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A REVIEW OF THE GEOLOGY AND GEOPHYSICS OF CHRISTMAS ISLAND AND THE CHRISTMAS RISE

by

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FOREWORD

Reviews have been made of the geology and geophysics of most Australia's island territories, and other records in this series by the same author are:-

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SUMMARY

Christmas Island, situated in the northeastern Indian Ocean, consists of a basaltic volcanic core on which coralline limestones were deposited during the Eocene and again in the Miocene. Phosphate deposits derived from guano form the basis for the island's economy, and reserves are considerable.

Geophysical coverage of Christmas Rise is sparse but indicates that sedimentary thicknesses do not exceed 500 m. From magnetic anomaly dating and Deep Sea Drilling Results the sea-floor around the rise is interpreted to have been formed from a spreading centre to the north of Christmas Island. This spreading centre is postulated to have been consumed at the Sunda Trench. Prospectivity for other minerals besides phosphate and for petroleum is poor.

INTRODUCTION

Christmas Island lies in the northeastern part of the Indian Ocean (Fig. 1) at 10.5° south and 105.5° east, and was discovered by William Dampier in 1688. Its extensive phosphate deposits were discovered in 1887, mined from 1897, and have since become Australia's principal source of phosphate raw material. Christmas Island became a territory of the Commonwealth of Australia in 1958. The island is 143 km^2 in area and is shaped roughly like the outline of the letter 'T'.

INVESTIGATIONS

The geology of Christmas Island has been studied by several authors most of whom were assessing the phosphate deposits. Andrews (1900) produced a monograph on the island which includes extensive data on the flora and fauna; Campbell-Smith (1926) studied the volcanic rocks, and Trueman (1965) reported on the geology and mineralogy of the island. The Bureau of Mineral Resources (BMR) undertook several studies of the island's morphology and geology (Warrin, 1958; White & Warrin, 1964; Barrie, 1967; Riverau, 1965). A geophysical investigation using magnetic, electrical, gravity, and refraction techniques was undertaken in 1973 by BMR (Polak, 1975). Marine investigations are scarce in the vicinity of the island. The Russian oeeanographic vessel R.V. Vitiaz (Bezrukov, 1973) recovered several rock samples from seamounts near Christmas Island and ran some reflection profiling tracks in the area. Marine geophysical tracks along which reflection, refraction and magnetic data were recorded are shown in Figure 2. A deep-sea drilling site was completed on leg 22 (Von der Borch, Sclater, et al., 1974) and is located 220 km east of Christmas Island. The D.V. Glomar Challenger recorded a reflection profile close to the island during this leg. The locations of the drill sites and the ship's track are shown in Figure 1.

MORPHOLOGY

Christmas Island is one of a series of submarine seamounts which rise above the 5500 m deep abyssal areas of the West Australian Basin (or Wharton Basin). The island forms part of the Christmas Rise which is symmetrical and sharp-crested. Slopes on the flanks of the rise average between 5° and 8°. From the bathymetric charts (Fig. 3) the base of the seamount on which the island is situated is seen to be roughly circular in outline. The island itself rises in a series of wave-cut terraces and cliffs to a height of 330 m above sealevel. About 100 km to the north of Christmas Island lies the 6000-m deep Sunda Trench.

GEOLOGY

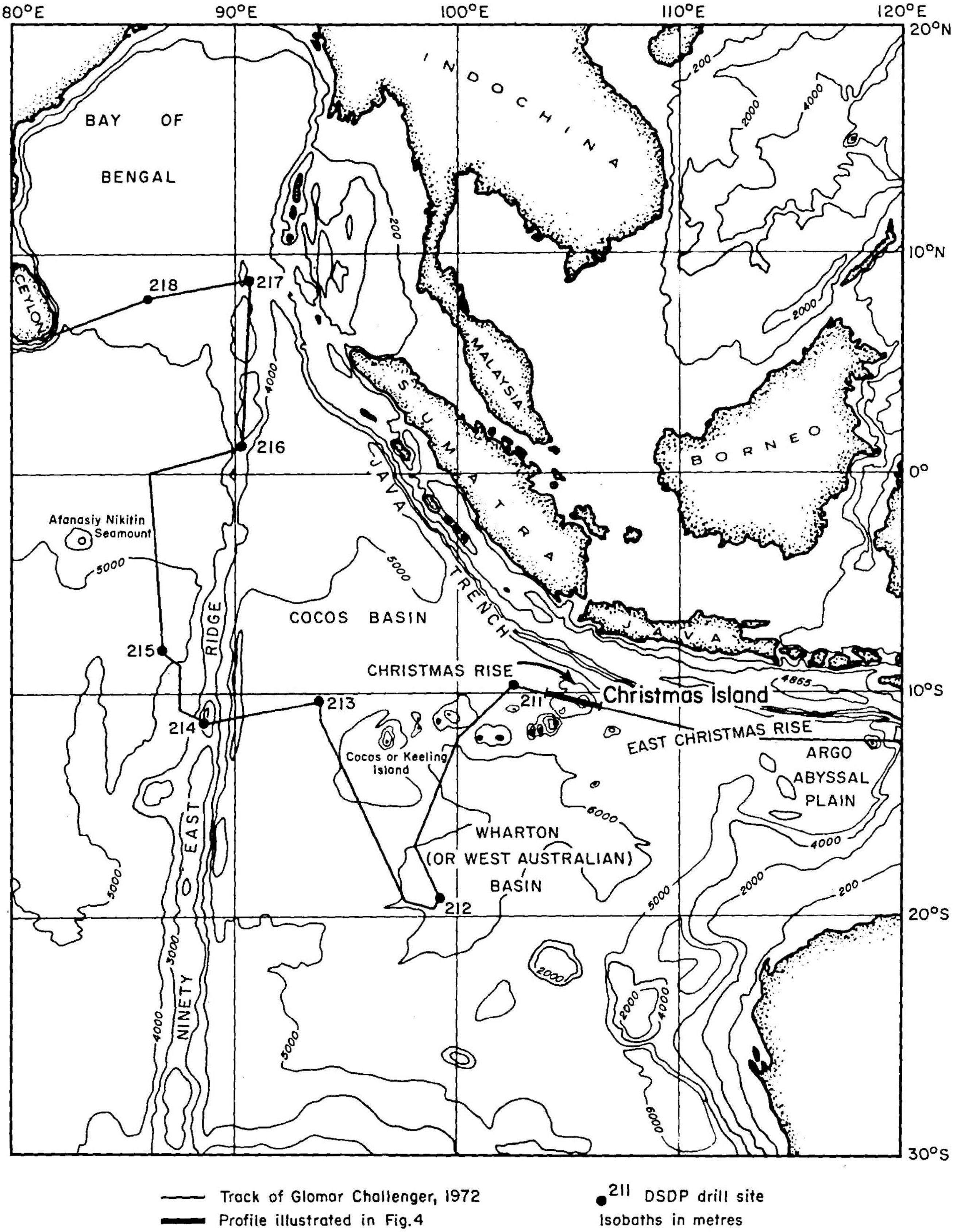
The core of the island is composed of volcanic material which is dominantly basaltic. Rocks such as alkali-trachyte, trachybasalts, olivine basalts, limburgite, and probably nepheline basinite crop out on the island (Campbell-Smith, 1926). The volcanic core is overlain by a sequence of Cainozoic limestones, which were deposited during the development of an atoll reef. The oldest sediments are thin Eocene limestones and conglomerates which, according to Andrews (1900), are interbedded with volcanics. These are overlain by a thick sequence of Miocene limestone and the island is surrounded by a Recent atoll reef. No Oligocene material is present probably because the island was a seamount during this period (Barrie, 1967).

The phosphate deposits on the island are derived from bird and animal excreta. These guano deposits have been leached and reworked by rain and sea water to form thick blankets of oolitic and pisolitic phosphate over a deeply etched limestone surface. Some of these deposits contain up to 40% P_2O_5. The distribution of phosphates, their genesis, and the assessment of their reserves has been extensively dealt with by Barrie (1967). He estimated that the phosphate ore reserves exceed 200 million tonnes.

From reflection profiles obtained during leg 22 of the Deep Sea Drilling Project (Veevers, 1974) the Christmas Rise appears to be almost devoid of sediments. Figure 4 shows the interpreted profile across the region (the track is shown in Fig. 1). Between the Christmas Rise and the east Christmas Rise the basement topography is irregular and sediments up to 500 m thick mantle the basement. West of Christmas Island other seamounts from part of the Christmas Rise. Sediments partly cover the basement of the Cocos Basin.

The sediments in the Cocos Basin were drilled during the DSDP at site 211, and Figure 5 shows the major results. The site was drilled in a waterdepth of 5528 m and penetrated to 447 m (Von der Borch et al., 1974). Basement at this site consists of amphibolite-bearing basalt and is overlain by Upper Cretaceous nannofossil ooze and ash. The overlying unit is a ferruginous clay intruded near its base by a 10-m thick diabase sill. About 200 m of Pliocene sands derived from the Nicobar Fan, and siliceous oozes overlie the brown clay. The uppermost 100 m of section consist of pelagic siliceous oozes and ash beds of late Pliocene and Quaternary age. The ash beds probably originated from island arc volcanism to the north. An age of between 72 m.y. and 80 m.y. is given for the sediment/basement contact (Sclater et al., 1974). Some pyrite mineralization associated with the diabase sill was observed in the core (Hekinian, 1974).

FIG. 1



LOCALITY OF CHRISTMAS ISLAND

(After Bathymetric map of Indian Ocean, Central Headquarters, Geodesy and Cartography, State Geological Commission of USSR, Moscow, 1963

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DSDP Site 212 was located in the deep part of the West Australian Basin some 1200 km southwest of Christmas Island. Basalt was drilled at 516 m below the sea-floor and an Upper Cretaceous age was estimated for this basalt (80 - 110 m.y.). Overlying this basaltic basement are Upper Cretaceous sediments, middle Eocene and early Miocene chalk and brown clay units, and late Miocene and mid-Pliocene nanno-oozes at the top of the column. This hole provided confirmatory evidence that the West Australian Basin is younger than the pre-Mesozoic Ocean proposed previously to account for the poor computer fits of Gondwanaland in this region (Smith & Hallam, 1970).

The seamounts south of Christmas Island were sampled during the 54th cruise of the R.V. Vitiaz (Bezrukov, 1973). The samples indicate that rocks similar to those on Christmas Island are present. Fragments of ultrabasic rocks, slabs and concretions of manganese ores, phosphorites, and calcareous rocks were recovered from the seamounts. From Shcherbakov seamount which has a minimum depth of 1473 m, several shallow-water calcareous rocks and phosphate lenses were lifted during this cruise. It can thus be inferred that this and probably other seamounts in the region reached the ocean surface at one time but subsequently subsided to their present depth.

GEOPHYSICS

The area around Christmas Island has been sparsely surveyed. Marine geophysical surveys have been made by Japanese, American, and Russian research vessels (Fig. 2) but few of the results have been published. Regional synthesis of the evolution of the Indian Ocean have been published by Mckenzie & Sclater (1971) and Sclater & Fisher (1974). Recent geophysical investigations on Christmas Island by BMR (Polak, 1975), made in search of groundwater, have yielded several interesting results. The island has a magnetic anomaly which reaches a maximum of about 1000 nT. Remanent magnetization measurements on the volcanic rocks indicate that both reversely and normally magnetized lavas are present. Unfortunately alteration of the samples collected so far prevents reliable K-Ar dating.

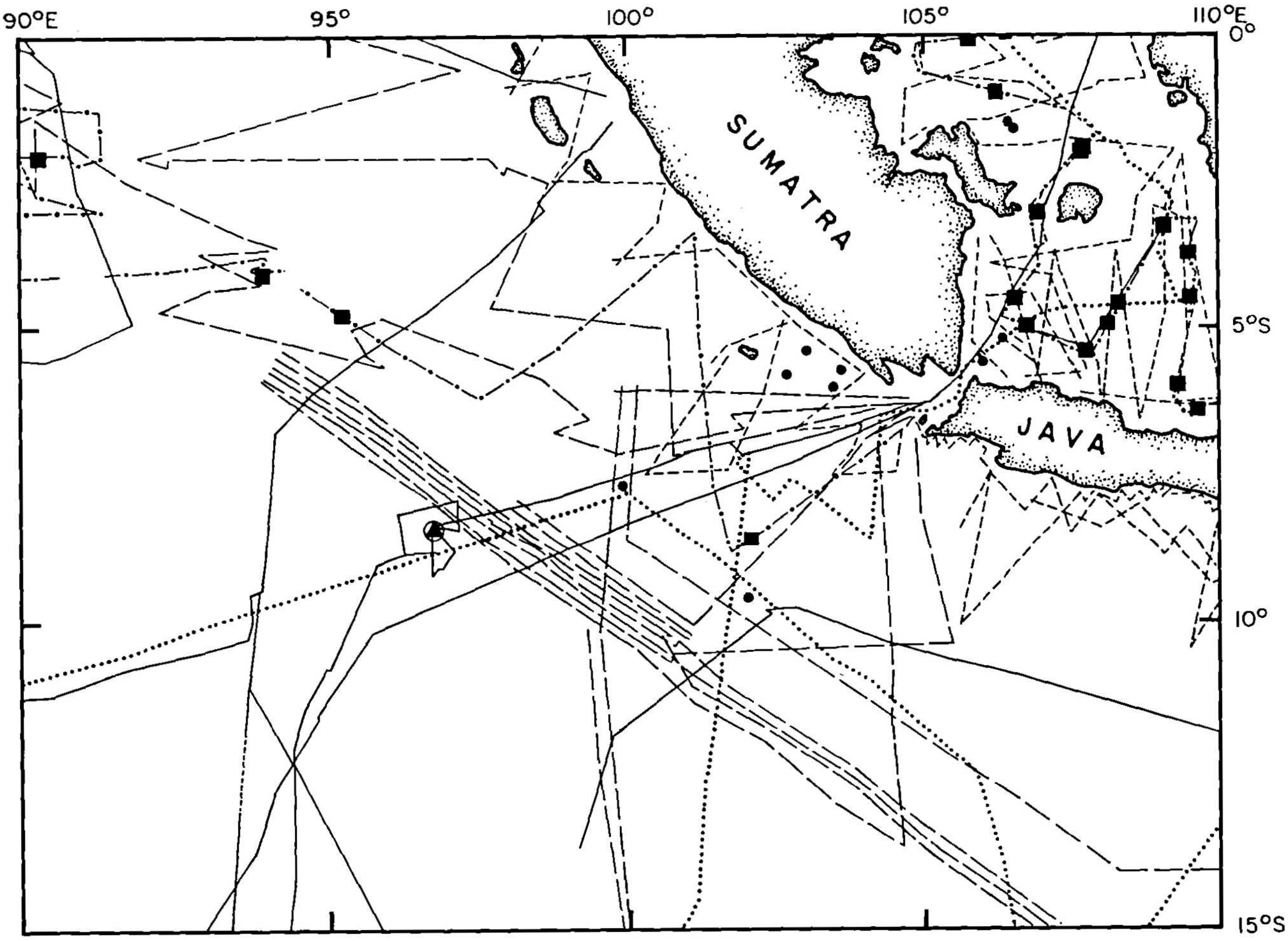
Free-air gravity anomalies over Christmas Island are positive and up to 360 mGal. The island is probably not compensated at depth, in contrast with the Ninetyeast Ridge which has a free-air anomaly of about 25 mGal and which is compensated, according to Bowin (1973). Similarly a Bouguer anomaly maximum of 330 mGal is centred on the island (Polak, 1975). Refraction work to the west of Christmas Island indicates a normal oceanic crust, about 6-7 km thick, composed of about 2 km of material with a velocity of 4-6 km/s, and 4-5 km of material with 6.5-7 km/s (Laughton, Matthews, and Fisher, 1970). The heat flow in the region of Christmas Island is normal for an oceanic area with values ranging from 1.13 to 1.87 μ cal cm^{-2} s^{-1} (see Sclater & Erickson, 1974 Fig. 1).

Magnetic anomalies in the Indian Ocean have a very complicated pattern which has only recently been unravelled (Sclater and Fisher, 1974). West of the Ninetyeast Ridge easterly-trending anomalies identified as numbers 5 to 16 and 21 through 33b increase in age northwards (Fig. 6). East of the Ninetyeast Ridge the anomalies 19 to 33b decrease in age northward, and several fracture zones complicate the pattern of sea-floor spreading in this area. Magnetic lineations southwest of Christmas Island in the West Australian Basin were mapped by Falvey (1972) but their age and relation to the rest of the Indian Ocean has not been resolved.

EVOLUTION

Although the evolution of the Indian Ocean, and in particular the Ninetyeast Ridge, is now partly understood, theories concerning the origin of features like Christmas Island are still largely conjectural. From DSDP results and the interpretation of magnetic lineations recognized in the Indian Ocean, Sclater & Fisher (1974) have postulated that a spreading ridge which was offset by fracture zones was situated off the northwest coast of Australia from about 100 m.y. B.P. until about 32 m.y. B.P. (Fig. 7). The series of ridges and seamounts which includes Christmas and Cocos Island appears to lie on a structural discontinuity. This could have formed as a result of a difference in spreading direction between the West Australian Basin and the Late Cretaceous sea-floor to the northwest. Alternatively, the volcanic seamounts may have been formed later as a result of the Australian plate's movement over a 'hot spot' or mantle plume. Emergence followed by submergence during the Tertiary resulted in the absence of Oligocene material and the accumulation of an Eocene and Miocene succession of limestone. The Recent raised terraces on Christmas Island are evidence that the area is still subject to uplifts. As the present rate of convergence of the Indian Plate and the Eurasian plate at the Java Trench is 3.6 cm/year one can predict that Christmas Island, 140 km away from the trench, will be consumed in about 3 to 4 million years.

FIG. 2



MAJOR COMPILATION SOURCES

- ● Sonobuoy ········· Lamont-Doherty
- ——— Scripps
- — — US Navy
- ■ Sonobuoy ·—·—· Woods Hole
- ----- Other
- Scripps refraction station

MARINE GEOPHYSICAL TRACKS

(after Hayes, Lamont-Doherty Geological Observatory, 1974)

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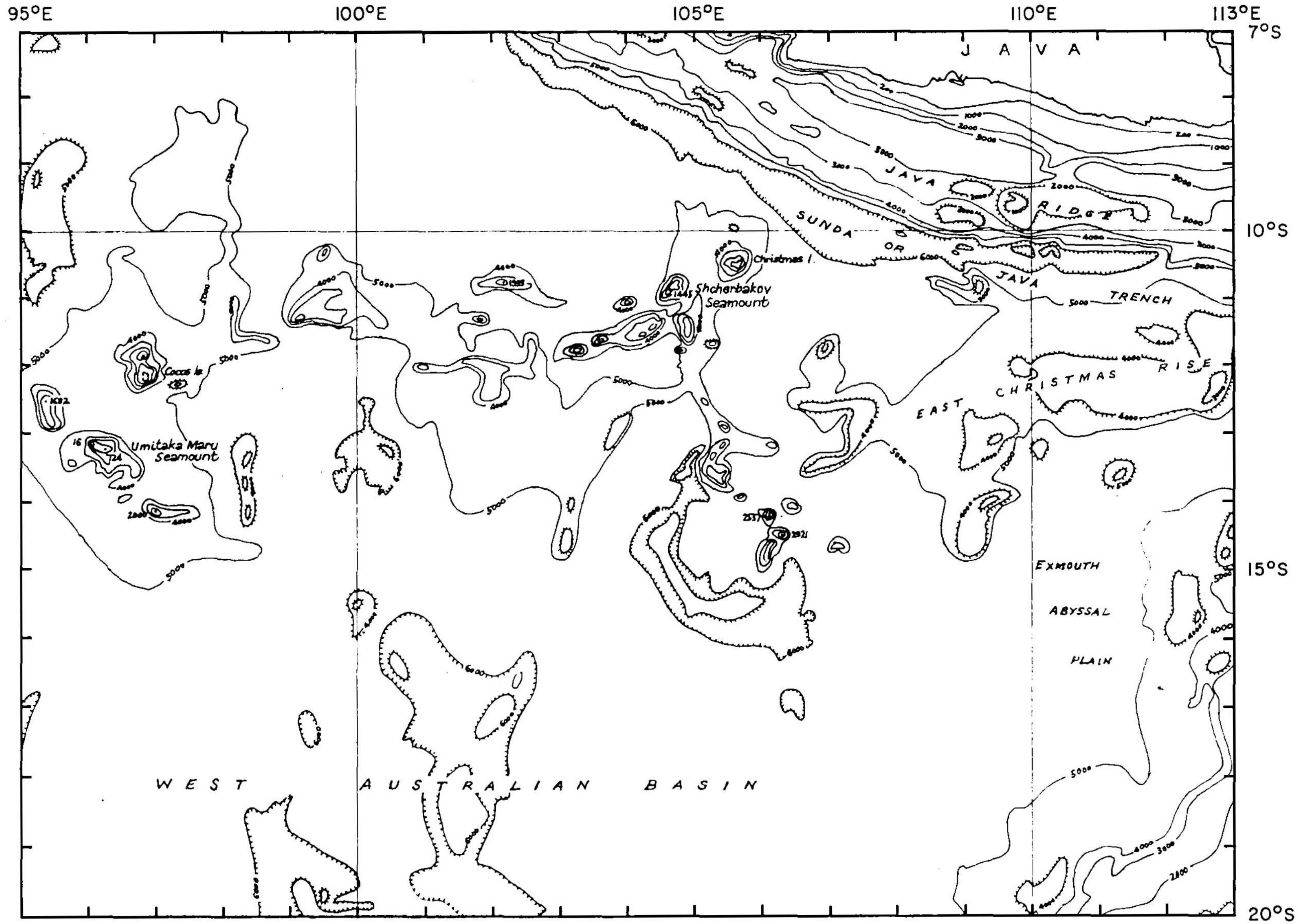

BATHYMETRY AROUND CHRISTMAS ISLAND

(Detail of General Bathymetric Chart of the Oceans, Sheet AIII, Hydrographic Office, R.A.N. Sydney, Australia, 1975)

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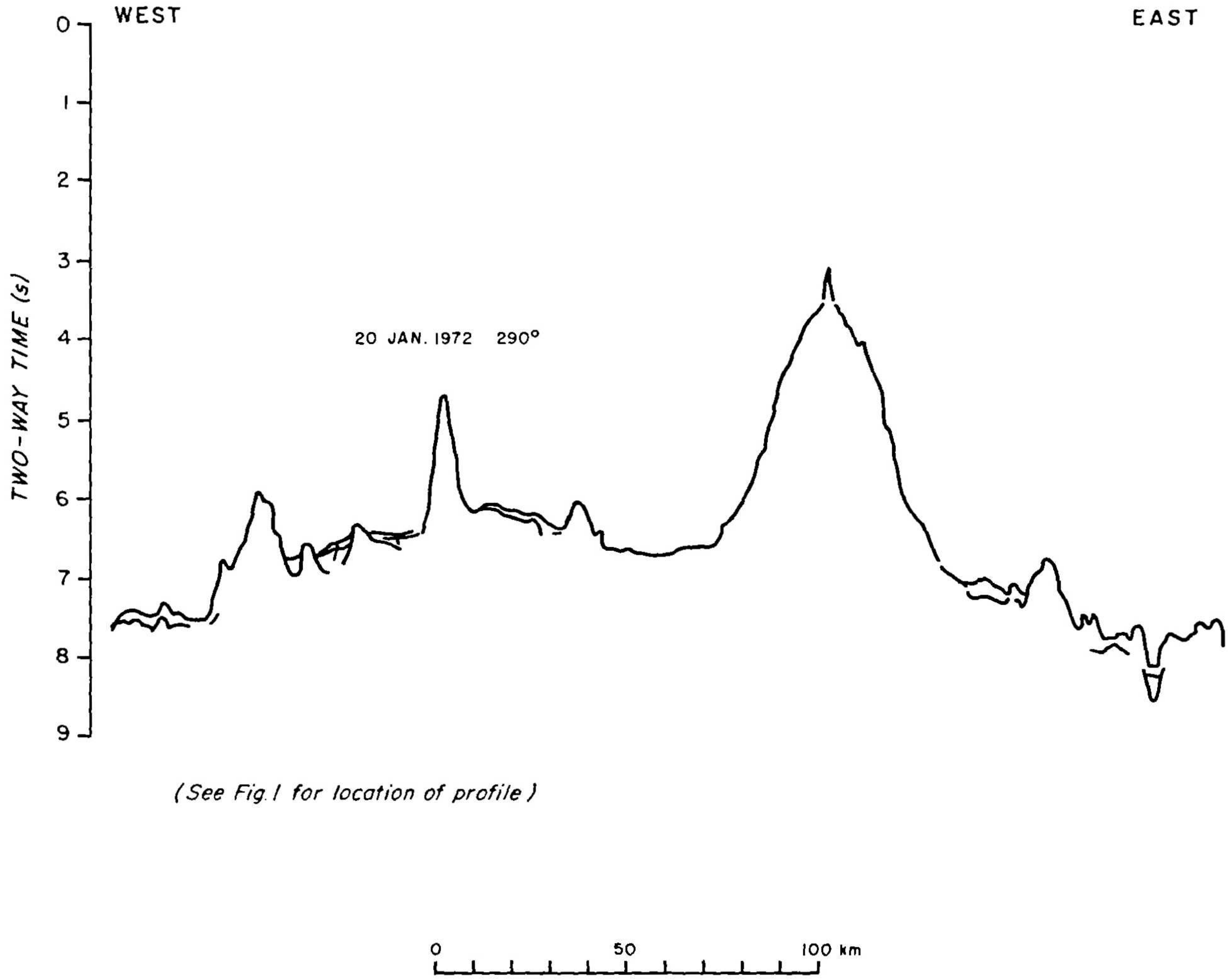
FIG. 3

FIG. 4

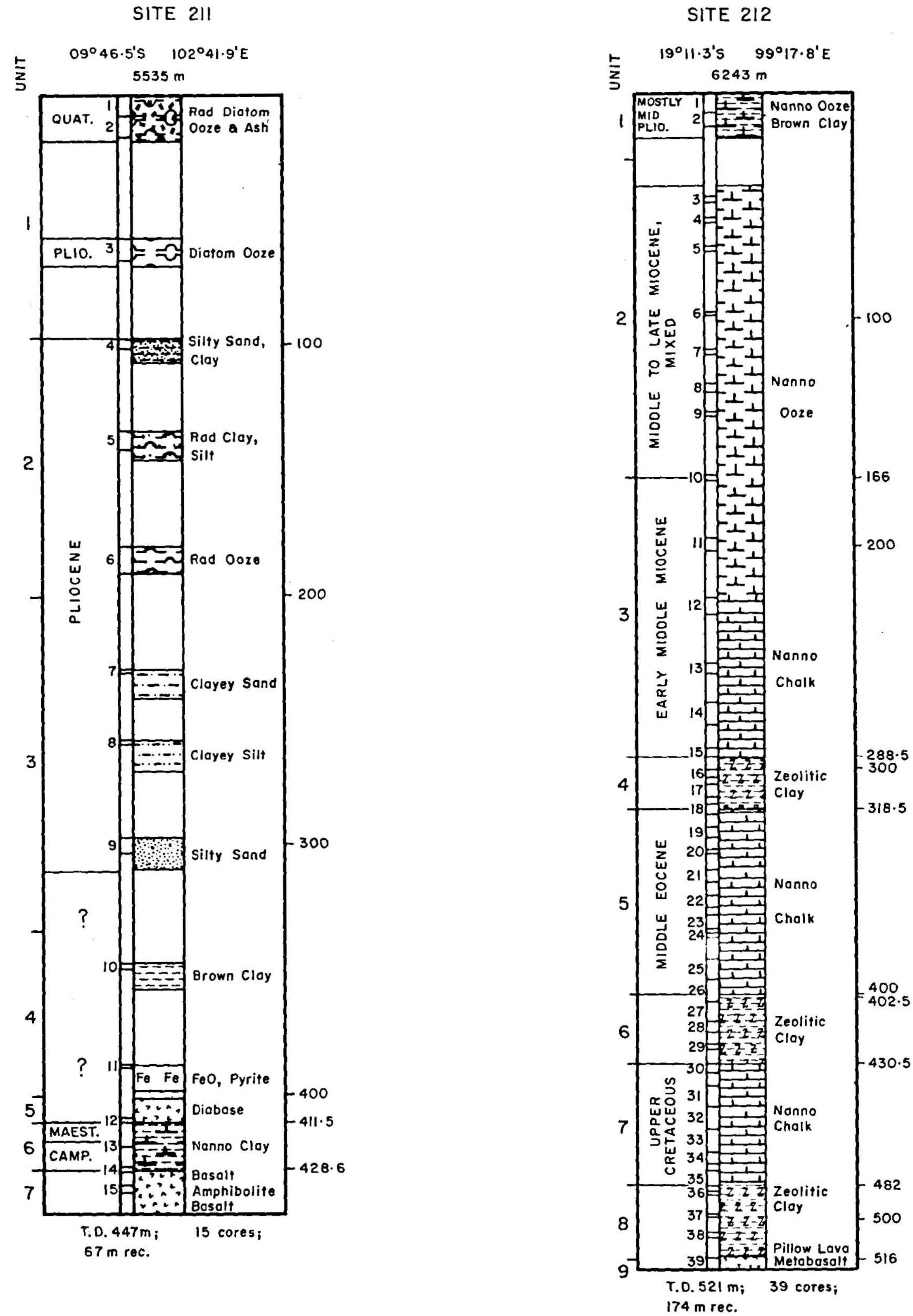


(See Fig. 1 for location of profile)

GLOMAR CHALLENGER SEISMIC REFLECTION PROFILE
ACROSS THE CHRISTMAS RISE

(after Veevers, 1974)

FIG. 5

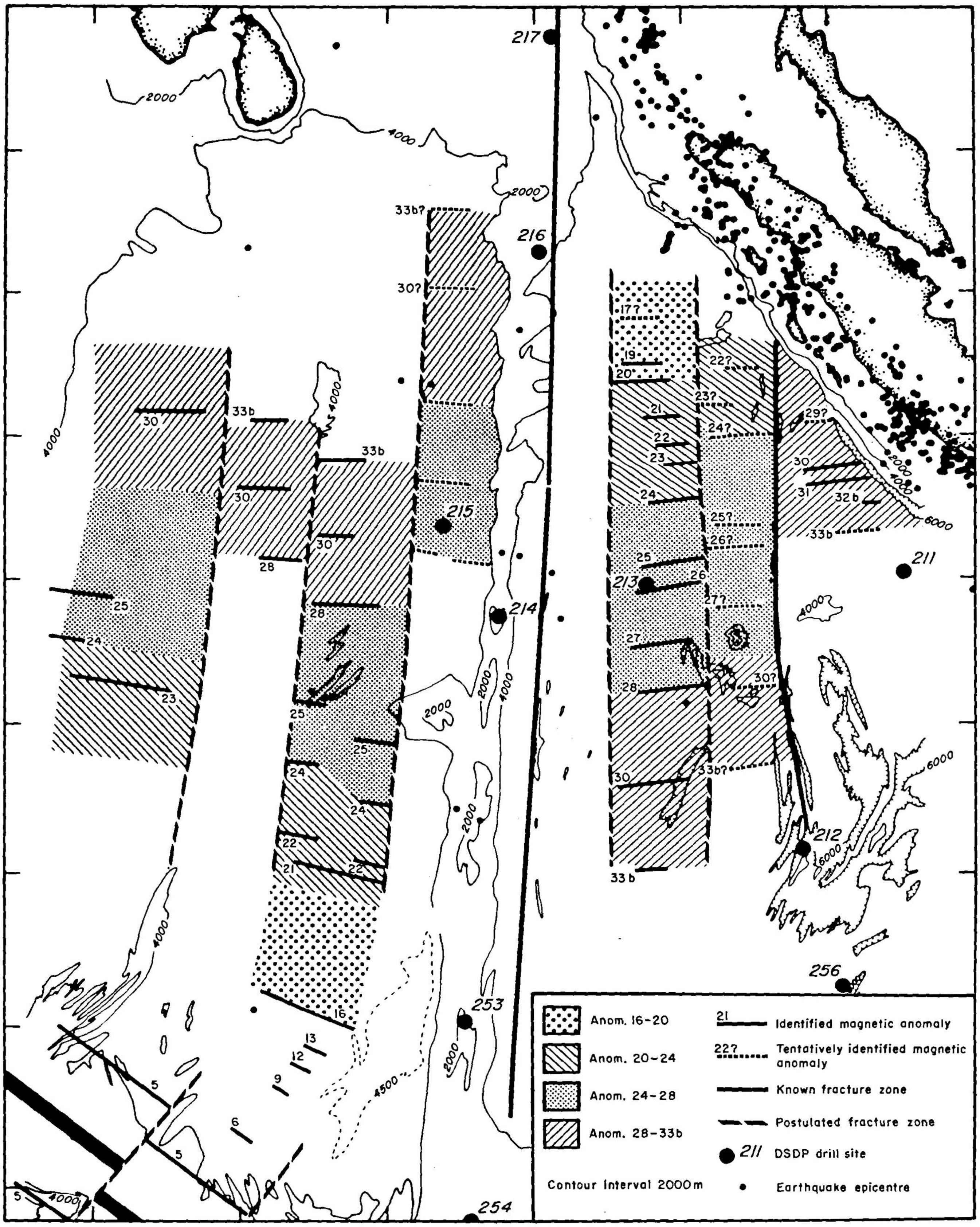


(See Fig.1 for location of sites)

MAJOR LITHOLOGIC RESULTS OF DSDP SITES 211 AND 212

(after Sclater et al., 1974)

FIG. 6



TECTONIC SUMMARY OF THE EASTERN INDIAN OCEAN, SHOWING MAGNETIC ANOMALIES

(after Sclater & Fisher, 1976)

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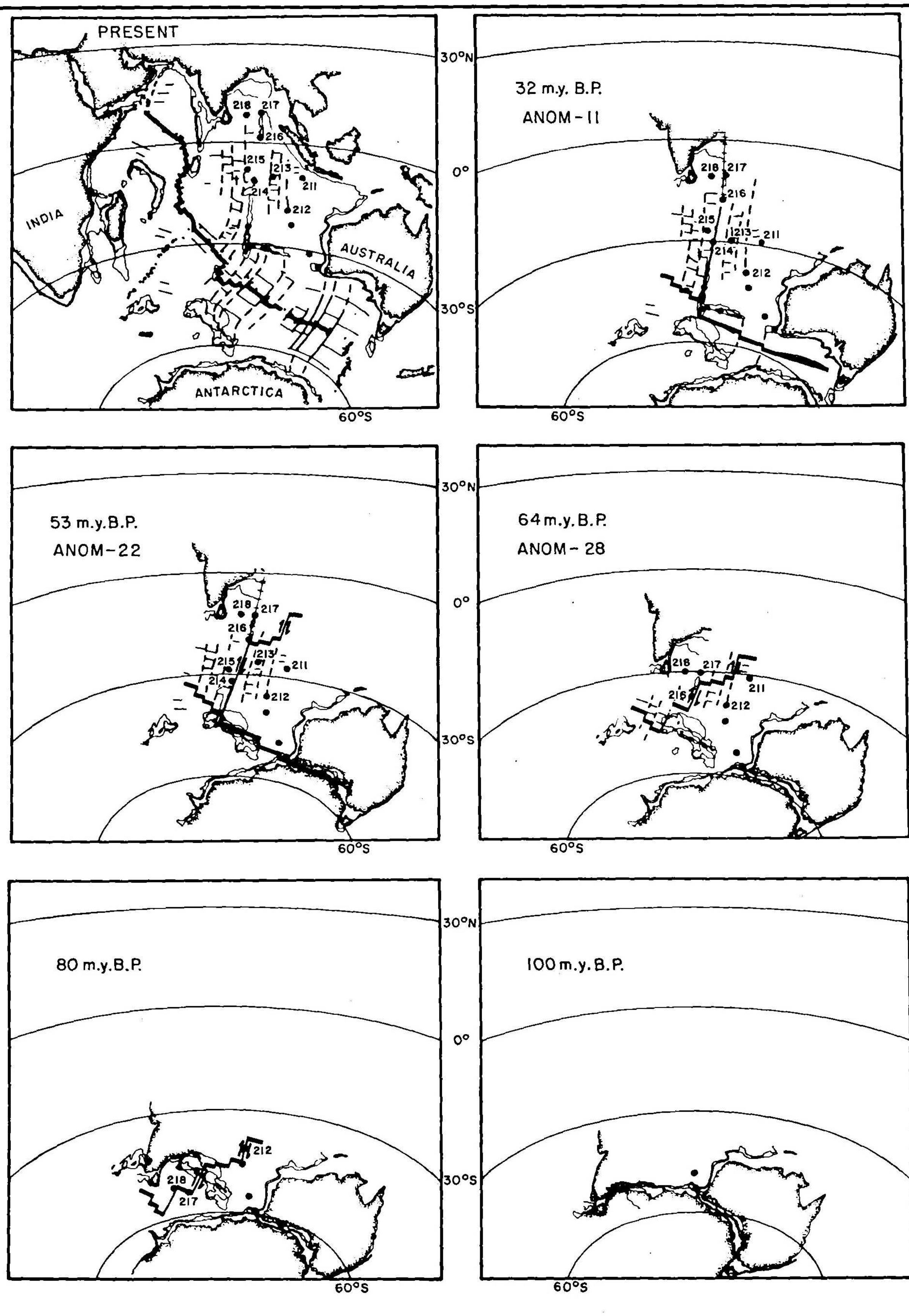
FIG. 7



Active spreading centre
Known fracture zone
Projected fracture zone
Identified magnetic anomaly
•212 DSDP drill site from Leg 22

TECTONIC EVOLUTION OF THE INDIAN OCEAN

(after Sclater & Fisher, 1974)

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PROSPECTIVITY

Christmas Island forms a major source of phosphate at present and the assessment of its reserves suggests that it will be of continuing importance to Australia. The prospectivity for other types of economic deposits is poor. There appears to be no mineralization associated with early volcanic activity on Christmas Island and the lack of sediments on the Christmas Rise indicates that prospects for hydrocarbon accumulation are poor in the area surrounding Christmas Island. Iron mineralization associated with a diabase sill drilled at site 211 during the DSDP program is not likely to be widespread and furthermore is of depths below the sea-floor and in water-depths which would make recovery uneconomic.

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