The present relief of the Atlas Mountains is the result of selective reactivation of Mesozoic faults by late Tertiary and Quaternary tectonics. These late movements probably remobilized the Mesozoic salt, producing higher elevations over the salt-filled grabens.

The late Cenozoic stresses have their greatest release where Mesozoic carbonates and clastics bordered Paleozoic or Precambrian metamorphic and igneous complexes. The present High Atlas Mountains were activated along faults parallel to the Mediterranean trend, where the Precambrian is contiguous to the Mesozoic carbonates (Fig. 3). The same geological situation pertains to the Middle Atlas Mountains, which are contiguous to the metamorphosed Paleozoic rocks of the Moroccan Meseta.

Tensile stresses were dominant in Morocco during the early Mesozoic. The orientation of the fault planes suggests that the tension was connected with the opening of the Atlantic and the Mediterranean. These faults became dormant or subdued during the Jurassic, when the area was subjected to marine inundation that blanketed the earlier facies and structures with limestones. By Late Jurassic, sufficient new crust had been added to isolate Morocco from the dynamics of sea floor spreading. The tensional tectonic style of the earlier Mesozoic suggests that, even then, the area was marginal to the zone of spreading.

Much of the pre-Mesozoic "basement" consists of thermally metamorphosed and intruded Paleozoic strata. In fact, strata as young as Westphalian (*2, 4*) have been affected, as well as older sediments. These metamorphosed terranes have been termed "Hercynian" (*2, 3*) (a mid-Carboniferous orogeny) whereas they have a much more complex and long-ranging history.

It seems likely that thermal events, with attendant orogeny, immediately preceded Mesozoic tension. If we assume that this tension represents the closing phase of African involvement in continental drift, then the preceding thermal events may represent the effects of early intrusions into the continental crust as the zone of spreading was initiated. A similar sequence of metamorphism followed by tensional faulting has been described for a portion of Baja California, an area presently undergoing drift (*10*).

If it is assumed that both the earlier thermal events and the later tensional events are the sequential results developed in response to a zone of spreading, then more than 100 million years were required for mantle dynamics to break up this portion of Pangea.

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Age of the Floor of the Eastern Indian Ocean

Abstract. *Deep sea drilling in the eastern Indian Ocean shows that the oceanic crust off Western Australia is approximately 140 million years old and becomes younger to the west; this dates the initial opening of the Indian Ocean.*

In the reconstruction of continents to restore the ancient supercontinent of Gondwanaland the positions of the continents around the Indian Ocean have been especially enigmatic. Several papers have suggested fits of the continents based mainly on a fit of the margins of bordering continents (*1*), on extrapolations of marine geophysical structure to the edges of the ocean (*2, 3*), and on geological similarities of bordering continents (*4*). These studies indicate that the Indian Ocean has opened by the mechanism of sea floor spreading and continental drift, but with complications caused by the existence of more than one major spreading pattern. The marine geophysical record since the beginning of the Tertiary or the Late Cretaceous (the last 75 million years) has clarified the more recent history of the ocean. Before that time the record is obscure. Recognizable linear magnetic anomalies are useful for dating sea floor younger than about 75 million years, but linear magnetic features can rarely be recognized in the area that is presumably older. Accordingly, the age of initial rifting of the bordering continents and the direction of their initial movement have been matters of controversy.

On leg 27 of the Deep Sea Drilling Project (*5*) a series of holes have been drilled through the sediment cover and to the ocean basement in the area off Western Australia—an area which was previously thought to be the oldest in the Indian Ocean, if not in all the oceans of the world (*6*). Five holes were drilled during November and December of 1972 (*7*). The results for four of these are relevant to the question of the age of the sea floor (*8*). In addition, on leg 22 of the project holes were drilled in and near the Wharton Basin, and these help to define age gradients in the oceanic crust (*9*). Figure 1 shows the location of these holes and Table 1 gives the ages found or extrapolated for the sediments immediately above the basaltic basement.

Using the set of basal ages given in Table 1, one may draw a general set of isochron lines through the eastern Indian Ocean, as shown in Fig. 1.

Those lines show an age of Tithonian (or latest Jurassic, about 140 million years) for the initial rifting of Western Australia. Isochron lines drawn in the curvature of the western edge of the Australian continent (*10*) conform to the ages obtained by the drilling, which suggests that the continent that abutted Australia (India?) moved in a generally westerly direction for about 80 million years after rifting (*11*).

There are few other marine data from the eastern Indian Ocean to substantiate these general age contours. Falvey (*3*) discovered magnetic trends that are parallel to these isochrons in the Argo Abyssal Plain, although he apparently incorrectly identified the magnetic anomalies when he assigned ages of 55 to 75 million years to them.

Although considerable other marine magnetic data now exist off Western Australia it has been difficult to follow magnetic trends over any appreciable distance. This suggests that the general area may comprise a number of smaller tectonic plates separated by fracture zones which are now relatively inactive. If this is the case then the age contours shown in Fig. 1 only approximate the detailed age structure. The Cuvier Abyssal Plain may be a small plate since it is located between the Wallaby Plateaus, which have the general appearance of a continental fragment, and the Exmouth Plateau, which is known to be mostly continental. This may be the reason that the 140-million-year isochron cannot be extended to near site 263. To the immediate west of Perth, at 32°S, magnetic trends run counter to the isochron lines if the lines are extrapolated into that area.

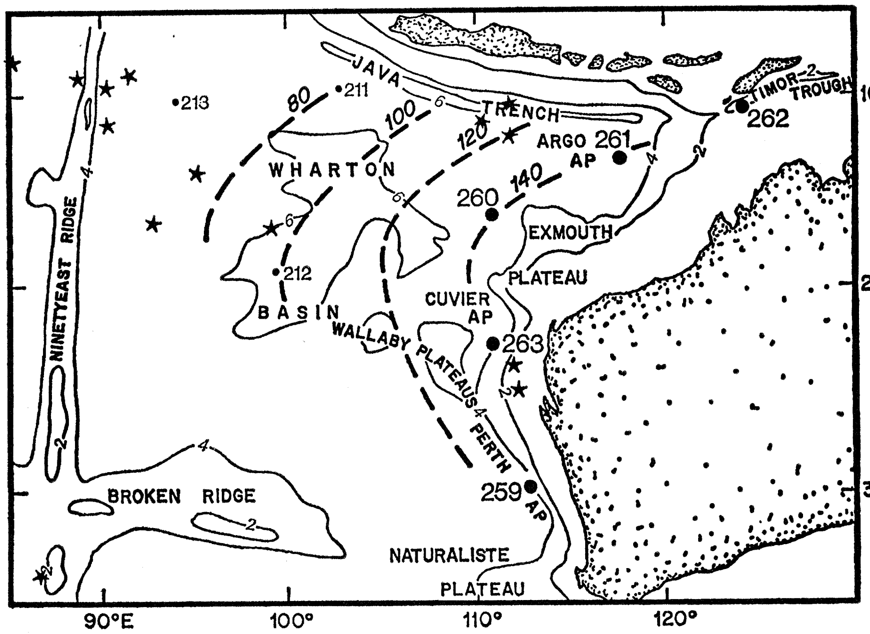

Fig. 1. Map of the eastern Indian Ocean showing drill sites for leg 27 (large dots) and leg 22 (small dots) of the Deep Sea Drilling Project and estimated age of the ocean floor in millions of years (dashed lines). Stars indicate the locations of precisely located earthquakes, excluding those near the Indonesian Arc, for the period before 1966 (*12*). Continuous lines show water depths in kilometers. Abyssal plain is abbreviated AP.

A few earthquake epicenters are found scattered about a line that extends from the Cuvier Abyssal Plain in a northwesterly direction to Ninetyeast Ridge. Sykes (*12*) suggested that these epicenters could be a nascent island arc. It would appear, alternately, that these epicenters could define a mildly active transform fault. The abrupt scarp at the northern face of the Wallaby Plateaus and topographic features in the Wharton Basin lend tenuous support to this hypothesis. Slippage of small tectonic plates along this fault as continents separated could make a detailed refitting of continental margins more complex than had been previously assumed.

Cretaceous clays and oozes drape the basalt basement, have a thickness of 200 to 300 m near Australia, and grade to zero thickness near the center of the Wharton Basin. Contours of Cretaceous sediment thickness will very nearly parallel the age contours shown in Fig. 1. These extensive Cretaceous sediments are unconformably overlain by horizontally stratified turbidites.

Reports on the nature of the sedimentary column and the underlying basalt as found in these cruises of the Deep Sea Drilling Project will be published after studies now being undertaken have been completed. The

Table 1. Lowermost sediments above basalt. The abbreviation m.y. is used for million years.

Site	Water depth (m)	Depth below sea floor (m)	Geologic age	Age (m.y.)	Principal basis of age determination; comments
211	5535	428.5	Late Cretaceous (earliest Maastrichtian to earliest Campanian)	75	(*9*)
212	6243	516	Close to Early Cretaceous–Late Cretaceous boundary	85–110	Late Cretaceous (65 to 100 m.y.) sediments dated 30 m above basalt (*8*).
213	5611	152	Late Paleocene	54–58	(*9*)
259	4712	307.5	Early Cretaceous (Barremian or older)	118–136	Basalt altered, probably rapidly quenched with seawater during rifting. Calpionellid microfossils.
260	5709	323	Early Cretaceous (Berriasian)	136	Basalt probably a sill. Nannofossils: *Polycostella senaria* and *P. beckmanni.*
261	5687	532.5	Early Cretaceous–Late Jurassic (Berriasian–Tithonian)	140	Fine-grained basalt including pillow basalt. *Coccolithus deflandrei, Nannoconus colomi,* and diverse calcareous and arenaceous benthonic foraminifera.
263	5065	780 (est.)	Early Cretaceous (Late Albian)	100	Basalt not reached: 746 m of sediment drilled before mechanical problem forced site to be abandoned, estimated 4 m to basement. Nannoplankton with *Eiffelithus turriseiffeli* indicates Late Albian.

oceanic basement off northwest Australia is some of the oldest yet found and approaches the age found in the western North Atlantic (*13*).

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5. The Deep Sea Drilling Project is a joint project of five oceanographic institutions in the United States and is funded by the National Science Foundation. Its purpose is to drill deep holes in the sea floor for geological research.
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8. A fifth hole was drilled in the Timor Trough, which is underlain by continental crust.
9. C. von der Borch *et al.*, *Geotimes* (June 1972), p. 15; in leg 22 initial report, in preparation. On leg 26 holes were drilled in the eastern Indian Ocean, but the results have not yet been published.
10. The edge of the Australian continental block includes the Naturaliste Plateau [T. J. G. Francis and R. W. Raitt, *J. Geophys. Res.* **72**, 3015 (1967)], the Exmouth Plateau, and the Sahul Shelf [J. J. Veevers, *Palaeogeogr. Palaeoclimatol. Palaeoecol.* **6**, 125 (1969)], which extends from Timor to the northwestern Australian coastline.
11. Australia was attached to Antarctica until about 55 million years ago, at which time it started moving north and away from Antarctica.
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14. We would like to thank Captain J. A. Clarke, Master of *Glomar Challenger*, and the ship's crew; J. A. Ruddell, Drilling Superintendent, and his crew; C. A. Morris, Operations Manager; T. B. Gustafson; all the Deep Sea Drilling technical staff; and Dr. N. T. Edgar, Chief Scientist of the Deep Sea Drilling Project for considerable assistance. We also wish to thank the Bureau of Mineral Resources (Australia), Lamont-Doherty Geological Observatory of Columbia University, and the University of New South Wales for supplying seismic data prior to drilling. Contribution No. 2966 of the Woods Hole Oceanographic Institution.

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Laser Transit-Time Measurements between the Earth and the Moon with a Transportable System

Abstract. *A high-radiance, pulsed laser system with a transportable transmitting unit was used at Agassiz Station, Harvard College Observatory, Harvard, Massachusetts, to measure the transit times of 25-nanosecond, 10-joule, 530-nanometer pulses from the earth to the Apollo 15 retroreflector on the moon and back.*

On 23 September 1972, the transit time of a laser pulse from the earth to the moon and back was measured six times at Agassiz Station, Harvard College Observatory, Harvard, Massachusetts. The laser pulse was directed to the Apollo 15 retroreflector on the moon by a transportable transmitting unit located 237 m from the 1.5-m telescope used to detect the returning pulse. All six transit times were measured with a combination of delay circuits and a fast oscilloscope. Three of these returns, which were stronger than the rest, were also measured more precisely with a time-interval counter.

Residuals for all the measured transit times were calculated from a special ephemeris at the University of Texas (*1*). These residuals (observed values minus the computed values) tended to increase with epoch (time of transmission of the laser pulse) over the period from $6^h\ 36^m$ to $8^h\ 12^m$ universal time during which they were obtained.

The best-fitting straight line through the residuals from the counter readings had a slope of $+0.35$ nsec/min with a standard deviation of 3.1 nsec. The best line through the residuals of the six oscilloscope readings had a slope of $+0.18$ nsec/min with a standard deviation of 2.5 nsec. The differences in the results from the two sets of data are not significant.

The slope of the straight line through the residuals is related to the error in the station's geocentric coordinates. If one assumes the error to be entirely in latitude, the local hour angle of these observations implies that a slope of 1 nsec/min corresponds to 1 arc sec, or 23 m at the station's 42.5° latitude. Hence, the slopes are consistent, with an error of about 15 m expected in the conversion of the station's coordinates from the North American Datum to a geocentric system.

The configuration of the transportable laser system, which can be used with other large telescopes, has been described elsewhere (*2*). The exceptionally high radiance of the system's neodymium-glass laser permits the use of a transmitting telescope, the diameter of whose aperture is only 0.2 m. It also increases the probability that each return generates at least one photoelectron. The system's pulse repetition rate is 0.2 per minute. A further report on its operation will be presented elsewhere (*3*).

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