49. TECTONIC AND PALEOGEOGRAPHIC SYNTHESIS OF LEG 27[1]

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INTRODUCTION

Most of the cores recovered from the four deep-sea sites on Leg 27 are Late Jurassic and Early Cretaceous in age, so that it is to the history of this restricted interval that most of our information applies. This was the time of initial break-up of Gondwanaland. Because of the paucity of sea-floor-spreading magnetic anomalies of this age, the drilling results of Leg 27 provide the most comprehensive record of this event.

McKenzie and Sclater (1971) deal with the evolution of the Indian Ocean since the Late Cretaceous and thus do not touch on the earlier Mesozoic evolution recorded at the eastern edge of the ocean.

Two hypotheses regarding the tectonics of the eastern Indian Ocean have been recently published. Veevers et al. (1971) postulated that continental separation by sea-floor spreading off southwest Australia was in a westerly direction normal to the north-trending Darling Fault; Falvey (1972) and Johnstone et al. (1973) postulated that separation was in a northwest direction, along a transform fault marked by the present Wallaby-Perth scarp. New information from the ocean floor off southwest Australia presented below favors Falvey's (1972) general view that spreading was towards the northwest. In fact, our reconstructions follow Falvey's (1972) scheme, except that we reverse the order of events; spreading started in the northwest and extended later to the southwest.

GEOLOGICAL AND GEOPHYSICAL DATA

This tectonic and paleogeographic synthesis of the eastern Indian Ocean and the adjacent continental margin is based on the following data:

1) The basement ages and paleo-oceanographic implications of Sites 259, 260, 261, and 263;

2) The variations in thickness of the Late Jurassic and Early Cretaceous claystone layer that drapes oceanic basalt;

3) The correlations between oceanic and continental geology;

4) Sea-floor-spreading magnetic anomalies;

5) Physiographic lineaments of the oceanic floor; and

6) The fracture pattern of the adjacent continent.

Each of these sets of data is discussed in turn below.

1) The basement ages of the oceanic sites of Leg 27 are derived from the ages of the oldest datable sediment recovered, as given in Table 1.

Oceanic basement was not reached at Sites 260 and 263. Acoustic basement at Site 260 is a basalt sill overlain by middle Albian sediments. A set of sea-floor-spreading magnetic anomalies (Falvey, 1972) suggests that oceanic basement at Site 260 is slightly older than that at Site 261, and an age of 155 m.y. is adopted. The bottom of Site 263 is thought to be within a short distance of acoustic basement, and the age of the oldest sediment recovered is, therefore, taken to approximate the age of the basement. According to the evidence provided by dinoflagellates or nannofossils, this age is 115 m.y. or 103 m.y.

With allowance for the inferred spreading directions and rates, and for the distance of each site from the oceanic margin, the best estimates of the inception of spreading in the region of the sites are given in Table 2.

The paleobathymetry is clear at Site 263 only: the lower part of the penetrated section is a deposit of shallow-water origin and is succeeded by deeper-water sediment.

2) In the eastern Indian Ocean, sea floor older than Late Cretaceous (>100 m.y.) has not been found west of long 100°E; or, in other words, the Late Jurassic and Early Cretaceous claystone layer is thickest at the eastern margin of the ocean, against Australia, and it wedges out in a generally westerly direction.

3) Site 263 is linked stratigraphically and structurally with the adjacent continental margin, and Site 259 is linked stratigraphically. These stratigraphic links reflect the similar history of the regions sampled by these sites and the adjacent continental margin.

4) Falvey (1972) described a set of magnetic anomalies from the Gascoyne and Argo Abyssal plains and identified them with anomalies 23 to 32 of the Heirtzler et al. (1968) scale. Drilling at Site 261 showed that these identifications are wrong—the oldest anomaly is about 160 m.y. (not 75 m.y.) old—but the anomalies are nonetheless useful in indicating the trend of spreading. Falvey (1972) determined a pole of rotation from the anomalies. We used this pole in our reconstructions, but are conscious that much more evidence is required to define it precisely.

Heirtzler (this volume) mentions a group of northeast-trending magnetic anomalies from the region west of Perth that probably indicate the trend of spreading here.

5) West and northwest of Perth there is a set of small, northwest-trending sea-floor ridges (shown in the Atlas of the International Indian Ocean Expeditions, Wyrtki, 1971) of unknown origin. They lie at right angles to the trend of the magnetic anomalies 500 km to the southeast and are presumed to mark the direction of spreading.

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TABLE 1
Oldest Datable Recovered Sediment

Site	Age: Stratigraphic	Age: m.y.B.P.	Remarks	
259	Earliest Aptian	112	Age of sediment immediately above oceanic basalt basement	
260	Middle Albian	105	Age of sediment immediately above basalt sill	
261	Late Oxfordian	152	Age of sediment immediately above sill that overlies oceanic basalt basement	
263	Barremian or middle Albian	115 or	According to evidence from dinoflagellates	basalt not reached
		103	According to evidence from nannofossils	

TABLE 2
Position Spreading Path and Calculated Age of Rifting

Site	Distance (km)[a]	Time (m.y.)[b]	Age (m.y.B.P.)[c]
259	330	11	123 Hauterivian
261	220	7	159 Callovian
263	30	1	116 Barremian or 104 Albian

[a]Along spreading direction from oceanic margin.

[b]Required to generate this distance of sea floor at assumed rate.

[c]Of inception of oceanic margin

6) Veevers and Johnstone, and Veevers and Heirtzler (this volume) describe the chief continental and continental-oceanic lineaments, including the Wallaby-Perth scarp, and the scarps bounding the southwest and northeast sides of the Cuvier Abyssal Plain. Since the main set of orthogonal northwest and northeast trends on the continent and continental margin lies parallel to the magnetic and physiographic lineaments of the ocean floor, we assume that the continental lineaments may be used as guides to the direction of spreading.

Certain assumptions had to be made beyond the material described above. The Wallaby Plateaus are assumed to be continental in structure. The only evidence of this is the seismic profile of part of the Wallaby Plateaus shown by Veevers and Heirtzler (this volume), which corresponds with that of the Exmouth Plateau. The southwest part of the region (west and northwest of the Naturaliste Plateau, which is also assumed to be continental) is assumed from the complex pattern of magnetic anomalies to be made up of several narrow compartments of oceanic crust bounded by fracture zones. The basement ages of Sites 256 and 257 (Leg 26) in this region were not used in the detailed reconstructions, but are generally consistent with the notion of northwest spreading in several narrow transform-fault bounded blocks.

The rates of spreading have had to be assumed since the magnetic anomalies in the northwest are not clearly identifiable with any standard set of anomalies, and no compartment bounded by fracture zones has more than one drilling site. A second basic assumption is that the lineaments of the continental edge are guides to the direction of spreading.

These uncertainties show clearly that our synthesis is preliminary only and that most details away from the drilling sites are tentative. Despite these limitations we believe that the reconstructions are of value in suggesting the main lines of geological development and should provide a rational starting point for any future work in the region.

The following synthesis, embodied in a set of reconstructions, stems from the ideas presented above. The present coastline and 4-km isobath shown in Figure 1, and present geographic terms, such as Timor and Exmouth Plateau, are used solely for reference purposes and carry no paleogeographic implications.

RECONSTRUCTIONS

Callovian—160 m.y. (Figure 1)

As shown by the age of basement at Site 261 (and Site 260 also, by magnetic correlation with Site 261), sea floor was first generated in the Callovian along trends denoted by Falvey's (1972) magnetic anomalies, which define a pole of rotation off the eastern tip of Timor. The transform faults shown in Figure 1 are hypothetical. The southernmost one corresponds to the scarp along the northeast side of the Cuvier Abyssal Plain.

Timor had just emerged from a marine episode that lasted from the middle Triassic to the end of the middle Jurassic, when it underwent a phase of folding, called the Betanean by Audley-Charles (1968). The Exmouth Plateau stood high at this time (Veevers et al., in press) and shed sediment (including part of the basinal Dingo Claystone and neritic Learmonth Formation, and the seaward facies of the Wallal Sandstone in Bedout-1 Well) into a trough on its landward side. The rest of the region was elevated above sea level.

There is no obvious sign of land northwest of the spreading ridge. As argued by Veevers et al. (1971), the long history of marine deposition along the northwest margin of Australia indicates proximity to an ocean, which also provided a source of the epicontinental trough sea behind the Exmouth Plateau. We conclude, therefore, that the spreading ridge was initiated at, or close to, the previous continental margin along the edge of Tethys. The rest of the region shown in Figure 1 was land, including parts of Antarctica and India.

Late Oxfordian—152 m.y. (Figure 1B)

From the Callovian to the late Oxfordian, the sea floor between the dotted lines in Figure 2 was generated by sea-floor spreading at an assumed half-rate of 1.25°/m.y. (equivalent to 3.5 cm/yr in the Argo Abyssal Plain). The Timor/Ashmore Reef area remained elevated above sea level, as perhaps did the Exmouth Plateau (Veevers et al., in press), but behind the half-arch of this elevated land the epicontinental sea expanded westward into the onshore Canning Basin to deposit the Alexander Formation and Jarlemai Siltstone (McWhae et al., 1958; Veevers and Wells, 1961). It also expanded northward and locally broke through the half-arch to connect with the widening Tethys, which, judging from its calcareous deposits on the ridge crest at Site 261, was probably temperate to warm.

Earliest Cretaceous—136 m.y. (Figure 1C)

Spreading continued, basalt erupted at Scott Reef and Ashmore Reef, and the epicontinental sea expanded landward.

Hauterivian—120 m.y. (Figure 1D)

A new regime of spreading started at this time. After a history of continuous rifting since the late Carboniferous (Veevers, 1971; Johnstone et al., 1973), the southwest margin ruptured near Perth and Northwest Cape, and probably immediately west of the Wallaby Plateaus. The direction of subsequent spreading is suggested by the trends of (a) the magnetic anomalies west of Perth, (b) the oceanic ridges south of the Wallaby Plateaus, (c) the Wallaby-Perth scarp, and (d) the southeast and northeast borders of the Cuvier Abyssal Plain. These trends are broadly consistent with a pole of rotation in the region of lat 60°S, long 75°E. This interpretation uses the older of the two possible ages for the base of Site 263—the younger age provides the other interpretation shown in Figure 5.

Rupture was manifested by the rearrangement of horsts and grabens that produced the intra-Neocomian unconformity, the eruption of the Bunbury Basalt along the landward extension of the fracture zone delineated by the Wallaby-Perth scarp, and the first marine incursion in the southern Perth Basin (presumably linked beneath the present margin to the ocean or epicontinental sea of the northwest margin).

Aptian—112 m.y. (Figure 1E)

By the beginning of the Aptian, three small ocean basins had opened at an assumed half-rate of 1°/m.y. Being largely land-locked, these basins accumulated dominantly detrital sediments, and at Site 263, the sediments of this age represent the distal part of the neritic transgressive sand and shale of Pendock-1 well and neighboring region.

The half-arch of the outer northwest margin, including Timor, is now below sea level. The epicontinental sea covered the entire margin (except for locally uplifted areas such as the Ashmore/Sahul Shoals area) and an epeiric sea covered much of the continental interior (Veevers and Evans, 1973). This Australia-wide Aptian transgression and the inundation of the half-arch are of the same age. How the two are related, if at all, is unclear.

The continental crust separated from western Australia by the newly generated sea floor is taken to mark the first appearance of India as a separate entity. By India, we imply nothing more specific than a continental mass once including the blocks of India, Broken Ridge, and Kerguelen Plateau.

Albian—106 m.y. (Figure 1F)

The ocean basins off the southwest continued to spread, and a correspondingly greater circulation of their waters led to a decreasing amount of organic carbon and an increasing amount of carbonate deposited in the bottom sediments, as seen at Sites 259 and 263. The retreat of the sea from the Canning Basin was probably due to the uplift of the interior of the Australian continent (Veevers and Evans, 1973).

Cenomanian—100 m.y. (Figure 1G)

With continued spreading off the southwest, India was isolated from Australia and Antarctica, and the entire margin became fully oceanic, with the main oceanic circulation dominated by a current from the south. As a result of rifting between Australia and Antarctica that started in the Late Jurassic, a shallow arm of the sea spread as far east as the Eucla Basin on the southern Australian margin.

The foregoing interpretation uses the older age for Site 263. The alternative younger age for Site 263 is adopted in the reconstruction for the Cenomanian shown in Figure 2. The only difference from the corresponding Figure 1G is that the Cuvier Abyssal Plain was generated some 12 m.y. later in the Albian, so that by the Cenomanian this ocean basin was still narrow.

Santonian—80 m.y. (Figure 1H)

By the Santonian, the shallow sea over the Australia-Antarctica boundary may have penetrated eastward to the Pacific, causing a major change in circulation. The west-wind drift possibly passed along this channel, and currents from the north brought warmer water to the Western Australian margin. A hiatus in deposition occurred during this change (generally in the Turonian and Coniacian—see fig.4 of Veevers and Johnstone, this volume), and by the Santonian, carbonate sediment was deposited along the entire continental margin. Except for a regional hiatus in the Danian, possibly reflecting circulation disturbances connected with the inception of sea-floor spreading between Australia and Antarctica in the late Paleocene (Weissel and Hayes, 1972), carbonate sediment has continued to be deposited along the western margin to the present day and has been the source of the displaced carbonate sediment that makes up the horizontally stratified surface layer of the abyssal plains.

ACKNOWLEDGMENT

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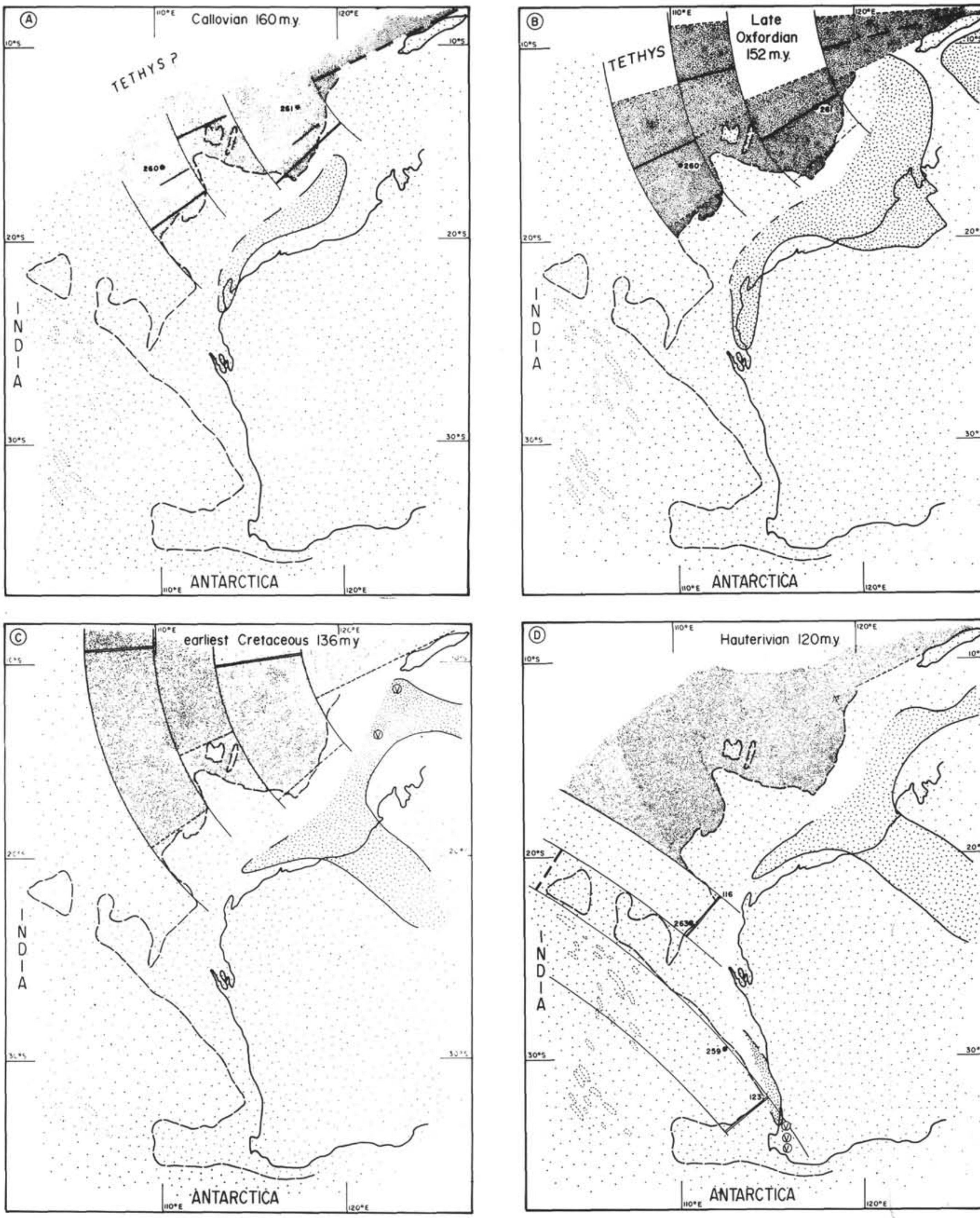
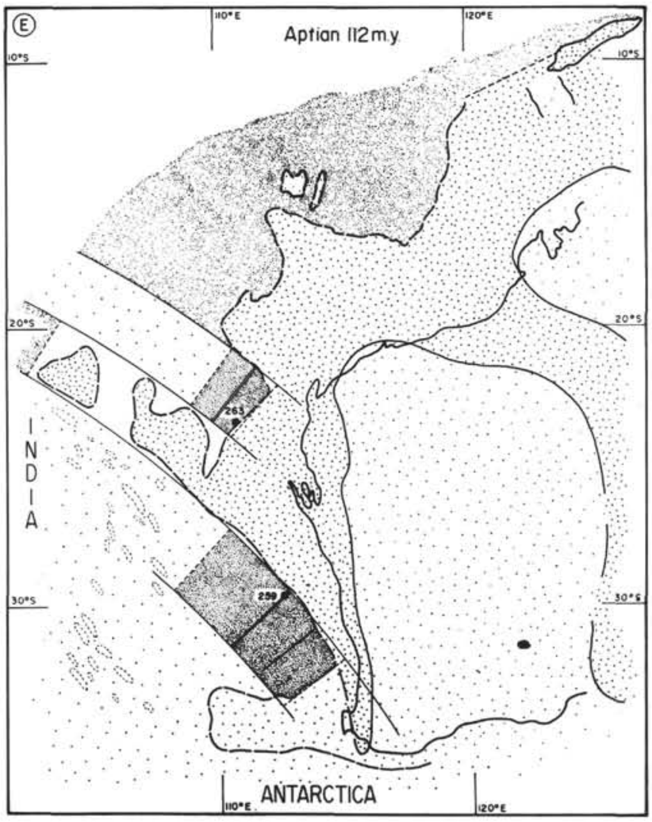
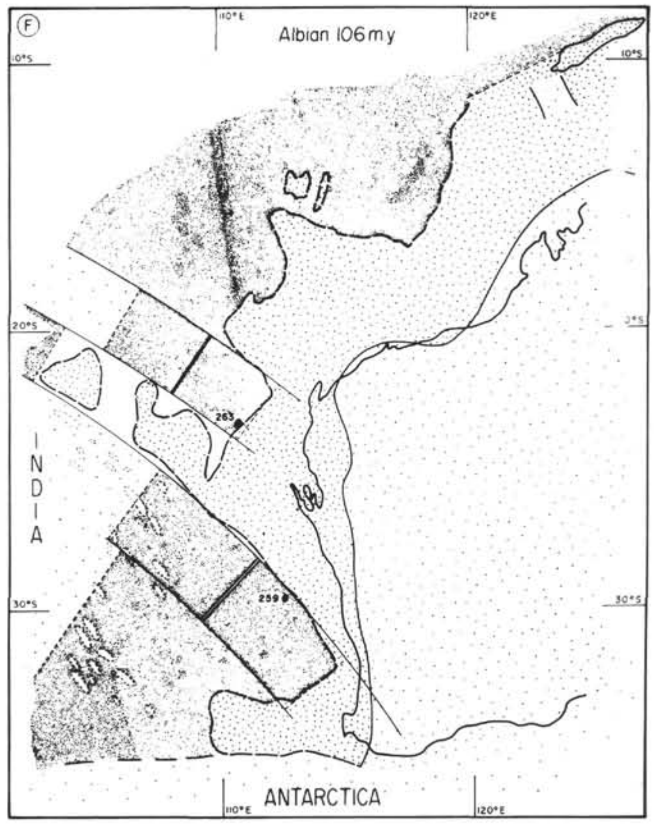
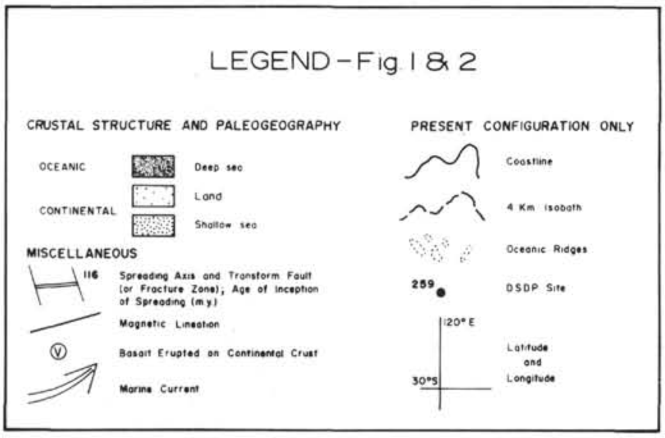


Figure 1. *Tectonic and paleogeographic reconstructions for the eastern Indian Ocean: (A) Callovian (160 m.y.), (B) Late Oxfordian (152 m.y.), (C) earliest Cretaceous (136 m.y.), (D) Hauterivian (120 m.y.), (E) Aptian (112 m.y.), (F) Albian (106 m.y.), (G) Cenomanian (100 m.y.), (H) Santonian (80 m.y.).*







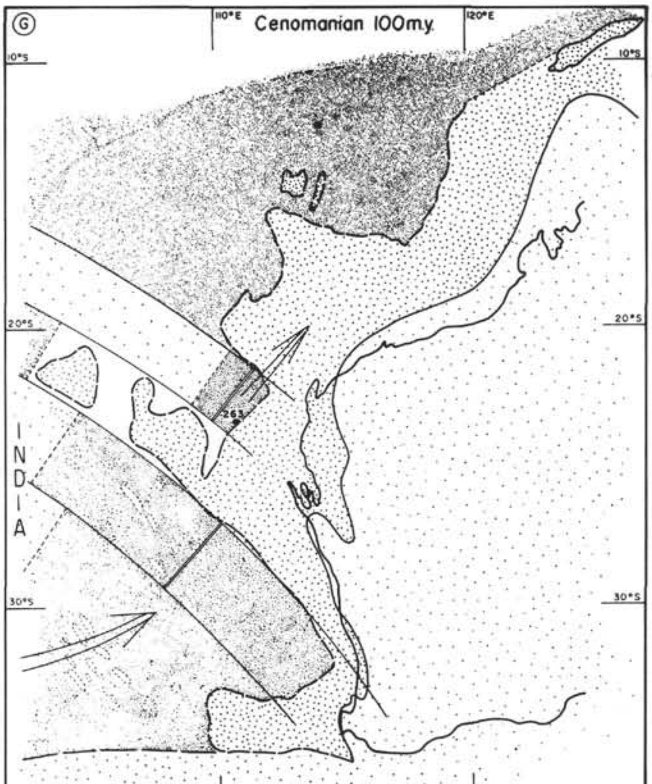


Figure 1. *(Continued).*

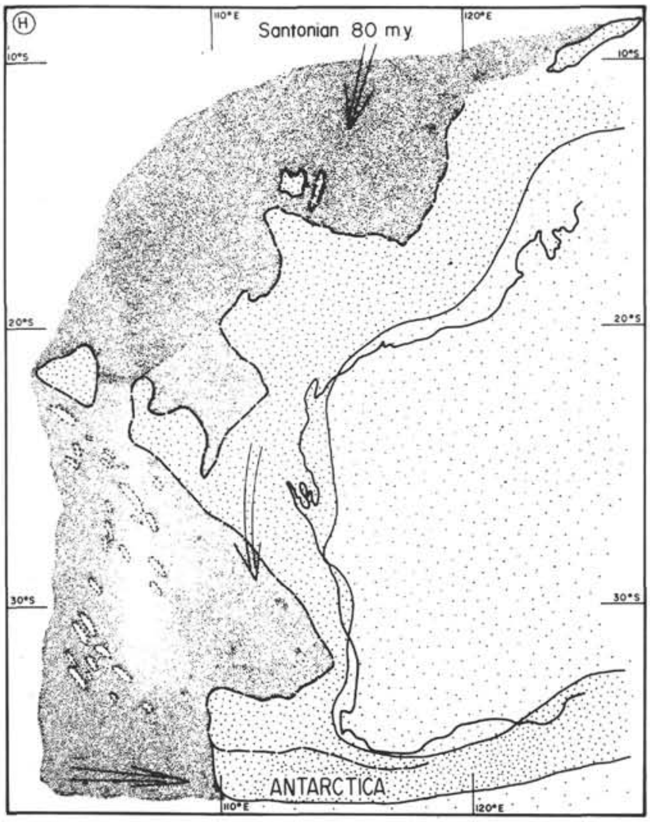


Figure 1. *(Continued).*

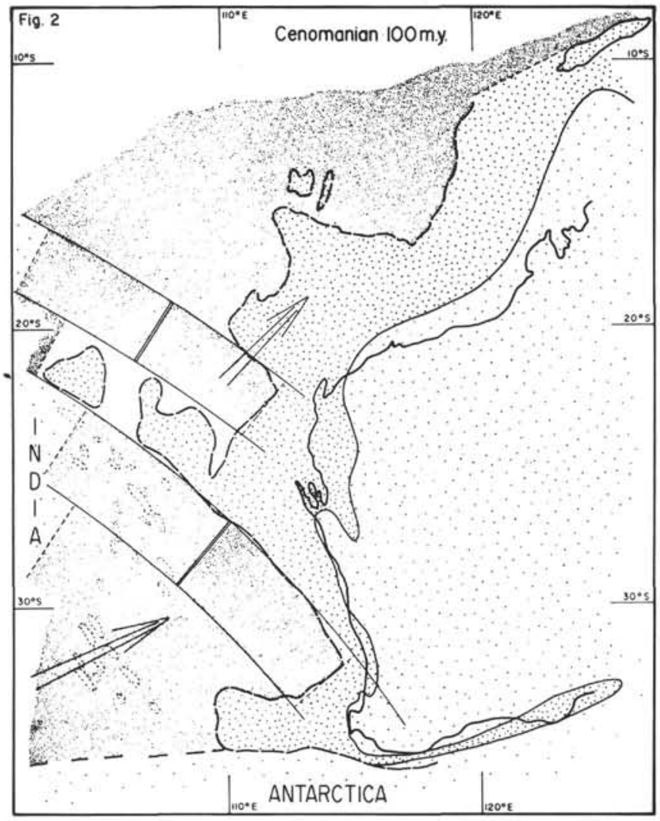


Figure 2. *Tectonic and paleogeographic reconstruction for the eastern Indian Ocean for the Cenomanian (100 m.y.).*

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