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MORPHOLOGY OF THE EAST AUSTRALIAN CONTINENTAL MARGIN BETWEEN 21°S AND 33°S

by

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CONTENTS

FIGURES

CONTENTS

SUMMARY

Bathymetric interpretation of the eastern Australian continental margin between 21° and 33°S has delineated a wide continental shelf and gently inclined continental slope in the north and a narrow continental shelf and relatively steep continental slope in the south. The generally flat shelf of the Capricorn Channel is interrupted by coralline reefs and reefal banks of the Capricorn and Bunker Groups, and by ancient river channels and sand waves in Hervey Bay. To the south the shelf is in many places terraced and small banks occur on some of the terrace edges. The continental slope is cut by numerous canyons which channel terrigenous sediments to the floor of the Tasman abyssal plain.

INTRODUCTION

During the Bureau of Mineral Resources' marine geology survey of eastern Australia in 1970 about 3000 km of continuous echosounding profiles were run across the continental shelf and upper continental slope; these were normally carried out between sea bed sample stations. Position accuracy nearshore and within radar range (45 km) of the coast or islands was good. Generally the eastern end of each traverse was determined by dead reckoning.

Additional sources of data used were the published hydrographic charts and the unpublished 1:1 million Oceanic Soundings, Areas 352, 382, and 413, compiled by the Royal Australian Navy Hydrographic Office.

REGIONAL BATHYMETRY

The regional bathymetry of the northwestern Tasman Sea is shown in Fig. 1. It covers that part of the Australian continental margin and western Tasman Sea between latitudes 21° and 33°S, including the southernmost part of the Great Barrier Reef and the northern Tasmantid seamounts.

North of the Tasman Basin lies the Cato Trough, a narrow depression which broadens gradually northwards. South of 21°S the trough slopes gently southwards and it is separated from the Coral Sea Basin to the north by the Capricorn Sill, northeast of Marion Reef (Krause, 1967). On the eastern side of the Cato Trough there are a line of seamounts with coral reefs developed on their crests. From north to south these are Kenn Reef, Wreck Reef, and Cato Reef. These are considered to be part of the Tasmantid seamount chain (Krause, 1967).

To the west of Cato Trough the sea floor rises to the southern part of the Marion Plateau (Gardner, 1970), a gently sloping platform between 200 and 600 m with an average seaward gradient of 0.3°. The Marion Plateau is one of a series of marginal plateaux that occur on the continental margins of northern Queensland and southern Papua. It is separated from the Queensland Plateau by the Townsville Trough, but is much shallower than the Queensland Plateau, which has an average depth of 1100 m (Gardner, 1970). The edge of the Marion Plateau does not descend directly to the Coral Sea Basin, as do the other three plateaux, but slopes down to the Townsville Trough to the north and Cato Trough to the east.

Saumarez Reefs occur on top of a bank rising from the floor of the Marion Plateau. The bank is probably similar to the reefal banks on the Queensland Plateau, in that it has been built up by reef growth keeping pace with the slowly subsiding platform; in contrast, Cato Island and the other seamounts probably have volcanic cores. The steep slope on the northern edge of Saumarez Reefs suggests that it may also be fault-controlled.

From the Marion Plateau the sea floor rises up a short and locally steep slope onto the continental shelf, the outer part of which supports the Swain Reefs at the southern end of the Great Barrier Reef. The bathymetric contours (Fig. 1) show a broad ridge extending from the southern tip of the

Swain Reefs in a southeasterly direction towards the junction of the Cato Trough and the northwestern Tasman Basin. Aeromagnetic data (Ellis, 1966) have shown a basement high to be present beneath the Swain Reefs, of which the ridge could represent an extension.

The Capricorn Channel occupies the area between the Swain Reefs and the reefs of the Capricorn and Bunker Groups. In the channel, the isobaths show a large embayment which slopes gently down to the Tasman abyssal plain. The 80 m and 100 m isobaths (Fig. 1) are considerably embayed and the floor of the channel in this region is a broad, flat plain with gradients of less than 0.1^{o} along the axis of the channel. To the northeast, the sea floor rises up quite sharply onto the Swain Reefs platform. Slope increases slightly between the 120 m and 200 m isobaths and then flattens to another broad plain between 200 and 600, morphologically continuous with, but possibly structurally unrelated to the Marion Plateau. Beyond the 600 m isobath the gradient increases and the sea floor descends gently to the northwestern Tasman Basin.

As Fairbridge (1950) has pointed out, it is impossible to define the structural limits of the continent in this area. There is no definite shelf break in the Capricorn Channel, and the average slope of the sea floor to the Tasman Basin is less than 2^{o}. This embayment of the continental margin in the Capricorn Channel is a manifestation of a large south-eastwards sloping trough which has been named the Capricorn Basin (Maxwell, 1968a).

The southwestern margin of the Capricorn Channel is bounded by the coral reefs and banks of the Capricorn and Bunker Groups. The reefs lie in two prominent trends, a major one northwest and a minor one approximately east. The major trend lies on the axis of a structural high known as the Bunker High (Maxwell, 1968a).

Between the mainland and the reefs the shelf is flat, depths gradually deepen eastwards to 40-50 m followed by a sudden rise to the reefs. On the seaward side of the reefs a platform extends for 10 to 20 km at a depth of 55 to 65 m before sloping down fairly steeply to the floor of the Capricorn Channel at 300 m. The steep gradient between 60 and 300 m on the upper continental slope between the Bunker Group and Fraser Island could indicate a normal fault which is hinged down to the southeast (Fairbridge, 1950). If such a fault exists it would mark the boundary between the Bunker High and the Capricorn Basin.

On the shelf between the Bunker Group and Fraser Island the 40 m isobath is embayed, and the 20 m isobath reveals roughly aligned banks, which Krause (1967) and Maxwell (1968a) have interpreted as being the submerged remnant of an ancient subaerial drainage system.

The continental shelf between 25^{o} and 27^{o}S consists of an almost horizontal plain 20 to 80 km wide with banks on the outer edge. The narrowness of the shelf near 25^{o}S is the result of the outbuilding of sand across the old continental shelf to form Fraser Island. The area of shelf has similarly been reduced off Brisbane by the development of Moreton and North Stradbroke Islands.

The shelf break occurs between 60 and 120 m, beyond which the sea floor slopes down gently to 300 - 360 m. Below this depth the gradient increases considerably and the main continental slope descends relatively steeply with an average gradient of 5°. Conolly (1969) found rugged topography of 10 to 40 m relief at the junction of the gently inclined upper continental slope and the relatively steeply inclined main slope. He suggests that the rough topography is a result of reefs built during times of lowered sea level; however, this would place sea level some 100 m lower than any previously recognized Pleistocene sea level (Dill, 1968; Jongsma, 1970). This implies that such reefs may be early to pre-Pleistocene or that the continental margin had subsided. Another explanation is that the rough topography is caused by consolidated rock cropping out at this junction; noncoralline bedrock is known to occur on the continental slope in this vicinity (Marshall, 1971).

Between Cape Moreton (27°S) and Coffs Harbour the shelf is a gently sloping plain 30 to 50 km wide, steepened in places (such as off Cape Moreton and Tweed Heads). The shelf break occurs between 120 and 180 m with a gently inclined upper continental slope which becomes progressively steeper to the south. The continental slope and rise are much wider in this area, with the rise extending to the Britannia Guyots (Conolly, 1969). This represents a greater degree of outbuilding of sediments on the outer continental margin than in areas immediately to the north and south. Indentation of the bathymetric contours off Tweed Heads and Coffs Harbour (Fig. I) indicates the presence of submarine canyons which cut deeply into the continental slope and even appear to incise the upper part of the continental rise, as evidenced by the pronounced embayment of the 4000 m isobath. Like the other submarine canyons on the eastern continental margin, they do not extend on to the shelf itself but first appear on the upper continental slope.

The shelf is narrowest between 30° and 31°S, where it is only 25 km wide, as compared to a world average of 78 km (Swift, 1969). The shelf break occurs between 100 and 140 m; the continental slope is very steep, with gradients of the order of 10°, and is dissected by several submarine canyons.

South of 31°S the continental shelf is represented by a continuously sloping platform with no definite shelf break except for a slight steepening between the 140 and 180 m isobaths. Farther south a more gently inclined shelf emerges once more, with a definite shelf break between 140 and 160 m. The continental slope is less steep and has an average gradient of 5°.

North of 32°S the gently sloping continental rise merges with the somewhat southward sloping Tasman abyssal plain. The floor of the Tasman Basin is one of varying topography, with the flat abyssal plain near the continent gradually passing into abyssal hill topography farther east. The abyssal plain is formed by sediments derived from the continental margin which blanket the abyssal hills on the western side of the basin (Van der Linden, 1970).

Rising from the floor of the Tasman Basin is a line of seamounts which lie between the Australian continent and the Dampier Ridge. The seamounts shown in Fig. 1 are, from north to south: Recorder Guyot, Moreton Seamount, Brisbane

Guyot, Queensland Guyot, Britannia Guyots, and Stradbroke Seamount. Together with the seamounts on the eastern side of the Cato Trough and other guyots to the south (Derwent Hunter Guyot, Barcoo Guyot, Taupo Guyot, and Gascoyne Guyot) they form the Tasmantid Seamount Chain. The seamounts and guyots rise from the floor of the basin to depths of 150 to 400 m below sea level, except for Stradbroke Seamount, whose summit occurs at approximately 900 m depth. The guyots are characteristically flat-topped and all have undergone varying degrees of subsidence. Although the crests and flanks are generally covered by calcareous sediments (including coral), basalt cobbles have been dredged from some of the southern guyots, and it is considered that they are volcanoes which originated in the mid-Tertiary. Although the gravity and magnetic measurements over the Derwent Hunter Guyot indicate a volcanic core (Woodward, 1970), the gravity and magnetic response over the northern guyots is only slight; however, this could be a function of water depth (P. Symonds, pers. comm.).

The overall picture is one of a wide continental shelf and gentle slope in the north, changing quite suddenly to a narrow continental shelf and steep slope south of 25°S. The steep slope is cut by numerous canyons, which open out into sediment fans on the continental rise, and sediments channelled down these canyons have formed an abyssal plain close to the continental margin. An almost linear chain of seamounts rises up from the abyssal plain along a north-south line between the 155°E and 156°E meridians.

MORPHOLOGY OF THE CAPRICORN AND CURTIS CHANNELS AND THE INTERVENING REEFS AND REEFAL BANKS

Capricorn Channel

The Capricorn Channel is a large embayment between the Swain Reefs and the Capricorn and Bunker Groups. Although the floor of the channel in most areas is almost horizontal and devoid of any relief, the echo sounding profiles have revealed a number of prominent features. Traverse I (Fig. 5) is a typical profile across the Capricorn Channel and it exemplifies three major topographic features that are present in this region[1]. The first is a series of reefal shoals and banks which extend northwestwards from the Capricorn Group (Fig. 1). In traverse I a reefal bank (Innamincka Shoal) rises to a least depth of 19 m below sea level. The second feature is a sand-wave province which is crossed in traverse I east of Innamincka Shoal. The third is a trough-like feature which was encountered on many traverses in the Capricorn Channel at a depth of about 200 m; a profile of the trough is shown at the eastern end of traverse I.

Sand-Wave Province

A zone of relatively high-amplitude sand waves was delineated during echo-sounding traverses in the Capricorn Channel; its approximate limits are shown in Figure 3. The zone varies in width from 3 to 11 km and is at least 60 km long in the north-south direction.

1 The locations of the traverses referred to are shown in Figure 2.

The sand waves show a great deal of variability in amplitude and wavelength. The amplitudes range from 2 to 20 m, and the significant wave height is 11 m. The significant wave height ($H_{\frac{1}{3}}$) is the mean height of the highest one third of the sand waves, and has been found to give the best relationship to hydraulic variables (McCave, 1971). The wave-lengths range from 150 to 1100m, the majority are between 200 and 500 m. Some error is involved in these measurements as insufficient data are available to determine accurately the orientation of the sand waves.

Both symmetrical and asymmetrical sand waves are present, as well as a number of 'cat-back' forms (van Veen, 1935). The asymmetrical waves usually have the lower amplitudes and tend to occur on the edges of the sand-wave zone. Their asymmetry indicates that movement is (or was) dominantly east-west, although a few asymmetrical waves show an opposite direction. The symmetrical sand waves occupy the central area and are the dominant wave type present (Fig. 4B).

The depths to the base of the sand waves range from 48 to 84m. The tidal range in the area is of the order of 3 to 4 m, and surface currents reach a speed of about 65 cm/sec. There is no information on bottom currents, but they are likely to be close to or less than the limiting velocity for sand wave formation suggested by McCave (1971). A dredge haul from the centre of the sand wave province recovered sand-size material which had a quartz content exceeding 90 percent of the total sample. As the sediments now being deposited on the shelf outside the sand-wave province consist of organic carbonate with subordinate fine-grained terrigenous material, it seems probable that the sand waves are relict features, unrelated to present conditions. There is some evidence that sediments shed by Innamincka and Guthrie Shoals are encroaching upon the sand-wave province (Fig. 3), and this suggests that these reefal shoals were formed after the sand waves; this agrees with Maxwell's (1968b) observations of relict sediments on the Queensland continental shelf.

Symmetry of sand waves formed by tidal currents is considered to be due to equal ebb and flood current velocities, whereas asymmetry is due to unequal ebb and flood velocities. The ebb and flood currents shown on the hydrographic chart in the vicinity of the sand waves have equal velocities, and as the majority of sand waves, especially the larger ones, are symmetrical, this favours tidal current formation. If hydrological conditions during the latter part of the Pleistocene were similar to the present-day conditions one would expect a higher tidal range in the vicinity of the sand-wave province during times of lower sea level; this would explain the occurrence of large-amplitude sand waves at depths of 50 to 80 m below present-day sea level.

200 m trough

The flat monotonous floor of the Capricorn Channel is broken by a trough at a depth of about 200 m (Fig. 4E). This feature is visible on echosounder and seismic records in the central part of the channel, but it fades out to the north at about 22°30'S, and to the south where the 200 m isobath approaches the Capricorn Group. To the north, the trough appears to be buried by sediments derived from the Swain Reefs, and to the south also there is seismic evidence that the trough once extended east of the Capricorn and Bunker Groups, but has subsequently been buried by reef-derived sediments.

Where the 200 m isobath approaches the Capricorn Group it swings from a southwesterly to a southeasterly direction, parallel to the line of reefs. Seismic traverses, one off the northern part of the Capricorn Group and another off the southern end of the Bunker Group, show a buried feature similar to the trough at about the same depth as the trough in the central part of the Capricorn Channel.

The trough has small-scale jagged topography on its western side, which is attributed to cemented calcareous material believed to have formed in an inter- or supra-tidal zone. The western edge of the trough is at a depth of 180 to 210 m, from which it slopes down relatively steeply (4-5°) to the bottom of the trough at 210 to 240 m. The trough is 200 to 800 m wide and generally has a smooth horizontal floor, indicating that it has been partly filled by sediment. The eastern edge is lower than the western, and it forms a ridge some 200 to 400 m wide at a depth of 200-220 m. In many places a small terrace is developed on the seaward side of this ridge at a depth of 210-220m.

The trough has been described by Wilson (1967) who commented on its straight trend and suggested that it could have been formed by faulting. However, his seismic profiles show no displacement of the shallow beds, and no displacement was observed in the 1970 BMR profiles. That the trough continues east of the Capricorn and Bunker Groups, as observed in the seismic reflection profiles, indicates that the trend follows that of the 200 m isobath (Fig. 1), and is arcuate rather than straight.

A similar feature has been found in the Arafura Sea at the same depth, from the bottom of which coral of shallow-water origin was recovered (Jongsma, 1970). A dredge haul from the trough in the Capricorn Channel recovered dolomite tubular structures which are almost certainly casts of mangrove root*.

The evidence strongly suggests that the Capricorn Channel trough is related to an ancient strandline, although its form presents some puzzling features. The steep slope on the eastern (landward) side probably represents the shoreline, which past-submergence scour may have contributed to the formation of the trough itself. The low ridge on the seward side is possibly an old sand bar, shell bank, or reef.

*Similar, Recent casts have been found in the intertidal zone in the Broad Sound estuary (P. Cook, per. comm.).

CAPRICORN AND BUNKER GROUPS AND REEFAL BANKS

The reefs of the Capricorn and Bunker Groups represent the southernmost development of surface reefs on the outer part of the eastern continental shelf of Australia. However, they are not barrier reefs, and they have little in common morphologically with the hardline or ribbon reefs of the Great Barrier Reef itself, of which the southern extremity is considered to be the Swain Reefs (Yonge, 1930). Morphologically they are similar to the inner platform reefs farther north, which lie between the outer barrier and the mainland.

The physiography of the reefs that make up the Capricorn Group has been described in detail by Maiklem (1968) and Maxwell (1968a), and it is not intended here to elaborate on their results. However, little work has been done on the reefal banks to the north of the Capricorn Group or on the morphology of the sea floor to east of the reefs, and as these areas were traversed and sampled several times during the 1970 cruise, some details of their morphology is given.

Reefal Banks

The reefs of the Capricorn and Bunker Groups and the reefal banks are aligned northwest-southwest (Figs 1, 3). This trend is believed to reflect the Bunker High (Maxwell, 1968a), a structural high which separates the Capricorn and Maryborough Basins.

The banks between Moresby Bank and North Reef (Fig. 3) are aligned east-west, similar to the orientation of the reefs of the Capricorn Group. Maiklem (1968) considers that this orientation is a result of the tidal currents which flow from east to west and west to east in this area. The banks rise from depths of 55 to 60 m to depths ranging from 8 to 42 m; seas break over the shallower banks in bad weather (Australia Pilot, Vol. III). Most of the banks are fairly shallow, but 20 km northeast of Karamea Bank there is an un-named bank whose least depth is 42 m. This feature (Fig. 4D) has a similar profile to the reefs of the Capricorn Complex (Maiklem, 1968; p. 790), with fairly steep fore-reef slopes rising up to a reef flat, and a central depression which could have once been a lagoon. A dredge haul on the bank in 45 m of water recovered coral sand and gravel. The similarity in profile to existing reefs, and the presence of dead coral, leaves little room to doubt that this bank is a drowned reef which flourished when sea level was about 45 m lower than at present.

Other smaller reefal banks occur in the Capricorn Channel to the east of Moresby and Karamea Banks but at greater water depths. Two traverses crossed banks with a relief of 10 to 12 m at depths of 96 and 103 m while another traverse crossed a bank at a depth of 74 m standing 25 m above the surrounding sea floor. Traverse I (Fig. 5) shows a 12 m bank at a depth of

103m, 22 km east of Innamincka Shoal, and Fig. 4a shows the bank at 74 m. These banks formed earlier than the reefs and reefal shoals to the west, and were probably the forerunners of the reefs that flourished in this region at the end of the Pleistocene.

It is possible that the reefs and reefal banks were built up on sand waves that formed during a time of lower sea level. As the waters warmed and sea level began to rise, the crests of these sand waves could have acted as loci for reef-building communities, some of which have survived to the present day, while others were drowned during the rapid Holocene transgression.

Sea floor morphology east of the Capricorn-Bunker Groups

On the seaward side of the Capricorn and Bunker Groups a sub-horizontal platform extends for 12 to 19 km to the edge of the continental shelf. Depths on the outer part of the platform range from 57 to 64 m (traverses 2-5, Figs. 5-6), except near the southern end of the Bunker Group, where the edge of the platform occurs at a water depth of 78 m (traverse 6; Fig. 6). A number of reefal banks rise from this platform on its outer edge (traverses 3 and 6); these are usually small, but one bank (traverse 6) is 2.5 km wide and has a least depth of 18 m. The flatness of the platform is attributed to two terraces at 57 and 64 m which are quite wide in this area.

The edge of the platform is characterized by small jagged outcrops of coral; these could possibly be remnants of older coral reefs which were subaerially eroded during late Quaternary low sea level stands. At this point the sea floor begins to slope down to the floor of the Capricorn Channel at about 300 m depth. To the north and south (traverses 2 and 6) this slope is very gentle, and it is practically continuous with the sea floor farther east. However, traverses 3, 4, and 5 show relatively steep slopes, with gradients as high as 3.5° along traverse 3, which become progressively gentler to the south; there are relatively abrupt changes in slope between 200 and 300 m, which also become much gentler to the south. The upper part of this slope is indented with small terraces and nick points, whereas the lower part is smooth. Beyond the slope, the sea floor is flat and featureless with gradients of the order of 0.2°.

CURTIS CHANNEL

The Curtis Channel is the passage between the Queensland mainland and the reefs of the Capricorn and Bunker Groups. The channel is constricted near the southern end of the Capricorn Group by a line of reefs extending 28 km west-southwest of Heron Island to Polmaise Reef (Fig. 1). This line of reefs possibly marks a positive structural trend at right angles to that of the Capricorn - Bunker axis.

Overall the sea floor is smooth, except for some local steepening near shore and the presence of a reefal shoal (Rock Cod Shoal) 15 km south-west of Polmaise. Reef. This shoal is morphologically similar to the reefal banks farther north.

HERVEY BAY - BREAKSEA SPIT

Submarine Drainage System Hervey Bay

The continental shelf between the southern end of the Bunker Group and Fraser Island is 80 to 100 km wide and relatively shallow, the shelf break occurring at depths of 60 to 80 m. A large embayment of the 40 m isobath (Fig. 1) extends from the edge of the shelf southwest towards Hervey Bay, as well as minor embayments in the 60 and 80 m isobaths. Between the 40 m embayment and Fraser Island there are a series of submerged linear banks, and farther south in Hervey Bay there are narrow embayments in the 20 m isobath, More detailed contouring by Krause (1967) and Maxwell (1968a) has revealed a clearly defined drainage pattern. Krause found that the channels were cut to a base level of about 64 m which corresponds to a Pleistocene low sea-level stand which has been identified on the continental shelf of southern Queensland and northern New South Wales. At that time the Mary, Burrum, and Elliott Rivers (which now flow into Hervey Bay) entered the sea close to the edge of the present day shelf and their sediment load was delivered directly to the continental slope. Unstable conditions resulting in slumping and channel cutting are likely to have occurred.

Traverse 9 (Fig. 7), which crosses the upper slope and outer shelf, shows a depression approximately 3 km wide and 94 m deep on the upper continental slope. This probably forms part of a submarine canyon system whose presence is suggested by indentation of the bathymetric contours in this region (Fig. 1). A small depression some 600 m wide and 24 m deep which is present on the shelf farther south probably forms part of the same submarine channel system.

The preservation of the steep slope between 60 and 300 m and the incised nature of the upper continental slope indicate that this area was being kept continually clear of sediment. With rising sea level, towards the end of the Pleistocene, the amount of material contributed to the outer shelf and upper slope by the river system decreased. It is unlikely that the canyons are active today.

Sand Waves

Sounding traverses on the outer part of the continental shelf between the southern end of the Bunker Group and Fraser Island revealed the presence of two areas of sand waves: Herald Patches (24°13'S, 152°42'E), and Breaksea Spit, a bank extending north from Fraser Island (Fig. 1). The sand waves have amplitudes of 4 to 12 m and wave-lengths ranging from 100 to 1200 m.

Traverse 7 (Figs. 2, 7), which crosses Herald Patches, shows sand waves with amplitudes of 4 to 10 m and wavelengths ranging from 250 to 1200 m. The majority of sand waves are symmetrical or nearly symmetrical and they are therefore probably static. The crests of the sand waves are apporximately 20 m below sea level with a known least depth of 10 m, according to the Australia Pilot Vol. IV.

A photogeological map prepared for the Australian Gulf Oil Company reveals the presence of ten sub-parallel sand waves whose crest-lines run approximately northwest, the largest being about 8 km long.

Traverse 8 (Figs. 7, 8A) is a profile from west to east across the northern part of Breaksea Spit. On the western side the seafloor rises from 45 m onto the bank at 20 m which supports about twenty asymmetrical sand waves whose amplitudes range from 5 to 12 m and wavelengths from 200 to 500 m. Along this profile the asymmetry of the sand waves suggests movement in an easterly direction across the bank. The eastern edge of the bank is also the shelf break in this area, and beyond it the sea floor descends from 22 m, at a gradient of 3.5°, to about 150 m, after which it levels off slightly.

Traverse 9 (Fig. 7) is another profile across Breaksea Spit, but in a north-south direction. The asymmetrical sand waves have an average amplitude of 10 m and the observed wave lengths vary from 100 to 800 m. Depths decrease southwards and a least depth of 14 m was recorded.

From traverses 8 and 9 it would appear that sand is moving across the northern part of Breaksea Spit in an easterly direction, with the ebb tide, although the hydrographic charts record approximately equal flood and ebb tidal currents in this area. The only place where there is a significant difference in the flood and ebb current velocities is near Herald Patches, where the sand waves are apparently symmetrical! This problem can only be resolved when detailed information on the bottom currents is available.

Sand transported over the eastern edge of the bank rests on the relatively steep upper continental slope, where it may remain until over-steepening or storm surges cause it to be come unstable and move downslope in channels or in massive slumps. The morphology of the upper slope confirms such processes; the slope is considerably incised by 20-40 m deep gullies which are presumably the tributaries of a larger canyon.

Breaksea Spit

The bathymetric chart (Fig. 1) shows extension of the 20 m isobath for some 30 km north of Fraser Island. This encloses an area known as Breaksea Spit, a dangerous shoal consisting of dead coral and sand banks over which the sea generally breaks heavily (Australia Pilot, Vols III and IV). The spit extends to the edge of the continental shelf and effectively cuts off any movement of sand northwards. One of the major transporting agents in this region is longshore drift, which moves great volumes of sand in a northerly direction along the eastern shoreline of Fraser Island to Breaksea Spit, and along the spit to the edge of the shelf.

Sand built up on the edge of the continental shelf and upper slope is periodically removed by storm waves into the canyon heads north and east of Breaksea Spit (Fig. 8B). Krause (1967) considered that an indentation in the 3 fathom (5.5 m) isobath represented the head of a submarine canyon, surely one of the shallowest canyon head depths ever recorded if his supposition is correct. However, this indentation could also represent a channel cut by the strong tidal currents which flow across the spit.

During the late Quaternary, when sea level was lower, but not much lower than about 40 m, the movement of sand down the slope would have been accentuated because longshore drift would have transported the sediment directly onto the continental slope. However, when the shelf was completely exposed by eustatic lowerings of sea level below the shelf break, longshore drift would have diminished, and it is likely that the prevailing winds, the strongest and most regular of which are from the southeast, would have moved sand back across the exposed shelf towards the coast.

The submarine canyons which occur on the slope off Breaksea Spit appear to be in a youthful stage of development; they are not as deeply incised as the canyons farther south, and no clear canyon pattern appears to have emerged as yet (though this may be due to lack of detailed bathymetry). It would seem that the canyons only began to form during the late Pleistocene and that they are still downcutting and widening. The damage caused to a submarine cable in this area at the beginning of the century, and its eventual abandonment in 1923, is an indication that sediment is still moving down these canyons at the present time (Krause, 1967).

The asymmetry of the sand waves north of Breaksea Spit shows that the source of sediment is from the west, while longshore drift along Fraser Island is transporting sediment from the south. Both converge at the northern end of Breaksea Spit near the edge of the shelf, thus concentrating a great deal of sediment in a very narrow, unstable zone. That there does not appear to be any great degree of build-up of sediment on the shelf edge and upper slope indicates that the material is being regularly dumped down the continental slope onto the northwestern Tasman abyssal plain.

MORPHOLOGY OF THE CONTINENTAL SHELF AND UPPER CONTINENTAL SLOPE BETWEEN FRASER ISLAND AND TWEED HEADS

Shelf and Upper Slope off Fraser Island

The continental slope off Fraser Island widens from 22 km in the north to 70 km off the southern tip of the island; the width of the shelf with regard to the mainland is fairly uniform, being everywhere about 80 km. The shelf has a very gentle gradient of about 0.1° and is slightly undulating. The shelf break occurs between 60 and 80 m, becoming progressively deeper to the south, and a number of banks are built up at, or near, the edge of the shelf.

The most prominent bank, Gardner Bank, lies 16 km off the easternmost point of Fraser Island (Indian Head) and is delineated by the 40 m isobath near the edge of the shelf in Figure 1. The bank rises from a terrace at 57 m to a least depth of 24 m. Traverse 10 (Fig. 7) shows the bank to be about 6 km wide, with a relatively steep western side; the upper surface slopes to the east. Apart from the terrace at 57 m there are at least four terraces or nick points on the eastern and western sides of the bank, the most prominent ones occurring at 52 and 31 m. This indicates that Gardner Bank was exposed during a series of low sea-level fluctuations during the late Quaternary and that if formed a low-lying island at that time. A dredge haul on the southern edge of the bank recovered abraded coral gravel and sand.

About 2 km beyond the eastern edge of Gardner Bank a number of small jagged protuberances rise from the sea floor near the shelf break (traverses 10, 11; Fig. 7). These appear to be old coral reefs. Traverse 12 (Figs. 2, 9) shows a bank at least 4 km wide on the edge of the shelf, which rises from a depth of 64 m on its western edge, and is about 15 m high. On the eastern edge, the topography is quite rough and it appears to be coral outcrop. The eastern edge of the bank occurs at 64 m, which is also the shelf break at this particular locality. Sixteen kilometres farther south another bank, 3 km wide and 10 m high, was discovered, whose eastern edge, which is also the shelf break, occurs at 77 m.

The formation of these shelf-edge banks appears to be related to sediment build-up on the edge of the shelf during low sea-level stands and subsequent colonization by reef-building organisms. The original banks were built up by sand movement across the shelf during times of lower sea level, either by longshore drift or perhaps by aeolian processes. With rising sea level these sand bodies became offshore islands or shallow submerged banks which were colonized by reef-building organisms during the late Quaternary. The reefs probably flourished for a short time, but adverse conditions such as rapid rise in sea level or introduction of colder currents inhibited the growth of the reefs and they were gradually submerged.

East of Gardner Bank the shelf break occurs at a depth of 66 m, and the upper part of the slope descends gently with a gradient of 1.5°. Traverse 10 (Fig. 7) shows a prominent mound on the upper part of the slope, which, from seismic profiles, appears to have been formed by erosional processes. Usually, however, the sea floor on this part of the slope is quite smooth (traverse 11; fig. 7), and the upper slope forms a gently inclined platform; this is shown on the bathymetric chart (Fig. 1) by a widening of the isobaths between 200 and 500 m. The platform is inclined to the southeast; its edge is at 240 m to the north, and at about 600 m off the southern end of Fraser Island. This platform may be described as a marginal plateau, although its width of only 6 to 10 km makes it insignificant compared to the marginal plateaux farther north, such as the Marion Plateau. The southeastward slope of the platform may indicate some degree of tilting of the continental margin in this area. However, tilting would have to have been pre-late Pleistocene, as terraces and nick points on the upper continental slope are at a constant depth below sea level.

The edge of the platform marks the junction between the upper continental slope and the main continental slope, and at this point the gradient suddenly steepens from about 1.5° to as high as 10°. Rough topography is often present at the change of slope and Conolly (1969) considers this to be a result of reefs built up during times of lowered sea level. However, an outcrop of non-coralline rock of possible Pliocene age has been dredged from this vicinity (Marshall, 1971), and thus this rough topography is a result of bedrock cropping out on the sea floor at this depth.

At least two submarine canyons are present on the continental slope off Fraser Island. One canyon occurs at about 25°30'S and is shown by indentation of the bathymetric contours in Fig. 1. A second canyon cuts the slope at about 25°50'S, just off the southern tip of Fraser Island, but it is not as well defined by the isobaths as the northern canyon.

Double Island Point to Tweed Heads

South of 26°S, the continental shelf narrows from about 70 km to about 40 km, at 27°S. The shelf is relatively smooth and flat except for a line of coral banks 3.5 to 4 km west of the shelf break. These banks are similar to those off Fraser Island, except that most are farther west of the shelf break and deeper than those to the north. Barwon Bank lies on the outer shelf, some 4 km west of the shelf break, at a depth of 57 m, and is approximately 20 m high; it is shown on the bathymetric chart by the enclosed 40 m isobath at 26°35'S. This bank supports living coral and other reef-environment organisms. The other banks are not as well developed, being only 5 to 10 m high, and they occur at depths ranging from 83 to 96 m.

The shelf break occurs between 90 and 110 m and beyond it the upper slope descends gently with gradients of about 2°; to the south, near 27°S, this gradient decreases to about 1°. The upper continental slope extends for 10 to 14 km, although in places it is only a few kilometres wide where canyons have cut into it. The junction of the upper slope and the main continental slope ranges in depth from 144 to 450 m. Generally, this junction is encountered between 144 and 260 m, but at about 26°10'S there is a gently sloping platform similar to the one off Fraser Island, and this extends to a depth of about 450 m; no rough topography was observed at the junction of the upper continental slope and main continental slope between 26° and 27°S. The main continental slope descends quite steeply, with gradients as high as 11°.

In this area it is difficult to establish where the shelf break occurs. Between 26°15'S and 27°S, there is a poorly defined change in slope at a depth of 90 to 100 m, and below this a gently inclined platform extends to depths of between 144 and 260 m. This platform could be considered to be part of the continental shelf, as it is within the limits of continental shelf depths and the gradient is low. However, it is similar to the platform off Fraser Island, whose eastern edge occurs at depths as great as 600 m. For the sake of uniformity it is therefore intended to delineate the shelf break by the slight change of slope that occurs between 80 and 140 m, and use the term 'upper continental slope' for the gently inclined platform.

The continental slope between 26°30' and 27°20' is deeply incised by canyons, of which the two most prominent occur to the east and southeast of Barwon Bank (Fig. I).

Two large arcuate islands (Moreton Island and North Stradbroke Island) have been built up on the continental shelf off Brisbane. These islands are made up almost entirely of siliceous sand, which extends from about 60 m below sea level to as high as 280 m above sea level (Coaldrake, 1960). On the seaward side of the islands the shelf has a relatively steep gradient to about 60 m, especially off the northern part of Moreton Island

(Fig. I) where the continental slope starts almost immediately east of the island.

Traverse 13 (Fig. 9) is a profile across the continental shelf and upper continental slope off North Stradbroke Island. The shelf has a gradient of 0.7° to a depth of 85 m, after which a terrace extends for about 6 km. At the eastern edge of this terrace, the shelf break occurs at a depth of 88 m. North of 27°15'S coral banks are built up on the edge of the terrace; they are about 10 m high and 1 km wide.

The upper continental slope has a gradient of 1° down to a depth of 180 m, after which the gradient decreases and a gently sloping platform extends for about 7.5 km to a depth of 260 m. Rough topography on the eastern edge of the upper continental slope is probably bedrock cropping out on the sea floor; there is seismic evidence to support this. From 260 m the main continental slope begins to descend gradually, but steepens beyond 500 m.

MORPHOLOGY OF THE CONTINENTAL SHELF AND UPPER CONTINENTAL SLOPE BETWEEN TWEED HEADS AND NEWCASTLE

28° to 29°S

The shelf is 20 to 32 km wide with the shelf break at depths of 86 to 92 m. The shelf consists largely of a series of terraces which step down to a depth of 103 m; the most persistent terraces are at 64, 72, and 82 m. Traverse 16 (Fig. 9) shows terraces at 45, 51, 57, 64, 72, and 82 m. At places small banks 8 to 10 km high are present on the edge of these terraces; traverse 14 (Fig. 9) shows two banks, one at the edge of the 64 m terrace and the other at the edge of a 78 m terrace, and traverse 15 (Fig. 9) shows a coral bank at 92 m.

Beyond the shelf break the upper continental slope extends for 8 to 10 km before merging with the main continental slope. The depth at the edge of the upper slope varies between 200 m (traverses 15 and 16) and 270 m (traverse 14). The upper slope has a gradient of 1° to 1.3°, whereas the main continental slope has relatively steep gradients of 7° to 12°.

Two submarine canyons occur on the continental slope between 28° and 29°S. The northern canyon is situated on the continental slope offshore from the Tweed River and is here called the Tweed Canyon. The southern canyon occurs offshore from the Richmond River and is here called the Richmond Canyon. Although both canyons are off river mouths, there is no evidence of channelling of the surface of the shelf and both canyons appear to head at a depth of 160 - 180 m. Tweed Canyon is clearly displayed on the bathymetric chart (Fig. 1) to a depth in excess of 4000 m whereas Richmond Canyon seems to fade out before 3000 m, although this could be because soundings are inadequate.

Traverse 17 (Fig. 10) is a profile across both canyons on the upper continental slope at a depth of about 200 m. At this depth Tweed Canyon has an apparent width of 6.5 km with an axial depth of 757 m below sea level, and a wall height of about 480 m. The southern edge of the canyon is rugged for about 7 km, and bedrock is most probably exposed along this section of the seafloor as well as on the canyon walls. The topography then smooths out and continues at a depth of about 200 m for 26 km. Richmond Canyon shows an apparent width of 13 .5 km acorss the profile, and an axial depth greater than 800 m. The southern edge of Richmond Canyon has quite rough topography, with pinnacles of bedrock and a small canyon tributary giving relief of some 150 m.

29° to 30°S

The shelf is 28 to 38 km wide and has an average gradient of 0.15°. Traverse 18 to 20 (Fig. 11) cross the shelf in this area. The shelf break is at about 88 m near 29°S, but farther south it is at 102 to 113 m. Well defined terraces are present on the shelf at depths of 57, 64, 93, and 103 m.

Much of the surface of the inner shelf undulates to a depth of about 50 m. Traverse 18 (Fig. 11) shows fairly rough topography of some 8 m relief at a depth of 42 m, which dredging has proved to be a shell bank composed largely of gravel-size molluscan and bryozoan skeletal detritus. Other isolated areas of gravel are as much as 2 km wide, and some contain rounded terrigenous rock fragments of coarse sand to pebble size as well as shell gravel.

Near 30°S the rugged topography on the inner shelf is attributed to bedrock which either crops out on the seafloor or is buried under a thin veneer of recent sediment. Sparker records in this region show seismic basement gradually shallowing from the shelf edge to the inner shelf and eventually cropping out on the inner shelf. A number of islands (e.g. North Solitary Island) rises from the seafloor some 5 to 11 km offshore, as well as numerous shoals and rock pinnacles, some of which are exposed above sea level. Along the coast Palaeozoic rocks form prominent headlands, and so it is probable that the shoals to the east, and seismic basement, consist of rocks of the same age. Similar conditions on the inner shelf extend as far south as Coffs Harbour.

From the shelf break the upper continental slope extends to depths of 300 to 440 m with a gradient of 1 - 2°, but near 30°S (traverse 20) the upper slope has a gradient of about 2.3°. This steepening of the upper continental slope near 30°S is believed to be related to the presence of canyons in this vicinity. The main continental slope has gradients of 7° to 14°, the steeper slopes being related to canyon development.

30° to 31°S

The continental shelf between 30° and 31°S has a width of 25 to 28 km, and an average gradient of 0.3°. The shelf break increases in depth southwards from 100 m at 30°S to about 140 m near 31°S. Terraces are present at various levels on the shelf, the most persistent ones occurring at 64, 103, and 113 m. They often give the shelf a step-like profile.

The upper continental slope is usually smooth and convex in profile, but in places at about 200 m the upper slope levels out somewhat, and in one echosounder traverse three low mounds or ridges were encountered at this depth. These are 15 to 30 m high and range from 700 to 1100 m in width. Phosphatic gravel was dredged from this locality, as well as at similar depths on other parts of the upper continental slope between 30° and 31°S (von der Borch, 1970:

Marshall, 1971). It would appear that these mounds have been formed by concentration of gravel-size sediments on ancient strandlines.

The continental slope is strongly dissected in this area (Fig. 1) by numerous canyon heads and tributaries on the upper slope, which merge into at least five canyons farther down the slope. Many small to medium size rivers enter the sea in this area, but the surface morphology provides no evidence of an ancient drainage system on the shelf. However, these rivers must have crossed the continental shelf during low sealevel stands, and supplied large volumes of sediments to the continental slope, resulting in development of submarine canyons.

Since the canyon system is so large one would expect a large amount of sediment to be present on the abyssal plain at the base of the canyons. Eade & Van der Linden (1970) have described cores taken on the outer continental margin and western abyssal plain at about 31°30'S (cores Z2101 and Z2102). Both these cores have an appreciable terrigneous content and they show features indicative of rapid sedimentation from a much shallower environment.

South of 31°S

The continental shelf immediately south of 31°S consists of a relatively steeply inclined platform with a gradient of about 0.5° (traverse 21; figs. 2, 11). The bathymetric chart (Fig. 1) shows no definite shelf break above 400 m, but near 32°S a shelf break begins to emerge once more at 140 to 150 m; traverse 21 (Fig. 11) possibly shows a shelf break at about 140 m.

Traverse 21 shows rough topography at depths of 170 to 260 m, and a plateau-like feature is present at a water depth of about 215 m. Dredging proved that bedrock crops out at this locality, but no sample was recovered.

EUSTATIC SEA LEVEL CHANGES

Echosounding traverses of the continental shelf and upper continental slope reveal many terraces and nick points probably related to Quaternary low sea-level stands. Some of these terraces can be traced throughout the whole region whereas others appear to be more restricted. Terraces were encountered in almost every traverse, but are best developed on the seward side of the Capricorn and Bunker Groups, and on the shelf and topmost part of the upper slope south of Fraser Island.

The most persistent terraces occur at depths of 57, 64, 77, 85, and 103 m below present sea level; they can be traced from the Capricorn Channel south to 32°S especially the 57 and 64 m terraces. The consistent depth indicates crustal stability during the late Quaternary, unlike the offshore Sydney Basin, where Phipps (1966) has reported warping of late Quaternary terraces by as much as 30 m.

The deepest eustatic feature encountered is the 200 m trough in the Capricorn Channel, but there is no evidence of terraces or nick points at this depth farther south. However, as mentioned previously, a similar trough has been recorded in the Arafura Sea at approximately the same depth and a shallow-water coral from this locality dated by the uranium series method gave an age older than 170 000 years B.P. (Jongsma, 1970). Dill (1968) has reported the presence of terraces at depths ranging between 182 and 214 m on the continental slope around most of Australia. As Jongsma (1970) has suggested, these deeper terraces were possibly formed during the Riss glacial, whereas terraces at higher levels were probably associated with the Wurm glacial and Holocene transgression.

Maxwell (1968a) has recorded stillstands at 29, 58, 66, 88, and 102 m on the Queensland continental shelf, which corresponds approximately with those observed during the BMR's 1970 survey. According to Maxwell there was a transgression from 102 to 29 m, with stillstands at 88 and 66 m, followed by a regression to 58 m. This was followed by spasmodic transgressions to 37 and then 18 m. His results are based on morphological observations and not on radiocarbon dating.

To the east of the Capricorn and Bunker Groups the 57 and 64 m terraces are well developed and form a platform some 12 to 19 km wide. Small terraces and nick points are present at 84, 94, 103, 110, 122, 132, and 160 - 162 m, although not all of these occur on any one traverse. The two dominent terraces are at 94 and 160-162 m (traverses 3-5). Samples of shallow-water coral and beach rock have previously been recovered by submersible at about 175 m and have been dated at 13 600 to 17 000 years B.P. (Veeh & Veevers, 1970). It appears that the terrace at 160 - 162 m was formed at about this time, when sea level began to rise after the Wurm glacial maximum about 15 000 years B.P. The higher terraces and nick points probably were formed during stands of fairly short duration as sea level rose to its present position.

The 57 and 64 m terraces are prominent on the shelf south of Fraser Island and banks are built on them as far south as Tweed Heads (e.g. Gardner Bank and Barwon Bank). South of Tweed Heads terraces are commonly well developed, and there is evidence of at least seven stillstands of sea level during the late Quaternary. Generally, terraces or nick points below 103 m are uncommon. However, the terraces may have been too small to be detected by the wide-beam echosounder used (a Simrad 'Skipper' 38.5 Kc/sec).

Beachrock was dredged from a depth of 183 m just south of Port Macquarie, although no nick point was detected by the echosounder at this point. The rock consists of a porous aggregate of shells and coarse iron-stained sand grains cemented by calcite (aragonite); it has not been dated at present. Farther south beachrock has been dredged at depths of 128 - 137 m (Smith & Iredale, 1924), and Phipps (1970) has reported a radiocarbon date of 17 900 ± 600 years B.P. on similar material recovered from a depth of 128 m. However, the beachrock was most probably formed later, as the complete sample was dated, and shells separated from the matrix gave a date of 24 000 ± 1 000 years B.P.

In any correlation of Late Quaternary eustatic sea level changes and their relative ages, various factors have to be taken into consideration. One difficulty is to determine whether or not the continental margin has remained stable during sea level fluctuations. Vertical movements of the continental margin can arise from either tectonic or isotatic processes, or both. Tectonic warping has been known to occur on continental shelves during the late Pleistocene, such as on the continental shelf off Sydney (Phipps, 1966). Isostatic movements can be of two types: glacio-isostasy and hydro-isostasy. Glacio-isostasy causes uplift or downwarping of the land mass in response to changes in the load of ice (e.g. Fennos-Candian Uplift), whereas hydro-isostasy is essentially downwarping during times of transgression due to the increasing load of water; according to Morner (1971a) there is very little hydro-isostatic uplift during regressions.

Another factor is the reliability of the radio-isotopic dates that have been used to determine the various ages of these eustatic events. Contamination is always a possibility where marine sediments are concerned. Borings by algae and fungi of mollusc shells (Perkins & Hasey, 1971) as well as formation of micritic envelopes by algae (Friedman et al., 1971) can contaminate the material. Even peat and wood are suspect as they may be contaminated by modern carbon, giving a date that may be some thousands of years younger than the true age (Morner, 1971b).

With regard to eustatic sea level changes on the continental shelf of southern Queensland and northern New South Wales, there is doubt as to whether some parts of the shelf have remained stable during the Quaternary. It was mentioned earlier that the higher terraces, such as those that occur at 57, 64, 77, 85, and 103 m can be traced practically along the whole length of the shelf in this area, and that this indicates crustal stability. However, the 200 m trough in the Capricorn Channel is underlain by the Capricorn Basin, an area that subsided considerably during the Tertiary. It may still in fact, be subsiding, and the 200 m trough may have occupied a slightly higher position during the late Pleistocene. The slope on the seaward side of the Capricorn and Bunker Groups has been interpreted as a possible sediment-draped fault scarp and some subsidence may have occurred along this area during late Quaternary times. Wilson (1967) mentions an earthquake that took place on 7 June, 1918, whose epicentre was estimated to be beneath the Capricorn Channel; it may have resulted from movement along this fault.

The terrace dated by Veeh & Veevers (1970) at 175 m is some 45 m lower than the depth attributed to the lowest sea level stand during the second main Wurm Glacial maximum about 15 000 years B.P. This may indicate that there has been uniform subsidence of the sea floor east of the Capricorn and Bunker Groups since the late Pleistocene. If we take Morner's (1971a) view, that sea level was never lower than 85 m during the Wurm Glacial, it follows that the outer shelf has been subjected to downwarping by as much as 95 metres as a result of hydro-isostasy and tectonic instability.

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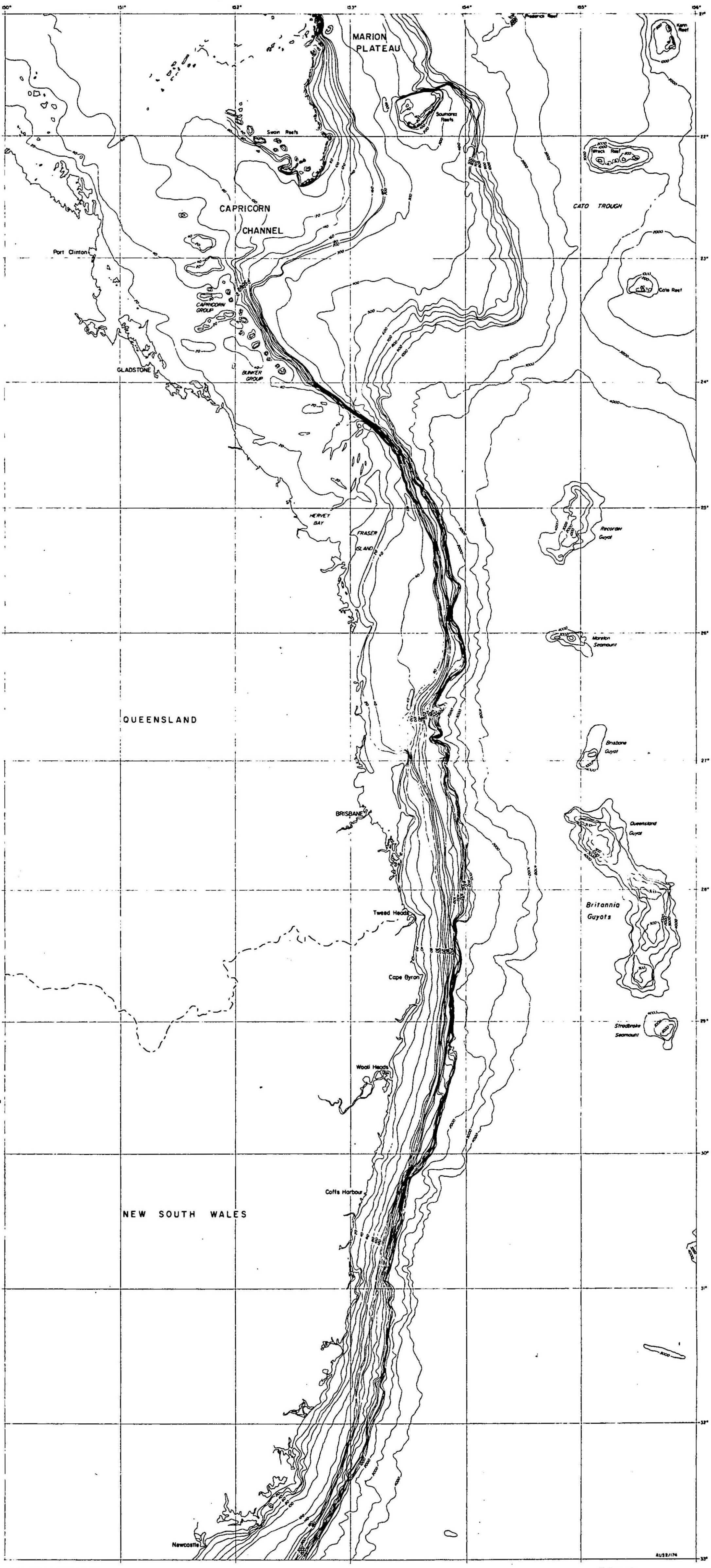
BATHYMETRIC CHART OF THE NORTH WESTERN TASMAN SEA



Bathymetry from Oceanic Soundings Nos 382, 352 and 413, prepared by the Hydrographic Office, R.A.N. for General Bathymetric Chart of the Oceans

To accompany Record 1972/70

10 0 10 20 30 40 50 KILOMETRES

MERCATOR PROJECTION

Depths in metres
Contour interval 20m (20 to 200m)
100m (200 to 1000m)
1000m (over 1000 m)

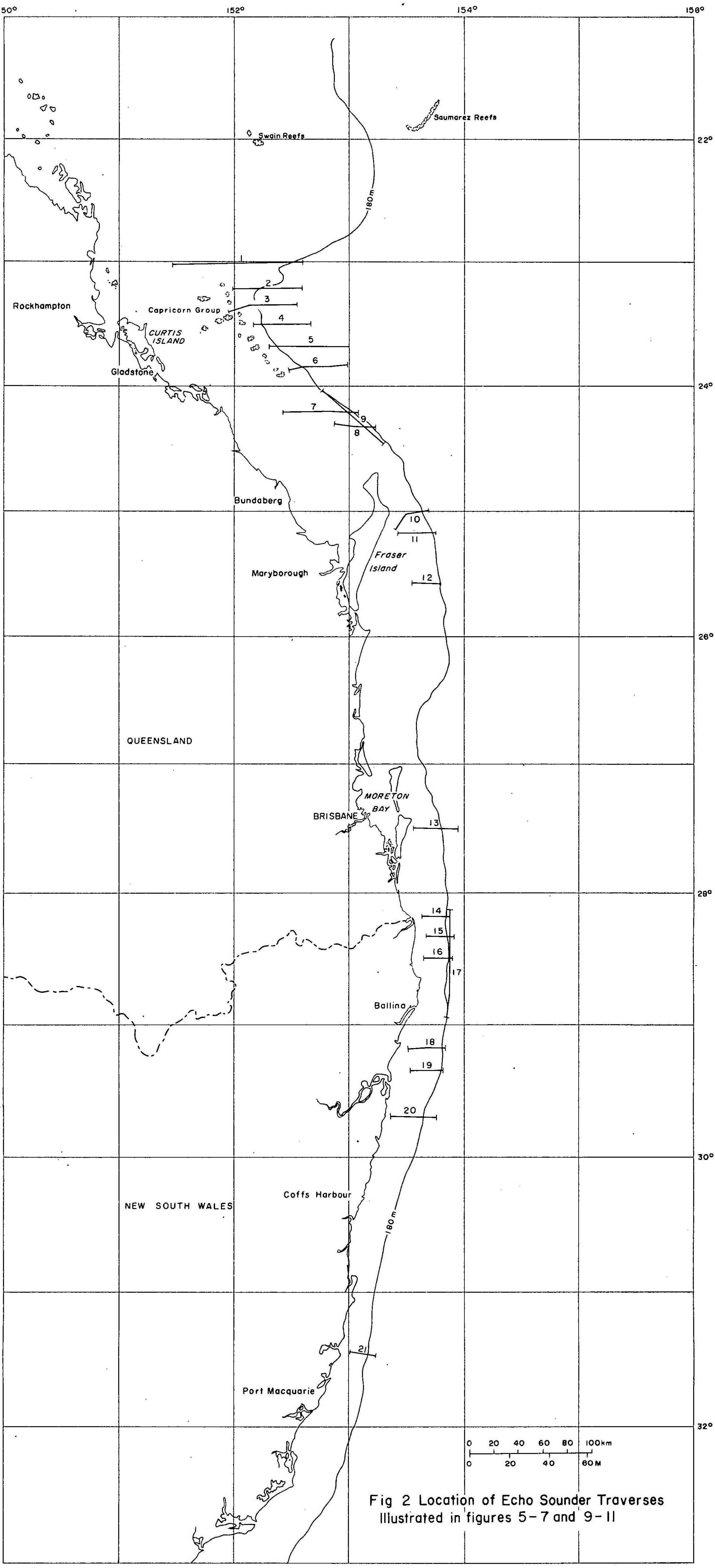


Fig 2 Location of Echo Sounder Traverses Illustrated in figures 5-7 and 9-11

To accompany Record 1972/70

AUS 6/5

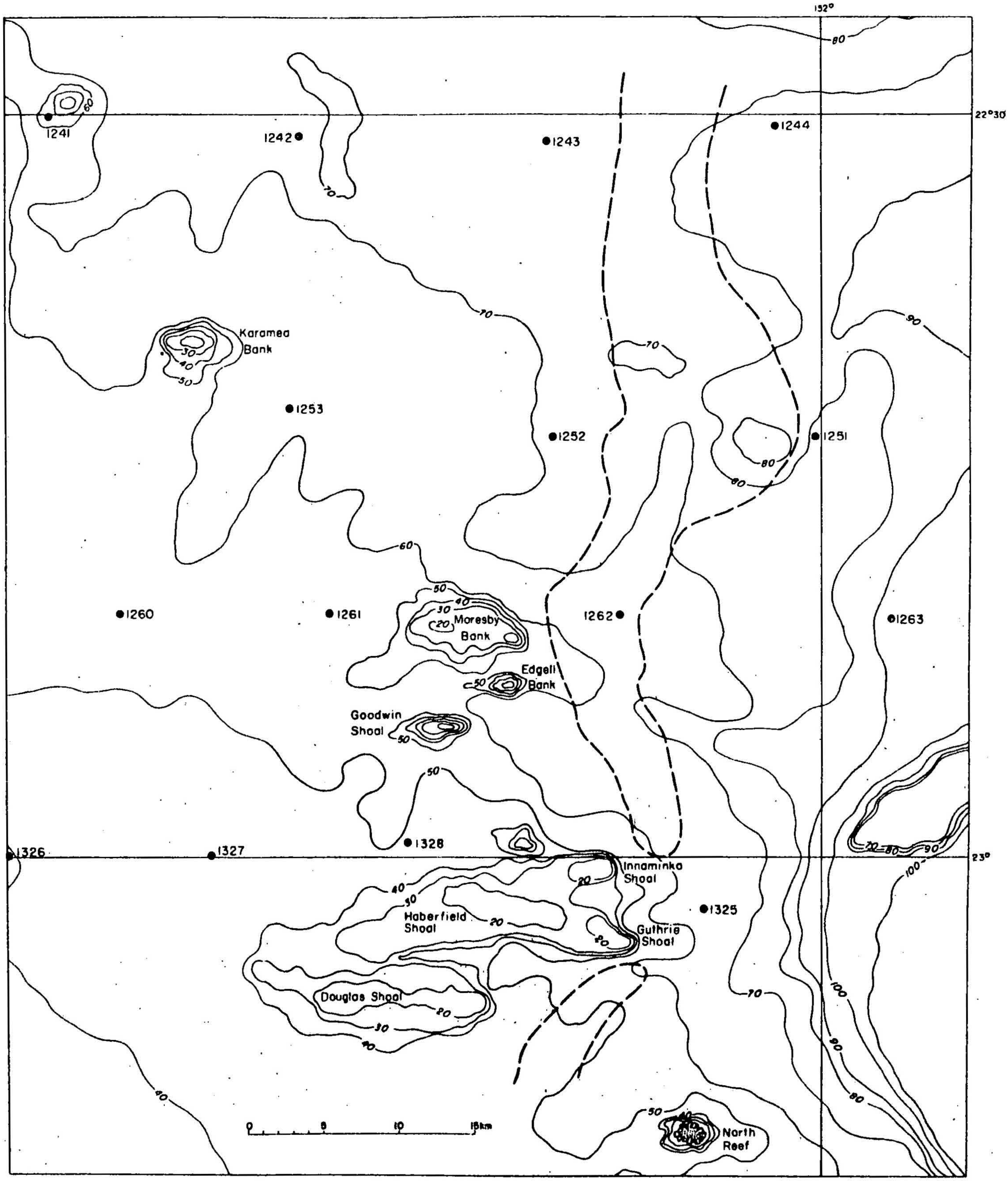
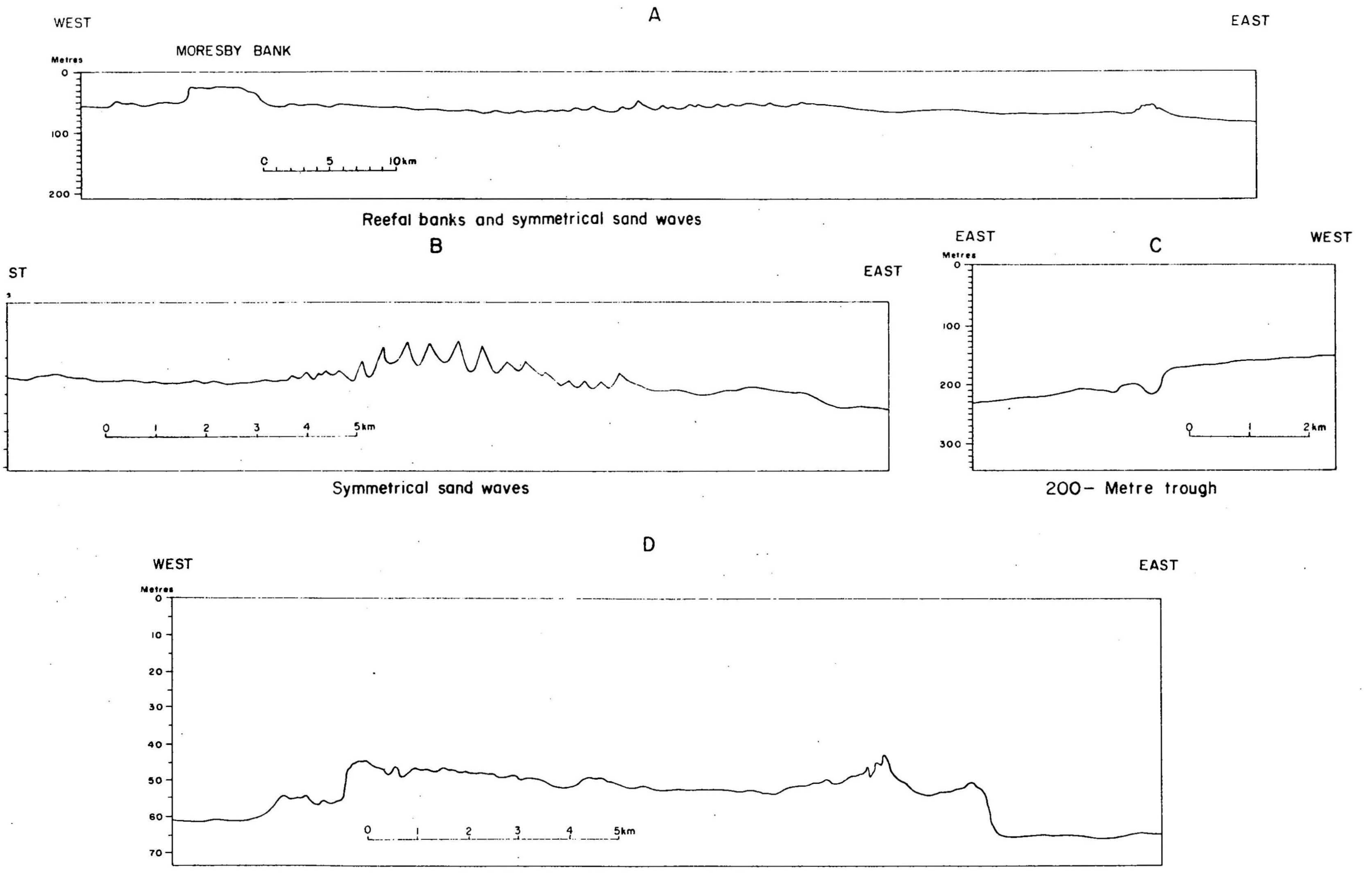


Fig 3 Bathymetric map north of the Capricorn group showing the distribution of the Reefal banks and the approximate extent of the sand-wave province (enclosed by broken lines)

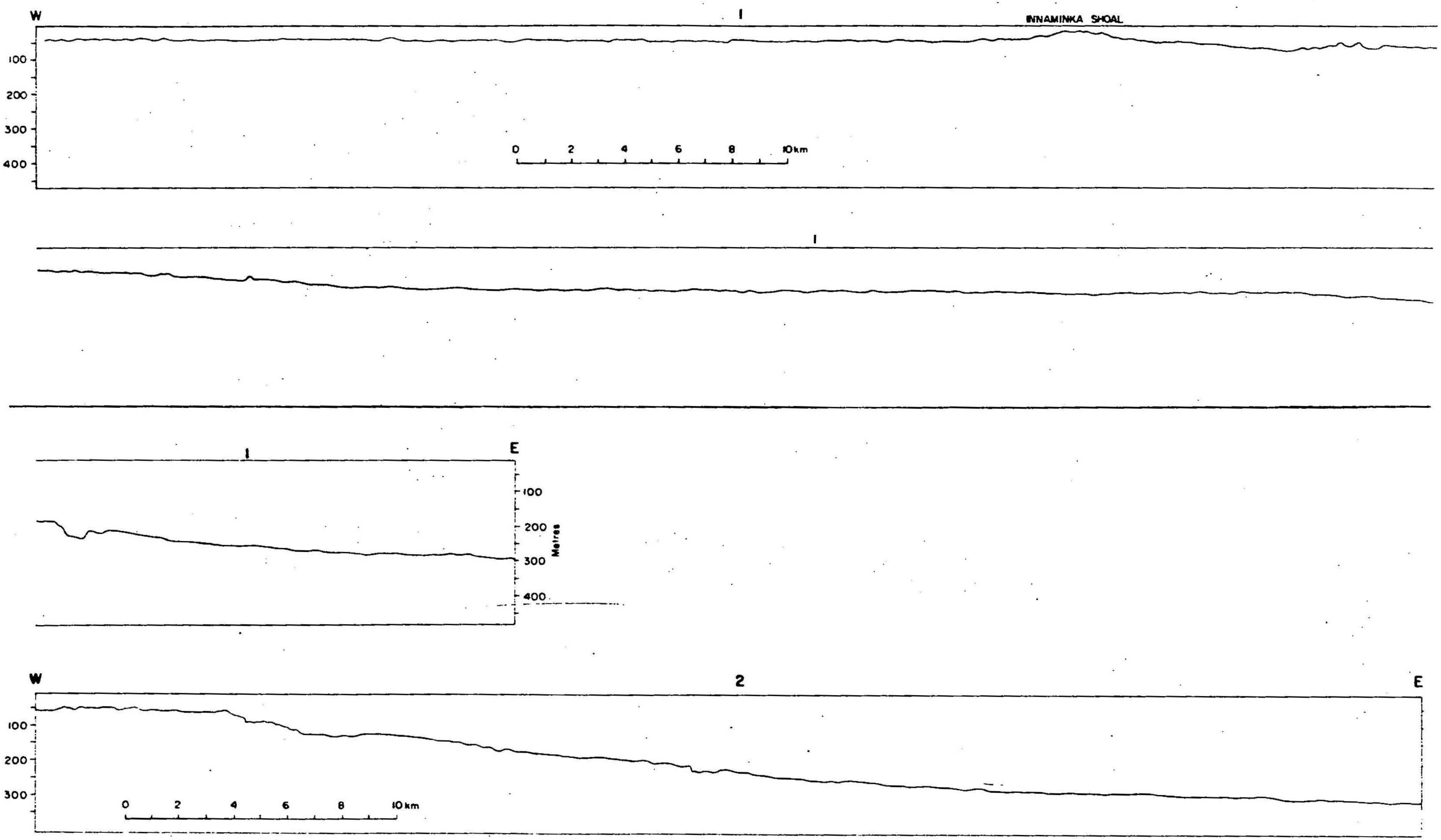
Contours in metres

To accompany Record 1972/70



To accompany Record 1972/70

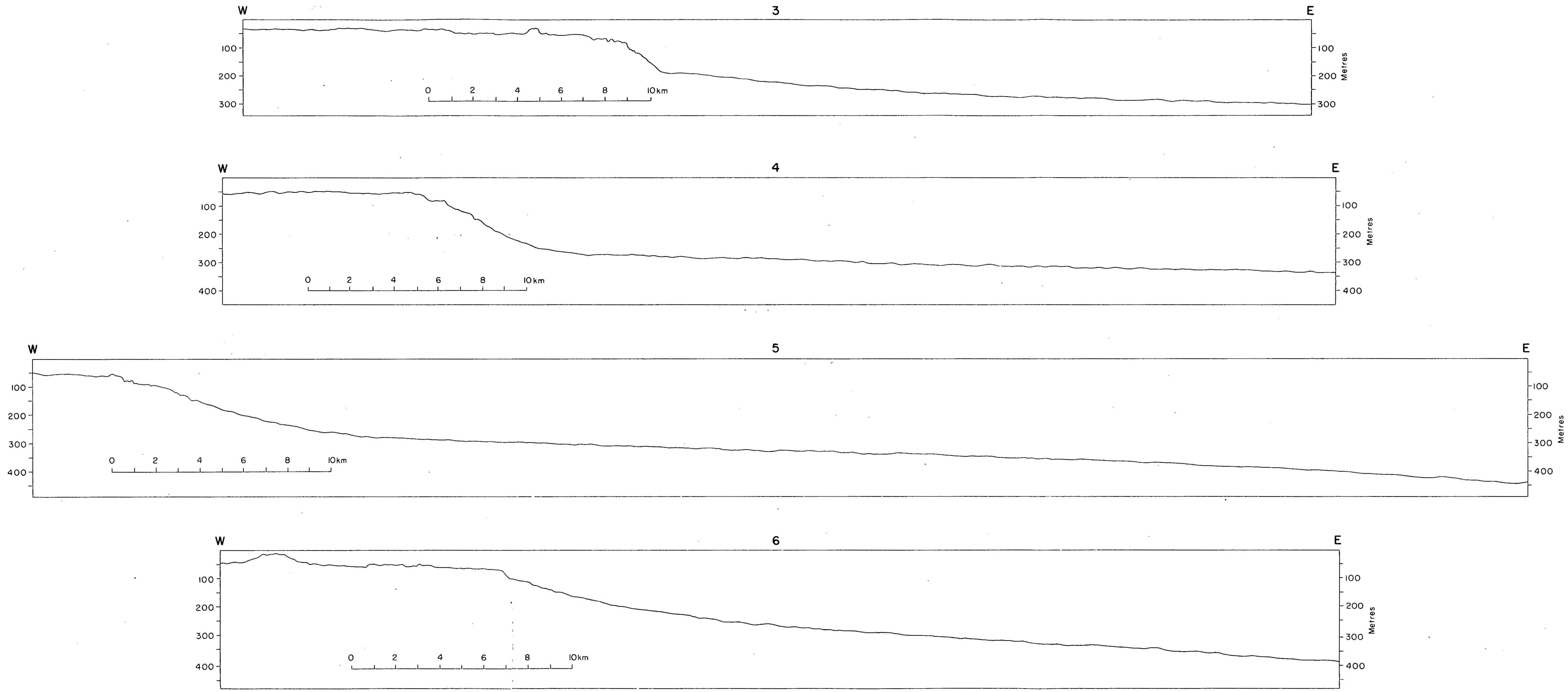
Fig 4 Topographic features in the Capricorn Channel



To accompany Record 1972/70

Fig 5

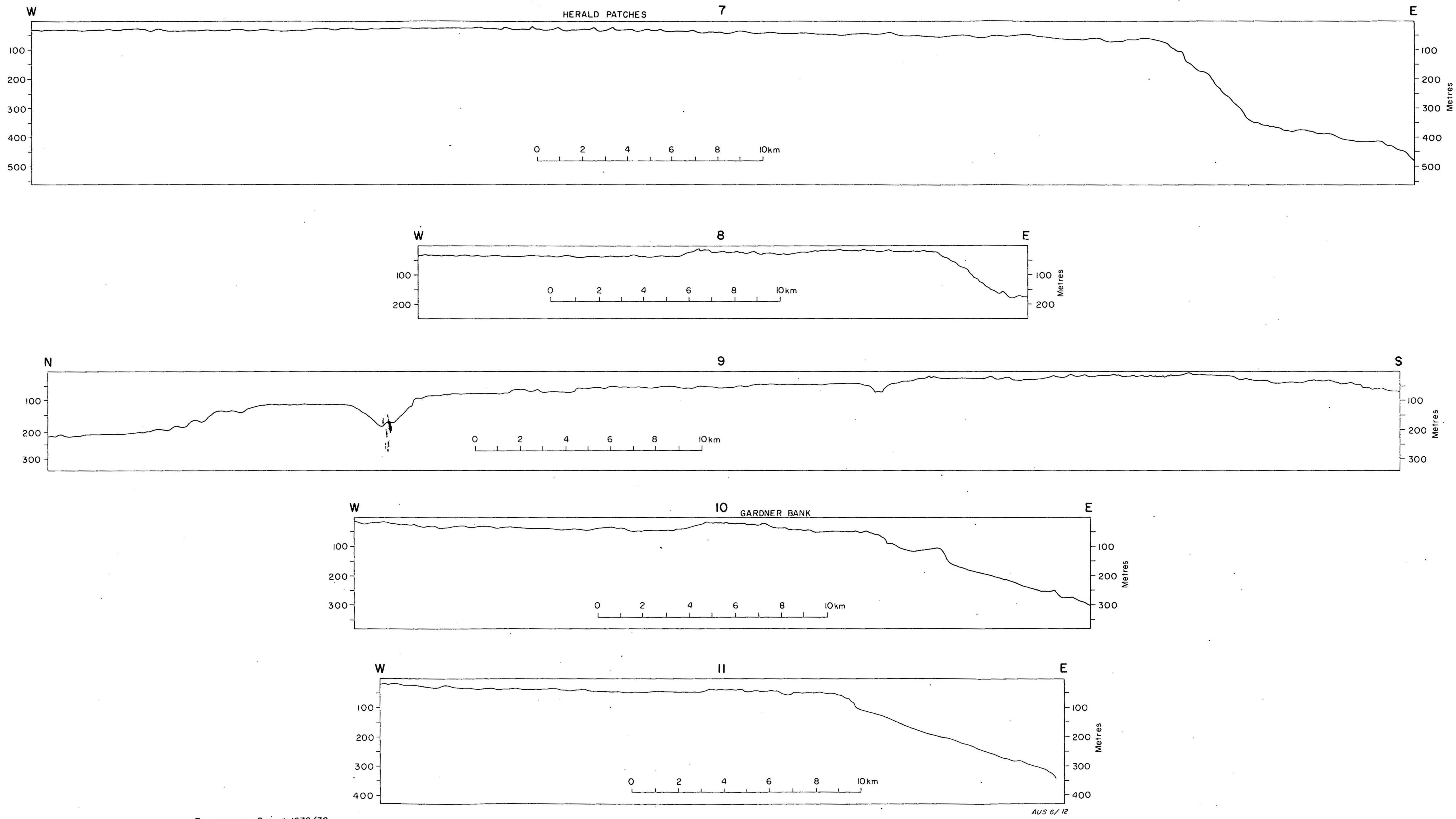
AUS 6/6



To accompany Record 1972/70

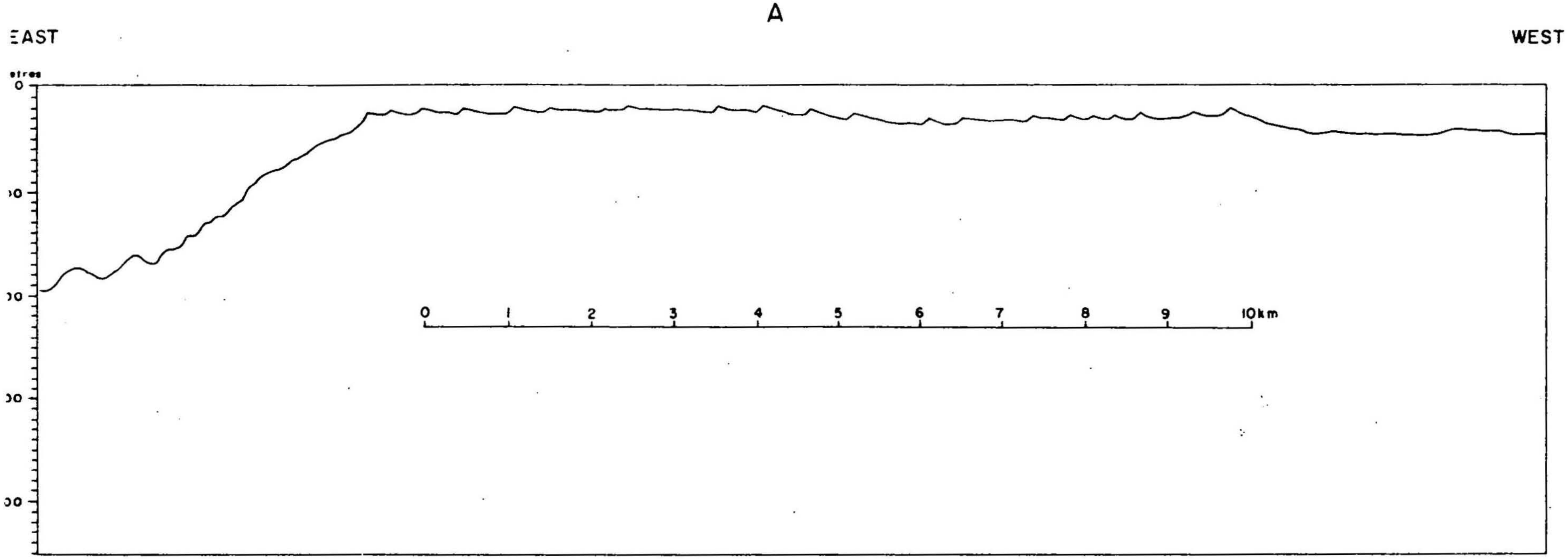
AUS 6/11

Fig 6

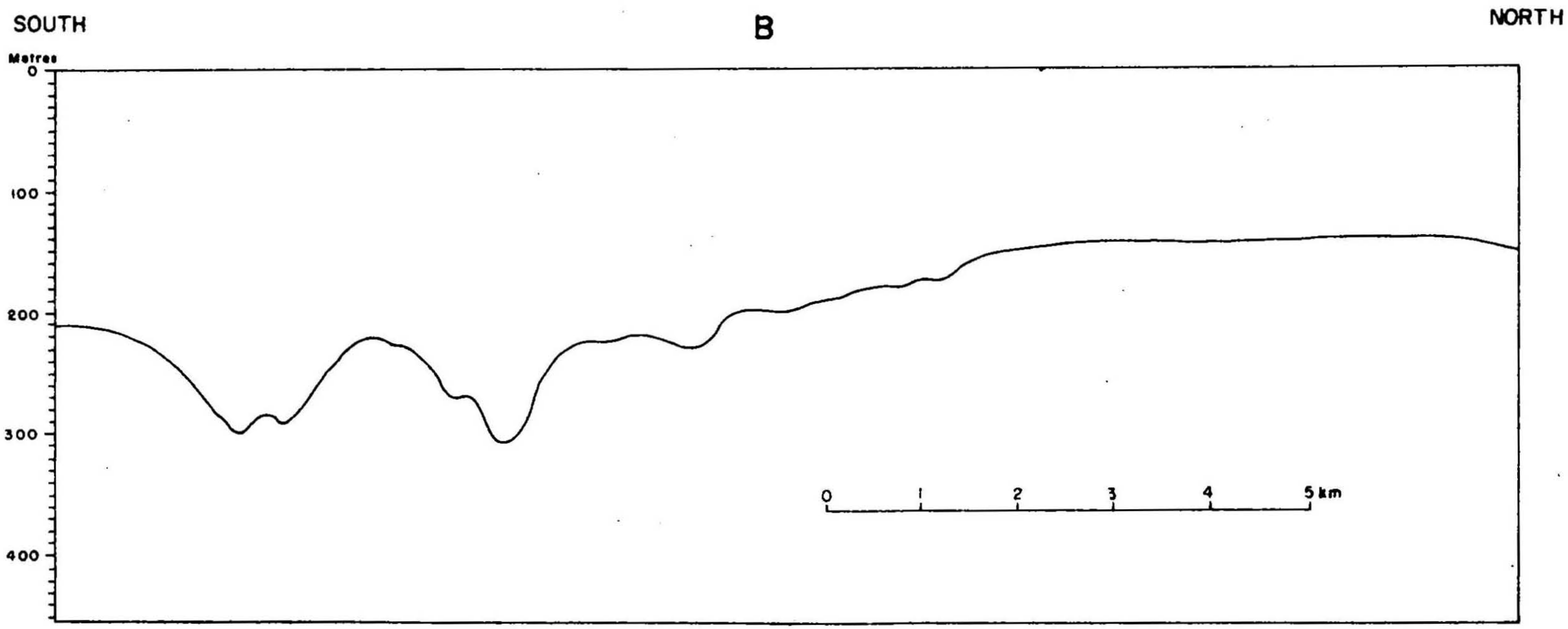


To accompany Record 1972/70

Fig 7



Eastern part of traverse 8 showing assymetrical sand waves on Breaksea Spit

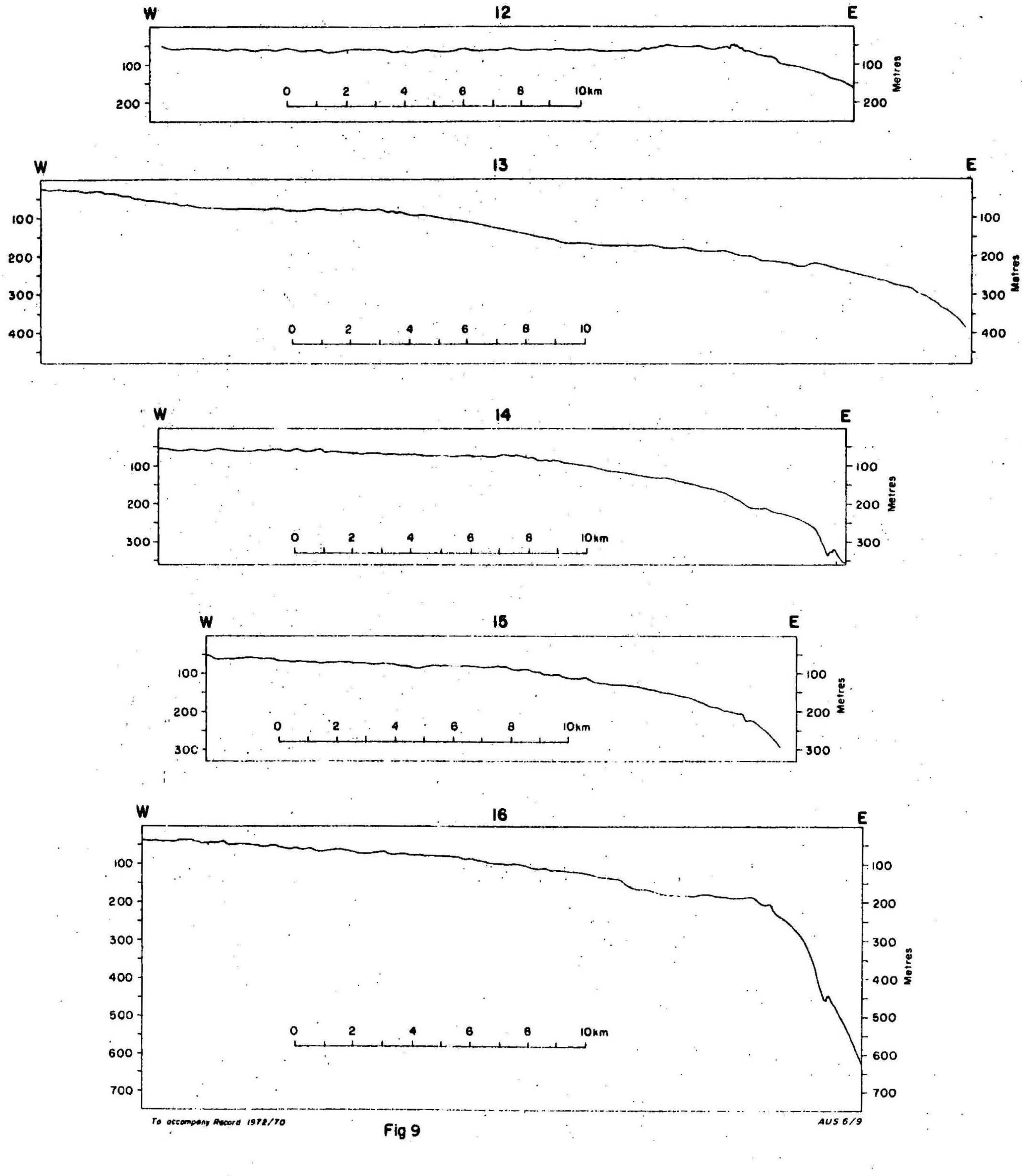


Submarine canyon heads east of Breaksea Spit

AUS6/2

To accompany record 1972/70

Fig 8 Topographic features — Breaksea Spit



To accompany Record 1972/70

Fig 9

AUS 6/9

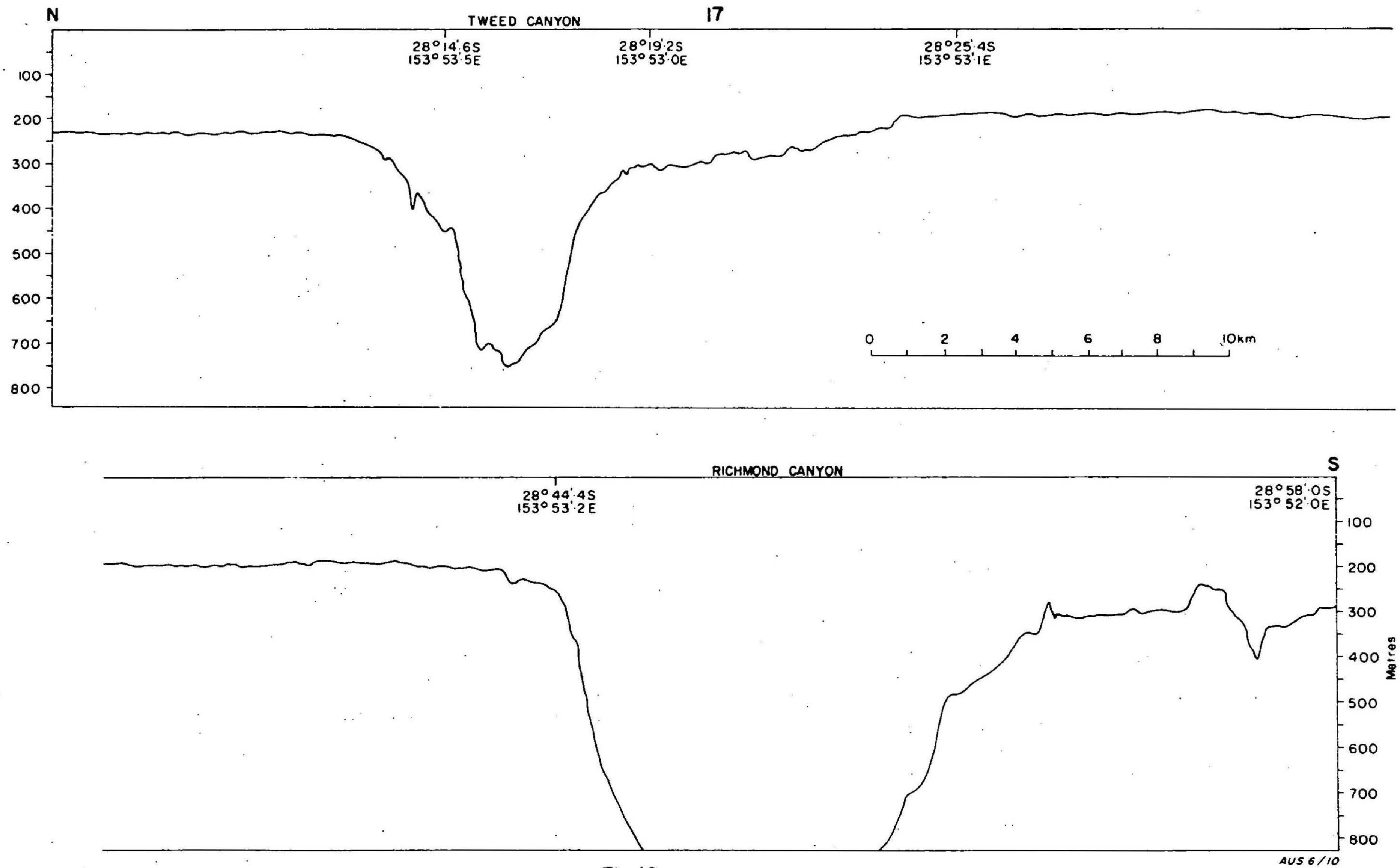
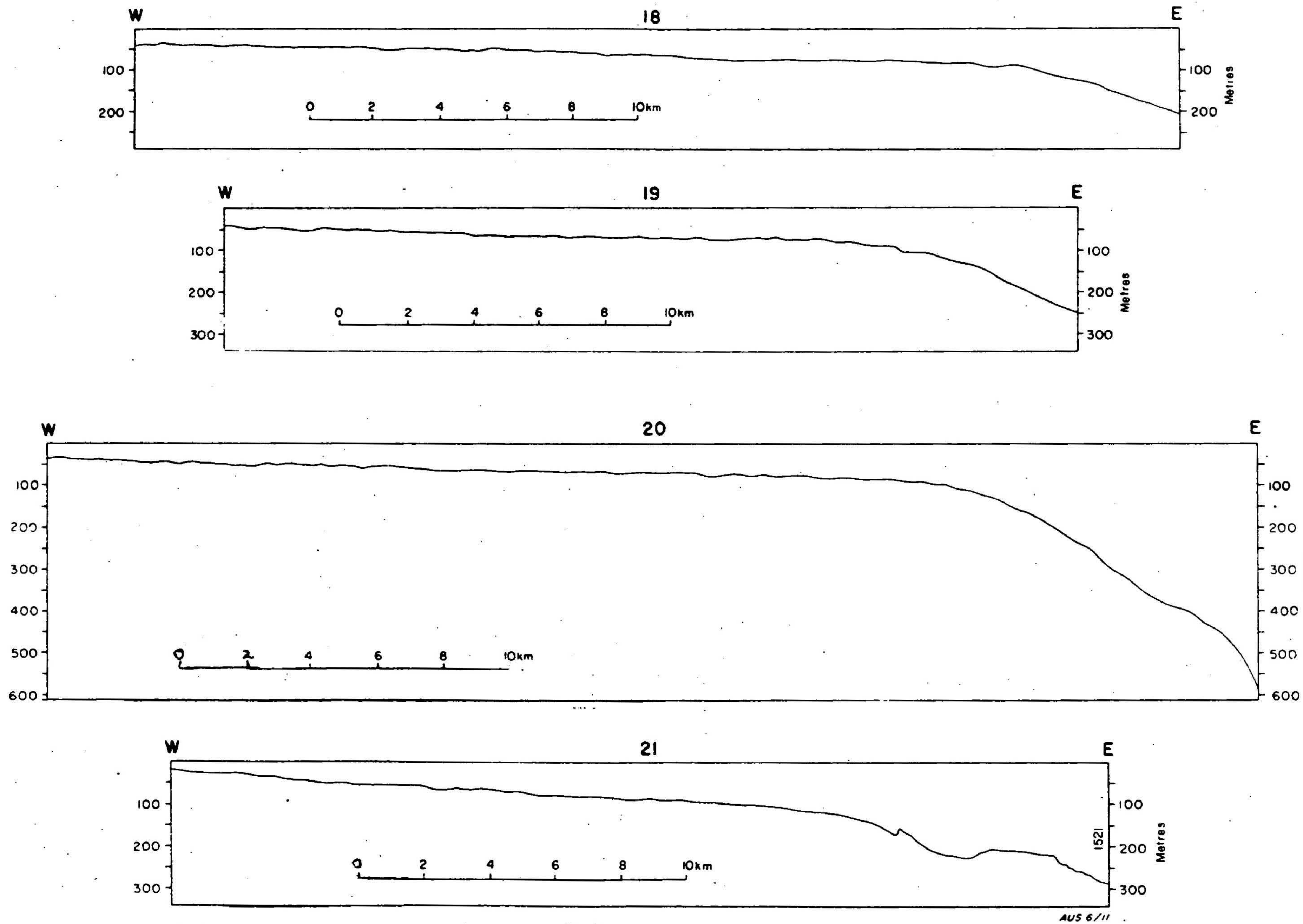

N
TWEED CANYON
17
28° 14.6S
153° 53.5E
28° 19.2S
153° 53.0E
28° 25.4S
153° 53.1E
100
200
300
400
500
600
700
800
0
2
4
6
8
10km
RICHMOND CANYON
S
28° 44.4S
153° 53.2E
28° 58.0S
153° 52.0E
Metres
AUS 6/10

Fig 10



To accompany Record 1972/70

Fig 11