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SEDIMENTS AND STRUCTURES OF THE AUSTRALIAN CONTINENTAL SLOPE BORDERING THE INDIAN OCEAN

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FOREWORD

This paper was forwarded to Professor Wolfgang Schott of the German Federal Geological Survey as a contribution to his paper as principal author for the presentation on the Indian Ocean for Panel 5 of the 9th World Petroleum Congress, Tokyo, 1975

CONTENTS

PLATES

SUMMARY

The Australian continental margin in the north contains the southern slope of the Timor Trough formed by gentle downwarping since the Pliocene. Elsewhere bordering the Indian Ocean the continental slope is mostly complex and largely block-faulted and has been formed by rifting, along the northwest and west coasts until the Jurassic and Cretaceous, and along the south coast until the Eocene.

The Timor Trough has a simple convex southern slope and irregular northern slope. Sedimentary sequences lie parallel to the sea floor in the southern slope, which appears to be overthrust by the northern slope. The youngest downwarped sediments are upper Pliocene.

The northwestern and western continental margin of Australia contains a complex slope with plateaus and terraces formed of faulted blocks of Late Triassic and earlier sediments overlain by extensive mantles of Lower Cretaceous and possibly Jurassic sediments. There are sedimentary troughs in the saddle regions of the Scott, Exmouth, Wallaby, and Naturaliste Plateaus. The Ashmore and Carnarvon Terraces are underlain by troughs of sediments bounded by marginal horst blocks.

The southern continental margin contains the Eyre and Ceduna Terraces in the slope of the Great Australian Bight and the extensive Tasmanian Plateau south of Tasmania. The Eyre Terrace has a thin mantle of sediments over an irregular block-faulted acoustic basement containing grabens of sediments. The Ceduna Terrace is underlain by a basin of ?Cainozoic sediments held behind a marginal barrier. Between the Ceduna Terrace and the Tasmanian Plateau, block-faulted pre-Tertiary sediments form the major part of the continental slope. Deep-water sedimentary basins are present at the base of the slope and in the continental rise to the west of the Ceduna Terrace.

The northwestern continental slope has probably the highest hydrocarbon potential. Parts of the less explored southern slope are also believed to have a fairly high potential.

INTRODUCTION

From December 1970 to January 1973 the Australian Bureau of Mineral Resources made a regional geophysical survey of most of the Australian continental margin with the particular objective of investigating the features and structures of the continental slope. Survey lines 20 to 30 nautical miles apart extend from near the coast to the foot of the continental slope at a water depth of about 4000 metres with some lines going beyond onto the abyssal plain (Plate 1). About 85 000 line nautical miles were surveyed. Areas on the northwest shelf and on shelf areas in the Timor Sea and Bonaparte Gulf surveyed between 1965 and 1968 were not resurveyed, but the slope regions beyond these shelves were transversed. Main areas not included in the survey were the Gulf of Carpentaria, the Great Barrier Reef, and Bass Strait.

Seismic, gravity, magnetic, and depth recordings were made. The seismic system comprised a 120-kilojoule sparker and a six-channel streamer. The first hydrophone group was 300 metres from the ship with subsequent channels at 200-metre intervals. Navigation was by a satellite Doppler and sonar Doppler combination. Ship speed was about 9 knots.

The processing of the data from this survey is not complete; so far interpretation has been done from copies of on-board monitor sections from a single seismic channel and preliminary gravity, magnetic, and bathymetric maps contoured from one-hourly data values computed on board ship.

The interpretation undertaken to date has been particularly oriented to slope features and is in terms of topography and morphology, sediment thickness and structure, basement depth and structure, and relative crustal thickness from gravity data (Watt, in prep.; Cameron and Petkovic, in prep.; Willcox, in prep. ; Pinchin and Cameron, 1974). Only in a few cases can ages of sediments be inferred from drillhole data available from the Deep Sea Drilling Project (Legs 22, 26, 27, and 28) and from exploration wells on the shelf. On average the seismic system could yield reflections to 2 seconds or about 2 kilometres beneath the sea floor. In some areas the sedimentary sequence was too thick for basement to be reached and the sedimentary thicknesses shown in Plate 3 are minimal. Whether sediments appeared well layered or acoustically transparent on the seismic record has been taken as an indication of their probable terrigenous or pelagic origin.

THE AUSTRALIAN CONTINENTAL MARGIN

The Australian coast bordering the Indian Ocean, as defined by the International Hydrographic Bureau in 1953, stretches from Torres Strait in the north to the Southeast Cape of Tasmania in the south. The continental slope off this coast runs from the eastern end of the Timor Trough off the Arnhem Land Peninsula round to the Tasmanian Plateau south of Tasmania.

While the reconstruction of the northwest and west coasts of Australia as apart of Gondwanaland remains doubtful, recent DSDP legs 26, 27, and 28 have established that the adjacent abyssal plains were formed in Late Jurassic to Early Cretaceous times (Luyendyk, Davies, et al., 1973; Veevers, Heirtzler, et al.; 1973; Hayes, Frakes, et al., 1973). Opening of the ocean floor and formation of the western margin was preceded by rifting phases from the Triassic and perhaps from as far back as the Late Carboniferous (Veevers & Evans, 1973). There is good agreement on the later separation of Australia from Antarctica in the Eocene, with combined evidence from DSDP legs 28 and 29, (Hayes, Frakes, et al., 1973; Kennett, Houtz, et al., 1973) magnetic lineations, and geology of the Australian coast. Earlier rifting phases along this nascent margin go back at least to the Late Jurassic (Griffiths, 1971).

Only about thirty percent of the length of Australian margin is of the simple form of shelf, slope, and rise. The remainder is complex and appears to be greatly affected by vertical and horizontal movements of blocks of continental-type crust, associated with the formation of the margins by rifting. Over several large areas, marginal plateaus exist at depths part way between the shelf at 200 metres and the ocean floor at 5000 metres and more (Plate 2). Thick sedimentary rocks cover parts of these plateaus (Plate 3).

Most of these plateaus fall into two distinct types: firstly, where a tableland is separated from the mainland by a trough or saddle usually having considerable sedimentary fill; and secondly, where the plateau is in the form of a step or terrace projecting from the continental slope. Nomenclature of some of these plateaus has varied from author to author. In this paper, features of the first type are named 'Plateau', as in Exmouth Plateau and Tasmanian Plateau; those of the second type are named 'Terrace', as in Ceduna Terrace and Carnarvon Terrace (Branson, 1974).

Gravity values over these plateaus and terraces indicate that the crust beneath them is intermediate between continental and oceanic in thickness, and closer to continental.

TIMOR TROUGH

The Timor Trough on the northern edge of the broad Sahul Shelf reaches a maximum depth of 3400 m southeast of Timor. Seismic sections (Plate 5) show a simple convex slope on the southern side with well stratified rock sequences beneath and parallel to the sea floor and an irregular steeper northern slope without distinct sedimentary structures. Reflection events in the southern slope appear to extend under the northern slope. In the southern slope there is some normal faulting with small inferred movement. Some small reverse faults occur within the younger sediments of the lower slope. In the axis of the Trough a thin wedge of flat-lying sediments thickens against the steeper northern slope.

Deep sea drilling at DSDP Site 262 (Plate 3) in the Trough axis penetrated pelagic oozes with turbidity current layerlying upper Pliocene shallow-water sediments (Veevers, Heirtzler, et al., 1973). A Pleistocene to Recent subsidence is inferred from these drilling results.

These combined results can be taken to indicate an overthrust of the island of Timor over the downwarped Sahul Shelf (Plate 4).

WEST AND NORTHWEST COASTS

The continental margin off the west and northwest coasts conforms to the simple topographic model of shelf, slope, and rise only in the 300 km interval from Geraldton to Perth. Four major marginal plateaus occur: the Scott Plateau northwest of Scott Reef, the Exmouth Plateau off North West Cape, the Wallaby Plateau west of Carnarvon, and the Naturaliste Plateau west from Cape Naturaliste (Plate 2). In addition there are at least two slope terraces: the northerly one, between Ashmore and Scott Reefs, is named the Ashmore Terrace, and the larger southern one, between North West Cape and Geraldton, is named the Carnarvon Terrace (Branson, 1974).

Seismic sections (Plates 6, 7, and 8) across the slope and marginal plateaus show much high-angle block-faulting consistent with a taphrogenic origin of the margin. Narrow regions of horst blocks parallel to the slope limit the outer edges of the Ashmore Terrace and part of the Carnarvon Terrace, and on the shelf side of these horst blocks sedimentary basins or troughs have formed.

The Scott Plateau is a prominent irregular morphological feature covering a total area of 66 000 km^2; its central region at about 2000 m depth covers 26 000 km^2. The saddle region to the east holds sediments at least 2 km thick.

EXMOUTH PLATEAU

The largest plateau in the region is the Exmouth Plateau (Plate 6) with a total area of 280 000 km^2; its central region is less than 2 000 m deep and covers 77 000 km^2.

The Exmouth Plateau comprises at least three major geological provinces. The largest and main sedimentary province lies south of a linear discontinuity along latitude 18°S (Hogan, 1974). Horst blocks form a borad elongate dome reaching a minimum depth of 840 m and with northeasterly plunge. Dips within the block-faulted sediments are dominantly easterly. The northern part of the plateau is formed of large horst blocks more than 50 km across with mainly westerly dips. The sedimentary mantle overlying the plateau is 0.5 to 1 km thick. It contains numerous minor unconformities and varies in type from well bedded sediments with varying dips to acoustically transparent sediments. The part of the plateau adjoining the continental shelf is a broad trough parallel to the northeast strike of the main structures on the adjacent shelf and containing at least 2 km of sediments.

Tentative correlation of the horizons in the southern area with the known sequences in the Rankin Platform on the adjacent shelf indicates a Late Triassic minimum age for the block-faulted sediments and a Cretaceous to Recent age for the sedimentary mantle (Hogan, 1974), which is consistent with the Late Jurassic or Early Cretaceous age of the adjacent abyssal plains. Low gravity values over the southern province of the Exmouth Plateau indicate a very thick total sedimentary section.

WALLABY PLATEAU

The Wallaby Plateau, a deep-water marginal plateau off Carnarvon (Plate 7) contains a number of faulted sedimentary blocks at its centre and in the northeast. The plateau extends over a total area of 120 000 km^2 and has a central dome covering 23 000 km^2 in water depth less than 3000 m. The sedimentary mantle covering the plateau fills small central grabens. In general this mantle is about 0.5 km thick, and at the saddle it is continuous with the sediments of the Cuvier Abyssal Plain.

CARNARVON TERRACE

The Carnarvon Terrace is a step-like feature in the slope between the Northwest Cape and Geraldton, widening to 100 km off Carnarvon and covering 70 000 km^2 in depths between 600 m and 2000 m. The main structure is controlled by block faulting. Near Carnarvon, towards the top of the slope few reflections are recorded within the faulted blocks. Farther south, sediments within the faulted blocks have an easterly dip, and north of Geraldton folding of the sediments is evident in a number of blocks. Near the shelf break on the inner part of the terrace the sedimentary mantle covering these fault blocks is less than 0.5 km thick. Beneath this terrace the sedimentary mantle has filled some small grabens. Below the terrace to the west, sediments more than 1 km thick cover the foot of the slope. These interfinger with the acoustically transparent sediments of the Perth Abyssal Plain.

NATURALISTE PLATEAU

The Naturaliste Plateau separates the structural regions caused by the separate episodes of taphrogeny on the western and southern coasts. Its total area is 120 000 km^2 with an elevated western region covering 46 000 km^2 at less than 2500 m depth. The massive central block has less faulting than other western marginal plateaus and slopes. The saddle region of the plateau contains a sedimentary basin which plunges northwards and merges with the continental rise bordering the Perth Abyssal Plain. A smaller sedimentary basin lies in the west of the plateau.

Seismic sections (Plate 8) across the Naturaliste Plateau show a number of widespread unconformities in a thin sedimentary mantle which is fairly transparent acoustically. Only minor reflection events are recorded from the underlying central block, which may be either sedimentary or metamorphic. Deep sea drilling on this plateau at DSDP Sites 258 (Luyendyk, Davies, et al., 1973) and 264 (Hayes, Frakes, et al., 1973) penetrated pelagic sediments containing several unconformities. The oldest rocks penetrated were probable Lower Cretaceous. The thickest accumulations of Lower Cretaceous and possibly older sediments occur in the sedimentary basins in the saddle (Plate 3) and on the western end of the plateau.

SOUTH COAST

Major features in the continental slope off the south coast of Australia are two terraces in the Great Australian Bight, the Eyre Terrace and the Ceduna Terrace (Plate 2), and a marginal plateau south of Tasmania, the Tasmanian Plateau.

Block-faulted sedimentary rocks in the slope between Kangaroo Island and the Tasmanian Plateau form features in the slope smaller than the Eyre and Ceduna Terraces. Upper Cretaceous and Tertiary accumulations occur over these features. The rest of the southern margin has a simple continental slope, cut by numerous canyons south of Adelaide and west of Bass Strait. Along the western coast of Tasmania (Plate 12) a major sedimentary wedge about 1 km thick at the foot of the slope interfingers with acoustically transparent sediments to form the continental rise.

The best structural and straitigraphic information on the southern margin comes from drilling in the Otway Basin. A block-faulted Mesozoic sequence is covered by an Upper Cretaceous and Tertiary mantle of land-derived sediments. From the similarities in structure along this margin it is possible that a similar model could apply over a large part of it.

EYRE AND CEDUNA TERRACES

The Eyre Terrace extends over 16 000 km^2 in water depths between 600 and 1000 m. East of the Eyre Terrace, the larger Ceduna Terrace covers 63 000 km^2 between 1000 and 2500 m and its outer limit is over 200 nautical miles offshore.

Seismic sections recorded across the Eyre and Ceduna Terraces indicate different origins for the two features. In the Eyre Terrace (Plate 9) a block-faulted acoustic basement is covered by a veneer of sediment 0.5 km thick. Basement also contains grabens filled with sediments up to 1 km thick beneath the general sedimentary cover.

On the Ceduna Terrace (Plate 10) over 2 km of well stratified sediments overlies a block-faulted sedimentary sequence. The upper stratified sediments form a basinal structure limited on the outer edge by a basement rise with west-northwest strike (Plate 4). South of the Eyre Terrace, in 2500 to 4000 m of water, a sedimentary basin in the lower part of the continental slope interfingers with an extensive continental rise containing over 1.5 km of probable pelagic sediments in places.

TASMANIAN PLATEAU

The saddle region at the northern end of the Tasmanian Plateau contains less than 0.5 km of sedimentary cover over block-faulted basement (Plate 3). Pockets about 30 km in extent contain up to 1.5 km of sediments. Metamorphic rocks encountered at DSDP Site 281 (Kennett, Houtz, et al., 1973) suggest a continental origin for the Tasmanian Plateau. The saddle region of this plateau has a magnetic anomaly field consistent with faulted metamorphic basement indicating the presence of a southward extension of the Tasman Geosyncline from Tasmania.

CONCLUSIONS

Therefore, in summary, geophysical investigation of the Australian continental margin bordering the Indian Ocean indicates a history of recent compression in the north in the Timor Trough area and an older history of tension and rifting elsewhere. The compression and overthrusting in the Timor Trough have brought shelf sediments and structures to the foot of the southern slope and underneath the northern slope to some extent. On the margin elsewhere the separate episodes of tension and rifting followed by the opening of the ocean floors in Jurassic and Cretaceous-Eocene times have created a number of areas of block-faulted and differentially subsidiseded continental rocks that have been later covered by mantles of sediments. These areas are now evident as the marginal plateaus and slope terraces described above.

Because of the large masses of sedimentary rocks and the many structures that are present, the potential for finding accumulations of hydrocarbons in the area of the continental margin described must be considered good. The prospects of the sedimentary rocks that antedate the episodes of taphrogeny are probably closely related to the prospects of similar rocks under the adjacent shelf, but as modified by the faulting and subsidence to which they were subjected. There is not sufficient information on the nature and age of the later sedimentary sequences that form the mantles and fill the troughs to evaluate their prospects. In particular the extent to which source rocks have been present in an environment suitable for the formation of hydrocarbons is not known.

The whole of the southern slope and axial zone on the Timor Trough must be considered prospective as the sedimentary sequences are more than 2 km thick and probably terrigenous.

The northwest and western slope from the Scott Plateau to the Exmouth Plateau, together with parts of the Carnarvon Terrace, contains areas with thick sedimentary sequences. On the Exmouth Plateau an extensive area of thick sedimentary rocks with a broad central high must be considered prospective. On the adjacent shelf, hydrocarbons are found in association with Jurassic and Cretaceous source rocks (Powell & McKirdy, 1972). The extent to which these Jurassic and Cretaceous rocks are present in the slope and plateau areas is not known. The extent to which they are present in the trough that separates the tableland of the Exmouth Plateau from the mainland is probably important to the prospectivity of the area.

On the Naturaliste Plateau, only the saddle and western sedimentary basin are considered prospective.

On the southern continental slope the prospectivity is greater from the Ceduna Terrace eastwards because of the greater thicknesses of sediments and the more favourable structures.

The Tasmanian Plateau was not surveyed and its potential is not known.

It is therefore seen that although the overall prospectivity of the continental slope and its associated features must at present be rated as good our knowledge is fragmentary. Definite answers will not be obtained until stratigraphic holes are drilled, particularly on the marginal plateaus and slope terraces. In addition it would help to have more and better seismic work to try to link the sediments of the deeper margin to known sequences on the continental shelf.

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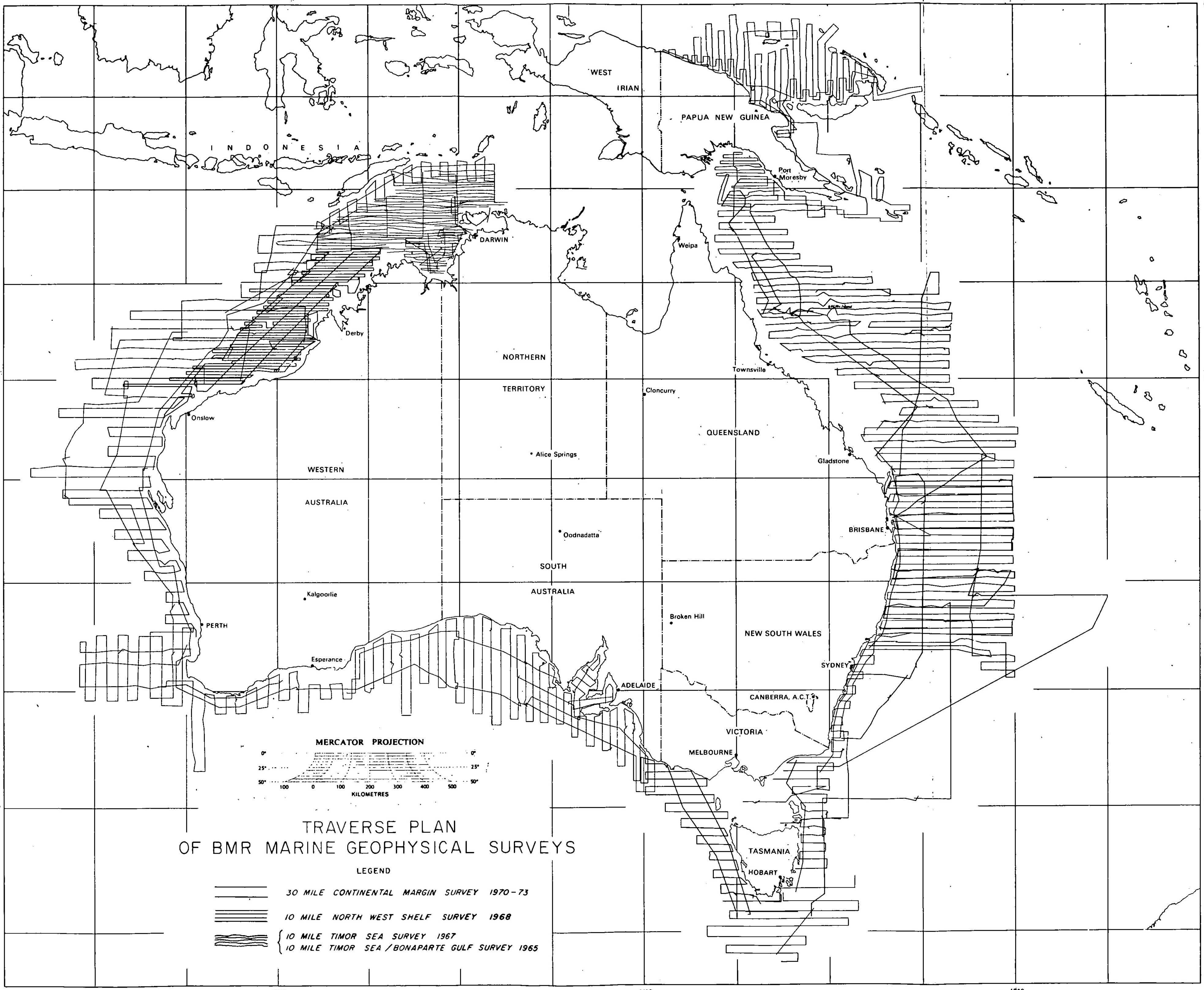


TRAVERSE PLAN OF BMR MARINE GEOPHYSICAL SURVEYS

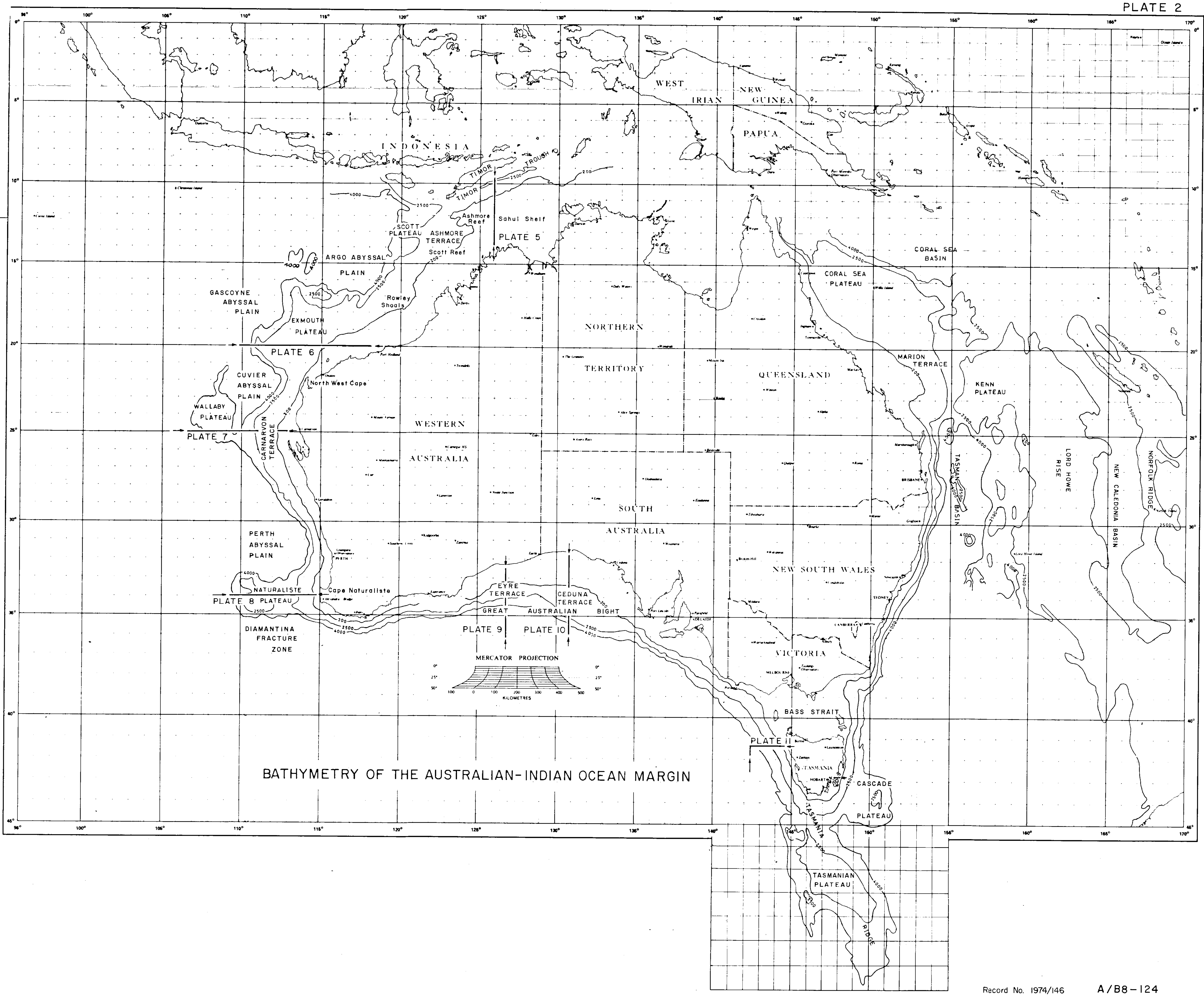
LEGEND

30 MILE CONTINENTAL MARGIN SURVEY 1970-73

10 MILE NORTH WEST SHELF SURVEY 1968

10 MILE TIMOR SEA SURVEY 1967
10 MILE TIMOR SEA / BONAPARTE GULF SURVEY 1965

PLATE 2



BATHYMETRY OF THE AUSTRALIAN-INDIAN OCEAN MARGIN

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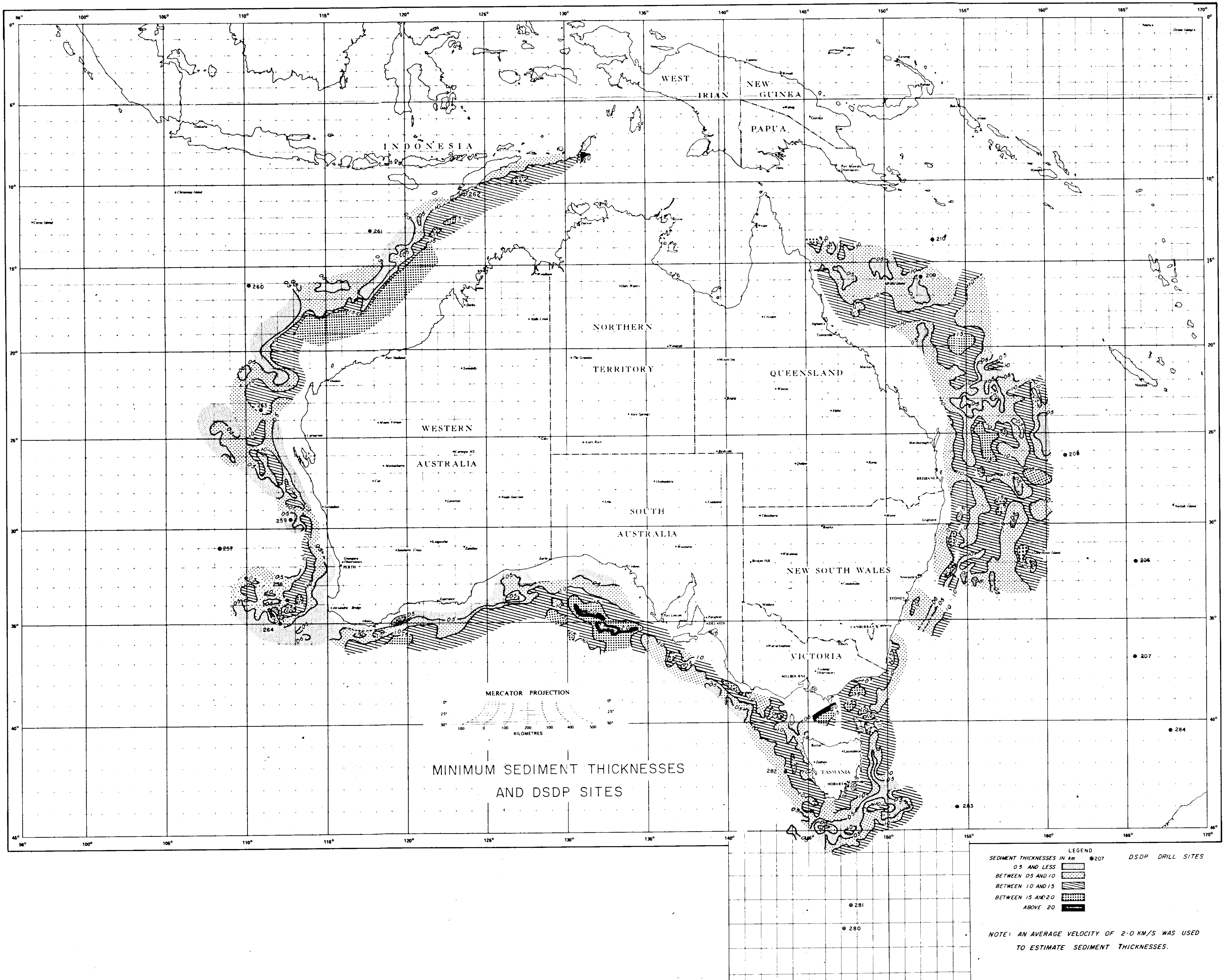

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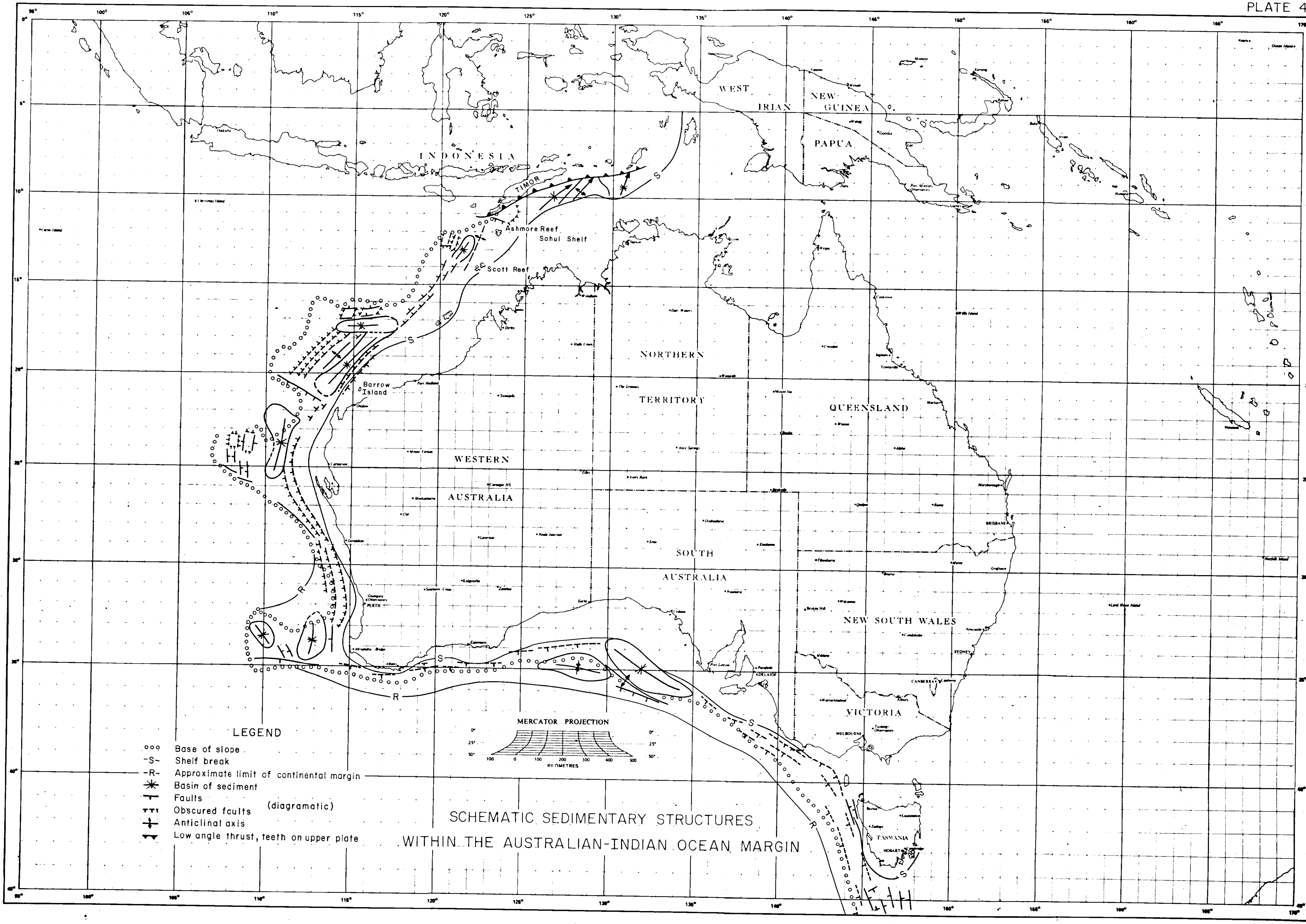
PLATE 4



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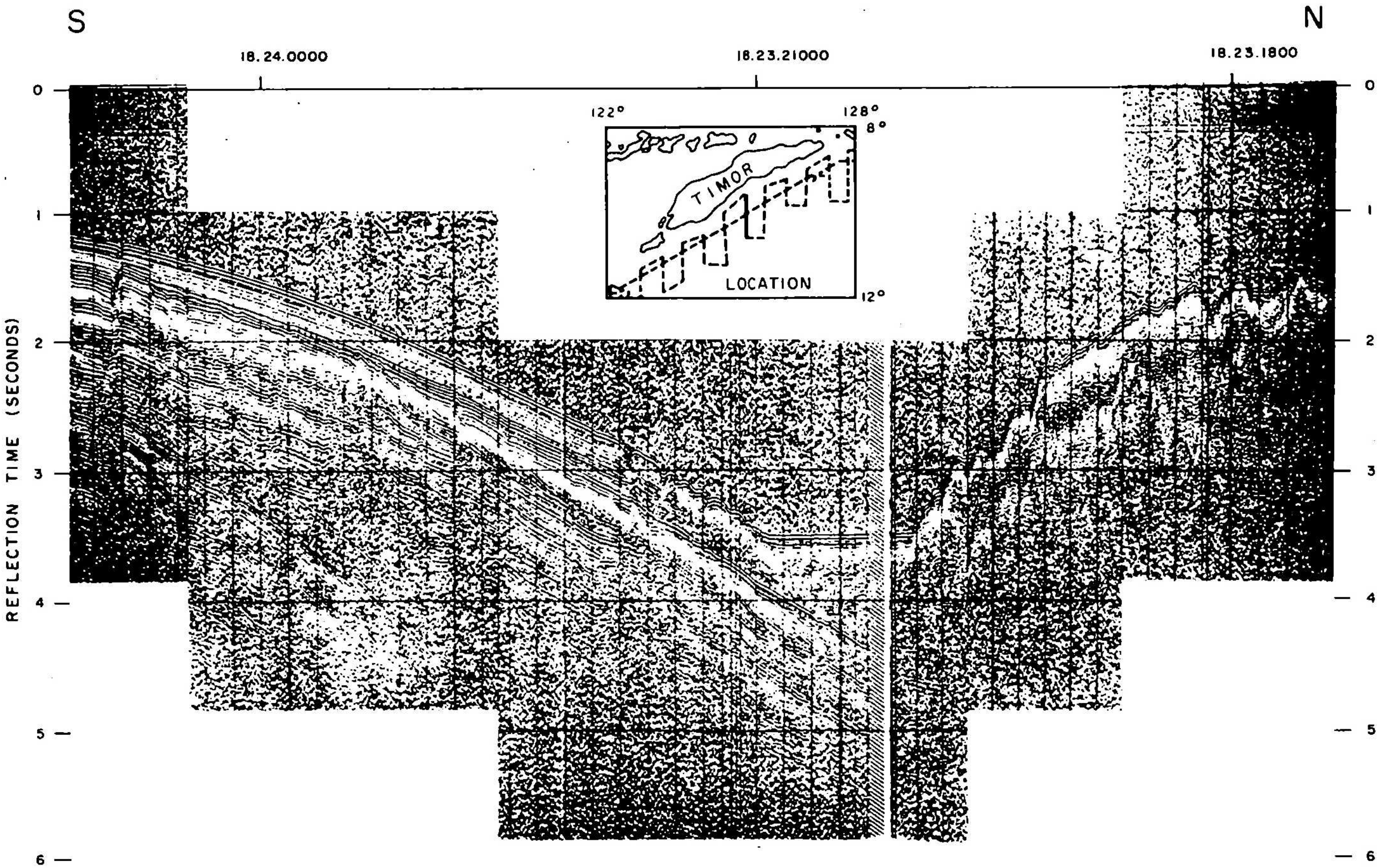

Approximate
Horizontal scale
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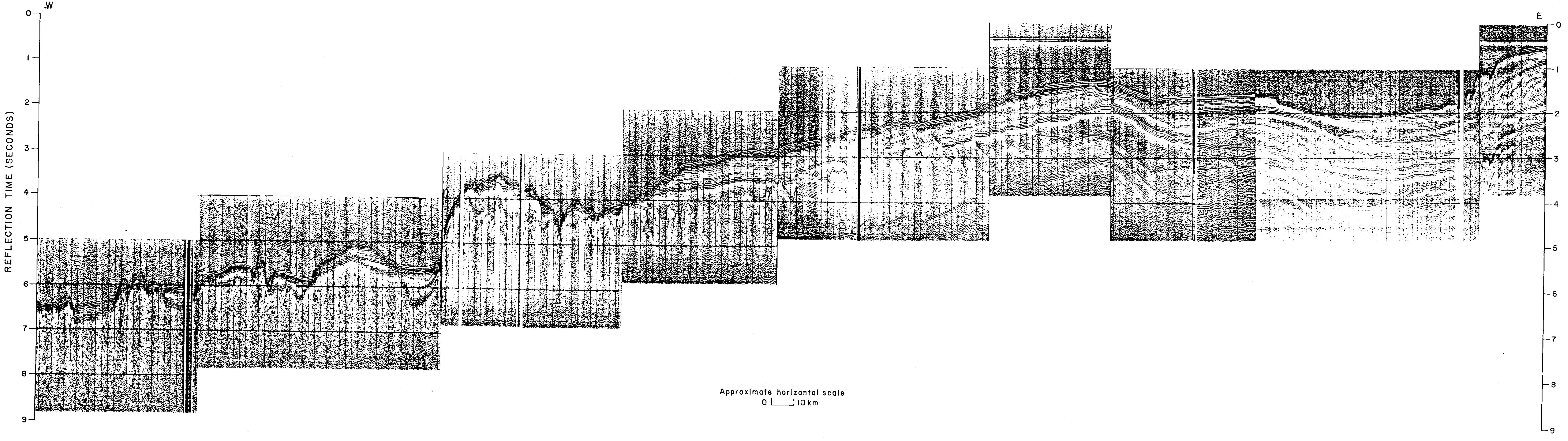
LINE 18/025

TIMOR TROUGH SEISMIC SECTION

Bureau of Mineral Resources
Australia

C51/B8-47A

PLATE 5



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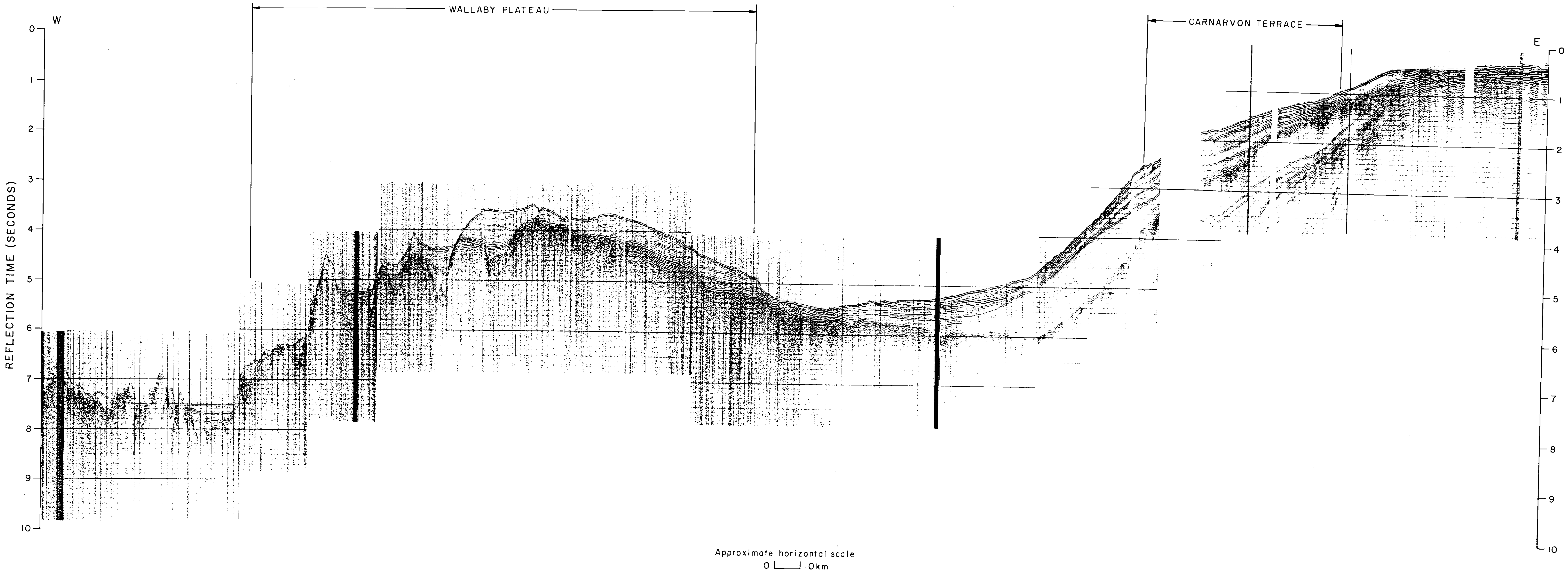
EXMOUTH PLATEAU SEISMIC SECTION



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CARNARVON TERRACE, WALLABY PLATEAU
SEISMIC SECTION

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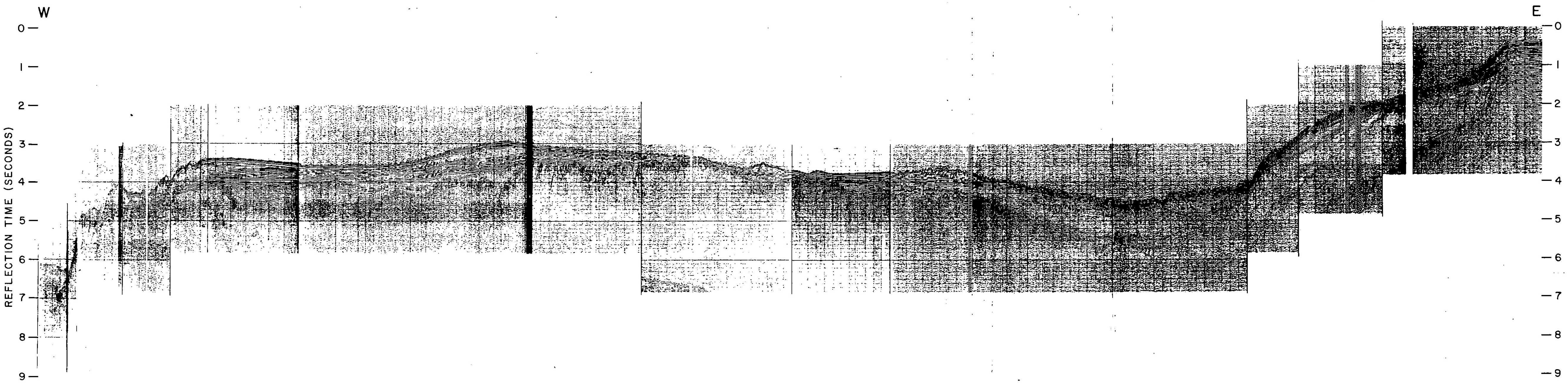

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LINE 19/002

NATURALISTE PLATEAU SEISMIC SECTION

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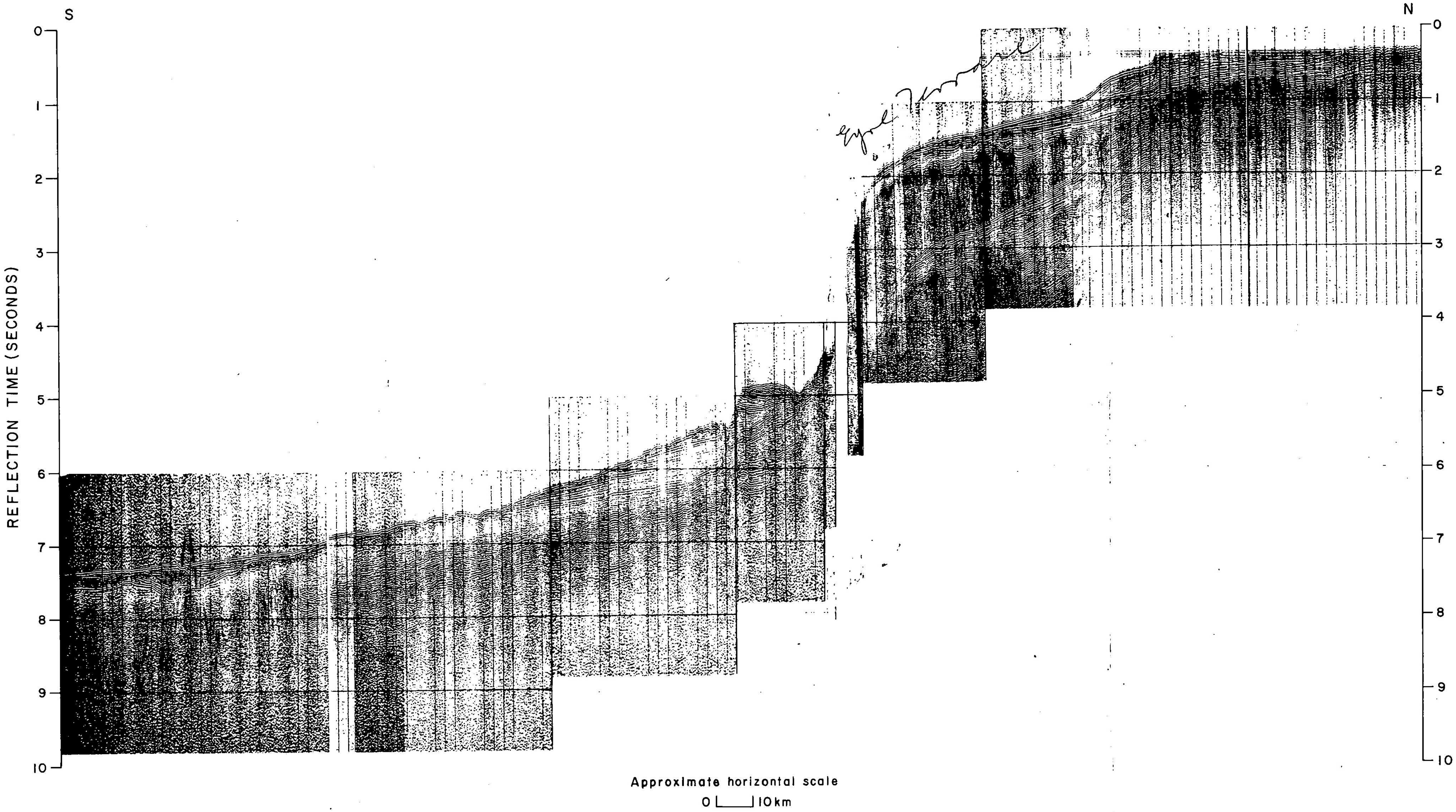
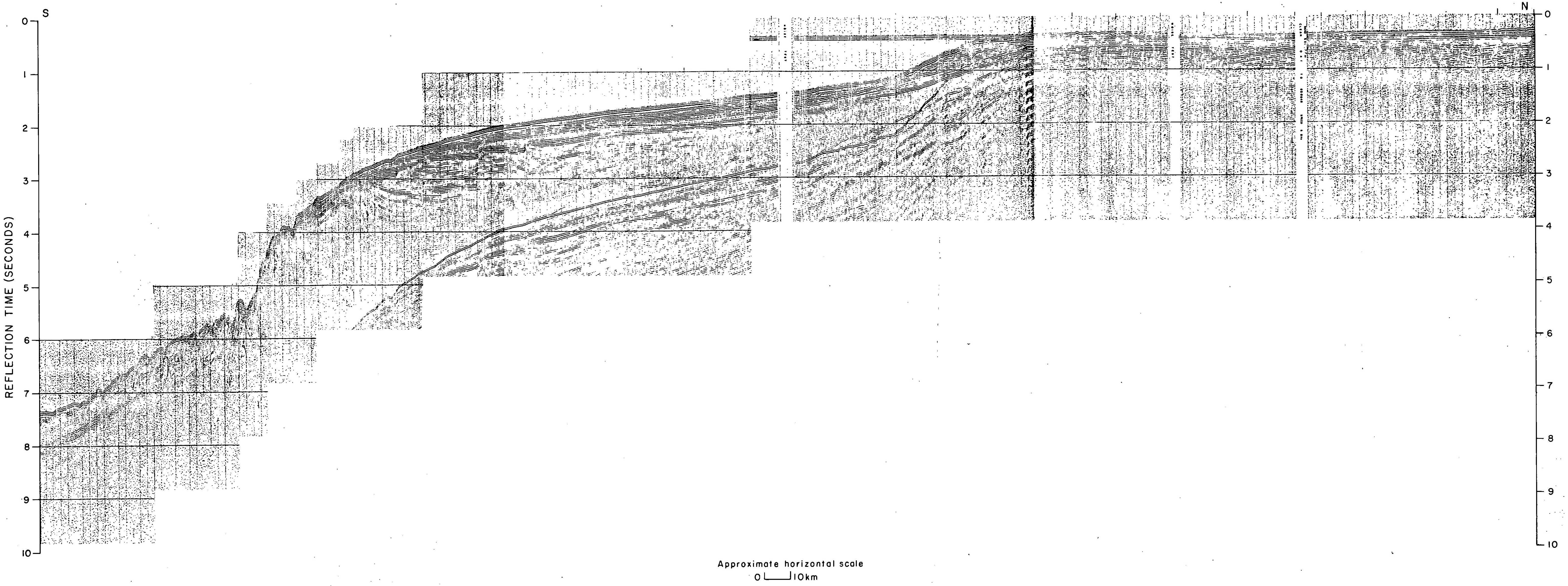


LINE 16/166

EYRE TERRACE SEISMIC SECTION



LINE 16/136

CEDUNA TERRACE SEISMIC SECTION

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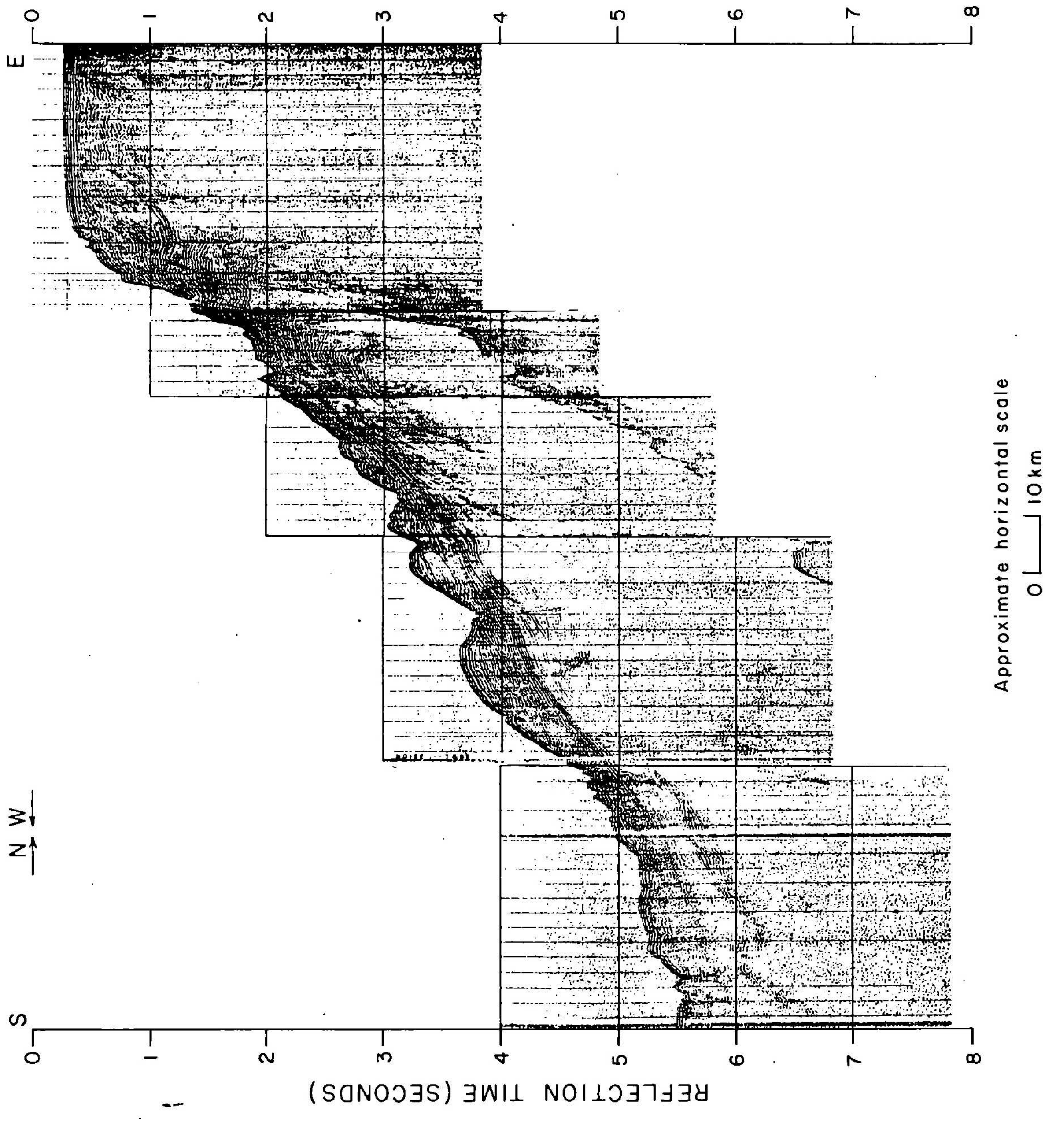

LINE 16/017

WESTERN TASMANIA SEISMIC SECTION