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AN INTRODUCTION TO DEEP SEA DRILLING IN THE INDIAN OCEAN,(U)
1977 J G SCLATER, J R HEIRTZLER N00014-75-C-0291

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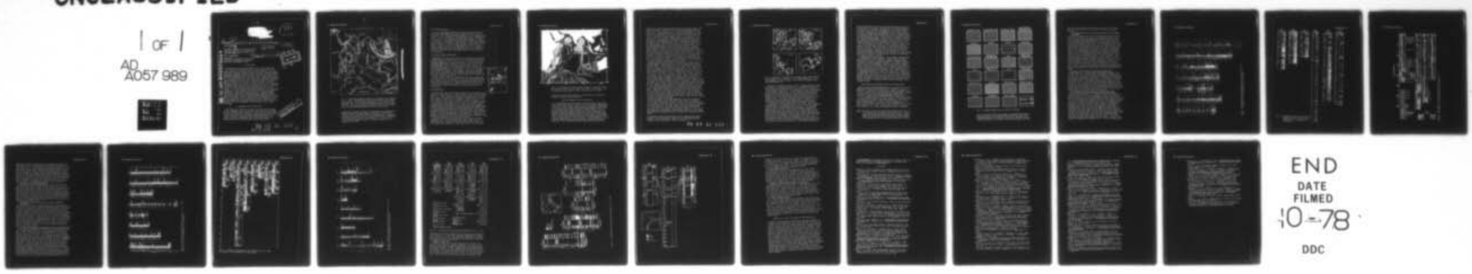

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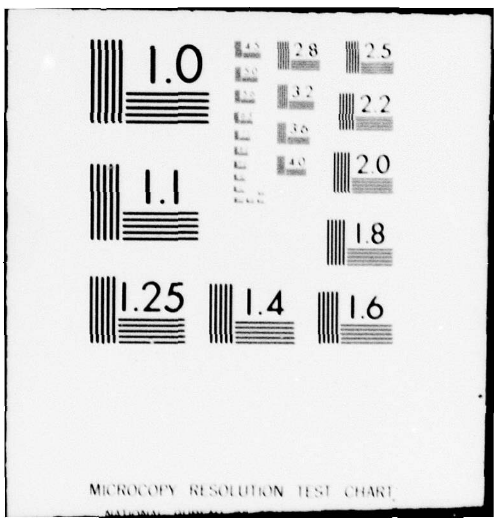
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(10) CHAPTER I. AN INTRODUCTION TO DEEP SEA DRILLING IN THE INDIAN OCEAN,

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Introduction

The Indian Ocean is the most complex of the three major oceans. It has structures which are peculiar to this ocean as well as a large assortment of features which are found elsewhere. The early work in the ocean was carried out aboard the DANA, SNELLIUS, MABAHISS, CHALLENGER, ALBATROSS, and OB (Yentsch, 1962) and the results were published by Wiseman and Seymour-Sewell (1939), Seymour-Sewell (1925) and Fairbridge (1948, 1955). The first really substantial investigation of the ocean came with the International Indian Ocean Expedition which extended from 1959 to 1966. During the course of this expedition ten countries and forty-six ships took part in loosely coordinated cruises to the ocean. A compilation of the data from these cruises has been completed in Atlas form (Udintsev et al., 1975) and we present a chart of the general bathymetry from this Atlas as Figure 1. The International Indian Ocean Expedition resulted in the publication of much scientific work and led directly to a series of expeditions to undertake specific objectives. Perhaps the most successful of these was the drilling program carried out between 1971 through 1972 by the D/V GLOMAR CHALLENGER. The purpose of this paper is to present a simple description of the morphology and structure of the Indian Ocean, to review the problems presented to the D/V CHALLENGER before drilling commenced and to present, within this general context, the highlights of the findings of the drilling program.

Morphology of the Indian Ocean

Many bathymetric charts of the Indian Ocean have been published. The most detailed of these, Laughton et al. (1970) for the Arabian Sea and Carlsberg Ridge, Fisher et al. (1968) for the Somali Basin, Fisher et al. (1971) for the Central Indian Ridge and portions of Sclater and Fisher (1974) have been compiled by Udintsev et al. (1975) to produce a bathymetric chart of the whole ocean. Our modification of this chart (Figure 1) shows the principal

Fig. 1. Principal bathymetric features of the Indian Ocean (Udintsev, et al., 1975). Triangles mark the Deep Sea Drilling Sites and dots the epicenters occurring between 1963 and 1973 taken from the ESSA earthquake tape. To contrast the spreading center with the aseismic ridges, we have shown earthquakes along the active mid-ocean ridges, but not in the Java-Sumatra Trench or other off axis areas.

morphological features on which are superimposed the earthquake epicenters from the mid-ocean ridges and the sites of the Deep Sea Drilling holes in the Indian Ocean. The nomenclature of the major features has often given rise to confusion especially in comparisons of Russian work with that of western countries. In this study we have attempted whenever possible to follow the nomenclature of Laughton et al. (1971).

Mid Ocean Ridge System

The major topographic feature in the Indian Ocean is the broad active mid-ocean ridge system which starts in the Gulf of Aden (Laughton et al., 1970) and trends southwest as the Carlsberg Ridge into an en echelon pattern of transform faults and spreading centers (Fisher et al., 1971) called the Central Indian Ridge. At 25°S, 70°E this ridge bifurcates into the Southeast Indian and Southwest Indian Ridges. The Southwest Indian Ridge eventually joins the mid-Atlantic Ridge at the Bouvet Triple Junction. The Southeast Indian Ridge, a broad swell with less rough topography than the other ridges, trends southeast to the Amsterdam and St. Paul Islands and then almost due east between Australia and Antarctica joining up with East Pacific Rise after some major offsets at the Macquarie Triple Junction.

The Aseismic Ridges and Plateaus

Characteristic of the Indian Ocean is the abundance of relatively shallow ridges and plateaus that are free from earthquake activity. The most prominent of these features are the Chagos-Laccadive and Ninetyeast Ridges both of which are thought to be oceanic and the Seychelles Bank which is attached to the Mascarene Plateau. The Seychelles Bank is known to be continental (Matthews and Davies, 1966) and is thought to be a micro-continent split from India during the northward movement of that continent. The origin of the Mascarene Plateau is unknown. Other aseismic ridges of considerable morphological importance are the Mozambique and Madagascar Ridges, the Crozet and Kerguelen Plateaus, Broken Ridge and the Wallaby and Naturaliste Plateaus (Figure 1).

Further aseismic ridges and islands which show up as morphological features but are less extensive in size are the Rodriquez Ridge, the Ob Seamount Province and the Cocos-Keeling, Christmas group of islands in the Wharton Basin. Because all these features are relatively small and appear of secondary importance they are not discussed either in this introduction or in the papers presented in the volume.

The Ocean Basins

The mid-ocean ridges, the aseismic ridges and the continental shelves divide the Indian Ocean into a number of more or less isolated basins (Figure 1). These ridges and the continental edges have a very large effect upon the distribution of sediments. Seismic reflection data have enabled an isopach map of sediment thickness (Figure 2) to be constructed which shows that 40 percent of the total sediment present is to be found in the Arabian Sea and in the Bay of Bengal, probably from Himalayan erosion (Ewing et al., 1969). More recent seismic studies in the Bay of Bengal by Curray and Moore (1971) suggest that sediment thickness may exceed 12 km and that Himalayan denudation may be proceeding at an average rate of 70 cm/1000 years. Other thick terrigenous sediments are found off East Africa and in the Mozambique Channel. South of the polar front, high biological productivity has given rise to thick accumulations of siliceous ooze. Elsewhere the sediments are relatively thin and on the crestal area, 100 km on either side of the ridge axis, they are virtually absent.

Scattered seismic refraction stations from a variety of sources (Laughton et al., 1971) illustrate that, except under the micro-continents and the ridge axes, normal oceanic crust is found. The only seismic data available on a mid-ocean ridge is in the complex

Fig. 2. An Isopach map of unconsolidated sediments contoured in two-way reflection time in seconds (at 0.1 sec contour intervals). 1 sec is equivalent approximately to 1000 m (from Ewing et al., 1969).

area of the Central Indian Ridge and this data does not yield much information about the deep structure.

Tectonic Synthesis of the Indian Ocean

It is impossible in a short review to do anything other than highlight the work and theories that have led to our present understanding of this very complex ocean. Perhaps the most important contributions that came out of the International Indian Ocean Expedition were those of Vine and Matthews (1963) and Heezen and Tharp (1965). Vine and Matthews (1963) developed the concept of sea floor spreading by an analysis of magnetic anomaly observations across the Carlsberg Ridge. They presented strong evidence that this active ridge was a spreading center. Heezen and Tharp (1965) made the first major attempt to describe the physiography of the Indian Ocean. They emphasized the entire mid-ocean ridge system and the large fracture zones offsetting the ridge axis. They contrasted the broad ridge system with the long linear smooth topped aseismic ridges such as the Chagos-Laccadive and Ninetyeast Ridges. Later work by LePichon and Heirtzler (1968) and Fisher et al. (1971) and Ewing et al. (1969) supported many of their suggestions. In particular LePichon and Heirtzler (1968) showed that the rate of separation on the active ridge axis increases from near 1 cm/yr (half rate) on the Carlsberg Ridge to greater than 3 cm/yr (half rate) on the Southeast Indian Ridge. At the same time as this analysis of sea floor data was underway McElhinney (1970) published an analysis of paleomagnetic data from the surrounding continents. He concluded that initial movement within Gondwanaland began during the Upper Permian, when Africa and Antarctica together made a northward and counterclockwise movement away from the other continents, which remained stationary. The final break-up occurred during the Upper Cretaceous, with Indian and Australia separating from Antarctica and drifting to their present positions during the Tertiary. There was little movement between either Africa, South America, or Antarctica and the present South Pole during the Tertiary, but India must have moved 59° or 5500 km, between earliest Eocene and the Miocene (the latter is the time of formation of the Himalaya). This corresponds to a rate of drift of 11 cm/yr. Similarly, Australia moved northward at 8 cm/yr between the Oligocene and the present.

During the International Indian Ocean Expedition a large quantity of residual magnetic anomaly data was collected along track by various research vessels. Two compilations of this data have been published (Sclater et al., 1971 and Udintsev et al., 1975). Most of this and much other magnetic data collected during and after the International Indian Ocean Expedition was first used by Fisher et al. (1971) and then McKenzie and Sclater (1971) to examine the evolution of the ocean from the late Cretaceous to present. Fisher et al. (1971) showed in a topographic chart that rather than being a simple north-south ridge with a central deep, as suggested by Heezen and Tharp (1965), the Central Indian Ridge consisted of a complex suite of en echelon fracture zones and active spreading centers trending N60°E. Further, they and McKenzie and Sclater (1971) assuming a constant spreading rate about the present pole of motion showed that the Mascarene plateau fit snuggly into the Chagos-Laccadive Ridge in the earliest Oligocene. This new feature, stretching from Mauritius to the Maldives, was perpendicular to the older anomaly sequences in the Arabian Sea and Central Indian Basin. McKenzie and Sclater (1971) made this discovery the basis of a tectonic evolution in the whole ocean (Figure 3). They recognized only four plates, Africa, India, Australia, and Antarctica, and from the Eocene to present assumed only three plates. Prior to the Eocene, Australia and India were separated by an active transform fault running parallel to the Ninetyeast Ridge.

Working backwards in time and terminating in the Late Cretaceous, McKenzie and Sclater (1971) identified three phases of spreading:

(a) Present to Oligocene (present to 36 Ma). This period was dominated by the closing of the Red Sea and the Gulf of Aden, slow spreading on the Carlsberg (1.2 cm/yr half rate) and Southwest Indian Ridges (1.0 cm/yr half rate), and faster rates on the Central Indian (2.0 cm/yr half rate) and Southeast Indian Ridges (Figure 3b). The uplift and denudation of the Himalaya occurred during this time and the phase terminated with the Mascarene Plateau fitting into the Chagos Laccadive Ridge.

For the rest of this introduction, we do not reference each report whenever a site is mentioned. However, if we cite something from a paper in the Initial Report, then we reference it.

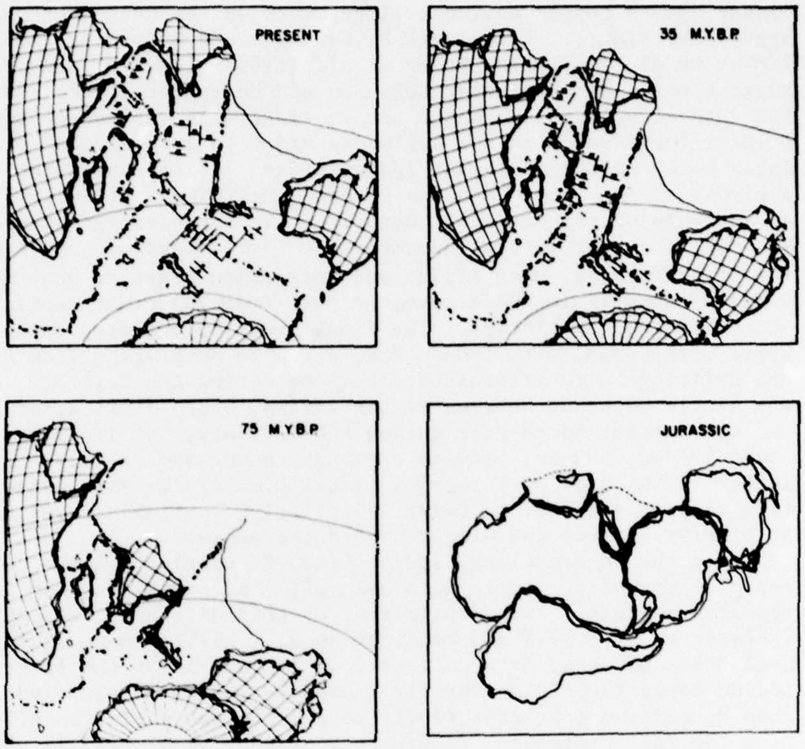


Fig. 3. Stages in the evolution of the Indian Ocean (after McKenzie and Sclater, 1971): a) present; b) at 35 Ma (anomaly 13); c) at 75 Ma (anomaly 32) and d) prior to the breakup of Gondwana (after Smith and Hallam, 1971).

(b) Eocene to Paleocene (36 Ma to 53 Ma). The main movement during this phase is the continued separation of the Australian part of the Indian plate from Antarctica at 2.5 cm/yr (half rate). Relatively little movement is apparent on the Carlsberg and Central Indian Ridges in the northwest Indian Ocean. On the Southwest Indian Ridge the anomalies from the Mascarene basin abutt those on the Crozet basin and thus during this time span the ridge has changed from an en echelon set of ridges and transform faults into one long continuous transform fault. This phase terminates with the connection of Australia to Antarctica and the juxtaposition of the south end of the Ninetyeast and Broken Ridges against the Kerguelen Plateau.

(c) Paleocene to Late Cretaceous (53 Ma to 70 Ma). This period is dominated by the southward movement of the Indian plate, separated from Australia by the Ninetyeast transform fault. Two spreading centers, south of India and north of the Seychelles (Figure 3c), generated sea floor that is now found in the Crozet basin and the Central Indian basin on one hand, and in the Arabian basin and the basin north of the Seychelles on the other. These spreading centers were linked by the Southwest Indian transform fault, which continued south of Africa to meet with the Africa/Antarctic ridge. The Seychelles spreading center was terminated in the west by the Owen Fracture Zone. The northern side of the Indian plate must have lain in a subduction zone in the Tethys Sea. The southward movement of

India started slowly 53 Ma but accelerated between 65 and 70 Ma to a total rate of 17 cm/year. The slow start is probably related to the collision of India with the subduction zone to the north and the onset of the uplift of the Himalaya. It is possible that the post 70 Ma movements could be extrapolated back in time (perhaps to 100 Ma), bringing India farther south until its southern tip met the spreading center and its northeast section reached the southern end of the Ninetyeast Ridge. In this model, the seafloor south of the Seychelles and Madagascar should be older than 75 Ma, although the northward movement of the Seychelles and the growth of the Amirante Island Arc may have obscured any traces of the old crust.

(d) Late Cretaceous to Jurassic (75 Ma to 140 Ma). Owing to the absence of clearly identified magnetic lineations McKenzie and Sclater (1971) could not extend the tectonic history back beyond the Late Cretaceous. They were unable to account for either the ocean crust generated between Africa and Antarctica or for the apparent displacement of Madagascar from East Africa. These motions must have occurred before 75 Ma and were related to the breakup of the original Gondwana continents.

(e) Gondwanaland Reconstructions. Many possible reconstructions of Gondwanaland have been suggested. Holmes (1965) includes an excellent short review of the early attempts. Magnetic anomaly information presented by Weissel and Hays (1972) between Australia and Antarctica and paleomagnetic evidence have tended to support simple variations on the DuToit (1937) position of the continents. This fit has received much support by the computer analysis of continental coastlines by Smith and Hallam (1970). Their preferred fit was that most generally accepted for the continents before the D/V CHALLENGER entered the Indian Ocean (Figure 3d). Another fit considered was a modification of that of Wilson (1963) suggested by Crawford (1969) where Indian fits into the west coast of Australia. However, as will be seen in the next section, this fit is not compatible with magnetic anomaly information and the basement ages inferred from holes in the Wharton Basin (Sclater and Fisher, 1974; Luyendyk, 1974).

Major Problems Undertaken by DSDP in the Indian Ocean

Before the D/V GLOMAR CHALLENGER entered the ocean the J.O.I.D.E.S. Indian Ocean Advisory Panel consisting of E. Bunce, R. Fisher, J. Heirtzler, M. Langseth, R. Schlich and M. Talwani (Chairman) set up a suite of major tectonic and sedimentological objectives. In this section we outline these objectives and the attempts made by the scientists on board the D/V GLOMAR CHALLENGER to meet them.

In our topographic map of the Indian Ocean we present the position of all the sites drilled in this ocean (Figure 1). Compilations of the lithofacies sections for Leg 22 (Von der Borch et al., 1973), Leg 23a (Whitmarsh et al., 1974a), Leg 23b (Whitmarsh, et al., 1974b), Leg 24 (Fisher et al., 1974), Leg 25 (Schlich et al., 1974), Leg 26 (Davies et al., 1974), Leg 27 (Veevers et al., 1975) and Leg 28 (Hayes et al., 1975) are presented as Figure 4 through 11.

NOTE: The dates used in this review differ slightly from those in the original paper by McKenzie and Sclater (1971). We have chosen to use the new dates because they are better established and conform well with the Deep Sea Drilling information presented later in this volume (Sclater et al., 1974).

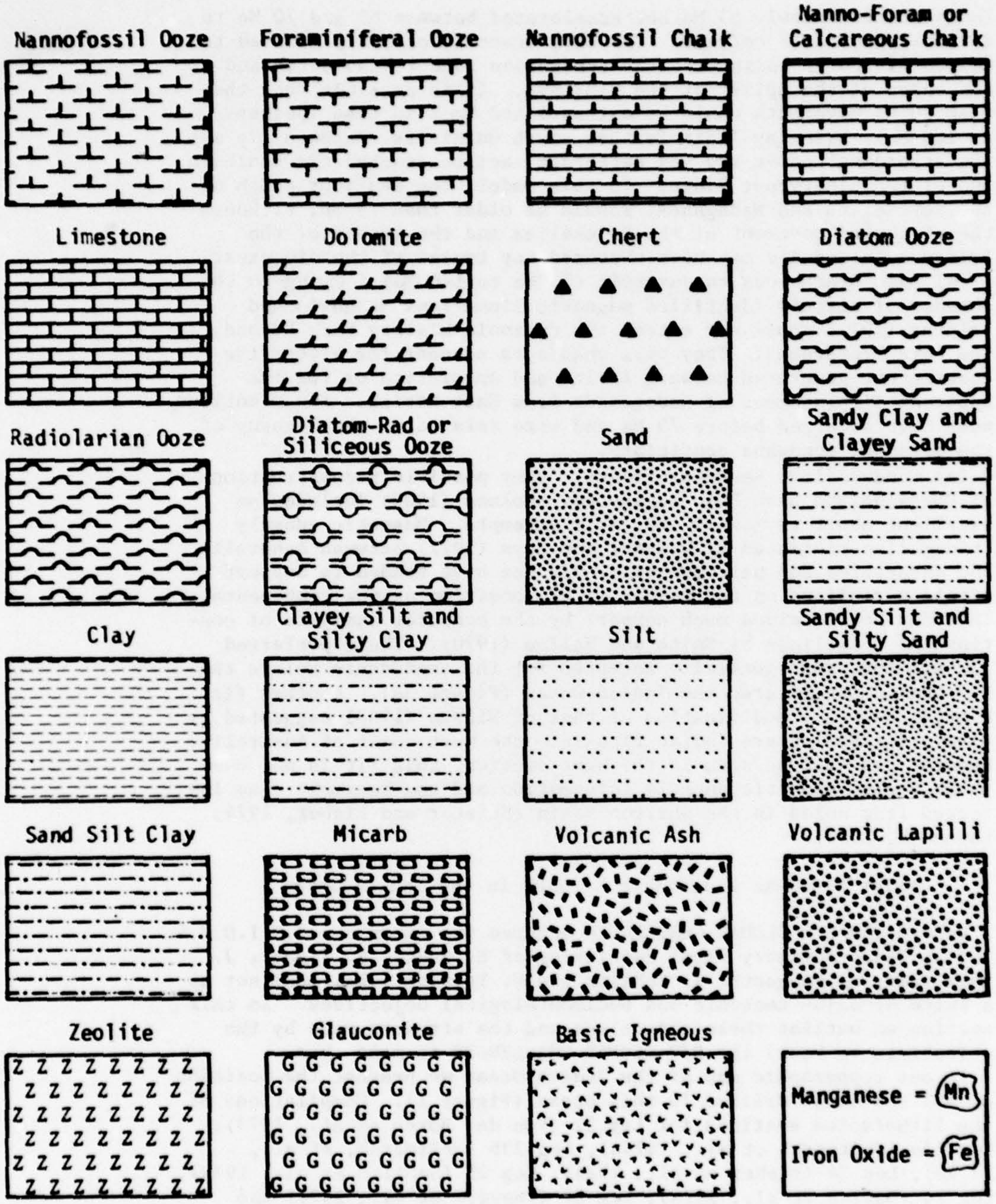


Fig. 4. Standard symbols used to illustrate lithology.

holes on legs 22, 26 and 27 was placed in the Wharton Basin and two holes were located in the Somali Basin on Leg 25 and one in the Mozambique Basin on Leg 25 and 26. The holes in the Wharton Basin were most successful. They showed that the basin aged to the south

We discuss the three sites around and to the south of the Tasman Rise from Leg 29 (Kennett et al., 1975) but we do not show any sections.

1) The Reconstructed Position and Early History of the Gondwana Continents

From the tectonic history set out by McKenzie and Sclater (1971) outlined in the previous section it was clear that back to 70 Ma the tectonic history of the Indian Ocean was well known in all except the Wharton and Mozambique Basins. Prior to this time very little was known about this history. As a consequence, a suite of in the Late Cretaceous (sites 211, 212, 213 and 256) and that in the Early Cretaceous and Jurassic this basin and the Argo Abyssal Plain became older to the southwest (sites 260, 261, 263). An excellent review of the implications of these sites is presented by Veevers (1977) in a later paper in this volume. The holes in the Somali Basin did not reach basement but indicated that west of the Chain Ridge the basin is at least as old as Late Cretaceous (site 241). The two holes in the Mozambique Basin are quite confusing. They imply that the basin ages to the south. This direction is opposite to that proposed by Bergh and Norton (1976) who surveyed a well identified magnetic anomaly sequence southeast at site 250. A possible explanation is that the basalt recovered at site 248 is a sill and is much younger than the crust on which it is located. Apart from those in the Wharton Basin, the sites in the basins were not as useful in helping elucidate the reconstructed position of the Gondwana continents and the early history of the ocean as had been hoped.

2) The Post 70 Ma Tectonic History of the Indian Ocean

Though there was a consensus as to the general features of the tectonic history of the Indian Ocean as presented by McKenzie and Sclater (1971) significant problems still remained. These included (a) the exact timing of the break apart of the Mascarene Plateau and the Chagos-Laccadive Ridge (site 238); (b) the dating of the ocean crust either side of the Ninetyeast Ridge (sites 213 and 215); (c) the age of the crust to the west Chagos-Laccadive Ridge (site 220); (d) the age of the Arabian Sea south of the Asian continent (sites 221 and 222) and just north of the Seychelles (site 236); and finally, (e) the age of the Mascarene Basin south of Mauritius (site 245). In general these sites tended to confirm the tectonic history outlined in the previous section with minor modifications.

3) The Origin and Tectonic History of the Aseismic Ridges

From the point of view of the tectonics this project and the drilling between Australia and Antarctic were two of the major successes of the project in the Indian Ocean. First a suite of five holes from Legs 22 and 26 along the Ninetyeast Ridge (sites 254, 253, 217, 216, 214) demonstrated unequivocally that this ridge was attached to the Indian Plate, was formed at sea level at a spreading center, and sunk at the same rate as the plate to which it was attached. A discussion of the implications of these results is presented by Luyendyk (1977) later in this volume. Drilling on the Chagos-Laccadive Ridge (site 219) and on the Mascarene Plateau (site 237) also showed that these ridges had once been at sea level and had subsided to the depth predicted at the same rate as the oceanic crust to which they were attached. Drilling on the Madagascar Ridge (sites 246, 264) was inconclusive as the sites did not reach basement, drilling on the Mozambique Ridge (site 249) showed it was early Cretaceous and gave a very important control date on the age of the breakup of Gondwanaland (Luyendyk, 1974). Site 255 on Broken Ridge

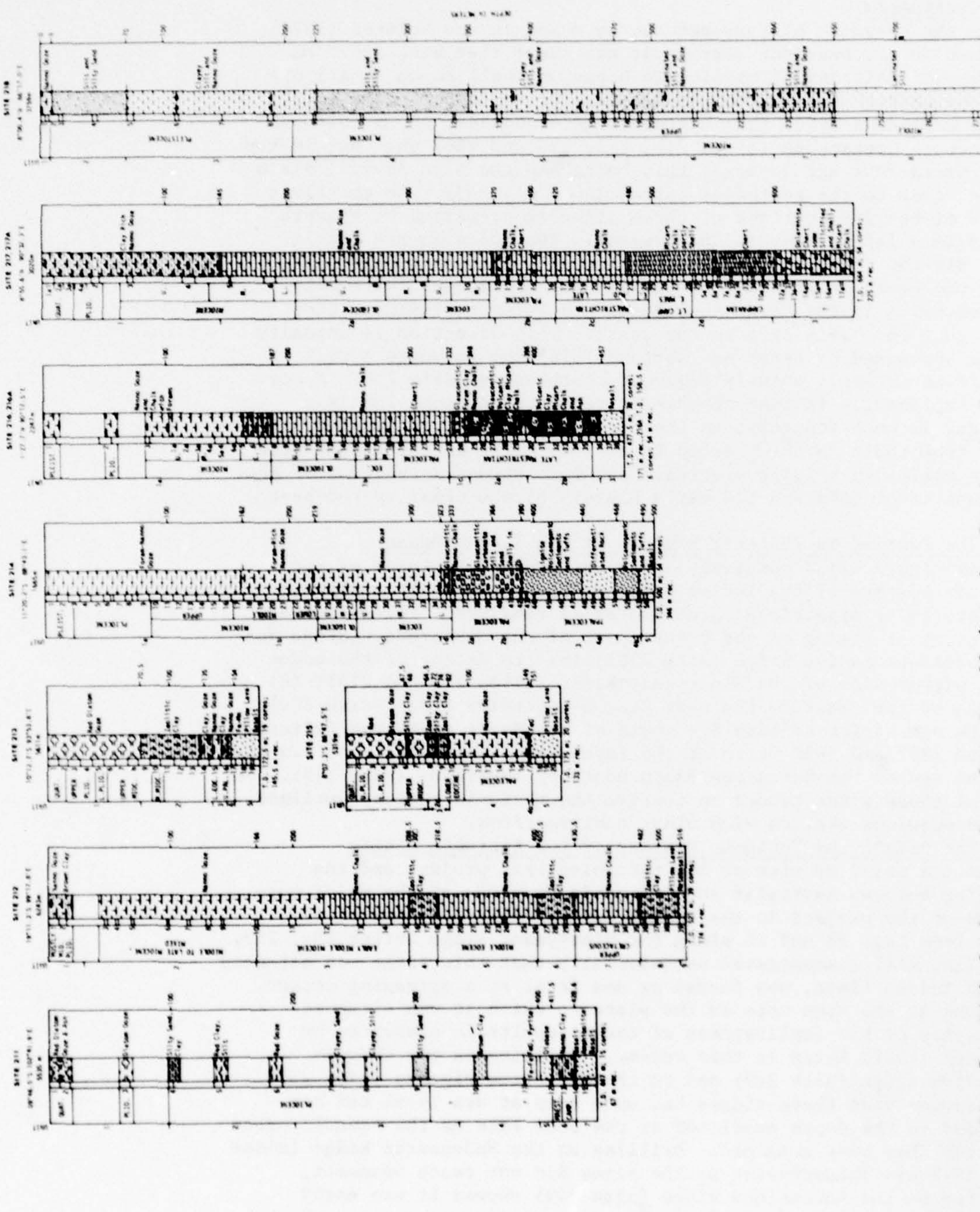


Fig. 5. Lithofacies sections from Leg 22 (von der Borch, et al., 1974). See figure 4 for an explanation of the symbols.

Fig. 6. Lithofacies sections from Leg 23a (Whitmarsh, et al., 1974a). See figure 4 for an explanation of the symbols.

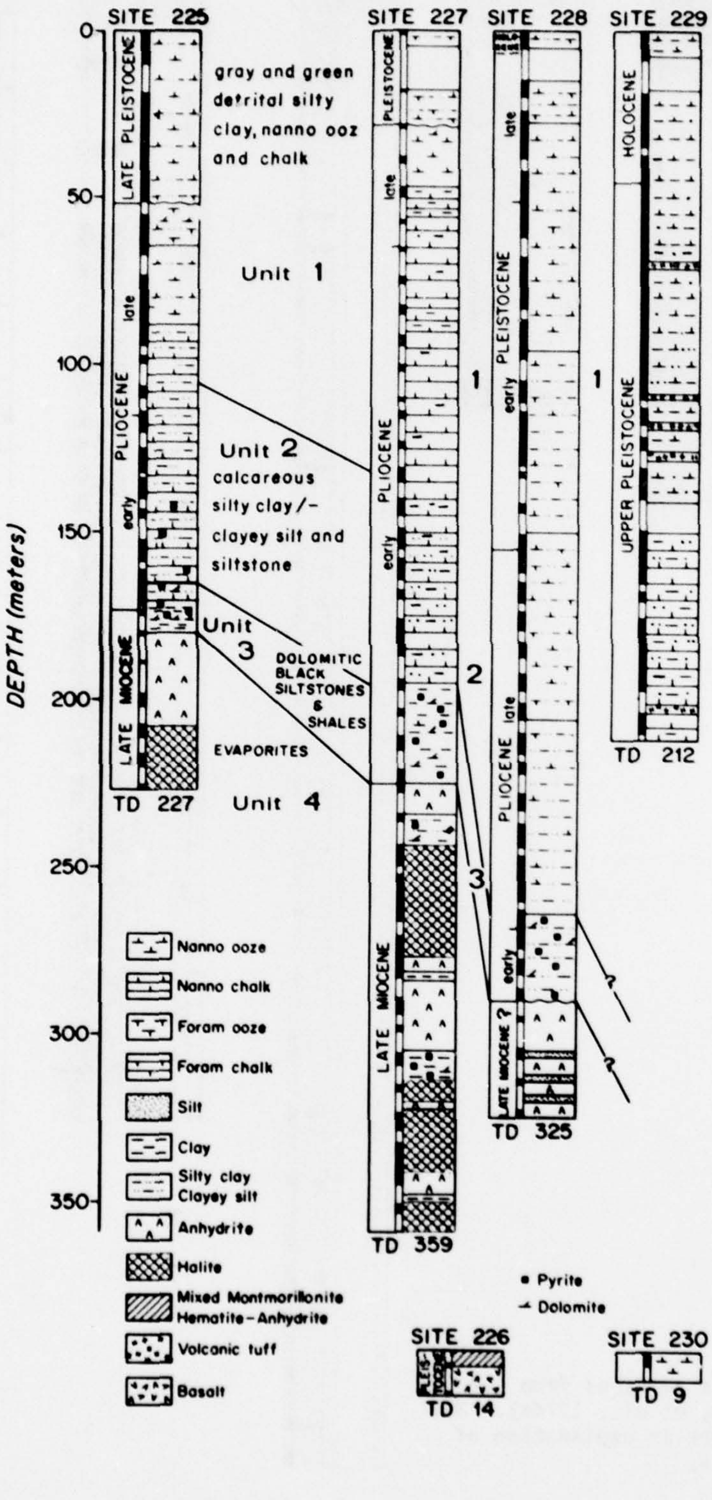


Fig. 7. Lithofacies sections from Leg 23b (Whitmarsh, et al., 1974a). See figure 4 for an explanation of the symbols.

showed that it has a complex history of subsidence and uplift terminating with uplift in the Eocene and then a slow subsidence to the present depth. The drilling on the aseismic ridges had two other implications. First their basement ages provided estimates of the age of the regional oceanic crust and second the detailed sections enabled estimates to be made of their subsidence history. In the case of the Ninetyeast Ridge this first point helped constrain the position of India within Gondwanaland (Sclater and Fisher, 1974) and the second was invaluable in the construction of the paleobathymetric charts. Sclater et al. (1977) and Davies and Kidd (1977) later in this volume make considerable use of these histories and charts in their synthesis of the sediments recovered in the Indian Ocean.

4) The History of Antarctic Glaciation

The distribution of the facies boundaries and of the first ice-rafted detritus in Leg 28 (sites 268, 267, 266) off the coast of Antarctica present major evidence concerning glaciation on Antarctica. These studies and oxygen isotope work on site 284 from DSDP Leg 29 (Shackleton and Kennett, 1975) were presented as evidence that the major glaciation in Antarctica did not begin until the Late Oligocene. During the Miocene the sites close to Antarctica indicate that the climate gradually deteriorated and cool waters pushed further north until the end of the Miocene when a major glacial pulse occurred involving a rapid building and subsequent retreat of the Antarctica ice sheet (Hayes and Frakes, 1975).

5) The Opening of Australia and Antarctica and Circumpolar Circulation

Much of the latter part of Leg 29 was devoted to the problem of timing and the nature of the breakup between Australia and Antarctica. Site 281 on the southern extension of the south Tasman Rise bottomed is continental granite indicating that this whole feature was continental. Further, Kennett et al. (1975) using the reconstructions of Weissel and Hayes (1972) pointed out that this Rise which originally abutted Antarctica did not pass the edge of the Antarctic continent until the late Oligocene. They suggest that just after this happened a shallow and deep water circumpolar current became activated and that this current caused the pronounced Oligocene hiatus in the holes just south of the Australian continent (sites 282, 280). This is one of the few cases where a sediment hiatus can be related to changes in possible circulation patterns. It has major implications for the study of paleo-oceanography.

6) The History of the Large Sedimentary Basins in the Indian Ocean

Clearly the D/V CHALLENGER is not capable of drilling deep enough in the large sedimentary basins to get a complete stratigraphic sequence. Thus a limited objective involved drilling in the distal sections of four of these basins. On Leg 22 the end of the Bengal fan was drilled (site 218) and in the sediments recovered there was evidence that there had been at least four major pulses of sedimentation across this fan since the middle Miocene. On Leg 23 a widespread lower Middle Eocene chart reflector was discovered in the southeast Arabian Sea. On Leg 25, site 241 in the Somali abyssal plain terminated in a Turonian (middle Cretaceous) claystone and sandstone. It appears that the relatively high sedimentation rates and bore rates in the sedimentary record in the 1174 m hole can be both due to epeirogenic movements of Africa and to the initiation of a current system that increased productivity in the surface waters. Site 250 in the Mozambique Basin shows that since the Miocene sediments have been under the control of active bottom circulation flowing clockwise.

Other objectives of the sedimentary drilling program were the in-

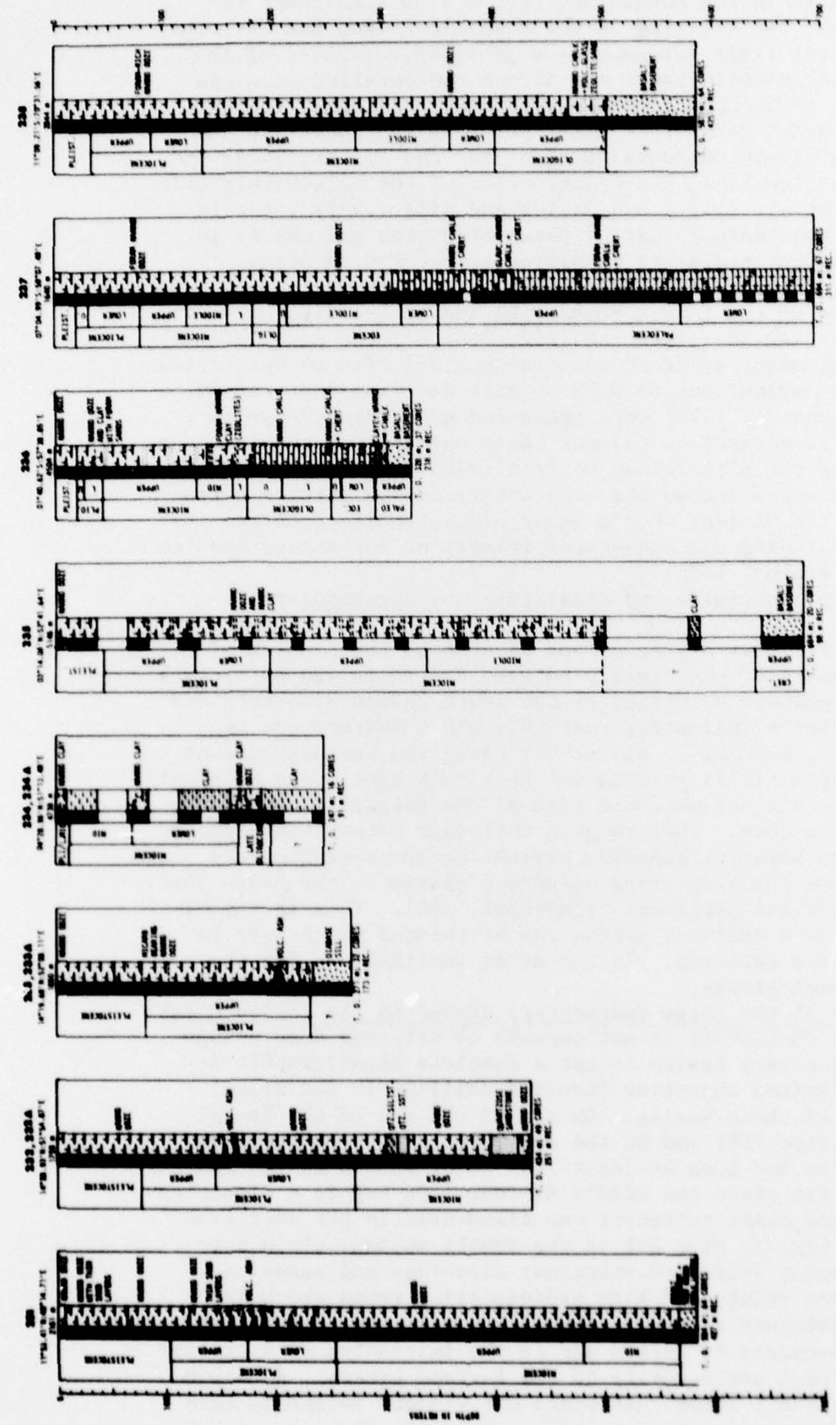


Fig. 8. Lithofacies sections from Leg 24 (Fisher, et al., 1974). See figure 4 for an explanation of the symbols.

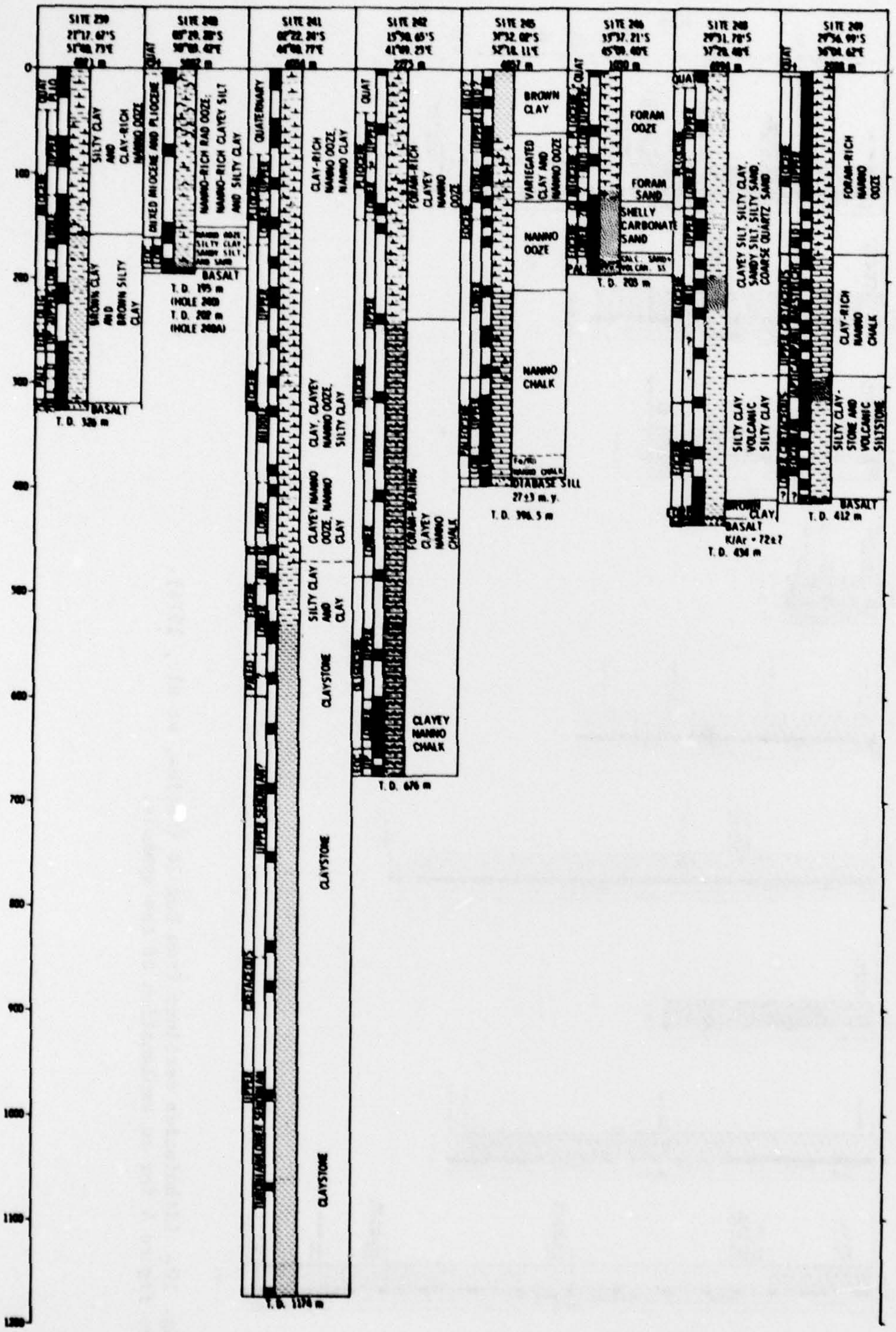


Fig. 9. Lithofacies sections from Leg 25 (Simpson, et al., 1974). See figure 4 for an explanation of the symbols.

Fig. 10. Lithofacies sections from Leg 26 (Davies, et al., 1974). See figure 4 for an explanation of the symbols.

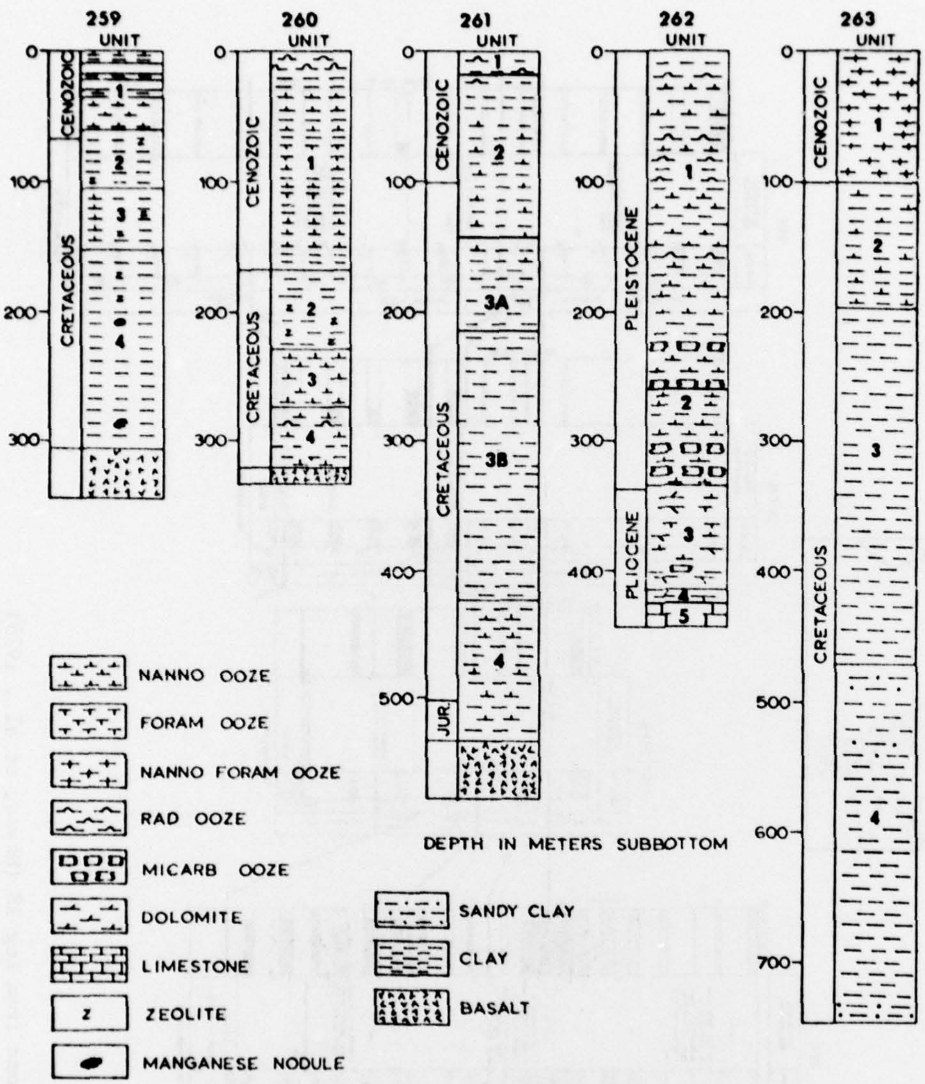


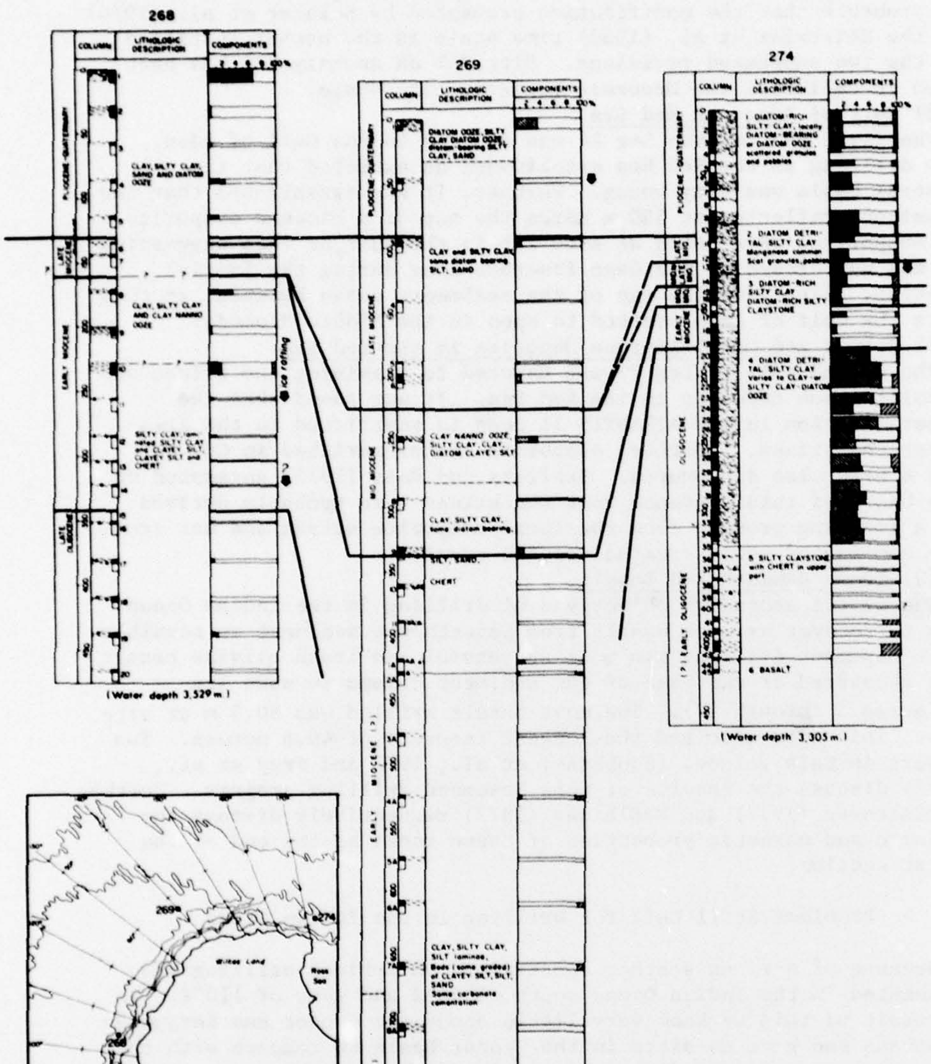
Fig. 11. Lithofacies sections from Leg 27 (Veevers, et al., 1975).

vestigation of near coast sediments off the west coast of Australia (sites 257, 260, 261, 263) and the general examination of volcanogenic sediments. In this volume Cook (1977) examined the sediments of the eastern Indian Ocean and Vallier and Kidd (1977) review the volcanogenic content of the cores.

7) Magnetic Time Scale

A series of holes, 214, 234, 239, 245, 265, 266 and 267, were drilled on well identified magnetic anomalies. All those on crust younger than anomaly 13 seemed to agree well with the Heirtzler et al. (1968) time scale. However, those older than Eocene gave ages considerably younger than that predicted by this time scale. This led Sclater et al. (1974) and Schlich (1975) to revise the Heirtzler et al. (1968) geomagnetic time scale. There is still some controversy over site 239. But the latest analysis of sediments above

Fig. 12. Lithofacies sections from Leg 28 (Hayes, et al., 1975).


268
269
274
COLUMN
LITHOLOGIC DESCRIPTION
COMPONENTS
PLIOCENE-QUATERNARY
CLAY, SILTY CLAY, SAND AND DIATOM OOZE
CLAY, SILTY CLAY AND CLAY NANNO OOZE
ice rafting
SILTY CLAY
(Water depth 3,529 m.)
DIATOM OOZE, SILTY CLAY DIATOM OOZE, diatom bearing SILT, CLAY, SAND
CLAY and SILTY CLAY, some diatom bearing SILT, SAND
CLAY NANNO OOZE, SILTY CLAY, CLAY, DIATOM CLAYEY SILT
CLAY, SILTY CLAY, some diatom bearing,
SILTY, SAND,
CHERT
CLAY, SILTY CLAY, SILT laminae, Beds (some graded) of CLAYEY SILT, SILT, SAND
Some carbonate cementation
(Water depth 4,282 m.)
1. DIATOM-RICH SILTY CLAY, locally DIATOM-BEARING or DIATOM OOZE, scattered granules and pebbles
2. DIATOM DETRITAL SILTY CLAY
3. DIATOM-RICH SILTY CLAY
DIATOM-RICH SILTY CLAYSTONE
4. DIATOM DETRITAL SILTY CLAY
5. SILTY CLAYSTONE with CHERT in upper part
6. BASALT
(Water depth 3,305 m.)
Wilkes Land
Ross Sea
DIATOMS
NANNOPLANKTON
DETRITAL
MISCELLANEOUS
LOWEST ICE-RAFTED DEBRIS

basement is evidence that these are younger than those initially reported (see Sclater et al., this volume). If substantiated, it is probable that the modification presented by Sclater et al. (1974) of the Heirtzler et al. (1968) time scale is the better justified of the two suggested revisions. Site 261 on anomaly M22 has been used to calibrate the Mesozoic magnetic time scale.

8) Gulf of Aden and Red Sea

The first part of the Leg 24 was devoted to the Gulf of Aden. The drilling in the Red Sea established as expected that the central basin was very young. Further, it was established that the prominent reflector at 500 m marks the top of a Miocene evaporite. No evaporites were found at site 231 in the Gulf of Aden suggesting it was not closed by the Owen Fracture Zone during the initial opening. Also from the age of the sediments above basement at this site the Gulf of Aden started to open in the Middle Miocene.

9) Brines and Metalliferous Deposits in the Red Sea

The second part of Leg 23 was devoted to examining the brines and metalliferous deposits in the Red Sea. It was found that the mineralization in the ATLANTIS II deep is restricted to the area under the brines. Further, evaporite shales enriched in Cu, Zn and B were also discovered. Stoffers and Ross (1975) suggested on the basis of this evidence that the brines were probably derived by a leaching process from the local evaporite strata and not from the cooling of newly created oceanic crust.

10) Fresh Unweathered Basalt

One of the secondary objectives of drilling in the Indian Ocean was to recover as much basalt from beneath the sediment as possible. This basement drilling was most successful and fresh olivine basalt was recovered at the base of the sediment column on each leg (Figures 5 through 12). The most basalt drilled was 80.5 m at site 238. This site also had the longest recovery of 40.6 meters. Two papers in this volume, (Subbarao, et al., 1977 and Frey et al., 1977) discuss the results of this basement drilling program. Further, Christensen (1977) and McElhinny (1977) respectively discuss the seismic and magnetic properties of these rocks at the end of the first section.

Problems Still Left for Drilling in the Indian Ocean

Because of serious weather constraints no serious drilling was attempted in the Indian Ocean south of 40°S and west of 110°E. As a result of this we know very little about the Crozet and Kerguelan Plateaus and have no sites in the Crozet Basin to compare with the sites in the Australia/Antarctic Basin further to the east. This absence of sites leads to serious problems in interpreting the pre-Oligocene circulation patterns in the ocean. Also, there is an absence of high latitude sites in the southern ocean in either shallow or deep water. Thus there is a lack of a continuous shallow water carbonate reference core close to Antarctica and an absence near the Antarctic coast of sites that would help elucidate the glacial history of Antarctica and the westward flow of bottom water from the Weddell Sea into the Indian and Pacific Basins. Further problems that are of interest to resolve are the carbonate sedimentary history on either side of the major ridge systems, deep drilling on the Madagascar Ridge to check if it is continental or not, and finally some deep penetration drilling on the aseismic ridges to examine their origin. It is hoped that in a later phase of the Deep Sea Drilling Project an attempt will be made to undertake each of these problems.

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