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ORIGIN OF THE SHELF BREAK OFF SOUTHEAST AUSTRALIA

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SUMMARY

Sediment-covered continental margins commonly provide evidence of outbuilding of the continental shelf; seismic sections reveal structures which resemble those of the classical prograding delta, although the scale is large and dips are very low. It is widely accepted that the main morphological features are usually not in equilibrium with the present depositional regime and were developed during periods of low sea level in the Pleistocene. In particular, the shelf break is assumed to mark wave base during glacial stages and variations in its depth at the present day are attributed to Quaternary earth movements and other causes.

Evidence from seismic reflection profiles across the southeast Australian continental margin indicates that in some areas eustatism has not influenced the shelf-break zone. Where this is the case, insufficient sediment has accumulated along the rifted continental margin since the opening of the Tasman Sea to compensate for subsidence and to raise the sea floor to within reach of wave-base erosive influences during low sea levels. In some instances there is no evidence of outbuilding, and the sediments are draped over basement structures; thus the change of slope at the shelf break is the surface expression of basement relief and changes in the depth of the shelf break are related to changes in depth of basement. Therefore it is not necessary to invoke neotectonism to explain variations in the depth of the shelf break.

Other seismic sections reveal clear evidence of outbuilding of the wedge of sediments which accords with the generally accepted concept of continental shelf development. It is suggested that moulding of the major morphological elements of the outer shelf and development of the shelf break may have occurred as early as the late Miocene.

The buried basement surface is commonly smooth at the crest of the continental slope, and irregular under the shelf. The smooth surface may be a marine abrasion platform formed during the initial transgression across the continental margin after rifting and opening of the Tasman Sea in the Late Cretaceous. The basal sediments resting on irregular basement under the outer shelf are probably continental in origin.

INTRODUCTION

One of the important morphological features of the continental margin is the shelf break, which is the change in slope marking the outer edge of the continental shelf and forming the junction between the essentially flat shelf landwards and the continental slope seawards. The definition of the shelf break in the recent AGI Glossary of Geology (Gary et al., 1972) is brief but adequate: it is "an obvious steepening of the gradient between the continental shelf and the continental slope". In the present paper the physiography and sub-surface structure of the shelf break of an area off southeast Australia are described and an attempt is made to formulate conclusions on its origin and subsequent modification. These conclusions are at variance with ideas on the origin of the shelf break stated or implied by (several) writers in recent years.

Geological and geophysical surveys by the Bureau of Mineral Resources since 1970 have provided a large amount of information on the relief and structure of the southeast Australian continental margin. Most of this region was previously very poorly known, with the exception of parts of the offshore Sydney Basin where reconnaissance seismic and magnetic data had been collected by petroleum exploration companies. The results of some of the recent BMR work have been described in several unpublished reports (see list of references), and publication of others is planned. Reports based on earlier data from this region include those of Phipps (1963, 1966), Kamerling (1966), Conolly (1969) and Galloway (1970).

The seismic profiles used to illustrate this paper were drawn from sections obtained in 1972 during the multisensor reconnaissance geophysical survey of the continental margin by contractors to the BMR. Low energy, comparatively high resolution seismic sections obtained in the same area by the BMR during marine geological surveys in

1970 and 1972 have been used to assist interpretation of the continental margin profiles.

THE SHELF BREAK IN GEOLOGICAL LITERATURE

The classical theory of continental shelf development made use of the concept of the marine profile of equilibrium and envisaged an inner wave-cut terrace or abrasion platform merging seawards with a wave-built terrace of delta-like form. The continental slope was believed to be formed of foreset beds and the shelf break was considered to mark wave base, the depth above which erosion and transport took place and below which wave-induced water movement became negligible and deposition of sediment could occur. These ideas were reproduced in one form or another in numerous research papers and textbooks up to 10 or 15 years ago despite the fact that the ability of the sea to erode much below low-tide level had been questioned by many authors, possibly first by Hutton in the 18th Century (see Fairbridge, 1952, for a historical review of this question), and despite the fact that the presence of old sediments on the outer shelf in many areas cast serious doubts on the reality of the wave-built terrace (Shepard, 1948). The concepts of the marine profile of equilibrium and wave base at the shelf margin were later convincingly challenged in a series of closely argued papers (Dietz & Menard, 1951; Dietz, 1952, 1963), and it came to be generally believed that the gross morphology of the shelf and shelf-break are related to Pleistocene eustatic low sea levels and not to modern conditions. Thus Curray (1969) wrote 'The shoreline during maximum low stages of sea level lay approximately at the edge of the continental shelf. The shelf break must then be related to depth of this maximum lowering. ...They (Dietz & Menard) concluded then, as have most other marine geologists, that near-shore erosion during the maximum low stand of sea level was responsible for formation of the shelf break'.

It was, of course, widely appreciated that other factors have influenced the depth of the shelf break and the physiography of the shelf itself. The following comment from a recent textbook may be taken as representative of modern views: 'Obviously, the depth of shelf margins is related to the amount of deposition since sea level rose after exposing the outer shelf to wave erosion during the Wisconsin glacial stage, and is dependent on the effect of ocean currents, like the Gulf Stream, in either preventing deposition or eroding the bottom. Furthermore, there has been much warping and faulting of continental margins since the last period of low sea level'. (Shepard, 1973, pp. 277-8).

Thus, while it has been widely recognized that the depth of the shelf break may have been strongly influenced locally by special circumstances, for example by ice-scouring in high latitudes or by very rapid depositon off modern deltas, the relatively constant depth of this feature around the world's continents has led geologists to relate it to eustatic events, usually to the last glacial maximum, and to attribute variations in its depth to sedimentation, differential compaction of sediments, erosion, isostatic movements, and tectonism during the Holocene.

THE SHELF BREAK OFF SOUTHEAST AUSTRALIA

The southeastern margin of continental Australia (Fig. 1) is formed of a belt of strongly folded Lower Palaeozoic rocks in which are developed rather shallow Late-Palaeozoic and Mesozoic intracratonic basins containing largely undeformed continental and shallow marine sediments. On the continental shelf, both basinal sediments and ancient fold rocks are unconformably overlain by a seaward-thickening wedge of later sediments which attains a maximum thickness of about 800 m near the edge of the shelf. The continental margin is of the rifted Atlantic type and is uncomplicated by major intrusions, block-faulting, and development of marginal plateaux.

Few of the BMR's shallow seismic sections provide much detail of structures within basement underlying the sedimentary cover on the continental shelf, and as a result the offshore boundaries of the intracratonic basins are not well known. Most profiles, however, show some structures within the overlying sedimentary column and the basal unconformity (usually acoustic basement) is generally well displayed. No drilling has been undertaken on the continental shelf in this area, and there is no direct evidence of the age of this sedimentary sequence. It is possible that the basal sediments on the upper continental slope are pre-Tertiary, but there can be no doubt that the bulk of the section is Cainozoic. An unconformity in the upper part of the sequence is visible in many of the high-resolution seismic sections in the region of the offshore Sydney Basin (not shown in the illustrated profiles). Much of the present-day sea floor on the continental shelf is non-depositional, and other disconformities undetected in the seismic profiles almost certainly occur lower in the sequence.

Figure 2 shows diagrammatic sections across the shelf-break zone drawn from profiles spaced 100-200 km apart along 1000 km of continental margin. The variations in gross morphology displayed by these profiles are typical of other areas of the Australian continental margin and have many counterparts off other continents. In three profiles (1, 3 & 7) the shelf break is clearly defined, although its depth varies considerably. In the remainder the transition from continental shelf to continental slope is more or less gradual and may take place in two or more changes of slope (e.g. profiles 2, 4). In one profile (5) the stepped nature of the upper continental slope is the result of normal faulting in basement, and faults with subdued surface expression are inferred in profiles 6 and 7 also.

In the illustrated sections the shelf break ranges in depth from about 140 to 375 m, and the extreme range known in this area is 130 to 440 m. There is no evidence from the eastern Australian margin of features related to former low sea levels at depths greater than about 220 m. Dill (1968) has reported the presence of narrow terraces at depths of 182 to 214 m around Australia, and Thom et al. (1972) recorded a terrace at about 200 m east of Sydney. Eustatic features which occur in shallower are characterized by remarkable uniformity of depth over wide areas, indicating that no significant warping of the margin has occurred, at least in the Holocene (Veeh & Veevers, 1970; Jones, 1973 a & b, 1974). The effects of Pleistocene and early Holocene low sea levels are preserved as nick points and extensive terraces on the continental shelf down to a depth of about 160 m. Evidence of fossil shorelines at greater depths are also preserved locally, but these take the form of very narrow terraces or notches cut into the uppermost continental slope and are too small to be shown at the scale of the illustrated sections. One of these narrow terraces, at about 165 m depth, has been dated at 13 600 to 17 000 years BP (Veeh & Veevers, 1970). The most widespread terrace on the outer shelf off southern Queensland and central New South Wales is at 80 to 100 m, and its good state of preservation suggests an early Holocene age also.

Beachrock dredged from 128 m near Sydney gave an isotopic age of 17 900 $\pm$ 600 years BP (Phipps, 1970); however, this was a total-rock date, and the age of formation of the beachrock is certainly younger as shells separated from it gave an age of 24 600 $\pm$ 1000 years. It can therefore be assumed that terraces above about 160 m were formed, or at any rate modified, during the Holocene transgression and that shelf breaks at these shallow depths were similarly resculptured. This is not the case with shelf breaks at greater depths.

Although it seems that large-scale warping of the edge of the shelf has not taken place during the Holocene, there is no evidence about the range of vertical earth movements which may have occurred during the Pleistocene and Late Tertiary. It could therefore be argued that existing deep shelf breaks are the result of a combination of progradation and erosion during ancient low sea level still-stands, and have been downwarped to their present depths. These processes must have sometimes been operative. However, the seismic sections clearly show the extent to which the gross morphological features of the present-day sea floor are controlled by the shape of the buried basement surface. Deep shelf breaks off eastern Australia show considerable variation in depth from place to place, and these variations are linked to variations in depth to basement. This relation is illustrated in Figure 3 in which the depth of the shelf break and the depth of the major change in slope of basement beneath the shelf break are plotted for seven sections between 28°20'S and 30°45'S. The seven sections were chosen because each has a clearly defined shelf break and a sharp increase in gradient of basement surface under this shelf break, as in profile 3 of Figure 2, which eliminates subjective bias in selection of the points at which the depths are measured. In some instances also (e.g. profiles 1, 4, 6) the wedge of sediments at the shelf break has every appearance of being draped over basement, with no indication from either internal structure or surface relief of outbuilding processes. We believe there is no evidence to suggest that surf-base erosion or progradation of the sediment wedge has played any part in the development of the shelf break in the profiles cited. Deposition has been restricted, and insufficient sediment has built up upon the outer margin of the shelf to bring it within the influence of erosion during periods of low sea level.

Other sections (profiles 5 and 7) show equally clearly that outbuilding of the continental shelf has taken place by progradation of the sediment wedge, as in the generally accepted concept of continental shelf development. In these cases the influence of basement relief on present sea-floor morphology is to some extent masked by the overlying sediments, and the shelf break is a function of progradation and low sea level erosion rather than a reflection of basement surface. The time of the eustatic low sea level during which this erosion and progradation took place is not known. The gross morphology of the shelf-break zone in these areas may record the influence of glacial stages preceding the Wisconsin, possibly as old as Late Tertiary. Compelling evidence of a major glacial stage in the latest - Miocene has recently been provided by DSDP drilling in the Ross Sea (Hayes et al., 1973).

Whether or not sufficient sediment is laid down to build a prograded shelf edge with an erosion-formed shelf break must depend on the balance between deposition and subsidence. There are no grounds for postulating significant variations in sediment supply, and it follows that deposition has been locally restricted, probably by deep currents. There are enough oceanographic data available to suggest that the present-day East Australian Current could effectively modify sedimentation. The East Australian Current is a major south-flowing western boundary current which reaches its maximum velocity near the outer edge of the shelf between latitudes 28° and 30°S. Surface currents of up to 4 knots (over 200 cm/s) have been recorded, and the influence of the current extends to depths of more than 1000 m. The strength of the current decreases rapidly south of 32°S, where its place is taken by several large anticyclonic eddies. The seismic sections suggest that there is a relation between sediment thickness and the East Australian Current; there is a significant increase in the thickness of the sedimentary sequence from profile 5 (32.5°S) southwards, and the only section showing obvious outbuilding of the shelf and a well defined shallow shelf break is the southernmost at 35.8°S, well outside the influence of the current.

BASEMENT RELIEF

Hayes & Ringis (1973) recognized linear magnetic anomalies in the central Tasman Sea, whose centre of symmetry coincides with a buried basement ridge; this suggests that the marginal basin was formed by seafloor spreading from a now-extinct, north-northwest-trending, accreting plate margin. Identification of the magnetic anomalies indicates that spreading took place from 80 to 60 m.y. ago (Late Cretaceous to Paleocene), a conclusion supported by results from the only DSDP hole so far drilled in the Tasman Basin, (hole 283 on Leg 29) which recovered Late Cretaceous sediments above basaltic basement (Kennett et al., 1973). Continental reconstructions propose a fit between the southeast Australian margin and the continental crust forming the Lord Howe Rise. It is likely, therefore, that the southeast Australian margin is of the rifted Atlantic margin type and that separation of the Lord Howe Rise took place in the Late Cretaceous; we suggest that the steeply inclined basement surface under the present-day continental slope represents the little-modified original rift scar.

Several of the seismic sections, particularly numbers 4 and 5, show that the surface of basement immediately above the major change in gradient at the crest of the basement slope is remarkably smooth, in contrast to its irregular nature landwards. A possible explanation of this may be that the smooth surface represents an abrasion platform developed during the initial transgression of the sea across the rifted margin. One can further speculate that the irregular basement surface landwards is a subaerial erosion surface which had been at least partly buried by continental or paralic sediments before it was transgressed by the sea at the end of the Mesozoic or in the Early Tertiary.

CONCLUSIONS

The depth of the shelf break off southeast Australia ranges from about 130 to about 440 m. Erosional features on the sea floor formed when sea levels were lower than they are today are widespread and well preserved down to a depth of about 160 m and are locally recognizable down to about 220 m. The few isotopic dates available indicate a latest-Pleistocene age for the well preserved terraces and nick-points at depths shallower than 160 m, and there is no evidence of significant warping of the shelf during the Holocene.

Where the shelf break is shallower than about 200 m, the seismic sections provide evidence of upward and outward building of the sedimentary wedge, and planation of the outer shelf sediments to form terraces. In these places the shelf break is related to wave base during periods of low sea level. The main morphological elements may have been sculptured before the latest Wisconsin glacial stage, and indeed may date back to the Late Tertiary.

Eustatic influences have apparently played no part in the formation of deep shelf breaks; where the shelf break is deeper than about 200 m, its depth is related to the depth of basement under the sedimentary sequence at the edge of the shelf, and the morphology of the present sea floor reflects the relief of the buried basement surface. Insufficient sediment has accumulated on the rifted continental margin since its submergence to bring the sea floor within range of wave-base erosion during periods of low sea level. The East Australian Current restricts sedimentation on the outer shelf today, and similar deep currents have probably caused non-deposition and even erosion in the shelf-break zone throughout the Late Cainozoic.

The east-west seismic sections indicate that in a number of places the surface of buried basement is remarkably smooth over a distance of about 10 km on the landward side of the major change in slope of basement at the crest of the continental slope. We can speculate that this smooth surface is a marine abrasion platform formed at the time of the initial submergence of the continental margin.

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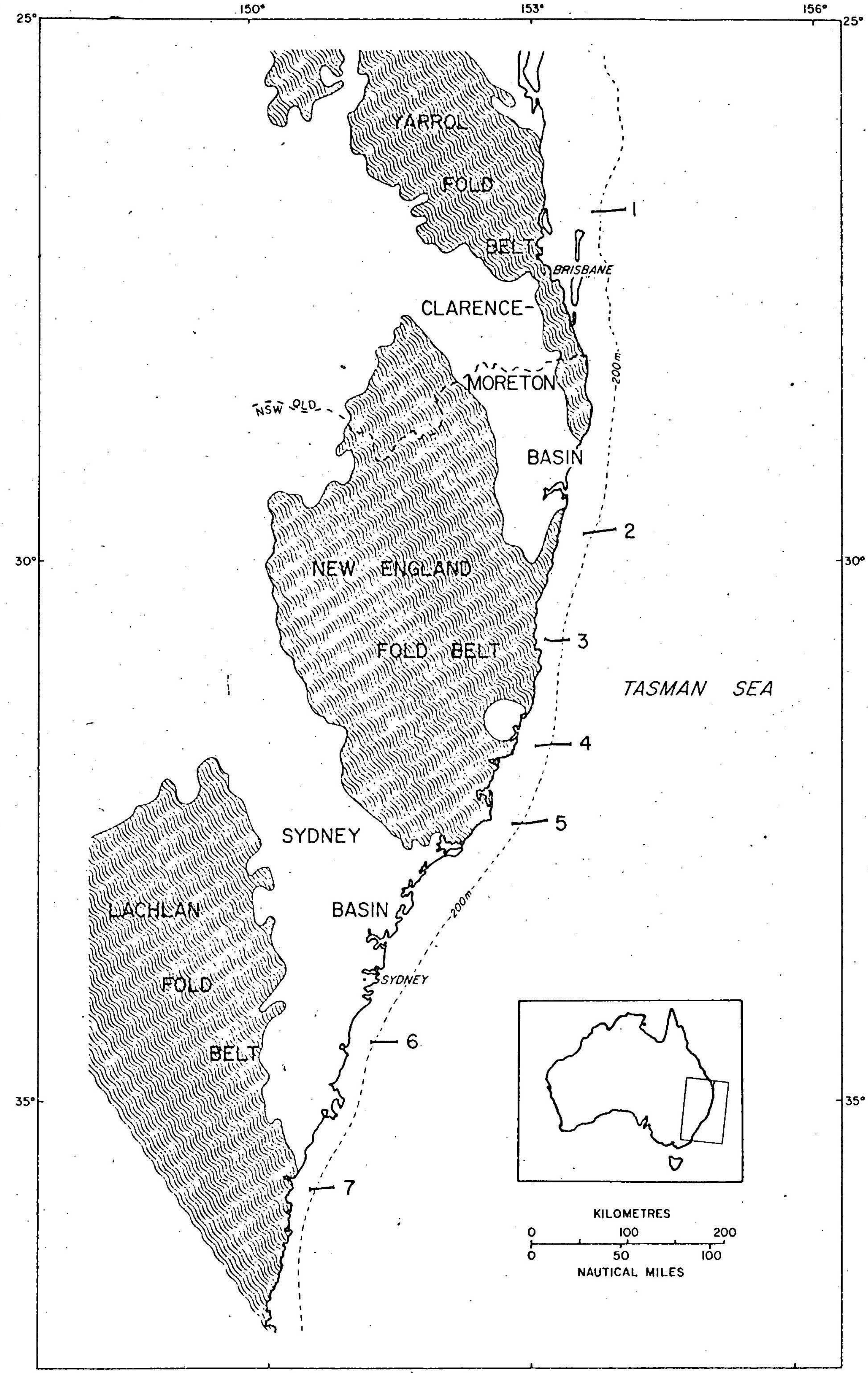

Fig. I. LOCATION MAP

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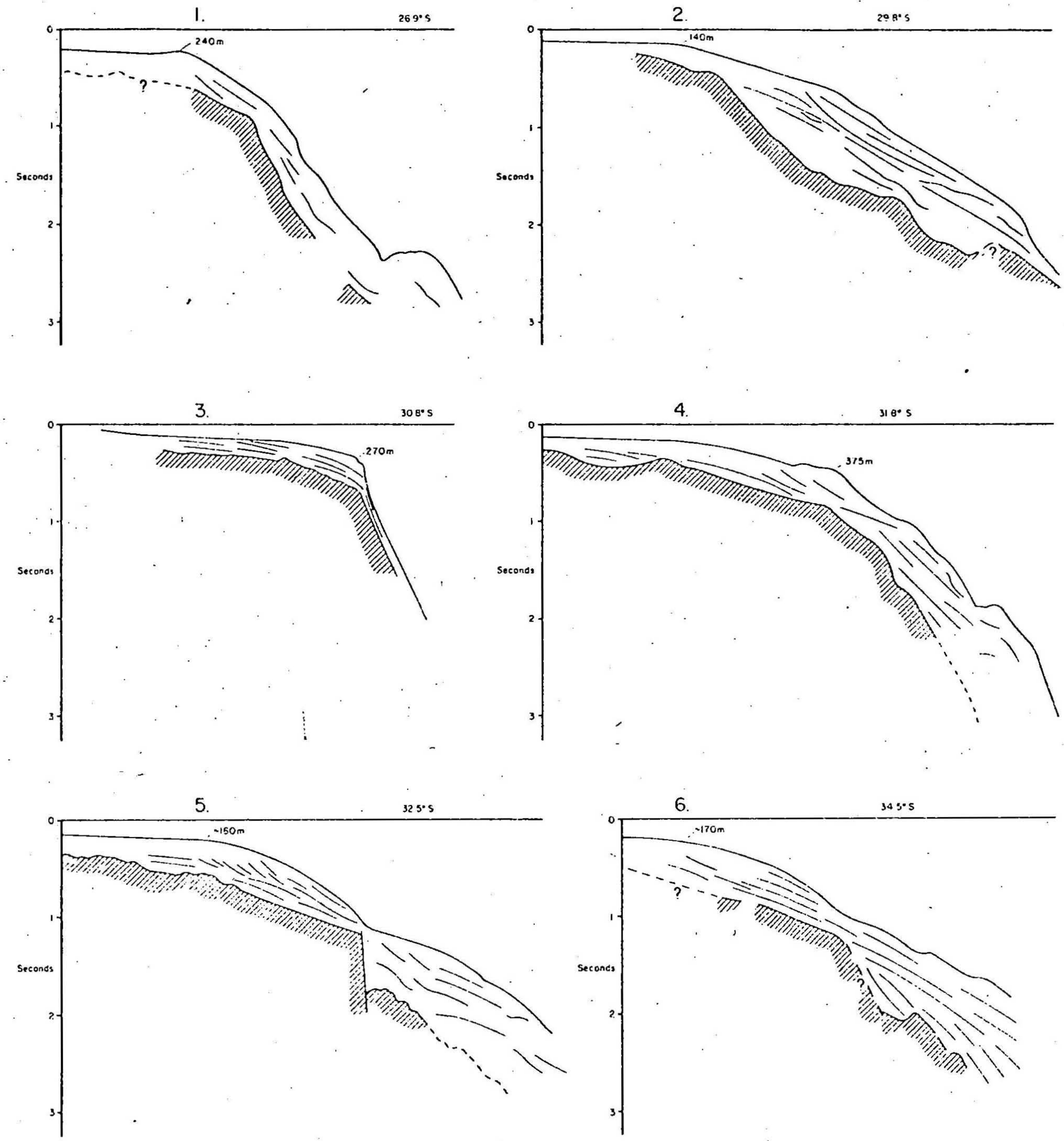

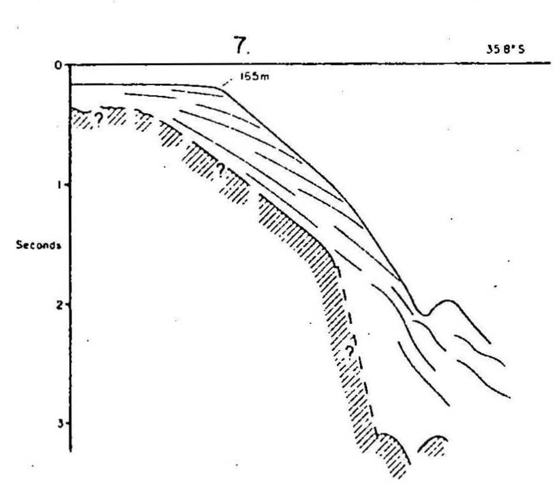

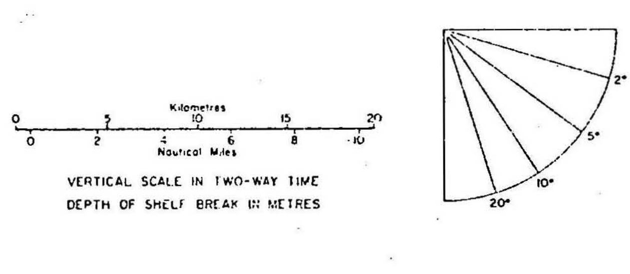

Fig.2. DIAGRAMMATIC SEISMIC SECTIONS

LOCATIONS SHOWN IN FIGURE I.

To accompany Record No. 1974/86

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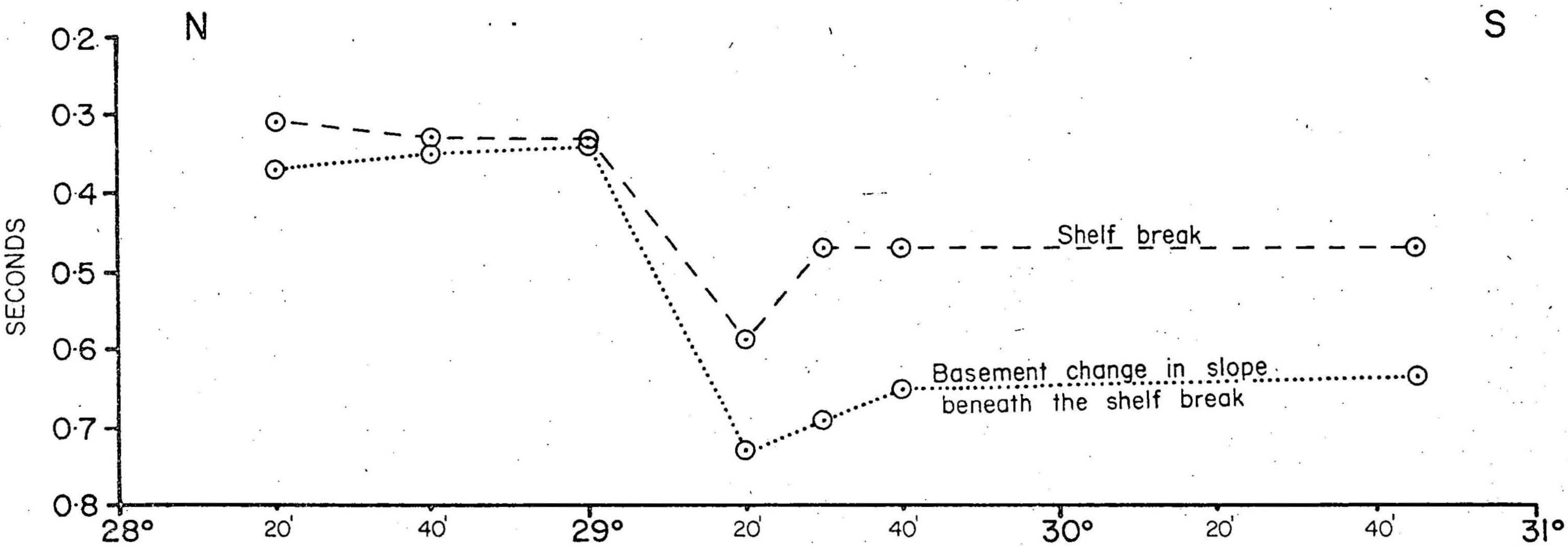

Fig. 3 Depth relation between the shelf break and the change in slope of basement beneath the shelf break in seven east-west seismic sections. Vertical scale in seconds two-way time (0·1s equals 75m in water, and about 100m in sediment)

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