ESTUARINE SEDIMENT REGIMES

FAR SOUTH COAST

N.S.W.

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HIGHER DEGREE THESIS (PhD)

AUTHOR'S CONSENT

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The Academic Senate on 12 December 1979 resolved that the candidate had satisfied requirements for admission to this degree. This thesis represents a major part of the prescribed program of study.

CERTIFICATE OF ORIGINALITY

The work presented in this thesis has not been submitted elsewhere for a higher degree, and is my own work, except where otherwise acknowledged.

R.W. Kidd

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DEDICATION

This dissertation is dedicated to my wife Liz,
my parents and my trusty VeeDub; without their
help and support it would not have been possible.

Let the downpour roil and toil!
The worst it can do to me
Is carry some garden soil
A little nearer the sea.

. ... Robert Frost

SUMMARY

This dissertation presents the results of an integrated regional study of sediment exchanges between land and sea along a relatively unspoiled section of coastline in southern N.S.W. The regional climate is a temperate one with no seasonal moisture deficiency, while the shoreline is subject to a microtidal, high energy swell regime. Grainsize distribution, quartz roundness and sand mineralogy of sediments collected from fourteen rivers, their estuaries and the impounding barrier sands are analysed in order to determine the source(s) of local coastal sands. The factors and processes which control sediment distribution patterns in the three environments are also considered.

Comparatively angular, poorly sorted river sands and gravels with significant proportions of non-quartz minerals are deposited at the heads of smaller estuaries as deltas. River mud accumulates on estuary floors as prodelta deposits or is flushed through the system and dispersed at sea. Estuary basin floors have been partly buried by landward prograding flood tide deltas whose sands are derived from the rounded, well sorted, predominantly quartzose sands which dominate most of the coastal embayments. Four estuaries have been infilled to the extent that terrigenous sands now travel through them to the sea. At two localities, advanced infilling reflects the dominance of fluvial activity, at another two, flood tide currents have performed the same role.

Rates of terrigenous infilling are explained mainly by runoff and lithological characteristics of the drainage basins. Maximum infilling has occurred where large rivers drain granite catchments. Rates of infilling from seawards are greatest where inlet closure is least likely, a situation favoured by large tidal prisms, persistent stream flow and lower levels of incident wave power.

In essence, most of the estuaries are sediment traps for both terrigenous and marine sands at the present time. Delivery of sand to the beaches from the continental shelf appears to have ceased; headland erosion is an unimportant source. Carbonate sands are a minor component of the coastal sediments. As estuary infilling nears completion, the potential for delivery of terrigenous sand to the sea by coastal rivers may be realised.

CHAPTER ONE: INTRODUCTION

Rapidly increasing commercial and recreational demands upon the resources of the coastal zone are now provoking intense investigation of this region in Australia. One important aspect of the overall problem concerns the transfer of sediment between the coastal rivers, the sea and the intervening estuaries, and the manifestation of these exchanges in the landscape. Such exchanges may be regarded as losses or gains to a coastal sediment store and the balance between them is indicated either by recession, progradation or positional stability of the shoreline. Sediment may be gained via longshore transport from adjoining shores, onshore transport from the continental shelf, erosion of rock shores, erosion of the hinterland and via biological activity within the store itself. Sediment may also be lost via longshore and offshore transport, deflation and via estuary infilling. To date, scientific investigations have been confined to individual exchanges like these and, as far as the author is aware, no-one in this country has yet conducted an integrated regional programme which documents and interprets sediment exchanges and their geomorphological expression as inter-related elements of a larger coastal sediment exchange system. This study attempts to do so for a comparatively undeveloped area of southern New South Wales.

1.1 Regional Setting

The southeastern continental margin of Australia comprises a narrow, often discontinuous coastal plain at the foot of the Eastern Highlands and is dissected by numerous rivers and streams which are estuarine in their lower reaches. Most of the estuaries are at least partially impounded by sand barrier beaches which are recessed between often extensive tracts of cliffed rocky coast. The shoreline is a high wave energy, microtidal environment and it is fronted by a narrow and relatively steep continental shelf.

During the last glacial(s) the coastal rivers deeply incised their valleys in response to the lowered base level, and probably delivered considerable volumes of terrigenous sediment to the continental shelf. Recent geophysical investigations for example, have confirmed the existence of relic river channels cut in bedrock up to 137 metres below present sea level (Albani, Carter and Johnson, 1973; Albani and Johnson, 1974). The postglacial rise in sea level between c 17000 years B.P. and c 6000 years B.P. prompted barrier regression across the continental shelf and alluviation of the drowned coastal river valleys. Stratigraphic investigations together with radiometric dating of many coastal sand deposits have demonstrated that the sea attained its present level around 6000 B.P. and that it has not changed appreciably since then (Hails, 1965; Thom <u>et al</u>., 1969; Gill and Hopley, 1972; Thom <u>et al</u>., 1972; Thom and Chappell, 1975). Progradation of the existing barriers appears to have commenced around 6000 B.P. and ceased around 4000 B.P., while valley alluviation has continued at varying rates till the present day (Langford-Smith and Thom, 1969; Thom, 1974).

1.2 Selection of the Study Area

The specific area selected for investigation (see figure 1) is part of the Far South Coast region of N.S.W. Within its boundaries there are fourteen barrier beaches ranging in length from 500 metres to nearly four kilometres, and which impound streams draining catchments that range in size from 10 to 1900 square kilometres. The region is essially a rural one featuring dairying, crOpping, timber felling and fishing as the main commercial activities, and it also draws considerable revenue from tourists during vacation periods. There are a number of particular advantages in selecting this area.

i) Very little research has been conducted there, and the few studies that are available indicate that more intensive investi-

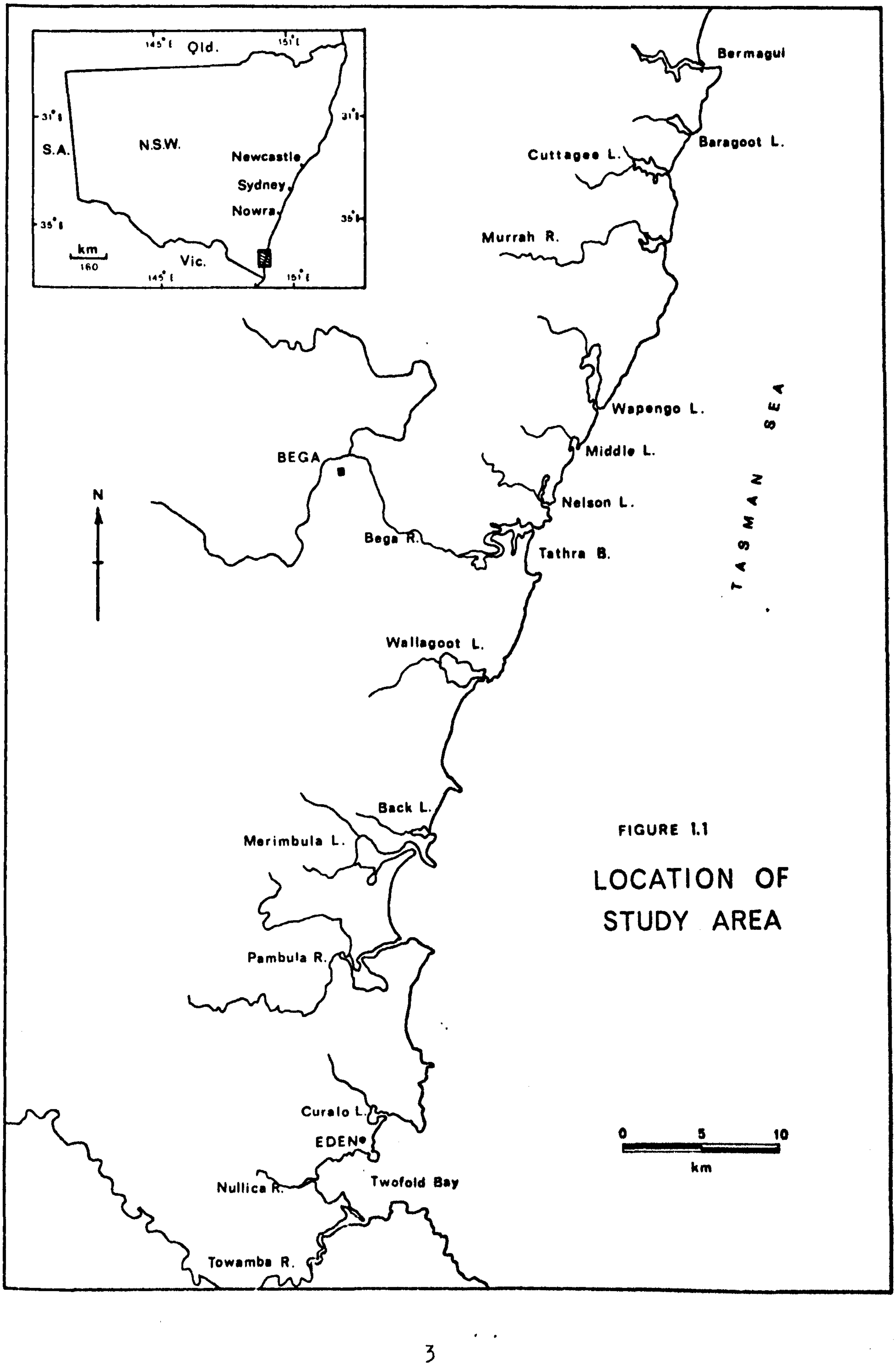


FIGURE 1.1

LOCATION OF STUDY AREA

gations would be fruitful.

ii) Although there is a basic regional uniformity, there is also considerable local variability among the fourteen river-estuary-beach systems in the area. This not only facilitates development of a regional model, it also permits comparative evaluation of individual attributes.

iii) The region has not been substantially modified by Man. None of the beaches have been mined and there are no training walls, breakwaters, major dams or causeways; bridges are few and clearing of vegetation has been confined mainly to the floodplains. Gravel extraction has reduced the bed load available for transport in the Pambula and Towamba rivers, and at some localities oyster leases may have encouraged minor sedimentation.

iv) It provides one of the last opportunities in N.S.W. to investigate essentially natural systems. Accordingly, the results should not only fulfil the nominated scientific objectives, but may also provide a basis for responsible resource management in future years.

1.3 Previous Work

Some of the component sediment exchanges within the coastal system were apparent to the first settlers in the district but actual investigations of them are few in number and most post-date 1960. The existence of numerous estuaries along this coast was first established in 1797 by Surgeon George Bass, who with six oarsmen, rowed a whaleboat south of Sydney to chart Bass Strait and to explore the southern coastal regions of the new colony. Amongst other things Bass recognized the impounded character of many of the estuaries and appropriately named one of them Barmouth Creek (this was probably the mouth of the Bega River - Bowden, 1952). After hearing reports of Bass' journey, settlers from "older" centres further inland moved to the south coast where they began to extract timber from the native forests and to establish huge pastoral leases. By the mid 1800s a coastal shipping trade was flourishing and the estuaries had become important routes by which produce was transported to ocean-side wharves from the preferred areas of settlement in the river valleys (Bermagui School Centenary Committee, 1976; Ferguson, 1974; Jeans, 1972; Wellings, undated). The river mouth bars posed considerable risks to vessels attempting to cross them and eventually they attracted the interest of engineers. Shellshear (1884) postulated that the bars were formed when sand was transported into the estuaries by flood tides after initial disturbance by waves breaking in the shallow nearshore waters. After deposition in calmer estuarine waters, the sand was effectively trapped because its remobilization by ebb tide currents was impossible without prior agitation by waves. Shellshear also noted the importance of exposure in as much as bars were better developed in inlets that were more exposed to wave activity.

Halligan (1906, 1911) discusses coastal sediment transport in general and its effects on "bar harbours" in particular. As a hydrographer he was familar with the southward moving East Australian ocean Current and he suggested that it was deflected whenever it encountered a large headland, thus producing northward flowing counter currents which were responsible for moving beach sediments northwards. Although this model was not at all well received by his audience, many of his field observations were not disputed. For example, he noted that sand at the river mouths exhibited a greater affinity with the clean, rounded quartz sand of adjoining ocean beaches, than with the alluvium upstream, and he emphasized the role of flood tide currents in moving this sediment into the estuaries. He also noted that rivers only transported small amounts of sediment during floods and that most of this load was trapped within the estuaries.

Ford (1963) reiterated Halligan's comments about the textural differences between the fluvial and marine sands, but it was Hails (1967, 1969, 1969a) and Bird (1967) who undertook the first detailed study of coastal sediments in the area. Both identified the typical marine sand found on most of the ocean beaches as being medium sized, moderately well sorted, subrounded and essentially quartzose in character. Bird also recorded low (<5%) feldspar levels and ironstaining of many of the quartz grains, and supported Hails' conclusion that these sands had been transported landwards from the continental shelf where they had been extensively reworked during fluctuations in sea level. Bird also noted the absence of similar quartzose material on the shelf at the present time (Shirley, 1964; see also Chapter 3) and concluded that delivery of this sand had ceased. Thom (1974) considered that cessation of barrier progradation around 4000 B.P. was probably closely related to diminution of this offshore sediment supply.

Ford, Hails, Bird, Post (1973) and Roy and Peat (1975, 1976) agree, on the basis of sedimentological and morphological evidence, that much of the marine sand has been directed into the estuaries to form reverse tidal deltas or thresholds which advance slowly landward over the muddy floors of the deeper estuarine basins, in the manner suggested by Shellshear. Moreover, river sands and gravels terminate as small deltaic deposits on the landward margin of these basins, and only part of the suspended load escapes to the sea during floods.

A few exceptions to this general pattern of sedimentation do occur. Hails drew attention to the coarse, angular character of Whale Beach sands in Twofold Bay, and noting their similarity to river sands further upstream, concluded that fluvial sands were being delivered to the nearshore zone by the Towamba River during floods, and subsequently redeposited on Whale Beach by wave action. Hails seemed unsure though of what was happening elsewhere in Twofold Bay. At one stage (1967, p 1064) he suggests that Boydtown and Aslings beach sands are in part similarly derived but later (p 1066) suggests that this is not the case and that marine sands are being transported into the estuaries instead.

Bird (1967) independently noted the coarseness and angularity of Whale Beach sands but also recorded a high proportion of feldspar in them (25%). This, together with the advanced stage of infilling reached in the Towamba estuary (Kiah Inlet) led him to support Hails' conclusion that this river was supplying sand to the coast at the present time. Observing similar degrees of infilling in the Shoalhaven, Moruya and Bega estuaries, Bird suggested that these rivers were also delivering sand to the coast, but he offered no sedimentological evidence to support this assertion. Wright (1967, 1970) observed that longshore trends of mean grainsize and sorting along Seven Mile Beach in Shoalhaven Bight were inconsistent with the longshore distribution of wave energy and argued that the anomaly could be explained satisfactorily in terms of contemporary additions of fluvial sand to this beach after floods.

Longshore sediment transport appears to be a small scale, bidirectional phenomenon confined to individual embayments. Ford (1963) recorded that such transport changed direction in response to changes in the direction of approach of the incident waves. Bird (1967) also observed this pattern and noted that there was no morphological evidence to support the notion of nett sediment drift in either direction. By implication he suggested that each embayment represents a discrete sediment compartment. Within Twofold Bay, Hails observed substantial sedimentological differences between the sands of neighbouring beaches and concluded that little if any sediment was transported around intervening headlands.

Both Hails and Bird have argued that cliff and headland erosion is an insignificant source of beach sediment and cite the huge volumes and the textural maturity of the beach sands as supporting evidence. The marked absence of well developed shore platforms in all but the weakest rocks outcropping along the coast between Bermagui and Twofold Bay also supports this assertion (Bird and Dent, 1966).

Integration of all the foregoing evidence reveals an overall picture of sediment exchanges on the N.S.W. south coast which conforms in large part with a recently devised model (Davies, 1974) wherein changes in sediment budgets are related to fluctuations of sea level. Following the postglacial sea level rise, sediment appears to have been transported landwards to form barrier beaches which at least partially impounded the drowned river valleys and coastal lowlands (phase 2 of Davies' model). Since then, onshore transport has probably ceased and the coastal rivers have filled the estuarine sediment traps at varying rates according to their discharge, catchment lithology and the initial volume of their drowned valleys (Bird, 1967; Jennings and Bird, 1967). At most localities, estuary infilling by fluvial and marine sands is continuing slowly but the beach sediments are not being replenished via rivers, headland erosion or littoral drift. Losses due to deflation appear to be negligible. The lack of supply, coupled with losses via inlet filling suggest a deficit in the sediment budgets at these localities (phase 3) but given the absence of a sustained pattern of shoreline recession it seems more likely that losses to the estuaries are small and that the sediment budgets are more or less balanced. In a few exceptional cases estuary infilling is nearing completion and the rivers appear to be delivering new supplies of sand to the coast. At these localities neither sustained shoreline recession nor progradation is evident and the sediment budgets are also probably balanced with a slight possibility of a small surplus (phase 4).

In toto, this generalized pattern of coastal sediment exchange appears to make sense although it differs from the one that appears to operate on the north coast of N.S.W. where sediment budgets exhibit sand deficits in the form of sandy shorelines which are experiencing continued recession, a phenomenon which has persisted for much of this century (for example see Langford-Smith and Thom, 1969; Thom, 1974; Roy and Crawford, 1977). On the south coast, persistent shoreline erosion is not apparent from historical records and field observations, and beach monitoring programmes have only recently been established (for example see Thom et al., 1973; McLean and Thom, 1975). At the specific level too, many problems await resolution. Very little is known about some components of the system such as rates of littoral drift and estuary infilling, and much of the evidence about other components is equivocal (for example, the delivery of fluvial sand to the coast at present). Thom (1972, 1974) and Foster (1974) have emphasized the need to resolve such problems and urge that the various components of the coastal sediment system be investigated thoroughly. Similarly oriented studies have often been conducted overseas (for example Chamberlain, 1968; Pierce, 1969; Bowen and Inman, 1966; Stapor, 1971, 1973) but should be especially useful in southeastern Australia where numerous but rapidly diminishing opportunities for responsible coastal planning are still available.

1.4 Objectives and Method of Approach

The specific objectives of this dissertation are fourfold.

i) To establish the source(s) of coastal sediments and the relative importance of each, particularly the role of rivers as contributors of sand to the coast.

ii) To establish the patterns of sedimentation within the estuaries and on adjacent ocean beaches.

iii) To investigate some of the factors and processes responsible for (i) and (ii) above.

iv) To assess the geomorphological manifestation of these interactions in the landscape.

To achieve these objectives, attention was directed firstly toward establishing the characteristics of the sediments in each of the fourteen selected river-estuary-beach systems. Fluvial sediments and the relationship with their respective catchment lithologies are examined in Chapter 2 and are followed by consideration of the beach sediments and their likely origins. In Chapter 4, discussion focusses upon the sediments found within the estuaries, at which point the overall pattern of coastal sedimentation becomes apparent. In following chapters, the factors and processes which are responsible for the mobilization and distribution of the sediments are discussed, as are the landforms which have resulted from such activity. Again the fluvial, marine and estuarine environments are considered in turn. Finally all the strands are drawn together, the model is placed in a wider geographic perspective, and the implications of the study are assessed.

CHAPTER TWO ORIGIN AND NATURE OF THE RIVER SEDIMENTS

This chapter seeks to establish a set of parameters which best characterize the sediment available for transport to the sea by local coastal streams. The original source of the sediment is of fundamental importance and therefore the regional and local geology is used as a starting point for discussion. Although mass wasting and fluvial processes operating within the catchments also affect many of the sedimentological parameters, it is not intended to explore these interactions in depth. To do so using a few samples from a small number of streams would be futile, and in terms of the thesis' objectives, largely irrelevant. Rather it is intended to establish a set of characteristics to which reference may be made in subsequent chapters which assess the likelihood of these fluvial sediments reaching the beaches and the intervening estuaries and lagoons.

2.1 Regional Geology

The southern coastal belt of New South Wales between Batemans Bay and the Victorian border lies within the southeastern zone ofthe Southern Highlands Fold Belt. Structurally it is part of the Lachlan Geosyncline and as such has become progressively more stable after four major orogenic movements during the Paleozoic (Packham, 1969; Scheibner, 1972).

Ordovician flysch sediments form a basement which has been repeatedly deformed into a series of tight, steeply dipping folds, the axes of which trend regionally northwards. Large composite batholiths such as the Bega Granite intruded these metasediments during the lower to middle Devonian. Both are overlain in part by middle to upper Devonian volcanic and sedimentary sequences of the Eden-Comerong-Yalwal Rift Zone, a discontinuous graben within the underlying basement (McIlveen, 1975). Tertiary and Quaternary deposits of relatively limited areal extent apppear to have suffered negligible deformation which suggests that the area has been tectonicly stable apart from the Kosciusko epeirogenic uplift of the Eastern Highlands (Brown et al., 1968; Hall, 1959).

2.2 Local Geology and Catchment Lithologies

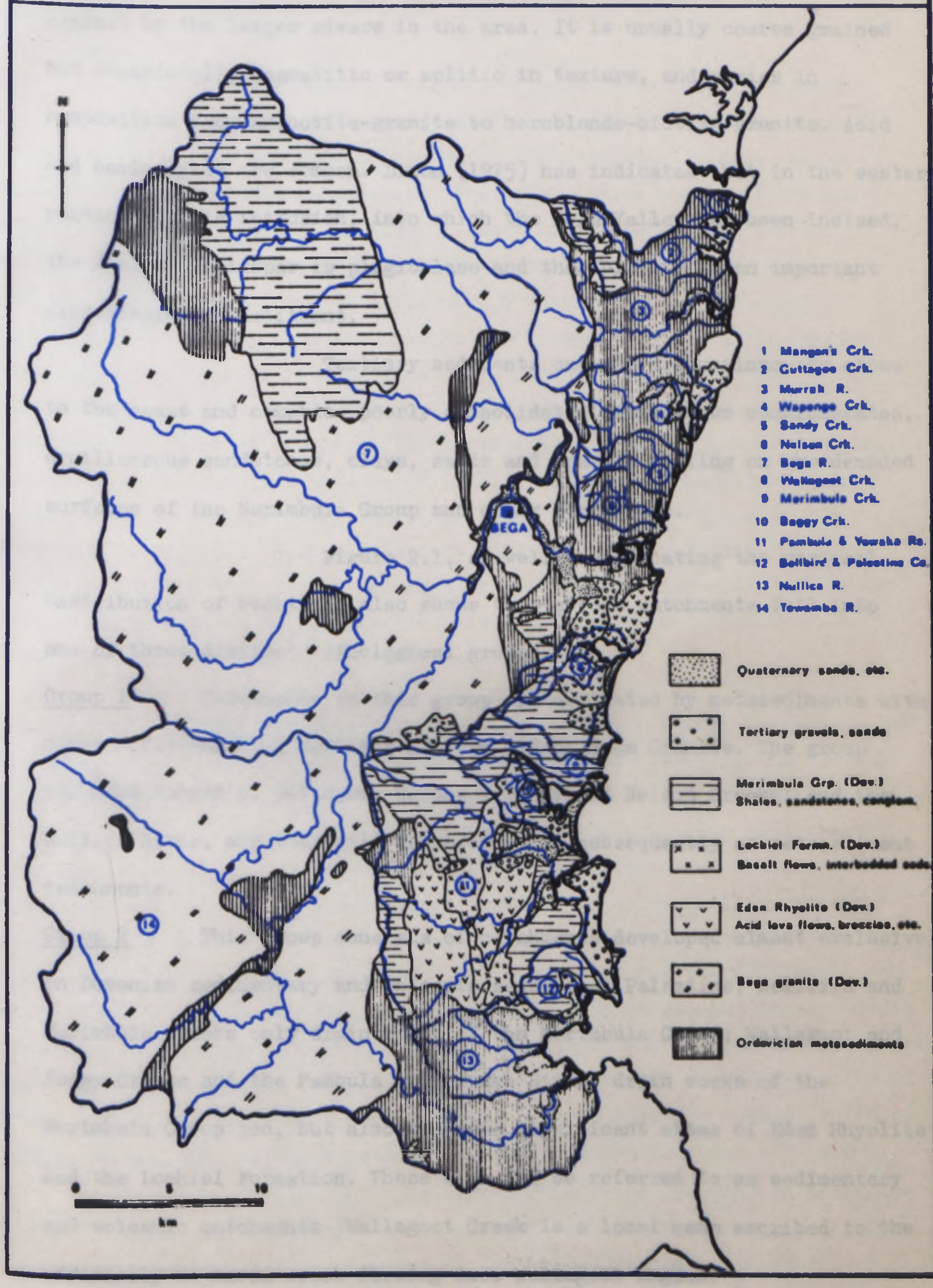
Figure 2.1 and the accompanying discussion summarizes the catchment lithologies of coastal streams in the study area and draws heavily from many published reports (Brown, 1930, 1931, 1933; Hall, 1959, 1969a, 1969b; Steiner, 1972; Webby, 1972; Etheridge et al., 1973, and McIlveen, 1975).

The Ordovician basement outcrops extensively within ten kilometres of the coast and thus dominates the lithology of many of the smaller stream catchments. Outcropping rocks are mainly indurated siltstones and sandstones, quartz greywackes, slates, phyllites and metaquartzites. The sandstones and greywackes are poorly sorted and mineral grains within them are subangular to subrounded.

Devonian sediments and lava flows are confined to an area within 15 kilometres of the coast between Wallagoot Lagoon and Eden. Three units are present, the basal one being a series of terrestrial acid lava flows, breccias and agglomerates known collectively as the Eden Rhyolite. A small portion of this unit also outcrops further north near Wapengo Lagoon.

Overlying the Eden Rhyolite are the Lochiel Formation and the Merimbula Group. The former is limited to the Lochiel-Pambula district and consists of a number of subaerial basalt flows with interbedded sediments and acid lavas. The interbedded sediments consist of arkosic sandstones and conglomerates, and red mudstones. The Merimbula Group is wholly sedimentary and is dominated by an arkosic red bed sequence of red shales and subangular arkosic sandstones and conglomerates deposited by intramontane braided streams. Uppermost members of the Group are

CATCHMENT LITHOLOGIES (FIGURE 2·1)



indicative of an alluvial plain environment.

The Bega Granite is a massive lower (?) Devonian intrusion which usually outcrops at least ten kilometres from the coast. It coincides with the areas of greatest relief and elevation and is drained by the larger rivers in the area. It is usually coarse grained but occasionally pegmatitic or aplitic in texture, and varies in composition from muscovite-granite to hornblende-biotite-granite. Acid and basic dykes are common. Dixon (1975) has indicated that in the eastern portion of this intrusion, into which the Bega Valley has been incised, the dominant feldspar is plagioclase and that biotite is an important mineralogical constituent.

Tertiary sediments outcrop discontinuously close to the coast and comprise poorly consolidated ferruginous conglomerates, argillaceous sandstones, clays, sands and gravels resting on the denuded surfaces of the Merimbula Group and other formations.

Figure 2.1, as well as indicating the regional distribution of rocktypes also shows that stream catchments fall into one of three distinct lithological groups.

Group 1 Catchments in this group are dominated by metasediments with minor occurrences of Tertiary gravels and/or Bega Granite. The group includes Mangan's, Cuttagee, Wapengo, Sandy and Nelson Creeks, and the Nullica River, and they will be referred to subsequently as metasediment catchments.

Group 2 This group consists of catchments developed almost exclusively on Devonian sedimentary and volcanic sequences. Palestine, Bellbird and Merimbula Creeks only drain rocks of the Merimbula Group; Wallagoot and Boggy Creeks and the Pambula and Yowaka Rivers drain rocks of the Merimbula Group too, but also traverse significant areas of Eden Rhyolite and the Lochiel Formation. These will all be referred to as sedimentary and volcanic catchments Wallagoot Creek is a local name ascribed to the officially un-named creek flowing into Wallagoot Lagoon.

Group 3 These catchments are dominated by granite and are drained by the Bega, Towamba and Murrah rivers. The first also drains a large area of Merimbula Group sediments in its upper reaches; all three flow through the lowland belt of metasediments. They will be referred to as granite catchments.

2.2 Sampling and Methodology

Up to three samples of bedload material were collected above the tidal limit of each stream using a grab sampler lowered from a small inflatable boat. The location of the tidal limit in each stream was extracted from appropriate topographic maps; such limits represent the points where "under normal conditions there is no discernible rise or fall of water level in response to tidal fluctuations in the adjoining ocean waters" (Mr. T. Ryan, Survey Section, N.S.W. Lands Dept., pers. comm.). Sediment at this location was considered to be representative of material available for transport to the sea and to be entirely derived from fluvial and mass wasting processes operating on all the rocks exposed in the catchment. Three lakes are each fed by two streams. At Pambula and Curalo lakes where the two tributaries join below tidal limits, bed load samples were collected from each tributary and since there was no difference in sub-catchment lithologies, sedimentological data were combined (eg. fig. 2.3). Merimbula Lake is also fed by two streams however the lesser Bald Hills Ck was not sampled as it enters the lake via a usually dry, ineffectual, vegetated channel partly infilled by local farmers.

Samples were analysed for their gravel and fines content, the latter being extracted by wet sieving. After washing, drying, disaggregation and splitting, sand fractions were sieved at 1/2 phi intervals for 15 minutes on an Endecott shaker. New eight inch (÷ 200mm) stainless steel sieves were used; the same sieves and shaker were used throughout to ensure consistency of technique and results. The weight percentages of the sieve fractions were plotted as cumulative distributions on probability paper as recommended by Folk (1966) but the four standard moment statistics were calculated for each grainsize distribution as advocated by Seward-Thompson and Hails (1973). Only moment values are quoted in this thesis and they are derived from the size distributions of the sand fractions. The problem of open-ended distributions such as occur in river sediments was considered to be of minor consequence, and would have affected graphic measures similarly (Folk, 1966). The phi (Ø) grainsize scale of Krumbein (1936) was used throughout.

A petrological microscope with a flat stage was used to determine grain roundness and mineralogy from thin sections of plastic mounted, acid washed subsamples. Feldspar grains were identified on the basis of birefringence, cleavage, twinning and in doubtful cases by checking for biaxiality via observation of the isogyre pattern in the interference figure. Roundness was estimated using scaled down replicas of the two dimensional visual comparison charts prepared by Krumbein (1941), and values range from 0.1 (very angular) to 0.9 (very well rounded). Samples were coded, and all estimates were made by the author alone to minimize bias. A minimum of ninety quartz grains was counted on each slide. Grain shape was not analysed.

Sand mineralogy was determined using the area method (Galehouse, 1971) whereby every grain in marked strips or sub-areas is counted, thus producing number percentage values. This also avoids the tedium of the fleet method and the bias of the line method. As well as counting specific minerals, quartz grains were classified as stressed or unstressed. Stressed grains include polycrystalline ones as well as those showing strong undulose extinction, and are presumed to have been derived from low grade metamorphic rocks in the metasediment catchments. Although Blatt and Christie (1963) suggested that this technique has little value in provenance studies, Folk (1968) and particularly Basu et al. (1975) have attested its usefulness when trying to distinguish pluton-derived quartz and low rank metamorphic quartz of medium sand grade.

Roundness and mineralogy values quoted are derived from a number of thin sections. Therefore the total grain counts from which the average values were derived commonly exceed 500, in which case the results are reliable to within ± 5% (Van Der Plas and Tobi, 1965). Average values of all the parameters recorded from the stream sediments are tabulated in figures 2.2 and 2.3.

Appropriate parametric or non-parametric tests have been used to establish the statistical significance of many of the conclusions in this thesis. In all such cases, the null hypothesis was not rejected unless the probability of doing so in error was equal to or less than 0.05.

2.3.1 Grainsize Characteristics

Appreciable amounts of gravel were present in all the bed load samples, the overall average proportion being approximately 30% by weight. Sediment derived from granite catchments tended to be lowest

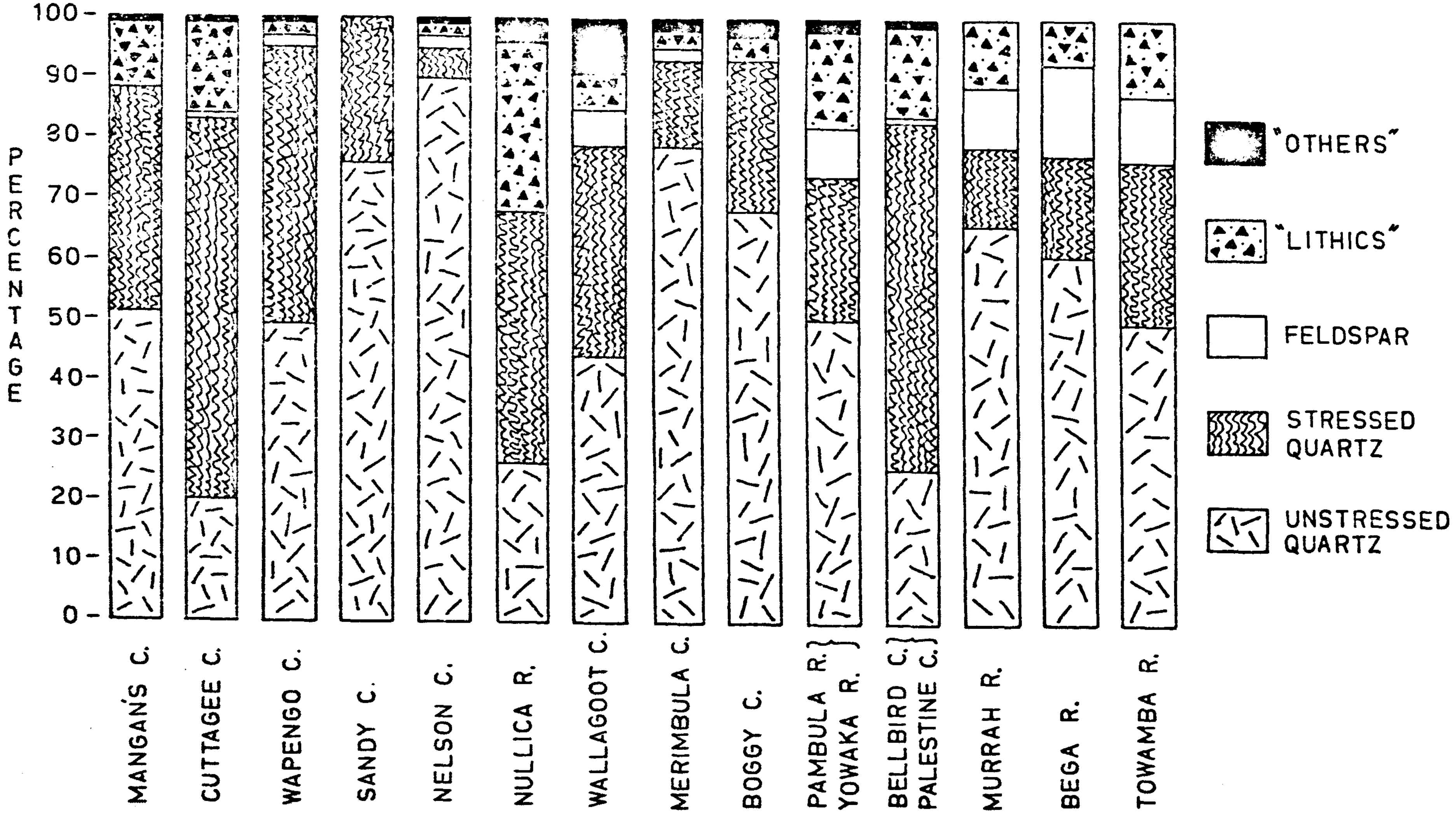
Catchment		Gravel %	Mean φ	Sorting	Skewness	Kurtosis	Round.
METASEDIMENT	1	39	.21	.88	.56	2.64	.27
	2	52	.09	.99	.74	4.39	.28
	4	39	.29	.82	.97	4.36	.31
	5	35	.13	.73	.79	3.91	.33
	6	<5	1.28	.72	-.38	3.65	.27
	13	72	1.00	.98	-.14	2.66	.26
Group Mean		40	.50	.90	.42	3.60	.29
SEDIMENTARY AND VOLCANIC	8	29	-.22	.91	.82	3.02	.27
	9	<5	1.01	.83	.62	3.71	.22
	10	25	.57	.87	.32	2.54	.22
	11	31	.62	.69	.41	2.80	.22
	12	31	.77	.81	.03	2.68	.26
Group Mean		24	.55	.82	.44	2.95	.24
GRANITE	3	<5	.47	.46	-.22	2.82	.29
	7	28	-.03	.62	-.44	3.12	.24
	14	20	.21	.81	.60	2.68	.20
Group Mean		18	.22	.63	-.02	2.87	.24

Figure 2.2a Grainsize and Quartz Roundness of local river sands

Catchment Lithology	% Qtz. unstressed	% Qtz. stressed	% Feldspar	% Lithics	% Others
Metasediment Catchments	52	36	1	10	1
Volc. & Sed. Catchments	53	31	3	9	4
Granite Catchments	59	19	12	10	-

Figure 2.2b Average mineralogical composition of catchment river sands.

FIGURE 2·3 MINERALOGY OF RIVER SANDS



in gravel content and many of the pebbles present were actually metasediment fragments from slopes bordering the lower reaches of these streams. The scarcity of granitic gravel reflects the initial distribution of grain-sizes within the Bega granite and is probably reinforced by the deeply weathered nature of this particular rock mass.

River sediments from metasediment catchments contained significantly higher proportions of gravel, with a group mean of nearly 40%. Granules and pebbles from non-granite areas were generally either pure quartz or lithic fragments, the composition of which matched the outcropping rock types in the respective catchments.

As would be expected, fines were generally absent. Traces (less than 1%) were present in samples from streams draining metasediments but material of this calibre clearly comprised the great bulk of sediment in river banks and flood plains.

The mean grain sizes of the sand fractions were nearly all coarser than 1 phi, and the greater part of each distribution lay within the coarse-very coarse sand grades. Distributions were usually unimodal but most samples were at best only moderately sorted. Compared to other catchments, streams draining granite tended to produce the coarsest and best sorted sands but only the latter feature was statistically significant when the distributions of the parameters from each catchment group were compared using the Mann-Whitney U test (Siegel, 1956). The trend to better sorting probably reflects the relative textural uniformity of the granite and possibly reflects more selective sorting in the longer streams with bigger discharge which drain this rock type.

Sands were often significantly skewed, usually in a positive direction. This appears to be typical of river sediments (Folk, 1968; Friedman, 1961) but may reflect, at least in part, the artificial truncation of the grainsize curves due to the exclusion of the gravel fraction. Most samples were mesokurtic; those which deviated were signifi-antly leptokurtic. No statistically significant differences were established between grouped catchment sands using the third and fourth moments.

2.3.2 Quartz Roundness and Sand Mineralogy

All samples were characterized by quite angular quartz grains with mean roundness values ranging from 0.20 to 0.33. Quartz derived from metasediments was significantly more angular than that from other rocks. All three sediment groups contained approximately 84% total quartz as determined by counting from thin sections, but when this figure was reduced to component quartz types, it was evident that metasediment sands were richer in stressed quartz grains.

Feldspar content was quite low in sands from metasediment catchments (1%) and is probably derived from the granite which often occurs as minor outcrops in their headwater regions. In sands derived from granite catchments the average proportion of felspar was much greater at 12%. The proportion of lithic fragments was fairly consistent throughout at approximately 10% but their composition was clearly consistent with their respective catchment lithologies. Opaque and non-opaque heavy minerals were lumped tpgether as "others"; they were not analysed in any detail. Photomicrographs of some representative thin sections are included as plates 2.1 - 2.6.

2.4 Review

The coastal streams within the study area carry a supply of coarse grained, moderately sorted, angular sands with significant amounts of gravel. The sands are essentially quartzose but the actual quartz type and the variable proportions of accessory constituents such as feldspar and lithic fragments also indicate the influence of the respective catchment lithologies.

The river sand characteristics must reflect the combination of two factors, one being the source rocks from which the sediments were derived and the second being the subsequent modifications undergone during transport. Actual grain size, roundness and mineralogy appear to be more dependent on source than do sorting and skewness, and are therefore likely to be the most useful guides when assessing the degree to which local beach sediments are supplied with sand from the local rivers. The poor sorting and positive skewness values exhibited by the river sands are typical of values obtained from similar environments elsewhere in the world (Folk, 1968) but their usefulness as indicators of fluvial sediment supply will probably be greatly reduced by their modification in the local high energy beach environment.

Captions to accompany plates 2.1 - 2.6

All the photomicrographs were taken in polarized light with crossed nicols. In nearly all cases the modal grain size is approximately 1 phi (0.5 mm). Only portions of thin sections are shown because in this page format the entire fields of view cannot be usefully displayed. The portions shown illustrate the important characteristics of each sediment type and are at least qualitatively representative of the parent samples. The numbers in brackets identify the sample from which the thin section was obtained.

Plates 2.1, 2.2 show sand grains derived from Group 3 catchments (granite). Both stressed and unstressed quartz grains are evident, together with a few feldspar grains. Note the degree of angularity of both minerals.

Plates 2.3, 2.4 show some sand collected from the bed of two streams draining Group 2 catchments (Sedimentary and Volcanic). Again, unstressed quartz grains are dominant and the grains are quite angular. Note the rounded lithic (basalt) fragment in the Pambula River sample.

Plates 2.5, 2.6 illustrate the mineralogy and roundness of sands derived from Group 1 catchments (metasediments). The larger proportion of stressed quartz grains is apparent and some grains display recrystallization patterns. Again, grains are quite angular.

PLATE 2·1

BEGA R.

FELDSPAR (F)
QTZ.(STRESSED) Qs
QTZ.(UNSTRESSED) Qu

(57)

PLATE 2·2

MURRAH R.

(45)

PLATE 2·3

PAMBULA R.

Lithic fragment
(basalt) L

(10)

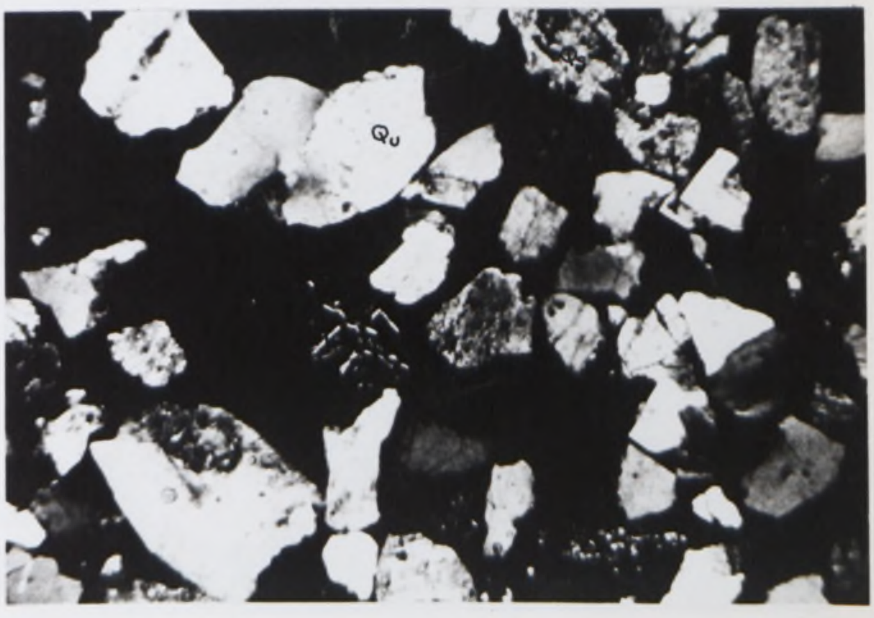


PLATE 2·4

MERIMBULA CREEK

(6)

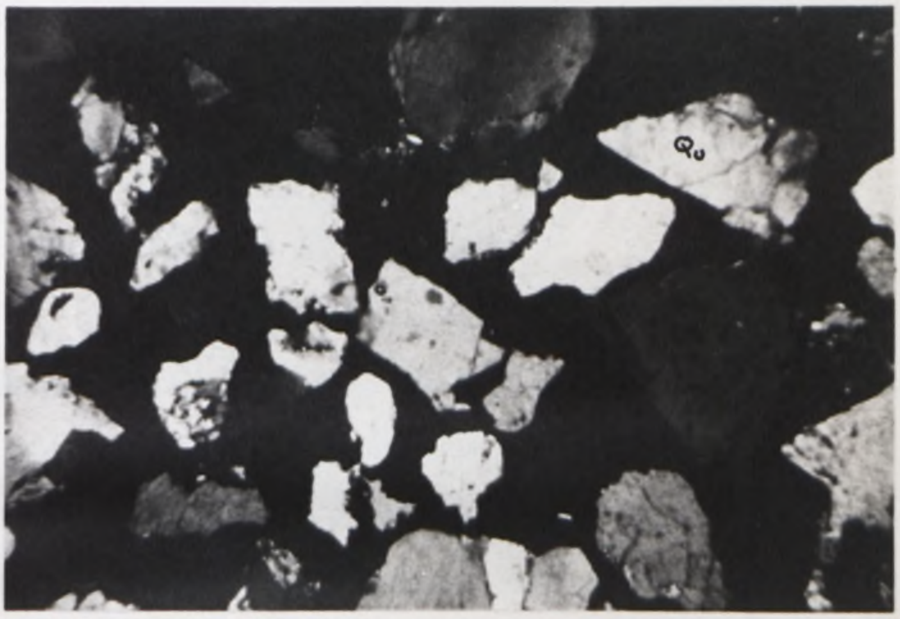


PLATE 2·5

WAPENGO C.

(104)

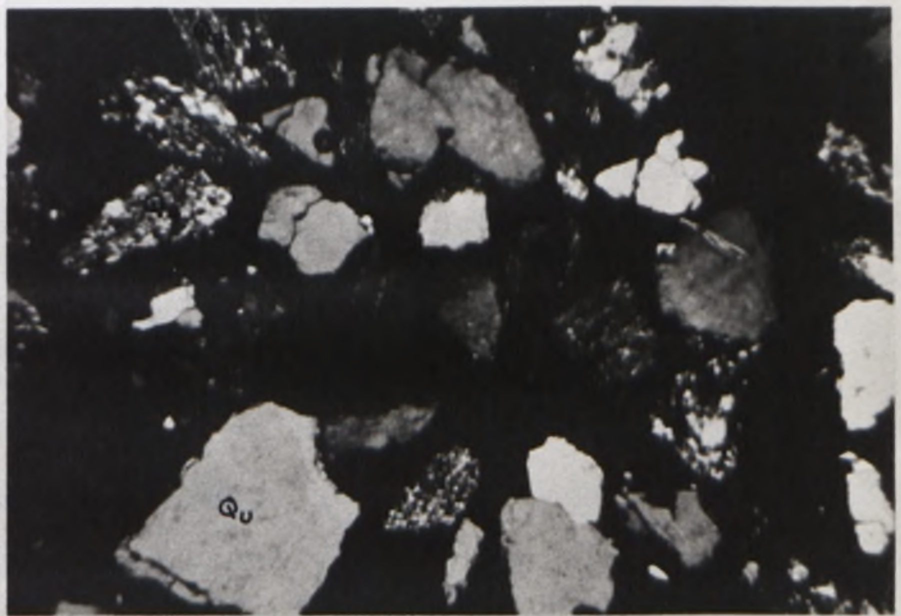
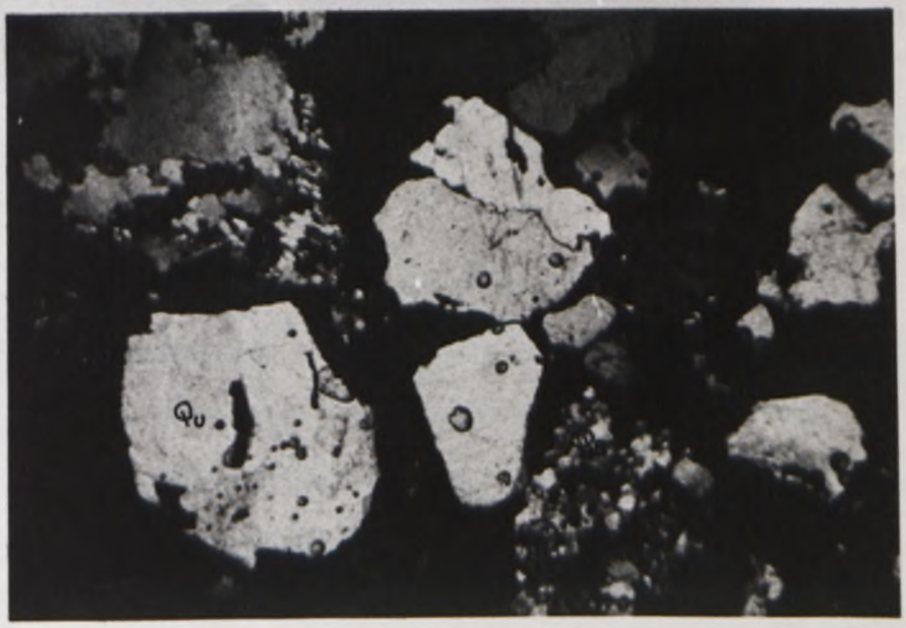


PLATE 2·6

SANDY C.

(359)



CHAPTER THREE BEACH SEDIMENTS

The sedimentological and mineralogical characteristics of beach sands are also functions of the source(s) from which the sands were derived and the nature and magnitude of the processes operative at the time of deposition. In this chapter, beach sands from the study area are first compared on a between-beach basis, followed by an examination of sediment variability within individual embayments. Sediment from the nearshore zone of a few beaches is also described. By recognizing and eliminating those characteristics which are clearly manifestations of shore processes alone, the most likely origin(s) of the beach sands, and the degree to which they are being replenished is assessed.

3.1 Sampling and Laboratory Procedure

Initially, two to four equi-spaced samples, each weighing approximately 250 grammes, were collected from each beach listed in figure 3.1. (and refer Appendix A3i in rear pocket) The number collected depended on the length of the beach being sampled. Resampling was conducted later to check for any temporal variations and six of the longer beaches were resampled more intensively to establish whether or not the smaller number of samples collected previously were statistically representative of the beach sediment populations from which they were drawn.

Samples were always taken from the beach face approximately midway between high and low tide levels as recommended by Bascom (1951). Textural separations and the determination of grain roundness and mineralogy followed the procedure described previously for the river sediments, with appropriate modifications dictated by the general absence of gravel and mud. The proportion of calcareous material was calculated from the loss in dry weight after dissolution of samples in 10% hydrochloric acid.

3.2 Comparison of Beach Sediments Between Beaches

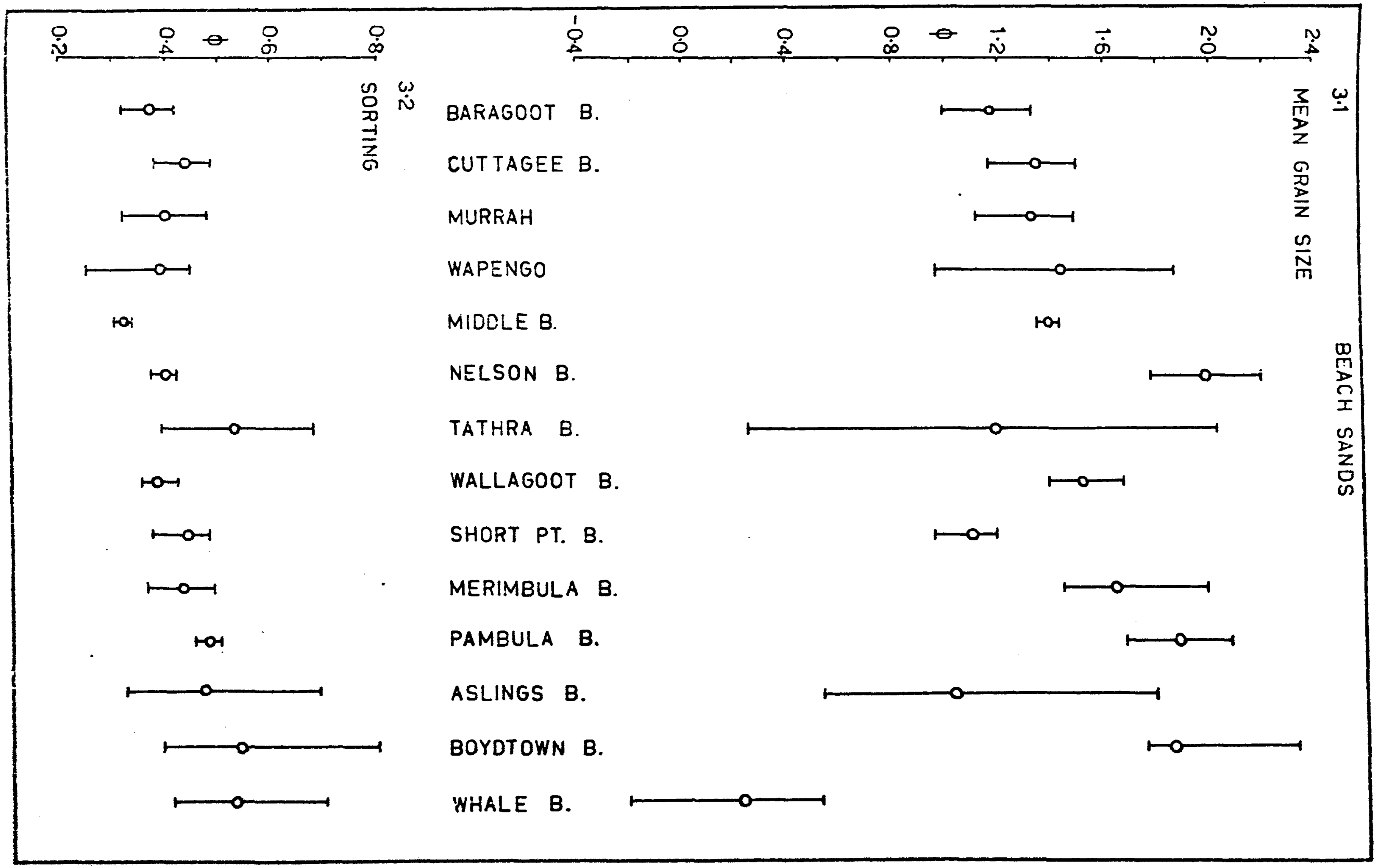
3.2.1 Grainsize Distributions

Most beach sediments examined were composed entirely of sand sized material finer than -1 phi (2.0 mm) and coarser than 3 phi (.125 mm). Samples from four beaches contained small but measurable proportions of gravel by weight. At Murrah and Aslings beaches only traces (<1%) were recorded, but samples from Tathra and Whale beaches averaged 1% and 2% respectively.

Aerial observations during floods revealed plumes of turbid water extending seawards for varying distances from all river mouths. Those issuing from the larger rivers such as the Bega, often extended more than one kilometre out to sea and persisted for many days. In view of the high wave energy conditions along this coast though, it was not surprising that silt and clay size material was absent from all the beach samples analysed. Material of this calibre is presumably dispersed by waves and currents to ultimately settle out in the deeper waters of the adjoining continental shelf.

Figure 3.1 is a plot of mean grainsize of sands on the various beaches. The small circles represent the average of all sample means from a particular beach, and the length of the protruding bars indicates the spread of sample means about the group average. Beach names are listed according to their geographic location from north to south and intervening spaces are not to scale. It should also be recalled that Wapengo has no ocean beach as such; values plotted refer to a beach immediately inside the entrance to this estuary.

In gross textural terms there are three main groupings of beaches. Nelson, Pambula and Boydtown comprise one group

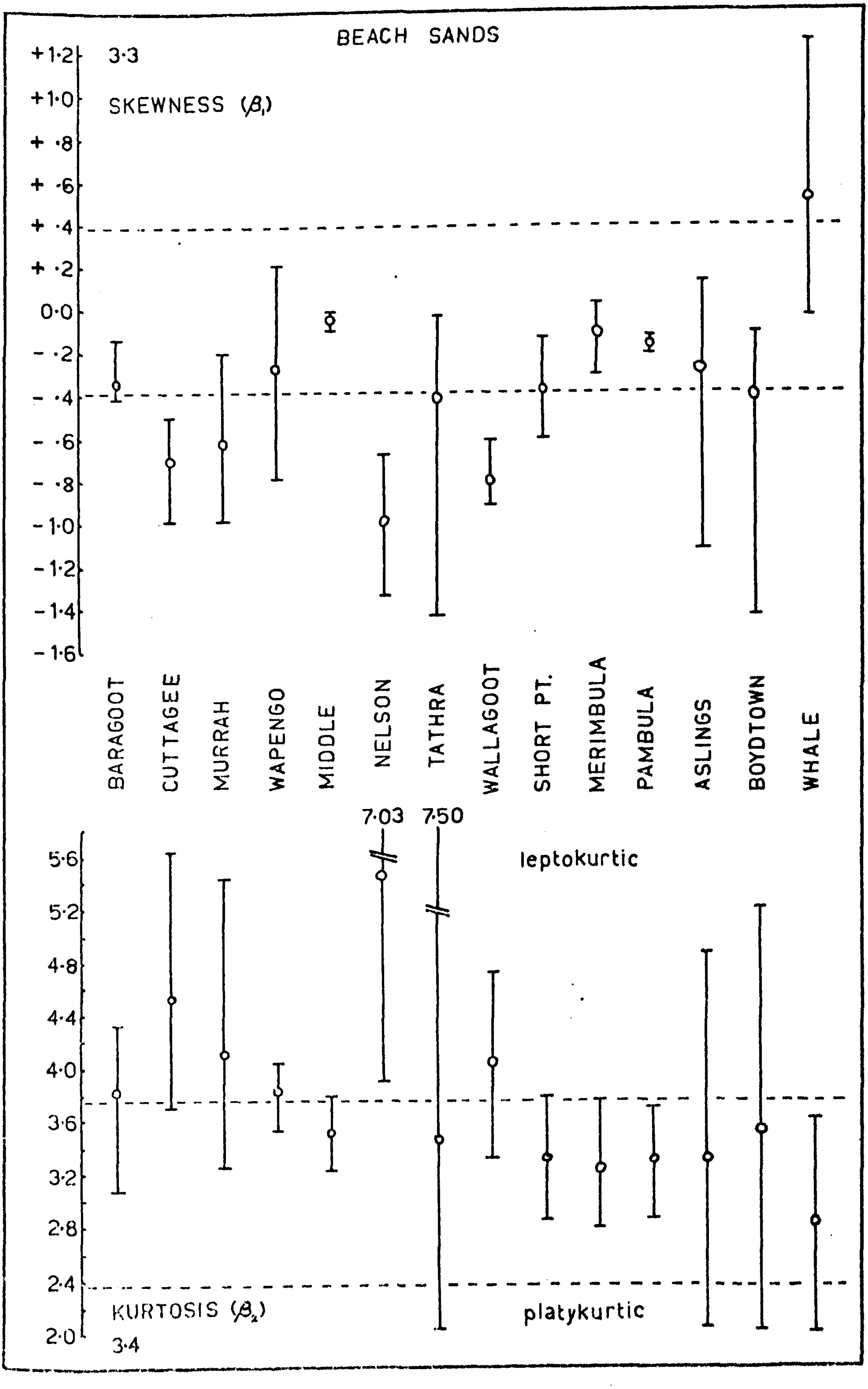

3·1
MEAN GRAIN SIZE
BEACH SANDS
3·2
SORTING
-0·4
0·0
0·4
0·8
ϕ
1·2
1·6
2·0
2·4
0·2
0·4
ϕ
0·6
0·8
BARAGOOT B.
CUTTAGEE B.
MURRAH
WAPENGO
MIDDLE B.
NELSON B.
TATHRA B.
WALLAGOOT B.
SHORT PT. B.
MERIMBULA B.
PAMBULA B.
ASLINGS B.
BOYDTOWN B.
WHALE B.

of fairly fine grained beaches averaging 48% fine sand, whereas Whale, Tathra, Aslings and Short Point beaches average 61% coarse sand. The remaining seven beaches (Baragoot, Cuttagee, Murrah, Wapengo, Middle, Wallagoot and Merimbula) average 76% medium grade sand. An overall trend for sands to be finer on more southerly located beaches is apparent, particularly if the three beaches inside Twofold Bay are excluded, but application of the Spearman Rank Correlation test (Siegel, 1956) yielded a correlation coefficient r_s of 0.42 which was statistically insignificant.

When individual beaches are considered, Whale Beach stands apart as the coarsest with sample means ranging from -.22 phi to +.52 phi. Samples from this beach averaged 92% coarse sand (>0.5 mm). Tathra and Aslings beach sands, as well as being coarser than most, also displayed considerable variation in mean grain size. At the former this is readily explained by the existence of a very well defined longshore trend from fine at the southern end of the beach to coarse at the north, but at Aslings Beach such a well defined trend was not apparent. Nelson, Pambula and Boydtown beaches are finer grained than most; at Boydtown samples averaged 53% fine sand and sample means were as fine as 2.32 phi.

Figure 3.2 indicates the overall mean and variation of sorting values of sand samples from each beach. Most sands lie well within the well sorted category of Folk (1968) with values less than 0.5 phi. Not one sample was poorly sorted, The main exceptions to the general pattern are Tathra, Boydtown and Whale beaches, sands from which are generally only moderately sorted. A few samples from Aslings Beach also fall into this category. All four display considerable variation in sorting values; at Tathra this again probably reflects the variation in wave energy along the beach, and in Twofold Bay reduced wave energy is at least partly responsible.

In figure 3.3 skewness values are plotted and it is evident that most beach sands tend to be negatively skewed. This accords with results for beach sands elsewhere in the world and appears to be a


BEACH SANDS
3·3
SKEWNESS (β_1)
BARAGOOT
CUTTAGEE
MURRAH
WAPENGO
MIDDLE
NELSON
TATHRA
WALLAGOOT
SHORT PT.
MERIMBULA
PAMBULA
ASLINGS
BOYDTOWN
WHALE
7·03
7·50
leptokurtic
KURTOSIS (β_2)
3·4
platykurtic

general phenomenon resulting from selective removal of finer grained particles by swash and wind action (Mason and Folk, 1958; Friedman, 1961; Koldijk, 1967). Whale Beach departs from this trend with an overall mean positive skewness indicating that samples from this site commonly contain excess material finer than the mean. Friedman (1961) recorded a similar anomaly in beach sands on southern Padre Island, Texas, opposite the Rio Grande delta, and suggested that these particular sands had retained the positive skewness typical of river sands because they had not come into equilibrium with their new environment. Blake (1968) reported similar results at Pegasus Bay in New Zealand. This may also be the case at Whale Beach, particularly in view of the diminished wave activity within Twofold Bay. It may also reflect artificial truncation of the grainsize distributions due to the exclusion of the gravel fractions which averaged 2% by weight. If the latter was the case though, a similar anomaly would be expected to occur at Tathra Beach where nearly the same proportion of gravel was recorded.

Figure 3.4 shows that the majority of beach sands analysed were mesokurtic, that is, their grainsize distributions closely approached log-normality. A number of samples from Tathra, Aslings, Boydtown and Whale beaches tended to be platykurtic, a feature which often indicates bimodality (Folk, 1968), but this was not evident in any of the raw frequency distributions. Other beaches were strongly leptokurtic, particularly the sands from Boydtown and parts of Tathra beaches. In these samples a narrow well sorted modal class was predominant with smaller proportions of less well sorted grains throughout the fine and coarse tails of the distributions.

Comparison of figures 3.1 - 3.4 reveals varying degrees of correlation between the four parameters. To check such associations, the results were tested using the Spearman Rank Correlation test. The results are shown in table 3.1.

Table 3.1 Association between beach sediment grainsize statistics

Mean	v	Sorting	$r_s = 0.16$	Not Significant
Mean	v	Skewness	$r_s = 0.18$	Not Significant
Mean	v	Kurtosis	$r_s = -0.33$	Not Significant
Sorting	v	Skewness	$r_s = 0.09$	Not Significant
Sorting	v	Kurtosis	$r_s = -0.53$	Significant
Skewness	v	Kurtosis	$r_s = -0.76$	Significant

Only two statistically significant associations were evident and both involved kurtosis. More poorly sorted sands tended to be platykurtic, a not unexpected result, and positive skewness was also associated with platykurtosis. There was no significant association between sorting and skewness though.

3.2.2 Beach Carbonate

The carbonate fraction of the beach sands was generally quite low with values ranging from less than 1% to 17% by weight (figure 3.5). The bulk of this material was composed mainly of shell fragments and only minor proportions of bryzoan structures and echinoid spines. Samples from Wallagoot, Short Point and Whale beaches were especially low in carbonate having average values less than 2%. Nelson and Pambula beaches averaged 9% and 10% respectively whereas samples from Boydtown and Cuttagee beaches contained more than 14% of such material.

The proportion of beach carbonate often declines near river mouths where tributary streams are actively supplying the shore with mineral sand, as is the case in Hawaii (Inman, Gayman and Cox, 1963) and in Tasmania (Davies, 1972, 1973). At these localities detection of such an effect is facilitated by the high ambient beach carbonate levels (usually greater than 50%); much lower proportions were recorded in this study area (figure 3.5) and no dilution effect is apparent. Whereas Whale Beach partially impounds the second largest river in the region, and is probably supplied with considerable quantities of sand from it,

BEACH SANDS

FIG. 3·5 CARBONATE

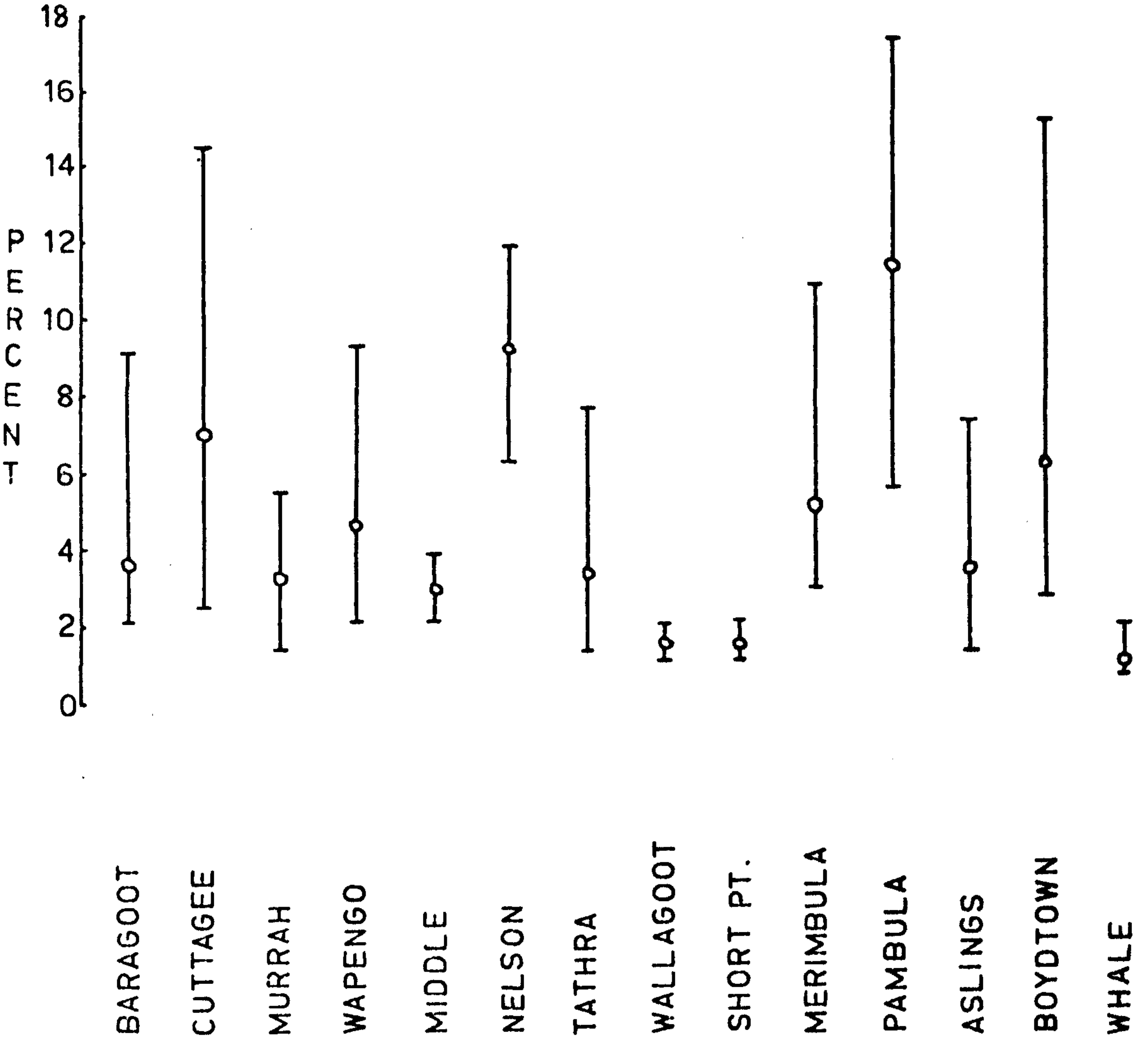
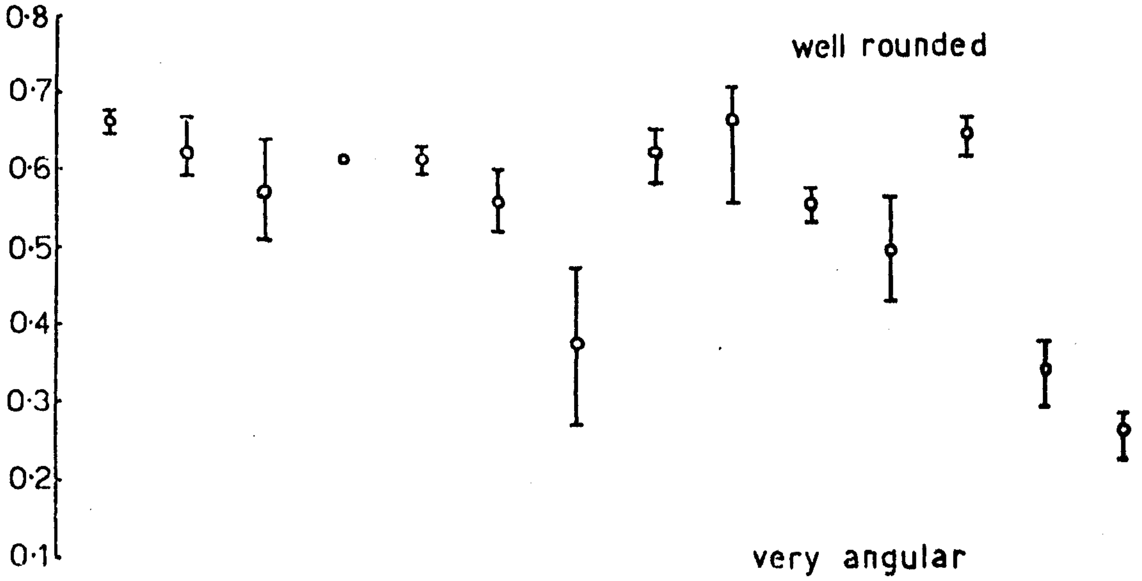


FIG. 3·6 ROUNDNESS (QTZ)



the proportion of carbonate, although low, is much the same as the proportions found on Wallagoot and Short Point beaches, both of which are only linked to small, ephemeral streams by intervening lagoonal sediment traps. Similarly, even though the Bega River is probably another active source of sand, the amount of carbonate in Tathra Beach sands is not exceptionally low. Also, the amounts and variations of beach carbonate within Twofold Bay are very similar to those on the ocean beaches, which suggests that variation in wave energy is unimportant. Other factors such as the proximity of a beach to biogenously productive areas must exert greater control over carbonate levels.

3.2.3 Quartz Roundness

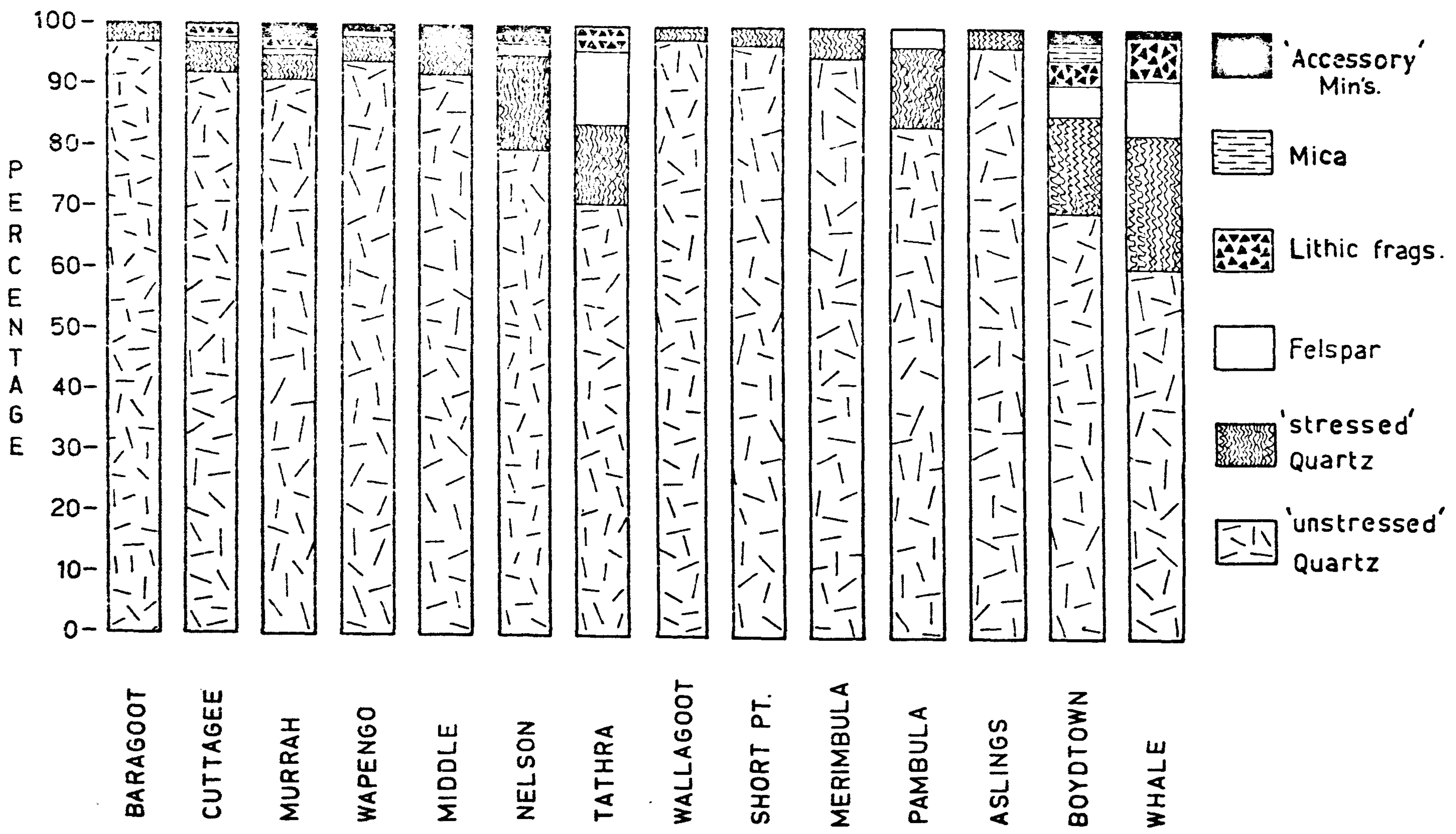
The roundness of quartz grains is plotted in figure 3.6 and shows that the majority of beach sands analysed consisted of subrounded to fairly well rounded quartz grains. Only one sample from Wapengo "beach" was examined for this parameter. Whale and Boydtown beaches within Twofold Bay are notable exceptions to the overall trend; grains at the former are especially angular. Of the comparatively exposed ocean beaches, Tathra sands are least rounded; a similar but weaker trend at Pambula was statistically significant.

All the sample distributions of grain roundness were unimodal, and at Merimbula, Pambula, Tathra, Murrah and Nelson beaches, within-sample variations were greatest. Variations in wave energy do not explain satisfactorily the observed differences in roundness values. Within the relatively sheltered environment of Twofold Bay, Aslings and Whale beach sands are rounded to remarkably different degrees; similar anomalies are evident on the ocean beaches. It appears that Whale, Tathra and Boydtown beaches are being replenished with more angular quartz from tributary streams and/or erosion of nearby cliffs.

3.2.4 Beach Sand Mineralogy

In figure 3.7 the average mineralogical compositions of the beach sands are shown. Quartz dominates all samples, averaging 95%

FIGURE 3·7 MINERALOGY OF BEACH SANDS



overall, and accounts for the entire mineral fraction at Baragoot, Wallagoot, Short Point, Merimbula and Aslings beaches. The proportion of stressed quartz is greatest in samples from Whale, Tathra, Boydtown, Pambula and Nelson beaches, but is consistently lower elsewhere. The low levels at high energy beaches such as Baragoot and Wallagoot for example, probably reflects long term preferential breakdown of the crystalline quartz delivered to the shelf during the last glacial. At the other localities, diminished wave energy may be partly responsible for the higher proportions of stressed quartz, but it is also indicative of contemporary supply from the Towamba, Bega and possibly the Nullica Rivers. Minor amounts may also have been derived from headland erosion.

The non-quartz fraction is greatest at Whale Beach (17%) followed by Tathra (16%) and Boydtown (14%). Sands at these three beaches also contain at least 4% feldspar; at Tathra and Whale beaches the respective proportions average 12% and 9%. As well as being softer than quartz, feldspar has three well developed cleavage planes and is therefore prone to rapid breakdown in a high energy environment. Its presence in significant proportions on the ocean beach at Tathra especially, is indicative of contemporary supply by rivers. In view of the subsequent reworking it would have had to have survived to be present in today's beach sands it is unlikely that the feldspar is a relic of fluvial deposition on the shelf during the last glacial. Furthermore, although not analysed in great detail, inspection of 100 feldspar grains from Whale and Tathra beaches yielded average roundness values of .38 and .47 respectively, values which are not commensurate with a long period of reworking in a high energy marine environment. Individual roundness values ranged widely, with many well rounded grains being observed as well as very angular ones. The latter at least must have been delivered to the coast quite recently.

Mica, both muscovite and biotite, was recorded only at Boydtown Beach, where wave energy is very low. Nearby metasediment headlands are possible sources as is the granite catchment of the neighbouring Towamba River. Biotite, more so than muscovite is very susceptible to breakdown and its presence also suggests contemporary supply from the hinterland.

Heavy minerals (excluding mica) were scarce (< 5%) and were not analysed intensively. Opaque grains, mainly ilmenite, magnetite and haematite were observed in most samples and in some samples from Murrah Beach, hornblende grains were often present. The latter were probably derived from the gabbro outcropping at the southern end of the beach. The small heavy mineral fractions of Boydtown, Aslings and Merimbula barrier beaches have been analysed in some detail by Hails (1969). At the latter two localities the mineral suites were found to be very similar and were dominated by opaques and tourmaline (together at least 70%), whereas at Boydtown tourmaline was only a minor component, the dominant minerals being opaques and hornblende. The heavy minerals at Boydtown were also observed to be much more angular than those of the neighbouring beaches. Hails concluded that the Nullica River is supplying small amounts of sand to Twofold Bay at the present time, but at the same time noted that abrasion would be considerably reduced in the lower wave energy environment at Boydtown.

Lithic fragments were another minor constituent in some beach sands. In general they comprised particles of metasediments and were found in small quantities on shorter beaches bounded by prominent headlands of this rock type. They therefore provide evidence for a minor input through headland erosion. Some representative photomicrographs of the beach sands are included as plates 3.1 - 3.12.

3.2.5 Review

When considered individually, many of the sediment parameters are equivocal in determining the origin(s) of the beach sands investigated. This applies particularly to the grainsize statistics and beach carbonate levels. When viewed collectively though, a clearer picture emerges and some general conclusions can be drawn with reasonable confidence.

Whale and Tathra beaches both have significant proportions of gravel; their sands are relatively coarse, only moderately sorted, quite angular and contain 10% feldspar on average as well as smaller but important proportions of lithic sand. The occurrence of these two mineralogical components and the angularity of the grains is indicative of replenishment from the granite catchments of the Towamba and Bega rivers. It is also evident that only very minor contributions result from erosion of metasediment headlands bounding both beaches. The latter situation is not surprising since weathering of these rocks can produce only fine sands and muds in quantity and these are unlikely to settle out in an active swash zone.

Variations in some of the other parameters appear to be related more to the different energy levels on these two beaches. Tathra beach sands are negatively skewed as is usual for beaches, but the positive skewness recorded at Whale beach matches that of sands in the Towamba and other local rivers. It seems that the sheltered environment at Whale Beach has allowed the survival of sediment characteristics imparted by fluvial processes, whereas at Tathra these have been at least partially replaced by values typical of a high energy ocean beach environment. Here, greater wave activity has removed and/or prevented the deposition of much of the finer sands resulting in negative skewness, but has not been able to reduce the overall size range of particles to the extent necessary for good sorting values to be recorded. The differences in intensity of wave activity appear to be manifest in the kurtosis values as well. Whale Beach sands are significantly platykurtic, whereas those at Tathra are mesokurtic.

The evidence from Boydtown samples suggests that this beach too is being replenished with terrigenous sands. Sediment here consists mainly of moderately sorted, fine grained, angular quartz sands with considerable admixtures of calcareous fragments, feldspar, mica and heavy minerals. As before, weathering and erosion of metasediments in nearby headlands and in the Nullica River catchment would produce only fine quartz sand and mica with larger quantities of mud. It is therefore possible that sediment has been delivered from both these sources but unlike other beaches, the lower wave energy has permitted their deposition on Boydtown Beach. Morphological and hydrological evidence to be discussed later indicates that the Nullica River can only deliver this sediment during floods.

Boydtown beach sands also display a mineralogical affinity with sands from the neighbouring Towamba River which is a more probable source of feldspar and biotite since it drains a granite catchment. During floods the Towamba River often destroys nearly half Whale Beach barrier and fills Twofold Bay with turbid water. Coarse sand and gravel settle rapidly very close inshore but the finer sands travel further offshore. Rough seas generated by the same flood-inducing storms could maintain suspension of the very fine sand and mica flakes and, as such conditions often persist for at least two days, redistribution of some of this fine grade material to more sheltered areas within Twofold Bay is likely. When calmer conditions return, constructive waves gradually move some of this material shorewards, but only at Boydtown where wave activity is least vigorous is it deposited and incorporated within the beach sands.

The remaining beaches also have much in common and consist of medium grained, fairly well sorted, well rounded quartz sands, most of which are mesokurtic and negatively skewed. The non-quartz fraction is usually very low and often non-existent. These characteristics are similar to those expected of sands that have been worked for a long time and carried in from the continental shelf following the Holocene marine transgression. The yellow colour of the sands due to the ironstaining of the quartz is prominent and supports this assertion. Such staining is usually presumed to have occurred in the subaerial environment of the exposed continental shelf when sea level was lower during the last glacial (Emery, 1965; Bird, 1967) although evidence from the Atlantic shelf of the United States (Judd et al., 1970) shows that some rivers may have supplied large quantities of ironstained quartz to the shelf at the same time. The latter situation has not occurred in this study area since at Boydtown, Whale and Tathra beaches where there appears to be a continuing accession of terrigenous sediment, the sands are browny-grey in colour. On all beaches, sand colour becomes whiter as the proportion of calcareous material increases.

Although many minor sedimentological differences within this remaining group of beaches can be explained by variations in wave energy, other anomalies require alternative explanations. Nelson Beach is one such case, since its sands are finer grained than most, slightly more angular and strongly leptokurtic. Pronounced kurtosis is typical of multiple source sediments (Folk, 1968) and at Nelson Beach this may reflect the presence of a comparatively large non-quartz fraction. This beach is only 500 metres long and is recessed between two prominent headlands and this, coupled with reduced wave energy could encourage retention of finer grained weathering products from nearby cliffs. Since this material can only be distributed within a relatively small sand body, its concentration is increased with a resultant affect upon kurtosis and mean grain size. Nelson Creek, like the Nullica River, drains a metasediment catchment and may transport finer sediment through its substantially infilled estuary during floods. The volume of sediment from both river and cliffs must be quite small though; probably sufficient to affect the beach sand characteristics slightly but insufficient to obscure the origin of the bulk of the sand population. Another, though remote possibility is the collection of very fine sand brought down by the Bega River during floods and transported northwards under the influence of southerly waves generated by the same storms. Such material would have to travel nearly two kilometres past the intervening rocky shore.

Sands on Merimbula and Pambula beaches also depart from the general trend by being significantly more angular and finer grained. An obvious supplementary source is the arkosic sandstone and siltstone redbeds of the Merimbula Group which outcrop on adjoining headlands. These rocks have been extensively eroded and now exhibit well developed shore platforms backed by cliffs which are being rapidly degraded. The sediment so produced is mainly fine grained angular sand and some of it must eventually be deposited on Merimbula and Pambula beaches. It is unlikely that local streams are supplying similar material to the beach because they all flow first into Merimbula and Pambula lakes, both of which are large, lagoonal sediment traps.

It also appears that the Murrah River is supplying little if any sand to the coast at present. This is surprising because it is the fourth largest river in the area and drains deeply weathered granite in its upper and more elevated reaches. The apparently reduced degree of quartz rounding at Murrah Beach was not statistically significant when compared with the values from adjacent beaches, and the heavy mineral fraction recorded is more likely to have come from the gabbro outcropping at the southern end of the beach. The feldspar content however is unlikely to have been produced by headland erosion at either end of the beach, and may indicate that sand is being supplied by the river, but in extremely small quantities.

3.3 Examination of beach sediments within individual beaches

Discussion so far has been based on between beach comparisons which required grouping of the relevant data. This approach may obscure more subtle clues to sand origins which may only become apparent when sediment variability within particular beaches is examined. For example, the composition of beach material may vary near eroding headlands, or at river mouths through which sediment is transported, but when parameter values from these sites are grouped with those from other parts of the beach the importance of the former may not be recognized.

Any conclusions about variations within the smaller beaches must be qualified by the relatively small numbers of samples collected from them. In these cases, assessment of the statistical significance of the results was limited to comparisons of cumulative grainsize distributions using the Kolmogorov-Smirnov two sample test (Siegel, 1956). Where sample numbers were greater, distributions of actual statistics were compared using parametric correlation techniques (Yeomans, 1968). Correlations in the latter category are summarized in figure 3.8. Wapengo beach was not included in these comparisons.

Baragoot, Tathra and Aslings beaches displayed statistically significant longshore trends in mean grain size; at the first two beaches, sands became finer towards the south whereas at Aslings Beach, sands at the northern end are finest. On Nelson and Merimbula beaches where longshore sampling was not intensive, sands at the northern end were significantly coarser than those at the southern end. At all five beaches the distribution of mean grain size appears to match the distribution of wave energy after refraction of the dominant southeasterly swell. Finer sand is deposited towards the end of the beaches where waves are most refracted and energy correspondingly lowest.

At Tathra, the longshore trend has undoubtedly been accentuated by the concentration of coarse fluvial sand near the mouth of the Bega River at the northern end of the beach. Here, mean grain size was 0.75 phi but decreased progressively to 2.03 phi at the southern end.

The only significant sorting trend recorded was at Wallagoot Beach where sorting was better at the northern end. At Tathra and all the other beaches, sorting values were quite randomly distributed.

Merimbula beach sands were more negatively skewed towards the northern end but a similar trend at Baragoot was statistically insignificant. At Tathra, sands were more negatively skewed at the southern end of the beach, a pattern differing from that expected with northerly

BEACH	MEAN	SORTING	SKEWNESS	KURTOSIS	CARBONATE
BARAGOOT (n = 13)	r = 0.74 t = 3.66 *	r = 0.04 t = 0.13	r = 0.29 t = 1.01	r = 0.28 t = 0.97	r = 0.05 t = 0.17
MURRAH (n = 15)	r = 0.23 t = 0.85	r = 0.22 t = 0.81	r = 0.10 t = 0.36	r = 0.24 t = 0.89	r = 0.32 t = 1.22
TATHRA (n = 15)	r = 0.95 t =10.97 *	r = 0.11 t = 0.40	r = 0.92 t = 8.46 *	r = 0.68 t = 3.34 *	r = 0.81 t = 4.98 *
ASLINGS (n = 8)	r = 0.72 t = 2.54 *	r = 0.44 t = 1.20	r = 0.05 t = 0.12	r = 0.49 t = 1.38	r = 0.88 t = 4.54 *
BOYDTOWN (n = 8)	r = 0.51 t = 1.45	r = 0.26 t = 0.66	r = 0.54 t = 1.57	r = 0.13 t = 0.32	r = 0.31 t = 0.80
WHALE (n = 9)	r = 0.32 t = 0.89	r = 0.18 t = 0.48	r = 0.11 t = 0.29	r = 0.06 t = 0.16	r = 0.13 t = 0.35

Figure 3.8 Correlation between Various Sediment Parameters and Distance Along Beach. (An asterisk * denotes a statistically significant correlation).

increasing wave energy. This reversal may represent a progressive southward loss of inherited positive skewness as distance from the Bega River mouth increases.

Longshore differences in kurtosis were only evident at Nelson and Tathra beaches and both were more leptokurtic at their southern end. At Tathra, sands were slightly platykurtic towards the northern end of the beach and this also probably reflects increasing northward proximity to the mouth of the Bega River.

Beach carbonate levels at Cuttagee, Nelson, Tathra, Merimbula and Pambula beaches increased southwards; at Aslings Beach the opposite occurred. In all six cases the pattern was one of higher carbonate near extensive tracts of sheltered rocky shorelines where one could expect fairly large proportions of molluscs and other marine dwelling, shell bearing organisms. The trend at Tathra may also represent a dilution affect due to delivery of fluvial sand to the northern end of the beach.

Roundness and mineralogy was determined for insufficient samples to permit valid statistical testing of longshore trends in these parameters, but qualitative comparisons only indicated a large proportion of more angular quartz grains at the southern end of Merimbula Beach. There was no apparent trend for increased proportions of lithic sand near headlands, nor for more feldspar and other non-quartz minerals near river mouths.

These results provide only minor amplification of earlier conclusions and the trends that were observed appear closely linked to the longshore distribution of wave energy. At Tathra, a pattern of northward increasing wave energy combined with the supply of sand and gravel from the Bega River to the northern end of the beach has produced a very well defined longshore pattern of sediment distribution. Further north of the study area, at Seven Mile Beach, longshore sedimentological trends are also controlled by proximity to a river mouth sediment source.

However, in contrast with Tathra, the Shoalhaven River delivers sand to the southern end of the beach, and does so in quantities sufficient to over-rule rather than reinforce the longshore sedimentological trends expected to develop in response to the northerly increase in wave energy (Wright, 1967, 1970).

At Whale and Boydtown beaches, the only other two beaches at present receiving significant supplies of terrigenous sand, wave energy appears too greatly reduced to effect significant longshore organization of beach sediments. At Whale Beach any semblance of sedimentological organization would be destroyed by recurrent flooding of the Towamba River during which the central portion of the barrier beach is often removed.

3.4 Temporal Variability

Most beaches were sampled at least three times between June 1973 and January 1975 in order to minimize any bias that may have arisen in the results if sampling had been conducted once only. Accordingly it was possible to assess, albeit crudely, the temporal variability of beach sand parameters . It was not intended to assess regular seasonal trends; such studies require intensive resampling at very short time intervals (for ezample see Davis and Fox, 1975; Thom et al., 1973).

The results reveal a surprising stability in the values of nearly all parameters. Aslings and Boydtown beaches became significantly coarser after a series of storms in mid 1974, but at all other beaches, none of the changes observed were statistically significant, and were often contradictory. Only one parameter exhibited a consistent response to these storms. The proportion of beach carbonate declined substantially everywhere and had not been restored to former levels six months later. This phenomenon may reflect preferential removal of carbonate by the storm waves or it may be a dilution affect due to remobilization of large quantities of comparatively shell free sand from the badly eroded foredunes. As usual, the storms were accompanied by severe flooding in the Bega and Towamba rivers both of which probably delivered fluvial sands to the nearshore zone. No localized dilution effects were evident at Tathra and Whale beaches but may have been masked by the general reduction in beach carbonate levels.

In an enlarged time frame the values of the sedimentological parameters at Merimbula, Aslings and Boydtown beaches were very similar to equivalent values recorded between 1962 and 1965 by Hails (1967) and in 1962 by Davies (1973, pers. comm.)

3.5 Validity of the Sampling Scheme

After an investigation of 25 beaches along the eastern Australian coast between southern Queensland and eastern Victoria, Rosenberg (1971)reported statistically significant and consistent across-shore and longshore sediment trends and concluded that the latter were in response to a pattern of northerly increasing wave energy along the beaches studied. Her conclusions were based on one sample from each of four equi-spaced sites along each beach.In this thesis, sample numbers were boosted by resampling the same sites at different times, but the question remains of whether or not three or four samples collected in this manner are representative of the beach sand populations from which they were drawn at a particular time. More intensive resampling of three of the longer beaches permitted testing of this hypothesis.

Baragoot, Murrah and Tathra beaches were selected as representative beaches since they exhibit markedly different degrees of longshore sediment organization and have different histories in terms of sediment supply. Samples were collected at intervals ranging from 150 metres to 250 metres and the resulting sample sizes are indicated in table 3.2. A subset of three or four equally spaced sites was selected from a beach and the values of the various parameters from the subset were compared with the complete set of equivalent values from the same beach using the Mann-Whitney U Test (Siegel, 1956). The procedure was repeated at the other beaches in turn. Insufficient determinations of roundness and mineralogical values precluded testing of these parameters, but the sedimentological results are summarized below in table 3.2.

Table 3.2 Testing the "representativeness" of samples

BEACH	MEAN	SORTING	SKEWNESS	KURTOSIS	CARBONATE
BARAGOOT $U_{crit} = 4$	$U_{cal} = 18.5$	$U_{cal} = 18$	$U_{cal} = 17.5$	$U_{cal} = 19.5$	$U_{cal} = 11.5$
MURRAH $U_{crit} = 10$	$U_{cal} = 22.0$	$U_{cal} = 26$	$U_{cal} = 23.0$	$U_{cal} = 15.0$	$U_{cal} = 23.0$
TATHRA $U_{crit} = 6$	$U_{cal} = 18.5$	$U_{cal} = 18$	$U_{cal} = 18.5$	$U_{cal} = 20.5$	$U_{cal} = 20.5$

Baragoot n = 13, Murrah n = 15, Tathra n = 16

H_o : subset values = parent set
H_a : subset values ≠ parent set
Reject H_o if $U_{crit} > U_{calc}$

In each case, the smaller number of samples produced average parameter values which were not statistically significantly different to those calculated using a sample size approximately five times as big. It is concluded that three or four samples are statistically representative of the beach sand population from which they are drawn. They were quite capable of producing representative whole beach averages for the various parameters and were sufficient in number to recognizeand define any longshore sediment trends that were present.

3.6 Nearshore Sediments

Nine to twelve samples were also collected from each of the nearshore zones of Tathra, Merimbula and Aslings beaches to depths of approximately 15 metres. They were taken from the nearshore bar an outer bar and intervening trough if present, and from one or two sites in deeper water. An echosounder was used to record depths and to locate submerged bars. Three sampling traverses were run perpendicular to the shore from points off the southern and northern ends and the centre of each beach. At Aslings Beach the middle run was omitted. Random sampling of Twofold Bay sediments offshore from Boydtown and Whale beaches was also conducted.

The results for Tathra, Merimbula and Aslings nearshore zones are summarized in figure 3.9 and the equivalent beach face figures are included for comparison. At all locations, sands became progressively finer further offshore and the proportion of calcareous matter increased dramatically, especially in depths exceeding ten metres. Sands also tended to become more platykurtic with increasing depth but skewness trends were equivocal. Off Tathra and Aslings beaches sands became more negatively skewed in deeper water, whereas the opposite occurred at Merimbula. The latter case may reflect accession of very fine detritus from erosion of nearby headlands.

Feldspar was an important mineral constituent (8%) in Tathra nearshore samples, and was evenly distributed. Mica was only present in deeper water sites and values there averaged 4%. The same pattern occurred off Aslings Beach but the proportion was smaller (2%). Mica was absent from all nearshore samples at Merimbula. Quartz roundness was equivocal. At Tathra values remained much the same throughout the nearshore zone averaging 0.41 whereas off Merimbula and Aslings beaches, grains tended to be more angular in deeper water.

At Tathra, observed trends were often interupted by the presence of a second nearshore bar. At this point sands became a little coarser, less platykurtic and contained less carbonate than adjacent samples. The trough separating it from the first bar seemed to be a trap for finer sands and shell fragments.

At all three locations there was a very strong similarity between beach sands and those of the corresponding nearshore zone, particularly the nearshore bar, and no evidence to contradict earlier conclusions based on comparisons between beaches was apparent. Also,

TATHRA	Beach 0.0m	Bar 1 4.0 m	Trough 8.0 m	Bar 2 7.0 m	11.0m	14.0m
Mean (Ø)	1.30	1.54	2.00	1.78	2.13	2.23
Sorting	.52	.52	.44	.50	.45	.55
Skewness	-.53	-.61	-.42	-.50	-.45	-.47
Kurtosis	3.62	3.78	4.86	3.71	5.42	6.04
Carbonate %	3.33	4.99	7.28	5.98	13.56	28.92
Roundness	.37	.43	.41	.40	.37	.40
Non-Qtz. %	16	18	11	15	9	16

MERIMBULA	Beach 0.0 m	Bar 4.0 m	6.0 m	11.0 m	14.0m
Mean (Ø)	1.64	1.86	1.80	2.31	2.32
Sorting	.43	.52	.52	.58	.54
Skewness	-.13	-.17	-.26	-.54	-.66
Kurtosis	3.22	2.89	2.90	4.14	4.95
Carbonate %	5.09	9.28	19.26	34.72	52.78
Roundness	.55	.54	.54	.51	.48
Non-Qtz. %	0	3	2	5	7

ASLINGS	Beach 0.0 m	Bar 4.0 m	7.0 m	12.0 m	15.0 m
Mean (Ø)	1.08	1.18	1.71	2.38	2.42
Sorting	.48	.60	.58	.55	.63
Skewness	-.29	-.20	-.66	-.34	-.52
Kurtosis	3.27	2.78	4.29	4.10	3.63
Carbonate %	3.31	3.54	11.44	44.10	64 03
Roundness	.64	.64	.52	.55	N/A
Non-Qtz %	3	3	8	7	N/A

Figure 3.9 Sand characteristics at specified depths in nearshore zone of Tathra, Merimbula and Aslings beaches, N.S.W. N/A indicates not analysed.

longshore trends in nearshore sands parallelled those observed in beach face deposits. Tathra bar, trough and deepwater samples all became progressively finer, more negatively skewed, more leptokurtic and richer in carbonate towards the southern end of the bay, but as was the case on beach face samples, no sorting trend was apparent. At Merimbula the only trend observed was a southward fining of nearshore samples, and off Aslings beach no significant longshore trends occurred at all.

Within the southern portions of Twofold Bay only twelve random samples were collected from depths up to 15 metres, but the results broadly support the conclusions from the other three areas. The most obvious trends were for increasing carbonate and diminished mean grainsize values in deeper water. Muds were an important sediment component in depths exceeding 5 metres, the average proportion being approximately 10% by weight. Gravel was not detected in any samples, even from the nearshore bar of Whale Beach. Mean grainsize averaged 2.41 phi overall but in Nullica Bay sands were finer at approximately 3.0 phi. Off Whale Beach they averaged 1.96 phi.

Carbonate levels were high throughout but increased to an average level of 25% in depths exceeding 10 metres. Lowest values were recorded within 800 metres of Whale Beach and averaged only 5%. Sorting was poor generally (0.70) and on Whale Beach bar only improved to 0.43. All samples were negatively skewed except those adjacent to Whale Beach where positive values were recorded. Quartz grains were very angular in all samples, the average value being 0.35 and, as was the case with kurtosis, there were no apparent trends.

Samples contained 77% quartz on average with minor components of lithic sand (4%), feldspar (6%) and mica (6%). The remaining 7% consisted mainly of opaques and a small proportion of hornblende. Apart from the absence of mica in the Whale Beach bar sands, no preferred distribution of mineral components was apparent.

3.7 Offshore Sediments

Offshore sediments were not sampled at all for this study but the numerous interpretations of sedimentological and seismic data collected during cruises over the southeastern portion of Australia's continental shelf (Bembrick, 1973; Davies, 1975; Davies and Marshall, 1972; Kamerling, 1966; Phipps, 1963, 1967; Shirley, 1964) reveal an essentially simple and continuous morpho-sedimentary pattern normal and subparallel to the N.S.W. coast, a pattern with which the nearshore sediments already described conform strongly.

Extending seawards from the shore to depths of approximately 100 metres is a shoreline zone of often irregular topography which slopes seawards at 1 to 2 degrees and which terminates as a distinct break of slope. Adjoining it is a flat and very smooth to slightly irregular shelf plain zone which extends out to depths of approximately 150 metres. The entire shelf is less than 30 km wide and beyond it, the continental slope, featuring occasional submarine canyons, drops rapidly to the ocean floor.

Three shelf sediment facies of unconsolidated sands have been recognized. The shoreline zone is thinly mantled by a seaward thinning wedge of quartzose sands which contain up to 50% shell carbonate. They are moderately well sorted, fine to coarse grained sands which tend to be coarser near headlands and occasionally finer near some river mouths (for example, the Hunter River at Newcastle). A strong affinity exists between these sediments and those collected from the nearshore zone during the present study, particularly those sediments from the deeper areas beyond the nearshore bars of the ocean beaches.

A seaward thickening wedge of highly calcareous (60 - 90%) poorly sorted coarse sands and bioclastic gravels cover the outer shelf plain and much of the upper continental slope, near which point the maximum thickness of this facies ($\approx$500 m) is attained. Many of the sands, both mineral and calcareous are ironstained which suggests that these sediments are at least in part relic deposits of a lower sea level stand.

An intermediate zone outcrops between these two facies and in part overlies them. This is a terrigenous facies consisting of muddy, fine grained, moderately to well sorted, mainly quartzose but frequently calcareous sand, and is thought to represent the fine suspended load delivered to the sea by rivers during floods.

The spatial arrangement of these shelf sediment facies conforms with Veevers' (1967) model of continental shelf sedimentation; in this region though, with only a few exceptions, the nearshore sand bodies have not resulted from contemporary fractionation of the sand and mud loads of the rivers as they debouch into the sea. In most cases, such fractionation must occur within the estuaries where sand and gravel is effectively trapped and only the mud and finest sands escape to the sea in suspension.

3.8 Review

Analysis of beach and nearshore sediments has provided considerable information relevant to the origin(s) of the coastal sands and the nature of the coastal sediment budgets in the study area. Sands on the majority of beaches display features which are diagnostic of considerable reworking, and it seems very likely that they have been carried in from the continental shelf since the postglacial rise in sea level. Minor variations between sediments in these beaches reflect varying wave energy conditions at each locality. There are no detectable inputs of sand to them from local coastal streams except at Nelson and contributions from cliff erosion are generally unimportant. These deposits will be referred to collectively as marine sands in ensuing discussion.

Whale and Tathra beaches are obvious exceptions to this general pattern and it is clear that their sands have been and continue to be supplied by the Towamba and Bega rivers which drain large, elevated, granite catchments of high relief. Boydtown and to a lesser extent Nelson beaches are also being replenished with terrigenous sediment from local streams and/or erosion of headlands. At Boydtown the input is more apparent because diminished wave activity allows more of the fine grained detritus to be deposited on the beach, whereas at Nelson only the coarser components of this material are deposited. The latter are still sufficiently fine grained, compared with other sand on NelsonBeach to effect minor changes to the sedimentological parameters recorded but are unable to disguise the source of most of the sand population. It also seems likely that Boydtown beach receives fine sands (quartz, feldspar and mica) indirectly from the Towamba River after major floods as hypothesised earlier. Analysis of Twofold Bay floor sediments supports this idea.

Erosion of headlands and rocky shores has contributed very little sediment to the beaches. Many of the exposed rocks are quite resistant to wave attack as evidenced by the scarcity of shore platforms along this section of coast, and more often than not, the detritus produced is too fine to be deposited on the high energy beaches. Exceptions occur at Merimbula and Pambula beaches and possibly at Boydtown and Nelson beaches.

The limited evidence obtained from the nearshore zones shows that the "beach" sediments do not extend far offshore before being replaced with a finer grained, more calcareous sand. The general organization of sands in this zone supports the neutral zone concept of Ippen and Eagleson (1955) and also suggests that shoreward transport of mineral sand from the shelf has probably ceased. Evidence from other parts of southeastern Australia led Davies (1974) to similar conclusions.

Furthermore, the beach sediments are confined to discrete compartments between which little or no sediment is exchanged.

Tathra, Aslings, Boydtown and Whale beaches definitely contain discrete sand populations. Merimbula and Pambula appear likely to be separated by a small intervening headland, however this barrier is largely ineffectual and together these two beaches comprise a single compartment from which no sediment escapes. There is no reason to suppose that the remaining beaches are different in this respect, but on the basis of the sedimentological evidence one cannot dismiss the possibility of sand transport between them.

Strong littoral transport requires, inter alia, a strong longshore wave power component and data from a later chapter indicate that this does not exist. Also, the existence of longshore sediment trends related to the longshore distribution of wave energy supports the existence of discrete compartments, because such longshore trends would be destroyed by longshore drifting of sediment.

Examination of local beach sands coupled with that of local river sands indicates that this length of coast is one of impeded sediment transport. Most of the beach sands appear to have been transported shorewards following the Holocene postglacial rise in sea level and can be considered as relic deposits given the apparent cessation of supply from the continental shelf. Only in a few cases are beaches being replenished with sand from rivers and/or erosion of headlands. Carbonate sediment is produced biogenically within the nearshore zone, and there is some recycling of mineral sand from eroded foredunes after coastal storms.

Captions to accompany plates 3.1 - 3.12

These photomicrographs were also taken in polarized light with crossed nicols. Unless otherwise specified, most grain diameters are between 1 and 2 phi.

Plates 3.1 - 3.6 illustrate typical marine sands, that is, those that have been transported landwards from the continental shelf since the postglacial rise in sea level. Grains are almost entirely quartzose and are well rounded.

Plates 3.7 - 3.8 illustrate sands from Whale and Tathra beaches, both of which are being supplied with fluvial sand at the present time. Note the presence of feldspar, and the greater angularity of the quartz grains compared to those in the first six plates.

Plate 3.9 depicts sand from Murrah Beach where a much wider dispersion of roundness values is indicative of a basic population of mature sands to which another small population of relatively immature fluvial sand is being added. Feldspar is a minor but an important diagnostic component.

Plates 3.10 - 3.12 represent sands from three other localities where other factors are operative. At Pambula Beach, a sub-population of finer (2-2.5 phi) angular quartz grains is intermixed with other typically marine sands. The former are most probably derived from erosion of the sandstones which outcrop in nearby headlands.

The modal size of the Boydtown beach sands shown in Plate 3.11 is approximately 2.5 phi. Note the general angularity of the grains. They are quite different from the typically well rounded quartz sands found on most of the ocean beaches. Plate 3.12 shows a high magnification view of some other well rounded quartz grains which dominate the beaches found just inside the entrance to Wapengo Lagoon. These too are relic marine sands that have been transported landwards from the continental shelf.

PLATE 3·1

BARAGOOT B.

(244)

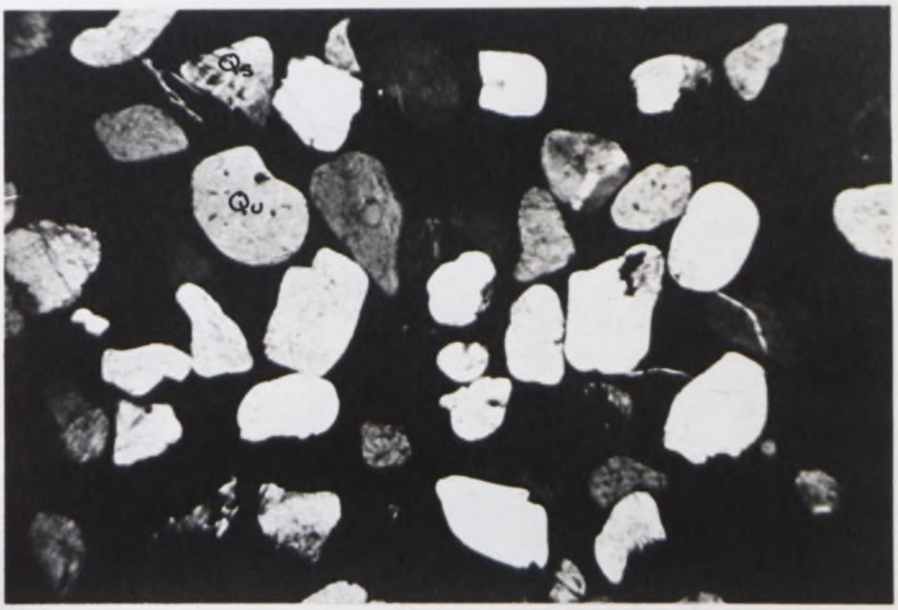


PLATE 3·2

CUTTAGEE B.

248)

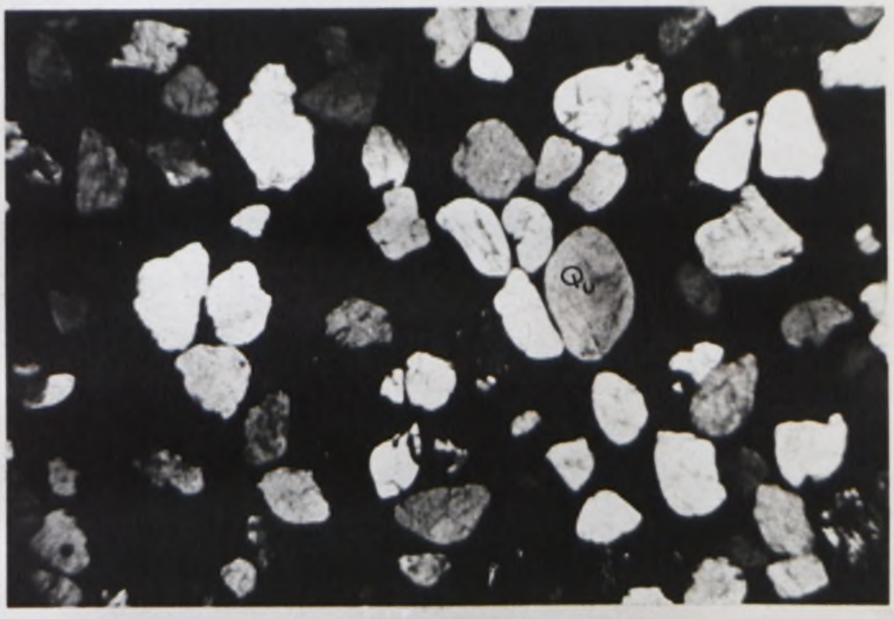


PLATE 3·3

WALLAGOOT B.

(70)

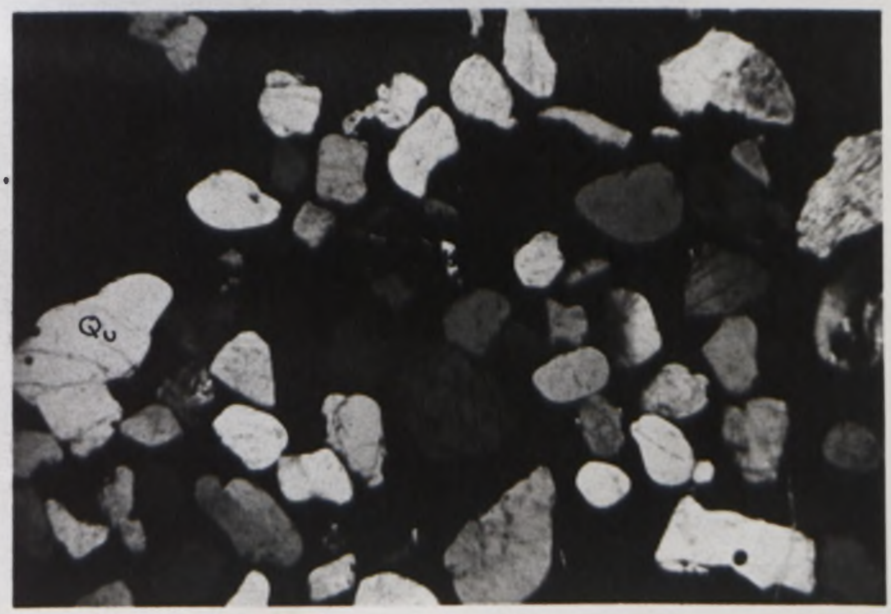


PLATE 3·4

MERIMBULA BEACH

(7)

PLATE 3·5

ASLINGS B.

(265)

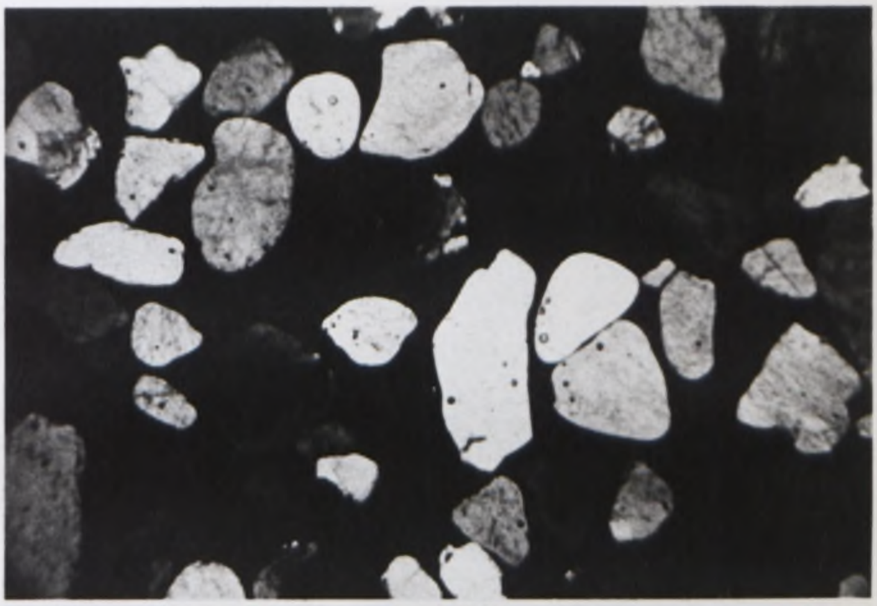


PLATE 3·6

SHORT PT. B.

(268)

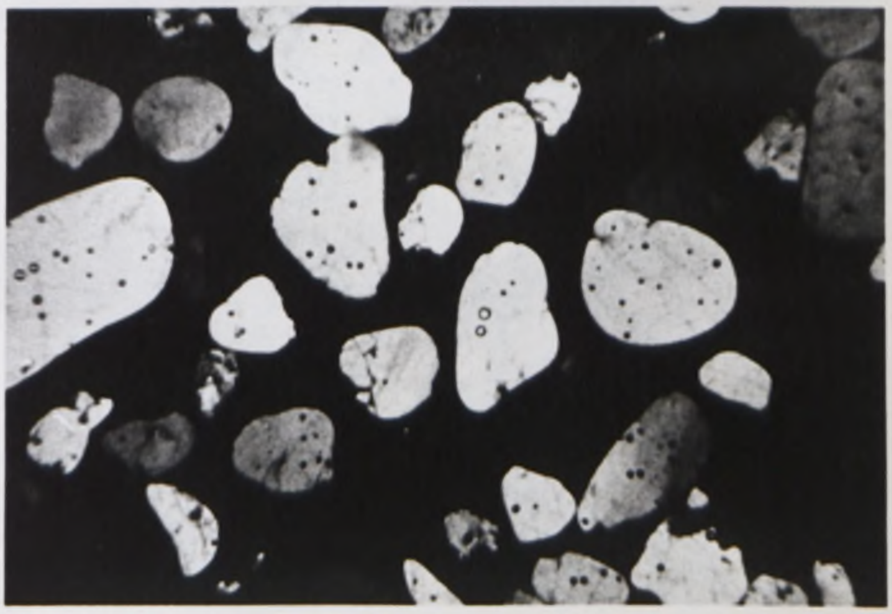


PLATE 3·7

WHALE B.

(20)

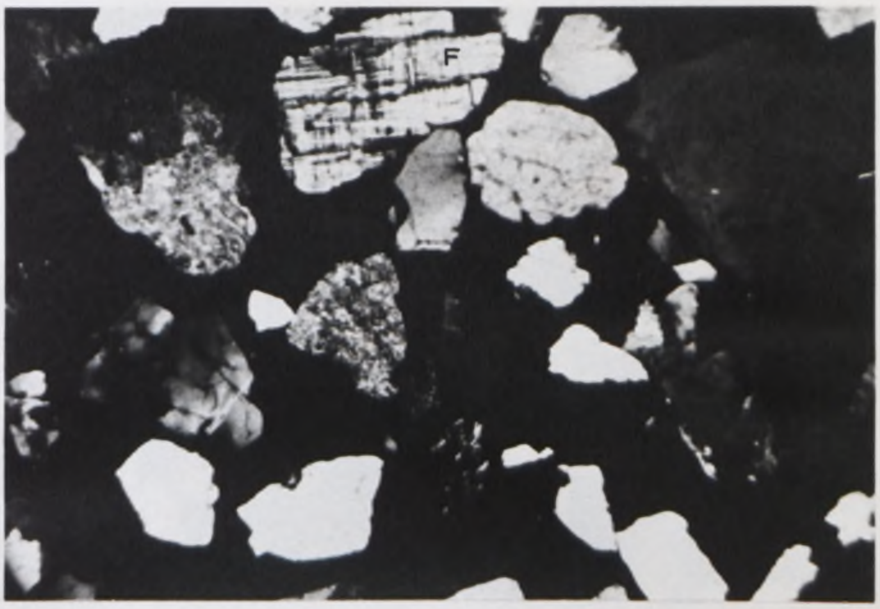


PLATE 3·8

TATHRA B.

(257)

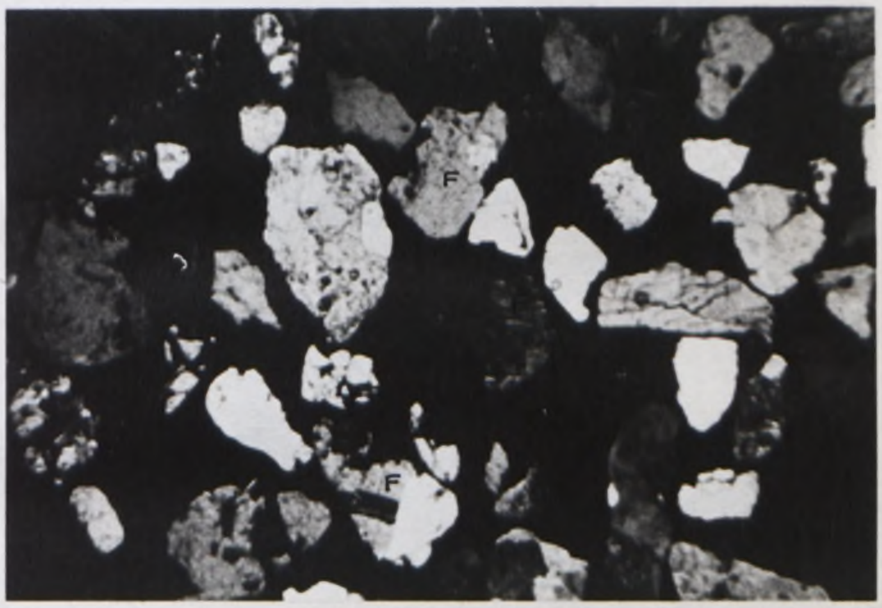


PLATE 3·9

MURRAH B.

(329)

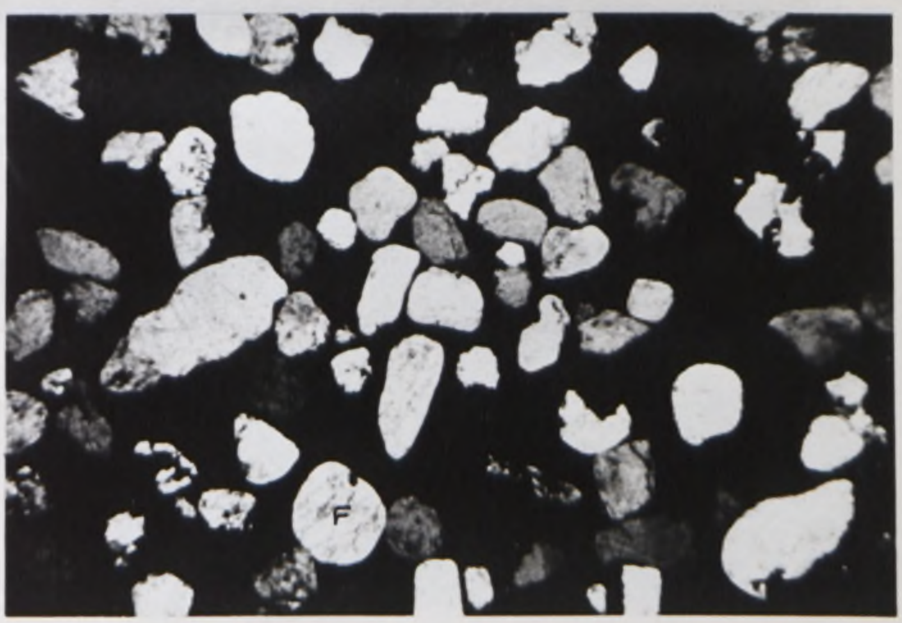


PLATE 3·10

PAMBULA B.

(266)

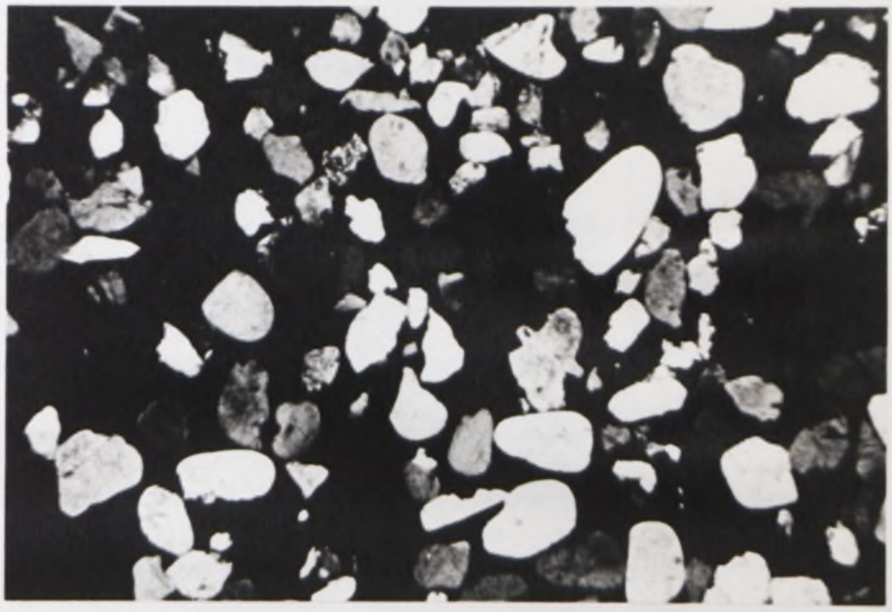


PLATE 3·11

BOYD TOWN BEACH

(260)

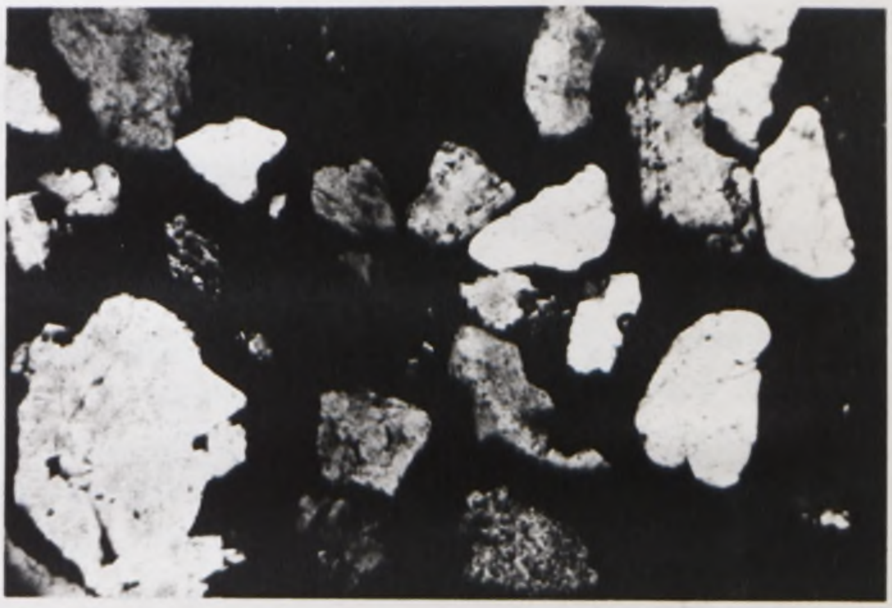
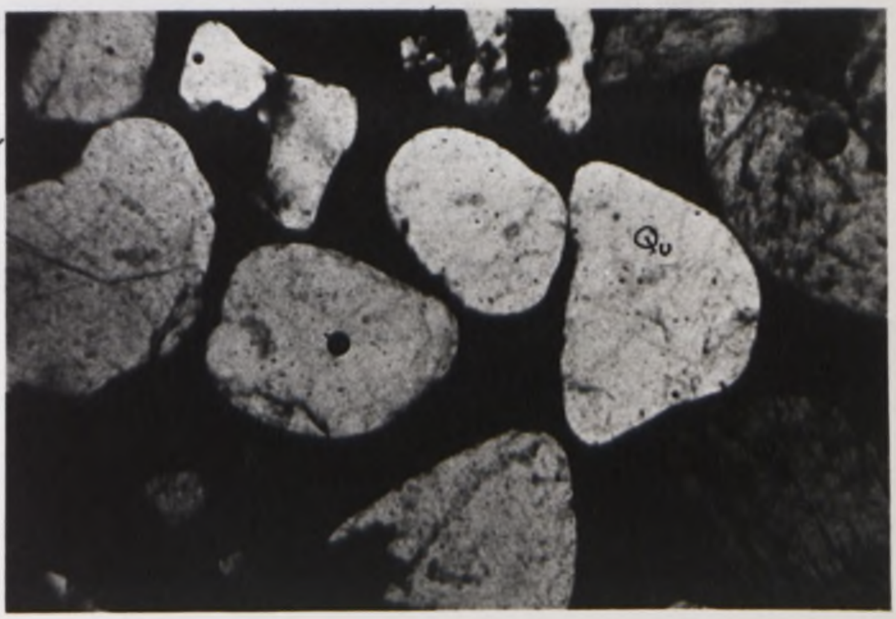


PLATE 3·12

WAPENGO "B"

(253)



CHAPTER FOUR: SEDIMENTS IN THE ESTUARIES

It is apparent that the majority of beaches are not being replenished with sand by local rivers. The two exceptions are fed by the larger Bega and Towamba rivers which have infilled their valleys substantially and thus facilitated "through transport" of sediment to the coast. Similar degrees of infilling have occurred in the estuarine sections of the Nullica River and Nelson Creek but as yet, the evidence from these two localities has not permitted unequivocal conclusions to be drawn about the origin(s) of the infilling sediments. Analysis of the sediment from the estuarine sections of all the rivers should resolve the remaining uncertainties.

4.1 Sampling and Laboratory Analysis

Subaqueous samples were obtained by lowering a grab sampler from an inflatable boat, the position of which was determined by taking compass bearings to at least three landmarks. Usually, only surficial samples were collected, and all sites were marked on large scale air photographs (1:18000). Maps showing the location of sample sites, together with tables of sample data are included as appendices in the rear pocket. Laboratory analysis was the same as for the river and beach sediments except for some estuary floor samples which required initial treatment with hydrogen peroxide to remove organic matter.

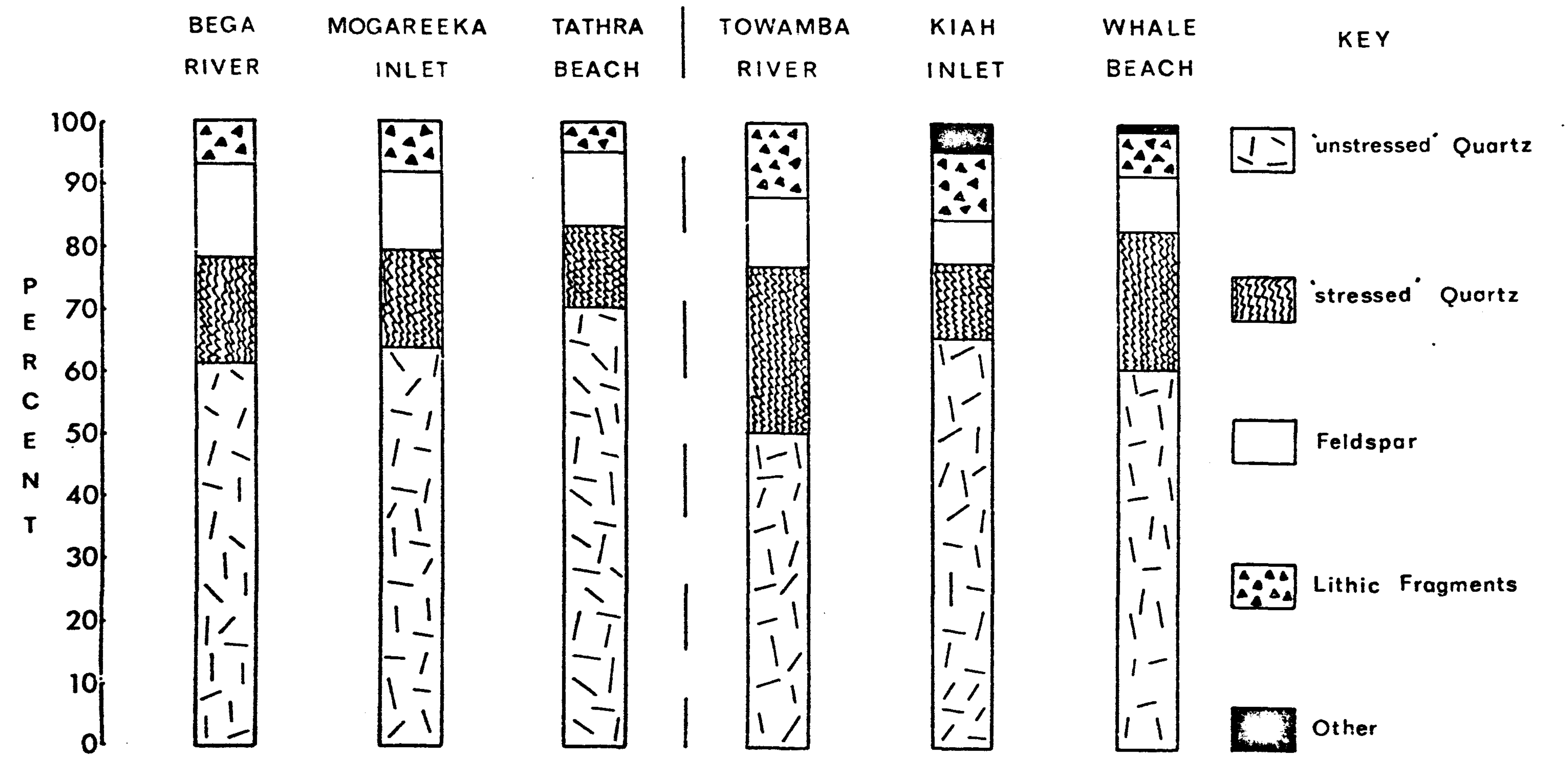
4.2 Sediments in the Bega and Towamba River Estuaries

Figures 4.1 and 4.2 summarize the sedimentological and mineralogical characteristics of the sands collected from Mogareeka and Kiah inlets, these being the names given locally to the estuarine portions of the Bega and Towamba rivers respectively. Corresponding values from the associated beaches and rivers are also included to allow comparison

		RIVER	ESTUARY	BEACH
PERCENT GRAVEL	B	28	22	1
	T	20	14	2
PERCENT COARSE & V.C. SAND	B	89	79	46
	T	84	84	92
PERCENT MEDIUM SAND	B	11	18	43
	T	14	14	8
PERCENT FINE AND VERY FINE SAND	B	10	3	11
	T	2	2	-
MEAN GRAIN SIZE (Ø)	B	-.03	.19	1.19
	T	.21	.19	.23
SORTING	B	.62	.69	.53
	T	.81	.66	.53
SKEWNESS	B	-.44	.41	-.42
	T	.60	.12	.52
KURTOSIS	B	3.12	3.30	3.44
	T	2.68	2.04	2.82
Quartz Roundness	B	.24	.24	.37
	T	.20	.19	.25
PERCENT CARBONATE	B	-	1	3.41
	T	-	1	1

Figure 4.1: Sedimentological characteristics of sands from the Bega and Towamba rivers, their estuaries and the adjoining beaches. B = Bega River system; T = Towamba River system .

FIGURE 4-2 Average Mineralogical Composition of Sands from Beach, Estuarine and Fluvial Environments of the Bega and Towamba river systems.



of the sediments from the different environments and also to demonstrate the continuity of sediment transport through these two estuaries.

Gravel and coarse sand dominate the estuary sediments at both localities with fines being present only in very small proportions in samples from sheltered backwaters. The proportion of gravel declines from 30% and 20% immediately above the tidal limits of the Bega and Towamba rivers to 17% and 12% just landward of their respective river mouths, but very little reaches the sea, as indicated by the low values recorded in the beach samples. The possibility of it being deposited "permanently" in the nearshore zone where incident waves are unable to move it onto the beach is precluded by the absence of such material in nearshore samples.

The coarse sand content averaged 73% and 83% in Mogareeka and Kiah inlet samples and the average mean grain size of sands from both areas was 0.19 phi. The sands were only moderately sorted and positively skewed throughout. Those from Mogareeka Inlet were mesokurtic overall but those from Kiah Inlet were significantly platykurtic. These values indicate negligible resorting by tidal currents. The proportion of calcareous material was extremely low and never exceeded 4% by weight. Quartz grains were angular to subangular in both estuaries. The non-quartz fraction was dominated by feldspar and lithic fragments and at Kiah Inlet, a few backwater samples contained traces of mica.

Overall, the evidence indicates that sands throughout the length of these two estuaries are of fluvial origin, and despite the modifications due to wave action, the basic sedimentological affinity between the beach and river sands remains unobscured.

4.3 Sediments in the smaller estuaries

With the exception of Nelson and Nullica, the remaining estuaries display a marked spatial discontinuity in their sediment transport patterns. River sediments are intercepted and trapped in an estuarine basin which effectively prevents all but suspended muds reaching the sea. Three distinct depositional units result - stream channel deposits below tidal limits which usually terminate as small fluvial deltas, threshold or reverse tidal delta sands which partially seal the estuaries from the sea, and between these two units, an estuarine basin. Sediments from the three units are considered separately.

4.3.1 Stream Channel Sediments Below Tidal Limits

The attributes of these sediments are shown in figures 4.3 and 4.4 and demonstrate a strong affinity with the fluvial sediments sampled above tidal limits. Gravel was an important component of many samples but the proportions recorded were considerably less than those from river sediments further upstream. Very small amounts of fines (<5%) were found in a few samples collected from subaqueous delta lobes. The proportions of coarse, medium and fine sand varied a lot, but the former group was usually dominant and this is reflected in the mean grain size values. Fine sand was most common on the distal extremities of the deltas. Sorting was consistent throughout and only rarely were samples even moderately sorted. Skewness and kurtosis values generally indicated log-normality of grain size distributions.

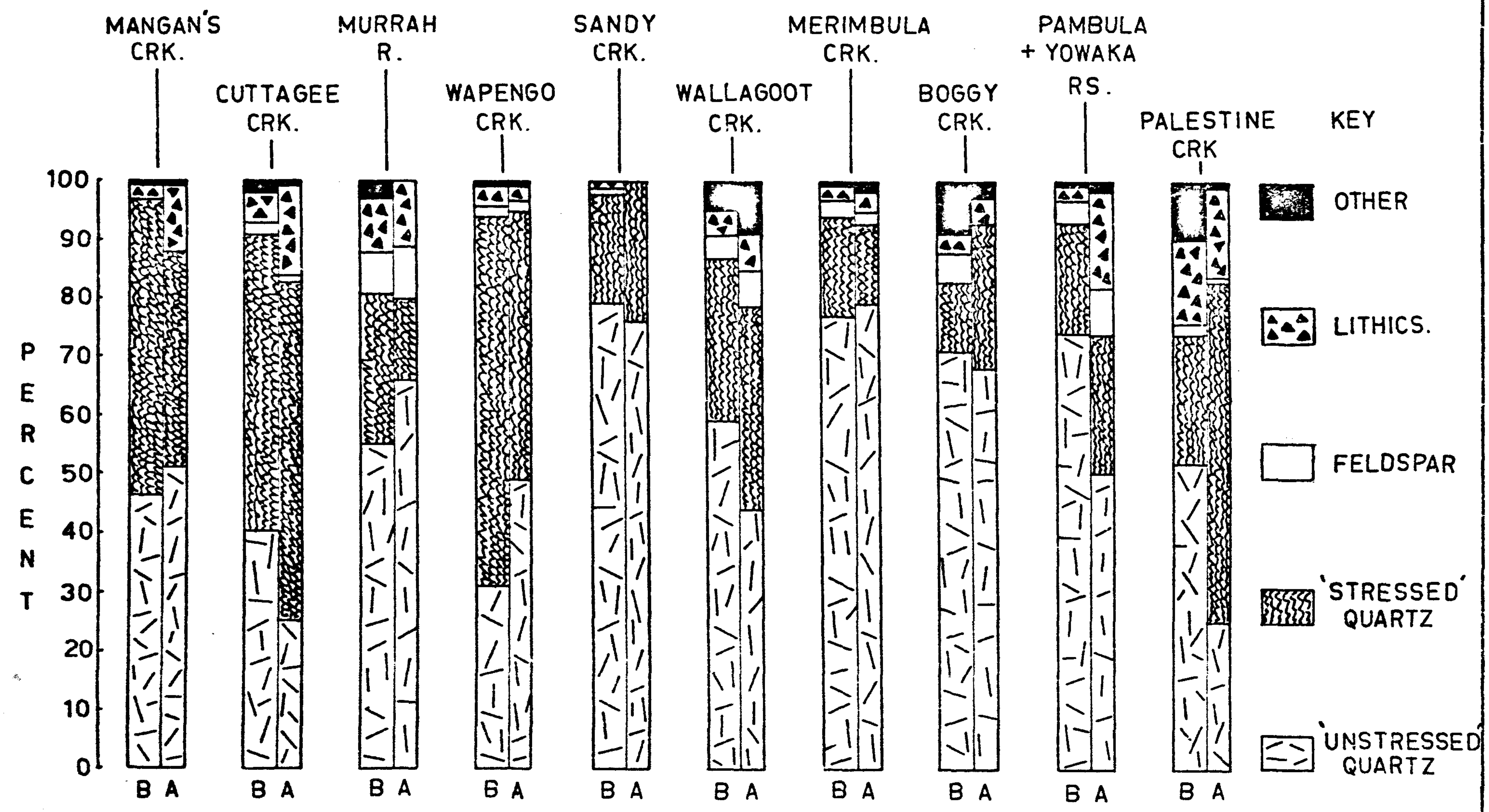
Quartz grains were subangular to angular and the mineralogy of samples was consistent both with samples from above tidal limits and with the respective catchment lithologies. Calcareous material was usually absent and even in areas leased to oyster farmers the proportion never exceeded 3.5% by weight.

Consistent and often substantial downstream changes in sedimentological parameters were also evident, sands becoming finer, slightly better sorted and more rounded downstream. The short lengths of the stream sections involved (maximum 5 km) suggest that selective sorting due to preferential transport of finer and/or rounder grains is more important than abrasion. Mineralogical variability downstream was considerable but inconsistent, and reflects the relatively small number of samples analysed.

STREAM	PERCENT GRAVEL		MEAN (Ø)		SORTING		SKEWNESS		KURTOSIS		ROUNDNESS	
	B	A	B	A	B	A	B	A	B	A	B	A
Mangan's Creek	30	39	.64	.21	.80	.88	.54	.56	3.70	2.64	.43	.27
Cuttagee Creek	1	52	1.58	.09	.67	.99	.14	.74	4.09	4.39	.32	.28
Murrah River	11	<5	1.11	.47	.66	.46	-.14	-.22	2.66	2.82	.33	.29
Wapengo Creek	0	39	2.00	.29	.75	.82	.33	.97	2.76	4.36	.31	.31
Sandy Creek	8	35	.69	.13	.66	.73	-.01	.79	2.75	3.91	.46	.33
Wallagoot Crk.	8	29	1.92	-.22	.89	.91	-.52	.82	2.94	3.02	.39	.27
Merimbula Crk.	<1	<5	1.57	1.01	.64	.83	.00	.62	4.25	3.71	.46	.22
Boggy Creek	<1	25	2.31	.57	.59	.87	-.14	.32	4.01	2.54	.31	.22
Pambula/Yowaka R	<1	31	1.65	.62	.60	.69	.32	.41	3.87	2.80	.33	.22
Palestine Crk.	<1	31	2.14	.77	.85	.81	.21	.03	2.52	2.68	.43	.26

Figure 4.3 Comparison of average sediment characteristics of River Samples Above (A) and Below (B) Tidal Limits.

FIGURE 4·4 COMPARISON OF RIVER SAND MINERALOGY ABOVE (A) AND BELOW (B) TIDAL LIMITS



4.3.2 Threshold Sands

Figures 4.5 and 4.6 summarize the characteristics of the threshold sands at the mouth of the estuaries and indicate a very strong affinity with nearby beach sands. Gravel and fines were absent and medium sand was the dominant grade recorded. Mean grain size values varied little between thresholds only ranging between 1.11 phi and 1.75 phi. The sands were moderately well sorted and were lognormally distributed on the basis of the skewness and kurtosis values. Shell fragments averaged only 3% by weight. Quartz grains were the main mineralogical component and these grains were typically well rounded and iron-stained.

These threshold sands represent a sub-population of "marine" sands from the adjacent beach zone and have been transported into the estuaries by tidal currents. At a few sites, onshore winds occasionally add backbeach and dune sands to the thresholds. Despite the basic homogeneity, the threshold sands are not identical to the beach sands and their grainsize distributions have been slightly modified due to the different mode of transport and the lower energy environment within the estuaries. Although only a few of these differences were statistically significant, the majority were consistent. In general, threshold sands were finer, less negatively skewed, increasingly leptokurtic, less well rounded and contained reduced proportions of calcareous material and an increased proportion of non-quartz minerals than their counterparts on the beaches.

Sedimentological variability was also apparent within individual thresholds but the patterns were rarely the same in all estuaries. The only parameters which varied consistently, parallel to the general direction of tidal flow, were sorting, kurtosis and the proportion of calcareous material. As distance from the sea increased, sands became marginally less well sorted, the carbonate levels declined, and the grain size distributions tended to become slightly leptokurtic. Cuttagee, Curalo and Wapengo threshold sands became less negatively skewed, more angular and

FIGURE 4·5 COMPARISON OF SOME BEACH (B) AND THRESHOLD (T) SANDS

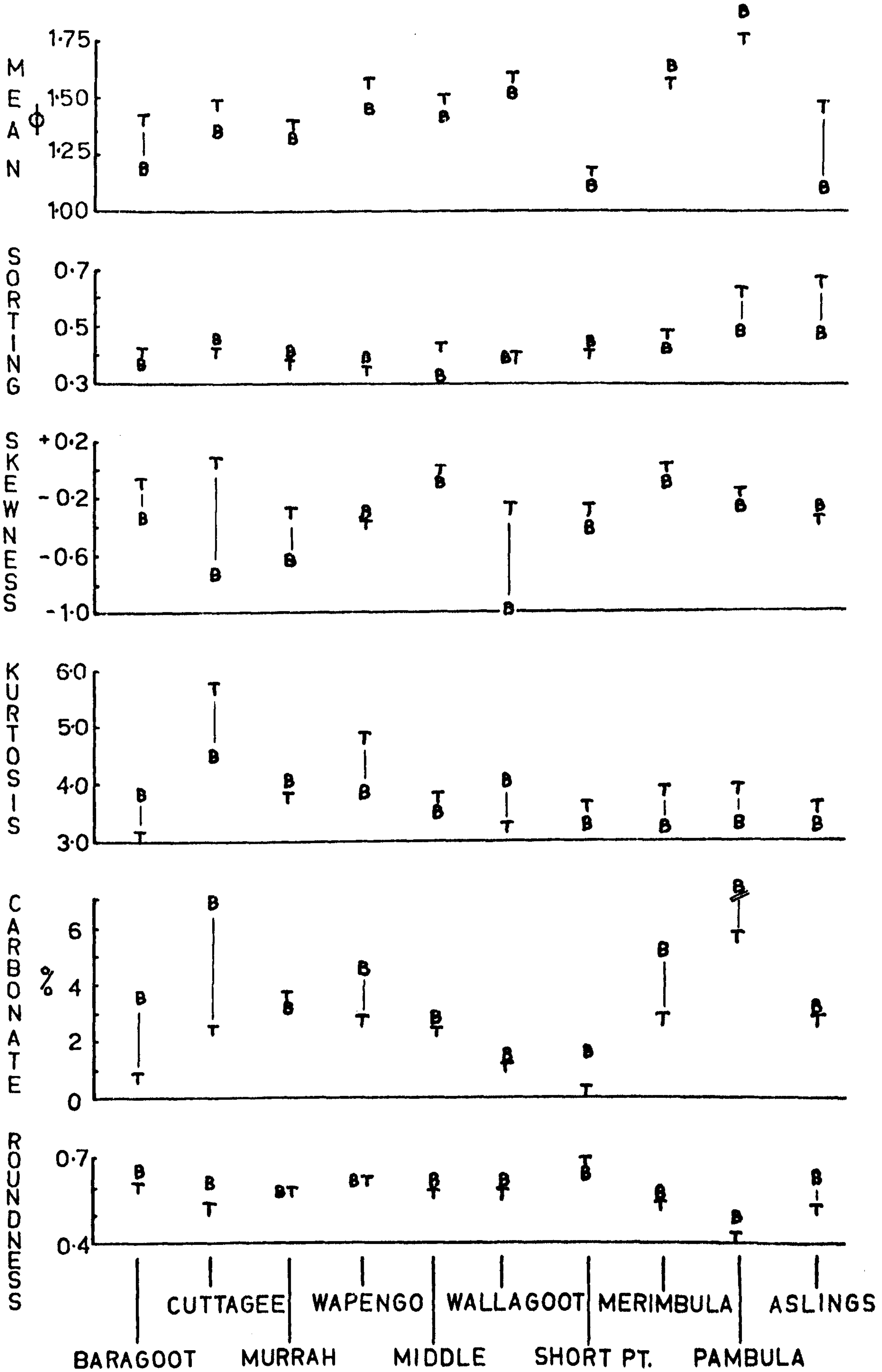
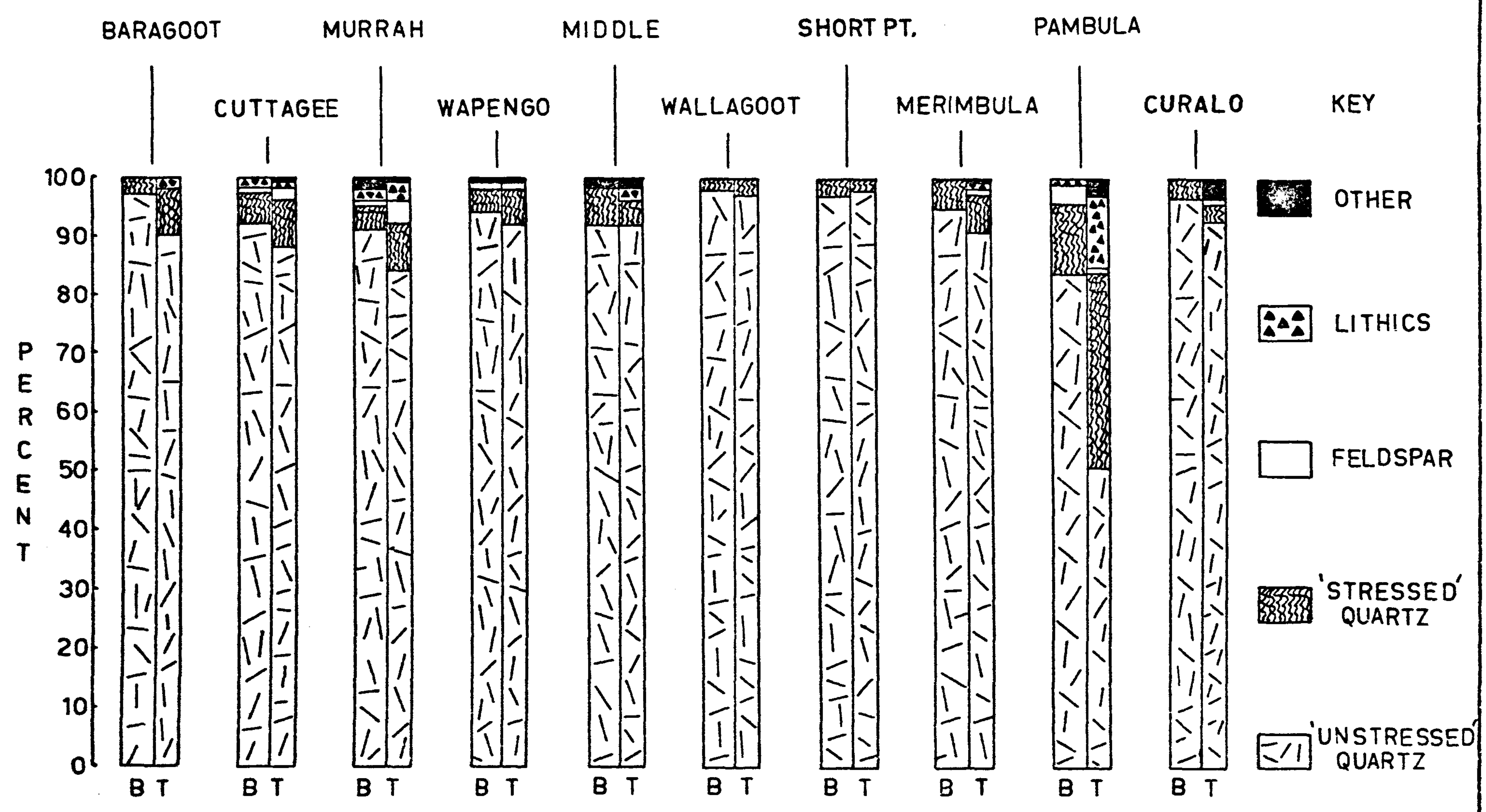


FIGURE 4·6 COMPARISON OF BEACH (B) AND THRESHOLD (T) SAND MINERALOGY



contained greater proportions of non-quartz minerals further from the sea. At these two localities the distal sections of the thresholds are quite close to the distal lobes of the stream deltas and it seems that small amounts of fine fluvial sand are transported over the small intervening water gap and are deposited on the threshold. A few samples from these sites also contained traces of mud (<5% by weight). At Cuttagee, steep bedrock slopes border the landward portions of the threshold and slopewash probably contributes small amounts of "immature" sediment. These additional sediment inputs are undoubtedly partly responsible for the observed modifications of sand roundness, mineralogy and the grainsize distributions.

At Wallagoot and Merimbula where adjoining bedrock slopes are generally less prominent, such trends are not developed. However at Merimbula there was a statistically significant difference across the threshold such that sands on the northern side were coarser and less negatively skewed than those on the southern side. Slopewash from bedrock slopes bordering parts of the northern shore must be partly responsible but the effect is probably enhanced by the delivery of sandy detritus by storm water drains from the township centred on the northern side of the estuary.

The colour of the threshold sands also changes according to proximity to the sea and the extent to which they have been colonized by various organisms. Near the mouth of the estuaries where clean marine sand is most frequently deposited, sands are yellow and the biological component is quite small. Further into the estuaries the intertidal and channel sands support large colonies of soldier crabs and more sedentary molluscs which by regurgitation and excretion impart a grey tone to the sands. At Merimbula, discolouration was even more marked near the storm water channels. Overall though, the physical characteristics of the sands remained unchanged and their marine origin was quite apparent.

4.3.3 Basin Sediments

The estuarine basin which characteristically separates seaward moving river sediments from landward moving marine sediments within this group of estuaries is a very low energy environment and this is strongly reflected by the sediments in it. Mud is the dominant component of the floor sediments in all the basins and sand is only a significant element near the shoreline and the deltas. Usually, samples from the deepest and lowest energy areas contained less than 5% sand by weight and the sediment simply comprised a black, often malodourous mud with minor amounts of whole shells and shell fragments. Silt was the main constituent and the silt/clay ratio rarely fell below 5:1. These samples also contained a high proportion of decayed organic matter, the proportion of which was not calculated, but after treatment with a solution of hydrogen peroxide samples commonly diminished in volume by more than 50%, and some retained a bituminous residue.

When sands were present in appreciable quantities they were nearly always of fluvial origin. They were fine grained, moderately to poorly sorted, slightly positively skewed and contained significant amounts of feldspar and lithic fragments. Quartz grains were angular to subangular. Such sands were often found a few hundred metres away from the river deltas, whereas the more rounded marine sands were rarely found more than 5 to 10 metres beyond the base of the landward margin of the thresholds.

Closer to the shore the amount of mud declined until on small beaches subjected to wind waves generated within the estuary, muds were absent. These "beach" sands were composed largely of debris washed down from bordering slopes and/or material produced by shoreline erosion. Beaches nearer the threshold or river delta displayed a greater affinity with the sediments from these particular bodies.

Overall, sediment on the floors of the estuarine basins was dominated by silt and lesser proportions of very fine sand derived from erosion of the hinterland. Field observations indicated that transportation and deposition of this material only occurs during and immediately after flooding of the tributary streams.

4.4 Sediments in the Nelson and Nullica Estuaries

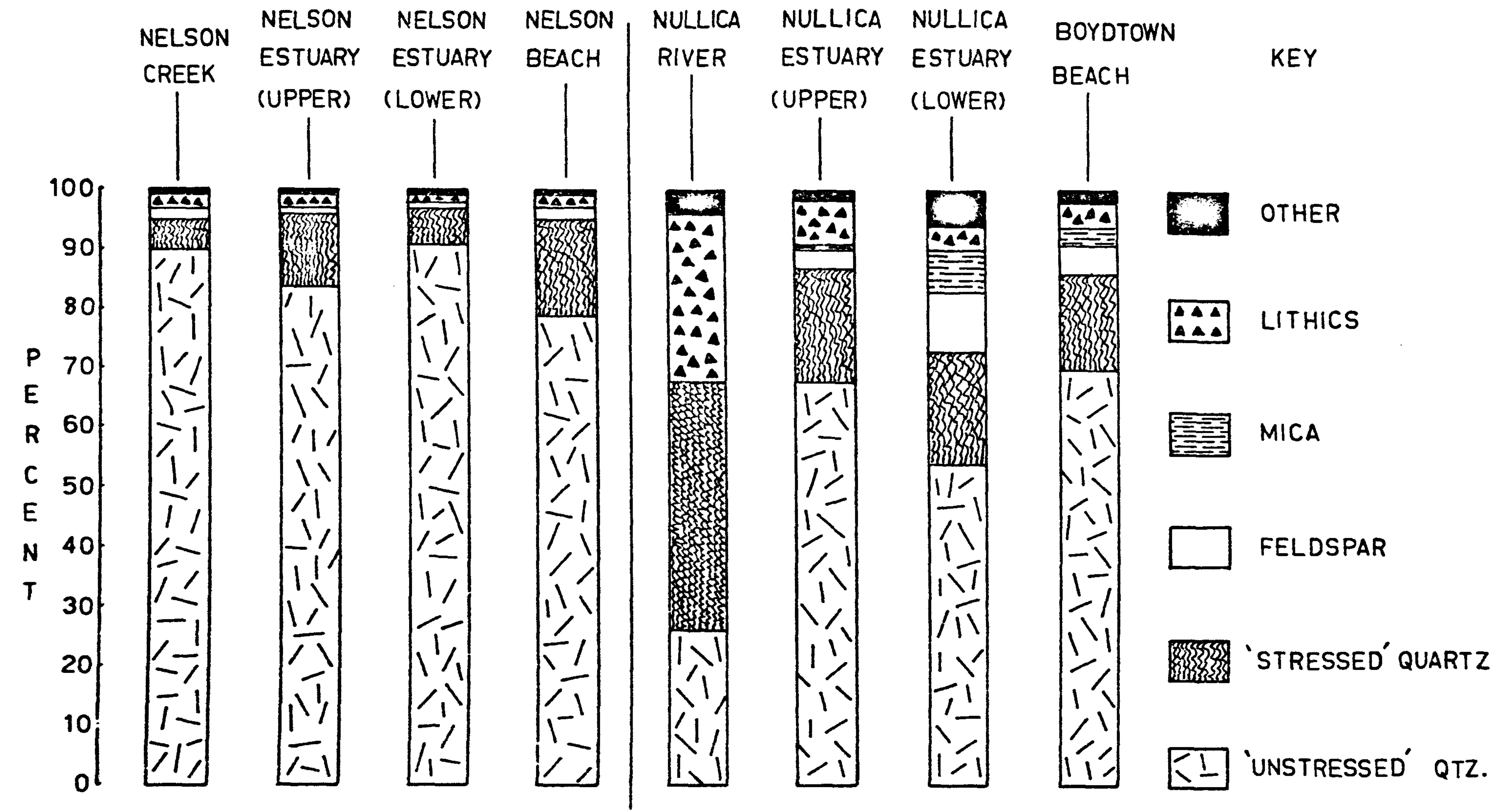
Both these estuaries have been substantially infilled along their length to the extent that it is impossible to define the thresholds, stream deltas or intervening basins clearly. At each locality it was obvious that sands identical to those on adjoining ocean beaches have been transported considerable distances landwards, but 100 metres or so upstream from the inlets sand origins were not immediately apparent due to a grey tone imparted to the sediments by the animals and plants which thrive in the calmer estuarine environment. Two hundred to three hundred metres further upstream these sediments gradually merge with the muddy sands of what passes for the intervening basins in these two estuaries. Unlike other localities, the "basins" are short, narrow and shallow; they are really only recognizable by the muddy nature of their floors. They mark the landward limit of sand movement from the lower reaches of these estuaries, but the passage of fluvial sand in the opposite direction during floods would not be severely inhibited by their presence. Thus the absence of a deep intervening estuarine basin permits partial mixing of the two main sediment populations; the difficulty in separating the sediment types is well demonstrated by the data shown in figures 4.7 and 4.8.

Much of the sediment data are equivocal in their indications of sand origins in these two estuaries. Traces (less than 1% by weight) of gravel were recorded in a few samples from the central reaches of both estuaries but particles of this size are rarely transported far downstream below tidal limits. Gravel sized lithic fragments adorned many of the small beaches along the estuary shores but most of these have been washed down from adjoining slopes. Coarse sand is an important component of sediments above tidal limits in both rivers but the proportion diminishes downstream and medium and fine sands predominate in the central reaches.

		RIVER	ESTUARY (upper)	ESTUARY (lower)	BEACH
PERCENT GRAVEL	Ne	5	trace	trace	-
	Nu	30	trace	-	-
PERCENT COARSE SAND	Ne	29	11	7	4
	Nu	44	24	7	11
PERCENT MEDIUM SAND	Ne	60	51	60	42
	Nu	38	47	40	40
PERCENT FINE SAND	Ne	11	38	33	54
	Nu	18	29	53	49
MEAN GRAIN SIZE (ø)	Ne	1.28	1.75	1.73	1.99
	Nu	1.00	1.47	2.01	1.86
SORTING	Ne	.72	.63	.44	.40
	Nu	.98	.76	.64	.54
SKEWNESS	Ne	-.38	-.31	-.63	-.99
	Nu	-.14	-.15	-.21	-.42
KURTOSIS	Ne	3.65	3.77	4.25	5.46
	Nu	2.66	3.05	3.44	3.53
QUARTZ ROUNDNESS	Ne	.27	.41	.48	.54
	Nu	.26	.37	.29	.33
PERCENT CARBONATE	Ne	-	3.04	3.05	9.10
	Nu	-	2.73	10.35	6.13

Figure 4.7: Sedimentological characteristics of sands from Nelson Creek and the Nullica River, their estuaries, (upper & lower reaches) and adjoining beaches.
Ne = Nelson; Nu = Nullica

FIGURE 4·8 COMPARISON OF RIVER, ESTUARY AND BEACH SAND MINERALOGY: NELSON + NULLICA R. SYSTEMS



Mean grain size also diminishes downstream and there is an overall improvement in sorting. These trends result partly from the effects of preferential transport and partly from the inherently better sorting of the finer marine sands, the proportion of which naturally increases nearer the sea. The estuarine sands also became increasingly negatively skewed and more leptokurtic nearer the sea due mainly to changes in the tails of the grainsize distributions as the sediments respond to downstream variations in the nature and strength of the transporting medium.

The proportion of calcareous material was fairly constant throughout Nelson estuary but the recorded levels were considerably lower than those measured in the beach sands. In the lower reaches of the Nullica Estuary the presence of many oyster leases appears to be responsible for the sharp increase in carbonate levels.

Quartz roundness was a very useful indicator of sand origin and revealed the extent of mixing of the two basic sediment populations. The average values suggest a progressive seawards increase in rounding and again this simply reflects the increasing proportion of more rounded grains from the beach environment. As distance from the sea increases so the proportion of angular and subangular grains increases until near tidal limits subrounded grains are very scarce.

Mineralogical data from Nelson and Nullica estuaries are particularly equivocal. At Nelson, sand composition is fairly consistent but it would be incautious to reach definite conclusions from these values alone. Used in conjunction with other data though it seems unlikely that Nelson Creek supplies significant amounts of sand to the beach even during floods and that most of the non-quartz fraction in the estuary sands has been derived from erosion of the cliffs and headlands bordering the beach. Comparatively low wave energy conditions permit retention of this finer detritus in the beach zone and from here it can readily be directed into the estuary.

At Nullica the situation is even less clear. The absence of mica from the river bed samples above tidal limits need not mean that the river is not carrying this mineral - rather, it is only in the quieter estuarine environment that it can be deposited. The absence of feldspar is surprising since it is very similar to quartz in terms of its hydraulic behaviour, and its presence in the estuary sediments lends some support to an earlier hypothesis that some of the sands on Boydtown beach may have been derived from the catchment of the Towamba River.

The bulk of evidence indicates that tidally induced landward transport is the dominant distributional agent in this estuary, but during floods river currents may temporarily reverse this situation. At such times fine angular fluvial sand probably reaches the sea and is eventually incorporated in Boydtown Beach sands, but it is also clear that the volumes of material so transported are very small.

4.5 Review

The contrasting patterns of estuarine sedimentation in this area are all characterized by competition between landward moving marine sands and seaward moving fluvial sediments. There also exists a basic continuum of estuary development and it is the combination of these factors which determines the probability of river sediments reaching the sea.

Initial drowning of the river valleys by the postglacial rise in sea level produced a series of sediment traps into which both fluvial and marine sands were and continue to be directed. In the study area most of these estuarine sediment traps are at present unfilled and it is therefore quite impossible for fluvial sands to reach the sea. Any fines carried through the systems in suspension are lost because the high wave energy prevents their deposition on the beaches. Only when infilling is nearly complete can this situation change and it is the larger discharge Bega and Towamba rivers draining elevated granite catchments which have been most successful in doing so. As well as controlling the pattern of estuarine sedimentation, they have delivered fluvial sand and gravel to the coast in quantities sufficient to preserve the fluvial character of the sands even in the beach environment. The smaller Murrah River which also drains a granite catchment has not quite reached this stage, although granitic sands extend well downstream to within 100 metres of the sea. Only small remnants of the estuarine basin exist at this locality and there is some evidence to suggest that very small amounts of fine, angular granitic sand may already be reaching the sea during floods and subsequently added to the beach sand population. Nelson Creek and the Nullica River may also be providing small amounts of fluvial sand to their adjoining beaches, although their catchments are not only small in area but are also developed in comparatively resistant rocks of low sand yield. Paradoxically, the small volumes of fluvial sediment available are able to pass through the estuaries during floods only because landward transport of marine sediments has so effectively filled most of their estuarine basins during non-flood periods.

The patterns of sediment distribution throughout each of the fourteen fluvial-estuarine-marine systems investigated are summarized in figures 4.9 - 4.18. Seven sediment facies have been mapped :-

i) River sands and minor gravel

ii) River muds

iii) Floodplain alluvium

iv) Immobile channel alluvium

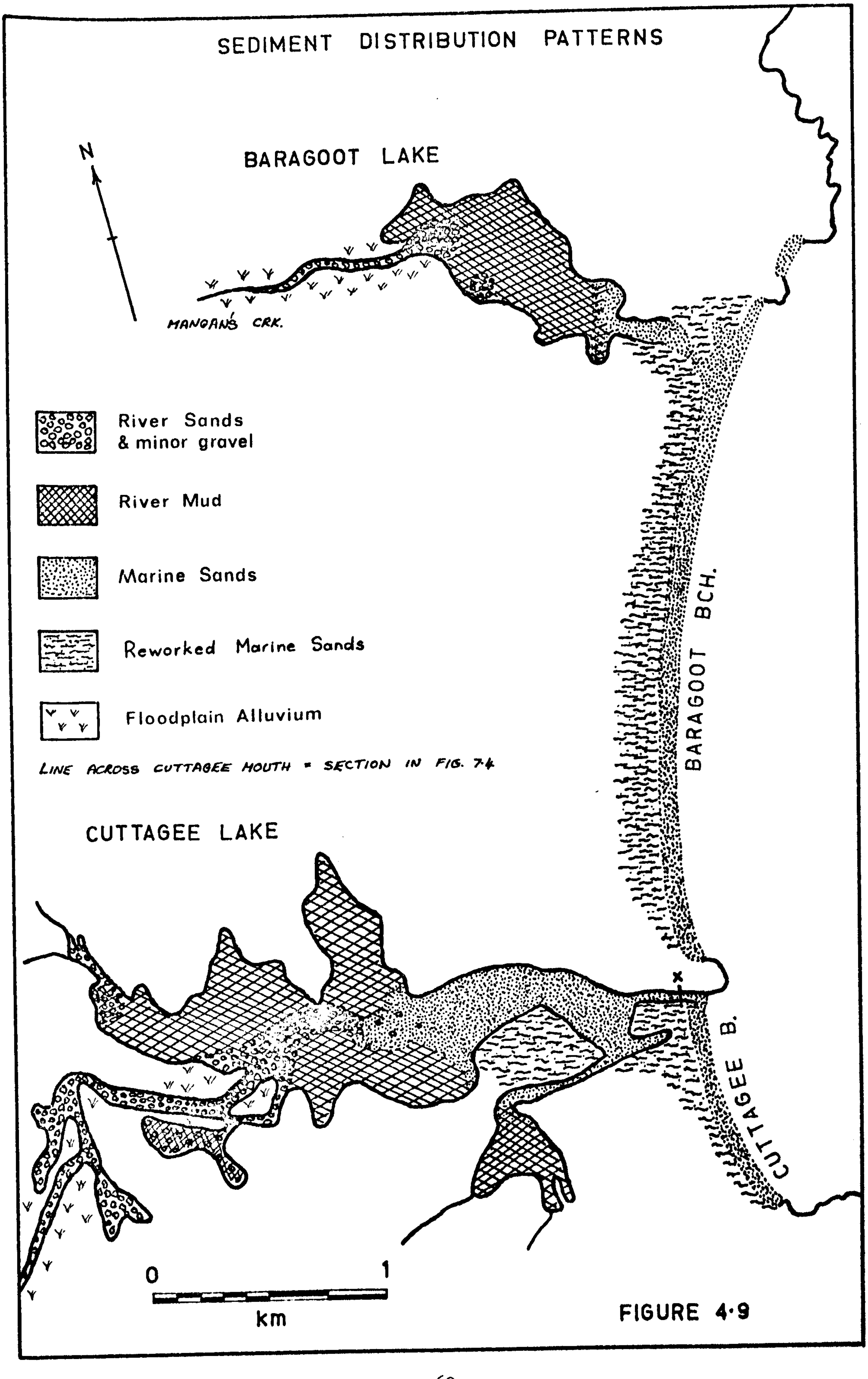
v) Marine sands (beach, nearshore & threshold sands)

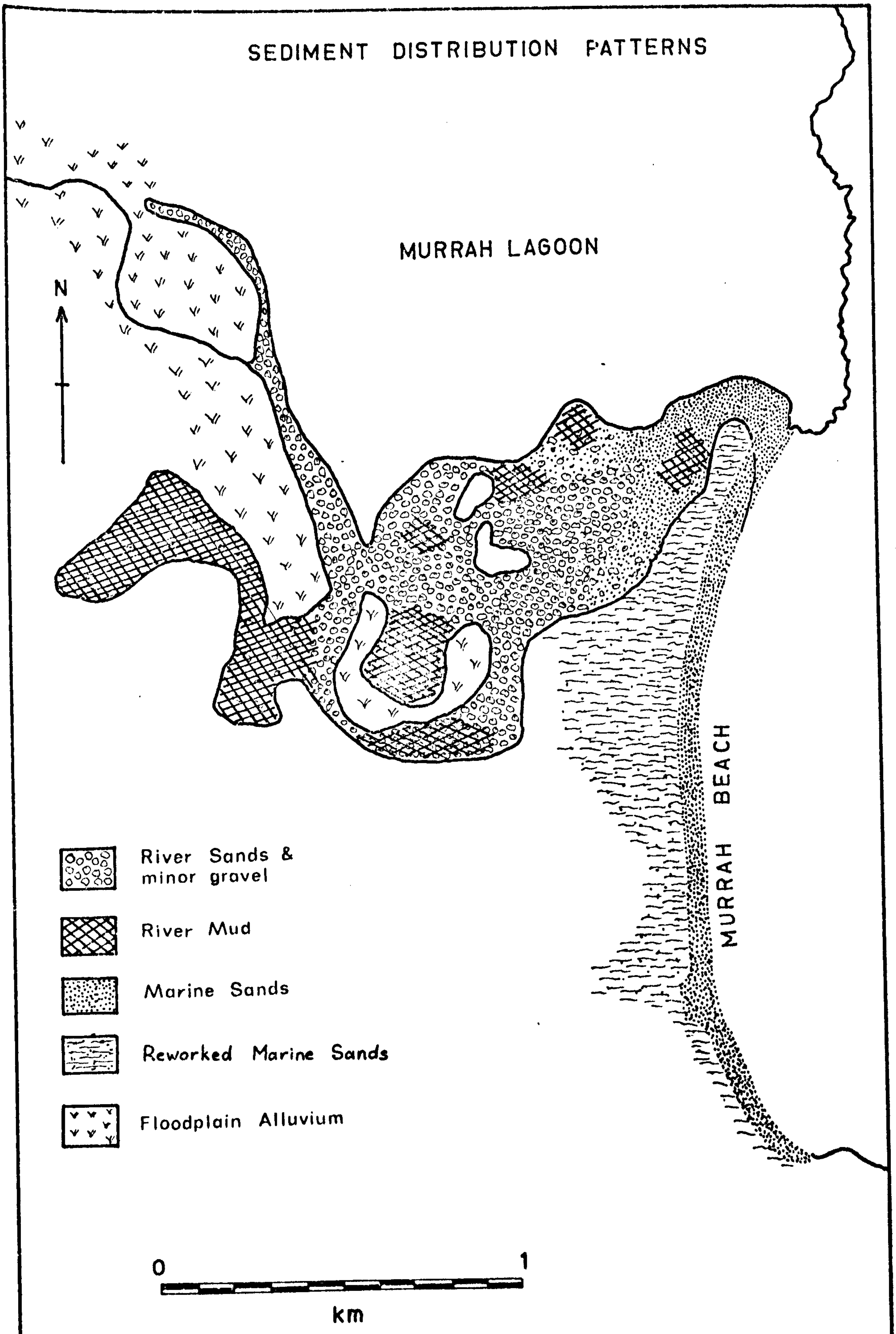
vi) Reworked marine sands

vii) Other sands

Most of these sediment units have already been discussed in some detail, however some additional summary comments may facilitate interpretation of the accompanying figures.

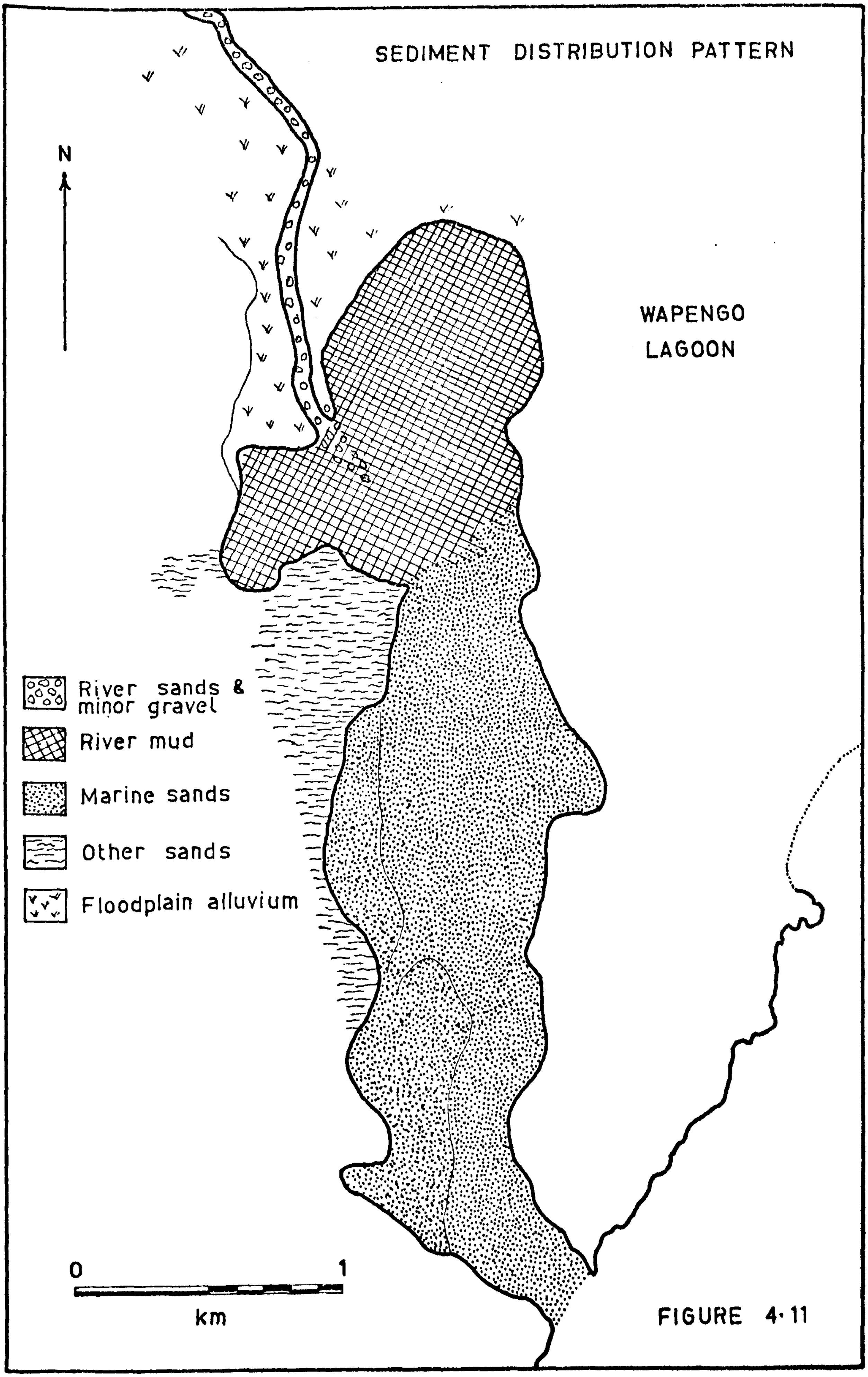
River Sands and Minor Gravels are usually confined to the upper reaches of the estuaries where they occur as small fluvial deltas. Two exceptions


SEDIMENT DISTRIBUTION PATTERNS
N
BARAGOOT LAKE
MANGAN'S CRK.
River Sands
& minor gravel
River Mud
Marine Sands
Reworked Marine Sands
Floodplain Alluvium
LINE ACROSS CUTTAGEE MOUTH = SECTION IN FIG. 7·4
CUTTAGEE LAKE
BARAGOOT BCH.
CUTTAGEE B.
X
0
1
km
FIGURE 4·9

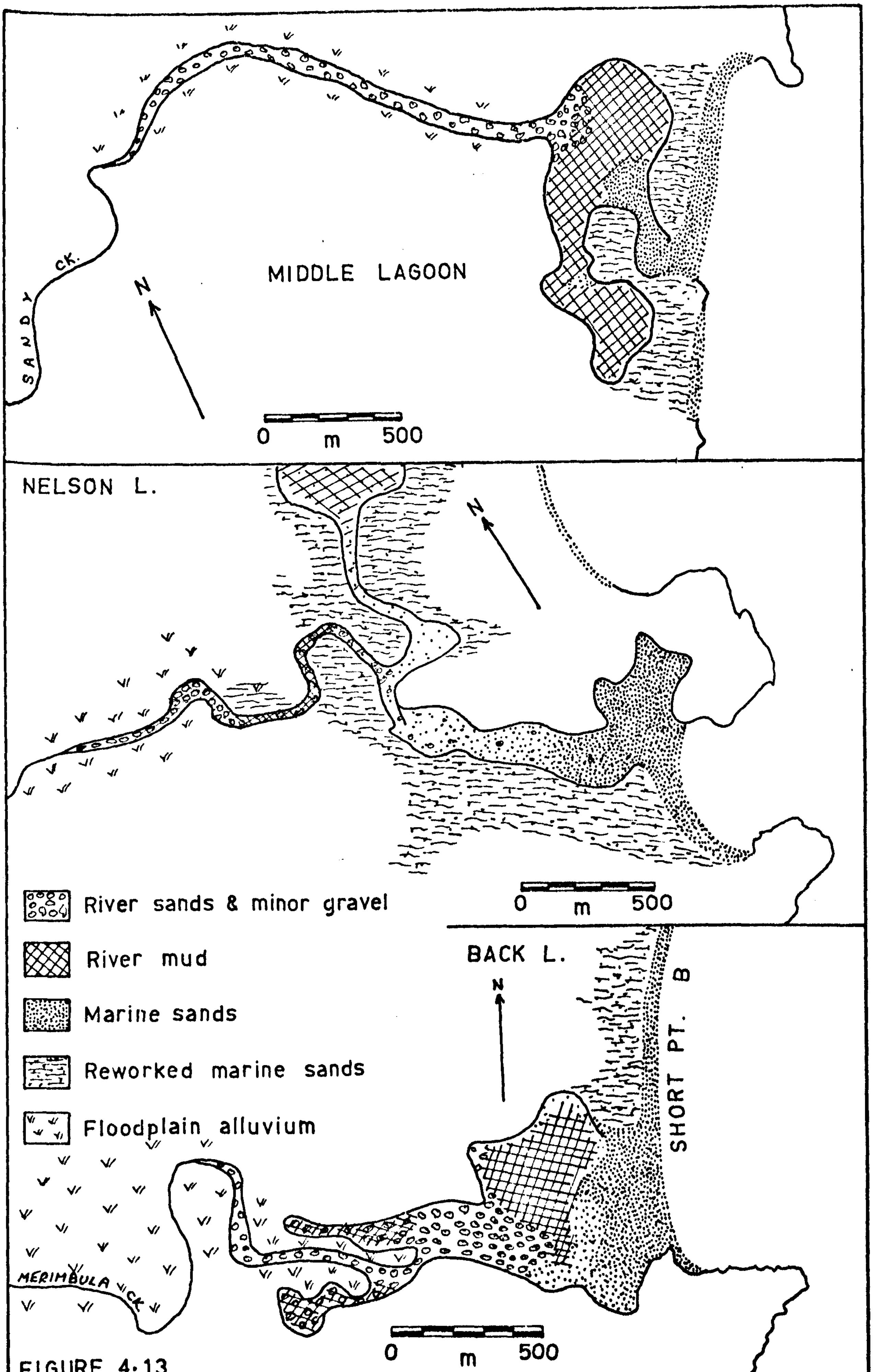


SEDIMENT DISTRIBUTION PATTERNS
MURRAH LAGOON
N
MURRAH BEACH
River Sands & minor gravel
River Mud
Marine Sands
Reworked Marine Sands
Floodplain Alluvium
0
1
km

FIGURE 4·10



SEDIMENT DISTRIBUTION PATTERN
N
WAPENGO
LAGOON
River sands & minor gravel
River mud
Marine sands
Other sands
Floodplain alluvium
0
1
km
FIGURE 4·11


MIDDLE LAGOON
SANDY CK.
N
0 m 500
NELSON L.
N
0 m 500
River sands & minor gravel
River mud
Marine sands
Reworked marine sands
Floodplain alluvium
BACK L.
N
SHORT PT. B
MERIMBULA CK
0 m 500
FIGURE 4·13

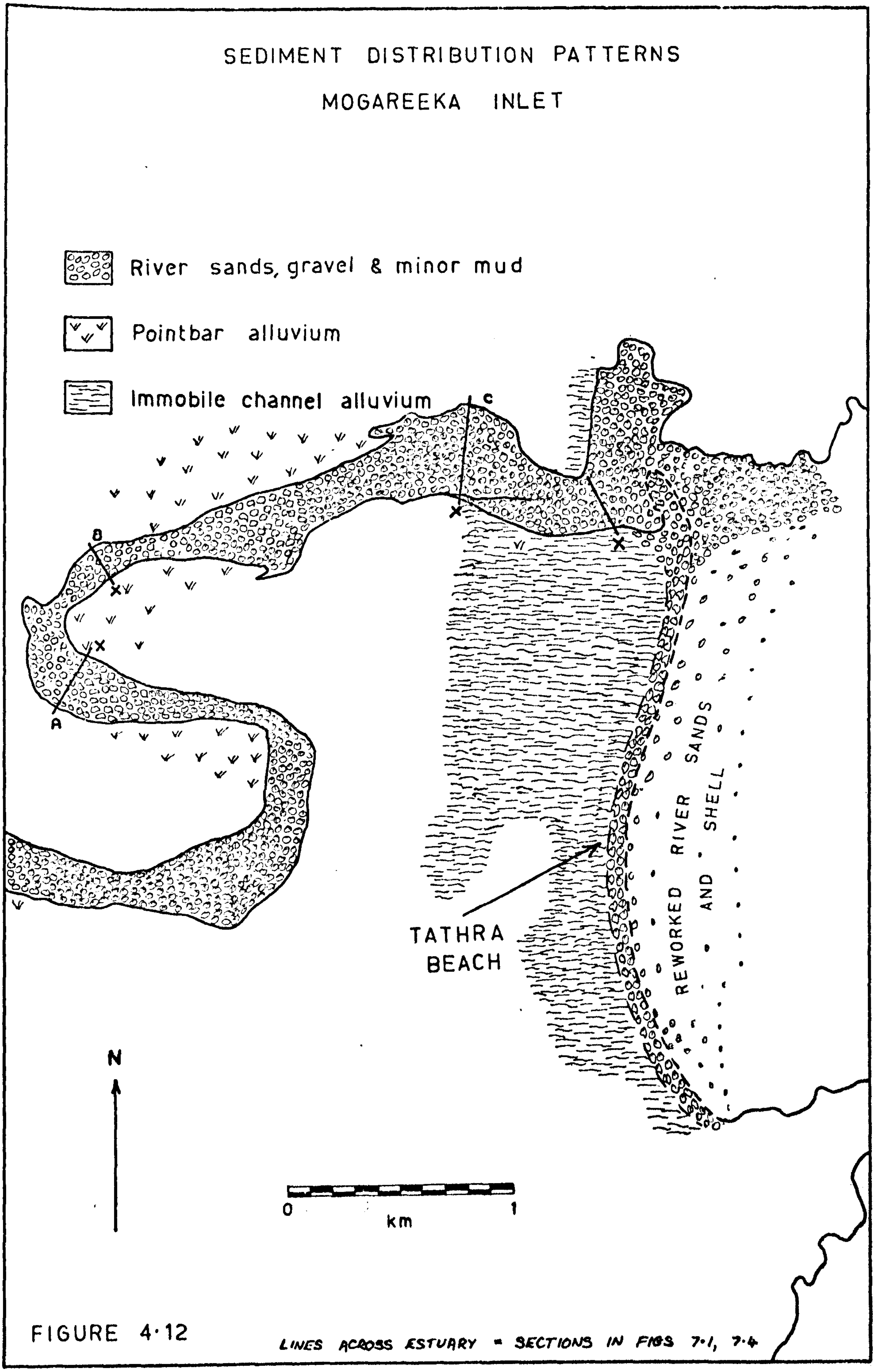

SEDIMENT DISTRIBUTION PATTERNS
MOGAREEKA INLET
River sands, gravel & minor mud
Pointbar alluvium
Immobile channel alluvium
A
B
C
TATHRA BEACH
REWORKED RIVER SANDS AND SHELL
N
0
1
km
LINES ACROSS ESTUARY = SECTIONS IN FIGS 7·1, 7·4

FIGURE 4·12

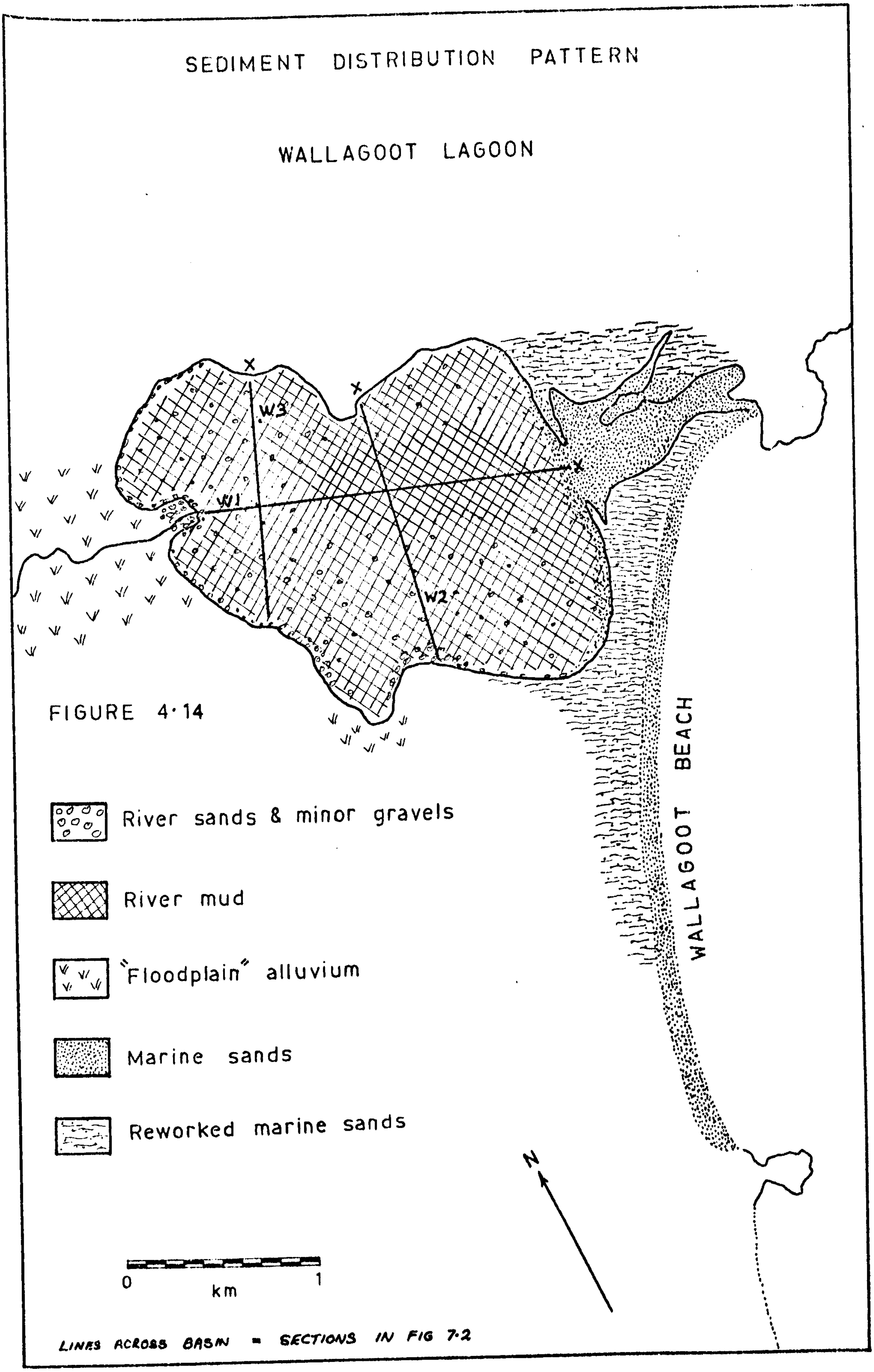
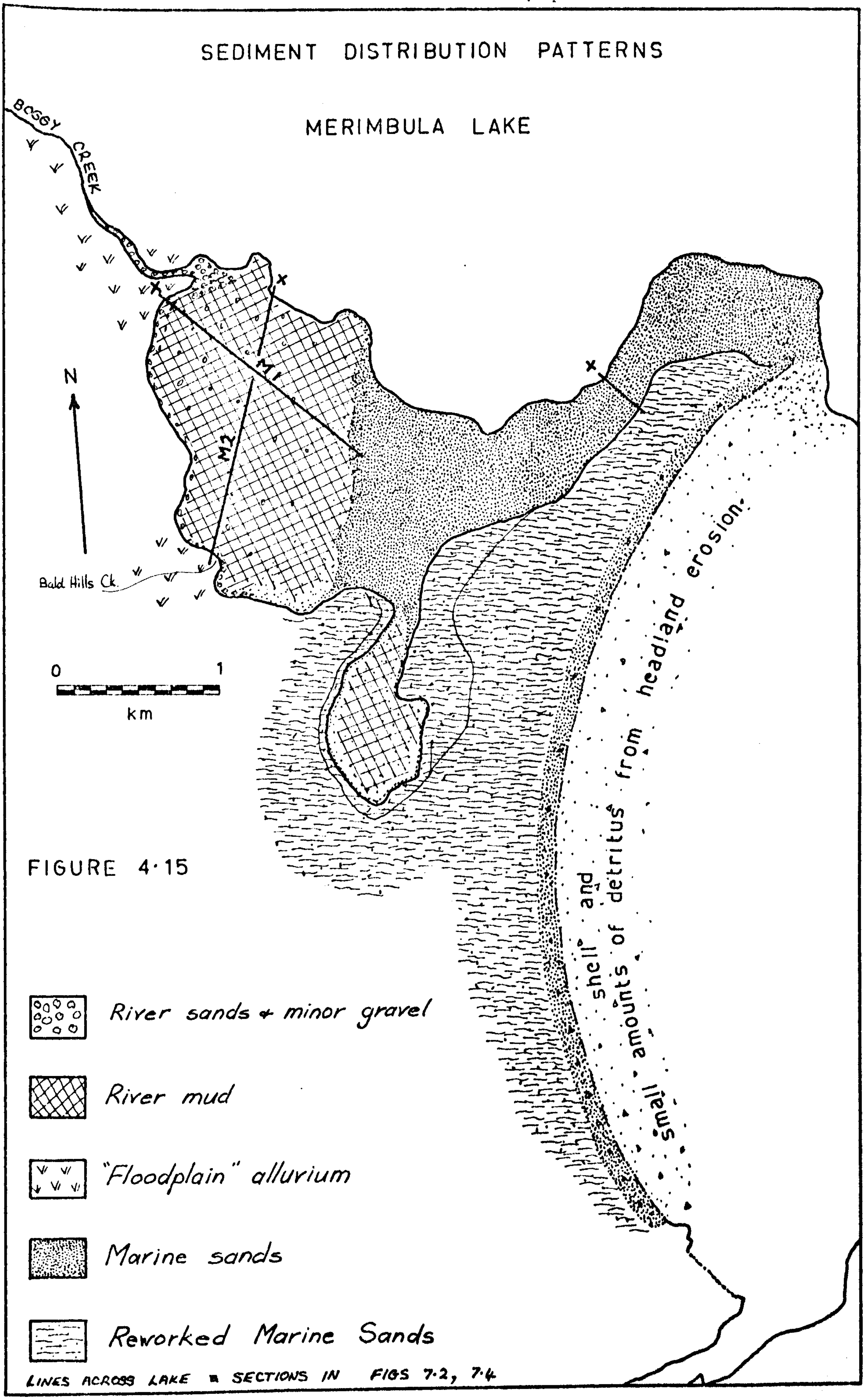
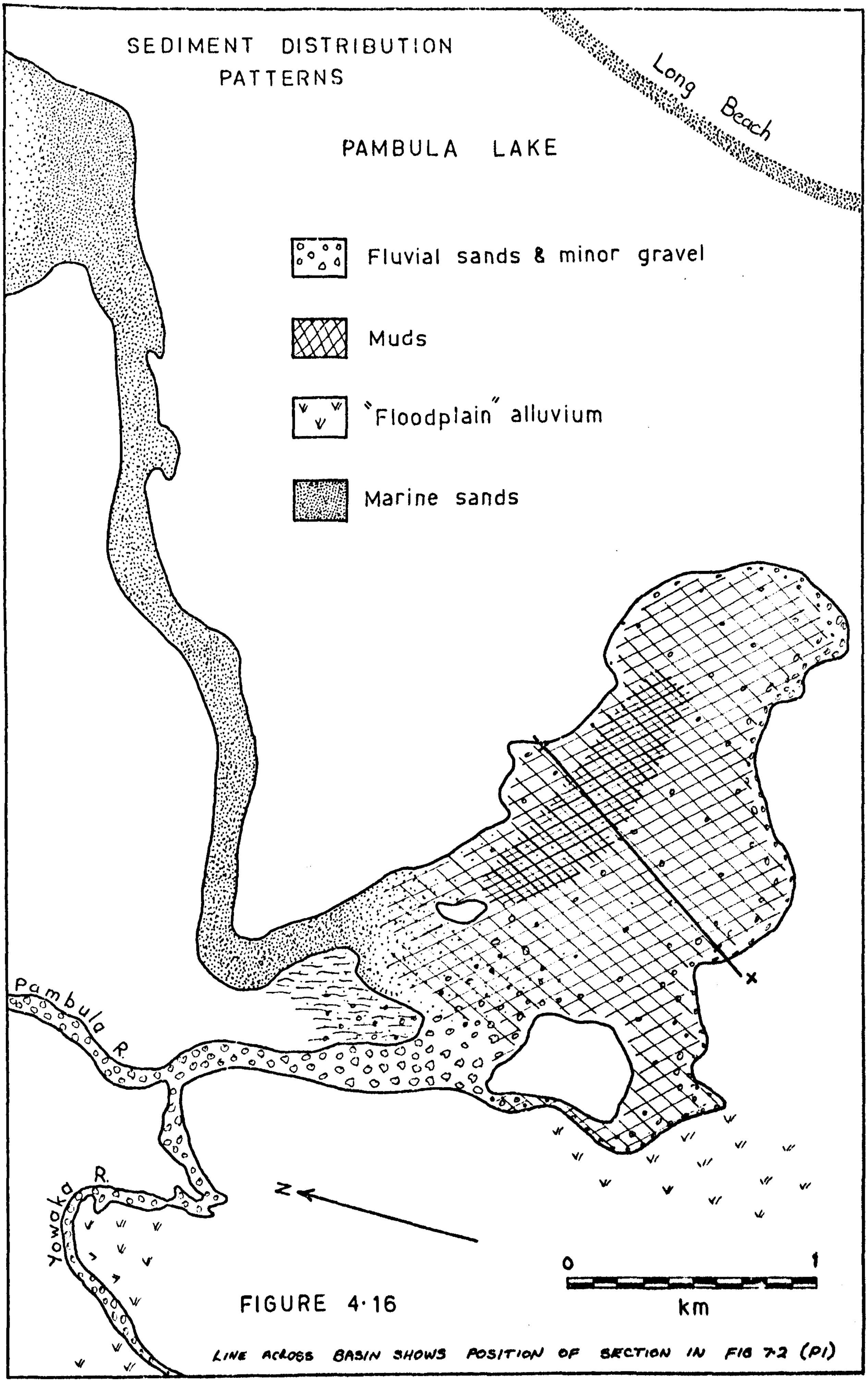

SEDIMENT DISTRIBUTION PATTERN
WALLAGOOT LAGOON
W1
W2
W3
WALLAGOOT BEACH
River sands & minor gravels
River mud
"Floodplain" alluvium
Marine sands
Reworked marine sands
N
0
km
1
LINES ACROSS BASIN = SECTIONS IN FIG 7·2

FIGURE 4·14


SEDIMENT DISTRIBUTION PATTERNS
MERIMBULA LAKE
BOGGY CREEK
N
M1
M2
X
Bald Hills Ck.
0
1
km
small amounts of detritus from headland erosion.
shell and
River sands + minor gravel
River mud
"Floodplain" alluvium
Marine sands
Reworked Marine Sands
LINES ACROSS LAKE = SECTIONS IN FIGS 7·2, 7·4
FIGURE 4·15


SEDIMENT DISTRIBUTION PATTERNS
PAMBULA LAKE
Long Beach
Fluvial sands & minor gravel
Muds
"Floodplain" alluvium
Marine sands
Pambula R.
Yowaka R.
N
x
0
1
km
LINE ACROSS BASIN SHOWS POSITION OF SECTION IN FIG 7.2 (P1)
FIGURE 4·16

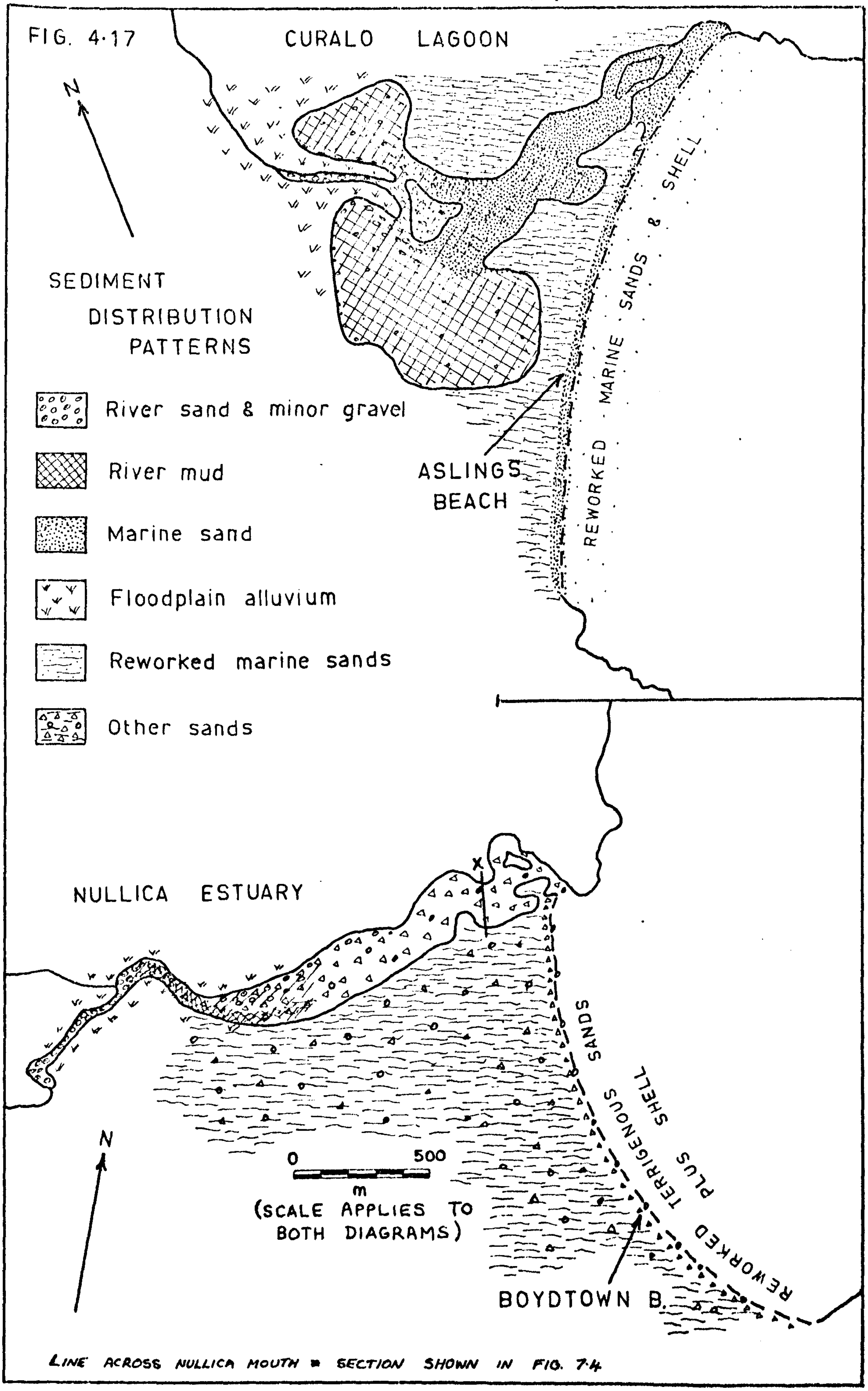
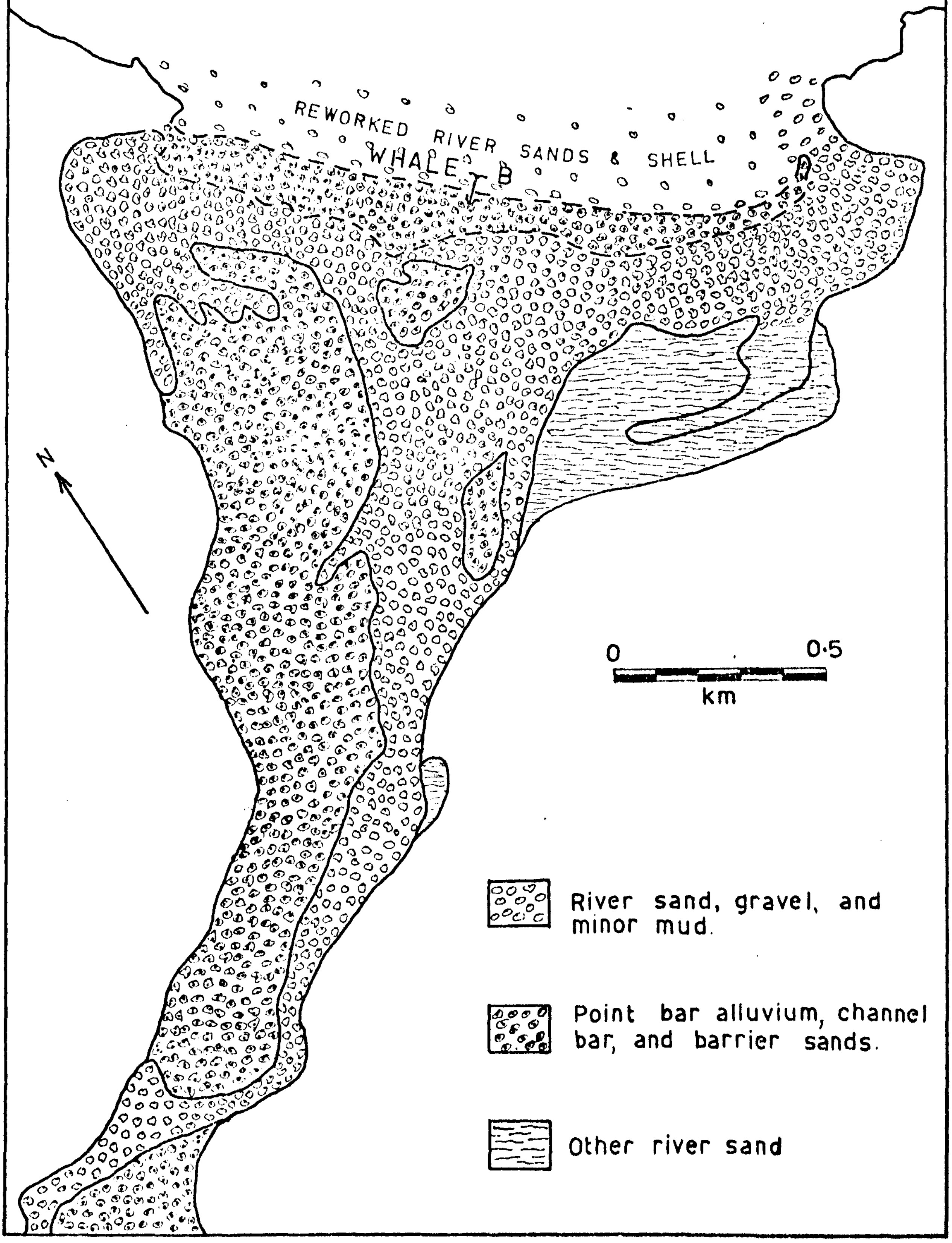


FIG. 4·17
CURALO LAGOON
N
SEDIMENT
DISTRIBUTION
PATTERNS
River sand & minor gravel
River mud
Marine sand
Floodplain alluvium
Reworked marine sands
Other sands
ASLINGS
BEACH
REWORKED MARINE SANDS & SHELL
NULLICA ESTUARY
X
N
0
500
m
(SCALE APPLIES TO
BOTH DIAGRAMS)
SANDS
SHELL
TERRIGENOUS
PLUS
REWORKED
BOYDTOWN B.
LINE ACROSS NULLICA MOUTH = SECTION SHOWN IN FIG. 7·4

FIGURE 4·18 SEDIMENT DISTRIBUTION PATTERNS

KIAH INLET



are the Bega and Towamba rivers which have effectively filled their estuaries and are delivering such material to the nearshore zone and adjoining beaches. Small amounts of this sediment also occur as wave reworked deposits around the upper margins of most estuaries in the study area.

River muds occur mainly as prodelta deposits, the surfaces of which form the floors of the estuarine basins. These deposits may be many metres thick. River muds also occur as a minor component of delta and threshold sands but they are absent from the nearshore zone and beaches due to the high wave energy environment.

Floodplain alluvium is a mixture of the foregoing sediments and has been mapped purely as a morphological unit. It is a reservoir of fluvial sediment which if mobilized, may be delivered to the estuaries or the sea.

Immobile channel alluvium constitute another though more temporary store of fluvial sands and gravels. They are often vegetated but are very likely to be mobilized by large floods, particularly if the river changes its channel. In aerial extent this alluvium represents a large component of the bed load of the Bega and Towamba rivers. Finer grained alluvial sands may also be trapped in backwaters where it is colonized by saltmarsh (for example at Kiah Inlet).

Marine sands is a collective term applied to the relic material which has undergone extensive marine reworking since its initial deposition on the continental shelf. Although most commonly evident as beach sediment, it is also found within the estuaries as threshold sands, and it also extends seawards into the nearshore zone where it grades rapidly into a predominantly calcareous sand of biogenic origin.

Reworked marine sands have been moulded into foredunes or even more extensive progradational features of Holocene age. Field inspection of these sands with a hand lens showed that they are the same as the marine sands found on most of the ocean beaches. They are generally medium grade, well sorted, well rounded quartz sands. Ironstained grains are evident, but landward of the foredunes, weak podzolization of the sands has obscured and/or removed the orange colour. Shell material is usually absent. At many localities these deposits form part of the estuary shoreline and when eroded by lake waves, release small volumes of sand into the estuary.

Other sands comprise miscellaneous cases which cannot be placed within any of the other categories. At Tathra, for example, fluvial sands and gravels have been deposited in the nearshore zone by the Bega River, but have been subsequently transported to the beach by wave action. Some of the beach material has also been remoulded into a foredune. A series of barrier beach ridges lies landward of the foredune, but casual inspection of their surficial sediments showed that they too represent bodies of fluvial sand that have been emplaced by marine and/or aeolian processes. A very similar situation exists at Boydtown.

Another extensive relic feature lies to the west of Wapengo Lagoon. Sands within it appear finer grained and more angular than the marine sands on the adjacent threshold, and may represent an old aeolian accumulation of fine river sands from Wapengo Creek. The sediment distribution patterns at these three localities represent significant departures from the regional norm, particularly in terms of the Holocene barrier progradation phase; all three await detailed stratigraphic investigation.

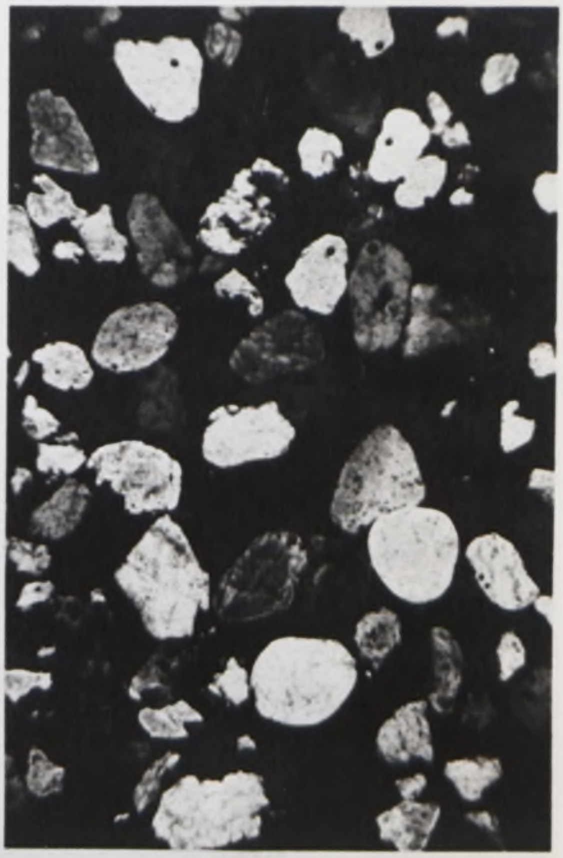
Availability of sediment and a river regime which encourages its active downstream transport and distribution are basic requirements for an active supply of sand to the coast. Such supply may be encouraged or thwarted by other forces in operation nearer the sea, and it is the variable nature of the resultant interactions that have determined the nature of sediment budgets in this area. The environmental controls of, and the landforms resulting from such interactions are discussed in the following chapters.

Captions to accompany plates 4.1 - 4.8

Plates 4.1-2 and 4.3-4 are couplets which effectively highlight the differences between sands found on fluvial deltas and those found on the threshold near the mouth of the same rivers. In both cases the threshold sands are very well rounded and "cleaner" than their fluvial counterparts. Grain diameters in plates 4.2 - 4.4 are approximately 1 - 1.5 phi. Those in plate 4.1 are smaller (2 - 2.5 phi). Boggy Creek delta lacks sands in the medium coarse grade.

Plates 4.5-6 and 4.7-8 are also couplets, this time from two localities where there is no well defined intervening estuarine basin, and fluvial sands extend right to the mouth of the estuary. Note the angularity and feldspar content of these granitic sands and the strong similarity between elements of each couplet. Grain diameters are approximately 1 to 1.5 phi.

PLATE 4·1 BOGGY CK. DELTA (107)



Pl. 4·2 MERIMBULA L. THRESHOLD (78)

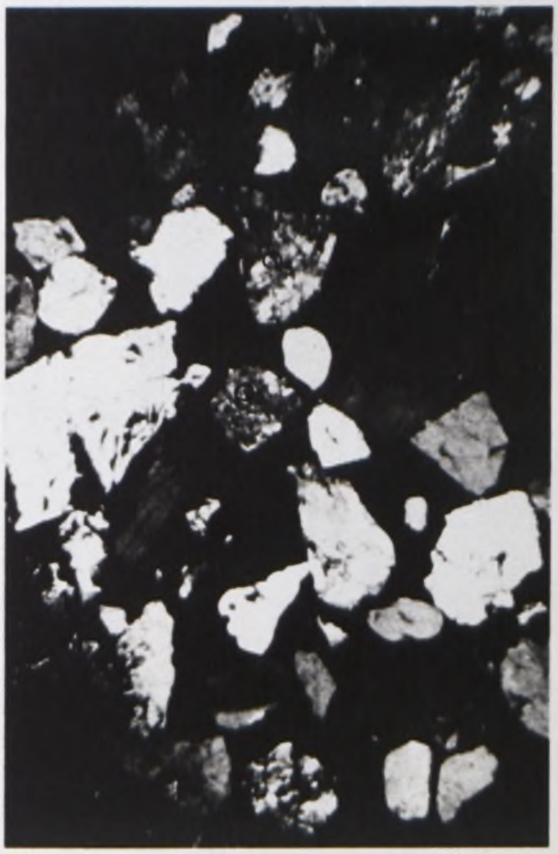
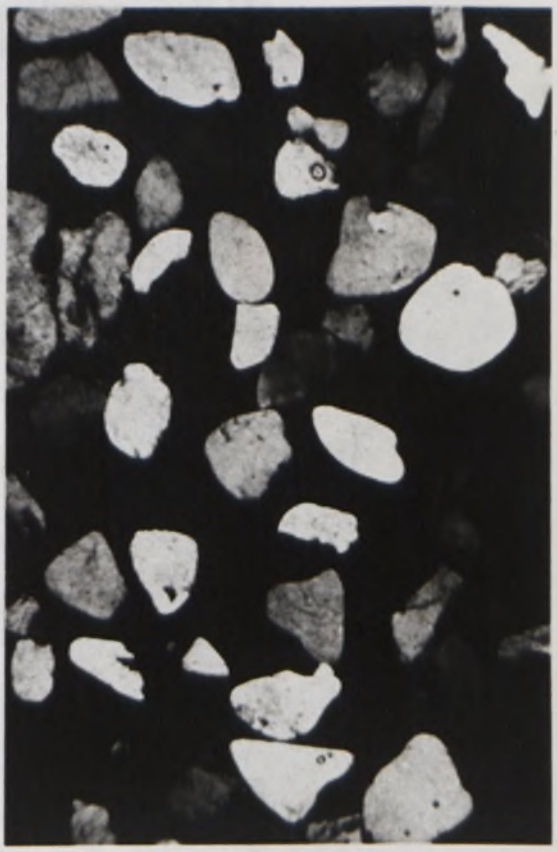
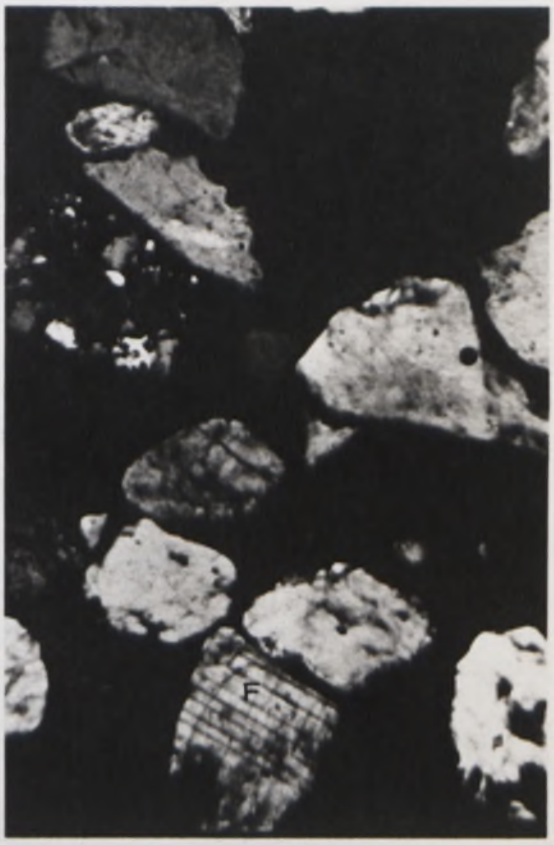


PLATE 4·3 MANGAN'S CK. DELTA (185)



Pl. 4·4 BARAGOOT L. THRESHOLD (191)

Pl. 4·5 BEGA R. ESTUARY (214) (upstream)



Pl. 4·6 BEGA R. ESTUARY (222) (near mouth)

Pl. 4·7 MURRAH ESTUARY (324) (upstream)

Pl. 4·8 MURRAH ESTUARY (327) (near mouth)

CHAPTER FIVE: STREAM FLOW, SEDIMENT TRANSPORT & FLUVIAL DEPOSITION

Now that the characteristics of the local sediment budgets have been established, attention can be directed toward the factors which control the systems of sediment distribution and exchange, as well as toward the landforms which have evolved in response to them. As before, the fluvial, marine and estuarine environments are considered in turn, although the boundaries between them are sometimes rather arbitrary due to the overlap which occurs. Within the context of this study, the coastal rivers warrant attention because inter alia .....

- They excavated the valleys which became the estuaries following postglacial drowning.
- They dictate the rate at which the estuaries are infilled with the denudation products from the drainage basins.
- Their flood waters are the usual means by which closed inlets are opened, and after opening, it is stream flow which assists tidal currents to maintain the opening, and thus paradoxically facilitate infilling of estuaries with marine sand transported from the nearshore zone.
- They introduce freshwater to the estuaries, and the manner in which this mixes with the denser saline water may affect sedimentation patterns, vegetation communities and landform development within the estuarine environment.

Clearly the main controls of the above processes are the discharge regime and the sediment load of the tributary streams. Assessment of these controls in this area is severely limited by the lack of pertinent data, and to a large extent must be inferred from the relatively abundant climatic data and from the physical characteristics of the catchments.

5.1 Catchment Topography

The fourteen drainage basins range in size (planimetric area) from 10 to 1900 square kilometres (table 5.1), but nearly three quarters of the streams drain catchments less than 65 square kilometres in area. As in chapter two the names Bega and Pambula are used

Table 5.1 Catchment Areas (kms^2) & Maximum Elevation of Divides (m)

River	Area	Height	River	Area	Height
Mangan's Ck	10	120	Wallagoot Crk	30	300
Cuttagee Ck	62	300	Merimbula Crk	32	420
Murrah R	220	700	Boggy Crk	21	300
Wapengo Ck	64	360	Pambula R	300	600
Sandy Crk	29	230	Palestine Crk	19	300
Nelson Crk	27	270	Nullica R	45	400
Bega River	1900	1200	Towamba River	990	1000

in a collective sense and include the catchments of other named tributaries such as the Brogo and Yowaka rivers. The larger rivers (Bega, Towamba and Murrah) reach further inland and are thus able to drain the Bega granite (figure 2.1) which releases abundant quartz on breakdown, whereas most of the remaining streams are confined to the fairly resistant, relatively quartz-poor metasediments. Exceptions include the Pambula River and Wallagoot, Boggy and Merimbula creeks, all of which drain the Devonian sediments and volcanics. In addition to this lithological distinction, the larger rivers drain more elevated country where annual rainfalls are greater. The Bega and Towamba rivers drain areas exceeding 1000 metres in elevation; the maximum elevation of the divides of the smaller streams rarely exceeds 400 metres. In table 5.2 the area of each catchment comprising average valley side slopes of specified declivities is shown. The slope categories conform to those used by the N.S.W. Water Resources Commission.

- rugged or mountainous 15 degrees
- hilly to steep 8 - 15 degrees
- undulating to hilly 3 - 8 degrees
- mostly flat 3 degrees

Slopes were measured from 1:25000 topographic maps with contour intervals of ten metres, and the component areas were measured with a planimeter.

Table 5.2 Land Slopes in each Catchment (kms^2, %)

Catchment	15^{o}	$8 - 15^{o}$	$3 - 8^{o}$	3^{o}
Mangan's Creek	1.5 (15)	2.4 (24)	4.7 (47)	1.4 (14)
Cuttagee Creek	45.3 (16)	9.9 (16)	5.0 (8)	1.9 (3)
Wapengo Creek	31.4 (49)	15.4 (24)	9.0 (14)	8.3 (13)
Sandy Creek	- (-)	21.5 (74)	2.9 (10)	4.6 (16)
Nelson Creek	20.5 (76)	4.3 (16)	0.8 (3)	1.4 (5)
Nullica River	40.1 (89)	3.6 (8)	0.3 (1)	0.6 (2)
Palestine Crk	9.1 (48)	6.7 (35)	1.7 (9)	1.5 (8)
Merimbula Crk	19.8 (62)	8.6 (27)	2.6 (8)	1.0 (3)
Boggy Creek	9.5 (45)	7.6 (36)	2.9 (14)	1.0 (5)
Wallagoot Crk	9.6 (32)	7.5 (25)	6.9 (23)	6.0 (20)
Pambula River	192.0 (64)	66.0 (22)	27.0 (9)	15.0 (5)
Murrah River	107.8 (49)	66.0 (30)	37.4 (17)	8.8 (4)
Bega River *	988.0 (52)	304.0 (16)	551.0 (29)	57.0 (3)
Towamba River*	811.8 (82)	118.8 (12)	49.5 (5)	9.9 (1)

* W.C. & I.C. data; Values in brackets = equivalent proportion of total area of specified catchment.

Considerable differences between catchments are evident. Sandy Creek, for example contains no areas of rugged terrain, and the Bega River, although it reaches furthest into the coastal ranges, drains proportionately less rugged terrain than many of the smaller streams. When the catchments are grouped according to their lithology and compared, no significant differences in the proportions of specified terrains are evident. When actual areas are considered though, a consistent and not unexpected trend is evident - the larger rivers drain greater areas of rugged country. Such differences should be manifest in the respective stream water and sediment discharge regimes. For example, the greater efficacy of slopewash on the steeper slopes coupled with a rock type which releases abundant sand on breakdown suggests that the Bega and Towamba rivers, and to a lesser extent the Murrah and Pambula rivers, experience substantially greater injections of sediment into their channels than do the lowland streams.

5.2 Climate

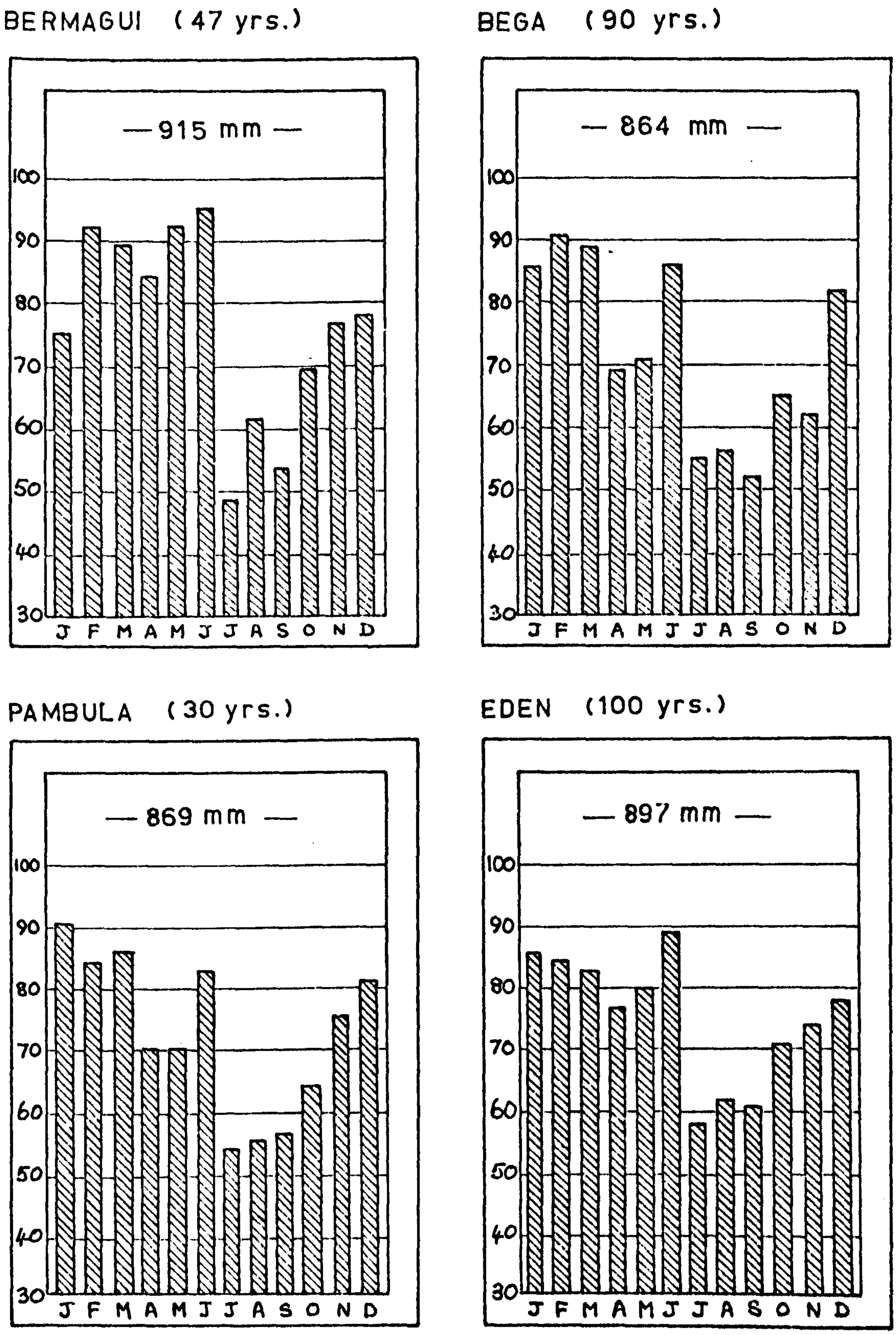
The climate of all but the most elevated parts of this coastal region falls within Koppen's Cfb classification and is essentially a warm, moist, maritime one characterized by

- mean minimum temperatures between 0.7°C and 15.7°C
- mean maximum temperatures between 16.0°C and 26.7°C
- no seasonal moisture deficiency on average

The main climatic control is the regular eastward progression of large anticyclones within the semi-permanent high pressure belt, together with the seasonal latitudinal migration of the belt itself. Generally, the anticyclones produce fine weather but they also often direct warm, moist, unstable air from the Tasman Sea toward the coast, where rainfalls of fairly short duration result from either orographic or frontal uplift of the maritime air. Heavier, more widespread falls which may continue for many days, occur when intense depressions in the south Tasman Sea, or tropical cyclones in northern N.S.W. and southern Queensland waters direct a similarly unstable but much more persistent air flow landwards. Such conditions are most frequent in winter and summer respectively and, together with any rain arising from the prevailing anticyclonic circulation, result in a fairly uniform distribution of precipitation throughout the year (Gentilli, 1972; Tweedie, 1966).

Actual plots of monthly rainfall at Bermagui, Bega, Pambula and Eden though (figure 5.1) do indicate a small seasonal variation with a small peak in late summer-early autumn, the driest months on average being the winter ones of June, July and August. In table 5.3 the probabilities of Bega receiving specified amounts of precipitation in

FIGURE 5·1 ANNUAL DISTRIBUTION OF PRECIPITATION AT FOUR SELECTED REGIONAL CENTRES



DATA FROM COMMONWEALTH BUREAU OF METEOROLOGY any month are shown, and illustrate the temporal variability of rainfall in the region, and also indicate that summer rainfalls are more reliable.

Table 5.3 Approximate Perecentage Chance of Bega Receiving Specified Amounts of Precipitation in any month, based on 90 years records.

Amount	J	F	M	A	M	J	J	A	S	O	N	D
13mm	93	82	82	80	77	77	70	66	84	89	86	88
25mm	84	64	70	68	61	66	50	53	61	75	74	75
50mm	63	42	50	45	39	45	28	32	33	48	38	53
76mm	43	29	32	31	20	33	19	21	18	28	25	37

Based on 90 years records there is only about a 30% chance of Bega receiving precipitation equal to or in excess of its average annual total. Spatial variability of rainfall within the area is mainly orographically controlled, the amount of rain received generally increasing with elevation. This is depicted in figure 5.2 which is a composite of diagrams produced by the W.C. & I.C. based on at least 65 years records at thirteen stations. Mean annual values range from approximately 760 mm in sheltered valleys and the coastal lowlands, to values in excess of 1270 mm in the elevated headwaters of the Bega River. A rainshadow exists in the centre of the Bega Valley (W.C. & I.C., 1966).

The very heavy falls of rain associated with an active depression centred over the Tasman Sea may occur in any month of the year (table 5.4); such falls usually occur about twice a year but tend to be heavier in summer.

Table 5.4 Maximum Precipitation (mm) Recorded in a 24 hr period since 1882.

Place	J	F	M	A	M	J	J	A	S	O	N	D
Bega	150	454	244	173	149	173	140	135	106	152	118	165
Pambula	152	248	134	157	85	142	72	129	97	84	117	165
Eden	260	281	160	104	267	103	96	127	91	84	111	137

The highest registration in any 24 hour period at Bega was 454 mm on February 26th 1919. Dry periods of short duration are not infrequent, but rarely exceed three or four months. There is at least a 90% chance of a

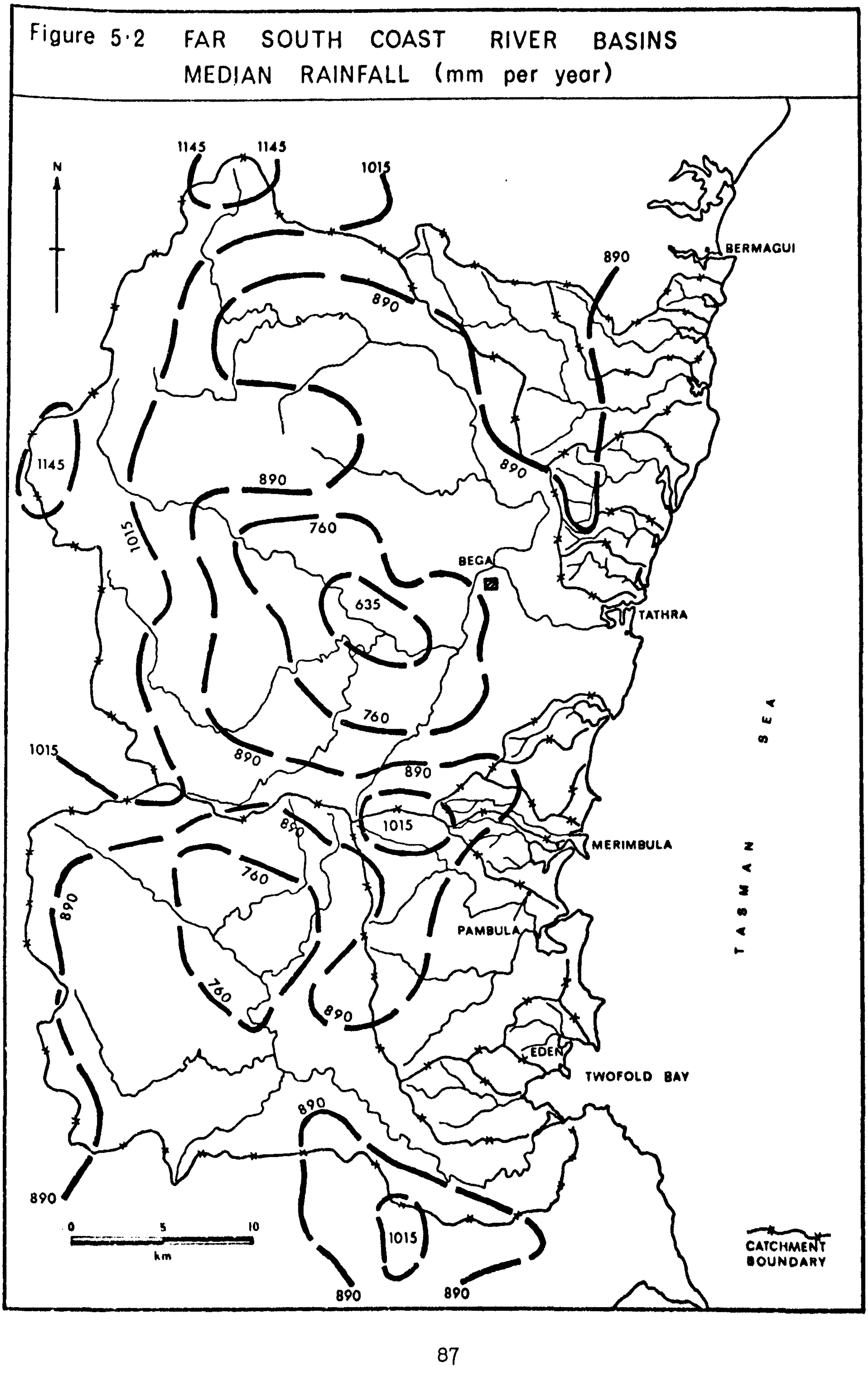


Figure 5·2 FAR SOUTH COAST RIVER BASINS
MEDIAN RAINFALL (mm per year)
N
1145
1015
890
760
635
BEGA
BERMAGUI
TATHRA
MERIMBULA
PAMBULA
EDEN
TWOFOLD BAY
TASMAN SEA
0 5 10
km
CATCHMENT BOUNDARY

station receiving at least 75 mm of rain in any consecutive three month period.

The mean daily temperature at Bega is 14.8°C and ranges from 8.7°C in winter to 19.9°C in summer; January and February are the hottest months (table 5.5).

Table 5.5 Average Monthly Temperatures (°C) at Bega (B), Merimbula (M) and Nimmitabel (N)

		J	F	M	A	M	J	J	A	S	O	N	D	Y
Max	B	26.1	26.7	24.9	23.2	19.3	16.7	16.6	17.6	19.6	21.7	22.6	24.8	21.8
Min	B	14.0	14.6	12.2	7.8	4.4	2.0	0.7	2.6	4.2	8.1	10.1	12.3	7.8
Max	M	23.8	24.7	22.8	21.4	17.8	16.2	16.0	16.5	18.2	19.8	20.1	23.2	20.0
Min	M	15.3	15.7	13.3	10.1	6.9	4.5	3.4	4.6	5.7	9.3	11.1	13.2	9.4
Max	N	23.0	22.9	20.4	17.0	12.1	9.0	8.3	9.9	12.8	16.4	17.8	21.3	15.9
Min	N	8.9	9.6	7.1	3.5	0.7	-0.9	-1.9	-0.9	0.7	3.5	5.0	7.2	3.5

Diurnal temperature ranges are small, particularly along the coastline where the average difference between daily maxima and minima varies from 8.5°C to 12.6°C. No climatic stations are maintained in the more elevated areas of the drainage basins, but data from Nimmitabel (1060 metres a.s.l.) which lies approximately 15 km west of the Bega River catchment divide is probably representative of these areas in terms of temperatures. Here, mean daily temperatures range from 3.9°C in winter to 15.5°C in summer. The mean daily minimum temperature in winter is -1.2°C. Frosts are rare along the coast but increase in frequency with increasing elevation and distance from it. Nimmitabel for example averages only 65 frost free days per year and frosts can occur at any time of the year.

Nine a.m. humidity levels are fairly high throughout the region at around 70%. Afternoon (3 p.m.) levels are generally lower but the reduction is greater at coastal stations than in the higher inland areas (table 5.6).

Table 5.6 Average monthly humidity at Bega (B), Merimbula (M) and at Nimmitabel (N).

		J	F	M	A	M	J	J	A	S	O	N	D	Y
9 am	B	65	72	75	79	79	85	84	78	70	67	64	62	73
3 pm	B	57	60	58	50	54	57	51	52	50	56	56	57	55

Table 5.6 continued.

		J	F	M	A	M	J	J	A	S	O	N	D	Y
9 am	M	73	77	73	71	74	77	74	73	63	65	70	66	71
3 pm		72	73	67	65	64	63	59	61	61	65	72	71	66
9 am	N	67	74	76	78	79	95	89	79	57	63	73	62	74
3 pm		52	58	53	51	58	70	62	54	40	48	57	48	54

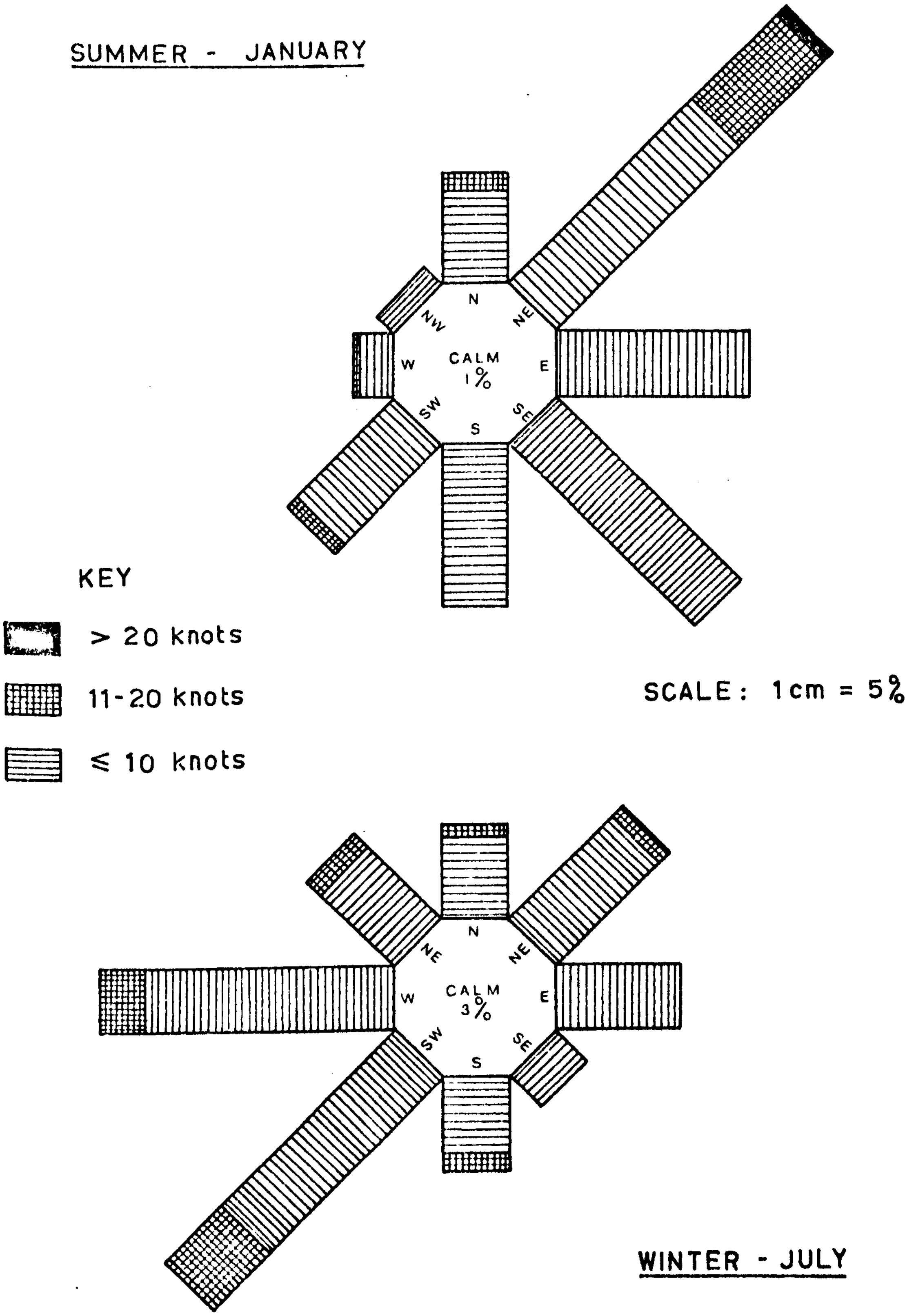
To date, no evaporation measurements have been recorded in the region.

Although records have been kept for only three years, wind data from Merimbula (figure 5.3) display a pattern which is basically similar to those of longer established stations further north on the N.S.W. coast. Three main components are evident. During winter months the greatest proportion of winds arrive from a westerly or south-westerly direction, while in summer, sea breezes from the northeast are prevalent, especially during the afternoons. Less frequent but often strong southerly and south-easterly winds associated with cyclonic depressions may occur throughout the year. As well as their climatic influence, the winds are also important in the generation of waves both at sea and within the estuaries; these latter effects are discussed in later chapters.

5.3 Vegetation

Catchment yields of water and sediment are also affected by the nature of the vegetation cover and may alter dramatically when this cover is removed, either by forestry operations, poor farming practices or urbanization (see for example Leopold, Wolman and Miller, 1964; Douglas, 1967; NSW Public Works Dept., 1969; Scholer, 1974). In this region, wet sclerophyll forest predominates and consists of a *Eucalyptus spp.* dominant tree story and a variably developed under story of sclerophyllous shrubs and small trees. In general, clearing has been confined to small areas of alluvial flats which border many of the rivers, but the degree of clearing varies considerably (table 5.7) Agricultural activities are most intensive in the Bega district where deeper granite derived soils on the less steep lower parts of the Bega River Valley have

FIGURE 5·3 PERCENTAGE OCCURRENCE: WIND SPEED & DIRECTION AT MERIMBULA (3 YRS. RECORDS) 1970-72



COMPILED FROM COMMONWEALTH BUREAU OF METEOROLOGY DATA

Table 5.7 Areas of Catchments Cleared of Natural Vegetation Cover

River Basin	Area (km^2)	Area (%)	River Basin	Area (km^2)	Area (%)
Mangan's Creek	0.8	8	Wallagoot C.	4.5	15
Cuttagee Creek	1.2	2	Merimbula C.	1.9	6
Murrah River	68.0	31	Boggy Creek	9.0	43
Wapengo Creek	8.3	13	Pambula R	48.0	17
Sandy Creek	9.6	33	Palestine C.	5.0	26
Nelson Creek	1.0	4	Nullica	0.7	½
Bega River	800 +	42	Towamba R.	65.0	8

been extensively cleared in order to provide pasture for dairy cattle, while the floodplain supports market gardening. Similar activities are pursued in the Pambula and Murrah valleys. At present, very little of the more rugged country has been cleared, but extensive clear-felling operations by the woodchipping industry are proposed in the very near future. Such operations will probably result in a significant increase in the volume of sediment eroded from hillsides until regeneration of the vegetation is well advanced. In some of the local National Parks, such effects have been observed when bushfires have been shortly followed by prolonged heavy rainfall (Alan Fox, N.S.W. National Parks & Wildlife Service, pers. comm.). Similar but more dramatic effects were observed approximately 100 kilometres further north during the disastrous 1860 floods when sand from the Araluen gold diggings partially blocked the escaping floodwaters of the Moruya River at Moruya, thus exacerbating the damage sustained by the township (Bayley, 1973).

5.4 Stream Flow

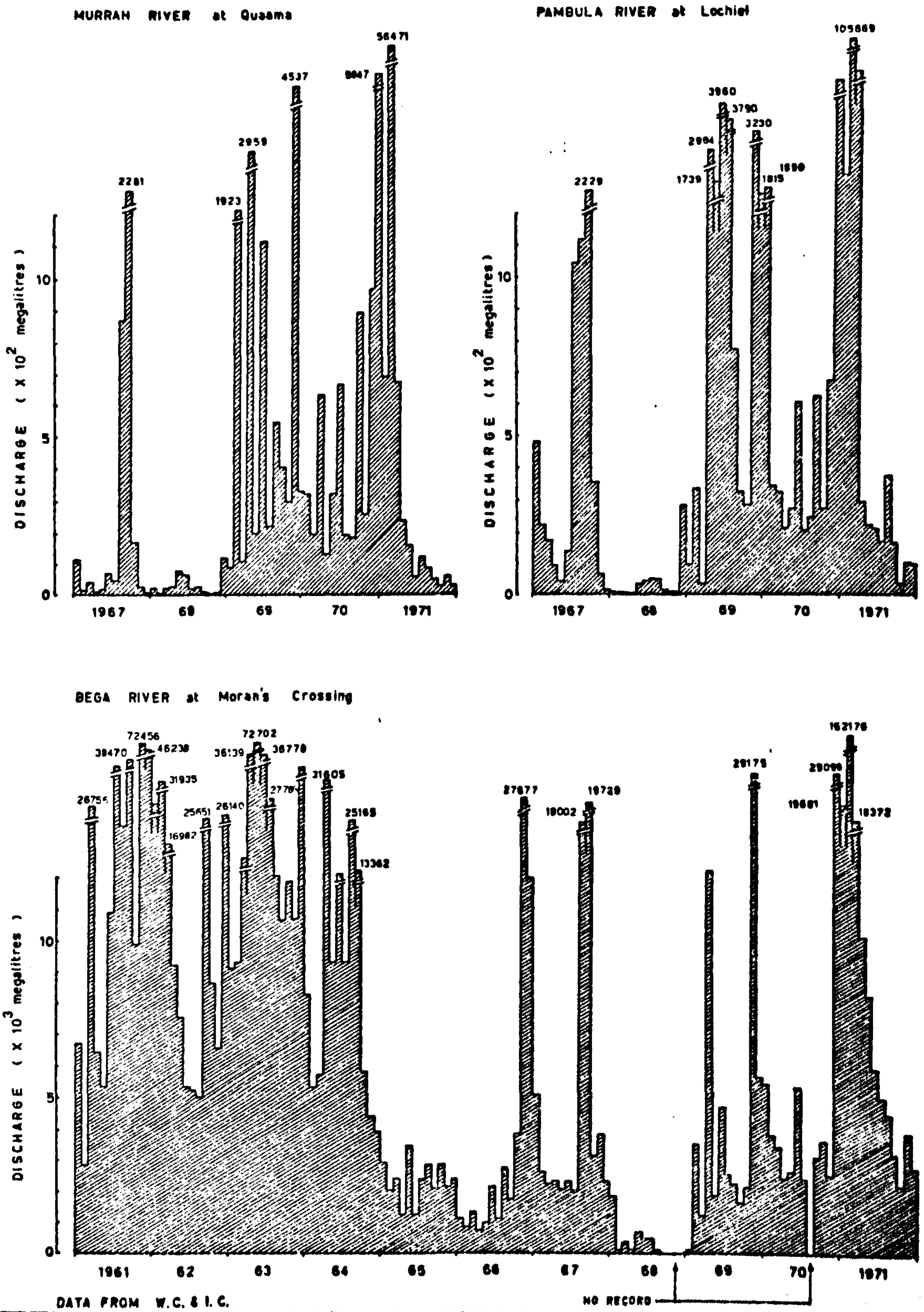
Discussion of stream flow relies heavily upon two Water Conservation and Irrigation reports (1966, 1968) and unpublished records of the same agency. To date, only the Bega, Towamba, Pambula and Murrah river systems have been gauged, and assessment of the discharge regimes of the other streams is based largely on extrapolation of the available data, inference from catchment characteristics, and on the author's field observations.

In figure 5.4 the hydrographs of monthly discharge at three gauging stations are shown, and indicate that variability of flow is characteristic of the region, with long periods of low flow as well as recurrent flooding. Monthly variations in the Towamba River for example, have ranged from 1% to 1700% of the mean monthly flow, while annual flow in the same river has ranged from 9% to 350% of the yearly average (W.C. & I.C., 1968). The lowest flow was recorded during the 1945 drought when, in May/June, the Bega River completely ceased to flow for nineteen consecutive days. Recent flood discharges are also indicated on the hydrographs (note breaks in scale); the highest values ever recorded are those of February 1971 when local residents and civil defence workers claimed that the river levels were the highest observed in fifty years.

The average monthly discharges of the four gauged rivers are shown in figure 5.5 and are based on all available flow data. Values for the Bega River system represent the summed gauged flow of the Bega River at Moran's Crossing and the Brogo River at North Brogo, whereas the Towamba, Pambula and Murrah river values are based on gauging records at New Building Bridge, Lochiel and Quaama respectively. Considerable variability is again apparent, the degree of which appears mainly to reflect the period of time for which records have been kept. The pattern may also be reinforced by the more persistent flow which could be expected in the larger rivers, given the basic climatic uniformity in the region. Least variation is demonstrated by the Bega river system values which are based on 28 years records. The Towamba, Pambula and Murrah rivers have been gauged for only 18, 7 and 5 years respectively. The monthly averages are also clearly distorted by extreme events, especially in the shorter records of the Pambula and Murrah rivers where, for example, the impact of the 1971 flood is readily apparent. No marked seasonality of flow is evident from the longer term records of the Bega and Towamba rivers; the small, late summer precipitation excess is probably countered effectively by the higher evaporation

FIGURE 5·4

HYDROGRAPHS OF MONTHLY DISCHARGE



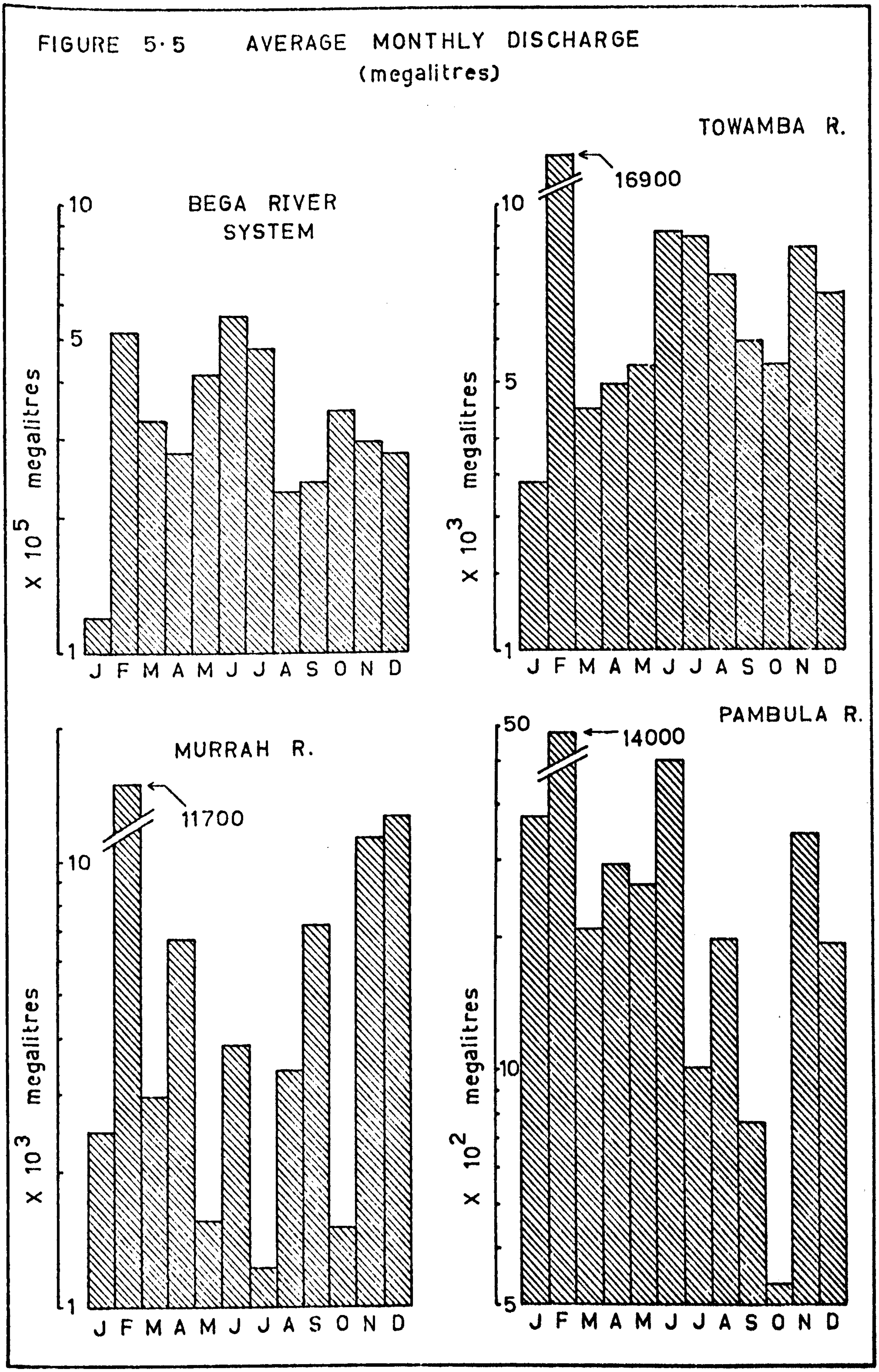
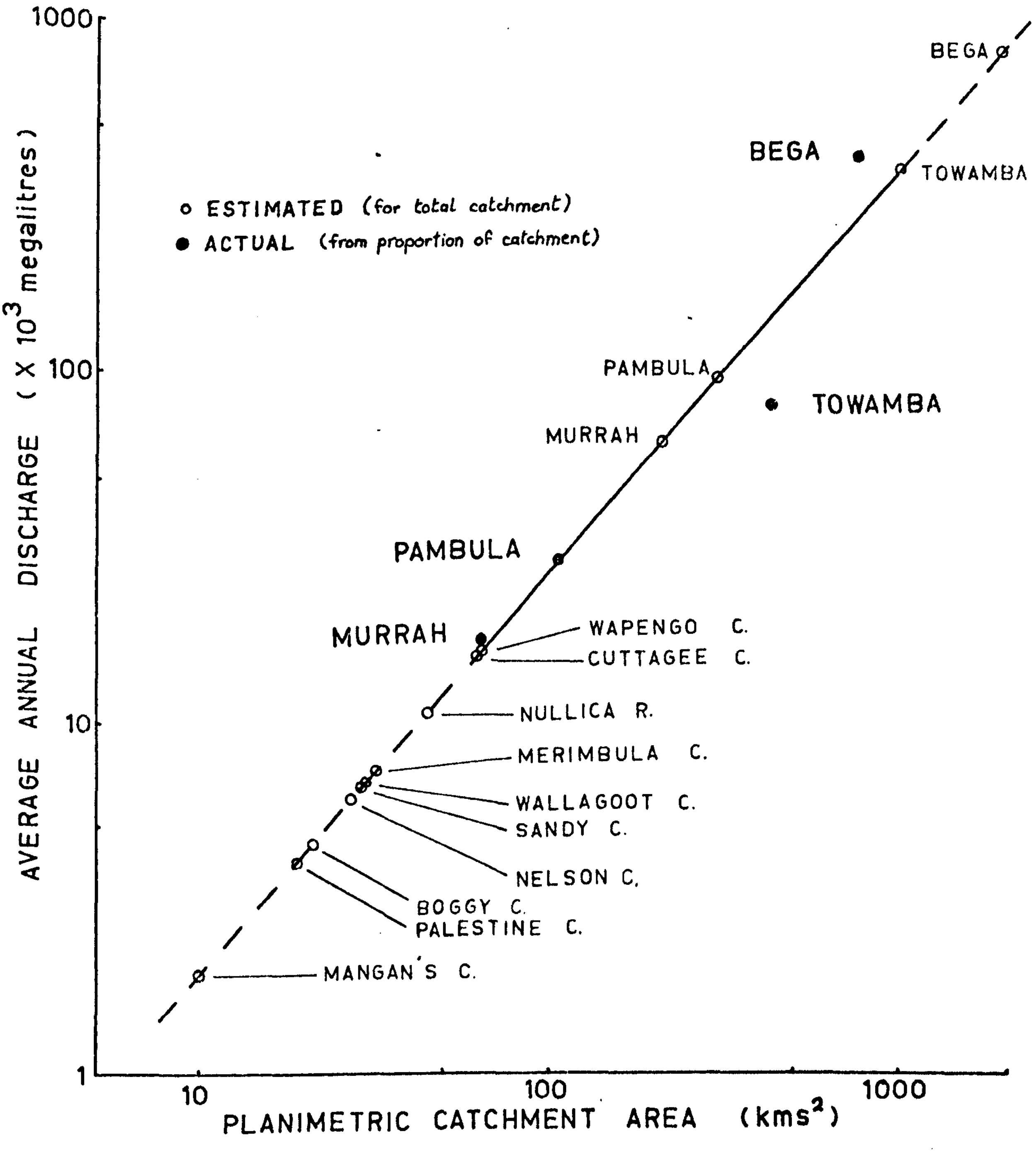


FIGURE 5·5 AVERAGE MONTHLY DISCHARGE
(megalitres)
BEGA RIVER SYSTEM
10
5
1
X 10^5 megalitres
J F M A M J J A S O N D
TOWAMBA R.
16900
10
5
1
X 10^3 megalitres
J F M A M J J A S O N D
MURRAH R.
11700
10
1
X 10^3 megalitres
J F M A M J J A S O N D
PAMBULA R.
50
14000
10
5
X 10^2 megalitres
J F M A M J J A S O N D

In order to estimate the average annual discharge from each drainage basin, figure 5.6 was prepared, wherein discharge is plotted against catchment area. The curve is based on W.C. & I.C. recorded discharges and the solid points represent total gauged flows. The proportion of each catchment monitored by these gauging stations is 40%, 43%, 36% and 28% for the Bega, Towamba, Pambula and Murrah river systems respectively. Statistical testing of the W.C. & I.C. data yielded a correlation coefficient (r) of 0.958 which was found to be statistically significant despite the small number of data points. The data were best fitted with a straight line when logarithmic axes were used. Similar logarithmic relationships between these two variables have been derived by other workers (for example, Leopold and Miller, 1956; Howe et al., 1967), although these studies were based on plots of flood discharge.

Extrapolation of the regression curve in each direction allows crude estimation of the average total annual discharge from the whole of each river basin. Obviously the results must be interpreted with great caution. For example the method assumes that the percentage runoff will be consistent throughout a given catchment; this is probably not so, and since most of the stream gauging stations are located in the steeper, more elevated headwater regions, a potential source of error is immediately apparent. Furthermore, the use of the linear regression model in this instance is at best, questionable (Poole and O'Farrell, 1971). Nevertheless the results do at least permit a simple ranking of the drainage basin discharges; certainly, application of more sophisticated runoff estimation models that are available is not warranted. The Bega and Towamba systems are clearly the most important, and the former can be confidently ranked highest of all. At the opposite end of the scale, Mangan's Creek is least important in terms of discharge, followed by Palestine and Boggy creeks. The Pambula, Murrah, Wapengo, Cuttagee and Nullica catchments can also be discriminated but within the remainder,

FIGURE 5·6 ESTIMATION OF AVERAGE ANNUAL DISCHARGE



Catchment	Area	Discharge	Catchment	Area	Discharge
Mangan's Crk	10	1905	Wallagoot Ck	30	6740
Cuttagee Crk	62	15533	Merimbula Ck	32	7260
Murrah R	220	66648	Boggy Ck	21	4473
Wapengo Crk	64	16110	Pambula R	300	95212
Sandy Crk	29	6483	Palestine Ck	19	3986
Nelson Ck	27	5971	Nullica R	45	10745
Bega R	1900	795365	Towamba R	990	375821

Area in kms²; Discharge in megalitres x 10³, per annum.

local variations in other factors such as the steepness of catchment slopes, and vegetation cover could upset the apparent ranking. Discharge from Wallagoot Creek for example could be less than suggested because very little of its catchment comprises steep slopes. On the other hand, the steep catchment terrains of Nelson Creek and the Nullica River must serve to increase both water and sediment discharge, and are probably at least partially responsible for the comparatively rapid rate at which these two streams have filled their estuarine basins with sediment. Generally though, there is little justification for trying to discriminate the middle ranking streams on the basis of the available data.

Field observations and discussions with local farmers support the general stream ranking in many instances, and demonstrates very clearly that flow in the smaller streams is much more variable. In 1973, after the region had received approximately 62% of its average annual rainfall during the previous twelve months, the eight lowest ranked streams all ceased to flow and according to local farmers it is not at all unusual for these streams to consist only of chains of pools. It appears that only in Cuttagee Creek and higher ranked streams can flow be regarded as perennial.

Such variability is of considerable geomorphic importance. For example, it appears likely that sediment transport and therefore delta growth and infilling of estuaries is dependent on flood discharges. Furthermore, a flood is usually required to open a closed inlet, persistent flow assists in maintaining the opening, while periods of low flow encourage inlet closure.

5.5 Sediment transport

Quantitative estimates of fluvial sediment loads are also restricted to the four rivers which have been gauged by the W.C. and I.C. To obtain these estimates, the curves prepared by Colby (1964) were used; these permit calculation of the total sand discharge (bed and suspended load) at a stream cross section on the basis of mean stream velocity, average depth of flow, and the median diameter of the bed material. This method has been tested with twelve other hydraulic sediment discharge formulae by a Task Committee of the A.S.C.E. (1971) and was found to be one of the most reliable. For this study, average stream velocities and depths of flow were compiled from W.C. & I.C. flow duration curves and rating tables for the four gauged stations and, by referring to the appropriate Colby curve, table 5.8 was prepared. More detailed tables are included as Appendix 1.

Table 5.8 River Flow (Q, cumecs) & Total Estimated Sand Discharge (Q_s, tonnes/day)

	Bega R *		Towamba R		Pambula R		Murrah R	
	Q	Q_s	Q	Q_s	Q	Q_s	Q	Q_s
1%	119	874	44	2682	28	594	23	278
2½%	86	392	27	1687	17	327	5	55
5%	45	68	19	977	5	35	3	21
10%	18	0	11	731	2	6	0.9	0
15%	N/C	N/C	N/C	N/C	1	0.5	N/C	N/C
20%	N/C	N/C	N/C	N/C	0.6	0	N/C	N/C
25%	N/C	N/C	5	69	N/C	N/C	N/C	N/C
30%	N/C	N/C	4	42	N/C	N/C	N/C	N/C
40%	N/C	N/C	3	0	0.3	0	N/C	N/C
50%	3	0	2	0	N/C	N/C	N/C	N/C

% values indicate proportion of time (since records commenced) that flow has equalled or exceeded the specified value of Q.
N/C = not calculated; * = combined values for Bega & Brogo rivers.

It is immediately apparent that in all cases there is no fluvial sand transport for 60 to 90% of the time, and that it is only during the less frequent, high discharge flows that substantial amounts of sand are moved. Clearly, the Towamba and Bega rivers, and to a lesser extent the Pambula and Murrah rivers have a much greater chance of supplying sand to and eventually filling their lower estuarine reaches, than have the remaining streams. Even assuming equivalent high discharge velocities in the latter, the much smaller channel dimensions predicate much smaller sand discharges. Also, the values tabulated should be regarded as potential sand discharges because there must be sufficient volumes of sand available for transport for them to be realized. In an earlier chapter it was suggested that this was not likely given the varying resistance of the rock types outcropping in the stream catchments.

5.6 Valley Fills and Floodplains

Consideration of the alluvial fills in the lower reaches of the various streams permits further comparative, though qualitative assessment of fluvial sediment transport. Varying amounts of alluvium are available for transport , either directly to the sea or to the head of the intervening estuarine basins (plates 5.1 - 5.3). In the Bega and Towamba rivers large sand and gravel point bars, and mid-channel shoals are common throughout the entire lower reaches and extend more than 40 kilometres upstream from the mouths of the respective estuaries. Similar shoals are located within 50 metres of the mouth of the Murrah river. However this is not the case with most of the other rivers and field observations support previous assertions stemming from the calculated total sand discharge rates. Streams draining the metasediments are clearly disadvantaged in terms of delivering non-lutaceous sediment to their lower reaches. Not only do their channels appear to store small total volumes of material, they also contain far greater proportions of gravel than the streams draining other rock types (figure 2.2a). Furthermore, given that mobilization of gravel requires greater stream competency, then these streams will move such material only during less frequently occurring higher velocity discharges.

Further information about valley fills is available from a few unpublished borelogs held by the N.S.W. Department of Main Roads. Sections across three rivers for which such data is available are shown in figure 5.7 and, although the drilling records do

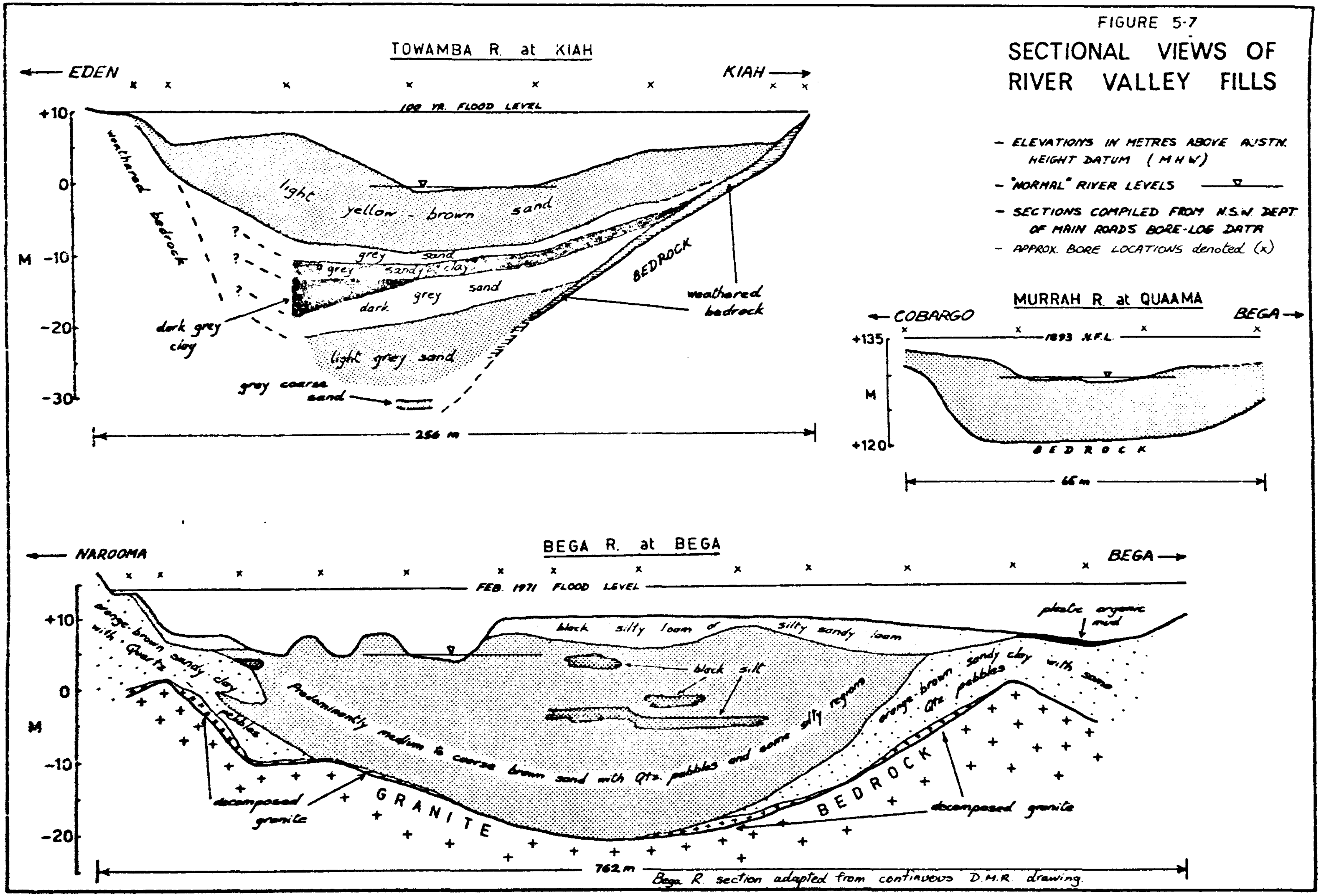


FIGURE 5·7
SECTIONAL VIEWS OF RIVER VALLEY FILLS

not lend themselves to detailed interpretation of the deposits, they do illustrate the degree to which the country rock has been incised and the extent to which the valleys have subsequently been filled with alluvium. Both the Bega and Towamba rivers have incised their valleys well below present sea level during former glacial periods. At Kiah, nearly 10 kms (by river) upstream from the sea, the bedrock/alluvium interface lies at least 30 metres below present sea level, while at Bega, approximately 21 kms (by river) upstream from the river mouth, the same interface lies about 20 metres below present sea level. A marked difference in sediment types is apparent at these sites. At Kiah, grey sands, sandy clays and clay form a sequence which may have been deposited in a low energy environment, possibly an estuarine one, during a phase of alluviation prompted by the postglacial rise in sea level. The light yellow-brown sand is contemporary alluvium which has prograded seawards, progressively filling the estuary. It is this material with which the sands of Whale Beach display a strong affinity at the present time. A similar sequence is not evident in the Bega River section; possibly estuarine conditions did not occur this far inland. The Bega River section also reveals deposits of 'orange-brown sandy clay with quartz pebbles' on either side of the river resting on weathered bedrock and underlying 'contemporary' alluvium. These deposits may be of Pleistocene age - relics of a larger, more continuous deposit, the bulk of which may have been removed by stream flow during the last glacial episode. The Murrah River section at Quaama has not been differentiated during drilling according to D.M.R. records.

Most of the rivers are flanked by variably developed flood plains, three of which are also evident in figure 5.7. Some also feature well developed terraces which are probably related to former wetter climatic phases during the last 30000 years or so (Walker, 1962; Young, 1976). In general the floodplains are only a minor landscape component though and simply comprise narrow and often discontinuous deposits clinging to steep valley sides. This situation is exemplified in the Towamba valley where alluvial flats account for less than 1% of the total catchment area of nearly 1000 km^2. In the lower third of the valley, particularly where the river flows through a narrow gorge incised into the more resistant Ordovician metasediments, the floodplain is largely discontinuous and widths on either side of the river rarely exceed 100 metres. The widest floodplain deposits occur near Pambula and Bega. At the former locality they are 1½ to 2 kilometres wide and feature many abandoned meanders which have been substantially infilled with overbank deposits during floods. Continuous floodplain deposits, often more than 500 metres wide occur downstream from Bega and similar features also flank the lower reaches of the Murrah River. Major floods have been a recurrent feature of life in riverside townships since they were first settled in the 19th century. Both Bega and Pambula were relocated after the floods of 1851, and in 1860 the Pambula River assumed its present northerly course across its floodplain near this town (Bayley, 1942, 1973; Ferguson, 1974). Contemporary floodplain accretion is not infrequent; after the relatively minor flood of March 1975 for example, large sheets and splays of muddy sands mantled paddocks and roadways often to depths in excess of 0.5 metres.

5.7 Deltas

Unlike the Bega and Towamba rivers which have substantially infilled their estuaries with fluvial sediment, the remaining streams debouch into estuarine basins wherein the seaward progress of river sands and gravel is marked by the presence of small deltas. Similar deltaic landforms are a common feature in most of the estuarine lagoons along the southeastern coast of Australia where small river valleys and coastal lowlands have been drowned by the postglacial rise in sea level and subsequently impounded by sand barriers. Examination of variations in delta morphology provides an additional means of assessing the sediment loads of their tributary streams.

The most prominent deltas are the cuspate-lobate forms which occur in Baragoot, Cuttagee and Wapengo lakes (plates 5.4, 5.8, 5.9) where the streams debouch into fairly broad basins via a single distributary channel flanked by a pair of sub-parallel levee banks. Usually the levees extend beyond the river mouth below water level forming subaqueous channel boundaries, the end of the submerged channel being marked by a terminal bar of gravelly sand. At high tide these subaqueous deltaic deposits are rarely covered by more than half a metre of water and thus on air photographs impart a digitate character to the delta as a whole. At low tide (when the lakes are open to the sea) their more elevated proximal sections are often exposed and experience minor reworking by small wind waves generated in the lakes. Similar wave reworking occurs around the delta perimeters and produces small beaches of fluvial sand. Sediments fine rapidly lakewards and are usually composed entirely of mud within 5 metres or so of the shore.

The levee bank crests stand highest of all the delta components and the land surfaces slope gently away from them towards the delta flanks. Distributary channel walls are almost vertical above low water level, but below this level they slope less steeply towards the sandy channel bed. Levee bank sediments were only examined in the field; all consisted of grey-black coherent sandy muds. At high tide, water levels rise to within half a metre of the levee bank crests and lower lying backswamp depressions fill with water if linked to the lake by smaller channels. Depressions not so linked fill with water only during heavy rain and floods, and slowly dry out by evaporation. During very high spring tides, banks near the mouth of Wapengo Creek are usually inundated with a few centimetres of water, but in general delta progradation by growth of levee banks appears to rely on flood discharges in the distributary channel. Overbank deposition of mud and lesser amounts of sand occurs only during floods, and recent splays of such material are commonly observed on the delta flanks indicating that delta progradation, by this mechanism at least, is continuing at the present time.

The submerged levees extend between 260 and 320 metres into the estuarine basins, a distance which on average is approximately equal to 6.5 times the average width of the distributary channel mouths (table 5.9, below).

"Lake"	Width of channel mouth (X) in metres	Length of submerged levees (Y) in metres	Ratio Y/X
Baragoot	35	240	6.9
Cuttagee	35	280	8.0
Wapengo	70	300	4.3

These results, together with the morphological characteristics of the three deltas, conform with results presented by Bates (1953) who established that river water debouching into a basin of denser water as a plane jet flow produces a distinctive pattern of sedimentation with an associated morphological zonation. For a distance of up to four times the width of the outlet (the "Zone of flow establishment") flow velocity remains constant along the jet's axis but diminishes rapidly towards the lateral boundaries of the jet. Such a velocity distribution pattern favours the formation of submerged sub-parallel levees bounding the core zone where no sedimentation occurs. Beyond this zone, axial velocity diminishes and sediment is deposited as a terminal transverse bar. This pattern is evident in plates 5.4, 5.8 and 5.9.

Very similar delta morphology occurs at the head of Back and Curalo Lakes (plate 5.5). At the former, where the initial valley was small and narrow, a relatively more advanced stage of infilling has been reached; backswamp depressions have been extensively filled by overbank deposition and widespread mixing of fluvial sands and muds on the very shallow lake floor has obscured any distinctive submerged deltaic forms that may have developed. This is also the case at Curalo Lagoon where the fluvial delta and marine threshold are offset from the lake basin proper thus allowing convergence of stream flow and flood tide currents at the northern side of the lagoon to produce amorphous sandy banks which are exposed at low tide. At both these localities where basin infilling is considerably advanced, the actual deltas display well vegetated digitate lobes which have protruded far into the lakes, and which at Curalo, appear to have prograded across threshold sands of marine origin. This situation may represent a more advanced stage of delta development which has not yet been attained at Baragoot, Cuttagee and Wapengo lakes, where only comparatively immature subaqueous digitate lobes are present. Progression of the sequence probably accelerates as the prograding lobes emerge, because lake fetches and therefore wave activity would be effectively reduced, thus allowing increased efficacy of fluvial deposition.

The apparent differences in the degree of delta development must also reflect differences in the original volume of the submerged river valleys as well as differences in the sediment discharges of the tributary streams. Using area as a guide to volume the smaller Back Lake and Curalo Lagoon would be expected to fill with sediment more rapidly than the larger lakes, assuming rates of sediment input were similar. The latter is not the case though and the differences have probably been exaggerated because erosion of the volcanic and sedimentary rocks in the catchments behind Back Lake and Curalo Lagoon releases larger volumes of sandy material than the metasediment catchments which feed the other three larger lakes.

An apparently anomalous situation exists at Pambula Lake where delta progradation is quite limited, even though the Pambula River is the third largest in the region, and also drains volcanic and sedimentary rocks. The anomaly is readily explained in terms of the initial size and configuration of the river valley following its submergence during the post glacial rise in sea level. At this time it appears likely that the lower reaches of the river consisted of two lakes connected by a narrow gorge, and that the lake furthest upstream has filled first to form a large expanse of alluvial flats. Downstream where the gorge joins the present day lake, large shoals of river sand are accumulating, and as at Curalo Lagoon, convergence of river and flood tide currents on the northern side of the lake has resulted in considerable mixing of sediment.

The number of distributary channel outlets varies at different localities, and provides more evidence for comparison of sediment supply rates. If the rate of supply is sufficient, the terminal bar will build upward rapidly until stream flow is blocked and eventually forced to find a new outlet (Bates, 1953). This situation has occurred at Wallagoot Lake and to a lesser extent at Curalo and Back Lakes, and emphasises the comparatively greater rate of sediment supply from the volcanic and sedimentary catchments. Similar development of much larger multi-outlet deltas has occurred elsewhere along the N.S.W. coast; for example at Lake Macquarie (Roy and Peat, 1975a), Tuggerah Lake (Turton, 1966), Lake Illawarra (Brown, 1969; Roy and Peat 1975b) and at Tuross and Coila lakes (Roy and Peat, 1976). In contrast, the presence of only one outlet at Baragoot, Cuttagee, Wapengo and Middle lake deltas emphasises the small sediment discharge of their tributary streams, all of which drain metasediment catchments.

The morphology of the deltas discussed so far also suggests that wind waves generated in these lakes have been ineffective in preventing progradation of protruding deltaic lobes. Where longer fetches exist this is not the case and the deltas exhibit more subdued outlines. The distal boundary of Wallagoot delta for example is arcuate in form and features sandy beaches (convex lakeward) and small curved spits (plates 5.10 - 5.13). Similar relict features and former channels are evident elsewhere on this delta, the general level of which is only 30cm or so above high water. A band of submerged sands and gravel, contiguous with and surrounding the delta perimeter, extends less than 20 metres into the lake. The contrast between this subdued plan form at Wallagoot and the lobate-digitate forms at other localities parallels the contrast between much larger scale deltas such as those of the Niger and Mississippi rivers (for example see Wright and Coleman, 1973) and represents differing balances between the opposing forces of fluvial and marine processes. In this particular instance the plan form of the Wallagoot delta reflects the dominance of lagoonal wave activity over the input of water and sediment by the tributary stream. Although a comparatively greater sediment discharge is responsible for the multi-outlet delta, wave action has reinforced the effect by limiting extension of the delta lobes into the estuarine basin. Not only have the lake waves directly moulded the delta perimeter into a arcuate rather than lobate form, they have also built sandy spits which have helped block former channel mouths thus encouraging channel diversion.

The small delta of Boggy Creek at the head of Merimbula Lake also appears to have been influenced by wave activity (plate 5.7). Here the delta has a broadly cuspate outline but instead of prograding directly into the lake, it has been deflected to one side and now flanks the northern bedrock shoreline of the lake. Submerged deltaic sediments protrude as a tongue narrowing toward its tip, and the slightly more elevated, but still subaqeous sediments forming the margins of this feature have been stabilised by oyster racks.

Delta morphology at the remaining lakes is rather indistinct; the estuarine basins have been substantially infilled and extensive mixing of sediments has occurred. The Nullica River delta for example is quite poorly developed, comprising three flat banks of sandy and occasionally gravelly mud standing about 30cm above high tide level. They are separated by small, shallow, sediment choked channels, some of which only carry water at high tide and during river floods. These banks also mark the confluence of a small, unnamed stream with the Nullica River and it is probable that the converging flows have precluded development of distinct delta lobes. Delta development may also have been restricted by the confining nature of the valley; the estuarine basin is nearly 1.5km long but the average width is less than 200m, and immediately downstream from the "delta" the maximum width is only 40m. A similarly confined situation exists in Nelson estuary and again, delta morphology is indistinct.

In Murrah Lagoon landforms such as large channel bars, old point bars and meander scrolls occupy most of the lake basin (plates 5.14 - 5.17). Protruding from the main stream channel which flows through these deposits is a large submerged tongue of river sands very similar in form to that of Boggy Creek at Merimbula. The pointed tip of this feature reaches to within 200 metres of the sea, and given the fluvial characteristics of the sand of which it is composed, it is evident that the Murrah River has almost filled its estuary and is approaching the stage reached by the much larger Bega and Towamba rivers which are already delivering small volumes of granitic sand to the nearshore zone during floods.

5.7.1 Temporal Changes in Delta Morphology

All the deltas appear to have grown during the last few decades, albeit slowly and intermittently. Evidence for this assertion is drawn mainly from aerial photographs taken by various agencies at different times since 1944. Only crudely qualitative assessments are possible; at all localities varying water levels make comparative interpretation difficult, and the quality of the older photographs is often somewhat limiting. Furthermore, at localities south of Wallagoot Lake, photographic coverage only extends back to 1962, and the magnitude of changes is even more difficult to ascertain.

In the metasediment areas north of Wallagoot

Lake where the photographic record extends back to 1944, the magnitude of change in the deltas has been sufficient to demonstrate that the greatest variations have occurred at the sites fed by the larger discharge streams such as Wapengo and Cuttagee creeks (plates 5.8, 5.9). Minor changes only are evident at Baragoot and Nelson lakes, while in the upper reaches of the Nullica estuary for which only ten years records exist, no changes are evident at all. At lakes where deltas are supplied with sediment from volcanic and sedimentary catchments air photographs also only cover a 10 year period, and changes appear similar to those observed at Baragoot. An exception, is the larger discharge Pambula River which exhibits considerable buildup of deltaic shoals where it debouches into Pambula Lake. Another exception is the delta constructed by Wallagoot Creek where substantial injections of sediment have occurred since 1944 (plates 5.10 - 5.13). At Murrah Lake which is supplied with granitic sand by the fourth largest river in the district, there have been substantial changes in the focus of deltaic deposition but such positional changes inhibit even qualitative assessments of the rates of sediment supply (plates 5.14 - 5.17).

It is apparent that the deltas are continuing to grow at the present time and there is some evidence that suggests that they are doing so at rates according to the size and lithology of the stream catchments. The rates are very slow, as is highlighted by the quite minor changes evident from photographs taken after the major floods of 1971, and at many localities change is indiscernible due to the short period for which records are available. Despite these limitations, the evidence, together with the observations of continuing growth in estuarine lagoons elsewhere in N.S.W. (Brown; op cit.; Roy and Peat, op cit.) supports Bird's argument (1962, 1970) in favour of progressive growth rather than partial submergence of a levee-bearing alluvial plain. On the other hand, Turton (1966) and Stockwell (1969) reported that the deltas in Tuggerah Lakes and Narrabeen Lagoon had not grown at all during 11 and 18 year long periods prior to 1965, both citing comparison of air photographs taken at different times during these periods as evidence. Both suggested that the deltas could be relict features relating to a former Holocene pluvial, however even if this explanation was correct, it cannot account for the continued progradation evident at other localities nearby. It is likely that, as Turton also suggests, the period of records is too short to show changes; by implication, stream sediment discharges are in general, also very small.

The absence of vegetation on the subaqeous levees, and the wave-worked perimeters of the subaerial portions of the deltas, suggests that progradation does not depend on the presence of stabilising plant species. Continuing levee growth has already been demonstrated; field observations revealed quite minor and only temporary delta shoreline erosion after periods of prolonged strong winds. On delta surfaces though, salt marsh successions are almost ubiquitous. They commence with Salicornia interspersed amongst patches of bare sand at or just above high water level, behind which on higher ground is a more extensive cover of the grass Sporobolus. Scattered clumps of Juncus occur throughout, and at some localities such as Baragoot, Back and Curalo lakes, occur as pure stands covering areas of 100 or so square metres. Further upstream toward the proximal regions of the deltas where banks are higher, Leptospermum thickets predominate as a low but very dense tree cover. Where lakes are more or less permanently open to the sea (for example Wapengo and Merimbula) sea water flows in twice a day with the flood tide, and coupled with low fresh water inputs from stream flow, creates conditions favouring establishment of mangrove stands. At Wapengo these may have encouraged sedimentation along the distal margin of the delta away from the river mouth. At both localities, oyster leases that have been established on the submerged portions of the deltas must have enhanced their stability, and may have accelerated sedimentation since their construction.

The vegetation must assist in establishing the delta surface by binding the sediment with plant roots, but it appears to play no role in the progradation mechanism itself. Bird (1967) has recorded similar observations elsewhere on the south coast of N.S.W. This situation contrasts with that in the Gippsland Lakes of Victoria where Bird (1961, 1962, 1970) has demonstrated a close relationship between delta progradation and the presence of Phragmites shoreline reedswamp. Since a permanent opening was dredged in the enclosing barrier in 1889, salinity levels have risen causing die-back of the Phragmites and thereby facilitating erosion of the now unprotected and over extended delta lobes. Had the Gippsland Lakes always had a permanent natural opening, it is unlikely that the Phragmites reedswamp would have been present, and the river deltas would have developed forms similar to those in N.S.W., rather than the very long digitate features that are now being destroyed.

5.8 Review

Despite the problems inherent in extrapolating from large to small catchments, the climatic, hydrologic, field and short term historical evidence collectively supports the conclusions advanced previously on the basis of sedimentological evidence alone. The larger drainage basins generate the greatest and more persistent river discharges and when these attributes are reinforced by a favourable catchment lithology such as granite and to a lesser extent sedimentary and volcanic rocks, significant quantities of sediment are transported to the sea. The largest streams such as the Bega and Towamba rivers have been most efficient in this regard and although they have had to fill initially more voluminous valleys, they have already largely done so and are supplying small volumes of river sand to the sea during floods. Intermediate sized rivers such as the Pambula and Murrah are approaching this stage - the latter is probably already doing so in very small amounts. The remaining streams have been less successful and are still building deltas seaward into their respective estuaries. Within this group, those supplied with sand from metasediment catchments are slowest of all. Sediment transport is an intermittent phenomenon since it is confined to infrequent high discharge events. The volumes moved are quite small. The evidence supports earlier conclusions that at most localities the sands forming the ocean beaches are relict deposits; replenishment with fluvial sand is unlikely for hundreds, possibly thousands of years.

Captions to accompany Plates 5.1 - 5.7

Plates 5.1 - 5.3 depict morphology typical of the lower reaches of the coastal rivers. The Bega River is shown at low flow, a few (6) kilometres upstream from its junction with the Brogo River. Note the large width/depth ratio and the abundance of sand and gravel in the channel. The channel is approximately 200 m wide at this point. The other two plates illustrate the ephemeral character of the smaller streams. Note too the amounts of sediment available for transport, and the large amount of gravel. Channel widths in these photographs are between 15 and 20 metres, and the banks stand 1 to 3 metres above the stream bed.

Plates 5.4 - 5.17 depict some of the river deltas in the region. Note the variations in form, and the subaqueous extensions of the delta lobes. Scale bars in plates 5.4, 5.5 and 5.7 represent ground distances of 200, 90 and 90 m respectively. Plates 5.8 - 5.17 demonstrate temporal variability of deltas over equivalent periods of time. The three localities show changes induced by streams draining each of the three basic catchment lithologies. Thus Cuttagee Creek (metasediments), Wallagoot Creek (volcanic sedimentary) and Murrah River (granite). Scale bars represent ground distances of 200, 90 and 200 metres respectively. Note the extension of the subaqueous lobes at Cuttagee, and the well defined core zone of the stream jet. At Wallagoot, the input of sand by the 1971 flood is evident, as are the effects of greater exposure to lake waves vis a more rounded delta outline, and the presence of numerous curved spits. In contrast with the forementioned localities where the estuarine basins are well defined, Murrah Lagoon is almost completely infilled with fluvial sands and fluvially moulded landforms extend to within 200 m of the sea.

Plates accompanied by the code letter F, L, or N are reproduced by courtesy of the Forestry Commission of N.S.W. (F), the N.S.W. Department of Lands (L) and the Division of National Mapping, Department of National Resources (N).

PLATE 5·1

Bega River

PLATE 5·2

Wallagoot Ck.

PLATE 5·3

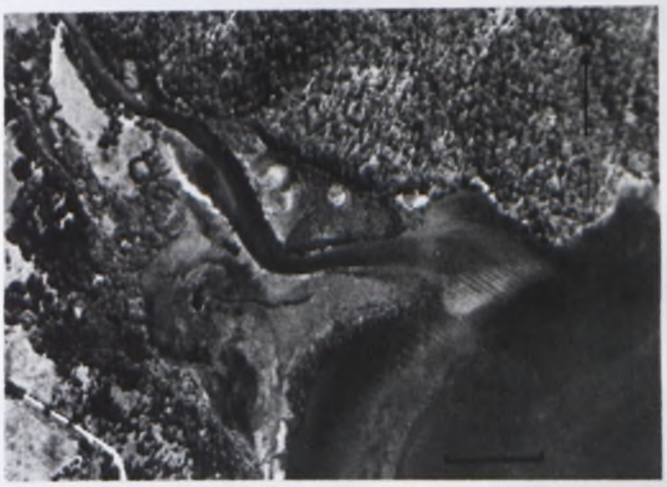
Boggy Ck.

(L)

Pl. 5·4 Wapengo Ck. delta

(L)

Pl. 5·5 Palestine Ck. delta

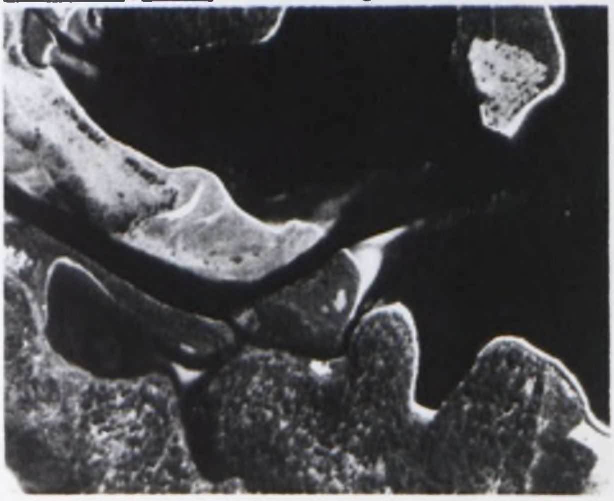


Pl. 5·7

Boggy Ck. delta

(F)

Pl. 5·8, 5·9 Cuttagee Ck. delta - Mar. 3, 1944 ; Jun. 4, 1972

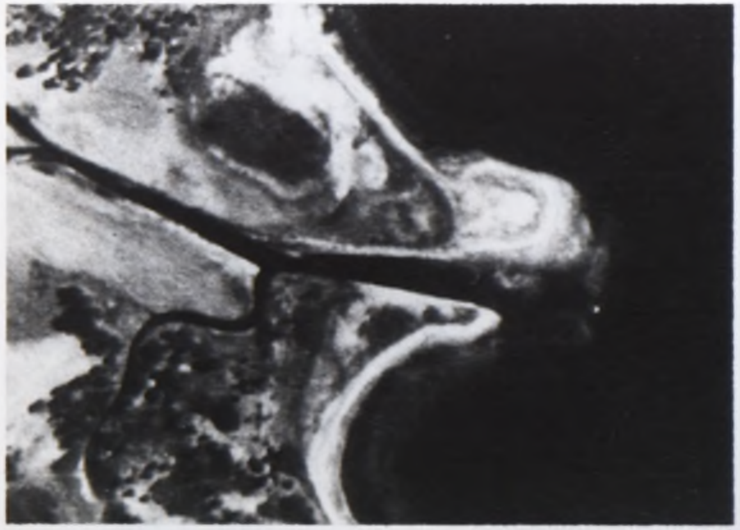


N)

(L

WALLAGOOT CREEK DELTA

Pl. 5·10



Mar 3 1944 (N)

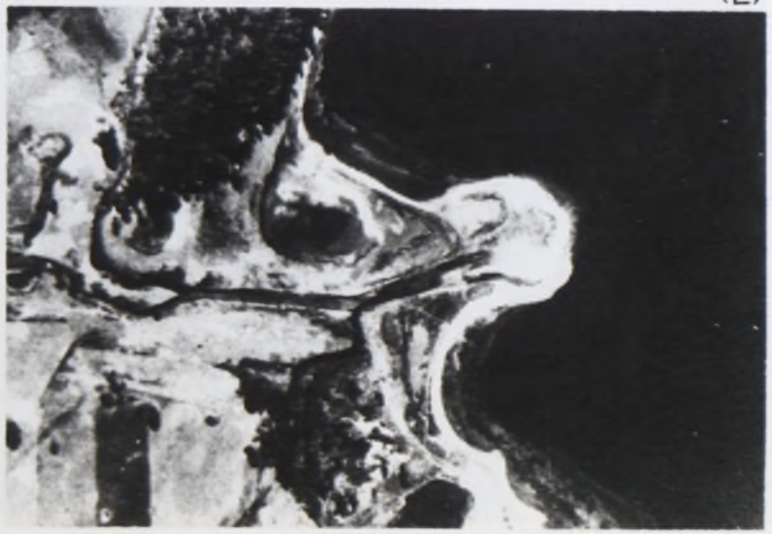
Pl. 5·11

Feb 22 1964 (F)

Apr 3 1971 (L)

Pl 5·12

Jun 4 1972 (L)



Pl 5·13

Pl. 5·14 Mar. 3, 1944 (N)

Pl. 5·15 Mar. 16, 1967 (L)

MURRAH R. DELTA

Pl. 5·16 Mar. 30, 1971 (L)

Pl. 5·17 Jun. 4, 1972 (L)

CHAPTER SIX THE WAVE REGIME AND ITS EFFECTS

The amount of wave energy imparted to a shore is an important factor influencing the distribution of beach sands and the sedimentological trends within them, and also affecting beach morphology and the behaviour of tidal inlets. In order to explore such relationships along this stretch of coast, recent wave data has been used to establish an annual wave climate for the region. The more important components of this are examined and include the average annual energy available for work, the variation of this energy between embayments and within particular embayments, and the proportion which is available for longshore transport of sediment. The geomorphological and sedimentological manifestations of these components are also discussed.

6.1 Wave Origins

In his discussion of global wave regimes, Davies (1964, 1972) suggested that the New South Wales coast is typical of a high energy East Coast swell environment dominated by a long period southeast swell which is generated by intense storm depressions many hundreds of kilometres away in the higher latitudes of the Southern Ocean. Geomorphological evidence in support of this is afforded by the close agreement between the alignment in plan form of present day beaches and the refracted wave pattern of this swell. Similar alignment of Pleistocene and Holocene barrier beach ridges right along the N.S.W. coast indicates that this situation has prevailed for many thousands of years and that locally generated waves have been unable to effect more than relatively short term changes in beach alignment, despite the temporally variable nature of the southeast swell compared for example, to its West Coast counterpart.

Superimposed on the background swell are waves generated by more localized meteorological conditions over southeastern Australia and the adjacent Tasman Sea. These conditions are controlled by the regular eastward progression of large anticyclones often blanketing the entire continent, coupled with the seasonal latitudinal migration of the semi-permanent high pressure belt of the southern hemisphere to which they belong (Gentilli, 1972). In summer, the anti-cyclones follow their most southerly paths, usually centred at about 35° South, and produce fine settled weather with attendant low seas. In winter, when the average central path of the highs is approximately six degrees closer to the equator, mid-latitude storm depressions reach further north and generate high waves in the Tasman Sea.

Thom <u>et al.</u> (1973) have documented seasonal beach profile changes along the Central and South Coast of N.S.W. and suggest that periods of wave activity generated by five major weather systems are responsible. Similar, though far less specific conclusions about the synoptic controls of waves in this region have been reported by earlier workers (Boleyn, 1967; Stone and Foster, 1967; Stone, 1969). The five systems described by Thom <u>et al</u>. are summarized below.

i) In winter, the Australian continent is often almost entirely covered by a large anticyclone, the southern portions of which are characterized by a persistent and often very strong westerly airstream. These offshore winds flatten nearshore waters and facilitate the constructional effectiveness of the long, low background southeast swell. In unprotected waters further offshore, very short period "chop" arises and travels away from the coast.

ii) During summer, a diurnal heat imbalance between land and sea together with the more southerly position of the anticyclone results in afternoon Northeast seabreezes of variable strength. Steep, short period waves result.

iii) Separating the anticyclones are smaller troughs of low pressure. Cold fronts associated with these small depressions often induce strong southerly winds with attendant large storm waves. Such conditions are usually short lived and are particularly common in winter months, although the famed southerly busters of summer are of similar origin.

iv) Occasionally, much more intense quasi-stationary low pressure cells develop and mature in the Tasman Sea producing very strong and persistent south to southeast winds which in turn generate very rough seas. These depressions are winter phenomena and because they are so deeply embedded in the atmosphere they usually persist for many days.

v) Tropical cyclones which develop in the Coral Sea also affect wave climate in southern New South Wales since they often migrate southward to positions off the southern Queensland and less frequently the northern N.S.W. coasts. They are normally confined to late summer and generate high energy waves which may approach the N.S.W. coast from between northeast and southeast depending upon how far south the cyclone travels before decaying.

According to Thom et al. (1973) the first two situations above are usually coincident with beach accretion, while erosive waves are associated with the latter three categories.

6.2 Previous Hindcast Analyses of Wave Climate on the N.S.W. C ast

A number of workers, oriented towards effective engineering design of coastal structures, have attempted quantitative analyses of wave climate along the N.S.W. coast between Sydney and the Victorian border. The first report was that of White (1966) whose results were later reviewed and expanded by the Department of Public Works (1970).

In these studies the likely wave conditions were described for Shellharbour, some 200 kilometres north of the study area. The results were obtained by hindcasting from 6 and 12 hourly synoptic charts for the years 1950 to 1965 inclusive using the Sverdrup, Munk and Bretschneider method. Statistics were prepared for deep water conditions, as well as for those in the proposed harbour, after due allowance had been made for refraction and shoaling. The results were only considered valid for the coast between Port Stephens in the north and Jervis Bay to the south.

Boleyn's 1967 report on wave conditions at Twofold Bay is somewhat inadequate, despite its immediate geographic relevance to the study area. From the 16 years of White's study, Boleyn selected the roughest (1956) and calmest (1965) years and then hindcast the wave conditions for only portions of these two years, thus including only 66% of annual wave occurrences. His often convoluted discussion fails to substantiate his general conclusion that deep water wave heights at Twofold Bay are on average 30% less than at Shellharbour. It is not clear from his discussion that decay distances for waves generated by Tasman Sea depressions are on average the same or greater for Twofold Bay; in fact the opposite appears more likely Twofold Bay is, as Boleyn earlier states, closer to the mid-latitude storm belt, and therefore likely to experience higher waves than Shellharbour. Indeed, recent, though relatively short term waverider buoy data from the Gold Coast in Queensland, and from Newcastle, Sydney and Port Kembla in N.S.W. suggests increasing wave heights southward along the N.S.W. coast (N. Lawson, Maritime Services Board of N.S.W., pers.comm.).

Another analysis of wave climate was produced by Wright (1967) for the long embayment at the mouth of the Shoalhaven River, approximately 120 kilometres south of Sydney. His study was based on observations of wave height and direction recorded at Point Perpendicular lighthouse at the northern entrance to Jervis Bay, while average wave periods were obtained from five years hindcasting. Wright acknowledged the limitations of his data and highlighted the differences between the two sets of records. Such discrepancies are best evidenced by the frequencies of direction of wave approach. Lighthouse observations recorded southeasterly swell 56% of the time and northeasterly waves 0.4%, whereas the hindcast analysis indicated northeasterly waves to be most frequent and southeasterly waves least so. This discrepancy is probably due to the arrival of swell waves from areas not considered during hindcasting. Also, the directional unreliability of lighthouse wave observations was often noticed during field work for this particular study, while the inaccuracy of visual estimates of wave height is well documented in the literature (see for example Davies, 1964; King, 1972).

In fairness of course, it should not be forgotten that the foregoing studies were based upon the best data available at the time. In recent years however, the advent of continuously recording waverider buoys has encouraged more sophisticated analysis of wave conditions. Since 1971 the Maritime Services Board of N.S.W. has maintained a number of such recorders in Botany Bay near Sydney as well as one in deeper water three kilometres offshore. Lawson and Abernethy (1975) have rigorously analysed the first three years of deep water records, and their results are superior to those obtained from hindcasting, particularly in terms of their continuity and objectivity. Of further advantage is that all waves are included in the record, unlike the hindcast records which excluded all waves less than three feet (0.9 m) high. Spectral analysis of waverider records can also reveal the presence of more than one wave train such as short period seabreeze generated waves superimposed on a background swell. Therefore, although the results are derived from a relatively short term record, they are the best currently available and accordingly they have been used in the following determination of the average annual wave conditions in the study area. Lawson (pers. comm.)

has suggested that the results are applicable to the Far South Coast nearly 350 kilometres south of Botany Bay; Stone (1969) and McLean and Thom (1975) lend support to this assertion.

6.3 Annual Deep Water Wave Climate, Far South Coast, N.S.W.

Wave trains rarely arrive at an ocean shore in regular formation; rather they are of varying heights and periods often approaching from more than one direction. The determination of an annual deep water wave climate requires that this assortment be reduced to representative and manageable height, period and direction combinations; this in turn facilitates subsequent refraction and shoaling analyses and calculation of the energy imparted to the shore.

6.3.1 Deep Water Direction of Wave Approach

Lawson and Abernethy (1975) have tabulated the probabilities of waves approaching Botany Bay from nine compass points between north and south. This data has been recast in condensed form to facilitate later computation, and as shown below, indicates the probability of waves of all periods and heights arriving from four 45° sectors centred on northeast, east, southeast and south. The respective probabilities are .212, .232, .270 and .286 and are plotted as vectors in figure 6.1. Also shown are the directional probability vectors of Boleyn (1967), Wright (1967) and P.W.D. (White) (1966).

The high proportion of waves approaching from the southeast quadrant is immediately obvious but beyond that, not insubstantial discrepancies are evident. For example there is considerable variation in the proportion of northeasterly waves, and although the data shown cover different time periods, it would be incautious to assume that such wide variations can be wholly explained as real, long term phenomena. Wright (1967) acknowledges that his value is very low and suggests that the short, and usually fairly small northeasterly waves might often pass unnoticed from a lighthouse sited more than 90 metres above the sea.

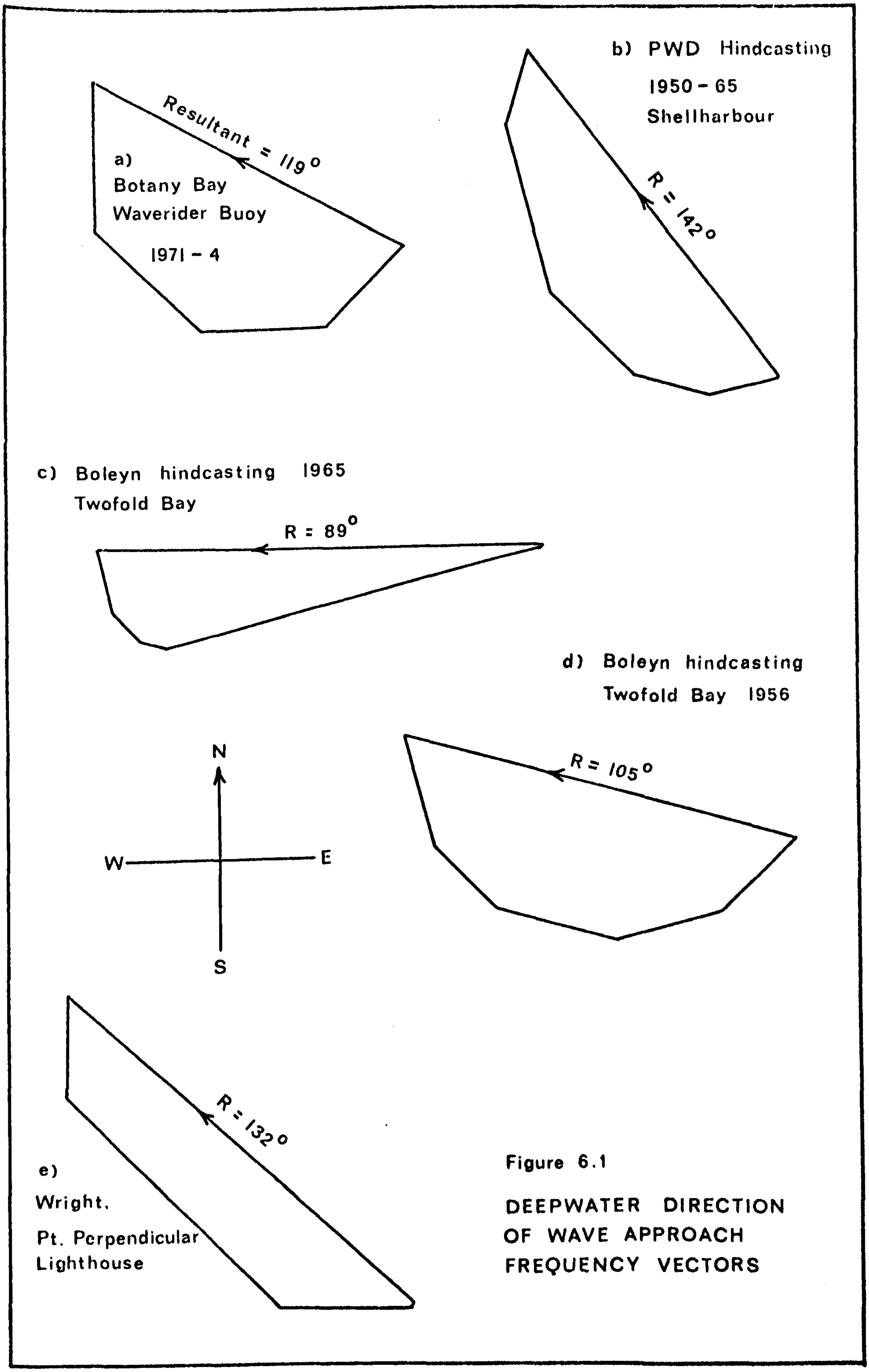


Figure 6.1

DEEPWATER DIRECTION OF WAVE APPROACH FREQUENCY VECTORS

Reflection of such waves from the vertical cliffs prevalent in the area, and the resultant interference with incoming waves may also render observation difficult. The other hindcast statistics also indicate a significantly smaller proportion of northeasterly waves; this may reflect a tendency for hindcasting to underestimate short period waves generally, or it may be due to the method's inability to cope with local seabreezes which result from diurnal heat imbalances rather than larger scale synoptic patterns. Stone and Foster (1967) emphasize the bias resulting from the exclusion of all waves less than 0.9 metres high by Boleyn and P.W.D., and together with Munro (1963) stress the difficulty of assessing the importance of northeasterly waves due to the lack of data concerning frequency, velocity and duration of the seabreezes which generate them.

All the reports mentioned so far agree that northeasterly waves are confined mainly to the summer months, whereas southerly waves occur throughout the year, although most commonly in winter. This not only reflects the seasonal variation of synoptic controls, it also suggests a source of error when applying the wave rider data to an area further south. Gentilli (1972, p. 113) points out that westerly winds are much more prevalent southward; this will not only affect the directional probabilities, it will also tend to dampen wave heights.

6.3.1 Deep Water Wave Height, Period and Wave Length.

Representative values of these parameters can be calculated readilyfrom the period-probability and height-probability tables of Lawson and Abernethy (1975, figures 4A, 4C). The relevant extracted values can then be substituted into the basic wave equations below:

i) $L_o = 1.56\ T^2$ (derived)

ii) $E = 1256.4H^2$ (derived)

where........ a) L = wavelength in metres

b) T = wave period in seconds

c) H = wave height in metres

d) E = total wave energy in joules/ metre width of wave crest per wave. The derivation of equation 2 is included as Appendix 2. Using the above information. Table 6.1 was constructed for waves approaching from the northeast sector.

Table 6.1 Northeast waves

T_z	T	$\bar{H}_s$	E	P_r	ε
4.50	6.36	1.11	97.7×10^3	.038	3.7×10^3
5.50	7.78	1.28	194.4×10^3	.065	12.6×10^3
6.50	9.19	1.44	343.2×10^3	.019	6.5×10^3

where T_z = zero crossing period as plotted by Lawson & Abernethy (1975).

T = wave period; $T = 1.414T_z$ (Abernethy & Lawson, 1973).

$\bar{H}_s$ = mean significant wave height. Significant wave height is the average height of the highest one third of waves in sample.

E = total wave energy (joules/metre/wave)

P_r = probability of occurrence of waves having nominated T_z.

ε = relative total energy = $E \times P_r$

Equivalent values for each of the other three directions are shown in tables 6.2 - 6.4.

Table 6.2 Easterly waves

T_z	T	$\bar{H}_s$	E	P_r	ε
4.50	6.36	1.07	90.8×10^3	.021	1.9×10^3
5.50	7.78	1.32	206.7×10^3	.046	9.5×10^3
6.50	9.19	1.50	372.4×10^3	.030	11.2×10^3
7.50	10.61	1.90	796.5×10^3	.009	7.2×10^3

Table 6.3 Southeasterly waves

T_z	T	$\bar{H}_s$	E	P_r	ε
4.50	6.36	1.08	92.5×10^3	.018	1.7×10^3
5.50	7.78	1.46	252.9×10^3	.046	11.6×10^3
6.50	9.19	1.74	501.2×10^3	.043	21.6×10^3
7.50	10.61	2.00	882.5×10^3	.019	16.8×10^3
8.50	12.02	2.37	1590.6×10^3	.009	14.3×10^3

Table 6.4 Southerly Waves

T_z	T	$\overline{H}_s$	E	P_r	$\mathcal{E}$
4.50	6.36	1.03	84.1×10^3	.027	2.3×10^3
5.50	7.78	1.41	235.8×10^3	.059	13.9×10^3
6.50	9.19	1.91	603.9×10^3	.070	42.3×10^3
7.50	10.61	2.32	1187.6×10^3	.035	41.6×10^3
8.50	12.02	3.10	2721.4×10^3	.008	21.8×10^3

Lawson and Abernethy actually plot values of T_z and a logarithmic transform of H_s; the calculations in this study used the same units, but for simplicity, the results are expressed in the following text as the more familiar units H_s and T. From the data above, two estimates of the average wave period for each direction can be calculated.

i) a simple arithmetic mean ...... $\overline{T} = \dfrac{\Sigma(P_r \times T)}{\Sigma P_r}$

ii) a weighted mean .... $\overline{T} = \dfrac{\Sigma(\mathcal{E} \times T)}{\Sigma \mathcal{E}}$

The values of each are shown below for each direction in table 6.5

Table 6.5 Average Wave Periods

DIRECTION	SIMPLE MEAN	WEIGHTED MEAN
NORTHEAST	7.53 s	7.95 s
EAST	8.14 s	8.90 s
SOUTHEAST	8.74 s	9.84 s
SOUTH	8.76 s	9.96 s

The weighted value is preferable because of the exponential relationship between wave energy, wave height and period, namely that energy E is proportional to the product of height and period both squared ($H^2 \times T^2$). Thus, if height is held constant, then a doubling of wave period results in a quadrupling of wave energy. The simple arithmetic mean summarizes the probability distribution of wave period alone, whereas the weighted mean summarizes the probability distribution of the energy associated with the waves concerned. As can be seen from table 6.5 the weighted measure is in all cases greater in numerical value than the unweighted mean; this adjustment reduces the bias towards shorter, lower energy waves which is inherent in the simpler measure.

Interpolation from Lawson and Abernethy's tables shows that the average significant wave height of northeasterly waves having an average period of 7.95 seconds, is 1.30 metres. By calculation the average wavelength is 98.6 metres. The same operations were performed for easterly, southeasterly and southerly waves and the summary values so derived are shown in table 6.6. They refer to deep water conditions and are considered to be representative descriptors of waves approaching from each of the four directional sectors.

Table 6.6 Average period, height and length of waves

DIRECTION SECTOR	$\overline{T}$ (seconds)	$\overline{H}_s$ (metres)	$\overline{L}_o$ (metres)
NORTHEAST	7.95	1.30	98.60
EAST	8.90	1.46	123.57
SOUTHEAST	9.84	1.86	151.05
SOUTH	9.97	2.12	155.07

6.3.3 Deep Water Wave Energy and Wave Power

Substituting the foregoing values into equation 2 it is possible to calculate the "average" deep water wave energy for each direction of wave approach. The values also permit the construction of wave refraction diagrams which indicate the degree to which this energy is dispersed as the waves approach the shore. The energy values can also be expressed in terms of wave power or energy per unit time, using the equation $P = nE/T$ (Wiegel, 1972) where n is the ratio of wave group velocity to phase velocity (C_g/C) for which Wiegel has tabulated values. Note that $n = \frac{1}{2}$ in deep water and approaches unity as depth approaches zero. Also, by multiplying each power value by the appropriate directional probability, an expression of relative wave power can be determined. The results are shown in table 6.7. The dominance of waves from the south and southeast sectors is well demonstrated, for not only

Table 6.7 Deep Water Wave Energy and Power

DIRECTION SECTOR	DIRECTIONAL PROBABILITY	WAVE ENERGY (joules/metre)	WAVE POWER (kilowatts/m)	RELATIVE POWER
NE	.212	209.4×10^3	13.2	2.8
E	.232	330.9×10^3	18.6	4.3
SE	.270	656.6×10^3	33.4	9.0
S	.286	875.6×10^3	43.9	12.6

refraction and shoaling must be examined.

As waves travel shorewards into shallower water their velocity becomes more dependent on water depth; their progress is increasingly retarded by frictional interaction with the seabed and a decrease in wave length and velocity results. Since waves usually approach a shore at an angle to the bathymetric contours, the reduction in velocity is not constant and the waves refract.

Wave refraction on the Far South Coast was simulated graphically by applying the technique developed by Johnson, O'Brien and Isaacs (1948) to the four representative wave trains detailed in table 6.6. Two bathymetric charts were used as base maps; Aus. 806 Gabo Island to Montagu Island 1:150000 and Aus. 191 Twofold Bay 1:25000 published by the Hydrographic Service of the Royal Australian Navy in 1956 and 1972 respectively. The former chart was improved to a small extent by incorporating additional data provided by the R.A.N. Hydrographer and the Director of National Mapping (pers. comms.).

Using the first chart, wave crests and orthogonals were projected shorewards from deep water to the approximate breakpoint depths of waves approaching the beaches between Bermagui and the Pambula River entrance, and to the point which enabled earliest transfer of the plot to the larger scale chart covering Twofold Bay and the beaches within it. The refracted wave patterns are reproduced at reduced scales in figures 6.2 - 6.13. Wave orthogonals and refraction coefficients are also shown.

do such waves contain more energy by virtue of their greater height and length, they are also the most common.

6.4 Wave Refraction, Shoaling and Nearshore Wave Power

Discussion so far relates only to deep water conditions, that is to depths which exceed half the wavelength of the approaching waves. Before the deep water wave climate can be related more directly to wave conditions at the shore, wave modification due to refraction and shoaling must be examined.

As waves travel shorewards into shallower water their velocity becomes more dependent on water depth; their progress is increasingly retarded by frictional interaction with the seabed and a decrease in wave length and velocity results. Since waves usually approach a shore at an angle to the bathymetric contours, the reduction in velocity is not constant and the waves refract.

Wave refraction on the Far South Coast was simulated graphically by applying the technique developed by Johnson, O'Brien and Isaacs (1948) to the four representative wave trains detailed in table 6.6. Two bathymetric charts were used as base maps; Aus. 806 Gabo Island to Montagu Island 1:150000 and Aus. 191 Twofold Bay 1:25000 published by the Hydrographic Service of the Royal Australian Navy in 1956 and 1972 respectively. The former chart was improved to a small extent by incorporating additional data provided by the R.A.N. Hydrographer and the Director of National Mapping (pers. comms.).

Using the first chart, wave crests and orthogonals were projected shorewards from deep water to the approximate breakpoint depths of waves approaching the beaches between Bermagui and the Pambula River entrance, and to the point which enabled earliest transfer of the plot to the larger scale chart covering Twofold Bay and the beaches within it. The refracted wave patterns are reproduced at reduced scales in figures 6.2 - 6.13. Wave orthogonals and refraction coefficients are also shown.

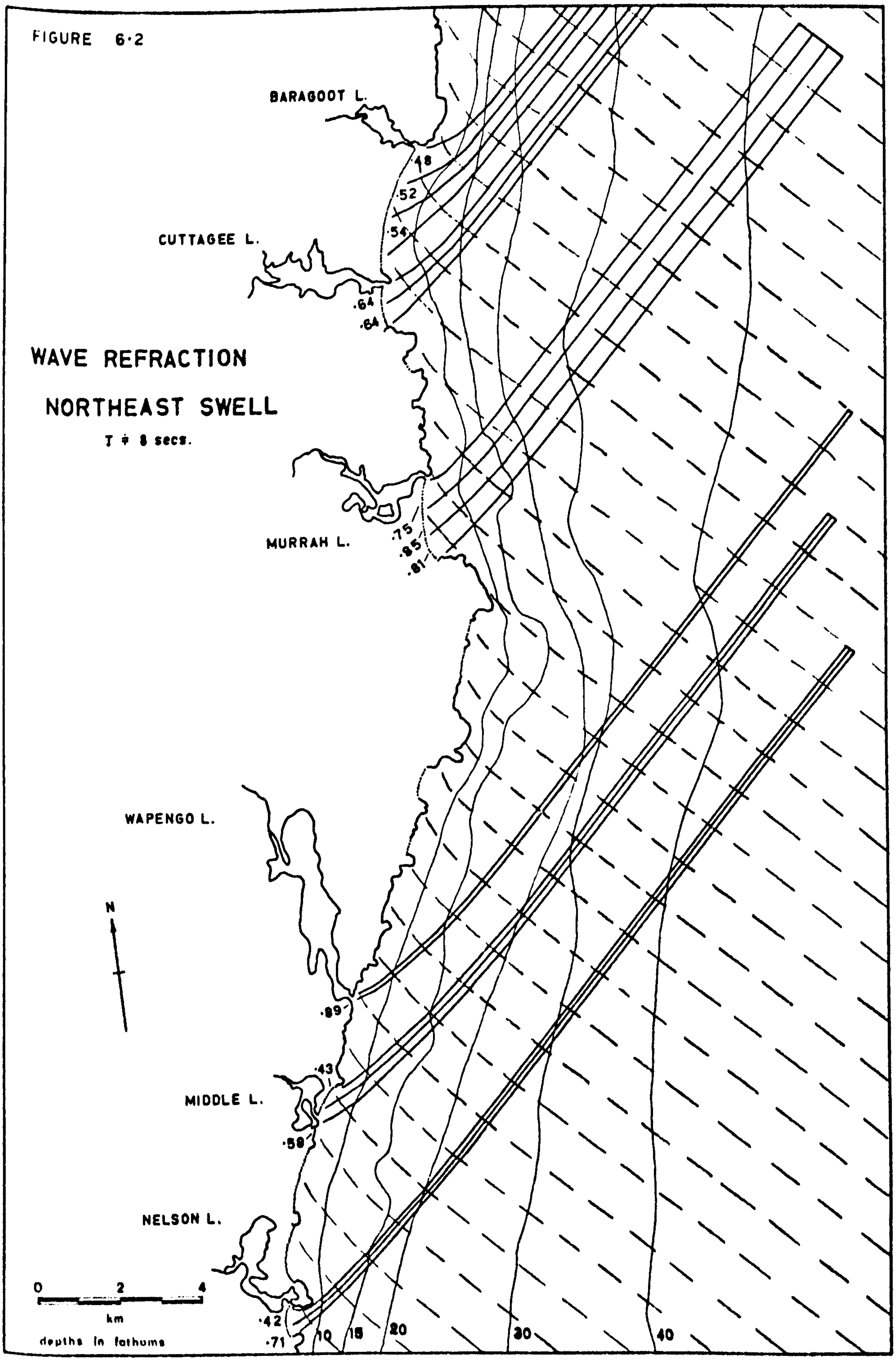


FIGURE 6·2
WAVE REFRACTION
NORTHEAST SWELL
T ÷ 8 secs.
BARAGOOT L.
CUTTAGEE L.
MURRAH L.
WAPENGO L.
MIDDLE L.
NELSON L.
N
0 2 4
km
depths in fathoms
10
15
20
30
40

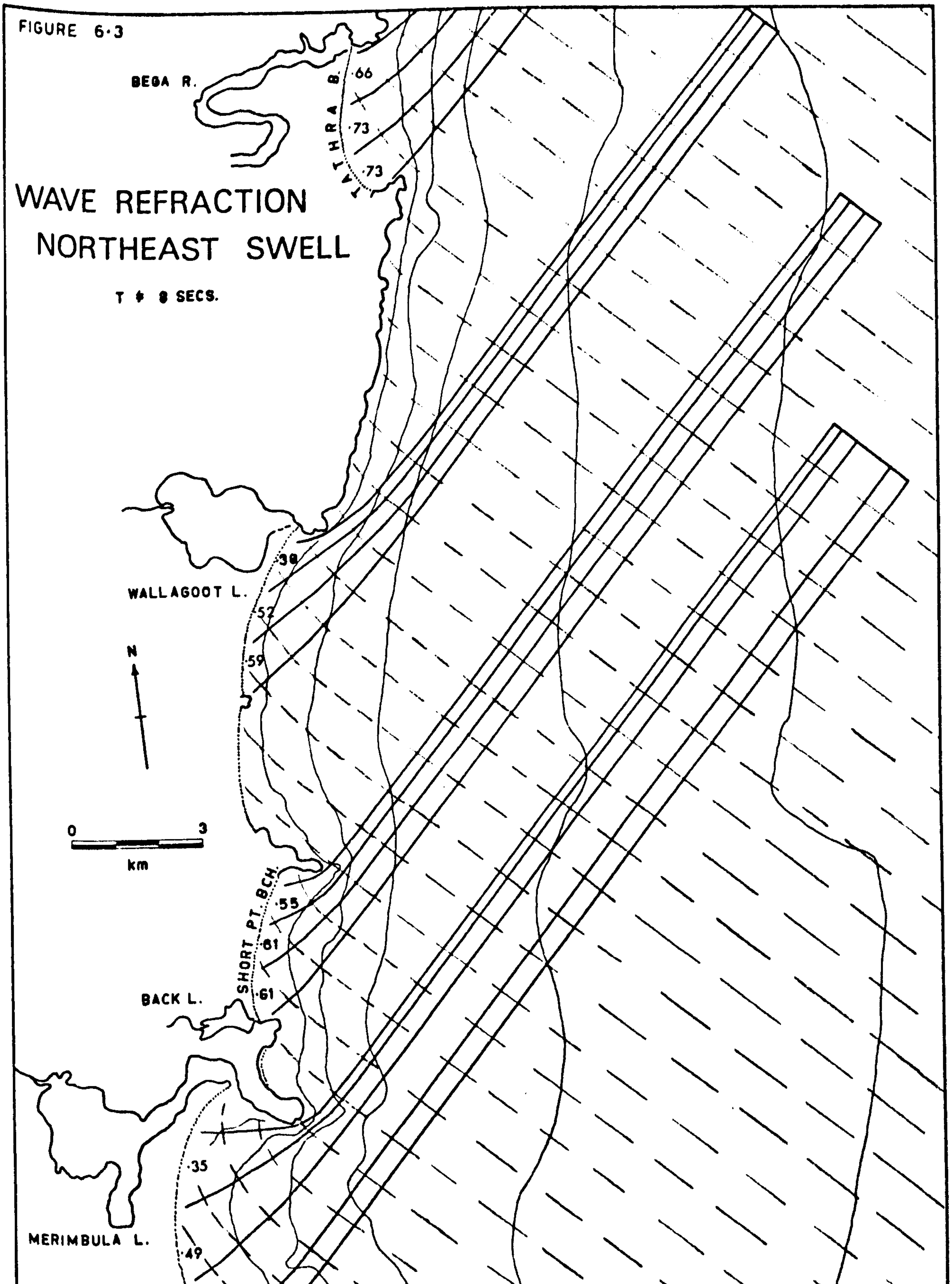


FIGURE 6·3
WAVE REFRACTION
NORTHEAST SWELL
BEGA R.
TATHRA B.
·66
·73
·73
WALLAGOOT L.
·38
·52
·59
N
0
3
km
SHORT PT. BCH.
·55
·61
·61
BACK L.
MERIMBULA L.
·35
·49
·77
·80
PAMBULA R.
10
15
20
30
40
depths in fathoms

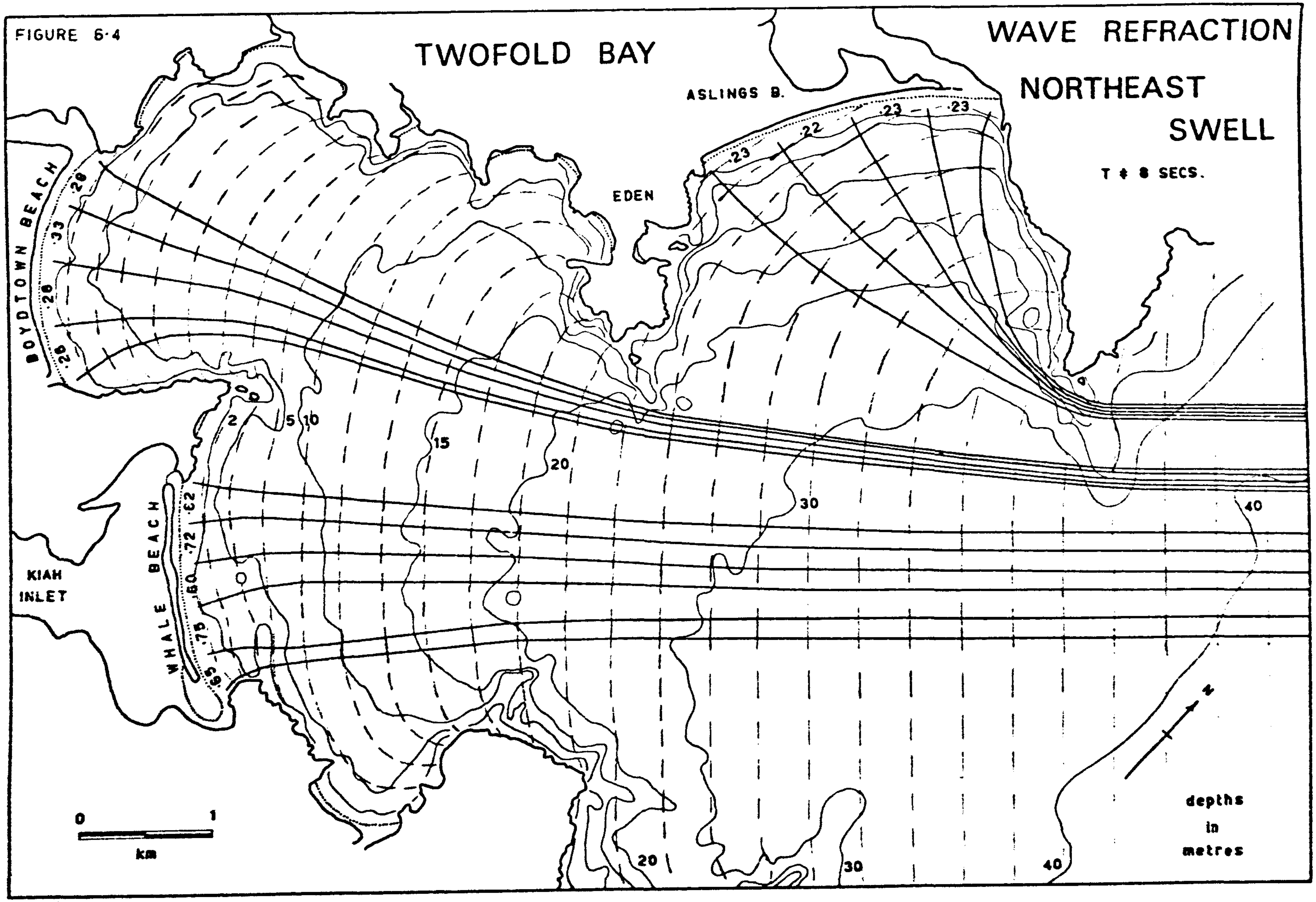

TWOFOLD BAY
WAVE REFRACTION
NORTHEAST
SWELL
T = 8 SECS.
ASLINGS B.
EDEN
BOYDTOWN BEACH
WHALE BEACH
KIAH
INLET
depths
in
metres
0
1
km

FIGURE 6·4

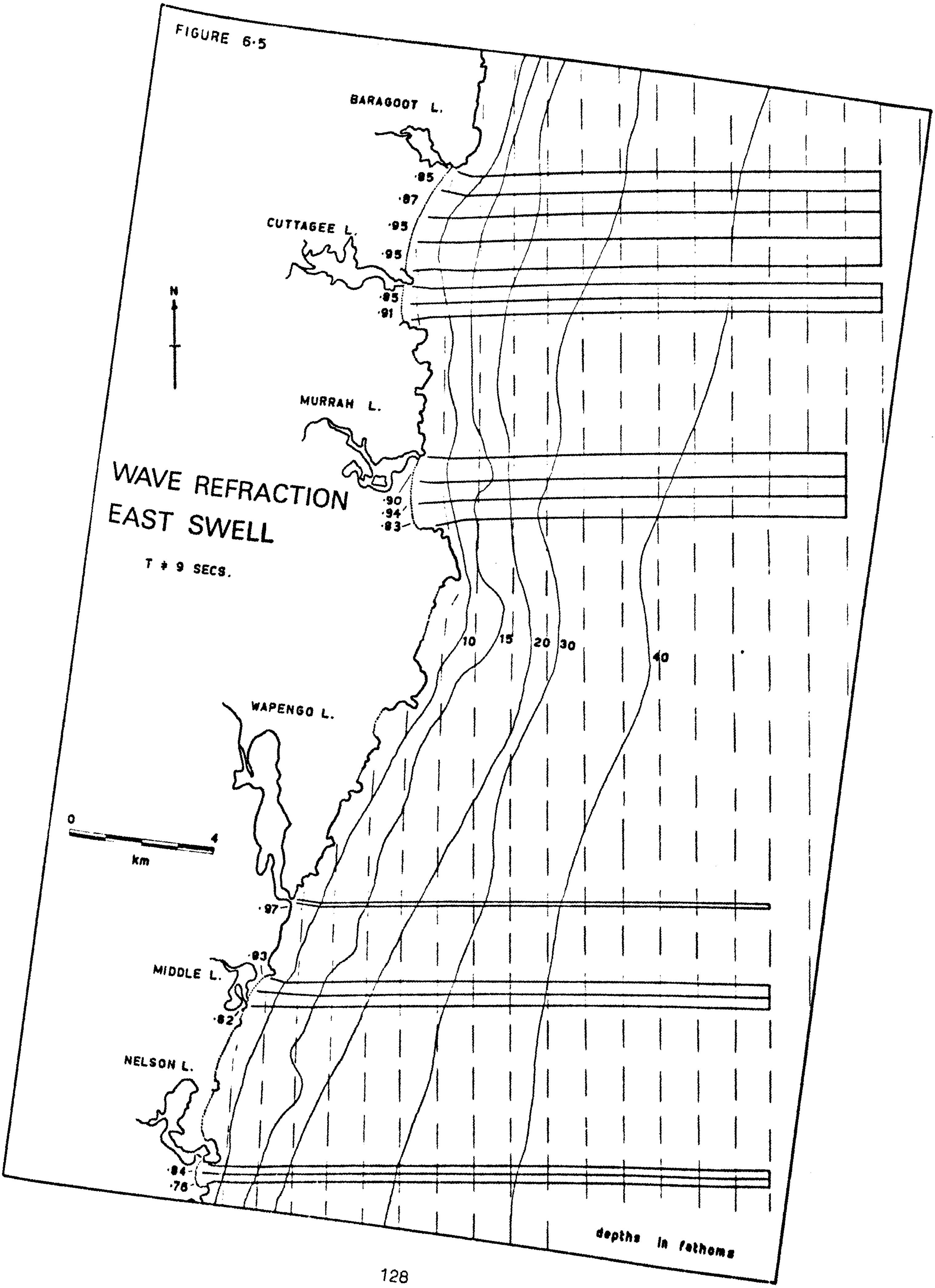


FIGURE 6·5
WAVE REFRACTION
EAST SWELL
T = 9 SECS.
BARAGOOT L.
CUTTAGEE L.
MURRAH L.
WAPENGO L.
MIDDLE L.
NELSON L.
N
0
4
km
·85
·87
·95
·95
·85
·91
·90
·94
·83
·97
·93
·82
·84
·76
10
15
20
30
40
depths in fathoms

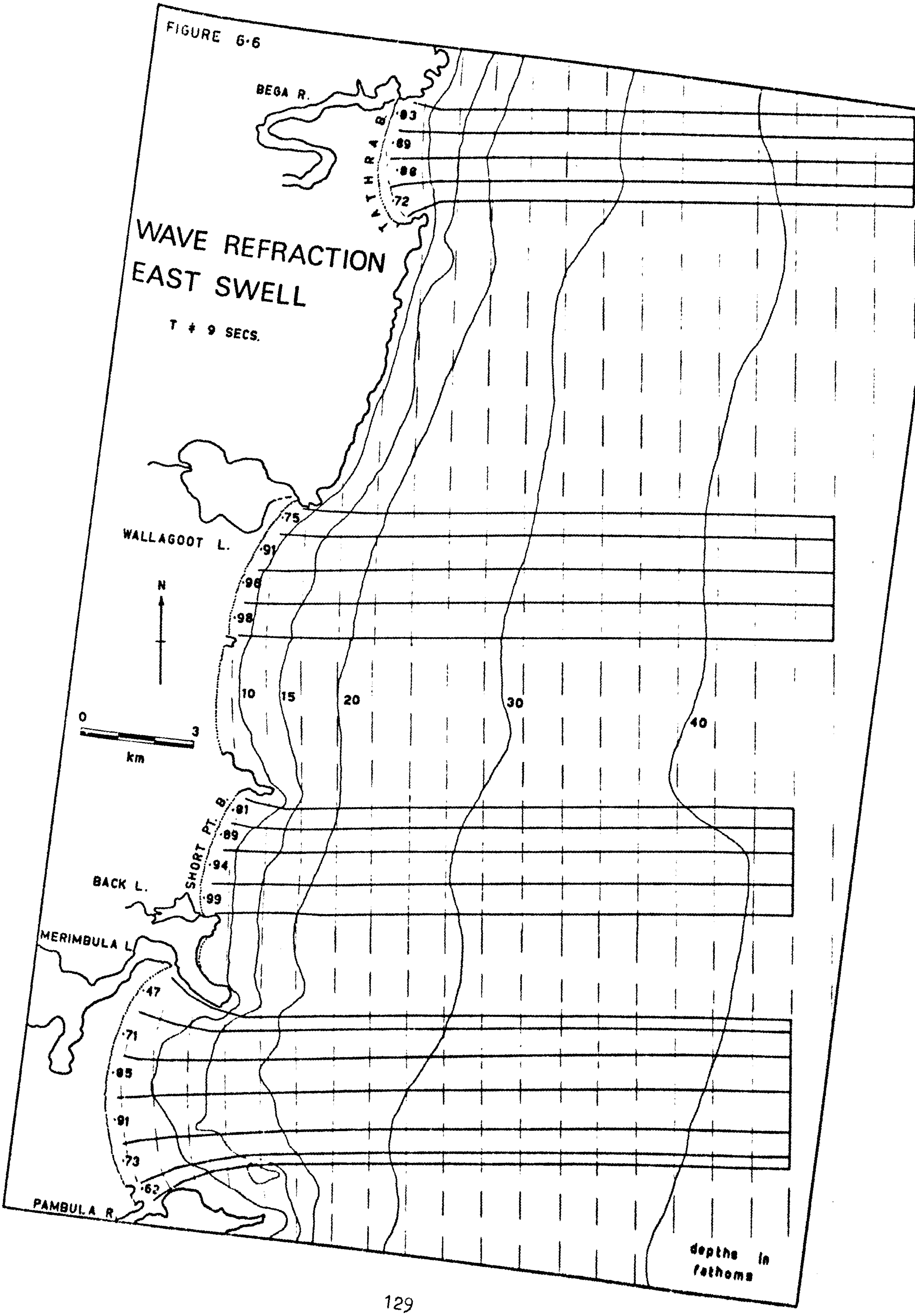


FIGURE 6·6
BEGA R.
TATHRA B.
·93
·89
·88
·72
WAVE REFRACTION
EAST SWELL
T ≑ 9 SECS.
WALLAGOOT L.
·75
·91
·96
·98
N
10
15
20
30
40
0
3
km
SHORT PT. B.
·81
·89
·94
·99
BACK L.
MERIMBULA L.
·47
·71
·85
·91
·73
·62
PAMBULA R.
depths in fathoms

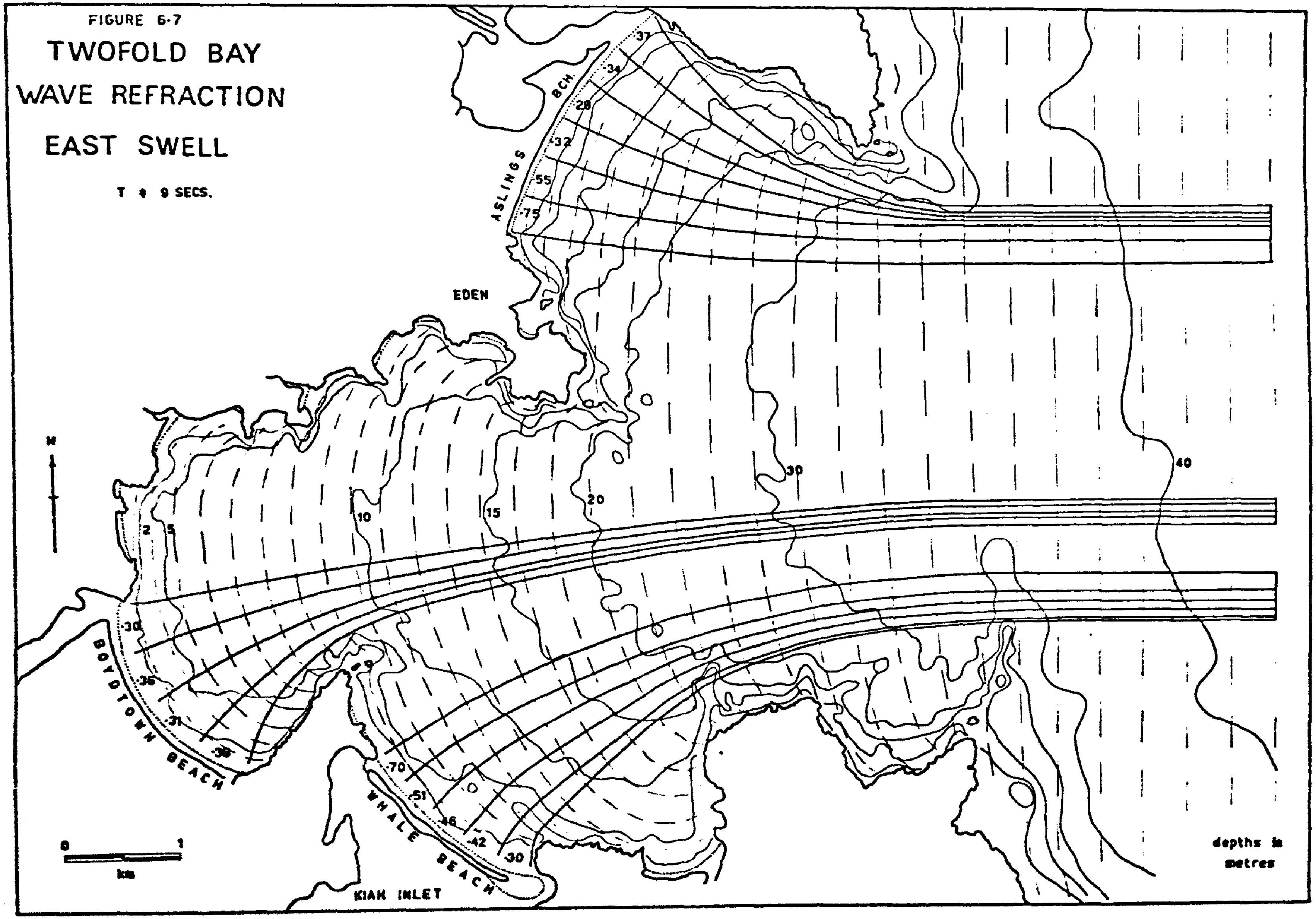
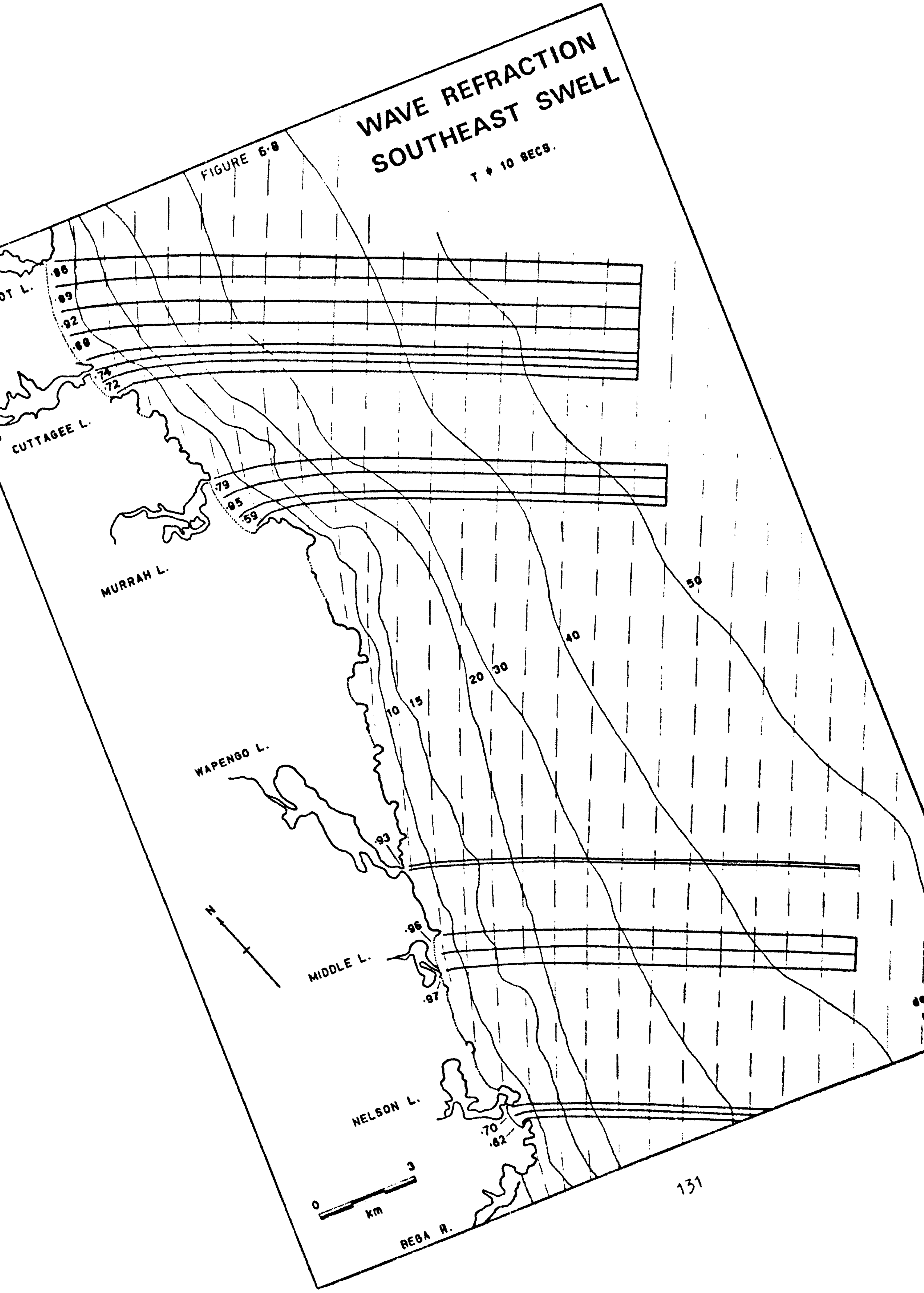


FIGURE 6·7
TWOFOLD BAY
WAVE REFRACTION
EAST SWELL
T = 9 SECS.


WAVE REFRACTION
SOUTHEAST SWELL
FIGURE 6·8
T = 10 SECS.
CUTTAGEE L.
MURRAH L.
WAPENGO L.
MIDDLE L.
NELSON L.
REGA R.
N
0
3
km
10
15
20
30
40
50
·96
·89
·92
·86
·74
·72
·79
·95
·59
·93
·96
·97
·70
·62

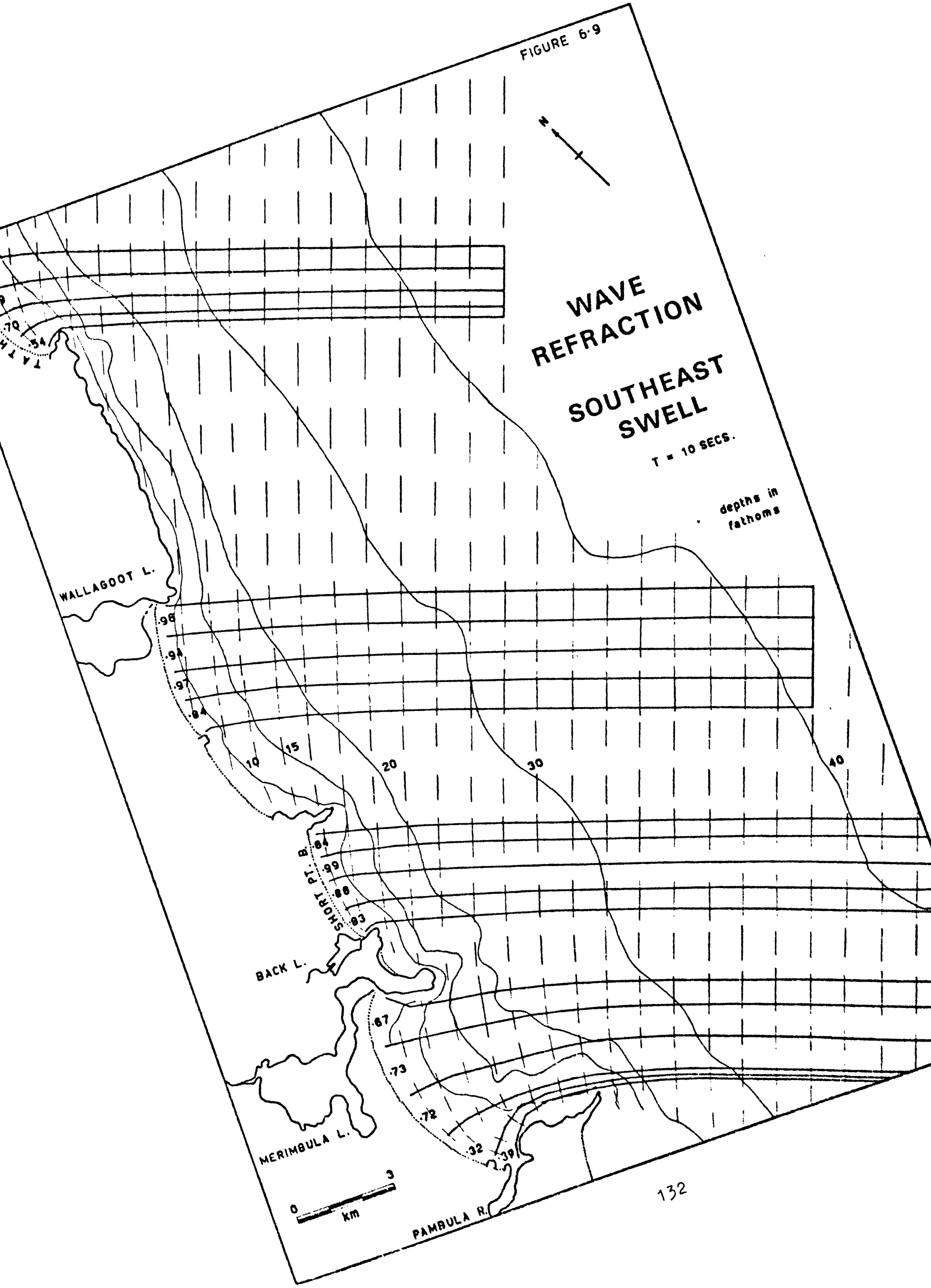


FIGURE 6·9
N
WAVE REFRACTION
SOUTHEAST SWELL
T = 10 SECS.
depths in fathoms
WALLAGOOT L.
SHORT PT. B.
BACK L.
MERIMBULA L.
PAMBULA R.
10
15
20
30
40
·70
·54
·96
·94
·97
·84
·84
·99
·88
·83
·67
·73
·72
·32
·39
0
3
km

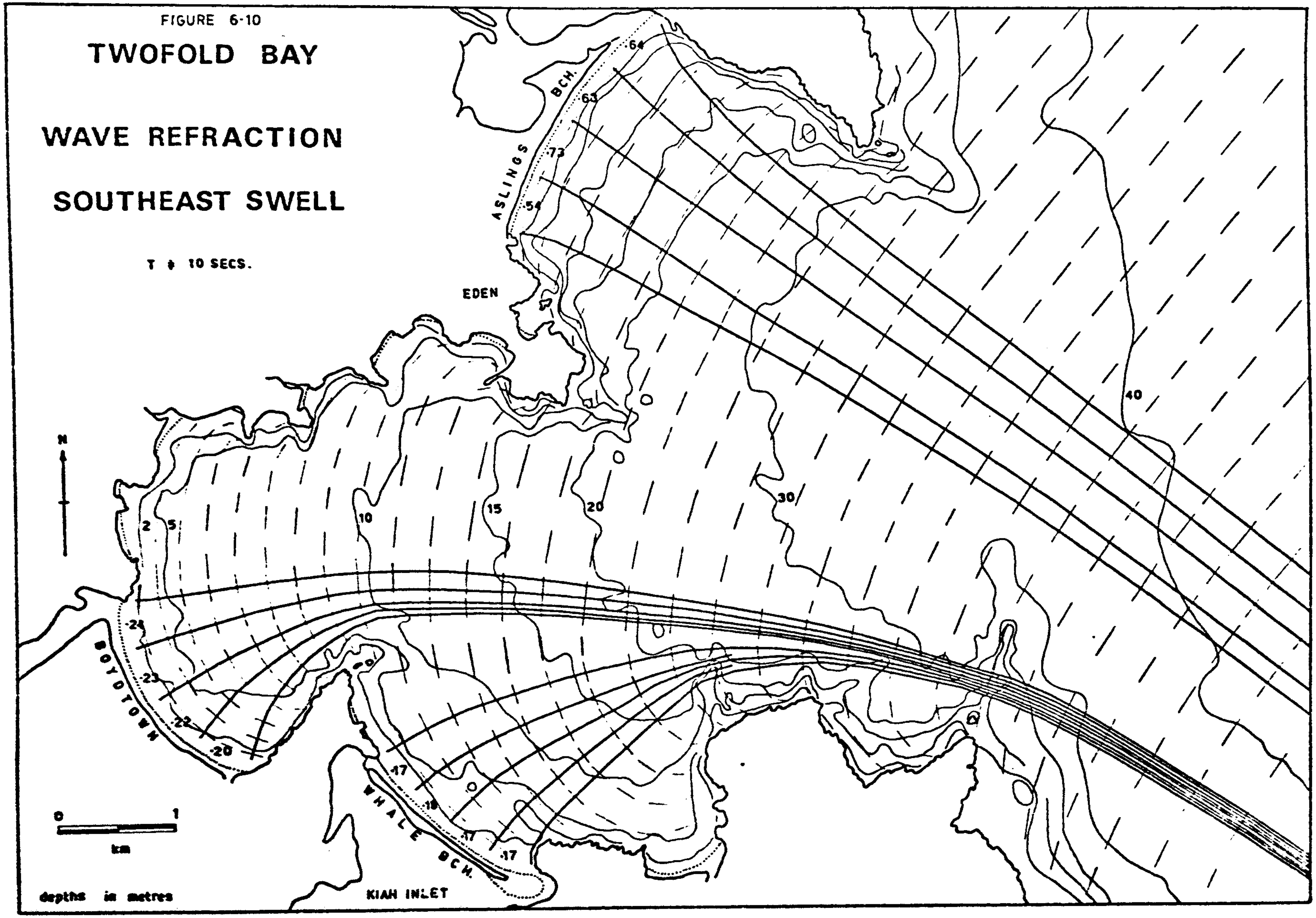


FIGURE 6-10
TWOFOLD BAY
WAVE REFRACTION
SOUTHEAST SWELL
T = 10 SECS.
EDEN
ASLINGS BCH.
BOYDTOWN
WHALE BCH.
KIAH INLET
N
0
1
km
depths in metres

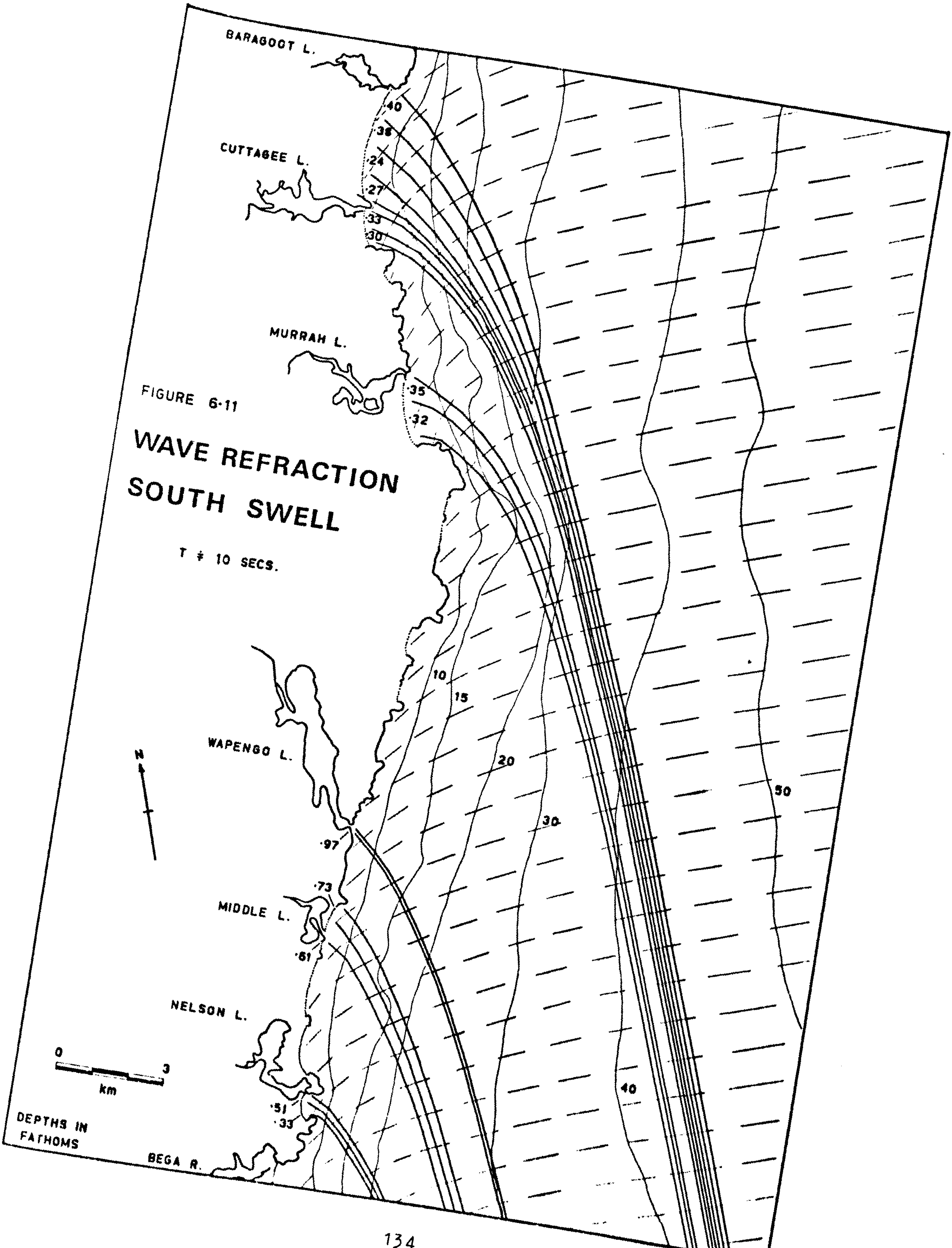


FIGURE 6·11

WAVE REFRACTION SOUTH SWELL

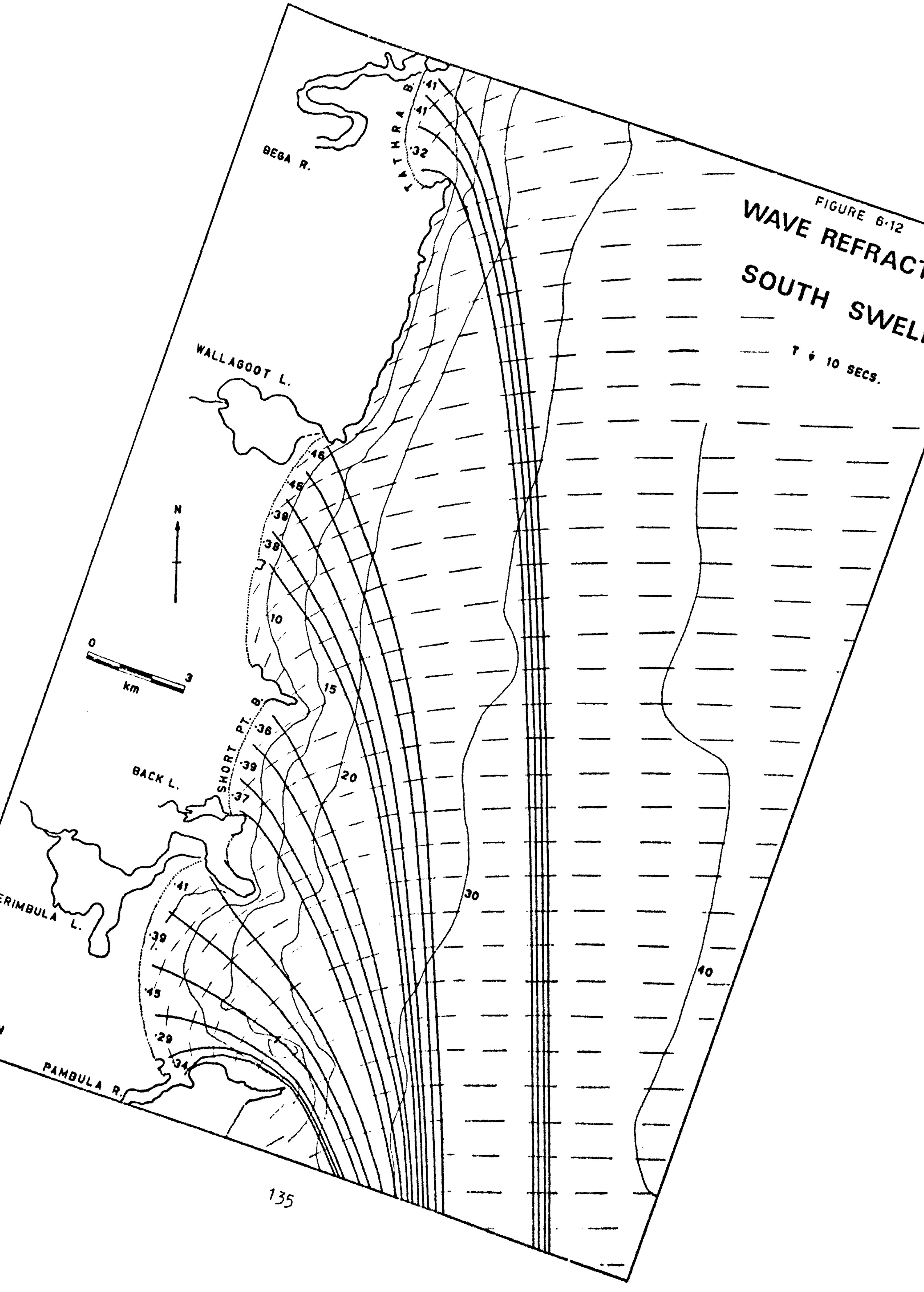


FIGURE 6·12
WAVE REFRACT
SOUTH SWEL
T ≑ 10 SECS.
BEGA R.
TATHRA B.
WALLAGOOT L.
N
0
3
km
SHORT PT. B.
BACK L.
ERIMBULA L.
PAMBULA R.
10
15
20
30
40

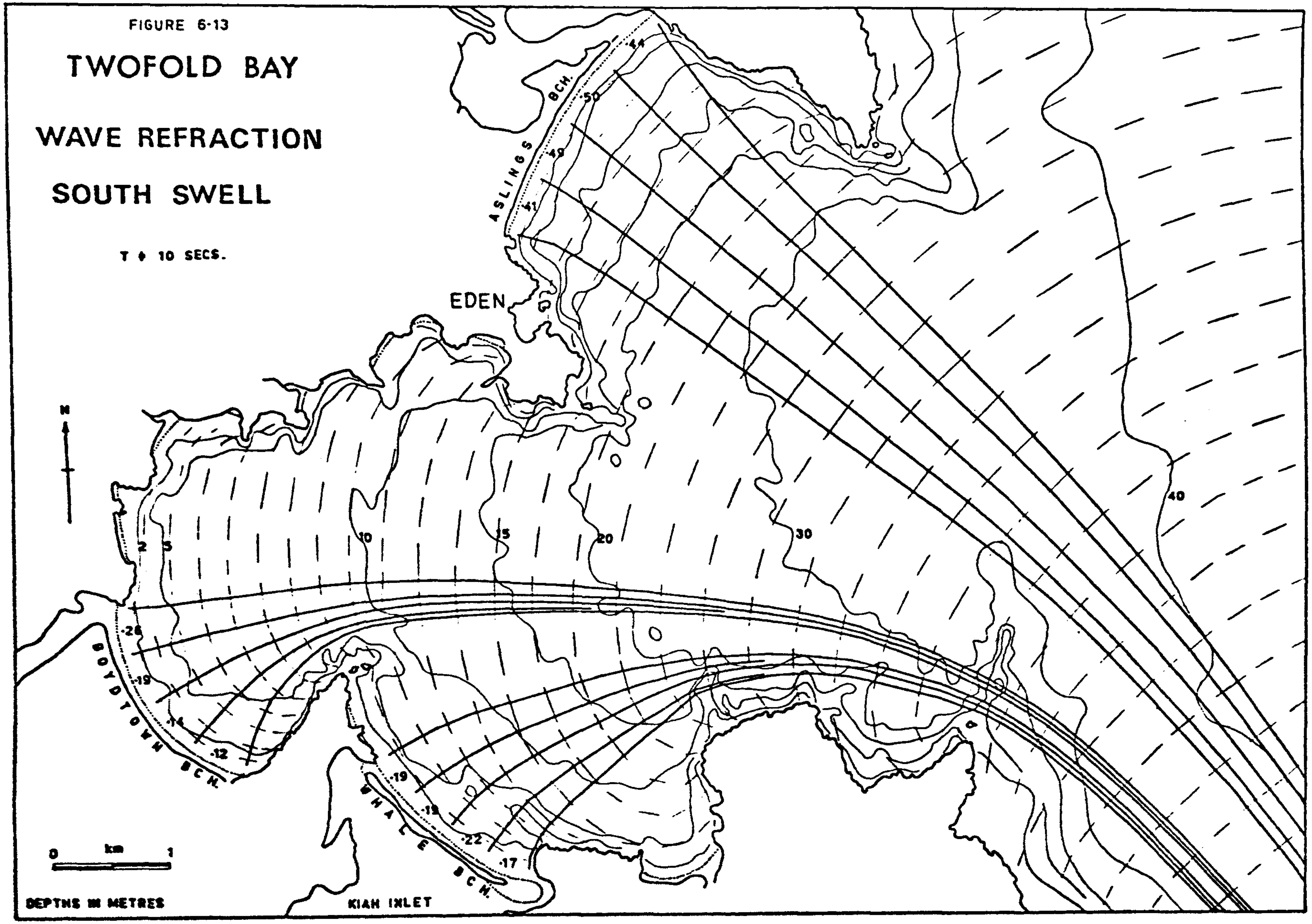


FIGURE 6-13
TWOFOLD BAY
WAVE REFRACTION
SOUTH SWELL
T = 10 SECS.
EDEN
ASLINGS BCH.
BOYDTOWN BCH.
WHALE BCH.
KIAH INLET
DEPTHS IN METRES
N
0 km 1
44
50
49
41
2
5
10
15
20
30
40
-26
-19
-14
-12
-19
-19
-22
-17

The latter were calculated using the standard equation $K_d = \sqrt{b_o/b}$ (Wiegel, 1972) where b_o and b are the spacing of any two orthogonals in deep and shallow water respectively. Orthogonals represent lines between which it is assumed wave power remains constant. Divergence of orthogonals, as occurs in bays, indicates lateral expansion of the wave crests with a corresponding decrease in wave height and the amount of energy per unit width of wave. The smaller the value of K_d the greater is this reduction. Convergence of orthogonals, as occurs near headlands, indicates lateral compression of wave crests and therefore an increase in wave height and unit width wave energy.

A number of general points are apparent from the diagrams.

i) Beaches inside Twofold Bay, particularly Whale and Boydtown beaches, receive significantly less wave energy than their counterparts facing the open ocean.

ii) Waves from the southeast best fit the plan form of most beaches. This reflects the general structural alignment of the coast and the greater length of waves approaching from this quarter.

iii) The shorter period northeasterly waves are least refracted, and approach the shore at various angles suggesting that they may be significant initiators of southward moving longshore currents.

iv) Wave energy is most reduced on those parts of beaches which are in the lee of protruding headlands.

The accuracy of the refraction coefficients on the ocean beaches is compromised by the small scale of the charts available, especially the lack of detailed soundings in the nearshore zone where most refraction occurs. This is particularly so in the small deeply recessed embayment backed by Nelson Beach, and the actual degree of refraction at this locality is probably greater than the simulated pattern suggests, in which case estimates of wave energy will be higher than they should be. The Twofold Bay results are much less affected by this problem and are limited mainly by operator error and that of the technique itself. Also, whereas tidal currents are of little consequene due to the small tidal range, the effects of caustics at the mouths of local rivers and of rip currents along the beaches have not been taken into account.

The decrease in wavelength and velocity as waves move into shallow water also results in shoaling - an increase in wave height caused by the longitudinal compression of wave power. Breakpoint depths were calculated for each direction of wave approach based on the average deep water wave heights in table 6.6 and allowing for the failure of linear progressive wave theory several wavelengths seaward of the breakpoint. The relevant d/L_o ratios were also calculated and the equivalent shoaling coefficients (D_d) and values of n ($n = C_g/C$) were extracted from tables produced by Wiegel (1972). Wave energy and power per unit width of wave crest just seaward of the breakpoint for each direction of wave approach at each beach were calculated using the formulae -

$$E_b = 1256.4\ H_b^2\ L_b$$

and $$P_b = nE_b/T$$

where $$H_b = H_o D_d K_d$$ ....Wiegel (1972)

The results are tabulated fully in Appendix 2b and are summarized in table 6.8. Losses due to friction between waves and the nearshore seabed have not been included; Wright (1975, 1976) has shown that such losses off the central N.S.W. coast are less than 5% of the incident deep water wave power. An index of average annual wave power after refraction and shoaling was calculated by summing the four products of wave power and directional probability at each beach. These are also shown in table 6.8 and are useful indicators of the relative wave energy environments of each embayment.

Table 6.8 Total Wave Power (P_b) and Longshore Power (P_l) after refraction and shoaling (Kwatts/m of crest).

BEACH	NORTHEAST		EAST		SOUTHEAST		SOUTH		ANNUAL	
	P_b	P_l	P_b	P_l	P_b	P_l	P_b	P_l	P_b	P_l
BARAGOOT	3.5	-1.5	14.6	-3.4	26.3	0	4.8	1.8	12.6	-0.6
CUTTAGEE	5.4	-1.8	14.4	-0.5	17.5	0.5	4.5	1.6	10.5	0.1
MURRAH	8.4	-2.8	14.9	-1.8	19.0	0.4	4.8	1.9	11.8	-0.4
WAPENGO *	10.5	-5.3	17.4	-3.0	29.1	0	42.2	20.7	26.2	4.1
MIDDLE	3.2	-1.6	12.4	-5.8	31.0	0	19.0	8.2	17.4	0.7
NELSON	3.6	-1.7	11.9	-0.6	14.4	0	7.2	2.3	8.9	0.2
TATHRA	6.8	-2.2	13.0	-1.4	19.0	0.4	6.9	1.7	11.6	-0.2
WALLAGOOT	3.2	-1.6	14.9	-4.8	28.3	0.6	7.9	3.0	14.1	-0.3
SHORT PT	4.7	-2.0	15.3	-2.4	26.3	0	6.0	2.6	13.4	-0.2
MERIMBULA	4.2	-1.7	10.2	-0.5	13.6	0.3	6.8	2.0	8.9	0.2
PAMBULA	8.5	-0.3	9.4	0	5.1	0	5.1	0.3	6.8	0.02
ASLINGS	0.7	-0.1	3.9	-0.3	13.6	0.3	9.3	0.5	7.4	0.1
BOYDTOWN	1.1	-0.1	2.2	-0.1	1.6	0	1.4	0.5	1.6	0.1
WHALE	6.1	-0.3	4.5	-0.1	1.0	0.02	1.6	0.5	3.1	0.1

Minus sign indicates longshore power directed southwards, + = north; * = Wapengo Lagoon entrance

Although the error in the values may be as high as 20% they do tend to confirm earlier conclusions about the distribution of wave energy based on the refraction diagrams alone, and they also support some of the assertions made earlier on the basis of sedimentological evidence. Wave energy within Twofold Bay averages less than one third that of the more exposed ocean beaches. Boydtown and Whale beaches rank lowest of all, while at Aslings beach, which has a more exposed southeasterly aspect, energy levels are much the same as those experienced at more sheltered ocean beaches such as Pambula. Small, recessed beaches such as Nelson experience significantly reduced levels of wave activity compared to the longer beaches like Middle and Baragoot which are bounded by comparatively small headlands. The protective influence of the large headlands at the end of Merimbula and Pambula beaches is also apparent. The entrance to Wapengo Lagoon ranks highest of all, which is not surprising because it is quite unprotected by protruding headlands or nearshore reefs. The tabulated annual values for wave power are substantially less than the average annual deep water value of 28.7 Kw/m. The reductions range from nearly 9% at Wapengo Lagoon entrance to nearly 95% at Boydtown Beach. The ramifications of these differences are discussed later.

6.5 Longshore Wave Power and its effects

An important component of wave power is the proportion directed alongshore when the waves approach the shore obliquely. This component controls the longshore sediment transport by longshore currents and beach drifting. Index values were calculated at each beach using the expression -

$P_l = P_b \sin\alpha \cos\alpha$ (Komar and Inman, 1970) where α is the angle between the wave crest and the shoreline.

The nett annual magnitude and direction of longshore wave power was also estimated in the same manner as the average annual total wave power. These values are also shown in table 6.8, but they should be regarded as maximum potential ones because they relate to waves immediately before breaking and, except within Twofold Bay, they incorporate substantial underestimates of refraction due to the lack of detailed bathymetry in the shallower areas of the refraction zone. Furthermore, at all localities the angle of incidence will continue to decrease landwards of the break-point with a corresponding diminution of the longshore wave power component.

It is apparent that only very small proportions of the incident wave power are directed alongshore. The values especially emphasize the very close alignment of beach plan forms to refracted southeasterly wave trains, a pattern which is controlled mainly by the overall SW - NE alignment of the coastline and which is encouraged by the ease with which the long period southeasterly swell is refracted.

Given that longshore transport of sediment is proportional to the amount of longshore wave power, it is also evident that at some localities nett transport is southwards, which indicates that the less powerful northeasterly and easterly waves are able to match the longshore transport initiated by the larger waves from the south. The apparent anomaly is readily explained by the differences in the period and obliquity of approach of the incident waves. Due to their shorter period, northeasterly waves are less refracted and so approach the shore more obliquely than their southerly counterparts. Comparatively greater refraction of the southerly waves also results in a comparatively greater reduction in effective wave height and thus energy near the break-point. This situation applies particularly to the ocean beaches; within Twofold Bay all waves are so strongly refracted that they arrive almost parallel to the shore irrespective of their deep water approach direction.

Actual sediment transport rates were calculated using the empirical relationship derived by Savage (1959) and often used by coastal engineers (for example, see Ewers and Foster, 1964). This method was chosen despite the dimensional difficulty of using longshore wave power and energy values (Inman and Bagnold, 1963; Longuet-Higgins, 1972); for most practical purposes this problem may be ignored (Galvin, 1972). The results are shown in table 6.9.

Table 6.9 Longshore Sediment Transport: (x 10^3 cubic metres/year)

BEACH	NORTHEAST	EAST	SOUTHEAST	SOUTH	NETT ANNUAL
Baragoot	-179	-358	0	+ 273	- 264
Cuttagee	-209	- 65	+ 84	+ 240	+ 50
Murrah	-298	-228	+ 76	+ 304	- 146
Wapengo	-477	-358	0	+2002	+1167
Middle	-179	-521	0	+ 801	+ 101
Nelson	-203	- 85	0	+ 320	+ 32
Tathra	-239	-169	+ 69	+ 280	- 59
Wallagoot	-179	-456	+ 92	+ 440	- 103
Short Pt	-226	-273	0	+ 360	- 139
Merimbula	-203	- 72	+ 61	+ 304	+ 90
Pambula	- 45	0	0	+ 57	+ 12
Aslings	- 24	- 52	+ 61	+ 88	+ 73
Boydtown	- 13	- 13	0	+ 11	- 15
Whale	- 51	- 20	+ 8	+ 11	- 52

(+) indicates northward transport; (-) indicates southward transport

The nett annual values are demonstrably too large, even if generous allowance is made for the longshore wave power values being maximum potential ones. At Tathra for example, the results suggest a nett annual southward drift of approximately 59000 cubic metres. Sedimentological evidence has indicated that there is no contemporary sand supply from the nearshore zone, from cliff erosion or from neighbouring beaches. Hydrological evidence suggests that the Bega River is incapable of supplying such a volume of sand to the coast each year. Therefore, the only way the calculated rate of sediment transport can be sustained is by erosion of the northern end of the beach. This would also be accompanied by accretion at the southern end but there is no field evidence at all to support the prevalence of either phenomenon. The same argument applies at all the other localities studied; other evidence from the north coast of N.S.W. also supports this conclusion. In the latter region there appears to be a similar absence of contemporary sand supply, but an active longshore transport system has been sustained by continued erosion of the sandy shoreline during the last century (Roy and Crawford, 1977). Comparison of old (1944) and modern (1972) aerial photographs reveals no similar pattern of continued shoreline retreat on the Far South Coast, while ground level beach photographs taken during the early 1900s (National Library of Australia, 1976; Bermagui School Centenary Committee, 1976) display scenes which are not significantly different to those which existed prior to the severe storms of mid 1974. A conversation with an elderly resident, Sister Pearl Corkhill, whose family first settled in the district in 1878, provided some confirmation of these observations.

More realistic nett annual rates of littoral drift (of the order of 10^4 m^3/year) were obtained at Port Kembla, N.S.W. by Healy and Lee (1975) who traced the movement of fluorescent sand grains in the surf zone. Unfortunately these values appear to have been somewhat summarily dismissed in favour of larger estimates (10^5 - 10^6 m^3/year) based on the more commonly used empirical relationships derived from non-Australian coastal data. There is an obvious need for research in this field within the high energy swell environment of eastern Australia.

Despite the shortcomings of the values calculated for this study, there is some field evidence which is relevant to qualitative assessment of drift patterns. All the beaches experience bidirectional longshore transport to some degree as the beach plan forms adjust to changes in the direction of wave approach, a situation observed previously within individual beach compartments in Tasmania (Davies, 1958). Longshore transport during these adjustments has been and continues to be an important factor in inlet closure. This is well demonstrated at Merimbula Bay which has inlets to Merimbula and Pambula lakes at its northern and southern end respectively. Local fishermen who regularly navigate their boats through these inlets have observed that when southerly waves persist for a few days, the entrance to Merimbula Lake becomes more shallow, whereas when northeasterly waves continue for a similar length of time, the same phenomenon occurs at the entrance to Pambula Lake. Local residents also confirmed that the spit which partially blocks the entrance to Merimbula Lake lengthens during prolonged periods of southerly waves.

Beach widths and the extent of beach cusp development also support the notion of small longshore sediment transport rates. During field trips, cusps were always present on beaches within Twofold Bay, where littoral transport would be expected to be least. They were often observed on the ocean beaches too but they were not nearly as persistent at these localities and disappeared whenever southerly, southeasterly and to a lesser extent easterly waves occurred. Nearly three quarters of the beaches studied are wider at their northern end, while the remaining ones maintained constant widths throughout their length. This pattern is inconsistent with the pattern that would be expected on the basis of the littoral drift estimates, because if it was consistent then Baragoot, Murrah, Tathra, Wallagoot, Short Pt, Boydtown and Whale beaches would widen southward. The observed pattern of northward widening is more consistent with increasing exposure to strong onshore southerly and southeasterly winds.

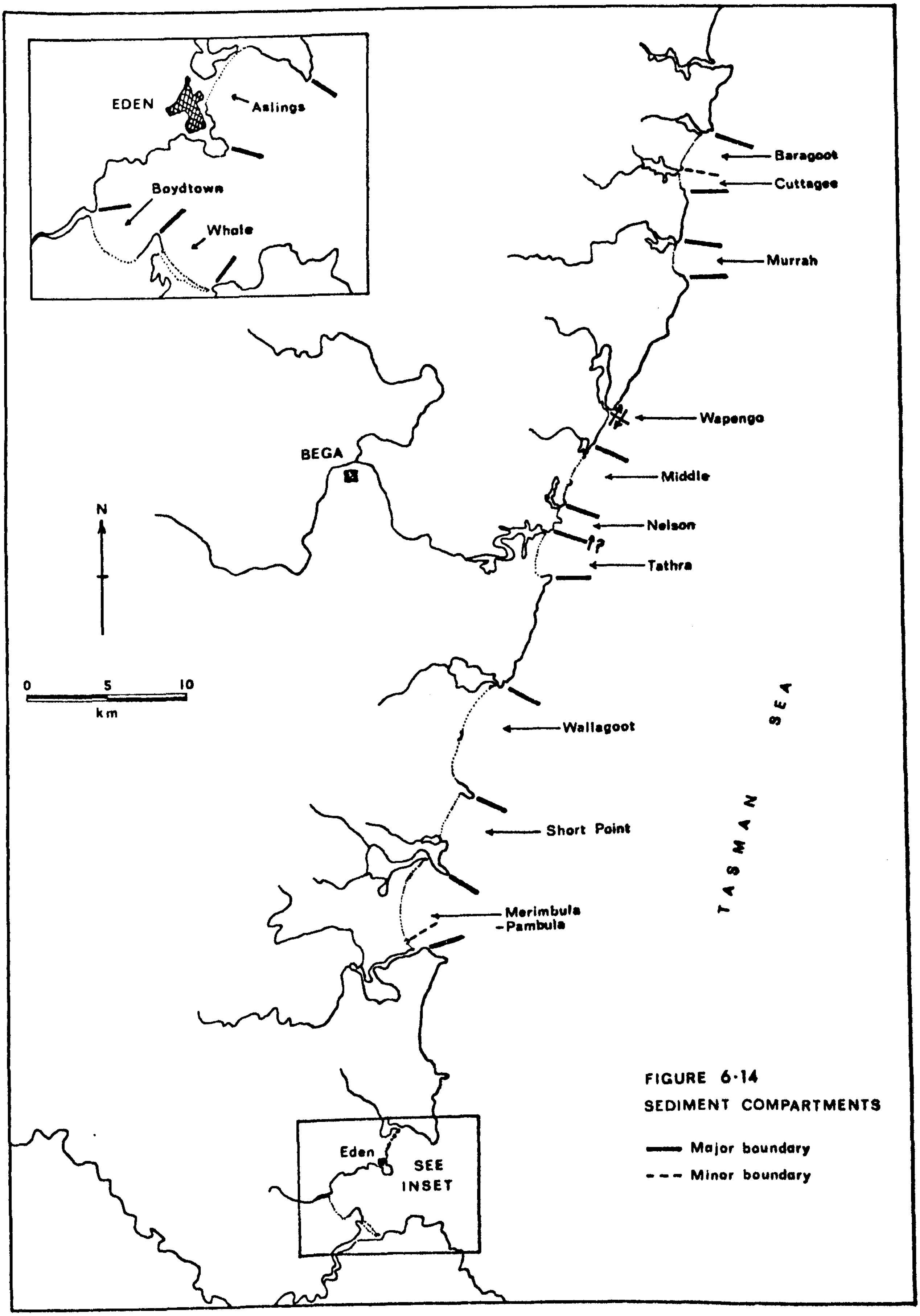
The irregular coastal outline also supports the notion of discrete sediment compartments between which little if any sediment exchange occurs. Sand can often bypass inlets (Bruun and Gerritsen, 1961; Bruun, 1966) and may also pass around headlands via longshore transport in the nearshore zone if conditions are favourable, although in this area it has already been established from sedimentological evidence that much of the drifting sand has been directed into the inlets to form reverse tidal deltas or thresholds. Longshore sediment transport past intervening rocky shores to the next embayment through beach drifting is very unlikely in this area, as are exchanges through longshore currents. A spring tide range of little more than one metre results in only very minor semi-diurnal relocation of the sandy shoreline and surf zone, such that bedrock headlands between which the beaches are recessed, are usually surrounded by water at least ten metres deep at low tide, and often extend seawards as submerged reefs.

Transport around headlands is only likely to occur during major southerly storms when the surf zone may extend more than 100 metres seawards from the beaches and the rocky shores are fronted by very turbulent water. Strong rip currents which travel seawards along the base of headlands during such conditions could also facilitate such sediment movements. These storms are infrequent though and they are usually of short duration.

Practically all the available evidence suggests a strongly compartmented coast as depicted in figure 6.14. Like southern Tasmania (Davies, 1973) individual compartments are the rule and the exceptions which do occur are only minor. Merimbula and Pambula beaches behave essentially as one unit within Merimbula Bay, and a similar situation probably exists at Baragoot and Cuttagee beaches. At the latter locality the sedimentological evidence is equivocal in this regard, but the shallow water in front of the small headland between them supports the possibility. At Wapengo it seems likely that sand may bypass the entrance in either direction although much is trapped within the inlet and redistributed upon the surface of the threshold. The possibility of Nelson Beach receiving small amounts of sand from Tathra Beach and/or the Bega River when storm and flood conditions coincide cannot be dismissed.

6.6 The Ramifications of Swash Alignment of the Beaches

Strong swash alignment of beach plans should encourage the development of associations between beach sediments and


EDEN
Aslings
Boydtown
Whale
Baragoot
Cuttagee
Murrah
Wapengo
BEGA
Middle
Nelson
Tathra
N
0
5
10
km
Wallagoot
TASMAN SEA
Short Point
Merimbula
-Pambula
FIGURE 6·14
SEDIMENT COMPARTMENTS
Major boundary
Minor boundary
Eden
SEE
INSET

energy levels similar to those recorded by Bascom (1951). A few such relationships were described earlier in chapter three. Furthermore, river mouths and lagoon entrances should be located where wave energy is least, because at this point, waves are least able to effect closure; similarly, barrier breaching by impounded flood water should occur where the berm crest is lowest (Bascom, 1954). Longshore variations in wave energy were estimated by calculating the incident wave power after refraction and shoaling at sections of individual beaches. The results are tabulated fully in the appendix but are summarized in table 6.10 below.

Table 6.10 Longshore Trends of Incident Wave Power at Nominated Beaches

BEACH	NORTHEAST	EAST	SOUTHEAST	SOUTH	NETT
Baragoot	S	S	C *	N	C--S
Cuttagee	No trend	S *	S *	N	S *
Murrah	C - S	S *	C - N	N *	C--N
Middle	S	N *	S	N	N *
Nelson	S	N *	S	N	N *
Tathra	S	C *	N	N	N *
Wallagoot	S	S	N	N	C
Short Pt	S *	S	C	C *	C-S*
Merimbula	S	S-C	C - N	C -N	C
Aslings	No trend	S	No trend	C	C-S
Boydtown	No trend	No Trend	N	N	N
Whale	No trend	N	No trend	N	N

Letter marks section of beach receiving most wave energy; thus North (N), South (S), Centre (C) and combinations thereof. An asterisk indicates that the difference is marginal (less than 20%).

At all ocean beaches wave power increases southwards when northeasterly waves are arriving at the shore. The pattern reverses when southeasterly and southerly waves occur although a few beaches experience maximum power levels along their central portions. In all cases wave power is least in the lee of protruding headlands where refraction of the incident waves is greatest. Within Twofold Bay similar trends are evident although they are less well defined and occasionally absent due to more uniform refraction patterns. When average annual values are considered, nearly all beaches appear to experience a nett northward increase in wave activity; at Aslings beach the opposite occurs and wave power increases southward. Although consistent, the variations are often small and at seven of the twelve embayments, they are less than 20%. In view of this, the general lack of longshore organization of sediments is not surprising, although in some cases recognition of such patterns may have been precluded by the small number of sediment samples collected. The correlations between various sedimentological parameters and assumed wave energy levels suggested in chapter three were substantiated when the calculated wave power values were used. The strongest associations occur at Tathra Beach, which also displays the best developed zeta curve plan form in the area. Here for example, the correlation coefficient between mean grainsize and wave power was 0.82. Beach face angles are also related closely to mean grainsize, with a trend toward steeper slopes in coarser sands being evident at all beaches. The relationship was especially well developed at Tathra (r_s = -0.95) where the longshore trend in mean grain size was matched by a progressive northward steepening of the beach face from five degrees to eleven degrees.

Many correlations were also apparent when data from all the beaches was compared, although only two were statistically significant. Lower energy beaches <u>tended</u> to be finer grained (r_s = 0.14) less negatively skewed (r_s = 0.41) and were <u>significantly</u> less well sorted (r_s = 0.51). These three associations are not unexpected but the trend to greater proportions of carbonate on lower energy beaches (r_s = 0.34), although not statistically significant, is contrary to the findings of other workers (for example see Davies, 1972, p 114). On this coast, the proximity of a beach to a rich shell producing area appears to be more important. The relationship between beach face slope and mean grain size was also strong when all the beaches were considered together;

again, steeper slopes were developed in coarser sands ($r_s = -0.82$).

In all cases, inlets are located at the far end of beaches where wave energy is less. In many instances though, the location is not coincident with the end experiencing least wave activity, but there is no evidence to suggest inlet migration due to longshore sediment transport. Accordingly, they may be termed swash deflected as opposed to drift deflected inlets (Davies, 1972). Their stability is assessed in the next chapter.

6.7 Review

Several sedimentological and geomorphological responses to the wave regime are apparent, but the important characteristic is the degree to which this length of coast consists of well defined sediment compartments. The beaches are in effect re-entrant traps within which practically all littoral transport is confined. A number of factors in combination are responsible for the development of this pattern. The general alignment of the coast and its indented character, together with its exposure to easily refracted long period swell ensures that most of the incident wave power is expended in the maintenance of swash aligned beaches. Estimates of longshore wave power appear sufficient to maintain an active system of longshore sediment transport but are at odds with morphological and sedimentological evidence which indicates that nett annual sediment movements within each embayment are quite small. The latter is reinforced by the relic nature of most of the beach deposits and the general absence of contemporary sand supplies from either coastal rivers or shoreline erosion. Overall, this coast is a strongly compartmented one featuring impeded sediment transport systems and essentially balanced sediment budgets.

CHAPTER SEVEN: THE ESTUARIES - PROCESSES & LANDFORMS

The patterns of sediment distribution and exchange within the estuaries have already been established, but variations in the observed patterns have yet to be explained. In this chapter the factors and processes which operate within the estuarine environment are considered and the extent to which the distribution of water and sediment is both an expression and a control of estuarine morphology is assessed. Tidal data is also combined with previously derived estimates of annual stream flow and wave activity to explain the magnitude and frequency of such exchanges.

7.1 Estuary Dimensions

There is considerable variation in the size and shape of the estuaries in this region, from the large, seaward-flaring funnel shape of Kiah Inlet to the tiny ovate lagoons such as Middle Lake. At a general level the estuaries can be placed in one of two categories. The first group comprises narrow, elongated water bodies bounded by conspicuous valley sides and oriented more or less at right angles to the general trend of the coast, while the second group comprises broader, ovate water bodies of comparatively simple outline. Members of the first group are often branched and represent typical drowned river valleys, whereas the second group represents drowned river basins bounded by now partly submerged coastal lowlands. Figures 4.9 - 4.18 provide representative examples of the two groups. The estuaries are also quite small in terms of measured surface area (table 7.1). The values tabulated represent the planimetric surface area bounded by the high tide shoreline extending from the estuary mouth to the upstream tidal

Table 7.1 Planimetric Surface Area of the Estuaries (km^2)

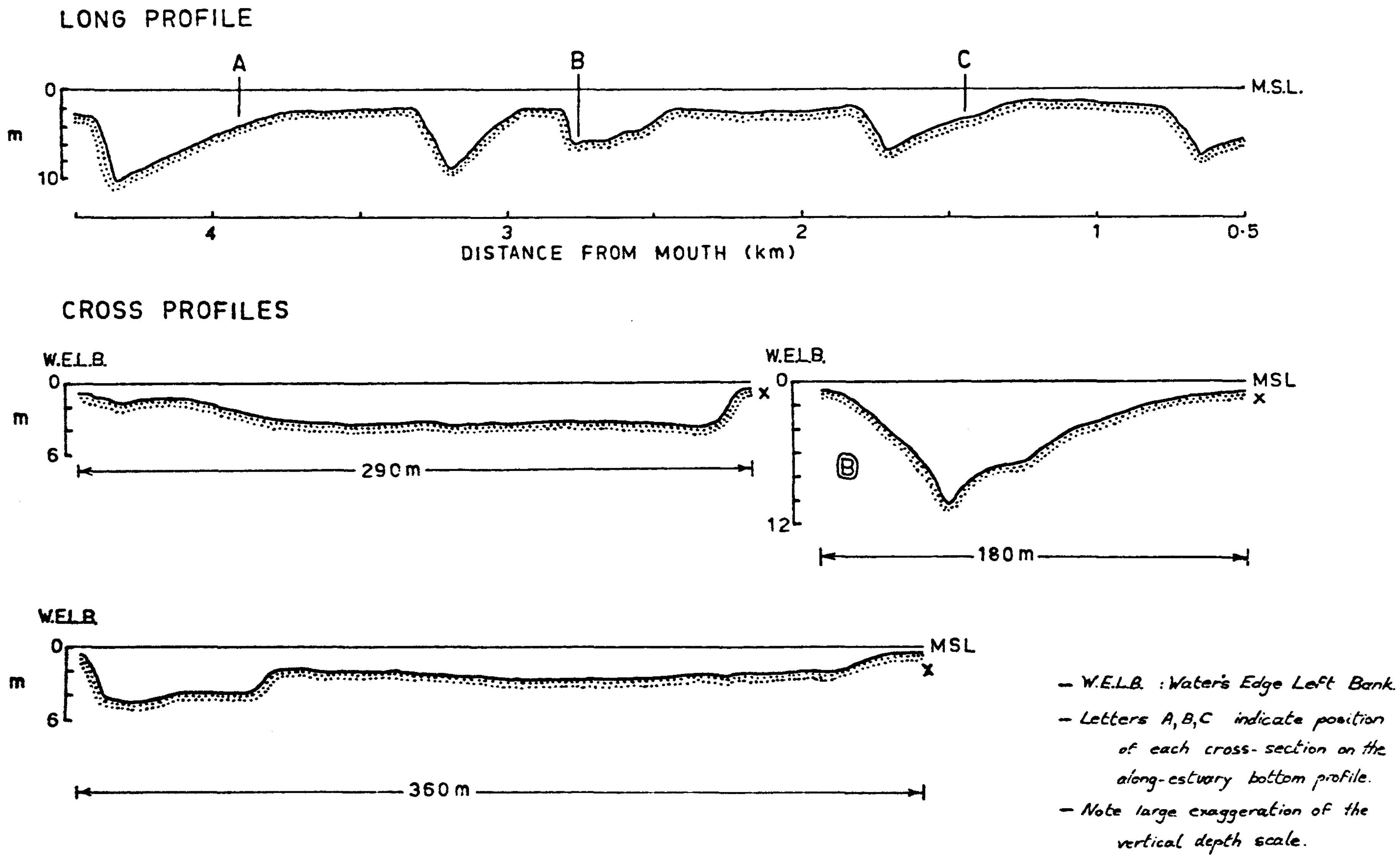
ESTUARY	AREA	ESTUARY	AREA
Baragoot Lake	0.5	Wallagoot Lagoon	3.8
Cuttagee Lake	1.2	Back Lagoon	0.5
Murrah Lagoon	0.9	Merimbula Lake	5.0
Wapengo Lagoon	2.5	Pambula Lake	4.4
Middle Lagoon	0.5	Curalo Lagoon	0.8
Nelson Lagoon	1.1	Nullica Lake	0.4
Mogareeka Inlet	3.0	Kiah Inlet	1.4

limit of the tributary stream. The longest estuary is that of the Bega River (Mogareeka Inlet) which extends nearly six kilometres upstream from its mouth, but the largest water body of all is Merimbula Lake which covers slightly less than five square kilometres.

During sampling of estuary bottom sediments, depths at various stations were measured using a lead-weighted rope marked in 0.1 metre divisions. In addition, straight line echosounder traverses at constant boat speed between points easily identified on 1:18000 air photographs enabled continuous bottom profiling. The results highlighted further the distinction between the narrow, elongated and substantially infilled estuaries such as Mogareeka and Kiah inlets, and the broader estuarine basins such as Merimbula and Wallagoot lakes.

In Mogareeka Inlet, water depths are generally quite shallow and only exceed 10 metres on the outer margin of a meander loop where lateral constriction of channel width by point bar accretion has prompted localized channel deepening (figure 7.1). In straight reaches both upstream and downstream of this point, where estuary widths exceed 300 metres, the main channel is less well defined within the channel floor sediments, and maximum depths rarely exceed four metres. This pattern was also observed in Kiah Inlet and Murrah Lagoon, although at both these localities water depths are usually less than two metres. The maximum depths recorded in these two estuaries were

FIGURE 7·1 MOGAREEKA INLET BATHYMETRY (28-3-74)



nine and three metres respectively and, as was the case at Mogareeka Inlet, these values were obtained in localized deep holes on the outer margin of bends in the respective rivers. At Mogareeka Inlet, a continuous long-channel echogram was also obtained by boating the length of the estuary and maintaining the boat's position midway between the banks (figure 7.1). This echogram revealed regularly alternating troughs and shoals, the latter features representing point bars which often extend laterally more than three quarters of the way acoss the estuary. The bars are flat topped for considerable distances and the shallowness of the water covering them suggests that wind waves within the estuary may occasionally rework their surface sediments. The submerged downstream face of each point bar is consistently steeper than its upstream limb, and channel cross-sections reveal steep lateral margins as well, a pattern which is consistent with the meandering downstream sweep of river water. The long-channel traverse was terminated 600 metres short of the sea due to dangerous boating conditions in the river mouth (bridge construction) but the persistence of the observed bathymetric pattern to this point indicates that flood tide currents are ineffective in transporting sediment upstream. Ebb tide currents are probably similarly ineffective transport agents given earlier evidence which indicates that the bulk of fluvial sediment transport occurs during river floods. Air photographs, together with field observations suggest that this is also the case in the estuaries of the Towamba and Murrah rivers. Comparison of 1944 and 1972 air photographs reveal only minor positional changes of the submerged bars, but more catastrophic changes on their subaerial distal portions. The latter have become vegetated over time and some have escaped destruction for nearly thirty years. Parts of others have been completely removed and many have been mantled with splays of sand during floods. This suggests that while significant volumes of sand are mobilized during floods, a positional equilibrium is maintained between the bars and the stream regime.

Most of the remaining estuaries exhibit a much simpler and very consistent basin-like bathymetry, some examples of which are shown in figure 7.2. Baragoot, Wapengo, Middle, Wallagoot, Merimbula, Pambula and Curalo lakes are typical. Echosounder traverses "along" these basins reveal smooth basin floors which deepen gradually away from the deltas of the tributary streams at gradients of 1 in 100 to 1 in 250, and which terminate abruptly at the base of the marine thresholds (for example see traverses W1 and M1 in figure 7.2). Across-basin traverses yielded more symmetrical echograms showing flatter but similarly smooth, usually featureless basin floors bounded either by bedrock margins with slopes of 1 in 12 to 1 in 30 or less steep sandy shorelines with slopes as small as 1 in 80. Similar patterns were observed within the individual basins which together make up the composite branched form of Cuttagee Lake. The only significant bathymetric irregularities were recorded on across-basin traverses in front of the mouths of tributary streams. At such sites, small bottom rises were evident and represent the subaqueous extension of the fluvial deltas (for example see traverse W3 in figure 7.2).

There also appears to be a strong relationship between basin widths and depths with wider basins tending to be deeper (figure 7.3). The average width of each basin was calculated by averaging the longest basin diameter and the longest diameter approximately normal to it in the same basin. Maximum depth values plotted are reasonably persistent within a basin; any small, localized depressions were excluded. The ten points plotted in figure 7.3 also include values from the three sub-basins of Cuttagee Lake and yielded a statistically significant correlation coefficient (r) of 0.92, but when the Cuttagee values are excluded, the correlation coefficient improves marginally to 0.94. On the basis of similarly strong correlations between the equivalent

FIGURE 7·2 BATHYMETRY OF SELECTED ESTUARINE BASINS

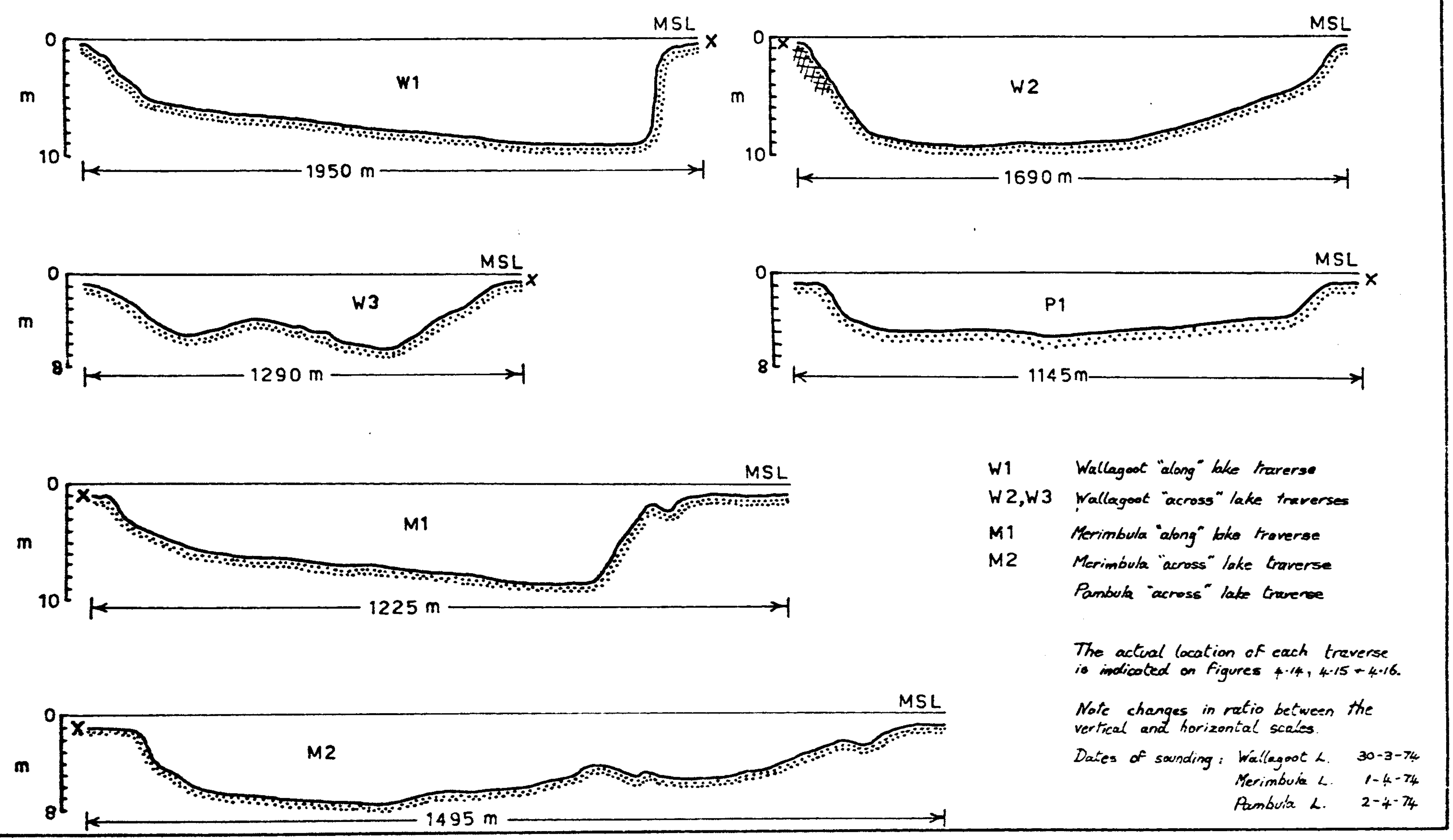
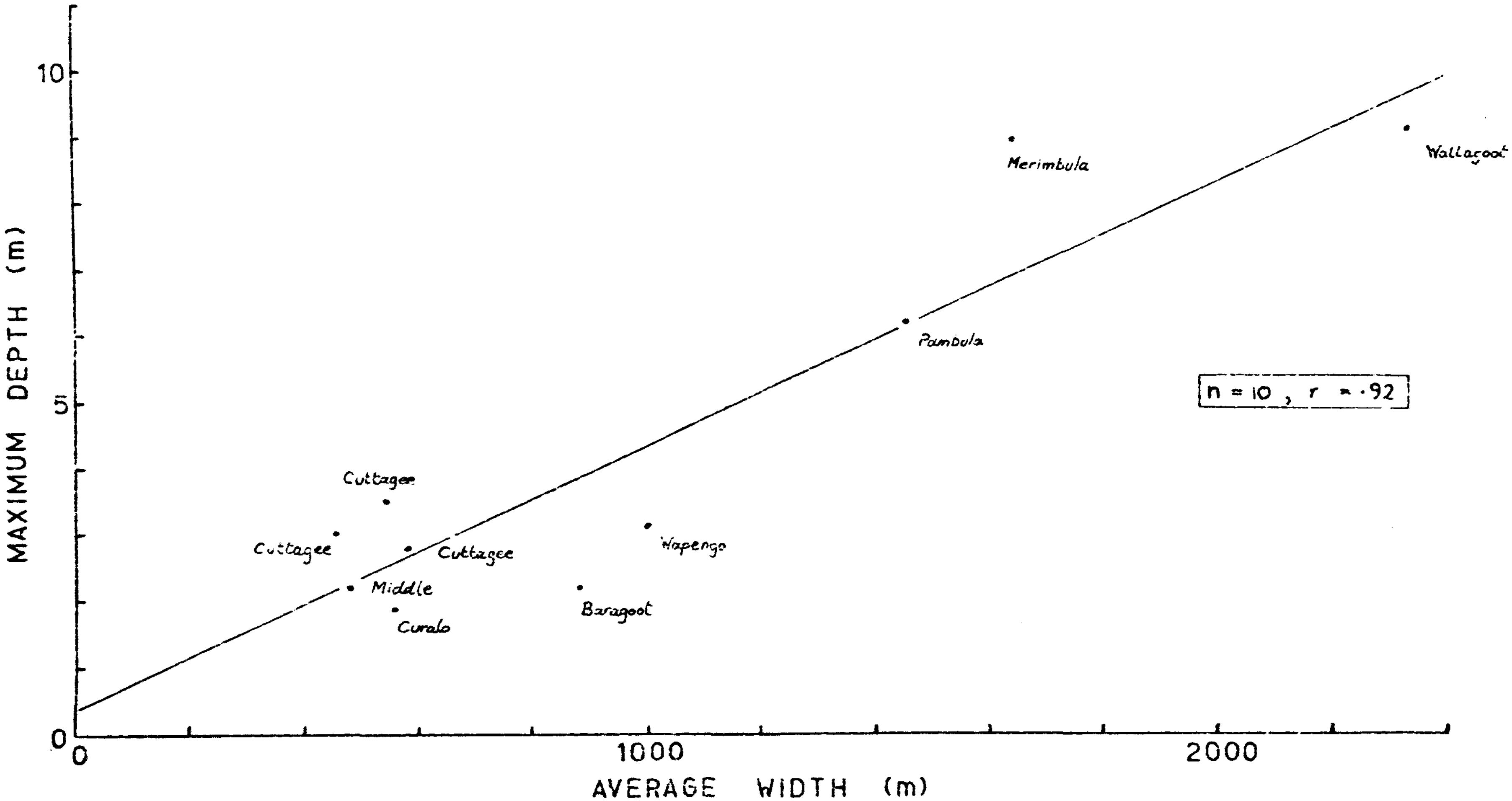


FIGURE 7·3 WIDTH - DEPTH RELATIONS OF ESTUARINE BASINS



dimensions of lagoons bordering the Gulf of Mexico, Price (1947) suggested that a long term equilibrium is maintained between these two parameters. Noting that the depth to which waves can disturb bottom sediments depends in part on wave dimensions and that these in turn are limited by the expanse of water over which the generating wind force can operate, Price argued that there exists a threshold depth for each basin and that shoaling beyond this level requires a diminution of basin width and fetch. If this is so, then from figure 7.3 it seems that the floor of Merimbula Lake, and to a lesser extent, that of Cuttagee Lake, have yet to attain their threshold depths. The remaining basins appear to have done so while Baragoot, Wapengo and Wallagoot lakes appear to be more shallow than they "should" be. In the latter situation, fetch diminution could be expected through deposition of wave disturbed sediment at calmer shoreline sites. Price (1947) termed this process segmentation, whereby shoreline deposits are moulded into spits which gradually extend into a basin, effectively dividing it into a number of smaller units. Segmentation in this manner has been observed by many workers (for example, Zenkovitch, 1959, 1967; Bird, 1967) but it has not occurred to any great extent in this area. Small bedrock promontories are common along the shores of most of the basins and in general, the small intervening embayments are the foci of shoreline sedimentation. In effect, the often irregular basin margins are becoming smoother and will eventually bound lakes of simpler plan form. The only effective basin segmentation evident in this area has occurred through progradation of stream delta lobes. Their continued growth will eventually reduce lake fetches greatly and thereby facilitate basin shoaling. Shepherd (1970) has reported similarly strong correlations between basin widths and depths within the Myall Lakes on the Central Coast of N.S.W. approximately 280 kilometres north of Sydney ($r = .76$, $n = 33$). He obtained an even stronger correlation ($r = .91$, $n = 33$) by comparing water depths with average annual hindcast wave energy values, thus strengthening the argument that effective wave scour is the main depth limiting mechanism. Roy and Peat (1976) reached similar conclusions on the basis of width-depth data collected from thirteen widely separated localities along the N.S.W. coast, but the correlation was weak ($r = .34$, $n = 13$) and only became statistically significant when an anomalously deep lake (Macquarie) was excluded ($r = .69$, $n = 12$). The weaker correlation is readily explained by their inclusion of lakes which had fundamentally dissimilar dimensions at the time of postglacial drowning due to differing nearshore gradients and topography of the continental margin.

The dimensions of an estuary, together with the tidal range within it, also determine the size of the tidal prism, an attribute of considerable relevance to estuarine morphodynamics. Tides along the N.S.W. coast are semidiurnal and have a very small range. At Bermagui, Merimbula and Eden, the mean range at springs is only 1.1 metres while the mean range at neaps is only 0.4, 0.7 and 0.6 metres respectively. As is usual, the ranges are even smaller within the estuaries. For example, 400 metres in from the sea at Merimbula the spring tide range is 0.9 metres, 1600 metres away at the road bridge it is 0.7 metres, while 2 kilometres further upstream and only 800 metres from the mouth of Boggy Creek the range at springs is only 0.3 metres (F. Lee, N.S.W. Public Works Department, pers. comm.). Tidal levels within the other estuaries were not monitored instrumentally during this study, but field observations revealed similar diminution of tidal ranges.

An immediate consequence of the very small tidal ranges and the prevalence of fairly steep shorelines bordering most of the estuaries, is the lack of intertidal slopes, which in turn limits the extent to which sediment can be redistributed and reworked around the estuary margins. This is particularly so where bedrock shorelines plunge directly to the estuary floor, but even where sediment is accumulating in the small shoreline embayments mentioned previously, the intertidal slopes are rarely more than 10 metres wide. The greatest opportunity for the development of such slopes is afforded by the shallower and flatter threshold surfaces. These will be discussed later.

In order to calculate the volume of the tidal prism in each estuary a mean tidal range of 0.5 metres was assumed. The resultant values shown in table 7.2 were calculated by multiplying the surface area of an estuary by this assumed tidal range, and making adjustments for small intertidal shoreline areas where the assumed tidal range exceeds the water depth.

Table 7.2 Volume of Tidal Prisms (10^6 cubic metres)

ESTUARY	PRISM VOLUME	ESTUARY	PRISM VOLUME
Baragoot L.	0.2	Wallagoot L.	1.8
Cuttagee L.	0.5	Back L.	0.2
Murrah L.	0.4	Merimbula L.	2.4
Wapengo L.	1.0	Pambula L.	2.0
Middle L.	0.2	Curalo L.	0.3
Nelson L.	0.4	Nullica L.	0.2
Mogareeka I.	1.4	Kiah I.	0.5

The estimates are necessarily crude but provide reliable order of magnitude measures; they are also potential values, since many of the estuaries are often closed off from the sea, in which instance the effective prism volume is zero.

Given that the probability of an estuary mouth being closed is at least partly controlled by the size of the tidal prism then it follows that Merimbula, Pambula, Wallagoot, Mogareeka and Wapengo lakes are most likely to be open to the sea. By implication, tidal currents and estuary thresholds should be best developed at these localities. The validity of these assertions and the extent to which they are refuted by the dominance of other factors is assessed in the following sections.

7.2 Estuary Thresholds (Flood tide deltas)

All the estuaries are connected to the sea at some time by constricted channels of variable stability. These channels traverse sandy deposits which are contiguous with the nearshore, extend landwards for varying distances as tidally inundated plains and which usually terminate abruptly within the estuaries as they drop steeply to the estuary floors. Bird (1967) has termed such deposits thresholds. All are fixed in position at the ends of embayments where wave energy is much reduced by refraction. There are considerable differences in the size and shape both of channels and thresholds (table 7.3, plates 7.1 - 7.12, and figures 4.9 - 4.18).

Table 7.3 Planimetric Surface Areas of Estuary Thresholds (km^2)

ESTUARY	THRESHOLD AREA	ESTUARY	THRESHOLD AREA
Baragoot L.	0.05	Wallagoot L.	0.5
Cuttagee L.	0.4	Back L.	0.03 *
Murrah L.	0.05 *	Merimbula L.	2.2
Wapengo L.	1.4	Pambula L.	1.0
Middle L.	0.1	Curalo L.	0.4
Nelson L.	0.4 *	Nullica L.	0.3
Mogareeka I.	0.3 *	Kiah I.	*

* indicates difficult to discern boundary.

The largest threshold is located at Merimbula Lake, where in terms of surface area, it has more than half filled the estuarine basin into which it is prograding. It is particularly well defined (plate 7.9 - 7.10) as is its smaller couterpart at Wallagoot Lake, and both demonstrate the landward widening typical of many of the other thresholds. At both localities, the steep landward margins are very prominent, and represent the distal faces of prograding tidal deltas (see bathymetric traces W1 and M1 in figure 7.2). The threshold of Curalo Lake is very similar in plan form, although it is much smaller in area. Other well developed thresholds occur at Wapengo, Pambula and

Cuttagee lakes, but they are much narrower and do not exhibit very marked landward flaring. The Pambula Lake threshold for example, occupies the 3.6 kilometre long, 160 metre wide bedrock gorge linking the estuarine basin to the sea.

In contrast, where overall estuary infilling has reached an advanced stage, the thresholds are less well defined. This is the case at Nelson Lake for example, where sand has been carried far upstream by flood tide currents, infilling most of the tidal basin and facilitating mixing of fluvial sand and muds with marine sands and organic detritus. At Kiah and Mogareeka inlets where infilling by rivers has been more effective, separation from the sea is effected only by narrow, incomplete, wave-built barriers of fluvial sand backed by submerged shoals of sand and gravel which are continually reworked by stream flow and tidal currents. These deposits, together with much of the barriers themselves are removed during floods (plates 7.1 - 7.8). Thresholds at Baragoot, Back and Middle lakes are the smallest of all, and in form are not unlike those of Kiah and Mogareeka inlets. However they are much more persistent features and do not experience such severe degradation during floods.

Assuming that threshold size is adequately represented by surface area, then it is apparent that a correlation exists between the volume of the tidal prisms and the size of the estuary thresholds. Application of the Spearman rank correlation test to the ranked data of tables 7.1 and 7.3 indicates that the association is statistically significant ($r_s = 0.85$, $n = 12$); a large tidal prism being associated with a large threshold surface area. Mogareeka and Kiah inlets were not included in this analysis due to the difficulty in measuring the surface area of their thresholds. These two estuaries are prime examples of the need to consider other factors such as high stream discharge.

An indication of the thickness of the threshold sediments is afforded by figure 7.4 which is based on bore-logs held by the N.S.W. Department of Main Roads and Mumbulla Shire Council. The threshold deposits shown are bounded on their northern side by outcropping bedrock, and on their southern margins by barrier beach deposits which extend to the southern end of each embayment. The bedrock basement appears to plunge deeply below these deposits towards the centre of each embayment. Boreholes sunk in the Merimbula barrier approximately 800 metres southwest of the drawn section and less than 400 metres from the present day ocean shoreline support this assertion since they reveal heavy grey clays beneath the barrier sands approximately 30 metres below present sea level. This also suggests that when sea level was lower during the last glacial, these rivers followed courses located further south towards the deeper areas of the present day embayments. As sea level rose, they presumably migrated northwards, until the existing situation was established.

Unfortunately, drill crews have only differentiated the threshold deposits in any detail at Mogareeka Inlet, a locality which probably has an atypical stratigraphic sequence given the conclusions drawn earlier in this thesis about sedimentation in the Bega River system. Thom and Chappell (1975) have suggested that sea level was at least 25 metres lower than present approximately 10000 years ago, in which case the bedrock basement shown in the Mogareeka Inlet section would have been submerged about this time. Subsequent and continuing alluviation of the drowned Bega River could be expected to produce an upward coarsening sequence similar to that observed, as increasingly coarser grained sediment was transported further downstream and deposited on top of the older and probably estuarine muds.

Alternatively, the medium to fine grained brown sands may represent part of a transgressive aeolian and/or marine unit which moved landward as sea level rose, and which has been overlain subsequently by more contemporary alluvium. It has already been established

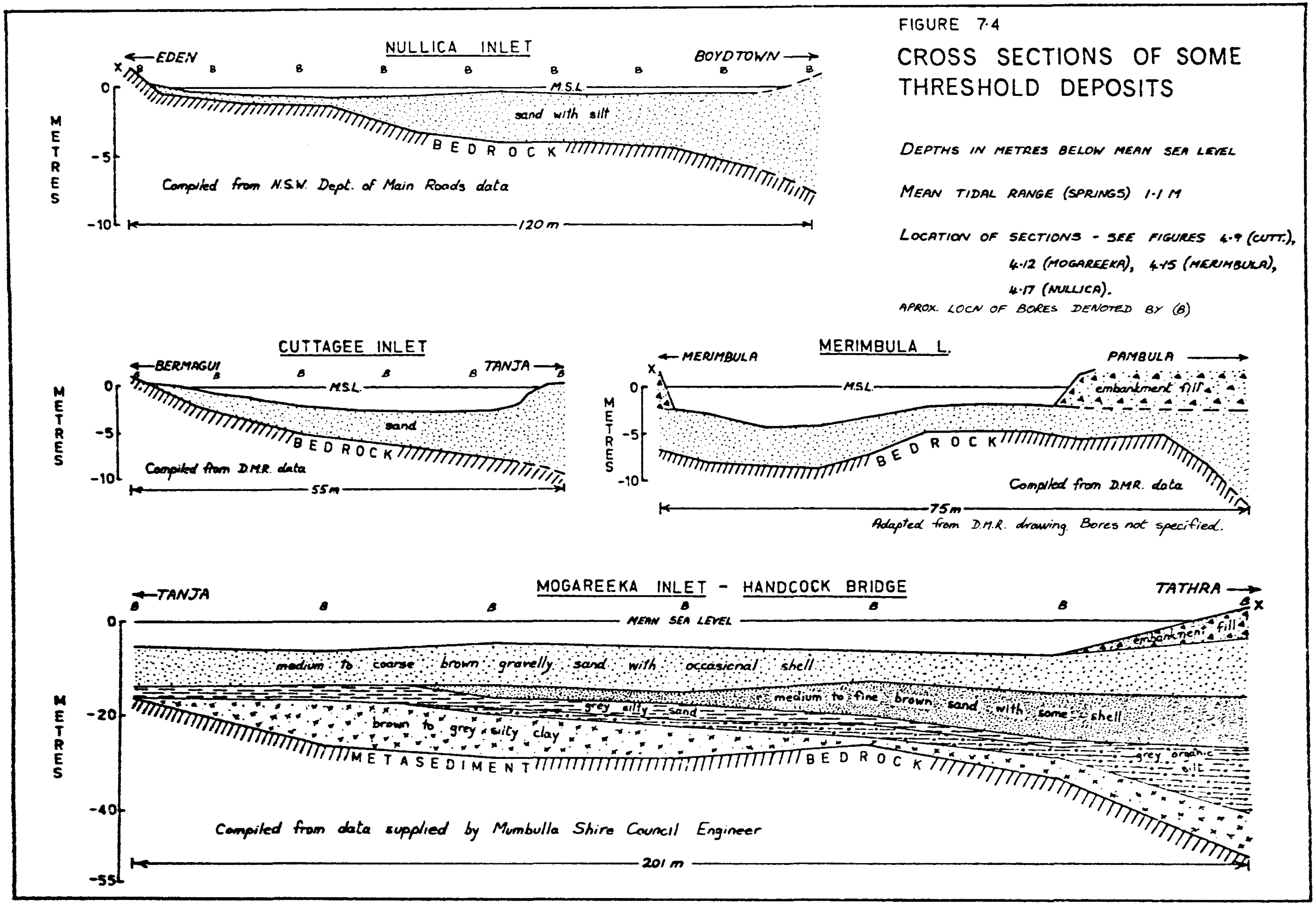


FIGURE 7·4
CROSS SECTIONS OF SOME THRESHOLD DEPOSITS

DEPTHS IN METRES BELOW MEAN SEA LEVEL

MEAN TIDAL RANGE (SPRINGS) 1·1 M

LOCATION OF SECTIONS - SEE FIGURES 4·9 (CUTT.), 4·12 (MOGAREEKA), 4·15 (MERIMBULA), 4·17 (NULLICA).

APROX. LOCN OF BORES DENOTED BY (B)

that the surficial threshold sands at Cuttagee and Merimbula lakes are marine in immediate origin and were probably transported shorewards following the postglacial rise in sea level. It is quite conceivable that a similar sedimentary unit is preserved at depth in Mogareeka Inlet. Clearly this is an area requiring further, more detailed stratigraphic investigation.

Threshold surfaces feature three distinct morphological units to which the terms high tide flats, intertidal slopes and subtidal zone are appropriate (Davies, 1972, p 172). The last unit is especially relevant to the movement of water and sediment about the threshold because it is within this zone that channels carrying the main tidal currents occur. On the smaller thresholds like those found at Baragoot and Middle lakes, one small, ephemeral channel is usual. Maximum channel widths rarely exceed ten to fifteen metres while at high tide, water depths are rarely greater than one metre. At low tide, there is often insufficient water to occupy the whole channel width and, if the lake becomes closed off from the sea, the channels often disappear rapidly as they are filled with wind blown sand. At Wallagoot Lagoon even larger channels are completely obliterated in this manner during periods of onshore winds because the threshold adjoins a large, partially mobile dune field.

At other localities such as Cuttagee, Wapengo, Nelson, Merimbula and Pambula lakes, the channels are open to the sea more often, tidal flow is more persistent, and deeper, wider, more stable channels have developed. The main channel at Merimbula for example , is approximately 50 metres wide and arcs tightly across the threshold downstream from the roadbridge (see plate 7.9). Its banks are generally very steep in this area, but are almost vertical along the outer curved margin where water velocities are greatest. Greatest channel depths occur where flow is laterally constricted, as is the case at the Merimbula road bridge (4.5 metres) and in the narrow, bedrock bordered, sand-choked gorge linking Pambula Lake to the sea (6.5 metres). Away from such constrictions, for example westward of the Merimbula bridge, the tidal channels become much less prominent and depths rarely exceed one metre at high tide.

Wapengo Lagoon threshold also features a large meandering channel which extends from the estuary mouth to the distal threshold margin (plates 7.11 - 7.12). It lacks the continuity of the Merimbula channel though and comprises four smaller interconnected channels each approximately 400 metres long, 40 - 60 metres wide and no more than two metres deep. Channel widths are fairly constant for most of the channel length but flare at their landward end where they merge with diamond shaped tongues of sand which Price (1963) called terminal channel fans. These deposits are always submerged but they are rarely covered with more than 50 centimetres of water at low tide. The overall appearance of each fan-channel unit is that of a kite, while the fans themselves are very similar in shape to some of the small stream deltas described previously (for example Boggy Creek delta at Merimbula Lake). Like these deltas, the terminal fans appear to have been moulded by jet flow. Their basic shape supports this assertion, but stronger evidence is provided by the fairly constant values of some morphometric ratios (table 7.4).

Table 7.4 Some Morphometric Ratios, Terminal Channel Fans, Wapengo L.

Channel Width (A) before flaring	Distance to Distal End (B)	Ratio B/A	Distance to Start of Deposition (C)	Ratio C/A
59 m	540 m	9.2	216 m	3.7
36 m	366 m	10.2	162 m	4.5
38 m	396 m	10.4	180 m	4.7
36 m	378 m	10.5	126 m	3.5

The distal end of each fan is consistently located approximately ten channel widths beyond the point where the channel begins to flare, while approximately four channel widths beyond the same point, deposition of sand commences, causing the now diffuse tidal flow to bifurcate. Similar ratio values for the second relationship have also been recorded from similar but much larger features by Price (1963) who concluded that plane jet flow (a tidal jet) was responsible.

The movement of sediment by flood and ebb tide currents in separate channels is well established (Robinson, 1960; Bruun and Gerritsen, 1961). At Wapengo, threshold channels carry both flood and ebb tide flow although the former dominates and is responsible for moulding the larger channel-fan deposits. Some of the fan surfaces are incised by small, shallow but distinct ebb tide channels which direct flow into the main tidal channels, the seaward ends of which feature small, convex seaward bars. Such features are indicative of a nett seaward flow and are more common near the mouth of Wapengo Lagoon where temporal coincidence and spatial separation of opposing flows is more pronounced. This is particularly so just after low tide when water commences moving upstream on the flood tide, while estuarine water continues to flow downstream at the same time, its seaward progress maintained by the momentum gained during the falling tide. Channel flow here is directed seawards, while the incoming tidal flow passes across adjacent sandy banks.

Unpublished records held by the N.S.W. Department of Public Works show that the flood tide dominates flow under the Merimbula road bridge, with peak spring tide current velocities averaging 1.1 m/sec (flood) and 0.6 m/sec (ebb). Eight hundred metres downstream from the bridge, current velocities are considerably reduced and the ebb tide flow becomes dominant. Average peak velocities here are only 0.6 m/sec (ebb) and 0.3 m/sec (flood), and vary little between the water surface and the channel bed. Small dunes with an average wavelength of approximately 20 metres are prominent in this area and their orientation matches the ebb tide dominated flow pattern. Flood tide flow pursues a less well defined course across the shallow sandy banks south of the main channel (plate 7.9). Separation of ebb and flood tide flow is also evident to a similar degree in the lower reaches of the channel linking Pambula Lake to the sea.

Aquatic vegetation is an integral component of the subtidal zone at many localities, with the eel grass Zostera occurring most frequently. At Merimbula, Pambula and Wapengo, the strap weed Posidonia is often present in the subtidal areas of the thresholds, but its preferred location appears to be the deeper floors of these estuarine basins. The very shallow threshold channels at Nullica are almost choked with Zostera, while at Curalo Lake it forms a nearly continuous carpet and any channels that may have been present on this threshold surface have been completely obscured. The dense growth at these two localities must impede estuarine sediment transport greatly, as well as supplying considerable amounts of organic detritus to the threshold sediments. At Merimbula, and to a lesser extent at Nelson Lake, thick beds of Zostera line the nearly vertical threshold channel walls, greatly enhancing their stability.

The subtidal areas are bordered by flat to gently undulating, usually unvegetated sandy banks lying above low water. Very gentle gradients and a small tidal range preclude the development of well defined channel systems and ensures that parts of threshold surfaces, often of considerable extent, experience minor reworking by small wind waves as the tide rises and falls. These sands are also strongly bioturbated by soldier crabs (Mictyris longicarpus and M. platycheles) and to a lesser extent by the gastropod Pyrazus, particularly in the more sheltered areas away from the estuary mouth.

High tide flats lie beyond the intertidal slopes but they are usually of very small areal extent. They are best developed in sheltered, indented areas of the larger thresholds where calm water conditions at high tide allow the suspended load of the estuarine waters to settle out. Accordingly, sediments on the high tide flats are much finer textured than those of the intertidal slopes. They are also quite organic, and near bordering bedrock slopes, small amounts of gravelly colluvium may also be present. Drainage channels are poorly developed and at mid tide the unvegetated areas comprise series of shallow, interconnected pools which gradually contract as the tide recedes. Patches of Salicornia together with isolated mangroves (Avicennia) are interspersed amongst the pools, although in many instances the Salicornia patches have coalesced to form extensive tracts of salt marsh.

The most extensive salt marsh successions occur along the western threshold margin of Wapengo Lagoon and along the south-eastern threshold margin of Merimbula Lake. The front of the marshes and the uppermost portions of the intertidal slopes are colonized by the mangrove Avicennia which at Merimbula forms quite dense stands less than two metres high. During storms, the mangrove pneumatophores often trap bundles of dead Zostera and stabilize splays of clean threshold sand deposited amongst them by waves. The mangrove belt is generally quite narrow and soon gives way to broad tracts of Salicornia within which many small clumps of subdominant plants are interspersed. These include Arthrocnemum at Merimbula and Juncus at Wapengo. Better drained areas towards the rear support the spikey grass Sporobolus and this eventually gives way to Eucalypt woodlands with occasional Casuarina. At other localities salt marsh is poorly developed and consists only of small areas of Salicornia and Juncus.

7.3 Temporal Stability of Thresholds

The temporal stability of thresholds can be examined at two levels. Near the mouths of the estuaries, dramatic changes occur during periods of high river discharge and/or rough seas, These modifications are considered in a later section. Towards the distal areas of the thresholds, where conditions are much calmer, more subtle changes occur which provide an indication of the rates of landward progradation and vertical accretion of the threshold deposits. In order to examine these changes, older vertical aerial photographs were compared with the most recent ones, although, as was the case when making similar comparisons of river deltas, the period of coverage was only 29 years for areas north of and including Wallagoot Lagoon and only 10 years for sites south of this locality. The other limitations such as different water levels, water clarity and photograph quality are also pertinent. Old maps were not consulted to establish temporal variability of threshold morphologies because comparison of recent (post 1970) 1:25000 topographic sheets with vertical air photographs of similar age revealed noticeable discrepancies which suggested that comparison of older maps was not warranted. Temporal variations of stream delta morphologies were not examined (using maps) for the same reason.

The greatest degree of change has occurred at Wapengo Lagoon but the volumes of sediment deposited appear to be very small. Terminal channel fans near the distal margin of the threshold appear to have experienced significant vertical accretion, while parts of the threshold margin itself have extended further into the estuarine basin (plates 7.11 - 7.12). Local oyster farmers and fishermen confirm these qualitative observations and assert that channel depths have decreased during the last 30 to 40 years, however none are able to furnish reliable estimates of the amount of deposition. All agree that the pattern of channels is very stable, and this is also supported by the aerial photographs.

At Merimbula, only very minor shoreline deposition is evident and there has been no change at all in the frontal outline of this threshold (plates 7.9 - 7.10). Given the very short period of records here, these results are not unexpected. Also, the greater depth of the estuarine basin into which this threshold is prograding would result in a slower rate of frontal extension than in shallower basins such as Wapengo, assuming that the volumetric rates of deposition were the same.

Both Wapengo and Merimbula lakes are always open to the sea and therefore experience continual tidally-induced movement of water across their thresholds. In contrast, Wallagoot Lagoon is frequently closed off from the sea, often for periods of a few months and the potential for threshold growth forward into the estuarine basin is greatly curtailed. The potential for vertical accretion is enhanced though and has been realized to a large degree. During the 29 years of air photograph coverage, numerous small areas of this threshold have become vegetated and now persist as stabilized sandy knolls. These can only encourage further accretion in the future particularly of the wind blown sand from the partly degraded foredunes nearby.

At other localities, no changes in the frontal margins of the thresholds are evident at all, and where channels are present, their positions have been quite persistent over time and appear quite able to survive floods. Only one historical record refers to threshold shoaling (Bermagui School Centenary Committee, 1976) and states that although Cuttagee Lake threshold is very shallow at present, it afforded free access to sailing vessels nearly 30 metres long during the mid 1800s.

During field work, minor threshold shoreline erosion was observed at Murrah, Wapengo, Middle, Nelson, Mogareeka and Merimbula lakes. Waves generated within these estuaries during periods of strong winds attack bordering sandy banks at their base, causing the unsupported sand burden to collapse. The detritus is subsequently reworked and distributed about the threshold surface.

On the eastern side of the threshold at Wapengo Lake, salt marsh is also being destroyed by wave attack during storms, but in addition it has been surmounted by a small, Sporobolus covered, chenier ridge approximately 25 centimetres high and extending subparallel to the cliffed marsh edge for nearly 200 metres. Bird and Barson (1975) have observed this phenomenon on a much larger scale in parts of Westernport Bay, Victoria, and argued that dieback of a frontal mangrove fringe had exposed the marsh to wave attack. This may also have occurred at Wapengo, but evidence related to such an occurrence is unavailable. Local residents are quite confident that the shoreline here has not changed during the 40 years they have lived in the area, and these observations are confirmed by aerial photographs taken 33 years ago. At all localities the degree of shoreline retreat is quite small and cannot be discerned by examining older aerial photographs.

Reference to photographs of similar vintage reveals that the rates of threshold accretion are very small at all localities and that these landforms have been quite stable for at least 30 years. Unfortunately, comparative rates of accretion at different sites cannot be determined with any confidence and it can only be argued that the larger thresholds have grown more rapidly, assuming that they all began to form at the same time. It is also likely that the rates of growth have diminished greatly since the cessation of sediment supply from the continental shelf. The lack of accretion indicates that the estuaries trap only small volumes of marine sand each year, and thus provides further evidence to support an earlier conclusion that the calculated volumes of nett annual longshore transport within the ocean embayments are quite unrealistically high.

7.3.1 Stability of Estuary Mouths (Inlets)

Although positionally stable, the seaward end of the thresholds often undergo quite dramatic morphological alteration, the basic pattern being one of gradual channel closure by waves and breaching of the resultant barrier by floods. During field work it was not only evident that some estuaries were open to the sea more often than others, it was also apparent that this phenomenon had considerable bearing upon the observed differences in threshold morphology. To test this idea, an index of inlet closure was devised, based on observations of the degree of channel constriction at the mouth of each estuary using all available air photographs back to 1943 and field records obtained since 1973. Each inlet was given a score of ten points if it was observed to be open at low tide, five points if open only at high tide, and zero points if closed at high tide. The index value was calculated by dividing the total points score for each inlet by the number of observations. The results are shown in table 7.5.

Table 7.5 Index of Inlet Closure (I)

ESTUARY	I	n	ESTUARY	I	n
Baragoot L.	2.5	20	Wallagoot L.	3.3	12
Cuttagee L.	6.2	21	Back L.	4.6	14
Murrah L.	9.8	21	Merimbula L.	10.0	17
Wapengo L.	10.0	18	Pambula L.	10.0	15
Middle L.	2.7	13	Curalo L.	5.0	14
Nelson L.	10.0	14	Nullica L.	8.8	13
Mogareeka I.	8.9	19	Kiah I.	10.0	12

I = closure index; I = 10 indicates inlet always open; n = no. of obsns.

An index value of ten indicates that an inlet is open to the sea at all times, while a value of zero indicates that an inlet is always closed, a situation not encountered with the estuaries investigated in this study. The results suggest that Wapengo, Nelson, Merimbula, Pambula and Kiah inlets are consistently open to the sea. This was confirmed by local residents.

In this region the degree of closure is a function of wave action which tends to close an estuary mouth by constructing a barrier across it, of tidal currents which, at least in the short term, work to maintain an opening, and of stream flow which not only breaches closed inlets after heavy rain but also works to maintain existing openings. In table 7.6 the way these forces interact to effect closure can be assessed by comparing the summary estimates of "average" wave, tide and stream activity with the value of the closure index at each inlet. The attribute values tabulated are average annual wave power, average annual stream flow, and the volume of each tidal prism, the final attribute having been equated crudely with tidal "power". All were derived in previous sections of the thesis.

Table 7.6 Closure Index .v. Tidal Prism, Stream Discharge & Wave Power.

INLET	CLOSURE INDEX	PRISM VOLUME (x 10^6 m^3)	Av. Ann. River Flow (10^6 mega-litres)	Av. Ann. Wave Power (Kw/m)
Wapengo	10.0	1.0	16.1	26.2
Nelson	10.0	0.4	6.0	8.9
Merimbula	10.0	2.4	4.0	8.9
Pambula	10.0	2.0	95.2	6.8
Kiah	10.0	0.5	375.8	3.1
Murrah	9.8	0.4	66.6	11.8
Mogareeka	8.9	1.4	795.4	11.6
Nullica	8.8	0.2	10.7	1.6
Cuttagee	6.2	0.5	15.6	10.5
Curalo	5.0	0.3	4.5	7.4
Back	4.6	0.2	7.3	13.4
Wallagoot	3.3	1.8	6.7	14.1
Middle	2.7	0.2	6.5	17.4
Baragoot	2.5	0.2	1.9	12.6

Some interesting associations emerge. At one end of the scale, high wave energy, small tidal prisms and small river discharges reinforce each other in effect and the inlets at Baragoot, Middle, Back and Curalo lakes are usually closed off from the sea. Not surprisingly these lakes are also characterized by very small thresholds. Wallagoot Lagoon is closed just as often but when it is open, the larger tidal prism produces stronger currents which over time have formed a larger threshold. Despite this, the frequency of closure induced by the high wave energy conditions has prevented the full potential for threshold development being realized, and the threshold at Wallagoot is much smaller than its counterpart at Merimbula where, although the prism is only slightly larger, wave energy is much less and the inlet is always open to the sea.

In apparent contradiction of the situation at Wallagoot, Wapengo Lagoon is always open to the sea yet its inlet experiences the highest incident wave energy in the region and its tidal prism is nearly 50% smaller. This anomaly can be explained by the entrance to Wapengo Lagoon being bounded by bedrock on both sides - in effect a permanently constricted opening which enhances the velocities of the tidal currents passing through it, thereby assisting them to counter closure by the higher wave energy levels. Instead, the waves mobilize the bottom sands which are subsequently transported into the estuary by flood tide currents to form the particularly well developed threshold with its attendant pattern of channels and terminal channel fans (plates 7.11 - 7.12).

At Merimbula, the usual topographic arrangement exists with only one side of the inlet being bounded by bedrock. Lower levels of wave activity together with the largest tidal prism in the area ensure a permanently open inlet and a very large threshold. Conditions at Pambula are very similar, although ebb tide currents are probably strengthened by outflowing river discharge. Kiah Inlet is always open too, its small tidal prism effectively offset by a very large river discharge and considerably reduced wave energy levels within Twofold Bay. The latter effect also operates at Nullica Inlet which is open quite frequently despite its small tidal prism.

In contrast to Kiah Inlet, Mogareeka Inlet is sometimes closed although it has a larger tidal prism and twice the annual stream discharge, but it also lacks the sheltered location of Kiah Inlet and waves are more able to effect closure, especially at times of prolonged low river flow. Occurrences of this kind demonstrate the problems of using "average" conditions.

The only major anomaly which is difficult to explain except by challenging the reliability of the tabulated values occurs at Murrah Lagoon which is open to the sea more often than Mogareeka Inlet. This is a little incongruous because Murrah Lagoon has a smaller tidal prism, it is fed by a much smaller river and its inlet experiences marginally greater wave energy. It is also a little surprising that Nelson Lake is open so often in view of its small tidal prism, low stream discharge and the moderately high wave energy levels at its entrance. It is likely though that the calculated wave power values here are larger than they should be, the overestimation being due to the difficulty of determining the pattern of wave refraction within this small, deeply recessed embayment. With lower wave power values the low tendency for inlet closure at Nelson is less anomalous than it would appear.

7.3.2 Inlet Breaching and Closure

In general, the high energy swell environment of the NSW coast encourages gradual closure of inlets until countered by a period of high river discharge. Conversely, closure is effected more rapidly at times of low river discharge. This pattern of inlet behaviour conforms in large part with that observed by other workers elsewhere on the N.S.W. coast (Halligan, 1906, 1911; Ford, 1963; Owen, in press) and with recent, more detailed studies at the mouth of the Shoalhaven River (Wright, 1976; Brown et al., 1977). Along the coast of Oregon and California, storm waves often block the mouths of rivers with large volumes of sand (Bascom, 1954) while along the U.S. Gulf coast such waves often work to breach bars and barrier islands (Emery and Stevenson, 1957; El-Ashry and Wanless, 1965; Scott et al., 1969; Pierce, 1970). Thom (pers. comm.) has suggested that overwash from storm waves aided by set-up and high tides interacts with high discharges to induce inlet breaching on the N.S.W. coast. The author has no field evidence from this study area to support or counter his suggestion.

When an inlet is only partially closed, its enlargement following prolonged rainfall in the catchment area is usually unspectacular, with the barrier being gradually scoured away until the channel dimensions are sufficient to accommodate the increased flow of turbid river water. When an inlet is closed completely the changes are often much more dramatic, especially if breaching coincides with low tide when the hydraulic head is greatly increased. As soon as the lowest part of the barrier is overtopped by the rising lake level, the impounded water flows slowly seawards down the face of the barrier, cutting a small channel as it does so. Thereafter, channel enlargement appears to develop exponentially until a torrent of water pours through the opening, which may be 50 metres wide only two hours or so after initial breaching. At this stage flow velocities often exceed 2 m/sec and standing waves up to 1 metre in amplitude are common. The effects are even more dramatic during major floods in the Bega and Towamba rivers (plates 7.1 - 7.8) where breaching often occurs at more than one point. During the record flood of February 1971, more than 700 metres of the barrier at Whale Beach was removed. The magnitude and frequency of floods in these two rivers also explains why thresholds have little chance of survival. This is also the case at Murrah Lagoon, while at Pambula inlet the impact of floods is much reduced by the size and position of the intervening estuarine basin which regulates flow more evenly.

In southern N.S.W. floods are usually accompanied by storm waves with both phenomena being generated by intense cyclonic depressions located in the Tasman Sea. Such waves rarely breach the the barriers of their own accord but they often scour the beaches and transfer large amounts of sand to the nearshore zone. As soon as river discharge has diminished sufficiently and seas have abated, this sand, together with that from the flood eroded barriers begins to move shorewards again. Swash platforms develop within a few days near the mouth of the estuary in a manner very similar to that described by Oertel (1972) and within a few weeks these deposits are usually welded to the shore and surmounted by beach berms. If tidal currents are not powerful enough to prevent it, the juvenile barrier gradually grows laterally and vertically and eventually seals off the inlet. If conditions are very favourable, even large breaches can be healed within a month of a major flood (plates 7.1 - 7.4). When periods of strong swell are unaccompanied by floods, berm growth is often accelerated and washover deposition delivers sand to the threshold areas immediately behind the barrier. Completely closed inlets remain so until the next flood and exchange of water occurs only as percolation through the barrier sands. Percolating flow can initiate piping and eventual breaching of the barrier, but this is an infrequent event which occurs only when impounded lake levels are unusually high and the barrier has been weakened by erosion during heavy seas.

7.4 Other Ramifications of Closure

The frequency of inlet closure also determines the flushing ability of an estuary as well as the salinity of its waters, both of which can affect sedimentation patterns. Suspended fines carried into an estuary by a river usually settle out in the less turbulent water of the estuarine basin and accumulate on the basin floor. Often, basin waters are not calm, and turbulence due to wind waves temporarily inhibits deposition of this sediment. Resuspension of fine textured estuarine deposits by wind waves is also an important sediment dispersal mechanism (Anderson, 1972). Some of the material either kept or placed in suspension will settle out in calmer, deeper areas, but a lot may also be flushed from the estuary and dispersed in the sea. The latter occurrence was frequently observed during field work, with water passing through an inlet on the ebb tide always somewhat turbid compared to the clear sea water which replaced it during the flood tide. The frequency of inlet closure is one obvious control of the efficacy of this dispersal mechanism and all else being equal, estuaries such as Baragoot, Middle, Back and Curalo lakes, which are frequently closed, should experience greater rates of mud deposition than others such as Cuttagee and Nelson lakes, which are open to the sea more often. On the other hand, greater frequency of closure will reduce the input of seawater and the resulting lower salinity may diminish flocculation rates significantly.

Flushing of fines is also more likely in the shallower estuaries, firstly because resuspension of bottom sediment by waves is less difficult, and secondly because the ratio of the tidal prism to the total volumetric capacity of the estuary is much larger. For example, during one tidal cycle, Nelson Lake exchanges a greater proportion of the water contained within it than does the deeper Merimbula Lake where the ratio of the tidal prism to the total estuary volume is much smaller.

The flushing ability or tidal ventilation of an estuary is therefore an important depth regulating mechanism with considerable bearing upon sedimentation and the basin width-depth relationships discussed previously. Basin segmentation for example, is less probable in well ventilated estuaries. In general, good tidal ventilation will inhibit deposition of fines until sedimentation reaches the stage where it begins to reduce the volume of the tidal prism itself, whereupon the probability of inlet closure will increase, flushing ability will decrease, and rates of deposition will accelerate.

The frequency of inlet closure also influences the salinity and circulation of estuarine waters, which in turn can affect clay flocculation and dispersal of bed load sands (see for example Rochford, 1951; Ippen, 1966; Simmons, 1966; Postma, 1967). In order to investigate some of these relationships, the salinity and temperature conditions of most of the estuaries in this region were surveyed during late summer of 1975 and again, less intensively, during the following winter. During the first survey, a conductivity-temperature probe was lowered from an inflatable boat and readings were taken at several depths at each station. Calibration curves were later prepared for this meter using known concentrations of KCl solution, and the conductivity readings were converted to salinity values ($^{o}/_{oo}$ parts per thousand). During the second survey a direct reading salinometer was used. Both devices compensated automatically for temperature differences. The results, other than those from Mogareeka and Kiah inlets are shown in table 7.7.

Table 7.7 Salinity & Temperature of Estuarine Basin Waters

BASIN	DATE	n	SALINITY (‰)	TEMPERATURE (°C)
Baragoot	January 1975 *	13	15.5	28.3
	July 1975	7	34.5	10.0
Cuttagee	January 1975	14	32.6	25.0
	July 1975	11	35.0	9.0
Murrah	January 1975	9	35.3	23.9
Middle	February 1975 *	9	17.4	29.2
	July 1975	4	32.0	18.0
Nelson	February 1975	3	32.6	26.9
	July 1975	6	33.5	18.2
Wallagoot	February 1975 *	18	24.8	27.8
	July 1975 *	10	23.5	14.3
Merimbula	February 1975	12	32.6	24.4
	July 1975	8	34.0	11.2
Pambula	February 1975	10	33.9	25.0
Curalo	February 1975 *	8	22.6	30.0
Sea Water	January 1975	2	35.3	24.4

An asterisk indicates that the estuary was closed off from the sea. Salinity & temperature values shown are average ones. (n = no. of surface values)

At all the localities shown in the table, the estuarine waters were thoroughly well mixed, there being no significant changes in salinity or temperature with depth. Variations were usually only of the order of $\pm$ 1°C and $\pm$ 2 ‰, and for this reason, only average values are shown. The only significant deviations from the tabulated figures occurred in the shallow, lower reaches of the tributary streams where temperatures were consistently higher. In the barely flowing Mangan's Creek which debouches into Baragoot Lake, temperatures of 31 °C were usual, while in the more strongly flowing Cuttagee Creek, water temperatures were approximately 28 °C.

In the estuarine basins of Baragoot, Middle, Wallagoot and Curalo lakes, which were closed off from the sea during the 1974/1975 summer, salinities were considerably less than that of sea water. Despite the dry summer, the influx of river water and precipitation exceeded evaporative losses sufficiently to effect substantial dilution of the basin waters. This effect is very pronounced in the smaller basins such as Baragoot. In contrast, water temperatures in these basins were 3.4 to 5.6 degrees warmer than those of ocean waters nearby. In the other lakes, which were open to the sea during the survey, salinities and temperatures did not differ greatly from sea water except at Nelson Lake where the shallow depths allowed sufficient heat absorbtion during a tidal cycle to increase water temperatures by 2.5 degrees.

The survey in winter 1975 was conducted after four months of greater than average rainfall. In June alone, rainfall at Bega was approximately four times the average for that month. Consequently increased stream discharge opened all the inlets but by the time sampling was conducted, Wallagoot Lagoon was already closed again and river flow had diminished. Basin waters were again thoroughly mixed and due to inlet opening and subsequent injections of sea water, they were much more saline than before. Only near the mouths of the tributary streams were salinity values reduced significantly by the continuing inflow of fresh water.

The long, narrow estuary of the Bega River (Mogareeka Inlet) displays a markedly different salinity pattern which varies with the rise and fall of the tide. This is particularly evident in figures 7.5a and 7.5b which illustrate the hourly changes in salinity at one cross-section of the estuary approximately four kilometres upstream from the mouth. Each sectional representation of the isohaline pattern is based on readings taken at 0.2, 0.5 and 0.8 times the depth at each of five stations spaced equally across the estuary. Each station was marked by an anchored, luminous buoy which ensured reliable boat positioning for observations during both day and night. It was intended to obtain readings every hour over one complete tidal cycle from low

FIGURE 7·5a SALINITY LEVELS — MOGAREEKA INLET

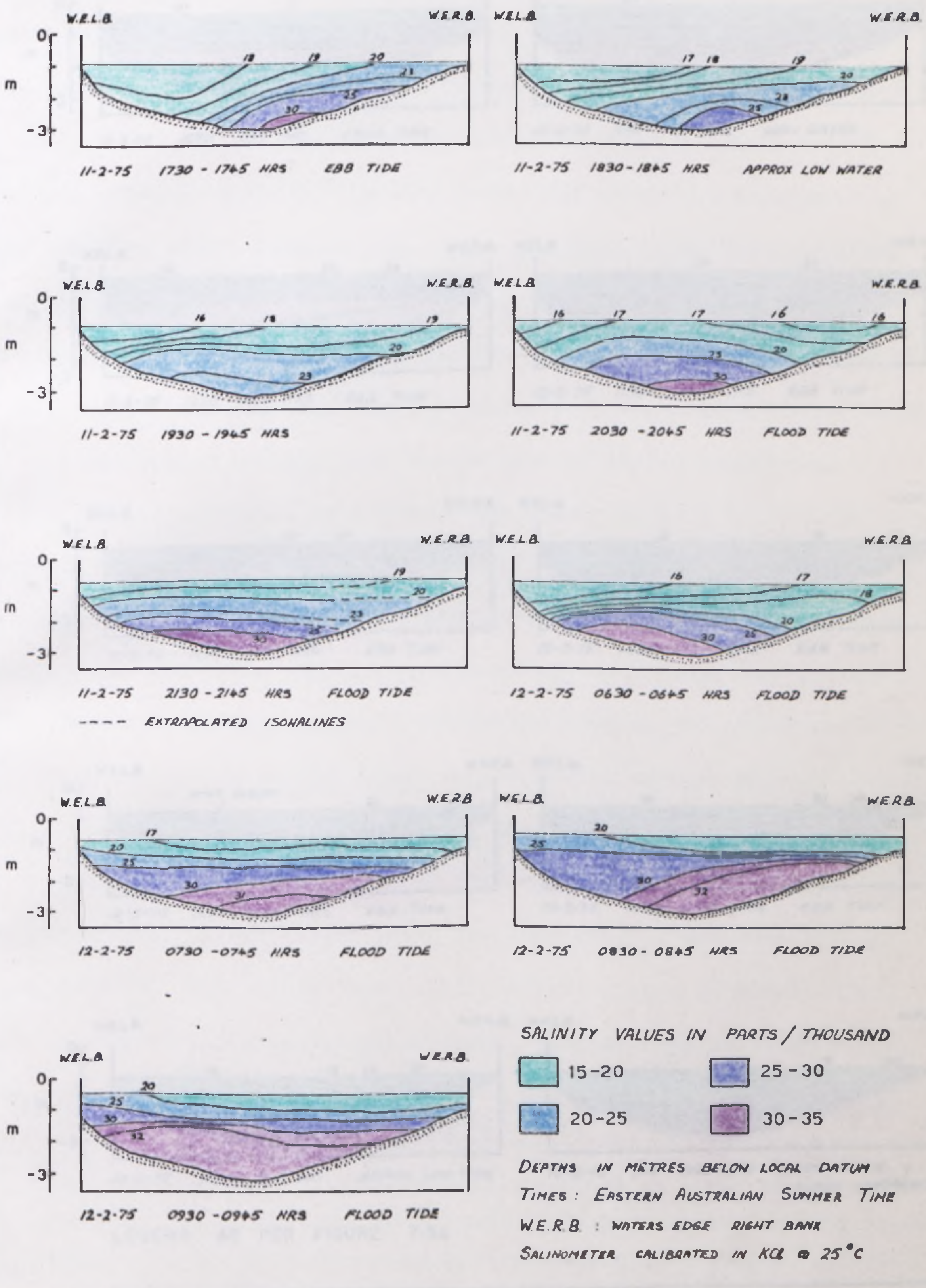
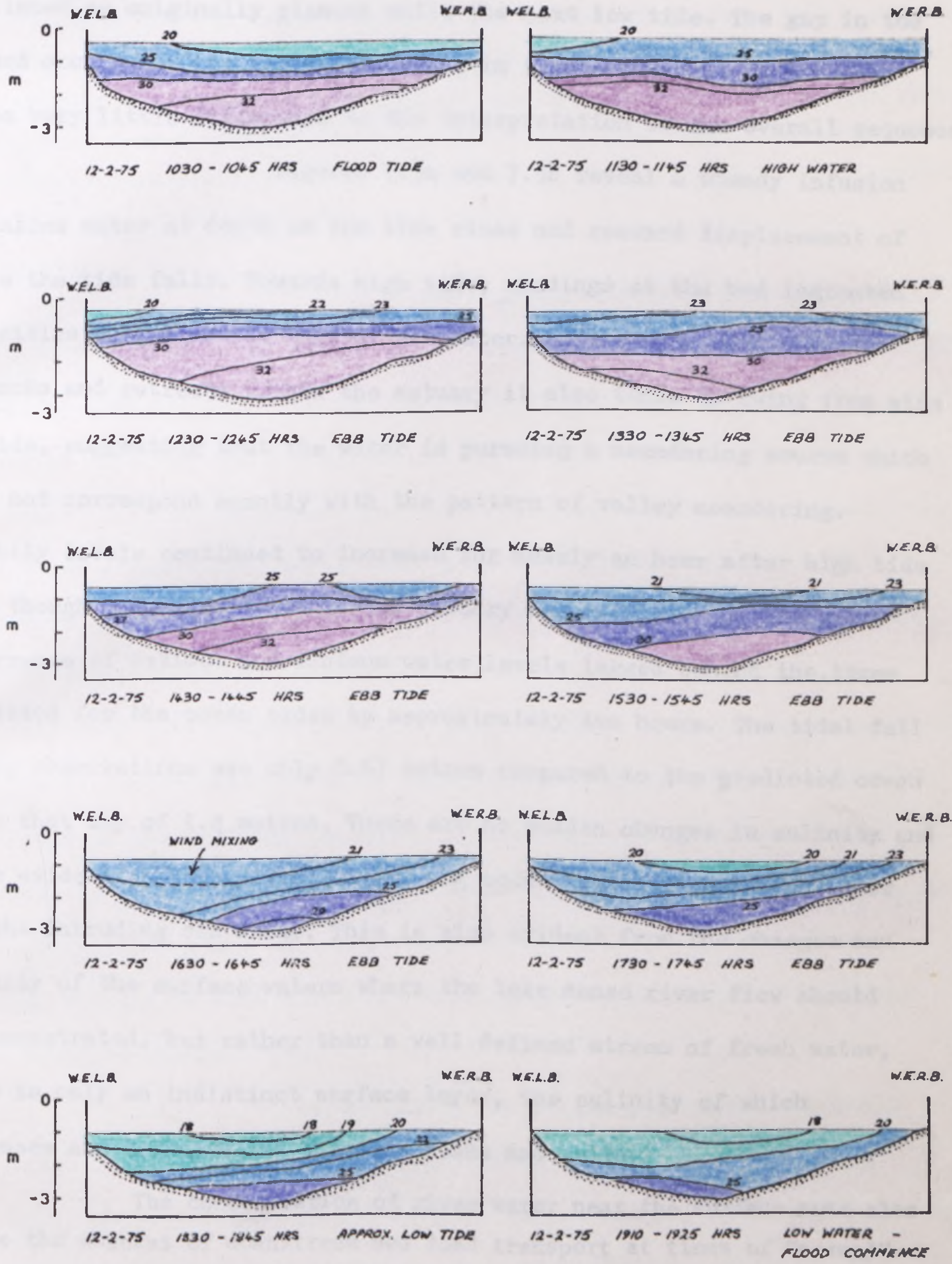


FIGURE 7·5b SALINITY LEVELS — MOGAREEKA INLET



LEGEND AS PER FIGURE 7·5a

water to low water but heavy rain brought the operation to a halt after only three hours of the rising tide. Observations were recommenced at approximately the equivalent position of the following cycle and continued as originally planned until the next low tide. The gap in the record occurs between sections 5 and 6 in figure 7.5a but it probably makes very little difference to the interpretation of the overall sequence.

Figures 7.5a and 7.5b reveal a steady infusion of saline water at depth as the tide rises and seaward displacement of it as the tide falls. Towards high tide, readings at the bed indicated salinities equivalent to that of sea water. As the more saline water advances and retreats within the estuary it also tends to swing from side to side, suggesting that the water is pursuing a meandering course which does not correspond exactly with the pattern of valley meandering. Salinity levels continued to increase for nearly an hour after high tide even though the water level in the estuary had dropped, while the occurrence of maximum and minimum water levels lagged behind the times predicted for the ocean tides by approximately two hours. The tidal fall during observations was only 0.67 metres compared to the predicted ocean range that day of 1.4 metres. There are no sudden changes in salinity and it is evident that fairly strong mixing occurs between the river water and the intruding sea water. This is also evident from the changes in salinity of the surface waters where the less dense river flow should be concentrated, but rather than a well defined stream of fresh water, there is only an indistinct surface layer, the salinity of which increases and decreases as the tide rises and falls.

The concentration of river water near the surface must also reduce the chances of downstream bed load transport at times of "normal" flow, and such transport must await times of high discharge. During floods saline water is completely displaced by river water which often extends seawards as large turbid plumes. The orientation of bed forms in Mogareeka Inlet also indicates that flood tide currents bringing the more saline water upstream along the bottom of the estuary are rather ineffective agents of bed load transport. This contrasts with other localities where the upstream limit of sea water intrusion is often a focus for shoaling.

Rochford (1951) claimed that the lack of marked stratification is typical of most estuarine systems in eastern Australia. A more recent study by Wright (1976) at the mouths of the Shoalhaven River revealed that at peak flood discharge seawater was flushed completely from the estuary but as river stage fell, vertical salinity gradients at the mouths varied in response to the levels of incident wave energy. Where wave energy was high, turbulence caused thorough mixing, while at the other more sheltered distributary mouth pronounced stratification was recorded with a buoyant plume of river water overlying denser sea water.

7.5 Review

The degree to which an estuary fulfills its role as a trap both for marine and terrigenous sediments depends not only upon the availability of a sediment source, but also upon the frequency of inlet closure. The latter factor depends in turn upon the nett interaction of stream discharge, tidal flow and incident wave power. Low levels of stream flow, small tidal prisms and high levels of wave activity at the estuary mouth enhance the probability of inlet closure, and estuaries which experience these conditions in combination, usually have little opportunity to trap landward moving marine sands, just as the suspended loads of these estuarine waters have little chance of escaping to the sea. The converse is also true and where an estuary is frequently open to the sea, a more dynamic water circulation pattern ensures greater rates of marine sand entrapment and the formation of larger thresholds with variably developed patterns of channels, banks and terminal channel fans.

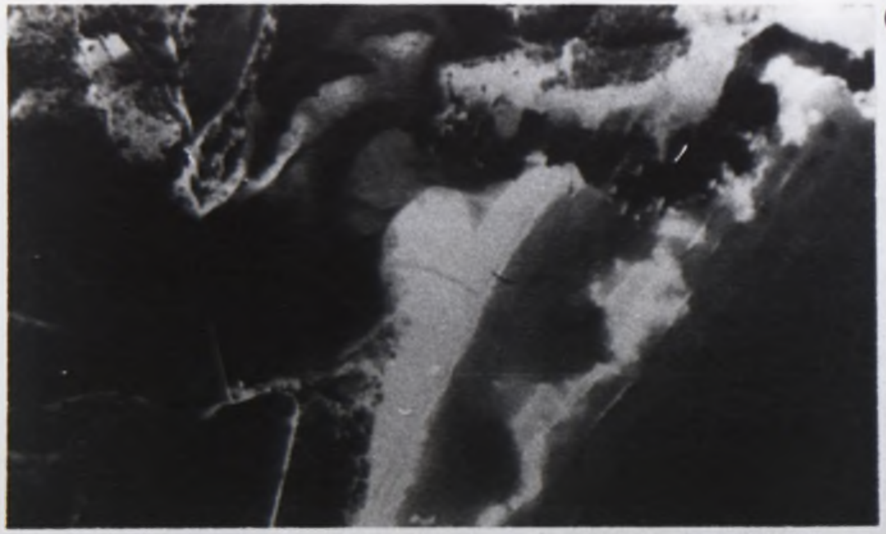
In contrast, the delivery of river sands and gravels to the sea is relatively unaffected by the degree of inlet closure. Where streams debouch into estuarine basins, their bed loads are deposited well short of the sea to form small deltas, and where the estuary has been almost completely infilled and the intervening sediment trap eliminated, the bed load sediments are only mobilized during floods which usually have little difficulty in breaching closed inlets.

Captions to accompany plates 7.1 - 7.12

Plates 7.1 - 7.8 illustrate the rather dramatic changes experienced by barriers at Mogareeka and Kiah inlets following major flooding of the Bega and Towamba rivers. They also illustrate the fairly consistent barrier plan form which is re-established after each flood. In February 1971 the biggest flood on record occurred, destroying the bridge at Tathra (cf 7.2, 7.3) and removing much of the barriers. At Whale Beach this damage is still evident in plate 7.7, whereas at Tathra,(plate 7.3 which was taken only four days later), the breach has been completely healed. This is a direct reflection of the reduced levels of wave activity at Whale Beach which enjoys a protected position within Twofold Bay. Note too the large nearshore bars and scour troughs offshore from each river mouth. Swash platforms are also evident in plate 7.2. Scale bars are equivalent to ground distances of 90 m at Tathra, and 150 m at Whale B.

Plates 7.9 - 7.12 The thresholds at Merimbula and Wapengo lakes represent particularly well developed tidal deltas. Both display patterns of channels and banks which are very stable over time and which appear unaffected by river floods. The barrier at the mouth of Merimbula Lake is frequently destroyed by floods but always re-establishes itself when conditions return to normal. Terminal channel fans are prominent at Wapengo Lagoon, but at Merimbula, the surficial threshold sediments are less mobile and have been stabilized by sea grass growth and construction of oyster racks. Small bars are also present offshore from these inlets and often occur at estuaries where strong tidal currents maintain permanently open inlets. Scale bars are eqivalent to ground distances of 350 metres at Wapengo Lagoon and 250 metres at Merimbula Lake.

Plates accompanied by a code letter F, L or N are reproduced by courtesy of the Forestry Commission of N.S.W. (F), the N.S.W. Department of Lands (L) and the Division of National Mapping, Department of National Resources (N).



Pl. 7·1 May 28, 1957

Pl. 7·2 Feb. 14, 1964

BEGA R. MOUTH

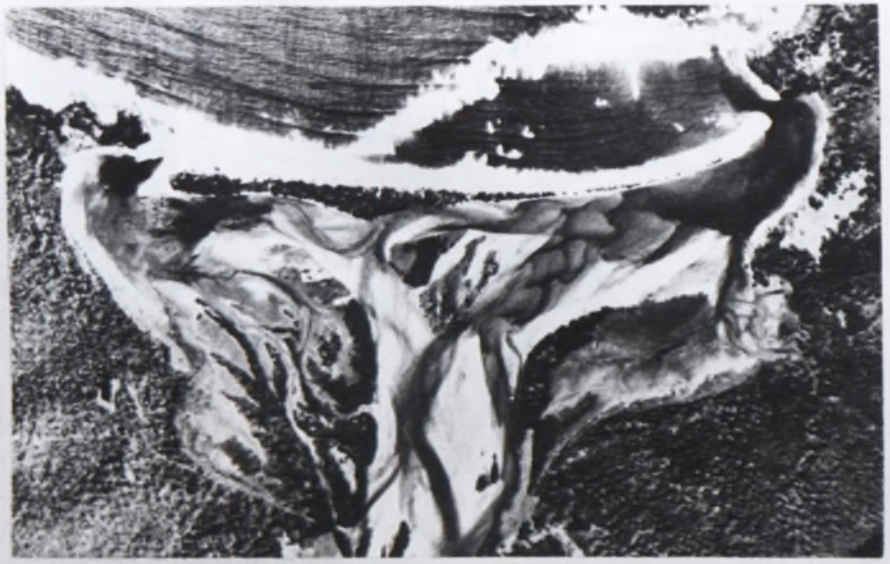
Pl. 7·3 Apr. 3, 1971

Pl. 7·4 Jun. 4, 1972

(L)

Pl. 7·5 July 1962

(F)



Pl. 7·6 Apr 6 1964

TOWAMBA R MOUTH - KIAH INLET

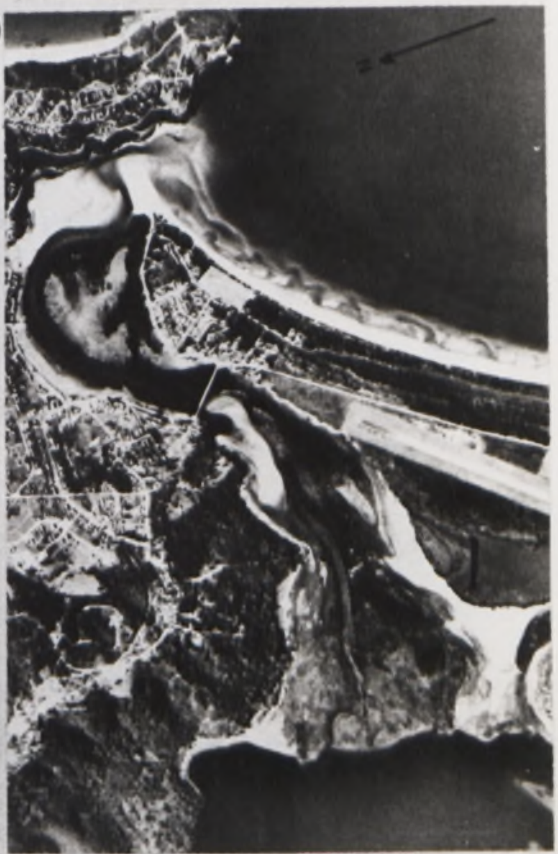
Pl. 7·7 Mar 30 1971

(L)

Pl. 7·8 Jun 4 1972

(L)

(L) (L)



Pl. 7·9, 7·10 MERIMBULA L. THRESHOLD - Jly 1962; Jun '72

Pl. 7·11, 7·12 WAPENGO L. THRESHOLD - Mar 3, 1944; Mar 30 '71

(N) (L)

CHAPTER EIGHT : RECAPITULATION AND CONCLUSION

The research upon which this thesis is based sought in general to determine the sources of sand found on the present day beaches in southern N.S.W. and in particular to determine the importance or otherwise of rivers as contemporary suppliers of sand to the coast. Having achieved this objective it was necessary to explain the forces and processes which control the observed sedimentation patterns and to consider the landforms which have resulted.

8.1 Review

Sedimentological and mineralogical analysis of the beach sands reveals that most of these deposits are very similar in character. The minor variations in attribute values that do occur are simply responses to varying wave energy conditions and do not disguise the common origin of these sands. In general, they are well sorted, medium grained, negatively skewed and predominantly quartzose with a pronounced scarcity of less resistant accessory minerals such as feldspar. The quartz grains are well rounded and many are ironstained. All these characteristics are indicative of textural and mineralogical maturity and are commensurate with a period of intense reworking. The most plausible explanation of their origin is that they are relict, and have been transported to their present positions since the postglacial rise in sea level. Prior to this, during the preceding glacial(s), they were probably deposited on the continental shelf by rivers and since then have been intensively re-worked in the high wave energy environment which prevails along the N.S.W. coast.

Major expections of this general situation occur at three localities. At Whale and Tathra beaches, sands are much coarser, less well sorted, less negatively skewed, more angular and contain at least 10% feldspar. They also lack ironstaining. Boydtown Beach sands are very much finer grained and contain significant amounts of feldspar, mica and heavy minerals. If these sands were all located within Twofold Bay, it could be argued that they have a similar origin to those at the other beaches, and have not experienced the same degree of reworking due to the markedly lower levels of wave energy within the Bay. The existence of similarly immature sands on the high energy ocean beach at Tathra demonstrates that this is not a satisfactory explanation. It seems more likely that they are being replenished with fresh, relatively unworked terrigenous sediment at the present time.

Comparing the characteristics of the fluvial and estuarine sediments shows that this is in fact the case. At the three anomalous localities, the sedimentological and mineralogical affinity between samples from the different environments is very strong and can be traced from the beaches concerned through the entire length of the respective estuaries to the stream bed deposits above tidal limits. In contrast, at the other localities, there is a marked dichotomy in the pattern of sedimentation. The relic beach sands block the seaward ends of the estuaries into which they are slowly prograding as reverse tidal deltas or thresholds, while further upstream, dispersal of immature fluvial sands and gravels terminates where the tributary streams debouch into each estuary to form small deltas. These two distinct sediment populations are separated by muddy estuary floors beyond which no fluvial sand is able to pass. At Mogareeka and Kiah inlets, well advanced infilling of the estuarine basins with granitic sands has effectively eliminated this hydraulic barrier and enabled bed load sediments to pass right through to the sea. At Murrah Lagoon this stage is being approached and river sands are now located less than 100 metres from the sea. There is some evidence to suggest that small amounts of these sands are already being added to Murrah Beach. Paradoxically, infilling of a basin from the seaward end can have the same effect. This has occurred in the Nullica

River estuary and explains why some Nullica River sands are able to reach Twofold Bay.

The juxtaposition of such different sediment populations at neighbouring ocean beaches also indicates that the length of coast studied is a strongly compartmented one with little material being transported around intervening landlands. This conclusion could be tested more thoroughly by S.C.U.B.A. divers examining in situ bottom sediments around headlands, especially those which separate embayments with quite different sediment populations. The movement of labelled sands under different wave conditions could also be monitored. Unfortunately a lack of qualified field assistants precluded such programmes in this study.

Calculations of longshore wave power suggest that there should be quite large nett annual volumes of longshore sediment transport in nearly all the embayments, but the sedimentological data, together with the lack of continued beach erosion or accretion show that these estimates are highly exaggerated. Further research is required in this field. Only Boydtown and Nelson beaches seem likely to benefit from such transport as they may trap fine grained sands from Whale or Tathra beaches during very strong southerly storms.

Analysis of the sediments in the nearshore zone of a few selected embayments shows that mineral beach sands are confined to a narrow strip towards the rear of each embayment and that they do not occur in significant amounts beyond depths of twenty metres. This suggests firstly that sand eroded by storm waves is not taken far out to sea and secondly that the supply of mineral sand from the continental shelf has ceased. Sands further offshore are biogenic in origin and represent a contemporary source of the beach carbonate found on all the beaches. This distribution of nearshore sediments also emphasizes the discrete and rather confined nature of each coastal sediment compartment.

Available sedimentological and mineralogical data, together with admittedly subjective examination of hand speciments in the field shows clearly that very little material is contributed to beach sand populations through erosion of coastal headlands. In addition the scarcity of shore platforms other than near Merimbula indicates that rates of cliff retreat are extremely slow, but an even more important factor is that the rocks which outcrop along this coast do not in general contain abundant quartz. More conclusive evidence must await further more detailed analysis of variations in sand roundness and mineralogy within individual embayments but although such work is probably warranted there seems little doubt that the results would support the evidence already available.

An item which should have received more attention is the type(s) of carbonate present in the sediments. Like the heavy minerals, the carbonate fraction is a very minor component of the total sediment population and since the main thrust of the sedimentological work was centred upon the mineral sands which comprise the overwhelming bulk of the sediments, analysis of the carbonate sand was restricted to evaluating their proportion by weight. In hindsight this may have been incautious because analysis of the composition of the shell material may well have yielded useful information about its source(s). For example shell material in the nearshore zone may have originated where it is located at present, or in deeper waters offshore, on reefs flanking headlands nearby or from the estuaries. Such study could also have been useful in determining carbonate sand movement within the estuaries, especially those of the Nullica River and Nelson Creek where mixing of terrigenous and marine sediments hindered interpretation of the deposits.

The factors which control the supply of sand to the coast by local rivers are the size, elevation and lithology of the catchments, and stream discharge. The majority of the estuaries receive only very small amounts of sand and gravel derived from small, low catchments developed in fairly resistant, quartz-poor metasediments or tracts of interbedded volcanic and sedimentary rocks with a slightly higher quartz content. In contrast, Mogareeka and Kiah inlets are supplied with sand by the two largest rivers in the district, both of which drain elevated granite catchments yielding abundant quartz-sand detritus. The Murrah River also drains granite but its smaller discharge has as yet prevented it from matching the extent of estuary infilling attained by its larger counterparts. Estimated catchment sediment yields are very small but appear to be reliable in view of the very slow rates of delta progradation and shoaling in the lower reaches of the tributary streams. The calculations also show that mobilization of bed load occurs only during periods of high river discharge, and at some localities it seems that there is no bed load transport at all for 90% of the year. It will therefore be at least hundreds if not a couple of thousand years before most of the estuaries are infilled and beaches everywhere begin to be replenished with fresh supplies of river sand.

Investigations of wave energy conditions within particular embayments reveals several sedimentological and geomorphological responses which support earlier remarks. Of particular relevance to the sediment budgets is the strong degree to which practically every embayment along this coast is a discrete unit displaying little or no interaction with its neighbouring compartments. The positional stability of sandy shorelines during the last thirty five years indicates that the sediment budgets are balanced at the present time and also suggests that the volumes of sand delivered to the nearshore zone by the Bega and Towamba rivers are quite small.

The lack of changes in threshold dimensions during the same period demonstrates that losses of sand from the beaches and nearshore zones to the estuaries are very small. Regionally high levels of incident wave power also work to effect inlet closure unless prevented from doing so by strong currents passing through the inlets. A high degree of closure in turn limits the flushing ability of an estuary such that suspended fines are less able to reach the sea, and more importantly, rates of entrapment of marine sands within the estuaries are diminished. The cessation of onshore sediment transport from the continental shelf probably over-rides these losses, and continued growth of threshold deposits, however slow, will probably rely upon small, intermittent injections of sediment derived from storm-eroded beaches. The slow rates of threshold growth mean that estuary infilling will depend more upon the supply of fluvial sediment, in which case the frequency of inlet closure will be of little consequence to the delivery of fluvial bed load material to the sea, since material of this calibre is mobilized only during floods which readily breach closed inlets.

Clearly the estuaries are key elements in these systems of water and sediment exchange between land and sea. When estuaries form as sea level rises they begin to act as repositories for sediment from both land and sea until they approach a common end point when infilling nears completion. The rate and manner by which this end point is reached varies according to the interaction of fluvial, tidal, and marine forces at work within or near each estuary. Thus, although the estuaries in this study area display characteristics which accord with the general microtidal estuary model presented by Hayes (1975), further breakdown is required to incorporate the regional variations in morphology and sediment facies. These patterns are summarized in Figure 8.1.

In summary, the postglacial rise in sea level produced a series of sediment traps in the form of drowned river valleys, and resulted in the subsequent transport of large volumes of previously reworked sands from the continental shelf to areas near the existing

Fluvial landforms prevail throughout. - point bars, dunes on bed. Poorly developed flood tide deltas often destroyed by river floods. Angular to subangular, poorly sorted granitic sands occur throughout.	River floods responsible for sediment transport. At times of lower flow, flood tide currents mould incipient flood tide deltas, and wave action very occasionally blocks most if not all the inlet mouth.	Salt and fresh water fairly well mixed generally although vertical salinity gradients are discernible. Stratification likely during floods when sea water is flushed out of the estuary + a turbid plume of fresh water issues from the mouth. *Phragmites* common on vegetated sand banks.	Mogareeka Inlet Kiah Inlet	Fluvial sand preserved. – not well sort nificant pro less resista esp. feldspa
A] Prominent flood tide deltas with well developed, stable patterns of tidal channels, formed in marine sands. Small estuarine basins floored with river muds. Small stream deltas of sand and gravel.	Large, effective tidal prisms ensure that inlets are always open. Small intermittent stream flow. Floods add sediment to small deltas.	Salinity slightly lower than seawater. Waters very well mixed - some stratification may develop in basin waters during floods. Mangroves + salt marsh best developed but of limited areal extent.	Merimbula Lake Wapengo Lagoon	Mature, iron s rounded, well s sands with mi Extensively re continental s Quaternary s fluctuations.
B] Largely infilled with marine and fluvial sediments which are interdigited in middle reaches. Separate stream and flood tide deltas are barely discernible as a result.	Small stream discharge but inlets always open - tidal prism effectiveness enhanced by reduced levels of wave energy at mouth.	Salinity as above (A). Small salt marsh patches along margins. *Zostera* beds on estuary floor in places.	Nelson Lagoon Nullica Lake	As above b terrigenous s present, esp Boydtown.
Small flood tide deltas of mature marine sands, bearing minor ephemeral channels. Distinct estuarine	Low stream discharges, small tidal prisms and high wave energy promote high frequency of inlet	Variable salinity levels depending on frequency and duration of inlet closure, + variability of	Baragoot Lake Middle Lagoon	Mature, iron well rounded, Qtz. sands wi carbonate. Ex

shoreline. This supply now appears to have ceased, and replenishment of beach sands requires the elimination of the estuary sediment traps by infilling. In the past, landward movement of marine sands into the estuaries has been responsible for varying amounts of infilling but now appears to be considerably less important. As yet, only the larger rivers with favourable catchment lithologies have been able to complete the task and it will be a very long time before the remaining rivers reach this stage.

Sediment budgets along this highly compartmented coast therefore seem to be balanced at the present time. Sediment losses due to offshore and longshore transport, estuary infilling and deflation are very small, as are the gains through onshore and longshore transport and shoreline erosion. Assuming that the sea remains at its present level, the only likely change in the future is a shift towards a positive sediment economy as rivers succeed in infilling their estuaries and begin to deliver terrigenous sands to the coast. Any shift in this direction will probably be quite small though, unless there is a dramatic increase in the rates of fluvial bed load transport which prevail at the present time.

Comparison of the main conclusions of this study with results from other areas along the N.S.W. coast shows that a quite persistent pattern of coastal sediment exchanges characterized by essentially balanced sand budgets prevails at least as far north as Newcastle, thereby encompassing slightly more than half the State's coastline. Reports from other areas with which the comparisons were made are Bird (1967), Brown et al. (1977), Ford (1963), Goodwin (1976), Post (1973), Roy (1977), Roy and Peat (1973, 1975a, b, 1976) and Wright (1967, 1970, 1976).

Practically all the coastal sands are relic and not only dominate the bayhead and barrier beach deposits along the coast, but have also been transported varying distances into the inlets to form estuary thresholds. Only where suitable catchment hydrology and lithology exists are significant amounts of fluvial sand being delivered to the coast and added to beach sand populations. Mud is ejected from all estuary mouths during floods, but is of no practical importance because the high wave energy environment precludes its deposition and retention on the beaches. It is a coast of impeded sediment transport characterized by discrete sediment compartments.

A slightly different situation exists on the northern coast of N.S.W. Here, larger rivers abound but none deliver sand to the coast at the present time (Roy and Crawford,1977). Fluvial sands are found only in the upper and central reaches of large channels which meander about extensive alluvial plains lying behind large sand barriers. In the lower reaches the channels pass through well rounded, well sorted, iron-stained quartz sands which have been brought in from the sea by flood tide currents and from reworking of the coastal deposits. Although these rivers have much larger discharges they have had to fill large embayments impounded by barriers and so have not reached the stage attained by the Bega, Towamba and Shoalhaven rivers.

In addition northern shorelines have been receding at a rate of approximately one metre per year during the last 40 to 100 years. This is indicative of negative sand economies and appears to be due to increased losses of sand via longshore transport which have been unaccompanied by any increase in inputs from other sources. The presence of much longer beaches separated by less prominent headlands has facilitated the development of an active longshore transport system and stems from the different structural alignment of the N.S.W. north coast (Langford-Smith and Thom, 1969).

8.2 Future work

Sediment analysis data, together with evidence obtained from field and photographic interpretation of relevant land forms permits confident assessment of the nature of sediment exchanges between land and sea within the nominated study area. Manipulation of other, often incomplete data from a variety of sources, together with some original field measurements by the author have prompted some qualitative assertions to be made about the magnitude of these exchanges. Assigning values to particular components of each sediment system is unwarranted at present given the limitations of the latter data set, and before definitive sediment budgets can be presented (such as that prepared by Bowen and Inman (1966) for part of the Californian coast) more work is required. Such work should encompass two time frames, firstly contemporary budgets, and secondly, the variations of budgetary components during (at least) the last 20 000 years or so.

Field monitoring programmes will be a major requirement in seeking to achieve the first objective, and could become dissertation topics on their own. Reliable measurements of water and sediment discharges are required for the drainage basins, particularly values which derive from infrequent flood events. These measurements are needed now while sufficient undisturbed catchments remain. Data pertaining to changing water and sediment discharge in catchments which have been or are now being cleared for a variety of commercial projects, and in catchments whose major channels are being dammed are no less important.

There is also a need for current velocity and sedimentation rate data within the estuaries, a task which was not within the scope of this study. Rates of sedimentation could be monitored quite readily but assessment of current velocities poses greater problems, not least of which is the difficulty of working during the extreme events when most sediment movement occurs. Constantly changing channel dimensions and patterns on the flood tide deltas, especially on the less stable ones will probably necessitate long field camps spread over some years.

Determination of budgetary variations since (and before) the last glacial episode requires intensive stratigraphic and seismic investigation augmented by radiometric dating of appropriate material. The volume of existing data such as that collected by the N.S.W. Department of Main Roads is small and interpretation of the available records is often limited for a number of reasons. Some records are incomplete, and as far as the author could ascertain, no bore samples have been retained. In addition all bores are logged with bridge foundations in mind rather than interpretation of Quaternary stratigraphy.

Embayment fills in toto deserve serious attention in this regard, but it would be particularly useful to devote some time to the stream and flood tide deltas. The former are well suited to simple coring and given the propensity for fire in the eucalypt woodlands and forests which mantle the catchments, ideal stratigraphic markers should abound within these deltaic deposits. In addition, the results of work by Coleman and Wright (1973) suggest that a much more precise expression of the equilibrium between stream flow, sediment supply and lagoonal wave activity could be obtained in a research programme which combined data collected on these three parameters with morphometric analysis of the deltas themselves. The location of flood tide delta surfaces near or below low tide level makes stratigraphic investigation of these deposits more difficult, but if undertaken they would probably yield valuable information about their rate of growth and the loss of sand from the nearshore zone. Again, such investigations lay outside the scope of this thesis.

8.3 Implications

The south coast of N.S.W. is facing rapidly increasing demands upon its natural resources, partly because it is relatively undeveloped and partly because of its proximity to Sydney,

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GLOSSARY

ESTUARY The definition adopted in this thesis is a simple modification of that used by Pritchard (1967) : " a semi-enclosed coastal water body which at times has a free connection with the open sea and within which sea water is at times measurably diluted with fresh water derived from land drainage". This definition can be applied without difficulty to all the water bodies investigated in this study, irrespective of their shape or the frequency with which they are open to the sea. The term lake is also often used as a collective synonym in the text, and stems from local residents who invariably use this word when referring to the estuaries. When an estuary is referred to individually by name in the text, the official recommendations of the N.S.W. Geographic Names Board have been adopted. Thus Murrah Lagoon, Merimbula Lake and Mogareeka Inlet are all estuaries.

INLET This term is used to refer to the mouth of any estuary, particularly during discussions about closure by wave-built barriers. This conforms fairly closely with American usage (for example see Price, 1963; O'Brien, 1971), but differs from other workers (for example see Davies, 1972, p162; Bird, 1972, p147) who use the term in a much more general way.

THRESHOLD This term appears to have been first adopted by Bird (1967) and is particularly useful in view of their morphology and function. They are reverse tidal deltas.

Appendix 1

The following tables summarize the values used to calculate sediment discharges using the method developed by Colby (1964). Percentile discharge flows were extracted from W.C. & I.C. flow duration curves and corresponding depths of flow were obtained from W.C. & I.C. rating curves. Typical average stream velocities at various discharges were collated from W.C. & I.C. current meter observations. Where necessary, values were estimated by extrapolation of plots of log Q v. log V. The four relationships all yielded statistically significant correlation coefficients (r) ranging from 0.69 to 0.99. Similar relationships between discharge and velocity are commonly observed elsewhere (for example see Morisawa, 1968). Knowing discharge (Q), velocity (V) and depth (D), corresponding values of cross-sectional area (A) and width (W) are readily calculated. Median grainsize of channel sediment (D_{50}) was obtained from cumulative grain size distribution curves of the relevant samples. Sediment discharge (Q_s) was then derived from the curves prepared by Colby. No corrections were applied for water temperature. Such corrections would have been very small, and of little consequence given that only order of magniyude estimates of sediment discharge were required in this particular study. Also, more refined estimates cannot be justified given the paucity of hydrological data in the region.

Notes to accompany table A1.

Percentage values in the left hand column indicate the percentage of time since records have been kept, that the nominated water flow has been equalled or exceeded. Units used are as follows - Discharge (cumecs), Cross-sectional area (m^2), Velocity (m/sec), Depth, Width (m), Median grain size D_{50} (mm), and Sediment discharge Q_s in tonnes/day. All values have been rounded.

Appendix Table A1

		Q	A	V	D	W	D_{50}	Q_s
Murrah R. at Quaama	1%	22.7	29	0.8	1.3	22	0.68	278
	2½%	4.5	7	0.6	0.8	9	0.68	55
	5%	2.7	5	0.6	0.7	6	0.68	21
	10%	0.9	2	0.5	0.5	3	0.68	-
Pambula River at Lochiel	1%	28.4	30	0.9	1.9	16	0.86	594
	2½%	17.0	20	0.9	1.6	12	0.86	327
	5%	4.5	7	0.7	1.1	6	0.86	35
	10%	1.9	3	0.6	0.9	3	0.86	6
	15%	1.0	2	0.5	0.8	2	0.86	0.5
	20%	0.6	1	0.5	0.7	2	0.86	-
	30%	0.3	0.7	0.4	0.6	1	0.86	-
Towamba River at New Building Bridge	1%	44.0	28	1.2	1.0	27	0.83	2682
	2½%	27.0	24	1.1	0.9	25	0.83	1687
	5%	18.6	18	1.0	0.8	23	0.83	977
	10%	11.0	13	0.9	0.7	19	0.83	731
	25%	5.0	8	0.6	0.5	16	0.83	69
	30%	4.1	7	0.6	0.4	16	0.83	42
	40%	2.5	5	0.5	0.4	13	0.83	-
	50%	2.2	5	0.5	0.4	12	0.83	-
Bega River at Morans Crossing	1%	45.4	60	0.8	1.9	32	1.17	139
	2½%	31.8	47	0.7	1.7	28	1.17	41
	5%	18.2	32	0.6	1.4	23	1.17	22
	10%	7.0	16	0.4	1.0	16	1.17	-
	50%	2.0	7	0.3	0.8	9	1.17	-
Brogo River at Nth Brogo	1%	73.8	83	0.9	2.0	41	1.17	736
	2½%	54.0	68	0.8	1.7	39	1.17	352
	5%	27.0	42	0.6	1.3	31	1.17	46
	10%	11.4	23	0.5	1.0	24	1.17	-
	50%	1.4	6	0.2	0.6	9	1.17	-

Appendix 2

2a Derivation of metric expression for wave energy

The total energy of a progressive wave per unit width of crest equals the sum of its kinetic and potential energies where half the energy is kinetic and half is potential (Wiegel, 1964, p 20).

$$E_k = \gamma H^2 L/16$$

$$E_p = \gamma H^2 L/16$$

Therefore ... $E_{total} = E_k + E_p = \gamma H^2 L/8$

where .... γ = specific weight of water (ρg).

Given that .. ρ sea water = 1.025×10^3 kg/m^3

and .... g = gravity = 9.806 m/sec^2

then .... $E = 1256.4\ H^2 L$

where .... E is in joules/metre of wave crest per wave and H, L are in metres.

2b Calculations

Before wave energy near the breakpoint can be calculated, values of D_d (shoaling coefficient), H_b (breaker height) and L_b (breaker length) are needed. These were obtained from tables in Wiegel, knowing values of H_o (deep water wave height) and K_d (refraction coefficient), and assuming that a wave will break when the ratio of wave height (H) to water depth (d) equals or exceeds 0.78. The extracted values were substituted in the formulae -

$$H_b = H_o . K_d . D_d$$

$$Eb = 1256.4\ H_b{}^2 L_b$$

and .... $P_b = nE_b/T$

Tables A2i and A2ii were compiled. The longshore components of wave energy and wave power were also calculated using the expressions -

$$E_l = E_b \sin\alpha\cos\alpha$$

and .... $P_l = P_b \sin\alpha\cos\alpha$

where .... α = acute angle between wave crest and shoreline.

Values of E_l and P_l are shown in table A2iii.

BEACH	NORTHEAST					EAST				
	H(m)	L(m)	E(*)	n	P(*)	H(m)	L(m)	E(*)	n	P(*)
BARAGOOT	0.91	27.11	28.2	.9751	3.5	1.63	40.33	134 6	.9629	14.6
CUTTAGEE	1.10	29.22	44.4	.9707	5.4	1.63	40.33	132.4	.9649	14.4
MURRAH	1.31	32.10	69.2	.9649	8.4	1.65	40.33	137.9	.9629	14.9
WAPENGO	1.43	33.86	86.9	.9609	10.5	1.77	40.99	161.3	.9614	17.4
MIDDLE	0.89	25.99	25.9	.9772	3.2	1.55	37.66	113.7	.9685	12.4
NELSON	0.93	27.11	29.5	.9751	3.6	1.52	37.66	109.3	.9685	11.9
TATHRA	1.21	30.22	55.6	.9690	6.8	1.56	38.97	119.2	.9670	13.0
WALLAGOOT	0.89	25.99	25.9	.9772	3.2	1.65	40.33	137.9	.9629	14.9
SHORT PT	1.04	28.19	38.3	.9731	4.7	1.67	40.33	141.3	.9629	15.3
MERIMBULA	0.98	28.19	34.0	.9731	4.2	1.42	36.96	93.6	.9700	10.2
PAMBULA	1.32	32.10	70.3	.9649	8.5	1.36	36.96	85.9	.9700	9.4
ASLINGS	0.48	19.13	5.5	.9873	0.7	0.97	30.23	35.7	.9799	3.9
BOYDTOWN	0.59	20.67	9.0	.9852	1.1	0.75	27.62	19.5	.9832	2.2
WHALE	1.15	30.20	50.1	.9707	6.1	1.02	31.48	41.1	.9784	4.5

Table A2i: Wave parameters after shoaling and refraction but before breaking.

*** : Energy values in 10^3 joules/metre; Power values in Kilowatts/metre.**

BEACH	SOUTHEAST					SOUTH				
	H(m)	L(m)	E(*)	n	P(*)	H(m)	L(m)	E(*)	n	P(*)
BARAGOOT	2.08	49.5	269.1	.9629	26.3	1.03	36.6	48.8	.9813	4.8
CUTTAGEE	1.75	46.3	178.1	.9688	17.5	1.01	35.2	45.1	.9825	4.5
MURRAH	1.82	46.3	192.7	.9688	19.0	1.03	36.6	48.8	.9813	4.8
WAPENGO	2.16	50.7	297.2	.9619	29.1	2.51	55.5	439.3	.9578	42.2
MIDDLE	2.21	51.7	317.3	.9605	31.0	1.81	47.5	195.5	.9685	19.0
NELSON	1.63	43.8	146.2	.9710	14.4	1.21	39.7	73.1	.9785	7.2
TATHRA	1.82	46.3	192.7	.9688	19.0	1.19	39.7	70.6	.9785	6.9
WALLAGOOT	2.13	50.7	289.0	.9619	28.3	1.27	39.7	80.4	.9785	7.9
SHORT PT	2.08	49.5	269.1	.9629	26.3	1.13	37.8	60.6	.9799	6.0
MERIMBULA	1.58	43.8	137.4	.9710	13.6	1.18	39.7	69.5	.9785	6.8
PAMBULA	1.06	36.0	50.8	.9807	5.1	1.06	36.6	51.7	.9813	5.1
ASLINGS	1.58	43.8	137.4	.9710	13.6	1.35	41.6	95.3	.9760	9.3
BOYDTOWN	0.66	28.9	15.8	.9875	1.6	0.64	27.7	14.3	.9892	1.4
WHALE	0.55	25.7	9.8	.9904	1.0	0.66	29.4	16.1	.9879	1.6

Table A2ii: Wave parameters after shoaling and refraction but before breaking.

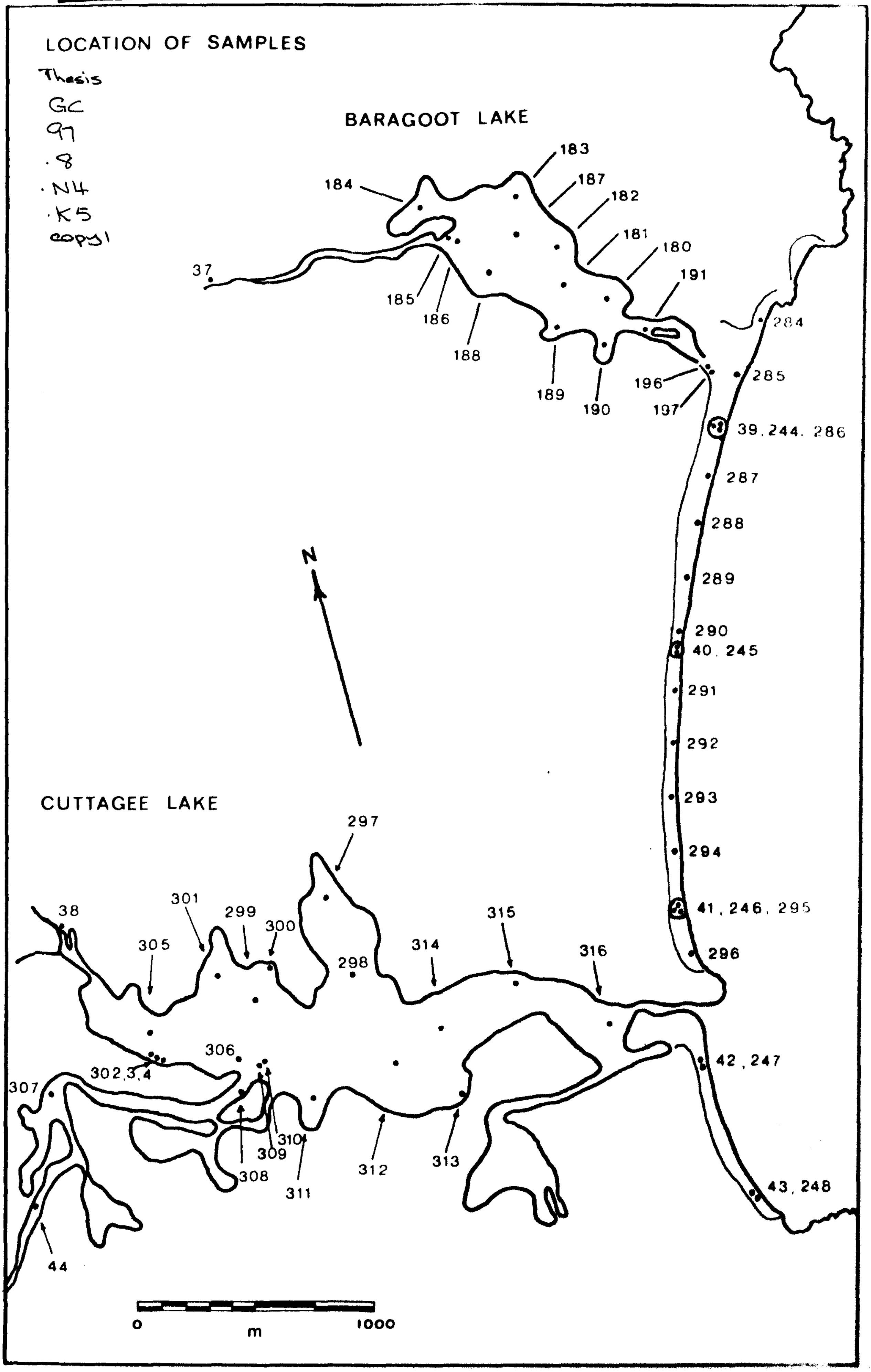
*** : Energy values in 10^3 joules/metre; Power values in Kilowatts/metre.**

BEACH	NORTHEAST			EAST			SOUTHEAST			SOUTH		
	sin∝cos∝	E_1	P_1	sin∝cos∝	E_1	P_1	sin∝cos∝	E_1	P_1	sin∝cos∝	E_1	P_1
BARAGOOT	.43	-12.1	-1.5	.23	-31.0	-3.4	0	0	0	.36	+18.5	+ 1.8
CUTTAGEE	.33	-14.7	-1.8	.03	- 4.0	-0.5	.03	+5.3	+0.5	.35	+15.8	+ 1.6
MURRAH	.33	-22.8	-2.8	.12	-16.6	-1.8	.02	+3.9	+0.4	.40	+19.5	+ 1.9
WAPENGO	.50	-43.5	-5.3	.17	-27.4	-3.0	0	0	0	.49	+215.3	+20.7
MIDDLE	.50	-13.0	-1.6	.47	-53.4	-5.8	0	0	0	.43	+84.1	+ 8.2
NELSON	.47	-13.9	-1.7	.05	- 5.5	-0.6	0	0	0	.32	+23.4	+ 2.3
TATHRA	.32	-17.8	-2.2	.10	-11.9	-1.4	.02	+3.4	+0.4	.25	+17.7	+ 1.7
WALLAGOOT	.50	-13.0	-1.6	.32	-44.1	-4.8	.02	+5.8	+0.6	.38	+30.6	+ 3.0
SHORT PT	.42	-16.1	-2.0	.15	-21.2	-2.4	0	0	0	.43	+26.1	+ 2.6
MERIMBULA	.40	-13.6	-1.7	.05	- 4.7	-0.5	.02	+2.8	+0.3	.29	+20.1	+ 2.0
PAMBULA	.03	- 2.1	-0.3	0	0	0	0	0	0	.05	+ 2.6	+ 0.3
ASLINGS	.17	- 0.9	-0.1	.07	- 2.5	-0.3	.02	+2.8	+0.3	.05	+ 4.8	+ 0.5
BOYDTOWN	.05	- 0.5	-0.1	.03	- 0.6	-0.1	0	0	0	.02	+ 0.3	+ 0.5
WHALE	.05	- 2.5	-0.3	.02	- 0.8	-0.1	.02	+0.2	+0.02	.02	+ 0.3	+ 0.5

Table A2iii: Longshore Components of Wave Energy and Wave Power; Units as for preceding tables.
+ indicates directed northwards, - indicates directed southward.

Appendix Table A2iv: Wave Power distribution within nominated bays. Values are entered in order from North (top) to South (bottom) and sections are of approximately equal length. Values are in kilowatts per metre.

	NE	E	SE	S	AV. ANNUAL
BARAGOOT	3.1 3.6 3.9	13.6 14.4 17.7 17.7	24.6 26.3 28.4 25.6	7.0 6.4 2.7 4.0	12.5 13.1 13.4 13.0
CUTTAGEE	5.8 5.2	13.6 15.3	14.8 19.4	4.8 3.9	9.8 11.0
MURRAH	7.3 9.7 8.8	16.5 12.8 17.7	20.7 23.7 13.0	5.4 4.8	12.5 12.9 10.9
MIDDLE	2.2 4.5	12.9 12.4	28.1 33.4	26.1 17.6	18.5 17.9
NELSON	2.2 6.3	13.3 11.1	13.1 16.6	22.4 10.6	13.5 11.4
TATHRA	5.8 7.1 7.1	12.9 14.6 14.4 9.7	26.0 26.3 16.6 11.9	7.3 7.3 4.5	13.3 14.0 11.0 8.3
WALLAGOOT	2.0 3.6 4.7	10.7 15.3 17.2 17.8	32.2 29.7 32.5 23.4	9.3 9.3 6.3 6.3	14.3 14.8 15.5 13.3
SHORT PT.	4.1 4.8 4.8	12.3 14.6 16.5 17.7	23.4 33.4 25.6 24.8	5.6 6.6 6.0	11.7 15.1 13.6 13.5
MERIMBULA	1.6 3.2 7.9	4.1 9.5 13.6 15.3 10.1	14.8 17.9 17.5 3.6	7.3 6.6 9.0 3.4	7.4 9.1 10.9 9.4 6.0
ASLINGS	0.7 0.7 0.6 0.7	1.1 2.2 1.5 1.9 4.9 10.7	13.6 13.1 17.9 11.9	8.4 12.1 10.6 7.3	6.4 7.2 8.4 8.4 7.9 7.9
BOYDTOWN	1.1 1.6 1.1 0.9	1.7 2.2 1.9 2.2	1.9 1.8 1.6 1.3	3.5 1.6 0.8 0.5	2.1 1.8 1.3 1.2
WHALE	5.1 6.9 4.8 7.6 5.6	9.2 4.3 3.9 3.1 1.7	1.0 1.1 1.0 1.0	1.6 1.6 0.2 0.1	3.9 3.2 2.5 2.6 1.9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CUTTAGEE LAKE
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182
183
184
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186
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188
189
190
191
196
197
284
285
39, 244, 286
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298
299
300
301
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43, 248
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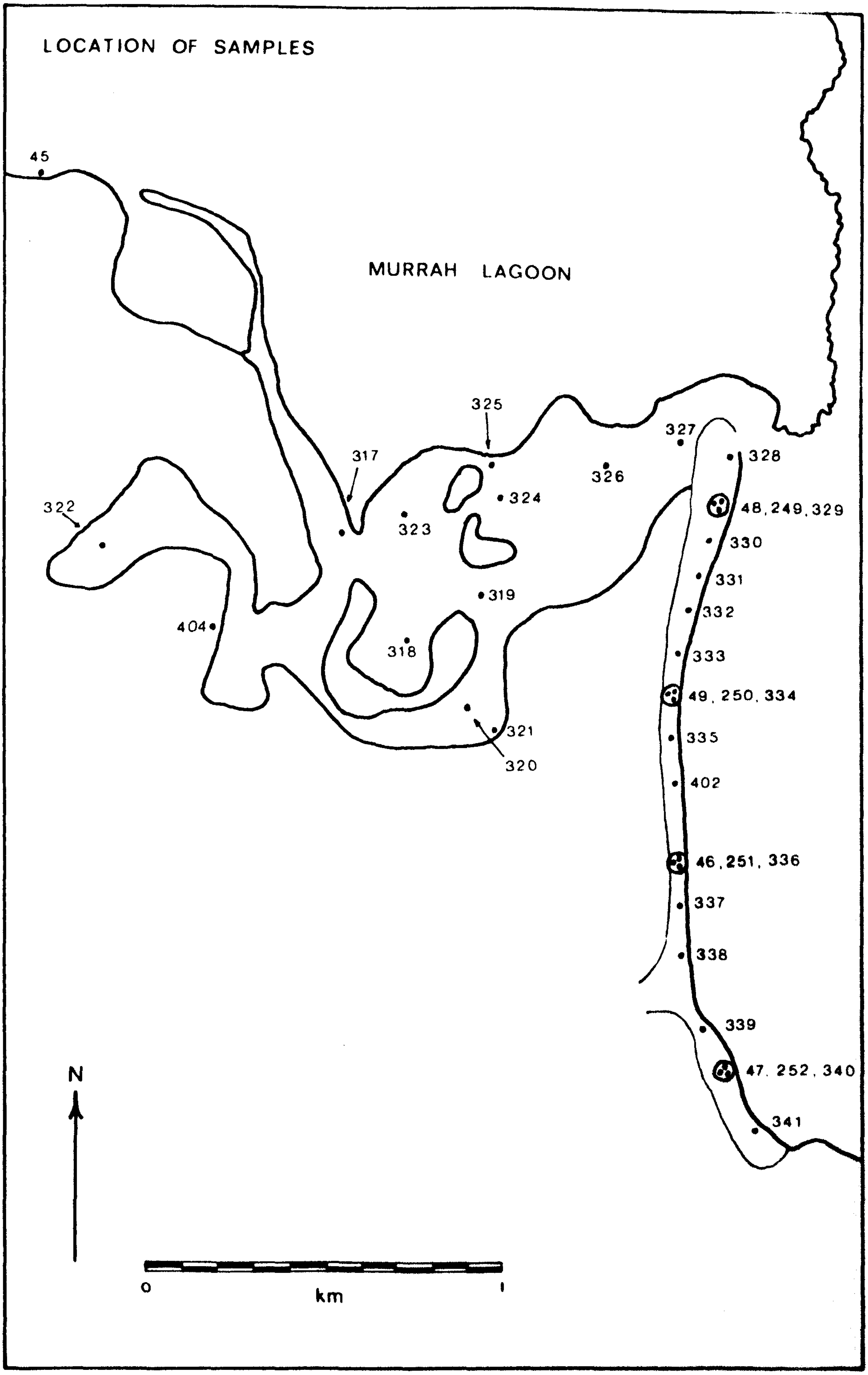
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332
333
49, 250, 334
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404
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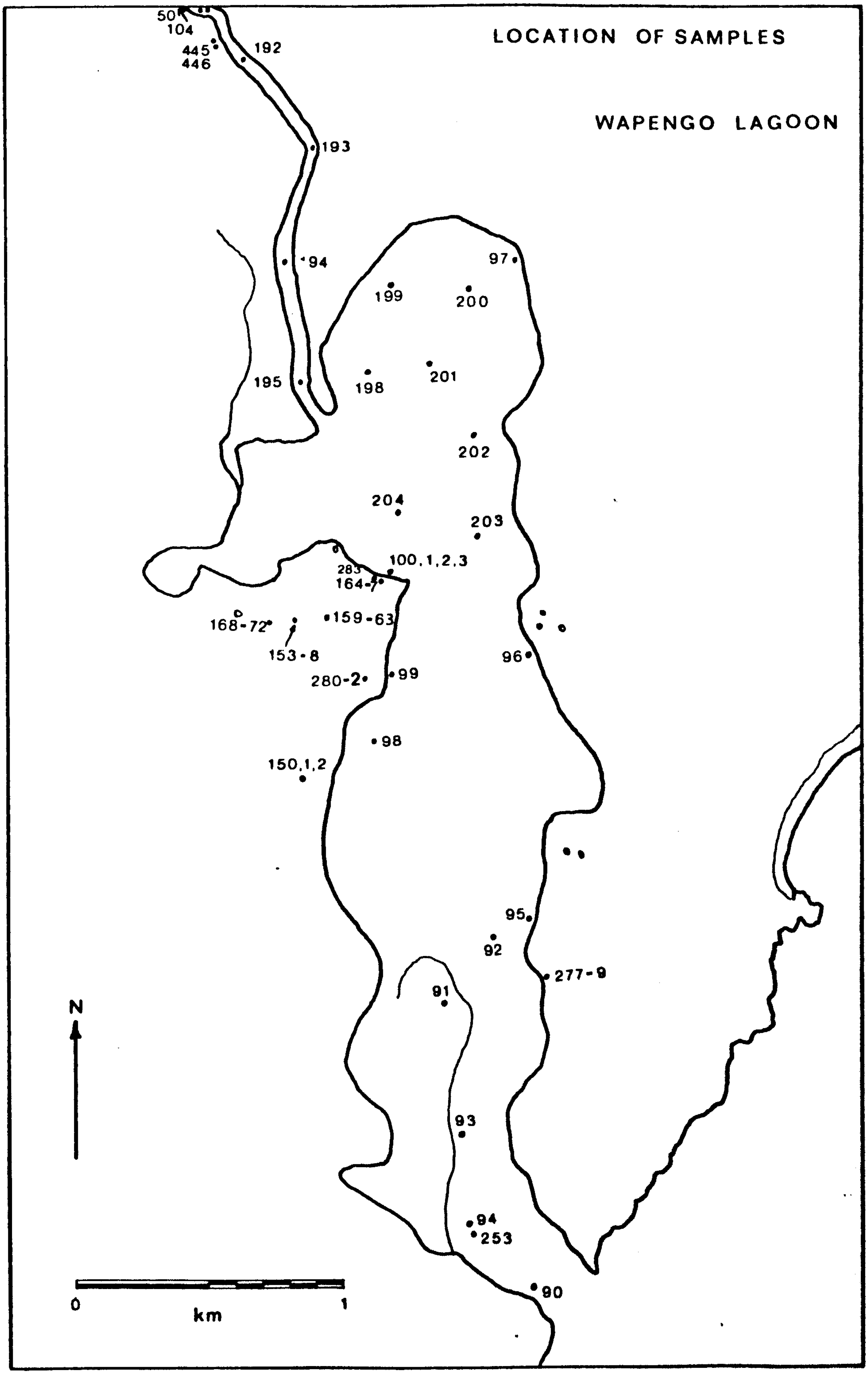
km
1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203
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283
164-7
168-72
159-63
153-8
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277-9
91
93
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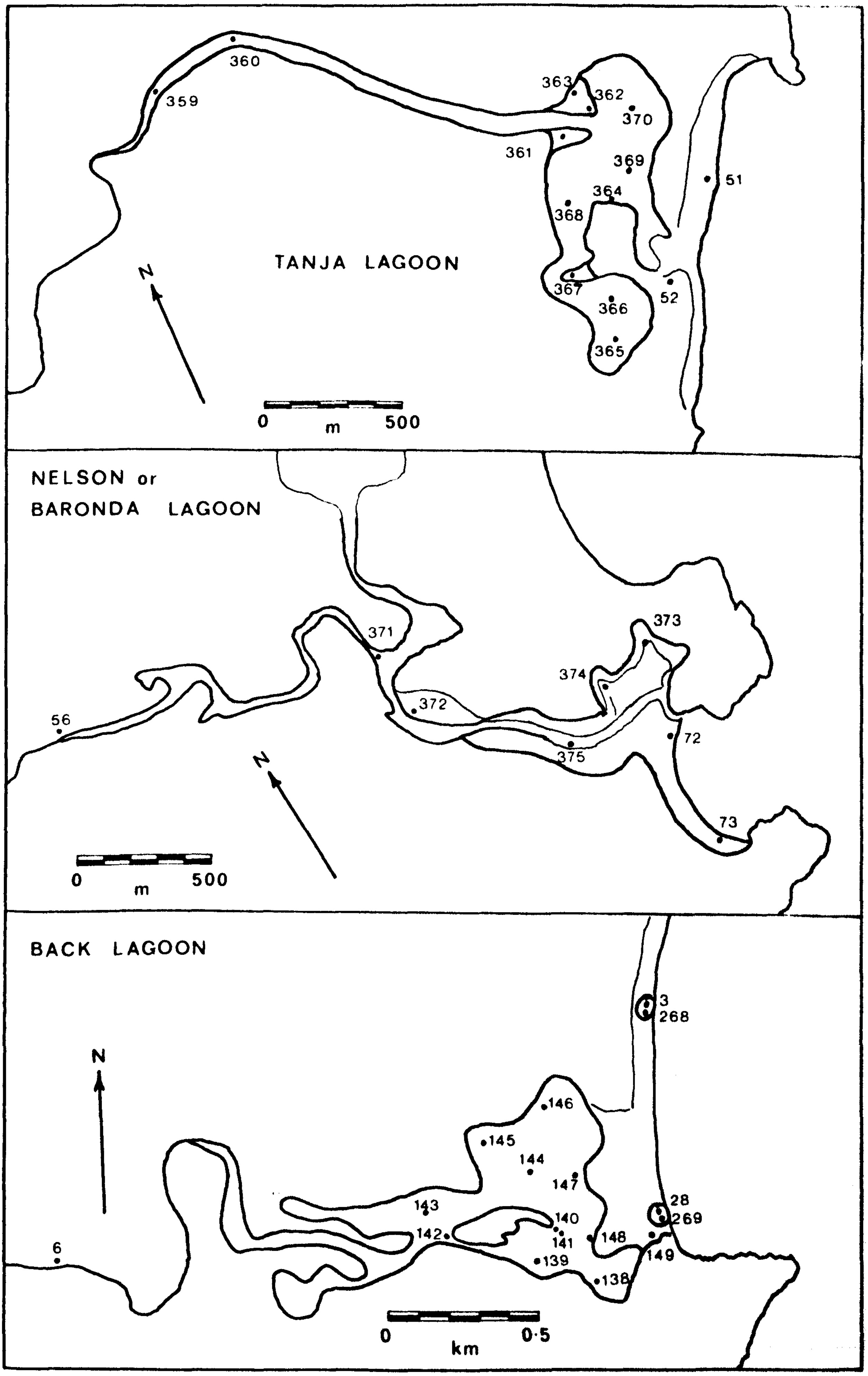
90
N
0
1
km


TANJA LAGOON
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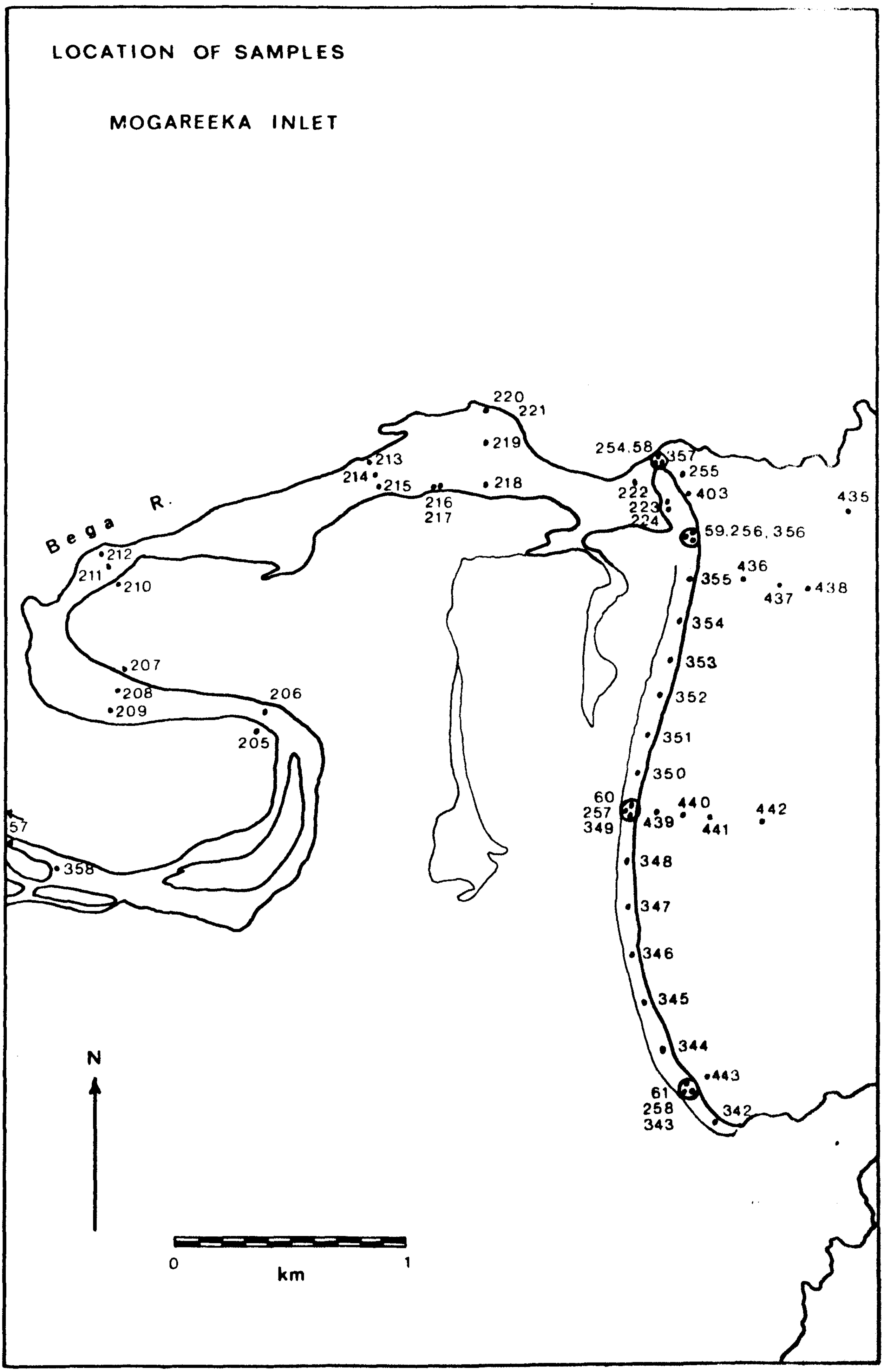
360
359
363
362
370
361
369
51
364
368
367
52
366
365
NELSON or
BARONDA LAGOON
371
373
374
56
372
72
375
73
N
0 m 500
BACK LAGOON
3
268
N
146
145
144
147
28
143
269
140
142
141
148
6
139
149
138
0 km 0·5



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223
224
435
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212
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353
208
206
352
209
205
351
350
60
257
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343
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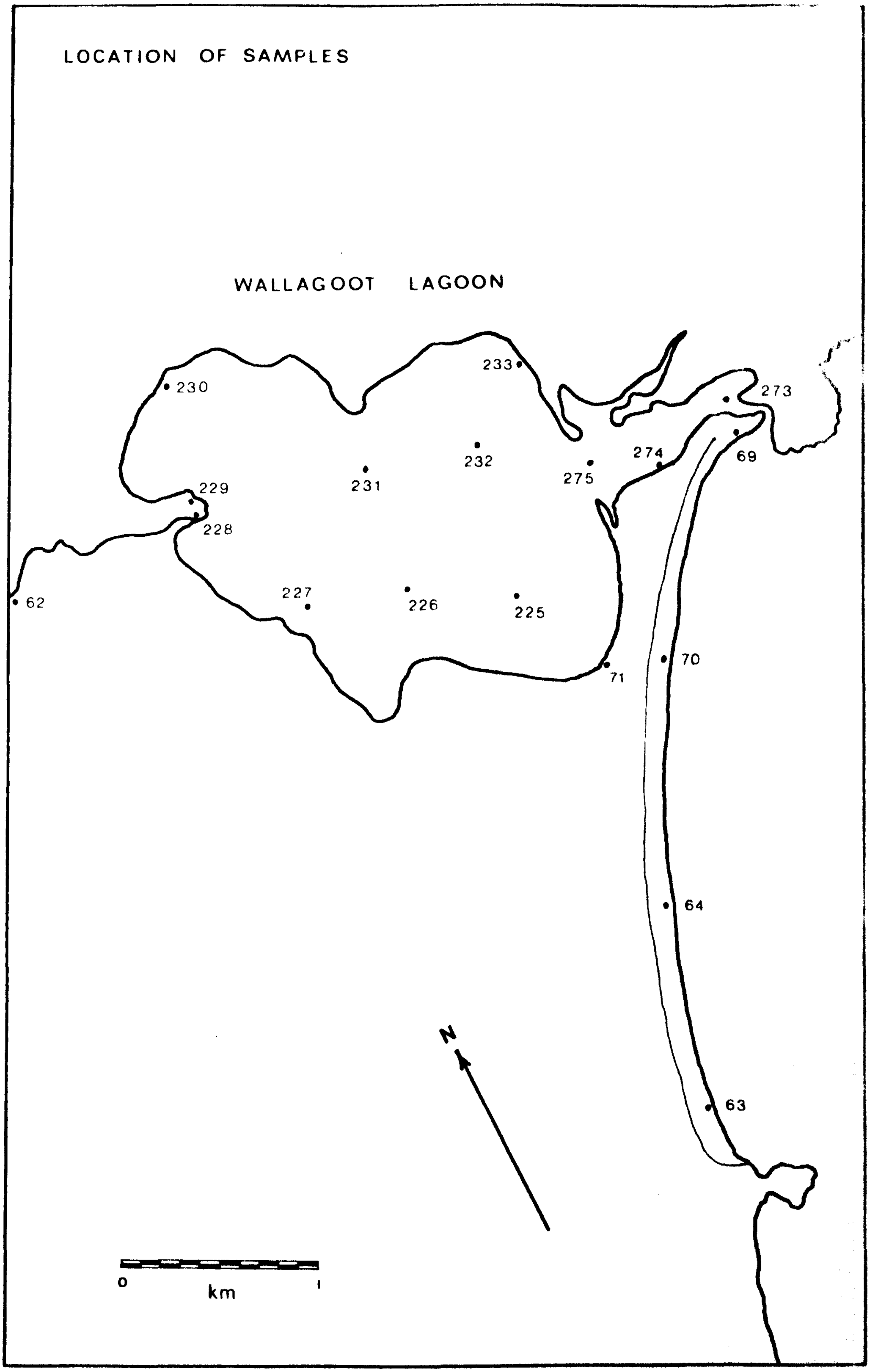
km
1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63
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km
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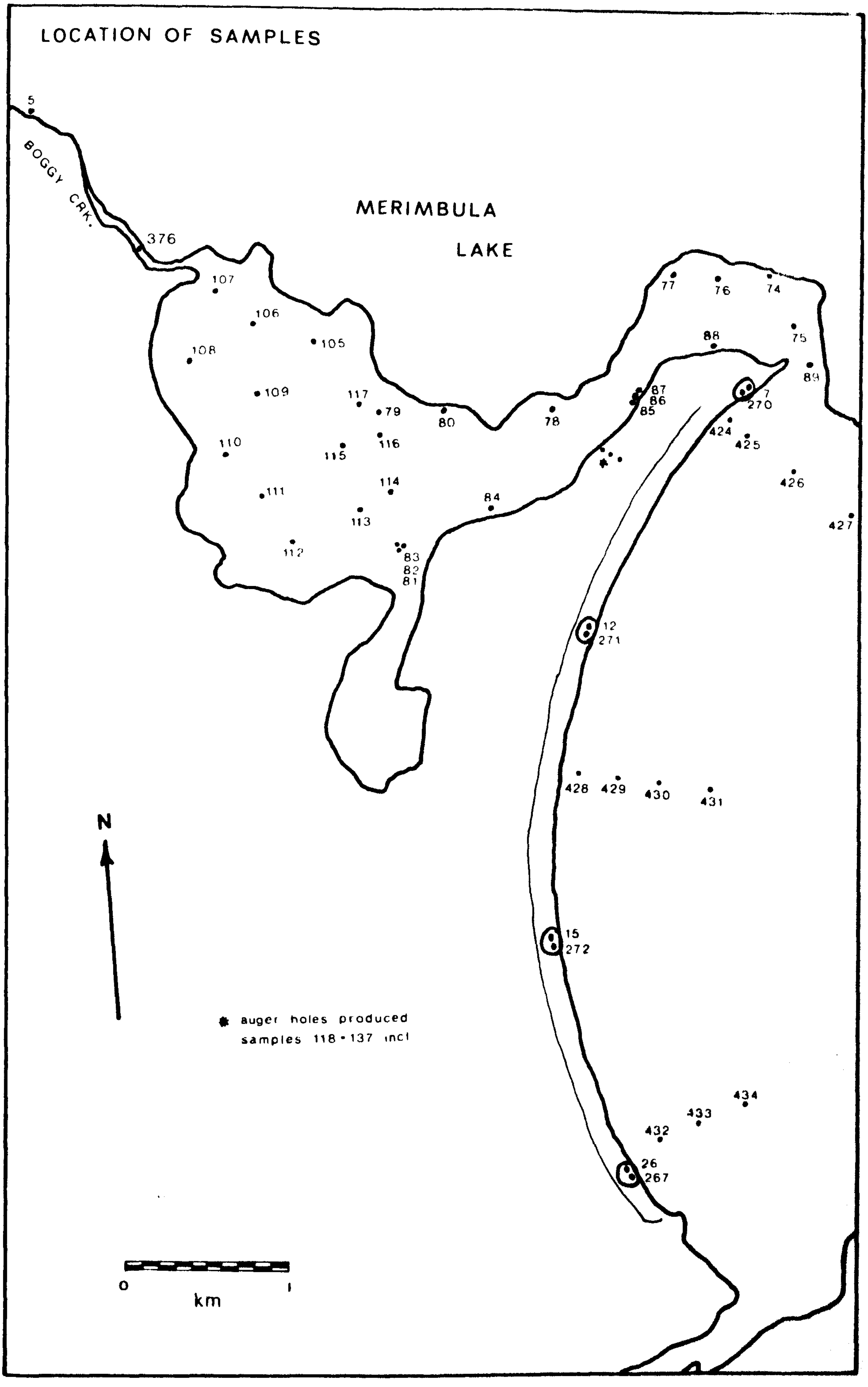
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BOGGY CRK.
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86
85
77
76
74
88
75
89
7
270
424
425
426
427
110
115
116
114
111
84
113
112
83
82
81
12
271
428
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431
N
15
272
auger holes produced
samples 118 - 137 incl
434
433
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267
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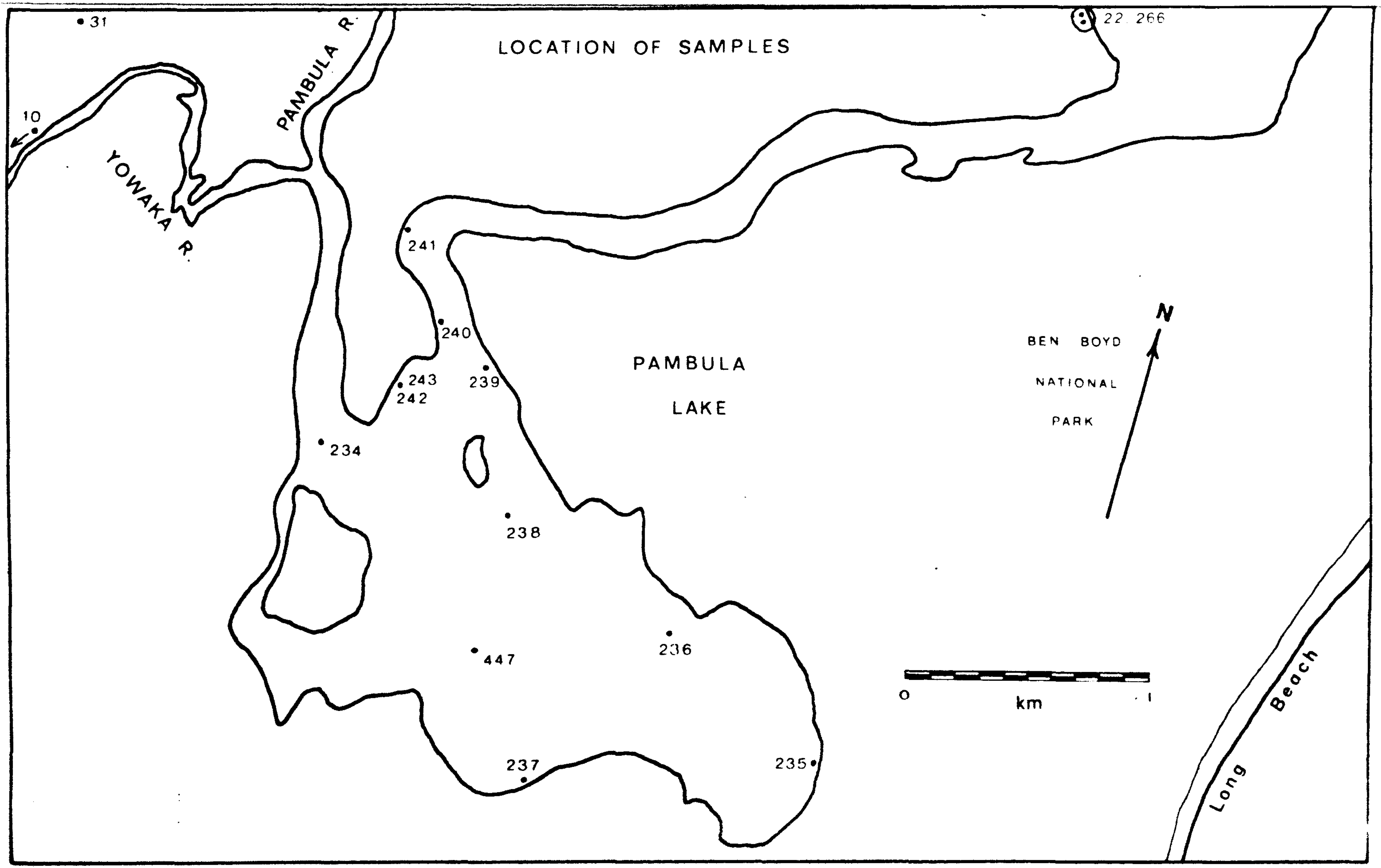
1
km



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YOWAKA R.
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BEN BOYD
NATIONAL
PARK
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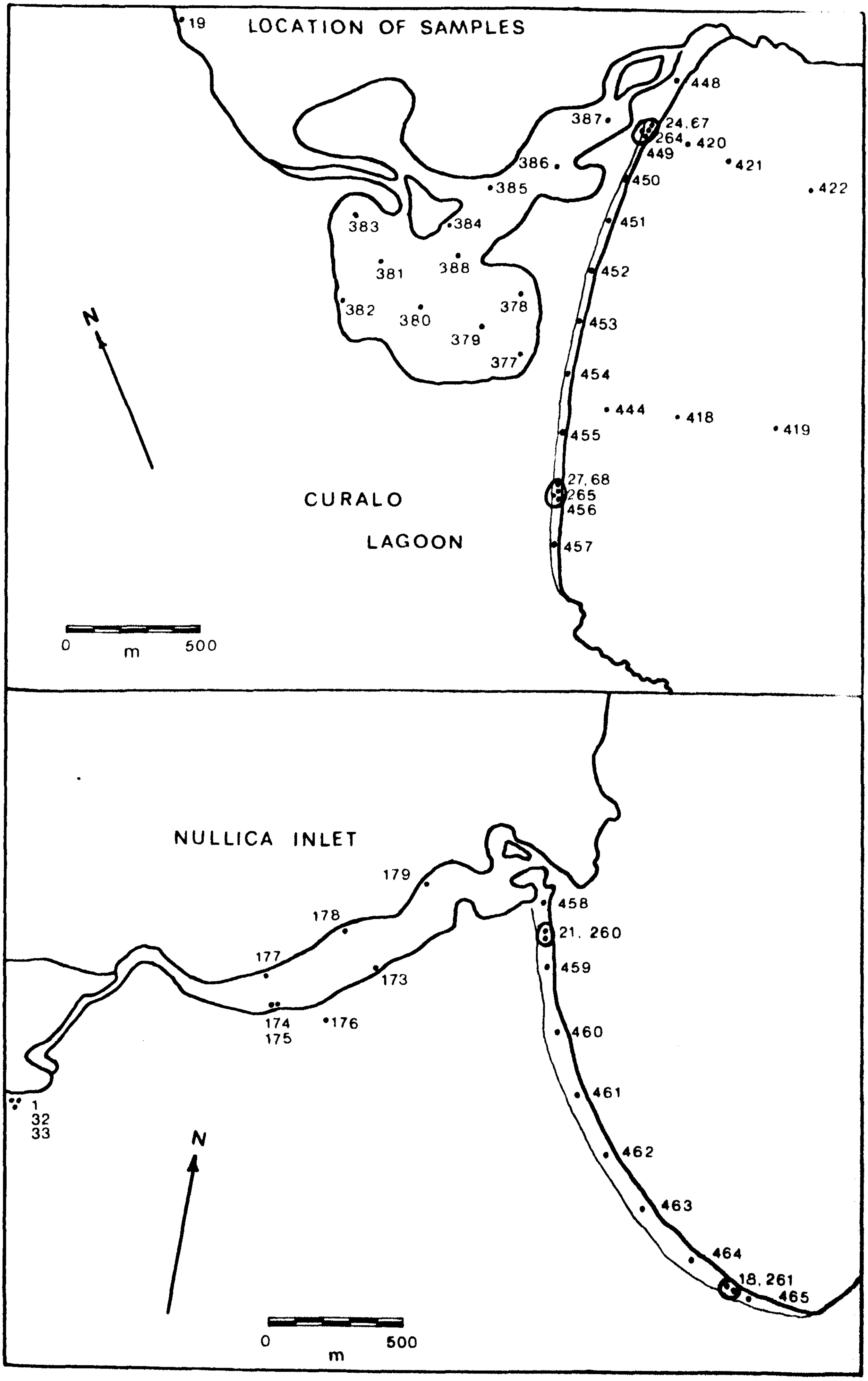
236
237
235
0
km
1
Long Beach



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379
377
454
444
418
419
455
27, 68
265
456
CURALO
LAGOON
457
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m
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NULLICA INLET
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458
178
21, 260
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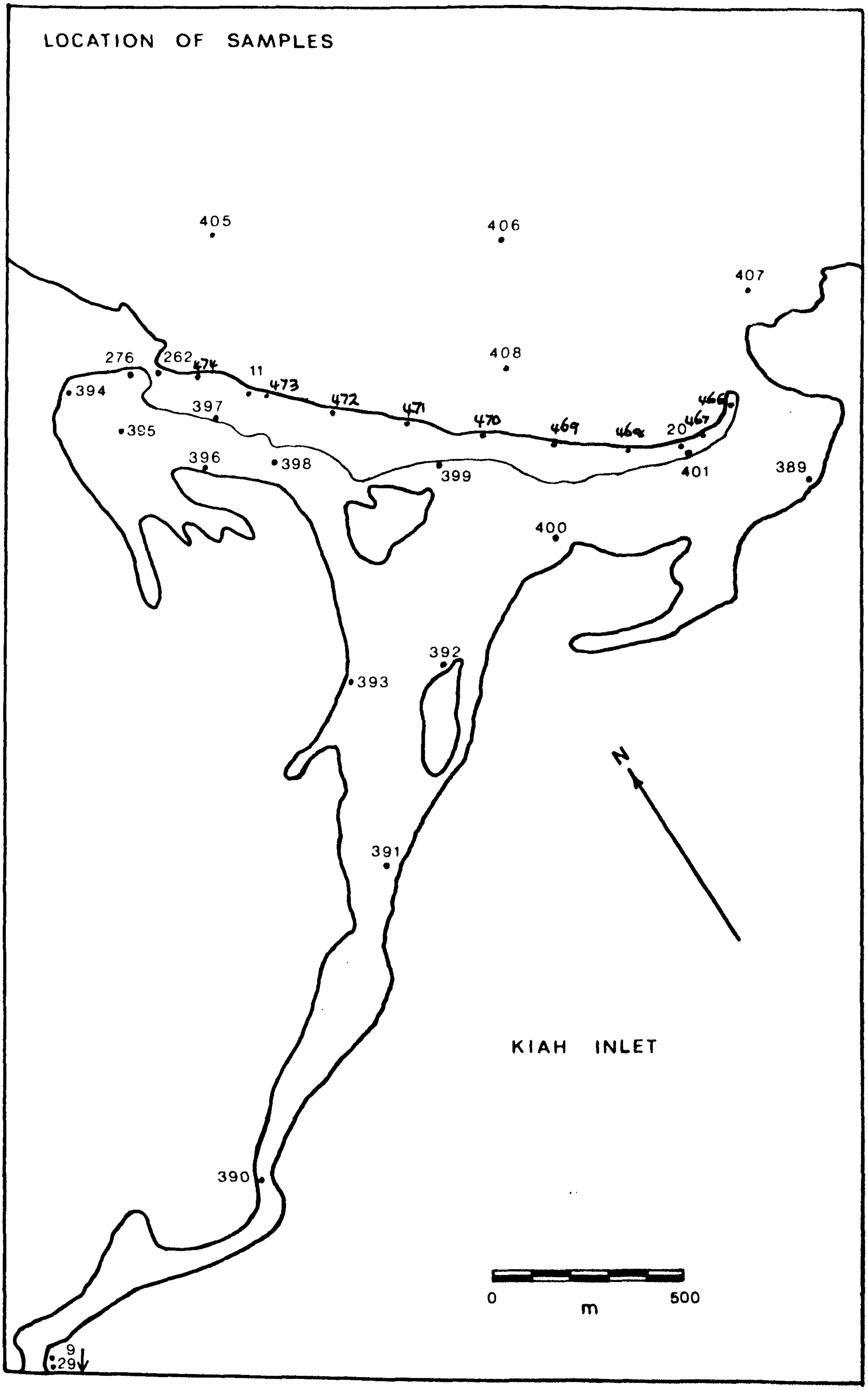
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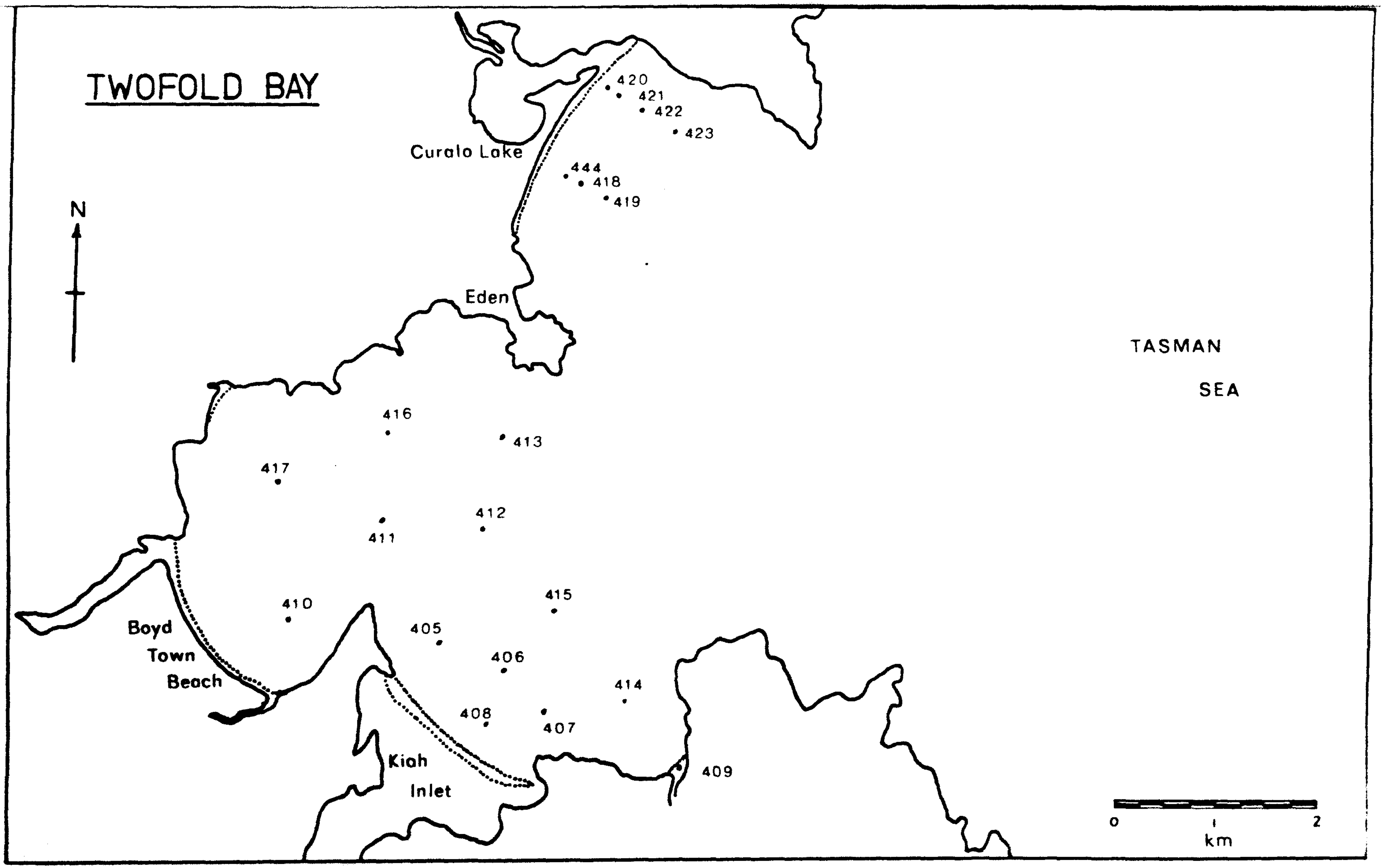
466
394
397
395
396
398
399
401
389
400
392
393
391
390
9
29
N
KIAH INLET
0
m
500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419
Eden
N
TASMAN
SEA
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417
412
411
410
415
405
406
414
408
407
409
Boyd
Town
Beach
Kiah
Inlet
0
1
2
km

Appendix Table A3ii: Shows for each sample (X) the proportion of gravel (A), Sand (B) and Fines (C) in weight per cent. Values of D indicate the proportion of $CaCO_3$ expressed as weight per cent of the sand fraction. "Trace" indicates less than 1% by weight. The gravel/sand boundary is 2.0 mm, the sand/fines boundary is 0.0625 mm.

X	A	B	C	D	X	A	B	C	D
1	60	39	1	0.0	34	0	100	0	6.9
2	49	50	1	0.0	35	0	100	0	15.0
3	0	100	0	2.0	36	0	100	0	19.5
4	8	92	0	5.7	37	46	54	0	0.0
5	38	62	0	0.0	38	46	54	0	0.0
6	0	100	0	0.0	39	0	100	0	6.4
7	0	100	0	5.0	40	trace	99	0	9.2
8	0	100	0	14.7	41	0	100	0	7.5
9	26	74	0	0.0	42	0	100	0	7.5
10	2	98	0	trace	43	0	100	0	14.5
11	10	90	0	1.2	44	72	28	0	trace
12	0	100	0	10.7	45	1	99	0	trace
13	0	100	0	1.5	46	0	100	0	3.9
14	4	96	0	5.6	47	0	100	0	4.7
15	0	100	0	5.5	48	0	100	0	3.8
16	0	100	0	0.9	49	0	100	0	3.4
17	0	100	0	0.9	50	69	31	0	0.0
18	1	99	0	14.0	51	0	100	0	2.1
19	31	69	0	0.0	52	0	100	0	3.9
20	8	92	0	1.9	53	0	100	0	3.3
21	0	100	0	14.9	54	1	99	0	3.1
22	0	100	0	17.0	55	0	100	0	2.4
23	16	84	0	6.2	56	2	98	0	1.4
24	0	100	0	3.3	57	1	99	0	0.0
25	0	100	0	1.3	58	0	100	0	2.2
26	0	100	0	20.4	59	0	100	0	1.9
27	0	100	0	4.5	60	trace	100	0	3.9
28	0	100	0	1.5	61	0	100	0	6.1
29	14	84	2	0.0	62	48	52	0	1.0
30	0	100	0	91.6	63	0	100	0	1.3
31	59	41	0	0.0	64	0	100	0	1.5
32	86	14	0	0.0	65	0	100	0	1.3
33	2	98	0	6.7	66	0	100	0	1.7

X	A	B	C	D	X	A	B	C	D
67	0	100	0	7.1	106	0	98	2	18.6
68	0	100	0	5.1	107	0	96	4	8.7
69	0	100	0	2.0	108	0	99	1	18.2
70	0	100	0	1.0	109	0	92	8	0.0
71	1	99	0	0.0	110	0	98	2	23.1
72	0	100	0	6.2	111	0	89	11	0.0
73	0	100	0	12.0	112	0	88	12	0.0
74	trace	100	0	3.1	113	trace	100	trace	0.0
75	trace	100	0	5.7	114	0	98	2	21.0
76	0	100	0	38.0	115	0	99	1	6.8
77	0	100	0	1.8	116	0	0	100	NA
78	trace	100	0	2.2	117	0	0	100	NA
79	0	100	0	1.8	118	trace	93	7	1.1
80	0	100	0	1.0	119	0	100	0	0.0
81	0	100	trace	2.4	120	0	100	trace	0.0
82	trace	100	0	3.7	121	0	0	100	NA
83	trace	100	0	1.8	122	0	0	100	NA
84	0	100	0	trace	123	0	99	1	0.0
85	0	100	trace	7.3	124	0	100	trace	0.0
86	0	100	0	trace	125	0	100	trace	0.0
87	0	100	trace	2.5	126	0	99	1	0.0
88	0	100	0	2.3	127	0	100	trace	0.0
89	0	100	0	9.8	128	0	100	0	0.0
90	0	100	0	9.3	129	0	100	trace	0.0
91	0	100	trace	4.0	130	0	100	trace	0.0
92	0	100	0	3.1	131	0	100	trace	0.0
93	0	100	0	2.7	132	0	100	trace	0.0
94	0	100	0	2.0	133	0	100	trace	0.0
95	1	99	0	1.3	134	0	94	6	0.0
96	1	99	0	1.3	135	0	92	8	0.0
97	53	47	0	trace	136	0	95	5	0.0
98	0	100	0	1.1	137	0	96	4	0.0
99	30	70	0	1.6	138	0	100	0	0.0
100	0	100	trace	trace	139	trace	91	9	0.0
101	trace	96	4	6.3	140	trace	100	0	0.0
102	trace	100	trace	2.9	141	0	99	1	0.0
103	trace	100	trace	7.3	142	2	98	trace	0.0
104	8	92	trace	0.0	143	trace	95	5	trace
105	0	98	2	7.8	144	trace	91	9	0.0

X	A	B	C	D	X	A	B	C	D
145	trace	91	8	0.0	184	0	0	100	N/A
146	0	95	5	0.0	185	26	69	5	1.4
147	trace	100	trace	0.0	186	33	63	4	2.7
148	0	100	0	0.0	187	0	0	100	N/A
149	0	100	0	0.0	188	0	100	trace	2.2
150	trace	99	1	0.0	189	0	0	100	N/A
151	trace	95	5	0.0	190	0	0	100	N/A
152	1	98	1	0.0	191	0	97	3	0.9
153	0	95	5	0.0	192	5	70	25	7.9
154	0	95	5	0.0	193	31	67	2	0.9
155	1	94	5	0.0	194	46	50	4	2.5
156	trace	99	1	0.0	195	0	95	5	0.0
157	0	99	1	0.0	196	0	100	0	3.2
158	trace	91	9	0.0	197	0	100	0	3.8
159	0	96	4	0.0	198	0	0	100	N/A
160	0	95	5	0.0	199	0	0	100	N/A
161	0	94	6	0.0	200	0	0	100	N/A
162	trace	95	5	0.0	201	0	0	100	N/A
163	0	99	1	0.0	202	0	0	100	N/A
164	trace	92	8	0.0	203	trace	75	25	5.4
165	trace	93	7	0.0	204	0	0	100	N/A
166	trace	91	9	0.0	205	1	99	trace	0.0
167	0	0	100	0.0	206	3	96	1	0.6
168	0	98	2	0.0	207	54	46	trace	0.0
169	trace	98	2	0.0	208	68	29	3	0.0
170	trace	95	5	0.0	209	1	98	1	0.0
171	3	93	4	0.0	210	10	90	trace	0.0
172	2	93	5	0.0	211	30	70	trace	0.0
173	0	96	4	20.9	212	45	55	trace	0.0
174	0	91	1	1.6	213	11	89	0	0.0
175	1	99	trace	4.4	214	6	94	trace	2.0
176	0	97	3	1.4	215	21	78	1	4.4
177	4	84	12	2.2	216	5	95	trace	0.0
178	0	95	5	1.4	217	0	0	100	N/A
179	0	95	5	8.8	218	25	75	0	0.0
180	0	100	trace	1.9	219	23	77	trace	0.0
181	0	0	100	N/A	220	0	100	0	0.0
182	0	0	100	N/A	221	0	0	100	N/A
183	0	0	100	N/A	222	0	100	0	1.5

X	A	B	C	D	X	A	B	C	D
223	0	100	0	1.0	263	2	98	0	4.7
224	0	100	0	0.0	264	6	94	0	2.5
225	0	100	trace	3.1	265	0	100	0	1.4
226	0	100	trace	2.6	266	0	100	0	5.4
227	18	82	trace	1.6	267	0	100	0	5.4
228	7	90	3	0.0	268	0	100	0	1.1
229	8	92	trace	0.2	269	0	100	0	1.1
230	9	91	0	0.2	270	0	100	0	2.9
231	0	0	100	N/A	271	0	100	0	2.9
232	0	0	100	N/A	272	trace	100	0	3.6
234	0	99	1	3.4	273	0	100	0	2.4
235	2	98	0	0.5	274	0	100	0	0.3
236	0	0	100	N/A	275	0	100	0	0.9
237	10	90	trace	1.5	276	0	0	100	N/A
238	0	0	100	N/A	277	0	0	100	N/A
239	0	99	1	24.0	278	0	100	trace	2.4
240	1	98	1	2.0	279	1	98	1	0.2
241	0	94	6	29.9	280	7	92	1	1.4
242	0	100	trace	1.3	281	30	70	0	0.1
243	0	99	1	0.4	282	66	33	1	0.1
244	0	100	0	3.5	283	0	96	4	10.1
245	0	100	0	3.2	284	0	100	0	3.0
246	0	100	0	2.4	285	0	100	0	2.5
247	0	100	0	2.5	286	0	100	0	2.4
248	0	100	0	3.6	287	0	100	0	3.1
249	trace	100	0	3.5	288	0	100	0	2.8
250	trace	100	0	4.0	289	0	100	0	2.2
251	0	100	0	1.4	290	0	100	0	2.8
252	0	100	0	2.3	291	0	100	0	2.5
253	0	100	0	2.5	292	0	100	0	4.6
254	3	97	0	1.4	293	0	100	0	2.9
255	6	94	0	1.4	294	0	100	0	3.1
256	trace	100	0	1.9	295	0	100	0	2.3
257	trace	100	0	1.9	296	0	100	0	2.3
258	trace	100	0	1.8	297	0	0	100	N/A
259	0	100	0	60.9	298	0	0	100	N/A
260	0	100	0	4.9	299	0	0	100	N/A
261	4	96	0	1.4	300	6	90	4	4.8
262	0	100	0	45.9	301	0	0	100	N/A

X	A	B	C	D	X	A	B	C	D
302	1	97	2	2.5	342	0	100	0	4.5
303	0	30	70	5.4	343	0	100	0	5.5
304	N/A	N/A	N/A	N/A	344	0	100	0	5.6
305	0	0	100	N/A	345	0	100	0	7.6
306	0	50	50	3.0	346	0	100	0	4.9
307	0	99	1	2.3	347	trace	100	0	4.0
308	trace	30	70	N/A	348	0	100	0	3.8
309	1	94	5	4.7	349	trace	100	0	3.5
310	trace	100	trace	2.1	350	0	100	0	2.3
311	0	0	100	N/A	351	trace	100	0	1.4
312	0	0	100	N/A	352	trace	100	0	1.5
313	trace	99	1	0.0	353	trace	100	0	1.5
314	trace	99	1	2.4	354	1	99	0	1.9
315	0	100	0	2.7	355	trace	100	0	2.5
316	0	100	0	2.0	356	trace	100	0	2.2
317	28	72	0	0.0	357	trace	100	0	1.8
318	0	80	20	1.0	358	54	46	0	0.3
319	17	83	0	1.5	359	29	71	trace	2.0
320	4	95	1	0.1	360	41	59	trace	1.7
321	1	98	1	4.3	361	20	80	0	1.4
322	1	9	90	9.1	362	1	99	trace	0.0
323	1	97	2	4.9	363	2	98	0	0.8
324	0	100	0	1.4	364	1	99	trace	1.7
325	2	16	82	2.1	365	0	100	trace	2.7
326	0	100	trace	1.8	366	0	15	85	3.7
327	0	10	90	6.6	367	4	96	trace	2.7
328	0	100	0	3.3	368	0	0	100	N/A
329	0	100	0	2.0	369	0	100	trace	0.9
330	0	100	0	2.6	370	0	0	100	N/A
331	0	100	0	2.3	371	0	100	trace	2.3
332	2	98	0	4.0	372	trace	99	1	3.8
333	0	100	0	2.7	373	0	100	0	0.6
334	0	100	0	3.3	374	0	100	0	5.1
335	0	100	0	2.7	375	trace	100	0	3.4
336	0	100	0	2.9	376	trace	50	50	4.9
337	0	100	0	2.7	377	0	30	70	0.3
338	0	100	0	5.5	378	0	100	0	0.2
339	0	100	0	4.3	379	0	99	1	2.6
340	trace	100	0	3.2	380	0	97	3	5.2
341	trace	100	0	2.6	381	trace	50	50	1.1

X	A	B	C	D	X	A	B	C	D
382	0	70	30	1.0	422	0	100	0	50.9
383	0	5	95	9.2	423	0	100	trace	64.0
384	0	99	1	3.9	424	0	100	0	8.7
385	0	95	5	0.0	425	0	100	0	19.7
386	0	90	10	1.5	426	0	100	trace	51.1
387	trace	100	0	7.9	427	trace	100	trace	37.9
388	0	95	5	0.4	428	0	100	0	12.3
389	8	92	0	3.7	429	0	100	trace	10.3
390	16	84	0	0.5	430	0	100	trace	47.6
391	12	88	0	0.7	431	0	99	1	67.7
392	6	94	0	0.6	432	0	100	trace	6.9
393	42	58	0	0.3	433	0	99	1	31.0
394	0	100	0	0.5	434	0	100	trace	9.2
395	0	90	10	0.1	435	trace	100	0	3.2
396	trace	99	1	0.0	436	trace	100	0	2.7
397	trace	100	0	0.3	437	0	100	0	13.6
398	8	92	0	0.9	438	0	100	0	14.6
399	15	85	0	2.0	439	trace	100	0	3.8
400	1	99	0	0.5	440	0	100	0	7.3
401	2	98	trace	2.5	441	0	100	0	6.0
402	0	100	0	2.5	442	trace	100	0	43.2
403	trace	100	0	4.3	443	trace	100	0	8.5
404	0	97	3	8.7	444	0	100	0	4.1
405	0	90	10	8.0	445	0	60	40	1.3
406	0	96	4	3.9	446	0	98	2	2.4
407	0	89	11	6.5	447	0	99	1	32.7
408	0	100	0	1.8	448	0	100	0	4.1
409	0	100	0	76.1	449	0	100	0	5.5
410	0	91	9	31.2	450	0	100	0	3.9
411	0	100	0	16.5	451	0	100	0	3.2
412	0	95	5	11.7	452	1	99	0	1.2
413	0	87	13	25.9	453	39	61	0	2.9
414	0	98	2	19.6	454	0	100	0	2.2
415	0	96	4	40.6	455	0	100	0	3.0
416	0	84	16	24.6	456	0	100	0	1.2
417	0	91	9	17.1	457	0	100	0	1.5
418	2	98	0	11.4	458	0	100	0	4.1
419	0	99	1	37.4	459	0	100	0	5.8
420	0	100	0	3.0	460	0	100	0	5.8
421	trace	100	trace	11.5	461	0	100	0	4.9

X	A	B	C	D	X	A	B	C	D
462	0	100	0	5.2	469	3	97	0	1.2
463	0	100	0	3.5	470	2	98	0	0.7
464	0	100	trace	6.5	471	0	100	0	0.6
465	0	100	0	2.6	472	0	100	0	0.7
466	0	100	0	0.6	473	trace	100	0	1.1
467	trace	100	0	0.4	474	trace	100	0	0.8
468	trace	100	0	1.4					

Appendix A3iii: Tables showing mean, standard deviation (sorting), skewness and kurtosis (moment measures) of sample sand fractions. Values are expressed in phi (Ø) units.

Sample	Mean	S.D.	SKEW.	KURT.	Sample	Mean	S.D.	SKEW.	KURT.
1	0.65	1.15	0.60	2.50	43	1.17	0.49	-0.53	3.68
2	0.89	1.12	0.24	2.39	44	0.31	1.09	0.42	2.29
3	1.13	0.42	-0.61	3.77	45	0.46	0.46	-0.22	2.82
4	0.47	1.19	0.41	1.54	46	1.47	0.37	-0.98	5.15
5	0.58	0.87	0.32	2.54	47	1.41	0.41	-0.64	4.39
6	1.03	0.83	0.62	3.71	48	1.40	0.41	-0.93	4.41
7	1.99	0.36	-0.18	3.11	49	1.36	0.38	-0.93	4.91
8	2.36	0.67	-1.32	5.20	50	0.28	0.95	1.05	3.88
9	-0.05	0.74	0.77	2.64	51	1.39	0.33	-0.05	3.78
10	0.65	0.59	0.12	3.10	52	1.35	0.35	-0.04	3.25
11	-0.20	0.70	1.11	3.21	53	1.46	0.41	-0.37	3.73
12	1.61	0.49	0.00	2.78	54	1.33	0.38	-0.30	3.17
13	1.41	0.43	-0.73	3.64	55	1.37	0.37	-0.22	3.20
14	1.52	0.91	-0.75	2.67	56	1.27	0.72	-0.38	3.65
15	1.44	0.49	0.03	2.92	57	0.56	0.61	0.42	3.51
16	1.17	0.29	-0.09	3.63	58	1.25	0.44	-0.20	3.15
17	1.23	0.28	-0.27	4.49	59	0.98	0.55	-0.16	2.69
18	2.32	0.80	-1.45	5.19	60	1.26	0.62	-0.68	3.10
19	0.79	0.81	0.03	2.68	61	1.97	0.38	-1.03	5.57
20	0.37	0.65	-0.05	2.03	62	-0.03	0.91	0.82	3.02
21	2.29	0.61	-0.82	3.57	63	1.39	0.42	-0.81	3.89
22	2.08	0.50	-0.19	2.85	64	1.52	0.38	-0.92	4.38
23	0.85	1.23	-0.17	1.41	65	1.38	0.39	-0.75	3.99
24	1.23	0.56	-0.79	3.53	66	1.40	0.43	-0.80	3.97
25	1.80	0.28	-0.12	3.49	67	1.79	0.48	-1.14	4.84
26	2.18	0.44	-0.44	3.49	68	1.61	0.40	-0.70	3.92
27	0.97	0.69	-0.24	2.34	69	1.67	0.35	-0.90	4.70
28	1.19	0.37	-0.14	3.11	70	1.49	0.36	-0.62	3.29
29	0.46	0.88	0.42	2.71	71	0.92	0.63	-0.72	2.77
30	2.24	0.42	-0.20	3.77	72	1.78	0.42	-0.65	3.88
31	-0.06	0.79	0.70	2.50	73	2.20	0.37	-1.33	7.03
32	1.24	1.08	-0.13	2.54	74	1.34	0.51	0.36	5.29
33	1.28	0.75	-0.90	2.93	75	1.42	0.41	0.28	3.57
34	1.64	0.43	-0.31	4.08	76	1.37	0.42	0.32	3.81
35	1.70	0.57	-0.59	3.53	77	1.48	0.54	0.27	3.35
36	1.87	0.39	-0.50	5.52	78	1.49	0.47	-0.42	3.74
37	0.23	0.88	0.59	2.64	79	1.44	0.45	0.14	2.99
38	-0.14	0.88	1.05	3.62	80	1.47	0.39	0.00	4.64
39	1.34	0.39	-0.14	3.06	81	1.75	0.55	-0.12	3.22
40	1.07	0.41	-0.52	4.31	82	1.71	0.55	-0.35	3.45
41	1.00	0.35	-0.29	4.32	83	1.74	0.53	-0.31	3.35
42	1.38	0.46	-0.84	4.45	84	1.66	0.33	-0.48	4.38

Sample	Mean	S.D.	SKEW.	KURT.	Sample	Mean	S.D.	SKEW.	KURT
85	1.97	0.48	-0.02	4.38	142	0.80	0.58	-0.11	2.89
86	1.70	0.31	-0.46	4.12	143	1.31	0.58	0.83	5.59
87	1.88	0.45	0.25	4.84	144	2.13	0.68	-0.36	3.81
88	1.70	0.46	-0.46	4.55	145	1.70	0.72	0.14	3.53
89	1.66	0.52	0.16	2.42	146	1.33	0.56	0.40	4.69
90	1.50	0.45	-0.78	4.05	147	1.25	0.48	0.08	5.51
91	1.76	0.41	-0.52	6.23	148	1.24	0.38	-0.35	3.21
92	1.64	0.38	-0.86	6.12	149	0.84	0.42	-0.26	3.17
93	1.48	0.32	-0.36	4.12	150	2.08	0.54	-0.41	6.01
94	1.88	0.25	0.21	3.87	151	2.10	0.52	-0.42	6.18
95	1.52	0.67	-0.60	3.42	152	2.09	0.54	-0.44	6.40
96	1.55	0.53	-1.09	5.30	153	2.03	0.57	0.02	4.81
97	0.12	0.83	0.13	1.68	154	2.02	0.51	-0.37	5.37
98	1.64	0.59	-0.02	4.30	155	1.90	0.59	-0.13	5.33
99	1.28	0.74	-1.22	4.44	156	1.85	0.55	0.68	5.57
100	1.60	0.40	-0.29	4.51	157	1.67	0.54	0.74	5.71
101	1.96	0.71	-0.17	3.81	158	2.02	0.40	-0.28	6.10
102	1.65	0.51	-0.17	5.84	159	2.09	0.57	0.22	4.89
103	2.01	0.56	-0.75	6.17	160	2.07	0.47	-0.04	5.46
104	0.30	0.69	0.89	4.83	161	2.08	0.50	0.09	5.05
105	1.65	0.67	1.06	4.60	162	2.00	0.45	0.12	5.52
106	3.15	0.93	-1.53	4.33	163	2.10	0.40	-0.15	7.43
107	3.29	0.49	-0.80	2.85	164	2.12	0.49	-0.65	6.04
108	2.30	0.82	-0.02	2.62	165	2.03	0.42	-0.53	6.93
109	1.74	0.79	0.03	2.86	166	1.99	0.51	-0.26	4.92
110	2.17	0.81	-0.35	3.72	167	N/A	All fines		
111	1.75	0.74	-0.23	3.17	168	1.94	0.58	0.20	4.61
112	1.90	0.55	0.01	3.86	169	1.94	0.53	0.03	5.04
113	1.81	0.51	-0.20	3.77	170	1.91	0.45	-0.24	6.47
114	1.79	0.69	-0.15	3.44	171	1.60	0.67	0.07	4.68
115	1.78	0.62	-0.13	3.57	172	1.34	0.61	-0.13	4.25
116	N/A	All fines			173	2.09	0.67	-0.26	3.06
117	N/A	All fines			174	1.78	0.64	-0.13	3.17
118	1.79	0.63	0.01	3.54	175	1.39	0.56	-0.26	3.84
119	1.74	0.53	0.31	3.63	176	1.84	0.55	-0.10	3.34
120	1.77	0.51	-0.01	3.23	177	1.25	1.10	-0.05	2.14
121	N/A	All fines			178	1.78	0.62	0.01	3.65
122	N/A	All fines			179	2.15	0.64	-0.39	3.60
123	1.76	0.56	0.49	4.07	180	1.34	0.49	0.67	4.98
124	1.71	0.51	0.19	3.57	181	N/A	All fines		
125	1.74	0.52	-0.04	2.97	182	N/A	All fines		
126	1.71	0.49	0.82	5.47	183	N/A	All fines		
127	1.66	0.42	0.24	4.55	184	N/A	All fines		
128	1.61	0.43	0.06	3.62	185	0.62	0.75	0.62	4.06
129	1.67	0.47	0.15	3.48	186	0.65	0.84	0.46	3.34
130	1.82	0.48	-0.19	3.61	187	N/A	All fines		
131	1.94	0.44	-0.29	3.58	188	1.90	0.63	-0.40	3.86
132	1.69	0.54	0.41	3.72	189	N/A	All fines		
133	1.74	0.52	-0.01	3.39	190	N/A	All fines		
134	1.74	0.52	-0.03	3.13	191	1.40	0.39	-0.10	3.05
135	1.73	0.54	0.01	3.07	192	1.30	1.08	0.42	2.34
136	1.80	0.57	0.17	3.14	193	0.39	0.63	0.22	3.00
137	1.80	0.57	0.02	3.11	194	0.35	0.94	0.92	3.71
138	1.26	0.38	-0.16	3.97	195	2.00	0.75	0.33	2.76
139	1.50	0.64	0.90	5.40	196	1.16	0.32	0.01	3.23
140	1.22	0.54	-0.23	4.04	197	1.54	0.35	-0.16	3.17
141	2.31	0.75	-1.17	4.52	198	N/A	All fines		

Sample	Mean	S.D.	SKEW.	KURT.	Sample	Mean	S.D.	SKEW.	KURT.
199	N/A	All fines			257	0.79	0.57	-0.10	2.73
200	N/A	All fines			258	1.66	0.50	-0.96	4.52
201	N/A	All fines			259	2.22	0.44	-0.57	4.95
202	N/A	All fines			260	1.91	0.45	-0.37	3.27
203	1.89	0.73	0.67	3.72	261	0.27	0.62	0.23	2.03
204	N/A	All fines			262	2.52	0.58	-1.28	6.20
205	0.72	0.59	0.33	4.10	263	0.78	0.60	0.20	3.15
206	1.07	0.80	1.15	5.53	264	0.53	0.67	0.12	2.13
207	-0.27	0.73	0.00	2.23	265	0.92	0.49	-0.26	2.93
208	-0.41	0.70	-0.40	2.20	266	1.62	0.45	-0.16	3.69
209	0.78	0.59	0.03	3.67	267	1.86	0.48	-0.49	3.20
210	0.24	0.70	0.66	3.34	268	0.96	0.48	-0.22	2.84
211	-0.10	0.71	0.22	2.29	269	1.13	0.47	-0.59	3.38
212	-0.08	0.77	0.45	3.41	270	1.62	0.41	-0.33	3.68
213	-0.03	0.60	0.41	1.85	271	1.56	0.40	-0.24	3.74
214	0.35	0.75	0.85	4.00	272	1.60	0.43	-0.06	3.11
215	0.15	0.76	0.97	4.44	273	1.63	0.40	-0.15	2.82
216	1.38	0.80	-0.38	2.92	274	1.49	0.34	-0.16	3.30
217	N/A	All fines			275	1.49	0.40	-0.39	3.49
218	0.01	0.65	0.21	2.45	276	N/A	All fines		
219	0.08	0.68	0.44	3.49	277	N/A	All fines		
220	1.71	0.39	-0.17	3.68	278	1.90	0.42	-0.48	5.24
221	N/A	All fines			279	1.71	0.55	-0.21	5.29
222	1.98	0.64	-0.44	2.06	280	2.05	0.66	-0.82	5.59
223	1.12	0.44	-0.04	2.91	281	-0.03	0.79	-0.05	1.90
224	0.96	0.55	-0.08	2.76	282	1.52	0.85	0.03	3.32
225	1.45	0.55	-0.24	5.20	283	1.87	0.64	0.09	4.44
226	1.08	0.73	0.13	3.10	284	1.14	0.35	-0.33	3.75
227	0.95	0.90	0.10	2.45	285	1.14	0.36	-0.47	3.69
228	2.38	1.12	-0.57	2.42	286	1.11	0.39	-0.59	3.99
229	1.46	0.66	-0.47	3.46	287	1.16	0.35	-0.29	3.80
230	0.93	0.69	-0.28	2.44	288	1.24	0.32	-0.19	3.97
231	N/A	All fines			289	1.22	0.33	-0.31	4.21
232	N/A	All fines			290	1.22	0.35	-0.38	3.78
233	1.40	0.33	-0.38	3.34	291	1.16	0.39	-0.45	3.83
234	1.65	0.60	0.32	3.87	292	1.17	0.37	-0.25	3.57
235	0.72	0.61	0.02	2.36	293	1.24	0.33	-0.13	3.47
236	N/A	All fines			294	1.22	0.37	-0.46	3.89
237	1.43	0.66	-0.61	3.85	295	1.26	0.34	-0.16	3.65
238	N/A	All fines			296	1.24	0.37	-0.41	3.80
239	2.56	0.81	-0.57	2.75	297	N/A	All fines		
240	1.12	0.70	0.00	3.04	298	N/A	All fines		
241	2.76	0.60	-0.85	5.11	299	N/A	All fines		
242	1.38	0.54	0.14	3.26	300	1.61	0.90	0.20	3.08
243	1.59	0.85	0.38	2.75	301	N/A	All fines		
244	1.18	0.38	-0.42	4.12	302	1.76	0.70	0.04	3.71
245	1.13	0.38	-0.62	4.31	303	2.11	0.74	0.07	3.21
246	1.15	0.42	-0.25	3.28	304	N/A	All fines		
247	1.36	0.41	-0.49	4.13	305	N/A	All fines		
248	1.51	0.38	-0.99	5.64	306	1.75	0.74	0.03	3.06
249	1.26	0.48	-0.83	3.93	307	1.49	0.42	0.06	7.25
250	1.15	0.45	-0.69	3.86	308	2.96	0.63	-0.77	4.18
251	1.50	0.37	-0.58	5.41	309	1.67	0.91	0.21	2.82
252	1.48	0.40	-0.48	4.71	310	1.49	0.43	0.06	5.36
253	0.97	0.48	-0.23	3.55	311	N/A	All fines		
254	0.56	0.58	-0.05	2.30	312	N/A	All fines		
255	0.26	0.58	0.18	2.02	313	1.48	0.41	0.43	7.72
256	0.68	0.53	0.18	2.86	314	1.57	0.46	0.75	6.71

Sample	Mean	S.D.	SKEW.	KURT.	Sample	Mean	S.D.	SKEW.	KURT.
315	1.39	0.42	-0.43	4.42	372	1.69	0.68	-0.34	3.98
316	1.45	0.38	-0.48	4.31	373	1.43	0.44	-0.12	3.06
317	0.02	0.66	0.21	2.10	374	1.97	0.38	-1.03	5.59
318	1.41	0.75	0.43	3.67	375	1.80	0.49	-0.75	4.09
319	0.08	0.65	-0.05	1.90	376	2.31	0.59	-0.14	4.01
320	0.55	0.82	0.55	3.50	377	1.28	0.64	-0.18	3.04
321	0.84	0.62	0.89	6.46	378	1.21	0.65	-0.26	2.81
322	1.61	0.96	0.09	2.72	379	1.87	0.67	0.05	3.89
323	1.01	0.69	0.63	5.00	380	1.97	0.87	0.25	2.85
324	1.11	0.47	-0.30	3.90	381	1.61	0.85	0.04	3.05
325	1.40	0.96	0.43	3.07	382	1.89	0.73	-0.19	3.21
326	1.04	0.58	0.25	4.93	383	2.14	0.85	0.21	2.52
327	2.13	0.86	-0.41	2.75	384	1.41	0.65	0.46	4.69
328	1.34	0.38	-0.33	3.71	385	1.33	0.67	-0.04	3.59
329	1.48	0.32	-0.41	3.23	386	1.42	0.59	-0.39	3.53
330	1.33	0.39	-0.54	3.73	387	1.53	0.65	-0.54	3.42
331	1.35	0.38	-0.43	4.39	388	1.41	0.57	-0.30	3.51
332	1.12	0.50	-0.84	3.78	389	1.68	0.63	-0.51	4.55
333	1.25	0.44	-0.83	4.37	390	0.17	0.74	0.15	1.99
334	1.23	0.41	-0.48	3.69	391	0.03	0.60	0.40	2.11
335	1.25	0.39	-0.46	3.57	392	0.12	0.63	0.49	2.12
336	1.42	0.35	-0.38	3.50	393	-0.34	0.68	-0.17	1.24
337	1.27	0.35	-0.18	3.42	394	0.55	0.75	1.25	4.46
338	1.27	0.35	-0.54	4.56	395	1.50	0.67	0.35	4.11
339	1.33	0.39	-0.56	4.30	396	1.12	0.72	-0.28	2.74
340	1.27	0.49	-0.58	3.65	397	1.01	0.78	0.08	2.30
341	1.26	0.44	-0.67	4.11	398	0.52	0.69	-0.01	2.12
342	2.03	0.42	-1.44	7.50	399	0.06	0.61	-0.30	1.91
343	1.99	0.39	-1.11	5.54	400	0.77	0.70	0.31	2.81
344	1.87	0.44	-1.03	5.52	401	1.19	0.83	-0.19	2.31
345	1.64	0.64	-0.75	2.95	402	1.19	0.44	-0.61	3.59
346	1.67	0.56	-0.77	3.34	403	0.83	0.53	-0.13	2.61
347	1.33	0.68	-0.54	2.57	404	2.04	0.55	0.24	4.70
348	1.37	0.58	-0.55	2.99	405	2.63	0.83	-0.69	3.19
349	1.38	0.56	-0.67	3.30	406	2.00	0.75	0.08	3.14
350	0.92	0.61	-0.03	2.46	407	2.10	0.93	0.14	2.52
351	1.13	0.45	-0.24	3.73	408	1.04	0.43	0.03	3.95
352	0.82	0.48	-0.22	3.15	409	2.04	0.52	-0.40	4.04
353	0.80	0.41	-0.07	3.39	410	3.02	0.62	-1.07	4.81
354	0.79	0.63	-0.14	2.23	411	0.55	0.46	-0.02	3.69
355	0.93	0.49	-0.22	2.87	412	2.71	0.83	-1.21	4.27
356	0.83	0.52	-0.18	2.74	413	3.17	0.68	-1.73	6.43
357	0.75	0.53	0.20	2.81	414	2.37	0.88	0.04	2.02
358	-0.62	0.62	-1.30	2.73	415	2.61	0.65	-0.27	3.57
359	0.16	0.72	0.94	4.33	416	2.91	0.63	-0.55	2.74
360	0.09	0.72	0.63	3.48	417	3.06	0.71	-1.40	4.90
361	o.13	0.65	0.34	2.31	418	1.58	0.63	-0.53	3.60
362	0.68	0.68	0.23	2.88	419	2.66	0.46	-0.06	4.04
363	1.26	0.64	-0.61	3.06	420	1.04	0.65	-0.12	2.56
364	1.23	0.70	-0.23	3.02	421	1.84	0.52	-0.78	4.98
365	0.86	0.51	1.51	8.50	422	2.10	0.64	-0.62	4.15
366	1.90	0.84	0.10	2.94	423	2.42	0.63	-0.52	3.63
367	0.68	0.71	0.25	3.16	424	1.73	0.49	-0.07	2.80
368	N/A	All fines			425	1.80	0.52	-0.26	2.90
369	1.65	0.58	0.92	4.66	426	2.19	0.49	-0.55	4.01
370	N/A	All fines			427	2.40	0.53	-0.88	5.45
371	1.81	0.58	-0.27	3.55	428	1.84	0.54	-0.25	2.77

Sample	Mean	S.D.	SKEW.	KURT.	Sample	Mean	S.D.	SKEW.	KURT.
429	1.73	0.57	-0.24	2.86	452	0.28	0.56	0.53	2.66
430	2.21	0.50	-0.75	5.21	453	-0.58	0.65	-1.04	2.14
431	2.24	0.54	-0.44	4.45	454	0.76	0.37	-0.50	3.45
432	2.02	0.54	-0.20	3.09	455	0.93	0.45	-0.19	2.99
433	2.66	0.57	-0.75	4.80	456	0.81	0.39	-0.40	3.08
434	2.16	0.76	-0.12	2.55	457	0.80	0.35	-0.18	4.49
435	1.25	0.56	0.01	2.74	458	1.80	0.55	-0.41	2.77
436	1.08	0.56	-0.19	2.74	459	2.05	0.40	-0.69	4.27
437	2.13	0.45	-0.41	5.42	460	2.09	0.39	-0.71	4.55
438	2.24	0.52	-1.02	7.18	461	2.12	0.45	-0.47	3.68
439	1.60	0.49	-0.53	3.75	462	2.03	0.46	-0.26	2.93
440	2.00	0.44	-0.42	4.86	463	1.70	0.53	-0.13	3.01
441	1.78	0.50	-0.50	3.71	464	1.75	0.63	-0.46	3.34
442	2.23	0.57	0.09	4.90	465	1.76	0.43	-0.32	3.78
443	1.93	0.51	-1.10	4.85	466	0.52	0.53	0.37	2.78
444	1.32	0.54	-0.28	3.00	467	0.05	0.46	1.03	3.60
445	2.35	0.82	-0.30	3.08	468	0.49	0.51	0.24	2.72
446	2.70	0.92	-1.01	3.69	469	0.01	0.57	0.58	2.00
447	2.38	0.67	-0.49	3.50	470	0.29	0.53	0.37	2.58
448	1.46	0.46	-0.46	3.13	471	0.40	0.41	0.33	3.27
449	1.28	0.44	-0.12	3.07	472	0.40	0.48	0.36	2.70
450	1.44	0.43	-0.38	3.31	473	0.38	0.42	0.16	2.72
451	0.63	0.32	-0.13	3.25	474	-0.22	0.56	1.26	2.99

Appendix A3iv: Tables showing percentage of 'unstressed' quartz (Qtz_u), 'stressed' quartz (Qtz_s), feldspar (Fel.), lithic fragments (LiF), mica (Mic.) and other accessory minerals (Oth.) in sample sand fractions. Average roundness values (R) are also indicated for the quartz grains (lower values = less rounding).

Samp.	Qtz_u	Qtz_s	Fel.	LiF.	Mic.	Oth.	R	Samp.	Qtz_u	Qtz_s	Fel.	LiF.	Mic.	Oth.	R
1	26	42	-	28	-	4	.26	59	74	15	4	7	-	-	.36
3	96	4	-	-	-	-	.62	60	66	7	19	8	-	-	.26
5	68	25	-	4	-	3	.22	62	44	35	5	7	-	9	.27
6	79	14	3	2	-	2	.22	69	98	2	-	-	-	-	.65
7	96	4	-	-	-	-	.55	71	96	4	-	-	-	-	.52
9	50	28	11	11	-	-	.20	73	83	6	3	-	6	2	.52
10	58	15	8	16	1	2	.22	78	93	7	-	-	-	-	.53
11	62	25	7	6	-	-	.22	79	87	5	5	2	-	1	.53
15	91	7	1	1	-	-	.57	82	94	3	3	-	-	-	.50
19	25	58	1	15	-	1	.26	83	90	6	4	-	-	-	.39
20	60	19	12	8	-	1	.27	84	93	4	3	-	-	-	.54
21	63	15	4	2	13	3	.28	104	49	46	3	1	-	1	.31
22	88	7	4	1	-	-	.42	107	71	8	5	-	-	16	.31
24	94	3	-	-	-	3	.64	109	79	6	15	-	-	-	.36
27	96	4	-	-	-	-	.61	111	80	11	5	-	-	4	.47
28	96	4	-	-	-	-	.64	112	85	5	4	-	-	6	.53
31	43	36	8	13	-	-	.23	114	89	4	4	-	-	3	.60
37	51	37	-	11	-	1	.27	115	91	5	3	-	-	1	.52
43	87	7	1	2	-	3	.59	138	97	3	-	-	-	-	.67
44	20	63	1	15	-	1	.28	139	90	8	1	-	-	1	.66
45	66	14	9	1	-	-	.29	140	91	9	-	-	-	-	.55
51	92	6	-	-	-	2	.61	141	75	17	2	4	-	2	.39
56	69	24	-	3	-	4	.27	142	84	11	2	3	-	-	.43
57	61	17	15	7	-	-	.24	143	69	23	3	3	-	2	.36

Samp.	Qtz_u	Qtz_s	Fel.	LiF.	Mic.	Oth.	R	Samp.	Qtz_u	Qtz_s	Fel.	LiF.	Mic.	Oth.	R
144	70	23	2	3	-	2	.38	286	97	3	-	-	-	-	.65
145	76	21	1	2	-	-	.42	310	40	51	2	5	-	2	.32
146	90	9	-	-	-	1	.61	313	86	8	2	3	-	1	.49
148	99	1	-	-	-	-	.68	314	84	8	2	4	-	2	.43
149	98	2	-	-	-	-	.69	315	89	7	1	2	-	1	.58
158	82	6	6	3	-	3	.39	316	95	4	-	1	-	-	.62
163	87	5	5	2	-	1	.35	317	27	53	4	16	-	-	.27
169	89	6	1	3	-	1	.44	319	50	30	12	-	6	2	.30
172	81	11	5	3	-	-	.36	324	68	11	7	10	2	2	.33
173	51	16	16	2	9	6	.27	327	73	9	4	3	3	8	.40
175	89	7	1	2	-	1	.40	328	84	7	4	4	-	1	.58
176	79	14	2	2	1	2	.35	329	89	5	3	1	1	1	.50
177	47	31	4	11	3	4	.33	333	91	6	-	3	-	-	.54
179	47	23	11	5	6	8	.30	334	91	6	-	3	-	-	.47
185	52	47	-	3	-	2	.45	336	93	4	-	1	-	2	.49
186	38	57	-	3	-	2	.40	337	94	3	1	1	-	1	.50
188	88	7	-	2	-	3	.50	340	96	4	-	-	-	-	.48
191	90	8	-	2	-	-	.60	341	97	3	-	-	-	-	.47
194	31	63	2	3	-	1	.31	343	86	11	3	-	-	-	.44
205	70	23	4	2	-	1	.24	346	75	8	15	2	-	-	.39
209	67	4	19	8	-	2	.25	347	71	14	12	3	-	-	.33
211	65	14	9	12	-	-	.25	351	73	19	8	-	-	-	.38
214	68	12	14	5	-	1	.26	355	72	14	9	5	-	-	.47
219	53	22	13	12	-	-	.21	356	58	12	25	5	-	-	.46
222	59	19	15	7	-	-	.47	359	76	24	-	-	-	-	.33
226	94	2	-	-	-	4	.39	360	75	24	-	-	-	1	.33
230	97	3	-	-	-	-	.39	361	78	22	-	-	-	-	.37
233	97	3	-	-	-	-	.58	363	80	17	1	-	-	2	.54
234	74	19	4	2	-	1	.33	364	91	7	1	1	-	-	.51
237	85	14	-	1	-	-	.23	365	98	2	-	-	-	-	.62
240	52	38	-	9	-	1	.33	366	84	13	1	-	1	1	.51
241	50	25	3	16	-	6	.34	367	70	30	-	-	-	-	.37
244	98	2	-	-	-	-	.67	369	92	4	-	2	-	2	.57
245	95	4	-	1	-	-	.66	371	76	19	1	2	-	2	.42
246	96	2	-	1	-	1	.67	372	91	6	-	2	-	1	.41
247	93	4	1	2	-	-	.67	373	92	6	1	1	-	-	.60
248	94	4	1	1	-	-	.60	374	93	5	-	1	-	1	.45
249	93	4	1	-	-	2	.57	375	89	7	1	2	-	1	.39
250	90	4	3	3	-	-	.64	383	52	22	2	14	-	10	.43
251	93	2	-	1	-	4	.60	385	87	4	2	6	-	1	.48
252	87	3	1	1	-	8	.58	388	98	2	-	-	-	-	.56
253	94	4	1	-	-	1	.61	391	64	9	6	21	-	-	.19
256	76	14	5	5	-	-	.32	397	78	13	-	9	-	-	.20
257	69	12	14	5	-	-	.34	401	69	11	6	-	8	6	.28
258	61	16	20	3	-	-	.37	405	58	19	5	4	6	8	.32
260	73	16	4	4	2	1	.30	407	61	3	5	6	11	14	.34
264	98	2	-	-	-	-	.66	409	54	22	5	8	3	8	.28
265	97	3	-	-	-	-	.65	410	62	11	6	2	11	8	.27
266	79	19	2	-	-	-	.56	411	72	13	9	5	-	1	.46
267	66	23	4	3	1	3	.48	412	56	14	6	3	9	12	.35
268	98	2	-	-	-	-	.70	413	88	5	6	-	-	1	.56
269	98	2	-	-	-	-	.69	414	52	27	4	7	4	6	.46
271	99	1	-	-	-	-	.56	415	59	17	7	5	5	7	.37
272	94	6	-	-	-	-	.53	416	52	16	3	4	14	11	.29
273	97	2	-	-	-	1	.58	417	63	15	6	3	5	8	.34
274	98	2	-	-	-	-	.56	418	84	4	1	5	3	3	.44
275	96	-	-	-	-	4	.53	420	96	2	-	2	-	-	.65

Samp.	Qtz_u	Qtz_s	Fel.	LiF.	Mic.	Oth.	R	Samp.	Qtz_u	Qtz_s	Fel.	LiF.	Mic.	Oth.	R
421	94	2	1	2	-	1	.60	437	69	22	6	1	-	2	.37
422	88	5	1	3	1	2	.55	438	69	26	5	-	-	-	.44
424	94	4	1	-	-	1	.56	439	70	8	11	11	-	-	.48
425	90	8	1	1	-	-	.54	440	76	13	7	3	2	-	.41
426	92	4	-	1	-	3	.49	441	67	22	6	3	-	3	.40
427	88	6	2	2	-	2	.49	442	56	15	12	4	9	4	.36
428	92	5	1	1	-	1	.52	443	72	9	12	5	2	-	.41
429	93	4	3	-	-	-	.54	444	94	3	2	-	-	1	.63
430	86	7	4	2	-	1	.46	449	98	2	-	-	-	-	.63
431	87	6	4	2	-	1	.47	456	96	4	-	-	-	-	.63
433	86	6	3	3	-	2	.49	461	83	4	5	3	2	3	.37
434	96	2	-	1	-	1	.59	464	87	3	5	2	1	2	.33
436	64	22	7	7	-	-	.39								

Appendix A3V: Locations of bridge sections not shown on maps in thesis.

Murrah R. at Quaama	COBARGO 1:25000 Sheet 8825-11-S	Grid Ref. 567599
Towamba R. at Kiah	KIAH 1:25000 Sheet 8823-1-S	Grid Ref 537843
Bega R. at Bega	BEGA 1:25000 Sheet 8824-1-S	Grid Ref 527378

REAR POCKET: ADDITIONAL APPENDICES