Reports

Tertiary Sediment from the Mid-Atlantic Ridge

Abstract. *Lower Miocene microfossils occur in basaltic glass in two dredge hauls from the crestal area of the Mid-Atlantic Ridge near 30°N. From the ridge and adjoining abyssal hills 43 pre-Pleistocene cores were identified, including one Cretaceous and four Eocene. Dredgings and cores now available suggest that the upper layer of the crust of the ridge is constructed of layers of interbedded sediments and basalt flows. The data rule out the possibility of large-scale continental drifting or spreading of the ocean floor since the Lower Miocene.*

The finding of well-preserved Miocene planktonic foraminifers and coccolithophorids in rocks from two sites on the Mid-Atlantic Ridge has a significant bearing on the geologic history of that part of the Atlantic and of the ridge as a whole.

The Mid-Atlantic Expedition of 1947 dredged hundreds of kilograms of cobbles and boulders from the Rift Valley and the crestal area of the ridge. The petrology of the rocks—predominantly pyrogenic—was briefly described by Shand (*1*). One of the two dredge hauls, A 150-RD 7, was from a depth of 4280 m in the bottom of the Atlantis fracture zone, which offsets the Rift Valley by 30 km near 30°N (Fig. 1, *2*). Two of the basalt boulders dredged were covered by layers of dark brown, vesicular, basaltic glass in which partially baked globigerina ooze was embedded (Fig. 2). Several boulders of limestone and of tuff-breccia consisting of basaltic glasses and brown-to-white coccolith-globigerina ooze were dredged from station A 150-RD 8—from 3700-m depth on the western flank of the Rift Mountain (Fig. 1)—and from about 200 km north of A 150-RD 7, 130 km from the Rift Valley. These partially altered globigerina oozes were dissolved with a saturated solution of hydrogen peroxide and the microfossils were recovered in the washed residues.

Two different assemblages of Miocene planktonic foraminifers occurred in two separate boulders of basalt (here designated boulders A and B) from haul A 150-RD 7, with admixture of modern species similar to those now living in the overlying water of the area. Miocene planktonic foraminifers generally display a light-brown-orange hue with smoother shell surface, whereas modern ones have a white-to-light-gray shell with spinose surface.

The Lower Miocene (Burdigalian) age of the fauna in boulder A is established by the presence of *Globorotalia fohsi barisanensis* LeRoy, *G. praescitula* Blow, and *Globigerina weissi* Saito (*3*). The fauna in boulder B includes *Globorotalia bykovae* (Aisenstat), *G. conica* Jenkins, *Globigerina concinna* (Reuss), and *Globigerinoides bollii* Blow, which indicate a Middle Miocene (Vindobonian) age. *Globoquadrina dehiscens* (Chapman, Parr, and Collins), which is common in both samples, is restricted in stratigraphic range to the Miocene (Fig. 3, *4*).

Coccoliths and related nanoplankton, which abound in both boulders, indicate mixing of Lower Miocene, Pliocene, and Pleistocene forms. *Discoaster brouweri* Tan Sin Hok, *D. challengeri* Bramlette and Riedel, and *D. pentaradiatus* Tan Sin Hok commonly occur; *Discoaster deflandrei* Bramlette and Riedel and *D. surculus* Martini and Bramlette occur, but not commonly.

In the A 150-RD 8 haul, two rather discrete Miocene planktonic foraminiferal assemblages occur together in the globigerina-coccolith ooze sediments (Fig. 3). The Lower Miocene (Burdigalian) fauna includes species such as *Globorotalia birnageae* Blow, *G. fohsi barisanensis* LeRoy, *G. fohsi fohsi* Cushman and Ellisor, and *G. praescitula* Blow, an assemblage similar to that found in A 150-RD 7. Species such as *Globigerina eamesi* Blow and *G. nepenthes* Todd, which are generally considered to be restricted to the Middle and Upper Miocene, are evidence of faunal mixing. Abundance of *G. dehiscens* also corroborates the Miocene age of the fauna. Nanoplankton diagnostic of the Miocene commonly

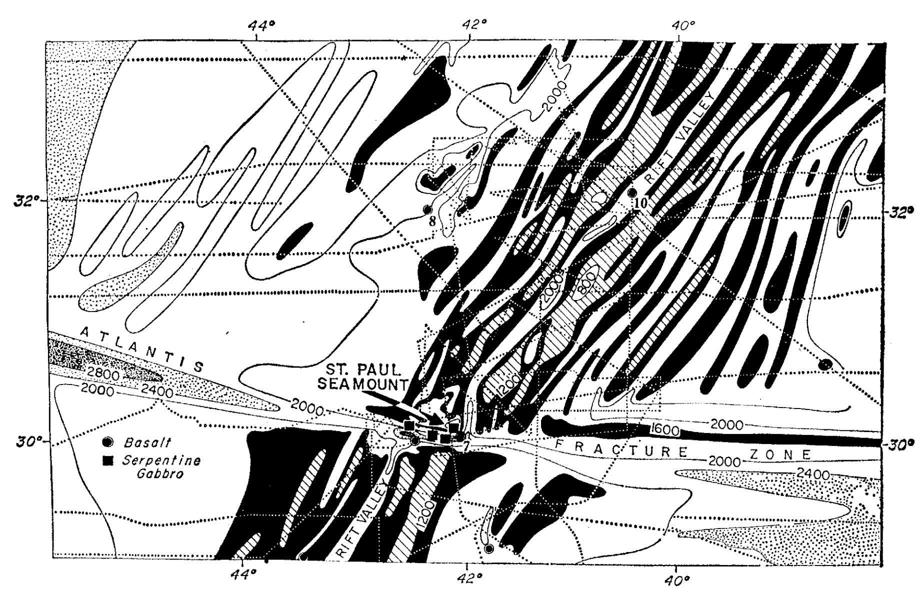

Fig. 1. Dredging on cruise A 150 near the Atlantis fracture zone. Numbers indicate dredging sites discussed in the text. Contour interval, 400 fathoms (732 m); dark area, 1200 to 1600 fathoms. [After Heezen and Tharp (*2*)]

includes *Discoaster deflandrei* Bramlette and Riedel.

Seismic-profile studies over the ridge by Ewing *et al.* (*5*) revealed only a very small amount of sediment. Photographs of the bottom often showed massive outcrops of lava flow (*5*). Cores showed that rocks underlie 1 to 4 m of foraminiferal sands over the ridge. Fragments of serpentinized rocks or of volcanic glasses were frequently brought up in the smashed cutting edges of coring pipes (*6*). Study of foraminifers from white globigerina ooze, attached to a basaltic boulder of the A 150-RD 10 dredge haul from the Rift Valley (Fig. 1), indicate the presence of cold-water fauna not older than Quarternary—lacking in *Globorotalia menardii* (d'Orbigny), and with right-coiled *Globorotalia truncatulinoides* (d'Orbigny) dominant; this ooze is taken to represent a glacial stage of the Pleistocene (*7*). Over the ridge, the oldest sediments cored are Upper Miocene (Table 1, *8*). All cores seem to indicate that the whole crestal area has been sufficiently active during recent geologic history to destroy most of the sediments accumulated; thus is explained the very small amount of unconsolidated sediments recorded by the profiler.

The finding of older Miocene sediments within volcanic glass may shed light on a possible process of sediment destruction near the Rift Mountain. The dark brown, vesicular, basaltic glasses that cover the surface of basalts show a typical polygonal structure. Each polygon is bounded by a thin seam of brownish orange-colored, baked globigerina ooze (Fig. 2); the central portion of each is filled with yellowish-brown palagonite. To explain structures commonly occurring in basalt, such as those variously called ellipsoidal, pillow, or globular, Osborn (*9*) experimented with structures that formed during the cooling of some optical glasses; he suggested that some of the structures in lava were similar to cellular structures developed in glass, and that they may have been formed by convection flow of lava, modified by horizontal movement of the stream, and rather rapidly quenched. Nayudu (*10*) showed that palagonitization of basaltic glass took place mainly at the interaction between hot lava and sea water or interstitial water. Such evidence suggests that submarine volcanic activity occurred after the deposition of Miocene planktonic organisms on the central part of the ridge, and that the pelagic deposits were either buried and destroyed, or baked to consolidation, by lava. It is not surprising, however, to find intact microfossils in the baked sediments: in calcareous tests, planktonic foraminifers resist at least 500°C (*11*).

In addition to the dredge samples from the Rift Valley and crestal area, many cores were obtained from the ridge and from adjacent abyssal hills (*12*). Of more than 300 cores examined, 43 penetrated pre-Pleistocene sediments. Ages range from Upper Cretaceous (Maestrichtian) to Pliocene (Table 2, Fig. 4). The sources of such ancient cores range from 35°N to 35°S, and we must emphasize that our conclusions may not apply to other sections of the ridge.

The Cretaceous core, RC 5-12, was raised from near the crest of an abyssal hill, less than 1200 km from the Rift Valley. The core is essentially a brown lutite (so-called "red clay"), underlain at 308-cm depth by very-pale-to-pinkish-gray calcareous ooze, in which foraminifers and coccoliths abound. The brown lutite is most probably Pleistocene, while the layers below contain Lower Maestrichtian (Upper Cretaceous) microfossils. Diagnostic planktonic foraminifers include *Globotruncana arca* (Cushman), *G. calciformis* Vogler, *G. fornicata*

Table 1. Sources and ages of pre-Pleistocene cores taken from the Mid-Atlantic Ridge. Abbreviations: L, Lower; M, Middle; U, Upper.

Cruise	Core				Age
	No.	Source	Water depth (m)	Distance to axis (km)	
A150	RD7	30°01′N,42°04′W	4280	10	L and M Miocene
V9	32	14°10′N,45°44′W	3623	90	Pliocene
V16	206	23°20′N,46°29′W	3733	110	U Miocene
V10	91	23°23′N,46°24′W	3540	110	Pliocene
A150	RD8	31°49′N,42°25′W	3700	130	L and M Miocene
V10	89	23°05′N,43°48′W	3525	170	Miocene
V20	242	23°22′N,43°39′W	4565	170	Pliocene
V16	21	17°16′N,48°25′W	3975	200	Pliocene
V9	29	3°47′N,34°47′W	4675	280	L Miocene
V16	35	17°39′S,15°06′W	3892	300	Pliocene
V12	5	21°12′N,42°21′W	3003	330	Pliocene
V16	205	15°24′N,43°24′W	4043	330	Pliocene
V10	94	24°56′N,48°59′W	4260	370	Pliocene
V16	23	13°15′N,40°40′W	4887	420	Pliocene
V20	241	22°08′N,41°30′W	4372	420	Pliocene
V4	53	33°05′N,29°18′W	2470	480	M Miocene
V19	307	26°22′N,38°50′W	4715	500	Pliocene
V16	208	27°44′N,49°55′W	4861	560	Pliocene
V17	166	34°56′N,45°21′W	4210	570	Pliocene
A153	144	33°08′N,48°08′W	4850	660	Pliocene
V14	4	15°29′N,40°31′W	4473	670	Pliocene
A150	24	29°02′N,51°02′W	4850	670	Pliocene
V17	163	27°58′N,34°08′W	5132	700	Pliocene?
V16	38	22°59′S,06°46′W	4925	700	Pliocene
RC8	2	11°12′N,48°05′W	4614	800	U Eocene
V12	4	24°17′N,53°04′W	5009	800	M Eocene
A180	25	30°15′N,28°30′W	1280	810	Miocene
V16	209	30°00′N,51°52′W	4673	850	L Eocene
V10	96	27°52′N,54°38′W	4680	950	Eocene
A180	32	29°07′N,26°15′W	5029	1100	Pliocene
V20	238	16°28′N,36°19′W	5233	1100	Pliocene
V16	40	26°16′S,03°01′W	4790	1100	Pliocene
RC5	12	26°35′N,56°29′W	5104	1170	Cretaceous
V17	162	24°58′N,28°56′W	5480	1300	Pliocene?
V20	207	22°06′S,00°19′E	5349	1300	Pliocene

Table 2. Sources and ages of pre-Pleistocene cores taken from Rio Grande Rise and Walvis Ridge. Abbreviations: U, Upper; C, Cretaceous; Ma, Maestrichtian; Mi, Miocene; E, Eocene; P, Pliocene.

Cruise	Core No.	Core Source	Core Water depth (m)	Core Age
V12	65	22°59'S,08°07'E	4118	UC(Ma)
V20	205	25°27'S,06°28'E	1626	UMi
V19	250	24°07'S,05°45'E	1600	UMi
V20	220	28°36'S,29°01'W	3601	UE
V20	219	29°02'S,29°13'W	3092	UMi
V12	19	29°52'S,36°48'W	2321	Mi
V16	187	31°28'S,40°05'W	3641	P

Plummer, *G. gansseri* Bolli, *G. havanensis* Voorwijk, *G. stuarti stuartiformis* Dalbiez, *Globigerinelloides aspera* (Ehrenberg), and *Planoglobulina glabrata* (Cushman). The lower part of the core contains a 15-cm zone containing moderate amounts of angular serpentinite pebbles. This zone probably stopped the corer and may in fact represent the basement rock in this part of the Atlantic; if so, the basal rocks were certainly formed before Upper Cretaceous time. Serpentinite from the Atlantic floor is hitherto reported from the median ridge (*1, 13*) and from the north wall of the Puerto Rico Trench (*14*). Seismic-profile records from along this track are rather poor and tell us little.

Three Eocene cores were raised from the abyssal hills to the west of the ridge, one from the Vema fracture zone (*15*), and one Middle Miocene core with reworked Upper Eocene–Lower Miocene faunas from the foot of Plato seamount. The three Eocene cores from the abyssal hills consist largely of alternating layers of light-tan-to-dark-brown calcareous lutites. The foraminiferal fauna is best developed in V 16-209 and V 12-4. Common species in V 16-209 include *Chiloguembelina midwayensis subcylindrica* Beckmann, *C. parallela* Beckmann, *C. wilcoxensis* (Cushman and Ponton), *Globorotalia aequa* Cushman, *G. planoconica* Subbotina, *G. pseudomayeri* Bolli; their association indicates Lower Eocene. The common foraminifer in V 12-4, *Sphaeroidinellopsis senni* (Beckmann), thrived in Middle Eocene. The third Eocene core from the hills, V 10-96, contains not planktonic foraminifers but coccoliths and broken specimens of benthonic foraminifers. Nanoplankton indicating Eocene in this core are *Discoaster barbadiensis* Tan Sin Hok, *D. saipanensis* Bramlette and Riedel, *D. tani* Bramlette and Riedel, and *D. tani nodifera* Bramlette and Riedel.

Core RC 8-2 derived from the south slope of the west end of the Vema fracture zone. Its Pleistocene portion (above 620 cm) shows slump structure; its Eocene portion consists of alternating layers of moderate-orange-pink foraminiferal and radiolarian calcilutite containing the radiolarian *Dictyophimus craticula* Ehrenberg (*16*). The fine fraction consists almost entirely of coccoliths, with a few diatoms in the siliceous zones. Common planktonic foraminifers include *Clavigerinella akersi* Bolli, Loeblich, and Tappan, *Globigerina soldadoensis soldadoensis* Bolli, *G. soldadoensis angulata* Bolli, and *Globorotalia aspensis* Colom, whose association diagnoses the Lower Middle Eocene.

The profile record taken just before this core shows a thin layer of homogeneous sediment, 0 to 100 m thick, that is conformable with the rough topography of the basement. The core was taken on a steep slope and probably sampled the layer, although it may have been the substratum, because the profile record stopped short of the core station. The homogeneous sediment layer can be traced beneath the level turbidite deposits of the

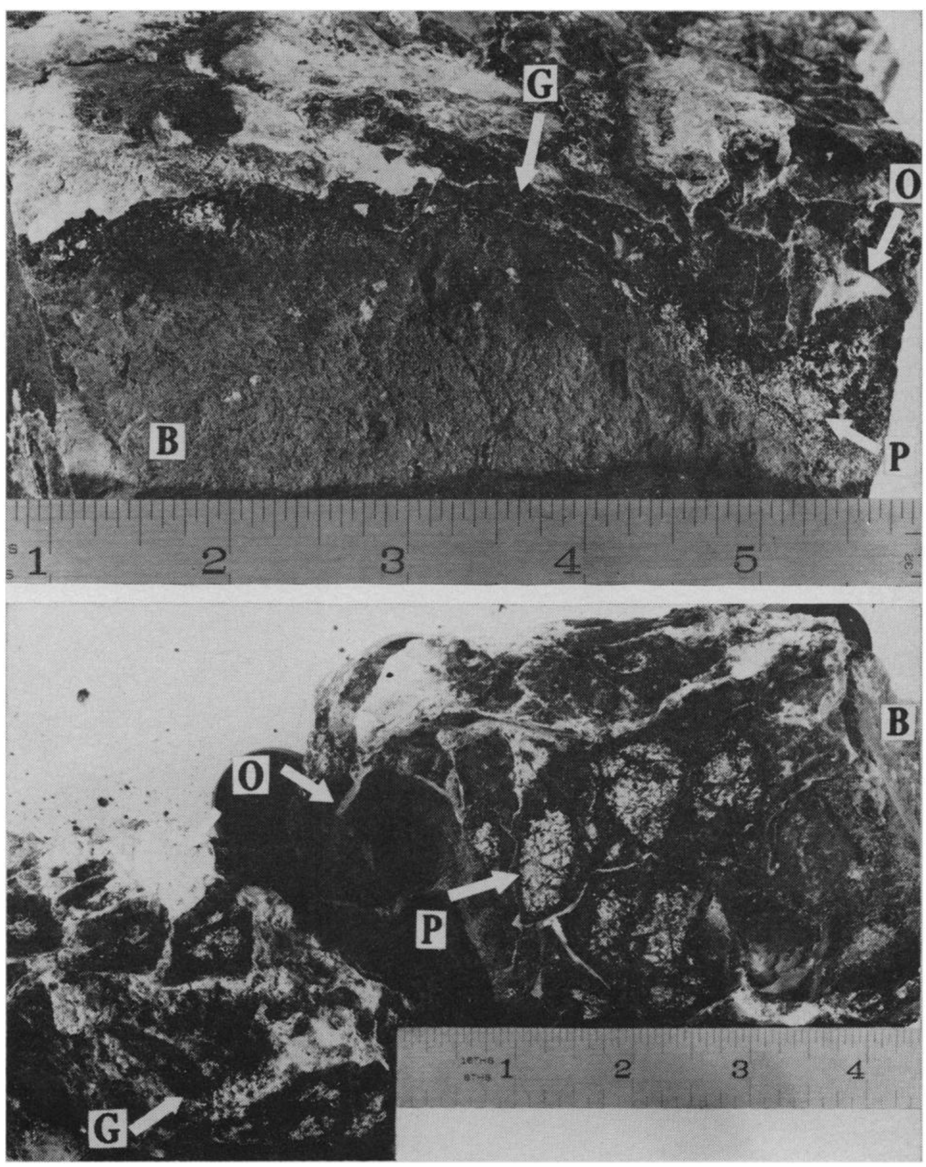

Fig. 2. Basaltic boulders [one from A 150-RD7 (top), two from A 150-RD8 (bottom)] bearing Lower Miocene microfossils. Arrows point to baked globigerina ooze (*O*), yellowish-brown palagonite (*P*), and layers of vesicular volcanic glass (*G*); Basalt (*B*); scales are in inches.

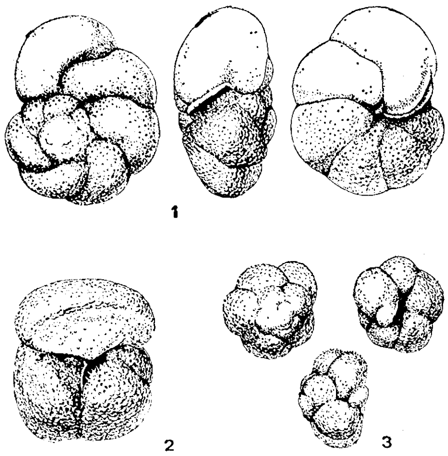

Fig. 3. Diagnostic species of Miocene planktonic foraminifers from A 150 dredge hauls. *1, Globorotalia foshi barisanensis* (0.45 mm, maximum diameter) from A 150-RD 7; *2, Globoquadrina dehiscens* (0.41 mm, maximum diameter) from A 150-RD 8; *3, Globigerina weissi* Saito (0.13 mm, maximum diameter) from A 150-RD 7.

Demerara abyssal plain and the long finger of this plain that forms the floor of the Vema fracture zone (*15*).

Reworked Upper Eocene and Lower Miocene faunas are represented in the Middle Miocene section of core V 4-53 from the southern slope of Plato seamount, 400 km from the Rift Valley. Species diagnosing Upper Eocene are *Hantkenina alabamensis* Cushman, *H. primitiva* Cushman and Jarvis, *Globigerapsis index* Finlay, and *Globorotalia centralis* Cushman and Bermudez; those indicating Lower Miocene include *Globigerinita dissimilis* (Cushman and Bermudez), *Globigerina angulisuturalis* Bolli, and *Globorotalia fohsi barisanensis* LeRoy. Faunal mixing indicates that Eocene and older Miocene sediments cropped out on Plato seamount at higher elevations while further down the slope Middle Miocene sediments were accumulating. Absence of Eocene and Lower Miocene faunas from the top 10 cm of the core suggests that these outcrops may have been eroded, or buried beneath younger sediments.

Five Miocene cores raised from the ridge (Fig. 4, Table 1) are generally of light-to-medium-brown, well-burrowed, calcareous lutites; foraminifers and coccoliths are common to very abundant (Table 3). Twenty-three Pliocene cores raised generally resemble in lithology the Miocene cores; Pliocene is indicated largely by discoasters (*17*) and the foraminifer *Globigerinoides fistulosus* (*18*). Riedel and Funnell (*19*) took the upper limit of occurrence of common discoasters to define the top of the Pliocene. Discoasters used by us to define the Pliocene are *Discoaster brouweri* Tan Sin Hok, *D. pentaradiatus* Tan Sin Hok, and *D. surculus* Martini and Bramlette.

We also report on pre-Pleistocene cores from Rio Grande Rise and Walvis Ridge (Table 2), including them because they are from topographic highs that run into the ridge from opposite sides. The Cretaceous core, V 12-65, was originally identified by Ericson as Maestrichtian; this age was confirmed by Todd. One of us (T.S.) found the following species, which indicate Middle Maestrichtian: *Abathomphalus mayaroensis* (Bolli), *Globotruncana arca* Cushman, *G. calciformis* Vogler, *G. gansseri* Bolli, *G. havanensis* Voorwjik, *G. lobata* de Klasz, *G. nothi* (Bronnimann and Brown), and *Racemiguembelina fructicosa* (Egger). Ewing *et al.* (*6*) suggested that both Walvis Ridge and Rio Grande Rise are recent features resulting from uplift in late Miocene or early Pliocene time; their upper surfaces are very level and contain sediment of the same type and thickness as do the adjacent basins. Nevertheless, the lack of significant modern sedimentation on the tops of their ridges is substantiated by the fact that Miocene and Pliocene sediments have been repeatedly cored from their flat tops. The oldest sediment yet cored from Rio Grande Rise is Upper Eocene (V 20-220), from a fault scarp on the north side, whereas one core from Walvis Ridge is Upper Cretaceous in age (V 12-65).

It is established that the Mid-Atlantic Ridge is the longest single continuous tectonic feature on Earth (*12*). Many theories have attempted to explain its origin and geologic history (*5, 20*).

Table 3. Five Miocene cores from the Mid-Atlantic Ridge containing microfossils. Abbreviations: R, Rare; C, common; P, present; A, abundant.

Species	Core				
	A180-25*	V4-53	V9-29	V10-89	V16-206
Planktonic foraminifers					
Globigerina angustiumbilicata Bolli			R		
G. bulloides d'Orbigny	C	R			
G. falconensis Blow		R	C		
G. nepenthes Todd		C		C	R
Globigerinella aequilateralis (Brady)		R	R	R	
Globorotalia fohsi barisanensis LeRoy			P		
G. mayeri Cushman and Ellisor			A		
G. menardii (d'Orbigny)		C		R	R
G. miotumida Jenkins				P	P
G. scitula (Brady)		R			
Globoquadrina altispira altispira (Cushman and Jarvis)				R	
G. altispira globosa Bolli		R	C		
G. conglomerata (Schwager)			A		C
G. dehiscens (Chapman, Parr, and Collins)		R			C
G. rohri (Bolli)			C		
Globigerinoides bollii Blow		R			C
G. obliquus Bolli		C	R	C	A
G. ruber (d'Orbigny)	C		R	R	
G. trilobus (Reuss)	A	A	R	A	C
Sphaeroidinellopsis seminulina (Schwager)		R		C	C
Orbulina universa d'Orbigny	P			R	R
Globigerinita bradyi (Wiesner)			A		
G. glutinata (Ehrenberg)	R	R	A	R	R
G. stainforthi (Bolli, Loeblich, and Tappan)			P		
Cassigerinella chipolensis (Cushman and Ponton)			C		
Nanoplankton					
Discoaster challengeri Bramlette and Riedel	P				
D. deflandrei Bramlette and Riedel	P				

* Originally identified as Miocene by D. B. Ericson.

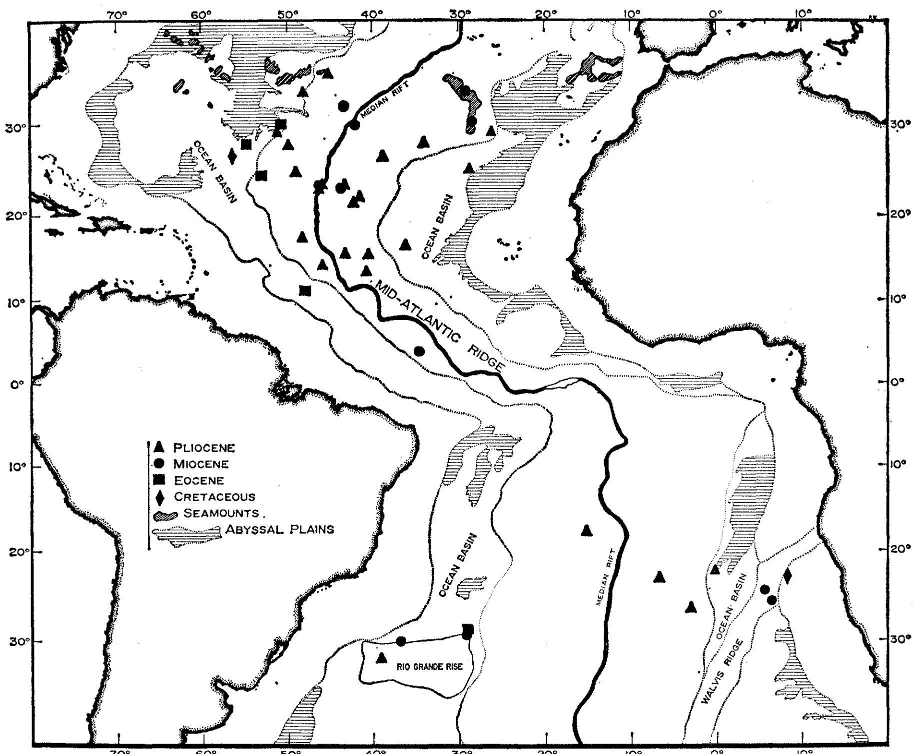

Fig. 4. Sources of pre-Pleistocene cores from the Mid-Atlantic Ridge, Rio Grande Rise, and Walvis Ridge.

One is tempted to review and assess these theories in the light of our present data. All such theories divide into two classes (*5*): one class considers that the locations of continents, ocean basins, and crust have been permanent; the other assumes that by some means the continents have drifted apart to create the Atlantic and Indian Oceans, and supposes that the crusts under the Atlantic and Indian Oceans are youngest at the median ridges and progressively older toward the continents (*21, 22*).

Wilson (*22*) and Van Andel *et al.* (*23*) have calculated the rate of drift. Wilson, using dates from islands, found that the average value for the maximum possible rate of drift was 3.5 cm/yr. The observed rate at which Iceland spreads was reported as 0.35 cm/yr (*24*).

Van Andel *et al.* (*23*), on the basis of topography, sediment cover, rock alteration, manganese coating on rocks, and a single Tertiary core, suggest that there is a large difference in age between the crest of the ridge and the flanks; they suggest that their results are compatible with any rate of drift from zero to 1 cm/yr.

In a general way, the samples now available show the sediments to be older with increased distance from the crest of the ridge—an observation qualified, however, by the fact that the region is not thoroughly cored (each core may be regarded as an outcrop averaging about 10 m in length and 6 cm in width). Furthermore, one should point out that most, if not all, of the Lower Tertiary sediments along the crest of the ridge may have been buried beneath basaltic flows, while areas distant from the crest are unaffected.

If we assume that the age of the serpentinite in core RC 5-12 is about 70 million years and that the age of the crest of the ridge is 25 million years (this report and *25*), we get a drift value, over a distance of 1170 km, of 2.5 cm/yr. Taking the age of the crest as zero we get a drift value of 1.6 cm/yr. If one assumes the former value and a constant rate, Africa and the Americas separated about 1.6×10^8 years ago, somewhere in Jurassic time.

The facts that two rock samples of Lower Miocene age have been dredged from the Rift Valley, and an age of 29 ± 4 million years has been derived from basalt from the crest of the ridge at 45°N (*25*), indicate that expansion or crustal movement, if any, ceased at least 20 million years ago. Another explanation is that the addition of new crust, during continental drift, occurred in such a way that patches of older sediment were left behind in the crestal area rather than being completely swept away from the axis. If the former explanation is true, the upper layer of the ridge crust was built up by interbedded sediment and basalt flows, and no sediment older than Miocene will be found exposed at the crest of this part of the ridge, unless in windows between flows. We believe that this view better accords with the pattern of distribution of sediment on the ridge (*26*).

TSUNEMASA SAITO
MAURICE EWING
LLOYD H. BURCKLE

Lamont Geological Observatory, Columbia University, Palisades, New York

References and Notes

1. S. J. Shand, *J. Geol.* **57**, 89 (1949).
2. B. C. Heezen and M. Tharp, *Phil. Trans. Roy. Soc. London Ser. A* **258**, 90 (1965).
3. W. H. Blow, *Bull. Amer. Paleontol.* **39**, 178 (1959); R. M. Stainforth, *Bull. Amer. Assoc. Petrol. Geol.* **48**, 1847 (1964).
4. H. M. Bolli, *Eclogae Geol. Helv.* **57**, 541 (1964); O. L. Bandy, *Micropaleontology* **10**, 1 (1964).
5. M. Ewing, J. Ewing, M. Talwani, *Bull. Geol. Soc. Amer.* **75**, 17 (1964).
6. M. Ewing, X. Le Pichon, J. Ewing, *J. Geophys. Res.*, in press.
7. D. B. Ericson, M. Ewing, G. Wollin, B. C. Heezen, *Bull. Geol. Soc. Amer.* **72**, 193 (1961).
8. R. Cifelli, *J. Marine Res.* **23**, 73 (1965).
9. E. F. Osborn, *J. Geol.* **57**, 73 (1949).
10. Y. R. Nayudu, *Amer. Geophys. Union Monogr.*, p. 6 (1962).
11. K. N. Sachs, R. Cifelli, V. T. Bowen, *Deep-Sea Res.* **11**, 621 (1964).
12. B. C. Heezen, M. Tharp, M. Ewing, *Geol. Soc. Amer. Spec. Papers* **65**, 1 (1959).
13. B. C. Heezen, E. T. Bunce, J. B. Hersey, M. Tharp, *Deep-Sea Res.* **11**, 11 (1964).
14. C. Bowin and A. Nalwalk, *Trans. Amer. Geophys. Union* **44**, 120 (1963).
15. B. C. Heezen, R. D. Gerard, M. Tharp, *J. Geophys. Res.* **69**, 733 (1964).
16. Radiolarian species identified by J. D. Hays, Lamont Geological Observatory.
17. M. N. Bramlette and E. Martini, *J. Paleontol.* **37**, 845 (1963).
18. D. B. Ericson, M. Ewing, G. Wollin, *Science* **139**, 727 (1963); R. Todd, *U.S. Geol. Surv. Profess. Papers 260-CC* (1964), p. 1067.
19. W. R. Riedel and B. M. Funnell, *Quart. J. Geol. Soc. London* **120**, 305 (1964).
20. B. C. Heezen, in *Continental Drift*, S. K. Runcorn, Ed. (Academic Press, New York, 1962), p. 235; J. T. Wilson, *Sci. Amer.* **208**, 86 (1963); *Nature* **207**, 343 (1965).
21. R. S. Dietz, *Nature* **190**, 854 (1961); H. H. Hess, in *A Study of Serpentinite*, C. E. Burk, Ed. (NAS-NRC, Washington, D.C., 1964), p. 169.
22. J. T. Wilson, *Nature* **197**, 536 (1963).
23. Tj. H. Van Andel, V. T. Bowen, P. L. Sachs, R. Sieber, *Science* **148**, 1014 (1965).
24. B. C. Heezen, *Sci. Amer.* **203**, 98 (1960).
25. P. E. Baker, I. G. Gass, P. G. Harris, R. W. Le Maitre, *Phil. Trans. Roy. Soc. London Ser. A* **256**, 568 (1964).

26. We thank Xavier Le Pichon, Manik Talwani, and J. I. Ewing. D. B. Ericson conducted the earlier phase of studies of the cores. Assisted by Nonr 266 (48), NSF, and the Institutional Scientific Research Pool of Columbia Univ. Contribution No. 887 from Lamont Geological Observatory.

20 January 1966