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ABSTRACT

The following paleontological and paleoenvironmental summary is based on three Deep Sea Drilling Project drill core sequences and a reconnaissance study of over 75 piston cores taken on the Falkland (Malvinas) Plateau. A Middle (?) to Late Jurassic inland sea transgressed the southwest portion of Gondwanaland, then became progressively more restricted until by Oxfordian times, predominantly pelagic and nektonic fossils were preserved, particularly coccoliths, belemnite rostra and arm hooks (onychites), and rare decapod remains. Stagnant conditions continued into the Early Cretaceous where well preserved marine palynomorphs and phytoplankton contributed to the high organic content of Aptian black sapropelic claystones deposited in a shallow, quiet water environment. Abrupt loss of all palynomorphs near the Aptian-Albian boundary coincides with the ventilation of this segment of the incipient South Atlantic Basin.

Sharp changes in the benthic foraminiferal populations in the late Albian are attributed to down flank subsidence of the Falkland Plateau as seafloor spreading widened the South Atlantic Basin. A prominant stratigraphic hiatus encompassing most of the Cenomanian-Santonian suggests erosion and dissolution of calcareous microfossils by cold bottom currents. A return to normal pelagic sedimentation and a sharp lowering of the CCD is evidenced by a thick late Campanian-Maestrichtian chalk sequence deposited at paleodepths close to present day.

The Tertiary sequence is characterized by sharp fluctuations of the CCD (low stands during the late Paleocene-early Eocene, Oligocene, Miocene, and late Quaternary) and strong erosional events (Cretaceous-Tertiary boundary, Miocene, Miocene-Pliocene boundary). Conspicuous reworking of microfossils throughout the Miocene sequence occured as a result of an increase in current velocity associated with the opening of Drake Passage and the establishment of the circum-polar current. A sharp change from calcareous ooze to diatom ooze and glacial marine sedimentation near the Miocene-Pliocene boundary plus erosional loss of considerable section represents intensification of the circum-polar current during the severe late Miocene Antarctic glaciation (Terminal Miocene Event).

INTRODUCTION

Presently situated at an intermediate depth in the southwest Atlantic sector of the Southern Ocean, the marine sediments of the Falkland (Malvinas) Plateau span at least 150 million years (Scientific Staff, JOIDES Leg 36, 1974), predating the separation of the Plateau from the southern margin of Africa during the breakup of southwestern Gondwanaland. Subsequently, the Plateau has been ideally located to record major oceanographic events in this part of the world, such as the mid-Cretaceous anoxic event, the Turonian erosional crises, the Cretaceous/Tertiary boundary event, and more recently, the opening of Drake Passage and the severe late Miocene glaciation of Antarctica.

This paper summarizes paleontologic and paleoenvironmental data from recent exploratory activities on the eastern extremity of the Plateau (the Maurice Ewing Bank; see location map) by the Deep Sea Drilling Project and Cruises 07-75 and 11-76 of the ARA ISLAS ORCADAS. Data is drawn largely from the DSDP Leg 36 Initial Reports (Barker, Dalziel, and others, 1977) and a recent summary of piston core studies by Ciesielski and Wise (1977).

Figure 1 is a geologic map of older (pre-Pliocene) sediments of the Maurice Ewing Bank. These are overlain unconformably by Pliocene to Recent glacial marine sediments and pelagic oozes sufficiently thin (generally less than 1 meter) to allow penetration by piston cores. Figure 2 is a geologic cross-section of the older sediments drawn along the seismic profile lines in Figure 1. Included are the lithologic sections drilled by DSDP Leg 36. These sections, along with basic paleontologic and sedimentologic parameters of the cores, are reproduced in more detail in Figures 3 and 4. The following narrative describes and comments on the information displayed chronologically, beginning with the deepest drill hole, DSDP 330 (Figure 3).

JURASSIC

Core 15 of Hole 330 contains a clean, olive-gray sandstone at the top of the basal sandy unit which Thompson (1977) cites as evidence for a marine transgression over the calcreted Precambrian basement of what was in Jurassic times the southwestern sector of Gondwanaland. Marine palynomorphs in the beach sand are rare (less than 1% of the flora), but Harris (1977) finds enough similarity between these and overlying floras to date the entire Jurassic sequence (Cores 15 to 5) as Oxfordian to Kimmeridgian in age. Hedlund and Beju (1977) disagree in part, placing Cores 15 and 14 in the Middle Jurassic. Although terrestrial palynomorphs are overwhelmingly dominant throughout, other marine elements gradually appear, beginning with bivalves in Core 14 followed by sporatic belemnites, radiolarians and calcareous nannofossils in Core 13. As the basin deepened, grain size, terrigenous fraction and bioturbation all decreased upward through the first 120 meters of section to Core 11 where the sediment grades into an extremely fine-grained Oxfordian sapropelic claystone deposited in a highly restricted environment far removed from an active source area. There, the sedimentation rate drops from upwards to 100 m/m.y. to a quarter of that value, and the organic content of the sediments rises appreciably (average 3%).

Increasingly restricted, perhaps by the then active volcanic chains along the Pacific margin of southwestern Gondwanaland (Barker and others, 1977), the shallow interior Oxfordian sea became sufficiently stagnant to inhibit bioturbation by infauna, but not sufficiently so to prevent epifaunal bivalves to reach local abundance. These include Inoceramus and a new Buchiidae described by Jones and Plafker (1977) as *Jeletzkiella falklandensis*. These authors suggest a probable water depth for all molluscan assemblages recovered from the drill holes as no greater than 200 meters, and possibly considerably less. Some nektonic molluscs flourished in the better oxygenated surface waters. Juvenile (but not adult) belemnites are common to abundant in Cores 330-8 to 330-5; an ammonite segment was noted in Core 8.

A further record of the cephalapod population is provided by some 150 specimens of microscopic scolecodont-like objects identified by Wind and others (1977) as onychites. Also known as cephalopod arm hooks, these objects fit around sucker disks to increase grasping efficiency. They were particularly well developed in belemnites (A. Seilacher, 1976, personal communication). No evidence of true scolecodont-bearing polychaetes was found (probably due to the presence of deoxygenated bottom waters), but a problematic claw-like microfossil from Core 330-6 has been identified as the clasper from a walking appendage of a decapod of the Family Glypheidae (Wind and others, 1976). This group flourished during the Jurassic, but was generally believed to have been extinct since the Eocene. Recently, a modern specimen was described from the South China Sea as a "living fossil" (Forest and others, 1976).

Although sparse, calcareous phytoplankton are extremely well preserved toward the top of the Jurassic section (Cores 8 to 5) and easy to extract for SEM study from the fine, dark clayey matrix. Assemblage diversity compares favorably with that encountered in the higher latitudes of the northern hemisphere (England, France). Marine palynomorph indicators (dinoflagellates, acritarchs, and Prasinophyceae) increase steadily in numbers toward the top of the Jurassic section with the peculiar exception of Core 8 where their numbers jump sharply. Harris (1977, personal communication), however, notes that 95% of that flora consists of Tasmanites which flood the samples to form a tasmanite or oil shale. The environmental preferences of these forms are not well understood.

In summary, the Jurassic section records a major marine transgression into the southeastern sector of Gondwanaland (correlative with transgressions into the Magallanas basin of South America and the Oteniqua and Algoa basins of South Africa; see Thompson, 1977). The epeiric sea became progressively more restricted until by Oxfordian time, the marine community consisted primarily of planktonic, nektonic, and some byssate attached molluscs that lived exclusively in neritic waters. Although far from an active source area, at no time did the environment become open marine. Basin depths remained quite shallow. Several new molluscs, onychites, and coccolith taxa are described from this part of the section in the Leg 36 Initial Reports.

CRETACEOUS

Neocomian-Aptian Anoxia

The depositional environment represented by the early Cretaceous cores is remarkably similar to that of the euxinic Oxfordian. The organic content rises to close to 6% in DSDP Core 330-4. The microflora contains early Cretaceous palynomorphs (Harris, 1977) along with a heavy mixture of reworked Oxfordian pollens, spores and coccoliths (Wise and Wind, 1977, Table 6C). Despite lack of evidence of any structural or lithologic discontinuity, Cores 330-4 and 330-5 are separated by a biostratigraphic hiatus representing up to 50 million years of time. The basin floor must have been uplifted close to or slightly above sea level, perhaps as the Falkland Plateau was being rifted from the southern margin of Africa (at about 127 m.y. according to Larson and Ladd, 1973).

Stagnation continued through the Aptian, with conditions highly unfavorable for the existence of most forms of marine life. Evidence of benthic epifauna and infauna is totally absent. The planktonic microfloras are generally impoverished except for sporatic blooms of stress tolerant coccoliths which, in one instance, produced a thin chalk laminae (Core Section 330-3-2). The dominant constituent of the chalk, Braarudosphaera, is an encystment form, tolerant of hyposaline and fluctuating continental margin environments. It has been labeled a "disaster form" by Fisher and Arthur (in press) who note its proliferation during times of environmental crises (example, the Cretaceous/Tertiary boundary event).

A notable feature of the braarudospaherid chalk is the exceptional preservation of the other coccolith species. An unusually large number of coccopheres are preserved, including those of fragile non-articulated forms found clustered, essentially intact. This requires deposition in extremely quiet, shallow waters with no subsequent disturbance by bioturbation, a further indication of the highly stagnant bottom conditions.

The development of euxinic depositional environments throughout most of the worlds oceans during the Aptian has been carefully documented by Fisher and Arthur (in press). They postulate the expansion and intensification of the oxygen minimum layer during what they label a "polytaxic" phase in the earth's climatic cycle. This condition develops during times of warm, globally equable climates resulting in reduced oceanic convection rates. They postulate similar conditions for the Oxfordian-Kimmeridgian.

Following much the same reasoning, Barker and others (1977) and Schlanger and Jenkyns (1976) present similar models which may be applied to the development of euxinic conditions on the Falkland Plateau and in the adjacent basins of the incipient South Atlantic to the north. Barker and others (1977) postulate the restriction of deep water circulation into the basins to the north due to presence of the Falkland Plateau which, during the Aptian, was still in contact with the southern tip of South Africa. The Plateau therefore served as a sill which prevented the introduction of deep, oxygenated water into the South Atlantic from the Indo-Pacific. A connection between the Mozambique Plateau and Antarctica may have served the same purpose (Thompson, 1977). The submerged crests of these plateaus would have also intersected the greatly expanded oxygen minimum layer where highly euxinic conditions prevailed. In the restricted South Atlantic basin, the "rain" of organic detritus from surface plankton as well as the influx of organic matter from terrestrial runoff along the narrow basin margins eventually depleted the available oxygen supply to the point that the entire basin may have become anoxic.

Albian Ventilation

On the Plateau, anoxic conditions ended rather abruptly in the early Albian with the deposition of light colored, well oxygenated nannofossil claystones. The carbonate content of the cores rises sharply from the Aptian as organic carbon plummets (Figure 3). Palynomorphs disappear entirely. Bivalves (Inoceramus, Buchiidae) reappear and become abundant (their fragments represent up to 70% of the coarse fraction of the cores) as do coccoliths and, in selected samples, radiolarians. Coccolith diversity more than doubles. Aucellina, an important bivalve guide fossil in Austral and Boreal regions, appears in DSDP 327A, Core 18, and persists through the upper Albian.

An Austral assemblage composed of numerous small planktonic foraminifera dominated by hedbergellids range throughout the Albian (Sliter, 1977). These are accompanied by occasional ostracods and a relatively diverse benthonic foraminiferal assemblage of large agglutinated and calcareous species which indicate a paleodepth of deposition between 100 to 400 meters. A gradual deepening of the paleoenvironment, however, is indicated by the slight reduction in benthonic specimens from Hole 327A, Cores 21 to 15 (Figure 3).

The dramatic change in depositional environment and in the attendant faunas and floras at the Albian-Aptian boundary is attributed to the passage of the eastern tip of the Falkland Plateau past the tip of Africa, thus allowing deep water exchange of oxygenated waters through the developing seaway between the Indian and Atlantic oceans (Barker and others, 1977, Figure 5b).

Late Albian Subsidence and Cenomanian-Santonian Hiatus

With continued sea floor spreading, the Plateau began subsidence down the ridge flank, the effects of which are strongly evident in the cores by the late Albian-Cenomanian. In contrast to the thick (140 m) early-middle Albian nanno-claystone section measured in Hole 327A, the late Albian-Cenomanian section spans only 40 meters. The Cenomanian (Core Section 327A-14-6) consists of a greenish gray clay with a carbonate content of only 5%. Foraminifera and calcareous nannofossils are moderately etched and poorly preserved indicating deposition in deeper water near or below the lysocline. Inoceramus prisms flood the samples, but other bivalve fragments are rare.

A sharp erosional hiatus separates the Cenomanian from an overlying 12 meters of Santonian variegated brown and mottled zeolitic clay, interbedded with diffuse zones of light greenish-gray micrite. These contain sporatic, strongly corroded calcareous microfossils deposited near the CCD which fluctuated above and below the site of deposition. At this point the foraminiferal planktonic/benthonic percentages reverse sharply (Figure 3), carbonate content approaches zero, and the sedimentation rate is minimal. Inoceramus prisms reach peak abundance in the lower samples of this unit, then fall off sharply in the upper samples where they are heavily corroded. Other organisms include rare ostracods and fish teeth, and abundant small (70 um), problematic calcareous objects that closely resemble marine algae (Sliter, 1977, Plate 14). The limited benthic foraminiferal assemblages consist primarily of rare agglutinated and resistant calcareous species which are equivalent to modern low-latitude assemblages from abyssal environments (2500 to 4000 meters). Another sharp hiatus separates the Santonian from the overlying Campanian carbonate ooze which contains bathyal rather than abyssal benthic foraminiferal assemblages.

Despite the deep water habitat suggested by the benthic foraminifers, no tectonic evidence exists to suggest that the Santonian dissolution facies was produced by pronounced structural subsidence (Barker, and others 1977). Instead, it is assumed that the Falkland Plateau followed a normal subsidence curve as it spread laterally away from the ridge crest (Sclater, and others, in preparation). Distant tectonic and global paleoclimatic events during the mid-Cretaceous, therefore, are believed to have combined to change the symmetry of the world's oceans, intensify cooler bottom water flow, alter basic circulation patterns, increase dissolution and raise the CCD in our study area. The flood of Inoceramus debris in the Cenomanian and lower Santonian samples probably represents winnowing and downslope transport of these objects from higher elevations on the Plateau due to increased current velocities or change in flow directions.

The same series of events is believed to account for the missing Cenomanian, Turonian, and Coniacian sediments represented by the hiatus below the Santonian. This hiatus is now widely recognized in DSDP drill sites throughout the southern hemisphere (Sliter, 1977, Figure 10) as well as in other parts of the world. Accordingly, Fisher and Arthur (in press) recognize the Cenomanian-Turonian as a crises or "oligotaxic" episode in the world's oceans. The various models postulated to account for these mid-Cretaceous events are too numerous and complex to outline here. Instead, the reader is referred to Fisher and Arthur (in press) and Sliter (1977) who explore these in some detail.

Campanian-Maestrichtian Carbonate Sedimentation

Normal pelagic sedimentation resumed during the Campanian-Maestrichtian when an appreciably lower CCD combined with a moderately high rate of clay and biogenic silica deposition allowed exceptionally good preservation of calcareous microfossils. Nineteen new coccolith taxa are described from this interval by Wise and Wind (1977). A number of these appear provincial to the cooler high latitudes. Foraminiferal assemblages at Site 327 continue to be strongly Austral in character. Palynomorphs assemblages reappear in the Maestrichtian, and are 89% marine, probably a reflection of the world wide reduction of terrestrial source area during this stage.

Part of a coring gap spanning the Campanian-Maestrichtian boundary has been filled by ISLAS ORCADAS Core 11-76-12 taken 52 kilometers north of the DSDP drill sites. A comparison of the calcareous faunas and floras with those of Hole 327A led Ciesielski and others (1977) to conclude that an exceptionally strong latitudinal surface water thermal gradient existed across the Plateau during the late Cretaceous. With circulation from the Pacific impeded or prohibited by the then extant South American-Antarctic isthmus, the Plateau apparently served as a major barrier in the Atlantic between cold (possibly upwelling) water to the south and warmer surface waters flowing from the North, a pattern that may have persisted well into the Tertiary. This interpretation may in part resolve some paradoxical questions concerning the existence of Austral foraminiferal faunas at the drill sites in close latitudinal juxtaposition to Transitional and Tethyian faunas in southern South America and South Africa (see Sliter, 1977). Similar problems of province mismatch are evident among the Mesozoic molluscan faunas. Those incongruties are not accommodated by the tectonic reconstruction model preferred by the majority of the DSDP Leg 36 shipboard scientists which fits the eastern Falkland Plateau prior to rifting snuggly against the Mozambique Plateau (Barker, and others, 1977). Accordingly, alternative tectonic models which position the Plateau initially in the region of the Antarctic Peninsula are presented by Jones and Plafker (1977) and Sliter (1977).

TERTIARY

The thick Campanian-Maestrichtian chalk sequence is capped by a hardground and erosional disconformity which marks an abrupt end of carbonate sedimentation. Current erosion must have been intense since palynomorphs indicate the absence of Danian sediments. The carbonate compensation depth stood well above the site of deposition since calcareous nannofossils are absent in the next 30 meters of section at Hole 327A. Paradoxically, carbonates were deposited intermitantly during the Danian at DSDP Site 323 in the Bellingshausen Sea on the Pacific side of the South American-Antarctic isthmus (Weaver and others, 1976). This is in contrast to the postulated worldwide rise in the CCD boundary which Worsley (1974) believes occurred prior to the Danian.

Paleocene deposition began with 20 meters of dark, zeolitic clay which contains a significant component (10 to 46%) of terrestrially derived organic matter (spores, pollen, tracheids). Up section these clays give way to diatom oozes in Core 327A-8 and coccoliths finally appear in Core 6 as the CCD gradually descended back to approximately 2500 m (assuming that the Plateau then was at about its present day water depth). The Paleocene diatoms, silicoflagellates, and radiolarians are exceptionally well preserved due to the light overburden (less than 100 m) and moderately high clay content of the sediment. Calcareous microfossils, poorly preserved at Site 327 due to the close proximity to the CCD, are better represented higher on the Plateau at Site 329 and in piston cores in age equivalent sediments (107-75-45, RC15-84) where carbonate values reach 80% (Figure 4). Calcareous planktonic assemblages are somewhat restricted in diversity due to the high latitude site of deposition, therefore somewhat provincial zonations were utilized for the coccoliths and diatoms by DSDP shipboard scientists. As in the Cretaceous, some coccoliths endemic to these latitudes are present in the Tertiary section (examples, Hornibrookina australis, Dictyococcites antarcticus).

Carbonate values in Hole 327A peaked in the upper Paleocene and lower Eocene, then fell to near zero. Due to drilling problems in cherty limestones at Site 329, most of our knowledge of rest of the condensed (less than 20 meters) Eocene section comes from piston cores which recovered middle Eocene zeolitic clays and upper Eocene diatomaceous ooze, all deficient in calcareous microfossils, an indication that the CCD fluctuated at shallow depths (~1500-2500 meters) throughout this epoch.

During the Oligocene the CCD dropped appreciable as relatively thick Oligocene chalks were deposited. These chalks contain reasonably well preserved siliceous microfossils in their upper part. Above an inferred Oligocene-early Miocene hiatus, an extraordinarily thick sequence of middle to late Miocene diatomaceous coccolith oozes accumulated on the higher elevations of the Maurice Ewing Bank. The calcarous microfloras of these deposits are extremely restricted in diversity, dominated by two or three cold water species (Haq, and others, 1977). Another important characteristic of the Miocene is the large number of older coccoliths, diatoms and radiolarians reworked throughout the sequence. The incidence of reworked coccoliths (Cretaceous, Paleocene, Oliogocene [primarily the latter]) is indicated in Figure 4 where the number of specimens per 10 fields of view of the microscope at 500X is recorded. One peak in this curve coincides with a warm peak in silicoflagelate relative paleotemperature curve of Busen and Wise (1977), an indication of a possible associated fluctuation in the dominant current direction. The abrupt change from Miocene carbonates to noncalcareous Plio/Pleistocene diatomaceous glacial marine clastics at Site 329 marks a major erosional disconformity seen throughout this region. Calcareous nannofossils are not present in the section again until the top few centimeters where a late Pleistocene-Recent coccolith ooze is presently accumulating.

The Tertiary sequence of the Maurice Ewing Bank records not only increasingly severe climatic deterioration from the late Eocene onwards, but the continuation of a complex erosional-depositional history which sculptured much of the present topography of the Bank. The erosional history is recounted by Ciesielski and Wise (1977) who recognize three primary episodes, two climatic and one tectonic in origin: 1). The Cretaceous/Tertiary boundary event which caused deep scouring and exposure of older Mesozoic units. 2) The opening of Drake Passage which Barker and Burrell (1975; see also this volume) believe formed a deep water conduit beginning about 29 m.y. B.P. for the establishment of the circum-polar current by the early Miocene. This event is responsible for the inferred Oliogocene/Miocene hiatus and the extensive reworking of Oligocene material into the Miocene deposits as the circum-polar current established a flow direction that impinged on the Maurice Ewing Bank. 3) The particularly severe late Miocene glaciation of Antarctica (Hayes and Frakes, 1975; Meyewski, 1973) which significantly increased the intensity of circum-polar flow to the point that circum-polar deep water impinging on the Bank from the southwest stripped away the upper sediment cover, exposing units at least as old as Maestrichtian (Fig. 5). The concomitant northward expansion of the Antarctic water mass forced the Polar Front (Antarctic Convergence) well to the north of the Bank shutting off appreciable carbonate deposition until the Southern limit of the Polar Front Zone migrated to its present position along the southern margin in late Pleistocene-Holocene times (Figure 5).

The late Miocene hiatus, so well developed on the Maurice Ewing Bank (Ciesielski and others, 1977; Ciesielski and Wise, 1977), has now been documented in many sectors of the Southern Ocean and its environs (Fig. 6). The agent of erosion, however, was not always the same. In the Ross Sea the unconformity was formed by the grounded ice sheet (Hayes and Frakes, 1975); along the adjacent abyssal margin (DSDP Sites 266 and 274), by bottom current winnowing (Frakes, 1975); in New Zealand, by glacial eustatic regression (Kennett and Watkins, 1974, as reinterpreted by Van Couvering and others, 1976, and Weaver, 1976); and along the Agulhas Plateau, by climatically induced intensification of local currents (Tucholke and Carpenter, 1977). At DSDP Site 328 (Malvins Outer Basin adjacent to the Falkland Plateau; Gombos 1977), the agent was probably antarctic bottom water rather than circum-polar deep water. Correlations of this "Terminal Miocene Event" elsewhere in the world are given by Van Couvering, and others (1976) and Peck, and others (1976).

The Pliocene-Recent history of the study area is complex and poorly understood from the DSDP drill records. It is, however, currently being worked out from the piston cores by Ciesielski (these proceedings).

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FIGURE EXPLANATIONS

Figure 1. Geologic map of older (pre-Pliocene) strata sampled on the Maurice Ewing Bank directly beneath a thin (1 to 2 meter) area-wide cover of Plio/Pleistocene siliceous ooze and glacial marine clastics (from Ciesielski and Wise, 1977). Superimposed on the map are GLOMAR CHALLENGER Leg. 36 and ROBERT CONRAD 16-06 seismic reflection profile tracks used in constructing the geologic cross-section in Figure 2. Bathymetry (in fathoms) from Lonardi and Ewing (1971).

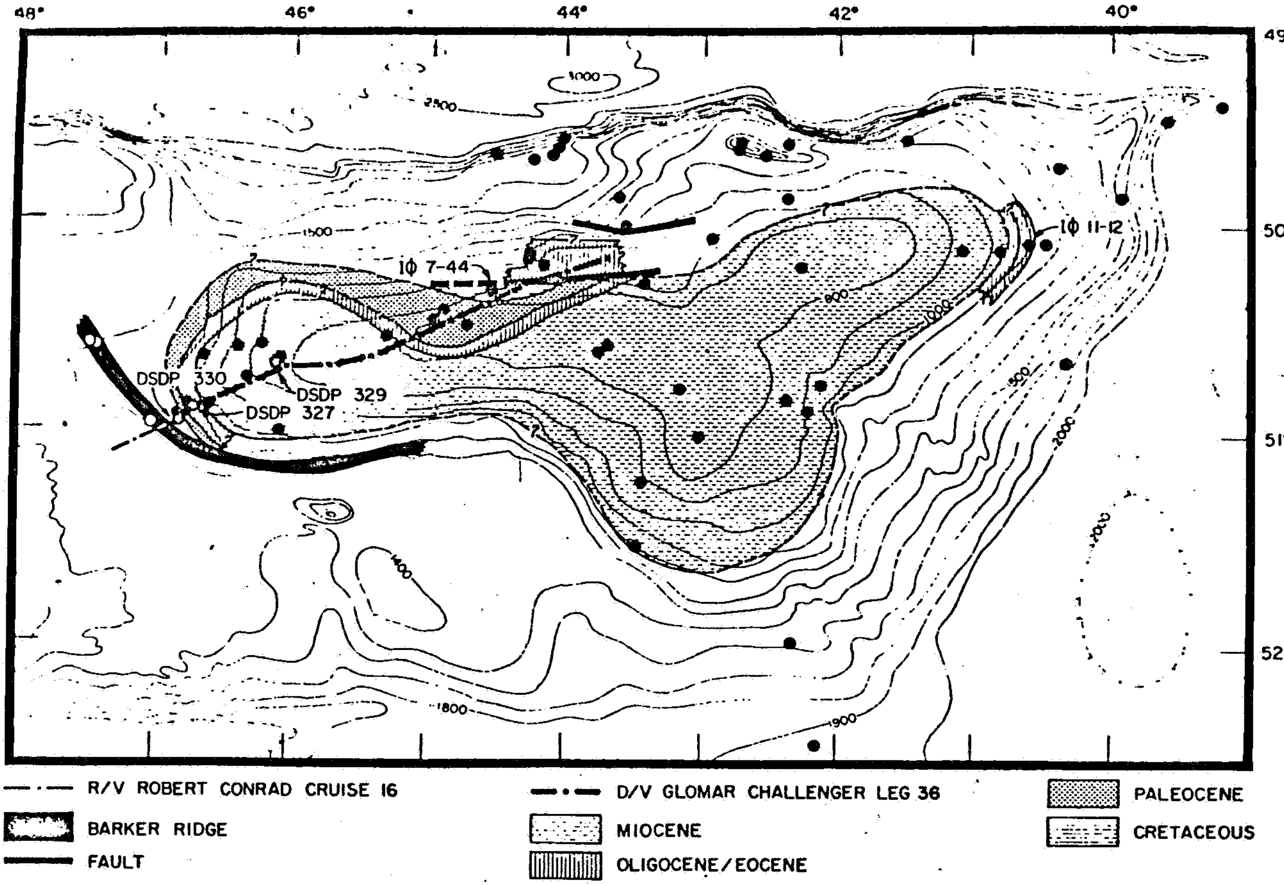
Figure 2. Geologic cross-section across the Maurice Ewing Bank as interpreted from piston and drill core data and from seismic profiles (from Ciesielski and Wise, 1977).

Figure 3. Paleontologic and lithologic properties of cores from Deep Sea Drilling Project Holes 327A and 330, and ISLAS ORCADAS Stations 07-75-44 and 11-76-12.

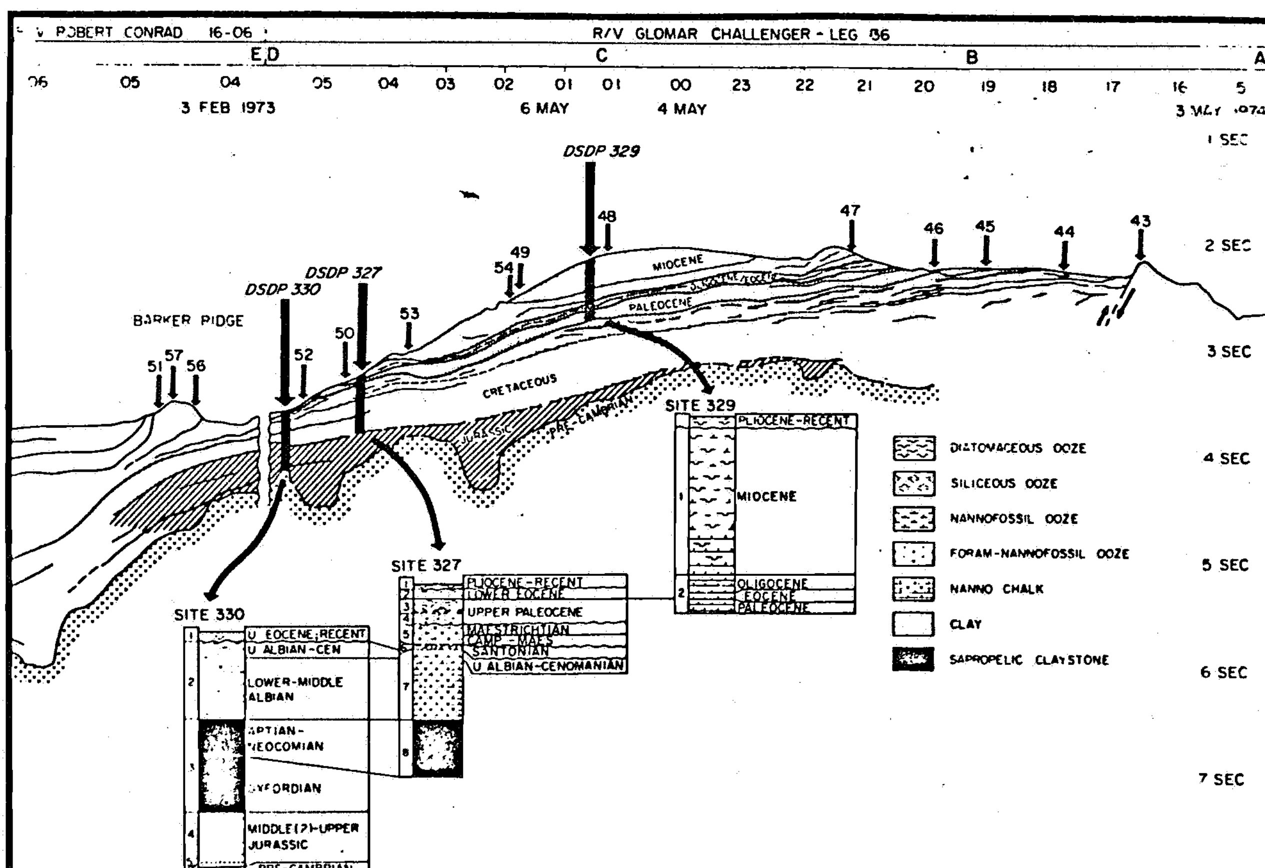
Figure 4. Paleontologic and lithologic properties of cores from Deep Sea Drilling Project Hole 329, ISLAS ORCADAS Station 07-75-45, and ROBERT CONRAD Station 15-84.

Figure 5. Scouring effects of circum-polar deep water during the "Terminal Miocene Event" as visualized by Ciesielski and Wise (1977). Land positions, bathymetry, and the present day position of the Polar Front are from Barker and others (1977, Figure 10).

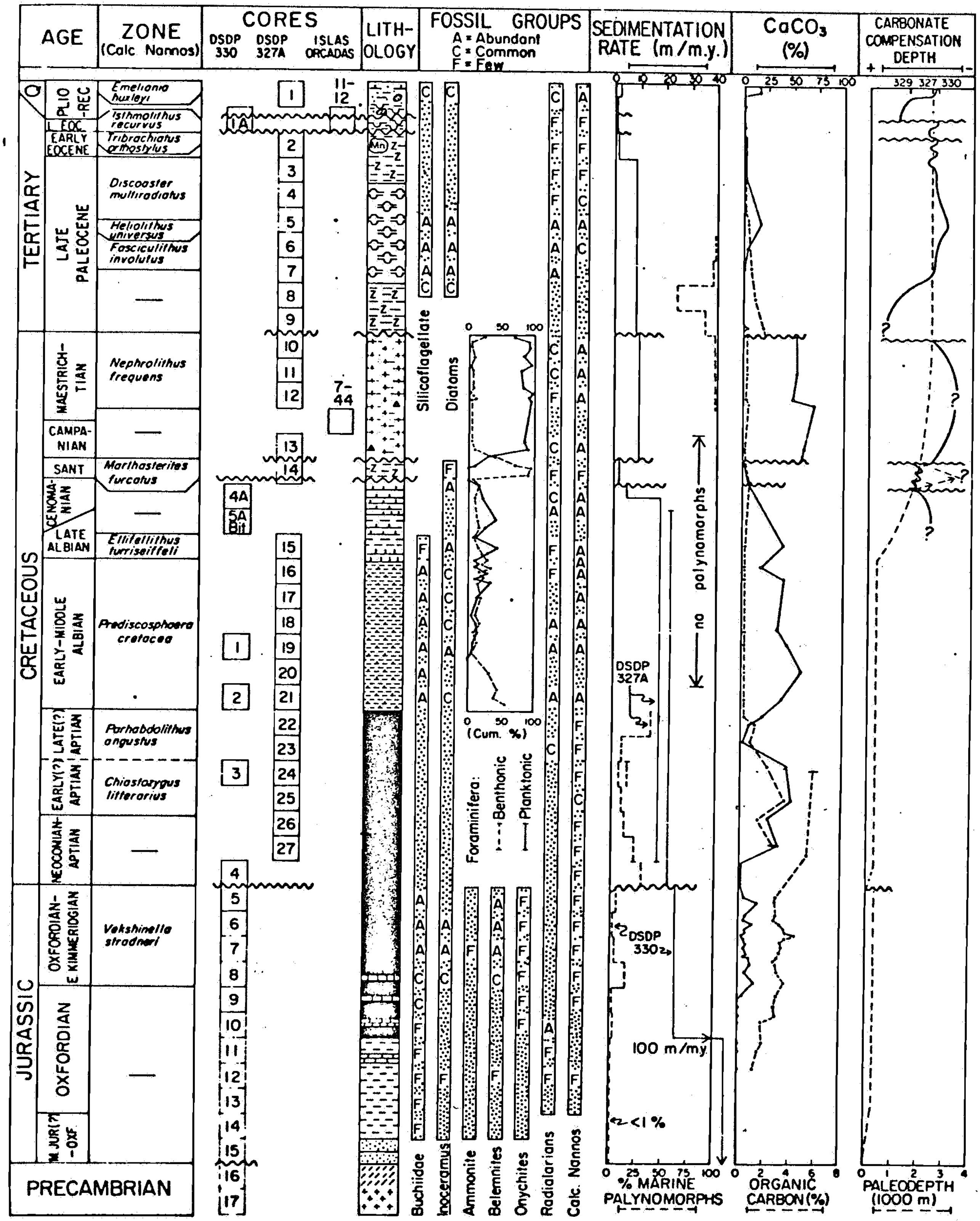
Figure 6. Late Miocene erosional and biostratigraphic hiatuses recorded in cores from the Southern Ocean and its environs as a result of the "Miocene Terminal Event".



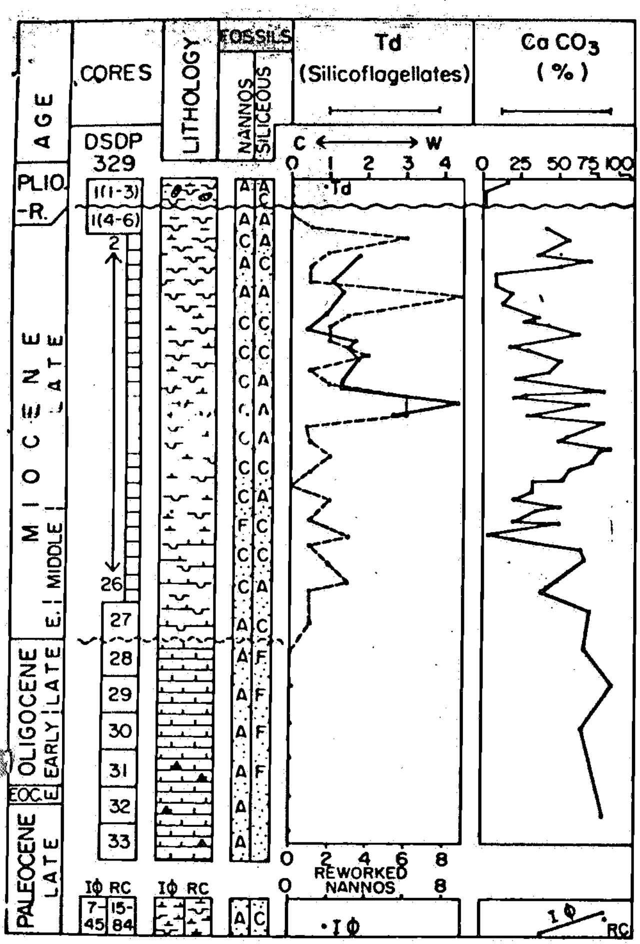
WISE ET AL. FIGURE 1



WISE ET AL. FIGURE 2



WISE ET AL. FIGURE 3



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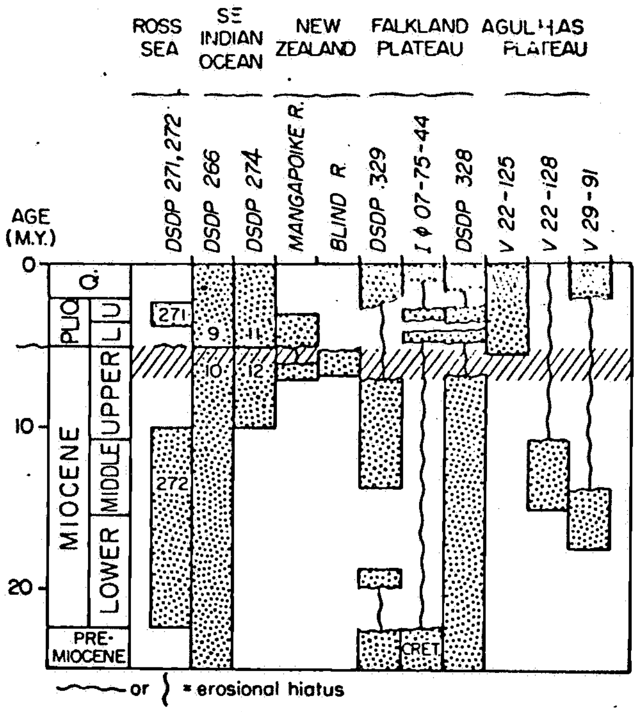

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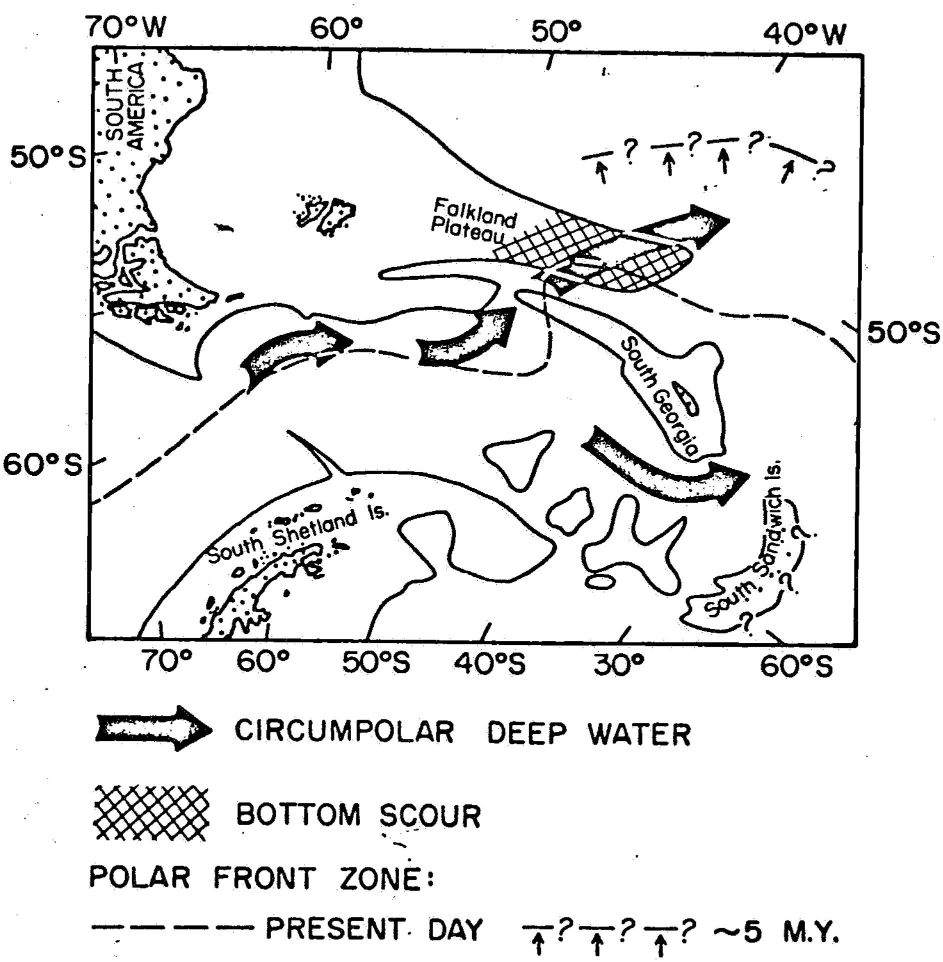

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