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Physiography of the Indian Ocean

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Physiography of the Indian Ocean

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As a result of the International Indian Ocean Expedition, the bottom of the Indian Ocean is now one of the best known areas of the ocean floor.

The Mid-Indian Ocean Ridge, a rugged mountain range, lies in the centre of the Indian Ocean. North-northeast trending fractures offset the axis of the ridge. In the Arabian Sea these fractures are right lateral; in the southwest Indian Ocean they are left lateral. Displacements range from a few miles* to over 200 miles.

The northeast Arabian Sea and the Bay of Bengal are occupied by huge abyssal cones built by sediments discharged from the Indo-Gangetic plain. Extensive abyssal plains lie seaward of the abyssal cones.

In low latitudes smooth topography is characteristic of the continental rise, the abyssal cones, and the oceanic rises. However, near the polar front smooth 'swale' topography laps over the normally rugged Mid-Oceanic Ridge. This 'swale' smoothing appears the result of the higher organic productivity of the Antarctic seas.

Microcontinents, mostly linear meridional ridges, are unique features of the Indian Ocean. These massive but smooth-surfaced blocks contrast markedly with the broad rugged Mid-Oceanic Ridge.

Introduction

The sounding profiles used in this study (figure 1) were obtained primarily by oceanographic research vessels and hydrographic survey ships. Three types of soundings are included:

(1) *Continuous precision echograms*. This category includes all modern high-resolution echograms. All soundings obtained by *Discovery*, *Vema*, *Dalrymple*, *Conrad*, *Atlantis*, *Atlantis II*, *Owen*, *Argo*, *Horizon*, *Chain*, *Pioneer*, and *Pathfinder* are in this group. Accuracy is better than 1 part in 3000; soundings were made once each second or approximately 15 ft. apart.

(2) *Non-precision continuous echograms*. This category includes soundings obtained with older commercial or naval-type sounders in which high resolution and precision in timing were not incorporated. Such soundings may be used for the interpretation of the higher relief but must be used with caution in the smooth areas of the ocean.

(3) *Discrete soundings*. Included in this category are soundings which were more widely spaced either because they were made as discrete observations or because the echogram was read at widely spaced points and the original records are not available for this study.

The preparation of a physiographic diagram of the Indian Ocean was initiated as an aid in defining the geological-geophysical objectives of the Indian Ocean Expedition. The resulting diagram published during the later stages of the expedition incorporates much of the data collected during the expedition (Heezen & Tharp 1964).

* Throughout this Discussion the unit 'mile' and the abbreviation 'mi' refer to the nautical mile.

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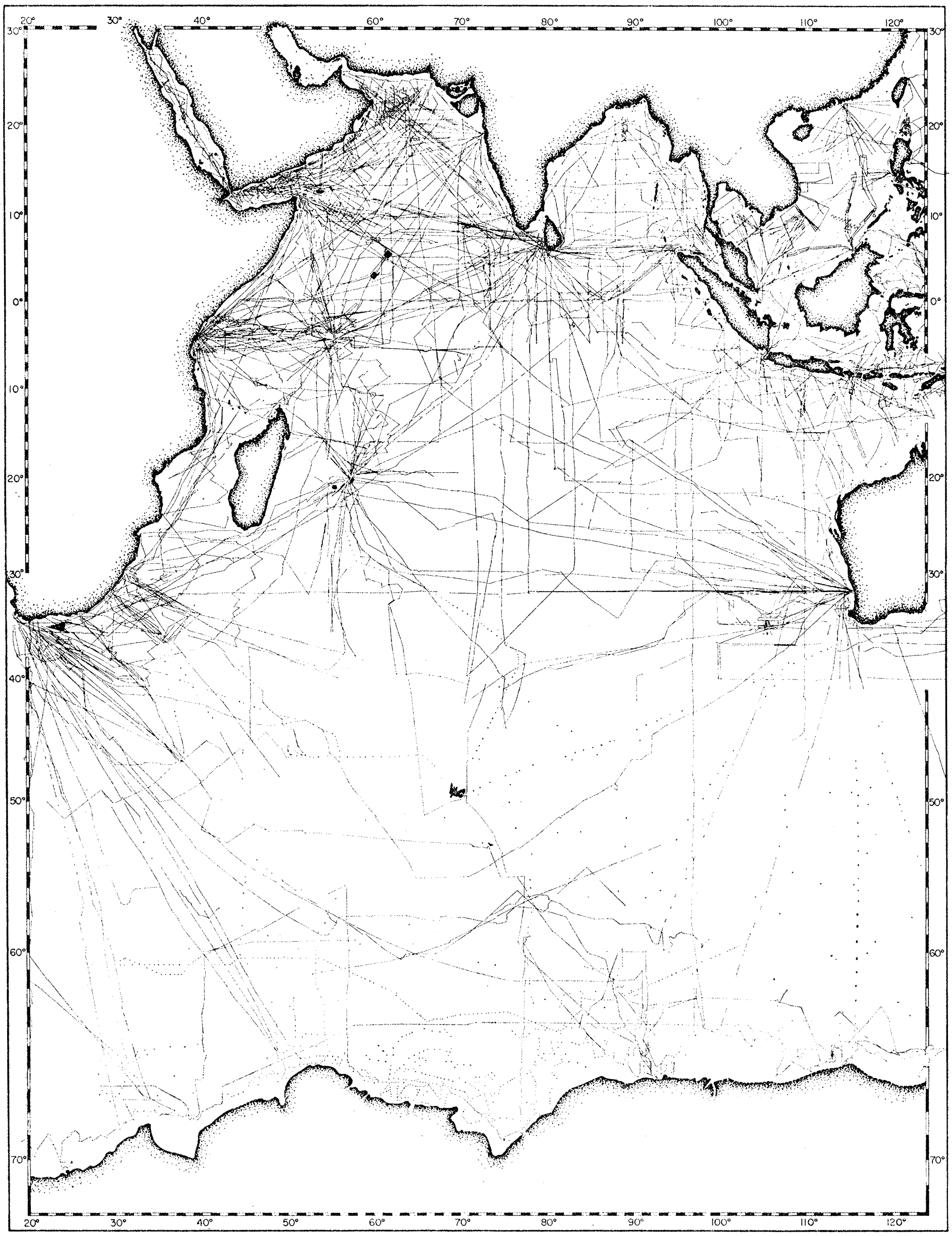

FIGURE 1. Echo sounding profiles in Indian Ocean.

PHYSIOGRAPHY

There are four major divisions of the physiographic regions of the Indian Ocean (figures 2 and 3).

(a) *Continental margin*

Category I (Heezen, Tharp & Ewing 1959) includes the continental shelf, which surrounds all continents and ranges in width from a few hundred metres around some oceanic islands to more than 200 km off Bombay (figures 4 and 5).

The continental shelves of the Indian Ocean are somewhat narrower on the average than those of the Atlantic. The depth of shelf break that forms the outer edge of the continental shelf of Asia, Africa, and Australia averaged 140 m. The shelf break of Antarctica usually exceeds 350 m and generally lies between 300 and 500 m.

FIGURE 2. Physiographic provinces of Indian Ocean.

Category II provinces including the continental slope, the marginal escarpments, and the landward slopes of trenches mark the boundaries of the continental blocks. Prominent features of the continental slope include benches and submarine canyons.

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FIGURE 3. Bathymetric sketch of the Indian Ocean. This sketch map was originally drawn at a scale of 1:10 million. The contours are necessarily generalized. In the rugged topography of the Mid-Oceanic Ridge only approximate stylized contour trends are shown, whereas on the abyssal cones, abyssal plains, and the continental rise the contours are more detailed and more closely represent the actual configuration of the sea floor. Contour maps of various portions of the Indian Ocean prepared by A. S. Laughton, D. H. Matthews, R. L. Fisher, G. L. Johnson, E. S. Simpson and J. K. Mallory and E. Westall, J. L. Faughn, V. Kanaiv, A. V. Zhivago, G. Udintsev and D. Krause were used in a supplementary fashion. (Depths in km; contour interval 0·25, 0·5 and 1·0 km.)

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Numerous submarine canyons indent the continental slope. Prominent submarine canyons have been discovered off the Ganges and Indus rivers (figures 4 and 5). Several prominent canyons occur off the Kenya and Tanganyika coasts. Several canyons on the

FIGURE 4. The Arabian Sea. A portion of the Physiographic Diagram of the Indian Ocean, published by the Geological Society of America (copyright 1964 by Bruce C. Heezen and Marie Tharp: reproduced by permission). (Depths in metres.)

FIGURE 5. The Bay of Bengal and Indonesian Arc. A portion of the Physiographic Diagram of the Indian Ocean, published by the Geological Society of America (copyright 1964 by Bruce C. Heezen and Marie Tharp; reproduced by permission). (Depths in metres.)

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continental slopes of Ceylon and India have recently been investigated. The continental slopes of the Indian Ocean have been explored to such a small extent that it is probable that only a small fraction of the total number of canyons have been detected.

Category III includes the continental rise which lies at the base of the continental slope. Maximum regional gradients range from 1:40 at the base of the slope to 1:1000 at the boundaries of the abyssal plains. The local relief of the continental rise is extremely low except for seamounts, canyons, and a few significant breaks in slope.

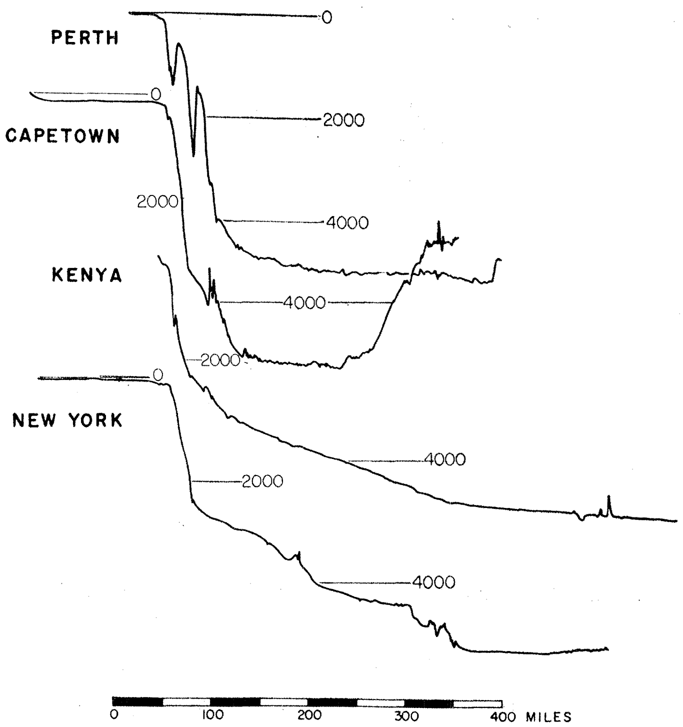

FIGURE 6. Topographic profiles of the Continental Margin. (Depths in metres.)

Submarine canyons that extend across the continental rise are generally small in cross-section and impossible to detect without the aid of modern precision sounders. Of the submarine canyons on the continental rise, few are adequately surveyed. Many sounding lines traverse the area immediately to the east of Ceylon, and there is no doubt whatsoever that canyons run south across Ganges Cone on the wide continental rise which fills the Bay of Bengal. The actual correlation of canyons in the eastern Arabian Sea and in the southern Somali Basin is uncertain, for there are insufficient precision profiles in this area, and no canyon has been followed by a zigzag survey.

Abyssal cones are associated with the Ganges (figure 7) and the Indus rivers. Both areas have been sufficiently investigated to firmly establish the existence of these cones; somewhat more information is available on the Indus cone (figure 5).

The arcuate Java trench bordering the Indonesian arc forms the northwestern boundary of the Indian Ocean between Burma and Australia (figure 8). A gentle outer ridge lies seaward of the trench. The southern and western boundaries of the outer ridge are subtle, and the data are insufficient to allow accurate mapping of this boundary.

(*b*) *Ocean-basin floor*

The most conspicuous provinces of the ocean-basin floor are the abyssal plains which stand out sharply (figures 2, 4 and 5). These are the flattest surfaces on the face of the earth. Regional gradients range from 1:1000 to 1:7000. Except for isolated peaks of buried hills and mid-ocean canyons, local relief does not exceed 1 to 2 m.

Abyssal plains, although well developed in the northern and southern parts of the Indian Ocean, are relatively poorly developed off Australia.

Abyssal hills characteristically lie along the seaward margins of the abyssal plains.

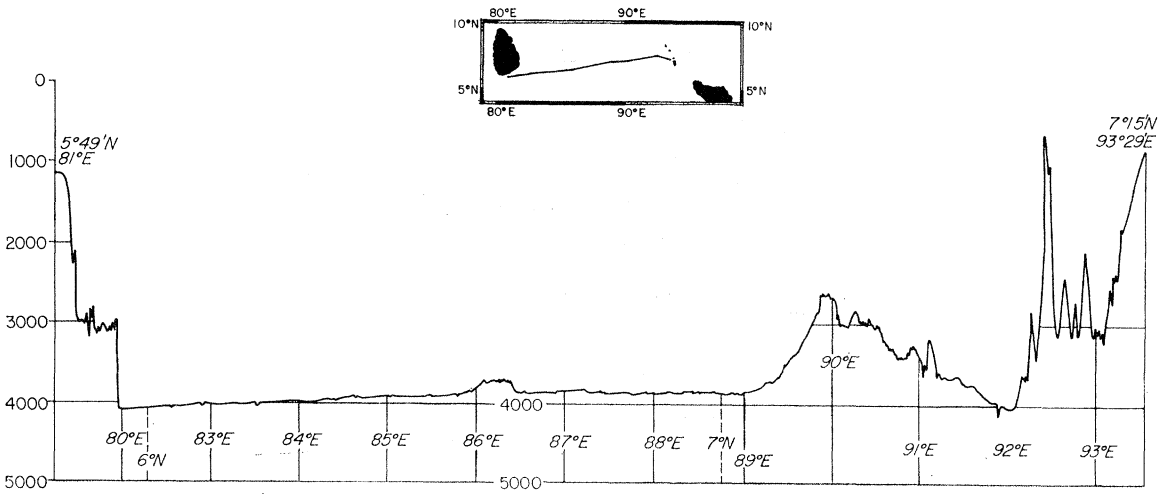

FIGURE 7. Topographic profile across the Lower Ganges Cone. (Depths in metres.)

Rarely can it be determined whether the relief of this province is characterized by linear ridges, lines of cones, or completely random hills. However, a detailed survey conducted aboard H.M.S. *Owen* in the abyssal hills to the northeast of the Seychelles indicated a marked linearity of the relief parallel to the axis of the Mid-Oceanic Ridge.

(*c*) *Microcontinents*; *plateaus and aseismic ridges*

One of the most notable characteristics of the Indian Ocean is the presence of generally north–south trending aseismic plateaus and ridges. One may consider Madagascar such a feature, as well as the continental projection which extends south from Mozambique (figure 2).

From west to east the following north–south trending linear microcontinents can be recognized in the northern part of the Indian Ocean: Mozambique Ridge, Madagascar Ridge, Mascarene Plateau, Chagos-Laccadive Plateau, Ninetyeast Ridge (figure 9). In the south, the Kerguelen Plateau has a strong meridinal linearity. The large east–west asymmetrical Broken Ridge lies east of the Ninetyeast Ridge near 30° S. Easily distinguished on morphological grounds from the Mid-Oceanic Ridge, the microcontinents are generally higher, blockier features with lower local relief.

Madagascar is clearly a microcontinent, and the granites of the Seychelles, together with seismic results discussed in this volume (p. 240), suggest that at least the northern portion of the Mascarene Plateau is also continental.

The Chagos are coral islands which rise from a long, broad, slightly curved plateau. The Ninetyeast Ridge is perhaps the longest and straightest ridge so far discovered in any ocean (figure 9). Completely unknown until discovered by the International Indian Ocean Expedition, this ridge has been traced from 10° N to 32° S. A series of associated but shorter subparallel ridges and trenches lie both to the east and to the west of the Ninetyeast Ridge.

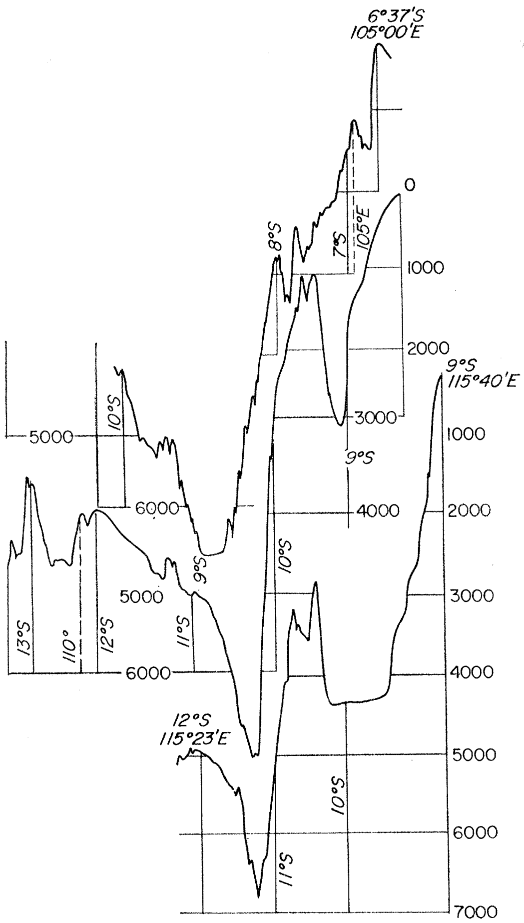

Figure 8. Topographic profiles of the Java Trench. (Depths in metres.)

Probably the most striking difference between the Indian Ocean and the South Atlantic is the presence of so many microcontinental aseismic ridges. In addition to the dominantly north–south ridges discussed heretofore, the prominent east–west Diamantina fracture zone extends 1500 miles westward from the southwest tip of Australia. Broken Ridge, which forms the northern boundary of the fracture zone, merges at 30° S with the Ninetyeast Ridge. Remarkably great depths have been found in the fracture zone—reliable soundings more than 7000 m have been reported.

(d) *Mid-Oceanic Ridge*

The most conspicuous feature of the Indian Ocean is the Mid-Indian Ocean Ridge, that section of the world encircling the Mid-Oceanic Ridge which lies as an inverted Y in the centre of the Indian Ocean (figures 4 and 10).

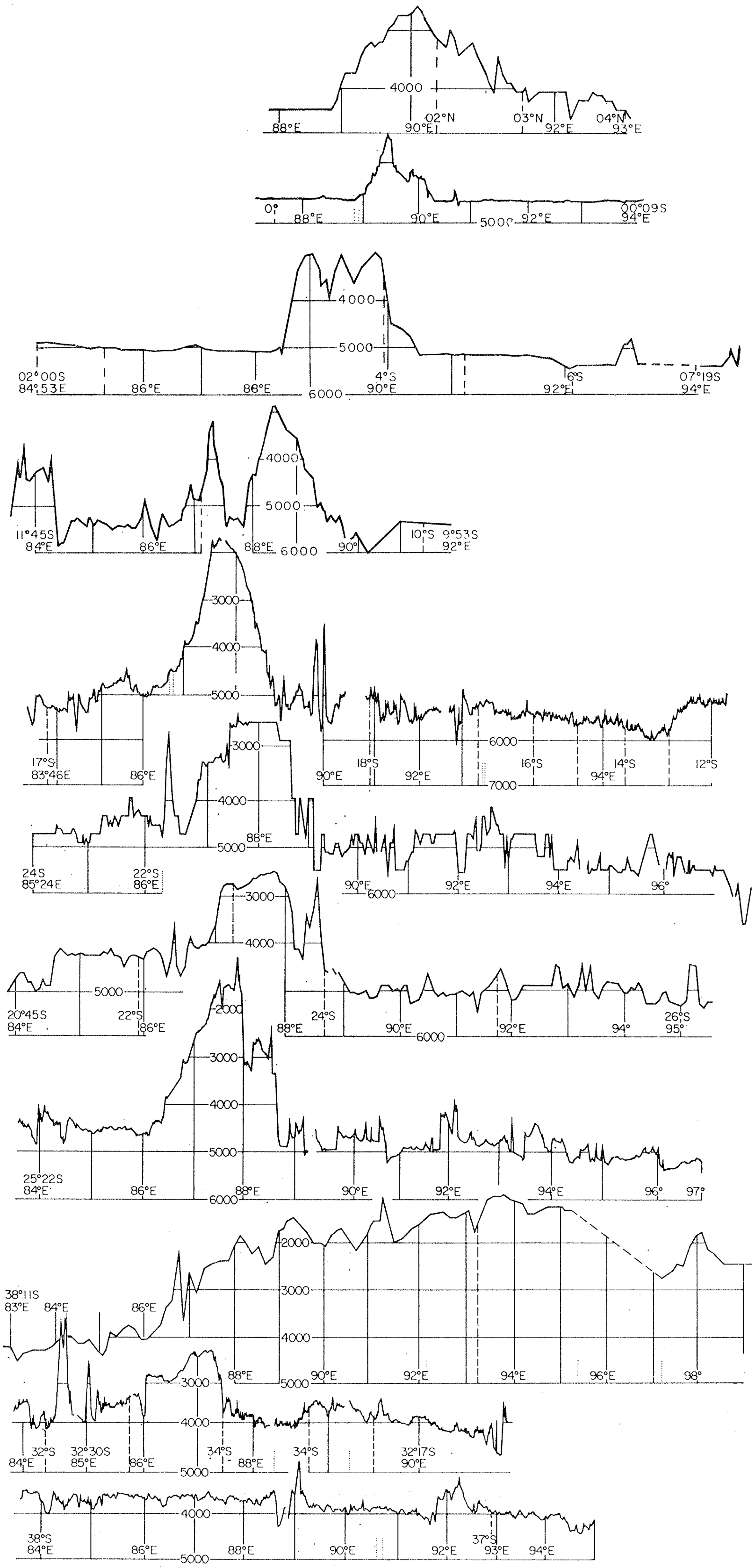

FIGURE 9. Topographic profiles of the Ninetyeast Ridge. (Depths in metres.)

The boundary between the Mid-Atlantic Ridge and the Mid-Indian Ocean Ridge is a purely arbitrary one along 20° E, which is the official and arbitrary division between the Indian and the Atlantic Oceans. The writers' use of the term Mid-Indian Ocean Ridge differs from the use in some popular atlases. As used here, the term Mid-Indian Ocean Ridge applies to that portion of the Mid-Oceanic Ridge which lies within the limits of the Indian Ocean. On some older maps the Chagos–Laccadive Plateau and the Kerguelen Plateau are shown as a single feature and called the Mid-Indian Ocean Ridge.

Along the axis of the Mid-Oceanic Ridge a depression or rift is characteristically found.

The Mid-Oceanic Ridge in the Arabian Sea is well defined by many profiles obtained by H.M.S. *Owen* and various other ships. Northeast of the Seychelles, *Owen* conducted a detailed survey on the crest of the Mid-Oceanic Ridge which, in this area, is known as the Carlsberg Ridge.

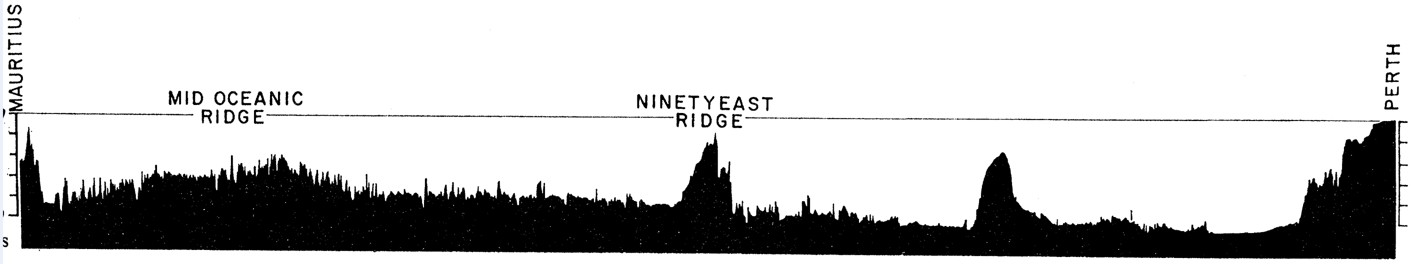

FIGURE 10. Topographic profile of the Mid-Oceanic Ridge and Ninetyeast Ridge between Mauritius and Western Australia.

(*e*) *Fracture zones*

The Indian Ocean is cut by several prominent fracture zones which offset the axis of the Mid-Oceanic Ridge. The Owen fracture zone, which lies east of Arabia and the Gulf of Aden, was surveyed in some detail by H.M.S. *Owen*, H.M.S. *Dalrymple*, and R.R.S. *Discovery* (figure 4). The axis of the Mid-Oceanic Ridge is offset by approximately 200 miles to the right (Matthews 1963). Recent displacement on this fracture zone is indicated by the Wheatley Trench, a sharp depression which drops more than 1000 m below the India Abyssal Plain. Several small right-lateral fracture zones offset the Carlsberg Ridge. One of these was investigated by H.M.S. *Owen* (Admiralty 1963). In the Gulf of Aden the Mid-Oceanic Ridge is offset by several left-lateral fracture zones that lie roughly parallel to the Owen fracture zone. In the southwest Indian Ocean the Mid-Oceanic Ridge is offset by a series of left-lateral fracture zones which have roughly the same orientation as the Owen fracture zone. The Malagasy fracture zone, which lies to the east of the Madagascar Ridge, appears to be a southern extension of the Owen fracture zone. The Amsterdam fracture zones offset the axis of the Mid-Oceanic Ridge in the region of St Paul and Amsterdam islands. These fracture zones appear subparallel to the Ninetyeast Ridge and have roughly the same north–south orientation as the fracture zones of the western Indian Ocean. Although the nearly north–south lineations are most prominent in the Indian Ocean, the Diamantina fracture zone and the Rodriguez fracture zone add a significant roughly east–west trend.

The rugged tectonic relief of the Mid-Oceanic Ridge normally contrasts markedly with the very smooth depositional topography of the continental rise and the almost perfect

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flatness of the abyssal plains (figure 2). In the Indian Ocean there are areas of smooth-rolling or swale topography apparently produced by the blanketing effect of thicker pelagic sediments. The flanks of the Mid-Oceanic Ridge south of the Polar Front are markedly smoother than the northern flanks north of the Polar Front. This may be the result of a higher rate of pelagic deposition resulting from the higher organic productivity of the Southern Ocean. The outer ridge south of the Java Trench is exceptionally smooth. The region surrounding Crozet, Marion, and Prince Edward islands represents an extreme case of smoothing. Only the narrow crest zone of the Mid-Oceanic Ridge exhibits the usual rugged topography; elsewhere in the area the bottom is extremely smooth. In the vicinity of Marion Island the smooth topography extends north of the crest of the Mid-Oceanic Ridge, blanketing the southern half of Agulhas Plateau.

The smooth areas in the western flank of the Mid-Oceanic Ridge north of the Seychelles and in the area southwest of Sumatra may be related to a higher equatorial productivity.

It is impossible to acknowledge here the many people who contributed data.

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