CHAPTER 1. INTRODUCTION

Sydney Beaches and indeed the majority of beaches along the South East coast of Australia are subject to orthogonal rather than longshore wave-power and for this reason, sediment movement is predominantly onshore-offshore. Studies of wave-sediment interaction at Narrabeen (Short, in press) suggest that the beach system operates as a compartment with the seaward boundary marked by a textural discontinuity. A number of studies along the Sydney Coast, have described local sediment (Gibbons, Dee Why 1967), rip-currents (McKenzie, 1958), Beach erosion (Foster et al, Cronulla, 1963), Bilgola, 1966, Avalon, 1967, Collaroy, 1968) and energy-sediment interaction (Cowell, Palm Beach, 1975), (Bryant, Palm Beach, 1976), (Lees, Cronulla, 1977), (Phillips, Dee Why - Long Reef, 1977). However, the submarine extent of the Sydney Beaches remains an unknown through essential factor in understanding beach sediment budgets.

Initially, this thesis was aimed at identifying the seaward extent of each beach system in terms of the null-point hypothesis and thus, the textural discontinuity.

The null-point concept and the closely related equilibrium profile attempts to model the complex nearshore wave-sediment interaction. The seaward-fining textural gradient characteristic of the nearshore zone, (Swift et al, 1971) is a result of the relationship between average sediment particle size and the amount of wave energy penetrating the sea-bed. The null-point concept utilizes asymmetric wave ripples as the fundamental hydraulic mechanism for nearshore transport. For any given grain size, a line of no movement or null-line exists where gravity and fluid forces balance and the grains are in a state of oscillating equilibrium (Swift, 1970). The equilibrium profile predicts a subaqueous slope in adjustment with the grain size and wave steepness. At some location on the subaqueous profile, depending upon particle size and energy input, there exists a point of incipient sediment motion (Johnson and Eagleson, 1966), seaward of which particles are beyond the wave-induced hydrodynamic forces of bed-sediment motion. Shoreward of this point the profile is in a state of established sediment motion. This point, surf base, is marked by a change in textural characteristics and slope and signifies the seaward extent of the beach system. In nature, surf base varies with wave-sediment interaction and a beach profile probably never attains true equilibrium. In addition, the null-point model omits and simplifies certain wave mechanisms and assumes a low angle uniform subaqueous profile. For this reason the application of the null-point model has had mixed results (Stanley et al, 1972).

Early consideration of equilibrium profiles assumed the whole continental shelf to be size graded (Johnson, 1919). More recent studies have shown many shelves to comprise a nearshore size-graded modern sand prism, relict shelf sand and modern shelf mud, with inputs to any of these from terrigenous sources, in situ weathering and biogenic activity. (Emery, 1968), (Nordstrom and Margolis, 1971), (Swift et al, 1971), (Summerhayes, 1969).

Along the Australian East Coast this sequence has been reported off Coolangatta (Smith, 1975), Newcastle Bight (Boyd, 1974), Narrabeen (Short, in press) and Port Kembla (Bosher, 1975). The textural discontinuity, indicating the boundary between the nearshore and relict sediments occurs typically between 15 and 25 metres depth, marking the seaward extent of the beach system.

Sediment sorting by shoaling waves is not restricted to textural gradients normal to shore, since within the limits of sediment availability, grain size increases with increasing wave energy (Wright, 1970). Many studies have shown textural gradients alongshore are related to wave energy, where longshore transport is negligible (Bascom, 1951), (King, 1972). This applies along a single beach and along a section of coast. Rosenburg (1972) and Bryant (1976) have demonstrated grainsize - energy relationships for a number of beaches along the New South Wales Coast.

These general observations of sediment sorting in relation to wave energy can be applied to Sydney Beaches to determine the sediment pattern and seaward extent of each beach system. However, the initial aim of examining the seaward extent of each beach system in terms of the null-point concept assumed a nearshore sediment ramp of fairly uniform slope. Subsequent echo-sounding data revealed that many of Sydney's Beaches were complicated offshore by inherited bedrock features. This relict morphology significantly influences the coastal morphodynamics and gives fresh insight to Sydney's coastal evolution.

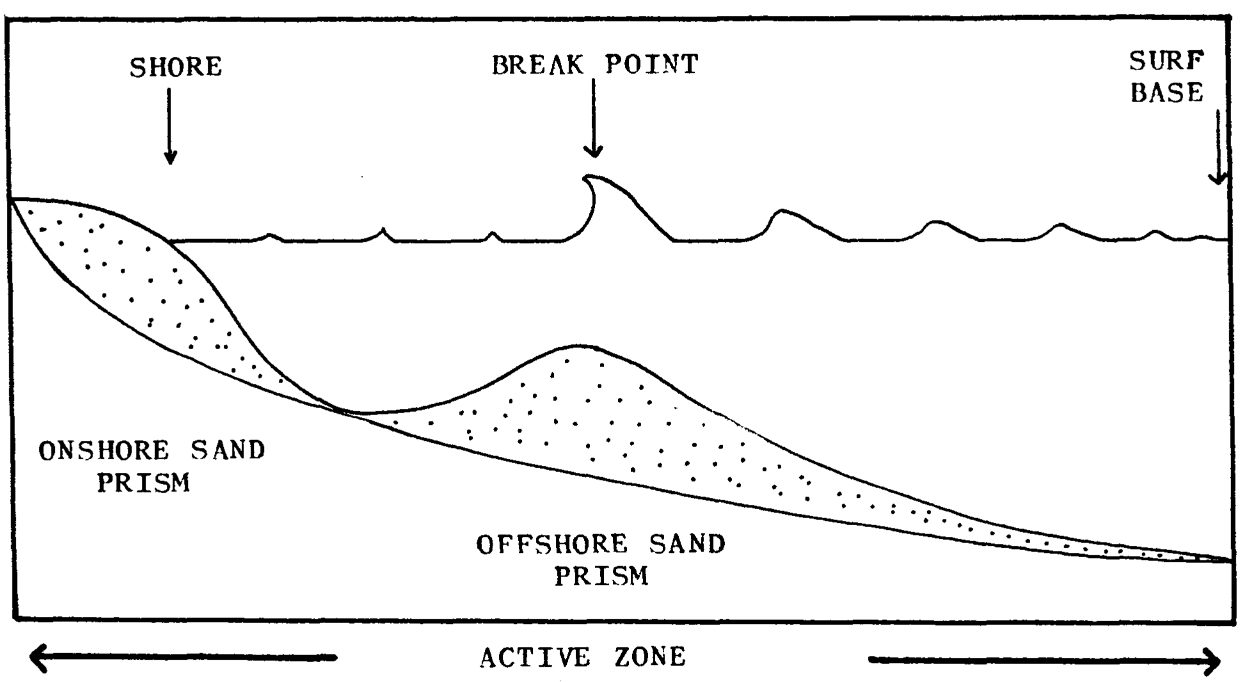
This thesis will examine 12 Sydney beach systems; (figure 1-2) considering first the bathymetry and sediment patterns individually (chapters 4 and 5) and second, the interaction between bathymetry, wave energy and sediments (Chapter 6). Chapters 2 and 3 provide a background to Sydney coastal evolution, the present wave climate and the theory of wave induced sediment movement.

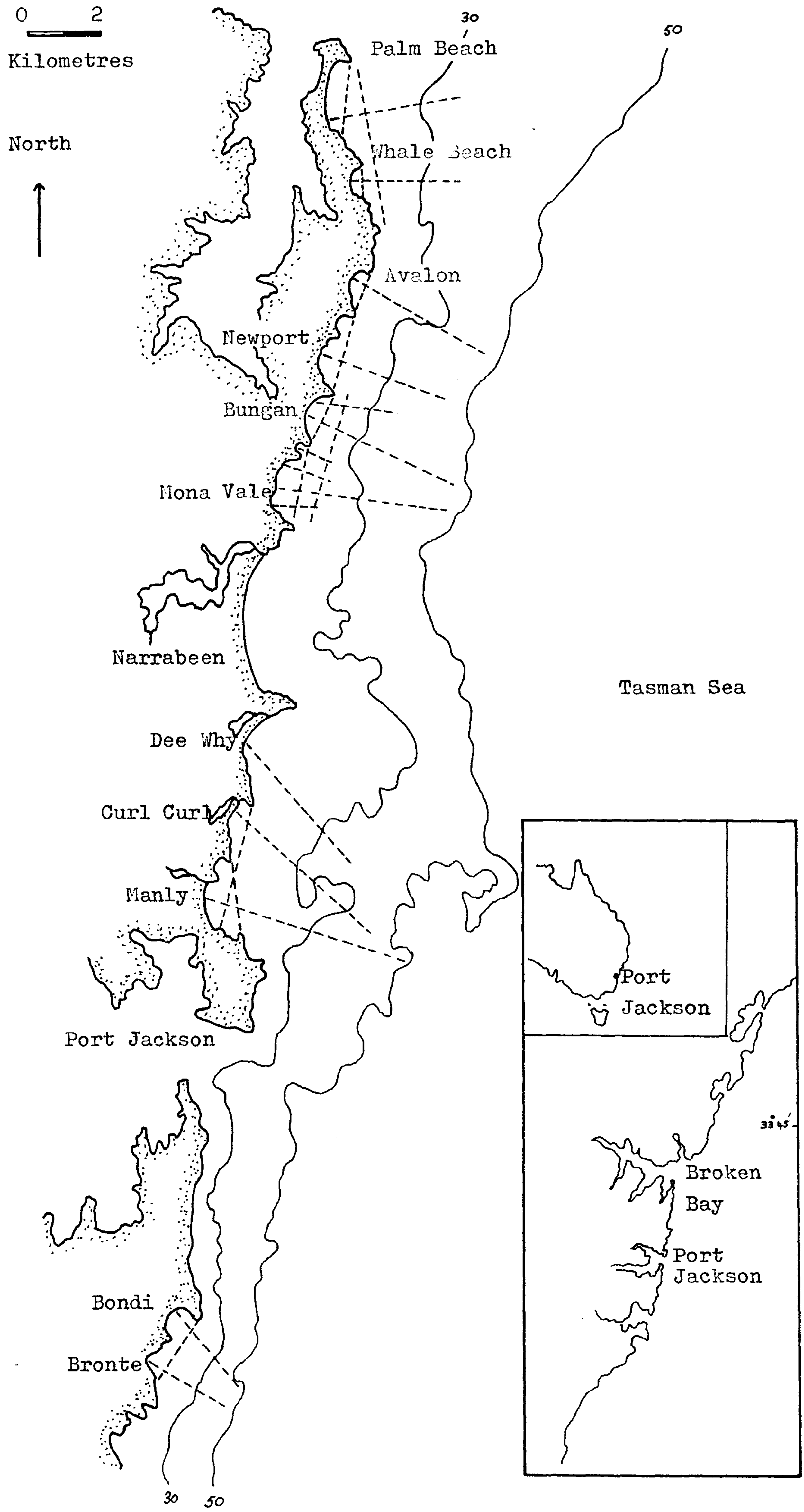
The framework for this study is spatial rather than temporal and therefore assumes that the sediment characteristics of each beach system records a semi permanent pattern of wave-sediment interaction. This seems justified given the general pattern of sediment response to nearshore wave conditions on many coasts (Stanley, et al, 1972) and the findings of Davies (1958), Wright (1970) and Bryant (1976) that the broad characteristics of beaches along the S.E. Australian coast reflect the dominant input of S.E. swell waves. This does not deny that beaches are temporarily variable, however the fundamental characteristics of the submarine portion of Sydney beach systems must be determined before any temporal relationships can be assessed.

For the purposes of this thesis a beach system refers to the sediment body that is actively part of the main beach. Therefore at Newport the beach system includes that material associated with Bilgola beach. Where the sand body is continuous along the coast the lateral boundary is arbitrary.

The beach system or active sediment zone is defined in Figure 1-1. Sediments actively associated with a beach comprise a seaward thinning onshore sand prism and a seaward thinning offshore prism. The active sediment zone is the surface expression of these components.

Figure 1-1 THE ACTIVE SEDIMENT ZONE




0 2
Kilometres
North
30
50
Palm Beach
Whale Beach
Avalon
Newport
Bungan
Mona Vale
Narrabeen
Tasman Sea
Dee Why
Curl Curl
Manly
Port Jackson
Port Jackson
Broken Bay
Port Jackson
Bondi
Bronte
30 50

CHAPTER 2. THE SYDNEY COAST: Solid Boundaries, Quaternary History and Sediments.

The coastal system operates by the mutual interaction of various inputs. Solid boundaries and sediments serve essentially as passive inputs to the system. These are subjected to the active forces of marine and subaerial inputs. The characteristics of each input and the degree of variation over time determines the resultant coastal form. In this chapter three factors important to the development of Sydney's coast will be discussed. First, the influence of geology on coastal configuration; Second, the implications of a Quaternary History of sea-level fluctuation on coastal evolution and third, sediment characteristics in terms of the coastal sediment compartment and the shelf as a whole.

The Solid Boundaries

Magnetic and seismic studies have shown that the Tasman Sea has evolved by a process of sea-floor spreading 60-80 million years ago (Hayes and Ringis, 1973). The resultant margin between continent and new ocean basin is characterised by a narrow shelf and relatively low relief coastal hinterland. These two characteristics significantly influence marine energy on the coast (Wright, 1976) and the supply of sediment. This is evident by comparison with the Pacific and Atlantic coasts of the Americas. The Pacific margin is a collision coast and its high continental relief has had a massive influence upon the sediment input and morphodynamics of both coasts by fuelling littoral drift and on the East coast causing extensive progrodation.

The continental shelf off Sydney is 32 kilometers wide with an average gradient of 0.5%. Two bedrock zones have been described. An inner irregular section extending from the shore to approximately the ¯100-¯110 metre depth contour 20-25 km. offshore and is marked by a basement ridge (Phipps, 1963), (Davies, 1975). Seismic reflection has indicated a

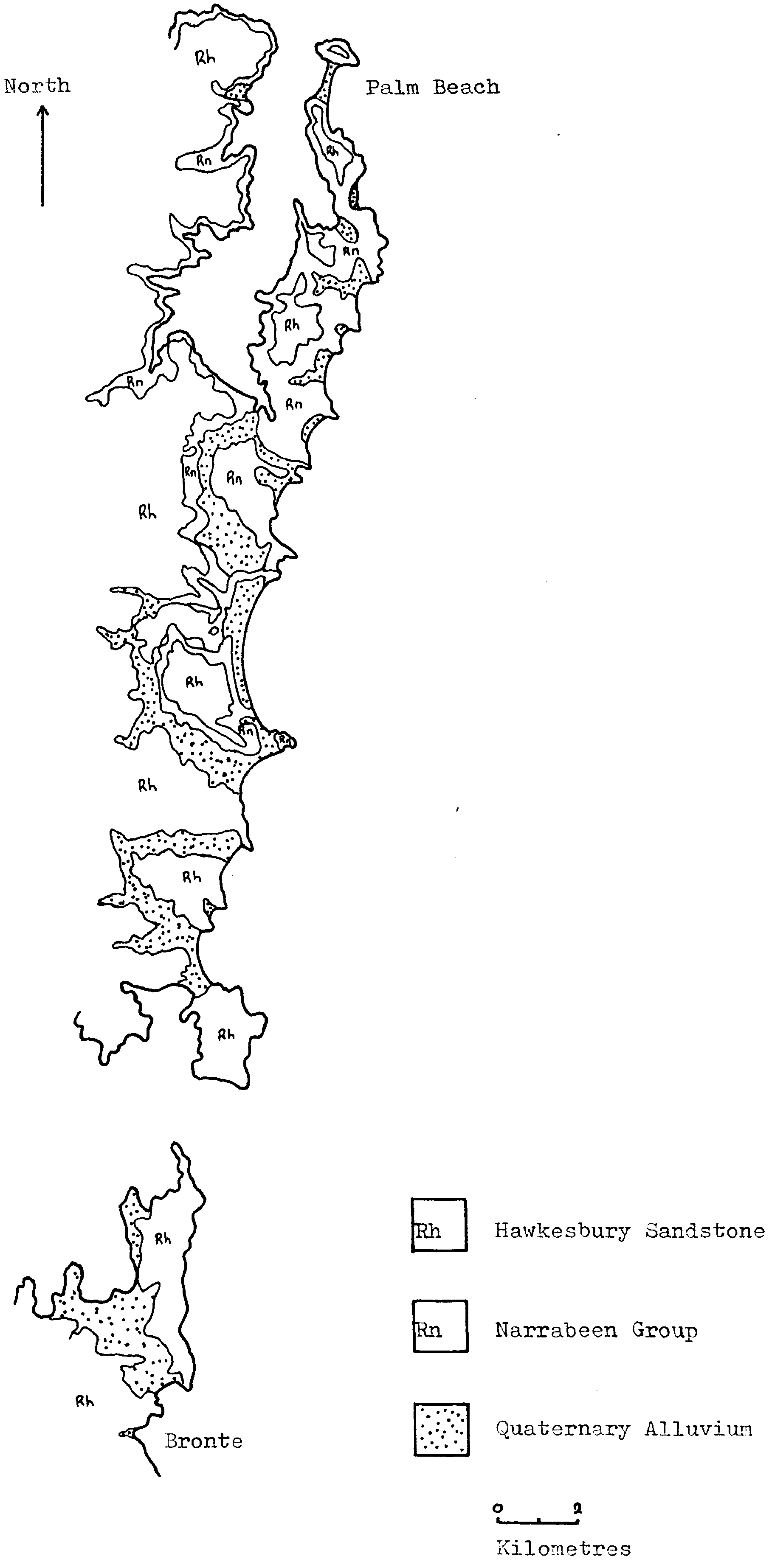
2^o-9^o westerly dip in the stratigraphy and probably corresponds to the Eastern portion of the Sydney Basin formation (Davies, 1975). Further offshore to the shelf edge at ~160 meters depth the bedrock topography is more uniform, with a slight easterly slope. By world standards the N.S.W. shelf is very narrow and steep. Depth to the shelf break along the S.E. Australian Coast varies from ~130 metres to ~440 metres. (Jones, et al, 1975), Stanley and others (1969) quote on average shelf break depth of ~30 metres. Although the S.E. Australian coast has long been regarded as structurally stable, Boyd (1974) has found evidence of extensive warping on the shelf between Port Stephens and Norah Head.

The geology of the Sydney region has had a primary influence upon the present coastal configuration. This influence is twofold; the Hawkesbury S.S. and Narrabeen Group have provided a relatively resistant boundary to the coast system and conversely, subaerial erosion of these rocks has created a distinct drainage pattern along the present coast and significant quantities of quartzose sediment.

The distribution of rock groups along the Sydney coast is illustrated in Figure 2-1. The boundary between the Hawkesbury S.S. and Narrabeen Group bisects the coast at Long Reef. Both types display strong jointing patterns associated with dykes which are dominantly South East - North West trending. The major coastal valleys also trend in this direction and Coenraads (1978) suggests that these valleys have developed from channel erosion along the planes of weakness. As a consequence the bedrock valley floors upon which the present beaches have been deposited, face South East, superimposed upon the major South West - North East trending New South Wales coastline. This has important effects upon Sydney's coastal morphodynamics.

Although the Hawkesbury S.S. and Narrabeen Group weather differently both provide a relatively resistant rock boundary to the coastline in the form of cliffs, platforms and submerged outcrops. The prevalence of rock along the coast is

Figure 2-1 Bronte-Palm Beach Geology.



obvious from the irregular coastal outline illustrated in figure 2-1. In fact, for the length of coastline between Bronte and Palm Beach of approximately 37 kilometers, there is 46% beach and 54% rock. Previous work on the submarine topography off Narrabeen (Short, in press) and observation of bomboras at Manly and Long Reef, indicate that submerged rock may be an important feature of Sydney's beach systems. Across the shelf, rock outcrops are common and in many places bedrock is covered by only a thin veneer of sediments due to the relatively small sediment supply. Consequently erosion of the shelf during sea-level fluctuations has been extensive. Phipps (1963) has correlated irregular cliffed profiles across the inner and mid shelf with the Hawkesbury S.S. and the smoother profiles with the Narrabeen Group.

The Sydney Basin rocks are rich in quartz sand particles. The Hawkesbury sandstones have a sandstone to mudstone ratio of 20:1 (Conaghan and Jones, 1974) and although this ratio is less for the Narrabeen group, together, these rocks have been a significant source of sand to the shelf off Sydney. Strong dissection of the Hawkesbury and underlying Narrabeen rocks and the incision of major rivers attests to this.

Quaternary History

Temporal variation of inputs is fundamental to coastal evolution. Two levels of variation are apparent. These are; high frequency fluctuations of marine and subaerial processes, such as wave climate and river competency, which are superimposed upon low frequency fluctuations such as long term climatic variation and sea-level changes. The effect of long-term climatic variation on coastal development has been subtle and little is known of its impact, excepting the relationship with sea levels. In contrast, changes in sea level have had a profound impact, operating as an in - dependent variable which not only determines the duration of coastal development but also influences sediment supply, solid boundaries and marine conditions. Wright and Thom (1977), point out that the dynamic adjustment of a coastline involves a series of stages, each stage bearing some degree of inheritance from the previous stage. The resultant coastal form will reflect both modern and inherited characteristics. Generally, where lower frequency changes have operated the inheritance factor will be most prominent. For example, on a Sydney beach, a nearshore bar will adjust fairly rapidly to new swell conditions, the bar morphology reflecting little of the previous swells. In contrast, coastal valleys hosting Sydney's Beaches show depths of incision congruous only with lower base-levels rather than the present sea level.

The Sydney coast owes much of its morphodynamics to inherited forms and the processes associated with sea level fluctuations. Evidence of former sea levels is apparent from Sydney's drowned river valleys, relict drainage channels and shelf characteristics. In fact, world patterns of sea level change indicate that sea level at present is unusually high.

Changes in sea level are caused by fluctuations in world ice volumes (glacio-eustasy) and tectonic and isostatic movements of the earths crust. Although differential movements of the earths crust complicate global correlation of sea levels, a world pattern of glacio-eustatic changes has been constructed for the past 240,000 years before present (Y.B.P.) using flights of coral terraces and O^{18} deep-sea cores (Chappell, 1974). Unfortunately the resolution is much poorer for sea level changes beyond 240,000 Y.B.P. Nevertheless, the late Pleistocene and Holocene fluctuations are possibly a fair indication of sea level fluctuations for the whole of the Quaternary Period.

The curve (figure 2-2) shows sea level to be at least 20 meters lower for most of the past 240,000 Y.B.P. Only one point approximates the modern level, at 120,000 Y.B.P. and three points occur below $^{-}$120 metres, at 150,000 Y.B.P., 55,000 Y.B.P. and the last at 17,000 Y.B.P. Application of this curve to specific areas such as the N.S.W. coast is limited by possible local effects of tectonics and isostasy. Glacio-isostatic rebound can be ruled out (Galloway, 1965) and so can vertical tectonic movements of significance. With these influences discounted Chappell and Thom (1977) believe the curve is globally applicable, taking into account variations in apparent amplitude due to hydro-isostatic adjustments caused by changing oceanic load. As previously discussed, there is evidence of warping on the N.S.W. shelf. Wright and Thom (1977) suggest slow subsidence of the continental margin due to sediment loading, which would cause the warping described by Boyd (1974).

Quantative evidence along the N.S.W. coast appears to support a Quaternary history of glacio-eustatic sea level change. However, Galloway (1970) proposed that many of the erosional features on the shelf are a result of sea level change due to tectonic modification of ocean floors, rather than tectonism or glacio-eustasism. Available evidence for sea level change on the N.S.W. coast comes from a radio-carbon date of 17,900 $\pm$600 Y.B.P. for beach rock at $^{-}$128 metres (Phipps, 1970), surf eroded features down to $^{-}$200 m (Thom, 1972), (Jones, et al, 1974), (Boyd, 1974), relict drainage patterns such as the Hawkesbury River extending to $^{-}$125 m (Albani and Johnson, 1974), bedrock channels off Bondi (M.W.S.D.B., 1976 - Appendix 2) and the fact that major land forms extend above and below present sea level (Galloway, 1970). This evidence at the least indicates extensive periods of lower sea level with several levels below $^{-}$125 metres.

Figure 2-2. <u>Sea Levels for the last 240,000 years.</u>
(from Chappell and Thom, 1977.)

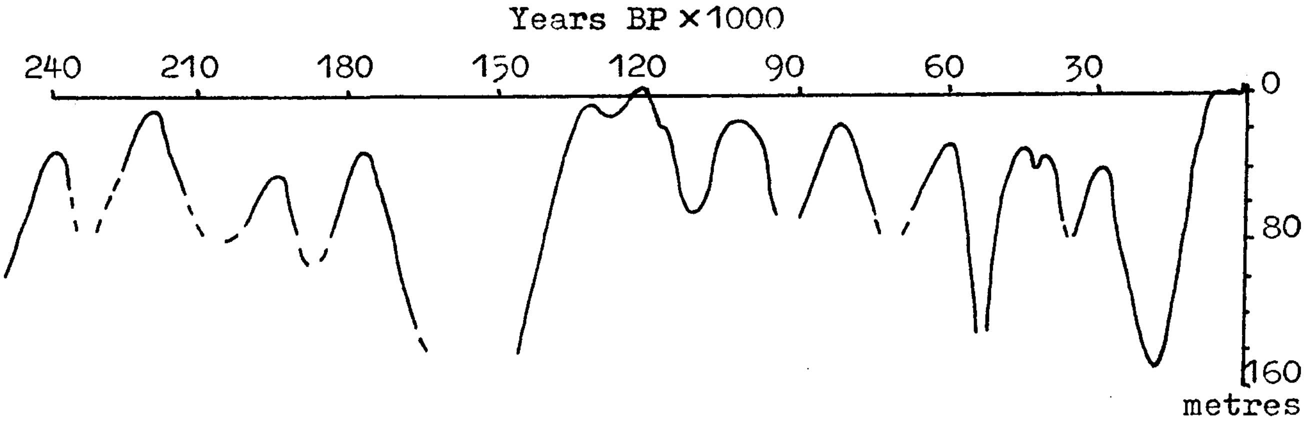
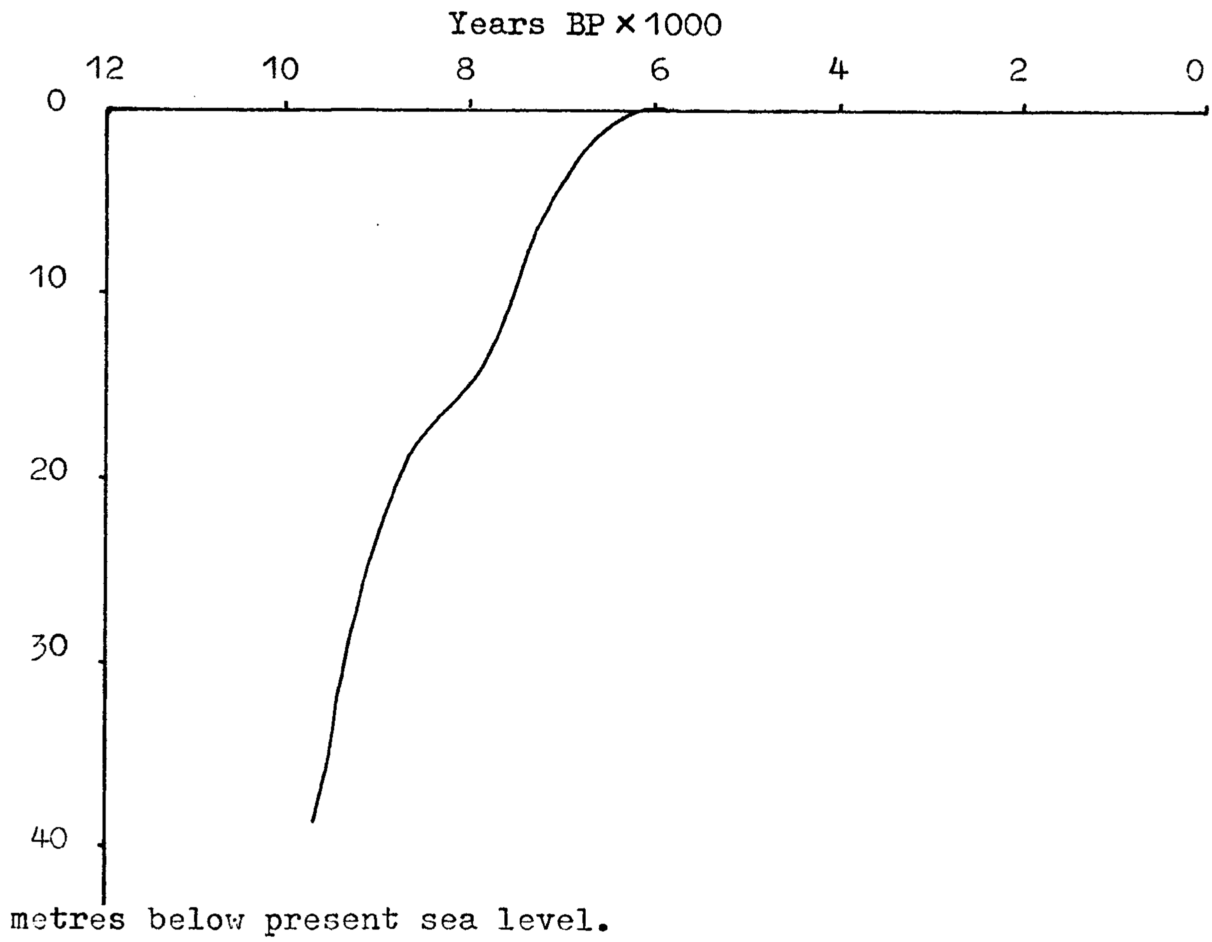


Figure 2-3. <u>Holocene Sea Levels for southeast Australia.</u>
(from Chappell and Thom, 1977.)



If evidence for the last glaciation in Australia (Bowler, et al, 1976), (Williams and Rognon, 1977), (Van Andel and Veevers, 1967) is combined with Chappell's sea level curve, it seems reasonable to place the last low-sea maximum at approximately 17,000 Y.B.P. and at $^{-}$120-$^{-}$130 metres depth. It is obvious however, that there is an extreme paucity of absolute dates available corresponding to submerged shoreline features along the South East coast of Australia.

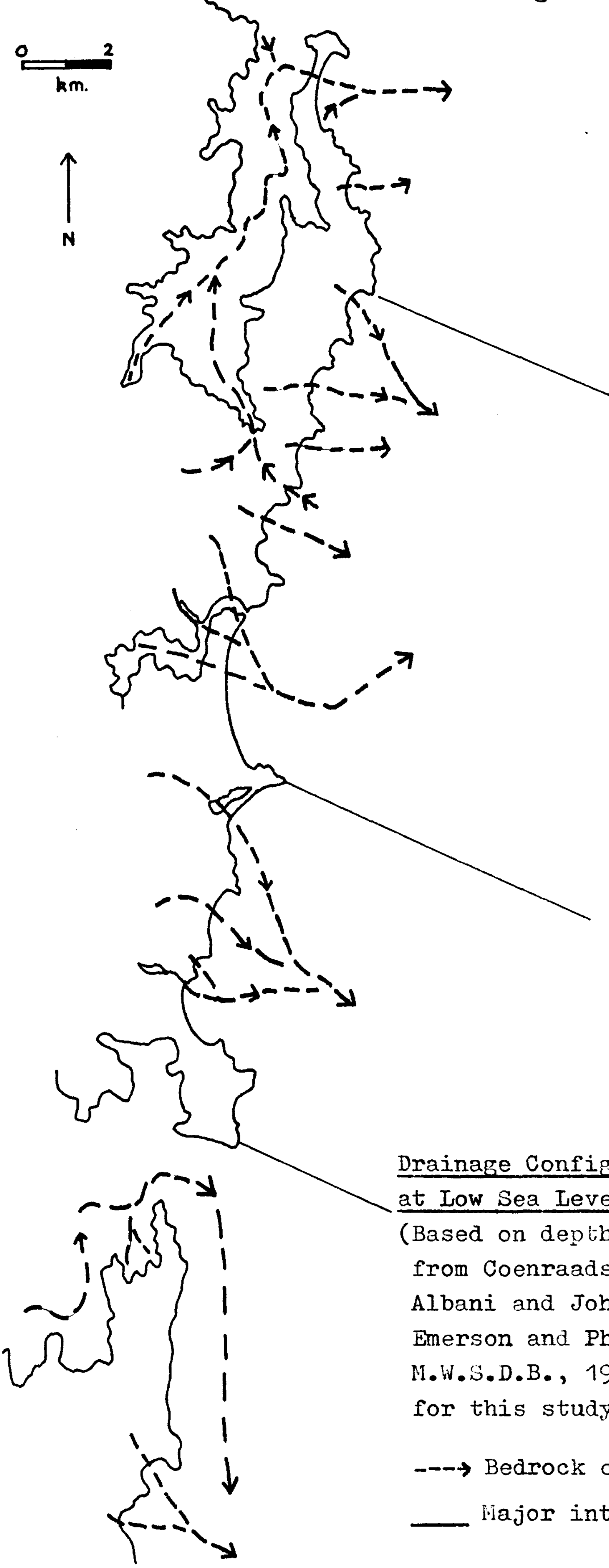
The rapid rise in sea level to its present position has left a relatively fresh and accessible record. The formation of barriers, lagoons and multiple beach ridges has provided absolute dates for a transgression terminating about 6,000 Y.B.P. (Thom and Chappell, 1975). Figure 2-3 shows the projected curve for this rise.

The implications of the Quaternary sea level changes to Sydney's coastal development are as follows. A regression of sea level to a lower position would enable river channels and tributaries to become more active, entrenching in the headwaters and depositing quartz-rich sediments along valley floors, at the shoreline and offshore. Small rivers would have flowed out of the present coastal valleys such as at Narrabeen to join the larger rivers, such as the Hawkesbury on the shelf.

Between Bronte and Broken Bay there are fifteen valleys, Port Jackson and Broken Bay being drowned. Seismic reflection has shown depths to bedrock from beach to valley floor to be $^{-}$10 m - $^{-}$35 m for the smaller valleys (Coenraads, 1978). At Broken Bay depth to bedrock is $^{-}$100 m (Albani and Johnson, 1974) and between the heads at Port Jackson $^{-}$250 m (Emerson and Phipps, 1969). The pattern of this relict drainage is illustrated in figure 2-4.

Galloway (1965b, 1970) argues that the well developed

Figure 2-4



<u>Drainage Configuration</u>
<u>at Low Sea Level</u>.
(Based on depths to bedrock
from Coenraads,1978.,
Albani and Johnson,1974.,
Emerson and Phipps,1969.,
M.W.S.D.B., 1976., and surveys
for this study.)

---→ Bedrock channel.

____ Major interfluves.

nature of these valleys, the extent of coastal cliff retreat and the surf eroded shelf features would require long periods of low sea level rather than as a result of the last short glacial and rapid rise in sea level as proposed by Phipps (1966) and Boyd (1974). This is the basis for his proposal for tectonoeustasy rather than glacio-eustasy. The seaward extent of Sydney's headlands (M.W.S.D.B. 1976), the slow rate of present retreat, the existence of inner barriers (Langford-Smith and Thom, 1969), submerged soil profiles (Albani, pers. comm.) and the numerous terraces would support this concept.

The last rapid rise in sea level (>10mm p.a.) during the Holocene, although not necessarily influential in modifying the solid boundaries, had a profound affect upon the sediment budget of the Sydney Coast. Transgression of the sea influences sediment supply in two ways. First, a rise in sea level reduced the competency of rivers to supply sediment to the coast by raising the base-level and by forming estuaries, which effectively trap river-borne sand and marine sand. Second, a rising sea level will move available sediment across the shelf. A portion of this material, consistent with the prevailing marine energy, will be incorporated in the new shoreline beach system leaving a residual sand sheet on the shelf. Thus, a transgression restricts the fluvial input of sand while at the same time supplying sand from the shelf. There are two exceptions to this sequence of events; where there is little available shelf sediments, or marine conditions are unable to move them and where river competency is too large for estuary formation, such as the Shoalhaven River. Neither of these exceptions apply to the Sydney coast.

All four Sydney estuaries, Broken Bay, Port Jackson, Botany Bay and Port Hacking exhibit a wedge of marine sand across their entrances. Infilling from fluvial sources is evident in the upper reaches of these estuaries, such as Cole and Candle Creek and in lagoons such as at Narrabeen.

Where only small rivers and tributaries operated along the Sydney coast during lower sea levels, shelf sediments were pushed into these valleys, forming pocket beaches in the smaller valleys such as at Bungan and Whale beaches, and creating barriers across the larger valleys, behind which lagoons have developed, such as at Mona Vale, Curl Curl and Narrabeen.

Sediments

The concept of a coastal sediment compartment outlined by Davies (1974) based upon Tasmanian Beaches is applicable to the beaches of Sydney. This concept is useful both as a means of quantifying the present beach systems and in identifying stages in the beach budget cycle over time.

For the Sydney Coast, the Holocene transgression in its early stage would have produced a positive sand budget for the beach system; the coast prograding under conditions of large onshore transport. The present budget of modern beach systems is negative, the coast is undergoing recession due to a lack of significant sediment input, but conceding heavy losses caused by inlet filling, deflation and possible sand movement offshore. Davies envisages the next stage to be a coast of equilibrium where the budget is balanced and the coastline is stable. Assuming a stable sea level, inlet filling would reach a climax, allowing significant input from rivers to equal losses from deflation and offshore.

The present negative sediment budget for the beach systems and the resultant receding shoreline has been well documented by Thom (1974) with specific events, such as the May-June 1974 storms reported by Bryant and Kidd (1975). The threat of lost buildings and land to councils and individual owners has prompted a review of real estate development along the shoreline and revetments. Sand replenishment may prove to be the most viable remedy given a ready source.

Roy et al (1977) and the P.W.D. (1977) confirm observations that negligible sand is reaching the beaches from rivers, such as the Hawkesbury. There is no quantative data indicating the amount of subaerial input from cliffs, platforms and beach catchments. However, the fact that on most beaches sand is diminishing rules out a significant addition from these sources. An exception may be the Eastern Suburbs beaches; this will be discussed in Chapter 5. Gain of material from offshore is to date largely unknown and the aim of this thesis is to investigate the characteristics of this zone. No significant input from this zone is apparent, this source probably terminated by 4,000 Y.B.P. (Thom, 1974) and evidence from Narrabeen (Short, in press), Davies, St. Helens, Tasmania (1974) and Newcastle Bight, Boyd (1974), suggest a distinct seaward boundary of the beach store at about $^{-}$20 metres. A not insignificant sediment input to Sydney's beaches is the contribution of marine organisms. Gibbons, Dee Why (1967) and Short, Narrabeen (in press), give values of 30-50 percent average shell content by weight. On the shelf off Sydney, Marshall and Davies (1978) report sediments composed almost entirely of skeletal carbonate, dominantly molluscs, bryzoan and foraminiferans. Only recently has it been recognised that carbonate rich sediments are not restricted to tropical shores and are more related to areas of low terrigenous sediment influx (Chave, 1967). This tends to support the concept of low sediment input, for Sydney's Northern beaches at least. An additional factor influencing biogenic input is wave energy, which is required to distribute the carbonate across the beach system. This material may be distributed from within the store or brought in under high wave conditions from offshore.

Losses to the beach store occurs mainly by deflation, building development on foredunes, sand mining and inlet filling. It has already been noted that Broken Bay and Port Jackson have a large wedge of marine sand extending some distance into their estuaries. Bryant (1976) suggests some material from Palm Beach is moving around the Barrenjoey tombola into Broken Bay. No studies have been published on this phenomena in Sydney. As with onshore transport, little or nothing is known of offshore losses of sediment from the store. During high wave conditions it may be possible for sand to move beyond the store, and thus, be lost to the system. Observation of Sydney beaches during storms suggests this may be happening. Losses due to littoral drift appear to be minimal since the major type of wave energy is orthogonal. This is illustrated by the alignment of Sydney's beaches to the dominant South-South East swell, swash deflected inlets (Davies, 1974), the irregular coastal plan and significant differences in sediment textural characteristics and composition within and between beaches, the subject of detailed discussion in Chapter 5. Furthermore, littoral drift requires an active supply of sediment, a requirement not met by Sydney's beach budgets.

It is remarkable that so little study has been made of the sedimentological properties of Sydney's beach sands. This necessitates a general statement that this material is most commonly medium sized iron-stained quartz sand. An obvious exception is the white sands of the Eastern Suburbs beaches and their smaller concentrations of shell. The difficulties of sampling beyond the wave break-point have restricted studies of the outer nearshore zone, the only information of this nature being Short's recent work at Narrabeen (in press), which has indicated a seaward fining textural gradient to around the $^{-}15$ metre depth. The seaward boundary is marked by coarser iron-stained sand, however, much of the outer nearshore zone is covered by rock outcrop. The most immediate questions are: Does this sequence apply to other beaches in Sydney and what is its significance in terms of beach budgets and coastal evolution.

An investigation of the sediments on the N.S.W. continental shelf by Shirley (1964) showed three zones, nearshore coarse sediments, mid-shelf fine terrigenous sediments and an outer belt of coarse calcareous material extending to the shelf edge. Working on the shelf between Port Stephens and Norah Head, Boyd (1974) found a similar distribution of nearshore coarse sand to commonly $^{-}45$ metres, a mid-shelf bimodal mixture of mud and sand between $^{-}60$-$^{-}120$ m and an outer shelf calcareous sand body beyond $^{-}120$ m. The concentration of carbonate increased with depth. The thin coarse outer band of nearshore sand occuring between $^{-}20$-30m and $^{-}45$ m Boyd interprets as a relict still-stand at this depth during the last transgression. Research is currently in progress on the shelf sediments off Sydney by Noreen Clark of Macquarie University.

From the foregoing discussion it appears that on the N.S.W. continental shelf there exists a lens of inner nearshore sediment graded by the present marine processes, seaward from $^{-}20$m-$^{-}60$m lies a coarser band of sediment not in equilibrium with the present marine conditions, although some reworking may occur by currents (Swift et al, 1971). Fine terrigenous material occurs on the midshelf, probably deposited from suspended fluvial load. Where currents and terrigenous input are least operative, biogenic activity is greatest producing high concentrations of calcareous material towards the shelf edge. This pattern of shelf sediments is shown in figure 2-5.

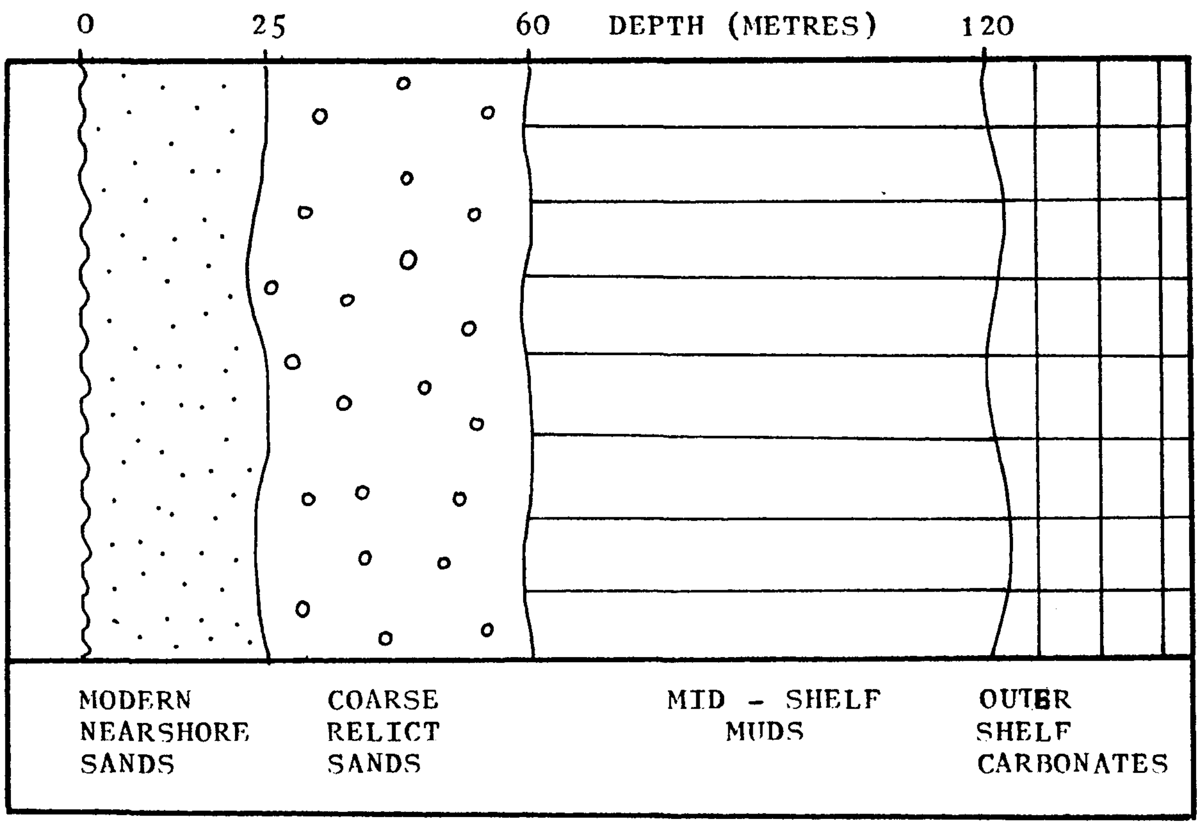


FIGURE 2-5 THE DISTRIBUTION OF SEDIMENTS ACROSS A SHELF

CHAPTER 3. THE SYDNEY COAST: Marine Energy and Sediment Dynamics.

Wave energy is the power source of a beach system. The nature and variability of the deepwater wave regime and the shallow water energy distribution is responsible for the pattern of sediments, where sediment input is low. In this chapter the character of the Sydney wave climate is identified and the implications of these characteristics on the beach form are discussed. The present theory of wave induced sediment motion is examined in relation to particle size gradings normal to shore and parallel to shore.

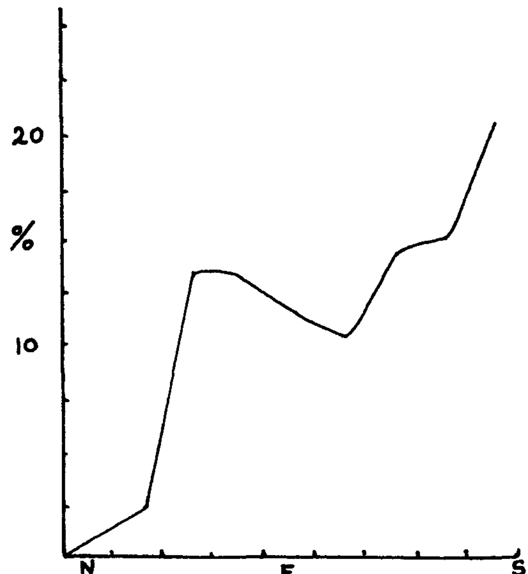
Marine Energy

The Sydney coast is subject to semi-diurnal microtides with a maximum range of 2.1 metres at the entrance to Broken Bay. Little is known of the tide induced currents and sediment movement along Sydney beaches. Tides are probably singularly unimportant in this respect, given the characteristic swell wave environment operating on the Sydney coast. However, a combination of king tides, storm surge and high waves can be a devastating force, illustrated by the May-June storms of 1974 (Foster et al, 1975).

The wave climate of the Sydney coast corresponds to the east coast swell environment outlined by Davies (1972), where swell waves emanate from the Southern Tasman Sea and Southern Ocean. Superimposed on this background wave climate is periodic cyclonic swell from the East, North East swell associated with tropical cyclones and multi-directional short period waves associated with sea breezes and local storms.

Quantative data on wave conditions for the Sydney coast is provided by a deep water wave rider buoy off Botany Bay, for the period 1972-1975 (Lawson and Abernathy, 1975). Figure 3-1, compiled by Bryant (1976) from the wave rider data shows a dominance of waves from the south quadrant, with secondary peaks from the East and North East. Lawson and Abernathy (1975) found no marked seasonal variation in the data although they feel this may change with further monitoring. In general, South East swell waves may occur throughout the year, with the occurrence of local cyclonic swell in autumn, tropical cyclone swell in summer and wind waves associated with sea breezes in summer. Wave periods range most commonly from 8 seconds, associated with sea-breezes and local storm waves, to 16 seconds associated with large swell waves from the South East.

FIGURE 3-1 WAVE DIRECTION FOR THE SYDNEY COAST



(from Bryant, 1976; based on data from Lawson and Abernathy, 1975).

Sediment Dynamics

Bryant (1976) has shown that mean settling velocity of foreshore particles correlate most closely with 10-12 second S.E. orthogonal wave power for South East Australian beaches. This supports earlier findings by Davies (1958) and Wright (1970) that these beaches are aligned to a 12 second South Easterly swell.

The dominance of orthogonal wave power implies that longshore wave energy gradients are secondary and therefore beaches along the South East Australian coast are swash aligned as opposed to drift aligned. Where sediment input is negligible, swash aligned beaches typically show particle size gradings both along a beach and along the coast corresponding to levels of orthogonal wave power. The distribution of wave energy along a beach and along a coast depends upon the deepwater wave type and the offshore bathymetry. The influence of bathymetry in redistributing wave energy in shallow water is well documented by King (1972), Wiegel (1964), and Holmes (1975). Inherent with swash aligned coasts is the textural gradient offshore, corresponding to the shore normal energy gradient on the sea bed. This zone of wave sorted sediments normal to shore is distinguished by seaward fining grain size and shore parallel depth contours.

Wave induced sediment movement results from horizontal water motion at or near the sea bed associated with elliptical motion produced by surface waves. In deep water, surface waves produce oscillatory water motion, however in depths less than half the deepwater wave length the circular paths of water particles are impeded by the sea bed, causing elliptical motion. Near the bottom, the elliptical motion is further reduced to horizontal to and fro movement. The maximum horizontal velocity, Um is given by equation (1).

Equation (1) $$Um = \frac{\pi H}{T \sin h\ (2 \pi h/L)}$$

(from Komar and Millar, 1973).

Where T is the wave period, L is the wave length, H is the wave height and h is the water depth. Thus, the bed velocity is a function of wave height, wave length and depth.

Each grain has a different threshold velocity of movement depending primarily upon the particle diameter and specific density. Komar and Millar (1973), have shown that particles with diameters less than 0.5 mm or 1 phi move within a laminar boundary layer due to laminar shear and larger particles move in response to a turbulent boundary layer. The threshold shear velocity of a particle in a beach system depends also upon the bed particle geometry and slope.

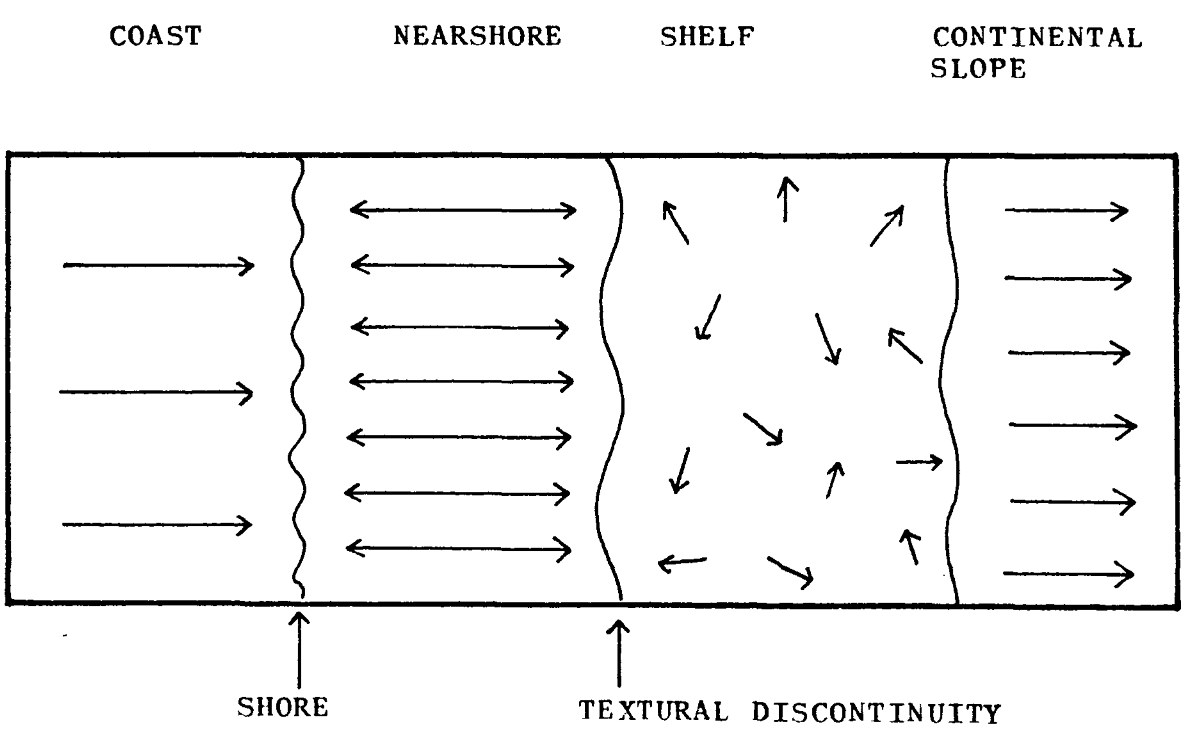
The mechanisms by which particles move normal to shore is a function of the differences in crest and trough velocity of the waves.

As the depth decreases, the horizontal boundary layer flow in shallow water has a stronger on shore component than offshore component due to greater crest velocity than trough velocity. This results in a net drift of sediment in the direction of wave propogation producing a wedge of sediment thickening towards the shore. In the offshore boundary zone, at depths where wave asymmetry is minimal but shear velocity can still disturb particles, the gravitational force of particles may exceed the fluid force, causing some particles to move offshore.

The sediment response to decreasing wave asymmetry with depth and thus decreasing bed shear velocities with depth, is for the smaller particles to move seaward to a position where fluid forces and gravitational forces balance for each particle. This is known as a null or equilibrium condition, where particles exist in oscillating equilibrium, given a fairly uniform slope increasing shoreward. The null point for larger particles is progressively nearer the break point, where fluid forces are large enough to compensate for the gravity forces. In effect, smaller particles move to areas of lower energy and larger particles move to areas of higher energy, where the fluid forces and gravity forces balance for each grain. This gives a sequence of seaward fining grain size in response to a shore normal gradient of bed shear velocities. This simple pattern is complicated by the relationships between boundary layer flow, bed particle geometry, sediment slope and particle size. The sorting of grains normal to shore involves slope adjustment by the re-arrangement of bed geometry and particle size in mutual response to bed shear velocities. Mutual adjustment between these gives the characteristic equilibrium profile, where depth contours are parallel to the wave crests.

The point of incipient sediment motion for the sub-aqueous profile of a beach system marks the most seaward limit of active sediment movement, or surfbase. Seaward of this point the wave induced bed shear stress is below the threshold velocity of sediments on this portion of the shelf. This implies a textural discontinuity, separating nearshore wave sorted sediments with shore parallel contours from shelf sediments worked by currents and periodic storm waves with irregular bathymetry. This sequence is illustrated in figure 3-2. Reference to figure 2-5

FIGURE 3-2 COAST AND SHELF SEDIMENT TRANSPORT MODEL (Modified from Swift, 1971).



indicates that the textural discontinuity is manifest typically as the boundary between a seaward fining and thinning nearshore sand body and a coarser relict sand body.

The components of the null-point concept; the point of incipient sediment motion, the oscillating equilibrium condition of particles, or null-point, and asymmetric wave-induced bed sediment motion are by definition temporarily variable. On a coast with negligible sediment input, a variable wave climate effectively controls the size sorting of sediments normal to shore and thus the variation in the point of incipient sediment motion and the location of the null-point for each particle, given an uninterrupted ramp of sand. This implies that these components are never static but exist in a condition of quasi equilibrium. Therefore, in view of the findings of Davies (1958), Wright (1970) and Bryant (1976), it is probable that if the null-point concept is applicable to Sydney beach systems, an average condition of wave sediment interaction exists corresponding to the dominant 10-12 second South Easterly swell.

The present theory for sediment distribution normal to shore, involving the null-point concept enables quantative calculations of the offshore boundary conditions of a beach system (King, 1972), (Johnson and Eagleson, 1966). The equations developed to approximate wave-induced particle movement normal to shore omit significant processes such as offshore transport by rip currents, the existence of multiple wave frequencies and boundary effects such as bathymetric irregularities. Furthermore, Wright and Thom (1977) suggest that some bed load may even move against net water drift. Although the theory predicts the simple seaward fining relationship and textural discontinuity, the short-comings are probably responsible for the contradictory results reported in experimental and field studies (Swift, 1971). Nevertheless the null-point concept is the most accurate available approximation of very complex nearshore hydrodynamic relationships and provides a model for reference and improvement with further studies.

No model exists for the sorting of particles parallel to shore under dominant orthogonal wave power, although evidence for this phenomena is abundant. (Rosenburg, 1974), (Bryant, 1976), (King, 1972), (Bascom, 1951), (Hails, 1975). Bryant (1976) has shown convincingly that longshore settling velocity gradings are closely related to longshore variations in wave characteristics for South East Australian beaches. However, the exact mechanisms for the sediment transport is not clear. Bryant (1976) points out that even on a coast where orthogonal wave power is dominant, longshore wave power can be significant and can temporarily dominate flow conditions.

It can only be postulated that shore parallel sediment gradings are associated with longshore energy distribution due to variations in the null-point mechanisms at each beach system and the existence of longshore currents generated by variations in wave height (Komar, 1975).

The temporal variability, pointed out in this chapter, characteristic of beach systems, makes them difficult to investigate. The following surveys, samples and data interpretation are presented with the assumption that the configuration of the beach systems and sediment patterns are relatively permanent forms, and superimposed on these are the temporal variations. This assumption is supported by the findings of Bryant (1976) and Johnson and Eagleson (1966) that over time, the form of beach trends can be basically stable. Of course exceptions are found in the long term shore retreat or progradation.

CHAPTER 4. BATHYMETRY: Survey Methods and Location, and Submarine Topography.

The most obvious expression of beach dynamics and morphology is found between the point of breaking waves and the foredune. However, the beach is a continuous system above and below sea-level. Indeed, material actively incorporated in the beach active zone may extend many times further offshore than onshore. Furthermore, the seaward zone of the beach system is a zone where wave energy is modified, sediments are mobile and beach material may be lost or gained to the system. The submarine portion of beaches is the least accessible to research and for this reason the coastal nearshore zone is a neglected area of study, falling between subaerial beach studies and shelf studies.

For the Sydney coast north of Botany Bay, soundings of the sea bed have been conducted by the Royal Australian Navy (R.A.N.) from Cape Banks to Ben Buckler (1950), Manly to Long Reef (1938), Long Reef (1973), and Newport to Broken Bay (1950-51). These soundings are the basis of the only published bathymetric charts of the Sydney coast. (R.A.N. Chart AUS 197). For the purposes of coastal studies these charts are inadequate in depths less than twenty metres both in terms of soundings and in defining the nature of the sea bed. In fact the 1938 survey would have employed a lead line rather than echo-sounding equipment. There has been no survey inside the 30 metre contour between Long Reef and Newport, except for recent work by Short (in press) at Narrabeen. Individual beach surveys to 24 metres depth at Palm Beach and Dee Why have been conducted by the P.W.D. since 1976, and by contractors to the Metropolitan Water Sewerage and Drainage Board (M.W.S.D.B.) at Turimetta Head, North Head and Malabar-Bondi (1976). Appendix 1 shows the coverage of these surveys and those completed for this study. Prior to this study, only three beaches have been surveyed in detail offshore, from a total of fourteen beach systems between Maroubra and Palm Beach. It is fundamental to an understanding of Sydney beaches that the submarine portion of each beach be surveyed, from the break-point to the innershelf, in an attempt to define the boundaries of the active zone and to investigate the nature of the sea bed.

This chapter first examines the methods employed to survey the nearshore zone and the location of survey transects. Second, the submarine topography of the beaches is examined in terms of sediment distribution and submerged bedrock features, with reference to 24 profiles and two bathymetric charts. The charts and profiles are compiled from surveys carried out between July 1977 and November 1978 and other sources cited in appendix 1. A model of offshore bathymetry for the Sydney coast is proposed.

Survey Methods and Traverse Locations

All surveys with the exception of one were carried out using Macquarie University's 5.4 metre aluminium Quintrex, (Plate 1) powered by twin 20 h.p. mercury outboards. A re-survey of the area Turimetta Head to Newport was conducted using the Sydney University vessel.

Soundings were made using a continuous trace Raytheon echo-sounder with the transducer mounted over the side. The sounding trace shows clear distinctions between rock and sediment (Figure 4-3). The method of position fixing is shown diagrammatically in figure 4-1.

FIGURE 4-1 METHOD OF POSITION FIXING

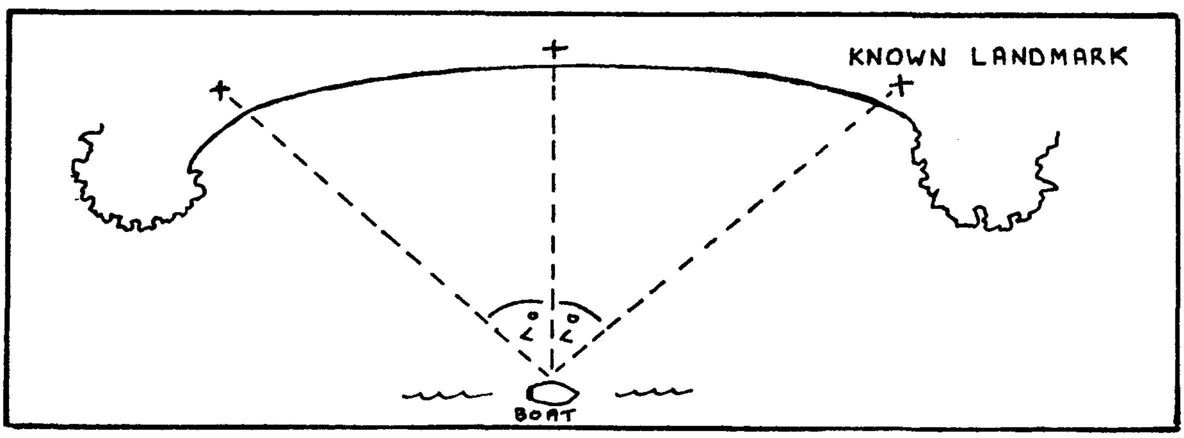


Plate 1 Macquarie University boat.

Using a sextant, two horizontal angles between three known landmarks are determined. The echo trace is marked with each series of sextant readings. For each traverse, sextant readings are made at regular intervals, giving a series of position fixed depths and a continuous trace of the sea bed. Depth soundings are accurate to $\pm$ 0.5 metres and in position to $\pm$ 10 metres, increasing seawards.

Plotted on figure 1-2 are the survey traverses carried out for this study. The standard survey technique employed two echo-sounding traverses to chart each beach, one parallel to shore, between headlands and one normal to shore, from the break-point to the innershelf. At Long Reef, where seas are particularly dangerous, detailed P.W.D. and R.A.N. surveys made it possible to omit the shore parallel traverse. Shore normal surveys were extended to above the high water level by levelling with a staff and range pole. The Mona Vale — Warriewood beach system was investigated in more detail, with shore normal traverses from the Southern, middle and Northern sections of the beach, from Mona Vale Basin and parallel to shore from Turimetta Head to Newport Reef. Additional soundings were taken off Manly, Bungan, Whale and Palm Beach. Total soundings covered approximately seventy kilometres of the sea bed.

The echo-sounding data is useful on two levels. First, the submarine topography of each beach can be assessed and second, by combining this data and that from other sources, a detailed pattern of offshore bathymetry emerges for the Sydney coast. Two charts are presented (inside back cover) of the coast between Shark Point and Ben Buckler and between North Head and Barranjoey. The compilation of these charts is explained in Appendix 1.

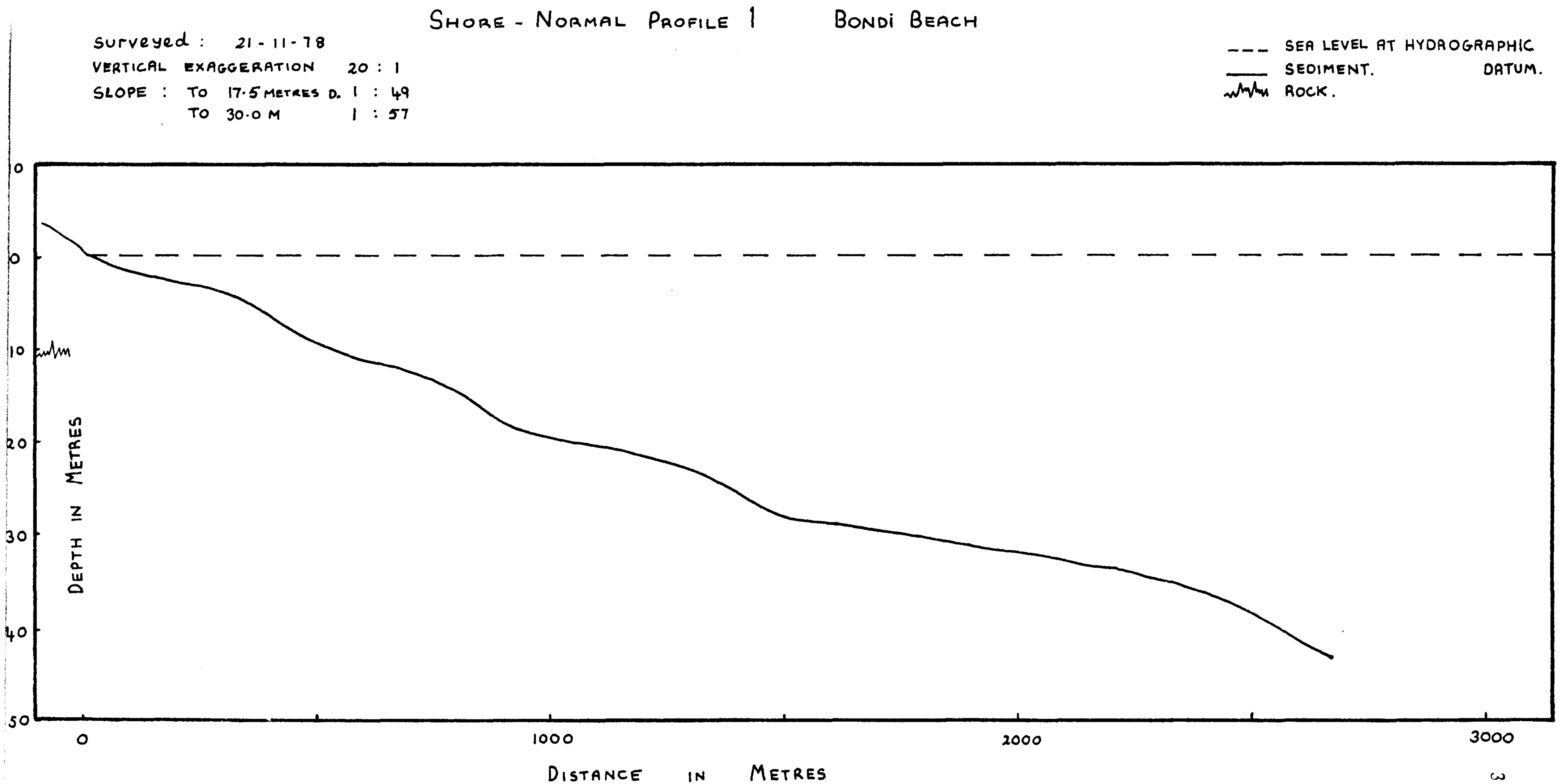
Submarine Topography

The submarine topography of the Sydney coast will be discussed in three sections. First, individual beach plans and profiles will be assessed and compared. Second, the gross patterns of bathymetry are identified and discussed, and finally, a model of offshore bathymetry is proposed for the Sydney coast.

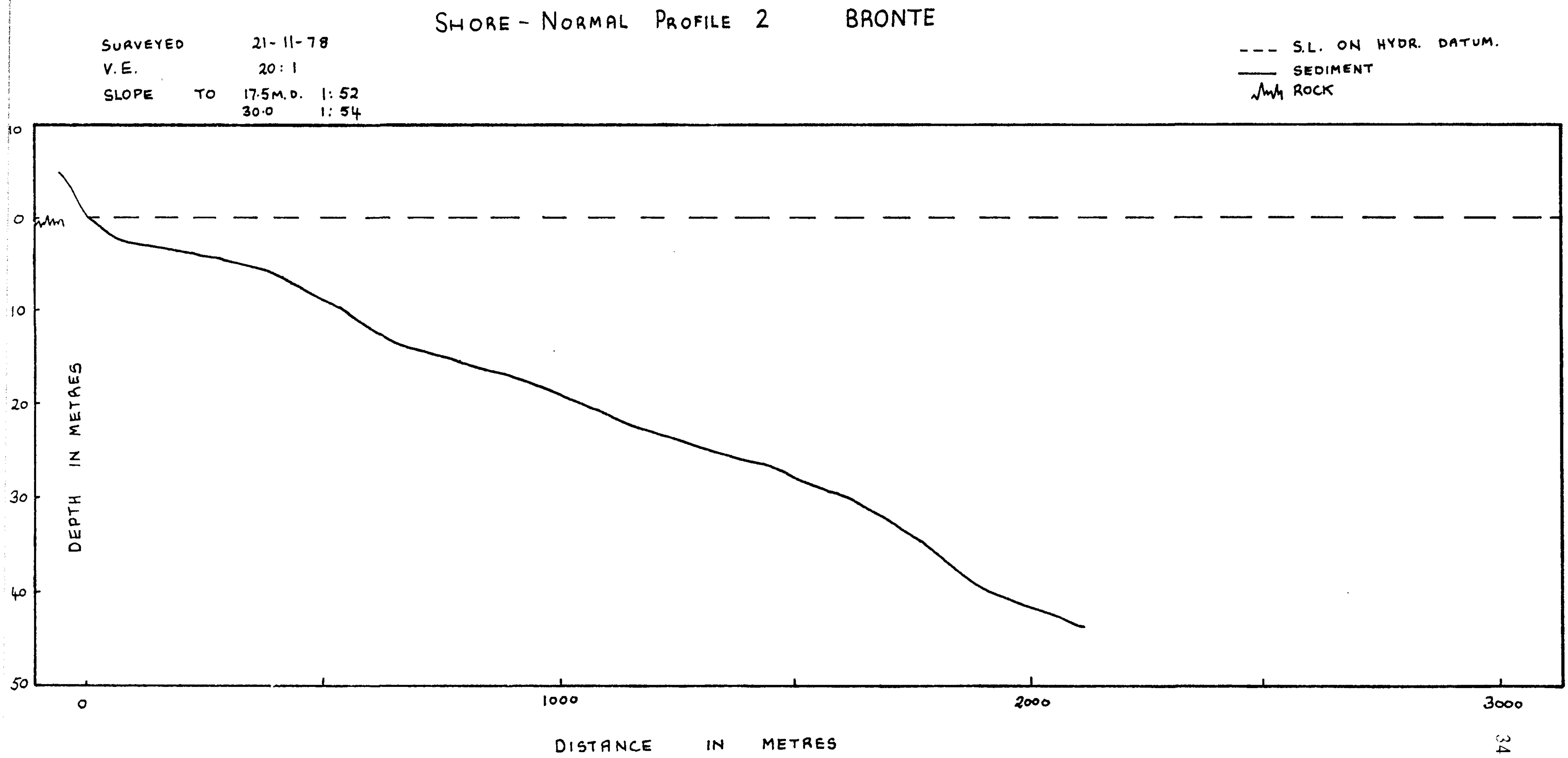
Beach Plans and Profiles: The submarine plans and profiles associated with each beach differ considerably in terms of sand and rock distribution, gradient and topography. Nearshore beach plans shown on Charts 1 and 2 indicate a remarkable variation in the morphology of the sand bodies associated with each beach. Only three beaches exhibit the sand ramp that could have been expected along much of the coast. The other nine beaches all display degrees of enclosure by submerged bedrock. Indeed, there is a continuum from the extensive sand ramps of Bondi and Bronte and Palm Beach to the small sand pockets of Whale, Avalon and Bungan beaches.

The extensive sand body off Bondi and Bronte beaches (Chart 2) is interrupted by submerged bedrock only off Bondi Point and adjacent to the rocky headlands. The shore parallel soundings constituting profile 1a, show that the rock outcrop off Bondi Point forms the divide between the deeper relict Bondi valley and the Tamarama - Bronte valleys. Therefore the longshore sand profile is asymmetric due to underlying bedrock relief rather than differences in sediment thickness. The shore-normal cross-sections (Profiles 1 and 2) are characteristically convex upward with similar gradients. Both profiles display a nearshore bar between 2 and 14 metres depth and a notably steep seaward slope beyond 30 metres depth.

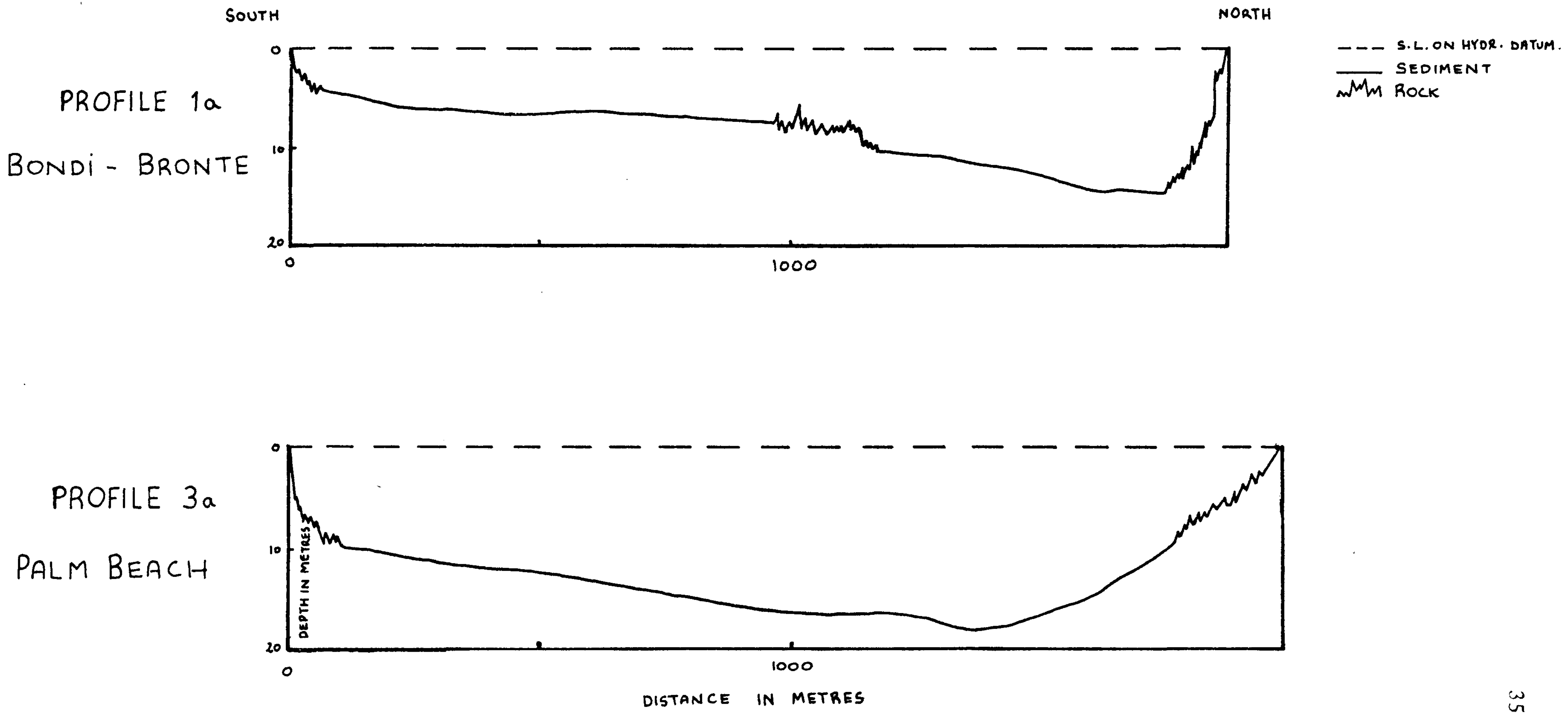
The sand body at Palm Beach (Chart 1), although extensive, is interrupted by a bedrock ridge which appears to be a



SHORE - NORMAL PROFILE 1 BONDI BEACH
SURVEYED : 21-11-78
VERTICAL EXAGGERATION 20 : 1
SLOPE : TO 17·5 METRES D. 1 : 49
TO 30·0 M 1 : 57
--- SEA LEVEL AT HYDROGRAPHIC DATUM.
—— SEDIMENT.
ROCK.
DEPTH IN METRES
0
10
20
30
40
50
0
1000
2000
3000
DISTANCE IN METRES


SHORE - NORMAL PROFILE 2 BRONTE
SURVEYED 21-11-78
V.E. 20:1
SLOPE TO 17.5M.D. 1:52
30.0 1:54
S.L. ON HYDR. DATUM.
SEDIMENT
ROCK
DEPTH IN METRES
10
0
10
20
30
40
50
0
1000
2000
3000
DISTANCE IN METRES

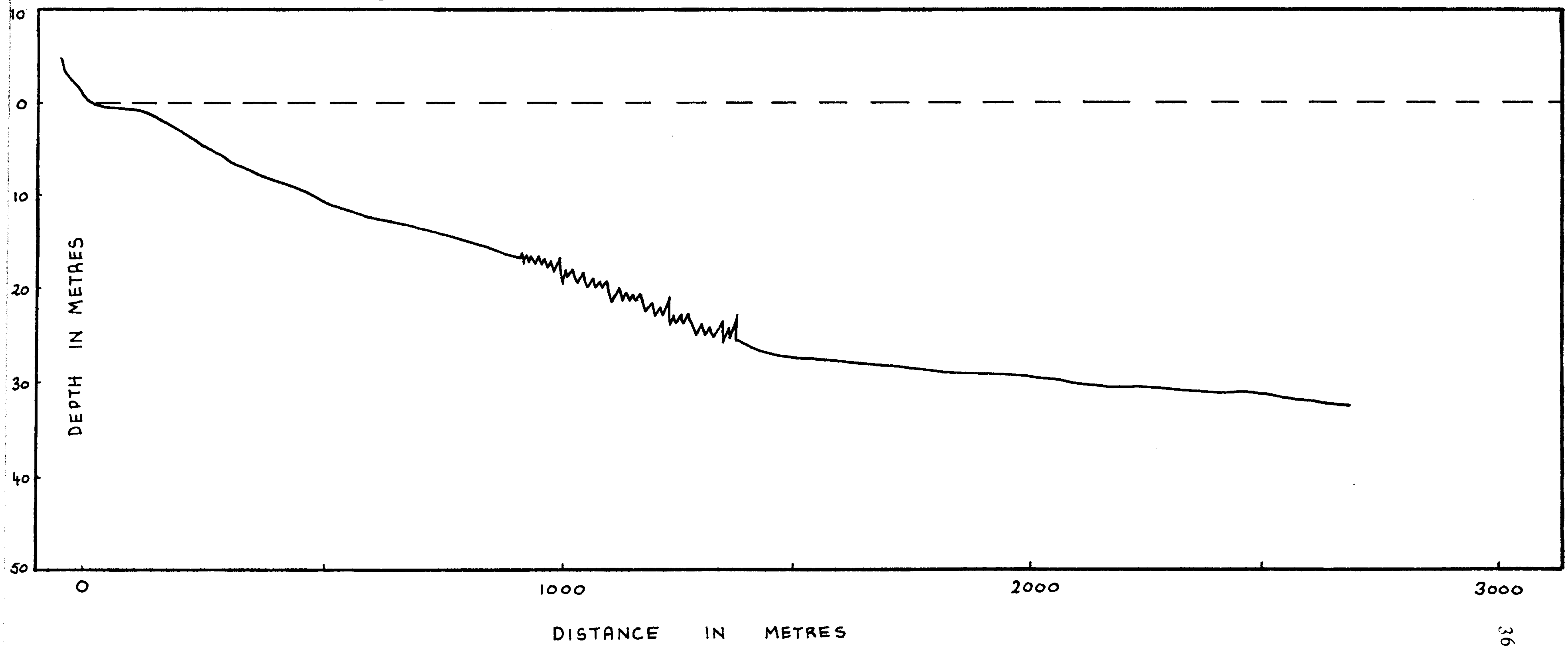
SHORE - PARALLEL PROFILES



SHORE NORMAL PROFILE 3 PALM BEACH

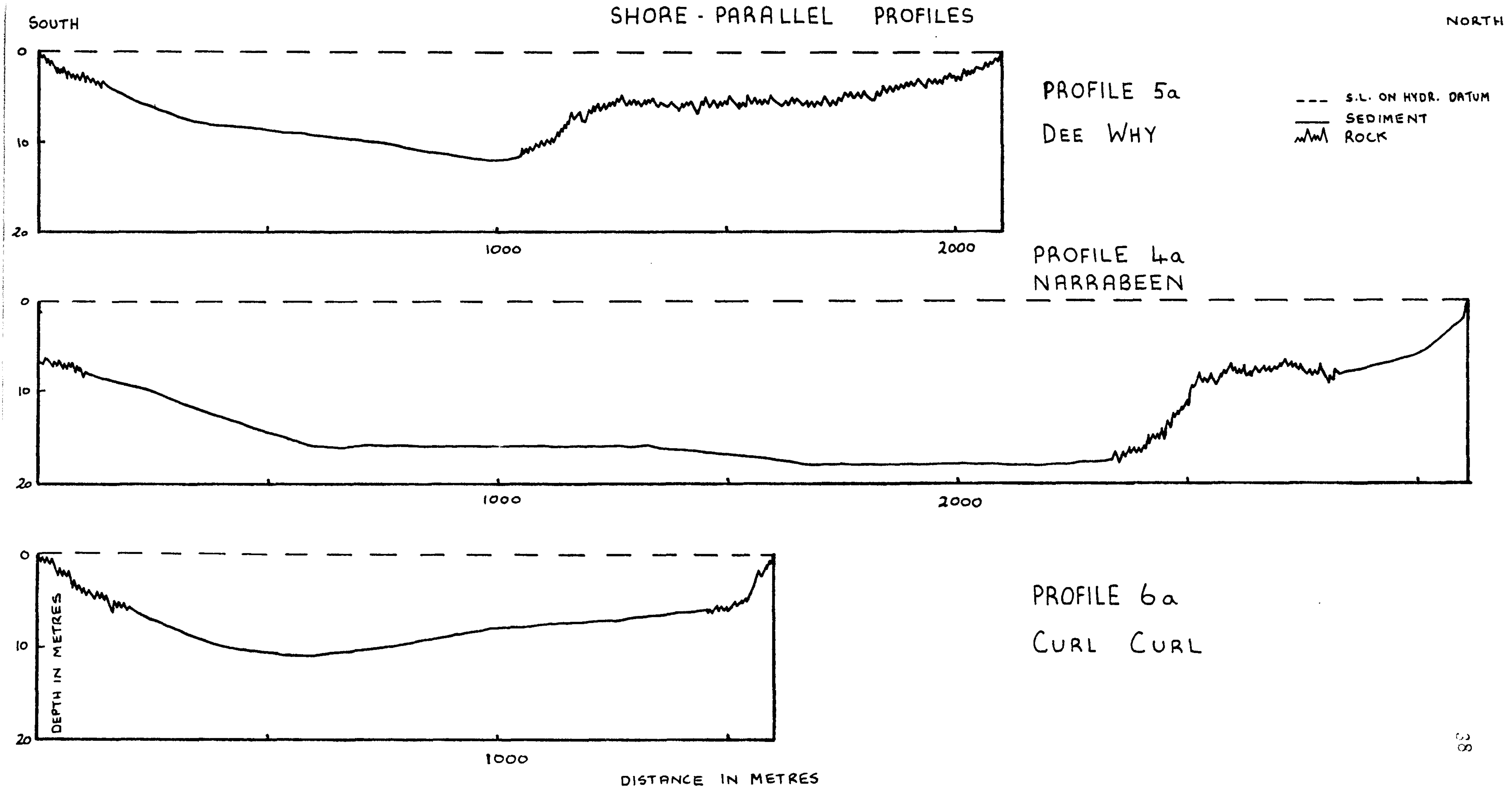
SURVEYED 14-11-77 - 8-6-78
V. E. 20:1
SLOPE TO 17.5m.o. 1:56
30.0 1:73

--- S.L. ON HYDR. DATUM.
——— SEDIMENT
⩘⩘⩘ ROCK

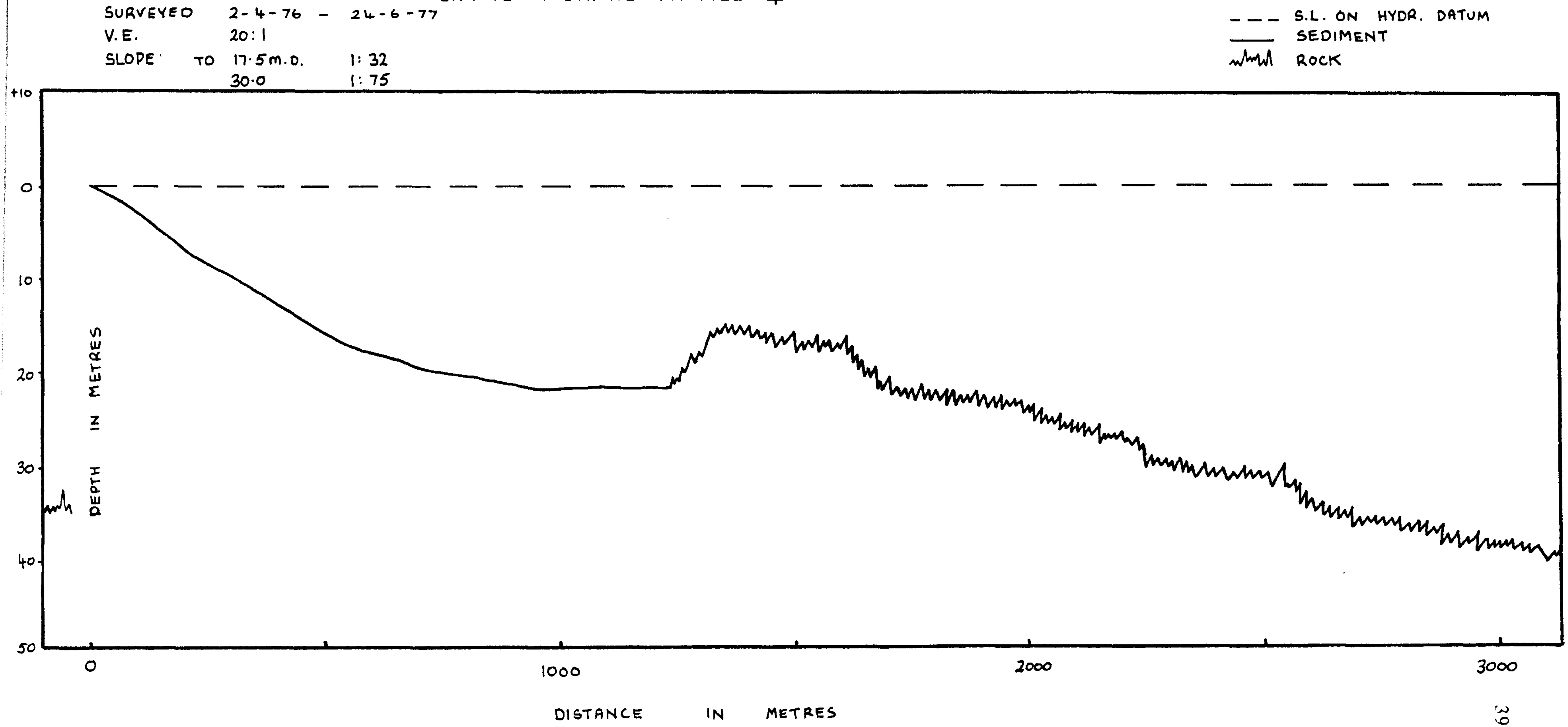


submerged extension of the South Palm Beach - Whale Beach headland complex, a feature not delineated by the geophysical surveys of Albani and Johnson (1974). The shore-normal profile (Profile 3) has a relatively low gradient of 1:73 to 30 metres depth, displaying the bedrock ridge between 17 and 26 metres depth. A major break in slope occurs at 27.5 metres depth. Profile 3a, parallel to the beach is inside the bedrock ridge and is strongly asymmetric, shallowing to the south. Reference to figure 2-4 shows that the bedrock cross-section is fairly symmetric, thus suggesting a thickening of the sand body to the south.

Curl Curl, Dee Why and Narrabeen beaches have effectively seaward narrowing and thinning bodies of sediment, terminated offshore by bedrock outcrop. Narrabeen and Dee Why beaches are bounded laterally by massive rock outcrops. Profile 4a parallel to shore at Narrabeen displays a symmetrical profile indicating a central relict channel system although there appears to be some thickening of sediment to the south. At Dee Why, profile 5a shows a sediment filled channel to the south of the embayment. The sand body associated with Curl Curl beach is laterally more extensive, probably merging with material off Dee Why. The shore-parallel profile is shallower to the north (Profile 6a), bounded to the south by South Curl Curl headland, which protrudes as a steep divide offshore. Breaks in this divide may permit some interchange of material with the Manly sediment system. The seaward zone of the Curl Curl sediment body is marked by a rock outcrop at 30 metres depth. The shore-normal profile displays a concave upward slope with a bar peaking at 10 metres depth. The slope flattens slightly at 22 metres depth and more significantly at 40 metres depth due to a sheer bedrock cliff. In contrast to Curl Curl, the Dee Why profile is much flatter (Profile 5) with a slope to 17.5 metres depth of 1:85. The sand profile


SHORE - PARALLEL PROFILES
SOUTH
NORTH
PROFILE 5a
DEE WHY
S.L. ON HYDR. DATUM
SEDIMENT
ROCK
PROFILE 4a
NARRABEEN
PROFILE 6a
CURL CURL
DEPTH IN METRES
DISTANCE IN METRES
0
10
20
1000
2000

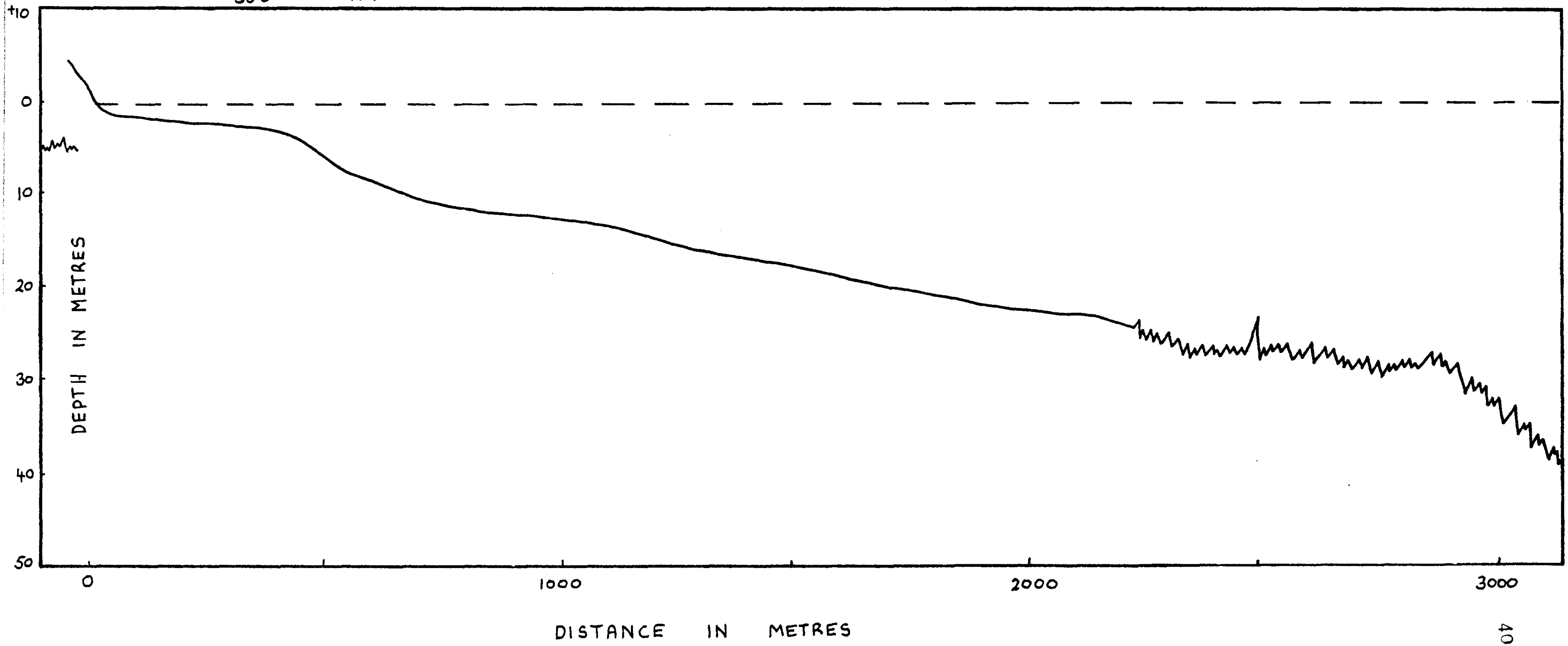
SHORE - NORMAL PROFILE 4 NARRABEEN (from SHORT, in press)

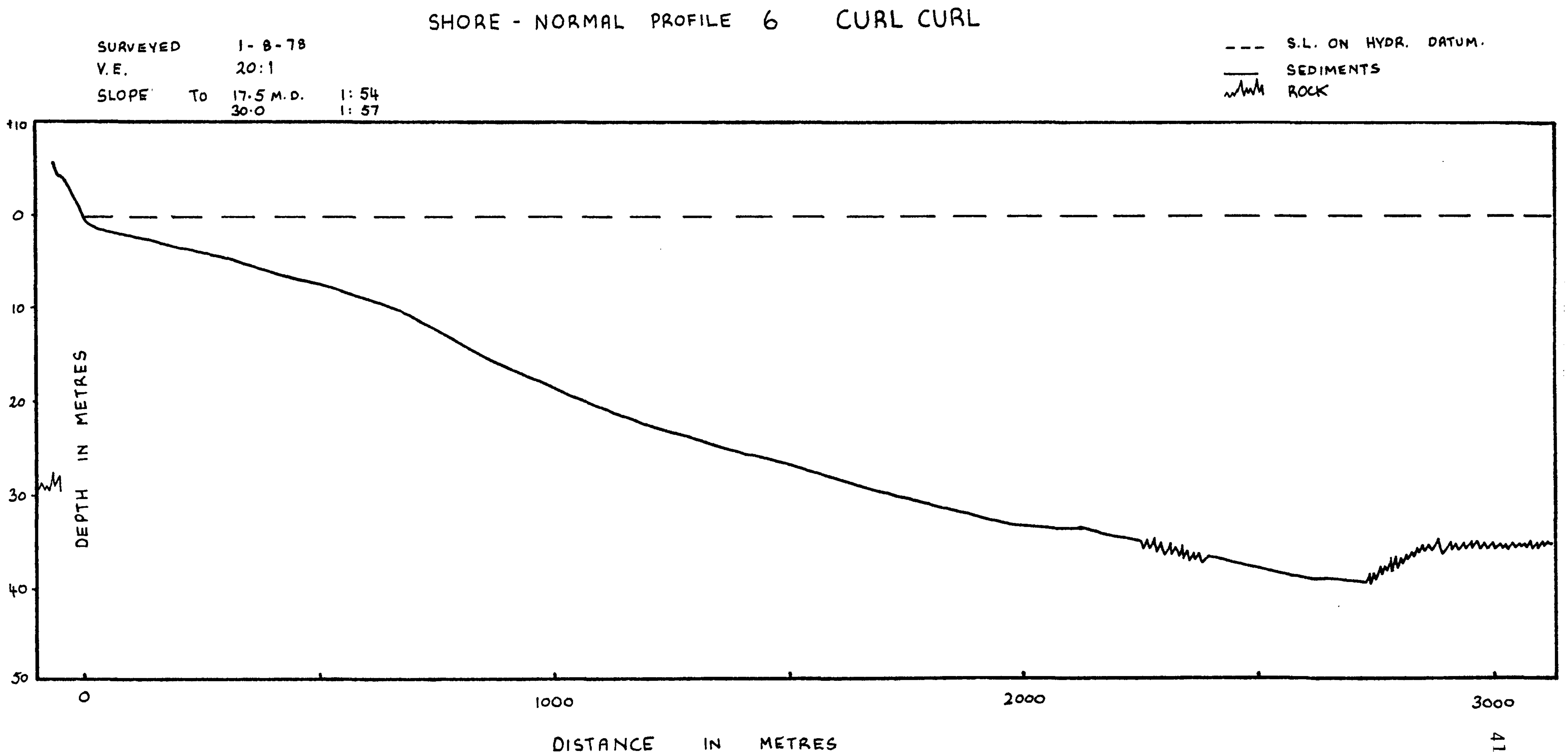


SHORE - NORMAL PROFILE 5 DEE WHY

SURVEYED 12-10-78
V. E. 20:1
SLOPE TO 17.5 M.D. 1:85
30.0 1:97

--- S.L. ON HYDR. DATUM
—— SEDIMENT
ROCK



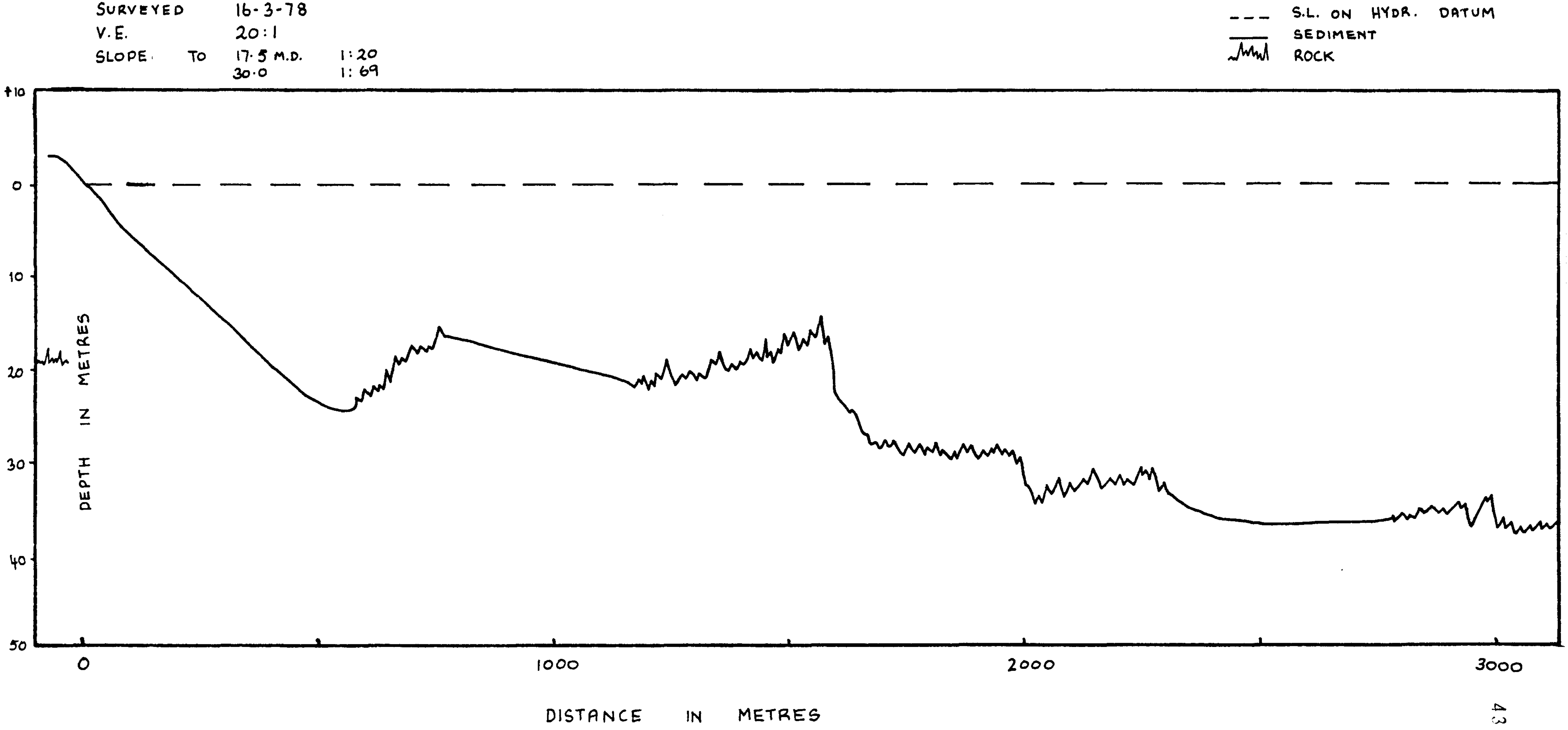

SHORE - NORMAL PROFILE 6 CURL CURL
SURVEYED 1-8-78
V.E. 20:1
SLOPE TO 17.5 M.D. 1:54
30.0 1:57
S.L. ON HYDR. DATUM.
SEDIMENTS
ROCK
+10
0
10
20
30
40
50
DEPTH IN METRES
0
1000
2000
3000
DISTANCE IN METRES

displays a prominent nearshore bar peaking at 4 metres depth. The sand body is terminated offshore by rock at 24 metres depth. A sheer 10 metre cliff forms the seaward boundary of the outcrop in 30-40 metres of water. The Narrabeen profile is distinctly steeper, 1:32 to 17.5 m and concave (Profile 4). Notable breaks in slope to a lower gradient occur at 18 metres and 22 metres on the sand profile. This profile, taken to the north of the embayment strikes across a shallow rock peak at 16 metres depth and outcrop extends to 42 metres depth. However, a cross-section taken towards the middle of the embayment would give a profile similar to that of Curl Curl and Dee Why, with rock outcropping at 25-35 metres depth offshore.

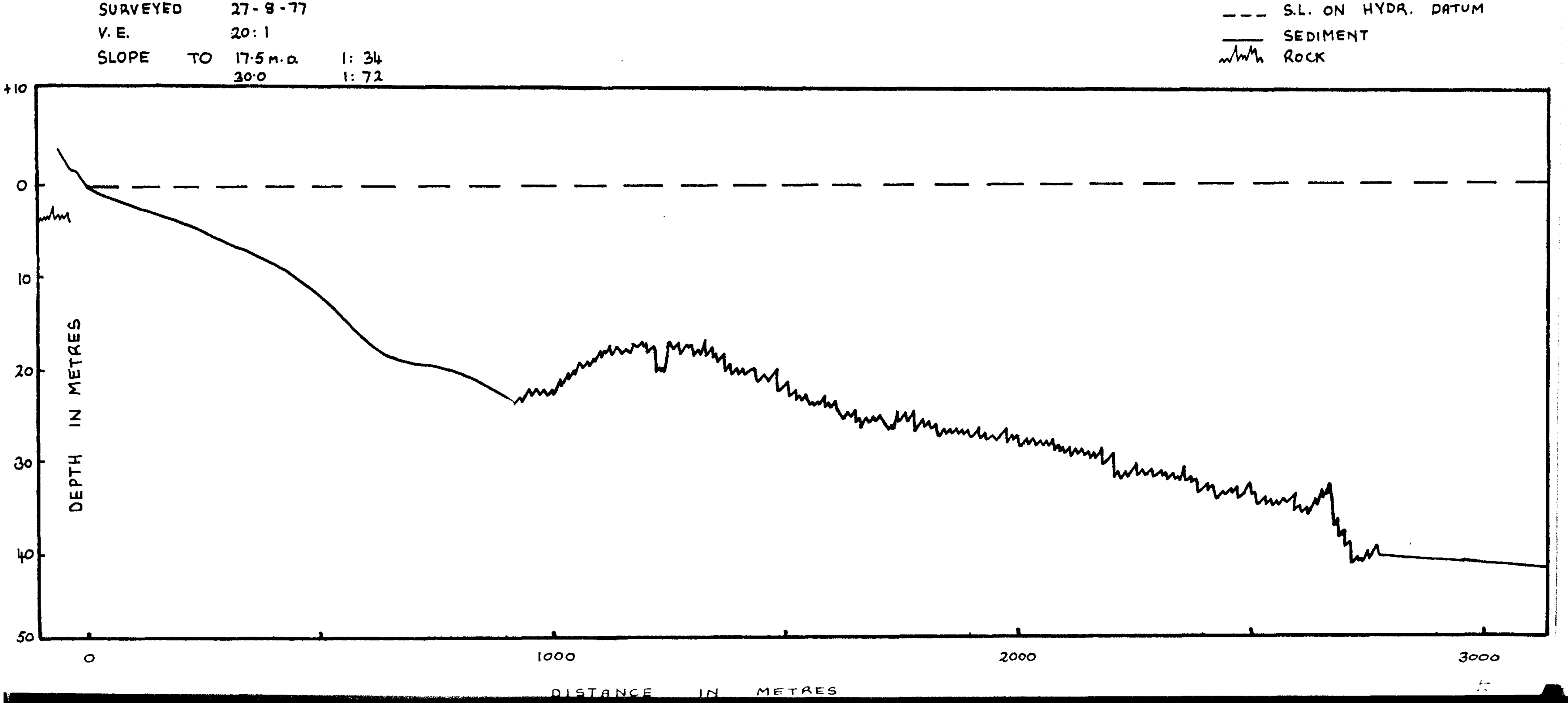
Whale, Newport, Bungan, Avalon, Mona Vale and Manly beaches all have restricted seaward thinning sandbodies due to enclosure by rock outcrop. Manly and Mona Vale beaches each display very steep sediment slopes, similar to that of Narrabeen. Profile 7, shore-normal to Manly Beach shows a restricted sand body extending only 550 metres offshore with an extremely steep gradient of 1:20 to 17.5 metres depth. The bedrock peak so close inshore, reaching 10 metres depth at its summit (Chart 1) must influence the associated sediment slope. The bedrock profile is rugged with cliffs up to 10 metres in height and patches of sediment in the depressions. Although not as steep, the Mona Vale shore-normal profile (Profile 8) is similar to Manly, with a sediment slope of 1:34 to 17.5 m depth, extending 950 metres offshore. Further seaward, the bedrock topography is very rugged with 10 metre sheer cliffs and depressions. The shore-parallel profile at Mona Vale (Profile 8a) shows sediment infilling of a bedrock valley to the South. A second smaller valley is evident to the North, apparently associated with the Mona Vale Basin bedrock depression. The Manly profile parallel to shore (Profile 7a) displays shallowing of sediment to the North probably due to the traverse location which is slightly oblique to the coast.

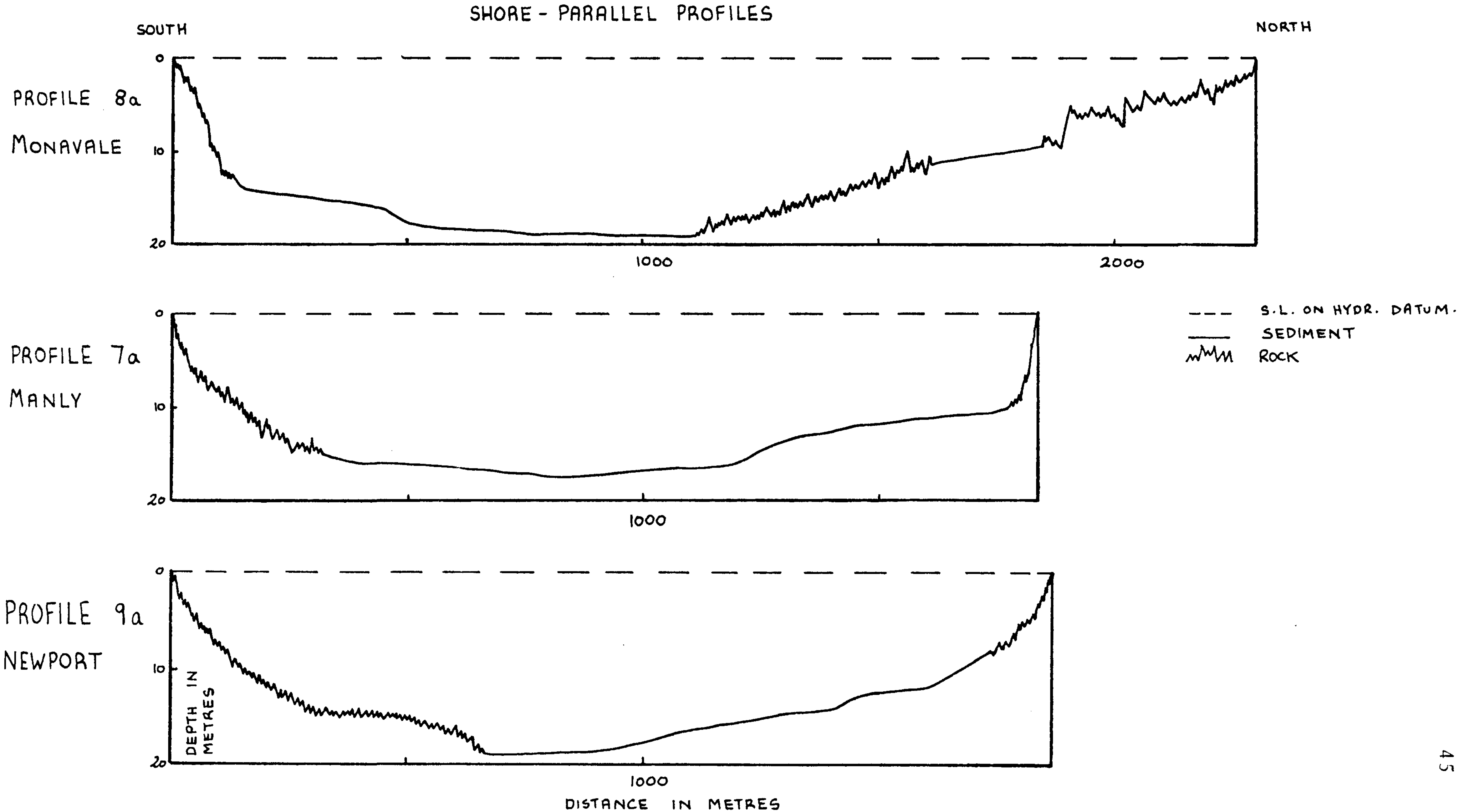
SHORE- NORMAL PROFILE 7 MANLY

SURVEYED 16-3-78
V.E. 20:1
SLOPE TO 17·5 M.D. 1:20
30·0 1:69



SHORE - NORMAL PROFILE 8 MONAVALE



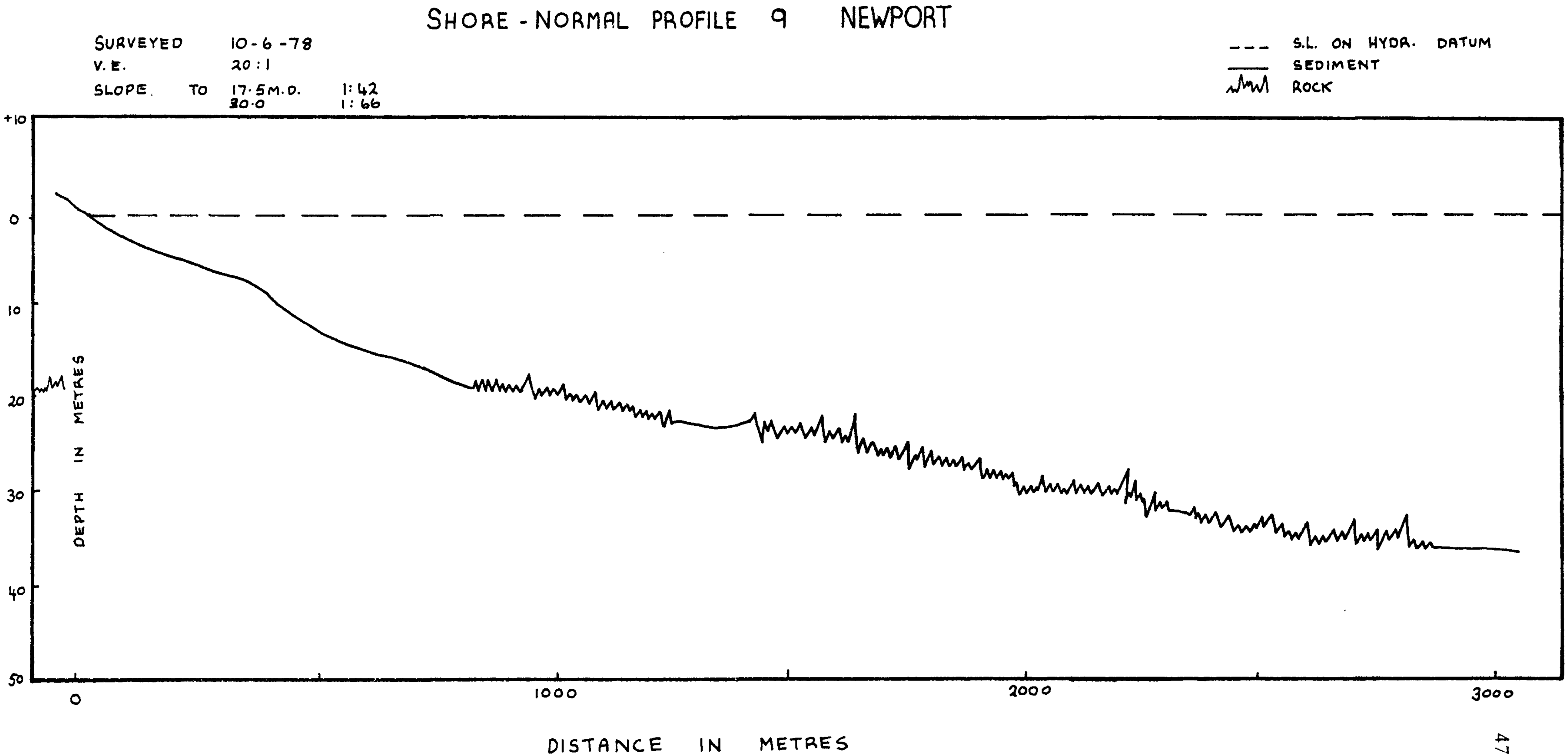


SHORE - PARALLEL PROFILES
SOUTH
NORTH
PROFILE 8a
MONAVALE
PROFILE 7a
MANLY
PROFILE 9a
NEWPORT
0
10
20
1000
2000
S.L. ON HYDR. DATUM.
SEDIMENT
ROCK
DEPTH IN METRES
DISTANCE IN METRES

The sand bodies associated with Whale, Newport and Avalon are also limited in extent both laterally and offshore. The profiles normal to shore (Profiles 9, 10 and 11) show the sand bodies extending no further than 1 kilometre offshore. Profiles 9 and 11 of Newport and Whale beaches have relatively steep sediment slopes, becoming less steep further offshore due to bedrock outcrops. The outcrop terminates beyond 26 metres depth off Whale Beach. The sediment profiles contrast with Newport displaying a convex upward slope, marked by an offshore bar peaking at 8 metres depth. The profile at Whale Beach is markedly concave upward, with no bar. Profile 10 of Avalon has a significantly low gradient slope of 1:57 to 17.5 metres depth and 1:85 to 30 metres depth. The profile is slightly convex upward exhibiting a small bar peaking at 7 metres depth. The low overall gradient (0-30m)at Avalon (1:85) is comparable to Dee Why (1:97) and this is due to the offshore extension of headland complexes at both sections of the coast. The shallow basement may also influence the sediment slope at these beaches.

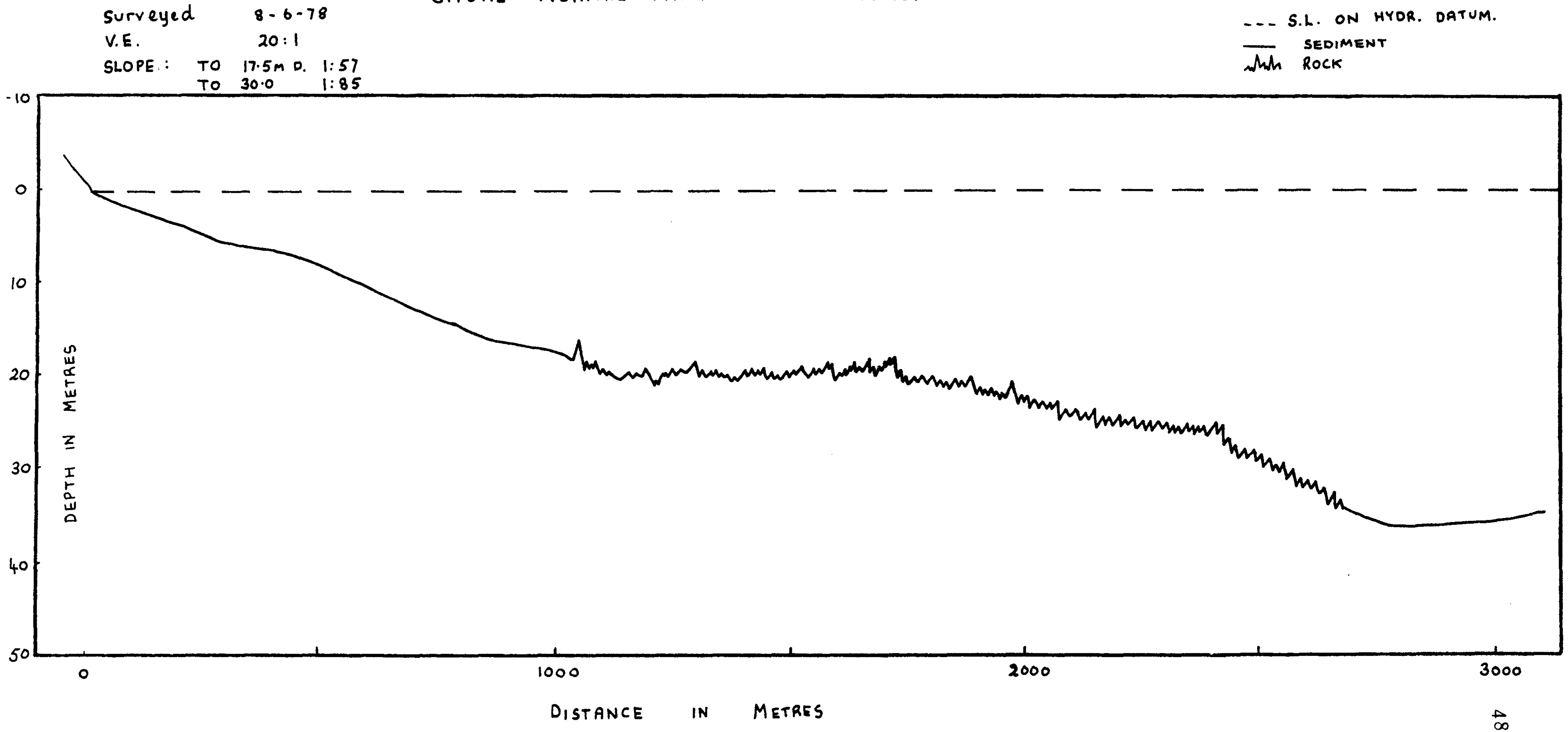
The shore-parallel profiles at Newport, Avalon and Whale Beaches are all different. Profile 11a of Whale Beach is asymmetric with sediment thickening to the South since the outcrops in the profile suggest a symmetric bedrock profile, trending to the North further offshore, (¯26m, Chart 1). At Avalon, (Profile 10a) the outcrops suggest deeper bedrock to the North of the valley, however, the sediment profile is flat. Newport (Profile 9a), is clearly assymetric, with sediment thickening to the North probably due to the oblique traverse line.

The sand body at Bungan Beach, though clearly restricted by outcrop, displays a wedge of sediment thickening to the North of the embayment (Profile 12a), since depths to bedrock here are greatest due to a clearly defined channel (Figure 4-2). The channel is well marked by infilled sediment to 1650 metres offshore and 26 metres depth. A section across the channel at 22 metres depth (Figure 4-4) shows a 200m wide


SHORE - NORMAL PROFILE 9 NEWPORT
SURVEYED 10-6-78
V.E. 20:1
SLOPE TO 17·5 M.D. 1:42
20·0 1:66
S.L. ON HYDR. DATUM
SEDIMENT
ROCK
+10
0
10
20
30
40
50
DEPTH IN METRES
0
1000
2000
3000
DISTANCE IN METRES

SHORE - NORMAL PROFILE 10 AVALON

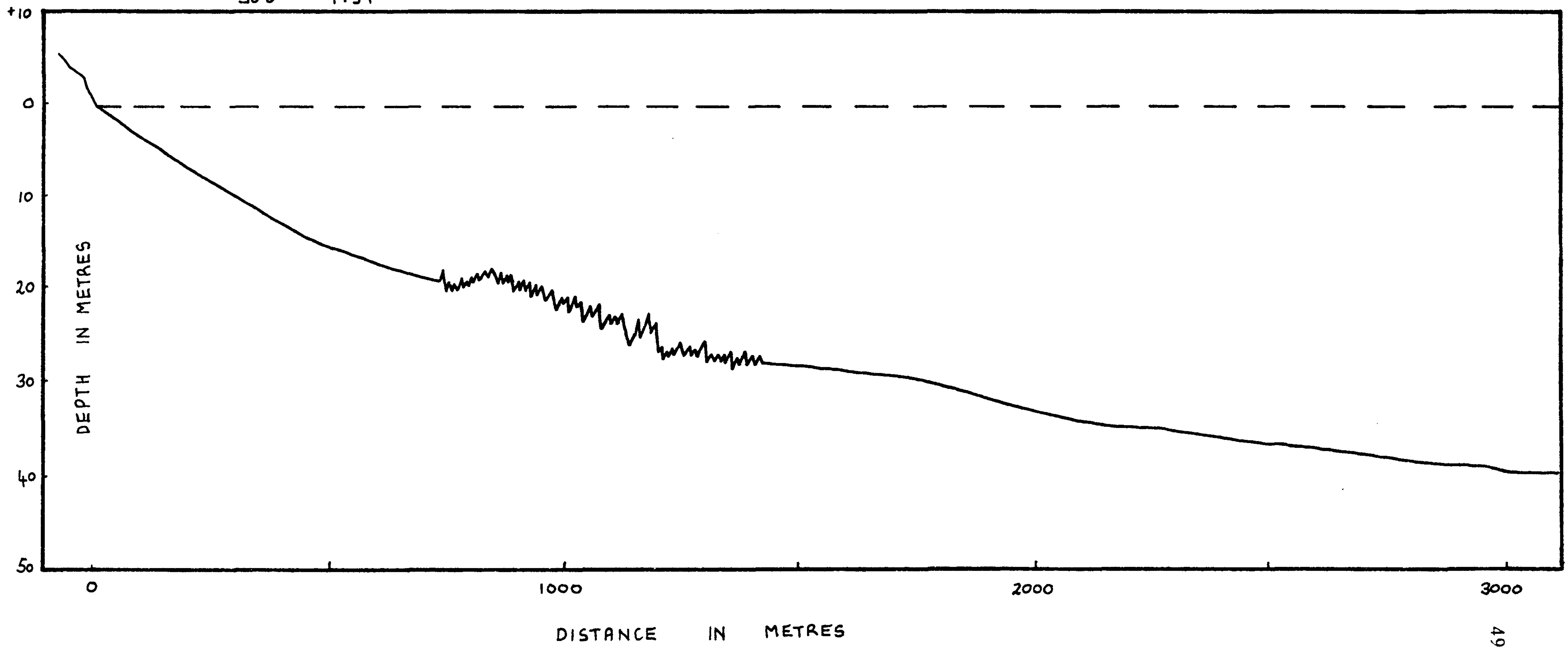
Surveyed 8-6-78
V.E. 20:1
SLOPE: TO 17·5m D. 1:57
TO 30·0 1:85

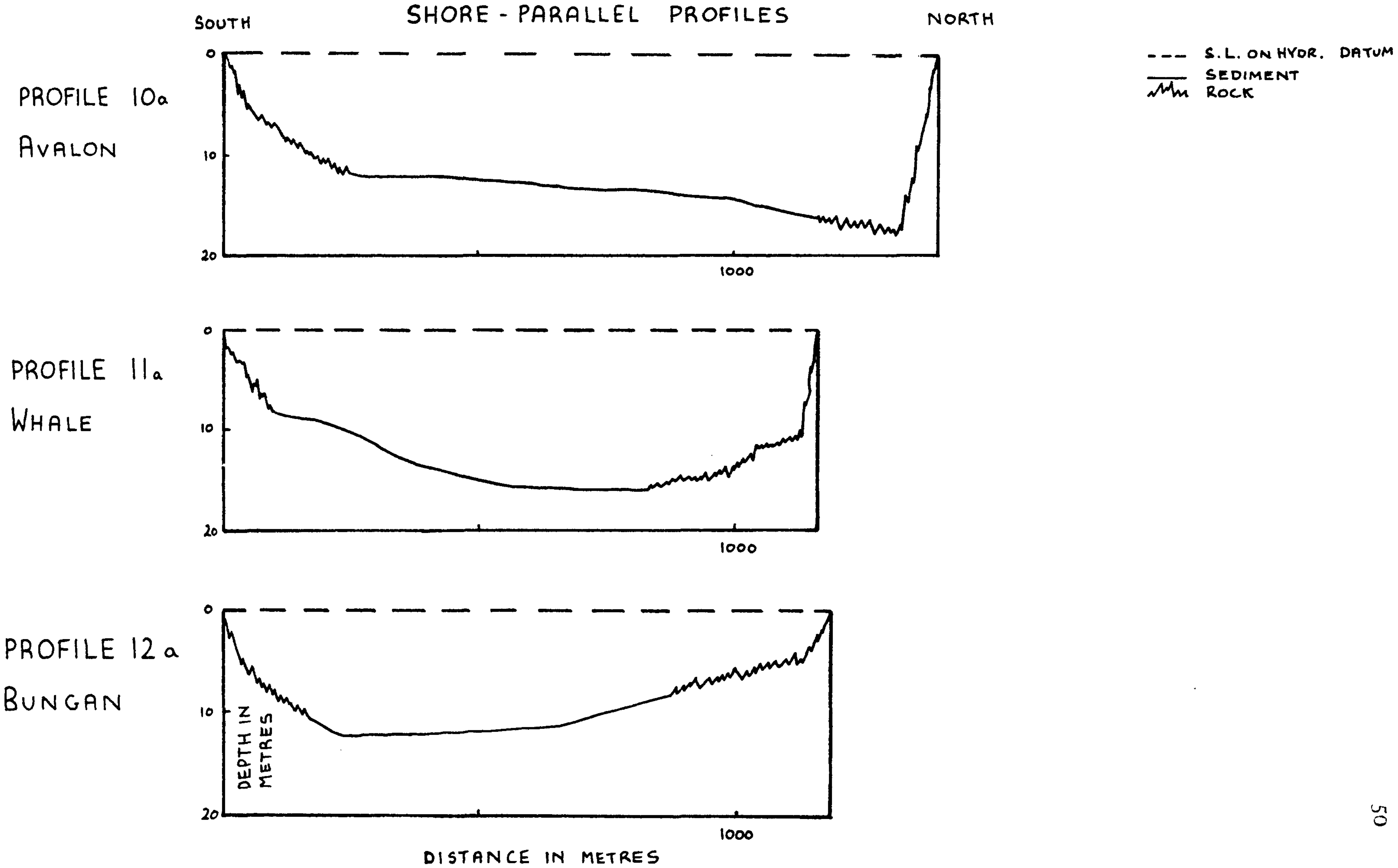


SHORE - NORMAL PROFILE 11 WHALE

SURVEYED 17-11-78
V. E. 20 : 1
SLOPE TO 17·5 M.D. 1:37
30·0 1:59

--- S.L. ON HYDR. DATUM.
——— SEDIMENT
ROCK





SHORE - PARALLEL PROFILES
SOUTH
NORTH
--- S.L. ON HYDR. DATUM
SEDIMENT
ROCK
PROFILE 10a
AVALON
0
10
20
1000
PROFILE 11a
WHALE
0
10
20
1000
PROFILE 12a
BUNGAN
0
10
20
DEPTH IN METRES
1000
DISTANCE IN METRES

SHORE-NORMAL PROFILE 12 BUNGAN

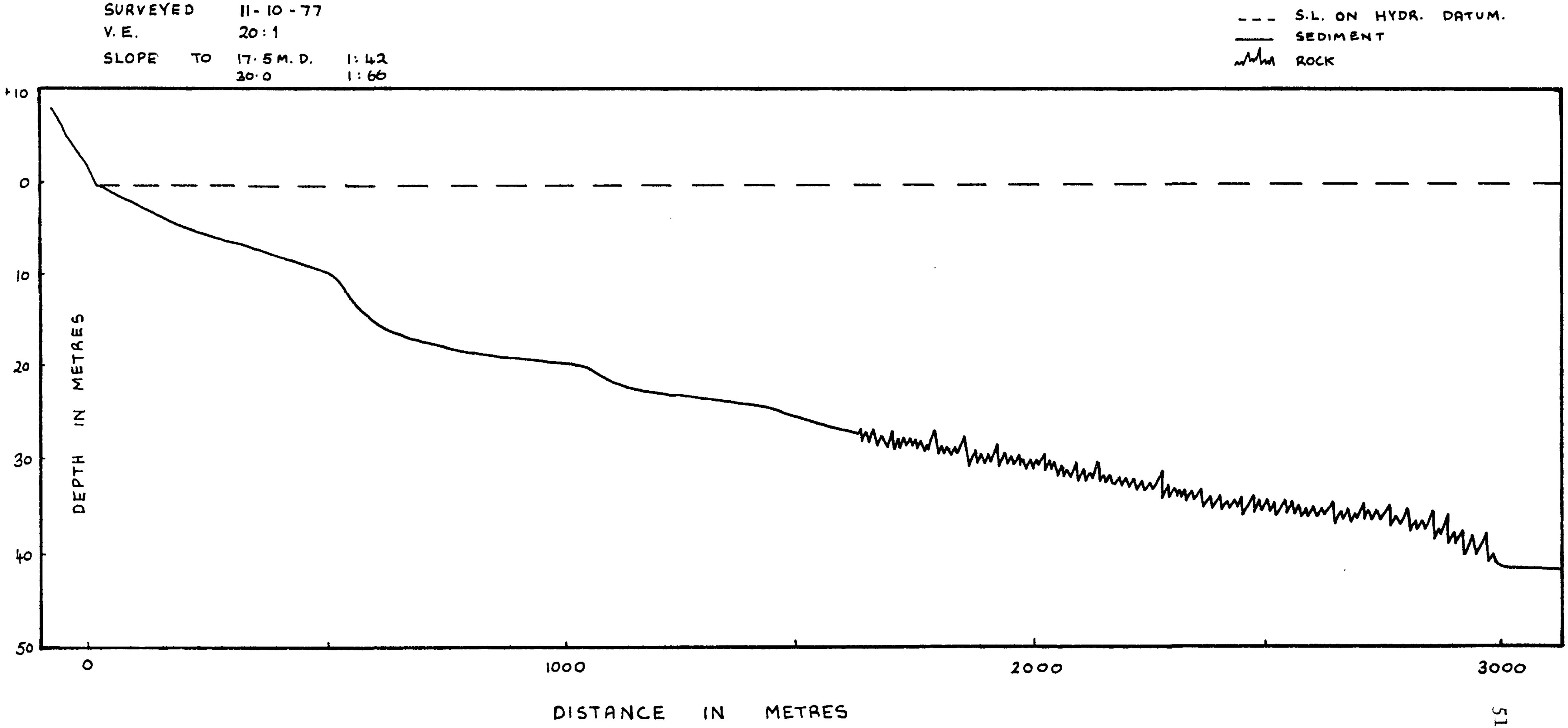
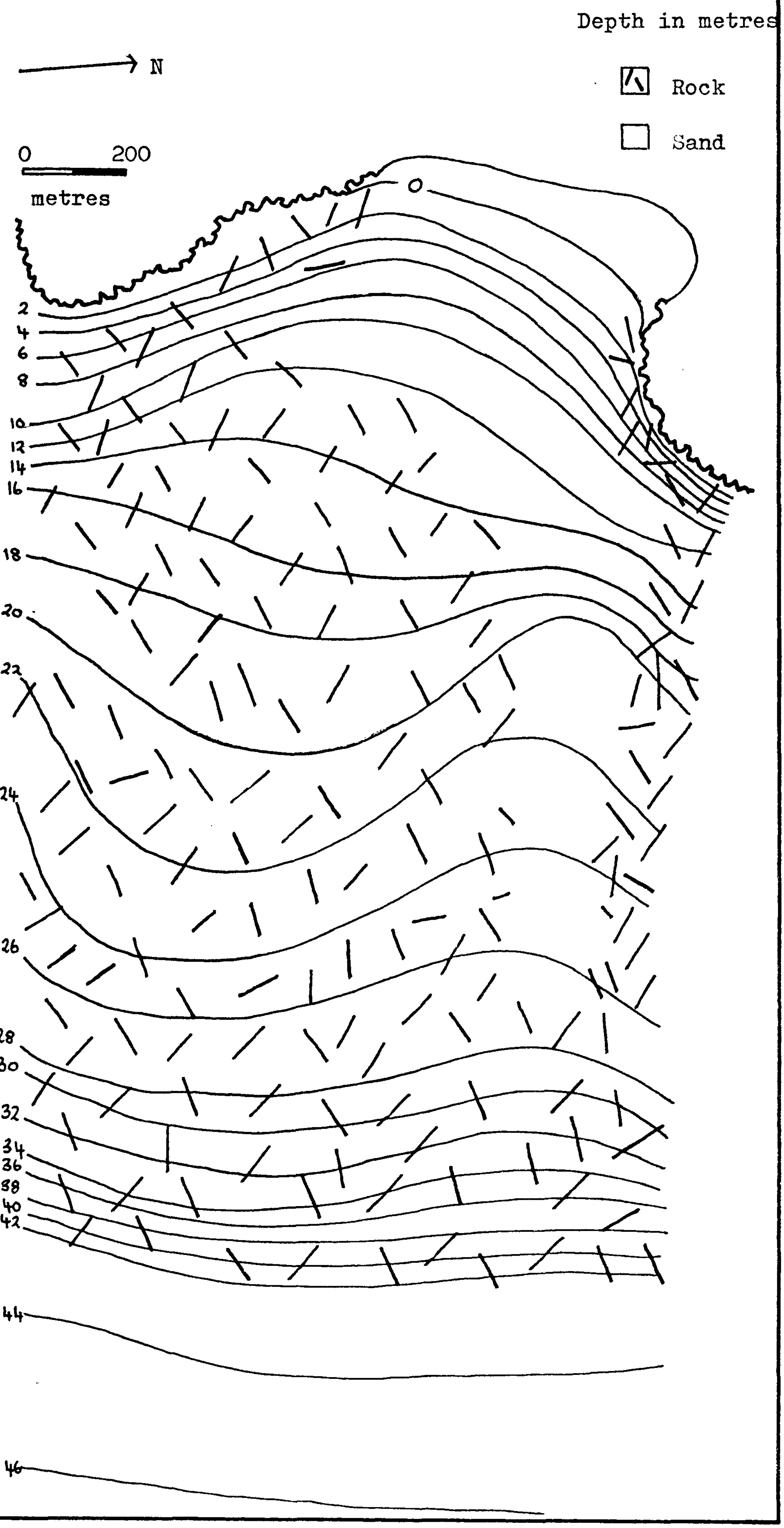


Figure 4-2 Bungan Beach Bathymetry.



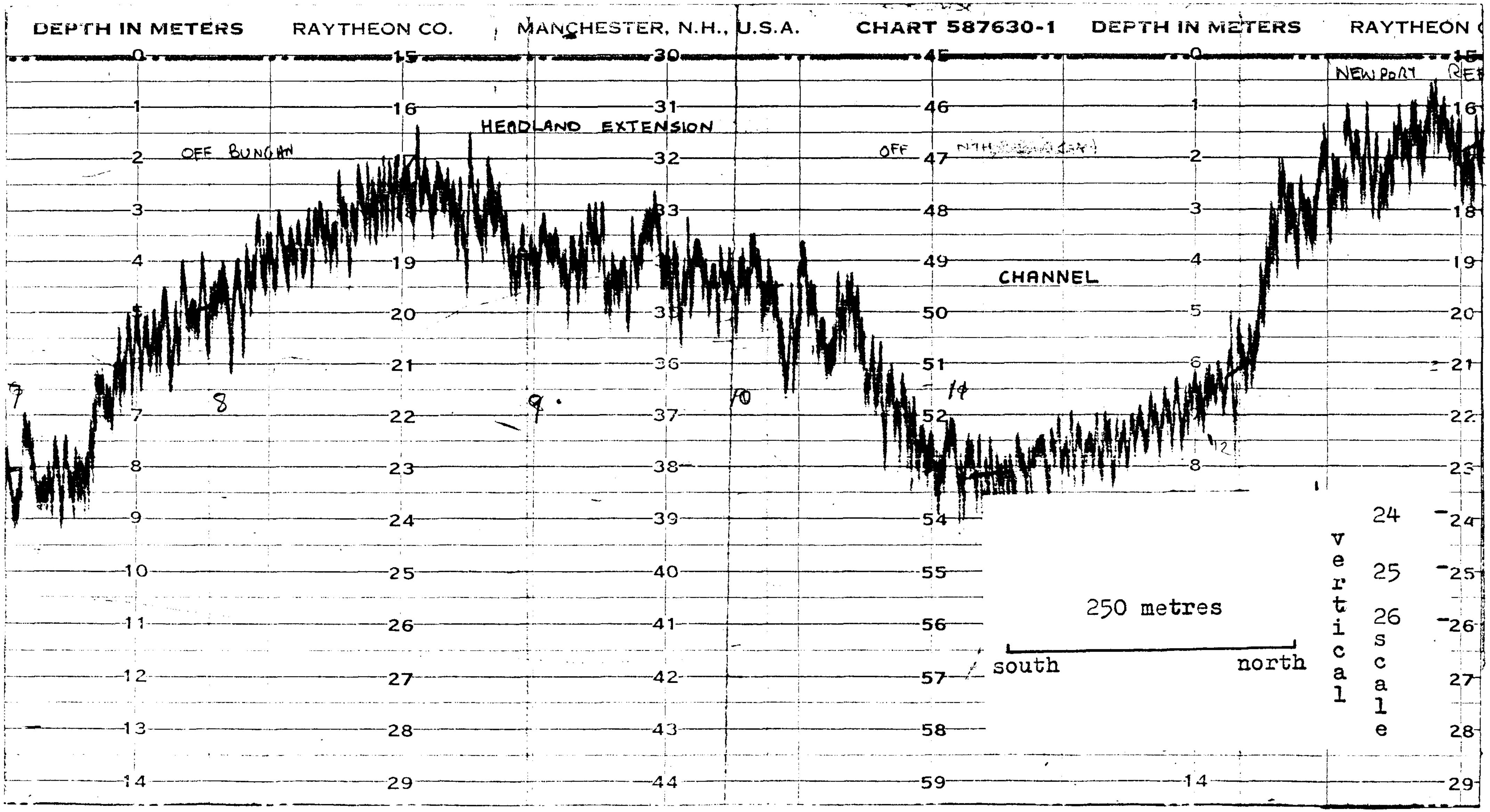


Figure 4-4 Echo-sounding trace parallel to Bungan beach. 700m offshore.

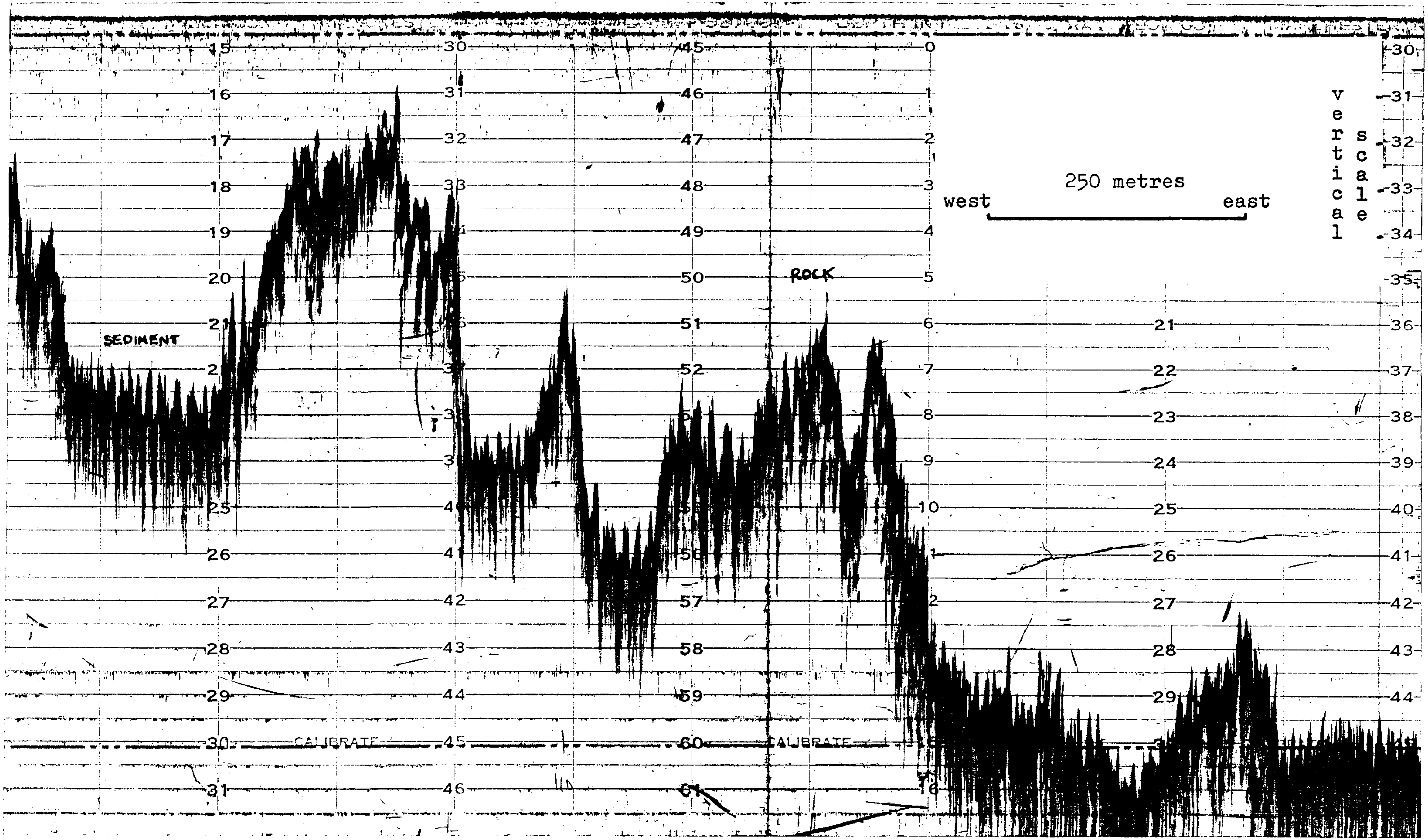


Figure 4-3 Echo-sounding trace perpendicular to Bungan beach, 3km offshore.

incision, bounded by 3-4 metre cliffs. Here also, the channel fill thickens to the north. Figure 4-4 also illustrates the extension offshore of the Newport-Bungan-Mona Vale headland complex. This feature forms the dividing range between the relict Mona Vale and Bungan catchments. The shore-normal profile of the Bungan sand body (Profile 12), shows a relatively low gradient slope (1:66 to 30 m depth). The sand profile is marked by a bar at 10 m depth. Seaward of the channel the bedrock relief is very rugged. Figure 4-3 shows the shear cliffs, peaks and depressions filled with sediment, on the echo-sounding trace 3 kilometres off Bungan. A cliff at 44 metres depth marks the seaward boundary of the outcrop.

Gross Patterns of Bathymetry: The coast between Shark Point and Barranjoey, depicted in Charts 1 and 2 is dominated by exposed bedrock. Profiles perpendicular to shore have shown an average gradient to 30 metres depth of 1:69, with a significantly lower slope across the shelf. The break in slope is commonly marked by a cliff exposed at 30 - 40 metres depth, with innershelf sediments at the base. Seismic surveys for outfall studies (M.W.S.D.B. 1976) off Turimetta, North Head and Ben Buckler (Appendix 2) show that the break in slope is due to basement control rather than a thick wedge of innershelf sediment.

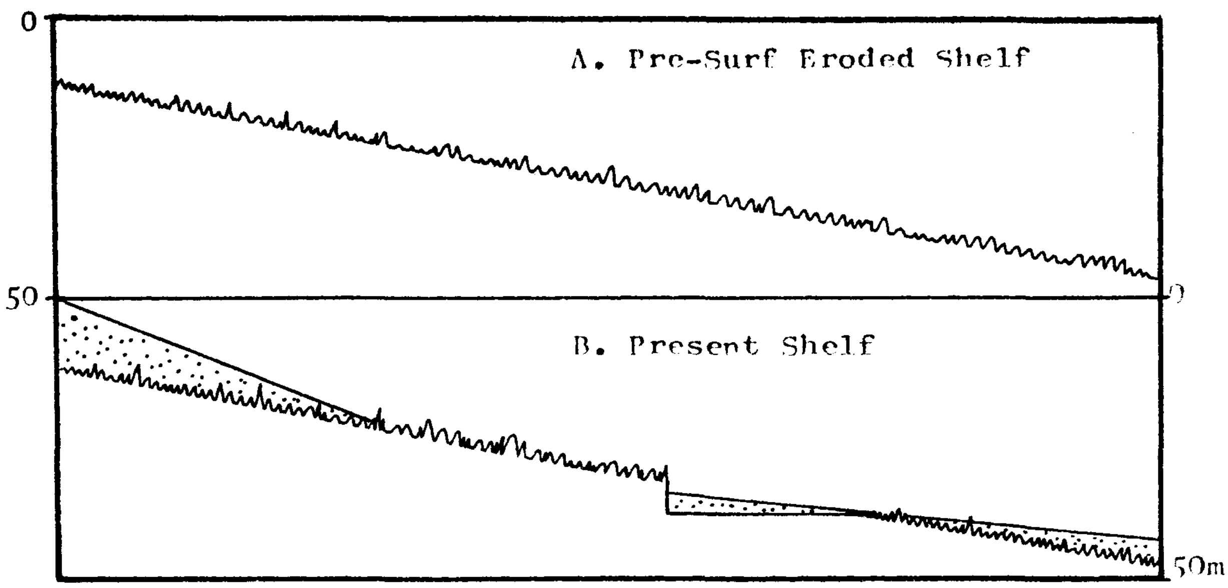
The nearshore basement topography consists of a series of relict drainage channels oriented South-East and infilled with sediment. The interfluves form headlands, that extend several kilometres offshore at North Head, Long Reef and Avalon. Each channel forms the foundation for the beach sediment systems and given an equal sediment input and basement gradient, the dimensions of the channel determine the size of the sediment body. At Palm Beach, Dee Why, Narrabeen and Curl Curl, the larger channels support the larger sediment bodies and conversely, the small sediment systems of Bungan and Whale Beaches are contained within small channels.

The Bronte and Bondi beach systems are an exception, where an extensive sand body is associated with a small channel network. Either these beaches have received a greater sediment input or the basement gradient is far steeper, or both. Sedimentological evidence is discussed in Chapter 5, however, Profiles 1 and 2 shore-normal, exhibit marked convex-upward profiles, which may indicate more abundant material. Where sediment supply has been relatively low, as along the northern beaches, deposition occurs only within the steeper, more uniform slopes of the relict channel beds. Thus, large areas of bedrock are left exposed. An examination of the bedrock gradients on Charts 1 and 2 show that there are significant differences. The bedrock gradient off North Head to 50 m depth is 1:64, whereas off Ben Buckler the slope is 1:32, that is, twice as steep. Off Long Reef the slope is 1:80 and off Avalon 1:84. Therefore, given an equal sediment supply, deposition off Bronte and Bondi is more likely to form a blanket coverage than off the northern beaches. At North Palm Beach, seismic results (Albani and Johnson, 1974) show that the bedrock gradient is very steep, in the order of 1:10 to 50 m bedrock depth due to strong channel development, and on this steep basement deposition is in the form of a sand blanket.

The overall steepening of basement to the south, along the Sydney coast may be due to lithological differences, both between the Hawkesbury and Narrabeen units and within them. An additional possibility is the existence of a large former drainage network. Evidence for this is apparent from the seismic profiles off Ben Buckler (Appendix 2) showing an extensive channel at 60-100m depth.

The bedrock bathymetry displays a number of features that indicate prolonged periods of lower sea level. Subaerial conditions are responsible for strong channel and interfluve development and rugged topography. Valleys have characteristically open-cross-profiles and graded long profiles, however, channel and interfluve development is poor below 40-50 metres depth. Given a lower base-level of ¯120 m depth, this suggests post fluvial surf erosion. Furthermore, well developed cliffs between 30 and 50 metres depth and a terrace at the cliff base, underlying the innershelf sediments (Appendix 2), supports the concept of active surf processes at these depths. Surf planation and cliffing of the valley floor would explain the separation of the inshore and offshore sand bodies at Narrabeen, Curl Curl and Dee Why. This is illustrated in Figure 4-5.

FIGURE 4-5 SHELF PLANATION



Together, these features support Galloway's (1970) concept of prolonged periods of lower sea level and a gradual transgression. Similar patterns of bathymetry have been reported in Australia by Boyd (1974) and Bosher (1975) and overseas, Hails (1975) reports relict drainage channels infilled by sediments in Start Bay, Devon. A relict cliffed shoreline is identified at 42 m depth.

The sediment bodies associated with each beach system form a continuum, comprising three modal types. First, the open sand ramps of Bronte, Bondi and Palm Beach. Second, the semi enclosed seaward-narrowing bodies of Narrabeen, Dee Why and Curl Curl beaches. Third, the enclosed sand pockets of

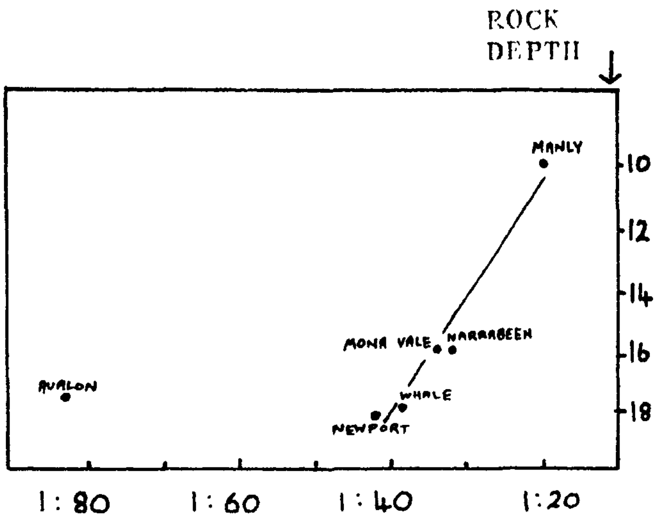
Manly, Newport, Mona Vale, Avalon, Bungan and Whale Beaches. In effect, this is a continuum of compartmentalization, where the open beaches are least partitioned and the closed beaches are strongly partitioned.

The shore-normal beach profiles range in slope from 1:20 - 1:85 to 17.5 m depth. (Table 4-1)

TABLE 4-1 SUBMARINE SLOPES

BEACH	SLOPE TO ¯17.5 m	SLOPE TO ¯30.0 m
MANLY	1:20	1:69
NARRABEEN	1:32	1:76
MONA VALE	1:34	1:92
WHALE	1:37	1:59
NEWPORT	1:42	1:66
BUNGAN	1:42	1:66
BONDI	1:49	1:57
BRONTE	1:52	1:54
CURL CURL	1:54	1:54
PALM BEACH	1:56	1:73
AVALON	1:57	1:85
DEE WHY	1:85	1:97

4-1a



The steepest slopes are associated with shallow bedrock outcrops, terminating the sand body in 17-20 metres of water. The outcrops commonly form a peak between 10 and 18 metres depth. At Manly and Narrabeen, these rock peaks rise to 10 m and 16 m, causing long period waves to shoal, and under these conditions are known as bomboras. There appears to be a positive relationship between shallow bedrock peaks and the steepness of the associated beach profile, (4-1a). Beaches associated with more extensive sand bodies exhibit lower slope between 1:42 at Bungan to 1:85 at Dee Why. The average slope is 1:56. Dee Why beach, resting on a very shallow basement has an exceptionally low gradient. Similarly, Avalon, although exhibiting a limited sand body, terminated by a shallow bedrock peak, also rests on a shallow basement. This could explain the anomalous plot in 4-1a since Avalon would be expected to have a steep beach profile congruous with Whale, Newport and Mona Vale beaches. It is necessary to note that beach profiles change rapidly and features such as bars and the overall sand slope will represent the conditions on and prior to the day of survey. Although no two beaches were surveyed on the same day, the great range in slopes and the inferred relationships to bedrock are considered pertinent.

The shore-parallel profiles show that the sand bodies associated with each beach rest upon relict drainage channels. The asymmetry of the profiles at Dee Why, Mona Vale and Bondi-Bronte is due to the asymmetric nature of the bedrock valleys. For most beaches, the sand bodies are largely symmetric, however, at Palm Beach, Whale and South Narrabeen the sediment appears to thicken to the south or to the north at Curl Curl and Bungan. This may be related to variations in energy distribution along the coast and is discussed in Chapter 6.

<u>A Model of Bathymetry for the Sydney Coast</u>: Three model types of beach sediment system have been identified in terms of sand and rock distribution and bathymetry.

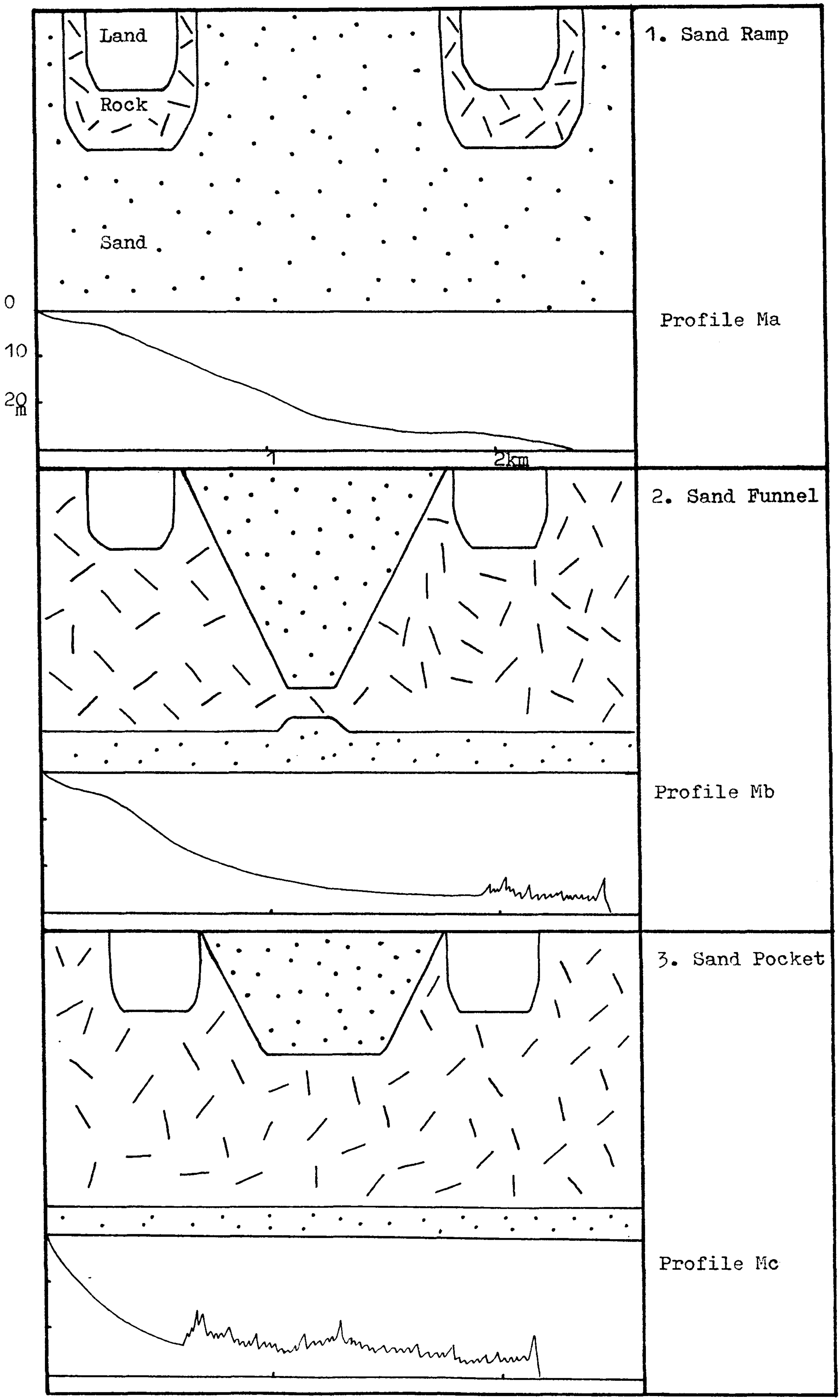
1. Open sand ramp.
2. Semi-enclosed seaward narrowing sand body or funnel.
3. Enclosed sand pocket.

Figure 4-6 outlines this model.

Profiles Ma, Mb and Mc depict the shore-normal profiles of each modal type.

Each modal type reflects the amount of sediment associated with a beach system, however, the exact seaward boundary of a beach active zone, although apparently distinguishable by bedrock in the pocket beaches, must be determined by sedimentological means.

Figure 4-6 A Model of Bathymetry for the Sydney Coast.



CHAPTER 5. SEDIMENTS: Methods of Sampling and Analysis, and Sediment Patterns.

Bathymetric surveys have shown the morphologic variation in the sediment bodies associated with each beach. However, the surface composition and seaward extent of each beach system must be assessed in terms of sediment characteristics. The pattern of nearshore sediments on many coasts records a sequence of seaward fining grain size, terminated offshore by a textural discontinuity (Emery, 1968),(Swift et al, 1971), (Nordstrom and Margolis, 1972), (Bosher, 1975), marking the seaward boundary of the active sediment zone. This pattern is a response to the hydrodynamic processes operating in the nearshore zone and is approximated theoretically by the null-point and equilibrium profile concepts. This chapter outlines the method of sediment sampling and analysis and then examines the sediment patterns. The sediment patterns are distinguished using the characteristics of mean diameter grain size, sorting skewness, carbonate content and iron staining. These characteristics are investigated on two levels. First, the pattern of sediments associated with each beach are identified, and second, the pattern of sediments are compared between beach systems in an attempt to identify gross patterns of sediment behaviour along the Sydney coast.

Sampling Methods

Sediment samples from the surface of the sea bed were taken at approximate 5 metre depth intervals, from the break-point to at least 30 metres depth, along traverses corresponding to the shore-normal sounding lines (Figure 1-2). Sampling depths between beach systems do not correspond due to differences in the tide and sea conditions on the day of survey and the degree of submerged rock outcrop along the traverse. All samples were recovered using a weighted drag bucket with an attached cloth bag capable of retaining a 500 g sample. The drag bucket was coupled to a nylon line threaded to a boom, and coiled onto a drum winch, (Plate 1). Although only one line of samples were taken for each beach, at Mona Vale, three sampling lines were made at the northern, middle and southern sections of the beach to examine the possibility of longshore variation in sediment characteristics. Additional longshore sampling lines are provided at Narrabeen by A. Short (in press). Swash and dune samples were recovered manually at points corresponding to the offshore sampling lines. Dune samples were taken only where dunes occurred at the sampling lines. The samples taken at each beach are listed in Appendix 3a.

Sediment Analysis

All textural analysis was performed using the settling tube technique. Reed et al (1975), and Bryant (1976) have demonstrated that the settling velocity of particles is a more accurate measure of sediment hydrodyhamic functions than sieving. Sieves measure particles according to minimum cross-sectional area without regard for grain density, whereas the settling tube measures the velocity of particles falling through a column of water (Reed, et al, 1975). Bryant (1975), using the Macquarie University settling tube to analyse over 3000 samples, obtained replicable results that correlated well against theoretical curves, and plots of the settling velocity of industrial glass spheres overlapped with sieved results.

The same settling tube system as used by Bryant (1976) was used for this study. The method of operation is described by Bryant (1976). Each sample is registered as a curve, representing cumulative weight distribution against time. Each sample curve is converted for computer input, and a computer programe calculates four moment measures; mean diameter grain size, sorting, skewness and kurtosis, according to Folk and Ward (1957).

Textural analysis by settling tube is still in the infant stage and although Bryant (1976) found excellent relationships between mean settling velocity, sorting and skewness and environmental conditions, the paucity of literature on the settling tube technique and its application indicates a need for more experiment. Two simple though significant problems were encountered during the operation of the settling tube for the present study. The weighting mechanism responsible for triggering the release of samples into the tube must not be permitted movement after the release, as this can set up vibration within the column, and fine material must be placed forward of the coarser particles, to facilitate total sample release.

Bryant (1976) found that settling velocity trends were unaffected by regional variations in carbonate content, particle shape and sphericity. Wave characteristics, hydrodynamic processes and sediment inputs were responsible for the variation in settling velocity parameters. For this study, the total sample distribution was used. However settling tube analysis of carbonate-free sand has been included for all samples due to the very large range in carbonate content. Carbonate content of the samples was assessed by washing a 50 g sample with dilute HCL, the sample was then rinsed with water, dried and reweighed. Sand grains were assessed for iron staining on the basis of colour, permitting the distinction of three staining levels for the samples; strongly stained, moderately stained and weakly stained. The results of all sediment analysis are tabled in Appendix 3a and 3b. All data pertaining to Narrabeen is from Short (in press).

Sediment Patterns

Mean diameter grain size, described in phi units provides the clearest textural pattern.

Figure 5-1 Mean diameter grain size in relation to datum.

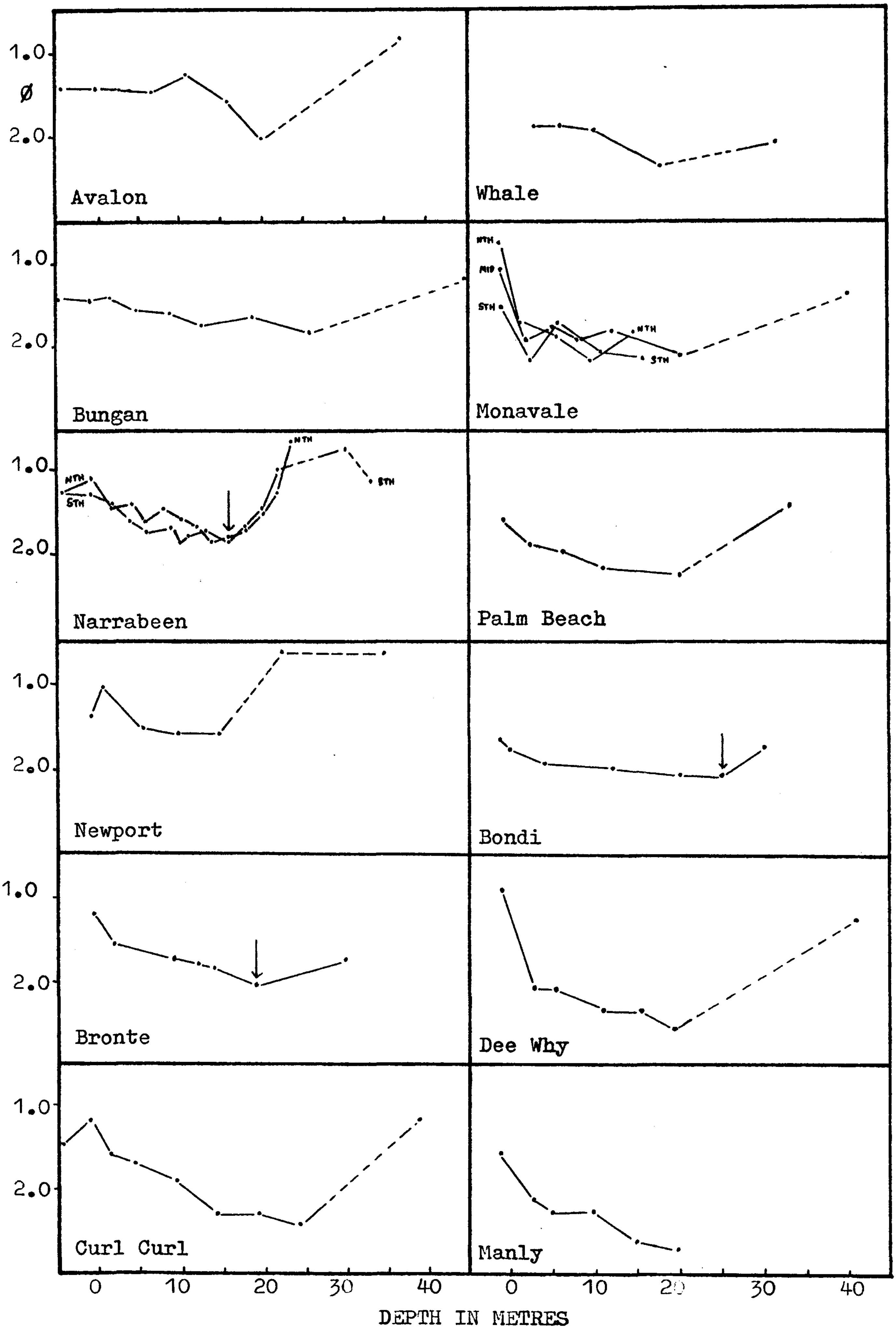


Plate 2 Photomicrograph of particles at the break point, Newport.

millimetres

Plate 3 Photomicrograph of particles at 15m depth off Newport.

Plate 4 Photomicrograph of particles at 35m depth off Newport.

Figure 5-1 shows the plot of mean diameter grain size against hydrographic datum for 12 Sydney beach systems. The material ranges in size from 0.6 phi to 2.75 phi with varying proportions of quartz and carbonate. The plots are typically u shaped indicating two coarse peaks, in the swash zone and beyond a certain depth offshore. The dune material is finer than that in the swash zone. There is clearly a trend of seaward fining grain size associated with each beach system. Beyond an inflection point marked with an arrow or rock outcrop marked by a broken line the material is significantly coarser. Thus, there are two texturally distinguishable bodies of sand along the Sydney coast; a series of seaward fining nearshore compartments and a largely continuous belt of coarse innershelf sand. This pattern is illustrated by Plates 2, 3 and 4. Plate 2 shows the coarse shell and ironstained quartz sand at the break point at Newport beach. At 15 metres depth, Plate 3, the particles are significantly finer. Plate 4 represents the coarse innershelf material at 35 metres depth, with organic fragments and iron stained quartz particles.

The null-point concept is therefore applicable to Sydney beach systems, where modern nearshore wave conditions have produced a textural gradient consistent with an expected energy gradient across the sea bed, normal to shore. However, the point of incipient sediment motion for a beach system does not comply to the null-point concept at many of the beaches due to bedrock interference. Nevertheless, the textural pattern enables identification of the seaward boundary of the near-shore zone, or active sediment zone. The seaward boundary is distinguished either by an inflection point on the grain size plots, marking a textural discontinuity or by rock outcrop. Only at three beach systems, Bondi, Bronte and Narrabeen, is the textural discontinuity manifest. The seaward boundary at the other 9 beach systems is marked by rock outcrop.

TABLE 5 -1

The depth of the seaward boundary of the active zone for each beach.

BEACH	BOUNDARY DEPTH (metres)
Avalon	20
Bungan	26
Narrabeen	14
Newport	15
Bronte	20
Curl Curl	25
Whale	17.5
Monavale	20
Palm Beach	20
Bondi	25
Dee Why	20
Manly	20

Table 5-1 summarises the depth at which the seaward limit of each beach system occurs. These range from 14 metres depth at Narrabeen to 26 metres depth at Bungan. Most commonly the boundary is located at 17-20 metres depth. Obviously the location of the seaward boundary depends to a certain degree upon the location of the sampling traverse and the sampling interval. Within sediment bodies enclosed by rock, sampling was carried out as far seaward as possible, with one sample beyond the rock outcrop, on the innershelf. On the more open sand bodies of Curl Curl, Bronte and Palm Beach, more detailed sampling between the last two locations offshore may yield inflection points slightly seaward of the present results. At Bronte, a sample at 25 metres depth is likely to yield a similar value to the adjacent 25 metre sample at Bondi. Similarly, at Palm Beach, samples taken to 28 metre depth, north of the rock ridge by the P.W.D. display seaward fining characteristics (John Hoffman, pers. comm.). For these beach systems the boundary depth accuracy is within + 5 metres depth and for the more restricted beach systems, + 2 metres depth.

The classic textural discontinuity is only apparent at Bondi, Bronte and Narrabeen, although more detailed sampling at Curl Curl and Palm Beach would probably confirm its existence at these beaches. The location of the inflection points indicates a zone of incipient sediment motion commonly around 25 metres depth. However, the inflection point at 14 metres depth at Narrabeen suggests that wave-sediment interaction mechanisms can vary considerably between beach systems. The detailed pattern at Narrabeen supplied by Short (in press), giving 2 metre sampling intervals also indicates a textural gradient coarsening offshore, seaward of the discontinuity. This trend implies some winnowing from the coarser innershelf material to the nearshore zone. This also illustrates that the seaward limit of the beach system is a zone rather than a sharp boundary, due to temporal variations in wave-sediment interaction.

At Avalon, Whale, Mona Vale, Dee Why and Manly beach systems the seaward fining textural gradient is terminated offshore by rock between 15 and 20 metres depth. Off Bungan, a weak trend of seaward fining is distinguishable to 26 metres depth, where the channel fill is interrupted by outcrop. For each of these beach systems the rock outcrop forms a barrier, in varying degrees of effectiveness between the nearshore sediments and the innershelf sediments.

Individual beach grain size plots vary in slope, to a certain extent, as a result of temporary stages in beach morphodynamics, since the beach systems were sampled over a period of 15 months. Many of the beach systems display a secondary inflection point, commonly between 10 and 15 metres depth, such as at Avalon, which suggests a relationship with the higher energy inner nearshore morphodynamics described by Short (1978). A comparison between the Avalon grain size plot and the shore-normal profile (Profile 10) shows the coarse peak in grain size at 10 metres depth corresponds to the offshore bar at 10 metres depth. This supports the contention that coarse berm and swash material move offshore to form a bar under certain conditions. The occurence of this secondary inflection point on many of the beach systems suggests that the nearshore active sediment zone comprises two zones. A high energy very mobile inner-nearshore zone to 10-15 metres depth, and a lower energy less mobile outer-nearshore zone, beyond 10-15 metres depth, where sediment interaction is in quasi-equilibrium, between periodic high energy storm events. A division at similar depths has been recognised for the nearshore zone off the northern N.S.W. coast, even though the Northern N.S.W. beaches are subject to different sediment transport conditions (P.W.D. 1978). Cheng (1979) has distinguished outer and inner nearshore catagories for beach sands at Newcastle on the basis of surface texture, using the electron microscope technique.

Secondary inflection points associated with nearshore processes cannot account for the overall variation in nearshore textural gradients for each beach system. Within a beach system these range from ø 1.46 - ø 1.87 between the break point and the boundary zone at Bungan to ø 1.63 - ø 2.48 at Curl Curl. Even where textural gradient slopes are similar between beach systems, such as at Manly and Curl Curl, the overall grain sizes differ considerably. Measured at the break point, the mean grain size ranges from coarse ø 1.07 at Newport to fine ø 2.16 at Manly. This range is illustrated by the photomicrograph (Plate 5) of particles at the break point at Manly, which clearly contrasts in size with the particles at the break point at Newport (Plate 2) and at Bronte (Plate 6). In fact, the material at 15 metres depth at Newport (Plate 3) is coarser than that at the break point at Manly. Table 5-2 shows the range in grain size for all beaches at the break point and the average size of the particles between the break point and the boundary zone. There is a fairly uniform spread of particle sizes from coarse to medium and it is significant that a very similar order occurs for the material between the break point and the boundary zone. This not only indicates that the break point is a very good measure of the overall grain size distribution of a beach system, but that each beach system is strongly individual in its grain size characteristics, suggesting negligible longshore transport of sediment along the coast.

It might be possible that differences in grain size between beaches is due to the sampling location rather than the sediment supply or wave energy distribution. Two wide beach systems, Mona Vale and Narrabeen have been sampled and analysed at intervals alongshore to assess this possibility. At Mona Vale, the grain size plots for the three traverses are remarkably similar, with the largest differences occurring

Plate 5 Photomicrograph of particles at the break point, Manly.

millimetres

Plate 6 Photomicrograph of particles at the break point, Bronte.

TABLE 5 - 2

Mean diameter grain size at the break point.

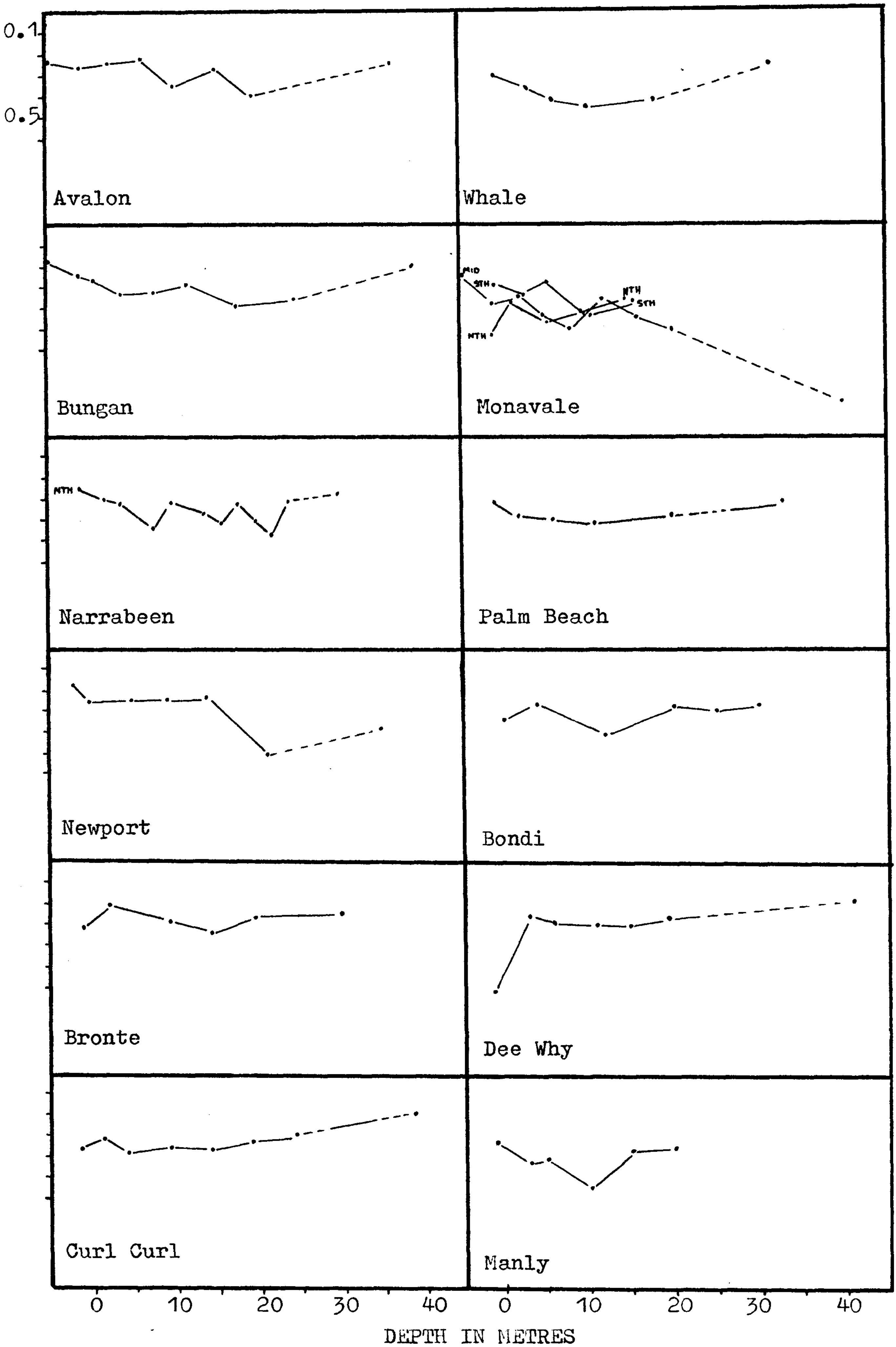
Mean diameter grain size across the nearshore.

BEACH	BREAK POINT ø	ACROSS THE NEARSHORE ø
Newport	1.07	1.44
Narrabeen (south)	1.35	
Narrabeen (north)	1.40	1.55
Bungan	1.46	1.66
Avalon	1.48	1.56
Bronte	1.60	1.83
Curl Curl	1.63	2.00
Bondi	1.79	1.96
Monavale (north)	1.84	
Palm Beach	1.86	2.05
Whale	1.88	2.05
Monavale (mid)	1.96	1.91
Dee Why	2.11	2.34
Manly	2.16	2.43
Monavale (south)	2.22	

between the break point and the fore dune. Table 5-2 shows that the grain sizes at the break point at the three locations do overlap with four other beaches, indicating a trend of coarsening from South to North. At Narrabeen, where longshore grain size gradients may be expected to be large, little difference is evident between samples at the northern and southern sectors of the beach. In fact the Narrabeen break point grain sizes do not overlap with any other beaches. Although long shore grain size gradients are to be expected for the beaches, the results from Mona Vale and Narrabeen clearly indicate that long shore gradients alone cannot account for the wide range in grain sizes between beach systems. Furthermore, temporal differences in grain size, caused by the 15 month duration of the sampling period cannot be responsible for the magnitude of variation, unless there is an active supply of sediment to the beach systems. Thus, two mechanisms could account for the pattern of sediments; an active supply of beachable material and/or preferential sorting by waves.

In Chapter 2 it was concluded that there is negligible material being added to the beach systems with the exception of carbonate, although these conclusions were based largely upon observation, rather than quantative data. If a significant supply of sediment is presently being added to the beach systems, and such material is reasonably diverse in grain size, then its presence will be made apparent by the measure of sorting. Figure 5-2 gives the plot of sorting against hydrographic datum, showing a 'u' shaped trend similar to grain size. A peak of better sorting occurs at the dunes, the break point and at the inntershelf. The fact that the innershelf material is very well sorted suggests that these sediments have been worked under high energy conditions, similar to the present nearshore environment and supports the argument of Emery (1968), Swift et al (1971), Nordstrom and Margolis (1972) and Boyd (1974), that the coarse material lying seaward of the nearshore size

Figure 5-2 Sorting in relation to datum.

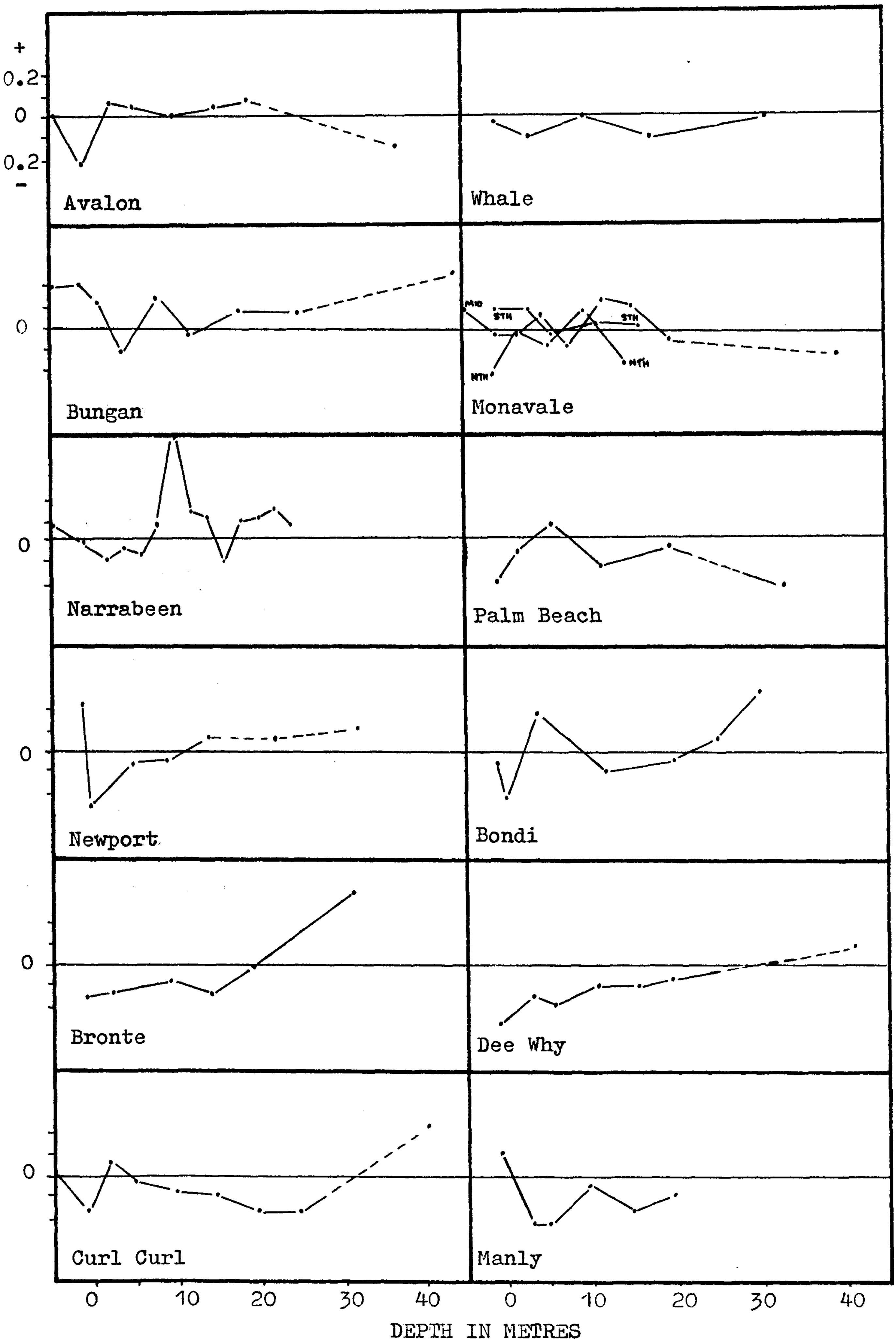


graded sequence is relict beach sand that has been left behind by a transgression of the sea.

Beyond the break point, sorting decreases with depth, however the inflection points of poorer sorting are shoreward of the boundary zone. This may indicate a mixing of outer and inner nearshore populations, commonly at 8-12 m depth. However, this trend may also be due to the sorting grain size relationship where finer sand is usually better sorted (King 1972). Variations in carbonate content influence the sorting pattern by dampening or amplifying the trends. In spite of the differences in relative sorting measures for the beach systems, clearly the values occur almost entirely between 0.15 and 0.5, indicating very well to well sorted sediments. In fact for over 100 samples analysed, only four were moderately well sorted (0.50-1.00).

A parameter more sensitive to low volume sediment inputs is skewness, which is geometrically independent of sorting and measures the symmetry of sample distribution. Negative skewness ($^{-}$.10 - $^{-}$1.00) indicates an excess of coarser material in the 'tail' of the curve, and positive skewness ($^{+}$.10 - $^{+}$1.00) indicates a tail of fines. The plots of skewness against hydrographic datum in Figure 5-3, show that the major inputs are additions of fines to the innershelf coarse mode, producing strong positive skewness. Since the material is very well sorted, the volume of material must be small, probably $< 5\%$. Nevertheless, deposition of such material implies very low energy conditions. At Palm Beach, both the innershelf and swash material is negatively skewed, suggesting a small input of a coarser secondary mode, probably related to the Hawkesbury River. Some samples are skewed as a result of biogenic input, such as at Bungan and Dee Why Beach systems (Appendix 3b). However, in general, dunes are positively skewed due to the removal of a coarse fraction during deflation and the swash and

Figure 5-3 Skewness in relation to datum.

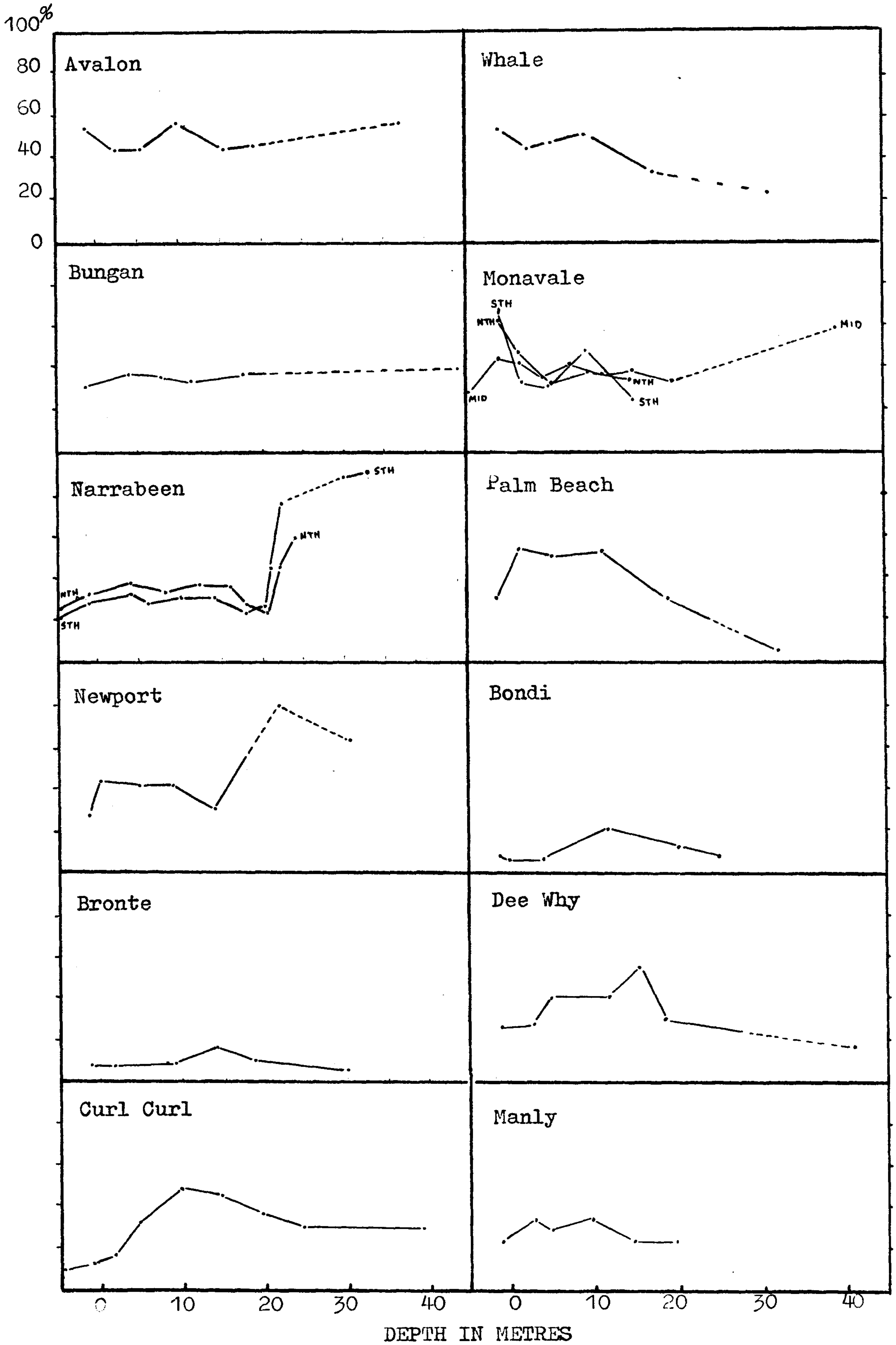


nearshore material is either symmetrical or trending towards negative skewness, since wave energy tends to remove the fines. Negative skewness, unrelated to carbonate content, occurs at the break-point at Bondi, Newport and across the nearshore zone at Manly, suggesting small additions of a coarse secondary mode to Bondi and Manly. At Newport, the extremely coarse primary mode suggests negative skewness by the removal of fines.

It can be concluded, that the only material diverse enough to cause the wide range in grain sizes between beach systems is being supplied to the sediment bodies in extremely small volumes, and even then, largely to the innershelf. Therefore, the distribution of grain sizes along the coast must be a result of preferential sorting by waves. The preceding textural interpretation, does not however, preclude a significant input of very well sorted material with a primary mode similar to the present beach material, since such an input is texturally indetectable.

Mean diameter grain size, sorting and skewness are all influenced to a certain degree by the carbonate content of the sands. Generally, carbonate content increases the grain size, decreases the sorting and produces negative skewness, due both to biogenic production within the sediments and differences in hydrodynamic responses. However, the pattern of sediment characteristics is not altered, even though the carbonate content is remarkably high. At the break points the average concentration is 32%, which supports the argument of Chave (1967), that shallow water carbonate rich sediments are not restricted to low latitudes. Unexpectedly, carbonate content does not simply increase with depth. Figure 5-4, showing the plot of carbonate content against hydrographic datum exhibits a common peak at 10-15 metres, the concentration may

Figure 5-4 Carbonate content in relation to datum.



then level off or decrease as at Curl Curl and Palm Beach. On the innershelf off Narrabeen, Avalon, Newport and Mona Vale, carbonate increases to at least 60%. On the basis of carbonate content, two catagories are apparent; nearshore sediments North of Port Jackson contain high levels, in the order of 36-% and those to the South, Bondi and Bronte, have very low levels, in the order of 10%. An intermediate zone is discernible, where several samples at Manly, Curl Curl, Dee Why and Narrabeen, have carbonate levels in the order of 10-25%.

Clearly, the biogenic input is a most important source of beach material, on a coast that is characteristically deficient in sediment supply. Indeed, in the majority of Sydney beach systems quartz detritus comprises little more than half by weight of the available sediment. Thus, since carbonate is a major component of most beach systems, its relative absence is significant at Bondi and Bronte in terms of the sediment budget. This poses the problem: are the Bondi-Bronte systems deficient in carbonate production relative to other beach systems, or is there a greater supply of quartz sand?

There are two factors responsible for the distribution of carbonate in sediments; habitat and wave energy. The most common type of carbonate in the Sydney offshore sediments are bivalves, gastropods, bryzoans, foraminiferan, echinoid stems and sponge spicules approximately in that order of abundance. Marshall and Davies (1978) sampling the shelf off Sydney, found concentrations of molluscs - 35-50%, bryzoans - 20-40% and foraminiferan - 30%. Similar concentrations are reported by Caldwell and Connell (1976) for the M.W.S. & D.B. Samples analysed for the present study indicate a dominance of molluscs in the nearshore zone, that are adapted to sandy habitats, and are thus not dependent upon the extensive submerged rock outcrops, characteristic of the bathymetry north of Port Jackson. Underwater observations indicate low levels of carbonate growth on these reefs. (A. Short, pers. comm.). The bulk of the carbonate production therefore, occurs within the sand bodies. Some differences in carbonate content across a beach system are due to preferential concentration by wave energy. This is probably responsible for the peak in concentration at 10-15 metres depth, rather than high production, since the particles are usually broken and well worn. However, there is not a sufficient energy differential between Bondi-Bronte and the other beach systems to cause the reported carbonate variation. This is substantiated quantatively in Chapter 6. It is concluded that the gross carbonate variation cannot be due to the presence or absence of growth inhibiting factors or energy differentials. This tends to support the observations of Chave (1967), that carbonate rich sediment will form anywhere in shallow water where terrigenous clastics do not dilute them.

It has been previously pointed out that the only material that could be entering the beach systems, must be very well sorted beach or dune sediments. At Bondi-Bronte, two sources are evident; relict sediments from the innershelf and dune sediments that underly much of the Eastern Suburbs. Although some material may be winnowed from the innershelf, the inflection points are not anomalous and further, it is difficult to envisage the mechanism responsible, being more efficient at Bondi-Bronte beach systems, than at Curl Curl, Narrabeen and Palm Beach. In contrast, extensive Pleistocene dune sands comprise much of the catchments of the Eastern Suburbs beach systems. Dune sands are characteristically low in shell content and the Pleistocene dunes particulary, are stripped of iron staining. Casual observation of the Eastern Suburbs beaches indicates white sands, in contrast to the yellow sands north of Port Jackson. The photomicrograph (Plate 6) of particles taken from the break point at Bronte, bears this out. The grains display weak or no iron staining and contrast markedly to those quartz grains at Newport (Plates 2 and 3). Examination of all the particles in the nearshore zone at the Bondi-Bronte beach systems show weak or no iron-staining, and moderate staining on the innershelf particles (Appendix 3a).

The abundance of particles in the nearshore zone of the Bronte- Bondi beach systems that are stripped of iron-staining suggest an input of dune sand from the surrounding catchment. A similar process has probably occurred at Maroubra and Coogee Beaches. This implies that 26% of sand by weight, in the nearshore zone at Bondi-Bronte has been supplied by dunes, based on the differences in carbonate content between the beach systems, North and South of Port Jackson.

Examination of iron-staining of all the samples (Appendix 3a) shows that not all the sediments in the northern beach systems are strongly iron-stained; in fact, there is a trend towards weaker staining at Dee Why, Curl Curl and Manly Beaches. Correlation with carbonate values at these beach systems suggests a possible input of dune sands to these beaches.

To conclude, the Bondi-Bronte beach systems and most likely, adjacent beach systems, have received Pleistocene dune sands from associated catchments. A smaller scale phenomenon may be operating at Manly, Dee Why, Curl Curl and possibly Narrabeen. However, it is beyond the scope of this study to investigate these implications further. Detailed sampling and carbonate analysis, and quantative data on iron staining concentrations may provide useful results in regard to Sydney beach budgets.

A Model of Sediment Patterns for the Sydney Coast

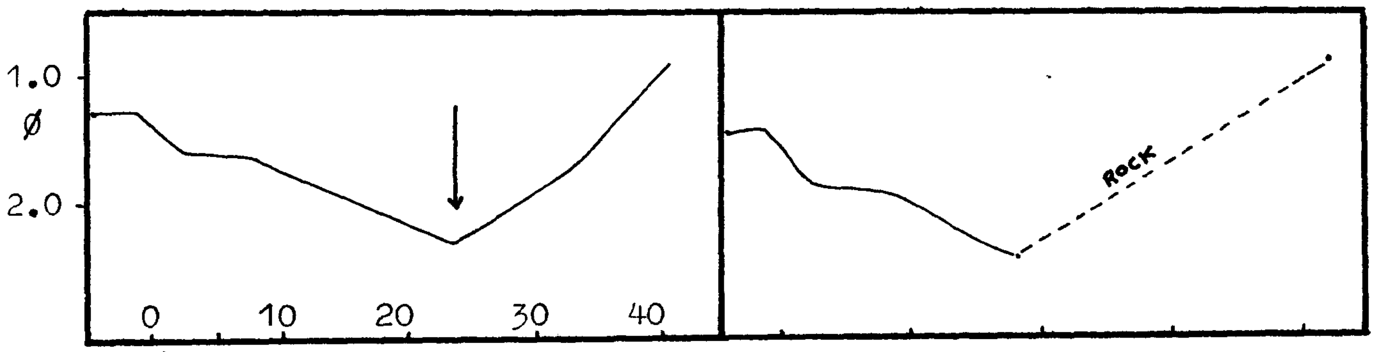
Figure 5.5 provides a model summary of the sediment patterns for the Sydney coast. Two texturally distinct sediment bodies have been identified. A nearshore body of material, comprising the beach system and an innershelf body. A pattern of seaward fining grain size marks all beach systems, with the seaward boundary zone marked either by a textural discontinuity, type A, or a rock outcrop, type B. The seaward boundary zone is most commonly oper ative between 18 and 25 metres depth. Onshore movement of innershelf material is unlikely at most of the beach systems due to the presence of a rock barrier. On the ramp and funnel beaches, some material may be winnowed from the innershelf, and there is evidence for this at Narrabeen. Grain sizes vary widely within a beach system and between beach systems in response to temporal and spatial variations in wave energy. Longshore grain size variations in a beach system may be expected to coarsen from South to North. The strongly individual grain sizes for each beach system indicate negligible transport of material along the coast.

The sediments are very well to well sorted, confirming the role of wave energy in preferentially distributing material in the nearshore zone and supporting the contention that negligible diverse sized material is being actively supplied. The very well sorted nature of the innershelf material suggests former equilibrium with nearshore hydrodynamics.

The overall carbonate content of the sediments is high, 30-40%, though this has little effect upon the textural patterns. Two major zones of carbonate concentration are distinguished. North of Port Jackson, high level carbonate, in the order of 30-40% in the nearshore zone, illustrated by type A. Type B displays the low carbonate characteristics

Figure 5-5

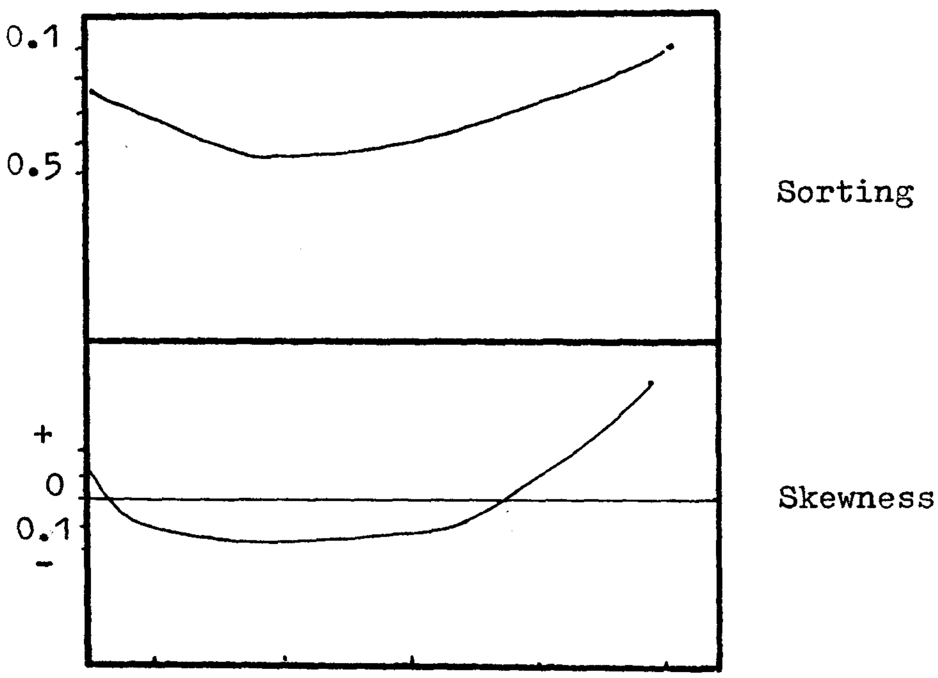
A Model of Sediment Patterns for the Sydney Coast.

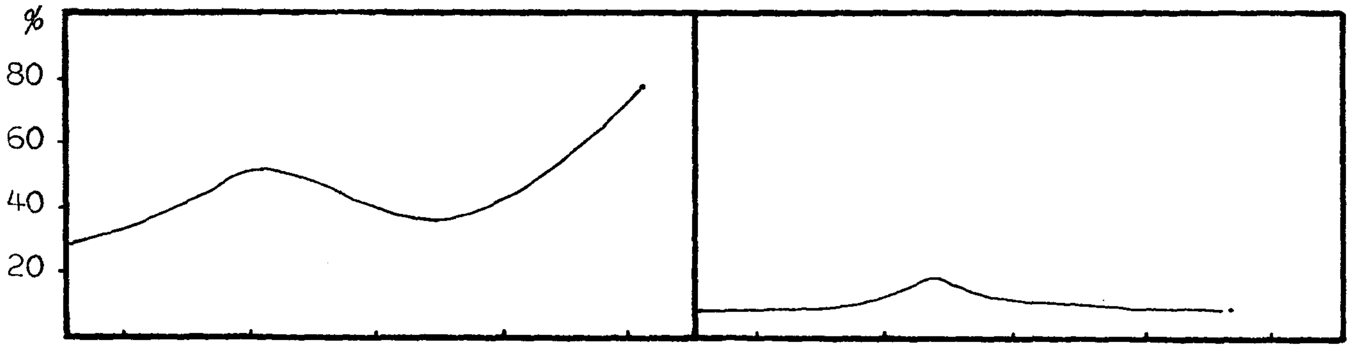


Depth m.

Mean Diameter Grain Size

A. Textural Boundary. B. Rock Boundary.





Carbonate Content

A. High. B. Low.

of the Bondi-Bronte beach systems, in the order of 10%. The Bondi-Bronte beach systems have been supplied by dune sand, characterised by a lack of iron-staining, which has diluted the carbonate content of these sand bodies.