimate the absolute ages of FADs and LADs of the G. crassaformis plexus. The absolute ages were calculated using sediment accumulation rates and calibrated against the time scale of Berggren et al. (1995).

3. Results on distribution of the Globorotalia crassaformis plexus in the Pliocene–Quaternary sediments of the Atlantic Ocean

As the holes discussed below are characterized by a similar pattern of stratigraphic distribution of the Globorotalia crassaformis members, their range is shown in Figure 2 using Site 397 as an example. The sites are described from the south to the north. DSDP Site 25 (0° 31’ S, 39° 31’ W) is the southernmost hole among those discussed in this paper (Fig. 1). In studies of its Pliocene–Quaternary sediments our purpose was to reveal the degree of representation of the Globorotalia
crassaformis plexus in the equatorial realm. This group is widespread in almost all climatic realms of the Atlantic Ocean and represents an important instrument for the zonal subdivision of deep-sea sediments. At the same time its subspecies had not yet been reported from the equatorial region. My investigation revealed that the subspecies G. crassaformis crassaformis, G. crassaformis viola, G. crassaformis hessi, and G. crassaformis ronda occur in all studied samples of Site 25. In the upper part of the section G. crassaformis imbricata was recorded (Sample 25-1-1, 80-82 cm). In cores 25-1 and 25-2 I have recognized Bolli's Quaternary Globorotalia crassaformis viola, Globorotalia crassaformis hessi, Globigerina calida calida, Globigerina bermudezi, and Globorotalia fimbriata Subzones (Bylinskaya et al., 2002).

DSDP Site 366 located in the tropical Atlantic (5º 41' N, 19º 51' W) is characterized by the following successive appearances of the forms of Globorotalia crassafor-
mis: G. crassaformis s.l. (=G. crassaformis crassaformis) appeared in the middle part of the Lower Pliocene in the Globorotalia margaritae Zone (Sample 366A-8-4, 71-73 cm), and close to the top of the zone the first occurrences of Globorotalia punccticulata and G. crassaformis viola were recorded. First specimens of G. crassaformis hessi were encountered in the Upper Pliocene Globorotalia tosaensis Zone (Sample 366A-4-4, 62-64 cm). At the top of the section G. crassaformis imbricata was found (Sample 366A-1, CC).

The piston cores obtained by the R/V “Akademik N. Strakhov” in the tropical Atlantic along 15º N recovered mainly Quaternary sediments, thus only the youngest data of members of the Globorotalia crassaformis plexus were traced. In core 32T2 the last occurrence of G. crassaformis ronda was recorded at 0.64 Ma and that of G. crassaformis hessi, at 0.19 Ma. G. crassaformis imbricata appeared within the Brunhes Chron at 0.58 Ma (Fig. 3).

Site 397 (26º 50' N, 15º 10' W) located nearby the northwestern coast of Africa at a depth of 2900 m, is characterized by a thick section of Upper Cenozoic sediments accumulated at a high deposition rate. The reliable paleomagnetic record obtained in Leg 47, permitted the re-estimation of FAD and LAD ages of planktonic foraminifera (Bylinskaya, 1999). The samples studied were taken every 1.5 m, which corresponds to a resolution of 0.02 m.y. First specimens of Globorotalia crassaformis crassaformis (Fig. 2) were recorded in the middle part of the Lower Pliocene Globorotalia margaritae Zone (Sample 397-38-3, 18-22 cm), within the Thvera Subchron of the Gilbert Chron at 5.06 Ma. This datum is considerably older than was previously estimated (Berggren et al., 1995). Next after G. crassaformis crassaformis, specimens of G. crassaformis ronda and G. crassaformis hessi were encountered upward in the section at Site 397 (Sample 397-34-7, 25-29 cm). They first appeared within the Nunivak Subchron at 4.5 Ma. Thus the FAD of the latter subspecies is older than in tropical and temperate regions. The FAD of G. crassaformis viola was recorded near the top of the Cochiti Subchron of the Gilbert Chron at 4.0 Ma (Sample 397-32-3, 20-24 cm). Its last occurrence marks the top of the Lower Quaternary subzone of the same name. At Site 397 this was recorded in Sample 397-12-1, 59-63 cm. The LADs of G. crassaformis ronda and G. crassaformis hessi correspond to the Upper Quaternary (Samples 397-3-5, 70-72 cm and 397-2-1, 79-83 cm, respectively). Globorotalia punccticulata appeared at Site 397 at the top of the Sidufjall Subchron, 4.88 Ma (Sample 397-37-1, 18-22 cm), above the FAD of G. crassaformis.

DSDP Site 608 (42º 50’ N, 23º 05’ W) was drilled on the southern flank of the King’s Trough, eastwards the Mid-Atlantic Ridge. The members of Globorotalia crassaformis plexus and G. punccticulata appeared in the middle part of the Globorotalia margaritae Zone (Bylinskaya et al., 2002). G. crassaformis crassaformis first occurred in Sample 608-16-5, 95-97 cm; slightly above (Sample 608-16-3, 96-98 cm) the appearance of G. crassaformis ronda and G. punccticulata are recorded. G. crassaformis viola starts from Sample 608-15-2, 95-97 cm, and still higher (Sample 608-13-6, 97-99 cm) G. crassaformis hessi appears. As seen from the foregoing, G. crassaformis hessi appeared later at higher latitudes than in subtropical regions. However, all these FAD events occurred in the Lower Pliocene. The LADs of G. crassaformis ronda and G. crassaformis hessi are recorded in the Upper Quaternary, as at Site 397 (Fig. 2).

DSDP Site 410 (45º 31’ N, 29º 29’ W) is located on the western flank of the Mid-Atlantic Ridge. At this site G. crassaformis crassaformis also appeared in the Lower Pliocene (Sample 410-19-3, 49-51 cm), upwards through the section it is followed by G. punccticulata and G. crassaformis viola (Sample 410-18-1, 99-101 cm) and still higher, by G. crassaformis ronda (Sample 410-16-4, 134-136 cm) and G. crassaformis hessi (Sample 410-15-3, 73-75 cm). Unfortunately, the studied samples from this site provide a comparatively low resolution and hence the actual FADs could differ slightly.

DSDP Site 609 is situated at 49º 53’ N, 24º 14’ W in the southern part of the boreal climatic realm. The Pliocene and Quaternary sediments at this site are about 350 m thick and have a reliable paleomagnetic record. The appearance of Globorotalia crassaformis s.l. (Sample 609-29-5, 100-102 cm) was recorded in the upper part of the Globorotalia margaritae Zone (upper Lower Pliocene) at 4.62 Ma (Fig. 3). Slightly above (Sample 609-29-3, 100-102 cm) I registered the first occurrence of Globorotalia punccticulata (Bylinskaya and Golovina, in press). G. crassaformis ronda and G. crassaformis hessi appeared at 4.51 Ma (Sample 609-29-2, 100-102 cm) and G. crassaformis viola at 4.18 Ma (Sample 609-28-1, 99-101 cm). The LAD of G. crassaformis viola was recorded in the mid-Matuyama Chron at 1.48 Ma (Sample 609-11-1, 105-107 cm). In the Upper Quaternary G. crassaformis ronda and G. crassaformis hessi successively disappear.

DSDP Site 611 was drilled in the boreal Atlantic at 52º 50’ N, 30º 19’ W. The thick Pliocene–Quaternary sequence recovered by the hole yields numerous but low-diversity planktonic foraminiferal assemblages. The first occurrence of the Globorotalia crassaformis members also corresponds to the upper Lower Pliocene. G. crassaformis crassaformis was recorded in Sample 611-
4. Discussion

4.1. The use of Globorotalia crassaformis subspecies in biostratigraphical zonations

Globorotalia crassaformis subspecies have been repeatedly used as index forms for subdivision of Quaternary sediments (Rögl, 1974; Krasheninnikov, 1979; Pflaumann, 1988). The listed researchers used for this purpose the low-latitude zonation of Bolli and Premoli Silva (1973) or Bolli and Saunders (1985), which includes the Globorotalia crassaformis viola and Globorotalia crassaformis hessi Subzones in the Lower Quaternary interval (Fig. 4). Berggren (1977) also used G. crassaformis in his zonal scheme. He used the event of its first occurrence to define the boundary between units PL1b and PL1c (Fig. 4), though he did not distinguish the subspecies. In so doing he considered that G. puncticulata (Fig. 5, 1-3) appeared earlier than G. crassaformis.

Subsequently Bolli's zonation was slightly supplemented and modified (Bylinskaya et al., 2002). We have changed the criterion for the boundary between the Globorotalia crassaformis viola and Globorotalia crassaformis hessi Subzones. It is defined not by the first
occurrence of the latter taxon but by the extinction of *G. crassaformis viola*. Along with the more detailed subdivision of the Middle Pliocene sediments within the *Globorotalia miocenica* Zone, we suggested an additional unit in the Lower Pliocene, i.e. the *Globorotalia crassaformis* Subzone, the base of which is marked by the first appearance of the plexus members (Fig. 4). Therefore, a considerably wider use of the taxa in stratigraphic zonations is possible.

As our studies confirmed, the members of the *Globorotalia crassaformis* plexus are widely distributed in Pliocene–Quaternary deep-sea sediments from the equatorial to the boreal realm. The northernmost point where I have recorded single specimens of *G. crassaformis crassaformis* and *G. crassaformis hessi*, is DSDP Site 408 at 63º N, i.e. in the subarctic region. As for the quantity of *G. crassaformis* specimens, they are usually relatively scarce, however, in some samples they constitute up to 2.6% of the total assemblage.

### 4.2. First occurrence of the *Globorotalia crassaformis* plexus members and *Globorotalia punctulata*

The problem of the first occurrences of *Globorotalia crassaformis* and the morphologically close *Globorotalia punctulata* is still not clearly understood. There are different viewpoints on this issue in the literature. Initially it was uniquely considered that *G. punctulata* appeared earlier (Berggren, 1972, 1977; Poore and Berggren, 1975, Dowsett, 1989), but other researchers marked that: “These two species, however, have almost identical FADs in the Leg 94 sites...” (Weaver and Clem- ent, 1986). The problem is in fact that *G. crassaformis* at early stages of its development is represented by rare and small specimens, which are not always recorded by a researcher. Questions arise as to the distinctions between *G. crassaformis* and *G. punctulata* and as to which of them actually appeared earlier.

Figure 5 illustrates the early *G. punctulata* (Fig. 5.1-5.3) and *G. crassaformis* (5.4-5.6) encountered in the same sample. It is obvious that they are extremely similar in size and morphology of the umbilical and spiral sides. The only feature that permits the distinction between them is the aperture shape: a high arch in *G. punctulata* and a low slit sometimes bordered by a rim-like lip in *G. crassaformis*. Since the aperture of small tests is often filled with organic matter and is not always clearly distinguishable, this may partly explain the contradictions as to the question on first occurrences of these species: they can be confused on cursory examination.

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**Fig. 4.-** Zonations that use the *Globorotalia crassaformis* plexus. Paleomagnetic subchrons: J–Jaramillo; O–Olduvai; K– Kaena; M–Mammoth; C–Cochiti; N–Nunivak; S–Sidufjall; T–Thvera.

**Fig. 4.-** Zonaciones que usan el plexus *Globorotalia crassaformis*. Subcrones paleomagnéticos: J–Jaramillo; O–Olduvai; K– Kaena; M–Mammoth; C–Cochiti; N–Nunivak; S–Sidufjall; T–Thvera.
My data based on a vast material (see Results) indicate that *G. crassaformis* appeared somewhat earlier than *G. puncticulata* and both FADs are diachronous in different climatic zones. Their earliest appearance data are marked in the subtropical realm. *G. crassaformis* at early stages of evolution is significantly smaller than *G. crassaformis* *crassaformis* specimens found in younger sediments, so I called it *G. crassaformis* s.l. However, their morphology is identical.

Our studies of planktonic foraminifera in the Pliocene–Quaternary interval in the Atlantic revealed that the *G. crassaformis* subspecies follow the same distribution pattern throughout most of climatic realms (Fig. 3). Berggren *et al.* (1995) placed the first occurrence of *G. crassaformis* within the Nunivak Subchron (4.50 Ma) and in the Mediterranean, at the Gilbert–Gauss boundary (3.58 Ma), respectively. The same age (4.50 Ma) is reported by Spencer-Cervato (1999). Dowsett (1989) dated this event as 4.70 Ma in the southeastern Atlantic. We recorded the earliest appearance of *G. crassaformis* s.l. (=*G. crassaformis* *crassaformis*) in the subtropical North Atlantic at 5.06 Ma and in the boreal realm, at 4.62 Ma (Fig. 3). According to our data, *G. puncticulata* first occurred in these regions at 4.88 Ma and 4.54 Ma, respectively.

In all the holes discussed the first occurrence of *G. crassaformis* *crassaformis* is followed by that of *G. crassaformis* *hessi* and *G. crassaformis* *ronda*. It should be noted that *G. crassaformis* *hessi* was originally described in the Caribbean as the index form of the Lower Quaternary *Globorotalia crassaformis hessi* Subzone (Bolli and Premoli Silva, 1973). Berggren (1995) reported the corresponding age of 0.75 Ma. According to our data, at the Rockall Plateau and further northwards it actually appeared in the Lower Quaternary (Krasenenikov and Bylinskaya, 1994). However, in Hole 366A (5° 40’ N) it occurs in Upper Pliocene sediments and at Site 368 (17° 30’ N), still lower, in the Pliocene *Globorotalia miocenica* Zone. As evidenced by our records, in the subtropical Site 397 (26° 50’ N) the oldest first occurrence of *G. crassaformis* *hessi* is recorded at 4.5 Ma, i.e. in the upper Lower Pliocene. Thus we conclude that it appeared in the Pliocene, whereas the Quaternary *G. crassaformis hessi* Subzone is actually the acme zone of this form, as it is most abundant and is represented by large typical specimens in these deposits. The first occurrence of this subspecies is a strongly diachronous event in different climatic realms (Fig. 3). *G. crassaformis hessi* last occurred in the Upper Quaternary at 0.1–0.2 Ma; this event marks the top of the *Globigerina calida calida* Subzone (Fig. 4). The extinction of *G. crassaformis ronda* is another marker event in the Quaternary and may serve as an additional tool for detailed subdivision of sediments. In all holes studied it is recorded close to the last occurrence of the nannofossil *Pseudoemiliania lacunosa* in the mid-Brunhes Subchron 0.5–0.6 Ma (Fig. 3).

The first occurrence of *G. crassaformis viola* corresponds to the top of the Cochiti Subchron of the Gilbert Chron at about 4.0 Ma, in the upper part of the Lower Pliocene *Globorotalia margaritae* Zone (Fig. 2). It should be noted that in almost all holes studied *G. crassaformis viola* appeared at a similar level, which is also confirmed by other researchers (Bolli and Saunders, 1985). The last findings of the taxon in the holes discussed were recorded at 1.45–1.5 Ma and mark the upper boundary of the Lower Quaternary *Globorotalia crassaformis viola* Subzone. Thus we infer that both events, i.e. the appearance and extinction of the subspecies, are most likely reliable data for biostratigraphy.

Finally in the equatorial, tropical, and boreal realms of the North Atlantic the appearance of *G. crassaformis imbricata* was recorded at approximately 0.5–0.6 Ma, in the lower half of the *Globigerina calida calida* Subzone (Fig. 3).

4.3. Some remarks on *Globorotalia aemiliana* as a related taxon

In the Mediterranean another related taxon, *Globorotalia hirsuta* *aemiliana*, was described (Colalongo and Sartoni, 1967), which was considered by the authors as transitional between *G. hirsuta* and *G. crassaformis*. It is now identified as a separate species, *G. aemiliana*. It is regarded to be of stratigraphic significance. The corresponding unit is included in Mediterranean zonations (Bizon, 1979; Iaccarino, 1985). Judging from the illustrations by Colalongo and Sartoni (1967, Fig. 2; Pl. 30, 31), it is distinctly closer to *G. crassaformis* than to *G. hirsuta*. Several forms illustrated by latter authors (Pl. 30, fig. 2a-c; Pl. 31, fig. 3) were subsequently synonymized with *G. crassaformis* (Valleri, 1984, p. 388). As may be inferred from the illustrations of Colalongo and Sartoni (1967), *G. aemiliana* closely resembles *G. crassaformis* *crassaformis* (Pl. 30, figs. 1a-c, 3a-c; Pl. 31, figs. 1a-c) and *G. crassaformis viola* (Pl. 30, figs. 2a-c; Pl. 31, figs. 3a-c, 4a-c). However, if they are identical, the name *G. aemiliana* has priority.

5. Conclusions

Members of the *Globorotalia crassaformis* plexus follow the same stratigraphic distribution pattern throughout most climatic realms in the North Atlantic. The earliest
form *G. crassaformis crassaformis* appeared at 5.06 Ma in the subtropical region and at 4.62 Ma in the boreal area. In the mid-Lower Pliocene it was followed by *G. crassaformis ronda*, *G. crassaformis hessi* (4.5 Ma), and *G. crassaformis viola* (4.0 Ma). The latter disappeared at approximately 1.45-1.5 Ma in the Lower Quaternary. *G. crassaformis ronda* and *G. crassaformis hessi* had their LADs at 0.5-0.6 and 0.1-0.2 Ma, respectively. The subspecies *G. crassaformis imbricata* first occurred in the Upper Quaternary at 0.58 Ma.

The problem of the first occurrences of *Globorotalia crassaformis* and *G. puncticulata* is still not clearly understood. Our data indicate that *G. crassaformis* appeared earlier in all sections studied. Specimens of *G. puncticulata* were first recorded at 4.88 Ma in the subtropical region and at 4.54 Ma in the temperate latitudes.

The stratigraphic significance of the *Globorotalia crassaformis* plexus which hitherto remained incompletely understood and controversial, is in my opinion proved. It is considerably greater than formerly recognized and *Globorotalia crassaformis* may be more widely used in the Pliocene-Quaternary zonations.

### 6. Systematic descriptions

In describing the studied planktonic foraminifera I followed the classification of Stainforth *et al.* (1975) and Bolli and Saunders (1985). The figured specimens and the collections studied herein are deposited in the Geological Institute, Russian Academy of Sciences, Pyzhevskii 7, Moscow 119017, Russia.

Order Foraminifera Eichwald, 1830
Family Globorotaliidae Cushman, 1927
Genus *Globorotalia* Cushman, 1927

**Globorotalia crassaformis crassaformis**
(Galloway and Wissler)
(Figs. 5.7 - 5.9)

*D. globigerina crassaformis* Galloway and Wissler, 1927, p. 41, pl. 7, fig. 12.

**Globorotalia hirsuta aemiliana** Colalongo and Sartoni, 1967, p. 267, pl. 30, figs. 3a-c, pl. 31, figs. 1a-c.

**Globorotalia crassaformis crassaformis** (Galloway and Wissler) – Pflaumann and Krasheninnikov, 1978, p. 891, pl. 6, figs. 1-3, pl. 7, figs. 5-7.

**Globorotalia crassaformis crassaformis** (Galloway and Wissler) – Bolli and Saunders, 1985, p. 233, fig. 36.6-7.

**Globorotalia crassaformis oceanica** Cushman and Bermudez – Bolli and Saunders, 1985, p. 233, fig. 37.11.

**Globorotalia crassaformis crassaformis** differs from *G. crassaformis oceanica*. The figured specimens followed the classification of Stainforth (1975) and Bolli and Saunders (1985). The figured specimens were first recorded at 4.88 Ma in the subtropical region and at 4.54 Ma in the temperate latitudes. Specimens of *G. crassaformis crassaformis* first occurred in the Upper Quaternary at 0.58 Ma.

The stratigraphic significance of the *Globorotalia crassaformis* plexus which hitherto remained incompletely understood and controversial, is in my opinion proved. It is considerably greater than formerly recognized and *Globorotalia crassaformis* may be more widely used in the Pliocene-Quaternary zonations.

**Remarks:** *G. crassaformis crassaformis* differs from *G. crassaformis oceanica* and *G. crassaformis ronda* in the strongly lobate and subacute peripheral margin and less inflated umbilical side. Its last chamber is always larger than the previous one.

**Distribution:** *G. crassaformis crassaformis* is a cosmopolitan form distributed as far as the northern boreal Atlantic. It ranges from mid-Lower Pliocene (upper half of the N18 Zone [Blow, 1969]) to Recent. The lowest occurrence was recorded in the subtropical realm at 5.06 Ma.

**Globorotalia crassaformis hessi** Bolli and Premoli Silva (Figs. 6.1 - 6.3)


**Globorotalia crassaformis hessi** – Bolli and Premoli Silva – Bolli and Saunders, 1985, p. 233, figs. 36.3-5.

**Globorotalia hessi** Bolli and Premoli Silva – Saito, Thompson, and Breger, 1981, p. 127, pl. 42, fig. 2a-c.

**Diagnosis and description:** Test medium to large in size, low-trochospiral, with four chambers in the final whorl. The peripheral margin is distinctly lobate from the spiral side, subacute to acute, in some specimens showing an imperforate rim. Chambers from the spiral side, ovate to subquadrate, from the umbilical side, subtriangular, moderately inflated, sutures depressed. The spiral side flat to slightly convex. Aperture interiomarginal, umbilical-extraumbilical, a low slit, sometimes bordered by a rim-like lip.

**Remarks:** *G. crassaformis crassaformis* differs from *G. crassaformis hessi* and *G. crassaformis ronda* in the strongly lobate and subacute peripheral margin and less inflated umbilical side. Its last chamber is always larger than the previous one.

**Distribution:** *G. crassaformis crassaformis* is a cosmopolitan form distributed as far as the northern boreal Atlantic. It ranges from mid-Lower Pliocene (upper half of the N18 Zone [Blow, 1969]) to Recent. The lowest occurrence was recorded in the subtropical realm at 5.06 Ma.
Remarks: *G. crassaformis hessi* differs from other subspecies in the distinctly quadrangular outline and large, robust test.

Distribution: It is recorded from the equatorial to high-boreal area, ranging from the mid-Lower Pliocene to the Upper Quaternary. The earliest appearance was recorded in the subtropical realm at 4.5 Ma.

*Globorotalia crassaformis imbricata*  
Krasheninnikov and Bylinskaya  
(Figs. 5.10 - 5.12)


*Globorotalia crassaformis imbricata*  

Holotype: DSDP Site 368, Core 1, core catcher (17°30' N, 21° 21' W, 3366 m), Upper Pleistocene.

Diagnosis and description: The subspecies is characterized by a slightly trochospiral test with 5-6 chambers in the final whorl, considerably overlapping on the dorsal side. Test medium in size, with a strongly lobate outline, 5–5.5 (up to 6) chambers in the final whorl, periphery subacute but no true keel. Spiral side flat, sometimes slightly convex. The 3 or 4 last chambers of the final whorl are characterized by a specific “imbricated” arrangement from dorsal view. Chambers, from the spiral side, lunate to subquadrate, flat, with strongly curved sutures; from the ventral side, subtriangular, strongly inflated, with well-depressed curving sutures. Umbilical area open, depressed. From the umbilical side, three early chambers of the final whorl are covered by irregularly disposed pustules. Aperture interiomarginal, umbilical-extraumbilical, a low slit fringed by a thin lip. Early chambers of the final whorl are covered with coarse pustules. Remarks: *G. crassaformis ronda* is marked by circular outline, tight coiling and rather small dimensions.

Distribution: It ranges from the mid-Lower Pliocene to the Upper Quaternary, disappearing at about 0.6 Ma.

*Globorotalia crassaformis viola*  
Blow  
(Figs. 6.7 - 6.11)

*Globorotalia (Globorotalia) crassaformis viola* Blow, 1969, p. 397, pl. 5, figs. 4-6.

*Globorotalia hirsuta aemiliana* Colalongo and Sartoni, 1967, p. 267, pl. 30, figs. 2a–c, pl. 31, figs. 4a–c.

*Globorotalia viola*  

*Globorotalia crassaformis viola*  
Blow – Bolli and Saunders, 1985, p. 234, fig. 36.1.

Diagnosis and description: A very low-trochospiral test, small to medium in size, with four chambers in the final whorl. The peripheral margin is rounded, in equatorial view the test is almost circular. Chambers from the spiral side, subquadrate, moderately inflated, closely arranged; from the umbilical side, almost triangular and strongly inflated. Aperture interiomarginal, umbilical-extraumbilical, a low slit fringed by a thin lip. Early chambers of the final whorl are covered with coarse pustules.

Remarks: *G. crassaformis ronda* is marked by circular outline, tight coiling and rather small dimensions.

Distribution: It ranges from the mid-Lower Pliocene to the Upper Quaternary, disappearing at about 0.6 Ma.

*Globorotalia crassaformis hessi*  
(Figs. 6.4 - 6.6)

Globorotalia (Turborotalia) crassaformis ronda Blow, 1969, p. 388, pl. 4, figs. 4-6.

*Globorotalia ronda*  
Blow – Saito, Thompson, and Breger, 1981, p. 132, pl. 44, figs. 2.3.

*Globorotalia crassaformis ronda*  
Blow – Bolli and Saunders, 1985, p. 233, fig. 37.10.

Diagnosis and description: A low-trochospiral test, small to medium in size, with four chambers in the final whorl. The peripheral margin is rounded, in equatorial view the test is almost circular. Chambers from the spiral side, subquadrate, moderately inflated, closely arranged; from the umbilical side, almost triangular and strongly inflated. Aperture interiomarginal, umbilical-extraumbilical, a low slit fringed by a thin lip. Early chambers of the final whorl are covered with coarse pustules.

Remarks: *G. crassaformis ronda* is marked by circular outline, tight coiling and rather small dimensions.

Distribution: It ranges from the mid-Lower Pliocene to the Upper Quaternary, disappearing at about 0.6 Ma.

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tures; from the ventral side, subtriangular, slightly inflated. Aperture interiomarginal, umbilical-extraumbilical, a low arch to slit, bordered by a thin lip.

Remarks: Typical forms, mainly in the low latitude area, have a complete peripheral keel and less convex spiral side. Specimens from the temperate realm are more biconvex, somewhat smaller, and possess a less distinguishable keel. Both ecophenotypes differ from other subspecies of *G. crassaformis* by a lower trochospiral and smaller tests, and by the presence of a keel.

**Distribution: Globorotalia crassaformis viola** was recorded from the uppermost Lower Pliocene to the Lower Quaternary. Its range is from 4.0 to approximately 1.5 Ma.

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8. References


