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MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

Aspects of the Geological History and Structure of the Northern Great Barrier Reef

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Aspects of the geological history and structure of the northern Great Barrier Reef

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[Plates 1 and 2; pullouts 1 and 2]

Continuous high resolution seismic profiling of the continental shelf near Cairns between latitudes 16° 15′ S and 16° 55′ S to depths of 70–120 m revealed a sequence of varied lithologies with major and minor disconformities in both reef and non-reef accumulations. The most conspicuous sub-bottom reflector (I) is a complex surface formed through marine regression, shelf emergence, and subaerial erosion, which has been dissected by an ancient drainage system represented by sediment filled channels. It occurs at approximately −67 m near Spur and Onyx reefs, has been deeply channelled below Trinity Opening, and generally rises towards the mainland. This surface marks a major disconformity representing a considerable hiatus in the development of the reef province, and has strongly influenced the distribution and thickness of both reefs and sedimentary accumulations formed during the succeeding marine transgression. While the age of reflector I is conjectural, the higher parts of this surface may have been emergent and non-depositional for longer periods than the lower parts, so that overlying sedimentary accumulations and reefs in contact with it may not be exactly contemporaneous.

A continental slope terrace at approximately −116 m may reflect a late Würm low stand of sea level, and periods of still stand during the Holocene transgression, or minor regressions may be indicated by minor disconformities, and by the marine terraces and changes in slope which occur at several levels, the most conspicuous occurring at −30 m on reefs of the marginal shelf.

The seismic profiles illustrate the form and internal structure of some sedimentary units, and indicate that the present viable outer reefs are merely remnants of more extensive precursors.

1. Introduction

Fairbridge (1950) and Maxwell (1968*a*) have provided comprehensive accounts of the Great Barrier Reef Province, and both authors discuss the probable influence of major tectonic features and postulated sea level changes on general reef distribution, in order to account for the major contrast in character of different regions of this reef province. There has been considerable debate regarding the significance of various bathymetric features in terms of the succession of sea level changes with reference to the Quaternary geological history of the Queensland continental shelf (see, for example, Thom & Chappell 1975).

In recent years, investigations of reef complexes in other parts of the world have resulted in a growing awareness of the influence of pre-Holocene surfaces on the form and distribution of Holocene coral reefs (see, for example, MacNeil 1954; Hoffmeister & Ladd 1944; Purdy 1974*a*), and it has been shown that Holocene sediment distribution patterns owe much to the influence of relict features (Purdy 1974*b*). On the Queensland shelf, relict sediments are considered to be widespread and important features of the present seabed (Maxwell 1968*b*; Maxwell & Swinchatt 1970).

Davies (1974), in estimating the position of the Holocene–Pleistocene junction beneath Heron Island Reef, has drawn attention to the possible significance of a solution unconformity at shallow depth, and there has been speculation regarding bathymetric evidence for ancient karst surfaces beneath Holocene reefs (see, for example, Davies 1975; Davies, Radke & Robinson 1976; Flood 1976*a*, *b*).

An opportunity to investigate these concepts, and other aspects of the geological history of the Great Barrier Reef in the Cairns area, with the use of high resolution reflexion seismic methods with accurate position fixing (Decca Hi-fix), was provided by the Royal Society (London) and Universities of Queensland Expedition to the Great Barrier Reef (1973).

Specific objectives of the seismic investigations were to determine lateral and vertical stratigraphic relations between reef masses and bedded sedimentary accumulations; define disconformities, and evaluate stratigraphic and geomorphological evidence for sea level changes; locate ancient drainage channels; determine reef thicknesses; ascertain the nature of reef foundations; determine the degree to which inherited features have influenced reef distribution and form; and to obtain a clearer picture of the geological history of this part of the Great Barrier Reef by assessing the sequence of palaeoenvironmental changes indicated by the stratigraphic record.

2. Geological setting

The present characteristics of the continental terrace, and adjacent Coral Sea Provinces, were initiated by Tertiary events. Extensive planation of the Australian continent in early Tertiary time was succeeded by widespread crustal warping and fracturing in the late Tertiary time; accompanied by arching of the Eastern Highlands and the subsidence along normal faults of adjacent areas to the east. This period of tectonic activity also promoted the development of the Queensland Trough and the separation of the Coral Sea Plateau from the Queensland shelf as a distinct reef province (Ewing, Hawkins & Ludwig 1970; Orme 1977) and subsequent subsidence of the Queensland shelf.

The major palaeoenvironmental changes which took place on the Queensland shelf are reflected in the six Great Barrier Reef Bores (Michaelmas Cay, Anchor Cay, Heron Island, Wreck Island, Aquarius No. 1, Capricorn 1A), which indicate in general a trend from non-marine conditions to the reefal environment of the present day. Reefal conditions '...similar to those existing along the inner parts of the Great Barrier Reefs first came into existence along the northeastern Australian shelf during the early Middle Miocene' (Lloyd 1973, p. 365). In the Capricorn Basin (Southern Region of the Great Barrier Reef) the change from non-marine to marine sedimentation occurred in the late Oligocene; subaerial erosion surfaces and submerged 'hardgrounds' on the upper continental slope suggest a period of uplift and non-sedimentation from late middle Miocene to Pliocene, followed, in the late Pliocene, by shallow-water sedimentation leading to reef-building conditions (Palmieri 1974). In the Cairns area the prevalence of a reefal environment on the marginal shelf since Pliocene times is implied by the Michaelmas Cay bore hole sequence (Richards & Hill 1942; Lloyd 1973).

Various bathymetric anomalies and shoreline features have often been correlated speculatively with previous stands of sea level. It is believed that with the onset of the Pleistocene, the emergence of the continental shelf and present coastal belt began, and that 'during the Riss and Würm glacials (120000–105000 years B.P. and 70000–12000 years B.P.) the greater part of the shelf was exposed' (Maxwell 1973, p. 266).

3. General physical characteristics of the area

The area with which the present investigation is concerned occupies the continental shelf near Cairns, between latitudes 16° 15′ S and 16° 55′ S. It lies in the northern part of the Central Region of the Great Barrier Reef Province as defined by Maxwell (1968*a*), which is here 60 km wide, and displays a semi-meridional trend of physiographic zones and sediment facies. Unlike the Northern Region, there is here no continuous barrier of shelf edge (ribbon) reefs, the most extensive reefs (Batt and Tongue Reefs, and the Arlington Complex) occurring on the inner part of the marginal shelf.

Depths are generally less than 30 fathoms (55 m) except where the main channels (Grafton Passage and Trinity Opening) extend across the marginal shelf. Bathymetric zones recognized by Maxwell & Swinchatt (1970) are: the near-shore zone extending from the coast to five fathoms (9 m), the inner shelf extending to 20 fathoms (36.5 m) forming a reef-free channel, and the marginal shelf extending to the shelf break at 40–50 fathoms (73–91 m).

This is a region of high rainfall (2032–3048 mm per year), with a maximum tidal range of 3 m. The nature and distribution of the sediments have been studied by Maxwell & Swinchatt (1970). Fringing reefs are present north of Yule point, although there is evidence that they did not begin as fringing reefs, but have acquired this state through progradation of shoreline (Bird 1971).

The adjacent mainland rises rapidly to the Atherton Tableland over 950 m above sea level, and the main rivers discharging to the sea in this area are the Daintree, Mowbrey, and Barron Rivers.

4. Methods

Continuous seismic reflexion profiling was carried out along traverses arranged as far as possible in two, more or less orthogonal, sets, namely roughly parallel to and at right angles to the edge of the continental shelf. This pattern was pursued in order to facilitate correlation of observed features. Decca Hi-fix control was employed as a means of accurate position fixing, fixes being taken at intervals of 5 min along the tracks.

For most traverses the equipment used comprised a 1kJ triggered capacitor bank driving either a Huntec ED.10 high resolution boomer, or a slightly smaller transducer of similar characteristics (Sargent 1969). The recording system comprised short 6- or 10-element hydrophone streamers coupled, via an input bandpass filter, to an E.G. & G. Model 254 graphic recorder. The sources normally operated at repetition rates of 2 pulses per second and the passband of the input filter was customarily set in the range 500–5000 Hz.

A magnetic tape recorder, run in parallel with the Model 254, recorded broadband seismic data, but the present interpretation is based entirely on the 28 cm wide Alfax monitor records produced by the graphic recorder.

The depth of sub-bottom penetration achieved by this system at operational speeds varied between 70 and 120 m, and the quality of the records produced was influenced strongly by sea state.

For deeper penetrations some traverses were undertaken with a 5 kJ sparker source. For these surveys the recording configuration remained unchanged, but the input filter low frequency cut off was adjusted to lower frequencies. The sparker records, while showing considerable loss in near-bottom resolutions, provided useful data on deeper reflectors.

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5. Results

In the discussion of the continuous seismic profiles it is (reasonably) assumed that the interpreted seismic reflexions are coincident either with significant geological interfaces referred to as 'surfaces' or with a layering (producing seismically reflective velocity contrasts) within consanguineous deposits. The sub-bottom velocity distribution in the area is not known, and sea water velocity has been used in reducing near-bottom interval times to thicknesses. Furthermore, no attempt has been made at this time to correct for the effects of recording system geometry and the apparent migration of dipping reflectors. As a result, the computed positions and depths of reflecting horizons are likely to be systematically displaced from their true spatial relations as may be revealed by confirmatory drilling. However, these effects will be generally small, and not of great significance in the framework of the present study.

Prominent reflectors may be produced by marked changes in lithology, varying degrees of cementation or solution, and mineralogical and textural changes. Hence, subaerially exposed,

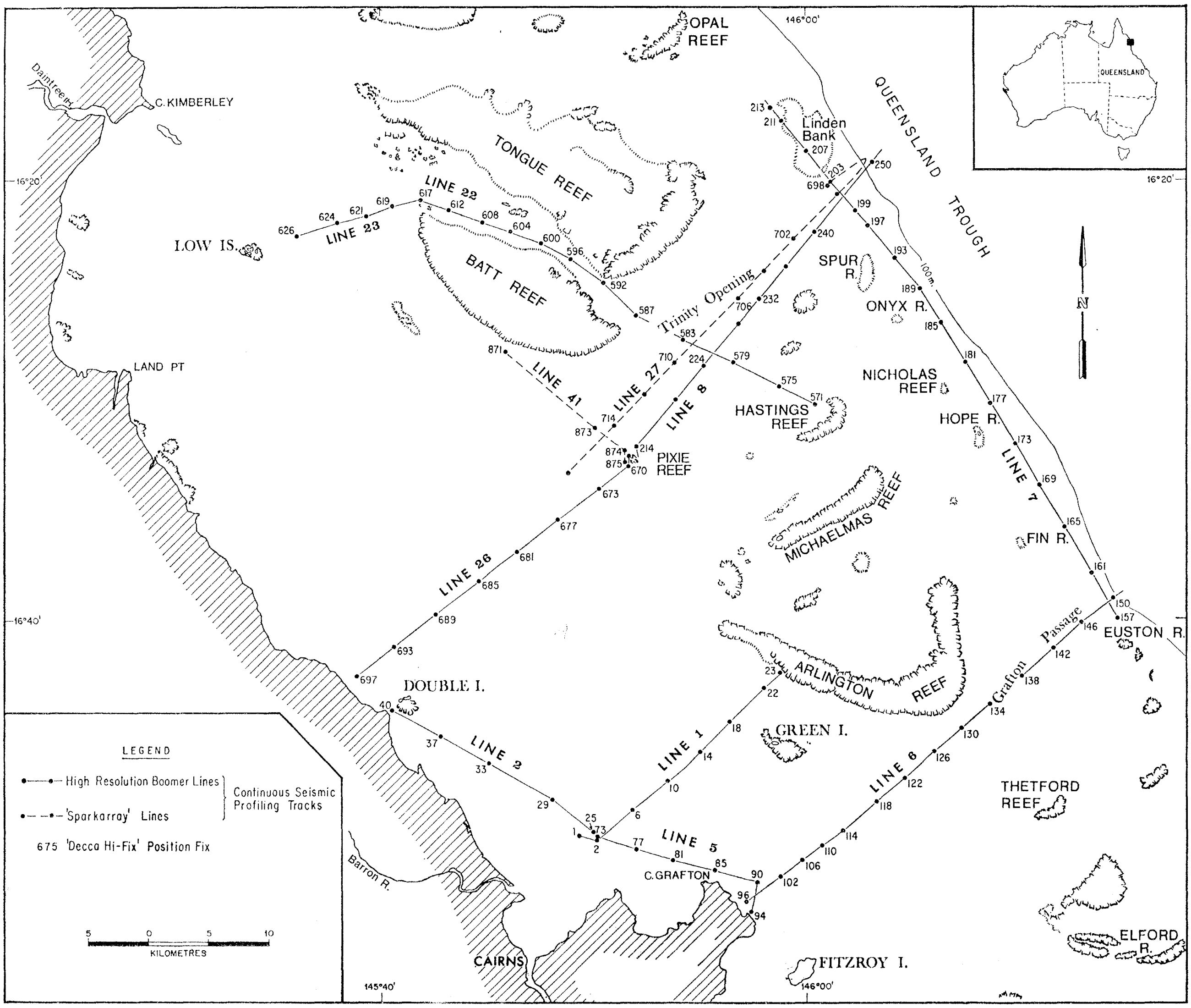

Figure 1. Map of the continental shelf near Cairns showing reef distribution and seismic profiling tracks.

weathered and cemented surfaces have marked reflectivity. Likewise, well sorted coarse-grained deposits may be differentiated, in some records, from those deposits which lack hydraulic classification and which contain quantities of carbonaceous matter, on the basis of their different acoustic properties. Similarly, well sorted quartz sands may be acoustically more transparent than carbonate shell sands. Owing to high attenuation of signals by reef masses it is often difficult to obtain definition of their internal structures, and consequently some of the major reflexions may lose clarity as they are traced into some of the thicker reef masses near the shelf edge.

Of the 47 profiles made in the Cairns Region during the 1973 Expedition, only 11 are considered in this paper (see figure 1), but these are sufficiently representative to demonstrate the broad geological characteristics of the area.

(*a*) *Seismic reflectors*

The seabed shows an interesting diversity of relief and acoustic properties, in consequence largely of the occurrence of both reef and non-reef facies. The seabed has very rugged topography where it rises abruptly over modern viable reefs, which are most numerous and extensive on the marginal shelf, in contrast to its flat or gently undulating nature over the sediment-covered inner shelf and inter-reef areas. Diversification of relief is also caused, locally, by ancient ridges and pinnacles which protrude above the seabed.

The greatest bathymetric relief (58 m) illustrated by the profiles is seen on profile 7 (plate 1) where Linden Bank rises to –15 m from the adjacent seabed, which at Trinity Opening lies at –73 m. On line 6, near the shelf edge the seabed is at –60 m; opposite the mouth of the Barron River on line 2 it lies at –12 m; and along line 22 (figure 2) it lies –37 to –40 m, rising to –15 m over the flanks of Batt and Tongue reefs, and falling to –53 m where the profile crosses Trinity Opening. Present seabed relief is influenced, therefore, not only by reef growth but also by ancient drainage channels.

Prominent sub-bottom reflectors are present, numbered I to III in increasing depth. All are shown on profile 22 (figure 2, pullout 1) and their form and relations with older and younger deposits indicate that they are erosion surfaces. Horizon 'S' is a subsidiary erosion surface present at shallow sub-bottom depth, particularly in channel filling deposits. There are also numerous minor reflexions within the reef masses, which may facilitate the reconstruction of the development of reef forms, though consideration of this aspect is beyond the scope of this paper.

(i) *Reflector I*

The most striking of all sub-bottom features is reflector I, which can be clearly seen in all seismic profiles, and which displays considerable relief. Beneath line 22 (see figure 2) it descends from a general level of –45 to –60 m beneath Trinity Opening, and rises to –30 m beneath Batt Reef.

Along line 7 the general level of reflector I is –67.5 m, rising to –47 m below some of the outer-shelf reefs, and falling to approximately –105 m at Trinity Opening (see figure 3, pullout 2 and plate 2). The irregular, channelled nature of surface I is also shown on profile 6 (plate 2). Along line 6, near the shelf edge, surface I occurs at a depth of 64 m below sea level and it is channelled to approximately –86 m.

It is apparent that reflector I, which in general rises towards the present shoreline, is an ancient erosion surface that transects both reef and non-reef bedded accumulations, and which has been dissected by an ancient drainage system into a series of ridges and small plateaux. In places on the marginal shelf it lies at shallow sub-bottom depth, especially where it occurs over eroded remnants of ancient reef masses, and, indeed, may locally form the present seabed.

(ii) *Reflectors II and III*

Reflector II, well defined in several of the profiles, lies 9–12 m below reflector I, but has been cut by the latter surface where ancient drainage channels occur, i.e. beneath Trinity Opening and below the northern end off Batt Reef (figures 2 and 3). Reflector III occurs at greater depth and has been detected only in profile 22 where it rises near the northern tip of Batt Reef. It is also probably an erosion surface.

(*b*) *Variations in thickness of sedimentary accumulations and reef masses*

The widely variable thickness of sediments overlying reflector I is well illustrated by profile 22, there being a cover of only 4 or 5 m over the higher, inter-reef areas of this surface, but a thickness of 34 m where line 22 crosses Trinity Opening. Locally there may be no overlying sediment where reflector I reaches the present seabed as a relict or exhumed ancient surface. Nearer to the shelf edge, along line 7, the thickness of sediment cover is in many places reduced to approximately 3 m, but beneath Trinity Opening deposits occupying an ancient drainage channel reach a thickness of 32 m (see figure 3 and plate 1, figure 2).

Along line 6 (plate 2), which completely crosses the continental shelf between the shelf edges at Grafton Passage and Cape Grafton, the thickness of sedimentary accumulations overlying reflector I varies from $2\frac{1}{2}$ m near the shelf edge to 21 m in the buried channel, which lies beneath the inner shelf zone at station number 115 (Decca Hi-fix position).

Wedging and lensing of sediment are commonplace and these phenomena can be seen particularly on lines 1 and 6 to be associated with reef masses, partly buried ancient ridges, and former drainage channels. In some areas wedges of sediment thin seawards from the present shoreline. Not only sediment source and dispersal factors, therefore, but also the configuration of surface I has influenced the variations in thickness of sedimentary accumulations above this reflector.

Surface I is clearly defined beneath many of the platform reefs, e.g. Tongue and Batt reefs, and it is noteworthy that the reefs developed on this surface pass upward from a lower massive

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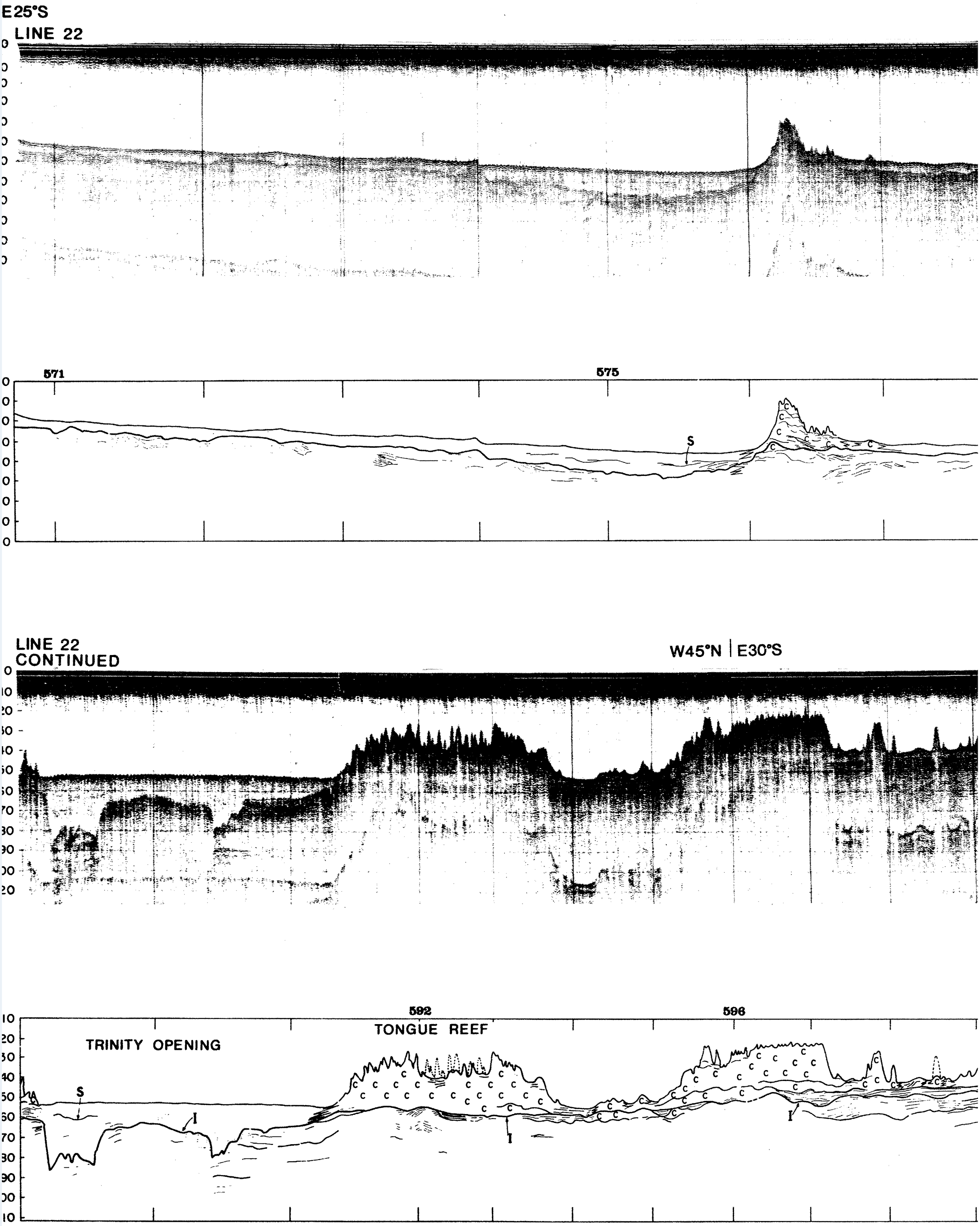
Description of figure 2

Figure 2. Continuous seismic reflexion profile (high resolution boomer) and interpretation along line 22, extending from the vicinity of Hastings Reef, along the marginal shelf to the northern tip of Batt Reef, viewed from the northeast. (Note that the interpretation sections begin at the 30 ms level, i.e. 22.5 m below sea level.)

A major disconformity occurs at reflector I which represents an extensive erosion surface formed during a period of shelf emergence. The channels at 583, 589 and 591 (Decca Hi-fix positions) are tributaries which unite to form the single channel shown on profile 7 (see figure 3 and plate 2) beneath Trinity Opening at the shelf edge. Facies changes between reef masses and inter-reef bedded sediments are evident, and rhythmically bedded accumulations are apparent above and below reflector I, particularly between 603 and 617 (Decca Hi-fix positions).

A figure of 1500 m/s, centrally bracketing the range of seawater velocity, has been used throughout this work. The reproduction of original seismic profiles have reference timing lines at 0.01 s intervals corresponding to an interpreted depth scale of 7.5 m per timing line interval. The velocity used is not confirmed by drilling or seismic measurements. However, on the basis of extensive (substantiated) experience this 1500 m/s figure is reasonable, and follows convention under the circumstances. An error of up to 10% underestimation of sub-bottom thicknesses is the most that is envisaged in deeply buried sections of these records.



E25°S
LINE 22
571
575
S
LINE 22
CONTINUED
W45°N
E30°S
TRINITY OPENING
TONGUE REEF
592
596
S
I

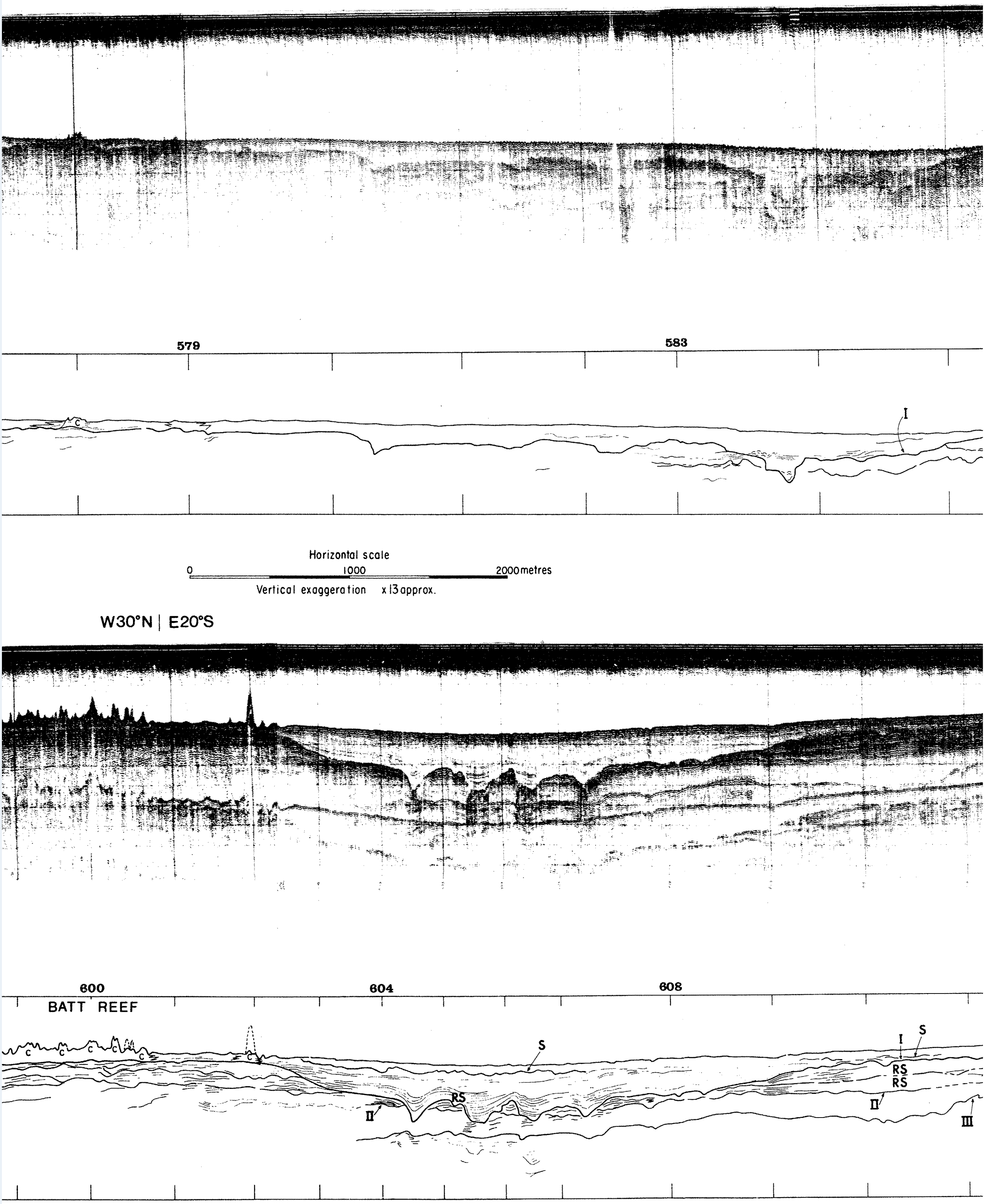


FIGURE 2. For description see opposite.

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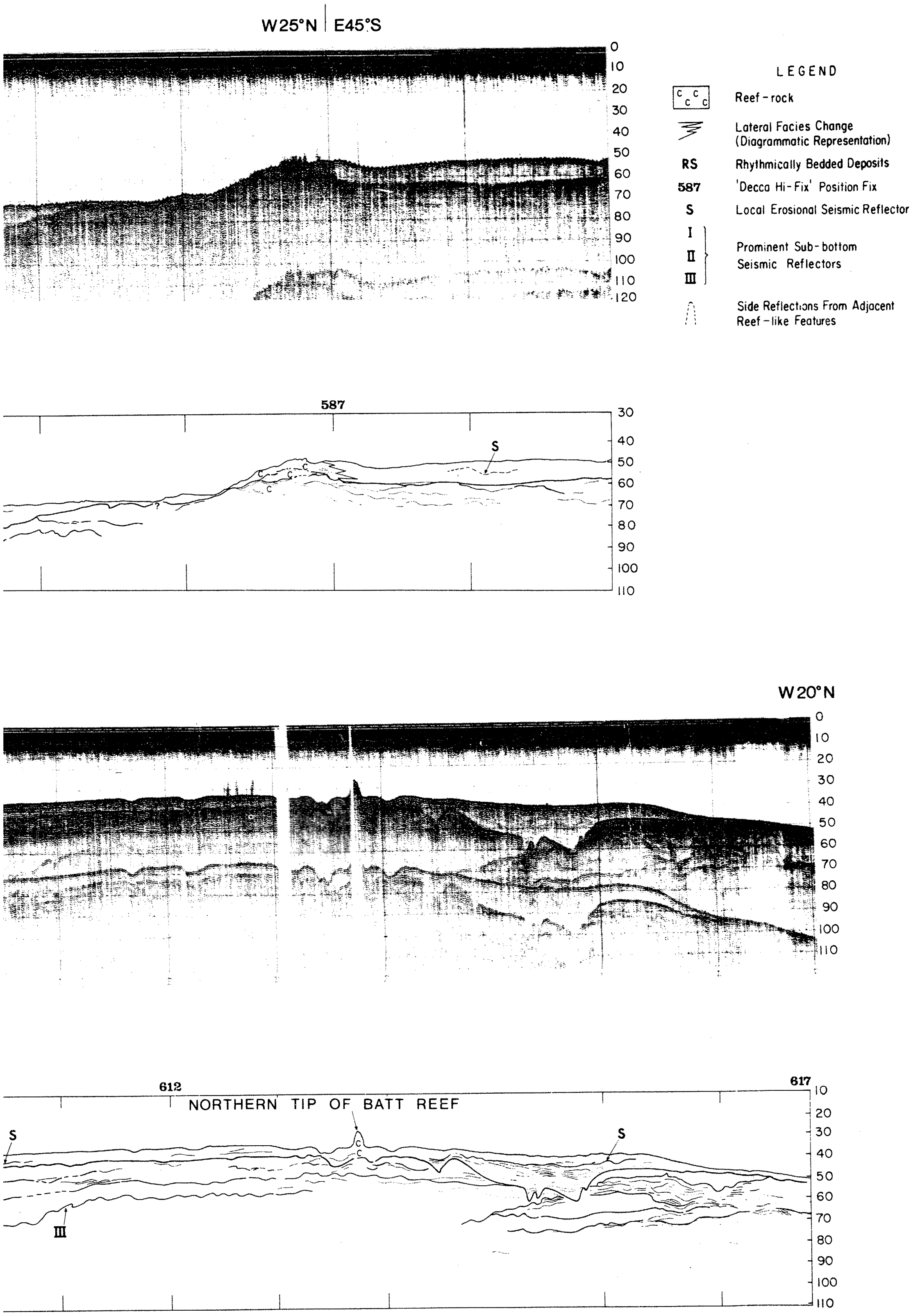
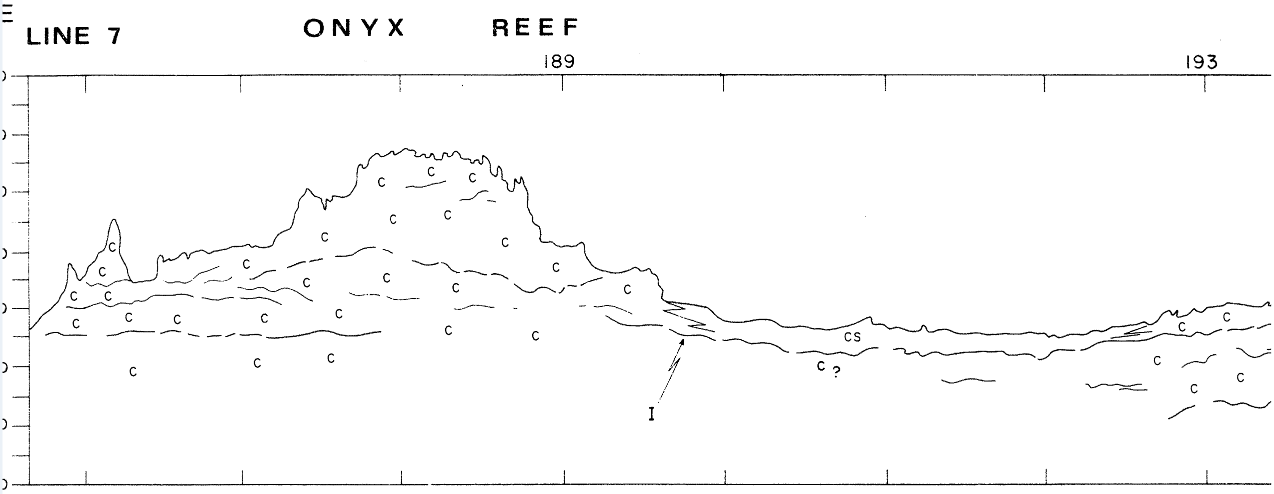
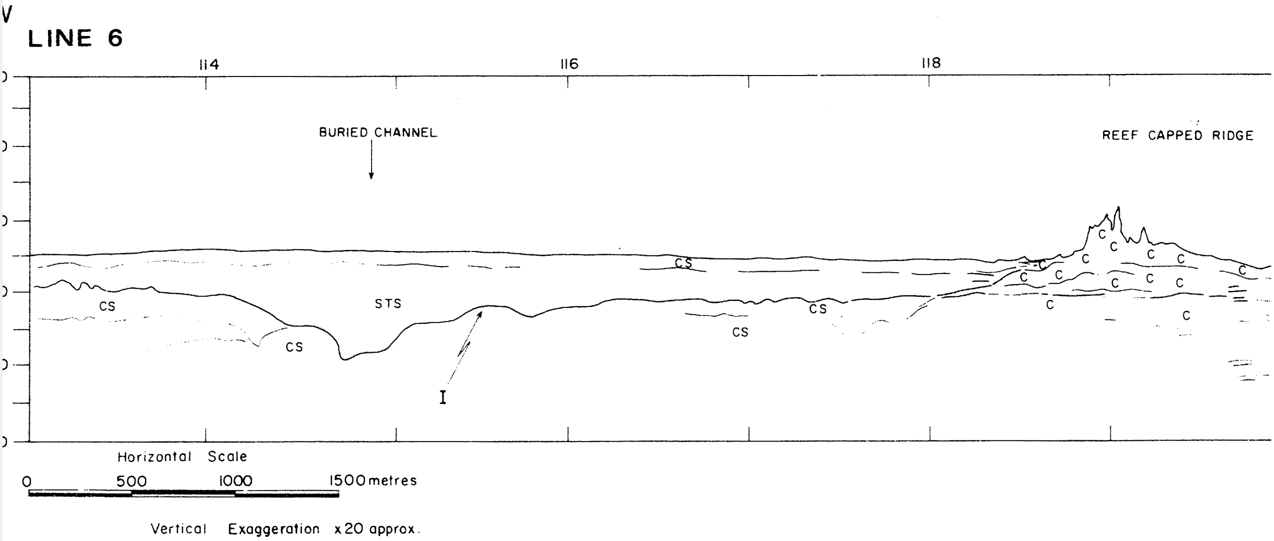

W25°N
E45°S
LEGEND
Reef - rock
Lateral Facies Change (Diagrammatic Representation)
RS Rhythmically Bedded Deposits
587 'Decca Hi-Fix' Position Fix
S Local Erosional Seismic Reflector
I II III Prominent Sub-bottom Seismic Reflectors
Side Reflections From Adjacent Reef-like Features
587
S
W20°N
612
NORTHERN TIP OF BATT REEF
617
S
III





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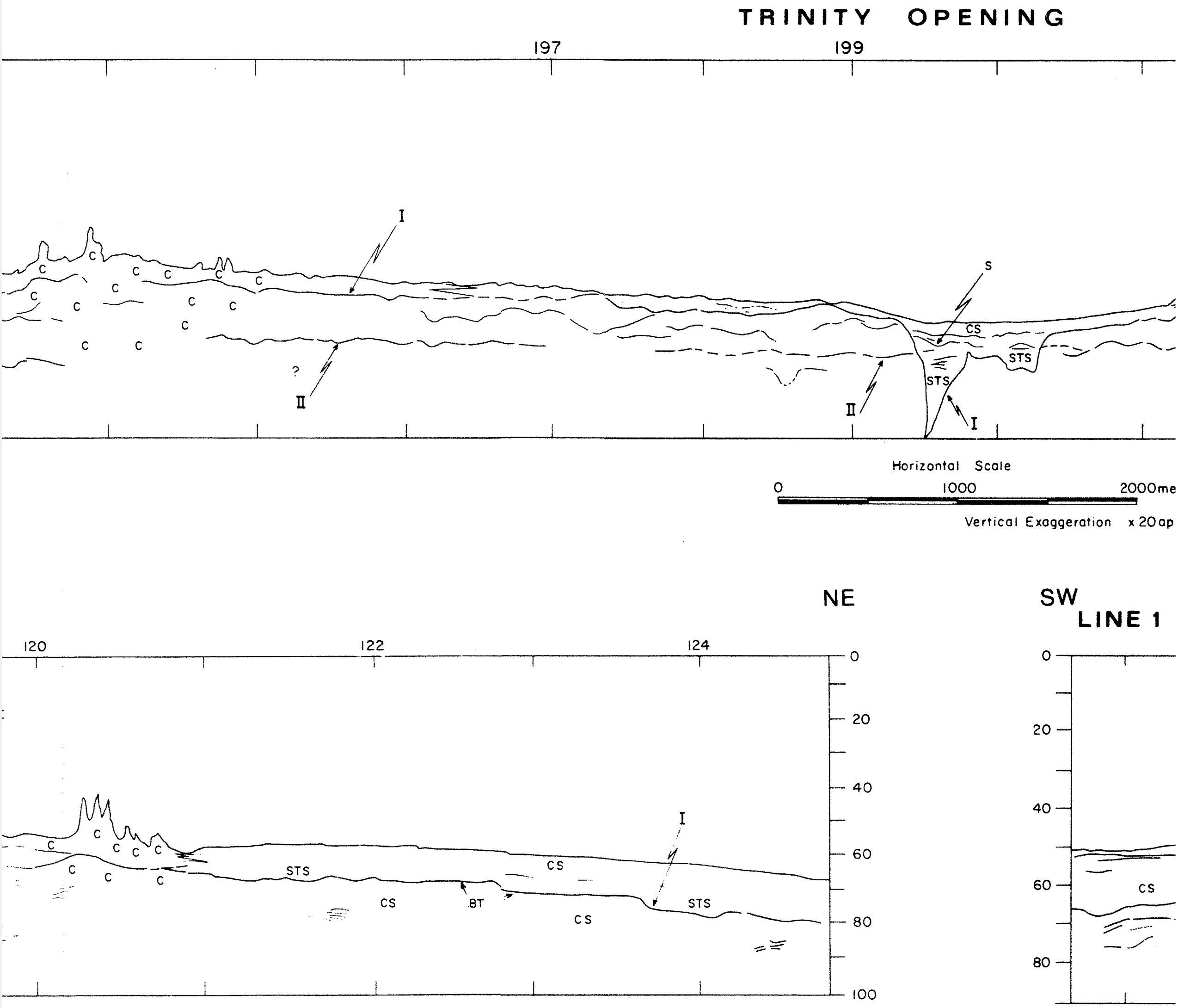


LEGEND

189 – Position 'Decca Hi Fix'.

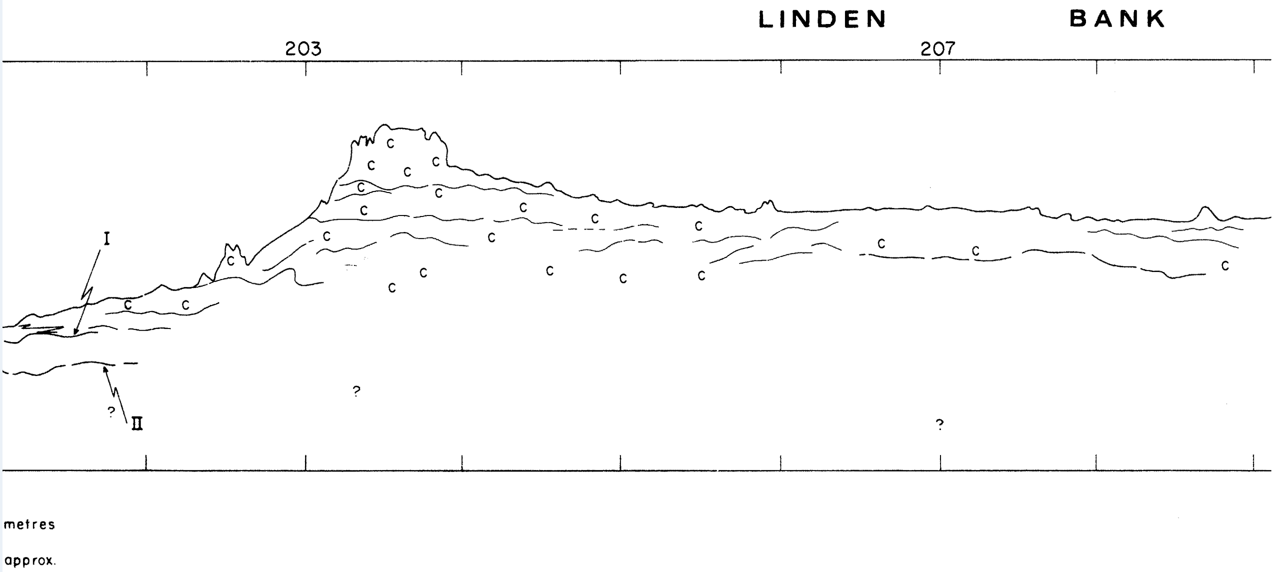
I, II – Major Seismic Reflectors.

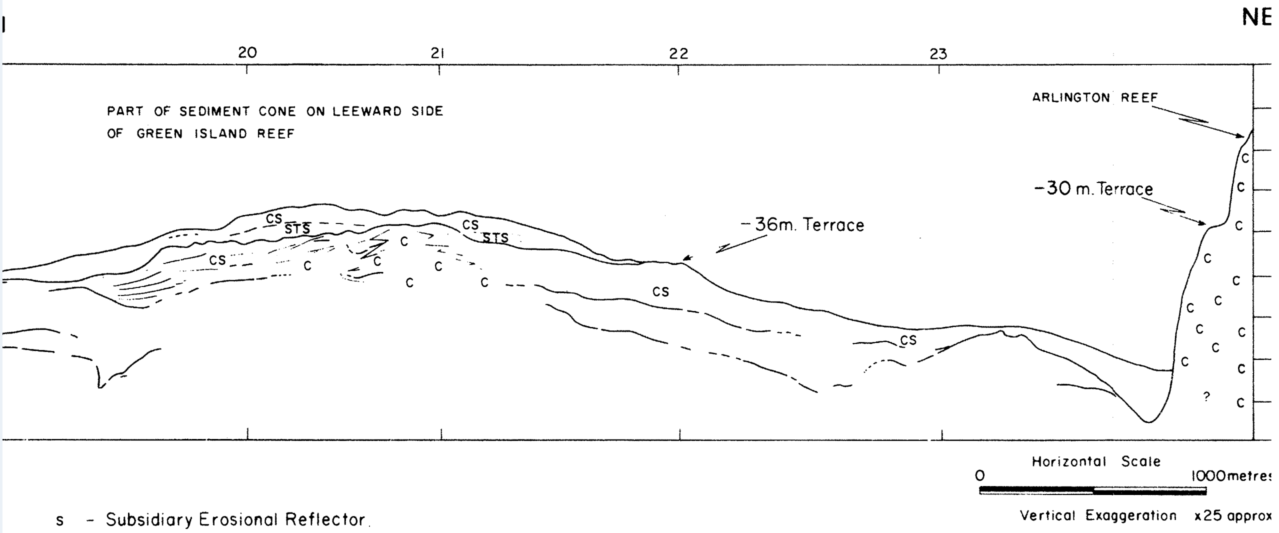
– Lateral Facies Change (Diagrammatic Representation).

cs – Bedded Sedimentary Accumulations.

BT – Buried Terraces.

Figure 3. For description see opposite.





s – Subsidiary Erosional Reflector.

c c – Dominantly Reefal.

STS – Seismically more transparent Sedimentary Accumulations.

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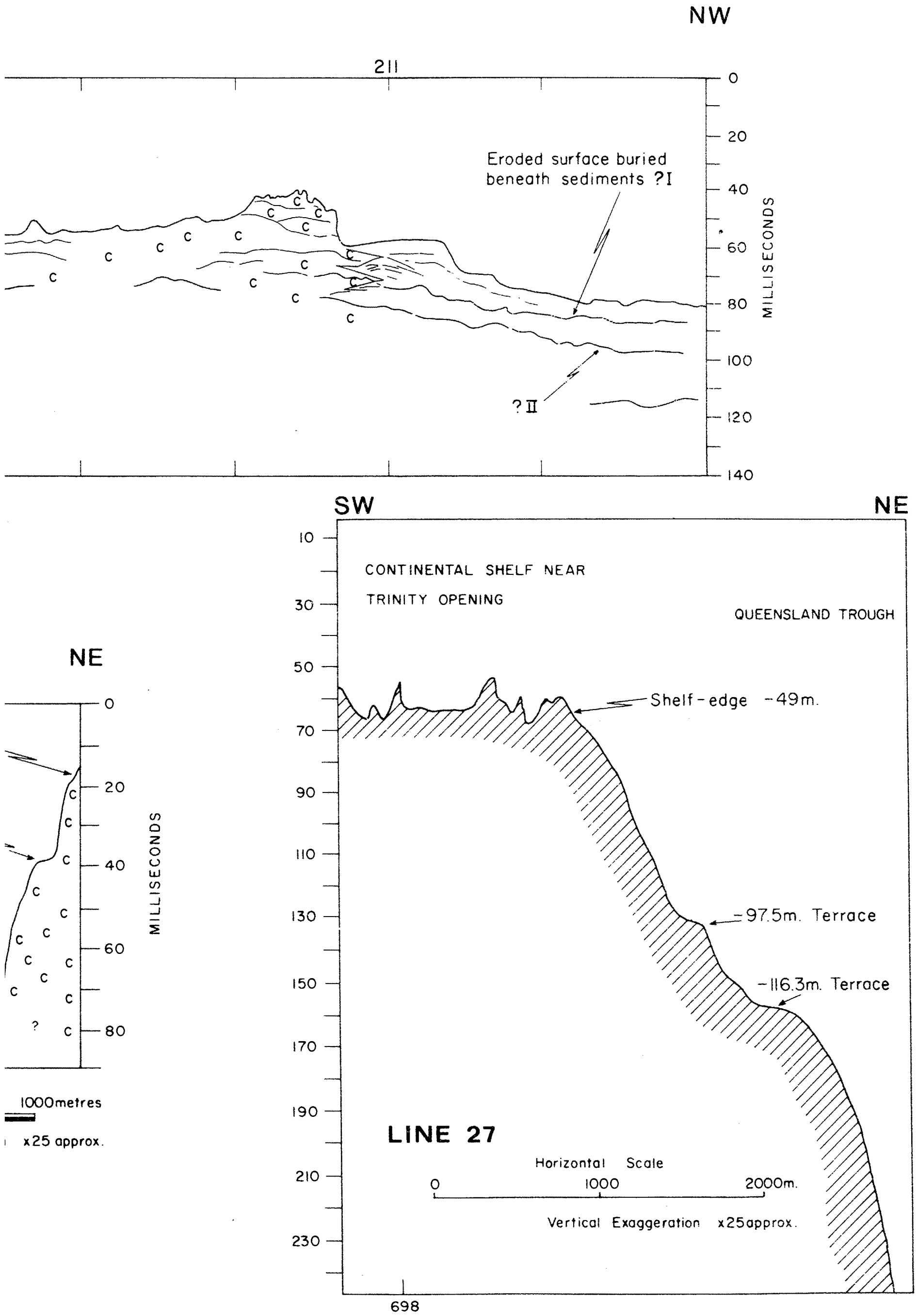
NW
211
0
20
40
60
80
100
120
140
MILLISECONDS
Eroded surface buried beneath sediments ?I
?II
NE
MILLISECONDS
1000metres
x25 approx.
SW
NE
CONTINENTAL SHELF NEAR TRINITY OPENING
QUEENSLAND TROUGH
Shelf-edge -49m.
-97.5m. Terrace
-116.3m. Terrace
LINE 27
Horizontal Scale
0
1000
2000m.
Vertical Exaggeration x25approx.
698

stage to a greatly diminished state at higher levels. This change occurs between the −30 m and −40 m levels, and is very noticeable at Pixie Reef, where a mere remnant of a much more massive and extensive reef structure rises above the −30 m level. The thickness of Tongue and Batt reefs shown on profile 22 (figure 2) ranges between approximately 7.5 and 22.5 m, but adjacent to line 22 these reefs reach the present sea level, suggesting that their total thickness may be 30 or 38 m. Vestigial erosion surfaces have been detected within some platform reefs implying that post surface I reef development was not uninterrupted. However, more extensive scrutiny of this evidence will be necessary before the stratigraphic significance of such features can be properly assessed.

It is not possible to give accurate figures for the thicknesses of the reefs near the shelf edge (line 7), since in most cases reflector I loses definition and cannot be traced continuously through the reef masses with certainty. However, although the upward trend of reflector I within reef masses may be due partly to lateral seismic velocity changes, the indications are that towards the shelf edge, reef masses are thicker and represent a more continuous sequence than the platform reefs on the western part of the marginal shelf.

Profile 6 (figure 3 and plate 2) shows an ancient ridge (Decca Hi-fix station numbers 118–121) forming the foundation for a younger reef mass which has been partly buried by flanking sediments, and which rises above the present seabed as a number of pinnacles to reach 30 m below the present sea level. This feature does not appear on bathymetric charts of this area, for there is no reef at or near sea level. Its present 'drowned' state suggests its inability to maintain an upward growth rate commensurate with sea level rise.

(c) *Buried drainage channels*

Not all of the ancient drainage channels are reflected by the present bathymetry, for some have been partially concealed by subsequent reef growth. Some buried channels trend more or less NW–SE along the continental shelf until they meet others which cross directly to the shelf edge. Line 6 (plate 2) is channelled in several places on the marginal shelf, but a major buried channel occurs beneath the inner shelf. The three sub-bottom channels shown on profile 22 at 583, 589 and 591 (Decca Hi-fix positions), join to form the single incised channel beneath Trinity Opening at the shelf edge (line 7, plate 1).

Description of figure 3

Figure 3. Interpretations of parts of the seismic reflexion profiles along lines 1, 6 and 7, and the morphology of the upper continental slope as shown on line 27.

Line 7. The section shown here lies near the shelf edge extending from a point adjacent to Onyx Reef north-eastward to the northern flank of Linden Bank. Seismic reflectors are obscure beneath the thick reef masses, but I is clearly channelled beneath Trinity Opening to a depth of approximately 105 m. General facies changes between reefal and inter-reef accumulations are indicated (compare with plate 1, figure 2).

Line 6. This is part of the interpretation of the profile which is shown complete in plate 2. The erosion surface, reflector I, is quite clear. It is channelled at 115 (Decca Hi-fix position), and passes beneath a partially buried reef mass between 118 and 121. At approximately 122–124, buried terraces occur at approximately −49 and −53 m. General facies differences are expressed in the channel filling deposits by variations in their acoustic properties.

Line 1. This part of profile number 1 lies just to the north of Green Island Reef and terminates at Arlington Reef. It shows reef rock and flanking sediment wedges on the leeward side of Green Island Reef and a partially buried terrace at −36 m. A narrow terrace is evident at −30 m on the outer slope of Arlington Reef.

Line 27. Profile of the upper continental slope at Trinity Opening showing a break in slope at −49 m and narrow terraces at −97.5 and −116.3 m.

On the marginal shelf, the channels, particularly those towards the shelf edge, are narrower, and simpler both in profile and in terms of channel filling deposits, than those detected beneath the inner shelf region. That shown on line 2 (plate 1) near the mouth of the Barron River for example, contains a sequence of rhythmically bedded sediments alternating with wedges and lenses of acoustically more uniform and more transparent sediment. There is bedding discordance, and differential compaction structures are evident where more recent sediment has compacted over an irregular erosion surface (see plate 1, figure 3).

(*d*) *Marine terraces*

Several marine terraces or marked changes of slope were encountered during the present investigation. On the continental slope, narrow terraces occur at approximately −98 m and −116 m (see figure 3). Terraces also occur on reefs near the shelf edge at −19.5, −45, −67, and −57 m, i.e. Onyx Reef (plate 1, figure 1); and adjacent to Euston Reef (line 6, plate 2) there is a leeward terrace of −48 m, and a seaward terrace at −60 m.

There is a marked planation at approximately −30 m on Pixie Reef, and at Arlington Reef there is a narrow terrace at similar depth. On Hastings Reef a marked break of slope occurs at −22.5 m. A partly buried terrace at −36 m occurs to leeward of Green Island Reef (figure 3, line 1), and completely buried terraces are evident on the continental shelf at −49 and −53 m (figure 3, line 6, and plate 2). The main terrace levels encountered during the present study are summarized in figure 4.

6. Interpretation

There is a major disconformity representing a considerable hiatus at reflector I, which is interpreted as an ancient surface produced by marine regression, shelf emergence, and subaerial erosion. Withdrawal of the sea resulted in the extension of rivers across the exposed shelf to the new shoreline near the present shelf break. A subsequent lowering of sea level and accompanying change of the base level of erosion, caused deeper channelling of the shelf edge to at least −116 m. At this time reef-rock of exposed shelf edge reefs may have presented a steep, probably cliffed, shoreline to the Coral Sea, breached in this area principally by rivers at Grafton Passage, Trinity Opening, and just to the north of Linden Bank. Consequently the exposed shelf surface developed considerable relief and a very diverse topography.

Where ancient drainage channels occur, the acoustic properties of the sequence immediately

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Description of plate 1

Photographs of parts of the seismic reflexion profiles (high resolution boomer) along lines 2 and 7.

Figure 1. The shelf edge rising from the 90 ms (−67.5 m) level to 26 ms (−19.5 m) near Onyx Reef, viewed from the northeast (line 7). A conspicuous terrace level occurs at 58–60 ms (−43.5 to 45 m), with other terraces at 67 ms (*ca.* −50 m), 70 ms (−54.15 m) and 77 ms (−57.75 m). Reflector I is present, but indistinct beneath the thick reef mass.

Figure 2. The southern part of Linden Bank rising to 20 ms (−15 m) from Trinity Opening at 97 ms (−72.5 m). The buried channel (B), and the reflectors I and II are shown.

Figure 3. A buried channel beneath the seabed (SB) at about 16 ms (approximately −12 m) to the northeast of the mouth of the Barron River. Wedging and discordant bedding are evident in complex channel filling accumulations which comprise rhythmically bedded sediments and acoustically more transparent deposits. An erosion surface (E) occurs at a major disconformity, above which differential compaction structures are evident, particularly between 29 and 30 (Decca Hi-fix positions).

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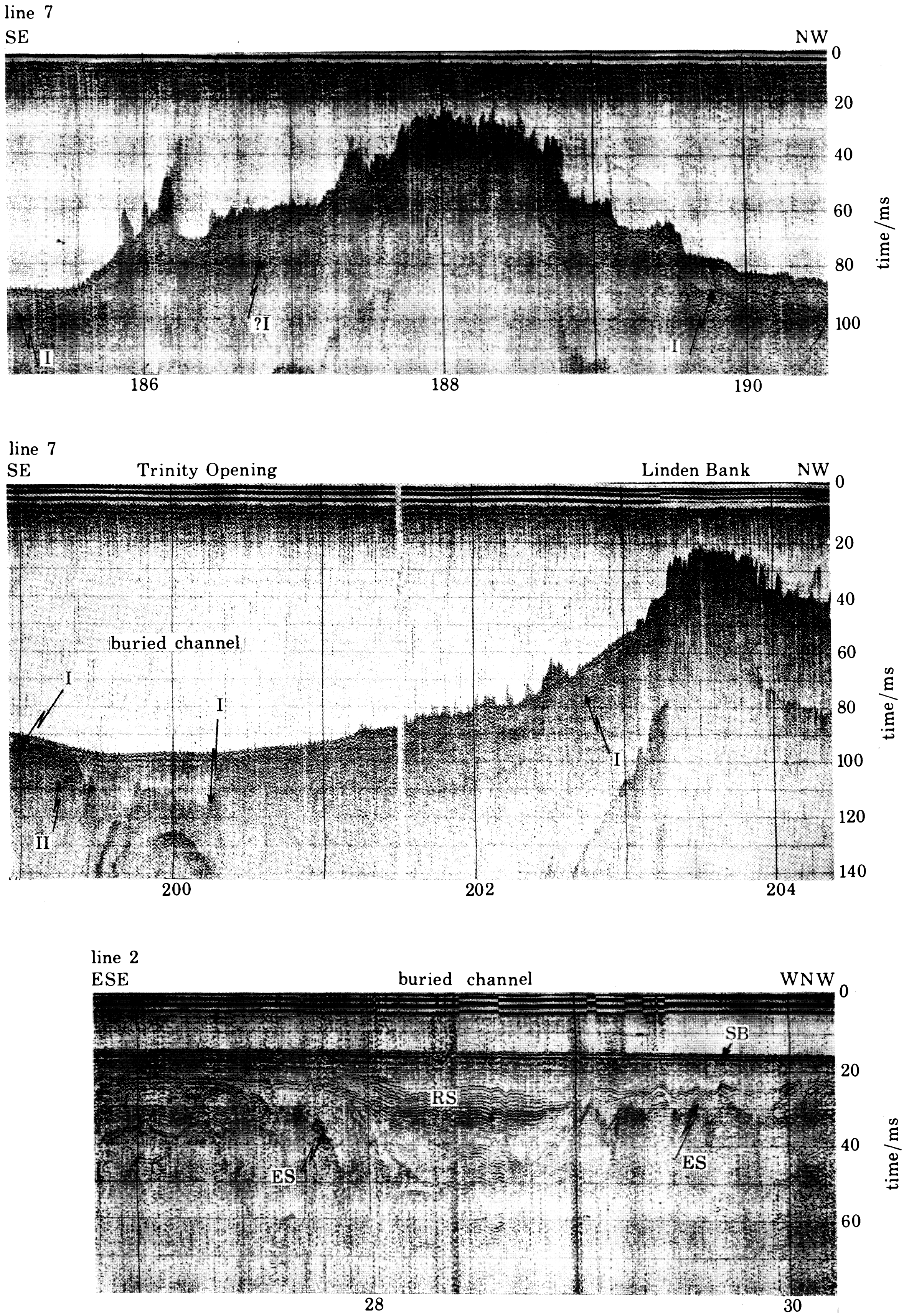

PLATE 1. For description see opposite.

(*Facing p.* 30)

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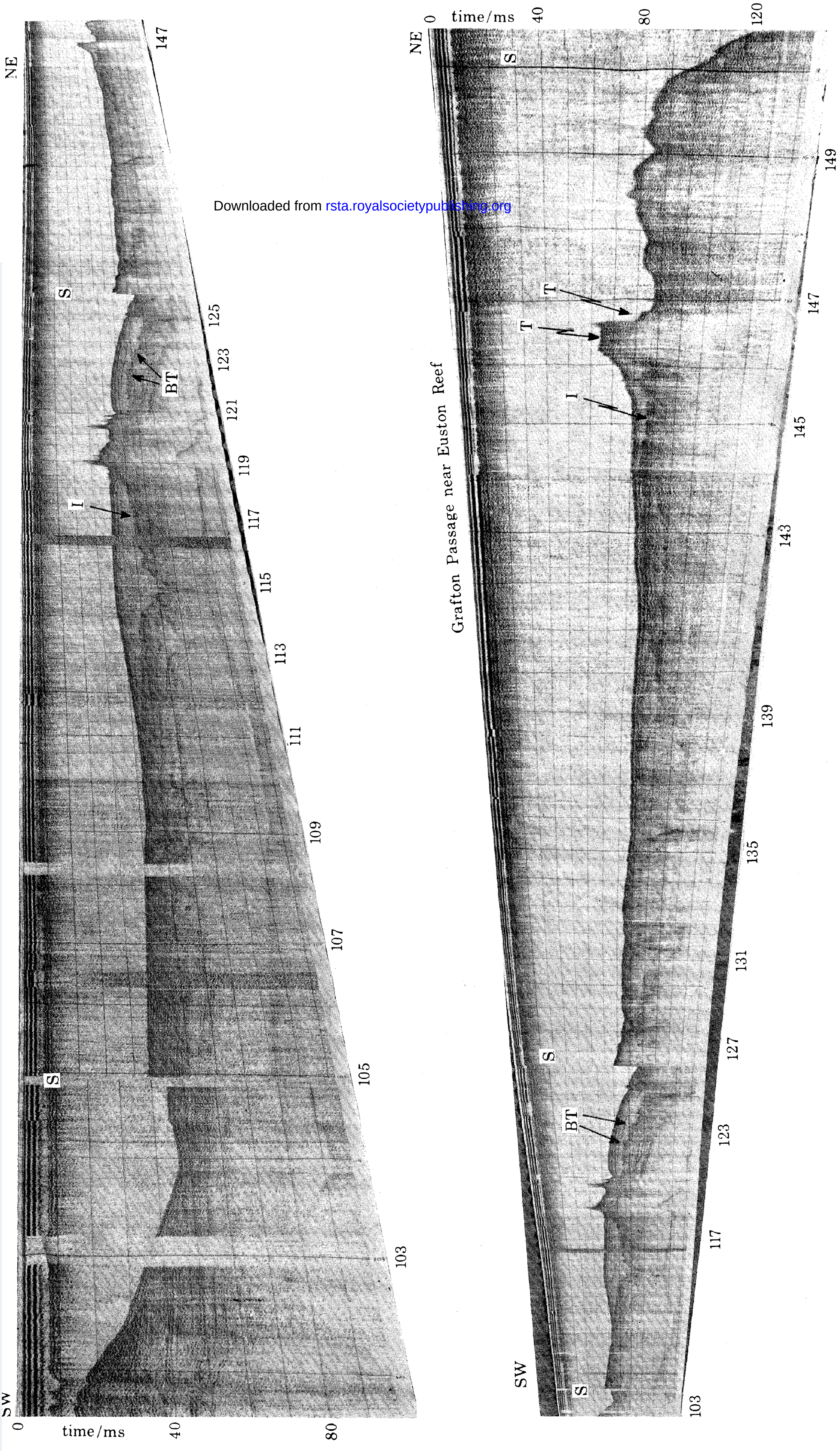
NE
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0
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123
125
147
Grafton Passage near Euston Reef
T
120
127
131
135
139
143
145
149

overlying reflector I suggest that the sea level rise at the commencement of the ensuing transgression caused the backfilling of stream channels with poorly sorted, dominantly terrigenous sediment. As the transgression proceeded, the higher parts of the 'marginal shelf' probably formed karstified islands, separated from each other and from the mainland by progressively broadening channels. This environment gradually changed in character from a fluviatile régime to a transitional marine stage still strongly influenced by low salinity and high turbidity discharge from the major streams, which inhibited reef growth over most of the shelf. However, when the rise of sea level became sufficient to submerge completely the entire shelf the effects of the non-marine influences waned, and reefs developed by pronounced lateral accretion. That later stages of reef accretion were dominantly vertical is indicated by the seismic profiles, so that many reefs, especially near the shelf edge, are mere remnants of more extensive precursors. This evidence, together with 'drowned' reefs below approximately −30 m might suggest that a more rapid rate of sea rise had occurred during later stages of the transgression.

7. Discussion

The information provided by the seismic profiles permits the determination of a sequence of geological events; the deduction of a probable succession of palaeoenvironmental changes; and the assessment of some controls on reef distribution, thickness and form. Therefore, in an attempt to present this information objectively, no assumptions have been made regarding the ages of the various erosion surfaces referred to in the preceding sections of this paper. However, it is now appropriate to consider the results of the seismic investigation in relation to some previously published views concerning the geological history of this part of the continental shelf. The only positive data regarding the stratigraphy of the shelf in the Cairns area are provided by the Michaelmas Cay bore, which was drilled to 600 ft (182.9 m), passing through reef-rock (378 ft, 115.2 m) followed by quartz–foraminiferal sands (Richards & Hill 1942), and although it has not been possible to date precisely any part of the core, none of it is older than Pliocene (Lloyd 1973). However, by analogy with evidence from the Heron Island Reef, Davies (1974), considering the Michaelmas Cay bore hole log, postulated a 'solution unconformity' at a core depth of 27 m (98.8 ft), which he proposed as the Holocene–Pleistocene junction. Subsequently Davies (1975) related this interpretation to bathymetric evidence for a −17 m (−55.7 ft) platform beneath Michaelmas Cay and adjacent reefs. However, because in the Michaelmas Cay bore no core was recorded between 42 ft (12.8 m) and 90 ft (27.5 m) it seems unlikely that

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Description of plate 2

Photographs of the entire seismic reflexion profile (high resolution boomer) along line 6, extending from the shelf edge at Grafton Passage to Cape Grafton. The most conspicuous feature is a major disconformity marked by reflector I, which is a markedly channelled erosion surface. A partially buried reefal ridge occurs at 119–121 (Decca Hi-fix positions), and adjacent, buried, seaward terraces are indicated at approximately 65 and 70 ms (*ca.* −49 and −53 m). Terrace levels near the shelf edge adjacent to Euston Reef are indicated at 64 and 80 ms (−48 and −60 m).

Figure 1. An oblique view of profile 6 from the southwest.

Figure 2. Profile 6 viewed obliquely from the east.

The profile represents a continental shelf width of 48 km, and the vertical exaggeration is approximately ×20, disallowing the effect of perspective. T, terraces; BT, buried terraces; I, major disconformity; S, scale change.

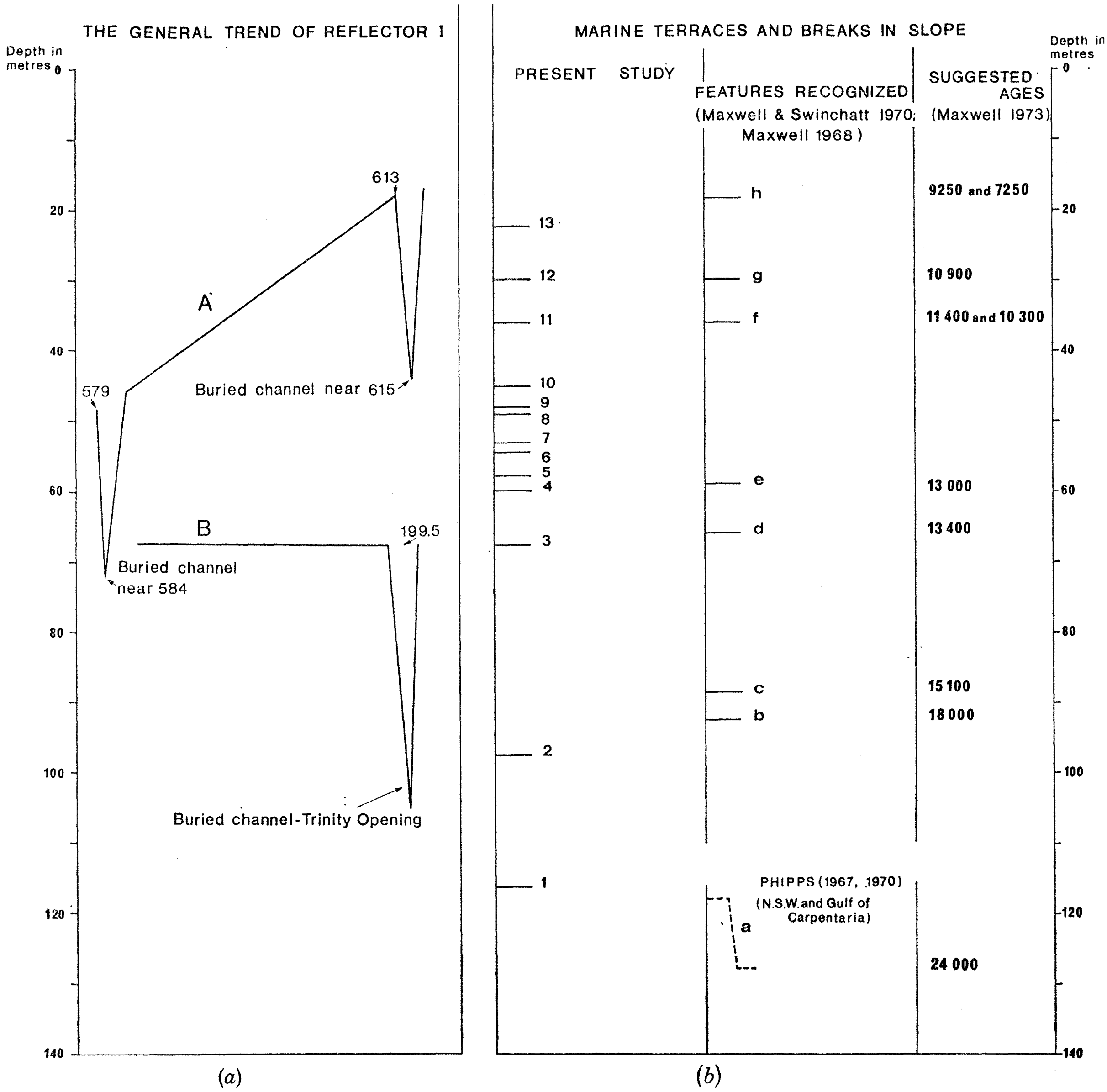

FIGURE 4. Diagrammatic summary of significant bathymetric levels. (*a*) The general trend of reflector I along line 22 (A) and along line 7 (B). (*b*) Marine terraces and breaks in slope. 1 (−116 m) and 2 (−97.5 m), narrow terraces on the upper continental slope; 3 (−67 m), 5 (−57 m), 6 (−45 m), 10 (−19.5 m), 4 (−60 m) and 9 (−48 m) terraces on reef masses near the shelf edge; 7 (*ca.* −53 m) and 8 (*ca.* −49 m), probable buried terraces on line 6; 11 (−36 m), partly buried terrace leeward of Green Island; 12 (−30 m), the well developed features on many reefs, for example at Pixie Reef and the Arlington Complex; 13 (−22.5 m), particularly evident break in slope at Hastings Reef. (a) (−119 m, −128 m) Recognized by Phipps (1967, 1970) in other areas (New South Wales and Gulf of Carpentaria); (b) (56 fathom†), (c) (48 fathom), (d) (36 fathom), (e) (32 fathom), (f) (20 fathom), (g) (16 fathom), (h) (10 fathom), features recognized on the Queensland Shelf (Maxwell 1968); e, f, and g are the conspicuous features recognized in the Arlington area by Maxwell & Swinchatt (1970).

† 1 fathom ≈ 1.83 m.

the position of the Thurber discontinuity (Thurber, Broecker, Blanchard & Potratz 1965) can be accurately determined.

Maxwell & Swinchatt (1970) pointed out that the most distinctive bathymetric features of the Arlington Reef Complex occur at the 16 fathom (*ca.* –30 m) level, and suggest that uniform depths at this level of the interior of the complex together with breaks in slope on the outer reef walls indicate the presence of a pre-Holocene reef platform. The persistence of such bathymetric features at the –30 m level in this general area is supported by the present investigation, but there is no universal correlation between this and the position of the major erosion surface (reflector I). The latter is the result primarily of erosion following a marine regression and shelf emergence, whereas the 30 m features are a consequence of events related to the succeeding transgression.

Of the seismic profiles considered in the present paper, that nearest to Michaelmas Reef is profile 22 (see figure 1), and at its closest approach the major disconformity, represented by reflector I, lies at a depth of about 40 m below sea level, where it occurs beneath approximately 5 m of sediment cover.

It is therefore likely that most of the Michaelmas bore sequence lies below the level of reflector I, and indeed, in the vicinity of the Arlington Reef Complex there may be a coincidence between the level of reflector I, the –30 m platform, and the Holocene–Pleistocene junction. Furthermore, evidence of a coral reef habitat extending to a core depth of 476 ft (145 m), well below the limiting depth for hermatypic corals, indicates subsidence of this area (Richards & Hill 1942), particularly since changes in water depth due to changes of sea level may not have been adequate to account for this sequence.

Although there are obvious constraints in comparing Quaternary eustatic oscillation curves with bathymetric features on the Queensland continental shelf and slope, Fairbridge's (1961) curve indicates that sea level may have prevailed below –40 m during the Riss, and both early and late Würm glacials. Consequently, under conditions of shelf stability during the later Pleistocene, part of the shelf may have been exposed for an extended period, and therefore the higher parts of reflector I may be the product of a considerable period of subaerial weathering and erosion. This erosion surface was submerged progressively during the succeeding, Flandrian transgression, and sediment accumulations and reef masses in contact with it may not be of uniform age, the hiatus represented by this surface varying considerably from place to place according to its elevation in relation to sea level. In consideration of this interpretation, the presence of erosion surfaces in sediment accumulations and reef masses which overlie reflector I, and the absence of absolute dates for any part of I, there is little value in speculation regarding reef accretion rates or sedimentation rates for the sequence overlying reflector I.

The dates suggested by Maxwell (1973) for the most prominent bathymetric anomalies are 10900 a B.P. for the –30 m features, and 13000 a B.P. for the 32 fathom (–59 m) terrace. A late Würm date may be indicated by the 116 m continental slope terrace by comparison with the –119 to –128 m terrace detected in the New South Wales and Gulf of Carpentaria areas (dated 24000 a B.P.) by Phipps (1967, 1970), which probably represent an erosional episode at approximately 24000 a B.P. (Maxwell 1973).

Figure 4*b* summarizes the significant bathymetric levels encountered in the Cairns area, and compares these with features recognized by previous authors. Figure 4*a* illustrates the general trend of surface I in relation to the present sea level.

8. Summary and conclusions

Among the prominent seismic reflectors revealed by this investigation, the most conspicuous (reflector I) is a major erosion surface representing a considerable hiatus in the development of the continental shelf as a reef province. This complex erosion surface, formed through shelf emergence and subaerial erosion has exerted a fundamental control on the attainment of the present physiographic characteristics of the Great Barrier Reef Province, strongly influencing both the distribution and thickness of reefs, and the distribution and thickness of sedimentary accumulations. Indeed, locally on the marginal shelf it may form part of the present seabed as a relict or exhumed surface. Evidence of an ancient fluviatile system which extended across this surface is provided by sediment filled channels.

The sequence overlying surface I provides evidence of the ensuing marine transgression during which reefs were regenerated near the shelf edge and re-established on inner parts of the marginal shelf. Periods of still-stand during the Holocene transgression or minor regressions are indicated by terraces or marked changes in slope, and by minor disconformities within both sedimentary accumulations and reef masses, the most marked bathymetric anomalies occurring at the -30 m level.

Some fundamental aspects concerning reef development in this area have been revealed by the seismic data, namely:

(1) Large platform reefs of the marginal shelf have developed on foundations of lithified sediments and/or an ancient reef rock. In some cases, elevations formed by remnant reef masses have formed sites for more recent reef growth.

(2) The location of reefs on ridges or small plateaux on the marginal shelf suggests a delay in the establishment of marine conditions suitable for reef growth until later phases of the transgression.

(3) The thickness of the platform reefs appears to bear a relation to the relief of surface I from which they rise.

(4) Reefs near the shelf edge are thicker than those on the western part of the marginal shelf, which implies the prevalence of a more continuously reefal environment near the edge of the continental shelf. They are also more extensive at depth, which suggests that formerly there was a more continuous barrier of shelf edge reefs in this area.

(5) The -30 m level is marked by changes of slope or by extensive terraces, and appears to make a significant period of still-stand during the Holocene Transgression, or alternatively it may be the result of a minor regression. Many platform reefs diminish upwards, especially above the -30 m level, reflecting perhaps a late period of dominantly vertical reef accretion in response to an increased rate of sea level rise.

There is a major area for speculation regarding the age of the erosion surface represented by reflector I, parts of which have been emergent for longer periods than others, so that overlying sedimentary accumulations and reef masses in contact with it may not be contemporaneous. Furthermore, the presence of subsidiary erosion surfaces above surface I indicates that the stratigraphic record is incomplete.

Thus, while this seismically based approach has revealed some of the fundamental characteristics of this part of the Great Barrier Reef, it has also raised further questions about its geological history. The complexity of the stratigraphic record of reef accretion and sediment accumulation under the influence of oscillating sea levels poses interpretation problems which may be solved only through systematic drilling related to more intensive high resolution seismic programmes.

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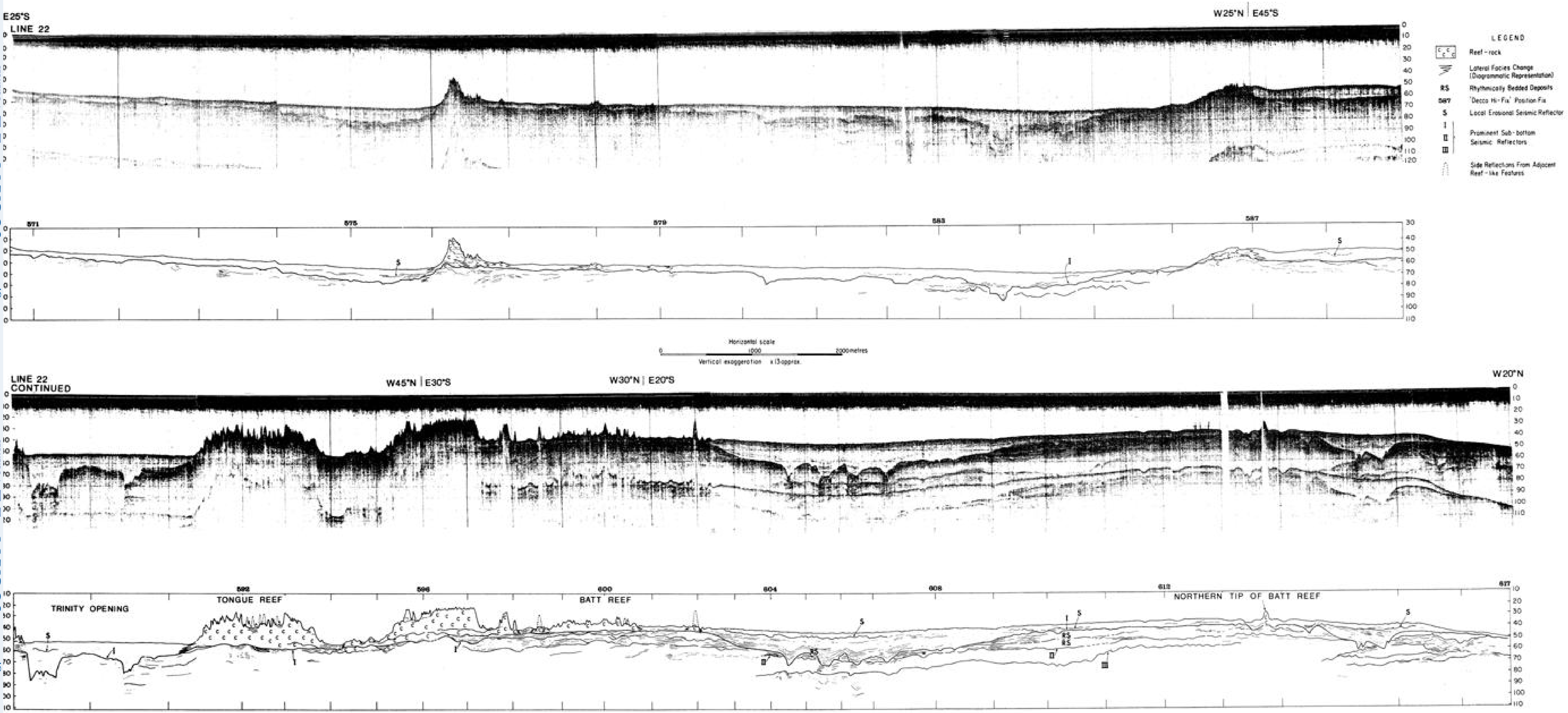

FIGURE 2. For description see opposite.

(*facing p.* 28)

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

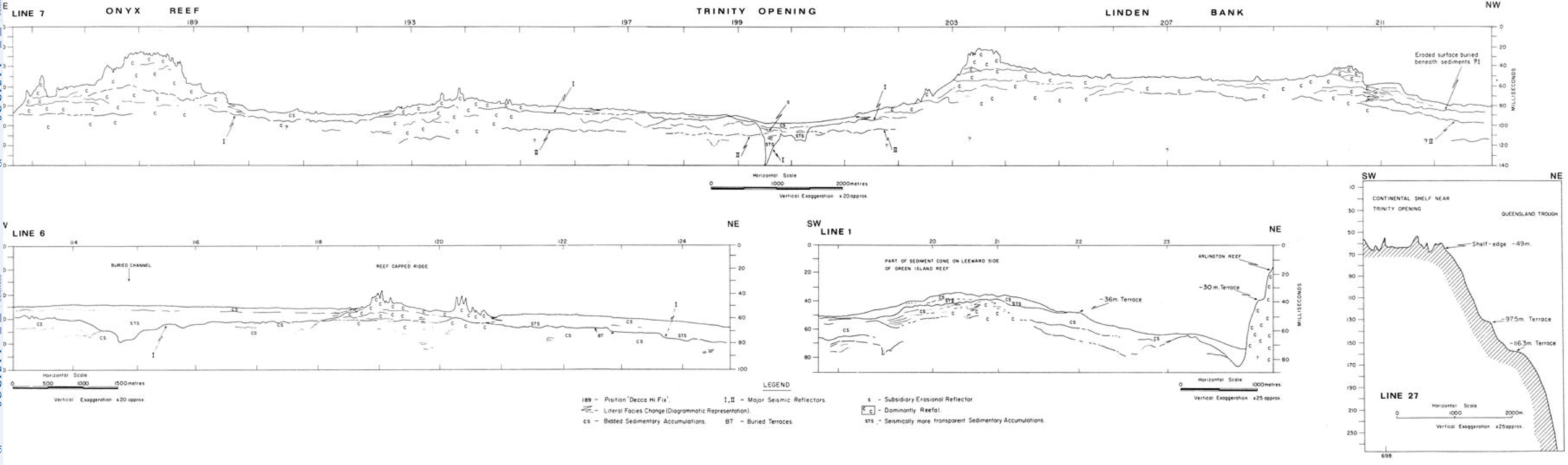

FIGURE 3. For description see opposite.

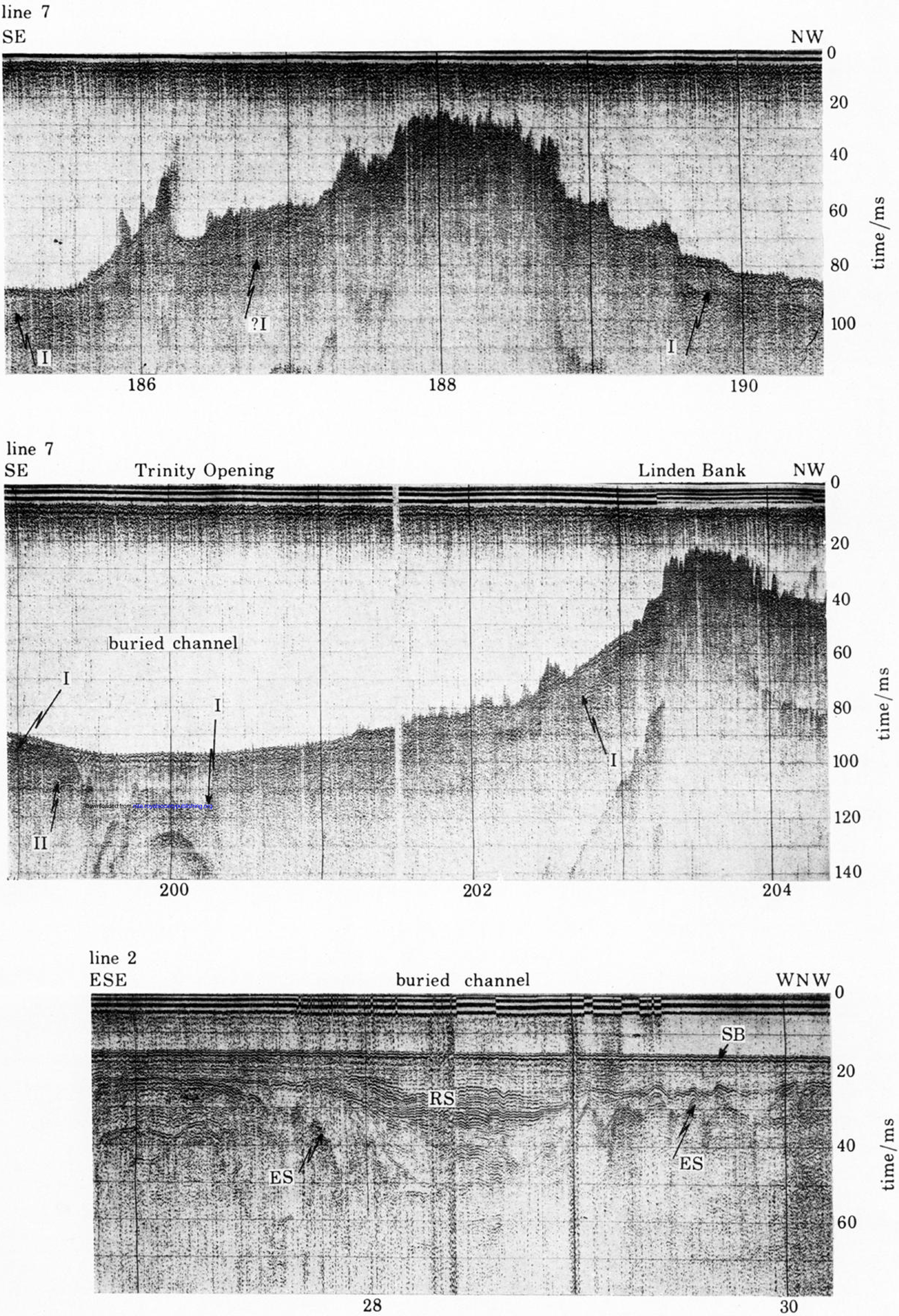

Plate 1. For description see opposite.


SW
NE
0
time/ms
40
80
S
I
BT
103
105
107
109
111
113
115
117
119
121
123
125
147
Grafton Passage near Euston Reef
T
120
127
131
135
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143
145
149