

13. PLANKTONIC-FORAMINIFER ASSEMBLAGES ACROSS THE MIOCENE/PLIOCENE BOUNDARY AT DEEP SEA DRILLING PROJECT SITES 415 AND 416, AND CORRELATIONS WITH OTHER NORTH-ATLANTIC SUCCESIONS

Maria Bianca Cita and Antonina Vismara-Schilling, Department of Geology and Paleontology, University of Milan, Milan, Italy

ABSTRACT

The Miocene/Pliocene boundary appears to correspond to an unconformity at DSDP Site 415 (northern flank of Agadir Canyon), whereas it falls in a strongly condensed section at Site 416A (Moroccan Basin). Condensation at the latter site, however, may be artificial and due to the coring process. The duration of the sedimentary gap at Site 415 is estimated to be approximately 2 m.y. by correlation with DSDP Site 397 (upper continental rise off Cape Bojador), where several datum levels in a high-sedimentation-rate continuously cored hemipelagic sequence are calibrated with a magnetic-reversal sequence.

Forms transitional from *Globorotalia miotumida* to *G. conomiozea* were recorded; however, there were no typical specimens of the latter taxon, whose areal distribution in the eastern North Atlantic apparently does not extend beyond 33° latitude.

The middle-Miocene (Serravallian) erosional episode, consistently recorded at drill sites in the eastern North Atlantic, interpreted as a response to the change in circulation pattern resulting from the cut-off of the Mediterranean seaway, might be recorded at Site 416. Uncertainty of the exact position of cores with respect to sub-bottom depth, however, prevents a full documentation of its occurrence at this site.

BACKGROUND

The sample request submitted to the scientific staff of DSDP Leg 50 and resulting in the present contribution was motivated by our interest (1) in the Miocene/Pliocene boundary in the open ocean, compared to that recently typified stratigraphically in the Mediterranean area (Cita, 1975a), and (2) in the evolution of planktonic-foraminifer faunas in the time interval corresponding to the isolation of the Mediterranean. Our previous experience on the eastern North Atlantic had shown that continuous marine successions straddling the Miocene/Pliocene boundary could be found (Cita, 1974; Salvatorini and Cita, 1979).

In particular, we were curious to investigate (1) whether at a latitude intermediate between that of Site 397 (~ 26° N) and that of Rabat (~ 33° N) (Figure 1) the same reduction in the number of keeled *Globorotalia* would be recorded when passing from the late Miocene to the early Pliocene, and (2) whether *Globorotalia conomiozea*, a supposedly medium- to high-latitude taxon, is present or not. This species in fact was consistently recorded in the Bou Regreg section near Rabat (Bossio et al., 1976; Wernli, 1977), whereas it was conspicuously absent in the Cape Bojador cores (DSDP Site 397) (Salvatorini and Cita, 1979; Mazzei et al.,

1979): its eventual occurrence in either the northern Site 416 or in the southernly 415 could permit tracing of the limits of its distribution in the eastern North Atlantic.

SITE 415

The four analyzed samples are from Sections 1 and 2 of Core 2, cut from 74 to 83.5 meters sub-bottom. A range chart of selected foraminifer species is represented in Figure 2, and some characteristic taxa are illustrated in Plate 1.

The sample from 29 to 31 cm in Section 1 of Core 2 yielded a rich and well-diversified faunal assemblage referable to Zone MP1 3 of Cita (1975b), which is characterized by the concurrent range of *Globorotalia margaritae* and *G. puncticulata*. This biozone belongs to the later part of the Zanclean Stage (early Pliocene). Also present are *Globorotalia crassaformis* and right-coiling *Globigerina pachyderma*. *G. crassaformis* overlaps the ranges of *G. puncticulata* and *G. margaritae* also at DSDP Site 397 (from Core 35 upward). The absence of *Globigerina nepenthes* suggests that the level under discussion postdates its last occurrence. Keeled *Globorotalia* belonging to the "cultrata" plexus are rare. The faunal assemblage is dominated by the genus *Globigerina*, by *Globorotalia margaritae* (also including the most advanced form *G. margaritae evoluta*), by *Globig-*

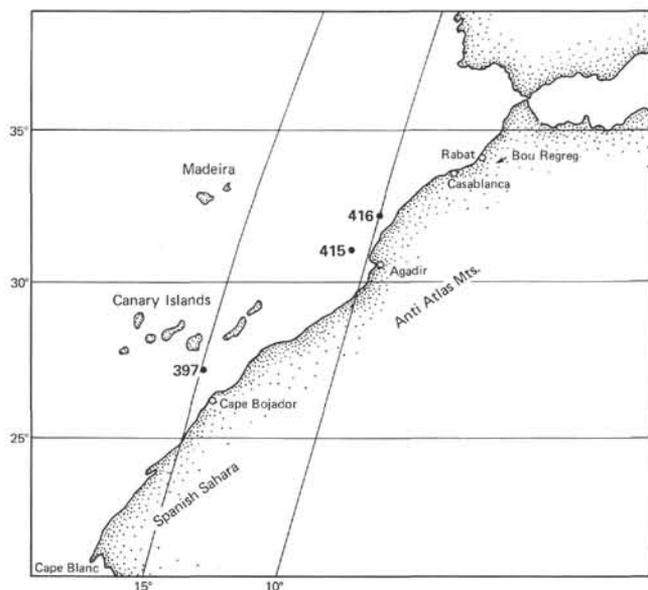


Figure 1. Sketch map showing the location of DSDP Sites 415, 416, and 397.

erinoides obliquus extremus, and by *Globorotalia humerosa humerosa*.

Samples 415-2-1, 115-117 cm and 415-2-2, 46-48 cm are very similar and consequently are discussed together. They are very rich in siliceous microfossils (radiolarians, siliceous sponge spicules) and show evidence of strong dissolution at depth, as proved by extended fragmentation of the foraminifer tests, and by thinned walls and enlarged pores. Dissolution is selective, which results in enrichment of solution-resistant taxa.

These samples yield typical specimens of *Globoquadrina dehiscens* whose last occurrence according to Berggren and Amdurer (1972) is a late Miocene biostratigraphic event (see also Berggren, 1977). The absence of *Globigerinoides obliquus extremus* and the occurrence of *Globorotalia linguaensis* are suggestive of an early-Tortonian age; however, none of these biostratigraphic indications is unambiguous. Indeed, the absence of *extremus* could be due to dissolution, whereas the presence of *linguaensis* (which becomes extinct prior to the first occurrence of *G. tumida plesiotumida*) could be due to reworking. In fact, in the lowermost investigated sample (Core 2, CC, 21-23 cm) the coexistence of *G. obliquus extremus*, of *Globorotalia tumida plesiotumida*, and of *Sphaeroidinellopsis subdehiscens* indicate Zone N.17, which is in agreement with the attribution of the radiolarian fauna to the *Sticochorys peregrina* Zone. The base of this radiolarian zone is calibrated to the middle part of paleomagnetic Epoch 6 and falls in the middle part of Zone N.17 (Ryan et al, 1974).

With reference to the zonation recently proposed by Salvatorini and Cita (1979), the two samples under discussion can be referred to the later part of Zone N.16, which has been emended in its upper boundary (first occurrence of *Sphaeroidinellopsis seminulina paenedehiscens*, instead of first occurrence of *Globorotalia tumida plesiotumida*) so that it is more restricted upward, corresponding to the lower part of Zone N.17. This interval

corresponds to the latest part of the Tortonian Stage (see Ryan et al, 1974).

The lowermost sample is considered more biostratigraphically reliable than the two higher ones, because it is less affected by dissolution: we did not record any specimen referable to *G. linguaensis* from the core-catcher sample. Siliceous microfossils, especially radiolarians, are less common than in the two overlying late-Miocene samples.

SITE 416

The three investigated samples are from Section 1 of Core 416A-1 (Figure 3). This core was cut from a nominal interval between 146 and 155.5 meters below sea floor but because of the coring technique employed it is possible that firm sediments from well above that interval entered the barrel inadvertently (see Site Report 416, this volume). The lowest sample (78-80 cm) was taken above an "apparent" unconformity recorded by the shipboard paleontologists (Figure 4), corresponding to a time gap of some 6 m.y. This unconformity, however, could also be (at least in part) an artifact of coring.

The faunal assemblages are rich and diversified: planktonic foraminifers outnumber the benthic ones by orders of magnitude.

The topmost sample (25-27 cm) is referred to the upper part of the *Globigerina nepenthes* Interval-Zone of Salvatorini and Cita (1979), which is early Pliocene (lower Zanclean). *Globorotalia margaritae* is abundant and occurs with a large species, also fairly abundant, which we provisionally refer to as *G. sp. cf. G. cibaoensis*. Also present are specimens of *G. humerosa humerosa*, which is restricted to the Pliocene (Natori, 1976; Salvatorini and Cita, 1979).

The second sample from the top (38-40 cm) is referred to the earlier part of the *G. nepenthes* Zone, of the latest Miocene (late Messinian). It yields *Globorotalia margaritae* in lesser abundance than the topmost sample. We frequently recorded in this sample *Globorotalia miotumida*, also including specimens transitional to *G. conomiozea*. The latter is a middle- to high-latitude species originally described from New Zealand (Kennett, 1966). According to Jenkins (1971), to Berggren and Amdurer (1972) and to Berggren (1977), *G. miotumida* and *G. conomiozea* belong to the same lineage, the latter deriving from the former. The main difference between the two taxa is a greater ventral inflation of the chambers in *G. conomiozea*. Our identifications of *G. miotumida* were corroborated by examination of hypotypes from southern Australia, kindly made available by Dr. C. Mallett.

We recorded in this sample sparse specimens of *Globorotalia crassaformis* and of *G. sp. cf. G. puncticulata*, which we consider probable down-hole contaminants from higher Pliocene levels, but which could also be related to the highly condensed section.

The third and lowermost sample investigated (78-80 cm) does not yield *G. margaritae*, and is referable to Zone N.17 (*Sphaeroidinellopsis seminulina paenedehiscens* Zone of Salvatorini and Cita, 1979), of late-Miocene age.

	Core 415-2			
	Section 1		Section 2	
	29-31 cm	115-117 cm	46-48 cm	21-23 cm
<i>Globigerina apertura</i>	X			X
<i>G. bulbosa</i>	X	X	X	X
<i>G. bulloides</i>	X	X	X	X
<i>G. falconensis</i>	X	X		X
<i>G. microstoma</i>	X	X	X	X
<i>G. nepenthes</i>		X	X	
<i>G. pachyderma</i>	X			
<i>G. quinqueloba</i>	X	X	X	X
<i>Globigerinoides obliquus extremus</i>	X			X
<i>G. obliquus obliquus</i>	X	X	X	X
<i>G. quadrilobatus</i>		X	X	X
<i>G. ruber</i>	X	X		X
<i>G. sacculifer</i>		X	X	X
<i>G. trilobus</i>		X	X	X
<i>Globorotalia acostaensis</i>	X	X	X	X
<i>G. continuosa</i>		X		
<i>G. crassaformis</i>	X			
<i>G. cultrata</i> group	X	X	X	X
<i>G. humerosa humerosa</i>	X			
<i>G. humerosa praeumerosa</i>	X	X		X
<i>G. linguaensis</i>		X	X	
<i>G. margaritae evoluta</i>	X			
<i>G. margaritae margaritae</i>	X			
<i>G. merotumida</i>			X	
<i>G. moitumida</i>	X			
<i>G. miozea</i>		X		
<i>G. obesa</i>	X	X	X	
<i>G. tumida plesiotumida</i>			X	X
<i>G. puncticulata</i>	X			
<i>G. scitula</i>	X	X	X	X
<i>Globigerinita glutinata</i>	X	X	X	X
<i>Globoquadrina altispira</i>	X	X	X	X
<i>Globoquadrina dehiscens</i>		X	X	X
<i>Hastigerina siphoniphera</i>	X	X		
<i>Orbulina bilobata</i>	X			
<i>O. suturalis</i>	X	X	X	
<i>O. univversa</i>	X	X	X	X
<i>Sphaeroidinellopsis seminulina seminulina</i>	X			
<i>S. seminulina paenedehiscens</i>	X			
<i>S. subdehiscens</i>		X	X	X
Zone	MPc 3		N.17	
Series	Pliocene		Miocene	
Stage	Zanclean		Tortonian	

Figure 2. Distribution of 40 species and subspecies of planktonic foraminifers in Core 415-2.

CORRELATIONS

Correlation Between Sites 415 And 416

The correlation is shown in Figure 4. We believe that all the investigated samples from Site 416 are older than the youngest studied sample from Site 415, and younger than the remaining three samples of Sites 415. There is evidence of a highly condensed sequence at Site 416, where biozones follow in their correct order, although strongly condensed and with some anomalies. This condensation may be real (as represented in Figure 4), or it may be artificial.

On the flank of the Agadir Canyon (Site 415) there is a biostratigraphically documented hiatus corresponding at least to the *Globigerina nepenthes* Interval-Zone which

extends from the middle part of paleomagnetic Epoch 5 to the middle part of the Gilbert epoch (see Mazzei et al, 1979). The hiatus probably extends back in time to include the latter part of Zone N.17. Indeed, we referred to Zone N.17 both the lower part of the investigated interval at Site 415, and the lowermost sample from Site 416. Although the difference is so small as not to be proved paleontologically in a straightforward manner, it is strongly supported by the difference in dissolution, and by content of biogenic silica. Dissolution is much stronger at the shallower Site 415, where siliceous microfossils are abundant, whereas it is conspicuously absent at Site 416. These observations suggest (1) that the sediments under discussion are not contemporaneous, and (2) that the sediments from Site 415 are older.

	Core 416A-1		
	Section 1		
	25-27 cm	38-60 cm	78-80 cm
<i>Globigerina bulbosa</i>	X	X	X
<i>G. bulloides</i>	X	X	X
<i>G. falconensis</i>	X	X	X
<i>G. microstoma</i>	X	X	X
<i>G. nepenthes</i>	X	X	X
<i>G. pachyderma</i>	X		
<i>G. quinqueloba</i>	X		
<i>Globigerinoides obliquus extremus</i>	X	X	X
<i>G. obliquus obliquus</i>	X	X	X
<i>G. quadrilobatus</i>	X	X	X
<i>G. ruber</i>	X		X
<i>G. sacculifer</i>	X	X	X
<i>G. trilobus</i>	X	X	X
<i>Globorotalia acostaensis</i>	X	X	X
<i>G. crassaformis</i>		X	
<i>G. cultrata</i> group	X	X	X
<i>G. humerosa humerosa</i>	X	X	
<i>G. humerosa praehumerosa</i>	X	X	X
<i>G. margaritae margaritae</i>	X	X	
<i>G. merotumida</i>	X	X	X
<i>G. miotumida</i>	X	X	X
<i>G. miozea</i>	X	X	X
<i>G. sp. cf. G. miozea cibaoensis</i>	X		
<i>G. tumida plesiotumida</i>	X		
<i>G. puncticulata</i>		X	
<i>G. scitula</i>	X	X	X
<i>G. sphericomiozea</i>		X	
<i>Globigerinita glutinata</i>	X	X	X
<i>Globoquadrina altispira</i>	X	X	X
<i>Hastigerina siphoniphera</i>		X	
<i>Orbulina suturalis</i>	X	X	X
<i>O. universa</i>	X	X	X
<i>Sphaeroidinellopsis seminulina seminulina</i>	X		X
<i>S. seminulina paenedehiscens</i>	X	X	X
<i>S. subdehiscens</i>			X
Zone		<i>G. nepenthes</i> Interval-Zone	N.17 (emended)
Series	Early Pliocene		Late Miocene
Stage	Zanclean		Messinian

Figure 3. Distribution of 35 species and subspecies of planktonic foraminifers in Core 416A-1.

In fact, previous studies by Berger and Von Rad on the North Atlantic (1972) showed that CCD progressively shallows as a function of increasing time in the Miocene, so that one can expect to find more dissolved sediments in the lower part of Zone N.17, referable to the Tortonian, than in its upper part, referable to the Messinian. At Site 397, where quantitative studies were carried out on several parameters connected with dissolution, the highest dissolved sediments were recorded in the late Tortonian (Cita and Spezzi Bottiani, 1979), and this agrees well with the present observations.

In conclusion, the sequence investigated at Site 416 is highly condensed; however, no significant time gap could be proved.

Correlation with the Bou Regreg Section of Central Morocco

A continuous marine section straddling the Miocene/Pliocene boundary has been described by several authors along the valley of the Bou Regreg River, near Rabat (see Feinberg and Lorenz, 1970; Cita, 1974; Bosio et al., 1976; Wernli, 1977). The outcrops are in part discontinuous, and the transitional beds between a silty marl unit of late-Miocene age and a blue marl unit of early-Pliocene age are not well exposed; however, the continuity of the section is fairly good.

The rich and diversified foraminifer assemblage of the late Miocene yields *Globorotalia conomiozea* in

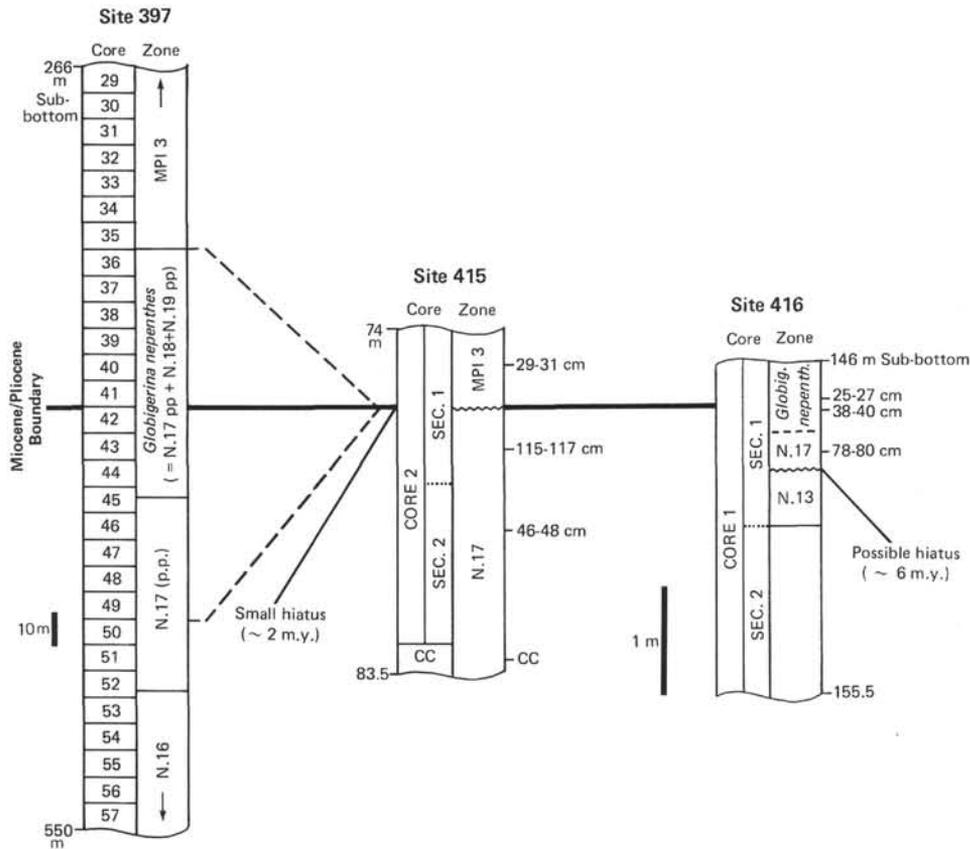


Figure 4. Correlation of the interval encompassing the Miocene/Pliocene boundary at DSDP Sites 397 (Cape Bojador), 415 (Agadir Canyon), and 416 (Moroccan Basin). "Condensation" at Site 416 could have resulted from coring.

some abundance, along with several other taxa belonging to the *Globorotalia cultrata* plexus. *G. margaritae* is first recorded in a transitional unit characterized by cyclic alternations of coarse sands and silty marls. The first occurrence of *G. margaritae* stratigraphically overlies a level where a rapid change in the coiling ratio of *Globorotalia acostaensis* from senestral (below) to dextral (above) is recorded. Both biostratigraphic events were also recorded at Site 397, respectively in the middle part of paleomagnetic Epoch 5 and at the base of Epoch 5 (Mazzei et al., 1979). The dominantly left-coiling of *G. acostaensis*, recorded in the core-catcher sample of Core 415-2, points to an age older than Epoch 5.

The condensed nature of the sections penetrated at both Sites 415 and 416 prevents following in detail the evolution of foraminifer faunas. The early Pliocene recorded at Site 416 can be correlated with the exposed section at Briqueterie de Sale, on the right bank of the Bou Regreg, whereas the early Pliocene of Site 415 is younger (Zone MP1 3, characterized by the concurrent range of *G. margaritae* and *G. puncticulata*); indeed, all the exposed section of the Bou Regreg predates the first occurrence of *G. puncticulata*.

Correlation With DSDP Site 397

The few samples from Sites 415 and 416 here considered can be correlated with the expanded late-Neogene

succession continuously cored off Cape Bojador (DSDP Site 397), where biostratigraphic zonations could be calibrated to the paleomagnetic stratigraphy (see Ryan, von Rad, et al., 1979; Mazzei et al., 1979, in press). Figure 4 shows such a correlation. In particular, the topmost investigated sample from Site 415 (29-31 cm in Section 1 of Core 415-2, approximately 74 m sub-bottom and approximately 2868 m sub-sea) can be correlated with Cores 34 to 35 of Site 397 (313 to 332 m sub-bottom, 3223-3242 m sub-sea).

The topmost sample from 416A (25-27 cm in Section 1 of Core 1; 146 m sub-bottom, approximately 4337 m sub-sea) can be correlated with Cores 38 to 39 of Site 397 (351-370 m sub-bottom, 3261-3280 m sub-sea).

A precise correlation of the late-Miocene samples is hampered (1) by the condensed sedimentary succession at Sites 415 and 416, and (2) by dissolution, especially at the shallower Site 415.

Factor (1) results in abnormal occurrences of taxa whose ranges do not overlap in more-expanded sections. For instance, *Globorotalia miotumida* does not co-exist with *G. margaritae* at Site 397 according to Salvatorini and Cita (1979), whereas both taxa are recorded together at 415 and 416. Factor (2) acts as "noise" in the biostratigraphic record.

It is worthwhile mentioning that the Miocene section of Site 397 is the most complete one from the eastern

Atlantic; however, one interval with slumps (within the late-Miocene foraminifer Zone N.16) and two minor hiatuses in the middle Miocene could be documented biostratigraphically.

The gap possibly existing at Site 416 in the Serravallian, where it encompasses Zone N.15, could be correlated with a similar one recorded not only at the up-slope Site 369 (off Cape Bojador), but also in the Sierra Leone Rise (Site 366; Leg 41) and in the Rio Grande Rise (Site 357; see Boersma, 1977; Berggren, 1977). The wide areal distribution of this submarine erosional phase of Serravallian age in the North Atlantic is pointed out. The hypothesis is put forward that this erosion is related to an important change in oceanographic regime and geostrophic thermohaline current pattern, related to the closure of the Mediterranean to the east, which resulted in the interruption of the equatorial current system, and hence in a reactivation of the North/South Atlantic boundary currents.

ACKNOWLEDGMENTS

Financial support has been provided by Consiglio Nazionale delle Ricerche through Grant 77.00763.89 to Cita. Technical assistance by G. Spezzibottiani, A. Rizzo and G. Chiodi is acknowledged.

We thank E. Vincent, I. Premoli-Silva, and G. Salvatorini for critical revision of the text.

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PLATE 1

- Figures 1-4, 7 *Globorotalia miotumida* Jenkins.
1. spiral view, $\times 90$. Sample 416A-1-1, 78-80 cm. Zone N.17, Tortonian.
2. as above.
3. as above, in umbilical view.
4. as above, in side view.
7. as above, in spiral view.
- Figures 5, 6 *Globorotalia tumida plesiotumida* Blow and Banner.
5. spiral view, $\times 90$. Sample 425-2, CC, 21-23 cm. Zone N.17, Tortonian.
6. as above, in umbilical view.
- Figures 8-10 *Globorotalia miozea miozea* Finlay.
8. spiral view, $\times 90$. Sample 416A-1-1, 78-80 cm. Zone N.17, Tortonian.
9. as above, in umbilical view.
10. as above in side view.
- Figures 11-14 *Globorotalia cultrata* (d'Orbigny).
11. spiral view, $\times 45$. Sample 415-2, CC, 21-23 cm. Zone N.17, Tortonian.
12. as above, in umbilical view.
13. as above, in spiral view.
14. as above, in umbilical view.

PLATE 1

