# 1. INTRODUCTION

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The twenty-third cruise of the drilling vessel *Glomar Challenger*, under contract to the JOIDES Deep Sea Drilling Project, lasted from 8 March to 1 May 1972. The cruise began at Colombo, Sri Lanka (formerly Ceylon) and ended at Djibouti in the French Territory of the Afars and Issas. A total of 12 drill sites was occupied, six each in the Arabian Sea and the Red Sea. At all sites there was an obvious interest in reconstructing the stratigraphic record both from a sedimentological and paleontological viewpoint. An objective of all the sites was also to sample and date one or more reflectors and to relate these to the regional stratigraphy. Because the scientific emphasis during the cruise was planned to shift from studies of deep-sea sedimentation and crustal history in the Arabian Sea to mainly detailed geochemical studies of heavy metal-rich muds and evaporite deposits in the Red Sea, five of the scientific personnel were changed near Djibouti on 12 April before *Glomar Challenger* entered the Red Sea.

## DRILLING IN THE ARABIAN SEA

During the 1961-1967 International Indian Ocean Expedition (IIOE) many oceanographic ships carried out geophysical and geological investigations in the Arabian Sea. Since that time various syntheses and analyses of the accumulated data have been published, and it was appropriate in 1972 to put newly developed hypotheses based on the IIOE data to the test of the drill.

The Arabian Sea is bounded to the west, north, and east by large continental areas and is only open on its southern side to the vast western Indian Ocean which extends southward to Antarctica. Formerly the Tethys Ocean lay to the north, but this disappeared when the northern and southern continents began to collide in the Late Cretaceous. As a result of the collision, a belt of high mountains was formed which today extends from the Himalayas to the Alps. These mountains not only subsequently produced vast quantities of detritus destined to find its way to the ocean basins but also, in company with the unified land mass formed by the continental collision, probably profoundly influenced the regional climate. Today the Arabian Sea suffers two annual monsoons which cause upwelling of nutrient-rich bottom waters along the margins. The seasonal upwelling has probably had a prolonged and distinct effect on biological productivity and sedimentation. Many of the surrounding land areas are now arid, and some contain extensive deserts. It seemed likely that windborne dust would have made an important contribution to the sediments of the Arabian Sea. To the sedimentologists, therefore, the deep-sea sediments of this region promised to contain substantial evidence of the history of the surrounding land areas.

The submarine bathymetry of the Arabian Sea is now well known ( Plate 1 in pocket at the back of the book). To the south it is bounded by the actively spreading Carlsberg Ridge which runs northwest-southeast from the mouth of the Gulf of Aden to west of the Maldive Islands. At its northwest end the ridge is offset in a right-handed sense by the Owen Fracture Zone. The ridge then continues as the Sheba Ridge into the Gulf of Aden. The Owen Fracture Zone is over 2000 km long. It parallels the continental margins of Somalia and Arabia, several hundred kilometers offshore, and probably continues northward onto the continent near Karachi. On the eastern side of the Arabian Sea the Laccadive-Chagos Ridge, a linear chain of coral atolls and reefs extending for 2000 km south of latitude 14°N, forms a prominent feature. Within the confines of the Owen Fracture Zone ridge, the Carlsberg Ridge and the Laccadive-Chagos Ridge, a huge prism of sediments—the Indus Cone and its southern extension, the Arabian Abyssal Plain—has accumulated. This feature occupies more than two-thirds of the floor of the Arabian Sea and has covered most of the irregular basement topography north of the Carlsberg Ridge. Thus, the above three ridges have played an important part in controlling the near sea-floor transport and distribution of sediments. They have also contributed to a situation in which bathymetric trends, so useful for detecting earlier patterns of sea-floor spreading, have been obscured by a thick sediment cover.

A recent compilation and analysis of magnetic anomaly profiles in the Indian Ocean led McKenzie and Sclater (1971) to postulate two periods of Tertiary sea-floor spreading in the Indian Ocean. These episodes were separated by a time of minimal spreading from about 55 to 35 m.y. ago. The directions and axes of spreading of the present phase differ from those of the previous phase. Several aspects of this hypothesis are tentative, especially the distribution and trend of the Early Tertiary fracture zones in the Arabian Sea and the precise limits in time of the spreading hiatus. Further, none of the older magnetic anomalies had been identified in the southeast Arabian Sea. These problems were all amenable to solution by drilling.

The coral-capped Laccadive-Chagos Ridge is an enigmatic feature of the Arabian Sea. It is seismically inactive, lacks signs of active volcanism, has no outcrops of basement rock, and has a crustal thickness intermediate between that of oceans and continents. Recent papers have proposed that it is an old fracture zone or that it is a volcanic ridge formed by the lithosphere passing over a hot-spot in the mantle. Different basalt types and ages of volcanism might be expected from the two hypotheses. Thus, drilling offered a chance of testing these proposals.

Paleomagnetic measurements on the Deccan traps have shown that 65 m.y. ago this part of India was situated at a latitude of 33°S. Clearly, therefore, India has moved a great distance to the north during the Cenozoic. Such northward movement across the equator may have been reflected in the faunas and floras accumulating in the ocean sediments. It will certainly have been reflected in the paleomagnetic vectors of the ocean sediments. Fortunately, the main magnetic effect will have been that the magnetic inclination at any one place will have changed systematically with time, and this should be detectable in samples taken from cores unoriented in azimuth. Thus paleomagnetic measurements promised to give detailed information about the northward motion of India in the Cenozoic. Such information has not been obtained before apparently due to a lack of suitable rock outcrops in India.

Between the Owen Fracture Zone and Arabia there is a region of unknown age with low magnetic relief and thick sediments. It is possible that this area has a long history going back to the Cretaceous. Holes were planned in this region to try and learn more of its origin and history.

The choice of drill sites in that part of the Arabian Sea to be visited during Leg 23 was constrained by the small number of available seismic reflection profiles and by the complete lack of site surveys. Nevertheless, it was possible to choose a group of sites which were pertinent to the major problems of the area discussed above. As it turned out, two unplanned sites were drilled, and one of the planned sites was omitted for lack of time. The extra sites were chosen on the basis of knowledge gained from our drilling results.

Thus, five important aspects of the history of the Arabian Sea were tackled. These were the origin of the Laccadive-Chagos Ridge (Site 219); the history and origin of the Indus Cone (Sites 221, 222); the Early Tertiary sea-floor spreading pattern (Sites 220, 221); the nature of the region between the Owen Fracture Zone and Arabia (Sites 223, 224); and the northward drift of India during the Cenozoic (based on paleomagnetic measurements on samples from all sites).

## DRILLING IN THE RED SEA

It is generally agreed that the Red Sea is a relatively young feature, probably formed within the last 20 m.y. Nevertheless, its youth has not prevented it from having a complex structure. The cruises of several oceanographic vessels have established that the central axial trough[1] of the Red Sea has been formed in about the last 3 m.y. by sea-floor spreading. Deep boreholes along the coasts and on the islands of the southern Red Sea, drilled in the search for hydrocarbons, have revealed the presence of great thicknesses of Miocene halite and evaporites. The few boreholes which have been drilled in the main trough have also found salt, but in no case was a true igneous basement reached. A major problem of the Red Sea is the nature of the crust underlying the main trough, excluding the axial trough. Unfortunately, the solution to such a problem was outside the capabilities of the drilling vessel *Glomar Challenger* both in terms of the penetration which could be achieved by the bit and of the water depth which had to exceed 900 meters if the acoustic positioning system was to function. This last factor placed severe restraints on where *Glomar Challenger* could drill in the Red Sea and effectively meant that drilling had to be restricted to about 15 percent of the Red Sea floor. Nevertheless, there were a number of important problems which promised to be soluble by drilling.

The brine pools of the Red Sea have been exhaustively studied-first by cruises of the Woods Hole Oceanographic Institution and then by the detailed surveying and sampling work of Preussag A. G. In spite of these valuable studies, it was still not known how thick the metal-rich muds of Atlantis II Deep were, to what extent the contemporary mineralization extends laterally below the sea-floor, or whether signs of earlier mineralization could be found beneath the sea bed around Atlantis II Deep. All these problems were tackled by *Glomar Challenger.* An extensive onboard program of geochemical measurements was especially carried out to help answer these questions. These operations accounted for about half our effort in the Red Sea.

Many line kilometers of seismic profiler track have now been obtained in the Red Sea. Except at the extreme ends of the sea, a sharp distinction can be made on these profiles between the axial trough and the remainder of the Red Sea. Outside the axial trough a strong reflector, occurring up to 500 meters below the sea bed, is recognized everywhere. It was clearly important to sample and date this reflector (names the S reflector) in order to better understand the seismic profiles.

As mentioned above, the axial trough is the longest continuous feature of the Red Sea floor. Its southern limit is found just northwest of Zebayir Island (15°N) where the trough is 1100 meters deep. South of this island there is an 800-meter-deep basin which merges at its southern end with the shallow sill region just north of the Straits of Bab el Mandeb. For several reasons (lineations on southern Red Sea volcanic islands, magnetic anomalies, gravity, thickness of sediments on seismic reflection profiles) it appeared possible that the axial trough did exist south of Zebayir Island, but that it lay beneath a thick cover of sediments. To test this hypothesis we drilled a hole in the basin, the southernmost point in the Red Sea with an adequate water depth for *Glomar Challenger's* operations.

Today the sill depth between the Red Sea and the Gulf of Aden is about 125 meters. Such a shallow sill is liable to have become subaerial during the glacial eustatic drops in sea level and to have had drastic effects on the flow of Gulf of Aden water into the Red Sea, necessary to make up the huge evaporation losses, even it it has suffered only minor vertical movments. A major paleontological objective, therefore, was to discover what fluctuations in faunas and floras have occurred during the Neogene and to try and relate these to possible changes in sill depth.

[1]Throughout this Initial Report the term axial trough has been used for the central 900-2500 meter deep trough about 40 km wide which is found north of 15°N; the term main trough has been used for the much wider trough over 550 meters deep which is found north of 19°N and within which the axial trough lies.

Although no site surveys had been specifically carried out in the Red Sea, the density of seismic reflection profile tracks almost made such surveys unnecessary. Thus, it was possible before the cruise to choose all the planned sites on the basis of existing single profiles. Due to the peculiar oceanographic conditions in the Red Sea, which result in strong and laterally variable surface currents, on several occasions while carrying out short pre-site surveys onboard *Glomar Challenger*, it proved very difficult to construct an accurate dead-reckoned track between satellite fixes on the basis of current vectors determined from earlier pairs of fixes. Thus, once having seen a suitable site on a seismic profile it was sometimes difficult, if not impossible, to reoccupy that position. Generally, the weather in the Red Sea was excellent for drilling. However, this was not so in the extreme south of the Red Sea (last two sites) where up to 65 mph southerly winds, and the seas they caused, hampered drilling operations. These winds are a normal feature of the region in the early summer.

Thus, four important aspects of the Red Sea were investigated. A site was occupied to determine the thickness of the metalliferous muds of Atlantis II Deep (Site 226). Two sites were drilled east of the deep to determine the lateral extent of mineralization and to identify the S reflector (Sites 225, 227). A further site was drilled with the latter objective on the west side of the Red Sea 260 km to the south (Site 228). An attempt was made to identify the axial trough south of Zebayir Island (Site 229), while nearby, another site was occupied to sample possibly the southernmost known occurrence of the S reflector (Site 230). Only four of these sites (Sites 225, 227, 228, and 229) achieved any significant penetration of the sea bed. These sites provided core material from which the Late Miocene to Holocene environmental history may be worked out.

## REFERENCE

McKenzie, D. P. and Sclater, J. G., 1971. The evolution of the Indian Ocean since the Late Cretaceous: Geophys. J. Roy. Astro. Soc., v. 25, p. 437-528.

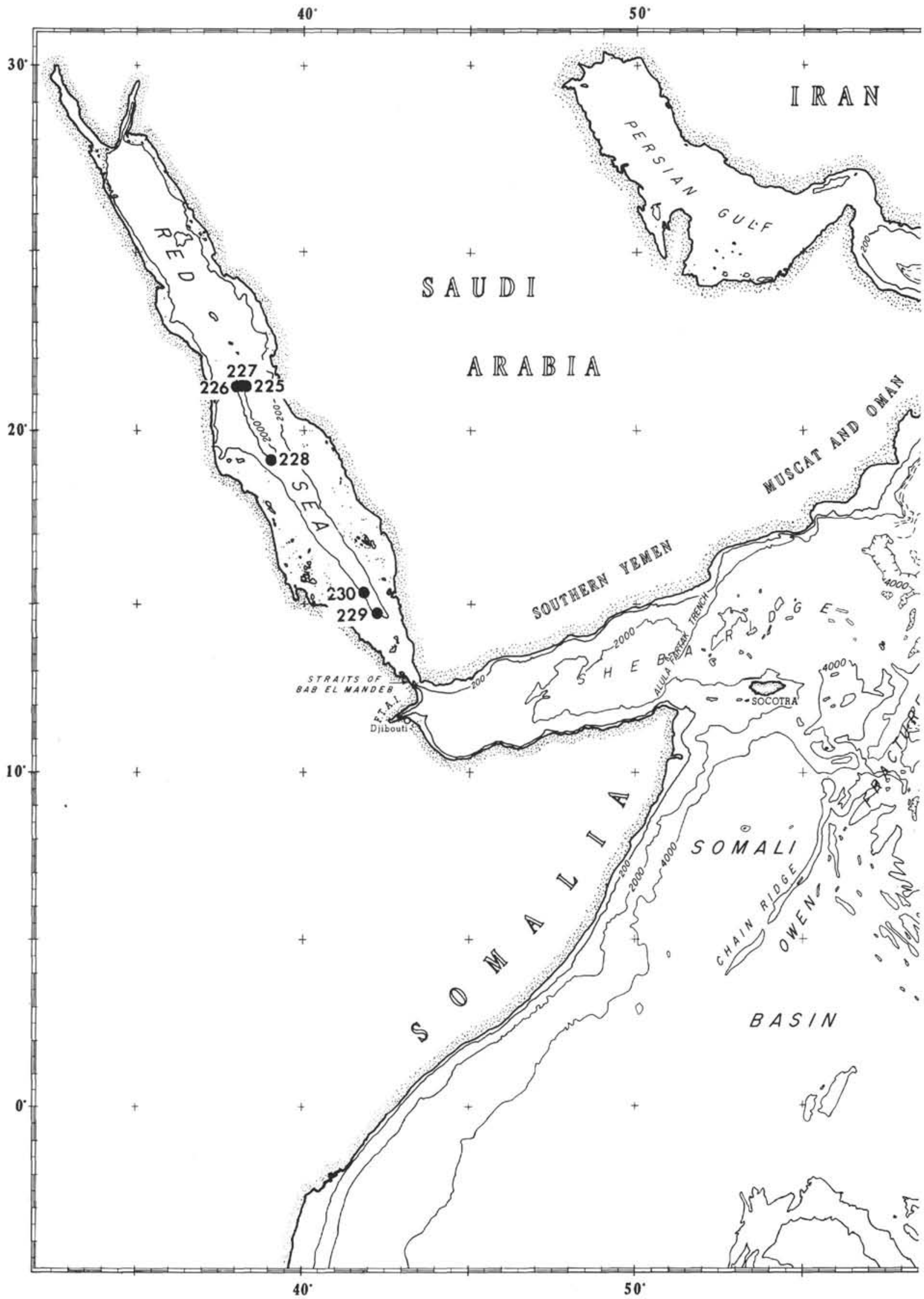


Figure 1. *Outline map of Arabian Sea and Red Sea showing main physiographic features.*

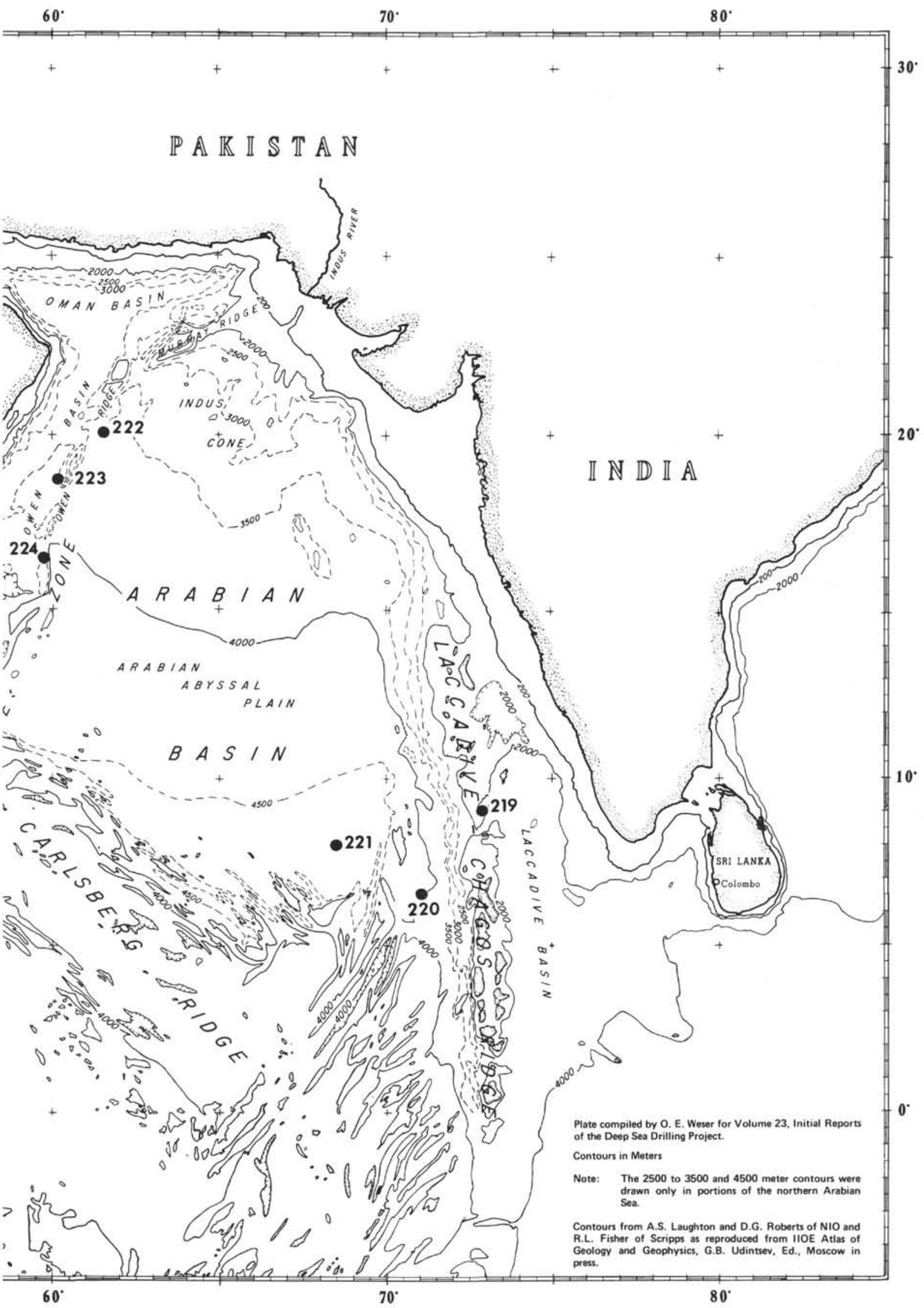


Plate compiled by O. E. Weser for Volume 23, Initial Reports of the Deep Sea Drilling Project.

Contours in Meters

Note: The 2500 to 3500 and 4500 meter contours were drawn only in portions of the northern Arabian Sea.

Contours from A.S. Laughton and D.G. Roberts of NIO and R.L. Fisher of Scripps as reproduced from IIOE Atlas of Geology and Geophysics, G.B. Udintsev, Ed., Moscow in press.