Bureau of Mineral Resources, Geology & Geophysics

RECORD

Record No. 1988/48

STRUCTURE, STRATIGRAPHY, EVOLUTION AND REGIONAL FRAMEWORK OF THE TOWNSVILLE TROUGH AND MARION PLATEAU REGION

-RESEARCH CRUISE PROPOSAL-
Project 9131.11

by

P.A. Symonds and P.J. Davies

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EXECUTIVE SUMMARY

Structure, stratigraphy, evolution and regional framework of the Townsville Trough and Marion Plateau region

Offshore northeast Australia contains some of the most significant features of the Australian continental margin such as the Great Barrier Reef, the largest epicontinental reef on earth, and the Queensland Plateau, the largest marginal plateau in the Australian region and one of the largest of its type in the world. Three major carbonate platforms occur off northeast Australia comparable in size to counterparts anywhere in the world today. The platforms are separated by rift troughs which contain areas of thick sediment deposited in environments varying from terrestrial, through marginal and restricted shallow marine, to deep open marine. Understanding the origin of these features is important because they constitute a modern analogue of a sedimentological and structural association - reef/adjacent rift trough/marginal plateau - which has been common throughout the geological record and in places has formed significant petroleum provinces.

During the last quarter of 1985 BMR conducted two **Rig Seismic** research cruises off northeast Australia and these produced exiting new insights into the margin, and resulted in the generation of a data set which is, in total, one of the best developed anywhere for such a passive margin association. As a result, the northeast Australian margin is rapidly gaining significance as a classic region in which to define and develop globally applicable models for passive margin and carbonate platform development, and to improve our understanding of economically important ancient analogues. The region is therefore of inestimable value to science and exploration, and this has been recognised by the advisory structure of the international Ocean Drilling Program (ODP), which has ranked proposals for scientific drilling off northeast Australia very highly.

The results of the 1985 **Rig Seismic** cruises indicated that the Townsville Trough is an area of significant petroleum potential in moderate water depth (< 2000m), and the current downturn in offshore exploration presents an opportunity to consolidate our knowledge of this feature, and therefore accelerate interest in it when exploration takes off again. Also, the the Marion Plateau, which was not examined during the 1985 cruises, represents a large area of poorly explored continental margin in relatively shallow water (< 500m), and it is possible that parts of this feature could have short-term exploration potential.

It is proposed that **Rig Seismic** conduct two cruises over the Townsville Trough/Marion Plateau region in September and November, 1987. The cruises will have a blend of regional framework, stuctural and sedimentological process, and resource related objectives, and will include time to carry out the pre-requisite site surveys over proposed ODP sites in the region. The cruises will utilise airgun (twin 10 gun arrays - 52.4 litre) multichannel seismic profiling, high-resolution (watergun) multichannel seismic profiling, gravity and piston coring, dredging, heat-flow measurements and side-scan sonar to meet the objectives. It is planned that the first cruise will have a duration of 32 days, leaving from Brisbane and finishing in Townsville; and that the second will have a duration of 24 days, leaving from Townsville and finishing in Sydney.

The major objectives of the cruises are:

1. to determine the exact structural style of the Townsville Trough, its relationship to the adjacent Queensland and Marion Plateaus, and its

implications to the development of the northeast Australian continental margin.

2. to establish a seismic stratigraphic framework for the Townsville Trough that will provide a basis for understanding the nature of the depositional systems and facies variations within it, and that will aid future exploration in the region.
3. to define the positions of the major depocentres and structural leads in the Townsville Trough.
4. to define play concepts likely to aid petroleum exploration from an analysis of the structural and sedimentological evolution of the Townsville Trough, and a preliminary understanding of its thermal and burial history.
5. to define the structural and sedimentological evolution of the Marion Plateau.
6. to determine the timing and the extent of reef growth on the Marion Plateau, and to define the causes of the demise of reef growth.
7. to define the relations between the evolution of the Marion Plateau and the Great Barrier Reef.
8. to determine any structural and stratigraphic relationships between coastal and shelf basins such as the Hillsborough, the Narrows and the Capricorn Basins, and the continental margin rift basin systems.
9. to conduct site surveys in support of the Ocean Drilling Program proposals.

Project Timetable

First half 1987:	evaluation of existing geophysical and geological data, and establish testable models and ideas.
4 September - 5 October:	first **Rig Seismic** cruise, Brisbane to Townsville.
30 October - 22 November:	second **Rig Seismic** cruise, Townsville to Sydney.
By November 1989:	public release of all geophysical and geological data from the cruises.

Project Leaders

P.J.Davies
P.A. Symonds

Consultation with Industry and Other Organisations

This project proposal has been developed in consultation with: Resource Assessment Division, BMR; Division of Petrology and Geochemistry, BMR; Geological Survey of Queensland; Great Barrier Reef Marine Park Authority; Australian Survey Office; Monash University; Rice University, Houston, USA; Lamont-Doherty Geological Observatory, New York, USA; Duke University, Durham, N.C., USA; Vrije Universiteit, Amsterdam, Netherlands; and aspects of the study have been discussed with various petroleum exploration companies such as Santos, International Petroleum Corporation, BHP, Amoco, and Elf Aquitane. Copies of the project proposal will be forwarded to the relevant state and federal authorities during August 1987.

CONTENTS

Page

7. Schematic profiles across the northeast Australian margin (after Falvey & Mutter, 1981). Locations of the profiles are shown in Figure 5.

8. Schematic profiles across the northeast Australian margin (after Symonds, 1988, in press). Locations of the profiles are shown in Figure 5.

9. Detailed bathymetry of the Townsville Trough/Marion Plateau area showing the location of 1985 **Rig Seismic** seismic data (after Davies, Symonds & others, 1987).

10. Detailed bathymetry of the southern Marion Plateau/Capricorn Channel area (after Marshall, 1977).

11. Regional setting, and location of the major sedimentary basins and onshore geological provinces (after Mutter, 1977).

12. Stratigraphy and correlation of drillholes in the 1987 study area (after Davies & others, in press; Ericson, 1976).

13. Stratigraphy of the DSDP sites in the western Coral Sea (after Taylor, 1977).

14 Distribution of 1970 - 1978 seismic data in the western Coral Sea by BMR, Shell, Gulf and Lamont-Doherty (after Mutter & Karner, 1980).

15. Distribution of post-1970 seismic data in the central Great Barrier Reef region by BMR, Shell and Gulf (modified from Symonds & others, 1983).

16. Location of Geophysical Service International (GSI) group shoot seismic lines over the Queensland Trough and Plateau.

17. Location of crustal seismic refraction profiles in the western Coral Sea. Also shows the locations of DSDP and some exploration company drilling sites in the region.

18. Conceptual evolutionary scheme for the development of the continental shelf in the central Great Barrier Reef province (after Symonds & others, 1983).

19. A portion of a Geophysical Service International (GSI) group shoot seismic line across the eastern Queensland Trough showing tilt blocks and thick sediment beneath the trough. Location shown in Figure 34).

20. Generalised time-stratigraphic cross-section from the Queensland shelf to the Coral Sea Basin (after Taylor & Falvey, 1977).

21. A portion of a GSI group shoot seismic line from the southern Queensland Plateau near the confluence of the Queensland and Townsville Troughs (location shown in Figure 34). The section shows shallow dipping reflectors which can be interpreted as a detachment or low-angle normal fault (DF), and these continue beneath a large basement tilt block (B). The block corner and associated syn-rift sediments (SR) have been planated, and late rift-phase sediments (LR) are ponded in the half graben and overlain by the Paleocene top-rift (break-up) unconformity (P).

E/O is the late Eocene - early Oligocene regional unconformity (after Lister & others, 1987, in press).

22. A portion of a 1985 BMR shipboard monitor seismic section from the Townsville Trough illustrating the character of the seismic sequences beneath it (after Davies, Symonds & others, 1987). Location shown in Figure 9.

23 Preliminary schematic map of the basin-forming structures beneath the Townsville Trough (after Davies, Symonds & others, 1987).

24 A portion of a stacked Shell seismic line across the eastern Townsville Trough showing the top of a south -dipping tilt block lying beneath the northern margin of the trough. Location shown in Figure 9.

25. A portion of a stacked 1985 BMR seismic line across the wesrern Townsville Trough showing a tilt block bounded by a south-dipping normal fault adjacent to the faulted northern margin of the trough. Faulted syn-rift sediments have infilled the half graben to the north of the block, and are overlain by onlapping ?late-rift and post-rift sediments which exhibit flexural and compaction drape over the block corner. Location shown in Figure 9.

26. A portion of a 1985 BMR shipboard monitor seismic section (highly exaggerated) across the eastern Townsville Trough showing a transverse stuctural zone - transfer fault - separating tilt blocks dipping in opposite directions. Note the drape in the sediments overlying the block corners. Location shown in Figure 9.

27. Schematic profile from the Queensland coast, across the Great Barrier Reef and Marion Plateau, to the Townsville Trough showing generalised rift-phase structuring, and the different phases of carbonate platform and reef development. Location shown in Figure 9.

28. A portion of a stacked 1985 BMR seismic profile across the northern margin of the Marion Plateau showing the reef-rimmed carbonate platform which underlies the plateau in this area. The location of the carbonate platform is shown in Figure 23, and the location of the seismic section is shown in Figure 9.

29. Portions of 1971 BMR single-channel seismic sections over the Marion Plateau. A shows platform reefs and associated lagoonal sediments across the plateau to the southwest of Marion Reef; B shows an escarpment on the edge of a reefal platform to the northeast of Swains Reefs - a possible dredge site during the first 1987 cruise. Locations shown in Figure 9.

30. Schematic north to south section illustrating the thickness variations of tropical and temperate facies. The northward -thickening tropical wedge implies that reef growth commenced earlier in the north than in the south. A representative seismic section illustrating the nature of seismic sequences forming the outer shelf/upper slope from the north-central Great Barrier Reef is also shown (after Davies & others, in press).

TABLES

INTRODUCTION

Offshore northeast Australia (Fig. 1) is an extremely complex product of rifting, seafloor spreading and margin accretion. The Great Barrier Reef is the largest epicontinental reef on earth and forms the western border of the area of interest. The Queensland Plateau is the largest marginal plateau in the Australian region and one of the largest of its type in the world. Three major carbonate platforms occur off northeast Australia comparable in size to counterparts anywhere in the world today. The Great Barrier Reef is as large as the Cretaceous and Jurassic reef systems of the eastern USA; the Marion Plateau is almost as large as the Blake Plateau and the Queensland Plateau is as large as the combined areas of the Great and Little Bahama Banks, off southeastern USA (Fig. 2). The Great Barrier Reef and the Queensland Plateau are separated by the north-south-trending Queensland Trough, and the Queensland and Marion Plateaus are separated by the east-west-trending Townsville Trough. Understanding the origin of these features is important because they constitute a modern analogue of a sedimentological and structural association - reef/adjacent rift trough/marginal plateau - which has been common throughout the geological record and in places has formed significant petroleum provinces. The geological development of north east Australia has juxtaposed rift sequences, thick fluvio-deltaic accumulations and coral reefs in a passive margin setting and is therefore of immense scientific interest. It is rapidly gaining significance as a classic region in which to define and develop globally applicable models for passive margin and carbonate platform development.

During September-October and November-December 1985 BMR used its research vessel **Rig Seismic** to conduct two cruises offshore from northeast Australia throughout the vast region between Townsville and the Gulf of Papua. The cruises were part of a study whose objectives were to determine the regional stratigraphy and structural framework; the relations between tectonics, sea-level change, and sediment style; and the lithofacies, age, and depositional processes adjacent to a large epicontinental reef system (Davies, Symonds & others,1987). Data were collected over the Townsville and Queensland Troughs, the Osprey Embayment, the Torres Shelf/Pandora Trough area, the outer shelf and slope of the Great Barrier Reef, and the western margin of the Queensland Plateau (Fig. 3); specific areas were surveyed in order to fill important gaps in the data coverage or to solve particular problems delineated by previous work in the region. The data include: 4030 km of multichannel seismic reflection profiles (both airgun and high-resolution sparker data), plus magnetic and gravity data; 9 sonobuoy refraction profiles; 207 km of side-scan sonar data; samples from 22 dredge at 17 stations and 190 m of core from 92 coring stations, which tripled the size of the regional data set.

An immediate and direct result of the two cruises has been the generation of a high quality tied data set across the series of rift troughs within the margin, particularly the Townsville, Queensland and Bligh Troughs. These data, together with new data from the slope of the Great Barrier Reef, the Osprey Embayment and Torres Shelf, provided exciting new insights into the reef/rift trough/marginal plateau association which is of major geological and economic significance; for example, in the Devonian of Western Australia and Canada, and the Cretaceous of the USA. The data set generated is, in total, one of the best developed anywhere for such a passive margin association. Therefore, the margin of northeast Australia is becoming a model for the interpretation of such ancient analogues and is of inestimable value to science and exploration. Further, the quality of the model is of such scientific importance that the need to test it is vital. The data obtained from the 1985 cruises has therefore formed the basis of an Ocean Drilling Program (ODP) proposal to address a series of global sediment and ocean history themes in the region. Eight scientific hydraulic piston core drilling sites have been given a high ranking by several panels of the ODP advisory structure, and the region is viewed as being unique in terms of the important facies and stratigraphic models it can provide for understanding ocean history, the evolution of passive margins and ancient carbonate depositional systems. In particular it will provide a model of carbonate platform development different to the Bahamas.

Although the 1985 **Rig Seismic** cruises greatly improved our understanding of the northeastern Australian margin, many gaps in our knowledge remain. In particular, the interpretation of the exact structural style of the Townsville Trough, and even the trends of some major features within it, are difficult to resolve because the regional seismic coverage is inappropriate to the structural complexity of the feature. The results of the 1985 cruises indicated that the trough is an area of significant petroleum potential in moderate water depth (< 2000m), and the current downturn in offshore exploration presents an opportunity to consolidate our knowledge of this feature, and therefore accelerate interest in it when exploration takes off again. Also, the southern portion of the northeast Australian region, including the Marion Plateau and its eastern and southern margins, was not examined during the 1985 cruises. The plateau represents 113,000 km^2 of poorly explored continental margin in relatively shallow water (< 500m), and it is possible that parts of this feature could have short-term exploration potential. The Marion Plateau is also important to understanding the evolution of carbonate platforms in the region, and it may represent the subsided forerunner to the Great Barrier reef.

Consequently, it is proposed that **Rig Seismic** conduct two cruises over the Townsville Trough/Marion Plateau region in September and November, 1987 (Fig. 4). The cruises will have a blend of regional framework, stuctural and sedimentological process, and resource related objectives, and will include time to carry out the pre-requisite site surveys over proposed ODP sites in the region. The cruises will utilise airgun (twin 10 gun arrays - 52.4 litre) multichannel seismic profiling, high-resolution (watergun) multichannel seismic profiling, gravity and piston coring, dredging, heat-flow measurements and side-scan sonar to meet the objectives.

REGIONAL TECTONIC SETTING

Continental margin development

The continental margin off northeast Australia lies to the south of the present day complex zone between the Australian and Pacific Plates. The most prominent deep feature within the region, the Coral Sea Basin, is one of a number of small, enclosed ocean basins in the southwest Pacific which are characterized by their lack of seismicity, normal heat flow and deeply subsided oceanic basement. Karig (1971) classified such basins as inactive marginal basins and envisaged the basins to be the result of back-arc spreading. We, like many of the more recent workers in the area (Taylor, 1975; Mutter, 1975; Taylor & Falvey, 1977), consider that the Coral Sea Basin formed by normal sea-floor spreading and is thus surrounded by a passive continental margin. Weissel & Watts (1979) identified linear magnetic anomalies in the Basin and dated its opening as Paleocene, but a recent analysis of seismic profiles across the Basin imply a slightly older latest Cretaceous breakup age (Symonds & others, 1984).

The passive continental margin off northeastern Austraia extends over a distance of about 2000 km between Fraser Is. in the south and Torres Strait in the north, and covers an area of some 930,000 km^2 (Fig. 1&5). The margin is comprised of a number of marginal plateaus and troughs - the Eastern, Queensland and Marion Plateaus, and the Pandora and Bligh Troughs, the Osprey Embayment, and the Queensland and Townsville Troughs - which are generally considered to be modified and subsided continental crust formed as a result of fragmentation of a northeastern extension of the Tasman Fold Belt, (Gardner, 1970; Ewing & others 1970; Falvey, 1972; Falvey & Taylor, 1974; Taylor, 1975; Mutter, 1977; Taylor & Falvey, 1977). This rift phase of development, which may have commenced in the Early Cretaceous, and was certainly in progress during the Late Cretaceous, preceded continental breakup and the formation of small enclosed ocean basins to the east (the Coral Sea Basin and Cato Trough) and to the south (the Tasman Basin). The Tasman sea-floor spreading commenced 80 m.y. B.P. - Campanian (Hayes & Ringis, 1973; Weissel & others, 1977; Shaw. 1978), and propogated northwards forming the Cato Trough and finally the Coral Sea Basin from 65 m.y. B.P. - Paleocene (Weissel & Watts, 1979). Sea-floor spreading ceased along the length of this system about 56 m.y. B.P. - early Eocene. Plate reconstructions of the region from Early Cretaceous to mid-Eocene times are given in Figure 6.

There has been considerable debate about the nature of the rift phase of development of the northeast Australian margin. Mutter (1975 and 1977) and Mutter & Karner (1978) argued that there was little evidence for the pre-breakup, rift-valley, or taphrogenic phase of development normally associated with continental rifting, beneath the continental margin around the Coral Sea Basin. Falvey & Taylor (1974), Taylor (1975) and Taylor & Falvey (1977), however, suggested that continental fragmentation in the region closely followed the usual sequence of events for the development of 'Atlantic-type' margins, and they inferred the presence of 'rift-valley' sequences beneath the Queensland and Townsville Troughs, and beneath the Coral Sea Basin margins of the Queensland, Papuan and Eastern Plateaus. Mutter & Karner (1980) suggested that the distribution of the marginal plateaus and troughs, and the geometry of the continent-ocean boundary in the area, may have resulted from the development of a series of interconnected, three-branch rift systems, as described by Burke & Dewey (1973) (Fig. 6). Symonds & others (1984) suggested that, in general, the development of the northeast Australian continental margin seems to have followed a commonly proposed sequence of passive continental margin evolution from uplift, through rifting accompanied by volcanism, to seafloor spreading in one of the arms of a complex rift basin system. This rift basin system is well developed, and still intact, along the western part of the region adjacent to the continental shelf, but is not so well developed adjacent to the Coral Sea Basin (Fig. 5). Prior to breakup the rift basins would have formed a radiating pattern centred on the northern Osprey Embayment (Symonds & others, 1984).

The nature and development of the northernmost part of the margin in the Bligh and Pandora Troughs region appears to be even more complicated. These features were originally thought to have developed during the episode of Late Cretaceous rifting that preceded the opening of the Coral Sea Basin (Taylor & Falvey, 1977; Symonds & others, 1984); however, the 1985 BMR seismic data tied to the Anchor Cay exploration well (Fig. 5) indicate that although Cretaceous and ?older rift phase sediments may uderlie the troughs, they owe their present form to a major Oligocene to late Miocene subsidence phase (Davies, Symonds & others, 1987). This subsidence phase coincides with the start of orogenesis in the New Guinea Orogen to the north (Pigram & Davies,1987), implying overprinting of the Cretaceous rift system by the effects of convergent tectonism.

The main stuctural elements in the offshore northeast Australian region are shown in Figure 5, and the general structural style of the region is shown in Figures 7 & 8 as schematic profiles based on the interpretation of seismic data.

Basin formation

Basin development in the continental margin of northeast Australia takes two main forms:

1) Coastal and shelf basins which formed as structurally controlled intracratonic downwarps containing conformable clastic rocks ranging in age from Middle Jurassic to Early Cretaceous, that were mainly deposited in continental to paralic depositional environments. This sequence is generally overlain by thin continental and coastal Cainozoic sediments. These basins may be the remnants of an elongate trough that once extended along the entire length of the present northeast Australian shelf and eastwards beneath the adjacent rift troughs (Symonds, 1983).

   Basins that fall into this category are the Papuan Basin (Tallis,1975; Wise, 1976; Smart & Rasidi, 1979), the Peninsula Trough/ Torres Shelf area (Doutch, 1976; Smart & Rasidi, 1979), the Laura Basin (De Keyser & Lucas, 1968; Day, 1976; Smart & Rasidi, 1979), the Styx Basin (Benstead, 1976), and the Maryborough Basin (Ellis, 1966; 1976). Depocentres of this type may also occur beneath the eastern Queensland plateau (Fig. 5).

2) Rift basins containing Cretaceous and early Tertiary sediments lying beneath the shelf and the Great Barrier Reef, the major troughs such as the Queensland and Townsville Troughs, and the flanks of the marginal plateaus. In the deeper rift troughs the depositional environments of the syn-rift and late-rift sediments probably range from continental to marginal marine and restricted shallow marine (Taylor & Falvey, 1977; Mutter & Karner, 1980; Symonds & others, 1983; Symonds & others, 1984). Basins that fall into this category are the Bligh, Queensland and Townsville Troughs, the western Osprey Embayment (Osprey Basin), single half grabens beneath the western Queensland Plateau, depocentres beneath the margins of the Coral Sea Basin and on the eastern flank of the Marion Plateau, the Hillsborough (Proserpine) Basin (Gray, 1976), and the Capricorn Basin (Ericson, 1976).

BACKGROUND OF THE STUDY AREA

Physiography

The area of interest for the 1987 cruises is the southwestern part of the Coral Sea, seaward of the Great Barrier Reef. Figures 4, 9 and 10 show the main physiographic elements, which are the Great Barrier Reef and adjacent slope, the Queensland and Marion Plateaus, the Queensland and Townsville Troughs, the Cato Trough, and the Capricorn Channel.

The continental shelf is dominated by the Great Barrier Reef and reaches a maximum width of about 350 km in the southern-most part of the region at about 22°S. The shelf break occurs at 100-200m. The slope of the Great Barrier Reef is steeply dipping and canyoned in the northern part of the area, particularly adjacent to the Ribbon Reefs; the slope decreases in the vicinity of Townsville and becomes very gentle adjacent to the Marion Plateau.

The Queensland Plateau is the largest marginal plateau of the Australian continental margin, being nearly twice as large as the Exmouth Plateau. As such it is one of the largest features of its type in the world. The plateau is roughly triangular with its western margin striking north-northwest, its northeastern margin facing the Coral Sea Basin and striking northwest, and its southern margin striking east-west. The western and southern margins are both bounded by linear troughs. Many valleys and canyons lead from the plateau surface into the troughs and the Coral Sea Basin. The plateau surface lies at a medium depth of 1100 m and away from reef areas is generally very smooth and flat. It exhibits a very gentle northwest tilt, its surface being most deeply submerged around Osprey Reef. Fairbridge (1950) interpreted this tilt to mean that the bathymetry of the plateau was controlled by tectonic rather than sedimentary processes. Fairbridge further observed that the plateau reefs grow from as much as 1500m below sea level, well beyond the normal ecological limit of reef growth, and this led him to suggest that the plateau had subsided to its present depth from an initial elevation close to sea level, with reef growth keeping pace with subsidence.

The northeastern margin of the Queensland Plateau is linear for more than 600 kilometres, suggesting that tectonic influences have shaped the plateau. This margin forms the lower continental slope leading down to the Coral Sea Basin. Slopes are relatively steep, ranging from 1:25 to 1:35 (by comparison a normal continental slope is about 1:40; Shepard, 1948), and have a convex profile. Extensive canyoning has modified the shape of the outer margin of the plateau. Immediately east of Lihou Reefs the plateau slope is complicated by the presence of two small terraces - one at a depth of 1400 to 1600m, and the other at 2200m. The latter has a shallow trough on its western edge. No similar structures occur on the slope between the plateau and the Coral Sea Basin and this may indicate that a different set of processes have shaped the slopes in these two areas.

The Queensland Trough occupies the region between the continental shelf and the Queensland Plateau between 14 S and 17 30'S, adjacent to the Great Barrier Reef. Its western margin is much steeper than its eastern margin, with gradients up to 1:3 (at 15 S). The trough has a smooth, flat floor which gently deepens to the north-northwest from about 1100m at its junction with the Townsville Trough. It joins the Osprey Embayment region at a depth of about 3000 m between the Queensland and Eastern Plateaus. The Queensland Trough is probably fed from both sides by canyons (Falvey, 1972). In the southern part of the trough, between Flinders and Bougainville Reefs, the west to east profile is simple, but north of Bougainville Reefs the profile becomes more complex and the trough is more constricted. The strike of the trough is that of the dominant structural grain of the Tasman Fold Belt in northern Queensland (Hill & Denmead, 1960). It mirrors the trend of, and has approximately the same strike extent as, the North Coast Structural High (Fig. 11). West of this high, structural depressions form the site of the Laura and Hodgkinson Basins. Such a structural framework onshore immediately west of the Queensland Trough led Mutter (1977) to speculate that the Queensland Trough lies along a structural 'low' of the Tasman Fold Belt.

The Townsville Trough has no clear relation to any known structure onshore, being roughly perpendicular to the main Tasman Fold Belt trend. Falvey (1972) suggested that part of the trough appears to be an offshore continuation of the Devonian to Carboniferous Broken River Embayment trend (Fig. 12). Mutter (1977) pointed out that it is equally possible that the trough reflects trends such as those of the Mellish Rise (Cullen, 1970) to the east. Solomon & Griffiths (1972) considered that the Broken River Embayment trend extended east and offshore to the head of the Townsville Trough, and that it is a Palaeozoic fracture zone. The trough has a symmetric U-shaped profile which is maintained over most of its length. At its eastern end, at about 154°E, a bifurcation sends one branch south into the Cato Trough and the other winding sinuously north into the Coral Sea Basin. Mutter (1977) speculated that sediment derived from the Queensland Plateau or Queensland mainland could reach the deep ocean floor via the Townsville Trough and its offshoots.

The Marion Plateau, which lies to the south of the Townsville Trough, is the smallest of the submarine plateaus in the region, and appears to form a simple extension of the continental shelf. It deepens gently from about 200-300m near the Great Barrier Reef to about 500m in the vicinity of Marion Reef at its extreme northeastern corner. The plateau may be considered to extend south of Saumarez Reef to include the Capricorn Channel area (Marshall, 1977). Its outer margin is formed by the slope leading down to the Cato Trough. It has a moderate grade and is cut by numerous canyons.

The Cato Trough is a north-south trending feature with a flat floor at a depth of about 3000m. It has a length of 400 km and broadens gradually to the north where it has a maximum width of about 150 km. To the south it passes through a narrow constriction into the northern Tasman Basin. A series of seamounts rise from the floor and margins of the trough and these are capped with coral reefs. Krause (1967) considered these to be part of the Tasmantid seamount chain.

The Capricorn Channel shapes the continental shelf and Marion Plateau at the southern end of the study area (Fig. 10). It occupies the area between the Swains Reefs and the reefs of the Capricorn and Bunker Groups. In the channel the isobaths show a large embayment that slopes gently ($< 2^{\circ}$) down to the Tasman abyssal plain. This channel is a manifestation of a large structural trough which has been named the Capricorn Basin by Maxwell (1968).

In summary, it is clear that the larger physiographic features off northeastern Australia comprise extensive troughs and plateaus which occupy the whole of the margin. There is no location where the margin has the simple shelf, slope, and rise configuration regarded as typical of rifted continental margins (Dewey & Bird, 1970). Mutter & Karner (1980) considered that the physiography reflected three major structural trends: the Tasman Fold Belt, the Paleocene Coral Sea breakup and an anomalous east-west trend. Any scheme proposed for the development of this margin must be able to explain the unusual development of margin features and the influence of these trend directions upon them.

Onshore/shelf geology

The coastal regions of Queensland are underlain by rocks of the Palaeozoic Tasman Fold Belt which extends from Tasmania in the south, to Papua New Guinea in the north (Brown & others, 1968). The western border of the fold belt consists of Precambrian metamorphics which, in the north at least, are separated from the Palaeozoic sediments to the east by a major fault - the Palmerville Fault (De Keyser, 1963; Willmott & others, 1973) (Fig. 11). 'Geosynclinal' sedimentation commenced in the early Devonian in the Hodgkinson Basin and continued through to the Carboniferous, interrupted by a number of orogenies. Relative to the width of the New England and Lachlan Fold Belt to the south, an extensive area of the Tasman Fold Belt in northern Queensland appears to be absent. This has led to the interpretation that the missing Middle-Upper Palaeozoic rocks lie beneath the Queensland Plateau (M. Ewing & others 1970).

Packham (1973) has interpreted the development of the eastern Australian region in terms of a stepwise easterly growth of the continent, outward from the Precambrian nucleus by development of Andean-type continental margins during the Ordovician-Permian. The easternmost portion of the fold belt off southeastern Australia has since been dismembered by sea-floor spreading in the Tasman Sea during the Late Cretaceous.

The Mesozoic-Recent geological history of Queensland is one of terrestrial to marginal marine sedimentation in basins and troughs bordering the Queensland coast. Principal among these are the Maryborough (Ellis, 1966; 1976), Styx (Benstead, 1976), Capricorn (Ericson, 1976), Hillsborough (Clarke & others 1971; Gray, 1976) and Laura (De Keyser & Lucas, 1968; Day, 1976) Basins (Fig. 6&7). A major hiatus is present in all onshore basins separating Early Cretaceous sediments from Late Tertiary-Recent terrestrial deposits which infill depressions in the old land surface. The only known possible Late Cretaceous deposits are found in the offshore Capricorn Basin (Ericson, 1976). These are terrestrial conglomerates and red beds which may have formed piedmont-littoral clastic wedges. Lack of diagnostic palaeontologic indicators prevents precise dating of the section, but the interval probably spans Late Cretaceous to Oligocene time. A thick section of non-marine sediments was deposited during the Early tertiary in the Hillsborough Basin to the northwest, and similar age sediments containing oil shales are found in the Narrows area near Gladstone (Fig.5) (Hekel, 1972). In the Capricorn Basin this sequence is unconformably overlain by late Oligocene marginal marine quartzose sands, which are in turn overlain by a Miocene-Recent marine, calcareous shelf facies, including coral reefs.

Geological sampling and drilling

Taylor (1977) listed over 120 core and bottom sample stations from the Coral Sea region, while Krause (1967) and Gardner (1970) have described smaller sets of samples from the same area. These cores and bottom samples were taken by several overseas institutes and also from Australian Navy vessels. They give an overall description of the surface sediment type for much of the margin although sites are sparse in the deeper, eastern parts of the Queensland Plateau and in the Townsville Trough, and are non-existant on the Marion Plateau. They show that the margin is at present receiving calcareous pelagic sedimentation. Some areas near to the Great Barrier Reef, and near to large reefs on the Queensland Plateau, have reef-derived detritus (Taylor,1977). The Coral Sea Basin, the Moresby Trough and the Papuan Plateau receive terrigenous sediment at present, largely deposited as turbidites.

The results of a detailed geological sampling program in the Capricorn Channel involving the collection of 143 small dredge samples combined with shallow seismic reflection profiling, bathymetric profiling and underwater photography has been described by Marshall (1977). The study showed that most of the inner shelf is covered by modern and relict terrigenous sands, but sediments in the Channel are mainly fine-grained. Carbonates are being supplied by the reefs and reefal banks. Away from the reefs, carbonate sediments are composed mainly of molluscan and foraminiferal remains.

In 1980/81 a joint BGR/BMR sampling cruise using the **R.V. Sonne** collected core and dredge samples from the Eastern Plateau, Osprey Embayment, northwestern and northeastern slopes of the Queensland Plateau, and the Moresby Canyon. Some of the palaeontological results of this cruise are discussed by Chaproniere (1983).

During the two 1985 BMR **Rig Seismic** cruises off northeast Australia samples were obtained from 22 dredge hauls at 17 stations, and 190 m of core was collected from 92 coring stations, which tripled the size of the regional sampling data set (Fig. 3). Davies, Symond & others (1987) summarises the recovery, age and various palaeontological information for the samples. High-resolution sparker profiles traversing the Great Barrier Reef slope and the Queensland Trough, combined with the results of the coring and dredging program have allowed the following conclusions to be drawn (Davies, Symonds & others, 1987):

. Nature and timing of reef growth in the Great Barrier Reef vary latitudinally: the reef is thick and has grown in more than one phase in the north, in contrast to its growth to the south.

. Distinct seismic packages can be identified and tied to major sea-level oscillations, and bedding and mineralogic changes in the cores may also relate to sea-level changes; the oldest sediment so far dated in the cores is Pliocene.

. The slope of the Great Barrier Reef is largely composed of fluvio-deltaic derived sediments, and was constructed by three main sedimentary mechanisms - low sea-level fluvio-deltaic progradation, low sea-level lower-slope fan deposition, and high sea-level gravity slumping; slumping is the main slope-building process in the central part of the GBR south of Townsville, whereas progradation and fan deposition are the main slope-building processes further north.

. The eastern margin of the Queensland Trough is dominated by carbonate from two sources - reefs on the Queensland Plateau, and plankton during high and low sea-level periods. The derivation of the clay and quartz in the cores is problematic but suggests turbidite deposition from a western source.

. The western side of the Queensland Plateau has a much thicker reef sequence than the Great Barrier Reef at similar latitudes; possible buried reefs beneath the plateau may have begun to grow in the early Tertiary and stepped eastwards as a result of subsidence.

. Seamount-like features as deep as 1200 m in the Queensland Trough have, atleast superficially, a shallow-water reefal origin. Dating of the rocks will allow us to estimate the subsidence rates of the trough and western Queensland Plateau (onboard estimates indicate Plio-Pleistocene subsidence of 100-500 m per million years, which is extremely rapid for a passive margin of this age and may reflect the effects of pulses of subsidence related to regional convergent tectonic events further north).

. The Plio-Pleistocene sedimentary record of the slopes and trough is thin. Sedimentation rates are shown in Table 1, and while the rates may be minimum figures there can be little doubt that throughout the area the Pleistocene is a condensed sequence and should therefore contain an excellent record of sea-level change.

The most important sources of geological data in the region are the Anchor Cay well in the north; the Michaelmas Cay bore off Cairns; the Aquarius-1, Capricorn-1A and Wreck Is.-1 wells, and the Heron Is. bore in or on the margins of the Capricorn Basin to the south; and the three drill sites of the JOIDES Deep Sea Drilling Project (Fig.1, 5 & 11). Sites 209 and 210 were drilled during Leg 21 of the project (Burns & others, 1973), and site 287 was drilled during Leg 30, with the object of reaching basement in the Coral Sea

Basin (Andrews & others, 1975). These sites are described below. Various information on the wells is summarised in Table 2.

On the shelf in the central Great Barrier Reef area about 150 vibrocores have been obtained using an Amos McLean Vibrocorer. The cores sampled to a maximum of 4.5m in water up to 70m deep. In addition, ten reefs have been studied in detail, with about 400m of core being obtained from 30 drill holes. The mechanisms of modern reef growth (Davies & Hopley, 1983) and the deposition of the near-surface inter-reef sediment (Davies & others, 1983) are relatively well understood in this area.

Stratigraphic control

Well control in the study area is really limited to the wells in the Capricorn Basin (Wreck Is.-1, Aquarius-1 and Capricorn-1A; Heron Is. bore), and DSDP site 209 on the easten part of the Queensland Plateau (Figs. 1, 5 & 11). The results of DSDP sites 210 and 287 in the Coral Sea Basin are regionally relevant and will therefore be discussed further, below.

The first exploration well in the Capricorn Basin, Wreck Is.-1, was drilled in 1959 by Humber Barrier Reef Oil Pty. Ltd. It reached a total depth of 579m after penetrating 31m of siliceous volcanic conglomerates. The most significant result was the identification of Miocene carbonates and clastics - proof of a Teriary marine basin in the area. In 1967 and 1968 the Capricorn-1A and Aquarius-1 wells were drilled in the Capricorn Channel by Australian Gulf Oil Company (Carlsen & Wilson, 1968a,b). Capricorn-1A reached a total depth of 1710m in equivalents of lower Grahams Creek Formation. Aquarius-1 was drilled 40 km to the northeast and penetrated basement of highly indurated and tectonised Palaeozoics at a total depth of 2658m. The stratigraphy and correlation of wells in the Capricorn Basin is shown in Figure 12.

The most important deep sea geological data are the three drill sites of the Deep Sea Drilling Project, drilled during legs 21 and 30.

DSDP site 209 was drilled on the eastern Queensland Plateau in 1428 m of water and penetrated three lithologic units (Fig. 13). It bottomed in late mid-Eocene glauconite-bearing bioclastics and foraminifera-rich sediment thought to have been deposited in upper bathyal to neritic depths, probably on the continental margin (unit 1). The overlying unit 2, which is of latest middle Eocene to late Eocene age, is comprised of detritus and foraminiferal ooze indicating subsidence of the margin. A major hiatus separates units 1 and 2, extending from late Eocene to late Oligocene and is probably the result of non- deposition and/or slight submarine erosion. This was followed by further subsidence to the present mid-bathyal depths and the deposition of almost pure foraminiferal and nannofossil ooze from the late Oligocene to the present. This stage of sedimentation was interrupted by a period of non-deposition or erosion during the middle Miocene.

The most important points to emerge from the data are:

. The site clearly records the history of subsidence of the Queensland Plateau from shallow water (neritic) in the late middle Eocene, to the present depth at the site of 1428 m (mid-bathyal).

. Sediments are dominantly foraminiferal ooze throughout with terrigenous content in the cores reducing in the upper units, particularly from middle to upper Eocene.

. A major period of non-deposition or submarine erosion spans most of the Oligocene. After this hiatus the sedimentary regime is almost purely pelagic carbonate ooze.

. The effects of submarine current activity are well recorded.

The Eocene/Oligocene hiatus has been attributed to submarine erosion caused by either a major change in circulation patterns following the final separation of Australia from Antarctica in the early Eocene (Kennett & others, 1972), or by the commencement of a significant equatorial circulation pattern (Taylor & Falvey, 1977). Winnowing is evident in the post-hiatus sediments, suggesting bottom current activity. Depositional patterns (Mutter,1977; Taylor & Falvey, 1977) also suggest the influence of currents on sedimentation.

DSDP sites 210 and 287 in the central Coral Sea Basin penetrated essentially the same lithologic sequences (Fig. 13). The more complete section was intersected at site 210. The bottom part of the section is comprised of early to late Eocene detrital clays and biogenic pelagic sediment which accumulated above the foram solution depth. The clays are thought to have been derived from high grade metamorphics and volcanics to the west (Burns & others, 1973). Deposition was interrupted in the late Eocene to early Oligocene by an erosional and non- depositional hiatus which is of regional extent and was caused by a marine bottom water current (Kennett & others, 1972; Edwards, 1975). Middle Oligocene nanno-oozes deposited near the carbonate compensation depth overlie the unconformity, and are followed by a late Oligocene to early Miocene period of non-deposition and/or erosion. Overlying this uncomformity is an early-mid Miocene abyssal clay indicating deepening of the sea floor to below the compensation depth. The clays are thought to have been derived from the Papuan area to the northwest (Burns & others,1973). During the late Miocene to late Pleistocene, turbidity currents deposited graded cycles of silt and clays with the sediment again being derived from sources in Papua New Guinea.

Symonds and others (1984) have set up a seismic stratigraphic framework for the northern part of the region mainly based on the interpretation of processed **SONNE** seismic data tied to the three DSDP sites. Davies, Symonds and others (1987) have established a seismic stratigraphic framework for the Townsville Trough based on the interpretation of the seismic monitor sections from the 1985 BMR **Rig Seismic** survey over this feature (Tables 3 & 4); these sequences will be discussed further in the section on **NEW RESULTS, IDEAS AND CONCEPTS**.

Geophysical data

Gravity and magnetic measurements, seismic reflection profiling, single-ship (sonobuoy) and two-ship seismic refraction profiling, and heat flow measurements have been made fairly extensively throughout the Coral Sea region (Figs. 3,&14-17). The data collection agencies fall into three distinct groups which appear to have had rather different objectives - BMR, oil exploration companies and academic institutes.

BMR collected gravity, magnetic, and seismic reflection profiling over the continental margin area during 1970/71 as part of the continental margin survey. It is the only agency which has collected regional data on a systematic survey grid (Fig. 14). Seismic reflection profiling was made with a 120 kJ sparker and six-channel hydrophone streamer. Magnetic measurements were made with a proton precession magnetometer, and gravity measurements with a LaCoste and Romberg stabilised platform gravimeter. Navigation control was available from the U.S. Navy Transit satellite system. Sonar doppler, electromagnetic and ship's pressure logs were used for dead-reckoning between satellite fixes. All data, except some reflection profiling and gravity data collected in moderate to rough weather conditions, are of reasonable quality.

BMR has also made gravity measurements in the Great Barrier Reef, and with the use of underwater instruments, on the continental shelf (Dooley,1965).

As well as this regional data set BMR has collected intermediate penetration seismic and magnetic data in the central Great Barrier Reef area between Cairns and Bowen (Fig. 15). This programme generated 1000km of single channel digital data (1981), 8000km of 24 - channel digital data (1982/83), and 3000km of high - resolution boomer profiles (1982/83). The sparker data was variously shot at 6, 12 and 18 fold on closely spaced (2km apart) lines in two areas on the shelf and on more widely spaced lines across the outer shelf/upper slope into the Queensland Trough. The data was recorded using a 9 kilojoule, 9-electrode sparker and a Decca Hifix 6 and Motorola miniranger navigation system.

During the 1985 **Rig Seismic** cruises off northeast Australia BMR collected 4030 km of multichannel airgun and high-resolution sparker seismic reflection profiles, plus magnetic and gravity data (Fig. 3) (Davies, Symonds & others, 1987). About 2350 km of these data are in the 1987 study area. Table 5 summarises the various seismic configurations used during the 1985 cruises. Navigation was by means of two Magnavox satellite navigators utilising the Transit satellite system, combined with Magnavox and Raytheon sonar-doppler sytems, Decca Hifix 6 radio navigation and a Magnavox T-SET receiver which utilised the Global Positioning System (GPS).

While BMR's surveys aimed at obtaining a systematic coverage of the margin as a whole using a variety of geophysical techniques, exploration companies have collected data largely from those areas where sediment thicknesses are fairly large, and oil prospectivity therefore high, and have mainly concentrated on obtaining high quality reflection profiles (Tables 6 & 7).

Exploration companies have also flown airborne magnetometer surveys throughout most of the continental shelf area, including the Capricorn Channel in the extreme south. The northeastern sheet of BMR's magnetic map of Australia (Bureau of Mineral Resources, 1976b) is a contoured compilation of existing magnetic data and shows exploration company information on the continental shelf and BMR information in deeper water.

Shell Development (Australia), Australian Gulf Oil and Geophysical Service International (GSI) have also conducted extensive regional work and have obtained high quality reflection profiles using relatively powerful energy sources and multi-channel streamers (Fig. 14 & 16). Digital processing has also been applied to these data to enhance record quality. High precision navigational equipment was used on the vessels working for both companies. Gravity and magnetic measurements were also made. These and other oil exploration company data will be discussed in more detail in the section on petroleum exploration in the region.

A number of vessels from overseas oceanographic and/or geological institutions have recorded geophysical information in the region, and some specific studies of the continental margin have been made. The most important of these is the two-ship seismic refraction program conducted co-operatively between the Lamont-Doherty Geological Observatory and the

University of New South Wales in 1967 (Fig. 17). Analyses of the reflection and refraction data were published by J._Ewing & other, (1970) and M._Ewing & other, (1970), and have subsequently been used by Gardner (1970), Falvey (1972), and Taylor & Falvey (1977). Lamont-Doherty, working with BMR, conducted a very comprehensive survey over the Coral Sea Basin in 1977, collecting bathymetric, gravity, magnetic and reflection seismic information.

Several expeditions of the Scripps' Institution of Oceanography have entered the area as part of more wide-ranging programmes, and collected geophysical data including seismic reflection and refraction profiles (Shor, 1967; Winterer, 1970). Gravity data from these expeditions and those of other institutions have been incorporatated into the BMR Gravity Map of Melanesia (Connolly & Murray, 1978), which includes the northern part of the continental margin of northeastern Australia. Falvey (1972) compiled a free-air gravity map of the Coral Sea region from data obtained by Scripps and other institutions, but was unable to include BMR data at the time. The gravity map of Australia (Bureau of Mineral Resources, 1976a) incorporates all available onshore gravity data with BMR offshore data.

In 1978 and 1980/81, 6500km of 24 fold seismic reflection data were collected by the **R.V. Sonne** in the northern part of the region, mainly around the margins of the Coral Sea Basin, as part of a joint BGR/BMR program.

Heat flow measurements have been made fairly extensively in the Coral Sea region. Most have been measured with shallow probes attached to conventional sediment coring devices, but values have also been obtained from the Deep Sea Drilling Project holes on Leg 21 (Von Herzen, 1973). The distribution of heat flow measurements in the region with their values have been described by Cull & Denham (1979). In 1986 BMR conducted a **Rig Seismic** cruise to measure heat flow in the Queensland Trough and on the Exmouth Plateau (Choi, Stagg & others, 1987). Fifteen good heat-flow measurements were obtained on a transect along the Queensland Trough, the average value being 58 mW/m^2 - close to world average - with extremes of 35 to 80 mW/m^2. As was to be expected, the new data show that there is a general correlation between basement structure and heat-flow: where the basement is shallow with thin sediment cover, the heat-flow values are higher than for those areas with thick sediments.

Bathymetry

Bathymetric data were collected by most organizations traversing the area. Bathymetric charts have been published by Krause (1967), Gardner (1970), Falvey (1972), Mutter (1974, 1977) and Taylor (1975). The most up-to-date compilation is that by BMR using the data available from all sources (for example see Fig. 9).

Petroleum exploration in the region

Oil exploration offshore from northeastern Australia began in the early 1960's with a series of aeromagnetic surveys which provided broad coverage of the continental shelf between Fraser Island and Torres Strait (Tables 6 & 7). Aeromagnetic coverage between Fraser Island and Cairns was flown for the Australia Oil and Gas Company in 1962 as the Great Barrier Reef Aeromagnetic Survey (62/1714). Other aeromagnetic surveys were flown for Australian Gulf Oil in 1964 in the Swains Reef/Capricorn Basin area (63/1712), and in 1969 between Bowen and Cairns (69/3012).

In our 1987 study region the early marine seismic surveys on the shelf were restricted to the area south of Proserpine and concentrated on the Capricorn Basin (Tables 6 & 7). Relatively detailed surveys were carried out for the Australian Gulf Oil Company in 1965 (65/11022) and 1966 (66/11093) using explosives and sparker source respectively. Several structural prospects were delineated, and two were tested by drilling - Capricorn 1A and Aquarius 1 (Table 4). Other marine seismic investigations have been carried out in the Hillsborough (Proserpine) Basin and the Styx Basin in Broad Sound for Ampol Exploration (Qld) Pty. Ltd. in 1964 and 1966, respectively.

Owing to the moratorium on oil exploration in the Great Barrier Reef, only reconnaissance surveys have been carried out off northeast Australia since 1969 and no wells have been drilled. Most of these reconnaissance oil company surveys were run off the continental shelf to the east of the Great Barrier Reef (Fig. 14). In early 1973 Gulf Research & Development Co. and Australian Gulf Oil Co. (Gulf, 1974) recorded a series of good quality 24-channel Aquapulse lines across the Queensland Plateau; on two lines from the Queensland Trough to the continental shelf to the east of Cairns and to the northeast of Townsville (Fig. 15); across the Townsville Trough, and along the continental shelf between the reefs from Townsville to Fraser Island, including several crossings of the Capricorn Basin (Fig. 14). In 1973 and 1974 Geophysical Service International (GSI) recorded a zig-zag pattern of seismic traverses for Shell Development (Australia) Pty. Ltd. east of the Great Barrier Reef from the north to the south of the region (Shell, 1977). Features covered by this survey are the Pandora Trough, the Eastern Plateau, the Bligh Trough, the Osprey Embayment, the Queensland Plateau, the Queensland and Townsville Troughs, the Marion Plateau and the Capricorn Basin. The data were recorded using airguns at 24-fold coverage, but initially most lines were only displayed single-fold by Shell. In 1979 GSI reprocessed much of the Shell seismic data in the Queensland Plateau area to give full 24-fold stacked sections, and this considerably enhanced the data quality. The most recent exploration company seismic data in the region was obtained in 1979 by GSI on a regular grid, with lines spaced about 50km apart, across the western Queensland Plateau, the Queensland Trough and the western Townsville Trough (GSI, 1980) (Fig. 16). The survey was recorded using a modern airgun system at 48-fold CDP coverage, and provides a good quality regional data set for understanding the structural development and depositional history of the Queensland Trough.

Tectono-stratigraphic development of the continental margin

The continental margin of northeast Australia consists of a submerged and dissected northeastern extension of the Tasman Fold Belt. The margin formed during a period of rift tectonism which culminated in the opening of the Tasman Basin in the south, and the Coral Sea Basin in the north. The margin is comprised of a series of plateaus separated by rift troughs (Fig. 5). The following general scheme for the tectonic and stratigraphic devolopment of the northeast Australian margin is really based on our understanding of the Queensland Trough area, and does not incorporate our most recent ideas based on post-1984 data. It does, however, provide a broad insight into the types of depositional systems that may have been operating during the various phases of margin development.

Pre-breakup development - Jurassic to Early Cretaceous

In the Jurassic to Early Cretaceous the northeast Australian continental margin, incorporating the present marginal plateaus and parts of Papua New Guinea, lay adjacent to the Pacific Plate. Dominantly left-lateral transform movement between the plates (Taylor & Falvey, 1977) may have activated an oblique wrench zone on the Australian continent (Symonds & others, 1984) and formed an elongate trough or 'infrarift' basin, which became a site of future rifting.

Continental breakup - Late Cretaceous to Paleocene

Uplift, rifting and volcanism in the Late Cretaceous formed the Bligh Trough, Osprey Embayment and Queensland Trough as part of a complex rift basin system that developed off northeastern Australia. The Townsville Trough, and a less well developed arm along the site of incipient Coral Sea Basin breakup, form other parts of the rift basin system. This westernmost rift basin controlled the location and form of the present day continental shelf. Continental breakup through sea-floor spreading commenced first in the Late Cretaceous in the Tasman Basin, and in the Coral Sea Basin at the very end of the Cretaceous. Sea-floor spreading was completed throughout the length of the eastern Australian margin by the early Eocene.

The Late Cretaceous to Paleocene interval was one of rift basin infill by alluvial fans along the scarps, and alluvial stream sedimentation in the centre of the troughs (Fig. 18a).

Recent seismic studies on the western flank of the Queensland Plateau and in the Queensland Trough have confirmed the presence of a very thick rift fill sequence of Mesozoic age (Fig. 19) with at least six places having total sediment thicknesses greater than 6km, and one section in the northwest where it is greater than 7.5km.

Post-breakup subsidence - Paleocene to Recent

Paleocene subsidence followed seafloor spreading, with transgressive onlap of terrigenous and pelagic sediment onto the rift separated plateaus throughout the Eocene (Fig. 18b). At this time, subsidence of the western rift basin continued about a hinge line beneath the present-day inner to middle shelf, and a marginal to open marine onlapping sequence was deposited.

The offshore plateaus and rift troughs experienced significant submarine erosion in the late Eocene to mid Oligocene, attributed to sub-tropical oceanic current influxes. Stabilisation of the sub-tropical ocean current system followed deepening of the basins and plateaus which in turn led to reef development on plateau highs in the late Oligocene to early Miocene and pelagic sedimentation in the deeper areas.

On the continental shelf in the central Great Barrier Reef significant continental shelf construction (both aggradation and progradation) characterised the time period late Oligocene to Pleistocene. Late Oligocene, late Miocene and late Pliocene to early Pleistocene progradational episodes occurred which were the result of fluvial and wave-dominated shelf-margin deltaic sedimentation during periods of low sea level (Fig. 18c). Uniform Pleistocene shelf subsidence led to massive shelf aggradation during a time of continuing shelf-edge progradation (Fig. 18d). Significant reef growth on siliciclastic, fluvio- deltaic foundations appears to have begun sometime in the Pleistocene. The development of a shelf-edge barrier caused a change in the style of sedimentation on the slope from progradational to mounded onlapping submarine fans and sheet- drape. Concurrent inner shelf sedimentation consisted of prodeltaic sediments associated with coastal wave-dominated deltas (Fig. 18e).

The Oligocene to Pleistocene history of the northern-most part of the continental margin, in the Gulf of Papua area, was somewhat different due to the start of orogenesis in the New Guinea Orogen to the north, related to convergent tectonism. This region will not be discussed further as it is remote from the 1987 study area.

The generalized time-stratigraphic cross section from the Queensland slope to the Coral Sea as shown in Figure 20 is broadly consistent with the development history outlined above. Structuring is primarily controlled by large scale normal faulting of Palaeozoic basement, and this can be quite low-angle in places (Fig. 21). The Oligocene to Recent section is almost completely undisturbed by faulting, although flexural and compaction drape over fault block edges has produced deformation at some locations. Both in frequency and intensity, faulting is clearly concentrated in the troughs. The dominant fault trend in the Queensland Trough is north-northwest, in contrast to the more northwest trend of the trough itself. The western margin of the Queensland Trough lies beneath the central Queensland continental shelf, and at the shelf edge further north; the eastern margin of the trough is defined by a series of en echelon horsts and grabens (Fig. 5). At the junction of the Queensland and Townsville Troughs fault trends are confused. Faulting beneath the western Queensland Plateau defines several grabens and half-grabens with significant strike length and containing several kilometres of rift-fill sediments. The faults bounding the half-grabens are commonly low-angle rotational normal faults (Fig. 21). The corners of fault blocks within the Queensland Trough and beneath the western Queensland Plateau are often planated as a result of subaerial or wave-base erosion. In fact beneath the plateau erosion appears to have proceeded to such an extent that only the last vestiges of rift-fill sedimentation remain.

Reef Development

Coral reefs occur throughout the offshore northeast Australian region in the Great Barrier Reef and its extension into the Torres Shelf area, on the Queensland and Eastern Plateaus, and between the Pandora Trough and the Torres Shelf.

Outside of the Great Barrier Reef, the Queensland Plateau represents the site of the most dense growth of coral reefs (Fig. 3). Currently coral reefs occupy 25% of the plateau surface, occurring in fifteen distinct reefal areas (Mutter 1977). Drowned reefs identified on echo and seismic profiles indicate that reef growth was more widespread in the past. In addition, possible buried reefs have been identified from more than 25 locations, three of which occur beneath the eastern flank of the Queensland Trough. At the present time, the reefs on the plateau occur along three major lineaments - (1) north-northwest along the western margin of the plateau; (2) north-south from Moore to Herald to Malay reefs; and (3) west-east along the southern margin of the plateau and including Malay, Tregrosse and Lihou reefs. Mutter (1977) concludes that reefs currently occur on top of major basement highs. In this region the distribution of reefs may be a key factor in understanding the post-breakup history of the region. The distribution of drowned reefs interspersed with living reefs poses the problem of the cause of such selective drowning. It is unlikely to have occurred as a result of regional environmental factors, but may be related to differential subsidence resulting from faulting. This implies Tertiary faulting for which there is little evidence on seismic sections. Eocene reef growth on the Queensland Plateau has been suggested by Mutter (1977) and Pinchin & Hudspeth (1975), and this prospect is the subject of continuing investigation. The tilt of the plateau to the north implies a progressive younging of the reefs to the south.

The reefs of the Great Barrier Reef form the western boundary of the study area. Recent published work in the Cairns to Bowen region indicates that this part of the Great Barrier Reef is mainly a Pleistocene feature (Symonds & others, 1983). Other unpublished BMR studies indicate the Great Barrier Reef is considerably older in the extreme northern section, probably Miocene and perhaps Eocene. The earliest reef growth in the region may have begun on basement highs on the Queensland Plateau in the early to middle Eocene (see later section on carbonate platform development), although some consider that reef growth did not commence until the late Oligocene and early Miocene following the stabilisation of an equatorial circulation pattern. The presently-growing reefs on the plateau are probably about 1000-1500m thick.

There is no direct evidence for substantial thicknesses of reef rock older than Pleistocene anywhere in the Great Barrier Reef, although the presence of middle Miocene limestones interpreted to be sheltered back-reef facies in the Capricorn Basin to the south, and at Anchor Cay well to the north, have been taken as indicative of Miocene reef development beneath the northeast Australian shelf. In the central Great Barrier Reef no large areas of buried reef have been discovered and reef growth probably only commenced in the Pleistocene. The reefs, which appear to be only 150-250m thick, grew on and occur within siliciclastic fluviatile and deltaic sediments. Reef growth occurred during short periods of high sea level, but the reefs were subaerially eroded during the intervening and longer periods of low sea level. Continued re-colonisation of the same sites throughout their growth history has produced reefs that are composite features made up of a series of remnant reefs separated by unconformities. A shelf-edge barrier reef system, now generally submerged, occurs along much of the central Great Barrier Reef province (Davies and Montaggioni, 1985). Unlike the Gulf of Papua area, it appears that the central Great Barrier Reef has been a major reef province only during its most recent stage of development.

NEW RESULTS, CONCEPTS AND MODELS

The 1985 **Rig Seismic** cruises off northeast Australia collected valuable new data sets over key areas of the margin in order to resolve specific structural and sedimentologic problems. These data, combined with all other data in the region, have been the subject of study since the cruises, and have resulted in the generation of a series of new ideas and models which describe various aspects of the evolution of the continental margin. These new concepts form the 'stepping-off' point for the proposed 1987 program, and many of the objectives of the cruises are based directly on our new understanding of the region. The major new concepts and models relevant to the 1987 study area are summarised below.

Townsville Trough

During the first northeast Australia cruise (Cruise 50), 1309 km of 48 channel seismic reflection data were collected in the Townsville Trough using a 2400 m streamer and two 500 cubic inch airguns (Table 5; Fig. 9). These data were acquired as eleven lines which form a zig-zag pattern between longitudes 149^{o}-152^{o} E connected by one tie-line running down the centre of the trough (Fig. 30). The cruise resulted in six complete or near-complete crossings of the Townsville Trough (lines 50/02-06 and

50/10-11), which average about 140 km in length and run in NW-SE and SW-NE directions from the southern margin of the Queensland Plateau and its associated reefs - Tregrosse and Lihou Reefs - to the northern margin of the Marion Plateau; two partial crossings (lines 50/07 and 50/09); and an ENE-WSW tie line (line 50/08), which is about 170 km long. Water depths on these lines range from about 250 m in the southwest on the upper slope adjacent to the Great Barrier Reef (lines 50/09 and 10), to nearly 2000 m in the east in the centre of the Townsville Trough (line 50/07) (Fig. 9).

The traverse plan for the cruise 50 seismic data in the Townsville Trough was designed to make effective ties with all previous seismic data in the region - the BMR Continental Margin survey sparker lines; two Shell airgun lines; two Gulf Aquapulse lines, one across the outer shelf and upper slope of the Great Barrier Reef ; and the GSI group shoot airgun network in the Queensland Trough via BMR high resolution sparker lines which were recorded in 1983 at the junction of the Queensland and Townsville Troughs.

The following discussion of the seismic stratigraphy and stuctural style of the Townsville Trough is based mainly on an interpretation of the shipboard single-channel digital monitor records as contained in Davies, Symonds & others (1987). Interpretation of the fully processed seismic data was underway at the time of preparation of this report, and any major differences in the interpretation of the two data sets will be pointed out. It needs to be stressed that the descriptions of the seismic sequences that follow, and that are contained in Tables 3 and 4, are based on the seismic character as observed on the monitor sections.

Seismic sequences

Davies, Symonds & others (1987) identified six major seismic sequences in the Townsville Trough, labelled TTA to TTD from the top downwards (Fig. 22), and their basic seismic characteristics, as shown on the onboard single-channel monitor sections, are summarised in Table 3. Other prominent sequences can be identified on some lines but they do not appear to be of regional extent. The seismic sequences and facies descriptions use the nomenclature and criteria of Mitchum & others (1977) and Sangree & Widmier (1977). The five unconformities separating the sequences have been assigned tentative ages based on a variety of considerations - late Eocene to early Oligocene, middle Eocene, Paleocene, Late Cretaceous (Campanian) and Early Cretaceous or older. The Paleocene and older unconformities have been assigned an age on the basis of tectonic and palaeo-environmental considerations, analogy with drilled Mesozoic basins to the north and south (Fig. 5), and interval velocities from our sonobuoy refraction profiles compared with other velocity information in the region (Taylor & Falvey, 1977; Rasidi & Smart, 1979; Symonds & others, 1984). The ages of the post-Paleocene unconformities have been derived from both palaeo-environmental considerations and a tentative tie via Shell and BMR seismic lines to DSDP site 209 on the Queensland Plateau (Fig. 11), over 200 km to the north. Owing to thinning and loss of stratigraphic sequences over the crest of the Queensland Plateau, and changes in their seismic appearance around reef areas, the tie to DSDP can only be made by seismic character correlation. This has led to difficulty in identifying the regional late Eocene to early Oligocene in the Townsville Trough, as is also the case in the Queensland Trough. The base of sequence TTB also has the characteristic onlapping ascribed to the 'regional' unconformity, or perhaps within the troughs the regional hiatus is not represented by any seismically identifiable unconformity at all. If the base of sequence TTB was taken as the Eocene/Oligocene unconformity then the base of sequence TTA could be the equivalent of the middle Miocene unconformity identified at DSDP 209 (Burns & others, 1973) and DSDP 287 in the Coral Sea Basin (Andrews & others, 1975).

The tectono-stratigraphic significance of the sequences is given in Table 4, together with their inferred age, structural style or form, speculative lithologies and facies, and associated regional tectonic events. The sequences are briefly described (from bottom to top) below:

Sequence TTF are pre-rift or infrarift (Falvey & Mutter, 1981) rocks which constitute the tilt blocks within the centre of the Townsville Trough and the planated platforms which flank the trough. In many places the top of sequence TTF is acoustic basement and may correspond to Palaeozoic metasediments, such as those of the adjacent onshore Hodgkinson Basin and other Tasman Fold Belt provinces, as well as possible Proterozoic rocks such as those of the Peninsula Ridge (Coen Inlier). In other places the sequence contains vague dipping reflectors (Fig. 22) which may correspond to Palaeozoic sediments or Mesozoic continental to marginal marine 'infrarift' sedimentation. Falvey & Mutter (1981) suggest that these sediments may have been deposited in prerift intracratonic downwarps along the sites of incipient rifting. The Laura Basin may be a remnant of such a system.

Sequence TTE is probably composed of Early Cretaceous to Late Cretaceous older continental, marginal marine and perhaps even very restricted shallow marine sediments that were deposited during the active extensional phase of basin development. The sediments onlap the tops of tilt blocks as a diverging wedge of reflectors (Fig. 22), and form diffuse mounds - possible alluvial fan deposits - against the fault scarps.

Sequence TTD is a Late Cretaceous to Paleocene late rift-fill phase of sedimentation, which onlaps sequence TTE. It is ponded in the depressions between tilt blocks but also generally covers the eroded corners of the tilt blocks (Fig. 22). It is absent over the platforms flanking the trough. Some faulting continued during the deposition of sequence TTD but block rotation was minimal. The consistent reflection character and onlapping form of this sequence may indicate that it was deposited in a restricted shallow marine environment. The unconformity at the base of sequence TTD may correspond to Campanian breakup and commencement of seafloor spreading in the Tasman Basin, and probably Cato Trough, to the south. This would have resulted in greater marine influence within the rift system to the north, particularly the eastern part of the Townsville Trough. Sequence TTD reflects this increasing marine influence.

Sequence TTC is a Paleocene to middle Eocene early post-breakup unit that was deposited during and following the Paleocene seafloor spreading that opened the Coral Sea Basin. It appears to be relatively uniform in thickness throughout the central Townsville Trough, and exhibits some flexural and compaction drape over the corners of buried tilt blocks. The hummocky and variable reflection pattern within sequence TTC (Fig. 22) may reflect a reduction in marine influence within the Townsville Trough, or greater terrigenous input into the trough from the subaerially exposed plateaus to the north and south, or a combination of both.

The middle to late Eocene sequence TTB and the early Oligocene and younger sequence TTA were deposited during the post-breakup sag phase of margin development under more open and increasingly deeper marine conditions. During deposition of sequence TTB parts of the Queensland and Marian Plateaus remained subaerially exposed. The consistent reflection pattern and high continuity of the reflectors within the sequence (Fig. 22) is probably indicative of relatively stable depositional environments within the

Townsville Trough. Pelagic ooze and low energy terrigenous and calcareous turbidites are probably the main components of sequence TTB. The unconformity at the top of sequence TTB is thought to represent the regional late Eocene to early Oligocene hiatus, which has been related to a major change in circulation pattern throughout the Australasian region resulting from plate tectonic effects (Kennett & others, 1972; Taylor & Falvey, 1977). There is a significant change in seismic character across the late Eocene to early Oligocene unconformity from sequence TTB to TTA (Fig. 22). Sequence TTA has a fairly consistent thickness in the centre of the Townsville Trough but it generally thins and onlaps onto the margins of the trough, particularly the southern margin. It has a variable reflection character and appears to be channelled in places. The sequence probably consists of pelagic ooze, calcareous and terrigenous turbidites and slump deposits. Sequence TTA was deposited during growth of the large platform reefs on the adjacent plateaus, and its variable reflection character may be an expression of the complex depositional system resulting from this environment.

Structure

The regional seismic grid that now exists over the Townsville Trough as a result of BMR's Rig Seismic cruise has allowed a greatly improved understanding of the structural development of this enigmatic feature of the northeast Australian continental margin; however, interpretation of the exact structural style, and even the trend of some major features, remains difficult because the regional coverage is inappropriate to the structural complexity of the region. A very preliminary picture of the structural style of the Townsville Trough is shown in Figure 23. Further refinement of the structure and a better understanding of the nature of the bounding and intra-basin faults, must await detailed interpretation of the stacked and migrated seismic data.

The main structural element of the Townsville Trough is a central rift basin up to about 100 km in width (Fig. 23). The rift basin appears to be split into two parts about a constrictian at latitude 151°20'E. The eastern part has a general east-northeast trend and the western part has a west-northwest trend. The rift basin is flanked by 'basement' platforms which underlie the Queensland and Marion Plateau margins to the north and south, respectively. The platforms dip towards the rift basin and range in depth from about 1.7s to 3s TWT below sea-level. The platforms themselves are disrupted by generally small-throw normal faults which tend to dip away from the rift basin creating small half grabens. The platforms have been strongly eroded and towards the end of the seismic lines they have a planated appearance. The basement platforms are not always featureless and in places contain vague complexly structured reflectors perhaps indicating that they are composed of a large variety of Palaeozoic and Mesozoic pre-rift and infrarift metasediments and sediments. The margins of the basement platform adjacent to the eastern part of the rift basin consist of northeast-trending (54°) and northwest-trending (315°) segments. The northern margin of the western part of the rift basin has a west-northwest trend - the trend of its southern margin is difficult to discern owing to masking of much of the the seismic monitor record by multiples arising from the shallower water of the slope of the Great Barrier Reef. There are indications that the west-northwest trend is not primary but can be resolved into the northeast and northwest trends of the eastern basin (Fig. 23). This implies that the northern margin of the western basin is composed of a series of short segments and that basin architecture is more complex as it approaches its junction with the Queensland Trough. Both margins of the basement platform generally dip at a relatively low angle (about 25-35°) beneath the sediments of the rift basin. In some places this dip corresponds to the top of a tilt block (Fig. 24), in other places, particularly on the southern margin, it appears to represent a low-angle normal fault plane.

Structural trends within the rift basin are difficult to establish owing to the line spacing; however, the high-standing blocks in the eastern part of the rift basin appear to mainly strike in a northeast direction parallel to the most prominent basin margin trend. Most are tilt blocks bounded by low-angle normal faults and half grabens, although horst blocks founded by high-angle normal faults are present in a few places . The low-angle faults are most commonly downthrown to the northwest. In contrast to the above, near the northern margin of the eastern part of the rift basin at about $150^{\circ}25'$E there are two tilt blocks which appear to have a northwesterly strike and to be bounded by faults downthrown to the southwest (Fig. 25). The significance of these structures to basin development remains unknown at this preliminary stage of the interpretation; however, they may reflect increasing complexity in rift basin structure to the west, and in particular near the junction of the eastern and western parts of the basin. The tilt blocks are often associated with a syn-rift sediment package and are onlapped by late stage rift-fill sediments (Figs. 22 & 25). The corners of some tilt blocks have been eroded and levelled (Fig. 22) but to a much lesser extent than those of the Queensland Trough. Block corners are commonly associated with the development of gentle anticlines in the overlying post-Late Cretaceous sediment as a result of flexural drape, differential compaction and re-activation of the bounding faults (Figs. 25 & 26).

On the seismic monitor sections a total sediment thickness of 2.5-3s TWT can be seen in places, of which about 1.5s TWT or more is rift phase sedimentation. On Shell line 1129 (Shell, 1977; GSI, 1980) across the eastern Townsville Trough 4s TWT of sediment is present of which about 2s TWT was deposited during the rift phase. Towards the western end of the central Townsville Trough the total sediment thickness appears to decrease to about 2s TWT, although it increases again to the south (on lines 50/009 and 010) beneath the slope of the Great Barrier Reef. The processed BMR seismic data indicates that there are several areas within the trough where the sediments are more than 4s TWT in thickness - particularly on the southern ends of lines 50/002 and 003, and at about longitude 150°E on lines 50/004 and 008.

An important feature of the structure of the eastern part of the Townsville Trough rift basin is the presence of subtle northwest-trending transverse lineaments (Fig. 23), which align with the generally right-lateral offsets of the basin margin. These can be quite difficult to map in the centre of the basin owing to the spacing and orientation of the seismic grid, the sediment thickness, the water bottom multiple and the relatively poor definition of the seismic monitor records. Their trend and character are best seen in the east on lines 50/006, 007 and 008. We have defined the transverse lineaments by terminations of basement highs and grabens, and along strike changes in the width, slope and character of these features, as well as changes in the direction of dip of the tops of blocks and their bounding faults (Fig. 26). The lineaments are commonly associated with basement depressions and synformal drape of the sediment fill to at least the Paleocene level (Fig. 26). On the monitor sections some of these zones could be interpreted as 'negative flower structures', which are normally related to divergent wrench faulting (Harding, 1985). There are also a few instances of possible 'positive flower structures' associated with broader transverse zones. The transverse zones correspond to structural complexities on the margins of the rift basin. One explanation of the traverse lineaments is that they are transfer faults, which essentially perform a similar function to oceanic transform faults within extended continental crust (Bally, 1981). The concept of transfer faults, which are accommodation structures that allow variations in the geometry of extension along the strike of the rift, has recently been applied to the North Sea by Gibbs (1984), to the Gippsland and Bass Basins by Etheridge & others (1984, 1985), and to passive margin evolution by Lister & others (1986). The recognition of the northwest-trending transverse lineaments as transfer faults, and the associated northeast trend as the strike direction of low-angle normal faults implies that at least the eastern part of the Townsville Trough formed by northwest-southeast extension. For the western part of the trough to have a similar origin, its northern apparently west-northwest-trending margin would need to be resolved into northeast and northwest-trending components, as mentioned previously. It needs to be stressed that at this very preliminary stage of interpretation the above ideas can only be considered as speculative. Other models for the origin of the Townsville Trough may also satisfy the observations - for example if it is found that the margins of the rift basin have a significant strike-slip component then a transtensional origin related to the development of an oblique-slip zone may be more appropriate.

Regional implications of the structural style

In summary, the preliminary structural picture that has emerged for the Townsville Trough, based on an interpretation of the onboard monitor sections, is one of high and low angle normal faults trending at about 54°, and cross-cutting lineaments trending at about 315°, which have compartmentalised the eastern part of the rift basin (Fig. 23). The latter are probably transfer faults which make an angle of about 99° with the regional extension direction, and their presence suggests that at least the eastern Townsville Trough formed by slightly oblique northwest-southeast extension. If this scenario is correct, and the Queensland Trough formed during the same episode of rifting/extension, then it implies that the basin-forming structures beneath this feature should have a greater wrench component associated with them. There is some evidence for this in the basement fault pattern associated with the Queensland Trough (Symonds & others, 1984) and the nature of its western boundary fault (Symonds and others, 1983). However, very low angle normal faults and highly rotated tilt blocks occur in a number of areas in the Queensland Trough (Figs. 19 and 21) indicating upper crustal extension has occurred in places; whether these are the result of simple extension, or the development of small transtensional basins within a major left-lateral oblique slip zone, will only be resolved by a detailed study of the Queensland Trough seismic data. An apparent change in the trend of structures within the Townsville Trough to the west of 150°15'E, and a zone of northwest-trending normal faults near the northern margin of the rift basin at 150°25'E (Fig. 23), point to complexities in the development of the trough that are difficult to explain using a simple extensional model. It may be that two different structural styles, different episodes of structuring, tectonic overprinting, or same combination of these have resulted in the present form of the Townsville Trough.

The northwest-southeast directed Cretaceous and ?older extensional event which appears to have produced the Townsville Trough is nearly perpendicular to the extensional stress field which resulted in the Paleocene-early Eocene opening of the Coral Sea Basin to the north, and the Cato Trough to the southeast. In fact the Townsville Trough runs parallel to the transform direction at the northern end of the Cato Trough. This could be taken to infer a transtensional strike-slip origin for the Townsville Trough; however, even if the margins of the trough were considered to be strike-slip structures there do not appear to be any major right-stepping en echelon strike-slip faults (nomenclature of Rodgers, 1980) in the correct position to create a zone of tension and a resultant pull-apart basin having the form of the eastern Townsville Trough. This implies that the northwest-southeast extensional stress field which produced the Townsville and Queensland Troughs pre-dated and was probably unrelated to the stress field which finally resulted in breakup and seafloor spreading in the Coral Sea Basin.

Development history

The structural style and seismic sequence geometry determined from the onboard seismic monitor sections are consistent with the following tectonic history. In the Jurassic to Early Cretaceous the northeast Australian continental margin, incorporating the present marginal plateaus and parts of Papua New Guinea, lay adjacent to the Pacific Plate. Continental to marginal marine sediments of this age were deposited throughout the region in intracratonic downwarps (e.g._the Laura Basin and the older part of the Papuan Basin). One of these elongate troughs or 'infrarift' basins may have extended along the Queensland Trough and into the Townsville Trough to form the locus of future rifting. During the Early to Late Cretaceous (pre-Cenomanian) and possibly during the Late Jurassic (syn-rift phase), northwest-southeast extension resulted in the low-angle normal faulting and block rotation which initiated the Townsville Trough rift basin. Associated wrenching, and possible transtensional pull-apart basin development produced, the Queensland Trough. The tectonism was probably accompanied by uplift in adjacent regions and by volcanism. In the Late Cretaceous, leading up to the Paleocene-Eocene opening of the Coral Sea Basin, a northeast-southwest extensional event may have been superimposed on the region resulting in reactivation and overprinting of the older basin-forming structures. During the period of Cretaceous extensional/rift tectonism continental, marginal marine and perhaps areas of very restricted shallow marine sediments were deposited in the developing half grabens of the Townsville Trough. From the Late Cretaceous to early Paleocene (late rift phase) movement on the normal faults continued, but at a greatly reduced level. Some of the tilt blocks were capped and buried by the late rift phase sedimentation, which exhibits flexural drape and thinning over the block corners. Increasing marine influence in the Townsville Trough probably followed Campanian breakup and seafloor spreading in the Tasman Basins and Cato Trough to the south. Restricted shallow marine sediments were deposited in the centre of the Townsville Trough, grading to marginal marine and continental on its flanks and on the adjacent emergent Queensland and Marian Plateaus. During the Paleocene to Eocene episode of seafloor spreading in the Coral Sea Basin to the north, only minor reactivation and structuring occurred in the Townsville Trough enhancing flexural and compaction drape in the early post-breakup sediments. At this time partially restricted shallow marine conditions probably existed in the trough, with paralic to shallow shelf environments on the trough margins. In post-middle Eocene time slow regional subsidence during the post-breakup sag phase of continental margin development resulted in shallow marine conditions being established on the Queensland and Marian Plateaus, although parts of both of these features were probably still emergent until at least the end of the Eocene. During the middle to late Eocene the Townsville Trough received neritic to deepwater high and low energy deposits which probably consisted mainly of terrigenous and calcareous turbidites. The early Oligocene a widespread unconformity resulted from the start initiation of a significant equatorial circulation pattern over the subsiding margin and basins is reflected by a widespread unconformity (Taylor & Falvey, 1977). Establishment of this subtropical to tropical circulation in the Oligocene may have triggered the initiation of reef growth on the plateaus and eventually on the adjacent continental shelf. In post-early Oligocene times, as the water depth over the adjacent plateaus increased, pelagic ooze, turbidites and slump deposits became the major components of trough sedimentation.

Carbonate platform development - the Marion Plateau

As mentioned previously the Marion Plateau appears to form a simple extension of the continental shelf unlike the other marginal plateaus in the region which are stucturally and bathymetrically separated from the adjacent continental shelf. A thick sedimentary section (up to 2 sec. TWT) occurs beneath the northern and eastern slope and rise of the plateau, but 'basement' beneath the plateau proper appears to be strongly planated and is covered by less than 0.5 sec. TWT of sediment (Fig. 27). This sediment is thought to be Oligocene to Recent in age based on tentative regional seismic ties to DSDP site 209 on the Queensland Plateau. The seismic character of this sequence indicates that is probably dominated by carbonate platform facies, and the areal distribution of these facies appears to have varied through time.

At the present day reefs on the plateau are restricted to Marion Reef in the northeast and Saumarez Reef in the southeast (Figs. 3, 9 & 10). The 1985 **Rig Seismic** seismic data across the northern margin of the plateau show buried reefs overlying a prograding sequence in the west, and buried shelf-edge barrier reefs (Fig. 28) in the east. Older BMR and commercial seismic data over the Marion Plateau indicate that an extensive carbonate platform covered most of the northern two thirds of the plateau and part of the southern plateau in the Swains Reef area, and reefal and lagoonal facies are discernible (Fig. 29) within the platform sequence. It appears that three distinct periods of reef growth occurred on the plateau, and the top of the second period of growth now lies about 450m below sea-level, similar to the level of reef drawback on the Queensland Plateau. The schematic section across the continental shelf and Marion Plateau in Figure 27 indicates that the area of reef growth on the plateau was far greater in the past than at the present day, and that these reefs are far older than those of the Great Barrier Reef directly to the west. Important questions that need to be answered are:

- by what mechanism were the reefs of the Marion Plateau killed off?
- why did reefs grow on the plateau at an earlier stage than on the Great Barrier Reef shelf?
- what is the relationship between the Great Barrier Reef and Marion Plateau carbonate platform development?

Our studies off northeast Australia have resulted in the development of an hypothesis to explain the evolution of margin facies, particularly the carbonate platforms, through time, and this is critical to understanding the sedimentologic evolution of the Marion Plateau. We contend that the sedimentological features off northeast Australia have been primarily controlled by three interrelated forcing functions: 1.Horizontal plate motion. 2.Climate/Oceanography/Sea Level 3.Subsidence. These have interacted to give rise to:

1. Clastic fluvio/deltaic sedimentation along the tropical continental margin and temperate(?)carbonate progradation along the margins of the Queensland and Marion Plateaus in the Eocene and Oligocene.
2. Initiation of reefs on the Queensland and Marion Plateaus in the early Middle Miocene.
3. Late Miocene subsidence resulting in stepback of the reefs on the Queensland and Marion Plateaus and re-establishment at a higher topographic level.
4. Pliocene subsidence leading to substantial stepback on the Queensland Plateau, drowning of the Marion Plateau and stepback of the Miocene barrier and platform reefs to their present

position on the Great Barrier Reef.

5. Post-Pliocene evolution of the Great Barrier Reef related to sea level control on fluvio-deltaic deposition and reef growth. Low and high sealevel reefs can be identified.

This hypothesis is supported by the following:

Horizontal Plate Motion

During the past decade, plate tectonic (Duncan, 1981) and magneto-stratigraphic (Idnurm, 1985) studies have provided a detailed reconstruction of the movement of the Indian -Australian Plate throughout the Cainozoic. Australia is a unique continent in both its shape and its apparent simple, generally northward, horizontal drift in the Cainozoic. The southern margin should contain in its sedimentary record a subtle imprint of longitudinal striping recording the movement through the temperate zones; such striping is likely to be subtle. On the other hand the eastern margin ought to show a very strong signal related to the superimposition of two sedimentary wedges - one temperate and thinning northwards and the other tropical and thinning southwards. This is, in fact, what is seen in the data (Fig. 30). The projected movement of Australia away from Antarctica in the Cainozoic is shown in Figure 31A, using the positions of Anchor Cay($9^{o}30'S$), Townville($19^{o}S$) and Heron Island ($24^{o}S$), to represent the northern, central and southern provinces of northeast Australia throughout the Tertiary (Fig. 31A). The total errors from all determinations in the Neogene is about 8^{o}, although an acceptable mean curve would show an error of approximately 4^{o}.

It is reasonable to anticipate that the dramatic latitudinal plate movement would have resulted in profound climatic changes along the eastern Australian shelf. Such changes should be clearly recorded in the continental margin sediments of the Great Barrier Reef region, with sediments deposited under temperate climatic conditions overlain by a southward-thinning wedge of sediments with tropical affinities. Analysis of the northward plate motion indicate that, relative to $23.5^{o}S$ (Tropic of Capricorn - approximately corresponding to the present southern limit of reef growth on the Great Barrier Reef):

- the transition from temperate to tropical climatic conditions in the northern Great Barrier Reef occurred between 16 and 25 million years ago;
- the central Great Barrier Reef was affected by a temperate climate until 10-15 million years ago;
- the southern region became tropical only in the last few million years.

An analysis of paleoceanographic and paleoclimatic considerations (see below) has shown that these variables do not significantly alter the above conclusions.

These conclusions must have an important bearing on the growth of carbonate platforms in the area. Most simplistically, it provides a rational basis for the northward thickening of the Great Barrier Reef sequence. More importantly, it imposes limitations on the growth of the three major carbonate platforms in the region - the Great Barrier Reef, the Queensland Plateau and the Marion Plateau.

Climate/Oceanography/Sea Level

At the present time - a period of high sea level, relatively warm climate and strong boundary currents - the carbonate sediments on the outer shelf of eastern Australia show a marked demarcation with latitude - distinct tropical affinities occur north of latitude 27°S and temperate affinities south of this latitude. Identifiable and linked relationships may also have occured in the past. In deciphering the likely signals we are dependant on studies of the DSDP holes drilled on the Lord Howe Rise to the east of Australia, and aimed specifically at defining palaeoclimate (Shackelton & Kennett, 1975; Murphy & Kennett, 1985; Kennett & von der Borch, 1985; Kennett, 1985,etc.).

An analysis of the above studies has enabled the construction of an indicative palaeotemperature curve for the Tertiary for the surface waters off northeast Australia (Fig. 31B.) The sealevel curve of Vail & others(1977) is shown in Figure 31C. Three very clear implications can be drawn from these data. First, temperatures in the early part of the middle Eocene were warm enough to have enabled coral reefs to have grown. In this regard it is noteable that Chaproniere(1983) recorded larger foraminifera in the early middle Eocene from the northwestern margin of the Queensland Plateau. This fauna is consistent with a sea-surface temperature range of 18-27°C. Secondly, much of the Tertiary from the late middle Eocene, through the Oligocene and into the middle early Miocene is characterized by temperatures which were not conducive to tropical carbonate platform development. Climates were probably temperate and sometimes cool temperate, and therefore this must must have been a period of no reef growth . Thirdly, the end of the early Miocene marks the period when northeast Australia was bathed in surface waters marginal to the support of coral reefs, i.e.probably comparable to those off northern New South Wales and southern Queensland today. While some reef growth may have been possible in the extreme north, it is most likely that prolific growth throughout much of the northern region began in the early middle Miocene. The isotope deduced palaeotemperature increase, coupled to the down-core petrographic data and the onshore palynologocal data, predict and confirm likely water temperatures of 20-25°C at this time. The climatic cooling experienced throughout the late Miocene would only have affected the southern Great Barrier Reef, which was not at the time in the tropics, although it is possible that reefs growing in the region of the Marion and Queensland Plateaus were stressed. The progressive development of the east Australian current would have intensified from 30 million years as collision with New Guinea in the north produced an increasing barrier to westerly flow in the equatorial zone and therefore diversion of warm tropical to sub-tropical waters to the south. This would have reached its peak of influence in the middle Miocene when climates were warmer.

In addition to physical oceanography and climate, the chemical oceanography of Neogene seas would have had an important bearing on the development of carbonate platforms in northeast Australia. The late early Miocene to early Middle Miocene apparently represents a time of increased ocean fertility commensurate with a postulated 2-3 orders of magnitude increase in phosphate levels(Riggs 1984). This greatly increased oceanic "phosphate spike" effected massive phosphatization of continental margin sediments throughout the world and such phosphatization is known to occur on the outer shelf of northern NSW (Cook and Marshall 1981). The implications of this event are great: increased ocean phosphate levels would likely inhibit the growth of coral reefs and promote a large increase in biomass production(Kinsey and Davies 1979). In short, coral reefs would not grow and early Miocene source rocks could have formed as a consequence of the high ocean fertility.

Subsidence

Some qualitative information regarding subsidence in northeast Australia can be deduced from platform morphology. The tilt of the Queensland Plateau to the north suggests differential subsidence in that direction. On both the Queensland and Marion Plateaus the clearly identified carbonate platform surface at 450-500m, and die-back or draw-back of the reefs on that surface, also suggests subsidence. Quantitative data can be derived through geohistory analysis of known wells, and this has been done for all drilled wells in the region, i.e. Anchor Cay, DSDP 209, Capricorn 1A and Aquarius. Each of these wells was analyzed using the geohistory techniques of Van Hinte(1978) and Falvey and Deighton(1982) and some of these subsidence curves are showned in Figure 32, and described below.

The Anchor Cay well at the northern end of the Great Barrier Reef province (Fig. 1&5) contains Triassic to Middle Jurassic siliciclastic rocks uncomformably overlain by a carbonate dominated section of Eocene to Recent age, with a hiatus in the early to middle Oligocene(Oppell 1970, Robinson Research, 1984). The pre-Eocene portion of the subsidence curve is speculative as it is difficult to ascertain how much section has been removed at the major unconformity. The Eocene and younger section corresponds to the time of northward drift of Australia and also the time of carbonate deposition at this site. Accelerated subdidence(Fig. 32B) affected this region between 25 Ma and 5 Ma ago at 50m/million years, and between 5Ma and the present at 140m/million years.

No petroleum exploration wells have been drilled on the Queensland Plateau. Our only way of understanding the subsidence history of this feature has therefore been to study DSDP site 209 drilled in 1428m of water (Fig. 32A). The well encountered a middle Eocene to Recent section with hiatuses in the early and middle Oligocene and middle Miocene. The Eocene section consists of ferruginous sand and ooze overlain by late Oligocene and younger cacareous ooze(Burns & others, 1973). The main subsidence phase of the plateau occurred in the period post-11Ma at an average rate of 40 m/million years.

Two petroleum exploration wells have been drilled at the southern end of the Marion Plateau in the Capricorn Basin (Fig. 1&5) i.e. Capricorn-1A and Aquarius-1. Basement consists of Cretaceous volcanics in Capricorn-1A and indurated ?Palaeozoic shale siltstone in Aquarius-1. Basement is overlain by ?Palaeozoic to middle Oligocene basal polymictic conglomerate and arkosic red beds overlain by shallow marine glauconitic and carbonaceous sandstones, which are in turn overlain by Miocene to Recent claystone and marl (Ericson, 1974). The subsidence curves for Capricorn and Aquarius (Fig. 32C) show a similar pattern of overall thermal subsidence punctuated by subsidence pulses between 16Ma and 11Ma and 2.5Ma and a present rate of 100m/million years.

The subsidence data from all the available wells indicate that northeast Australia has not subsided soley as a result of thermal cooling following sea-floor spreading. Clear subsidence pulses have occurred at different times in northeast Australia; however, all continental shelf wells show that the last major subsidence pulse has occurred since the Pliocene and was at a rate of the order of 100m/million years. This timing and rate accords well with subsidence estimates deduced from dredging drowned pinnacles on the southwestern margin of the Queensland Plateau. With the exception of the last Plio-Pleistocene subsidence pulse, the subsidence histories defined above are not sufficiently precise to be correlated with periods of reef growth. However, substantive use can be made of the subsidence curves when coupled with palaeolatitude determinations for the same site. For example subsidence undoubtedly causes changes in sediment style and type which would be different under temperate and tropical conditions.

We have attempted to show that vertical tectonics (rift-phase and sag-phase subsidence), horizontal tectonics (plate motion), and climate/oceanography/ sea-level have been controlling factors on the evolution of the carbonate platforms of northeast Australia. Platform development has taken place within a highly dynamic system which has resulted in process diachroneity, and thus a complex distribution of facies in time and space. The new insights we are gaining into carbonate platform development have a predictive capability which is important to hydrocarbon exploration at all levels from defining play types within carbonate platform depositional systems, to understanding facies, diagenetic and porosity variations in and around an individual reef. Many of the concepts that we are developing will be tested on the Marion Plateau during the proposed 1987 cruises, and by a proposed scientific ocean drilling program in the region.

OCEAN DRILLING PROGRAM PROPOSAL FOR NORTHEAST AUSTRALIA

Following the 1985 **Rig Seismic** cruises off northeast Australia an Ocean Drilling Program (ODP) proposal was prepared to address a series of global sediment and ocean history themes in the Great Barrier reef - Queensland Trough - Queensland Plateau - Marion Plateau region. Of the fourteen sites proposed (Fig. 4), eight hydraulic piston core sites have been given a high ranking by the Sediments and Ocean History Panel (SOHP) and the Western Pacific Panel (WPAC) of the ODP advisory structure, and it now seems quite likely that scientific ocean drilling may occur off northeast Australia in 1989. ODP site proposal summary forms containing the site description, scientific objectives, background information and operational considerations for all of the proposed sites are contained in Appendix A.

The region is regarded by the above ODP panels and the geoscientific community at large as an excellent example of a mixed carbonate/siliciclastic province in a passive margin setting, and is viewed as being unique in terms of the important facies and stratigraphic models it can provide for understanding ocean history, the evolution of passive margins and ancient carbonate depositional systems. The main global themes that wiil be addressed by scientific drilling in the region are:

(1) Cenozoic sea level changes, major global unconformities and sediment response to sea level.
(2) Basin/shelf sediment fractionation and basin fill history in response to sea level and subsidence history.
(3) Changes in paleoclimate related to plate position and the effects of these changes onsedimentation.
(4) Comparison of the tectonic and sediment history of a passive continental margin and an isolated plateau.
(5) Diagenesis of a mixed carbonate/siliciclastic province in an undersaturated ocean regime.

In order to ensure that the program goes ahead high quality site surveys are required over the proposed sites. We propose to carry out the site surveys during the first cruise of the 1987 northeast Australia program by recording high-resolution (watergun) multichannel seismic reflection, 3.5 khz and sidescan sonar data, augmented by coring. A summary of the ODP site survey data standards is given in Appendix B.

CRUISE OBJECTIVES

1. To determine the exact structural style of the Townsville Trough,its

relationship to the adjacent Queensland and Marion Plateaus, and its implications to the development of the northeast Australian continental margin. In particular:

- to determine the geometry and orientation of the extensional faults as precisely as possible, so that the kinematic framework of the rifting process can be established.
- to elucidate the structure of the Townsville Trough with its neighbouring domains, especially the Queensland Trough at its western end, and the ?ocean/continent boundary at its eastern (Cato Trough) end.
- to determine the geometry of the shallow platforms that bound the Trough to the north and south, and to understand the variation in the seismic character of the pre-rift rocks that form the platforms.
- to determine the timing of structuring within the Trough, particularly that producing late-stage reactivation of the primary extensional structures.

2. To establish a seismic stratigraphic framework for the Townsville Trough that will provide a basis for understanding the nature of the depositional systems and facies variations within it, and that will aid future exploration in the region.

3. To define the positions of the major depocentres and structural leads in the Townsville Trough.

4. To define play concepts likely to aid petroleum exploration from an analysis of the structural and sedimentological evolution of the Townsville Trough, and a preliminary understanding of its thermal and burial history.

5. To define the structural and sedimentological evolution of the Marion Plateau and in particular:
   - to determine whether Mesozoic basins underlie the plateau,and specifically whether there is a continuation of the Queensland Trough stucture beneath the northwestern portion of the plateau.
   - to determine the position of thick sediment sequences on the margins of the plateau - especially its eastern Cato Trough margin.
   - to define the mechanisms which effected the formation of the plateau.
   - to determine the timing and the extent of reef growth on the plateau.
   - to define the causes of the demise of reef growth.
   - to define the sedimentologic style on the plateau since reef growth ceased.

6. To define the relations between the evolution of the Marion Plateau and the Great Barrier Reef.

7. To determine any structural and stratigraphic relationships between coastal and shelf basins such as the Hillsborough, the Narrows and the Capricorn Basins, and the continental margin rift basin systems.

8. To conduct site surveys in support of the Ocean Drilling Program proposals. Fourteen sites will be surveyed with high resolution seismics, sidescan and sampling.

The 1987 Rig Seismic cruises over the Townsville Trough and Marion Plateau are continuations of the 1985 cruises. As such, new data and insites will be gained with respect to ideas generated from the results of the earlier cruises. In particular, some advances are expected with respect to the following:

- Why does the Marion Plateau appear as a terrace within the margin and not as a rift-bounded marginal plateau, such as the Queensland Plateau? Does such a rift feature lie buried beneath the western margin of the Marion Plateau forming a structural connection between the Queensland Trough, in the north, and the Capricorn Basin, in the south?
- What is the relationship, if any, between the Late Cretaceous - Tertiary coastal basins of Queensland and the development of the adjacent continental margin?
- Why is the GBR thin in the south and progressively thicker in the north?
- For what reason do the thickest reef sequences occur on the Queensland Plateau, the Marion Plateau and the northern end of the GBR?
- What is the age of reef initiation in northeast Australia?
- Why did reefs grow on the Marion Plateau before they did in the GBR proper?
- What caused the major stepback of the reefs on the Marion and Queensland Plateau?

CRUISE PLAN AND OPERATIONS

The 1987 research program off northeast Australia will consist of two cruises using BMR's chartered vessel **Rig Seismic**. It is planned that the first cruise (Rig Seismic cruise 15 - survey 75) will have a duration of 32 days, leaving from Brisbane at 0000 hours on Friday 4th September and finishing in Townsville on Monday 5th October. After a break of 24 days the second cruise (Rig Seismic cruise 16 - survey 76), which will have a duration of 24 days, will leave Townsville at 0000 hours on 30th October and finish in Sydney on Sunday 22nd November. There will be a total of 20 scientific and technical personnel on each cruise (Appendix C). A full list of equipment required for the cruises is given in Appendix D, and the proposed seismic source/receiver configuration and recording parameters are given in Appendix E.

The first cruise will consist of a high-resolution seismic reflection and sampling program focussing mainly on the Marion Plateau and around the proposed ODP sites. The proposed regional seismic tracks are shown in Figure 33. As well as these, a detailed grid of about six short seismic lines totalling approx. 12 nm will be shot over each proposed ODP site shown in Figure 33. 24-channel, 1msec. sampled, ?18-fold data will be acquired using the small diameter (GBR) Teledyne streamer and a new 15 cu.in. watergun, which is currently being purchased (Appendix E). This source will replace the sparker system used to obtain high-resolution data on previous cruises off northeast Australia. The basic cruise plan is as follows:

	Days
Transit from Brisbane to start high-resolution seismic in Hydrographer's Passage	1.7
Deployment and testing of seismic system	1.0
* Marion Plateau high-resolution seismic (Fig. 33)	10.0

Eastern Townsville Trough high-resolution transect (Fig. 33)	1.0
* ODP high-resolution seismic site surveys, including western Townsville Trough and Queensland Trough transects (Fig. 33) plus streamer recovery	8.0
Dredging on the northern and southern margins of the Townsville Trough (two sites) and the southern Marion Plateau, two coring transects across the Townsville Trough, including some heat-flow measurements, and two coring transects across the Marion Plateau - a total of about 87 cores.	9.0
Transit to Townsville	1.0
Total	31.7

Major down-time due to bad weather or equipment malfunction will obviously require modification of the above program.

* Permission will be sought from the Great Barrier Reef Marine Park Authority to carry out this phase of the program.

The high-resolution seismic data over the Marion Plateau (Fig. 33) has been positioned after an examination of all available seismic data over the feature. The lines will allow us to examine -

- the relationship between the Great Barrier Reef ?Pleistocene reefs and the Marion Plateau carbonate platforms.
- the western extent of ?Miocene carbonate platform development.
- the relationship of prograding wedges and the carbonate platform on the northern margin of the plateau.
- the nature of the 'backstepping' sequence from the plateau to the modern Great Barrier Reef.
- the various levels of carbonate platform development beneath the northern plateau and facies variations within the platforms.
- the nature of the pedestal beneath the Marion, Swain and Saumarez Reefs.
- the eastern limit of the ?Miocene carbonate platform and slope facies.

The second cruise will consist mainly of airgun seismic reflection work, including some sonobuoy refraction profiles, focussing on the Townsville Trough and northern Mariom Plateau, plus a few days of coring and sidescan sonar work around the proposed ODP sites. The proposed seismic tracks are shown in Figure 34. The data will be recorded as 96-channel (25m groups), 2 msec.sampling, and 24-fold at 12.5m CDP's, and will be shot using the new twin 26.2 litre (total of 56.4 litres) Texas Instruments 10 airgun arrays (Appendix E). This system should give vastly improved resolution and penetration over the two 8.2 litre guns (total of 16.4 litres) used during the 1985 cruise over the Townsville Trough, and will hopefully give full penetration to basement in the main depocentres where the sediments are more than 4 secs. (two-way-time) thick. The basic cruise plan is as follows:

	Days
Transit from Townsville to ODP site survey area off Cairns	0.8
Coring (13 sites) and sidescan sonar (4 sites) at proposed ODP sites, including transit time from Cairns area to the Marion Plateau area	4.0

Townsville Trough/Marion Plateau airgun seismic (Fig. 34) Made up of:			17.0
	Deployment and testing of seismic system and streamer retrieval -	2.0 days	
	Turns, including airgun maintenance/repairs -	2.0 days	
#	Data recording on line (Fig.34) -	13.0 days	
Transit from southern Marion Plateau area to Sydney			3.0
		Total	24.0

We are considering carrying out a seismic tie to DSDP site 209 on the Queensland Plateau north of Lihou Reefs during this phase of seismic work, in an effort to carry Eocene and younger seismic stratigraphy into the Townsville Trough/Marion Plateau area. The final decision on this must await an assessment of its importance and chance of success as against other program objectives.

The above schedule is fairly tight and obviously down-time due to bad weather or major equipment malfunction will require modification of the program, and perhaps the deletion of some of its components.

The airgun seismic data over the Townsville Trough and Marion Plateau (Fig. 34) has been positioned after examination of all seismic data in the area, including the processed 1985 BMR **Rig Seismic** data. These lines should allow us to achieve the following:

- Correlation of major stuctures throughout the trough by filling in the large gaps between the good quality data sets.
- Determine the sediment thickness and nature of basement in the major depocentres defined on the 1985 data.
- Understand the geometry and orientation of the extensional and transfer (transverse) faults on a series of closely spaced lines
- Determine the structure of the margins of the trough on a series of long lines from the Queensland to Marion Plateaus, carefully positioned so that they are parallel to and between transfer faults.
- Understand the structural style at the confluence of the Queensland and Townsville Troughs.
- Determine whether there is an extension of the Queensland Trough structures beneath the northwestern Marion Plateau.
- Gain an insight into the nature of the eastern Townsville Trough and its relationship to the Cato Trough.
- Some understanding of any structural and stratigraphic relationships between the coastal and shelf basins, and the deeper continental margin rift basin systems.

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Site Name	Hole Type	Location	W.D. (m)	Penetration (m)	E.D.T. days	E.L.T. days	Transit days	Expected Lithology	Assumed Av. Penetration rate m/hr
NEA1	APC/XCB	16° 38.7'S 146° 18.5'E	218	500	2.6	1.0		siliciclastics with one 50cm bed of carbonate	20
NEA2	APC/XCB	16° 38.2'S 146° 18.5'E	285	400	2.0	0.9		As above	20
NEA3	APC/XCB	16° 37.5'S 146° 19.2'E	412	300	2.0	0.9		siliciclastics	20
NEA4	APC/XCB	16° 26'S 146° 14'E	956	450	2.2	1.2		silic	20
NEA5	APC/XCB (800) RCB (100)	16° 37'S 146° 44'E	1620	900	8.5 – 12.5	1.5		mixed siliciclastics and pelagic carbonates	20 (800) 10
NEA6	APC/XCB	16° 27'S 147° 46'E	1050	300	2.5	0.9		"	10
NEA7	APC/XCB (300) RCB	17° 09'S 147° 19'E	1450	760	9 – 10.3	1.3		carbonates	20 (oozes) 5 (main
NEA8	APC/XCB	16° 30'S 148° 11'E	800	300	2.0	0.9		periplatform ooze	20
NEA9	APC/XCB	17° 52'S 150° 07'E	400	300	2.0	0.9		periplatform ooze	20
NEA10	APC/XCB RCB	17° 55'S 150° 15'E	487	250	9.0	0.8	28 hrs	carbonates	2
NEA 11	RCB	18° 8.6'S 149° 46.2'E	990	750	8.5 – 10.0	1.3		pelagic and reef to bank carbonates	20 (p) 5 (r&b
NEA 12	RCB	18° 44'S 149° 58.8'E	915	1000	9 – 13	1.5		mixed siliciclastics and carbonates	20
NEA 13	APC/XCB RCB	19° 11'S 150° 0.5'E	420	400	5 – 6	0.9		pelagics over ?reef/bank carbonates	20 (p, 5 (r&b,
NEA 14	APC/XCB RCB	19° 11'S 150° 01'E	420	350	5 – 6	0.9	TOTAL 38 hrs @ 10kts	" " "	"

SITE SURVEY DATA STANDARDS

X = Required

R = Requirement for Re-entry

H = Requirement for High Temperature Targets

( ) = Desirable

( )* = Desirable, but May be Required in Some Cases

TARGETS	A PALEO-ENVIRONMENT (SHALLOW PENETRATION)	B PASSIVE MARGINS	C ACTIVE MARGINS	D OCEAN CRUST WITH THICK SEDIMENT COVER	E OCEAN CRUST WITH THIN SEDIMENT COVER	F BARE ROCK DRILLING	G ASEISMIC RIDGES, OCEANIC PLATEAUS OR SEAMOUNTS
1. Deep Penetration SCS	(X)	(X)	X or 3	X or 3	X or 3		(X)*
2. High Resolution SCS	X	(X)	(X)	(X)	X	X	(X)
3. MCS, Including Velocities		X	X	X or 1	X or 1		(X)*
4. Crossing Seismic Lines or Survey Grid	(X)	X	X	X	(X)	(X)	(X)*
5. Seismic Refraction		(X)	(X)*	X	(X)	(X)	(X)*
6. 3.5 kHz	X	(X)*	(X)*	X	(X)*	X	(X)
7. Multi-beam Bathymetry	(X)*	(X)*	X or 8a	X	X or 8b	X	(X)* or 8a
8. Side Scan Sonar							
a) Shallow Source	(X)*	(X)*	X or 7		(X)	(X)	(X)* or 7
b) Deep Towed Source					X or 7	X	
9. Heat Flow		(X)*	(X)*	(X)	(X), H	(X), H	(X)
10. Magnetics & Gravity		(X)	(X)	(X)	(X)	X	(X)
11. Coring							
a) Paleo-environmental	X	(X)	(X)				
b) Geotechnical		R	R	R	R,H		R
12. Dredging					(X)*	(X)*	(X)*
13. Photography					(X)*	X	(X)
14. Current Meter (For Bottom Shear)	(X)*	(X)*	(X)*				(X)*

AMPLIFYING COMMENTS TO SITE SURVEY DATA STANDARDS - MATRIX

The TARGETS categories across the top of the matrix describe broad categories of drilling objectives. Individ 1 sites with multiple objectives may need to meet the requirements of two TARGET categories. Frequently sites will have shallow objectives (TARGET A), deeper sedimentary and/or basement objectives (TARGETS B, D or E).

TARGET A - Generally APC/XCB penetration.

TARGET B - Greater penetration than a few hundred meters on a passive margin.

TARGET C - Greater penetration than a few hundred meters on an accretionary wedge, fore arc or sheared margin.

TARGET D - Greater penetration than a few hundred meters in a deep ocean environment. Often includes basement penetration.

TARGET E - Sediment thicknesses of less than a few hundred meters in a deep ocean, ridge crest or fracture zone environment. Often includes basement penetration.

TARGET F - Bare rock drilling, usually on zero age crust.

TARGET G - Elevated features above the ocean floor. Widely varying sediment thicknesses. Sediment slumping may be a problem on flanks. Basement often an objective.

The techniques include commonly used geophysical and sampling techniques.

1) Deep penetration SCS - Large source Single Channel Seismic

2) High resolution SCS - Watergun Single Channel Seismic or small chamber airgun in some situations. Digital acquisition preferred, but usually not necessary.

3) MCS and velocity - Multi-Channel Seismic including velocity determination (stacking velocities, and semblance plots when accurate depths are critical). Velocity analysis to determine sediment thickness over proposed sites.

4) Crossing lines - A seismic grid and/or crossing lines over the proposed site. The density of the seismic grid required depends on each particular situation.

5) Refraction - Sonobuoy or Ocean Bottom Seismometer refraction profiles, Expanding Spread Profiles or wide angle refraction profiles.

6) 3.5 kHz - High frequency data for near bottom high resolution to resolve small scale features and give some indication of sediment type.

7) Multi-beam bathymetry - SEABEAM or SeaMARC II bathymetry or equivalent. In some cases the greater resolution of SEABEAM may be required. Areas where slumping may occur should have multi-beam bathymetry and/or side scan sonar.

8) Side Scan Sonar - The reflectivity image of side scan sonar is often needed to interpret multibeam bathymetric data.

   a) Shallow - Side scan sonar sources towed near the surface, e.g. SeaMARC II, GLORIA.

   b) Deep - Side scan sonar sources flown near the bottom, e.g. Scripps Deep Tow, French SAR, SeaMARC I.

9) Heat Flow - Pogo type profiles or piston core heat flow measurements in detail appropriate to the scientific problem.

10) Magnetics and Gravity - Regional magnetics should be available on any location for which the magnetic age of ocean crust is important. Gravity is seldom an absolute requirement; but should be obtained on any profiles for which subsidence studies are planned. SEASAT derived gravity information often complements the regional magnetic picture.

11) Coring - Cores should be taken near all paleo-environmental sites for stratigraphic control.

    All re-entry sites should be supported by cores, core descriptions and geotechnical measurements (see below for specific list). The two limiting factors for re-entry operation are:

a) Sufficient sediment thickness to set the re-entry core (more than 30 m).

b) Ability to wash through the sediment section.

The benefit of geotechnical information for re-entry operations is that wash-in capabilities are tied to formation strength. The manner in which geotechnical information is to be used within ODP will most likely evolve as the geotechnical data base is studied in the context of increasing experience in re-entry operations.

At present (1986), the following measurements of geotechnical properties on fresh piston cores are recommended as part of each site survey package for a re-entry site:

a) Penetrometer Strength
b) Vane Shear Strength (Natural and Re-molded)
c) Bulk Density
d) Water Content
e) Atterberg Limits (Liquid and Plastic)

Gradient and maximum and minimum values of the geotechnical properties listed above are also recommended.

For old piston cores, please provide any geotechnical measurements made when the core was fresh. Atterberg liquid and plastic limits should also be measured on old core material as this is one geotechnical observation which is still valid on partially dessicated material.

The above properties should be provided in conjunction with lithology and bedding.

Site proponents should contact the Science Operator (TAMU) for further clarification on the geotechnical requirements for their particular circumstances.

12) Dredging - May be required when basement drilling is included in the objectives.

13) Photography - May be required in TARGET E in the case of hydrothermal areas over sedimented spreading centers.

    Bare rock drilling sites will require extensive bottom photography, such as ANGUS coverage.

14) Current meters. Information on bottom currents will be required when bottom shear might be a problem. Shallow water sites may need tidal current information as well.

APPENDIX C : Scientific/technical personnel

The following personnel are currently assigned to the two 1987 **Rig Seismic** cruises off notheast Australia:

First cruise (NEA3) - Rig Seismic cruise 17 - survey 73

Scientists -	Peter Davies	Co-chief scientist
	Philip Symonds	Co-chief scientist
	Chris Pigram	
	David Feary	
	George Chaproniere	
	Norm Johnston	
	David Capon	
Technical officers -	Jenny Stuart	
	Gray Saunders	
	Chris Lawson	
	Neil Clark	
	Harley Reynolds	
	David Pryce	
	Lyndsay Miller	
	Gary Burren	
	Richard Schuler	
	TO mechanical - to be recruited	
	ESU officer - to be appointed	
Visiting scientists -	Andre Droxler	- Rice University, Houston, USA.
	Walter Pitman	- Lamont-Doherty, New York, USA.

Second cruise (NEA4) - Rig Seismic cruise 18 - survey 74

Scientists -	Peter Davies	Co-chief scientist
	Philip Symonds	Co-chief scientist
	Chris Pigram	
	David Feary	
	Trevor Graham	
	Norm Johnston	
	Frank Brassil	
Technical officers -	Ken Revill	
	Jim Bedford	
	Ian Roach	
	Jim Kossatz	
	Colin Tindall	
	Roger Curtis-Nuthall	
	David Holdway	
	Peter Harris	
	TO mechanical - to be recruited	
	GSI officer - to be appointed	
Visiting scientists -	Deborah Scott	- Duke University, Durham, N.C., USA.
	John Ladd	- Lamont-Doherty, New York, USA.
	? Piedermann	- Vrije Universiteit, Amsterdam, Netherlands.

APPENDIX D : List of equipment required

Geophysical

Airgun Seismic System

-2400 m Teledyne hydrophone streamer with 96x25 m groups
-Syntron RCL-2 individually addressable cable levellers
-2x1600 cubic inch (total of 52.4 litres) Texas Instruments airgun array
-3xBOLT 1500C 500 cubic inch airguns with wave-shape kits
-Teledyne gun signature phones, gun depth sensors, and I/O SS-8 shot sensors
-3 x Price A-300 compressors, each rated at 300 scfm @ 2000 psi
-1 x Price AGM W-2 compressor, rated at 200 scfm @ 2000 psi
-BMR designed and built seismic acquisition system based on Hewlett-Packard minicomputers and 48-channel digitally controlled preamp/ filters

High-resolution Seismic System

-450 m Teledyne 178 (small diameter) streamer with 12x12.5 m and 12x25 m groups
-Seismic Systems Inc. S.15 and S.80 waterguns
- a range of small BOLT airguns

Seismic Refraction System

-Reftek sonobuoy receiver
-Reftek 2 sonobuoys
-Yaesu sonobuoy receiver
-Spartan SSQ-57 sonobuoys

Bathymetric Systems

-Raytheon deep-sea echo-sounder; 2 kW maximum output at 3.5 kHz
-Raytheon deep-sea echo-sounder; 2 kW maximum output at 12 kHz

Magnetometer System

-2 x Geometrics G801/803 proton precession magnetometers; may be used as standard single-sensor cable or in horizontal gradiometer configuration
-Geometrics G803 proton precession magnetometer; single sensor cable

Side-scan Sonar System

-E.G.&G side-scan sonar system - model 990 SMS tow fish and model 996 SMS digital modem; 1000 m of tow cable

Heat-flow System

-1xNichiyu Giken Kogyo NTS-11AU thermal gradient probe
-needle-type thermal conductivity measuring equipment

Navigation Systems

GPS Navigation System
-Magnavox T-Set GPS navigator

Prime Transit System
-Magnavox MX1107RS dual channel satellite receiver
-Magnavox MX610D dual-axis sonar doppler speed log
-Robertson gyro-compass

Secondary Transit System
-Magnavox MX1142 single channel satellite receiver
-Raytheon DSN450 dual-axis sonal doppler speed log
-Robertson gyro-compass

Radio Navigation
-Decca HIFIX-6

Data Acquisition System

-data acquisition system built around Hewlett-Packard 2113 E-Series minicomputer, with tape drives, disc drives, 12" and 36" plotters, line printers, and interactive terminals

GEOLOGICAL

-deep-sea geological winch containing 10000 m of 18 mm wire
-gravity corer - maximum barrel length 10 m
-chain-bag and pipe dredges
-piston corer - maximum barrel length 10 m

APPENDIX E : Seismic source/receiver configuration and recording parameters

First cruise (NEA3) - Cruise 73 High resolution seismic using watergun.

Use Teledyne 178 cable (Great Barrier Reef streamer), and S.S.I S.15 and possibly S.80 pneumatic waterguns.

Streamer configuration:

```
                B1          B2                 B3          B4
        _______1___________1_________________1___________1_______
        TL:S:S:DT:A1:A2:A3:DT:Ad:A4:A5:A6:A7:DT:Ad:A8:A9:DT:S:TR:TB:
```

That is: 24 channels - 12 12.5m groups and 12 25m groups in 9 active sections (A1); total active length of 450m

4 depth transducers (DT)
4 birds (B1)
3 stretch sections (S)
2 adapters to convert 16 12.5m groups to 8 25m groups (Ad)

Gun depth: S.15 - 4.5m; S.80 - 6m
Cable depth: Approx. 7m

We will shoot the watergun at 12.5m intervals to give 18 fold coverage with 12.5m CDP's by combining first 12 channels of 12.5m groups into 6 channels of 25m groups. Another possibility is that we use a 24 channel 12.5m group streamer of 300m active length and shoot the small S.15 watergun at 6.25m to give 24 fold coverage with 6.25m CDP's. 6.25m shot distance requires a shot interval of about 2.4 secs. at 5 knots and could obviously only be used in very shallow water - zero delay with a record length of about 1.5 secs.

Both waterguns will be supplied with air from one compressor (W2 200scfm) as follows:

S.15 - shot interval 6.25m (2.43 sec at 5 knots) 24scfm
- shot interval 12.5m (4.86 sec at 5 knots) 12scfm
S.80 - shot interval 12.5m (4.86 sec at 5 knots) 95scfm

Recording parameters:	Sample rate -	1 msec
	Record length -	2 sec (check max.)
	Recording delay -	Variable, 100 msec units
	Amplifiers - gain	512 or 1024 dB
	- filters	low-cut 12 Hz
		high-cut 250 Hz
	Tape recording format -	BMR SEG-Y, 1600 BPI tape

Second cruise (NEA4) - Cruise 74 Main streamer with two airgun array - 52.4 litres total volume

Use the main Teledyne streamer with 96 channels of 25m groups in 24 100m active sections giving a total active streamer length of 2400m. The energy source will be two 26.2 litre Texas Instruments airgun arrays,one streamed from each side of the ship. Each array contains 10 2.62 litre (160 cubic inch) guns with two extra spare guns in each array. This will be the first use of the twin airgun arrays on a research cruise. They will be tested,along with the streamer during sea trials in August 1987.

We will shoot at a 50m shot interval (19.4 sec at 5 knots) to give 24 fold coverage with 12.5m CDP's.

Recording parameters:	Sample rate -	2 msec
	Record length -	10 sec ? (check max.)
	Recording delay -	variable, 500 msec units
	Amplifiers - gain	512, 1024 dB
	- filters	low-cut ?6 Hz
		high-cut 128 Hz
	Tape recording format -	BMR SEG-Y, 1600 BPI tape

N.B. Maximum water depth in which seismic data will be collected will be about 3000m or 4 sec TWT i.e. max. delay will be about 3.5 - 4sec.

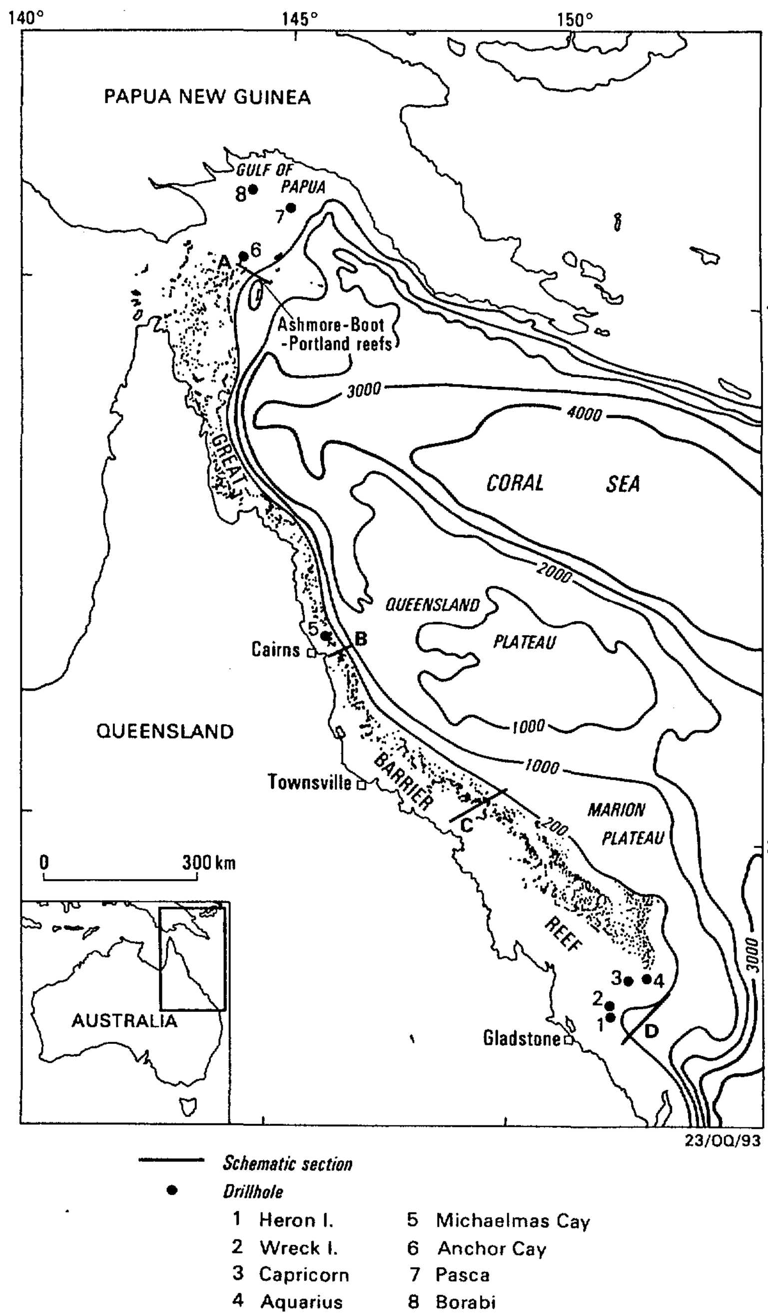

Figure 1. Locality map of northeast Australian region showing the locations of drillholes on the continental shelf (after Davies & others, in press).

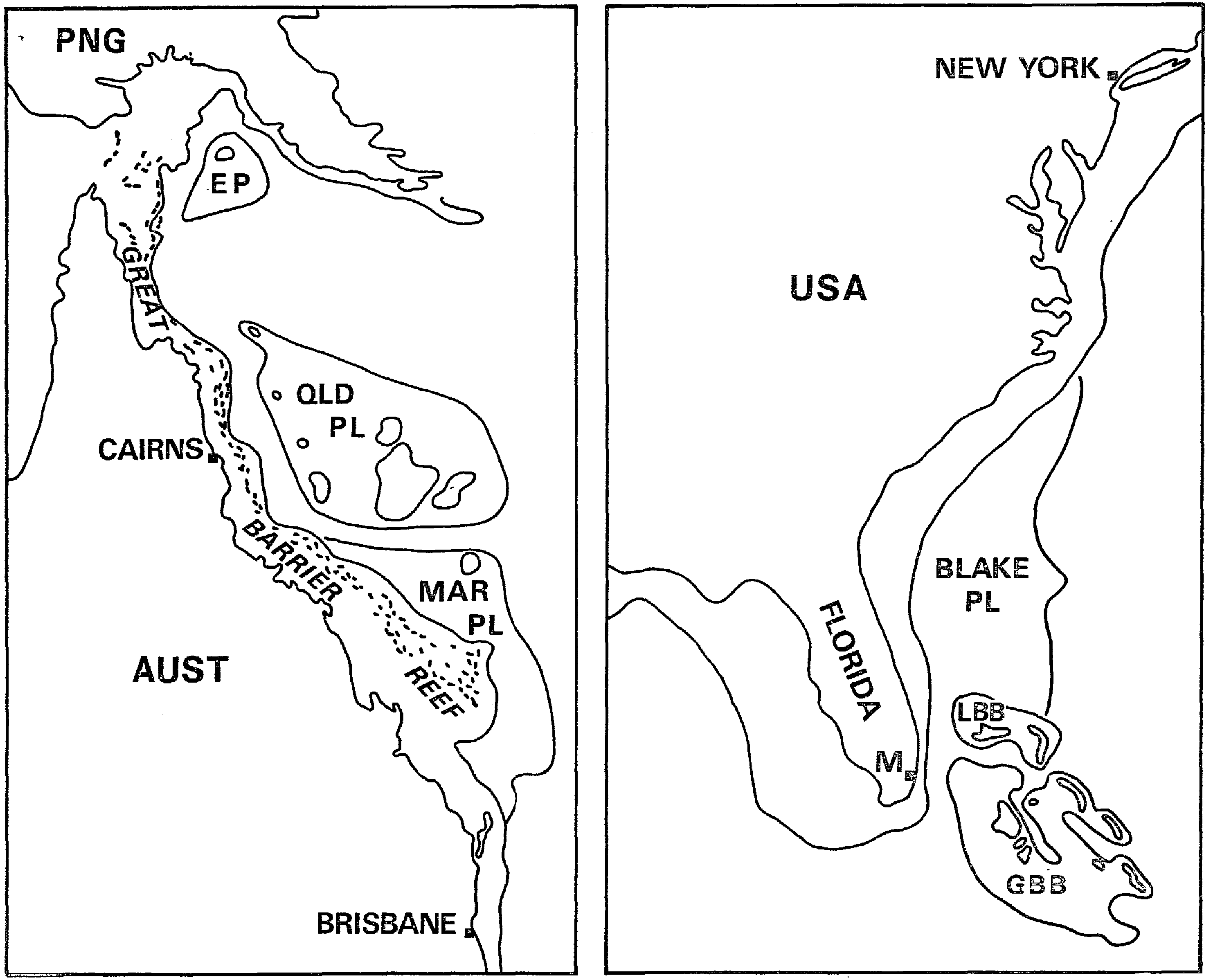

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Figure 2. Size comparison of the carbonate platforms of northeast Australia and the eastern United States of America (after Davies & others, in prep).

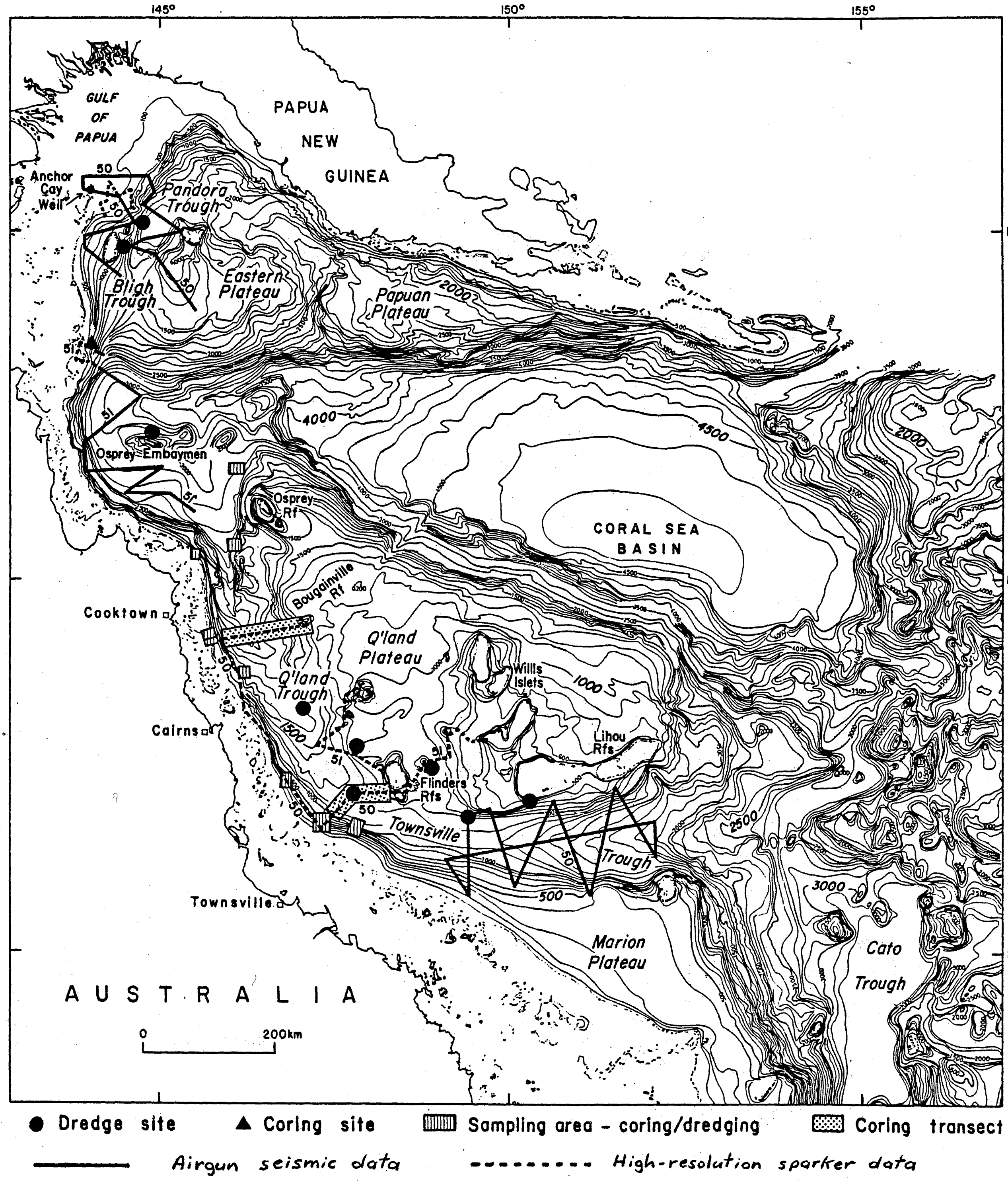


Figure 3. Map of major physiographic features off northeast Australia showing the type and disribution of the data collected during the 1985 Rig Seismic cruises (after Davies, Symonds & others, 1987).

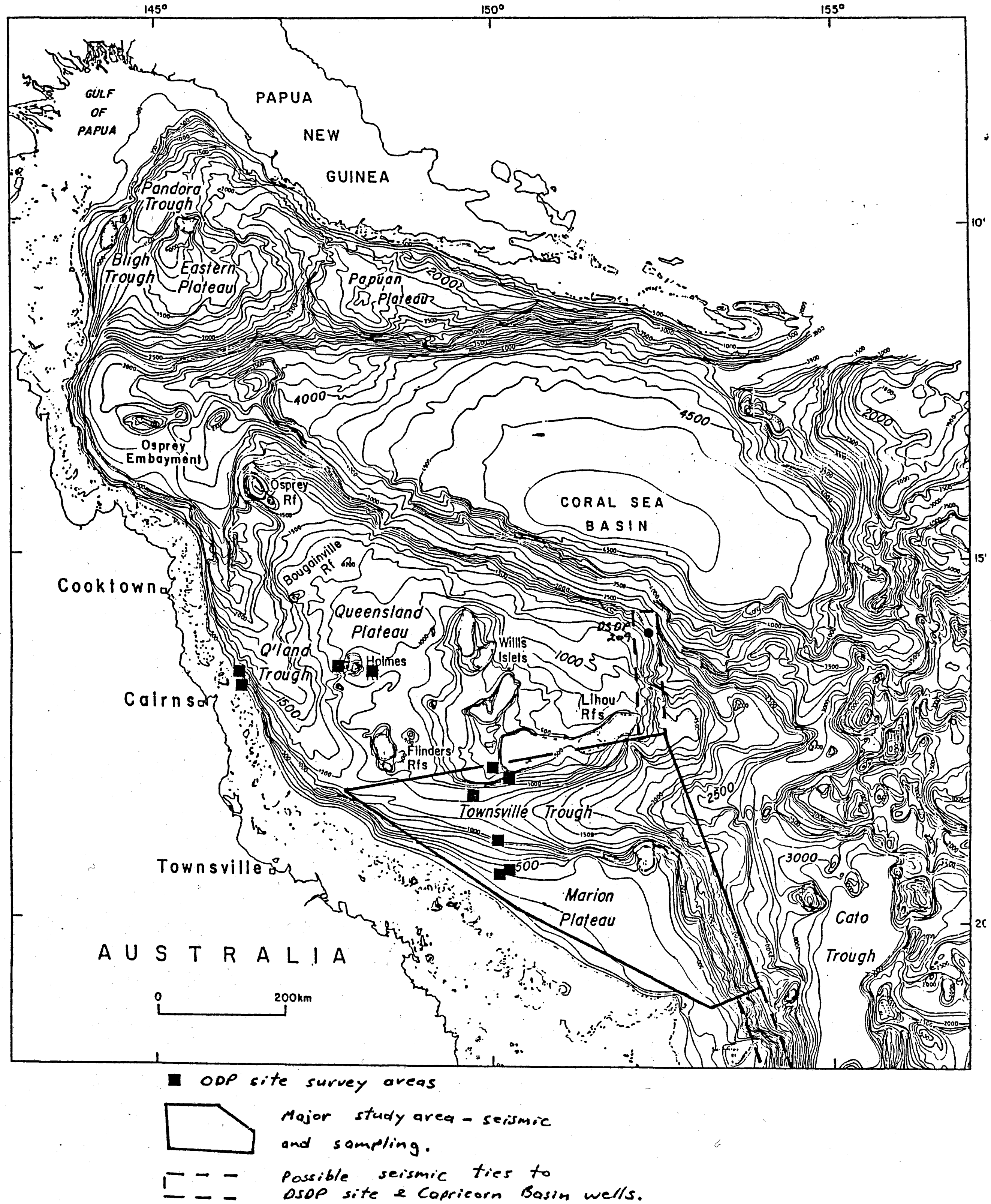


Figure 4. Proposed 1987 Rig Seismic study area showing the locations of the ODP site survey areas.

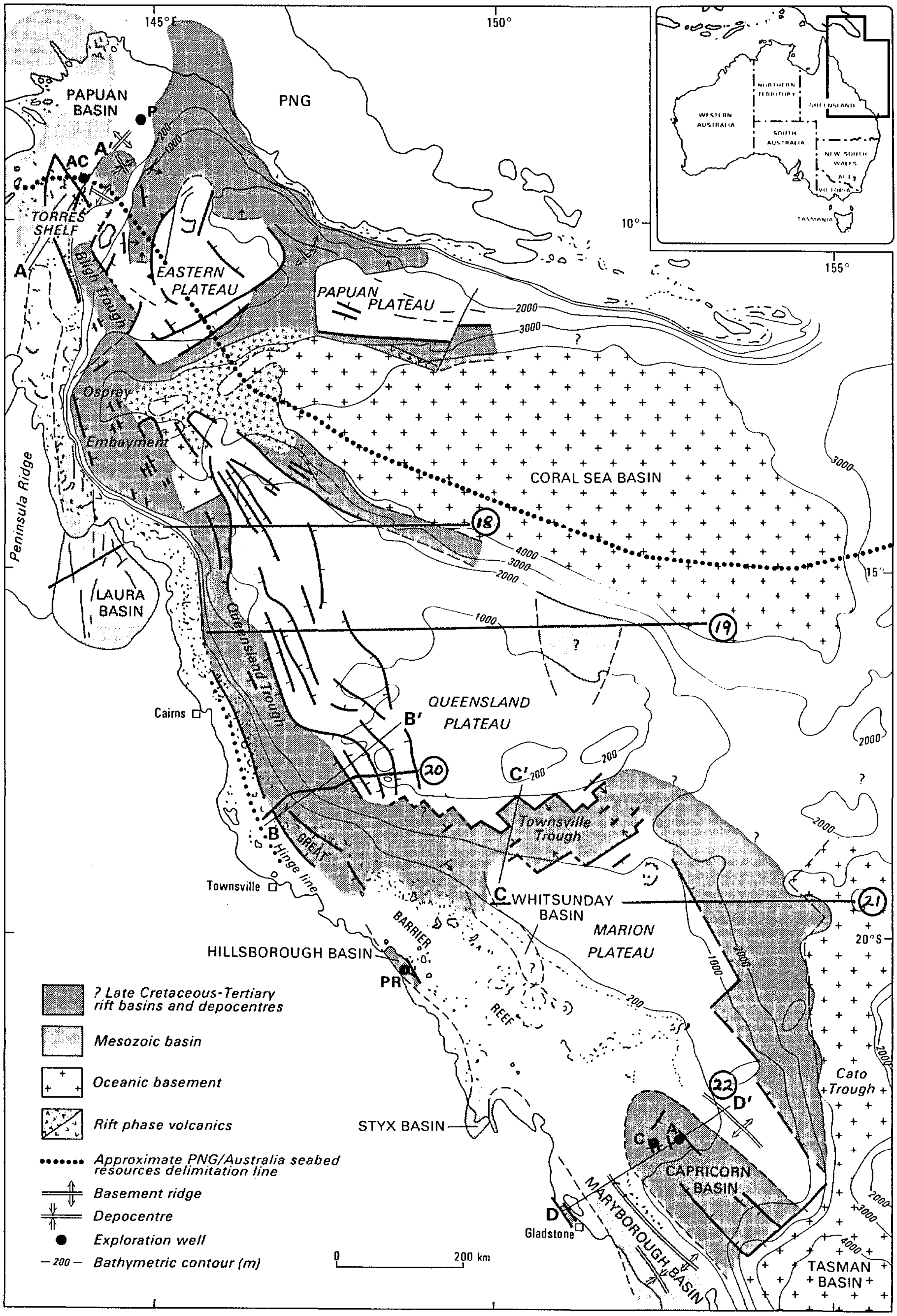


Figure 5. Major stuctural elements off northeast Australia. Shows the locations of the schematic profiles in Figures 7 and 8 (after Symonds, 1988, in press).

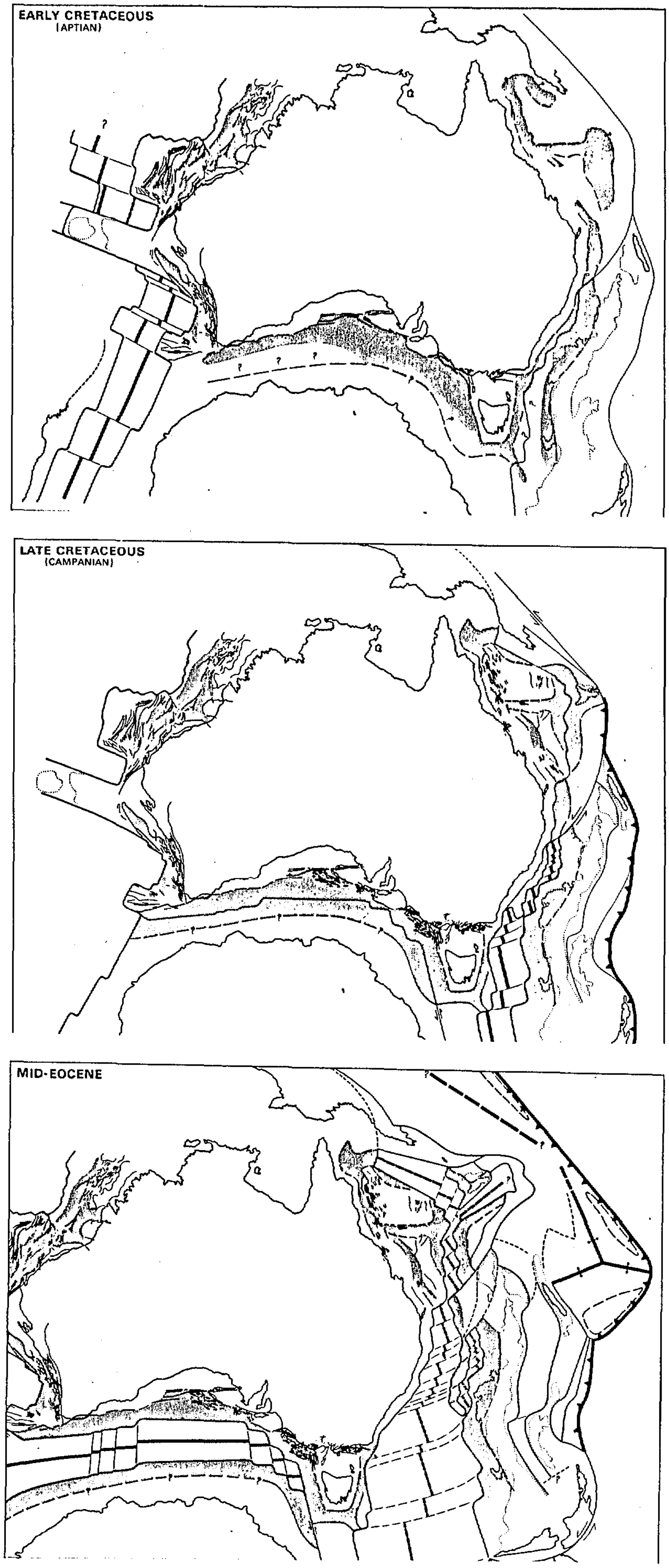


Figure 6. Plate reconstuctions of the Australian region from Early Cretaceous to mid-Eocene time illustrating the tectonic development of northeast Australian (after Falvey & Mutter, 1981).

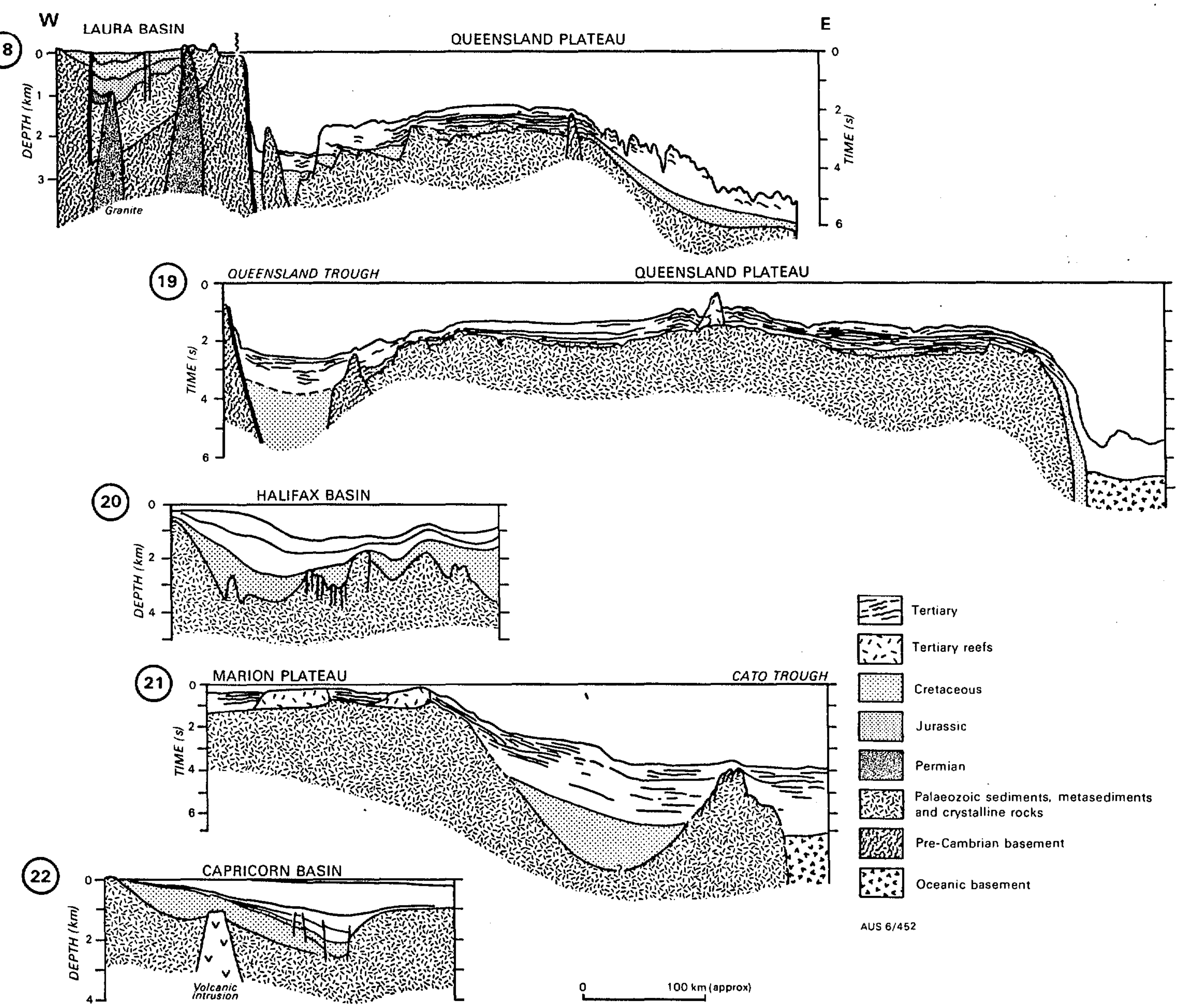


Figure 7. Schematic profiles across the northeast Australian margin (after Falvey & Mutter, 1981). Locations of the profiles are shown in Figure 5.

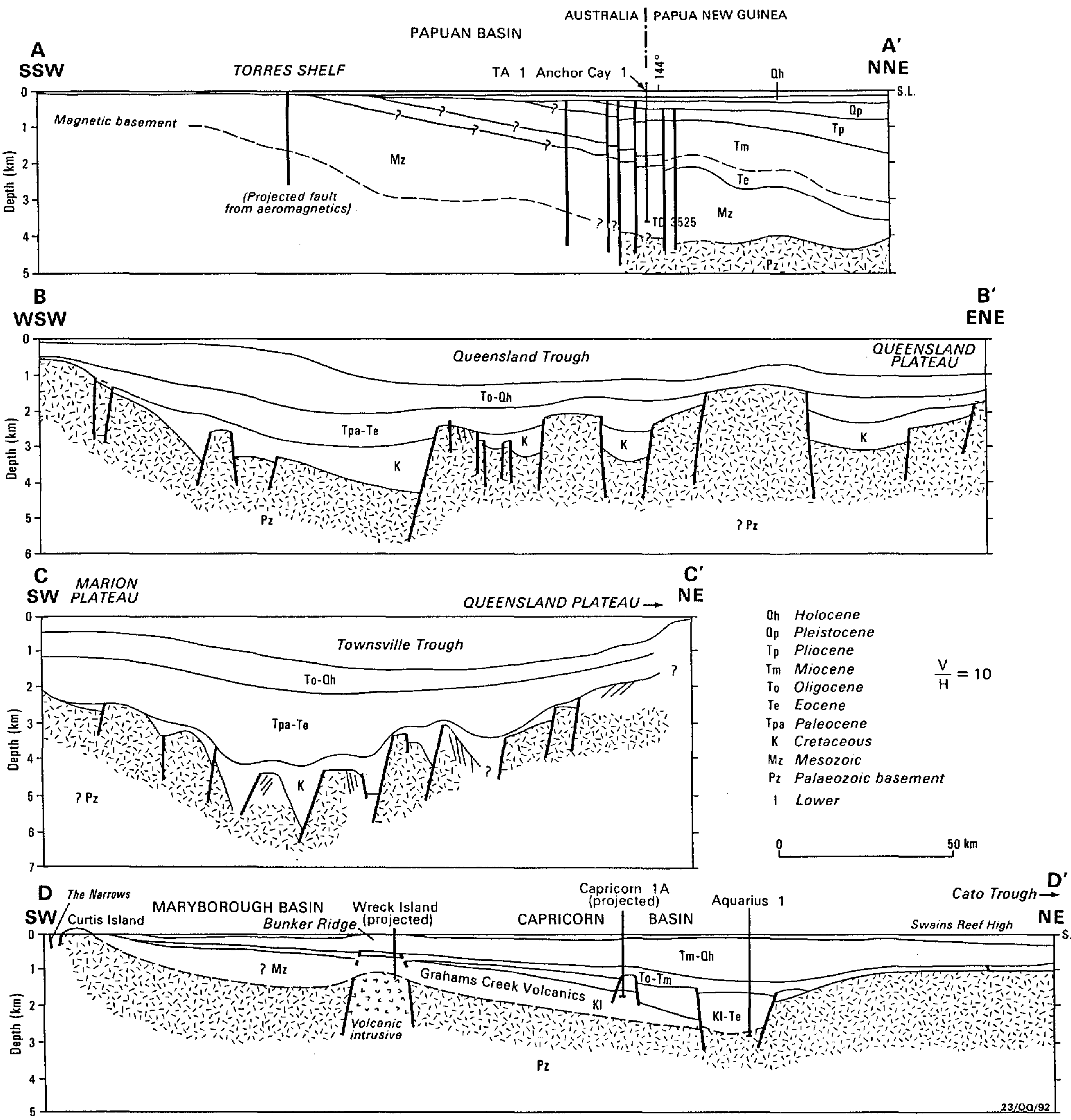


Figure 8. Schematic profiles across the northeast Australian margin (after Symonds, 1988, in press). Locations of the profiles are shown in Figure 5.

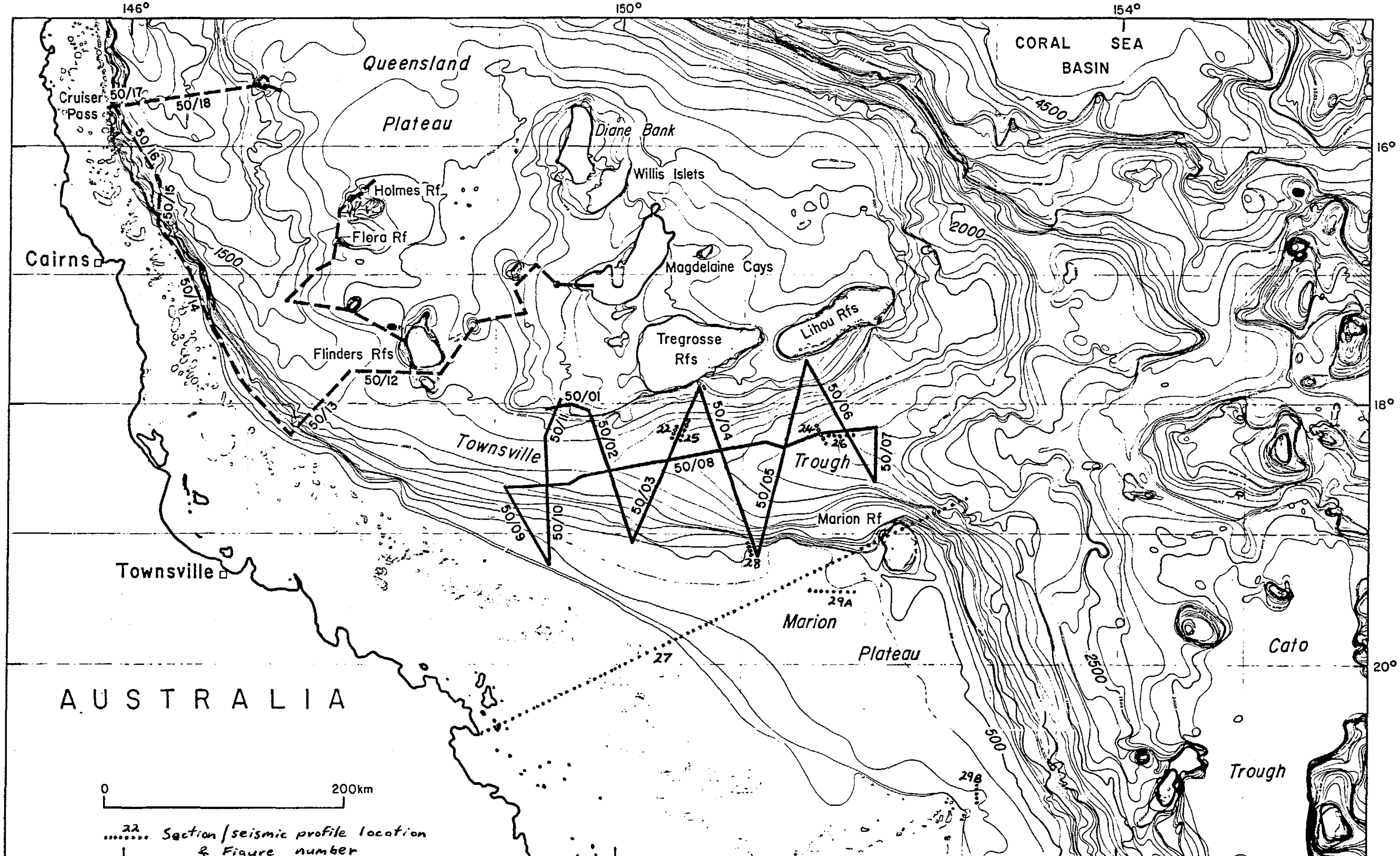


Figure 9. Detailed bathymetry of the Townsville-Trough/Marion Plateau area showing the location of 1985 Rig Seismic seismic data (after Davies, Symonds & others, 1987).

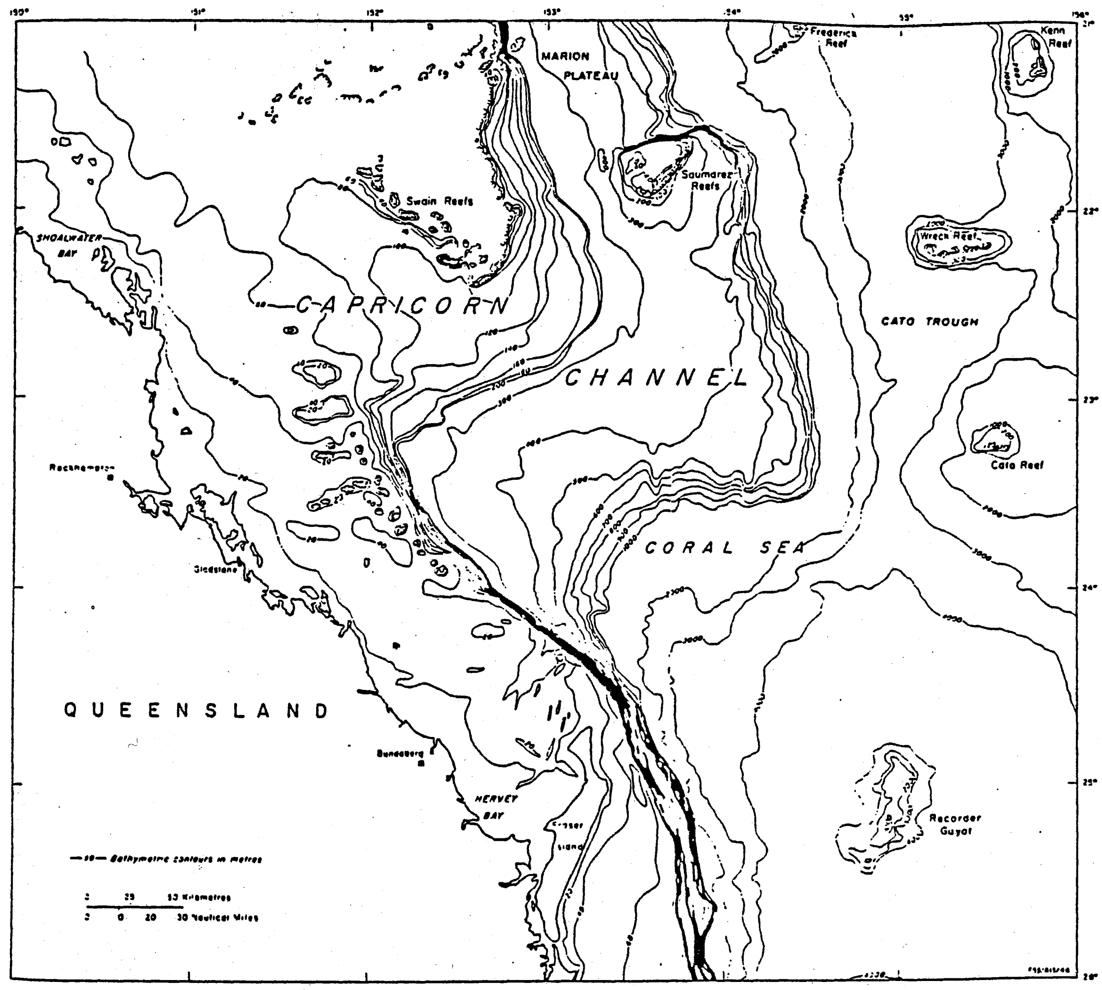


Figure 10. Detailed bathymetry of the southern Marion Plateau/Capricorn Channel area (after Marshall, 1977).

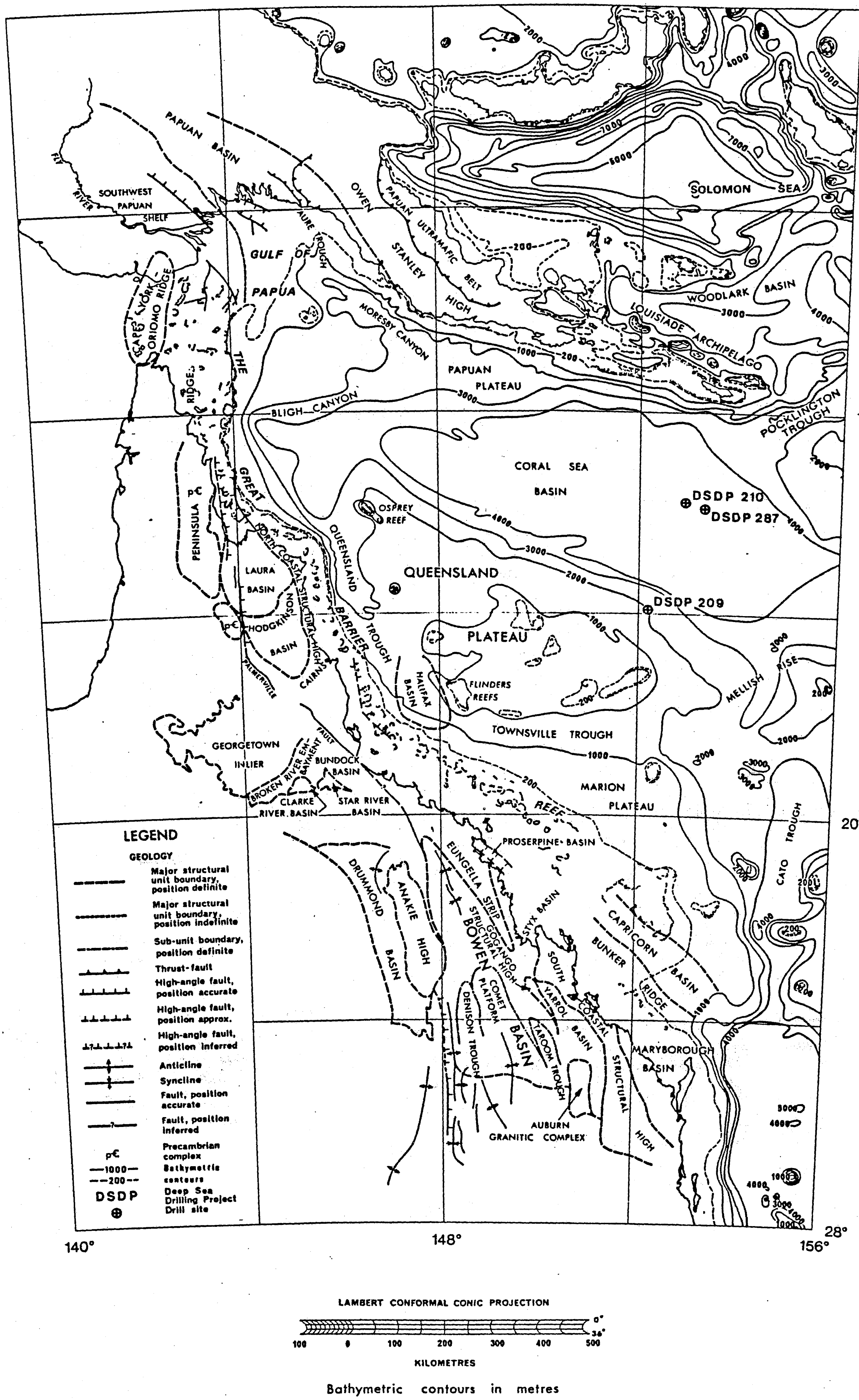
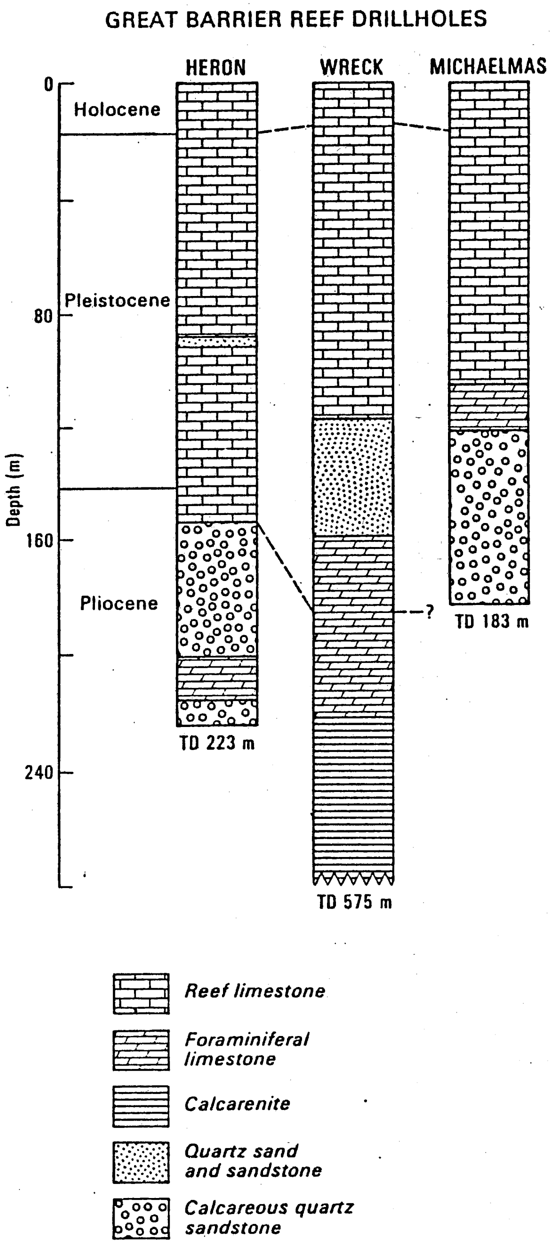
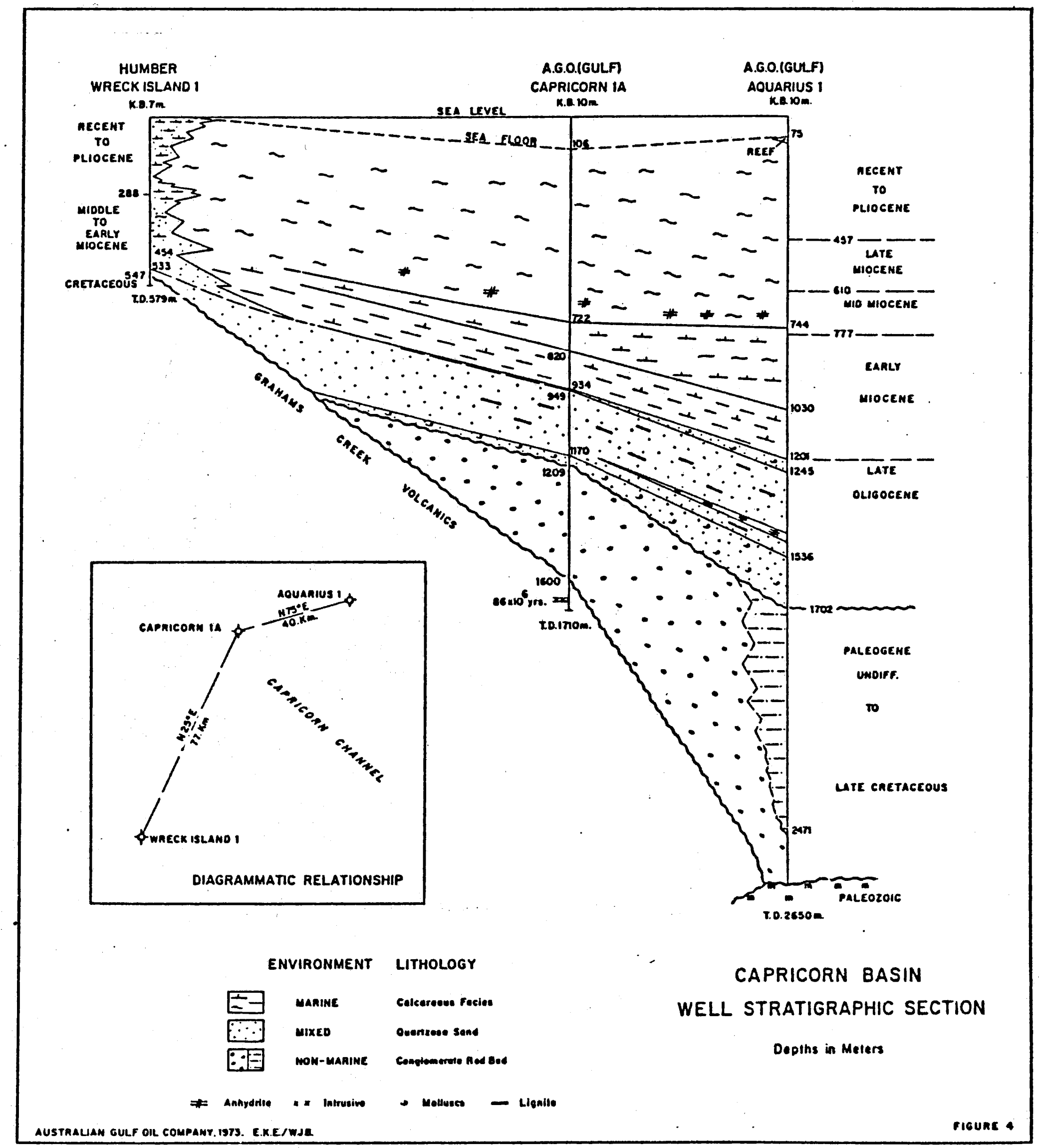


Figure 11. Regional setting, and location of the major sedimentary basins and onshore geological provinces (after Mutter, 1977).

Figure 12. Stratigraphy and correlation of drillholes in the 1987 study area (after Davies & others, in press; Ericson, 1976).





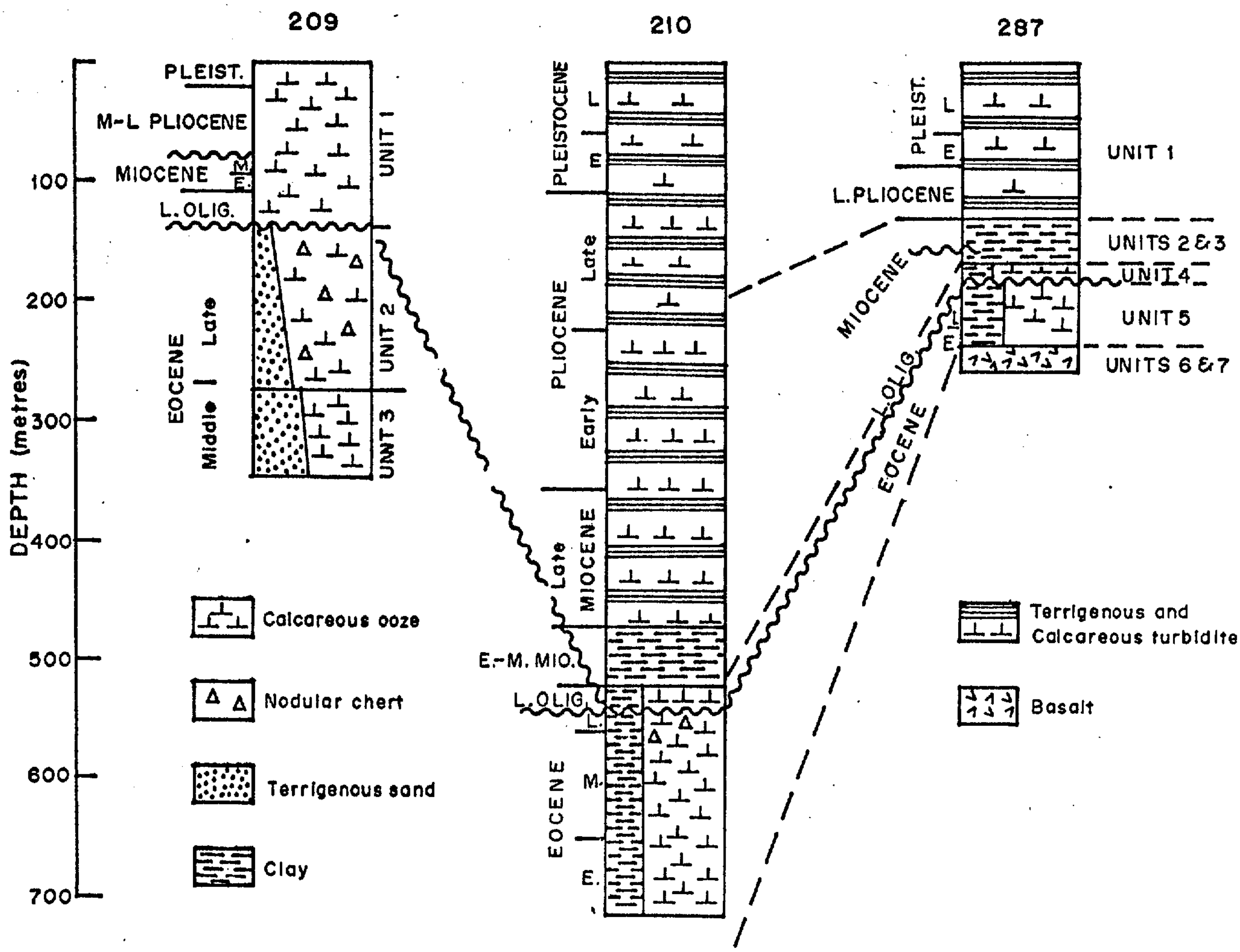


Figure 13. Stratigraphy of the DSDP sites in the western Coral Sea (after Taylor, 1977).

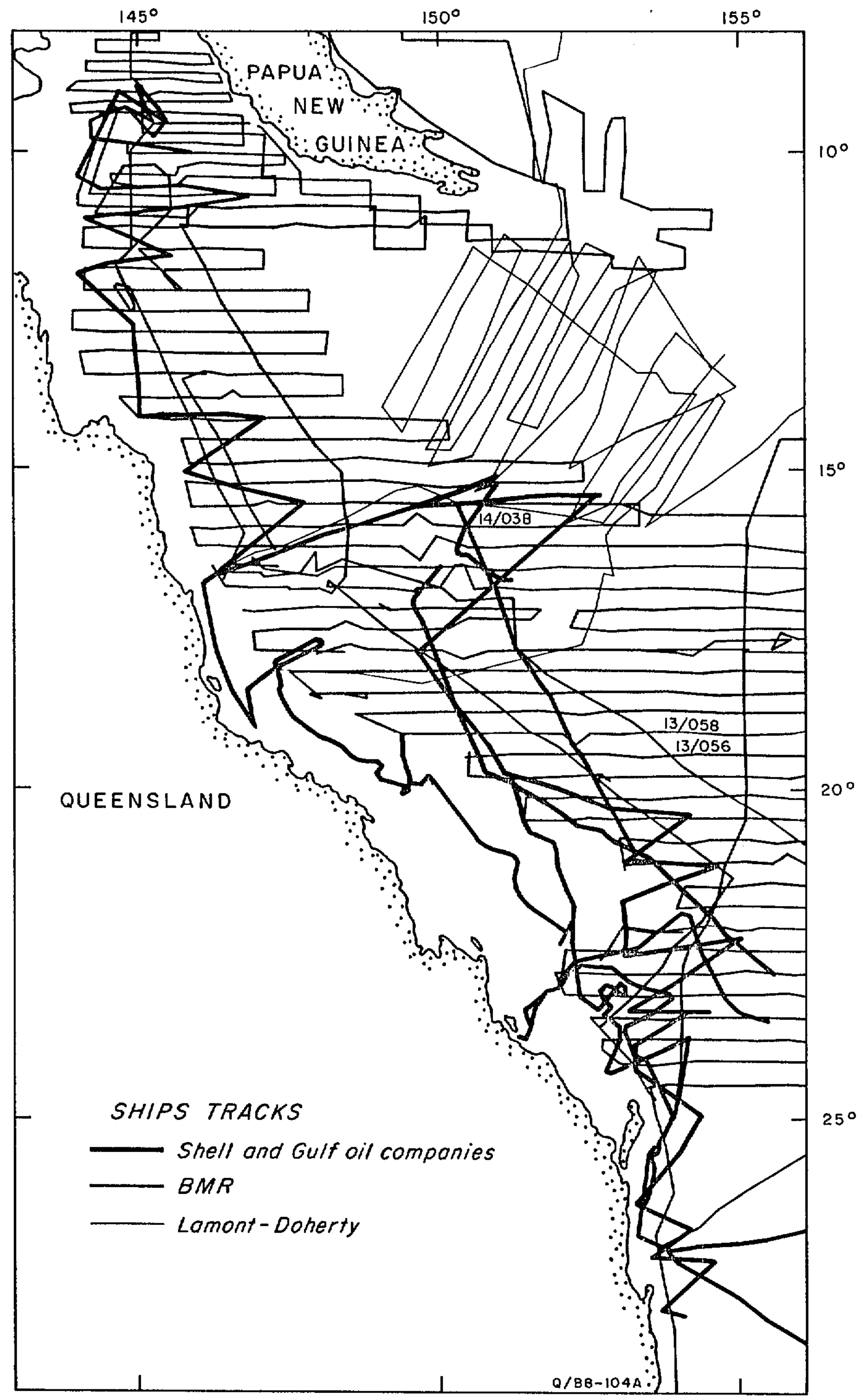


Figure 14. Distribution of 1970 - 1978 seismic data in the western Coral Sea by BMR, Shell, Gulf and Lamont-Doherty (after Mutter & Karner, 1980).

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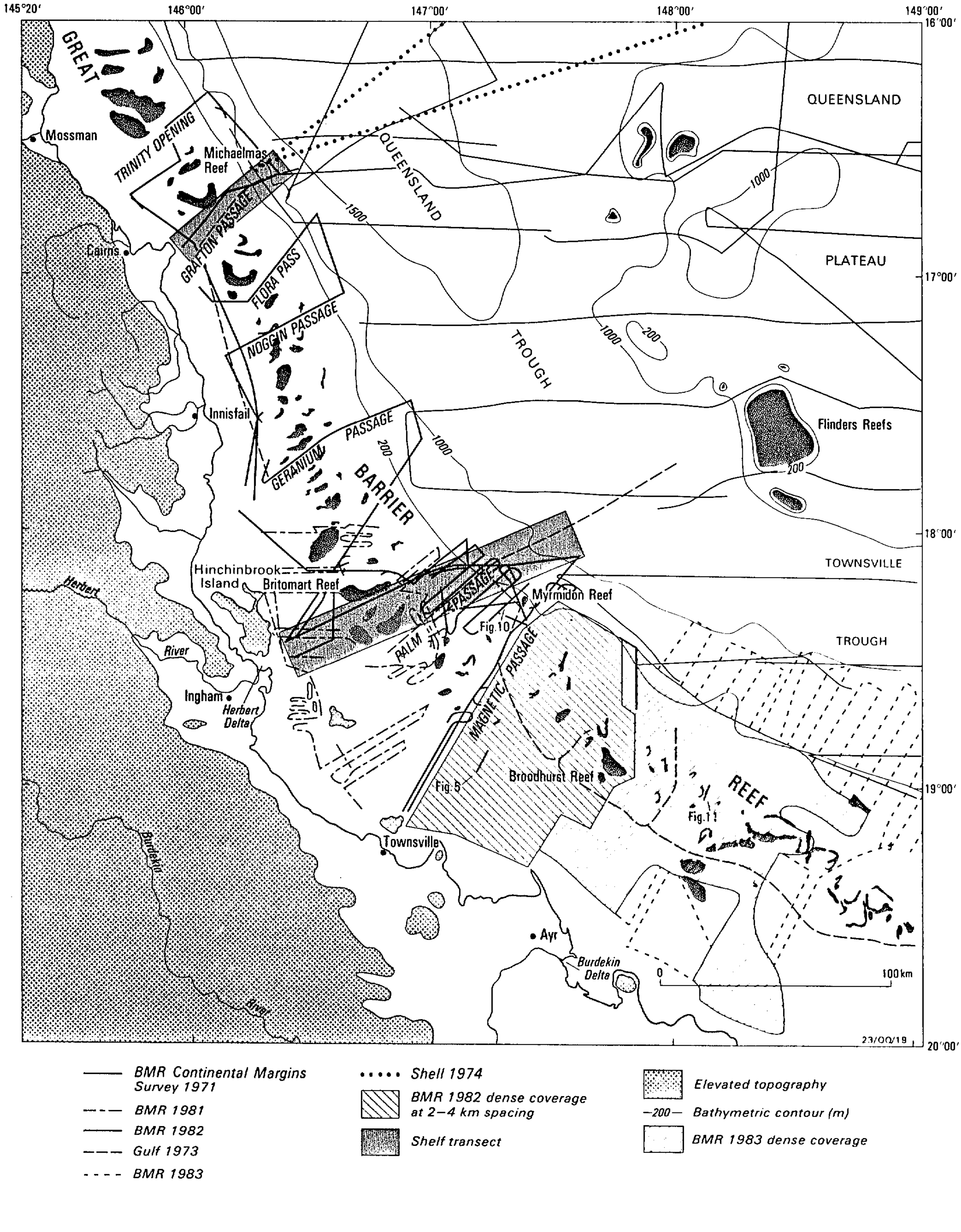


Figure 15. Distribution of post-1970 seismic data in the central Great Barrier Reef region by BMR, Shell and Gulf (modified from Symonds & others, 1983).

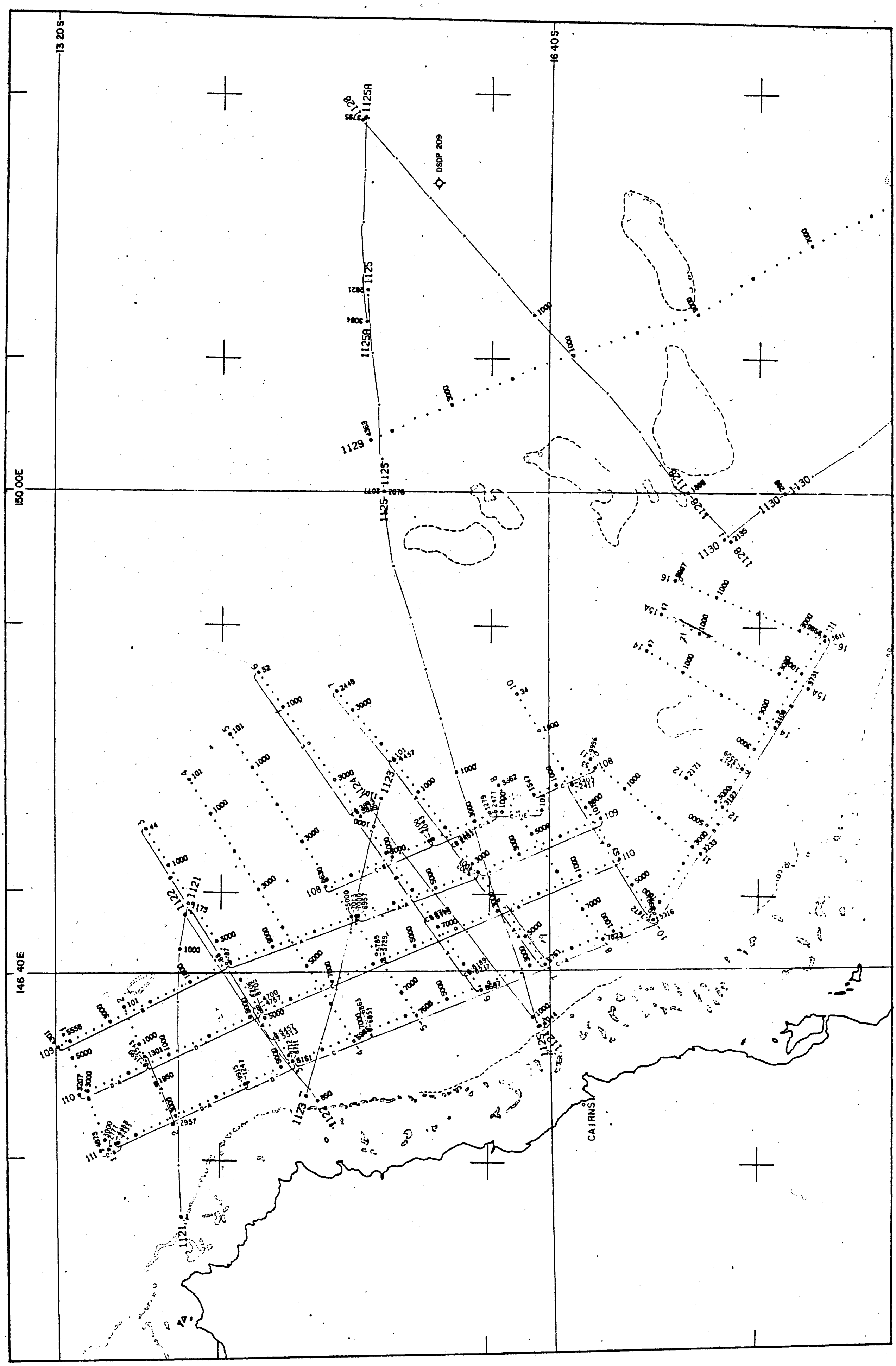


PLATE 2

Figure 16. Location of Geophysical Service International (GSI) group shoot seismic lines over the Queensland Trough and Plateau.

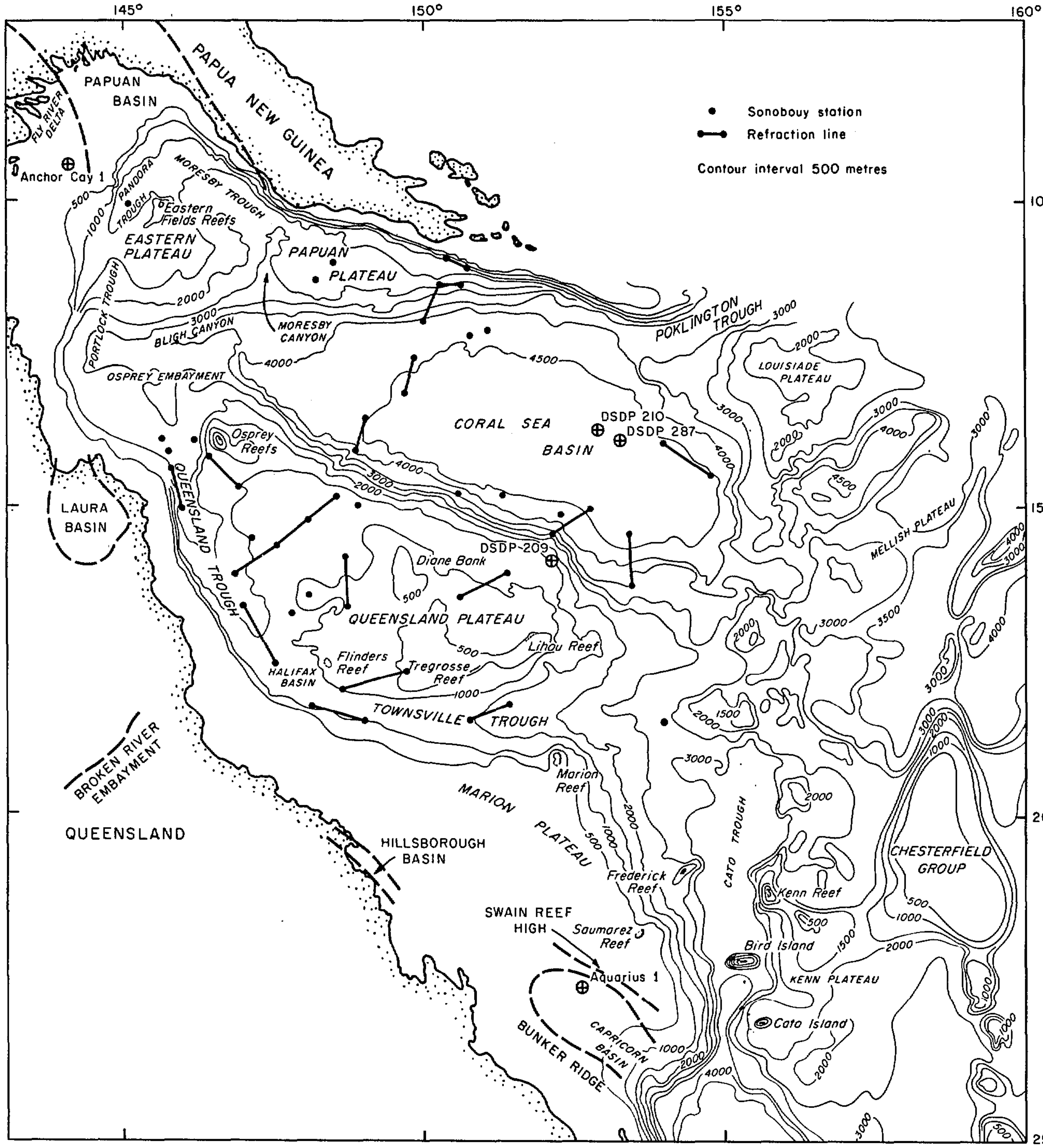


Figure 17. Location of crustal seismic refraction profiles in the western Coral Sea. Also shows the locations of DSDP and some exploration company drilling sites in the region.

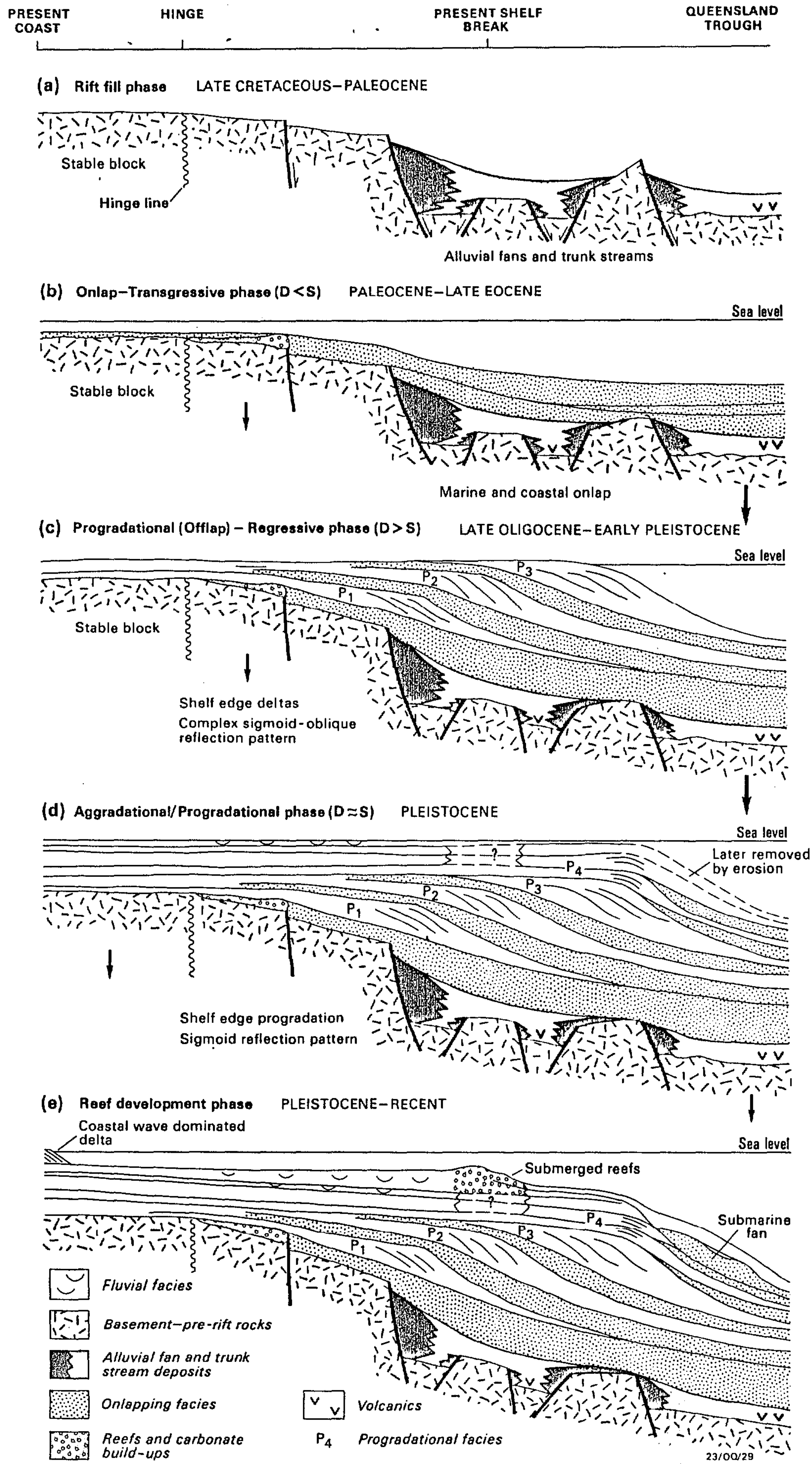


Figure 18. Conceptual evolutionary scheme for the development of the continental shelf in the central Great Barrier Reef province (after Symonds & others, 1983).

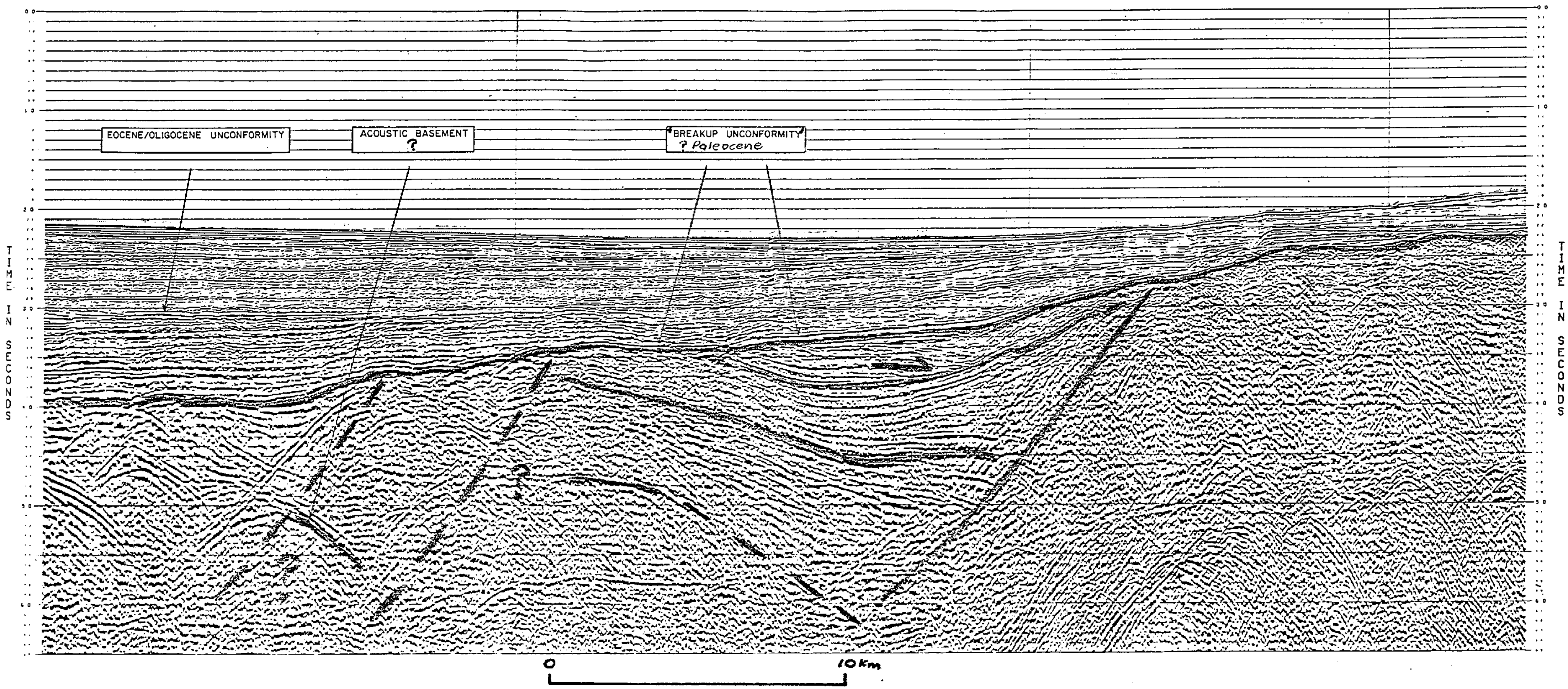


Figure 19. A portion of a Geophysical Service International (GSI) group shoot seismic line across the eastern Queensland Trough showing tilt blocks and thick sediment beneath the trough. Location shown in Figure 34).

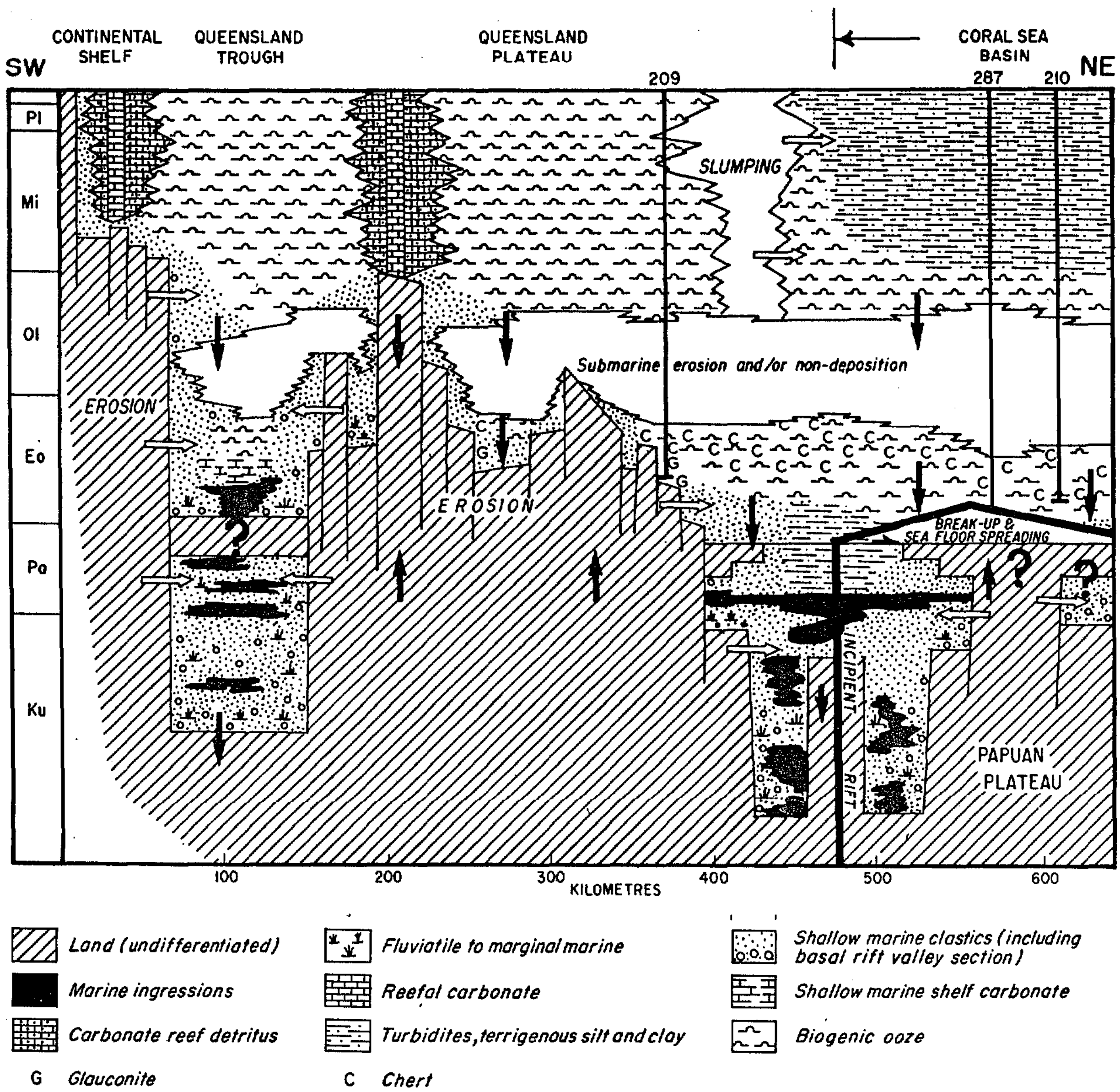


Figure 20. Generalised time-stratigraphic cross-section from the Queensland shelf to the Coral Sea Basin (after Taylor & Falvey, 1977).

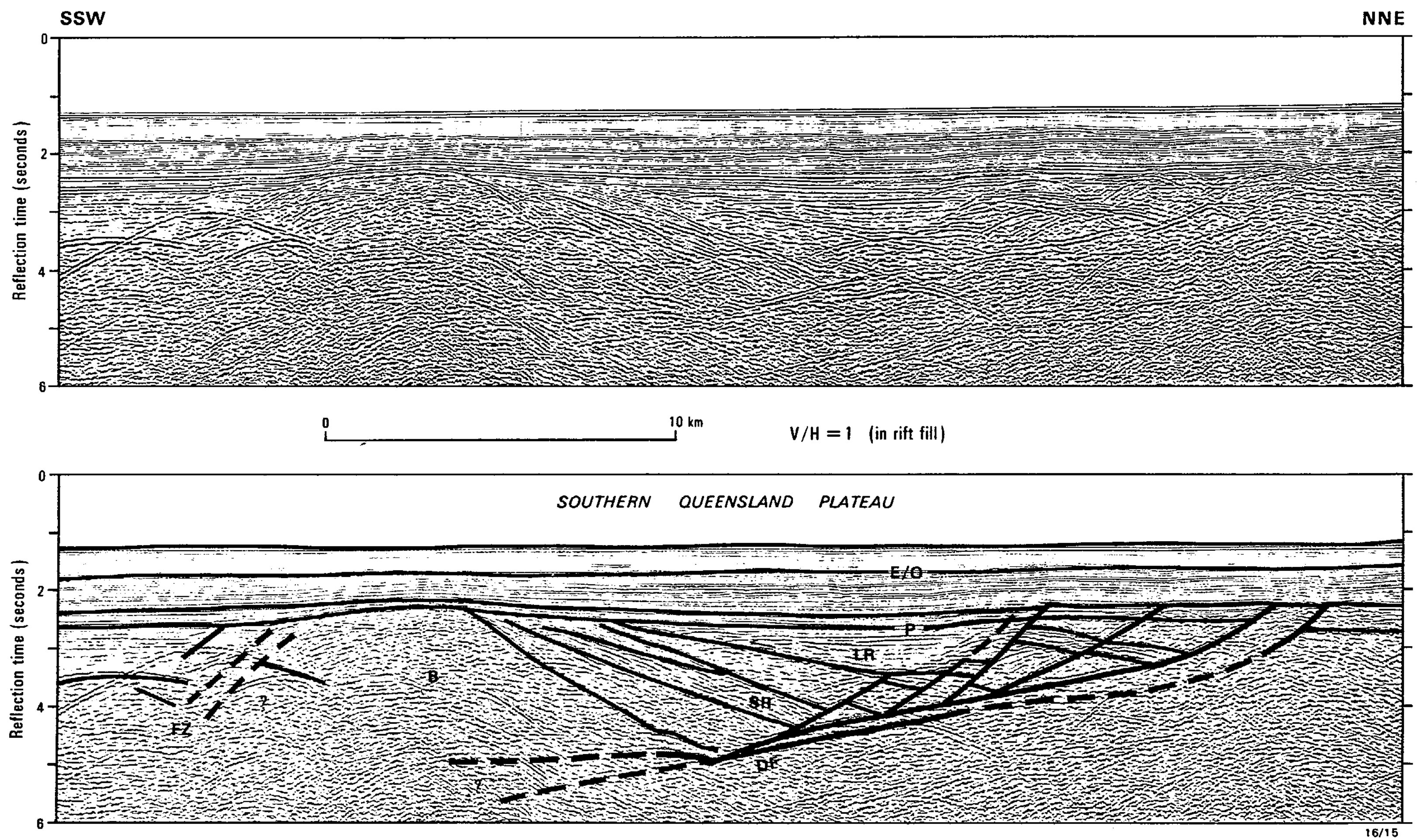


Figure 21. A portion of a GSI group shoot seismic line from the southern Queensland Plateau near the confluence of the Queensland and Townsville Troughs (location shown in Figure 34). The section shows shallow dipping reflectors which can be interpreted as a detachment or low-angle normal fault (DF), and these continue beneath a large basement tilt block (B). The block corner and associated syn-rift sediments (SR) have been planated, and late rift-phase sediments (LR) are ponded in the half graben and overlain by the Paleocene top-rift (break-up) unconformity (P). E/O is the late Eocene - early Oligocene regional unconformity (after Lister & others, 1987, in press).

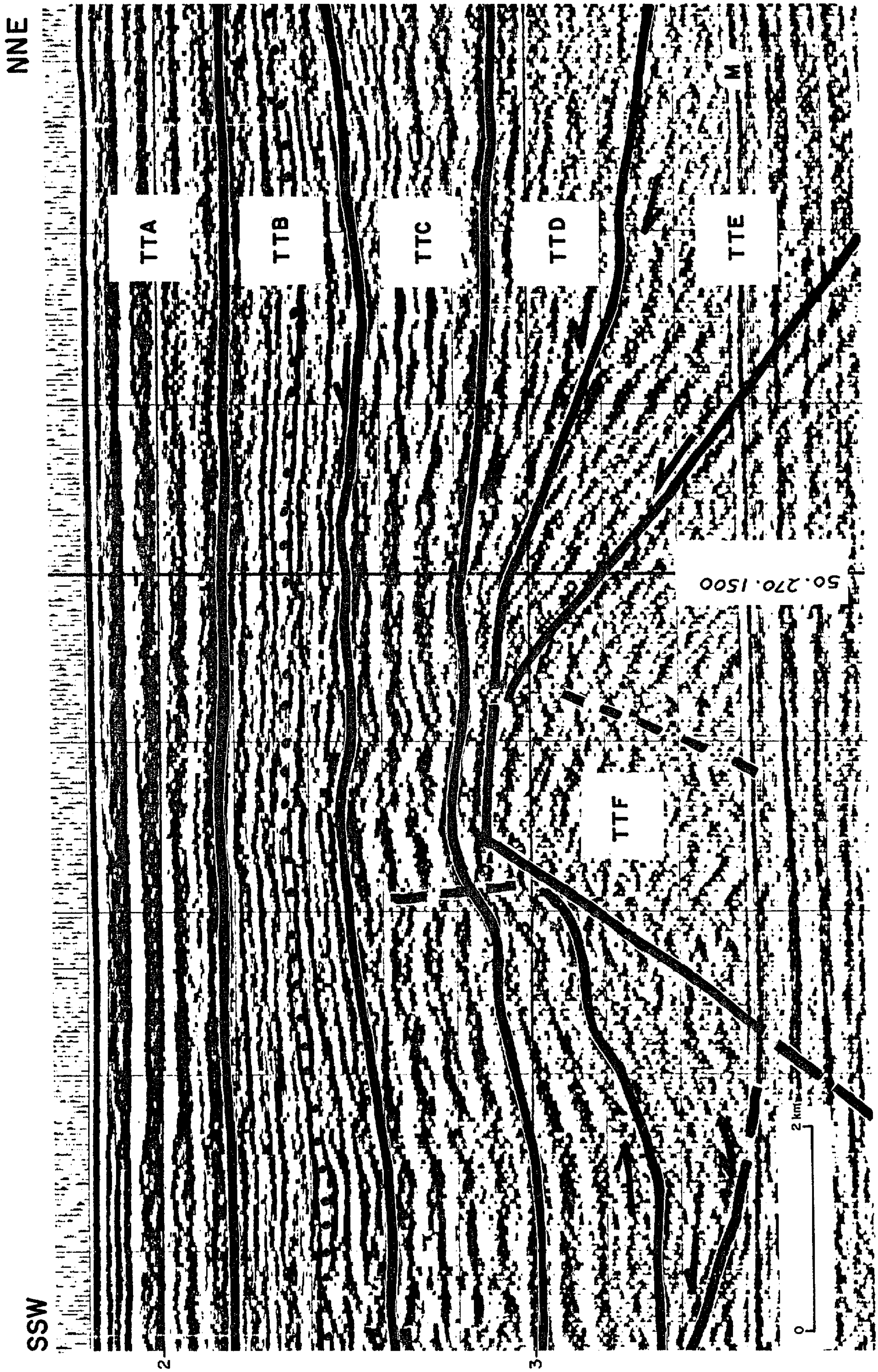


Figure 22. A portion of a 1985 BMR shipboard monitor seismic section from the Townsville Trough illustrating the character of the seismic sequences beneath it (after Davies, Symonds & others, 1987). Location shown in Figure 9.

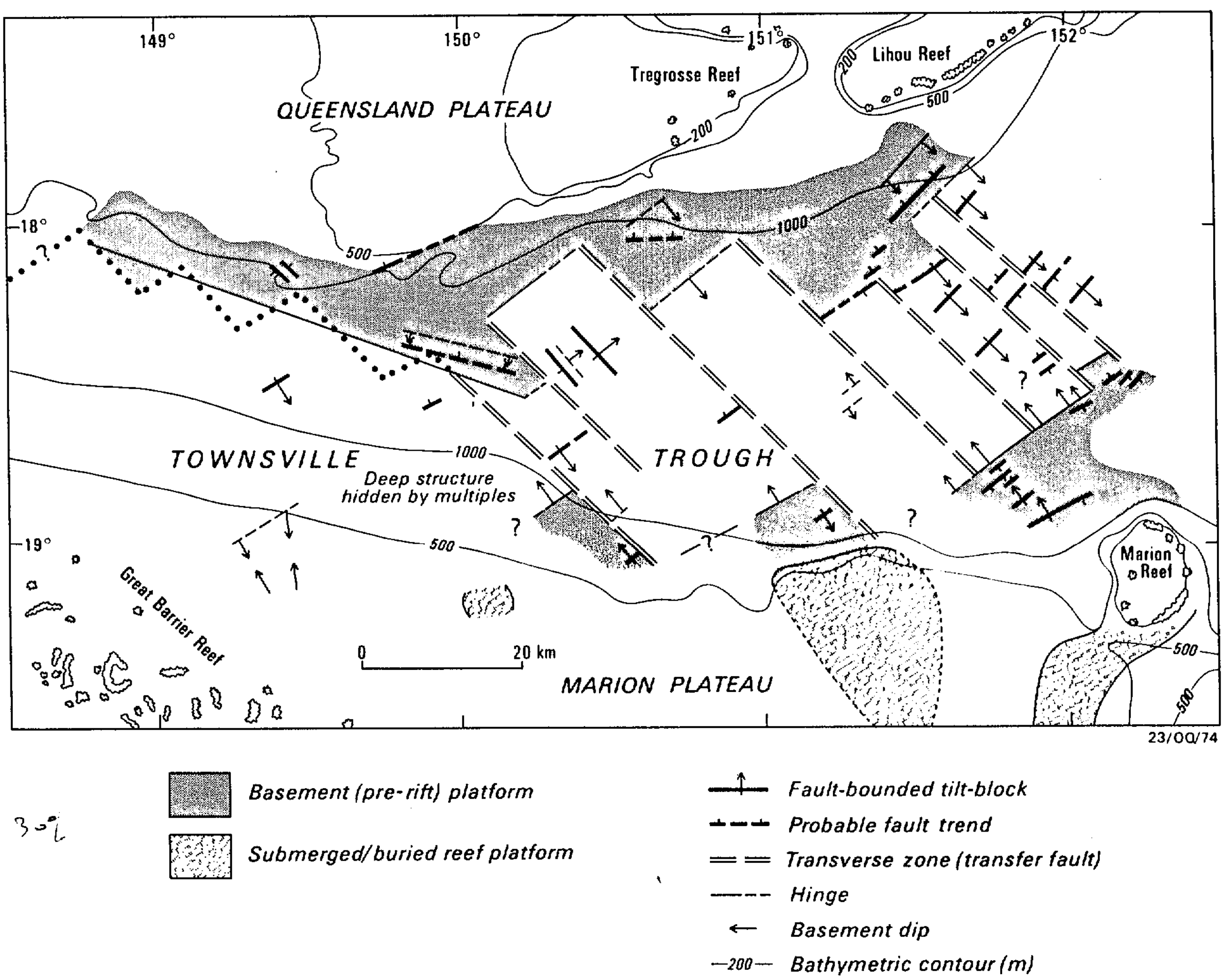


Figure 23. Preliminary schematic map of the basin-forming structures beneath the Townsville Trough (after Davies, Symonds & others, 1987).

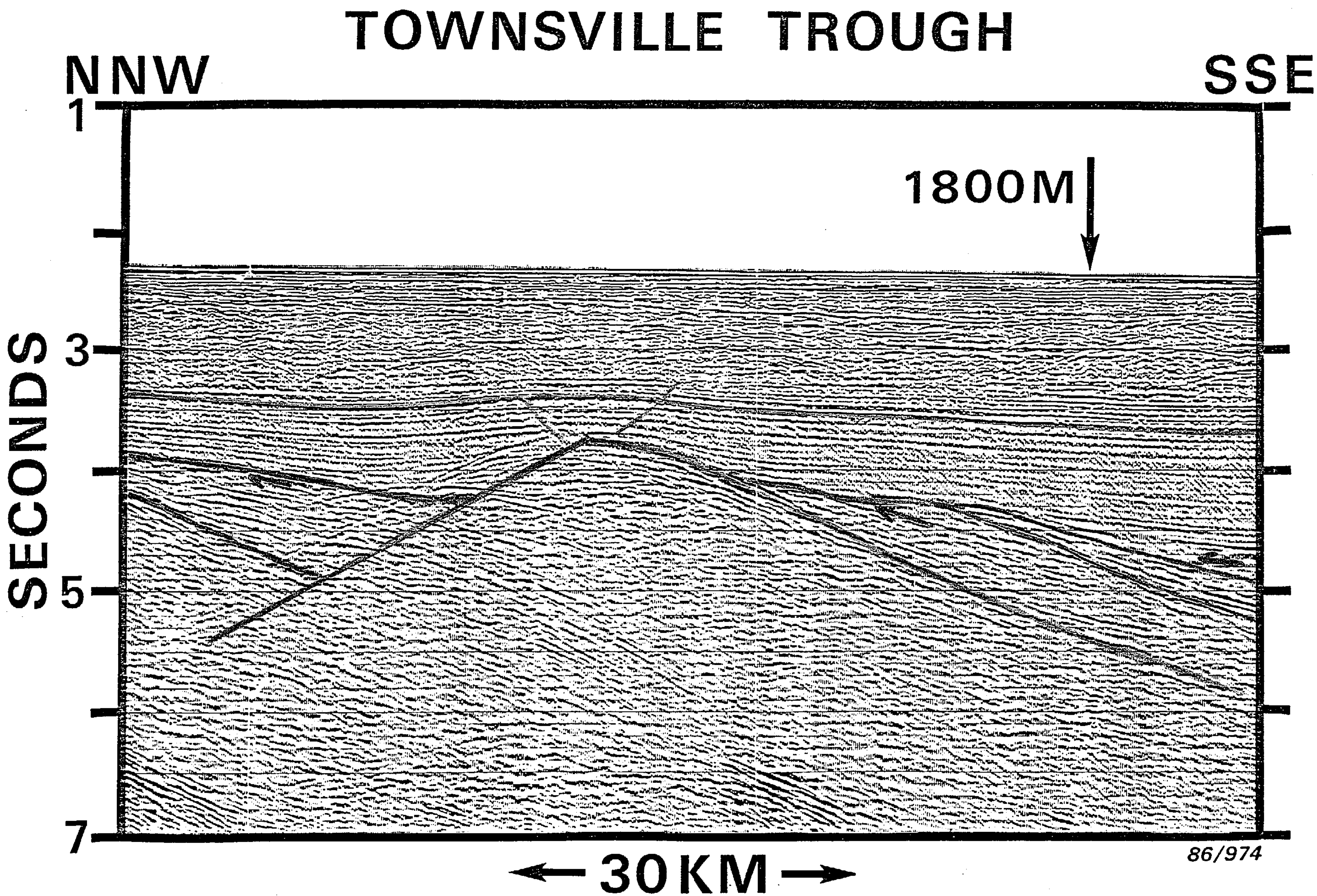


Figure 24. A portion of a stacked Shell seismic line across the eastern Townsville Trough showing the top of a south -dipping tilt block lying beneath the northern margin of the trough. Location shown in Figure 9.

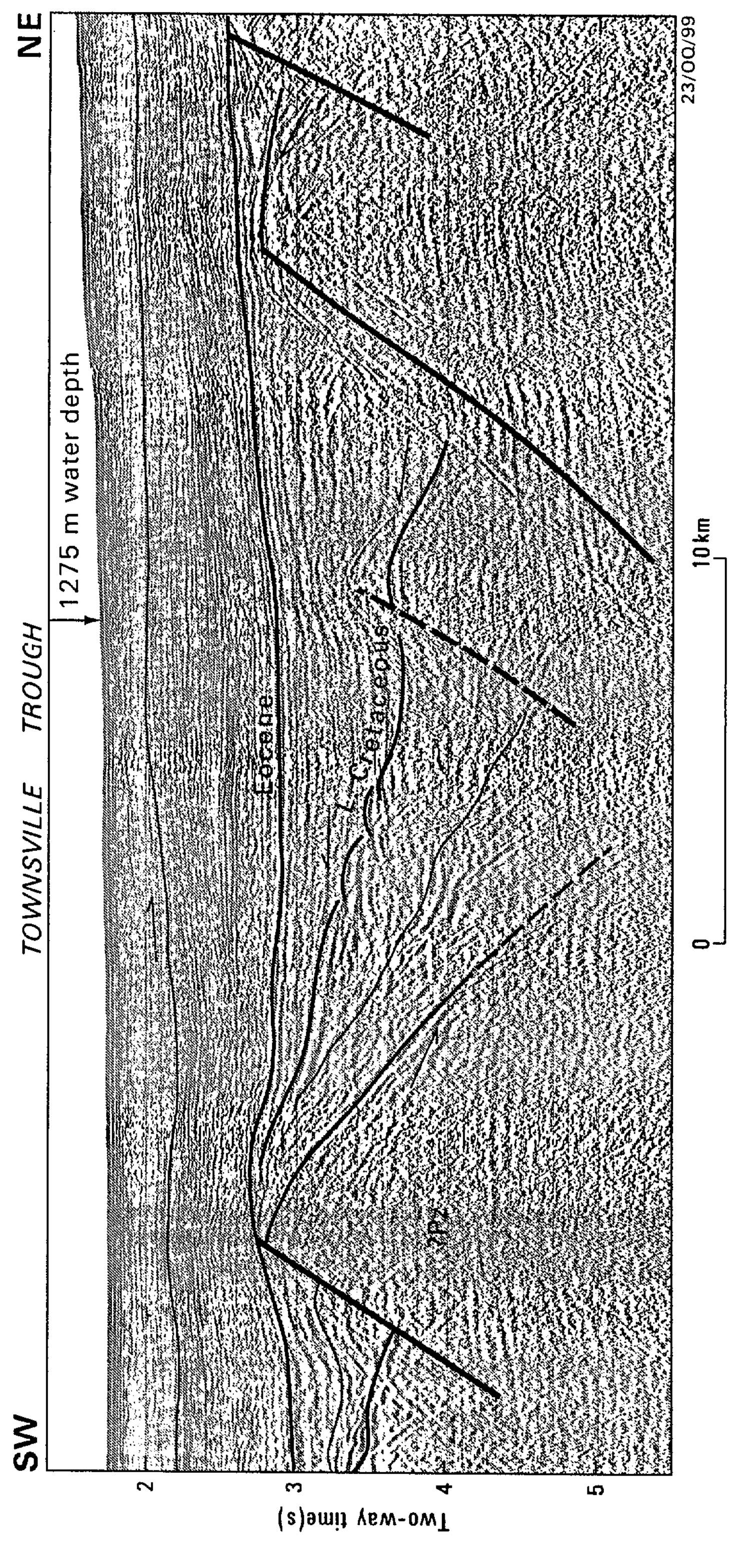


Figure 25. A portion of a stacked 1985 BMR seismic line across the wesrern Townsville Trough showing a tilt block bounded by a south-dipping normal fault adjacent to the faulted northern margin of the trough. Faulted syn-rift sediments have infilled the half graben to the north of the block, and are overlain by onlapping ?late-rift and post-rift sediments which exhibit flexural and compaction drape over the block corner. Location shown in Figure 9.

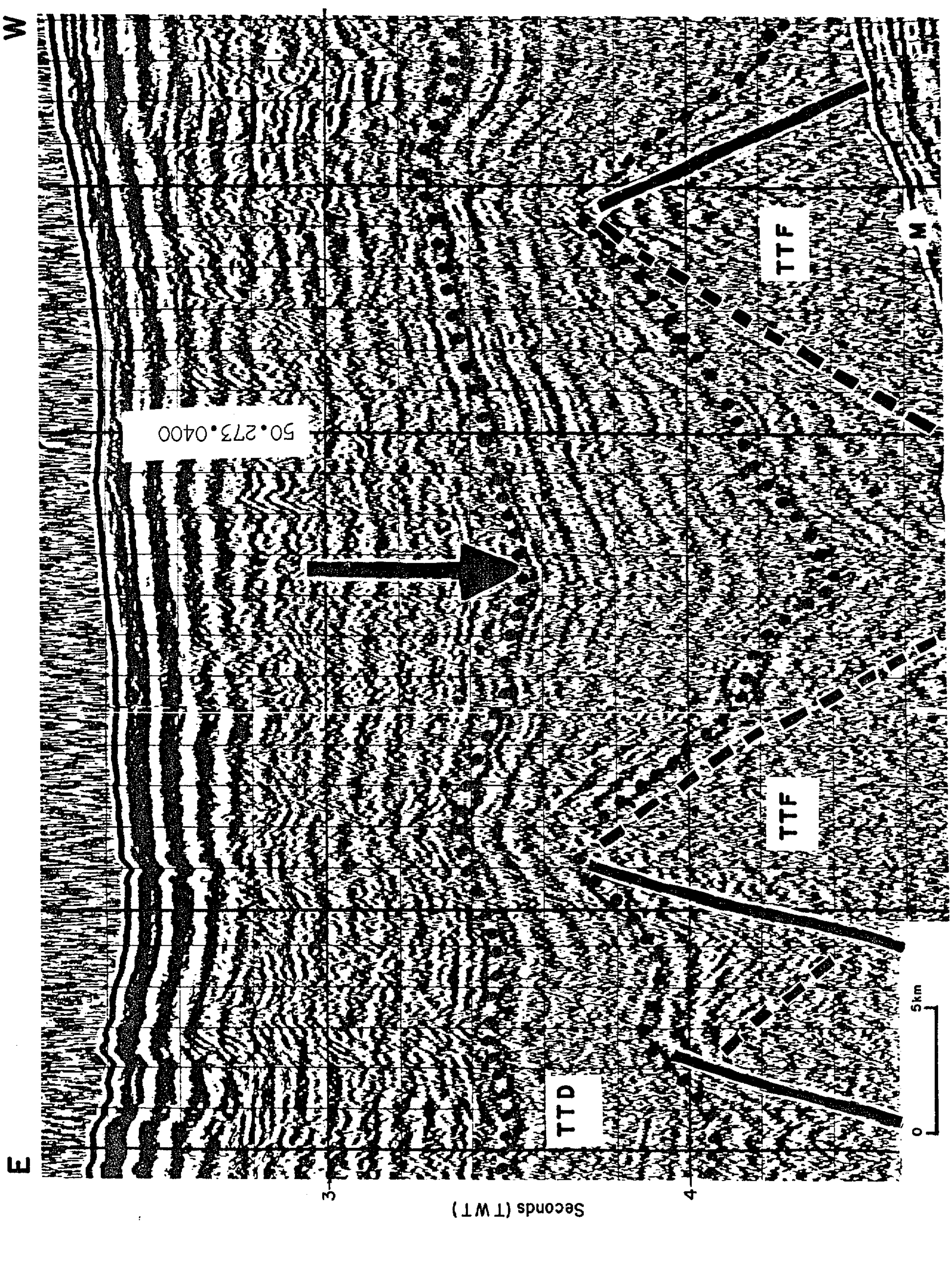


Figure 26. A portion of a 1985 BMR shipboard monitor seismic section (highly exaggerated) across the eastern Townsville Trough showing a transverse stuctural zone - transfer fault - separating tilt blocks dipping in opposite directions. Note the drape in the sediments overlying the block corners. Location shown in Figure 9.

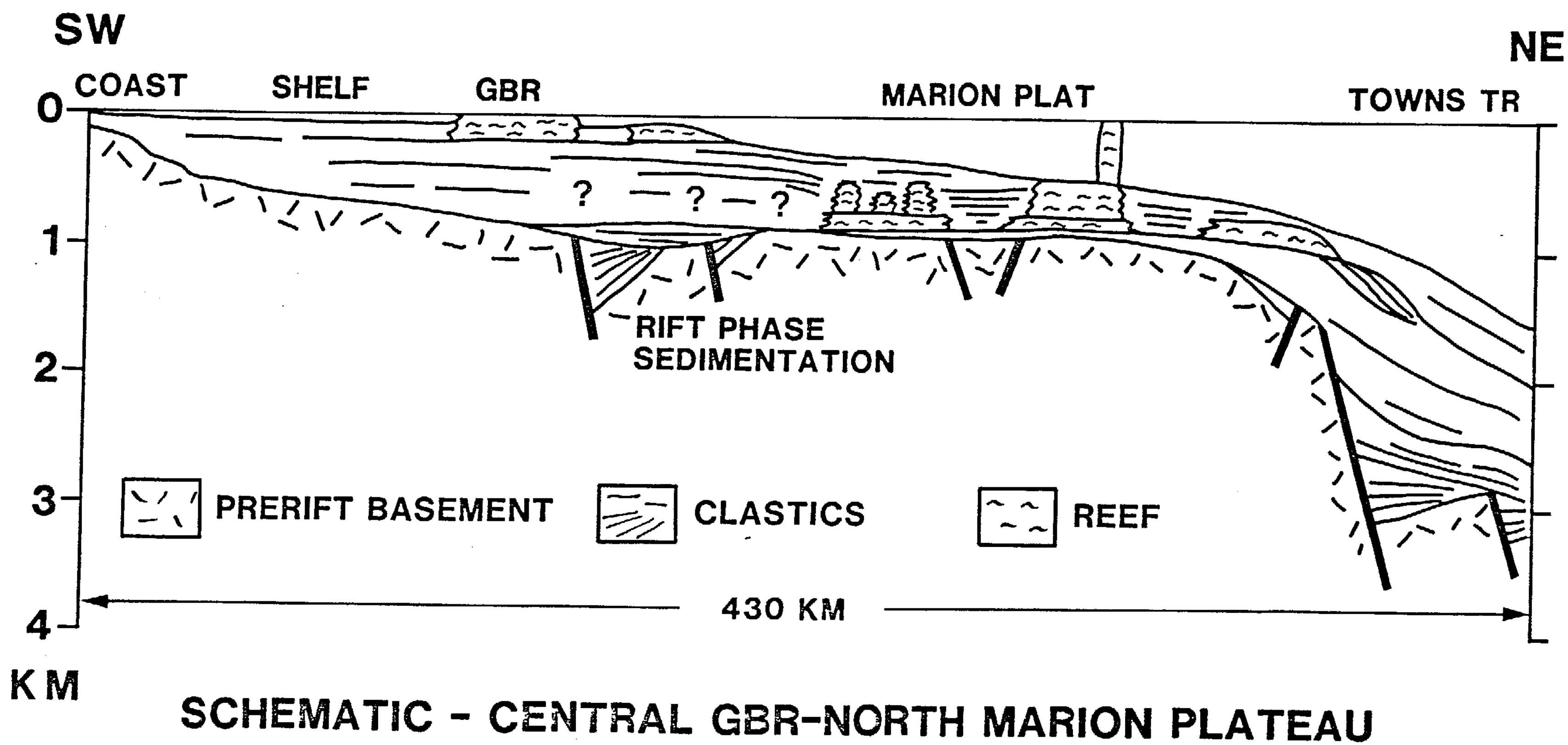


Figure 27. Schematic profile from the Queensland coast, across the Great Barrier Reef and Marion Plateau, to the Townsville Trough showing generalised rift-phase structuring, and the different phases of carbonate platform and reef development. Location shown in Figure 9.

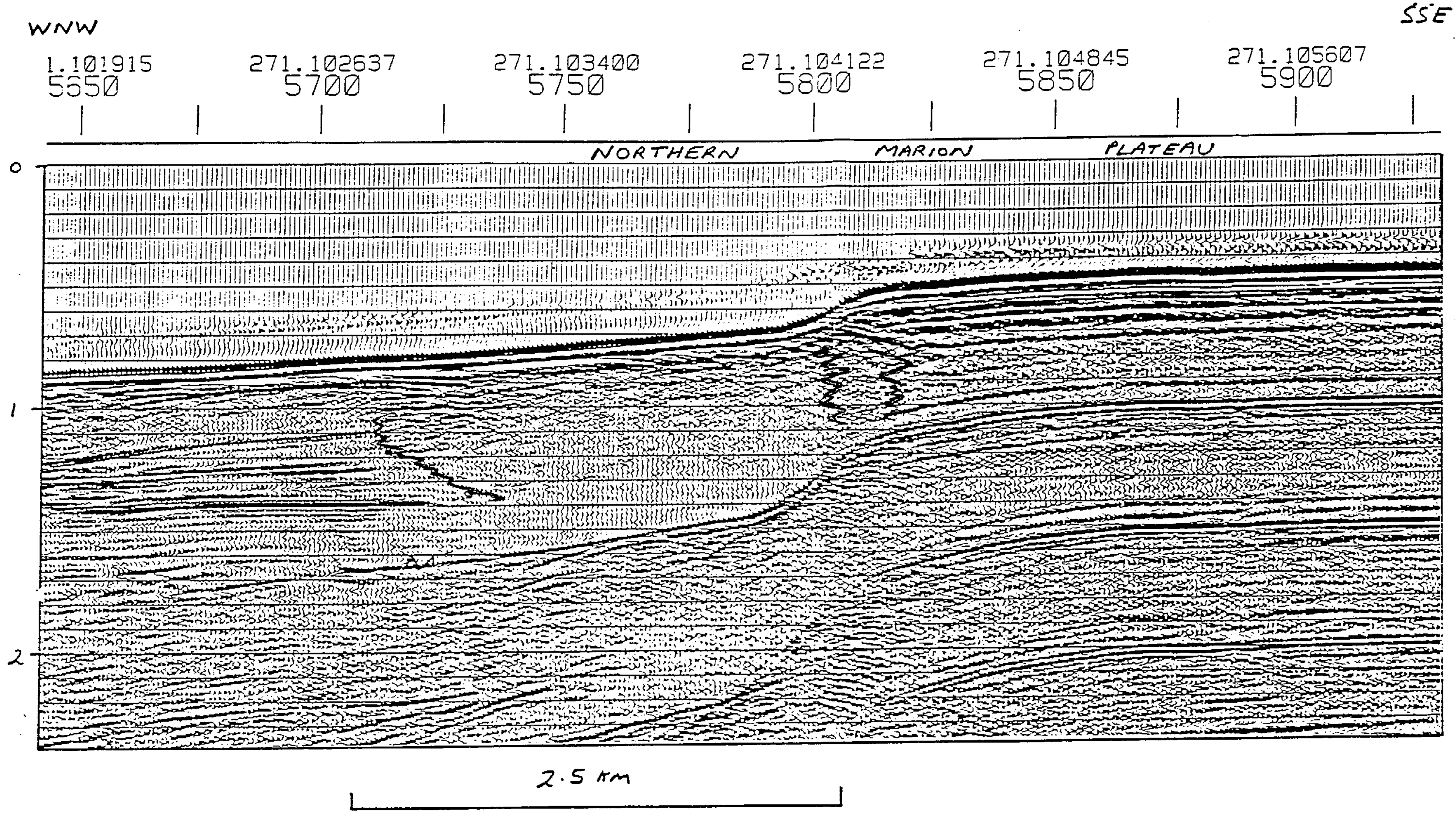
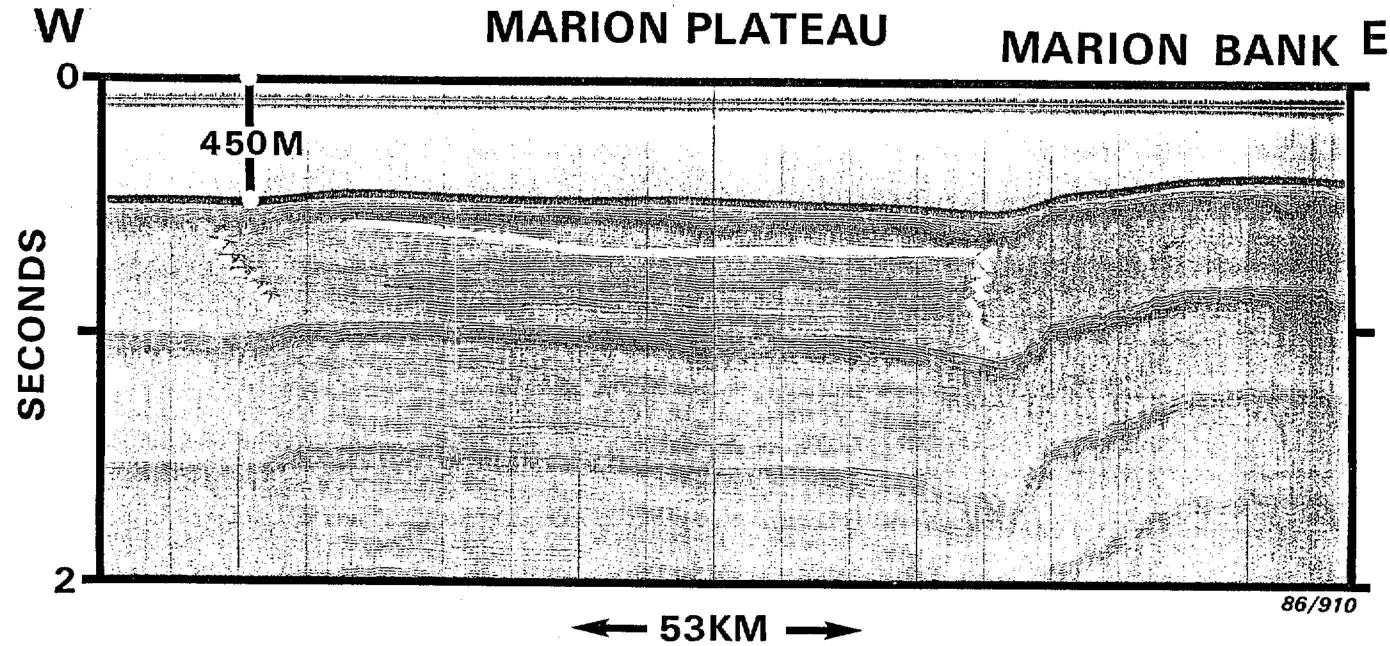


Figure 28. A portion of a stacked 1985 BMR seismic profile across the northern margin of the Marion Plateau showing the reef-rimmed carbonate platform which underlies the plateau in this area. The location of the carbonate platform is shown in Figure 23, and the location of the seismic section is shown in Figure 9.



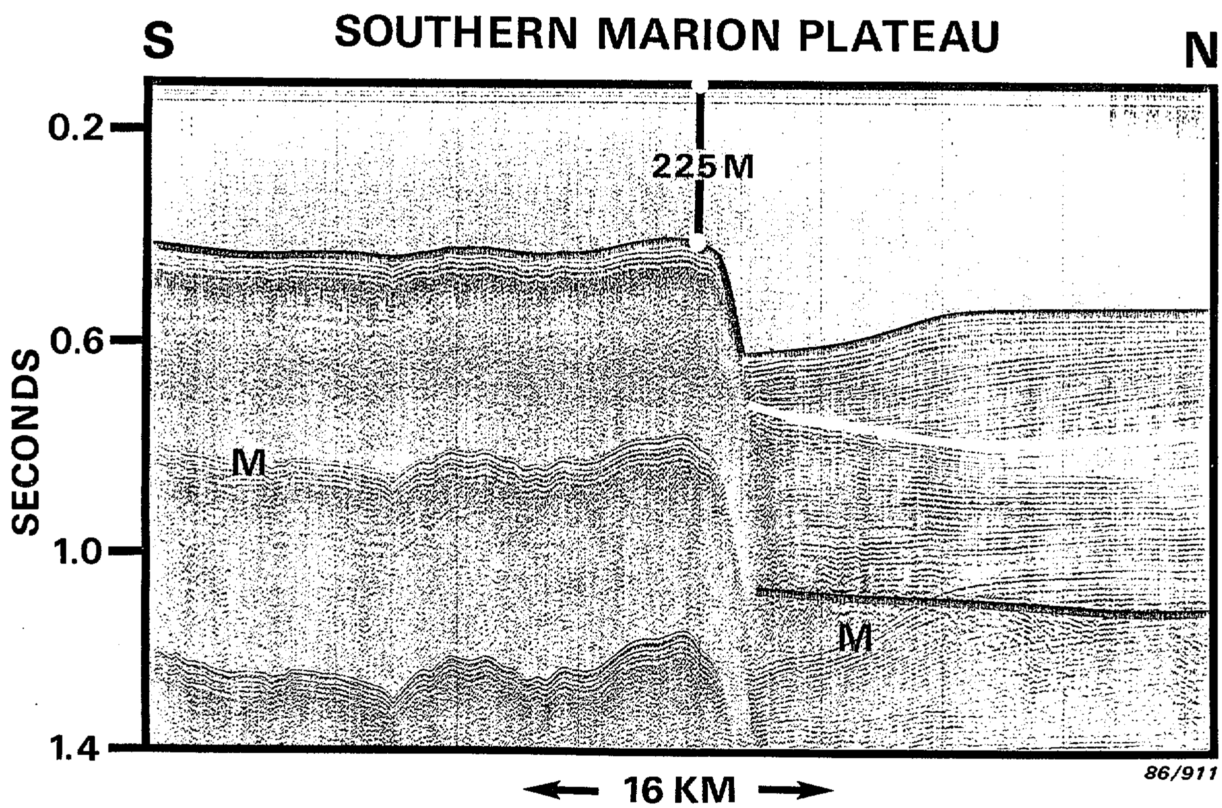


Figure 29. Portions of 1971 BMR single-channel seismic sections over the Marion Plateau. A shows platform reefs and associated lagoonal sediments across the plateau to the southwest of Marion Reef; B shows an escarpment on the edge of a reefal platform to the northeast of Swains Reefs - a possible dredge site during the first 1987 cruise. Locations shown in Figure 9.

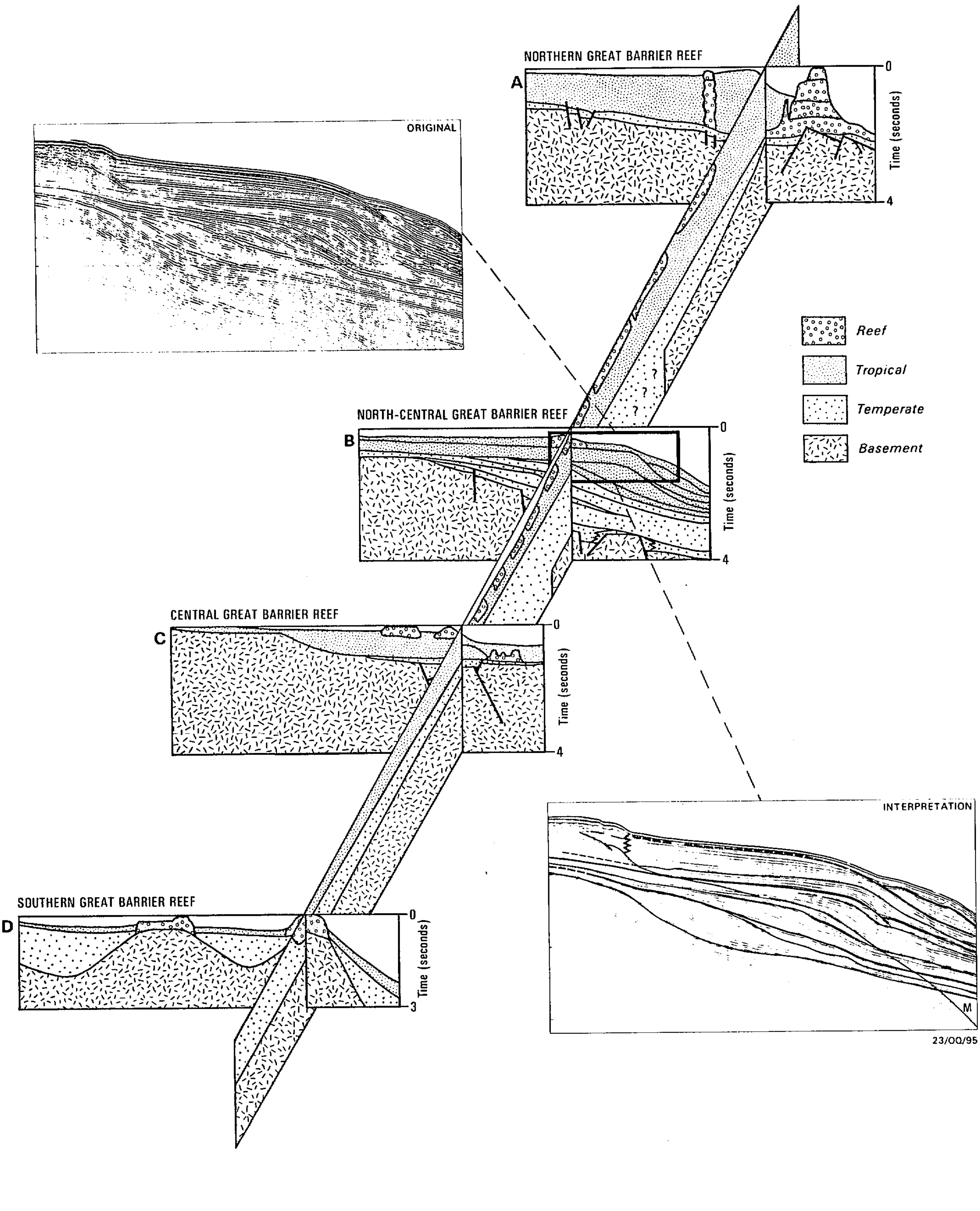


Figure 30. Schematic north to south section illustrating the thickness variations of tropical and temperate facies. The northward -thickening tropical wedge implies that reef growth commenced earlier in the north than in the south. A representative seismic section illustrating the nature of seismic sequences forming the outer shelf/upper slope from the north-central Great Barrier Reef is also shown (after Davies & others, in press).

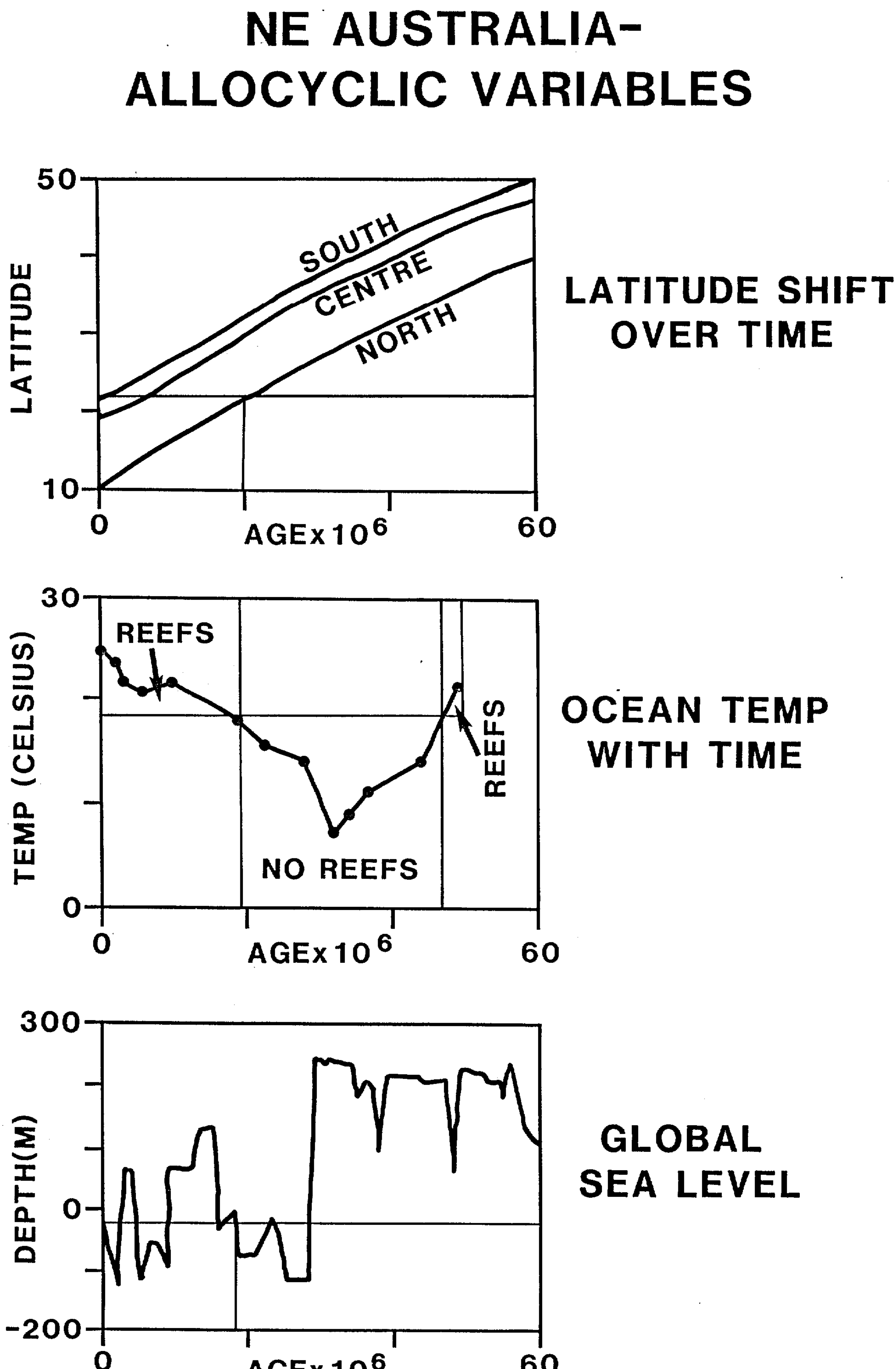


Figure 31. Variation through time of the allocyclic forcing functions which have controlled the sedimentological features in general, and the development of carbonate platforms in particular, off northeast Australia. Shows the influence of A - horizontal plate motion on latitude; B - climate/oceanography on ocean temperature; and C - sea level (after Davies & others, in prep).

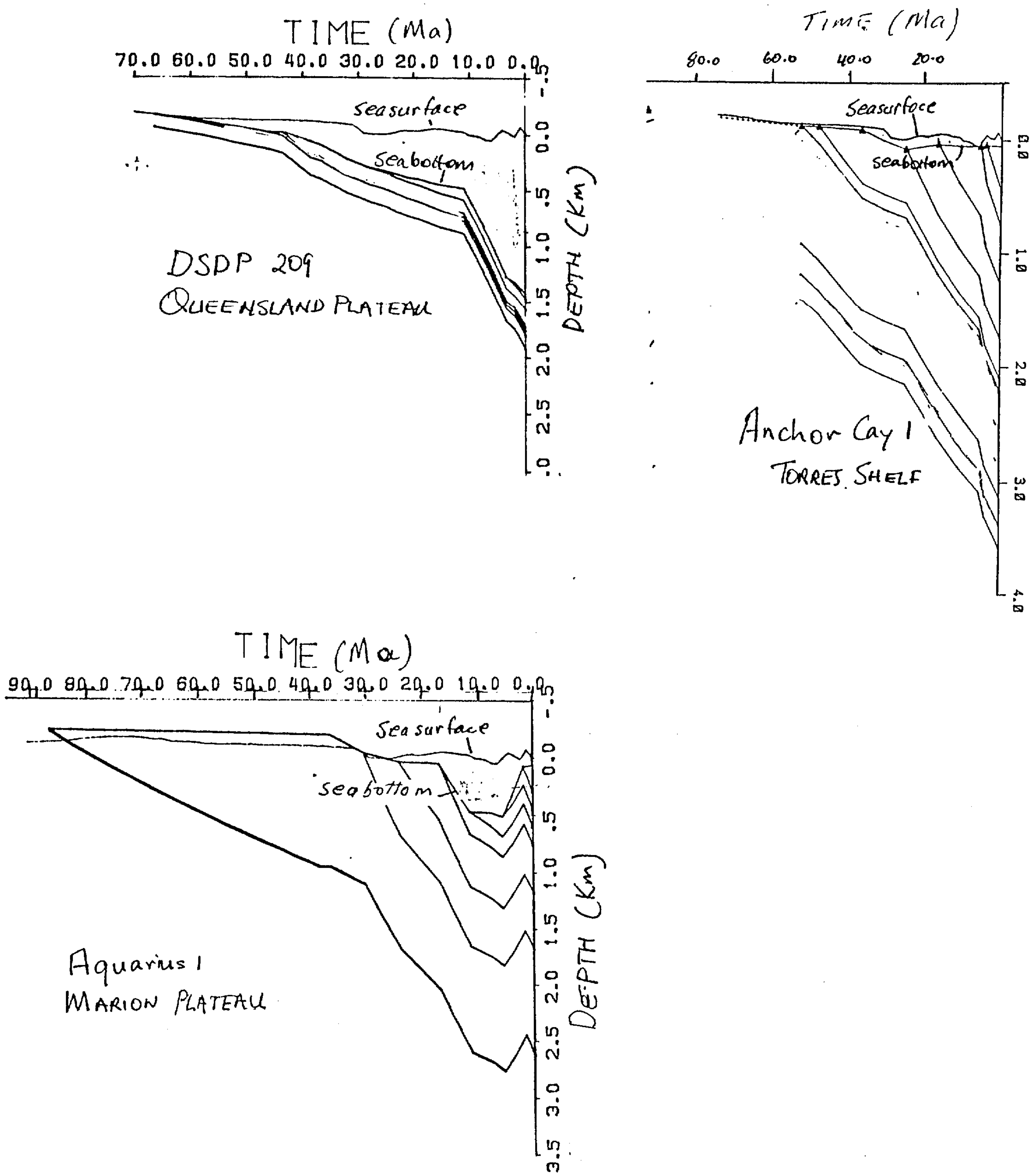


Figure 32. Subsidence curves for selected drillholes off northeast Australia: A - DSDP 209 (Queensland Plateau); B - Anchor Cay-1 (Torres Shelf, northern Great Barrier Reef); C - Aquarius-1 (Capricorn Basin, southern Marion Plateau). These were derived using the geohistory techniques of Van Hinte (1978) and Falvey & Deighton (1982), and show unusually high subsidence rates are occurring throughout the region today. In some cases the rates appear to be as high today as they have ever been in the past - an unusual situation for a passive margin supposedly subsiding under the influence of post-Paleocene thermal cooldown.

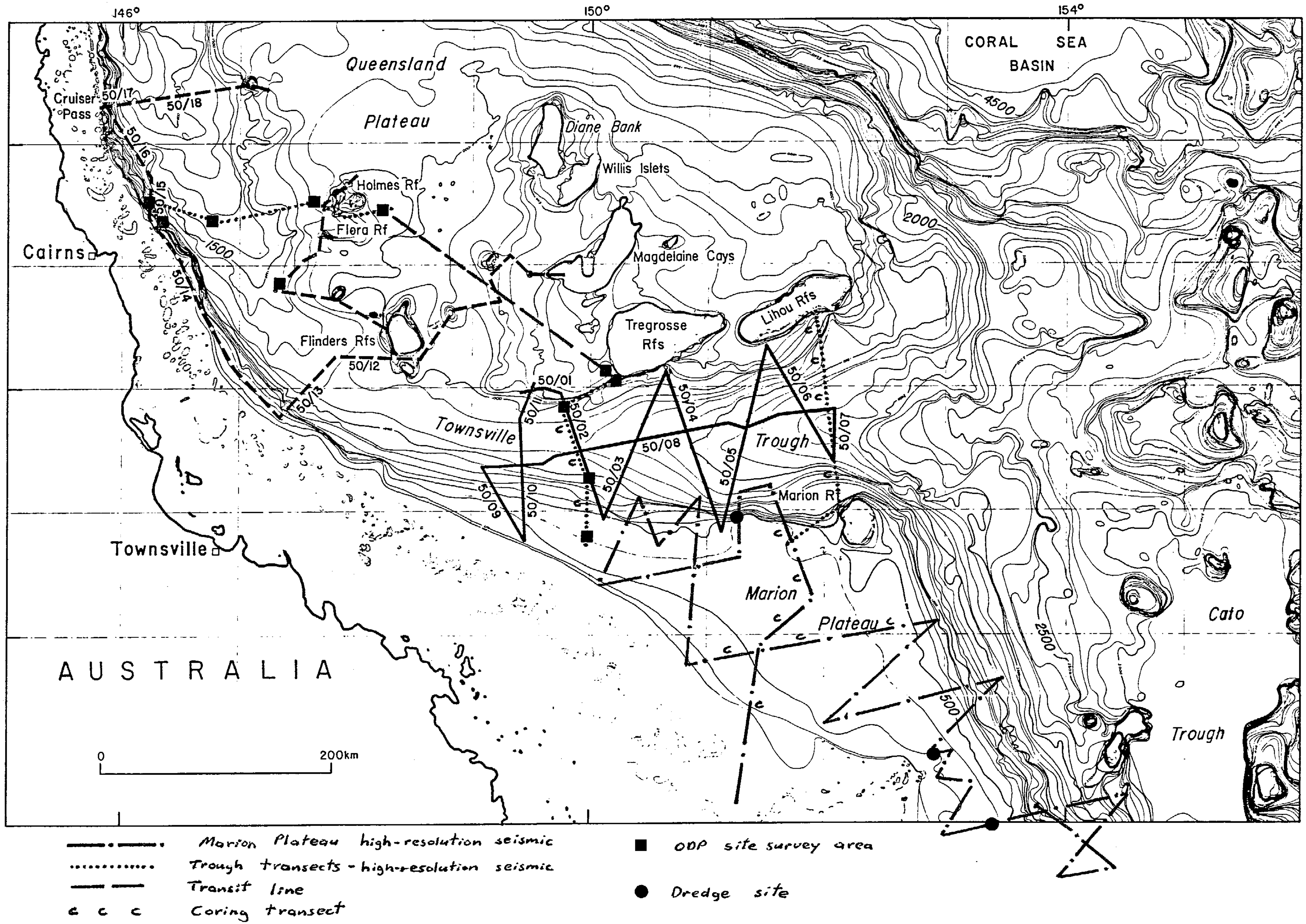


Figure 33. Locations of the high-resolution multichannel seismic lines, ODP site surveys (seismic), coring(+heatflow) transects and dredge sites proposed for the first 1987 northeast Australia cruise.

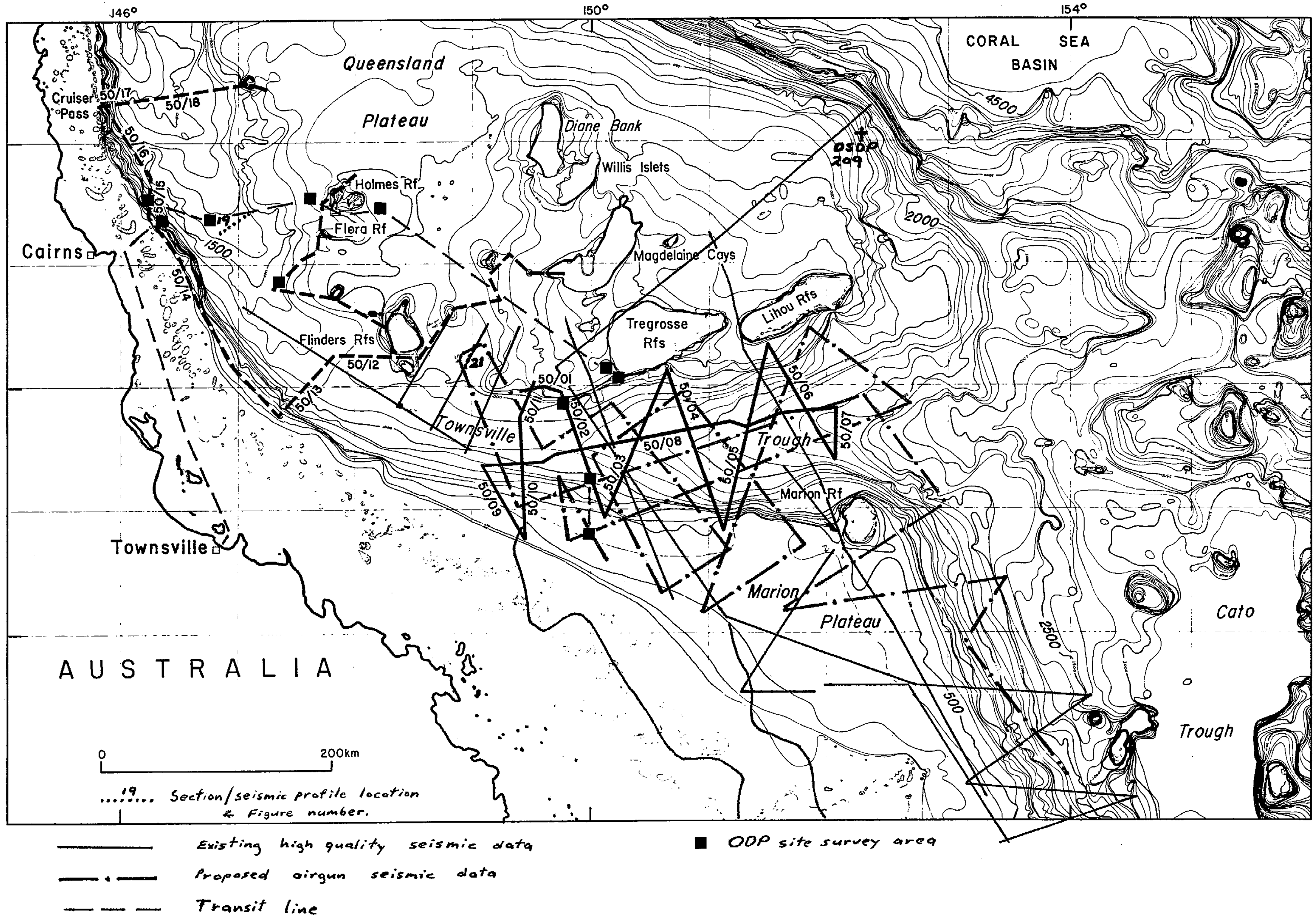


Figure 34. Locations of ODP site surveys (coring, heatflow and sidescan) and the airgun multichannel seismic lines, proposed for the second 1987 northeast Australia cruise.

Table 1. Sedimentation Rates on the Queensland Continental Slope and adjacent trough.

Western Slope		Trough		Eastern Slope	
Northern Transect, Latitude 15°41'S					
Depth	Sedimentation	Depth	Sedimentation	Depth	Sedimentation
444 m	22 mm.10^{-3} yrs	1020 m	2.2 mm.10^{-3} yrs	1871 m	3.0 mm.10^{-3} y
850 m	2.2 mm.10^{-3} yrs	1030 m	2.5 mm.10^{-3} yrs	1630 m	2.6 mm.10^{-3} y
946 m	2.3 mm.10^{-3} yrs	1800 m	2.5 mm.10^{-3} yrs	1590 m	0.1 mm.10^{-3} y
1024 m	2.3 mm.10^{-3} yrs	2080 m	2.1 mm.10^{-3} yrs	1545 m	1.0 mm.10^{-3} y
		2060 m	1.8 mm.10^{-3} yrs		
		1871 m	3.0 mm.10^{-3} yrs		
Central Transect, Latitute 18°10'S					
Depth	Sedimentation	Depth	Sedimentation	Depth	Sedimentation
230 m	1.0 mm10.$^{-3}$ yrs	1105 m	1.6 mm.$^{-3}$ yrs		
355 m	1.3 mm.10^{-3} yrs	1198 m	1.8 mm.10^{-3} yrs		
550 m	3.0 mm.10^{-3} yrs	1252 m	1.5 mm.10^{-3} yrs		
690 m	1.9 mm.10^{-3} yrs	1220 m	2.0 mm.10^{-3} yrs		
896 m	2.0 mm.10^{-3} yrs	1145 m	3.4 mm.10^{-3} yrs		
1105 m	1.6 mm.10^{-3} yrs	1150 m	2.0 mm.10^{-3} yrs		
		1190 m	2.6mm.10^{-3}		
		1036 m	2.5 mm.10^{-3} yrs		
		1190 m	3.4 mm.10^{-3} yrs		
Southern Transect, Latitute 18°26'S					
Depth	Sedimentation	Depth	Sedimentation	Depth	Sedimentation
327 m	25.0 mm.10^{-3} yrs				
598 m	25.0 mm.10^{-3} yrs				
740 m	2.3 mm.10^{-3} yrs				
895 m	5.0 mm.10^{-3} yrs				
1034 m	1.0 mm.10^{-3} yrs				
1180 m	1.6 mm.10^{-3} yrs				

TABLE 2 - Exploration wells - offshore and onshore Queensland

Well	No.	Title	Rig	Rig Release	K.B./S.L.	Basin	T.D.	Reached basement	Deepest Sed. horizon penetrated	Cost MM$	
*Anchor Cay No. 1	69/2000	Q/1P	Conception	6.5.69	10m/63m 34'/206'	Papuan	3623 m 11,888'	No	Mesozoic undiff.	1.73	p/a p/a
*Aquarius No. 1	67/4276	Q/4P	EW Thornton	27.3.68	10m/65m 32'/213'	Capricorn	2650 m 86095'	Yes	Early Cret. (Aptian)	1.101	"apparent drape over reef" after drilling no structur Recent reef in sea floor.
*Capricorn No. 1A	67/4269	Q/5P	EW Thornton	15.1.68	10m/106m 32'/347'	Capricorn	1710 m	Yes	Aprian	.99	p/a closed anticline.
Marina No. 1	62/1214	onshore	-	12.8.62	24m RT + 80'	Laura	1166 m 3829'	No	Permian (basalt)	.196	p/a Stratigraphic test - or small positive gravity anomaly.
Breeza Plains No. 1	70/650	onshore	-	14.8.70	19m KB + 61.8'	Laura	987 m 3238'	Yes	Permian	.288	p/a East flank of anticline.
Lakefield No. 1	70/650	onshore	-	29.8.70	32m KB +105.4'	Laura	930 m 3052'	Yes	Jurassic		p/a East flank of anticline.
Wreck Island No. 1	62/1021	onshore	-	14.6.59	7m RT + 22'	Maryborough	579 m 1898'	Yes	Miocene	.169	p/a Gravity high.
Proserpine No. 1	65/4149	onshore	-	28.7.65	7m RT + 23'	Proserpine	1295 m 4250'	Yes	L. Carb(?)	.108	p/a
Mackay No. 1	69/2022	Q/12P	Navigator	Proposed spud 1.3.1970. Est. duration 40 days	23 m RT + 77'	Proserpine	6600'	?	?	.82	Proposed well - never drilled located in inland waters 162P of Q/12P. Anticline.

*Denotes offshore well

(After McAvoy & Temple, 1978)

TABLE 3 Major Seismic sequences of the Townsville Trough.

SEQUENCE	Boundary Geometry		*Internal Reflection Properties				Average
	Top	Bottom	Configuration	Continuity	Frequency	Amplit.	Thickness (msecs TWT)
TTA	Seafloor	Generally concordant with some onlap & downlap	Subparallel	Moderate to high	Low	High	350-400
TTB	Gentle truncation	Concordant with some onlap	Subparallel to slightly divergent in places	High to moderate	High	High to moderate	300
TTC	Concordant with some gentle truncation	Concordant	Subparallel to quite hummocky in places particularly near base (variable)	Moderate to low in places		Variable, mod.-low	350-600
TTD	Gentle truncation to concordant	Onlapping	Sub-parallel to slightly divergent	High to moderate	Low to moderate	Moderate	250-600
TTE	Erosional truncation	Onlapping	Subparallel to divergent	Moderate to low	Low to moderate	Moderate to low	200- 600
TTF	Concordant and erosional truncation	Basement	Subparallel or reflection free	Low	Moderate	Low	Variable

* The description of internal reflection properties is highly generalised as there is considerable facies variation across the trough from one side to another and along its length.

TABLE 4 TECTONO-STRATIGRAPHIC SUMMARY FOR THE TOWNSVILLE TROUGH

Sequence	Inferred Max. Age Range	Tectono-Strati-graphic Unit	Structural Style/Form	Speculative Lithology/Facies	Regional Tectonic Events
TTA	Early Oligocene and younger	Post-breakup sag phase	Unstructured basin & slope front fill	Deep water to upper bathyal pelagic ooze; terrigenous and calcareous turbidites; slump deposits.	Deposited during regional subsidence phase following start of equatorial circulation pattern; plateau reef development.
TTB	Late to middle Eocene	Post-breakup sag phase	Unstructured; basin fill; some compaction drape	Deep water to neritic high and low energy deposits; terrigenous and calcareous turbidites	Deposited during slow regional subsidence phase; parts of Queensland Plat. still subaerially exposed. Effected by late Eocene lowstand.
TTC	Middle Eocene to Paleocene	Early post-breakup phase	Minor reactivation structuring near base; basin fill; flexural & compaction drape	Paralic to shallow shelf on trough margins - relatively restricted shallow marine in trough; shelf clastics, ooz & submarine fans	Deposited during opening of Coral Sea Basin by seafloor spreading - mag. anomalies 27-24. Adjacent plateaus largley subaerially exposed.
TTD	Paleocene to Late Cretaceous (Campanian)	Late rift phase	Continued movement on normal faults; flexural drape and thinning over tilt block corners. Fault controlled basin fill	Restricted shallow marine in centre of trough; continental to marginal marine on flanks and plateau	Deposited following breakup in Tasman Sea and possibly Cato Trough. Increasing marine influence in Townsville Tr. but possibly only sporadic in Queensland Tr.
TTE	Late Cretaceous to Early Cretaceous and possibly older Mesozoic	Early syn-rift phase	Significant normal & ? wrench faulting; half graben development	Continental, marginal marine to ? very restricted shallow marine in places.	Deposited during intense extensional tectonism/which produced northeast Australian rift system.
TTF	? Mesozoic to Palaeozoic & older	Pre-rift and ?infra-rift phase	Possibly gentle structuring in intracratonic downwarps along sites of future rifting	Continental to marginal marine. ?J-Pz sediments & metasediments; Proterozoic basement	Regional basin development as intracratonic downwarps - c.f. Laura and Papuan Basins

TABLE 5 SEISMIC SYSTEMS USED DURING THE NORTHEAST AUSTRALIA CRUISES

AREA	Cruise	Streamer Channels	Group Length	Source	CDP Fold	Amount (km)	Description of Lines
Townsville Trough	50	48	50m	2 airguns 1000 cu.in	24	1309	Zig-zag pattern of 8 lines across the trough & 1 tie-line down centre of trough, tieing into Shell & Gulf data
Queensland Trough/ GBR Slope	50	48	12.5m	9 kjoule sparker	24	571	2 lines across trough, connected by 1 line along GBR upper slope. Ties into BMR 1982 GBR sparker data
Torres Shelf/ Pandora Trough	50	24	25m	2 air-guns; 500-1000 cu.in	12	787	4 zig-zag lines across Eastern Plateau & Pandora Trough, 2 E-W lines across Torres shelf tieing to Anchor Cay well; 3 zig-zag lines across Bligh Trough. Ties into Shell, Sonne and Phillips data.
Torres Shelf	50	24	25m	7-9 kjoule sparker	24	186	Series of zig-zag lines across Torres shelf between Portlock RF. and Anchor Cay.
Raine Is.	51	24	25m	9 kjoule sparker	24	73	Series of lines into and out of GBR around Great Detached Rf.
Osprey Embayment	51	24	25m	2 airguns 1000 cu.in	12	586	5 zig-zag lines across western Osprey Embayment tieing into Sonne & GSI Group shoot data.
GBR Slope (east of Cape Melville)	51	24	25m	9 Kjoule sparker	24	46	1 line along upper slope just off GBR
Western Queensland Plateau	51	*16	25m	9 Kjoule sparker	16	472	Line NE from Flinders Rfs to Caringa Cays via Herald Cays; zig-zag line NW from Flinders Rfs. to Queensland Trough then then NE to Flora & Holmes Rfs.

* Used small diameter high resolution Teledyne streamer.

TABLE 6 - GEOPHYSICAL SURVEYS - OFFSHORE QUEENSLAND (After McAvoy & Temple, 1978)

SURVEY			COMPANY	CONTRACTOR	TENEMENTS	SEISMIC SOURCE	CABLE	RECORDER
Bunker Group S.	64/4505	4.2.64 - 7.2.64	Shell Dev.	Western Geo.	ATP 70P (Q/13P)	Expl.	600 m - 600 m 1200 m - 1200 m	FA-32
Mackay S.	64/4507	11.2.64 -19.2.64	Ampol Exp.	"	ATP 93, 94P (Q/12P)	"	7876 ft 3940 ft	West FA-32
ATP 104 P West S.	64/4554	1.11.64 -28.11.64	Marathon	Western	ATP 104P (Q/10P)	"	2400 m	WGC 24FA-40A
Hervey Bay S.	64/4569	8.3.65 -15.4.65	Shell Dev.	G. S. I.	ATP 70P (Q/13P)	"	1500 m	Shell QL-107 T.I. Exp. 8000-2
Torres St. - Pr. Charlotte	65/4599	14.5.65 - 5.7.65	Gulf Interstate O/S	Western	ATP 88P (Q/10P, 11P 1P, 2P, 3P)	"	600 m - 600 m	West FA-40
Swain Reefs S.	65/11022	17.7.65 -24.8.65	Aust. Gulf Oil	Western Geo.	ATP 90P (Q/4, 5P, 3P)	"	600 m - 600 m 1200 m - 1200 m	"
Northern Gt. Barrier R.S+M	66/11086	23.7.66 -17.9.66	Tenneco	Independent S G.A.I. M	ATP 88P (Q/1P, Q/10P) ATP 111P Q/11P, 2P	"	streamer 5400'	TIDFS 10000 Varian V4937
Capricorn Channel (Swain Reefs Phase 11)	66/11093	20.8.66 -24.11.66	Aust. Gulf Oil	United G.C.	ATP 90P (Q/4, 5, 6, 13P)	Spkr.	8040 ft	SIE PDR 70 (dig.)
Broad Sound S.	66/11134	17/11.66-19.11.66	Ampol Exp.	U.G.C.	Q12P	Spkr.	180 ft	
Triangle Reef S.	68/3008	23.3.68 -23.4.68	Tenneco	Western Geo.	ATP 88P (Q/1P) ATP 134P	Expl.	1200 m	SDS 1010
Warrior Reef S.	68/3011	25.4.68 -29.4.68	Amoseas	Western	ATP 133P (Q/10P 11P)	"	1200 m	SDS 1010
Hervey Bay S.	69/3002	19.1.69 -23.9.69	Shell	B.I.P.M.	Q13P	A/G	2700 m	Leach DS 1021
Pearce Cay S.	69/3024	23.9.69 -28.9.69	Texaco	Western	Q/10P	Aquapulse	5290 ft	SDS 1010
Offshore Laura Basin S.	69/3041	31.7.69 -22.8.69	Endeavour	U.G.C.	Q/9P	A/G	3940 ft	SIE DFS
Princess Charlotte Bay S.	69/3047	25.8.69 -31.8.69	Exoil-Flinders	"	Q/8P	"	3940 ft	EG & G 146
Gulf R & D Scientific Survey	73/21	22.2.73 -25.3.73	Gulf R & D	Gulf R & D	Q/4P, 5P, 6P, & 7P	Aquapulse	48 ch	GUS HDDR 4000
Barrier Reef A/M	62/1714	7.3.62 - 4.4.62	A.O.G.	Aero Serv. Ltd	(Q/4P,5P,6P,7P,13P)			
Gulf of Carpentaria A/M	62/1719	29.7.62 -16.8.62	Delhi	"	ATP-58P (Q/10P)			
C. York Peninsula A/M	62/1725	3.10.62 -16.10.62	Gulf Interstate O/A	"	ATP-88P (Q/1P,2P,3P,8P,9P,10P,11P)			
Swain Reefs A/M	63/1712	14.5.64 -20.9.64	Aust. Gulf Oil	"	ATP-90P (Q/4P,5P,6P)			
Cooktown A/M	68/3010	18.5.68 -18.6.68	Corbett Reef	"	ATP-127P (Q/8P, Q/9P)			
Townsville A/M	69/3012	6.3.69 -19.4.69	Aust. Gulf Oil	"	Q6P, Q7P			

TABLE 7 - COMMENTS ON GEOPHYSICAL SURVEYS, OFFSHORE QUEENSLAND (After McAvoy & Temple, 1978)

SURVEY	COVERAGE	MILEAGE	REFR.	GRAV.	MAG.	QUALITY	REMARKS
Bunker Group S.	100% 200%	183.4 m (293 km)	-	-	-	P	Shallow platform N of Fraser Is. No thickening of Tert. s. of Wreck Island.
Mackay S.	100% 200%	315 (504 km)	-	-	-	P - F	Trough 7000 (2134 m). No large structures.
ATP 104 P West S.	200% 300%	580 (928 km) 38 (61 km)				F	5000 ft (1525 m) of T? in west.
Hervey Bay S.	100% 400%	689 (1102 km)				P	Confirmed basement ridge Sandy C to Bunker Gp.
Torres St. - Pr. Charlotte	600%	567 (907 km)				F	7500 ft (2286 km) Pr. Charlotte B.
Swain Reefs S.	400%	519 (830 km)				P	Record quality poor, up to 8000' (2428 m) seds. in E
Northern Gt. Barrier R.S+M	300%	764 (1222 km)	-	-		F	Detailed two structures
Capricorn Channel (Swain Reefs Phase 11)	400% & 600%	1839 expl. (1942 km) 305 spkr. (488 km)		-	-	P	Maryborough, Capricorn Basins - little structures 5-8000 ft (1525-2438 m) sediments.
Broad Sound S.	100%	150 (240 km)				F	N/S Trough (narrow) faulted on W side.
Triangle Reef S.	600%	240 (384 km) 56 (896 km)	-	-	-	F	10000' (3050ft) in NE AP 88P Section thinning to W.
Warrior Reef S.	300% 600%	45 (72 km) 55 (88 km)		-	-	P - F	Section thins N, W & S from low 10000 ft (3050 m)
Hervey Bay S.	2400%	128 (205 km)	-			F	Thick section in Maryborough Basin. Faulting and folding
Pearce Cay S.	2400%	118 (189 km)				P	2 Major structural trends. Moderately thick section 3 basement features.
Offshore Laura Basin S.	600%	330 (528 km)				P	3150 ft (960 m) of sediments
Princess Charlotte Bay S.	600%	462 (739 km)				P - F	Trench 7500 ft (2286 m)
Gulf R & D Scientific Survey	2400%	1374 (2199 km)				P - G	Reconnaissance Halifax, Whitsunday and Capricorn Basins.
Barrier Reef A/M		5545					5000' sediments except in Maryborough Basin
Gulf of Carpentaria A/M		9756					0 (Horne Is) - 7000-8000 ft (2134-2438 m) (Morehead)
C. York Peninsula A/M		3294					Basement depth 0-8000 ft (2438 m) (Laura Basin)
Swain Reefs A/M		17668					5000-15000 ft (1525-4572 m) of sediments
Cooktown A/M		4844					Up to 8000 ft (2438 m) in Laura Basin
Townsville A/M		11879					Shallow Basement (L 5000 ft) (1525 m)