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MORPHOLOGY AND SHALLOW STRUCTURE OF THE CONTINENTAL SHELF OF SOUTHERN QUEENSLAND AND NORTHERN NEW SOUTH WALES

by

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ABSTRACT

The morphology and structure of the continental shelf between latitudes 25° and 32°S have been studied. The inner and mid shelf regions are relatively flat; the only areas which show topographic relief are some parts of the inner shelf where bedrock is exposed, scattered low shell banks on the mid shelf, and wide shallow channels which trend parallel to the coastline. The outer shelf is present seawards of a prominent terrace or nick point at 105 m. It forms a gently sloping, slightly convex surface with a gradient of up to 4°. The depth of the shelf break varies from 210 to 450 m. Variations in the depth of the shelf break are related to topographic variations in the underlying bedrock surface. The upper continental slope is relatively steep with gradients of 7° to 25°. Numerous submarine canyons have incised the continental slope, but they do not extend onto the shelf.

Shallow seismic reflection profiling has revealed that only a thin sequence of sediments is present below the inner and mid shelf, as well as on certain parts of the outer shelf. These sediments have been deposited upon a pronounced erosional unconformity (S_2) that forms an offshore extension of the mainland geology. A sudden change of slope of this bedrock horizon beneath the present shelf break indicates that the position and depth of the shelf break are controlled by the underlying structure. Reflections above S_2 show foreset bedding beneath the outer shelf which in places has been truncated by an erosional unconformity (S_1). It is considered that S_2 represents the breakup unconformity of the western margin of the northern Tasman Basin. The steeply dipping S_2 surface beneath the continental slope possibly represents the western boundary of the initial rift valley.

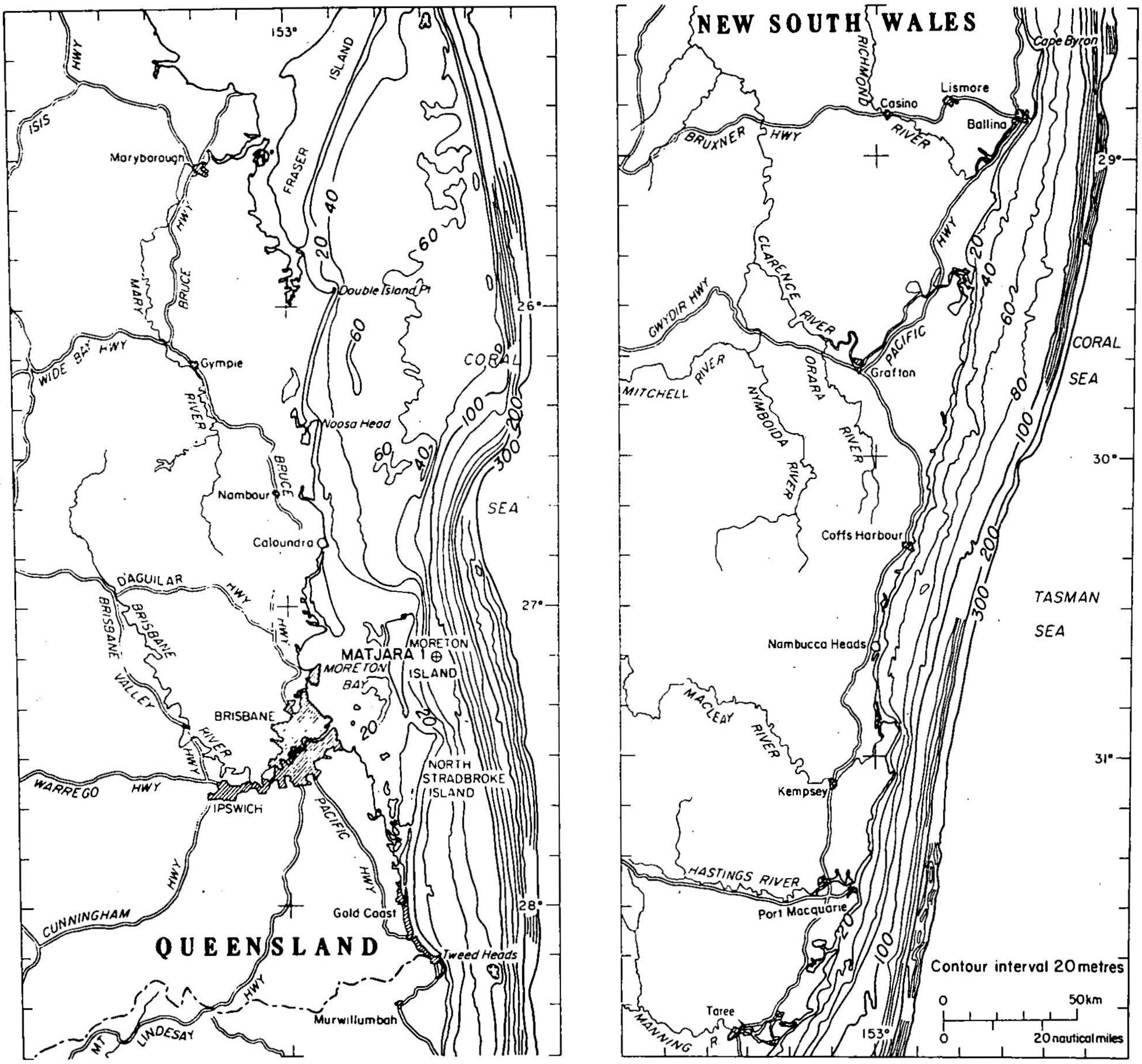

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Plate 1 Bathymetry of the continental shelf of southern QLD and northern NSW (to 300 metres)

INTRODUCTION

A marine geological survey of the continental shelf of southern Queensland and northern New South Wales (Fig. 1) was carried out in 1970 by the Bureau of Mineral Resources (BMR). During the 1970 cruise the continental shelf between the southern part of the Great Barrier Reef and latitude 32°S was surveyed (Jongsma & Marshall, 1971). The marine geology of the northern part of this area, between the Swain Reefs and Fraser Island, has been described by Marshall (1977). The survey consisted primarily of sea-bed sampling and shallow seismic reflection profiling. Sampling stations were positioned on a grid of 10 nautical miles (18.5 km).

Because of the narrowness of the shelf off northern New South Wales it was considered that the 10 n. mile sampling grid employed during the 1970 survey was inadequate. Therefore, additional, more closely spaced sampling stations were occupied on the northern New South Wales shelf during a BMR cruise in 1972 (Davies & Marshall, 1972). Additional seismic reflection profiling was also undertaken.

For both the 1970 and 1972 surveys BMR chartered the MV San Pedro Strait, an oil rig supply vessel of 330 tons gross, operated at that time by San Pedro (Offshore) Pty Ltd. The vessel had an overall length of 36.6 m, and was powered by two 456 horsepower diesel engines giving a cruising speed of 10 knots. Two winches capable of 5 tonnes draw were located on the main deck aft of the superstructure. Ample room on the main deck gave the party plenty of working space. Two portable laboratories owned by BMR were welded to the deck, and a large A-frame with a raised platform was positioned on the stern of the vessel to facilitate dredging operations. The San Pedro Strait was equipped with a Simrad "Skipper" 38.5 kHz echo-sounder, a Decca 202 radar unit, and an Arkas automatic pilot. The echo-sounder display was a straight-line dry-paper continuous record with a 2-range scale to a maximum depth of 1100 m. Position fixing of sampling stations and seismic traverses relied on radar when near the coast; the maxium radar range was 45 km. Celestial navigation and dead reckoning were used when the ship was out of radar range of land.

The vessel was well suited for the purposes of the survey, although she tended to pound heavily in head seas. During the 1970 survey rough seas hampered operations during late October to early December, and 8 days were lost as a result of adverse weather. Failure of the vessel's steering gear resulted in a loss of one week when the vessel returned to Brisbane for repairs. During the early part of the 1972 survey, during late February and March, 2 days were lost as a result of bad weather.

Offshore geology

The continental margin of southeastern Australia was formed by the opening of the Tasman Basin in the period from 80 m.y. to 60 m.y. BP (Hayes & Ringis, 1973). During this period seafloor spreading occurred along a NNW-trending ridge axis, and separated the Lord Howe Rise from the Australian continent. The spreading axis was offset by a series of right-lateral transform faults. Ringis (1972) considered the possibility that spreading in the northern Tasman Basin started in the Middleton and Lord Howe Basins (Fig. 1). He suggested that at about 70 m.y. BP the ridge axis jumped to the west, resulting in rifting between the Dampier Ridge and the east Australian margin. Weissel & Hayes (1977) supported this proposal, and maintained that it is not necessary to invoke a period of subduction at the east Australian margin, as had been proposed by Hayes & Ringis (1973).

Jongsma & Mutter (1978) noticed that the unusually steep continental slope along the southeast Australian margin shows little evidence of pre-rift tectonic elements typical of most Atlantic-type margins. They suggested that the whole pre-breakup rift valley remained attached to the Lord Howe Rise, and implied that spreading occurred along the western boundary fault of a pre-Tasman rift valley.

MORPHOLOGY

Regional bathymetry

The continental margin of southeastern Australia forms the western boundary of the Tasman Basin. To the east the basin is bounded by the Dampier Ridge[1] and Lord Howe Rise (Fig. 1). The northern Tasman Basin (24°-34°S) is usually less than 300 km wide, whereas the central part of the basin is over 1000 km wide. The sudden widening of the basin at about 34°S results from a change in trend of the Lord Howe Rise from north-south to northeast-southwest, as well as the termination of the Dampier Ridge at the same latitude.

Between 25° and 32°S the east Australian continental margin has a relatively narrow continental shelf, an unusually steep continental slope, and a poorly developed continental rise. The shelf varies between 25 and 90 km in width. It is widest in the north, offshore from Fraser Island, but south of 27°S it is usually less than 40 km. The depth of the shelf break is extremely variable. The continental slope has gradients of 7° to 12°, but locally it may be as steep as 25°. The slope is cut by numerous submarine canyons which extend to the floor of the abyssal plain. The continental rise is best developed between 27° and 30°S, where it is approximately 70 km wide. In this area the rise has an average gradient of 2°, and the junction between it and the continental slope is at about 1500 m (P.A. Symonds, pers. comm.). Elsewhere the continental rise is very narrow or is not present at all.

The abyssal plain of the northern Tasman Basin slopes very gently to the south, and the sea-floor is generally flat. Depths range from 4400 to 4800 m (Symonds, 1973). Small abyssal hills are scattered throughout the plain, and seismic reflection profiling has shown that these are local elevations of basement protruding through the sediment pile (Symonds, op. cit.). The abyssal plain forms the upper surface of a thick sedimentary blanket overlying irregular basement topography (Van der Linden, 1970). The sediments that form the abyssal plain have a high proportion of clastic material, indicating supply from the adjacent continental margin (Eade & Van der Linden, 1970).

Rising from the floor of the northern Tasman Basin is a line

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[1] The Dampier Ridge is called the Middleton Ridge on the GEBCO sheet prepared for the International Hydrographic Bureau committee on the naming of seafloor features.

of seamounts and guyots which form part of the Tasmantid seamount chain. A similar line of seamounts form the Lord Howe seamount chain to the east of the Dampier Ridge. The Tasmantid seamounts extend roughly north-south from 21°S to 36°30'S. The seamounts and guyots rise to depths of 400 to 130 m below sea level, except for Stradbroke seamount whose summit is approximately 900 m below sea level. Echo-sounding profiles (Van der Linden, 1970; Slater & Goodwin, 1973) show that the tops of the guyots are characteristically flat, suggesting that they were originally wave-eroded platforms that have subsequently subsided. Although the crests and flanks are generally covered by calcareous organisms (including coral), basalt cobbles have been dredged from some of the guyots (Slater & Goodwin, 1973). The Tasmantid seamounts are considered to be volcanoes which originated during the mid-Tertiary (Conolly, 1969). It has been suggested that they were formed by northward movement of the Australian plate over a fixed mantle plume (Vogt & Conolly, 1971).

The eastern margin of the northern Tasman Basin is formed by the Dampier Ridge. This is a north-trending, broken ridge, about 100 km wide. The top of the ridge has an average depth of 2500 m below sea level, with a known minimum depth of 1800 m. The ridge has fairly rugged relief, and basement crops out on the sea-floor in places (Symonds, 1973). The Dampier Ridge is separated from the Lord Howe Rise by the Middleton and Lord Howe Basins. The floors of these basins are higher than the Tasman abyssal plain. The southern end of the Dampier Ridge changes direction from north-south to northwest-southeast, and trends towards the Lord Howe Rise, but does not intersect it; there is a narrow connection between the Lord Howe Basin and the Tasman Basin which appears to separate the two ridges.

The orientation of the east Australian margin, the Lord Howe Rise, the Dampier Ridge, and the Tasmantid and Lord Howe seamount chains emphasise the predominantly north-south trends within the northern Tasman Basin. Superimposed on this is a secondary northwest-southeast trend, such as the change in direction of the Lord Howe Rise and the Dampier Ridge at the junction of the northern and central Tasman Basin.

The north-south trend implies some form of structural control, but this is at variance with the predominantly northwest-southeast tectonic trend, as delineated by magnetic anomaly profiles in the central Tasman Basin (Hayes & Ringis, 1973). This suggests that the northern part of the Tasman Basin may have formed under somewhat different circumstances from the central part of the basin.

Shelf bathymetry

On the widest part of the shelf off Double Island Point (26^{o}S) a sub-horizontal plain extends to the 80-m isobath, beyond which there is a marked steepening of the outer shelf (Plate 1). The 60-m isobath in this area shows numerous embayments, possibly related to a relict estuarine system. A number of banks are delineated by the 60-m and 40-m isobaths near the junction of the mid and outer shelf.

Off the northern tip of Moreton Island the isobaths define a relatively inclined shelf with a fairly constant slope. This levels off to the south between the mainland and the 100-m isobath, but shows the outer shelf to be slightly more inclined.

Between Tweed Heads and Coffs Harbour the inner and mid shelf regions, out to about the 100-m isobath, form a relatively flat surface followed by a marked steepening beyond 100 m. South of Coffs Harbour the junction between the mid and outer shelf is at about 120 m.

Numerous indentations of the isobaths occur on the outer shelf and upper slope, particularly off Noosa Head, Tweed Heads, Ballina, and north of Coffs Harbour at 30^{o}S (Plate 1). These define the heads of some of the more prominent submarine canyons that occur on the continental margin.

Shelf morphology

Inner shelf. Over most of the area the inner shelf is arbitrarily defined as that part of the sea-floor between the shoreline and the 60 m isobath. The limit of surveying during both cruises was generally the

20 m isobath, so there is little information about the sea-floor shallower than this depth. Most profiles across the inner shelf show it to be relatively flat or gently sloping. In some places the gradient of the inner shelf may be as high as 0.5°. On the inner shelf of northern New South Wales the sea-floor is often hummocky, especially near Coffs Harbour where there are several small offshore islands (the Solitary Islands). Jones & Davies (1979) have shown that this topography is related to outcrops of bedrock on the sea-floor or areas of very thin sediment cover. Figure 2 shows the extent of bedrock on the northern New South Wales inner shelf.

Mid shelf. The mid shelf is generally smooth with slight undulations (Figs 4, 5 & 7). In some areas, such as between 30° and 32°S, the mid shelf forms a gently sloping surface (Traverse 13; Fig. 7). The outer part of the mid shelf is relatively flat because of the presence of broad terraces. There is in places a change of slope at the inner shelf/mid shelf boundary with either an increase or, more commonly, a decrease in gradient on the mid shelf.

Numerous banks and hardgrounds are present on the mid shelf. Towards its outer edge many linear banks or ridges are developed (Jones, 1973a, b; 1974). Dredging has revealed that the banks, especially the outer ones, are composed predominantly of coralline algae; other components include molluscs and Bryozoa.

On the southern Queensland mid shelf, banks are present between 60 and 100 m. There are sometimes two subparallel lines of algal ridges, usually about 4.5 km apart. The algal ridges and banks show fairly low relief, and rise some 5 to 15 m above the surrounding sea-floor. A prominent shoal, Barwon Bank, occurs on the mid shelf at about $26^{\circ}30'$S. The bank rises to a minimum depth of 22 m (Jones, 1973a), and living coral was recovered there by dredging.

Scattered banks are present on the mid shelf off northern New South Wales and there are some discontinuous linear banks near the outer edge. The outer banks are slightly deeper than those on the southern

Queensland shelf, usually between 100 and 120 m. The inner banks are usually deeper than 75 m (Jones, 1974). The banks have a relief of about 5-7 m and are about 100-500 m wide. The southern banks contain a noticeably higher proportion of molluscs and Bryozoa, but coralline algae are still relatively abundant. Parts of the mid shelf are slightly undulating or hummocky, but this is unrelated to subsurface structures as is often the case on the inner shelf.

Jones (1973a, b; 1974) has delineated numerous shallow linear depressions on the mid shelf. They commonly follow a sinuous course roughly parallel to the coast, and may extend for up to 75 km. The depressions are most noticeable on the southern Queensland shelf, but are less well developed to the south. They are fairly subdued features being several kilometres wide, but not more than 4-5 m deep. Commonly the axis of the channel maintains an almost constant depth over its entire length. Jones (op. cit.) concluded that the channels represent a drowned system of coastal swamps and lagoons similar to those behind present-day beaches.

The boundary between the mid and outer shelf is well defined over most of the area. It usually occurs at the eastern edge of a predominant terrace or nick point at a depth of 105 m. Beyond the 105-m terrace the outer shelf is gently inclined, in contrast to the almost horizontal mid shelf. Off southern Queensland the sea-floor often changes slope abruptly at depths of 60 to 80 m and descends to the 105-m terrace (Fig. 8). In some places the 105-m terrace is not well defined, and the junction between the mid and outer shelf is present at the eastern end of an 82-m terrace.

Outer shelf. The outer shelf forms a gently sloping plain with gradients usually of the order of 1^{o} to 3^{o}. On some parts of the outer shelf, especially between 28^{o} and 30^{o}S, the gradient is as high as 4^{o}. In profile the outer shelf is usually convex upwards (Figs 4 & 7). In places the sea-floor levels off slightly just before the shelf break (Traverse 8; Fig. 5), and the sea-floor shows an eroded topography.

Seismic reflection profiling has shown that this decrease in gradient near the edge of the shelf is related to bedrock either cropping out on the sea-floor or being at very shallow depth beneath it.

Between 30^{o} and 32^{o}S changes of slope were identified on both bathymetric and seismic profiles; these are not observed elsewhere on the outer shelf. They range in depth from 187 to 293 m. As many as four changes of slope are present on some profiles. These changes of slope show no depth correlation, and it is concluded that they are not related to previous strandlines. Cobble and boulder size material has been dredged from one of these localities which suggests that they represent areas of lag deposits on the outer shelf.

In the same area (between 31^{o} and 32^{o}S) the bathymetric map (Plate 1) indicates irregular topography on the outer shelf. Echo-sounding and seismic reflection traverses (Traverse 13, Fig. 7 and Traverse 40A-B, Fig. 19) indicate that there has been considerable erosion on this part of the outer shelf.

Shelf break. The shelf break marks the boundary between the gently sloping outer shelf and the relatively steep continental slope. It is generally deeper on the continental margin of southern Queensland and northern New South Wales than most shelf breaks reported from other parts of Australia and other continents (Shepard, 1963). The depth of the shelf break varies between 210 and 450 m. On some profiles the sea-floor is so convex that it is difficult to place the position of the break at any one depth. Jones, Davies & Marshall (1975) have discussed the morphology and origin of the shelf break off eastern Australia. They concluded that deep shelf breaks are unrelated to eustatic processes, but are controlled by depth to basement.

Beyond the shelf break the upper continental slope is relatively steeply dipping. Gradients on the upper slope range from 7^{o} to 20^{o}.

Submarine canyons. The bathymetric map (Fig. 1 and Plate 1) show many indentations on the outer shelf and continental slope, and these are attributed to submarine canyons. Marshall (1972) recorded two submarine canyons on the continental slope off Fraser Island. One canyon occurs at about 25°30' and the other, just off the southern tip of Fraser Island, at 25°50'S.

A complex of submarine canyons is present on the continental slope between 26°10'S and 26°20'S. The submarine canyons in this vicinity are termed in this report the Noosa Canyon System. The upper part of the canyon system is shown in Traverses 19D-E, 28E-F, and 28G-H (Figs 12 & 14). Canyon heads are shown at a depth of about 225 m in Traverse 28E-F (Fig. 14) and deeper heads occur down the slope. The canyon system does not appear to extend onto the shelf, except in Traverse 19D-E (Fig. 12) where it has cut back into the outer shelf.

Another canyon, called here Moreton Canyon, is present on the slope to the south of the Noosa Canyon System at about 26°35'S (Traverse 29D-E; Fig. 15). There is some evidence of canyon heads to the south (Traverse 29A-B, Fig. 15) which might indicate other submarine canyons or a more extensive tributary system of Moreton Canyon.

Two large submarine canyons incise the continental slope between 28° and 29°S. The northern canyon situated on the slope offshore from the Tweed River has been called Tweed Canyon, and the southern canyon, offshore from the Richmond River, has been named Richmond Canyon (Marshall, 1972). 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 (Plate 1). Tweed Canyon is clearly displayed on the bathymetric map (Fig. 1) to a depth in excess of 4000 m. Traverse 9 (Fig. 6) is a profile across both canyons on the outer shelf/upper slope. Here, Tweed Canyon has an apparent width of 6.5 km and a wall height of some 480 m. The southern edge of the canyon shows rugged relief for about 7 km, indicating erosion of the upper sediment sequence. In Traverse 9 Richmond Canyon has an apparent width of 13.5 km and a wall height in excess of 600 m. The southern edge of the canyon has quite rough topography with ridges and small canyon tributaries showing relief of some 150 m. Canyon heads of the Tweed and Richmond Canyons are shown in Traverses 34F-G (Tweed) and 35B-C (Richmond) (Fig. 20).

The bathymetric maps (Fig. 1 and Plate 1) indicate another prominent canyon on the continental slope at 30^{o}S, north of Coffs Harbour. Successive profiles across this canyon, here called Wooli Canyon, are shown in Figure 21. Traverse 30I-H (Fig. 21) shows that the canyon cuts obliquely across the upper continental slope in a southeasterly direction. Bedrock crops out on the walls of the canyon (Traverse 30E-F, Fig. 21). This canyon is somewhat atypical in that there is no corresponding river onshore; the only major river in this vicinity is the Clarence River some 55 km to the north. It does not appear that the Clarence River ever entered the sea to the south of its present mouth as a prominent coastal range occupies this stretch of the coast. The apparent southeasterly trend of Wooli Canyon could indicate that the Clarence River at one stage extended across the shelf in a southeasterly direction towards the head of the submarine canyon. However, the narrow shelf and lack of any apparent barrier off the present river mouth raise serious objections to this interpretation.

Numerous submarine canyon heads (at least ten) are present on the upper continental slope offshore from Coffs Harbour (Traverse 32B-C; Fig. 22). The regional bathymetric map (Fig. 1) indicates numerous canyons on the continental slope between 30^{o} and 31^{o}S. Obviously a large canyon system is present on the slope in this area.

There is very little evidence to suggest that the submarine canyons are active at the present day. The heads of these canyons are present on the outer shelf or upper slope, and although the majority of canyons are present offshore from river mouths there are no obvious connecting pathways crossing the shelf. Echo-sounding and seismic reflection profiling show no channels on the sea-floor or beneath it. An exception is on the inner shelf off the Clarence River (see next chapter).

More detailed echo-sounding profiles (Jones 1973a, b; 1974) show that only broad, very shallow depressions are present, and these run parallel to the coast. Canyon downcutting on the slope probably started during the Tertiary, and it is likely that the main period of downcutting occurred during the Tertiary. It is also possible that the canyons were active during times of low sea level during the Pleistocene.

Terraces and eustacy

Evidence of terraces and nick points is widespread on the inner and mid shelf regions whereas terraces on the gently inclined outer shelf are relatively rare. Marshall (1972) recorded terraces at 57, 64, 77, 85, and 103 m and considered that these terraces are continuous to the north, as far as the Capricorn and Bunker Groups. Jones (1973a, b; 1974) recorded terraces on the southern Queensland and northern New South Wales shelf ranging in depth from 19 to 184 m, but with one exception they were not continuous throughout the entire area. The one terrace that is widespread is at 105 m. The position of this terrace has been marked on the seismic reflection profiles (Figs. 11-22). It was mentioned previously that this terrace commonly marks the boundary between the mid and outer shelf.

On the southern Queensland shelf the 105-m terrace is quite prominent and usually occurs at the base of a marked change of slope. This is shown in Figure 8. The wide-scale preservation of the 105-m terrace suggests that it represents a significant low stand of sea level on the east Australian shelf. Such an event is most likely to be the sea level during the last glacial maximum terminating about 15 000 years B.P. However, the 105-m terrace is considerably higher than last glacial maximum terraces that have been dated elsewhere from the east Australian shelf. A prominent terrace at 160-165 m off the Capricorn and Bunker Groups in the southern Great Barrier Reef has been dated at 13 600 to 17 000 years B.P. (Veeh & Veevers, 1970). Marshall (1977) considers that there has been some tectonic instability in this area. However, the 105-m terrace is also some 23 m higher than beachrock dated at 17 900 ± 600 years B.P. recovered in situ from the outer continental shelf off central New South Wales (Phipps, 1970). No material suitable for dating was dredged from the 105-m terrace during the 1970 and 1972 surveys. Until this is achieved it can only be concluded that the 105-m terrace represents a stillstand of some magnitude.

SHALLOW STRUCTURE

Method

Approximately 2300 km of shallow seismic reflection profiles were run during the 1970 survey, and an additional 800 km during the 1972 survey (Jongsma & Marshall, 1971; Davies & Marshall, 1972). The 1970 profiles (solid lines in Fig. 9) were run on a box-work pattern with east-west lines spaced approximately 18 km (10 n. miles) apart, joined by north-south profiles at each end. The 1972 profiles (broken lines in Fig. 9) were run south of Tweed Heads, mainly parallel to the coast, on the inner, mid, or outer shelf. The profiles figured in the text (Figs 11-22) are exclusively 1970 profiles. The 1972 profiles were used in the compilation of the structure contour and isopach maps.

The seismic profiling equipment consisted of a three-electrode Sparkarray sound source, coupled to an EG & G 232 A power supply unit, type 233 capacitor bank, and model 231 trigger unit. Normally the energy output was 1000 J, but in water deeper than 500 m the energy output was increased to 2000 J. The receiving system consisted of a 30-element MP7 or a 7-element Aquatronics single-channel hydrophone, and the records were produced on an Ocean Sonics GDR-T recorder using 48-cm wet paper. During the 1972 survey some of the records were produced on an EPC graphic recorder. The firing rate was once every second, and a 1-second sweep was usually employed. Ship speed while profiling was reduced to between 5 and 6 knots.

Seismic interpretation

Most profiles show a seaward-thickening wedge of sediments above bedrock. In some profiles the wedge of sediments thins beneath the outer shelf, and bedrock crops out on the sea-floor locally. Within the sediment sequence disconformities are present locally, and south of 28^{o}S a prominent disconformity is present in most profiles.

A. <u>The bedrock reflector</u> (S_2). The prominent reflector below the sediment wedge marks a distinct erosional unconformity between the sediments deposited on the continental shelf and the bedrock that forms an extension of the onshore geology. Numerous shallow bores drilled during heavy-mineral exploration have bottomed in bedrock in the near-shore zone. Sonobuoy refraction work by BMR in 1974 also showed a marked velocity increase at this horizon. The only deep well drilled offshore in this area (Matjara No. 1; Amalgamated Petroleum NL, 1968) recorded no cuttings above 150 m at which depth it was in Ipswich Coal Measures (Triassic). Only brief, discontinuous reflectors were sometimes observed below this horizon, which is referred to as bedrock in the following descriptions. The notation S_2 is used in the text-figure to conform with the usage of Davies (1975 & 1979) who has described the structure of the central and southern New South Wales shelf.

The S_2 structure contour map in reflection time (Fig. 10) shows the broad-scale topographic variations of the bedrock surface. Offshore from Fraser Island a wide topographic high or ridge extends east-northeast from the island with a well defined steepening at its eastern edge (Traverse 15A-B; Fig. 11). Beneath most of the southern Queensland shelf S_2 forms a gently dipping surface with indications of steepening beyond the 500-ms contour.

Offshore from Tweed Heads (28^{o}10'S) there is a marked increase in the gradient of S_2 below 200 ms, and a similar situation exists for most of the northern New South Wales shelf. Between 28^{o} and 30^{o}S, S_2 forms a broad, subhorizontal surface beneath the inner and mid shelf, as shown by Traverses 34 and 35 (Fig. 16). Between 30^{o} and 32^{o}S a more inclined surface is present below the mid shelf. Beneath most of the outer part of the northern New South Wales shelf there is a marked steeping beyond the 500-ms contour while in the extreme south the contours indicate a more gently dipping surface. Some comparison can be made between the attitude of the S_2 surface and the present sea-floor (Plate 1). This suggests that the relief of the sea-floor is partly controlled by the underlying structure, and that the shelf is not in equilibrium with present conditions. This is discussed further in a later section on the origin of the shelf break.

Offshore from the Clarence and Hastings Rivers indentations of the 100 and 200-ms contours indicate downcutting into the bedrock surface by these rivers. Because of the shallowness of S_2 beneath the inner shelf the downcutting could have occurred after deposition on the shelf commenced as well as before deposition. Beneath the upper continental slope the S_2 contours show numerous indentations, particularly between 29° and 31°S. Traverses 34B-C, 30D-E, 37A-B, and 39F-G (Figs 20 & 22) show examples of downcutting. In many places where the indentations are present there is no evidence of existing submarine canyons. It appears that the channels shown in the above traverses represent earlier periods of downcutting and possible canyon formation.

Bedrock is usually present at shallow depths beneath the sea-floor at the western end of most profiles, and its surface dips in an easterly direction beneath the mid and outer shelf. Below the inner shelf, bedrock is seldom more than 50 m below the sea-floor (seismic refraction data for unconsolidated coastal sediments indicate velocities of the order of 2 km/s, and this figure is used for depth calculations of the offshore sediment sequence). In some profiles (30A-B, 32A-B, Figs. 17 & 18) bedrock appears to crop out on the sea-floor, especially in the vicinity of small offshore islands. Jones & Davies (1979) from more detailed shallow seismic reflection profiling on the inner shelf have shown that bedrock outcrops are a common occurrence on the inner shelf off northern New South Wales, particularly between Yamba and Coffs Harbour (Fig. 2).

South of 29°S there is an increase in gradient of the bedrock surface beneath the mid shelf, and it dips at 2-3° below the outer shelf; north of 29°S this change of slope is not evident, and bedrock is subhorizontal or uniformly inclined.

Bedrock relief usually shows considerable variation below the shelf, clearly defining its erosional character, and in places relief is as great as 20-30 m. Profiles between 30° and 31°S (37B-C, 39E-D, 39E-F, and 39G-H, Figs 18 & 19) show a small rise in the bedrock surface beneath the mid shelf. This is analogous to the mid-shelf basement ridge[1] described by Davies (1975, 1979) beneath the central New South Wales shelf. The ridge is too small a feature to show up on the generalised structure contour map, but its position is indicated in Figure 10. It appears to be absent north of 30°S, and while it could not be traced to the south because of the poor record quality of much of traverse 40, it presumably represents the northern extension of the ridge described by Davies. In two profiles a small bank is present on the sea-floor directly above the basement high.

Between 28° and 29°S (Traverses 34 and 35, Fig. 16) bedrock is relatively shallow beneath most of the shelf, and beneath the outer shelf it is present close to the sea-floor. In two traverses (34C-D and 35C-D) it crops out on the sea-floor in the vicinity of the shelf break. A similar situation exists for part of the outer shelf offshore from Fraser Island (Traverse 15; Fig. 11). It is obvious that there has been very little sedimentation on these parts of the shelf, or that erosion has occurred.

In the vicinity of 30°S there is a bedrock ridge beneath the edge of the shelf (Traverses 30A-B and 30G-H, Figs 17 & 18). This ridge has a vertical relief of about 100 m and it has dammed sediments in the lower part of the sequence behind it. In Traverse 30A-B (Fig. 17)

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[1]The term basement as used by Davies (1975, 1979) and Jones & others (1975) is equivalent to the term bedrock which is used here. Basement is used in this text only when referring to results or conclusions presented by the above authors.

a reflection below S_2 rises and eventually merges with it. Considering the lack of reflectors below S_2 elsewhere, it is possible that this reflector represents the surface of an intrusion which has formed the ridge.

The most prominent feature of the bedrock surface is its sudden change of slope beneath the outer shelf, usually below the shelf break. While this change of slope of S_2 is not evident all along the southern Queensland shelf, it does appear south of 28^oS on most east-west profiles that extend to the edge of the shelf and beyond (Traverses 34E-F, 34C-D, 35A-B, 33C-D, 33A-B, 30A-B, 30G-H, 39A-B, and 39E-D, Figs 16-19). On the southern Queensland shelf the only traverse which shows the change of slope is 15A-B (Fig. 11). However, high-energy seismic reflection profiling conducted during the BMR continental margin survey does show that a marked change in slope of the bedrock horizon is present in this area. This change of slope is also present beneath the outer shelf or upper slope off central and southern New South Wales (Jones, Davies & Marshall, 1975; Davies, 1975).

Beneath the upper continental slope S_2 dips relatively steeply, usually about 20^o to 40^o, but locally it dips at 60^o (Traverse 34E-F, Fig. 16). In contrast to the topographic relief exhibited by S_2 beneath the shelf, it is quite smooth beneath the upper slope. Jones, Davies & Marshall (1975) postulated that the smooth basement beneath the upper slope could represent an abrasion platform developed during the initial transgression of the sea across the slope following rifting and opening of the Tasman Sea.

B. The sedimentary sequence. Reflectors above bedrock are predominantly planar and subhorizontal beneath the inner end and mid shelf; some gently dipping reflectors are present in the lower part of the sequence beneath the mid shelf. Below Barwon Bank (Traverse 21A-B, Fig. 13) it is noticeable that the subhorizontal reflectors begin to rise, indicating that the bank is built on a small structural high.

Jones & Davies (1979) recognised an upper and a lower sequence beneath the inner and mid shelf off northern New South Wales. They consider that the two sequences are separated by a disconformity. The upper sequence is usually acoustically transparent, and it thins seawards. Jones & Davies (op. cit.) interpretation of the upper sequence is that it represents the modern nearshore sand wedge together with Pleistocene components. The lower sequence is generally a seaward-thickening prism of sediment, transgressive onto bedrock. This forms the inner or western edge of the main shelf sequence.

Reflectors within the lower sequence show an onlapping relationship with bedrock. This usually occurs where the bedrock surface begins to slope down below the mid shelf or, in the south, on the eastern side of the mid-shelf basement ridge. On the western side of the basement ridge the sediments abut against it. Reflectors showing onlap with bedrock often coalesce to a common point, suggesting that this was the position of a previous shoreline that remained stable for some time. In some of the southern profiles reflectors higher in the sequence coalesce on bedrock at a more westerly point. The conclusion that can be made here is that sedimentation was not synchronous over the entire shelf, and that pulses of sedimentation progressed landwards. This could have been brought about by a combination of eustatic sea level rise and subsidence.

Offshore from the Clarence River, reflectors below the inner shelf show numerous channel structures (Traverses 33A-B, 33C-D, Fig. 17). Bedrock is very shallow in this vicinity, and it appears that the lower channels have been cut into it. This is supported by the indentation of the 100 and 200 ms contours offshore from the Clarence River in Figure 10. Channels higher in the sequence have been cut into post-S_2 sediments. In Traverse 33A-B the tops of the channels are truncated by a horizontal reflector some 30 ms below the sea-floor. This reflector is presumably the disconformity identified by Jones & Davies (1979) which separates their upper and lower sequence. In Traverse 33C-D some channels are visible in the upper sequence. However, the tie-line between the two traverses show that most channels are present in the lower sequence.

This indicates that approximately 30 m of sediment has been deposited on the inner Shelf since the last major period of channel formation. This precludes any extensive channel cutting during the last glacial, and indicates that most channel formation occurred during the early Pleistocene or Tertiary. The number of channels suggests that during periods of lower sea level the Clarence River formed either migratory channels or a braided river system across the inner shelf. The base of the channels is some 90 m below sea level, indicating a river gradient of about 0.4°. The formation of previous river channels supports the contention that a large proportion of the terrigenous sediments deposited on the shelf is fluvial.

Although the seismic sections show a predominance of planar, subhorizontal or gently dipping reflections, some reflectors do indicate disconformities within the sequence. While some of these disconformable reflections can be traced between traverses locally, there appears to be only one disconformity that can be correlated between traverses on a regional scale. This disconformity, designated S_1, is visible in profiles between 28° and 32°S where it forms a prominent reflection beneath the outer shelf and upper slope. Beneath the outer shelf it is usually parallel to the sea-floor, while below the shelf break it increases its gradient and slopes downwards (Traverses 34A-B, 35E-F, 33C-D, 33A-B, Figs. 16 & 17). The S_1 surface has the attributes of a previous sea-floor, showing a gently sloping outer shelf, a prominent shelf break directly beneath the existing shelf break, and a relatively steep upper slope. In places where there has been erosion on the upper continental slope, S_1 crops out on the sea-floor (Traverse 30G-H; Fig. 18). S_1 truncates the underlying sediments and onlaps the bedrock (S_2) surface beneath the mid shelf. Where basement is very shallow beneath the outer shelf S_1 was not observed (Traverses 34C-D, 35C-D, 35A-B, Fig. 16). In Traverse 34F-G (Fig. 20) there are indications that erosion has removed part of the sediment sequence, including S_1. This could explain the absence of S_1 in areas where S_2 is close to the surface.

The S_1 horizon appears to be a similar disconformity to the one described by Davies (1975, 1979) beneath the continental shelf between 32^{o} and 35^{o}S. On the basis of Gippsland well data, Davies considered that S_1 is equivalent to a middle to lower Pliocene unconformity. The shape of the S_1 surface, its attitude to the reflectors both below and above it, and the indication of a prolonged hiatus, suggest a prolonged period of regression and subsequent transgression on the shelf. S_1 represents the surface of transgression which truncated the underlying sediments and sculptured the sea-floor into a typical shelf profile.

On the southern Queensland shelf S_1 could not be recognised with any certainty. One exception is Traverse 19A-B (Fig. 12) where a prominent reflector truncates a lower sequence of foreset beds. Another prominent reflector is present close to the sea-floor on the outer shelf (Traverses 21A-B, 21F-G, 26G-H, Fig. 13), and in two traverses (21F-G, 26H-G) it appears to crop out near the edge of the shelf. This reflector, although smooth beneath the mid shelf, shows erosional characteristics, such as channel structures on the outer shelf. The undulating nature of the sea-floor near the shelf break in Traverses 21F-G and 26G-H is attributed to this reflector cropping out on the sea-floor.

Beneath the outer shelf and upper slope many traverses show a thickening wedge of sediments, and in some traverses (21A-B, 33C-D, 33A-B, and 30G-H, Figs 13, 17 & 18) foreset bedding is well developed. These large-scale foresets are usually observed below S_1, and they are truncated by S_1. Towards the base of the foreset sequence, near S_2, the angle of inclination is fairly low, while towards the top the angle of inclination increases. In Traverse 30G-H (Fig. 18) one sequence of foresets has its topsets truncated, and a second sequence has built out from it. These have then been truncated by S_1.

Beneath the outer shelf south of 29^{o}S reflectors in the lower part of the sequence are predominantly parallel to S_2, and in some traverses they are also parallel to the sea-floor (Traverses 37B-C, 38A-B, 39A-B, 39B-D, 39E-F, 39G-H, and 40A-B, Figs 18 & 19). This lower sequence (usually about two-thirds of the section) is truncated by S_1.

In profile it appears that the lower sequence has the attitude of low-angle foresets, whereas in reality they have been deposited uniformly on a subsiding S_2 surface and then truncated by S_1.

Above S_1 there is a difference in the style of bedding from that below it. Reflectors in the upper sequence show a draping of sediments over the S_1 surface, and the present sea-floor shows a similar attitude. This change in the style of bedding is possibly related to an increase in the water depth on the outer shelf since the formation of S_1, with a resultant decrease in energy and sedimentation rates. In one traverse (40A-B, Fig.19) fairly low-angle foresets are present above S_1, suggesting a higher-energy regime in this area.

Evidence of erosion beneath the outer shelf is shown in Traverses 30G-H and 40A-B (Figs 18 & 19). Beneath the canyon head in Traverse 30G-H the upper sequence contains irregular reflectors suggestive of erosion and subsequent infilling. In Traverse 40A-B (Fig. 19) reflectors in the upper sequence have been truncated, and crop out where there is a depression of the sea-floor. Channel structures are also present in the upper sequence beneath the eroded part of the outer shelf.

Beneath the upper slope reflectors, including S_1 and S_2, dip relatively steeply and commonly crop out on the sea-floor. Evidence of erosion is widespread, particularly in the vicinity of submarine canyons. In these areas reflectors show disrupted bedding, and they sometimes crop out on the walls of the canyons (Traverses 19D-E, 28G-H, 29D-E, 30I-L, 30H-I, 30G-F, and 32B-C, Figs 12, 14, 15, 21 & 22). Evidence of previous canyon heads that have now been infilled is shown in Traverses 28E-F, 29A-B, 30D-E, 37A-B, and 39F-G (Figs 14, 15, 20 & 22). The existence of previous canyon heads points to a pre-Pleistocene age for the initiation of canyon downcutting. This is in agreement with the ages of submarine canyons present on the southeastern and southern continental margin of Australia which are considered to have formed during the Tertiary (Davies, 1979; von der Borch, 1968).

There are marked contrasts between the thickness of sediment on the outer shelf and on the upper slope. Some traverses, particularly those north of 29°S, show a relatively thin sediment sequence on the outer shelf and a thick sequence on the upper slope (Traverses 15A-B, 34E-F, 34D-E, 34A-B, 35C-D, and 35A-B, Figs 11 & 16). South of 29°S the opposite is often the case, and there is a relatively thick sequence on the outer shelf and a thin sequence on the upper slope (Traverses 33C-D, 33A-B, 30G-H, 39A-B, 39B-D, and 40A-B, Figs 17-19). There is also a difference in the attitude of S_2 to the north and south of 29°S. Where sediments are thin on the outer shelf S_2 is subhorizontal, but where there is a relatively thick sequence on the outer shelf, S_2 is inclined at an angle of 2-3°. This suggests that the sediment load has caused depression and tilting of the bedrock surface.

An isopach map (Fig. 23) which shows the thickness of sediments above bedrock illustrates this contrast in the sites of deposition. Areas where there is very little or no sediment on the outer shelf are present off Fraser Island and between 28° and 29°S. Between 30° and 32°S thinning of the sediments on the upper slope is evident. In some areas, such as the southern Queensland shelf between 25° and 27°S, there is a continuous seaward thickening of sediments.

Other features illustrated by the isopach map include the thin sediment sequence below most of the inner shelf. The map shows that there is usually less than 50 m of sediment on the inner shelf, and in some nearshore areas there is none. Jones & Davies (1979) have delineated more extensive areas of bedrock on the inner shelf than shown here. A thickening wedge of sediments is present below the mid shelf between 25° and 27°S, and 29° and 32°S. Most of the mid shelf between 27° and 29°S has a relatively thin cover.

Amalgamated Petroleum NL (1968) indicated that only 24 m of unconsolidated sediments is present overlying bedrock in the Matjara No. 1 well. However, this was only an estimate because no cuttings were recovered from the top 150 m of the drilled sequence. From the isopach map it would appear that at least 100 m of sediment is present above S_2 in the vicinity of the well.

The origin of the shelf break

The shelf break off southern Queensland and northern New South Wales shows depths ranging between 210 and 450 m, which is considerably deeper than the world average for shelf breaks (about 140 m). The shelf break in this region is too deep to have been influenced by erosion during the last low sea level period in the Pleistocene, the process normally regarded as responsible for the formation of shelf breaks; its depth is related to variations in the depth of the bedrock surface (S_2), in particular to the depth of the abrupt change in slope of the bedrock surface beneath the shelf break (Traverses 15A-B, 34E-F, 34C-D, 35C-D, 35A-B, 33C-D, 33A-B, 30A-B, 30G-H, 39A-B, and 39B-D, Figs 11, 16 17, 18 & 19). This relationship between the depth of the shelf break and the depth of the change of slope of S_2 is illustrated in Figure 24. The shelf break between 28° and 31°S was chosen because the break is clearly defined, as is also the change in slope of S_2.

Jones, Davies & Marshall (1975) concluded that where the depth of the shelf break along the southeast Australian margin is greater than 200 m, its depth is related to the depth of basement (i.e. S_2), and that the morphology of the sea-floor reflects the relief of the buried basement surface over which the sediments are draped. Shelf breaks shallower than 200 m, such as on the central and southern New South Wales shelf, have been modified by wave base erosion during Pleistocene low sea levels. However, even here the depth of the shelf break still appears to some extent to be related to the bedrock morphology (Davies, 1979).

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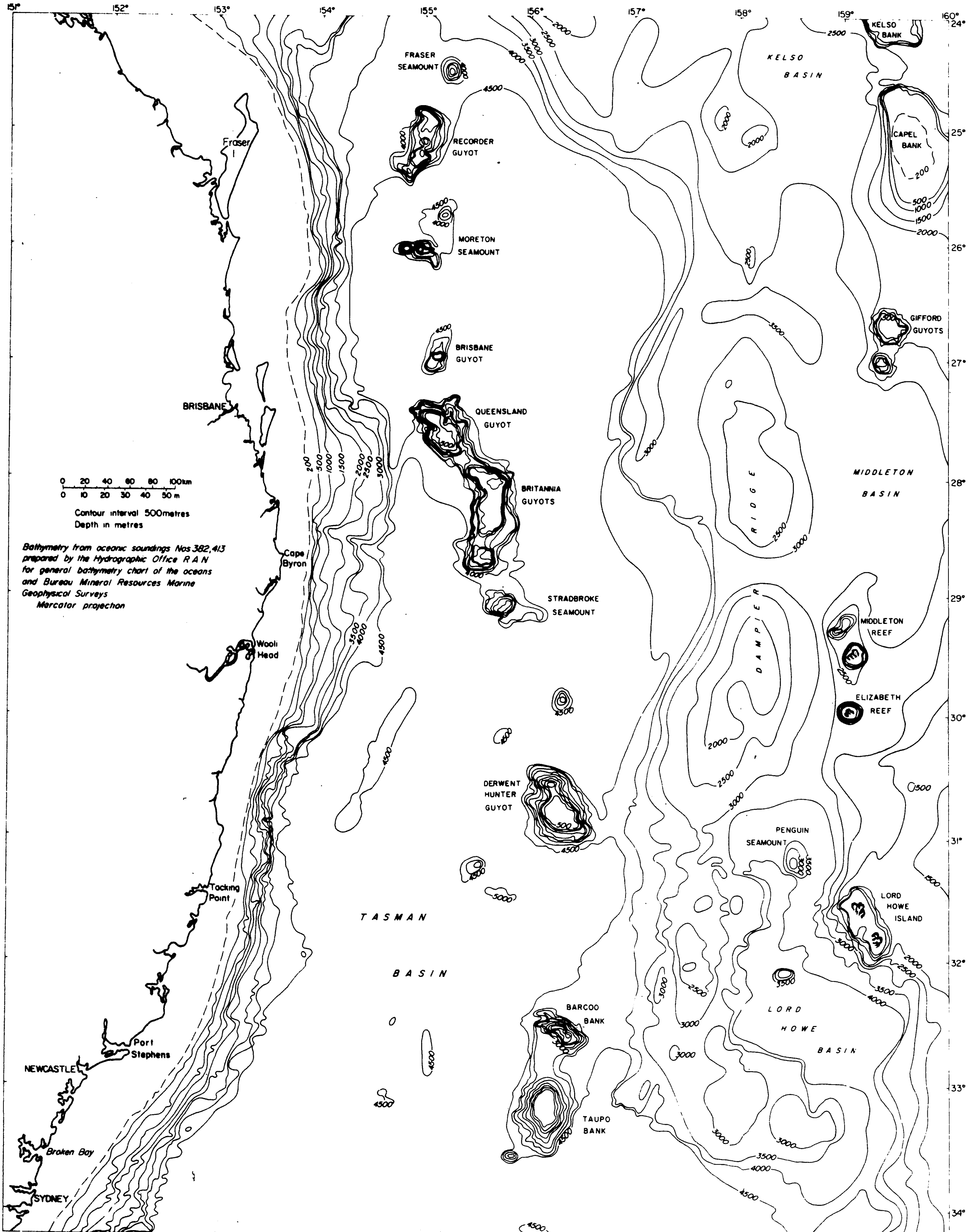

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AUS 6/413

Fig. 1 Regional bathymetry

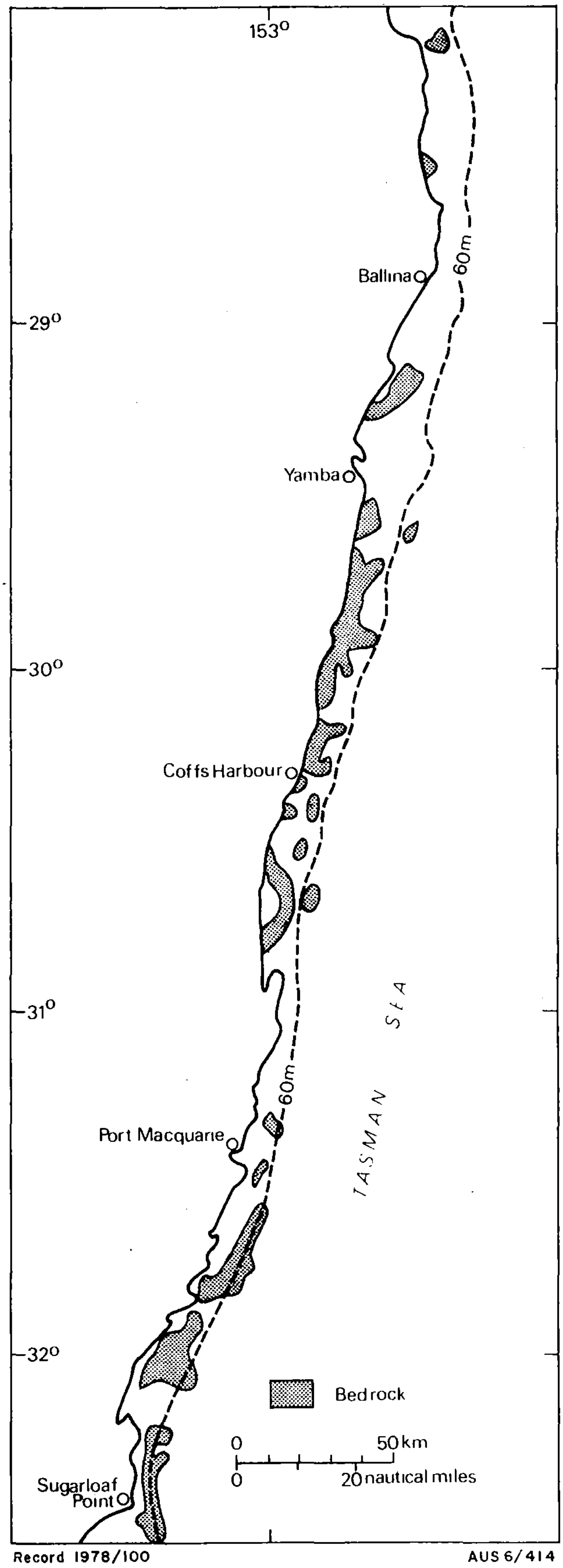


Fig. 2 Bedrock outcrop on the inner shelf of northern New South Wales (after Jones & Davies, 1979).

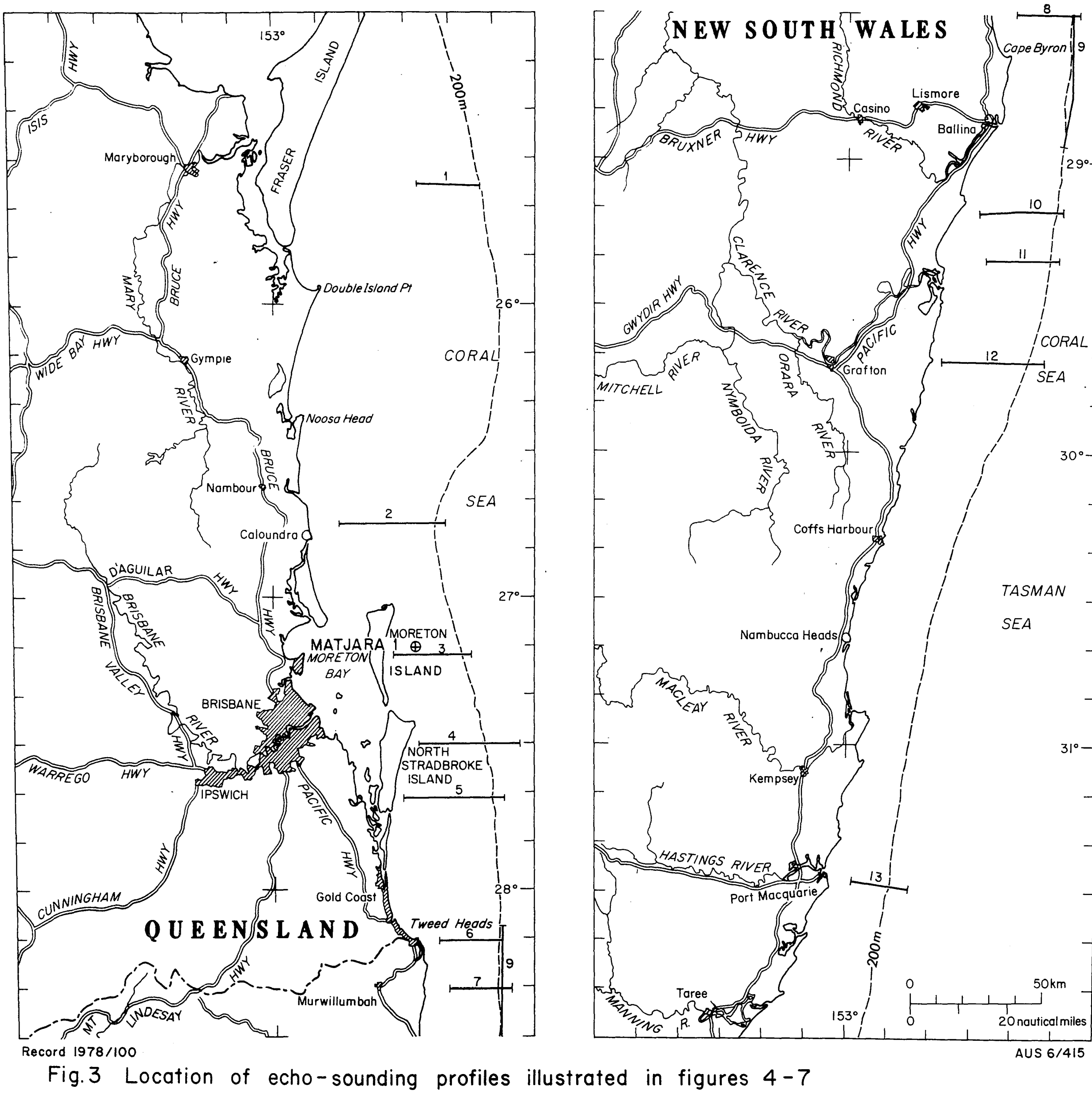


Fig. 3 Location of echo-sounding profiles illustrated in figures 4-7

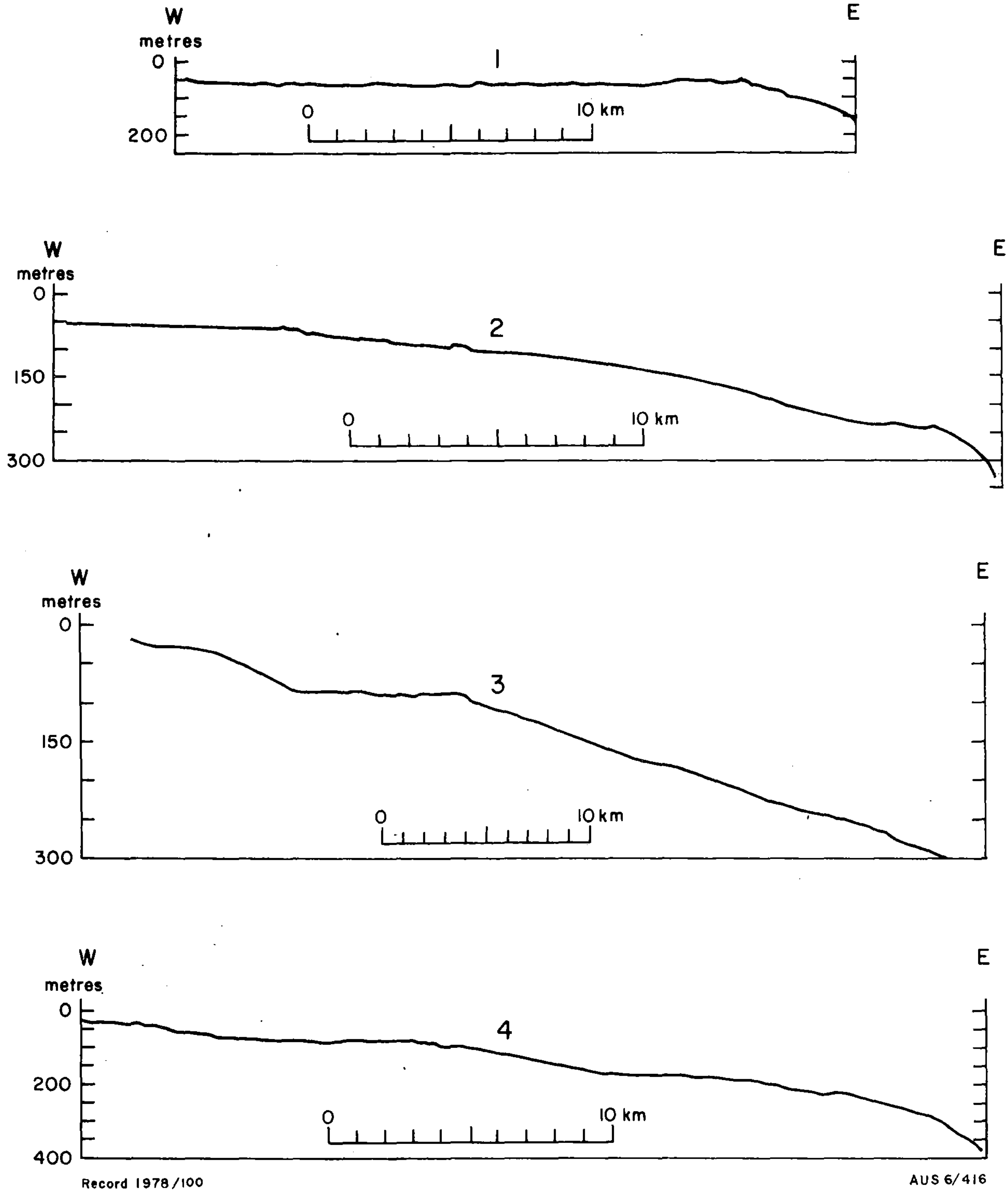
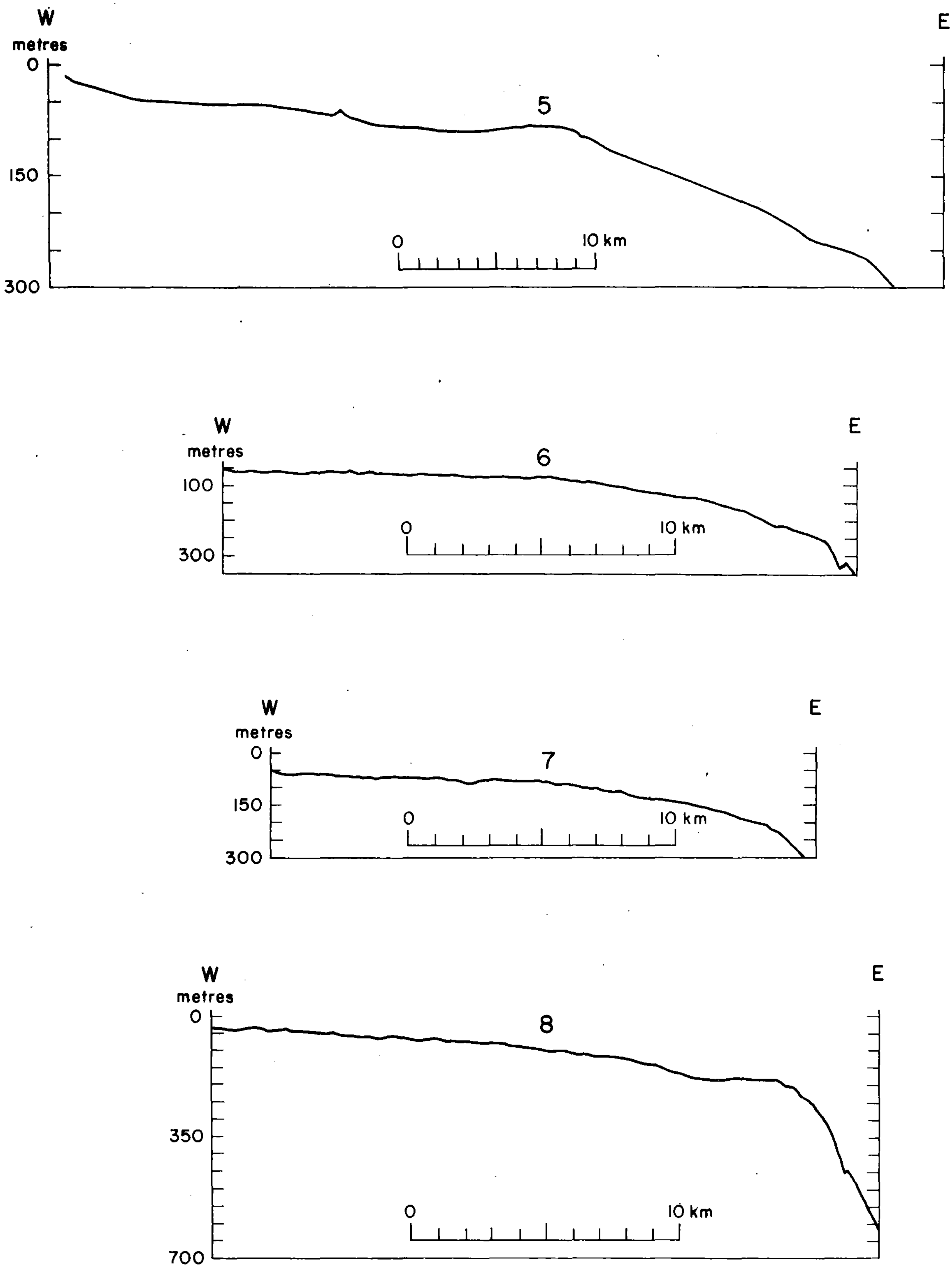


Fig. 4 Bathymetric profiles 1-4. Locations shown in Figure 3.



Record 1978/100 AUS 6/417

Fig. 5 Bathymetric profiles 5 – 8
Locations shown in Figure 3.

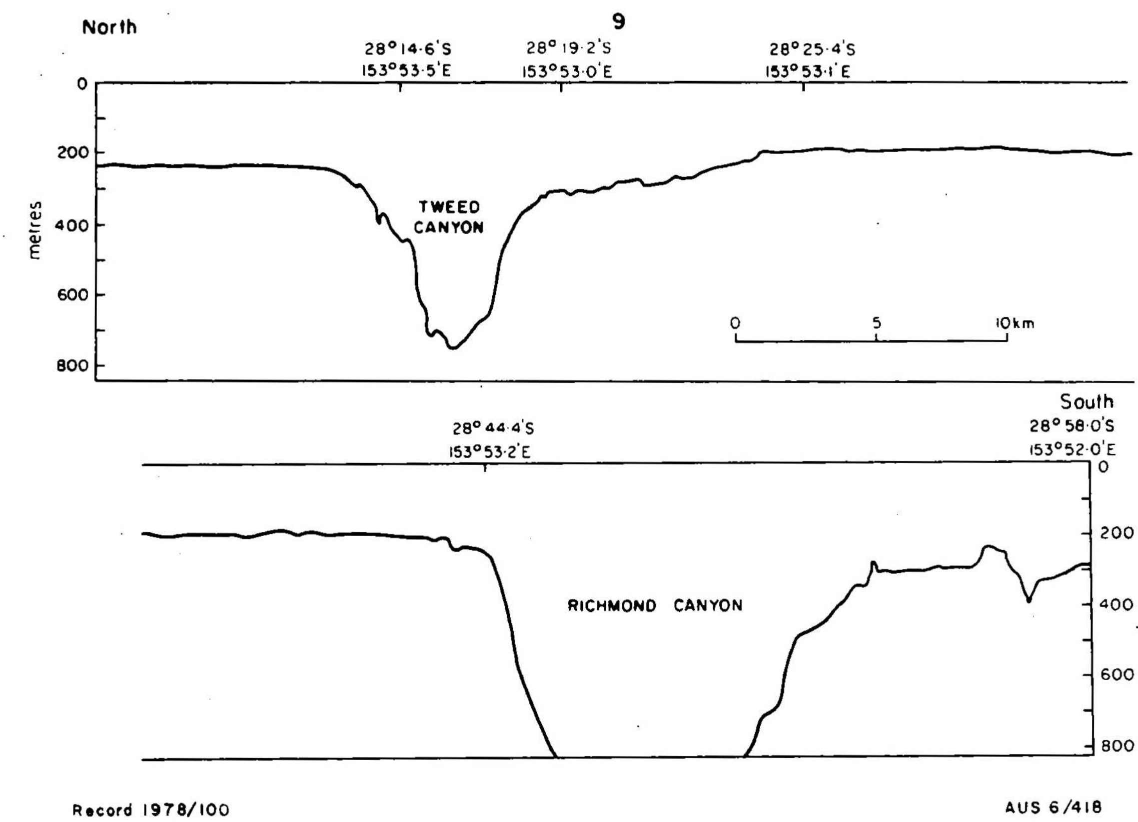
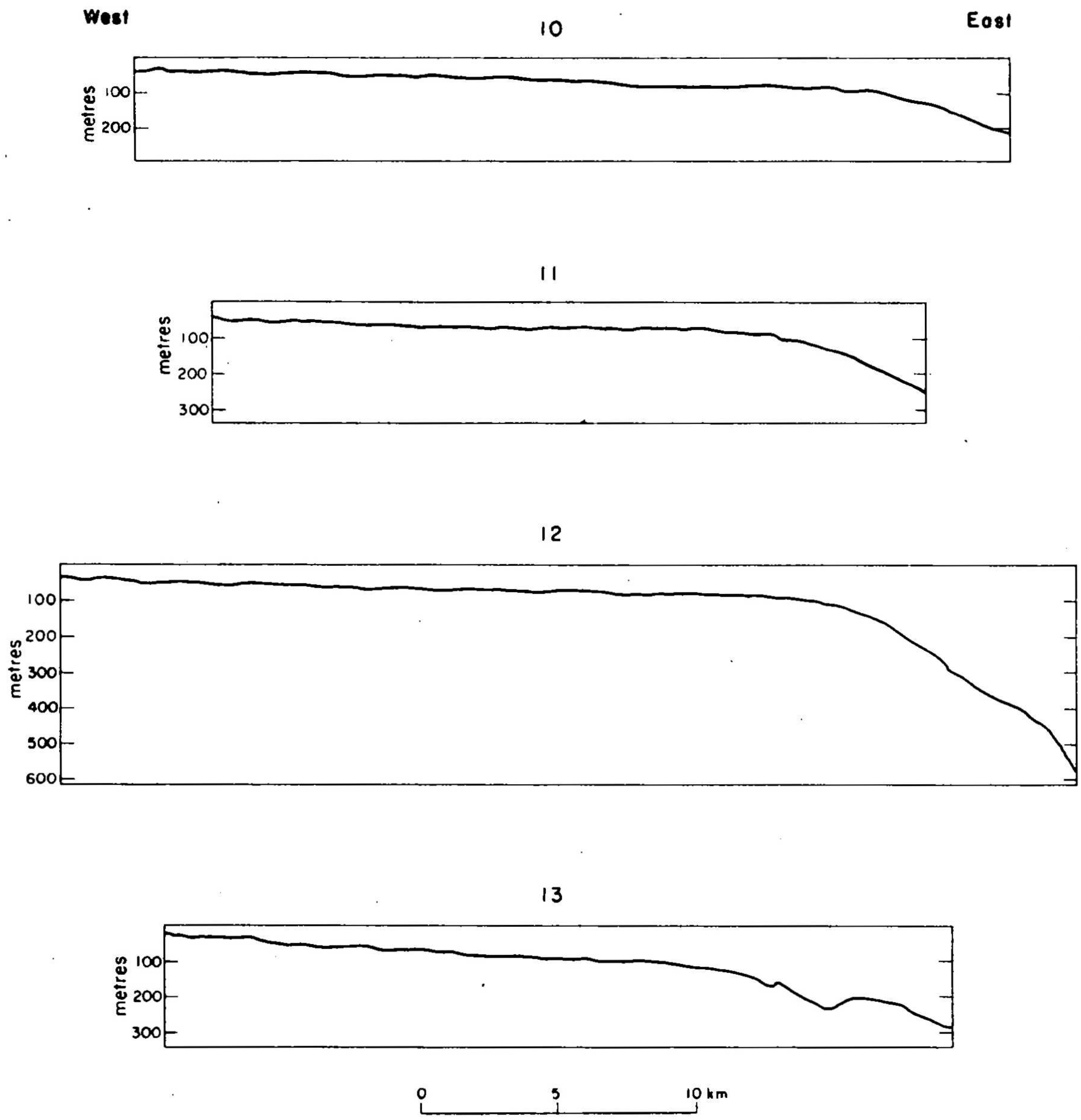


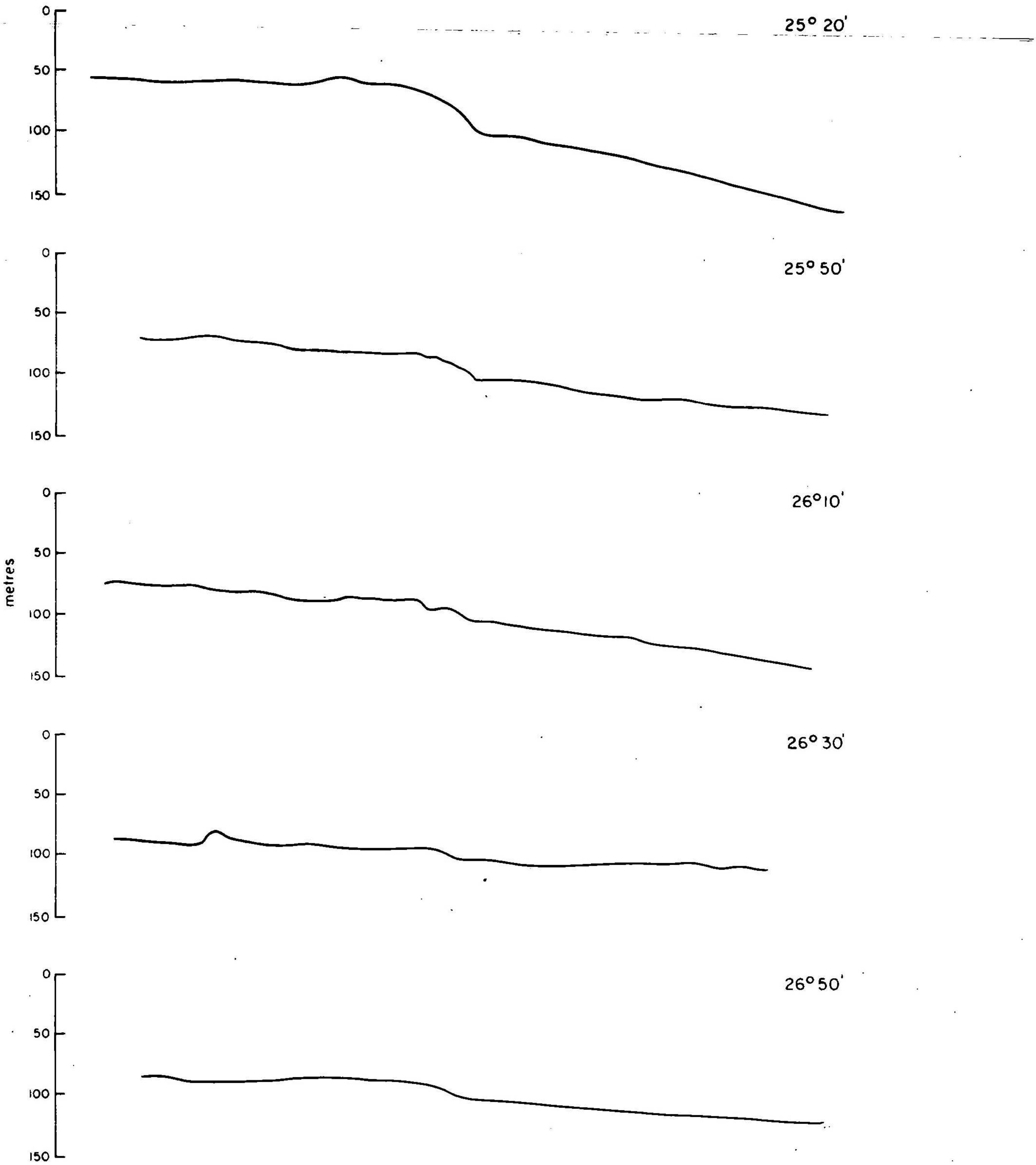
Fig. 6 **Bathymetric profile 9.** Location shown in Figure 3.



Record 1978/100

AUS 6/419

Fig. 7 Bathymetric profiles 10-13. Locations shown in Figure 3.



Record 1978/100

AUS 6/420

Fig. 8 Profiles across the 105-m terrace, southern Queensland shelf

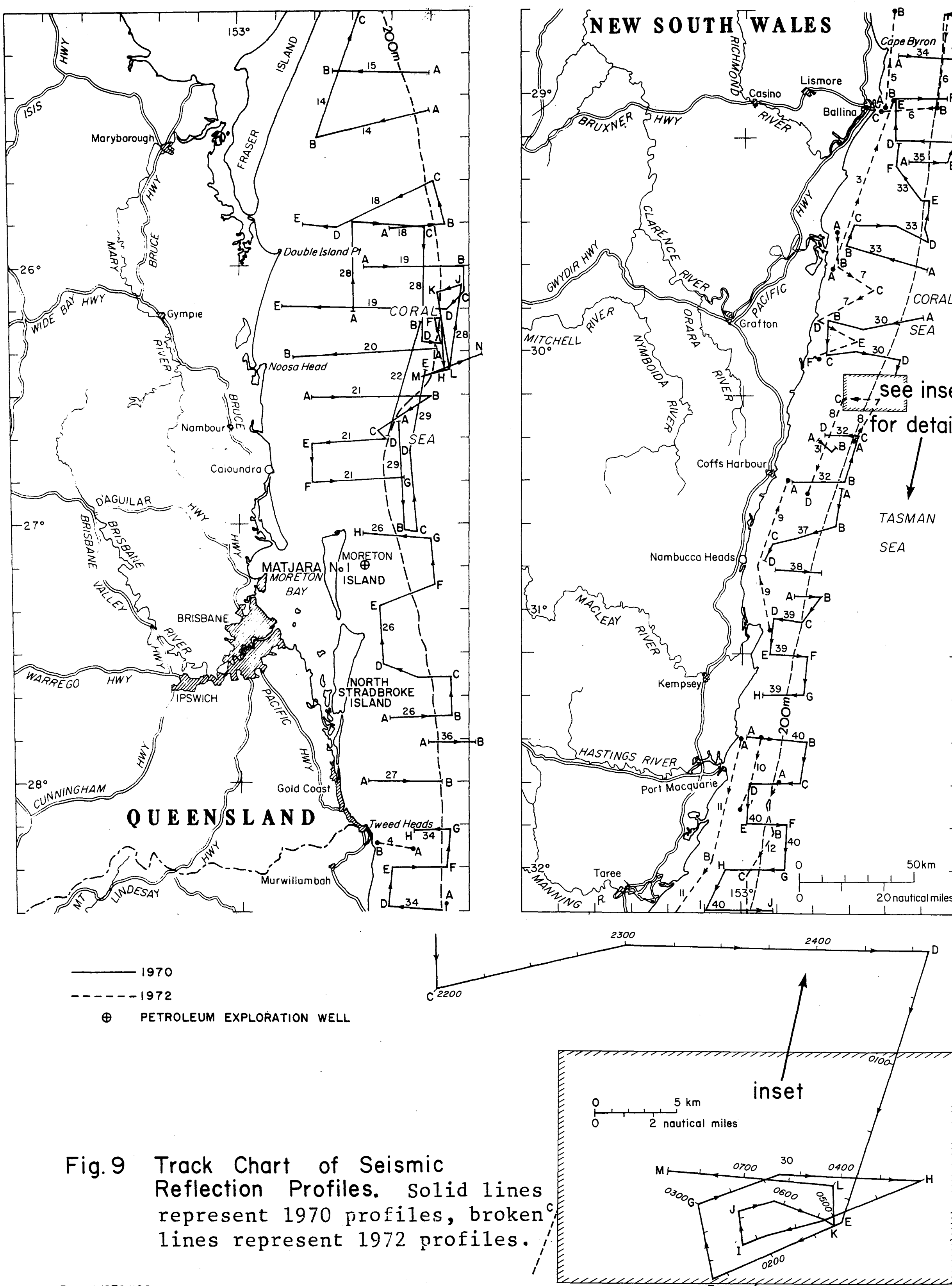


Fig. 9 Track Chart of Seismic Reflection Profiles. Solid lines represent 1970 profiles, broken lines represent 1972 profiles.

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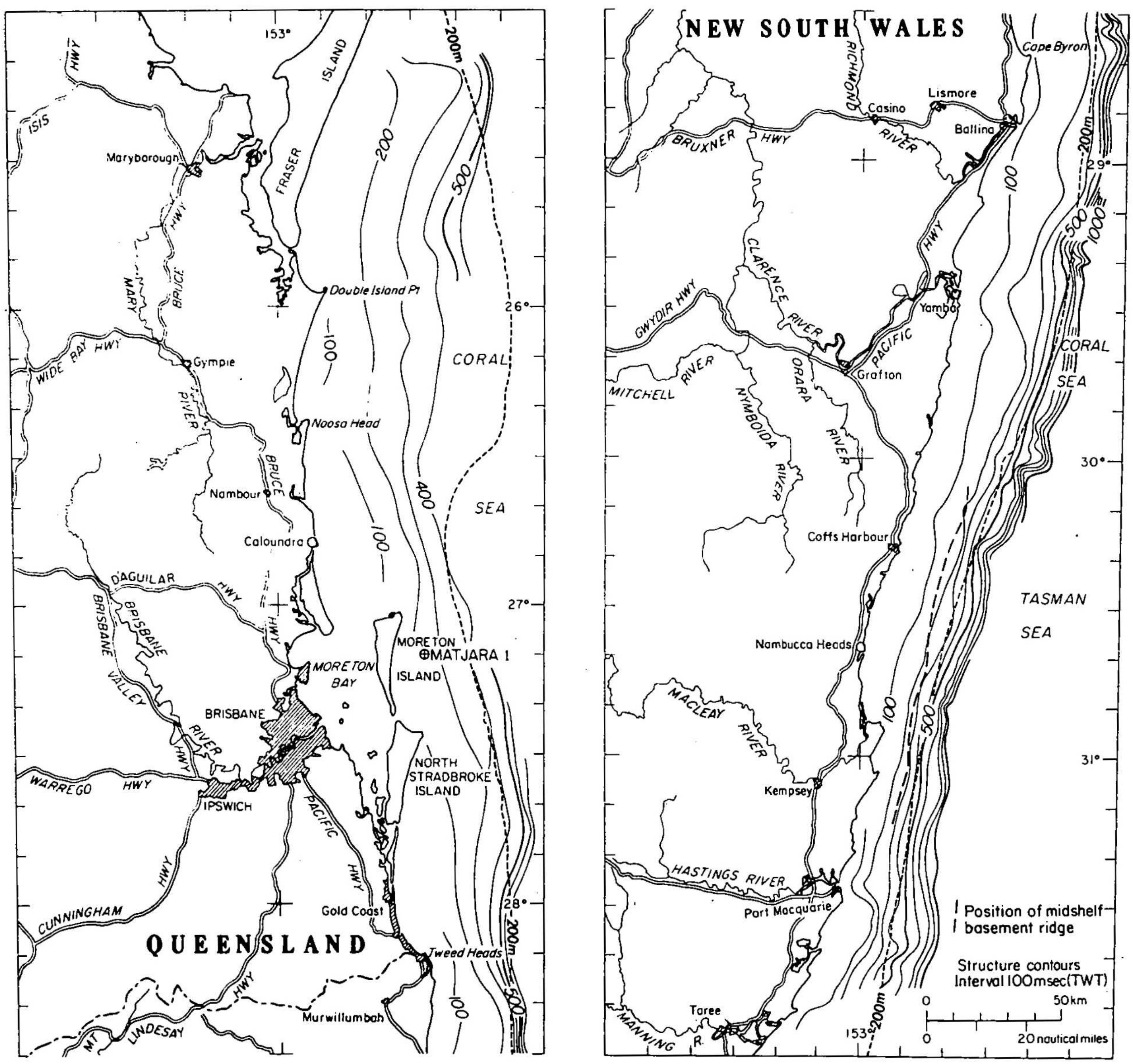

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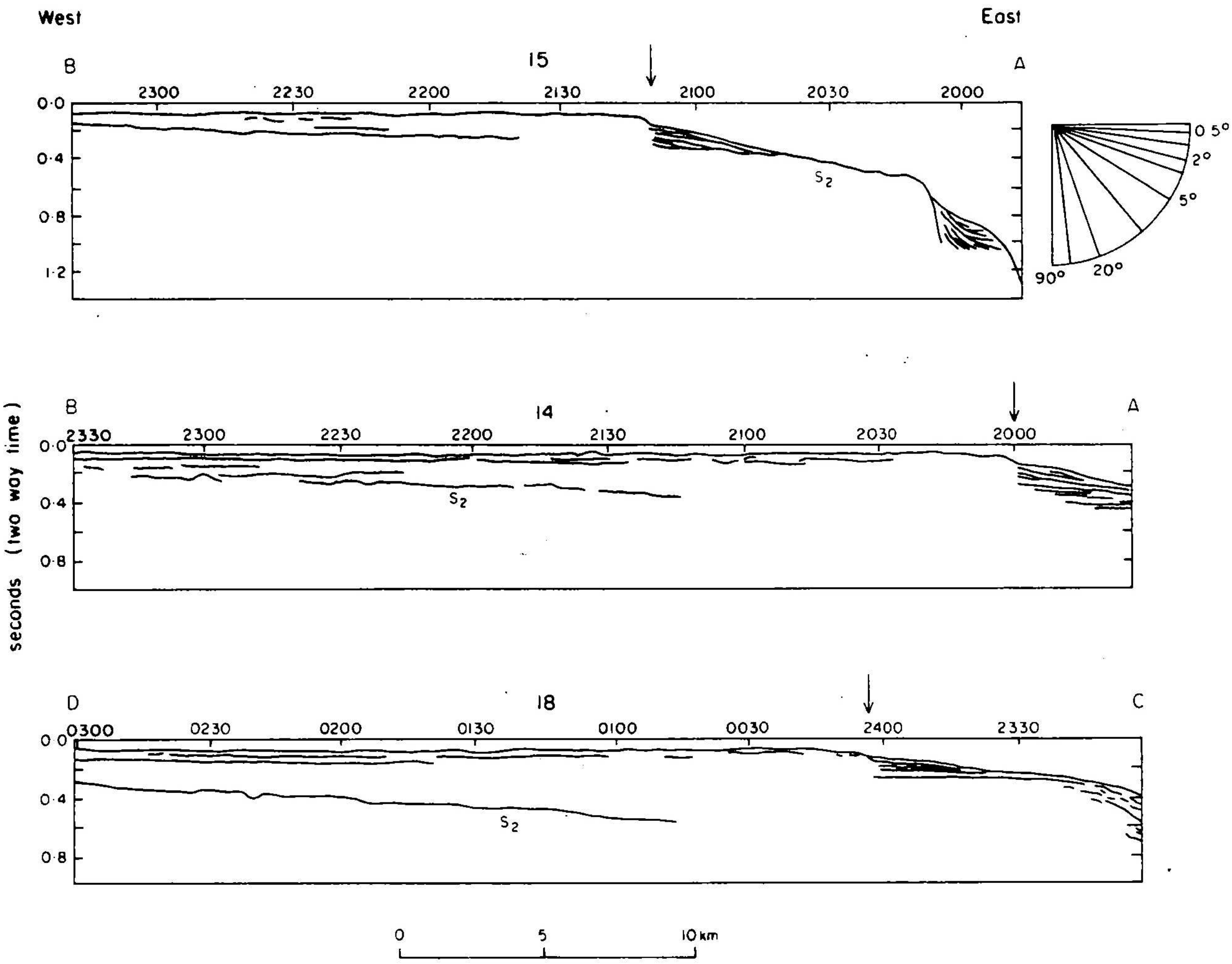
Fig.10. Structure contours on S_2. Contour interval 100 ms reflection time. Dashed line marks the position of the mid shelf basement ridge.



Record 1978/100

AUS 6/423

Fig. 11 Line drawings of seismic sections, profiles 15A-B, 14A-B, and 18C-D
Arrows mark position of 105-m terrace. Locations shown in Figure 9.

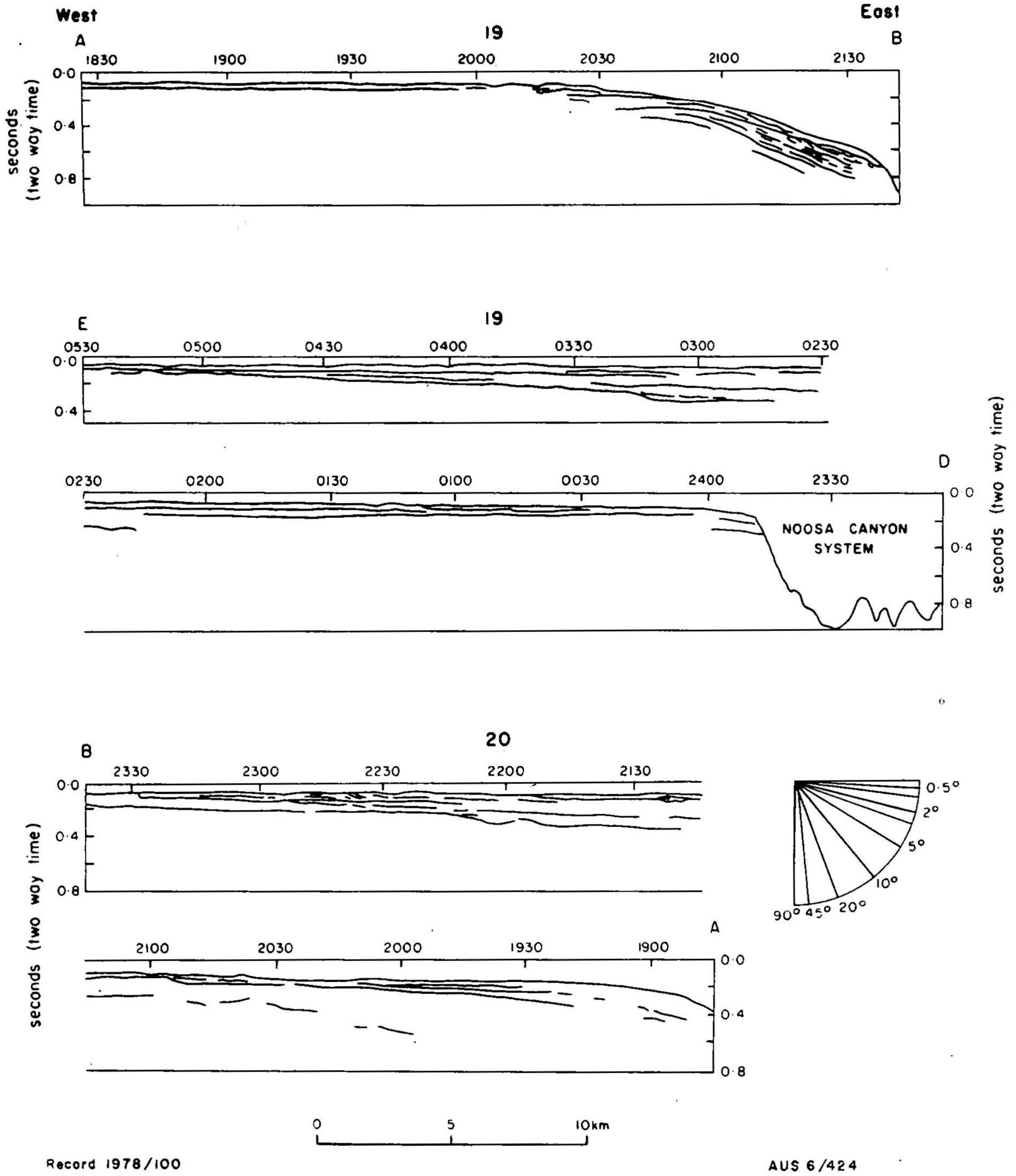
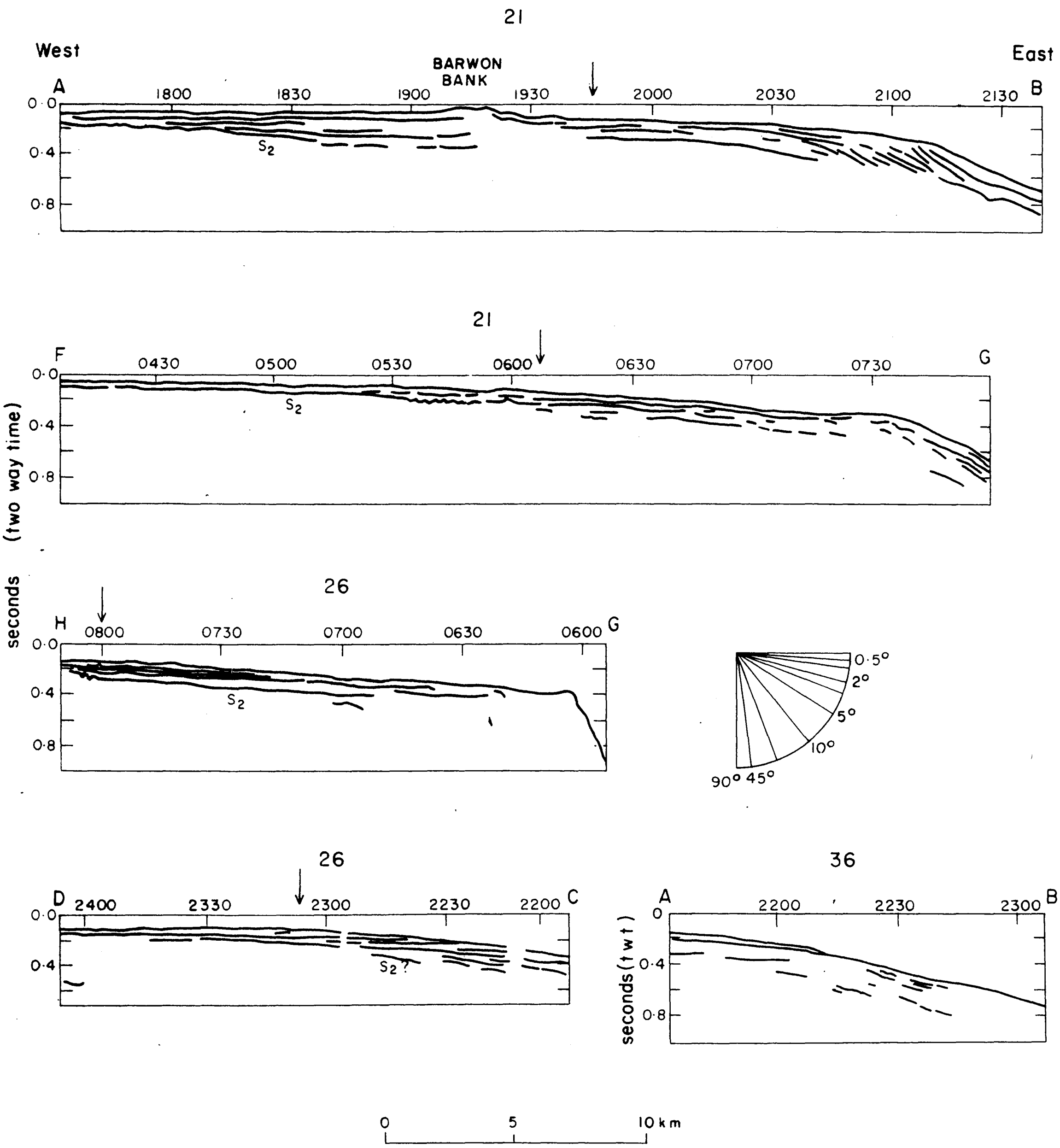


Fig. 12 Line drawings of seismic sections, profiles 19A-B, 19D-E, and 20A-B. Arrows mark position of 105 m terrace. Locations shown in Figure 9.



Record 1978/100

AUS 6/425

Fig. 13 Line drawings of seismic sections, profiles 21A-B, 21F-G, 26G-H, 26C-D, and 36A-B. Arrows mark position of 105-m terrace. Locations shown in Figure 9.

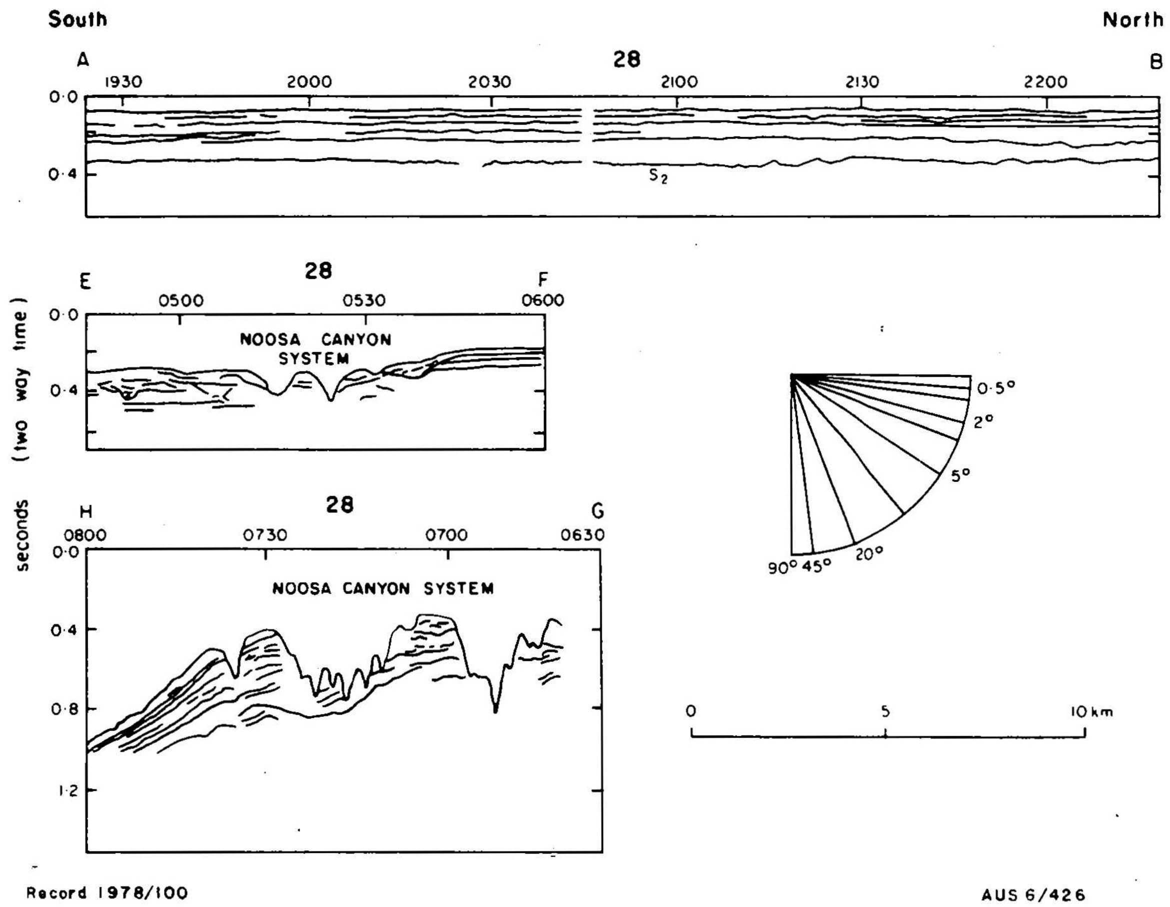
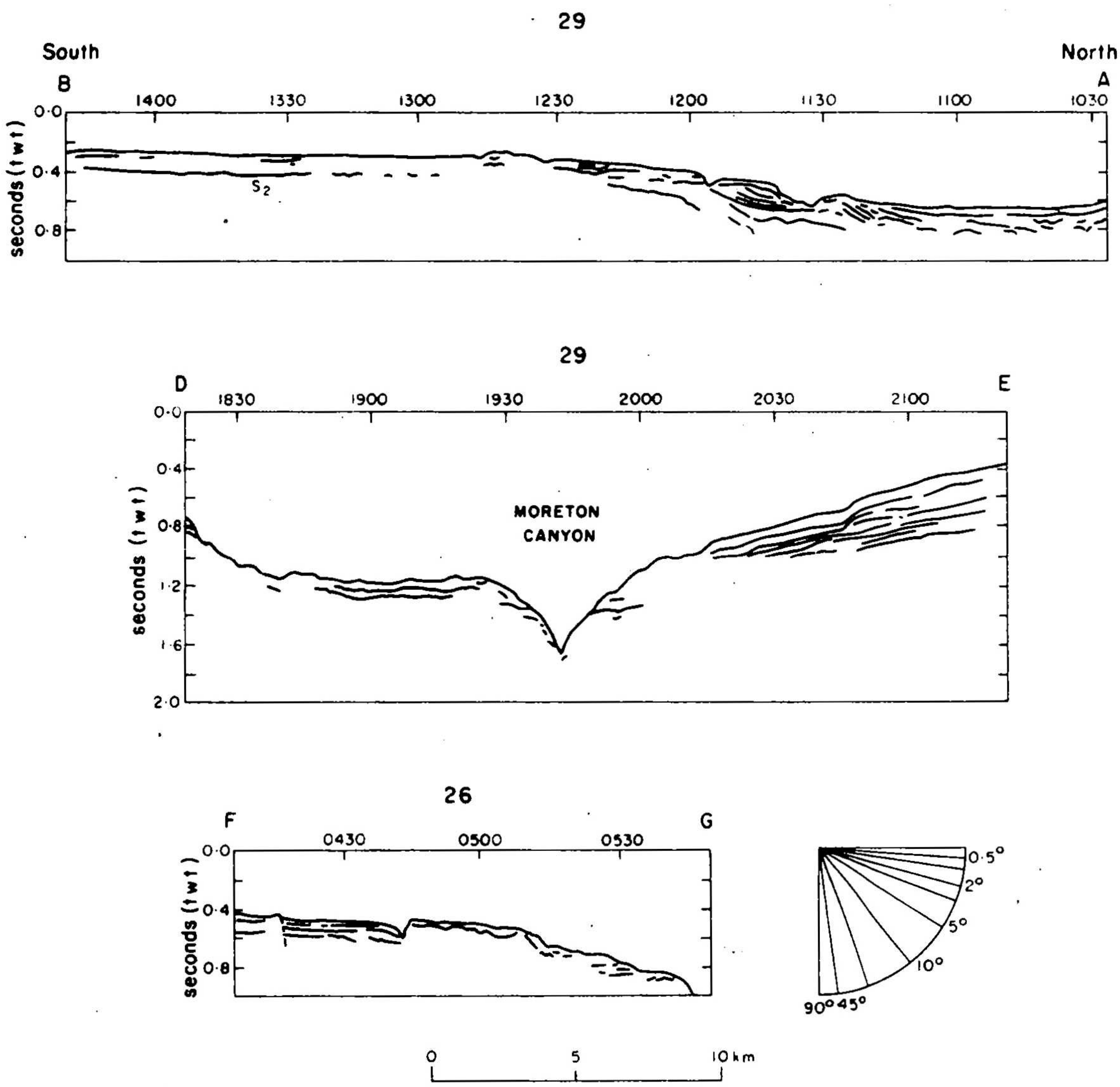
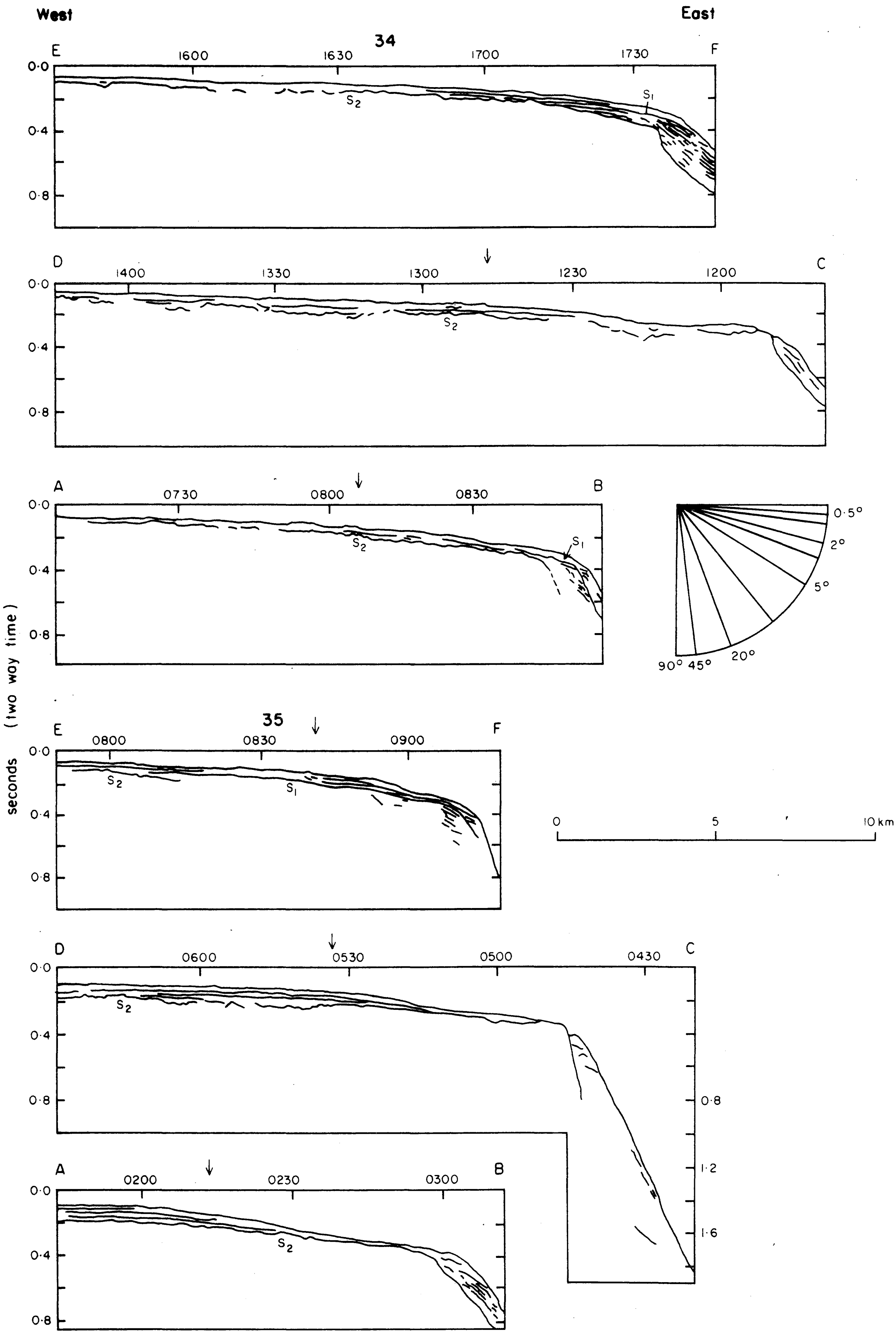


Fig. 14 Line drawings of seismic sections, profiles 28A-B, 28E-F, and 28G-I. Locations shown in Figure 9.



Record 1978/100 AUS 6/427

Fig. 15 Line drawings of seismic sections, profiles 29A-B, 29D-E and 26F-G. Locations shown in Figure 9.



Record 1978/100 AUS 6/428

Fig. 16 Line drawings of seismic sections, profiles 34E-F, 34C-D, 34A-B, 35E-F, 35C-D and 35A-B. Arrows mark position of 105-m terrace. Locations shown in Figure 9.

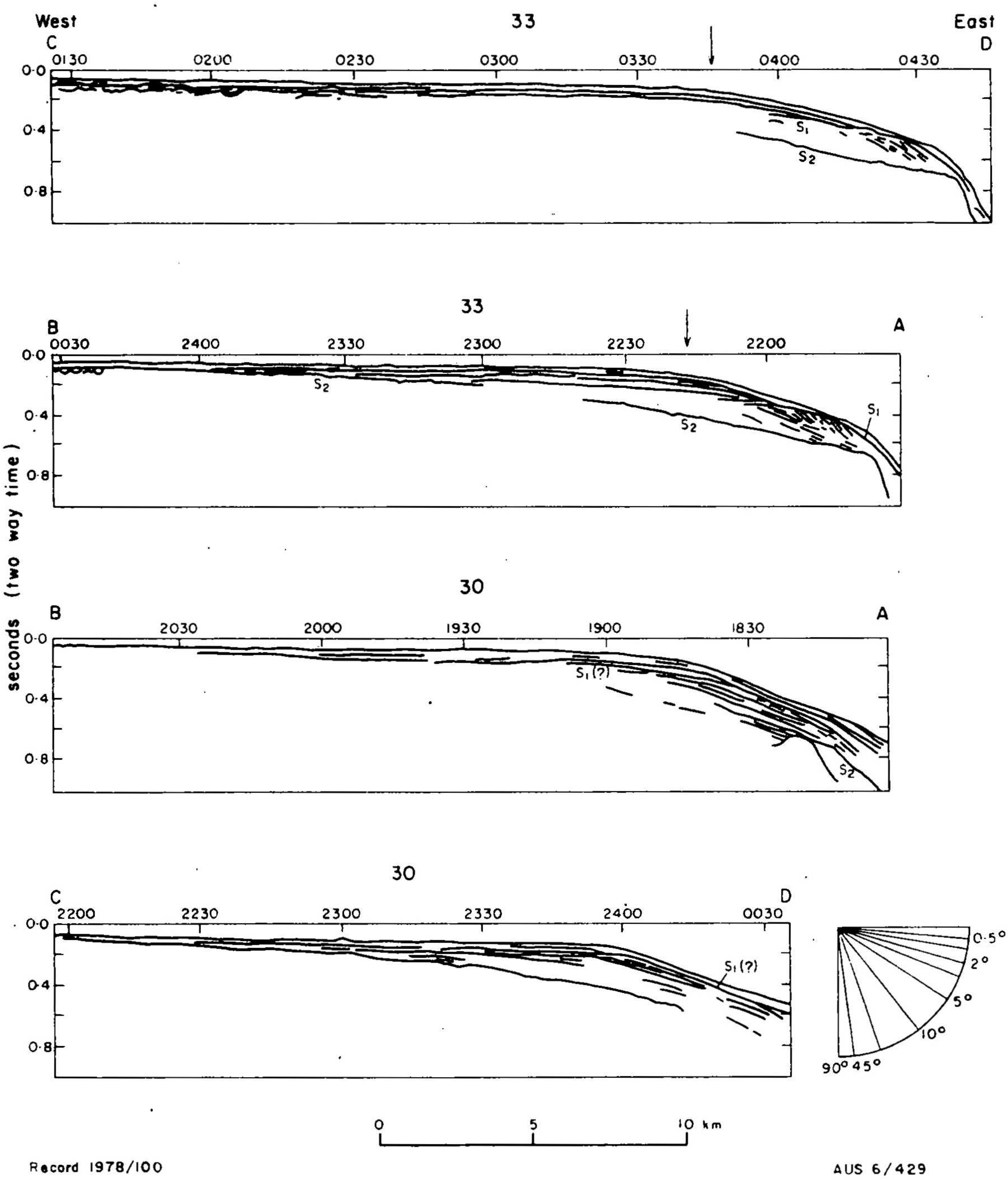


Fig. 17 Line drawings of seismic sections, profiles 33C-D, 33A-B, 30A-B, and 30C-D. Arrows mark position of 105$_{m}$ terrace. Locations shown in Figure 9.

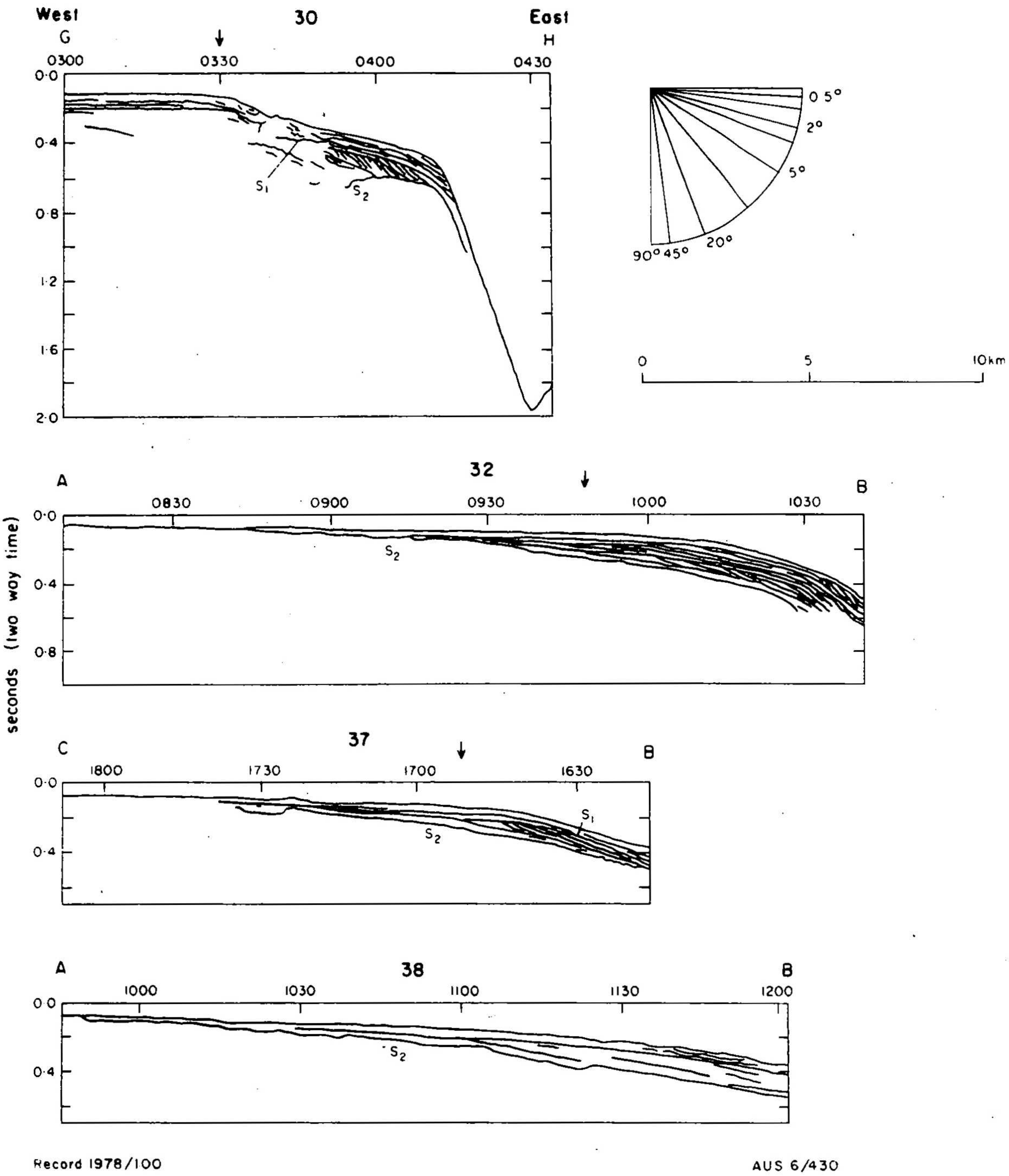


Fig.18 Line drawings of seismic sections, profile 30G-H, 32A-B, 37B-C, and 38A-B. Arrows mark position of 105-m terrace. Locations shown in Figure 9.

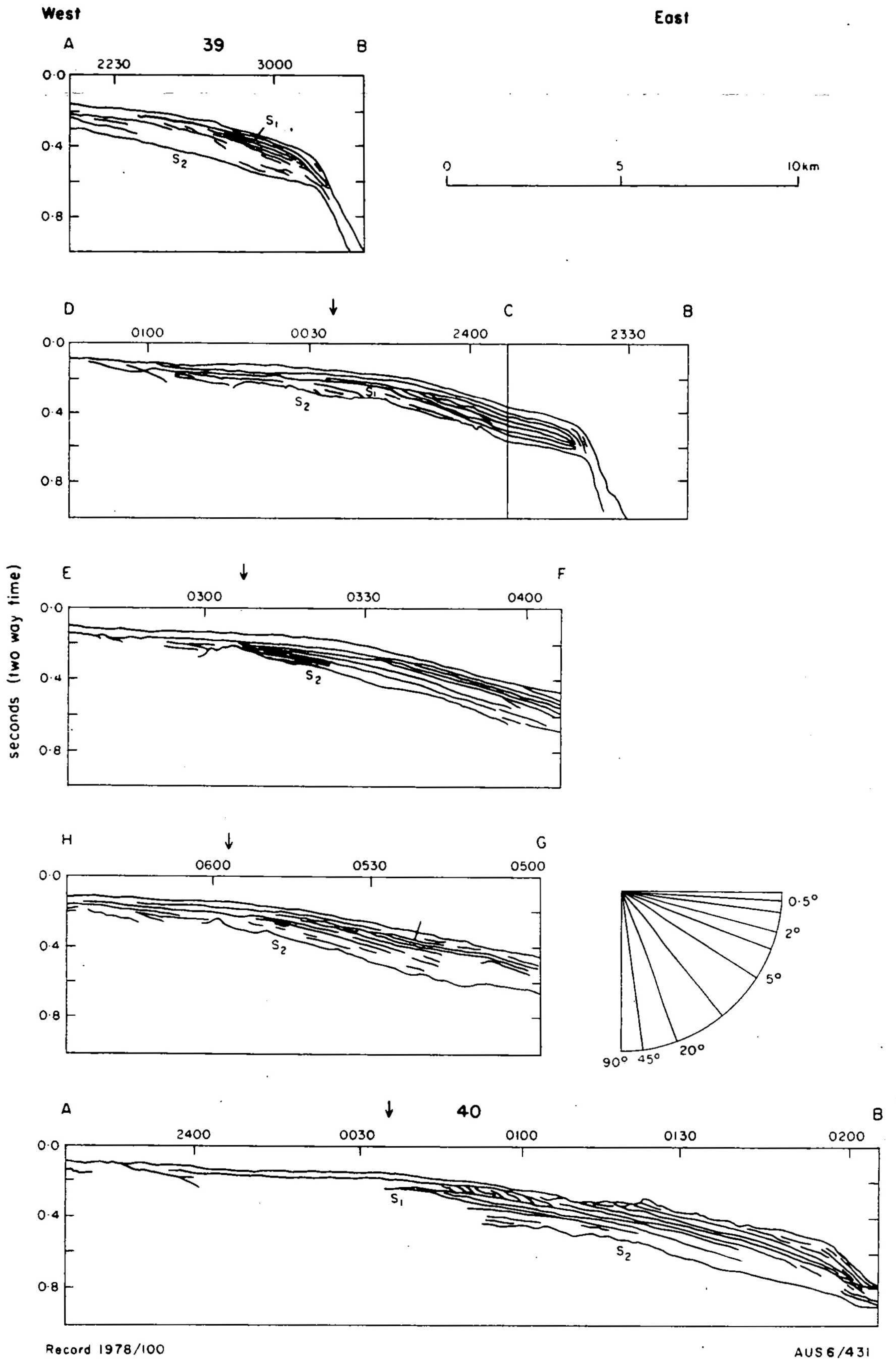


Fig. 19 Line drawings of seismic sections, profiles 39A-B, 39B-D, 39E-F, 39G-H, and 40A-B. Arrows mark position of 105-m terrace. Locations shown in Figure 9.

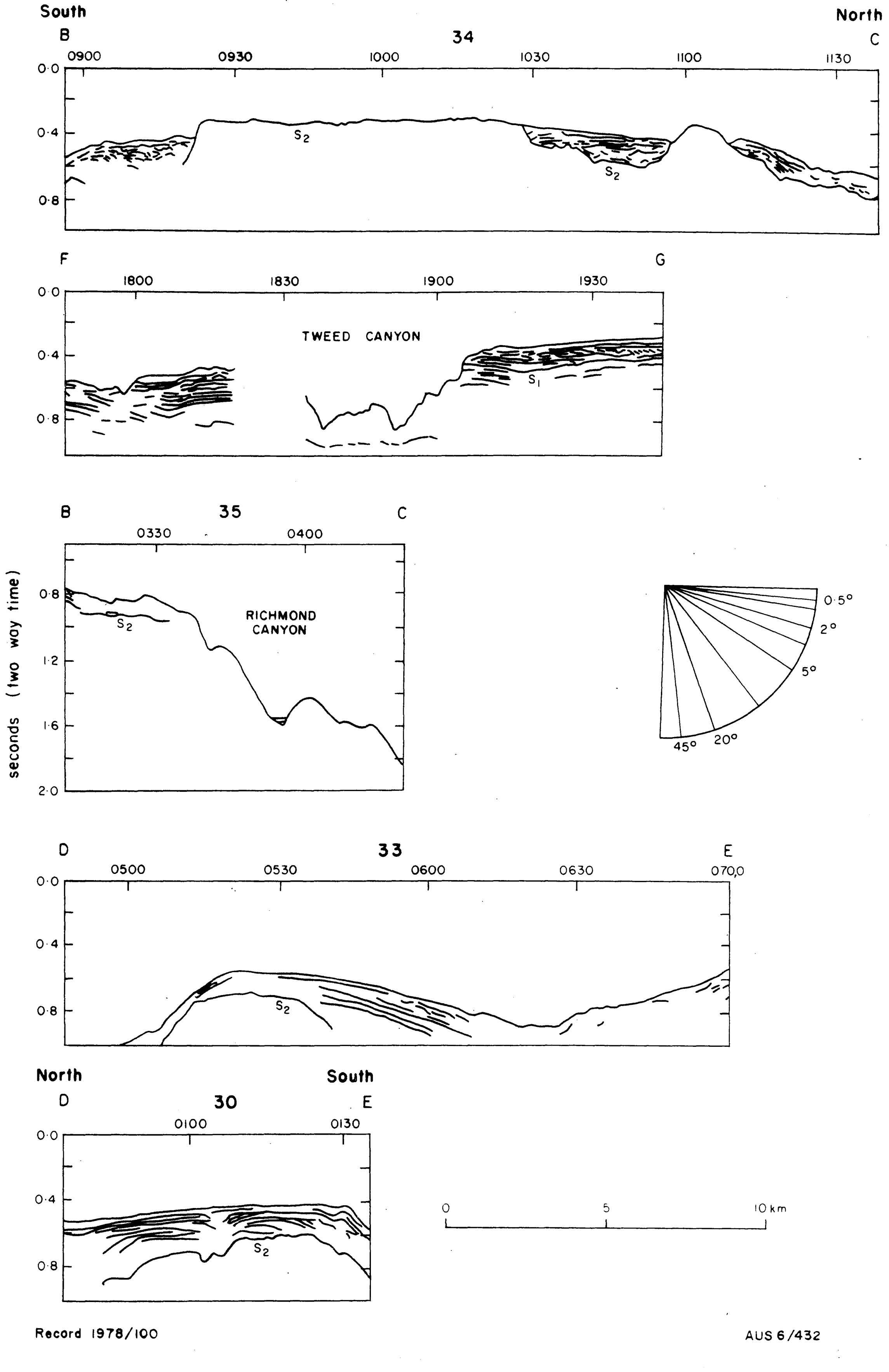


Fig. 20 Line drawings of seismic sections, profiles 34B-C, 34F-G, 35B-C, 33D-E, and 30D-E. Locations shown in Figure 9.

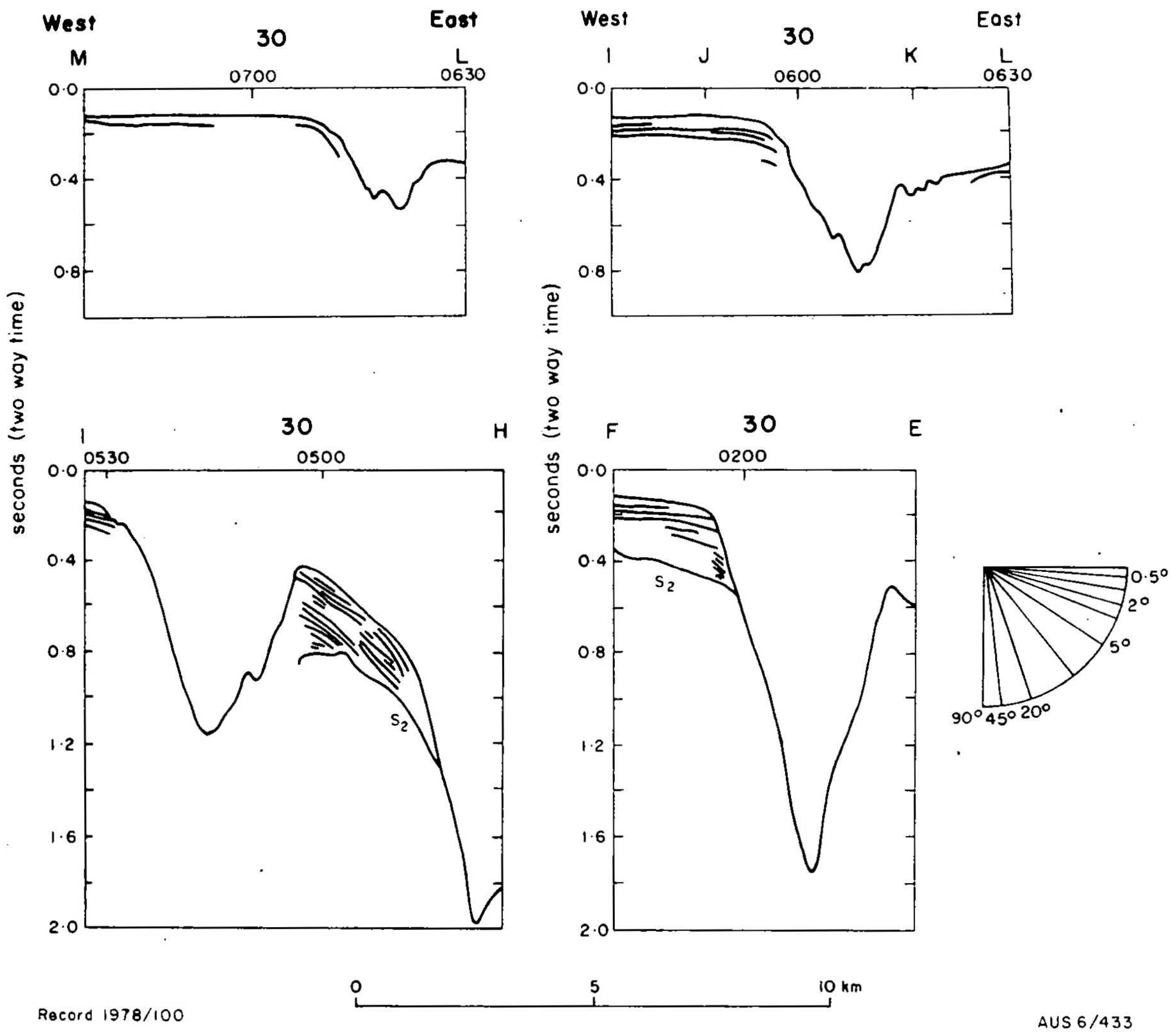


Fig. 21 Line drawings of seismic sections, profiles 30L-M, 30I-L, 30H-I, and 30E-F. Locations shown in inset of Figure 9.

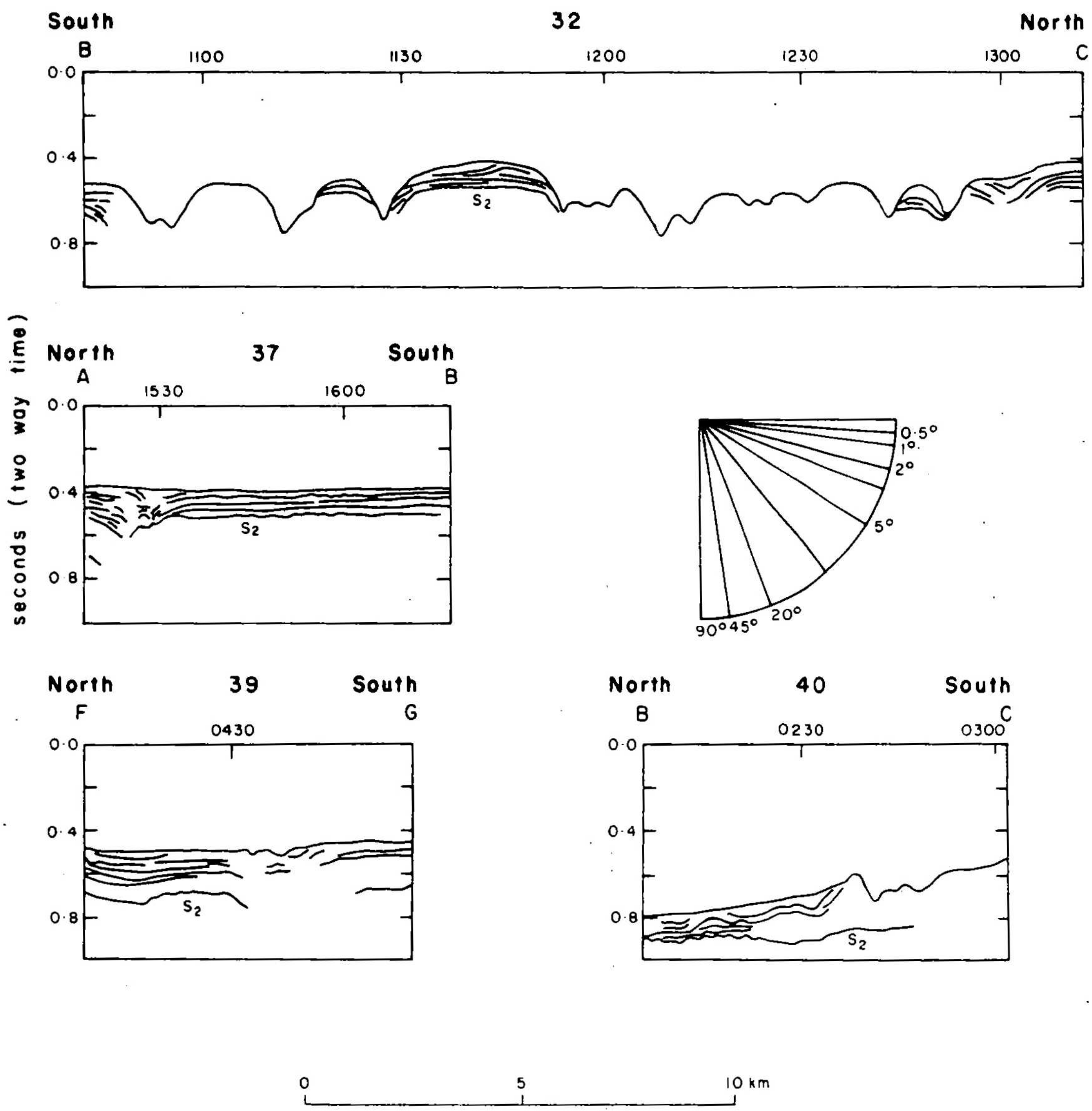


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Fig. 22 Line drawings of seismic sections, profiles 32B–C, 37A–B, 39F–G, and 40B–C. Locations shown in Figure 9.

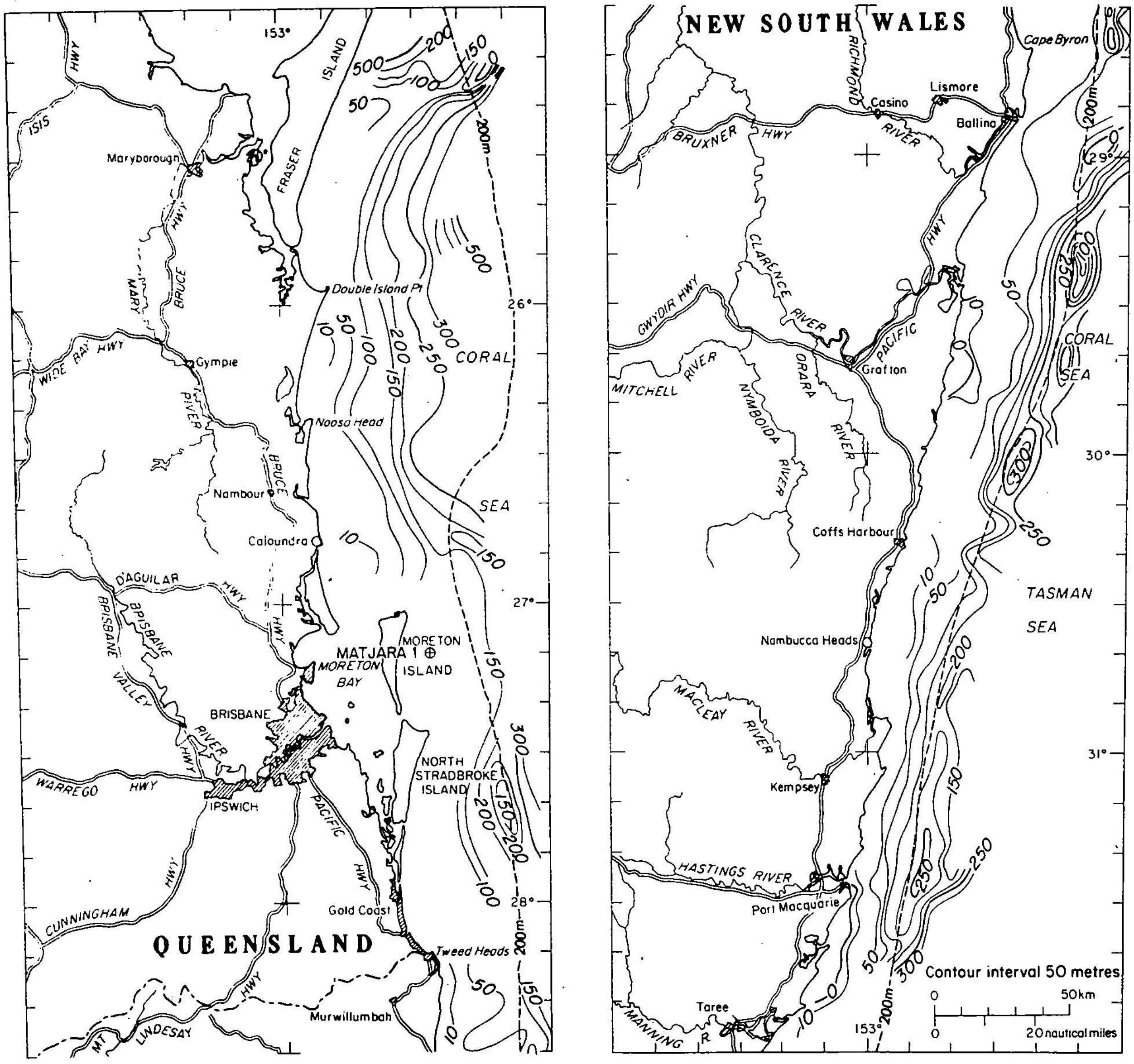
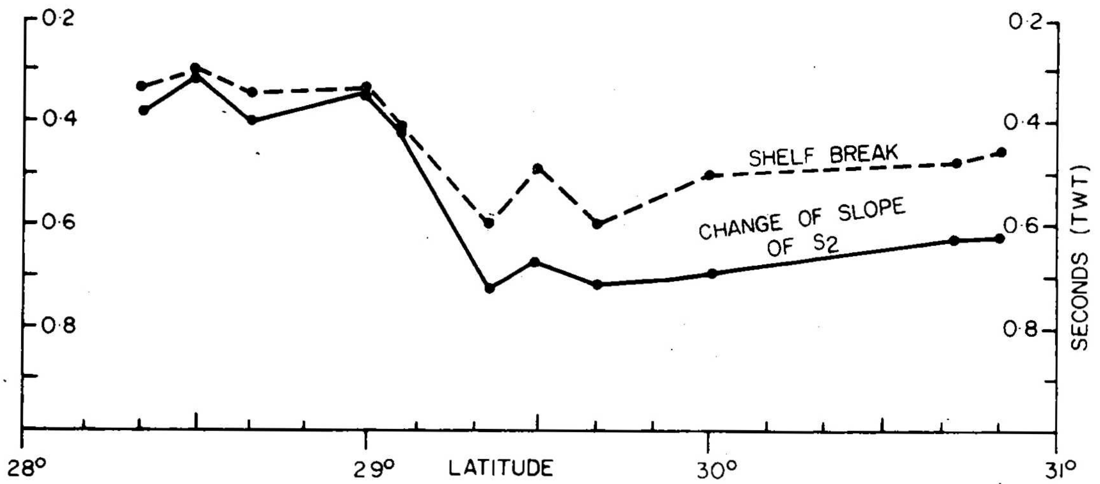


Fig. 23 Isopach Map showing Sediment Thickness above bedrock (S_2)
Contours in metres.



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AUS 6/436

Fig.24 N-S section along the shelf edge between 28^{o} and 31^{o}S showing the depth variation of the shelf break and the corresponding variation shown by the depth of the change of slope S_2.