36. BIOSTRATIGRAPHY OF LEG 81 SEDIMENTS—A HIGH LATITUDE RECORD[1]

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ABSTRACT

Leg 81 of the DSDP drilled four sites in a small area on the southwest flank of the Rockall Plateau. The biostratigraphy of the cores is based on six groups of microfossils: calcareous nannofossils, diatoms, dinoflagellates, planktonic foraminifers, radiolarians, and silicoflagellates. A good magnetostratigraphic record covering the interval from the top of the Brunhes to the Gauss/Gilbert boundary was obtained from one of the sites. Since magnetostratigraphy was not available for the older part of the section, it was not possible to estimate whether biostratigraphic indications in sediments older than 3.4 m.y. are diachronous or synchronous from low to high latitudes.

The biostratigraphic resolution is generally low for any single group, but higher resolution can be attained by using all available microfossil groups. A composite list of biostratigraphic events (mainly Neogene) is presented.

PROBLEMS OF HIGH LATITUDE BIOSTRATIGRAPHY

Resolution

The biostratigraphic resolution in any sedimentary sequence depends on the availability of suitable datum events. Tropical and subtropical environments generally are characterized by rapid evolutionary turnover among the oceanic microplankton, thus offering a large set of easily recognizable biostratigraphic events—such as first appearances and/or extinctions.

High latitude biostratigraphy has contrasting characteristics; the evolutionary turnover is low, thus limiting the number of datum events available for biostratigraphic determinations. This primarily results in decreasing biostratigraphic resolution as higher latitudes are approached in the case of any particular group of microfossils. Moreover, this reduces the possibility of a more precise sequencing of geological observations at high latitudes and their correlation to other areas. One route toward increasing biostratigraphic resolution lies, of course, in further investigations. It appears inconceivable that we have, at present, extracted all useful biostratigraphic information from the enormous pool of oceanic microfossils available, regardless of latitudinal position. But even so, it is difficult to foresee how future studies of single groups could drastically increase the biostratigraphic resolution of the high latitude areas, particularly when longer periods of time are considered. A crucial aspect of the high latitude problem is that we commonly have to rely on datum events originally developed for low latitude biostratigraphy, which leads to the question of accuracy of high latitude datum events.

Accuracy

High latitude areas generally provide more unstable conditions in the physical environment than their low latitude counterparts. Thus, high latitude areas often present environments close to the periphery of the ecological tolerance of many biostratigraphically useful microplankton species. This commonly leads to low relative abundances, discontinuous occurrences or absence of biostratigraphically important species. Seen in a temporal perspective, it becomes clear that changing latitudinal temperature gradients affect both the resolution and accuracy of high latitude biostratigraphy; species that normally thrive in low latitudes migrate into higher latitudes during times of climatically favorable conditions and vice versa. It follows that a biostratigrapher dealing with high latitude assemblages faces the problem of how to evaluate whether a studied extinction or appearance is paleoecologically controlled (instead of reflecting an evolutionary process). From this we may formulate two critical questions concerning the accuracy of high latitude biostratigraphy:

1. Are microfossil events which are used for biostratigraphic purposes synchronous or diachronous over latitudinal distances?

2. What degree of accuracy can be achieved when determining positions of datum events which are based on species of (very) low relative abundance?

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There is but one way to answer the first question: by establishing some reference sections in low and high latitude areas which are correlated by independent means—for example, by magnetostratigraphy.

The second question involves the problem of separating an indigenous presence of a rare species from the ubiquitous background "noise" of reworking or contamination caused by sedimentological or drilling processes. The use of quantitative data apparently represents the only means by which this question may be resolved acceptably. Pronounced and frequent variations in relative abundances of biostratigraphically important species were observed in the Leg 81 material, particularly in the Plio- and Pleistocene. Thus, from our experiences during Leg 81, it became obvious that quantitative data in combination with short sample intervals—ten centimeters or, at most, a few tens of centimeters in critical intervals—distinctly improved the possibilities of finding true ranges of "low latitude" index fossils.

Another aspect of the problem is that a comparatively small number of high latitude sites have been drilled by the Deep Sea Drilling Project (DSDP), which naturally limits the reference material available for detailed studies of high latitude biostratigraphy. Low percentages of core recovery, and severe drilling disturbances using the conventional rotary drilling technique, have also influenced the accuracy and resolution of high latitude biostratigraphy. The past few years of drilling with the hydraulic piston corer (HPC) has markedly increased core recoveries and vastly improved the condition of the cores obtained. However, very few HPC sites have been drilled at high latitudes. In fact, Hole 552A of Leg 81 represents the first successful site drilled with the HPC in high latitudes of the North Atlantic. This improvement of drilling technique is dramatically illustrated by comparison of the core photographs of Hole 116A (see Laughton, Berggren et al., 1972) with those from the uppermost nine cores of Hole 552A (this volume).

LEG 81 SEDIMENTARY RECORD AND MICROFOSSIL GROUPS STUDIED

Sediments recovered during Leg 81 can be assigned to two major categories: the deep-sea oozes of the upper part of the Cenozoic (including the uppermost Pliocene-Pleistocene interval showing ice-rafted debris intercalated with oozes), and sediments deposited in shallow-water environments of the early Cenozoic. The latter category is comprised primarily of material of terrestrial and volcanogenic origin. Major gaps occur in the stratigraphic record at all sites, separating the two above-mentioned sedimentary categories. These gaps represent the interval from the middle/lower Miocene back to the middle/lower Eocene. Some sites yielded remnants of Miocene to Eocene sediments, but these are of little consequence to the understanding of high latitude biostratigraphy and are therefore omitted from the discussion which follows.

The most useful upper Cenozoic data come from Hole 552A because of the superior recovery and moderate disturbance (although Site 555 shows the most expanded Miocene sequence). A near perfect magnetostratigraphic record has been obtained from Hole 552A, from the present back to approximately 3.4 m.y. ago (Gauss/Gilbert boundary) (Shackleton et al., 1984). It follows that reliable data regarding the question of dia- or synchroneity of datum events between low and high latitudes could be gathered only back to 3.4 m.y. ago.

Six groups of biostratigraphically useful microfossils have been studied from the upper Cenozoic sequences of Leg 81: calcareous nannofossils, diatoms, dinoflagellates, planktonic foraminifers, radiolarians, and silicoflagellates.

The results achieved should be viewed with reference to the geographic and paleoceanographic setting of the sites (Atlantic Ocean, 56° N.). For approximately the past 3.5 m.y., the present mode of North Atlantic circulation system has prevailed (Shackleton et al., 1984), with a transport of warm Gulf Stream waters across the Rockall area. This general current system presumably became intensified in mid-Pliocene times, as a consequence of the progressive closing of the Central American seaway (see Berggren and Hollister, 1977), but probably existed and influenced the Rockall area well before the Pliocene. The presence of the many observed "low to mid latitude" index fossils in this high latitude North Atlantic locality is related to this warm current system—a situation completely different from that in the North Pacific (compare with results obtained by Creager, Scholl, et al., 1973).

The lower Cenozoic sediments, represented by the lower Eocene (all sites) and the uppermost Paleocene (one site) also contain the above-mentioned microfossil groups. These sediments represent environments of deposition not comparable to those of the open ocean. Detailed comparisons of low vs. high latitude biostratigraphic resolution and accuracy are consequently of less value here. The major part of the detailed biostratigraphic information from this part of the column was provided by only two groups of microfossils: the calcareous nannofossils and the dinoflagellate cysts.

Each microfossil group and its contribution to the biostratigraphy of Leg 81 is briefly presented below. A composite tabulation of biostratigraphy of events (calcareous nannofossils, diatoms, foraminifers, and radiolarians) is presented as Table 1.

Calcareous Nannofossils

Calcareous nannofossils were studied by Backman (this volume); the group shows the most complete representation over the stratigraphic intervals drilled during Leg 81. The biostratigraphic resolution is low in some upper Cenozoic intervals, as compared to low latitude zonations—notably the lower Pliocene and the middle Miocene. The magnetostratigraphy established in Hole 552A provided the basis for demonstrating that the classical low-latitude datum events of the upper Pliocene, generally believed to be diachronous in high latitude areas, are synchronous in the Leg 81 material, presumably because of warm Gulf Stream circulation in high latitudes of the Atlantic.

In the early Cenozoic, low abundances (some intervals are completely barren) result in decreased resolu-

Table 1. Microfossil events at Holes 552, 552A, 553A, 554, 554A, and 555. Presented are core-section and centimeter intervals of the samples braketing the event. These are followed by depths below seafloor in meters. FAD and LAD indicate first and last appearance datum, and arrows indicate an evolutionary transition.

Event	Hole 552	Hole 552A	Hole 553A	Hole 554	Hole 555
LAD *Stylatractus* *universus*	1,CC 2,CC 3.40-51.00 m	1-3, 53-54 cm 2-2, 122-123 cm 3.54-6.73 m		2-3, 12-14 cm 3,CC 12.63-28.50 m	
LAD *Pseudoemiliania* *lacunosa*		2-3, 49 cm 2-3, 60 cm 7.50-7.61 m		1,CC 2-2, 85 cm 9.40-11.85 m	1,CC 2,CC 5.40-15.00 m
LAD *Calcidiscus* *macintyrei*		7-1, 70 cm 7-1, 90 cm 29.71-29.91 m		3-4, 50 cm 3-5, 35 cm 24.01-25.36 m	3-2, 145 cm 3-3, 80 cm 17.96-18.81 m
LAD *Discoaster* *brouweri*		8-1, 30 cm 8-1, 40 cm 34.30-34.40 m			3-3, 80 cm 3-4, 80 cm 18.81-20.31 m
LAD *Thalassiosira* *convexa*		8,CC 9-1, 63-64 cm 38.90-39.64 m			
LAD *Discoaster* *pentaradiatus*		9-2, 120 cm 9-3, 20 cm 41.72-42.22 m			
LAD *Discoaster* *surculus*		9-3, 40 cm 9-4, 10 cm 42.42-43.62 m			
LAD *Neogloboquadrina* *atlantica*		8,CC 9,CC 38.90-44.00 m			
LAD *Discoaster* *tamalis*		10-1, 20 cm 10-1, 90 cm 44.22-44.92 m			
LAD *Nitzschia* *jouseae*		10-2, 20-23 cm 10-2, 30-33 cm 45.72-45.82 m			
LAD *Globorotalia* *puncticulata*		9,CC 10,CC 43.90-49.00 m			
LAD *Stichocorys* *peregrina*	1,CC 2,CC 3.40-51.00 m	13,CC 14-1, 30-31 cm 63.90-64.31 m	1,CC 2,CC 74.90-113.00 m	3,CC 5-2, 35-37 cm 28.40-39.86 m	
LAD *Reticulofenestra* *pseudoumbilica*	2-1, 48 cm 2-1, 100 cm 51.49-52.01 m	13,CC 14-1, 30 cm 63.90-68.00 m		3,CC 5-1, 70 cm 28.40-38.70 m	
FAD *Discoaster* *tamalis*		14-2, 20 cm 14-2, 30 cm 65.71-65.81 m			
LAD *Globorotalia* *margaritae*		15,CC 16,CC 71.90-76.90 m	1,CC 2,CC 74.90-113.00 m	3,CC 5,CC 28.40-47.50 m	above 3,CC 24.50 m
FAD *Nitzschia* *jouseae*		16-4, 7-8 cm 16,CC 76.58-76.90 m		5,CC 6,CC 47.40-57.00 m	
FAD *Globorotalia* *puncticulata*	below 2,CC 51.00 m	19,CC 20,CC 91.70-94.90 m	below 2,CC 113.00 m		
LAD *Thalassiosira* *nativa*		21-1, 124-125 cm 21-3, 64-65 cm 96.25-98.25 m		5,CC 6,CC 47.40-57.00 m	
LAD *Globorotalia* *conoidea*		22,CC 23,CC 103.90-108.40 m	2,CC 3,CC 112.90-160.50 m	6,CC 7,CC 56.90-66.50 m	
Sphaeropyle robusta → *Sphaeropyle langii*	3-3, 70-72 cm 5,CC 111.71-136.40 m	25-3, 133-134 cm 26-1, 65-66 cm 117.84-119.16 m		5-5, 112-114 cm 8-3, 3-5 cm 45.13-69.54 m	above 5-4, 110-112 cm 39.62 m
LAD *Liriospyris* *cricus*	3-3, 70-72 cm 3,CC 111.71-117.40 m	26-3, 85-86 cm 27-1, 108-109 cm 122.35-124.59 m		5-5, 112-114 cm 6-6, 22-24 cm 45.13-55.23 m	above 5-4, 110-112 cm 39.62 m
LAD *Discoaster* *quinqueramus*	above 3-1, 1 cm 108.05 m	26,CC 27,CC 123.40-128.40 m		6-5, 46 cm 6,CC 53.97-57.00 m	3,CC 4,CC 24.40-33.90 m
FAD *Liriospyris* *cricus*	4-2, 91-93 cm 5,CC 119.92-136.40 m	28-2, 109-110 cm 28-3, 109-110 cm 131.10-132.60 m		7-3, 42-44 cm 7-4, 27-28 cm 60.43-61.78 m	5-6, 6-8 cm 6-4, 30-32 cm 41.57-48.31 m
FAD's *Thalassiosira convexa* and *T. miocenica*		28,CC 29-1, 137-138 cm 133.40-134.88 m		8,CC A1-1, 15-17 cm 75.90-76.16 m	5,CC 6-4, 76-78 cm 43.30-48.77 m

Table 1. (Continued).

Event	Hole 552	Hole 552A	Hole 553A	Hole 554	Hole 555
Stichocorys delmontensis → *Stichocorys peregrina*	5,CC 6-1, 82–84 cm 136.40–137.33 m	29-3, 54–55 cm 30,CC 137.05–143.50 m	3-2, 32–34 cm 7-4, 19–21 cm 152.83–212.70 m	8-3, 3–5 cm A4-1, 58–60 cm 69.54–105.09 m	6-4, 30–32 cm 6-6, 30–32 cm 48.31–51.31 m
FAD *Thalassiosira praeconvexa*				below A1-1, 15–17 cm 76.16 m	7,CC 8-3, 70 cm 62.40–66.21 m
LAD *Didymocyrtis laticonus*			6-6, 30–32 cm 7-4, 119–121 cm 206.31–213.70 m	A1-1, 18–20 cm A4-1, 58–60 cm 76.19–105.09 m	8-6, 66–68 cm 11-3, 92–94 cm 70.67–132.93 m
FAD *Discoaster quinqueramus*		32.CC 33,CC 153.40–158.50 m			
LAD *Globorotalia mayeri*	8,CC 9,CC 164.90–174.40 m	35,CC 36,CC 168.40–173.50 m	5,CC 6,CC 198.40–208.00 m	A2,CC A3,CC 94.90–104.50 m	16,CC 17,CC 185.90–195.50 m
LAD *Lithopera renzae*			6-6, 30–32 cm 7-4, 119–121 cm 206.31–213.70 m	A4-1, 58–60 cm A4-2, 2–4 cm 105.09–106.03 m	17-3, 104–106 cm 18-2, 73–75 cm 190.05–197.74 m
LAD *Tribrachiatus orthostylus*	14-2, 28 cm 14-2, 56 cm 214.29–214.55 m		11-2, 40 cm 11-2, 80 cm 247.91–248.31 m		above 27-1,5 cm 281.06 m
FAD *Discoaster lodoensis*	18-1, 81 cm 18-2, 24 cm 251.30–252.24 m		11,CC 12-1, 26 cm 255.40–255.77 m		
FAD *Tribrachiatus orthostylus*	21-3, 39 cm 282.40		12-1, 26 cm 12-1, 74 cm 255.77–256.25 m	A5-4, 92 cm A5, CC 118.43–123.50 m	31,CC 328.40 m

tion. Particular problems arose around the Paleocene/Eocene boundary. On the other hand, it was possible to achieve successful correlations between sites using local sequences of presence–absence data.

Diatoms

The diatom biostratigraphy of the high latitudes of the North Atlantic has been little studied. The detailed middle Miocene to Holocene work presented by Baldauf (this volume) thus constitutes a significant addition to the literature. The distribution of diatoms and other siliceous microfossils in the Leg 81 sequences is interrupted by two barren intervals: a late Miocene interval associated with the *Thalassiosira convexa* Zone, and a Pliocene-Pleistocene interval. These intervals are interpreted as reflecting silica dissolution or changes in rate of productivity related to the alteration of oceanic circulation. In spite of this, excellent results were obtained from the comparatively long diatom-bearing intervals of the upper Cenozoic. It was possible to establish correlations to existing low-latitude zonations of the Neogene—with regard to both the tropical Pacific and Atlantic Oceans. No serious problems were encountered in calibrating the diatom datum events to those of other microfossil groups. Less satisfactory results were obtained from the lower Eocene interval, principally because of poor preservation and discontinuous occurrences of specimens.

It may be concluded that, in particular, Neogene diatoms provide a hitherto underrated, but apparently very valuable, source for comparatively high resolution and accurate biostratigraphic interpretations in high latitude North Atlantic areas in some stratigraphic intervals.

Dinoflagellate Cysts

Harland (this volume) has made a detailed study of the upper Pleistocene; samples spaced at wider intervals were investigated down to the middle part of the Pliocene. Discontinuous representation of these microfossils in the stratigraphic interval studied obviously limits the biostratigraphic resolution attainable through long time periods. Nevertheless, dinocysts of the upper Pleistocene provide some events applicable for biostratigraphic correlation between the Rockall area on the one hand and the Bay of Biscay as well as the North Sea region on the other.

Miocene dinocysts have been studied by Edwards (this volume). In a comparatively small sample set, covering the entire Miocene, approximately 70% of the samples contained identifiable dinocysts. Preservation is variable, recovery was generally sparse. Site 555 provides a nearly complete middle and upper Miocene section, as well as a short lower Miocene part, which allows the documentation of the ranges of important dinocysts in the North Atlantic. An obvious problem of Miocene dinocyst biostratigraphy is that, as Edwards says, "It is difficult to compare Rockall Plateau material with other Miocene material because so little is known about the ranges of Miocene dinocysts." However, a few zonations exist which are derived from the northeastern Atlantic and the northwestern European region, and she was able to identify some Miocene dinocysts zones, albeit not all.

Dinoflagellates from the lower Eocene and the uppermost Paleocene interval have been studied by Brown and Downie (this volume). Much of this interval was studied by Costa and Downie (1979) at neighboring sites drilled during Leg 48 of the DSDP. These authors established a zonation, which generally appears applicable with regard to Leg 81 sediments. However, Brown and Downie stress the difficulties of biostratigraphic correlation over longer distances, i.e., between Rockall and the area offshore Canada. Furthermore, it should be noted that some discrepancies emerged between dinoflagellate-based correlations of Leg 81 sites and those based on calcareous nannofossils, magneto-, and lithostratigraphic indications. This implies that future work should seek to establish more accurate calibrations between the datum events of dinoflagellates and those of other microfossil groups, notably the calcareous nannofossils (see Costa and Muller, 1978; Morton et al., 1983).

Although the dinoflagellate biostratigraphy of the Leg 81 sediments demonstrates that this group may improve the overall biostratigraphic resolution in some stratigraphic intervals, it is likewise clear that the group needs to be studied more extensively. At present, it is difficult to evaluate the accuracy of the biostratigraphic indications of the group, and the level of resolution that might be achieved.

Planktonic Foraminifers

Huddleston (this volume) investigated planktonic foraminifers, and his results point in a direction inauspicious for high-latitude biostratigraphy: low diversities and a plethora of morphological variants (intergradations between species) severely limit the use of these microfossils as reliable biostratigraphic indicators during most of the Recent–Miocene interval in the high-latitude North Atlantic region. Even short-distance correlations seem difficult to achieve as different investigators become involved, because consistent taxonomic concepts cannot be applied. Low diversities and poor preservation, together with extensive barren intervals in the lower Eocene–uppermost Paleocene interval, gave poor results also in the early Tertiary sequences.

Silicoflagellates

Silicoflagellates were present in approximately half the samples investigated (see Bukry, this volume), with the upper Miocene and lower Pliocene yielding the richest assemblages. Despite the absence of some low-latitude index species, the presence of many other biostratigraphically useful species made it possible to correlate the Miocene-Pliocene interval into the low- and mid-latitude zonation system.

Bukry's (1981, 1983) development of calculations aimed at deriving relative paleotemperature values, which are based on "generic and morphological abundance data of silicoflagellates..." (see Bukry, this volume) have interesting biostratigraphic implications. He succeeds in demonstrating that peak-for-peak correlations can be established between paleotemperature curves derived from Leg 81 material on the one hand and low latitude eastern Pacific (Sites 503 and 504) material on the other.

Only a few samples were studied from the lower Eocene unit.

Radiolarians

Radiolarians (see Westberg-Smith and Riedel, this volume) show a distribution similar to that of diatoms in the Leg 81 sediments, with silica dissolution being an important controlling factor. Although it was difficult to apply low latitude zonations because of rare occurrences of critical species, it was nevertheless possible to obtain relatively detailed biostratigraphic information from the high latitude North Atlantic region. The Miocene and the lower Pliocene gave the best results. The lower Eocene unit was found to be practically barren.

CONCLUSIONS

1. Only the upper Cenozoic intervals (Recent to middle Miocene) are suitable for comparisons between the biostratigraphies of low and high (Leg 81) latitude areas.
2. The lower Cenozoic intervals (lower Eocene to uppermost Paleocene) represent shallow-water depositional environments. Results derived from the calcareous nannofossils and dinoflagellates suggest that previously established calibrations of datum events between the two groups need further study.
3. Any single group of microfossils provides a comparatively low biostratigraphic resolution, especially over longer periods of time.
4. The composite set of datum events gathered from the different groups of microfossils provides substantially increased biostratigraphic resolution in high latitude areas like the Rockall Plateau. Indeed, this procedure represents a simple and effective way to solve the problem of resolution in high latitude biostratigraphy.
5. Extreme morphologic variation in many of the biostratigraphically useful planktonic foraminiferal species seems to reduce the biostratigraphic value of this microfossil group in the Rockall Plateau area.
6. Many biostratigraphically useful index fossils show discontinuous occurrences or low abundances. Therefore, it appears advantageous to gather quantitative data, instead of relying on qualitative presence–absence data, partly in order to elucidate the patterns of occurrence of the index fossils themselves, and partly to distinguish the positions of datum events from the effects of reworking.
7. Short-period oscillations in relative abundance of biostratigraphically important species (signals which are assumed to reflect changes in the relatively unstable high latitude environments) necessitate sampling at closely spaced intervals.
8. It is of the utmost importance to establish unambiguous magnetostratigraphies in sedimentary sequences drilled at high latitudes. Until that is accomplished, biostratigraphers working with high latitude assemblages are forced to use ages of microfossil datum events which are derived from low latitude areas. Increased stratigraphic resolution and precise dating of sedimentary sequences represents one of the critical steps on the way toward a more fundamental understanding of geological cause-and-effect relationships.

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