BOULDER BEACHES:
A SEDIMENTOLOGICAL STUDY

by

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HIGHER DEGREE THESIS (PhD)

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The Academic Senate on 24 November 1981 resolved that the candidate had satisfied requirements for admission to this degree. This thesis represents a major part of the prescribed program of study.

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SUMMARY

Five boulder beaches along the central New South Wales coast were selected for the study of their sedimentary properties, form, and sediment transport. Each beach is aligned obliquely to the approaching waves and is composed of local sediment. One beach, which appears to have little or no recent sediment input, is considered to be a closed sediment system and the other four beaches, which appear to have recent sediment supply, are considered to be open sediment systems.

On the open system beaches, boulder size fines towards the embayment in the direction of transport, and on all beaches size fines up-beach (contrasting with the up-beach coarsening of pebble and cobble beaches). During transport, breakage and chipping diminish boulder size, and the products of these forms of abrasion constitute a subordinate fine population causing the distribution of size to be positively skewed, contrasting with most fine-sediment beaches which exhibit negative size skewness.

More boulders are oblate than prolate, but this may reflect geology rather than coastal weathering processes. In contrast to pebble beaches, no longshore or up-beach shape zoning exists, and boulder shapes are believed to be largely determined by geology. Boulder shape is not related to boulder size. Sphericity varies little within each beach and nowhere does it increase seaward as is common for pebble and cobble beaches.

Boulder roundness tends to increase longshore towards the embayment, and decrease up-beach. The relationships between boulder roundness and size may be influenced by sediment supply. Roundness and shape of boulders do not appear to be related.

Overall beach form is consistent and no rhythmic features could be identified. Surface packing or armouring occurs on all beaches and may contribute to beach stability. Foreshore slopes tend to be concave upward and range between 7^{0} and 12^{0}, significantly lower than the slopes of $\geqslant 24^{0}$ predicted in the literature for boulder-sized sediment. This anomaly may be explained by the fact that only very high-energy waves, which produce low beach slopes, are competent to transport boulders.

Boulder mobility is evident on all beaches and was monitored on one beach. Wave competency appears to determine the maximum size of transported boulders, and a competency model is proposed in which it is predicted that there exists a power relationship between transported particle diameter and significant wave height. Since boulder beaches and rubble coastal protection structures have environmental and compositional similarities, beach-boulder movement is examined in the light of engineering studies of protection-structure stability. Two no-damage design formulae were found to over-predict the movement of the smaller-sized beach sediment and under-predict the movement of the larger-sized sediment. This effect may be due to the packing of beach boulders.

Up-beach fining, positive size skewness, the absence of shape zoning, much particle breakage, the absence of sphericity grading, and low foreshore slope are all characteristics of the five studied boulder beaches which contrast markedly with the characteristics of pebble and cobble beaches. These findings, combined with the development of a reasonable predictive transport model, suggest that the studied boulder assemblages are organized and distinct coastal deposits, which may properly be termed beaches.

ACKNOWLEDGEMENTS

I should like to thank Professor J.L. Davies who, as my supervisor, has been a continued source of encouragement and helpful advice. I am also deeply grateful to my husband, Athol Abrahams, whose help, support, and confidence in me during all phases of this study have been invaluable. In particular, the text has benefitted from his reading and criticism.

I also wish to thank Valda Barnes for excellent field assistance and extraordinary friendship. For field assistance, I am also indebted to Susan Parsons, Jenny Barnes, Ted Bryant and Trevor Barnes. Their help is greatly appreciated. I should also like to thank Julian Orford for his interest in this work and our useful and interesting field excursion to several cobble beaches in south Wales.

Most computations reported in this thesis were performed by computer. I most gratefully acknowledge the computing assistance of Ted Bryant who wrote the programme used to calculate Zingg shape classifications and maximum projection sphericity. Particularly Jim Geismann and Chi Sham, and also Stephen Riley and Carolyn Holland provided assistance with computing problems. Thanks are also due to Chi Sham for drafting assistance and advice.

I wish to thank the New South Wales Public Works Hydrology Laboratory and the Maritime Services Board for providing data recorded by their wave-rider buoys, and for their willingness to be of assistance.

Also, I acknowledge the financial support provided by a Commonwealth Postgraduate Research Award.

Finally, I wish to thank my parents, Helen Oak and James Oak. Without their encouragement I could not have undertaken this project.

CERTIFICATE OF ORIGINALITY

The findings presented in this thesis are based on field work and analyses carried out by the author. Unless otherwise stated, these findings are entirely original and have not been submitted for a higher degree to any other university or institution.

H. Lorraine Oak

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LIST OF SYMBOLS

D	Particle Diameter
d	Water depth
d_b	Depth of water at breaking wave
d_s	Water depth at toe of structure
g	Gravitational acceleration
H	Wave height
H_b	Wave height at breaking (breaker height)
H_o	Deep-water wave height
H_s	Significant wave height
K_D	Armour unit stability coefficient
k	Runup correction factor for scale effects
	Diameter of blocks (only in Hedar Formula)
L	Wavelength
L_b	Wavelength at breaking
L_o	Deep-water wavelength
m	Beach slope
N_s	Design stability number for rubble structures
P	Statistical probability
R	Vertical elevation of runup (uprush)
r	Roughness and porosity correction factor
S_s	Specific gravity
T	Wave period
T_s	Significant wave period
W	Weight of individual armour unit
w_r	Unit weight of armour unit
w_w	Unit weight of water

α	Level of statistical significance
θ	Angle of slope with the horizontal
ρ	Powers visual roundness value
ϕ	Grain-size unit $\phi = -\log_2(\text{B axis})(\text{mm})$
ψ_p	Maximum projection sphericity

CHAPTER I

INTRODUCTION

The term "boulder" has been defined as a sedimentary particle having a diameter (or intermediate axis) greater than 256 mm (Wentworth, 1922a). Unfortunately, the precision of terminology found in studies of fine sediment in a coastal setting is frequently absent in the literature dealing with coarse sediment, and the term "boulder" has been used rather loosely.

Langford-Smith and Hails (1966) discuss raised "boulder" beaches along the coast of New South Wales. Actual sediment size is indicated for only one of these beaches, however it appeared to by typical of the 13 sites mentioned. The "boulders" were found to be "variable in size, with a modal diameter of about four inches" [101.6 mm](Langford-Smith and Hails, 1966, p. 352). Although some particle diameters may have exceeded 256 mm, this beach could not be classified as a boulder beach in a strict sedimentological sense. Swan (1975) also refers to the raised beaches described by Langford-Smith and Hails as "boulder" beaches, but uses the more precise term "pebble" to describe the beach particles he studied. Relict boulder beaches are also mentioned by Langford-Smith and Thom (1969), but no indication is given as to the actual size of the sediment being so classified.

But, and perhaps more seriously, sediment coarser than cobble size is often completely disregarded in coastal studies (e.g., Bird, 1972; Shepard, 1963). It appears to be widely accepted that, "sediment composing beaches ranges from fine sand to cobblestones several centimeters in diameter" (Strahler and Strahler, 1978, p. 340). Indeed, Kirk (1980, p. 189) states that "mixed sand and gravel shores present the maximum range of particle sizes to reworking by waves. . ."

However, some work on coastal boulders has been carried out. Kuenen (1947) considered the effect of water in faceting boulders in the shore zone, and Bartrum (1947) investigated the rounding of beach boulders. Shelley (1968) generated some interest in marine effects on boulders by examining the packing or fitting of boulders, and Hills (1970) discussed fitting, fretting, and imprisoned boulders. These studies examined boulders individually in a coastal context, but not as a sedimentary assemblage. Although boulders forming a raised beach at Boat Harbour, Port Stephens, New South Wales (see Langford-Smith and Thom, 1969, p. 580) were examined by Sussmilch and Clark (1928), the only previous investigation of a modern, active coastal assemblage of boulders appears to be an unpublished study by Eliot and Bradshaw (1975). In this study of a boulder "field" near Durras on the south coast of New South Wales, they found both lateral and transverse boulder-size grading. Longshore particle size decreased away from the headland, and up-beach particle size decreased landward. Cusps and spits formed by boulders were also noted in this work.

Langford-Smith and Thom (1969) reported that shingle and boulder beaches along the New South Wales coast are rare, often temporary, features. Bird (1972) refers to coarse-sediment beaches in Australia as pebble and cobble beaches, and he too believes them to be uncommon. This author, however, found 20 boulder beaches of substantial dimensions (approximately 100 m or longer) along the approximately 330 km length of the New South Wales coast between Myall Lakes and Jervis Bay. Thus, although boulder beaches may not be a common landform, they are not as scarce as previous writers have suggested.

Most of these boulder beaches are located along the flanks of headlands between the point of the headland and the embayment proper. For the purposes of this study, beaches so positioned will be referred to as "bay-side" beaches. Waves generally strike bay-side beaches obliquely, causing longshore variation in wave-energy expenditure. However, a few boulder beaches were found at the heads of embayments and these appeared to have become aligned to the approaching waves. Thus, wave-energy expenditure is probably fairly uniform along these beaches. None of these bay-head boulder beaches was included in this study. Field observations in the course of this work, however, have led the author to believe that because there is little longshore wave-energy variation, bay-head boulder beaches may have some sedimentary characteristics different to those of the studied bay-side beaches.

Although the bay-side boulder beaches are located adjacent to actively eroding cliffs, they are not backed by such cliffs. Thus it is clear that the boulders have been transported to their present position and the observed deposits are not coastal talus.

By investigating boulder size, shape, and roundness, beach form, sediment transport, and wave competence, this study seeks to demonstrate that wave-deposited boulders can and do form organized, sedimentologically unique coastal deposits, which may properly be termed beaches.

SELECTION OF STUDY AREAS

Five boulder beaches located along the central New South Wales coast between Myall Lakes and Jervis Bay were selected for detailed study of their sedimentological properties. These beaches, hereafter referred to as North Yacaaba, Copacabana, Bombo, Kiama, and Crookhaven (Figure 1), were chosen because only they satisfied the following criteria:-

1. Beach size: The beach must be at least 100 m in longshore length and 10 m wide at the narrowest point. These dimensions allow the examination of longshore and up-(down-) beach characteristics which would be more difficult to discern on a smaller boulder beach.
2. Sediment size: The mean size of the boulders (intermediate axis) over the entire beach must be 256 mm or greater (-8ϕ or less). This arbitrary size limit for boulders follows the Wentworth (1922a) classification of particle sizes. In order to satisfy this criterion, some beaches generally referred to as "boulder" beaches (*e.g.*, Langford-Smith and Hails, 1966) were excluded from study.
3. Permanency: The beach must not be a temporary feature exposed only by occasional storms. This was determined by observation, and questioning of local residents.
4. Natural State: To ensure that the beach form is the result of natural processes, the beach must show no evidence of human or animal disturbance or removal of sediment. This criterion excluded from study several boulder beaches. For example,

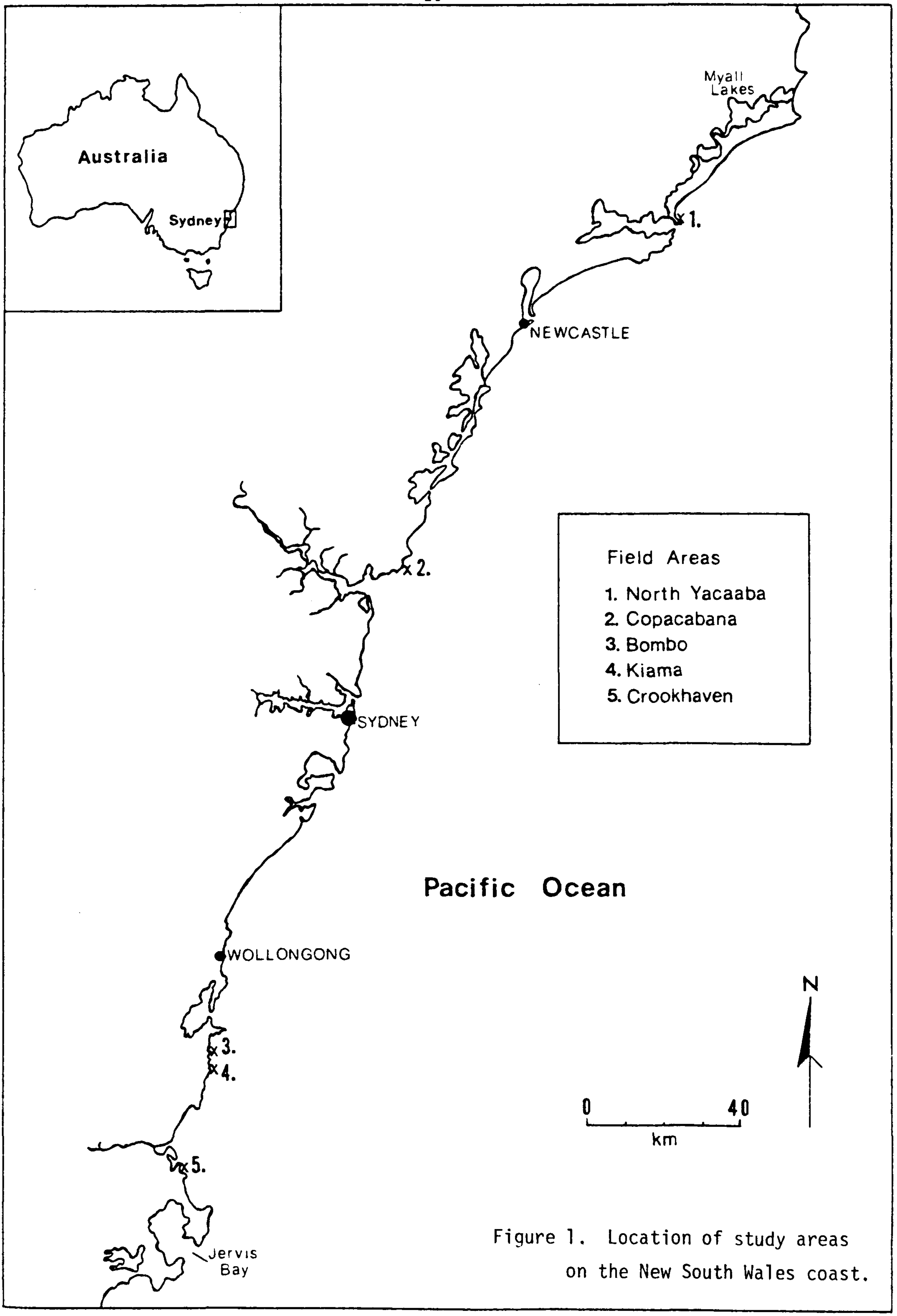

Figure 1. Location of study areas on the New South Wales coast.

Avalon Beach (northern Sydney) has had many boulders removed to be used as paving stones, and the boulder beach described by Sussmilch and Clark (1928) has had the landward section flattened.

5. Accessibility: It must be possible to gain access to the beach while carrying field equipment. Several boulder beaches sited from cliff tops could not be included in this study because access was too difficult.

STUDY AREAS

All five beaches are located in an area of similar meteorological conditions and uniform wave climate (Stone, 1969). In this east coast swell environment (Davies, 1964), southerly cyclonic depressions generate most of the waves. When these cyclones are located over the Tasman Sea, southerly storm waves are generated. Tropical cyclones can produce waves with a north-east to east approach, depending upon the southern extent of the cyclone. Various studies, however, have found that the predominant swell and storm waves approach this coast from a southerly direction (*e.g.*, Stone and Foster, 1967; Lawson and Abernethy, 1975).

North Yacaaba Boulder Beach

North Yacaaba boulder beach is located approximately 165 km along the coast north of Sydney on the north side of the north head (Yacaaba Head) of Port Stephens (Plate 1). Yacaaba Head is composed of Carboniferous Nerong Volcanics (Engel, 1962; Engel *et al.*, 1969), specifically andesite,

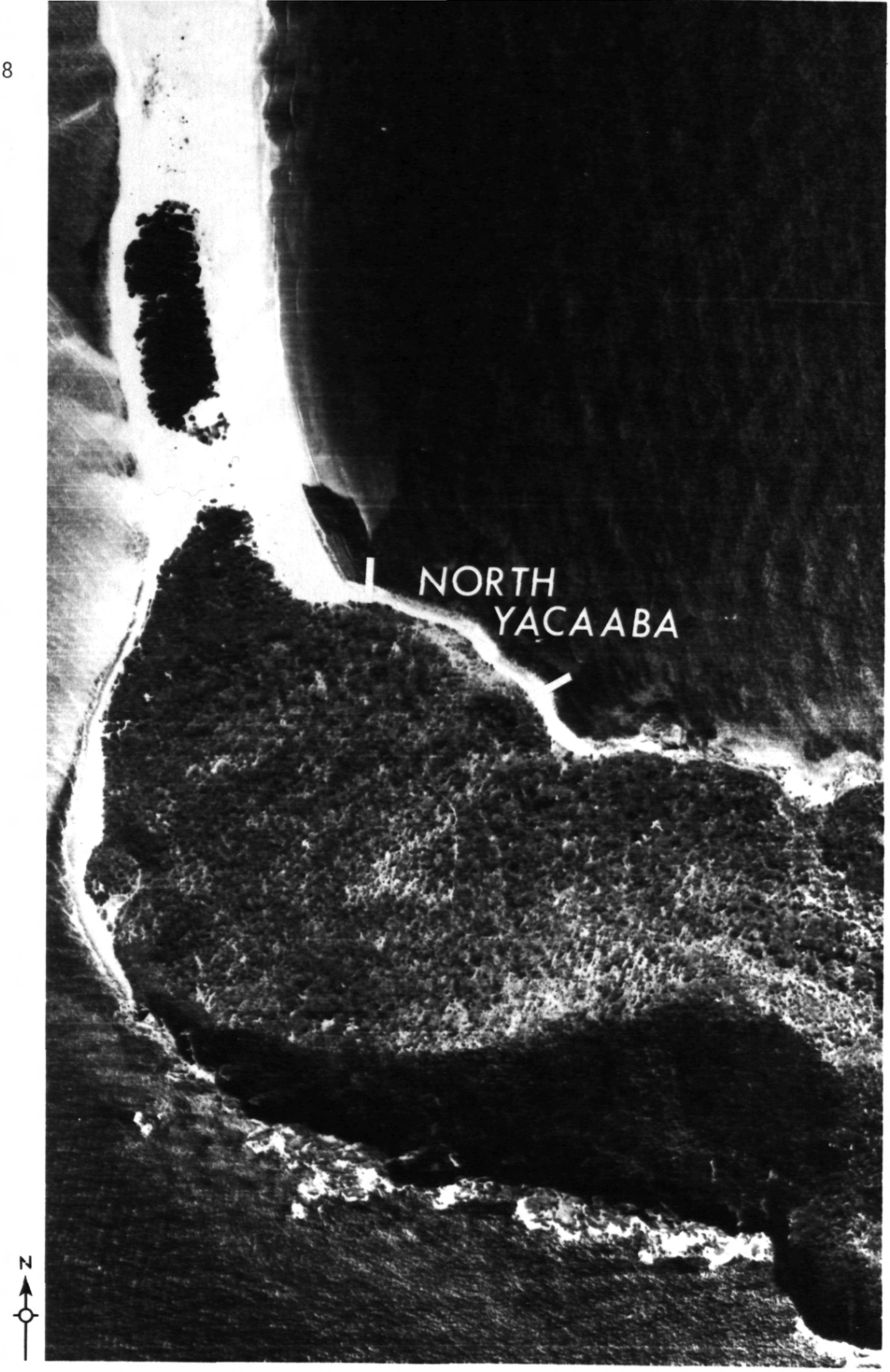

Plate 1. North Yacaaba boulder beach. Approximate scale 1: 8000

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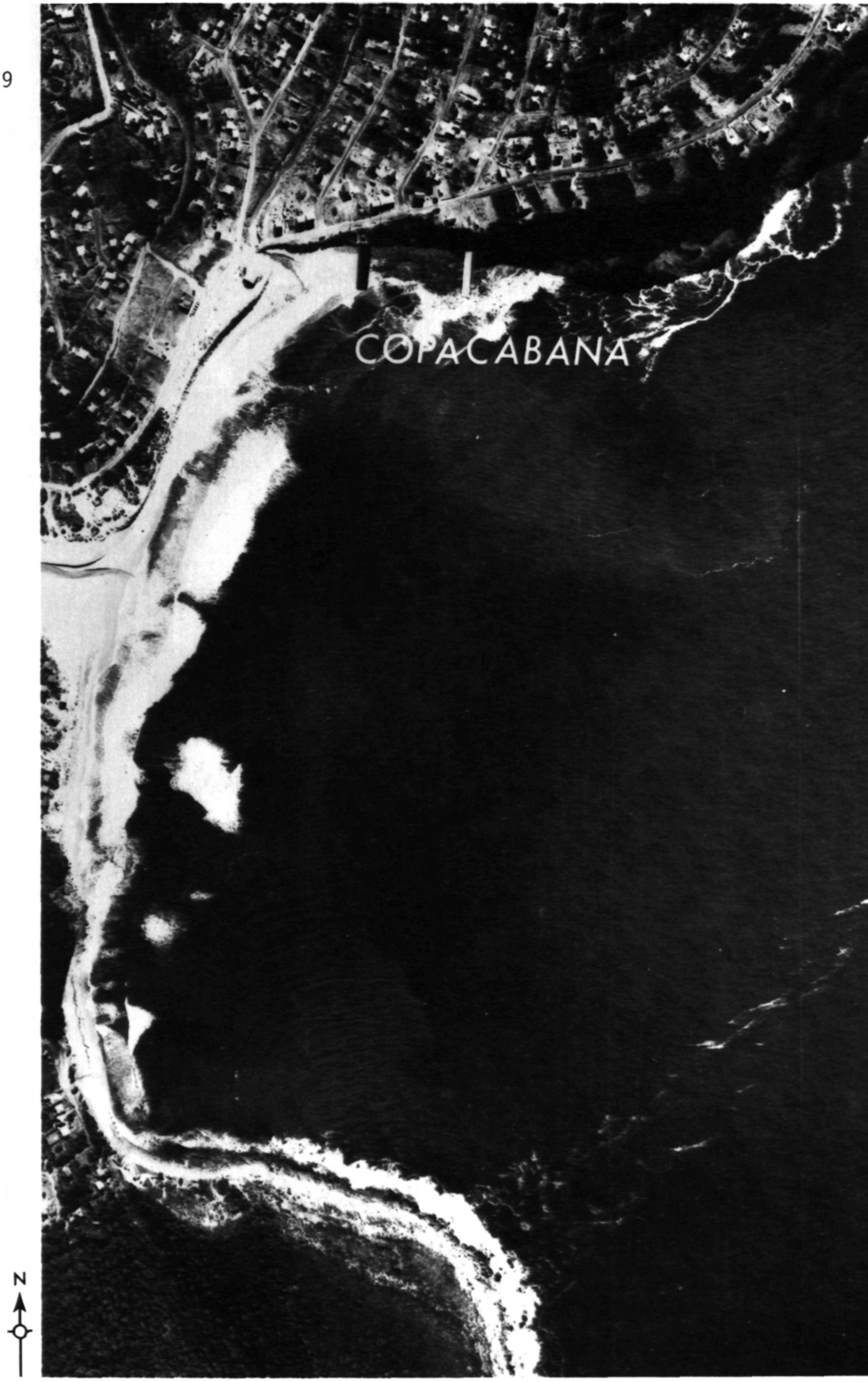

Plate 2. Copacabana boulder beach. Approximate scale 1:8000

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Plate 3. Bombo boulder beach. Approximate scale 1: 8000

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Plate 4. Kiama boulder beach. Approximate scale 1:8000

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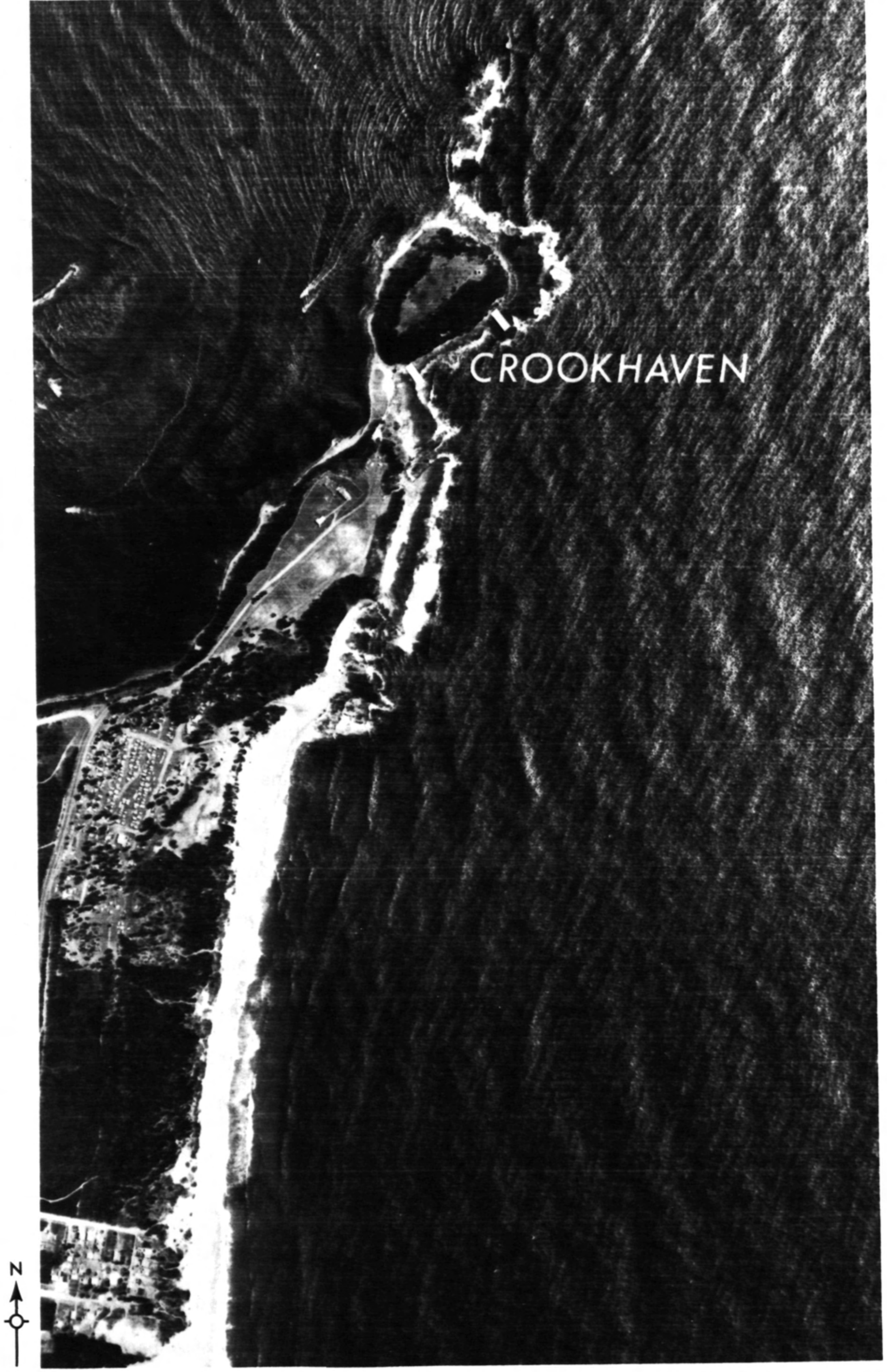

Plate 5. Crookhaven boulder beach. Approximate scale 1: 8000

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toscanite, and conglomerates (Sussmilch and Clark, 1928), and lithoidal toscanite occurs in proximity to the studied beach. The boulders forming the beach are of local origin, but the actual cliff source is almost totally degraded.

This north-facing beach is sheltered somewhat from open-ocean waves by a small offshore island (Cabbage Tree Island). Nevertheless, storm waves are of sufficient intensity to move and organize the boulders composing the beach. A bedrock outcrop occurs in the seaward portion of the beach near its centre.

Of the beaches studied, North Yacaaba has the greatest longshore length; 300 m. The narrowest width of this beach was found to be 17 m, with the average width close to 22 m. Seaward to landward profiles from the headland, mid, and embayment zones are presented in Figure 2. Mean foreshore slopes range between 7^o and 10^o, all profiles are backed by a degraded cliff, and no berm is present. From headland to embayment the tidal zone, approximately located by the upper limit of *Chamaesipho columna* (see page 44), includes progressively less of the boulder beach.

Although sand is associated with the beach (Plate 6), the boulder beach is not the result of recent exposure by storm waves. The supply of boulder-sized sediment to this beach appears to be extremely limited because the adjacent cliff, and major sediment source, is not being actively eroded under present-day conditions.

Copacabana Boulder Beach

Copabana boulder beach, 50 km north of Sydney, faces south and is exposed to the open ocean. This beach, as well as Bombo, Kiama, and

Figure 2a. Headland zone.

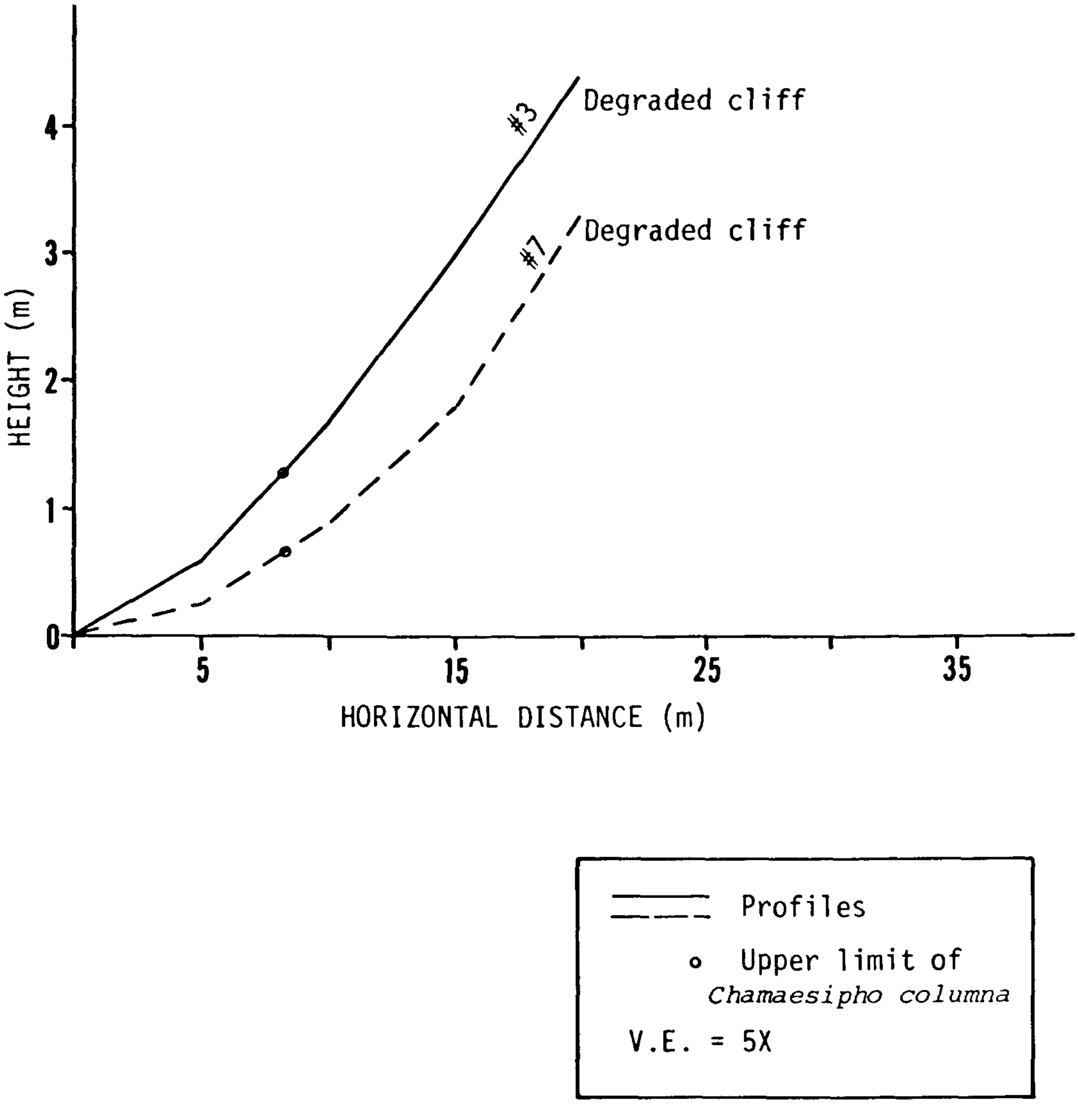


Figure 2. North Yacaaba boulder beach profiles numbered from headland to embayment, two per longshore beach zone.

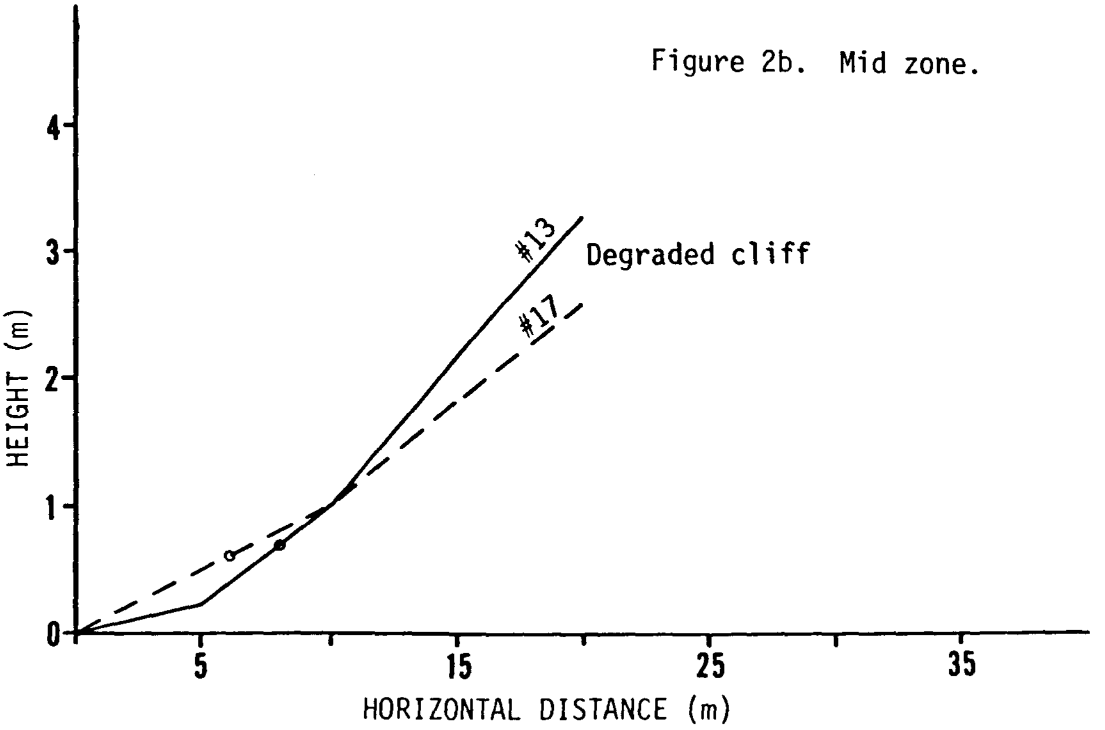


Figure 2b. Mid zone.
#13
#17
Degraded cliff
HEIGHT (m)
0
1
2
3
4
5
15
25
35
HORIZONTAL DISTANCE (m)

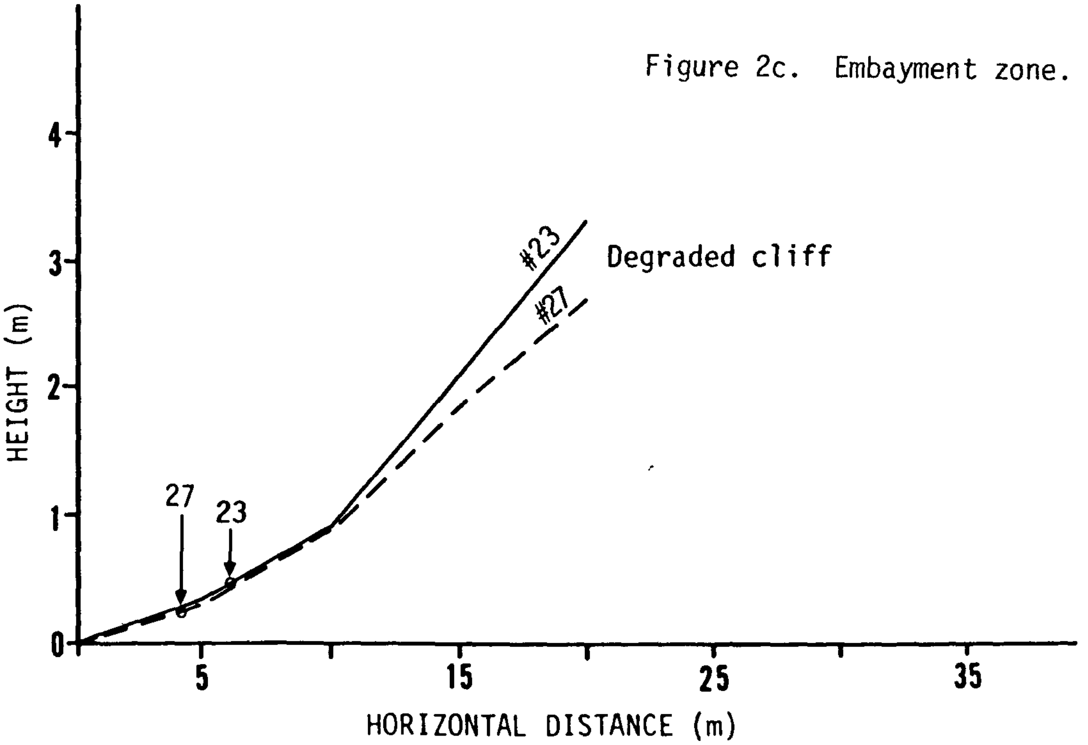


Figure 2c. Embayment zone.
#23
#27
Degraded cliff
27
23
HEIGHT (m)
0
1
2
3
4
5
15
25
35
HORIZONTAL DISTANCE (m)

Plate 6. North Yacaaba boulder beach.

Plate 7. Copacabana boulder beach showing imbrication and sand associated with boulders.

Crookhaven, are located in the broad structural unit known as the Sydney Basin. Tudibaring Head, the headland adjacent to, and the main sediment source for Copacabana beach (Plate 2) is composed of Gosford Formation Sandstone, which is part of the Triassic Narrabeen Group (McElroy *et al.*, 1969). This headland and the boulders on the beach correspond closely to the Mangrove and upper Ourimbah members. The Mangrove Sandstone tends to be well bedded with a pebbly base and yellow cavernous weathering. The lower portion of the Mangrove Sandstone is shaly sandstone and shale, and the Ourimbah Sandstone is fine to medium sandstone (McElroy *et al.*, 1969). Thus, the nature of the bedding in the cliff causes platy (disc-shaped) material to be liberated, greatly influencing the shape of sediment found on Copacabana boulder beach.

The longshore length of this beach is 150 m, narrowest width 17 m, and average width approximately 25 m. The mean foreshore angle varies between 7^{o} and 12^{o}. A shore platform underlies the headland zone which is backed by an active cliff. The mid zone is backed by a degraded cliff, and the embayment zone by a grassed rise. As can be seen from the profiles presented in Figure 3, no berm is present and the tidal zone changes little along this beach.

Sand is found with the boulders in the portion of the beach nearest the embayment, but the beach is not an ephemeral feature. Of the beaches studied, Copacabana exhibits the most consistent and pronounced imbrication, reflecting the predominance of disc-shaped sediment (Plate 7). After measuring and sampling of this beach were completed, some boulders in the seaward portion of the beach were removed to form a small breakwater and

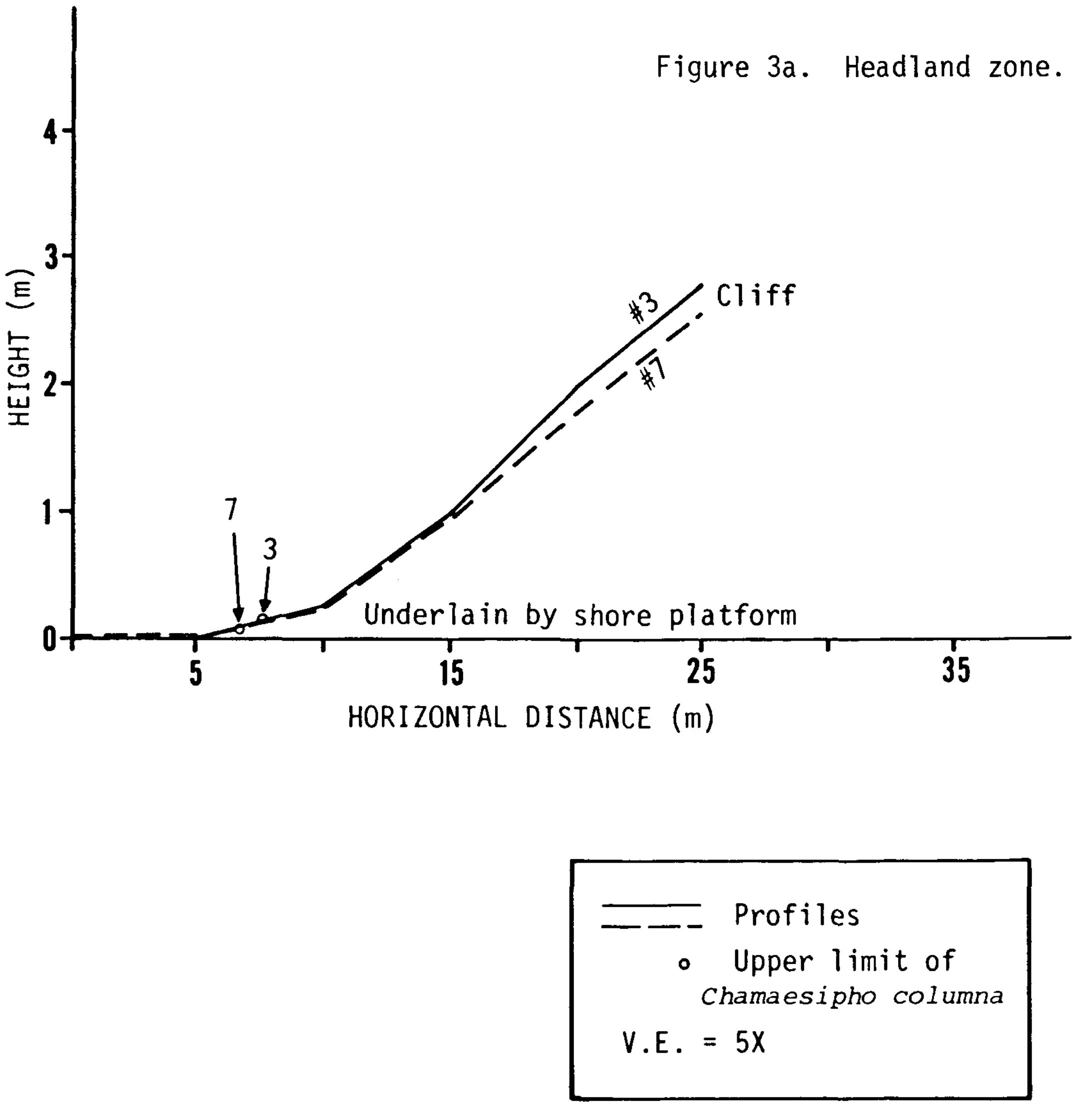


Figure 3. Copacabana boulder beach profiles numbered from headland to embayment, two per longshore beach zone.

Figure 3b. Mid zone.

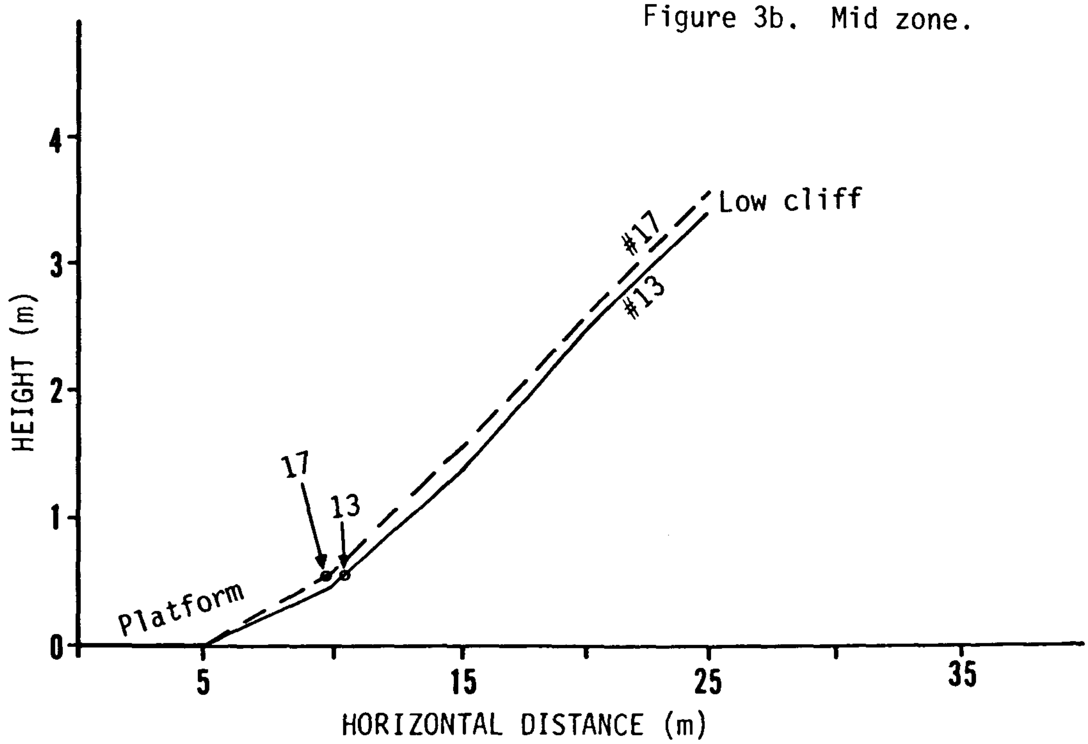
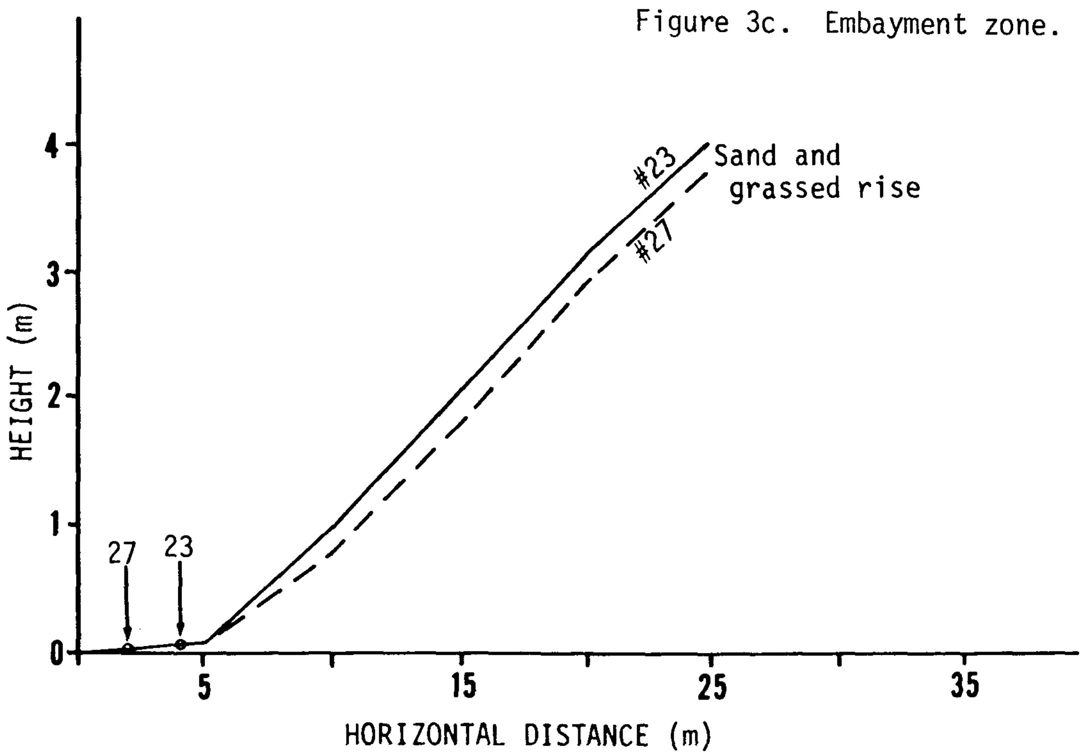


Figure 3c. Embayment zone.



swimming area. This disturbance had no effect on the present study, but renders the beach unsuitable for further research.

Bombo Boulder Beach

Bombo boulder beach is located about 95 km south of Sydney; it faces south and is exposed to the open ocean. Bombo headland and cliff (Plate 3) are composed of Bombo (also known as Bumbo) Latite, a member of the Geringong Volcanics, which are part of the Permian Shoalhaven Group. The latite is a medium-grained, medium-grey lava (Raam, 1969), and in this location exhibits striking columnar jointing. It is underlain by tuffaceous Kiama Sandstone which forms the shore platform. Many boulders which were originally rock refuse from a nearby latite quarry have been mixed by marine processes with naturally derived sandstone and latite boulders to form a boulder beach.

The shore platform forms a base for boulders near the headland while the other extremity of the beach is associated with and sometimes partially buried by a sand beach (Plate 8). The length of this beach, therefore, varies by several metres, depending on recent wave conditions. When measured and sampled in 1975, the boulder beach was 175 m long, which is probably near to its maximum length. The width averages 16 m, and the narrowest portion is 11 m wide. Bombo beach profiles (Figure 4) have mean foreshore angles ranging from 9^{o} to 12^{o}, and the headland zone is backed by an active cliff. No clear berm can be seen, however, a break in slope in the mid and embayment zones (see Figures 4b and 4c) indicates what, in the field, appears to be a berm feature.

Plate 8. Bombo boulder beach showing partial burial by sand in the portion of the boulder beach nearest the embayment. Wave approach can be seen to be oblique to most of the beach.

Plate 9. Kiama boulder beach showing oblique wave approach.

Figure 4a. Headland zone.

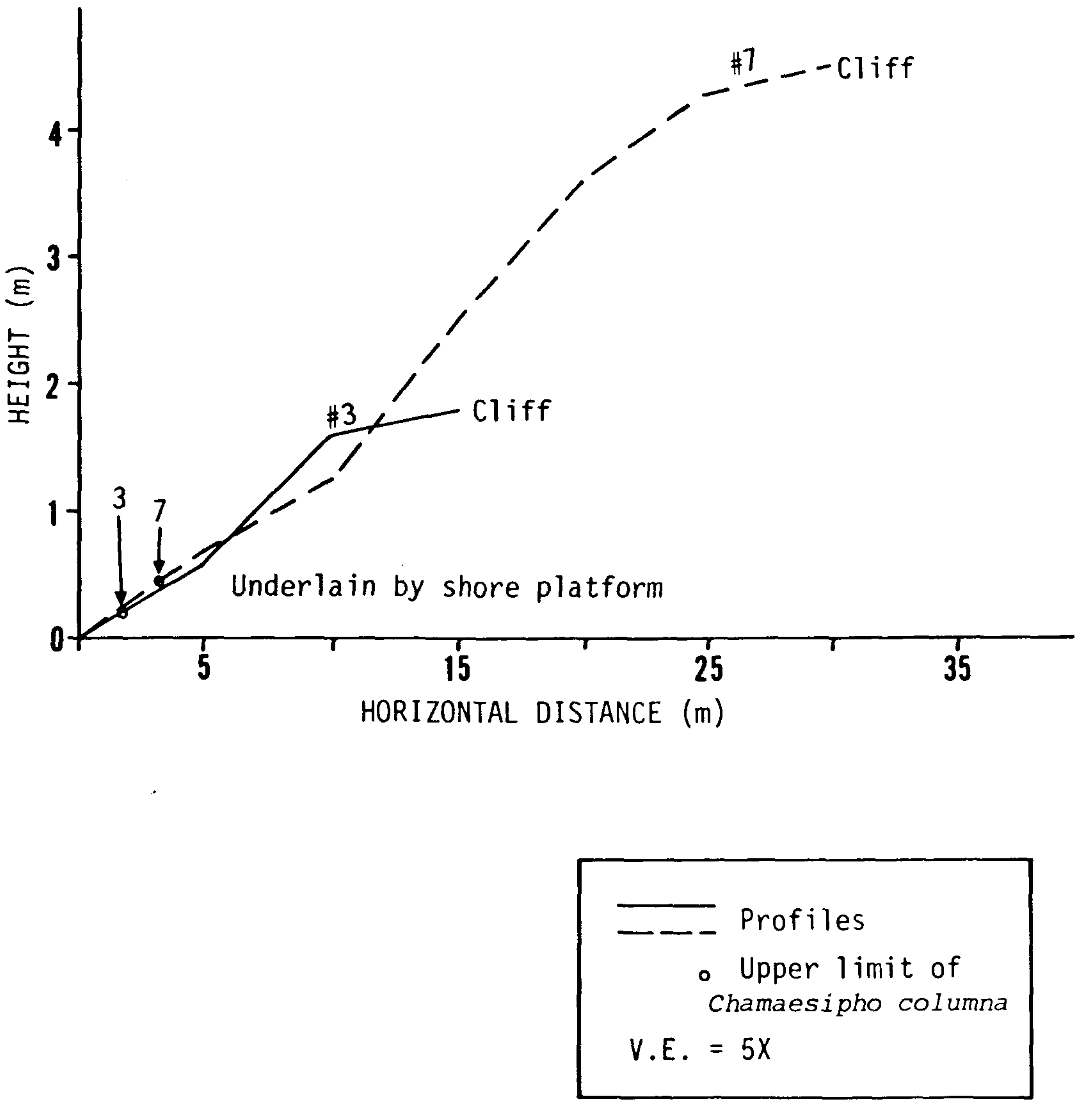


Figure 4. Bombo boulder beach profiles numbered from headland to embayment, two per longshore beach zone.

Figure 4b. Mid zone.

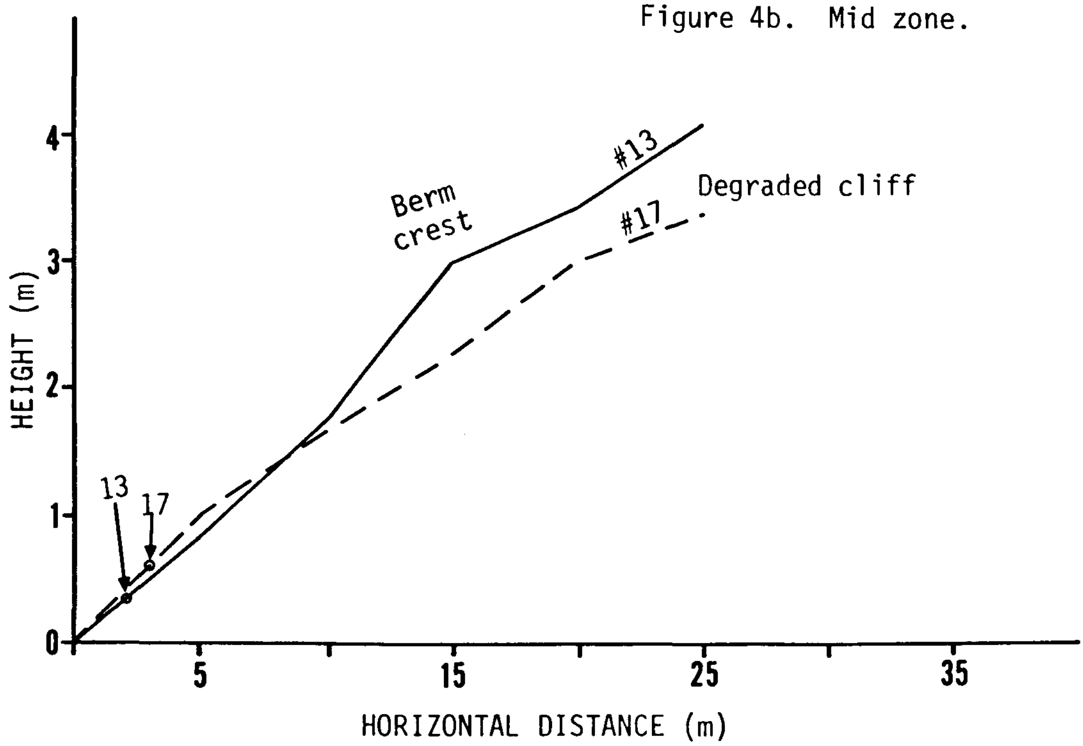
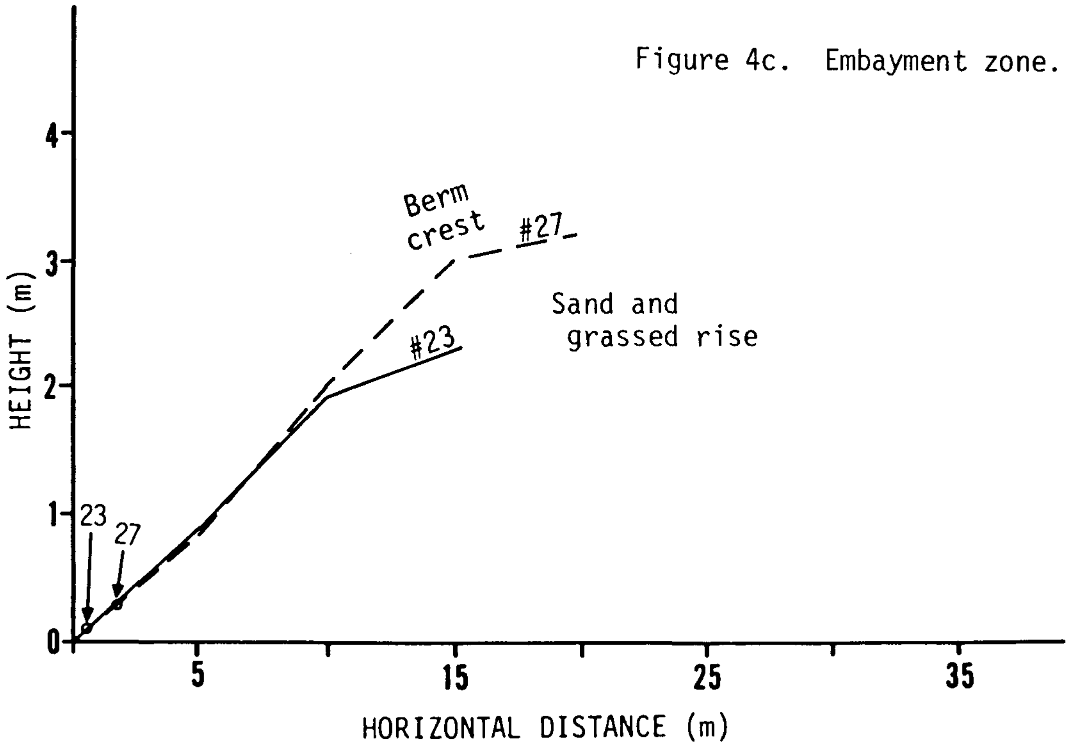


Figure 4c. Embayment zone.



Kiama Boulder Beach

Five kilometres south of Bombo boulder beach (100 km south of Sydney) is Kiama boulder beach which has a north-north-easterly exposure to the open ocean. Plate 4 shows the position of this beach which behaves as a sediment trap for material liberated from disintegrating cliffs extending approximately 1 km south. These cliffs are composed of Westley Park Sandstone (Branagan and Packham, 1970), the lowest member of the Geringong Volcanics. This formation is described as "shallow-water marine, highly fossiliferous, green-grey sandstones, with glacial erratics, minor silt-stones and conglomerates" (Raam, 1969, p. 367). There are no massive joint patterns or distinct cleavage planes which might influence the shape and size of particles produced by these cliffs. A shore platform provides a base and protection from waves for one-third of this boulder beach, while the remainder is underlain by pebbles, cobbles, and boulders; no sand is present (Plate 9).

The length of the beach is 150 m and the width averages 23 m, with the minimum being 17 m. The profiles of Kiama boulder beach are illustrated in Figure 5. Mean foreshore slope ranges between 6^{o} and 12^{o}, a cliff backs only the headland zone, and each profile shows a berm. Lichen colonization, noted on the profiles, was observed on many boulders in the landward portion of this beach and will be discussed further in Chapter VII.

Crookhaven Boulder Beach

The most southerly beach selected for study is at Crookhaven Head, about 125 km south of Sydney. The headland (Plate 5) is composed of well-

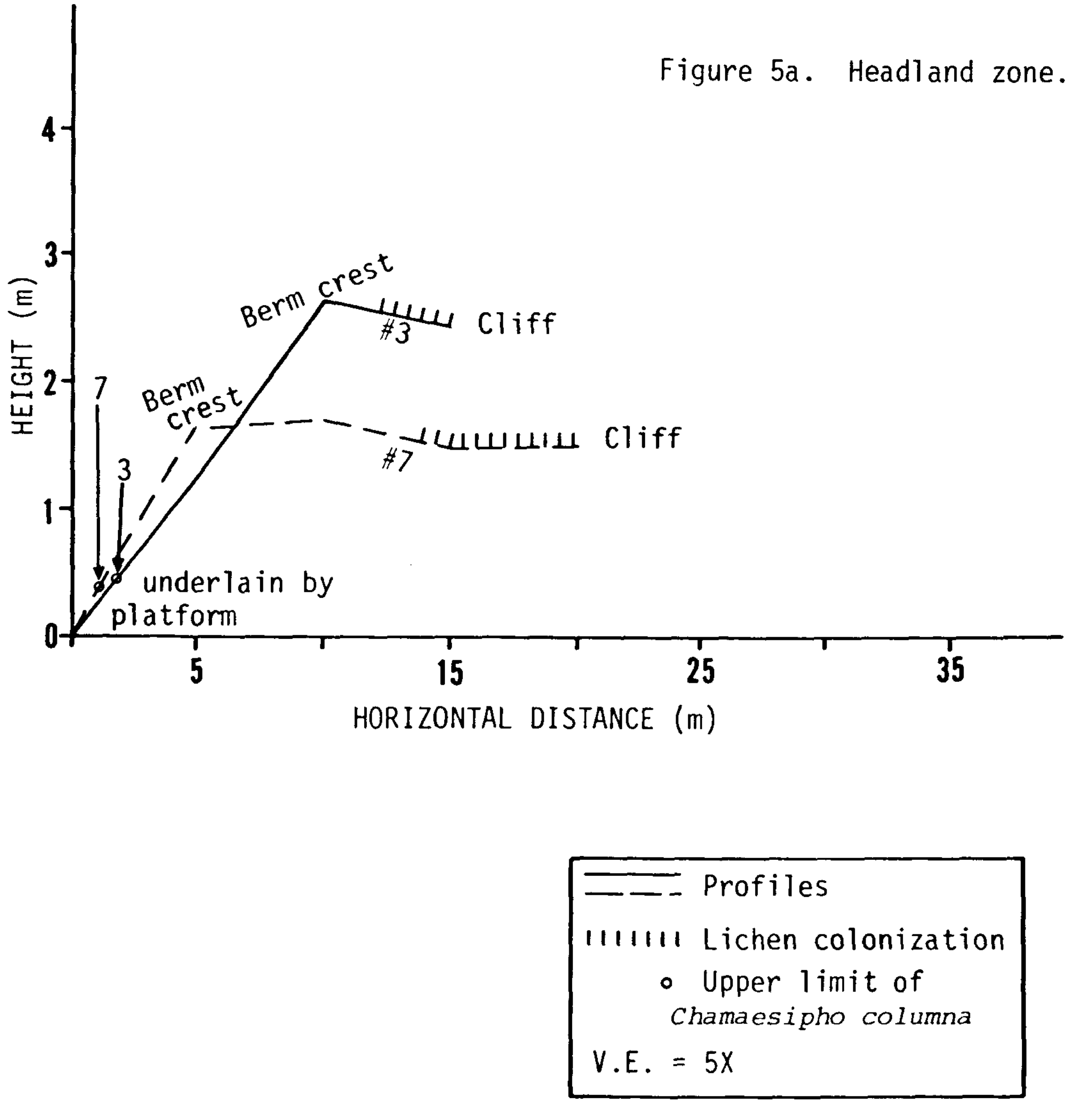


Figure 5. Kiama boulder beach profiles numbered from headland to embayment, two per longshore beach zone.

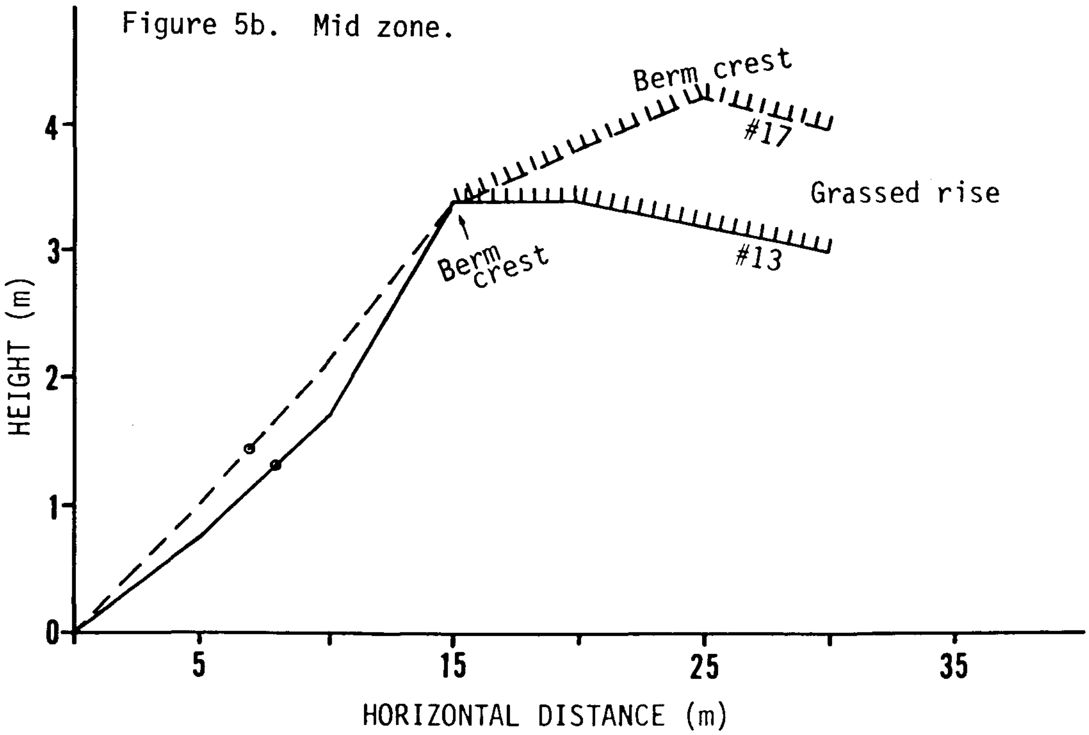


Figure 5b. Mid zone.
Berm crest
#17
Grassed rise
Berm crest
#13
HEIGHT (m)
0
1
2
3
4
5
15
25
35
HORIZONTAL DISTANCE (m)

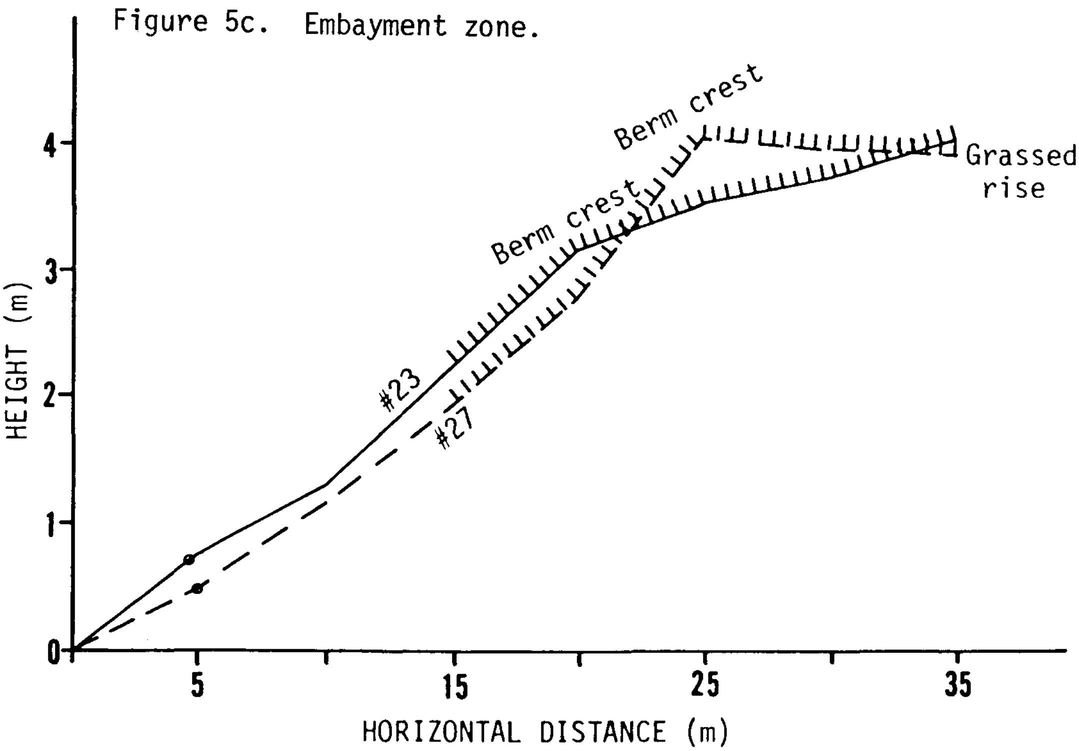


Figure 5c. Embayment zone.
Berm crest
Berm crest
Grassed rise
#23
#27
HEIGHT (m)
0
1
2
3
4
5
15
25
35
HORIZONTAL DISTANCE (m)

jointed sandstone and siltstone, and yields an abundant supply of large cubic blocks (reflecting the massive jointing pattern) to the boulder beach. This sandstone and siltstone is a lower member of the Permian Shoalhaven Group, and was considered by Nashar (1967) to be Wandrawandian Siltstone, a well-jointed silty sandstone with pebbly bands (McElroy *et al.*, 1969). More recently, it has been suggested by Gostin and Herbert (1973) that Crookhaven Head is composed of a member of the Conjola Sub Group.

Crookhaven beach is exposed to the open ocean and has an east-south-easterly aspect. No sand is associated with this beach, most of which is underlain by a shore platform (Plate 10). The longshore length is 150 m, average width is 24 m, and minimum width is 18 m. Figure 6 illustrates the profiles measured on Crookhaven beach, with the mean foreshore slope varying between 7^{o} and 9^{o}. No berm feature can be seen on this beach. The headland and mid zones are backed by a steep cliff while the embayment zone is backed by a low, degraded cliff, and all along this beach the tidal zone varies little. There is cavernous weathering of and lichen present on some landward boulders (discussed in Chapter VII).

<u>Summary</u>

In summary, Copacabana, Kiama, and Crookhaven boulder beaches are composed of various sandstones, whereas North Yacaaba and Bombo beaches consist mainly of volcanics. The joint configuration in the adjacent cliffs may be reflected in the size and shape of sediment supplied to each boulder beach; this is especially evident at Copacabana, where the cliff composed of thinly bedded sandstone produces disc-shaped boulders, and at Crookhaven, where large cubic blocks reflect the jointing pattern in the adjacent sandstone and siltstone cliff.

Plate 10. Crookhaven boulder beach.

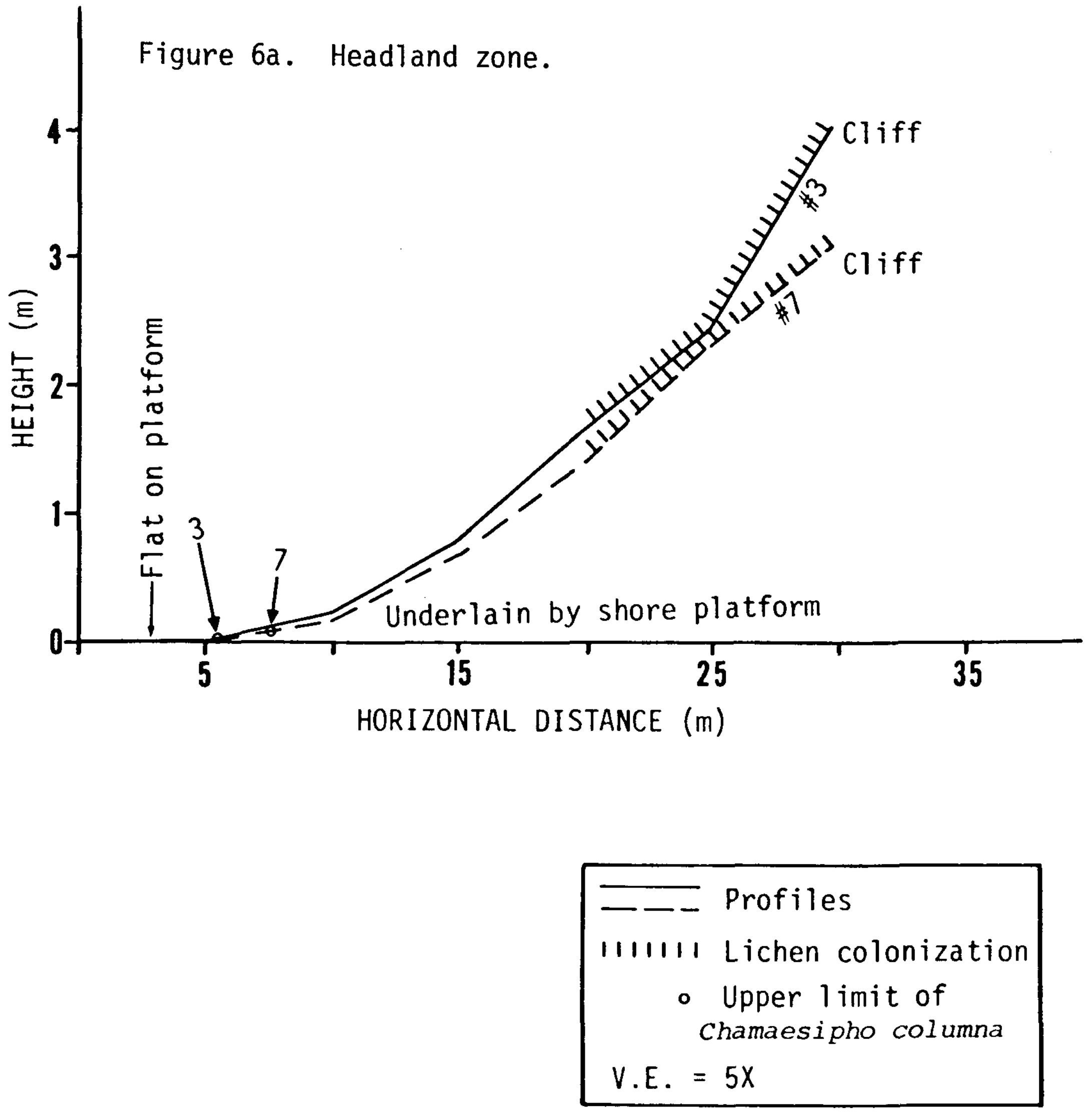


Figure 6. Crookhaven boulder beach profiles numbered from headland to embayment, two per longshore beach zone.

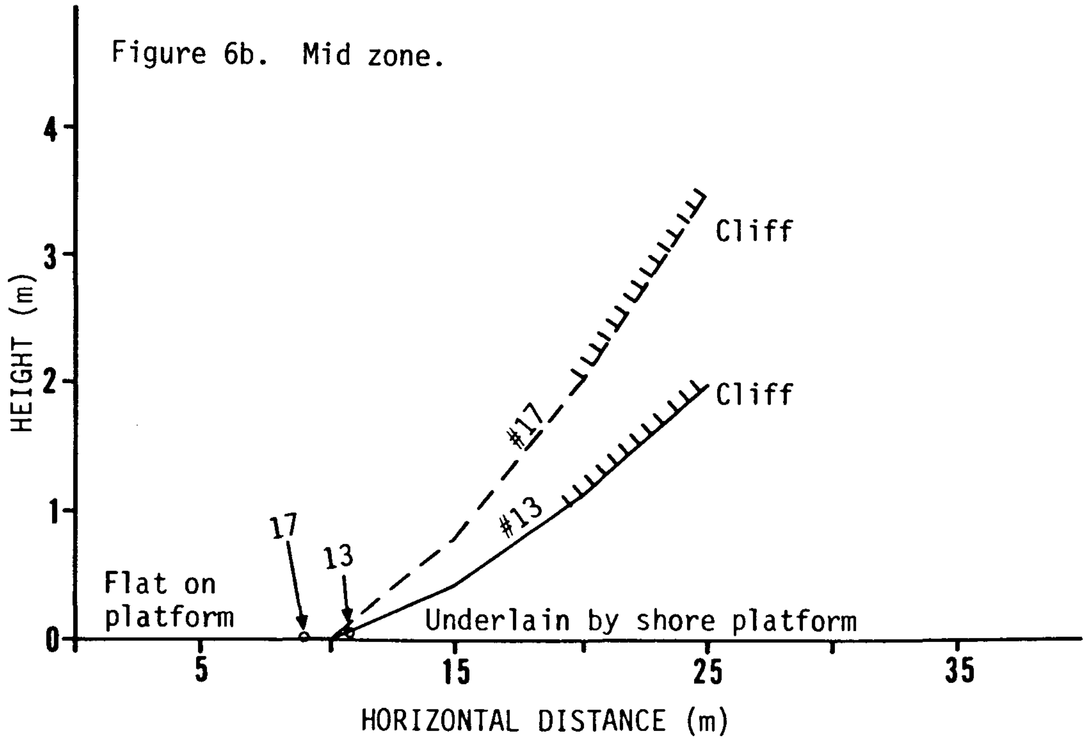


Figure 6b. Mid zone.
HEIGHT (m)
4
3
2
1
0
Cliff
Cliff
#17
#13
17
13
Flat on
platform
Underlain by shore platform
5
15
25
35
HORIZONTAL DISTANCE (m)

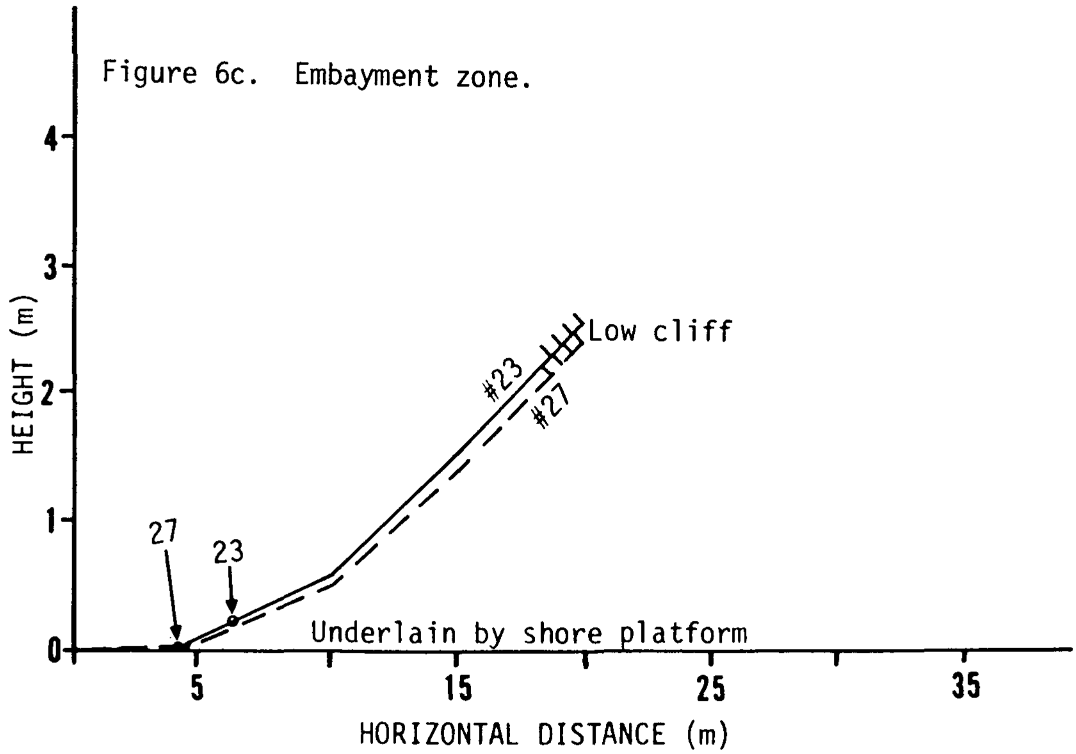


Figure 6c. Embayment zone.
HEIGHT (m)
4
3
2
1
0
Low cliff
#23
#27
27
23
Underlain by shore platform
5
15
25
35
HORIZONTAL DISTANCE (m)

Boulders are supplied in very limited quantities, if at all, to North Yacaaba beach, whereas there appears to be a steady input of fresh boulders at the other four beaches. On all five boulder beaches, sediment is of local origin, supplied mainly by the erosion of adjacent cliffs and possibly shore platforms (see Gill, 1971). Sand is associated with North Yacaaba, Copacabana, and Bombo beaches.

Since storm waves are the only waves competent to move the boulder-sized particles on the studied beaches, the profiles presented in Figures 2, 3, 4, 5, and 6 are storm-beach profiles. The mean foreshore slopes range between 6^{o} and 12^{o}, and the profile shape tends to be concave upward, a form considered indicative of high swash velocity (Dolan and Ferm, 1966). This concavity is particularly evident on Crookhaven, the beach which has the largest mean size of particles. Small-scale profile features (such as tidal ridges) were impossible to discern because of the great size of individual particles.

Because it was difficult and dangerous to obtain, no offshore information is included in the beach profiles. However, it is known that between Sydney and Jervis Bay, New South Wales, the nearshore profile is considered steep (Wright, 1976). Thus, the active nearshore zone is narrow and waves of high energy reach the studied beaches. Along this coast, "on the average only 3.4% of the incident wave power is dissipated before reaching the inshore zone. By contrast, friction-induced power expenditures over the low-gradient nearshore profiles fronting the coasts of Sergipe (Brazil), Santa Rosa Island (Florida, U.S.A.), Cape Henry to Cape Hatteras (U.S.A.), and Georgia (U.S.A.) average 29, 48, 58, and 84% respectively" (Wright, 1976, p. 633).

CHAPTER II

METHODS

FIELD METHODS

Sampling Technique

The unbiased selection of a representative sample of boulders from each beach is essential to the validity of this study. Because of the great size and weight of the material to be measured, a technique was needed which allowed the objective selection of each sample and its measurement *in situ*.

The most suitable sampling method was found to be a grid, similar to the system outlined by Krumbein (1953) and Wolman (1954). Columns were to be oriented normal to the low-water line, and rows parallel to the shore; one sample was to be taken from beneath each intersection point (Figure 7). Pacing was first attempted as a means of establishing this grid, but proved impracticable because the large sediment size made uniform pacing impossible. A grid of heavy rope was then constructed and samples taken at the intersection points of the rope grid when it was placed on the beach. This method too proved unsatisfactory because the rope grid was cumbersome and very difficult to lay over or move along the highly irregular surface of the boulder beach.

The third method attempted, and that eventually employed, was the most rigorous possible under the circumstances. A grid composed of approximately 30 profiles with an average of 10 sample points per profile was constructed for each beach using 30 m tapes. This was done by first measuring the length of each beach, and then locating the profiles at equal intervals along the beach. A tape was then stretched along each profile, and the sampling points located at fixed intervals along each profile. Since the tape was held taut

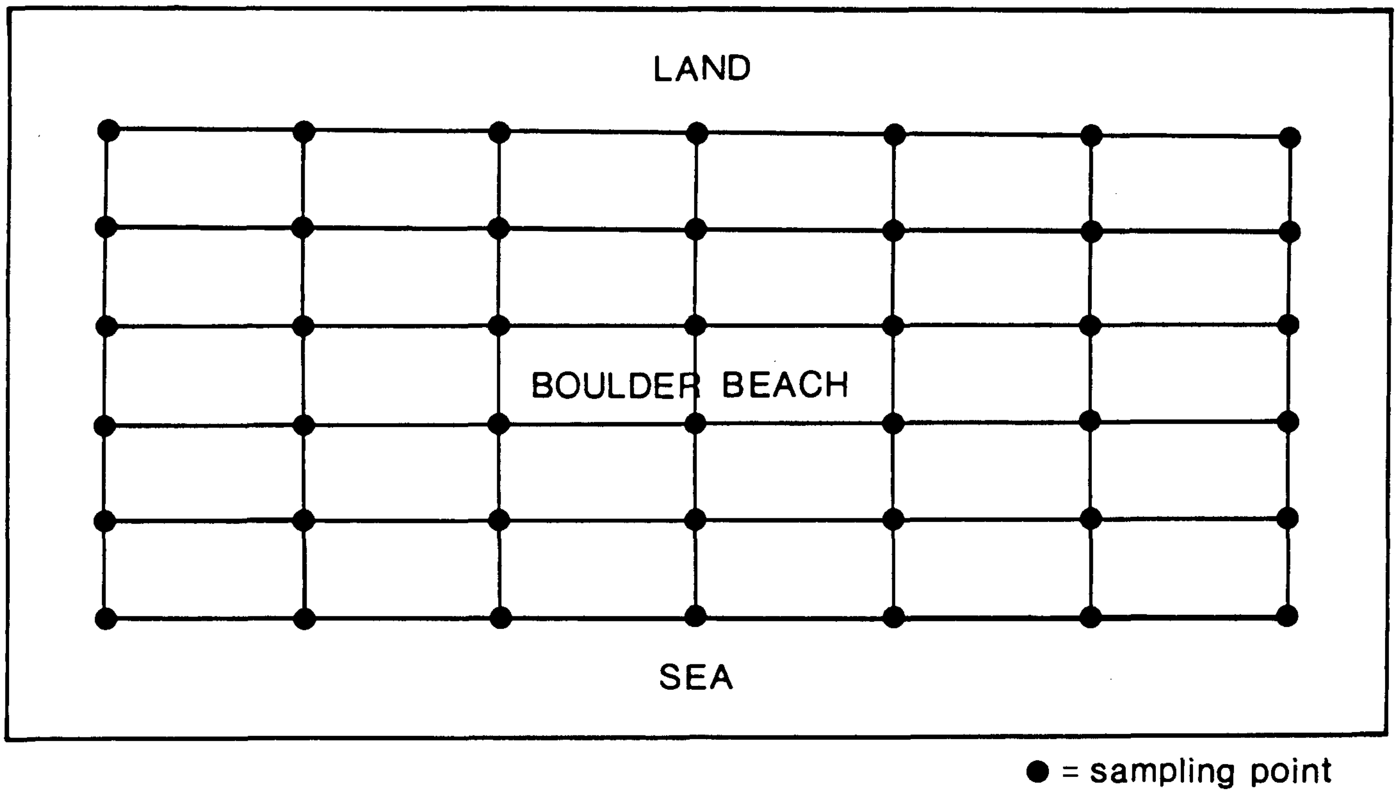


Figure 7. Grid for sampling boulder beaches.

at each end and placed over the beach, there was no foreknowledge of, or bias in, the location of sample points. This sampling method may be classified as "systematic point sampling" (Young, 1972, p. 145).

The mutually perpendicular long, intermediate, and short (A, B, and C) axes (Krumbein, 1941) of the particle beneath each sample point were measured to the nearest 0.5 cm with a linen tape measure. All particles at sample points were large enough to be measured in this fashion. At the same time, roundness of each sampled boulder was visually assessed. The grid position of each boulder was noted so that data could be analyzed by location. The basic data collected in this manner is included in Appendix VI.

All beaches were sampled to either their seaward limit or to the point where the beach was submerged at low tide. However, these beaches are surf beaches, consequently, low-water level at one beach on one day may not be equivalent to the low-water level on another day or on another beach. To facilitate valid between-beach comparisons, the establishment of a common height datum was essential.

The seaward portion of each studied beach supports *Chamaesipho columna*, a small, fixed barnacle which is a good "marker" species because its upper extent indicates the upper limit of the tidal zone (Dakin, 1973, p. 91). Therefore, when sampling, the position of the landward limit of the *Chamaesipho columna* zone was noted and plotted on the grid, thus providing a common environmental datum for the studied beaches.

For purposes of analysis, each beach was divided into three zones from sea to land (Figure 8). Thirds were chosen so that each zone would contain close to 100 measured boulders and because the tidal zone (as

Figure 8a. Up-beach zones.

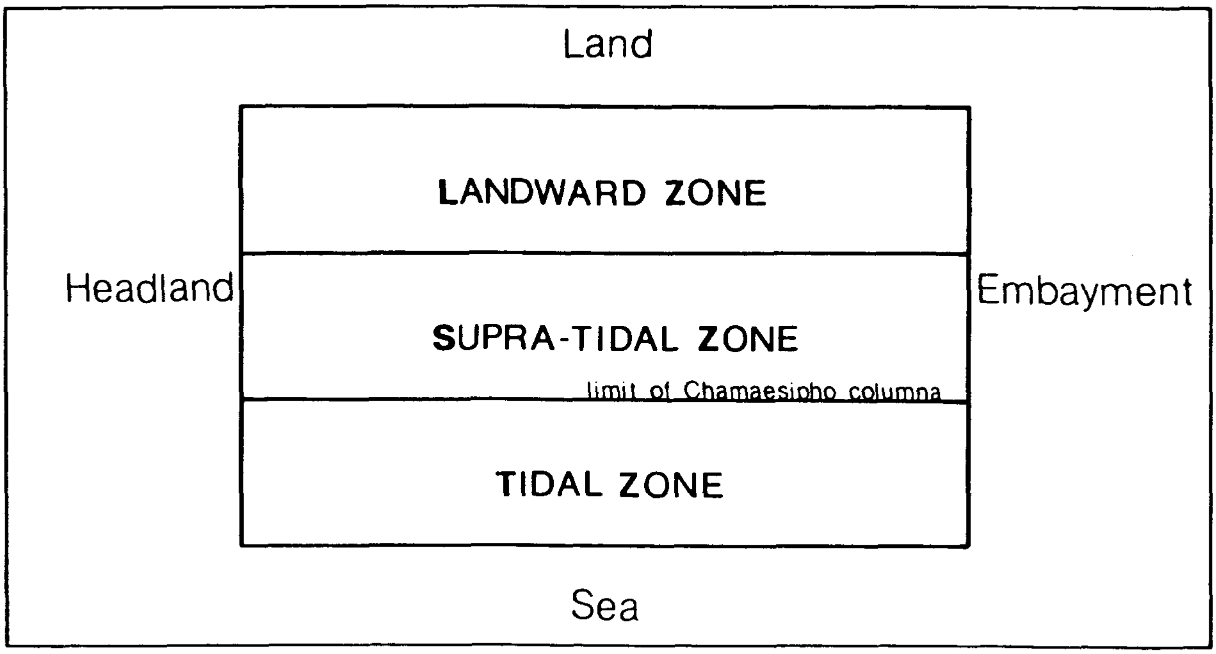


Figure 8b. Longshore zones.

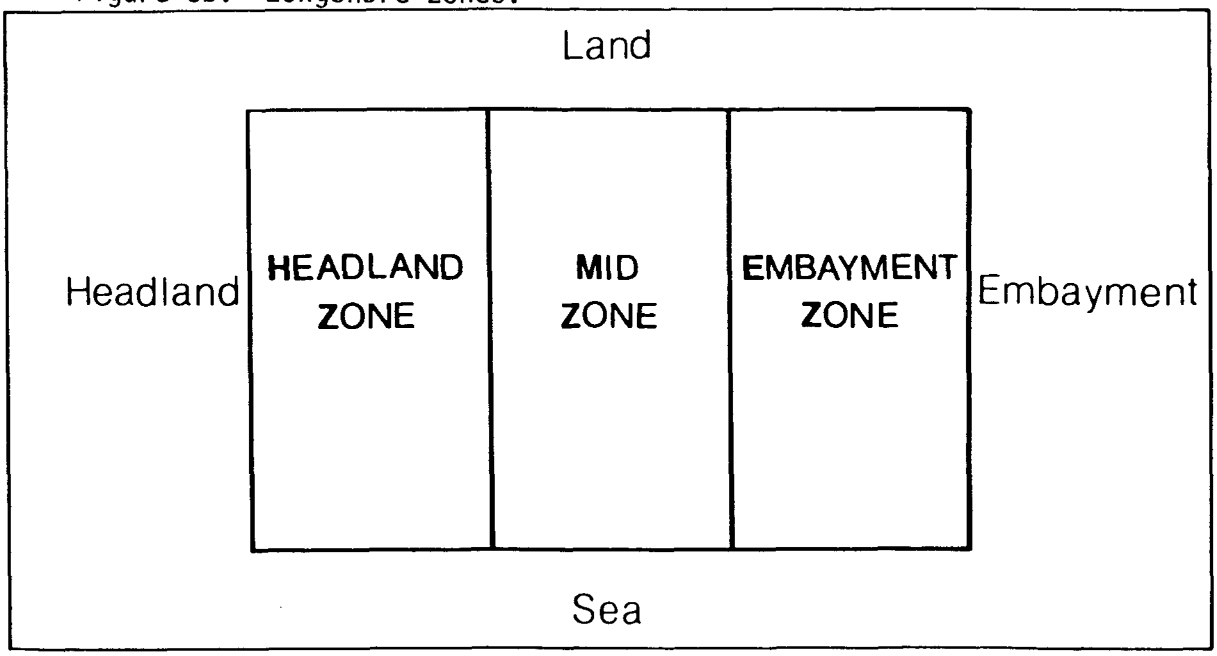


Figure 8. Zonal divisions of the studied boulder beaches.

indicated by the upper limit of the *Chamaesipho columna*) tended to occupy close to one-third of each beach. The tidal zone was considered as one unit and, if a berm were present, the upper two-thirds of the beach were divided at the crest. In the absence of a berm, the remaining area was equally divided. These three portions will be referred to as:

1) the tidal zone;
2) the supra-tidal zone;
3) the landward zone.

Each beach was also divided into three zones from headland to embayment. In this case, the division was simply into thirds, with each being referred to as:

1) the headland zone;
2) the mid zone;
3) the embayment zone.

Size Measurement

For each sampled particle, size, shape, sphericity, and roundness were assessed (values in Appendix VI). Sieve analysis is the most common method of obtaining size data for sedimentary material. Thus, when this technique is unsuitable, as is clearly the case in this study, it is highly desirable to collect size data in a form comparable to sieve analysis. Kellerhals and Bray (1971a, 1971b) have demonstrated that grid sampling is equivalent to bulk sieve analysis and that these two sampling methods are directly comparable.

Measurements of the B axis were used to indicate size and thus are equivalent to sieve measurement of size, since the B axis is the particle dimension measured by sieving (*e.g.*, Bluck, 1967). These measurements were converted from centimetres to *phi* (ϕ) units ($\phi = -\log_2$ mm : Krumbein, 1934, 1936, 1938) to maintain consistency and to facilitate comparisons with other sedimentary studies in which *phi* units are commonly used.

Udden's scale of size terms (Udden, 1914), as adopted by Wentworth (1922a), was used to establish the lower mean grain-size limit for a boulder beach. According to the Wentworth class limits, boulders have a median diameter equal to or greater than 256 mm, which is equivalent to a *phi*-scale value of -8ϕ.

Shape Classification

> Because the shape of irregular objects cannot be conceived in absolute quantitative terms, all measurements of this parameter must be arbitrarily defined and their use must be comparative (Moss, 1962, p. 338).

Shape, a measure of the relation between the three axial dimensions of an object (Krumbein, 1939; Folk, 1974), can be described by various methods (see Carver, 1971), but the most widely used are those proposed by Zingg (1935) and by Sneed and Folk (1958). Both of these methods of classification describe the shape by using measurements of the A, B, and C axes because, although the particles are not triaxial ellipsoids, statistically they may be considered as such (Krumbein, 1941).

Sneed and Folk identify 10 shape classes; but this number of divisions is too large to allow valid statistics to be obtained with a sample size of about 100 (each beach zone). Consequently, the Zingg (1935) classification of shape, which contains only four classes, was employed. Using the Zingg classification also facilitated comparison of the results from this study with those of Bluck (1967, 1969) who examined gravel beaches, and with the predictive shape research by Smalley (1966).

The Zingg shape classes were determined for each boulder by the ratios of the B and A axes, and the C and B axes as follows:

	B/A	C/B
SPHERE	$> 2/3$	$> 2/3$
DISC	$> 2/3$	$\leqslant 2/3$
ROD	$\leqslant 2/3$	$> 2/3$
BLADE	$\leqslant 2/3$	$\leqslant 2/3$

This method of shape classification provides a simple and objective measure of form, but since the resulting categories are nominal, statistical analysis is limited.

Another shape index was calculated for each sampled boulder. This index indicates the extent to which a particle approaches an oblate or prolate spheroid (Williams, 1965) and is found in the following manner:

If $\frac{B^2}{AC} > 1$, the ellipsoid is tending to be oblate;

If $\frac{B^2}{AC} < 1$, the ellipsoid is tending to be prolate.

(A = A axis, B = B axis, C = C axis)

Although this index has been criticized by Dobkins and Folk (1970), it is used in this study to give an indication of shape tendency, and to investigate the proposition that coarse material subjected to wave action tends to become oblate (Russell, 1939; Blatt, 1959).

Sphericity Measurement

Sphericity is a quantitative statement of how nearly equal are the three dimensions of an object (Folk, 1974), and is geometrically interdependent with shape (Whalley, 1972). A measure of sphericity may indicate settling velocity because when volume and density are constant, a sphere has the least surface area of any shape and, hence, the greatest settling velocity. Sphericity measurements may also be related to transport probability because particles with great surface area:volume ratios (*i.e.* low sphericity) are most easily entrained. Various indices of sphericity have been developed (*e.g.*, Wentworth, 1922b; Wadell, 1934; Corey, 1949).

Folk (1955) introduced an index of sphericity which Sneed and Folk (1958, p.118) termed "maximum projection sphericity", and defined in the following way:

$$\frac{\text{Maximum projection area of sphere of same volume as the particle}}{\text{Maximum projection area of the particle}}$$

which reduces to $(C^2/AB)^{1/3}$, where A = length of A axis, B = length of B axis, and C = length of C axis. In addition to settling velocity sensitivity, this sphericity measure has been found to correlate well with bed-load movement. "For rolling velocity, the correlation coefficient with maximum projection sphericity is 0.86 . . ." (Sneed and Folk, 1958, p. 123). Because of its possible relation to the behavioural characteristics of boulders, the maximum projection sphericity (ψ_p) was calculated for each boulder sampled in this study.

Roundness Assessment

Roundness refers to the degree of smoothness of corners and edges of a clastic fragment, and is a property distinct from shape or sphericity. Various methods have been developed to assess roundness through both laboratory measurement of particles (Wentworth, 1919; Wadell, 1932) and visual comparison (Russell and Taylor, 1937; Krumbein, 1941, Powers, 1953). Visual comparison charts illustrate the various roundness classes, and each particle is compared with images of defined roundness, and the roundness value of the most closely corresponding illustration is assigned to the particle.

Since roundness values in this study had to be determined in the field, visual comparison was the most efficient method. Nine roundness classes were suggested by Krumbein (1941) and presented as silhouettes. These silhouettes, however, were too simple to accurately assess values of three-dimensional forms, and the numerous classes representing slight roundness changes resulted in a time-consuming, and not always consistent, decision as to which value to assign.

Powers' visual roundness chart (Powers, 1953, p. 118) displays artificial images with their roundness determined by Wadell's (1932) method (which is the ratio of the average radius of curvature of the edges or corners of the sample to the radius of curvature of the maximum inscribed sphere). Only six roundness classes are used, and three-dimensional models of both high and low sphericity particles are displayed for each class. Thus, this method of roundness classification eliminated most of the disadvantages of the Krumbein visual comparison method, and the Powers' visual roundness chart, reproduced at a larger scale by Folk (1968), was used to assess roundness in this study.

Powers' six roundness grades are defined so that the class limits approximate a $\sqrt{2}$ geometric scale. Folk (1955) assigned *rho* (ρ) values to these class limits in order to simplify computations, just as Krumbein (1934, 1936, 1938) developed the *phi* scale for grain size.

All assessments of roundness were made by the author, so that values are consistent within this study. Although another operator might assign different absolute values, the relative values would remain. To ensure consistency, 100 sampled boulders were marked and reassessed one month after the initial roundness evaluation. There was so little difference between the two sets of roundness values that a statistical test was not necessary to establish that the readings were consistent.

Sedimentary Variation With Depth

Because of the great size of the individual particles, only the surface sediment of each boulder beach could be investigated. Where boulders were resting on shore platforms and sediment depth generally of only a few boulders, surface measurements appeared to be representative of underlying particles. However, where sediment depth is greater, surface particles may differ from those found deeper in the beach. Perhaps, as has been observed in fluvial studies, larger particles may be preferentially deposited at the surface (Leopold *et al.*, 1964, pp. 209-215), and also, smaller particles could filter through the large interstices of the surface beach boulders and become buried. Bluck (1967) excavated a number of trench sections across three gravel beaches in South Wales, and found that particles within the beach tended to be smaller and more spherical than those at the surface. Thus, since the sedimentary properties of particles deep within the boulder beaches may be unlike those which were measured, in this study the discussion of boulder-beach sedimentology is confined to the beach surface.

Measurement of Beach Slope

The beach slope was surveyed by using an Abney level and two ranging poles. On each beach, the angles of six of the 30 sampling profiles numbered from headland to embayment (two profiles per longshore beach zone, see figures 2, 3, 4, 5, and 6) were measured, with stations along each profile being located at 5 m intervals (see Young, 1972, pp. 114-147). Both ranging poles were kept vertical (see Abrahams and Melville, 1975) with the aid of a "Survey Chief" attached to each pole. This device is essentially a small spirit level which indicates whether or not the ranging pole is in a vertical position.

When the beach is composed of boulders, the measurement of beach slope presents a special set of problems due mainly to the great variations in micro-relief caused by the size of the boulders. In this study, therefore, to ensure that both poles were placed at relatively similar depths in the boulder beach, a 5 m cord was attached to each pole and held taut (Figure 9). The bottom 50 cm of each pole were divided into measured lengths which were numbered. The height of the cord was equal on the two poles, and was varied within the numbered section according to the size of the boulders. This method, combined with reasonable judgement, helped to eliminate situations of grossly unrepresentative slope measurements (Figure 10).

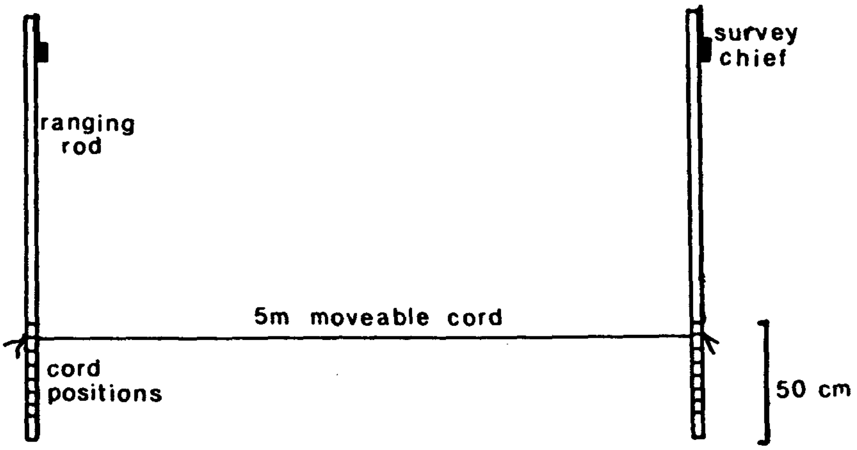


Figure 9. Beach angle measurement apparatus.

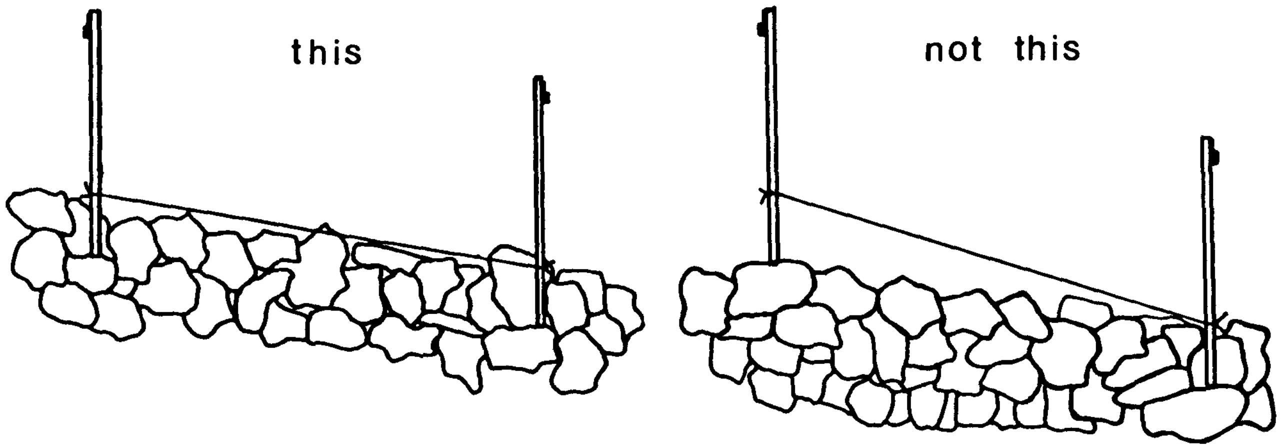


Figure 10. Use of beach angle measurement apparatus.

Monitoring of Boulder Movement

Kiama boulder beach was chosen for the monitoring of boulder movement because of all the studied beaches it is the least accessible and it is not adjacent to a beach suitable for recreation. For these reasons there was little chance of human interference with the marked boulders.

Three hundred boulders at the intersection points of a grid surveyed from a fixed bedrock position were marked and measured on Kiama beach so that any movement could be documented. Profiles were indicated by numerals and the grid points by letters (Figure 11). For example, profile 1 consisted of grid points labelled as 1a, 1b, 1c, . . . 1j, and this identification code was painted on each boulder. The paint was applied in such a fashion that even if a boulder were completely overturned, evidence of labelling would be visible. The A, B, and C axes of each marked boulder were measured and its position on the beach carefully noted. Two colours were used and alternated from profile to profile so that adjacent profiles were marked in different colours. This aided in the identification of transported boulders when abrasion had obscured the original markings. Boulders strewn across the platform adjacent to the studied boulder beach, and occupying the northern edge of a small boulder beach south of the studied beach (Figure 11) were painted with blue paint, a colour not used in the marking of Kiama boulder beach.

Initially, outdoor cement paint was used to mark the boulders, but even during periods of calm seas, the paint in the tidal zone would fade and be worn, often beyond recognition, in approximately 40 days. Late in the study, it was found that marine paint was more durable, but monthly maintenance of the marked grid remained essential.

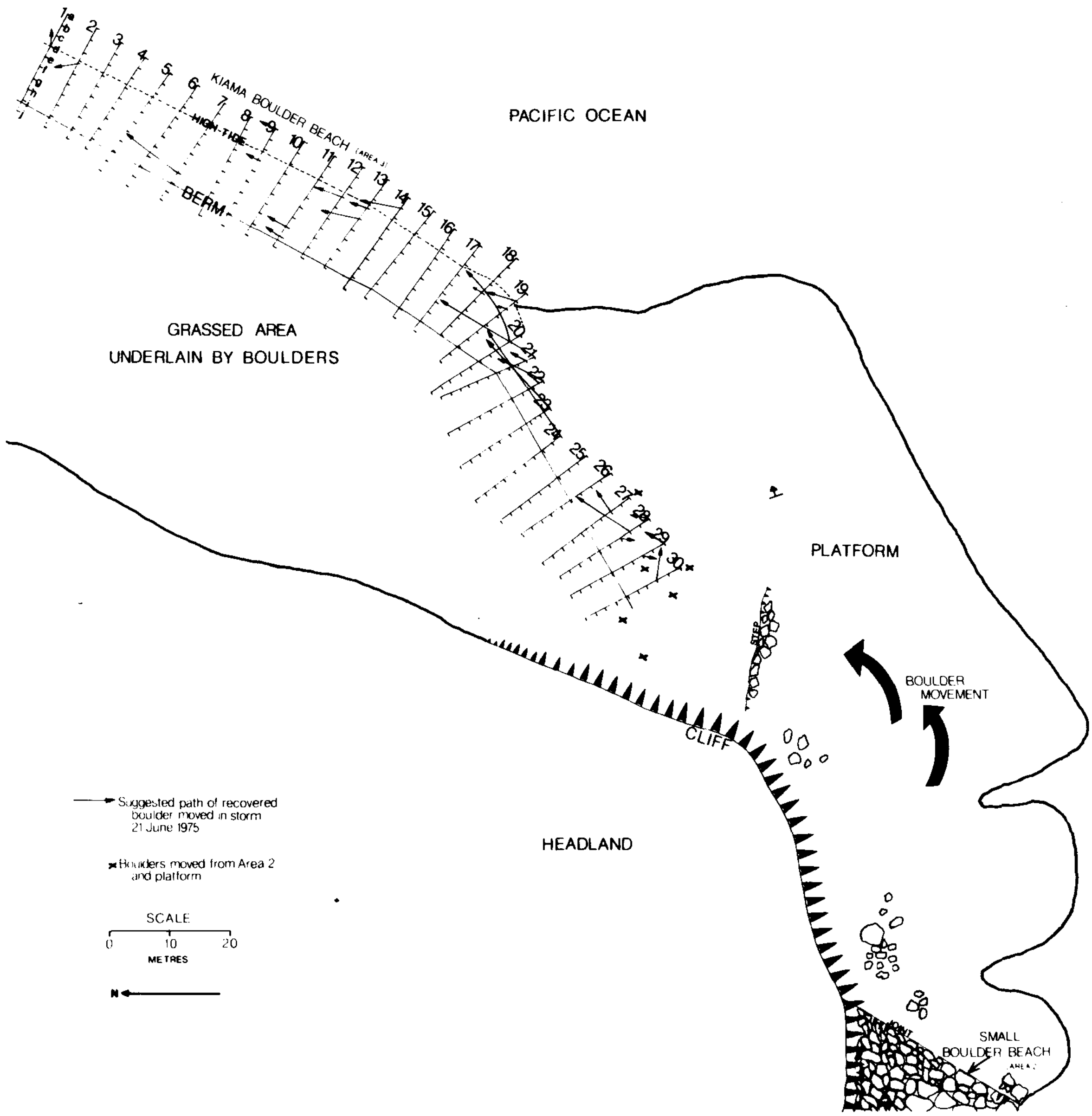


Figure 11. Field surveyed map of Kiama boulder beach showing profiles, sample points, and boulder movement.

Once a month and after every major storm during the two year period, June 1975 - July 1977, the beach was examined for evidence of boulder movement. Since the position of each marked boulder was known, the number of transported boulders could be readily ascertained. If the moved boulder was found, the distance and direction of the movement were measured. When a marked boulder was removed from its grid-point position, the boulder in its place at the grid point was marked and measured, so at all times a complete grid of 300 boulders of known size and position was maintained. Thus, the axial measurements, former positon, distance moved, and, when possible, distance moved and direction of movement were recorded for each boulder that was transported from its original grid-point position during the study.

WAVE-REFRACTION DIAGRAMS

Direct measurement of wave-energy expenditure on the boulder beaches was impossible. In a situation where boulder-sized sediment is being transported, it is likely that recording equipment would be destroyed. Therefore, wave-refraction diagrams (see Appendix I) were prepared to illustrate the *relative* energy expenditure and direction of wave approach on the five studied boulder beaches under different deep-water wave conditions. Royal Australian Navy Hydrographic Charts #808, #809, and #1070 were used to determine the bottom configuration and provide data for the construction of wave-refraction diagrams for the beaches. Additional information at a larger scale was available for Copacabana beach (Short, 1967) and Bombo beach (Stone and Gordon, 1970).

The actual construction of the wave-refraction diagrams was by the wave-front method (Wiegel, 1964, pp. 150-179). Since the available data do not warrant sophisticated analysis, this method was chosen, and because the wave crests are actually drawn they can be compared with field observations and air photographs, ensuring a realistic portrayal of the wave behaviour. All wave crests were first drawn in deep water with the waves approaching from the north-east, east, and south-east. Where data were available, crests were then extended into shallow water. A more detailed discussion of the wave-refraction diagrams is found in Appendix I.

QUANTITATIVE METHODS

All basic data were placed on computer cards with the data for each boulder recorded on a single card. These data include the X and Y coordinates indicating the exact position of the boulder in the sampling grid of the beach, the lengths of the A. B, and C axes, roundness (ρ class), shape (Zingg class), maximum projection sphericity (ψ_p), beach zone from headland to embayment in which the boulder was located, and beach zone from sea to land in which the boulder was located. The cards were grouped according to beach (see Appendix VI).

Because each boulder was represented by a separate card, information could be added as it was acquired. On Kiama beach (the beach monitored for movement), when a boulder was transported out of the grid to be replaced by another, the appropriate card was removed from the beach group and a new card was inserted, keeping the beach-grid record up-to-date. The moved boulder's card was marked with the date of movement, and then added to the group of cards representing transported boulders.

Following established convention, size-frequency curves were prepared with *phi* units on the abscissa, and the measure of frequency on the ordinate. Graphic methods have been employed in this study for illustrative purposes only, since all descriptive statistics have been found by the method of moments (Croxton, 1953; Chappell, 1967; Friedman, 1967; Davis and Ehrlich, 1970). The actual formulae employed may be found in *Statistical Package for the Social Sciences* (Nie *et al.*, 1975, pp. 183-185).

Descriptive Statistics

Since the mean is sensitive to the entire distribution, it is used in this study as the measure of central tendency for the interval and ratio level data (Pettijohn *et al.*, 1972; Briggs, 1977). Although often employed, the median is not a suitable measure of central tendency for skewed distributions (Folk, 1974). "The best measure of overall average size is the mean as computed by the method of moments" (Folk, 1966, pp. 80-81).

Roundness classes were determined in the field using the Powers method, so although the data are representative of a continuous scale, they are grouped into six categories, and the median is used as the measure of central tendency.

Following convention, the standard deviation is used as the measure of sorting. Sorting is not a statistical term, and "dispersal" better describes the standard deviation measure (Spencer, 1963). Since moment standard deviation has been employed, a sorting classification based on this statistic (Friedman, 1962) was used as a rough guide in assessing the sorting values found in this study (Table 1).

"Skewness is the tendency of a distribution to depart from a symmetrical form" (Croxton, 1953, p. 93). A positive (right) skewness value indicates graphic clustering to the left of the mean with a tail to the right. A negative (left) skewness value indicates graphic clustering to the right of the mean with a tail to the left. When the skewness value is zero, the distribution is symmetrical. In sedimentary studies, skewness is considered to be environment sensitive - that is, diagnostic of depositional environment (Friedman, 1961) - and a high degree of skewness may indicate the presence of more than one population (Folk and Ward, 1957; Spencer, 1963).

TABLE 1

GENETIC SORTING CLASSIFICATION BASED ON ϕ STANDARD DEVIATION*

Sorting Interval	Sorting Destination
0.50-0.80	Moderately well sorted
0.80-1.40	Moderately sorted
1.40-2.00	Poorly sorted
2.00-2.60	Very poorly sorted
>2.60	Extremely poorly sorted

*after Friedman, 1962, p. 750.

Kurtosis compares the spread in the centre of the distribution to the spread in the tails. In this study, when skewness and kurtosis are both zero, the distribution is normal. Kurtosis can measure bimodality in some instances (Darlington, 1970) but not in others (Hildebrand, 1971). Even the capacity of Kurtosis to measure "peakedness" is questionable since "almost any distribution may have a negative kurtosis value" (Chissom, 1970, p. 22).

Kurtosis has been used as an aid in the interpretation of sediment genesis (Folk and Ward, 1957), but only in conjunction with skewness. Friedman (1961, p. 517) also plots skewness against kurtosis, but indicates that kurtosis "provides a second dimension for the plot, but is not diagnostic of depositional environment." In this study, kurtosis was calculated for the distributions of size, roundness, and sphericity, however, this statistic did not appear to provide any additional information about the distributions. Given the problems in statistically interpreting kurtosis, and the fact that kurtosis did not appear to be useful in distinguishing between different depositional environments either within or between the studied beaches, the results for this statistic will not be discussed.

Trend Surface Analysis

Trend surface mapping is an appropriate method for the presentation of the boulder beach data because the discrete point samples are taken from a continuous surface (see Norcliffe, 1969). The contour maps obtained from trend surface analysis of size, shape, sphericity, and roundness of boulders on each studied beach provide a visual demonstration of the amount and direction of systematic variations. Meaningful and compact illustration of the dominant trends was the primary object of the analyses. However, since trend surfaces can be considered as "response surfaces" (Chorley and Haggett, 1965, p. 47), process can be inferred.

Trend surfaces were calculated and plotted by computer using the "Fortran IV and Map Program for Computation and Plotting of Trend Surfaces for Degrees 1 Through 6" (O'Leary *et al.*, 1966). The significant order was obtained by the application of the F test, and unless the term of order (K + 1) significantly improved the fit, it was dropped, and the fitting rested at order K (Chayes, 1970, p. 1273). In most cases, the significant order was quite low. Where higher orders were found to be significant, the complexity of the surface obscured its descriptive value, so a lower order is presented (see Robinson, 1970). The degree of explanation is statistically significant ($\alpha = 0.05$) for all trend-surface diagrams presented in this study.

The upper limit of the *Chamaesipho columna* (tidal zone) is indicated on each map. Therefore, the trend surface contour maps (diagrams) are directly comparable because they all contain a common reference point. To further enhance their comparability, regardless of actual beach orientation, the maps are presented with the headland zone (high wave-energy zone) to the left, as in Figure 12.

Each trend surface diagram, therefore, is a regularized and comparable representation of each beach, derived from the data collected in a grid pattern. It must be remembered, however, that these diagrams mould an irregularly shaped beach into a rectangle and a false impression of the beach may result (Figure 13).

Non-Parametric Statistics

Since all the sedimentary properties measured in this study (size, shape, sphericity, and roundness) were found to have non-normal distributions, non-parametric statistical tests were employed. A 0.05 level of statistical significance was used for every test. The following non-parametric statistical tests were utilized:-

1) Spearman rank correlation;
2) Kruskal-Wallis one-way analysis of variance;
3) Kolmogorov-Smirnov two-sample test.

These tests and their applications are discussed in Appendix II.

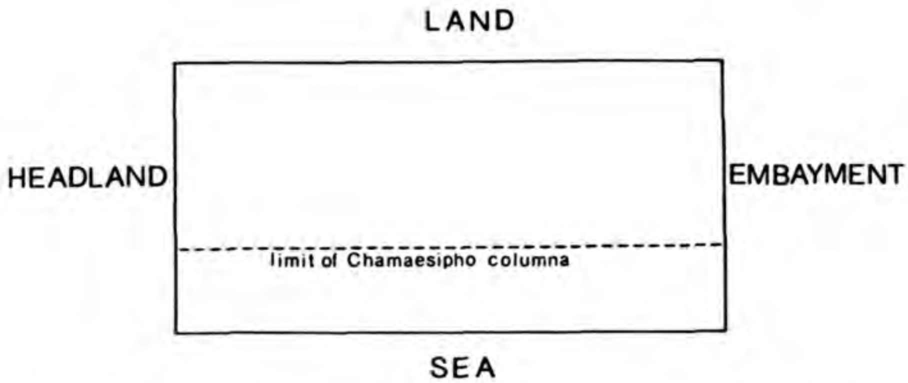


Figure 12. Boulder beach with regularized features.

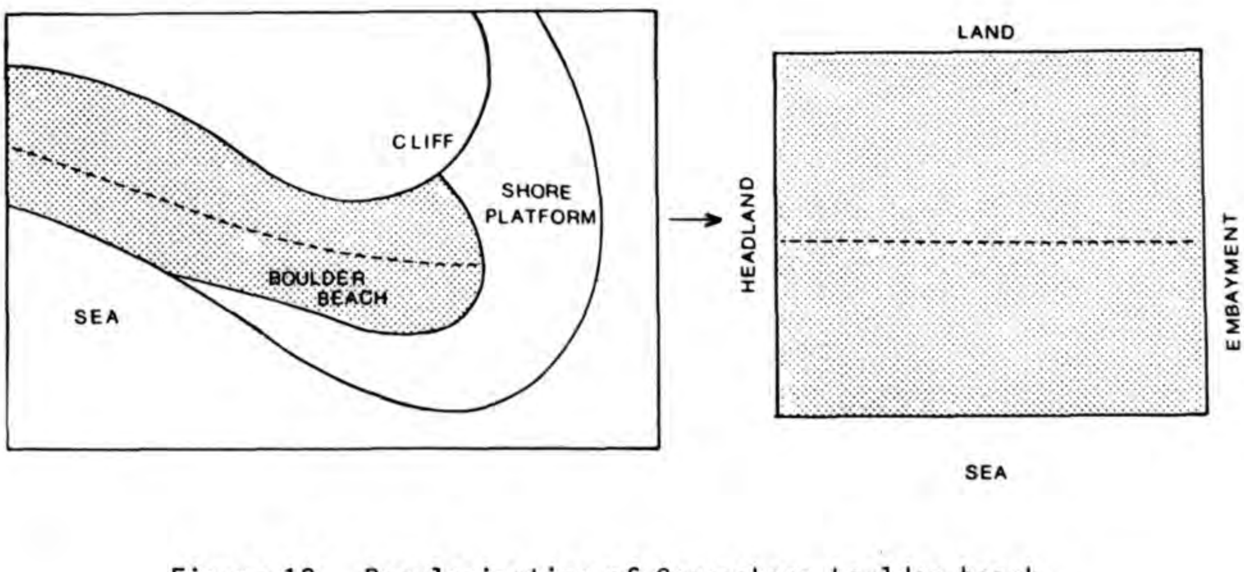


Figure 13. Regularization of Copacabana boulder beach.

CHAPTER III

BOULDER SIZE

Particle size is a basic sedimentary property, and sediment-size parameters have been shown to be sensitive indicators of both process and environment (Folk and Ward, 1957; Mason and Folk, 1958; Friedman, 1961, 1967; Chappell, 1967; Valia and Cameron, 1977). Following established convention, size of each boulder is given by the length of its B axis. This length, which was measured in centimetres, was transformed to *phi* (ϕ) units.

ALONG THE BEACH

Wave Refraction

All studied beaches are aligned obliquely to approaching waves. Thus, the wave forces acting upon each beach have two vector components: 1) a longshore component; and 2) an up-beach (swash) component.

In order to examine size grading along each beach, the longshore expenditure of wave energy was investigated by preparing wave refraction diagrams (Appendix I). North Yacaaba and Bombo were the only beaches for which near-shore bathymetry was available at a scale detailed enough to permit the calculation of meaningful refraction coefficients (Tables 2 and 3). The figures obtained for these two beaches show that there is a consistent decline in wave energy from headland to embayment, with the greatest energy concentration occurring when waves approach from the north-east. Although similar values are not available for the other beaches, it is clear that, regardless of the direction of open-ocean wave approach, aspect and exposure of each beach, the maximum wave energy is nearest the headland, and energy

TABLE 2

WAVE REFRACTION COEFFICIENTS* FOR NORTH YACAABA BEACH

Zone	Wave Approach Direction (12 Second Period) SE	E	NE
Headland	.60	.61	.63
Mid	.52	.50	.44
Embayment	.30	.35	.32

*$R = \sqrt{S_0/S}$

R = refraction coefficient

S_0 = distance between a pair of orthogonals in deep water

S = distance between those orthogonals at the shoreline

TABLE 3

WAVE REFRACTION COEFFICIENTS FOR BOMBO BEACH

Zone	Wave Approach Direction (12 Second Period) SE	E	NE
Headland	.89	.89	1.0
Mid	.77	.77	.84
Embayment	.63	.63	.63

(see Appendix I, Figures A1, A2, A3, and Figures A7, A8, A9)

expenditure decreases towards the embayment. (A more detailed discussion is found in Appendix I.) It should be borne in mind, however, that this overall wave alignment can be altered by small features of individual beaches (*e.g.*, the bedrock outcrop located near the central seaward portion of North Yacaaba beach), thus complicating the patterns of sediment transport and deposition on the boulder beaches.

Size Grading

Any longshore organization of sediment according to size may reflect the distribution of wave energy, direction of transport, and the nature and availability of sediment. As was mentioned in Chapter I, the rate of sediment supply appears to vary from beach to beach. In the field, the relative abundance of freshly supplied sediment could be discerned (Table 4), and when data analysis was complete, it was observed that the studied boulder beaches often fell into divisions which corresponded to the apparent relative rates of sediment supply. It must be stressed that the relative rates of sediment supply assigned to the boulder beaches have no quantitative value and are intended only for comparative purposes within this study. This grouping is intended merely as an aid in the interpretation of between-beach differences, and should not detract from the basic sedimentary similarity of the studied boulder beaches.

First, the particle-size analysis for beaches considered to have active sediment supply will be presented. Spearman rank correlation analyses revealed that three of those four beaches -Copacabana, Bombo, and Crookhaven- show a significant (α = 0.05) negative relationship between size and distance from the headland (see Table 5). This fining towards

TABLE 4

RATE OF SEDIMENT SUPPLY

Beach	Rate of Sediment Supply	Boulder Characteristics
North Yacaaba	Low	very worn
Copacabana	Moderate	angular, many discs
Bombo	Moderate	some quarry refuse, both angular and rounded
Kiama	Moderate	both angular and rounded
Crookhaven	High	extremely large, blocky and angular

TABLE 5

SPEARMAN RANK CORRELATION COEFFICIENTS FOR BOULDERS SIZE VS BEACH POSITION

	North Yacaaba N=298	Copacabana N=345	Bombo N=374	Kiama N=342	Crookhaven N=350
Size vs Poslong[+]	-.0382	-.2976*	-.2157	-.0041 (-.2802)[1]	-.2802
Size vs Posup[≠]	-.5177	-.2528	-.5078	-.5529	-.2127

[+]Poslong = Longshore beach position (profile by profile) with numerical increase from headland to embayment.

[≠]Posup = Up-beach position (grid point by grid point) with numerical increase from sea to land.

*twice underlined values significant at the 0.001 level of probability

[1]correlation coefficient for Kiama excluding the profiles located on the shore platform

the embayment may reflect (1) the ample input of boulders in the high-energy portion of the beach, and (2) the tendency for these boulders to yield finer material which is transported longshore to portions of the beach with lower wave energy.

The absence of a consistent relationship between size and distance from the headland on the fourth beach -Kiama- can probably be attributed mainly to the protection afforded the headland zone by a wide (50 m) shore platform with a surface above high-tide level. Much breakage and chipping occurs during the transport and deposition of boulders, and many of the fines so produced are trapped in the portion of this beach on the platform which is reached only by storm waves. The shelter provided by the platform (allowing the retention of fines) probably results in the sediment of the headland zone being finer than might otherwise have been expected, and hence complicates the relationship between sediment size and distance from the headland. However, when the ten profiles located in that portion of the beach on the platform are removed from the analysis, a significant negative size trend towards the embayment is evident over the remainder of the beach (see Table 5).

North Yacaaba (apparent poor sediment supply) fails to exhibit any relationship between sediment size and distance from headland (Table 5). This anomaly is possibly a function of the lack of boulder input in the high energy (headland) portion of the beach. Since storm waves are competent to remove many boulders which are no longer replaced by others, the headland zone has become depleted of large boulders, causing the mean size to decline. This feature of North Yacaaba beach appears to be the result of poor rate of sediment supply rather than any preferential longshore transport of coarser particles, as may occur on cobble beaches (Carr, 1969), because the coarsest material on boulder beaches is beyond the competency range of all but the highest energy waves.

From field observation and analysis of data gathered for this study, it appears that two major sediment supply and transport systems may be identified on the five boulder beaches:

1) the open system beach with varying rates of sediment input (Copacabana, Bombo, Kiama, Crookhaven), where the rate at which sediment is transported away from the higher energy areas appears to be equal to or less than the rate at which sediment is introduced into the system; and
2) the closed system beach with little or no sediment input (North Yacaaba), where the rate at which sediment is transported away from the higher energy areas appears to be greater than the rate at which sediment is introduced into the system.

Thus, on the open system beaches, where sediment supply is active (and which are not complicated by other factors, as at Kiama), there exists a general fining trend away from the sediment source in the direction of transport. In contrast, on the closed system beach (North Yacaaba) no such trend occurs.

A fining trend away from the sediment source was also observed by Eliot and Bradshaw (1975) on the boulder "field" they studied near Durras, New South Wales. This simple trend is the first indication that the studied boulder beaches may indeed be organized sedimentary units with properties reflecting the rate of sediment supply and the character of the waves that transport and deposit their constituent sediment.

UP THE BEACH

Spearman rank correlation analyses reveal an inverse relationship between size and position up the beach on all five beaches (Table 5). Eliot and Bradshaw (1975) also reported a similar trend in boulder size grading. This up-beach size fining stands in sharp contrast to the up-beach coarsening widely reported for pebble and cobble beaches (Bluck, 1967; Carr, 1969; Muir Wood, 1970, Bird, 1972; King, 1972, p. 300) and illustrated in Plate 11.

A particularly relevant study is that by Cox (1973) of eight pebble beaches along the New South Wales coast. On all eight beaches, Cox reported that sediment size increases in a landward direction. This trend is precisely the reverse of that found for the studied boulder beaches, which experience the same wave conditions. The purpose of Cox's study was to investigate process-form relationships for eight pebble beaches, including Pebbley Beach (Plate 11). However, "lack of available wave data prevented theoretical considerations from being applied to the beaches" (Cox, 1973, p. iv). Her major conclusion was that the variations in sediment characteristics between the studied pebble beaches were related to the degree of exposure of each beach to the wave environment.

The up-beach coarsening found on pebble and cobble beaches has been attributed to the more competent uprush depositing material too large for the less competent backwash to remove (King, 1972, p. 303). In contrast, on boulder beaches, it is suggested that porosity is so great that, under

Plate 11. Pebbley Beach, a pebble beach near Batemans Bay, New South Wales, showing up-beach coarsening of sediment.

most conditions, much of the uprush percolates into the beach. Thus the uprush loses energy as it travels up the beach, depositing increasingly finer sediment. Moreover, because the backwash is ineffective, the fines remain high on the beach. Accentuating this effect is the great size of the largest boulders which are too coarse to be transported in suspension, so they remain in the high-energy, seaward margin of the beach. Consistent fining away from the sea was found on all studied beaches and was observed by the author (but not measured) on other boulder beaches in New South Wales, Scotland, Wales, and Hawaii.

Up-beach fining was the only sedimentary characteristic that could be discerned by observation on bay-head boulder beaches. Waves approaching these beaches appeared to be aligned parallel to the beach (Plates 12 and 13). Thus, the wave forces affecting bay-head boulder beaches may have only one vector component: an up-beach (swash) component.

GRAIN SIZE REDUCTION

The term *abrasion* may be applied to "almost any mechanical process of size reduction" (Pettijohn, 1975, p. 46). On the studied boulder beaches two broad categories of mechanical breakdown were recognized: (1) attrition; and (2) breakage. Attrition is the gradual grain-by-grain reduction in size of a particle accomplished by the rubbing action or impact of another particle or particles. Sand blasting (Kuenen, 1955, 1956) is a form of attrition. Breakage is the more rapid diminution of size by fragmentation caused by impact which may occur when a particle is in motion or *in situ*. The term *chipping* is used when the original particle is much larger than the fragment(s) produced by breakage. *Crushing* occurs when a particle is reduced by impact

Plate 12. Bay-head boulder beach located approximately 1 km south of the studied Kiama boulder beach.

Plate 13. Bay-head boulder beach showing wave approach parallel to the shore. Location is approximately 1 km south of the studied Kiama boulder beach.

to many small fragments. *Fracturing* indicates that breakage has reduced a particle into several fragments, and if only two fragments are produced, the term *splitting* may be employed (Wadell, 1932).

Field observations suggest that the major process causing the progressive size diminution of sediment on a boulder beach is probably breakage. When a boulder is thrown up the beach, it may fracture on impact and/or it may break the boulder(s) it strikes (Plates 14 and 15). Breakage of boulders *in situ* is often facilitated by coastal weathering processes and lithological weakness. Breakage appears to affect the size distribution of sediment on a boulder beach, for the beach may be dominated by boulder-sized sediment, but the products of breakage (chips and fragments) are also present, giving rise to positively skewed size distributions.

Breakage was observed in all study areas, and provides another contrast with pebble and cobble beaches where breakage is minimal and size reduction is primarily by attrition (Dobkins and Folk, 1970). Bluck (1969) noted the importance of abrasion in general on cobble beaches, but found that breakage processes became progressively more important as sediment size increased beyond -7ϕ.

In addition to breakage, attrition, which varies with lithology[1] and wave competence, was observed to contribute to size decline. For example, many boulders were frosted by the impact of fines, and porous, paint-impregnated sandstone boulders in the tidal zone of Kiama beach required monthly paint applications. However, because of the observed frequency of

[1]For the purposes of this study, the term *lithology* refers to rock type, whereas *structure* is the arrangement of planes of weakness within a rock mass (*e.g.*, bedding jointing, and cleavage). The term *geology* embraces both lithology and structure.

Plate 14. Impact fractured boulder (A axis is 91 cm).

Plate 15. Impact fractured boulder showing shape alteration by breakage. Two sphere shapes have been produced by the splitting of a rod-shaped boulder.

breakage and the great size of the coarse material, breakage was judged the more significant cause of size reduction.

Because the size organization of the sediment on the studied bay-side beaches is a reflection of both the longshore and up-beach vector components of wave action, wave competence is likely a critical factor influencing the observed boulder size grading. On bay-head boulder beaches, probably only the up-beach vector component would be present. On all boulder beaches, however, finer material is transported to low energy positions, and where abundant, the products of chipping and crushing of boulders form a very mobile pebble or cobble beach within the more stable boulder beach.

TREND SURFACE ANALYSIS OF SIZE

The trend surface maps describing the organization of sediment by size on each beach are presented in Figures 14 to 18. The first-degree surface of North Yacaaba beach (Figure 14a) illustrates the regular up-beach fining trend. The slight decrease from headland to embayment, which can be seen on this diagram, was not statistically significant when tested by Spearman rank correlation of particle size and longshore position.

The second-degree surface (Figure 14b) again shows the up-beach fining trend, but also reveals what appears to be tidal effects. The portion of the beach above the limit of *Chamaesipho columna* can be affected only by storm waves and retains a regular size decrease, while the tidal zone is swept daily by waves which are small enough to be deflected by the bedrock protuberance, the position of which is shown in Figure 14b. This results in the transport of some smaller material towards the headland, lowering mean sediment size in this zone. The fact that size is so reduced at the highest energy (headland) portion of the beach suggests that supply of

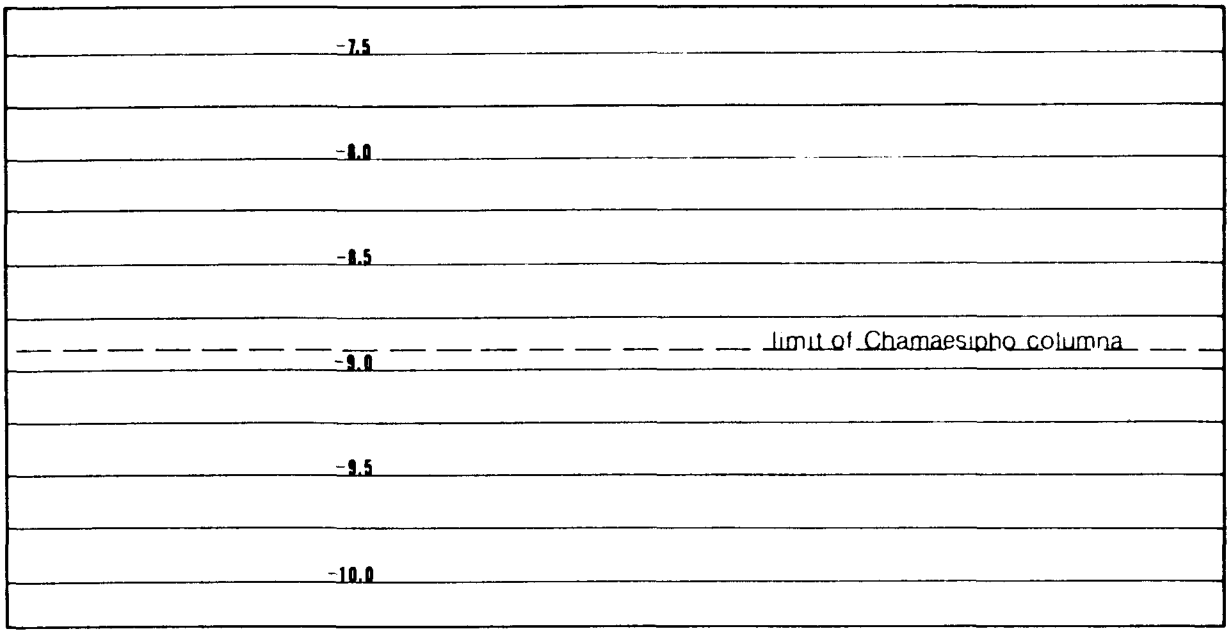


Figure 14a. First degree trend surface map of North Yacaaba boulder beach: *Phi* size.
Explained variance = 29.5% Significant at the 0.05 level

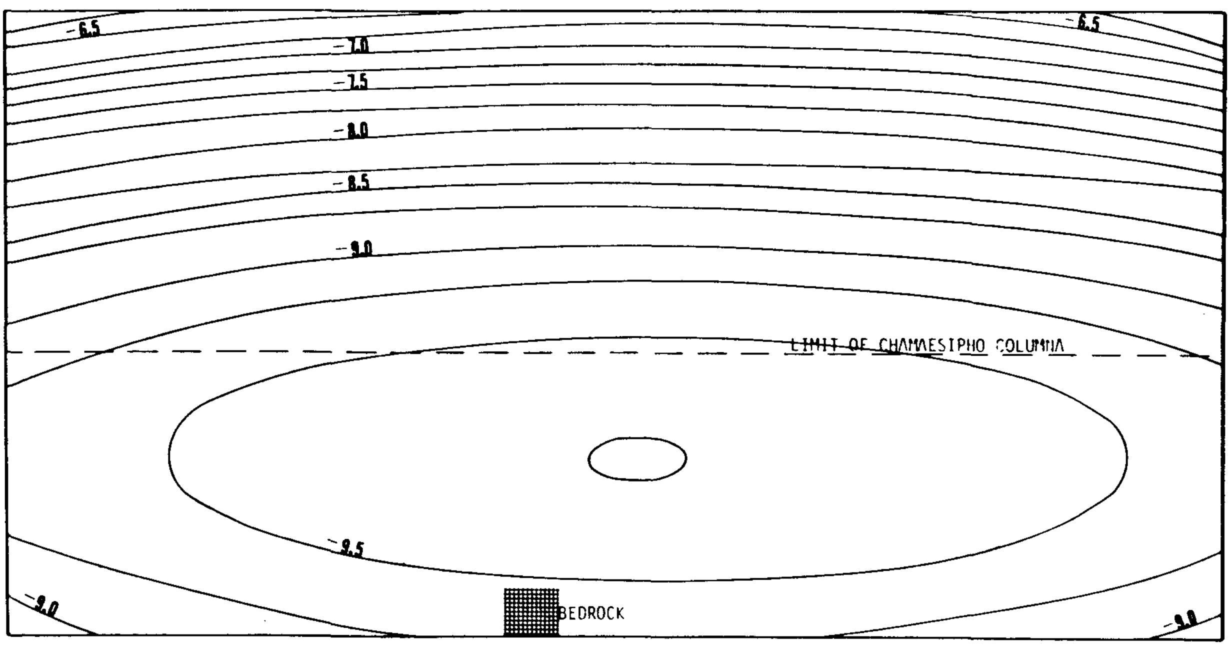


Figure 14b. Second degree trend surface map of North Yacaaba boulder beach: *Phi* size.
Explained variance = 37% Significant at the 0.05 level

large boulders is negligible, because such an input would compensate for the finer material washed towards the headland and boulder mean size would remain great. Higher-degree surfaces were not statistically significant.

Copacabana beach is highly irregular in shape. Consequently, it suffers somewhat in transition to the regular trend-surface map: the tidal zone, in particular, appears to contain far more sample points than it actually does (see Figure 13). The longshore and up-beach size trends are shown to be equally important on the first-degree surface (Figure 15a). The second-degree surface, however, shows the dominant longshore effect of the waves in the tidal zone, while the storm affected portion of the beach shows some longshore fining, but up-beach grading is more evident (Figure 15b).

On Bombo beach, the first-degree surface (Figure 16a) shows a regular longshore and up-beach (diagonal) fining trend which is also evident on the second-degree surface (Figure 16b). Thus both vector components of wave energy appear to influence sediment transport on this beach.

Once again, the strong up-beach fining trend is revealed in the trend-surface maps of size variation on Kiama beach (Figures 17a and 17b). These maps also show a slight coarsening trend towards the embayment. The headland zone of this beach is sheltered by a wide shore platform, and particle size in this area is smaller than might normally be expected, but this overall coarsening trend is inconsistent with field observations (see Plate 9). In addition, the trend is partly the result of the many extrapolated tidal zone values used to regularize the beach into a rectangular map. The shore platform provides elevation for the third of the beach nearest the headland (Plate 16) and at high tide, the most seaward beach boulders on the platform are barely wetted. Thus, on the trend-surface map, the tidal

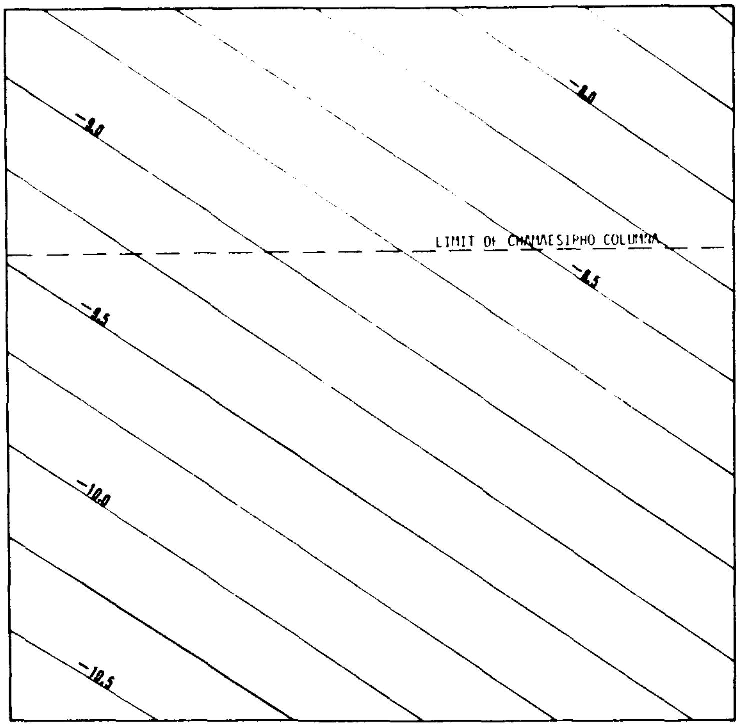


Figure 15a. First degree trend surface map of Copacabana boulder beach: *Phi* size.
Explained variance = 10% Significant at the 0.05 level

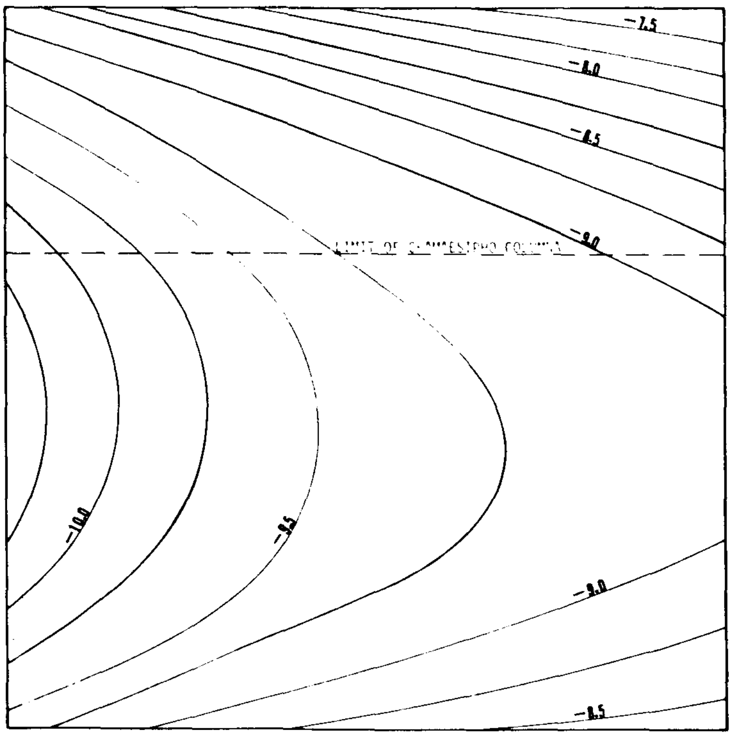


Figure 15b. Second degree trend surface map of Copacabana boulder beach: *Phi* size.
Explained variance = 13% Significant at the 0.05 level

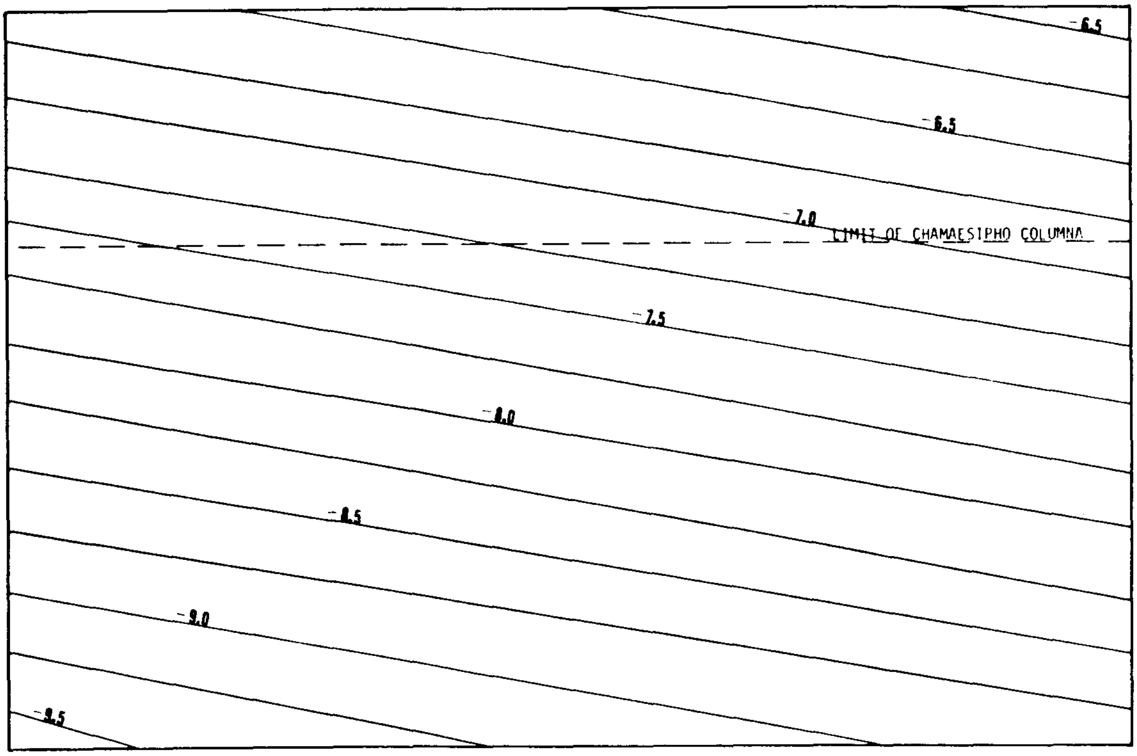


Figure 16a. First degree trend surface map of Bombo boulder beach: *Phi* size.
Explained variance = 26% Significant at the 0.05 level

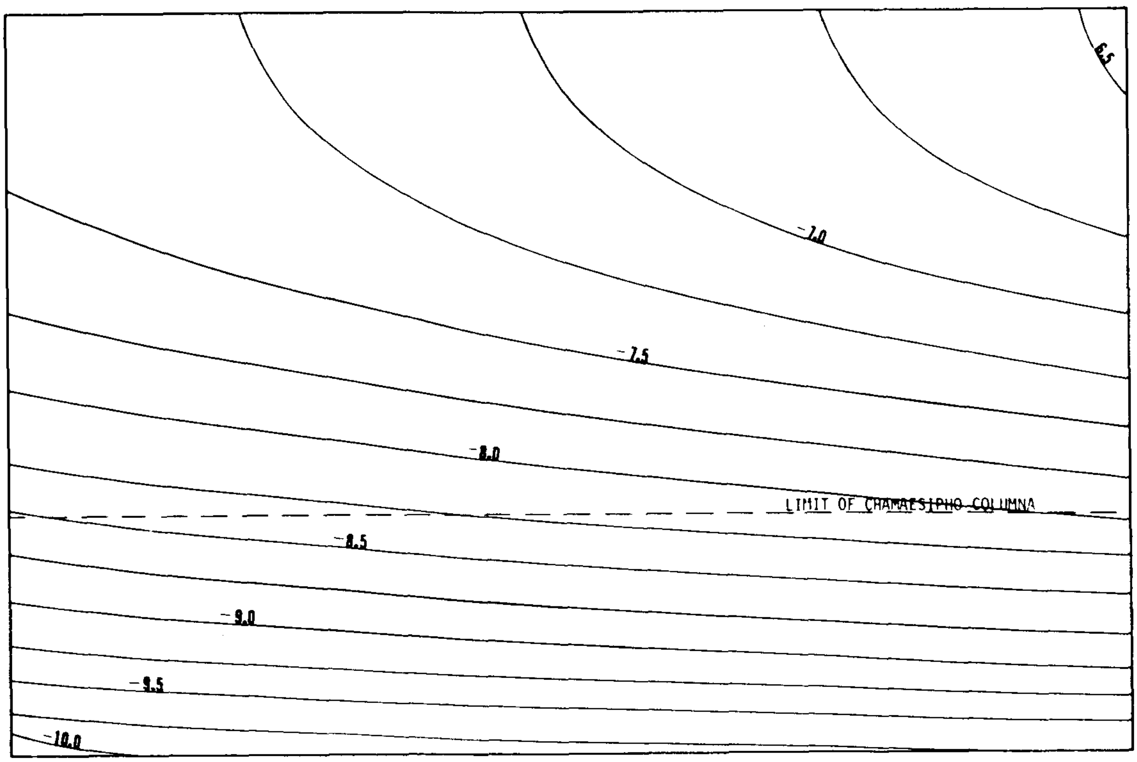


Figure 16b. Second degree trend surface map of Bombo boulder beach: *Phi* size.
Explained variance = 27% Significant at the 0.05 level

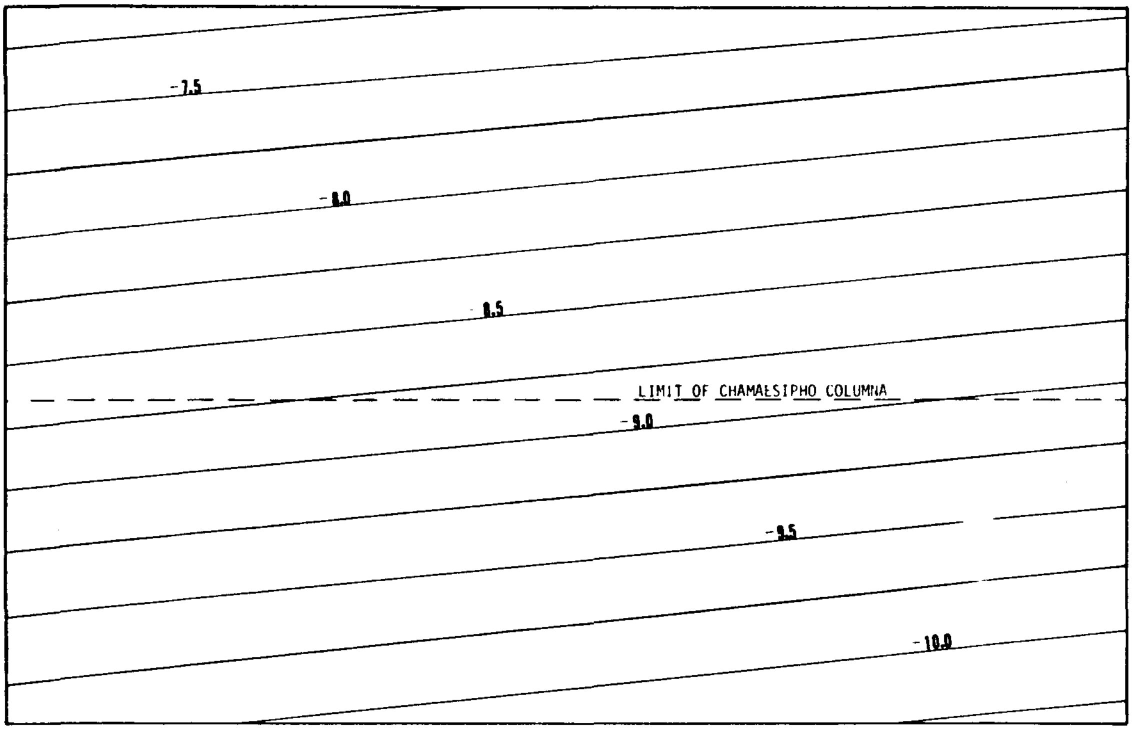


Figure 17a. First degree trend surface map of Kiama boulder beach: *Phi* size.
Explained variance = 25% Significant at the 0.05 level

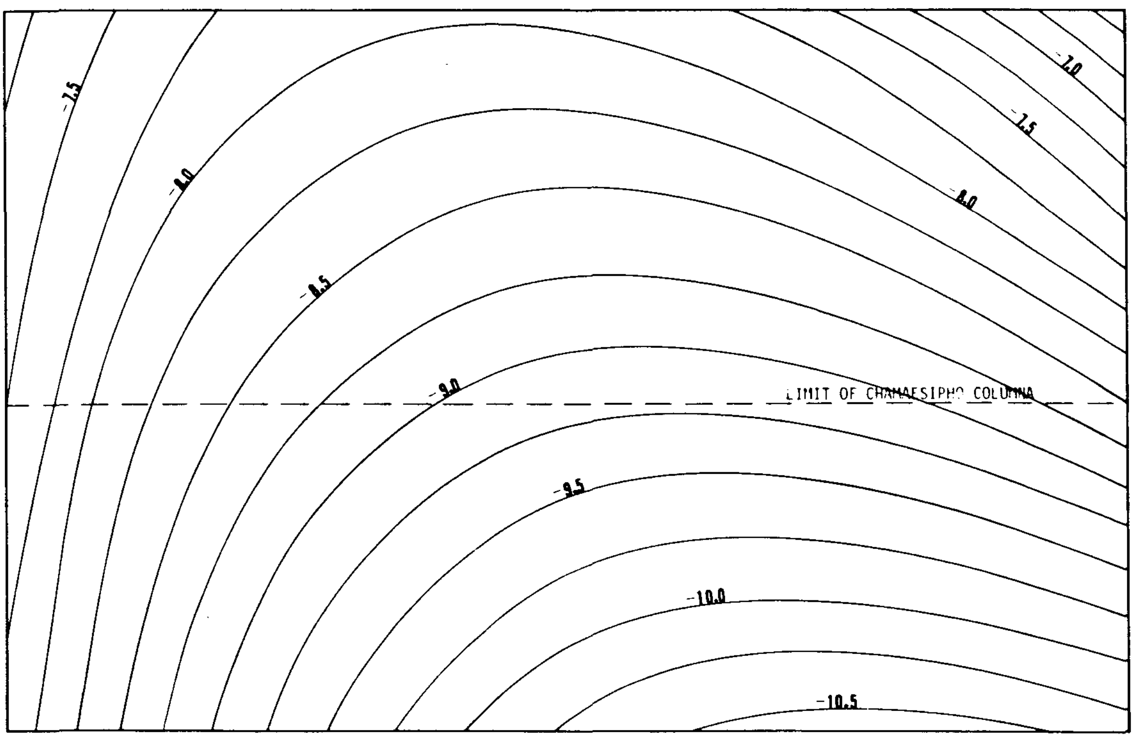


Figure 17b. Second degree trend surface map of Kiama boulder beach: *Phi* size.
Explained variance = 37.5% Significant at the 0.05 level

Plate 16. Kiama boulder beach headland zone which rests on a shore platform.

zone in this area is completely extrapolated.

Crookhaven beach has none of the local complications found on Kiama beach, and the sample points yield a simple trend surface in harmony with the major transport forces of the waves (Figures 18a and 18b). The abundant supply of large-size sediment is evident in the second-degree surface (Figure 18b) where the coarse material is shown to be concentrated in the headland (high-energy) zone of the beach. The high values found on both first- and second-degree surfaces reflect the large size of many boulders on this beach.

As might be expected, local conditions cause the trend surfaces to vary from beach to beach. However, these surfaces illustrate the very consistent and strong up-beach fining trend that is present on every beach, and the longshore fining trend on those beaches with active sediment sources. Where rate of sediment supply is low, the longshore size trend is poor. Unless there is sediment input into a boulder beach, the processes of removal and size diminution will cause depletion of the largest particles.

SIZE SORTING (STANDARD DEVIATION)

The standard deviation, as calculated by the method of moments, is employed in this study as the measure of sorting (see Friedman, 1962). *Phi* standard deviations for all five study areas fell between 1ϕ and 2ϕ, indicating that the beaches could perhaps be classified as poorly sorted (Folk and Ward, 1957; Friedman, 1962). This poor sorting is a general characteristic of the studied beaches and is the result of such beaches essentially containing two size populations: one of boulders and one of smaller fragments caused by boulder breakage, chipping, and shattering.

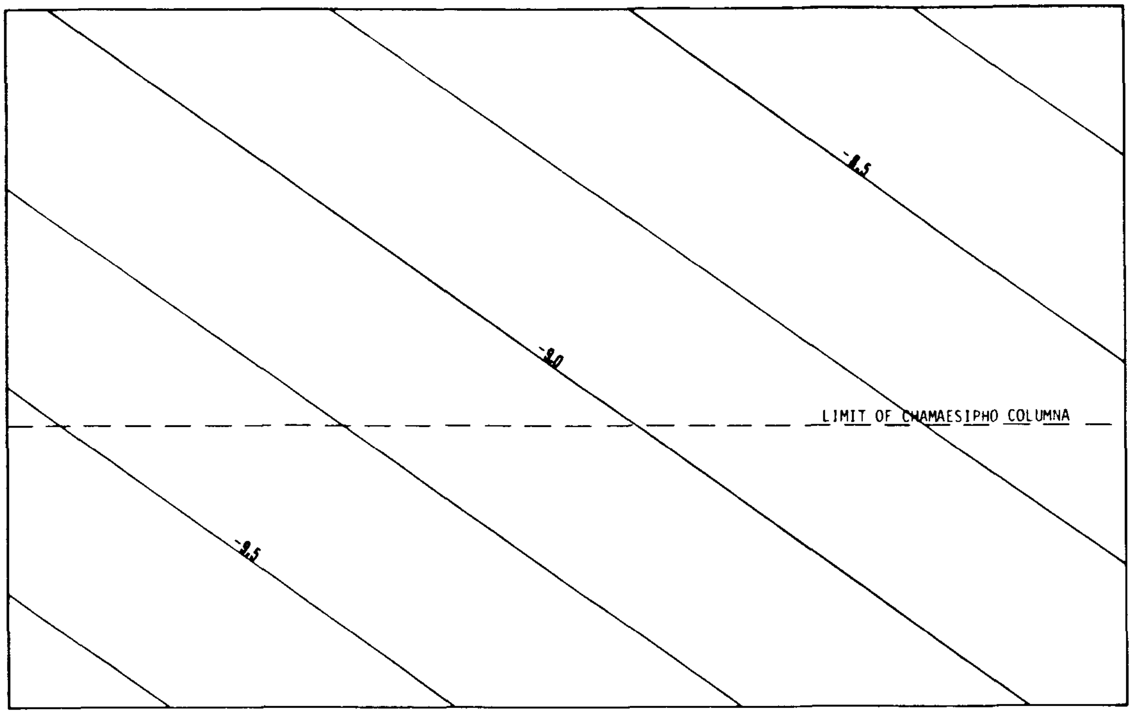


Figure 18a. First degree trend surface map of Crookhaven boulder beach: *Phi* size.
Explained variance = 9.5% Significant at the 0.05 level

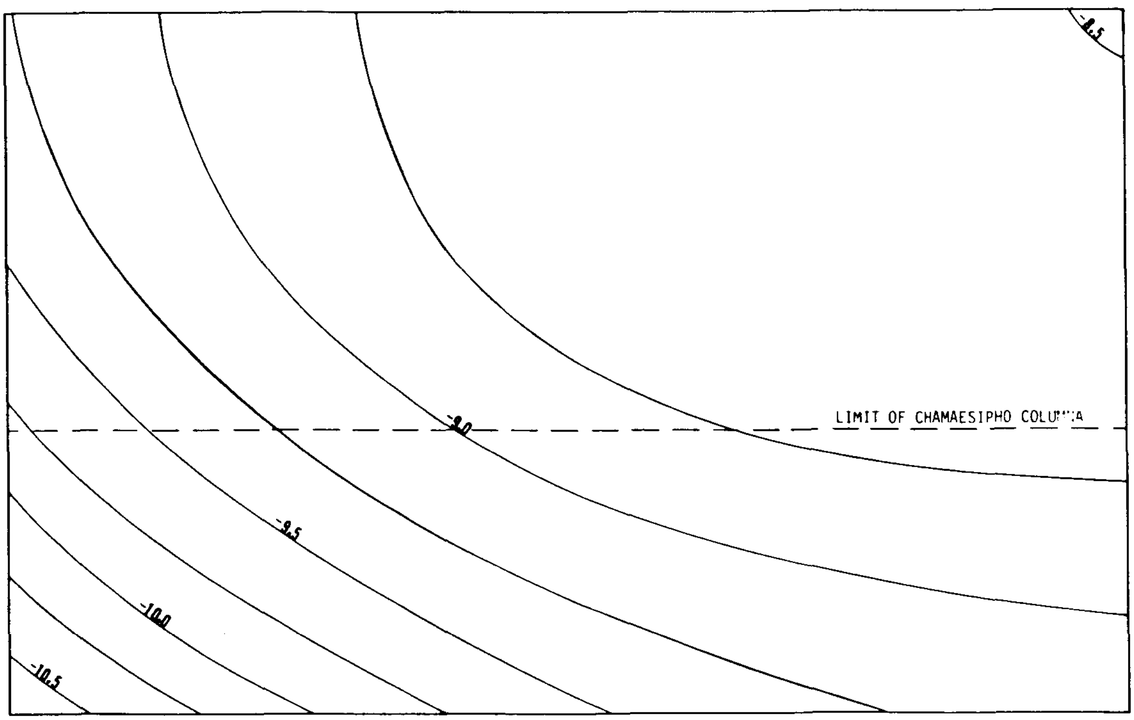


Figure 18b. Second degree trend surface map of Crookhaven boulder beach: *Phi* size.
Explained variance = 11.5% Significant at the 0.05 level

This small-size fraction was not investigated separately because it constituted a very small proportion of the measured particles.

Although a subordinate population of chips and fragments is probably typical of all active boulder beaches, the small material (> -7ϕ) was removed from the analysis to allow examination of the boulders as a distinct population. Table 6 shows that as fines were removed, the sorting improved. Since the unique sedimentary character of the studied beaches is a product of the organization of material of boulder size, this population is now considered apart from the fines, and an extension is proposed to Folk's graph of sorting *versus* size (Folk, 1974, p. 6). If basic populations can be identified by low sorting coefficients, then Figure 19 suggests that there exists a "basic sedimentary population" of boulders in addition to those of clay, sand, and pebbles (gravel).

SIZE SKEWNESS

Beach sediments are generally considered to exhibit negative size skewness resulting from the removal of fines by winnowing (Friedman, 1961; Duane, 1964). In contrast, the studied boulder beaches show positive or very-positive (classification according to Folk and Ward, 1957) size skewness (Table 7). The fine tail is lost on beaches composed of smaller-size sediment, but is retained by boulder beaches because although the entire beach is a disintegration system with the coarse material yielding fines, these fines are not winnowed out of the system. The merging of two populations to form one skewed distribution has been observed in various sedimentary assemblages (*e.g.*, Folk and Ward, 1957; Spencer, 1963). It can be seen in Table 7 that when the fine population is removed, skewness decreases.

TABLE 6

SORTING CHANGES WITH REMOVAL OF FINES

Beach	Entire Beach	Removal of Particles Finer Than -6 ϕ	Removal of Particles Finer Than -7 ϕ	Removal of Particles Finer Than -8 ϕ
North Yacaaba				
Mean (ϕ)	-8.660	-8.807	-9.014	-9.266
Standard Deviation (Sorting) (ϕ)	1.253	1.088	.866	.640
Copacabana				
Mean (ϕ)	-8.674	-9.038	-9.186	-9.415
Standard Deviation (Sorting) (ϕ)	1.605	1.114	.946	.776
Bombo				
Mean (ϕ)	-7.830	-8.066	-8.377	-8.878
Standard Deviation (Sorting) (ϕ)	1.266	1.048	.852	.681
Kiama				
Mean (ϕ)	-8.557	-8.654	-8.823	-9.085
Standard Deviation (Sorting) (ϕ)	1.153	1.022	.862	.688
Crookhaven				
Mean (ϕ)	-8.970	-9.126	-9.259	-9.405
Standard Deviation (Sorting) (ϕ)	1.191	.949	.755	.592

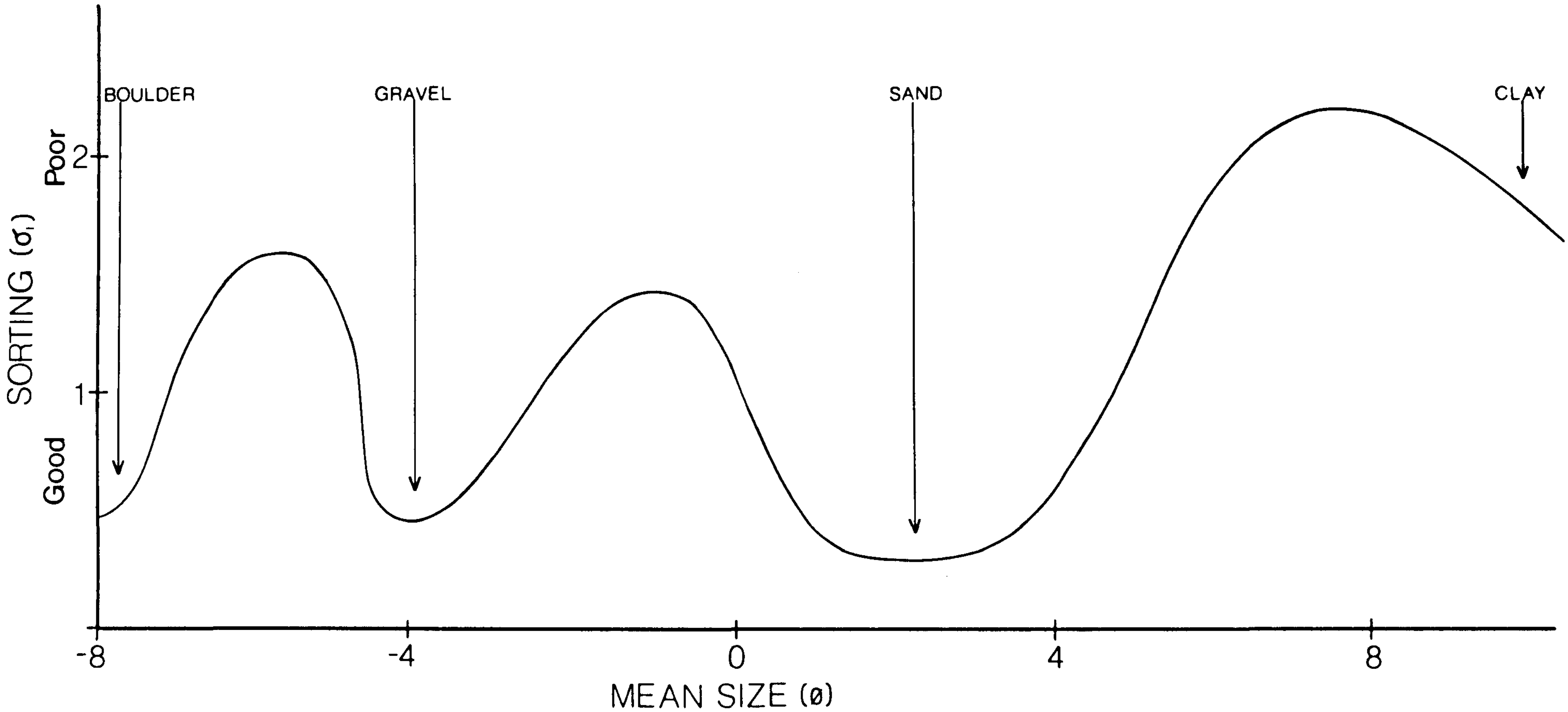


Figure 19. Basic sedimentary populations (based on Folk, 1974, p. 6).

TABLE 7

SKEWNESS CHANGES WITH REMOVAL OF FINES

Beach	Entire Beach	Removal of Particles Finer Than -6 ϕ	Removal of Particles Finer Than -7 ϕ	Removal of Particles Finer Than -8 ϕ
North Yacaaba				
Mean (ϕ)	-8.660	-8.807	-9.014	-9.266
Skewness	.808	.673	.332	- .314
Copacabana				
Mean (ϕ)	-8.674	-9.038	-9.186	-9.415
Skewness	1.325	.534	.148	- .108
Bombo				
Mean (ϕ)	-7.830	-8.066	-8.377	-8.878
Skewness	.248	- .226	- .677	- .953
Kiama				
Mean (ϕ)	-8.557	-8.654	-8.823	-9.085
Skewness	.658	.260	- .150	- .659
Crookhaven				
Mean (ϕ)	-8.970	-9.126	-9.259	-9.405
Skewness	1.453	1.178	.709	.248

A coarse tail does not exist on the studied boulder beaches because of any or all of the following reasons:

1) large boulders are liberated from a size-consistent joint pattern;
2) maximum wave competency determines the coarsest size; and,
3) *phi* intervals double in actual size, so the difference from one *phi* value to the next is maximized in the coarse material.

Thus, it would appear that positive size skewness is another sedimentary characteristic of boulder beaches which sets them apart from other beach types.

The proportion of fines found on each beach was consistently low (Table 8), but the actual size distributions varied from beach to beach. Degree of skewness is dependent on the size range between the boulder population and the subordinate fine population. For example, Kiama beach has a headland-zone mean sediment size much lower than Crookhaven beach, thus on Kiama the fines provide less contrast, resulting in relatively low positive skewness, Crookhaven beach, on the other hand, has very high positive skewness because the boulders being supplied to the portion of the beach nearest the headland are extremely large by comparison with the smaller boulders found towards the embayment. Thus the relative sizes rather than absolute values determine the overall statistical size characteristics of the boulder beaches.

TABLE 8

PERCENTAGE OF FINES IN EACH SAMPLE

Beach	% of Sample > -6 ϕ (B axis < 6.4 cm)	% of Sample > -7 ϕ (B axis < 12.8 cm)	% of Sample > -8 ϕ (B axis < 25.6 cm)
North Yacaaba	4.7	12.4	24.8
Copacabana	8.4	13.3	24.3
Bombo	8.8	16.7	49.0
Kiama	2.9	10.2	25.4
Crookhaven	4.2	8.8	16.2

COMPARISON OF SIZE STATISTICS

Mean Size *vs* Size Standard Deviation (Sorting)

In spite of diversity in size extremes among the studied beaches, fairly consistent mean size and standard deviation values were found from zone to zone and beach to beach. Table 9 shows that all mean sizes of beach sediment in the various zones fall between -7.5ϕ and -9ϕ, with most values between -8ϕ and -9ϕ. Standard deviation ranges from 0.76ϕ to 1.65ϕ, with most values between 1ϕ and 1.5ϕ.

Because wave energy decreases both longshore and up-beach, similar sets of mean size and sorting values result for each beach (Table 9). Individually,

TABLE 9

MEAN SIZE, SORTING, AND SKEWNESS OF EACH BEACH ZONE

Beach	Zone* Along The Beach 1	2	3	Up The Beach 4	5	6
North Yacaaba						
Mean Size (ϕ)	-8.6	-8.7	-8.7	-9.3	-9.0	-7.7
Standard Deviation (Sorting) (ϕ)	1.2	1.3	1.4	.8	.9	1.4
Skewness	.9	.8	.8	1.0	.8	- .1
Copacabana						
Mean Size (ϕ)	-9.2	-8.5	-8.3	-9.0	-8.8	-8.3
Standard Deviation (Sorting) (ϕ)	1.4	1.7	1.4	1.5	1.4	1.6
Skewness	1.1	1.1	.9	1.0	1.2	1.0
Bombo						
Mean Size (ϕ)	-8.1	-7.9	-7.5	-8.7	-7.9	-7.1
Standard Deviation (Sorting) (ϕ)	1.4	1.1	1.2	1.1	1.1	1.1
Skewness	.3	0	.6	.4	.4	.5
Kiama						
Mean Size (ϕ)	-8.5	-8.9	-8.3	-9.3	-8.3	-8.1
Standard Deviation (Sorting) (ϕ)	1.2	.9	1.2	1.1	1.1	1.0
Skewness	.6	.3	.5	1.2	1.2	.7
Crookhaven						
Mean Size (ϕ)	-9.5	-8.8	-8.7	-9.2	-9.0	-8.7
Standard Deviation (Sorting) (ϕ)	.8	1.2	1.3	1.1	1.2	1.2
Skewness	1.1	1.5	1.2	2.1	1.6	1.0

*Zone 1 = Headland Zone; 2 = Mid Zone; 3 = Embayment Zone; 4 = Tidal Zone; 5 = Surpa-tidal Zone; 6 = Landward Zone however, the behaviour of each beach reflects its unique combination of wave energy conditions, type of sediment and rate of supply. Figure 20 attempts to illustrate these variations which occur within a narrow range of mean size and standard deviation values. Only future research can determine if this range of size and sorting values is typical for all boulder beaches.

Unlike the other beaches, on Copacabana the sorting can be seen to improve from the centre of the beach to the embayment (Figure 20). This is probably because the sandstone boulders forming this beach are thin and fragile, and much sediment reaching the embayment zone, regardless of the competence of a particular storm, is small because much breakage occurs during transport. The other beaches have more robust boulders and show a decrease in sorting from the mid zone to the embayment zone, probably because the embayment zone serves as a "dump" or depository for varying sized fines (tiny fragments to small boulders), reflecting widely fluctuating wave competence over a long period of time.

Sediment supply seems to influence longshore sorting on the remaining four boulder beaches (North Yacaaba, Bombo, Kiama, and Crookhaven). Because of very little sediment input on North Yacaaba beach, no material of diverse sizes has been recently introduced. Sorting along the beach varied little, and no clear relationship could be found between size and size sorting.

Sorting improved from headland to mid zone on the beaches with moderate sediment supply - Bombo and Kiama. The mid zone appears to serve as a filter receiving selectively transported sediment from the headland zone and retaining sediment not transported to the embayment zone. Thus, since

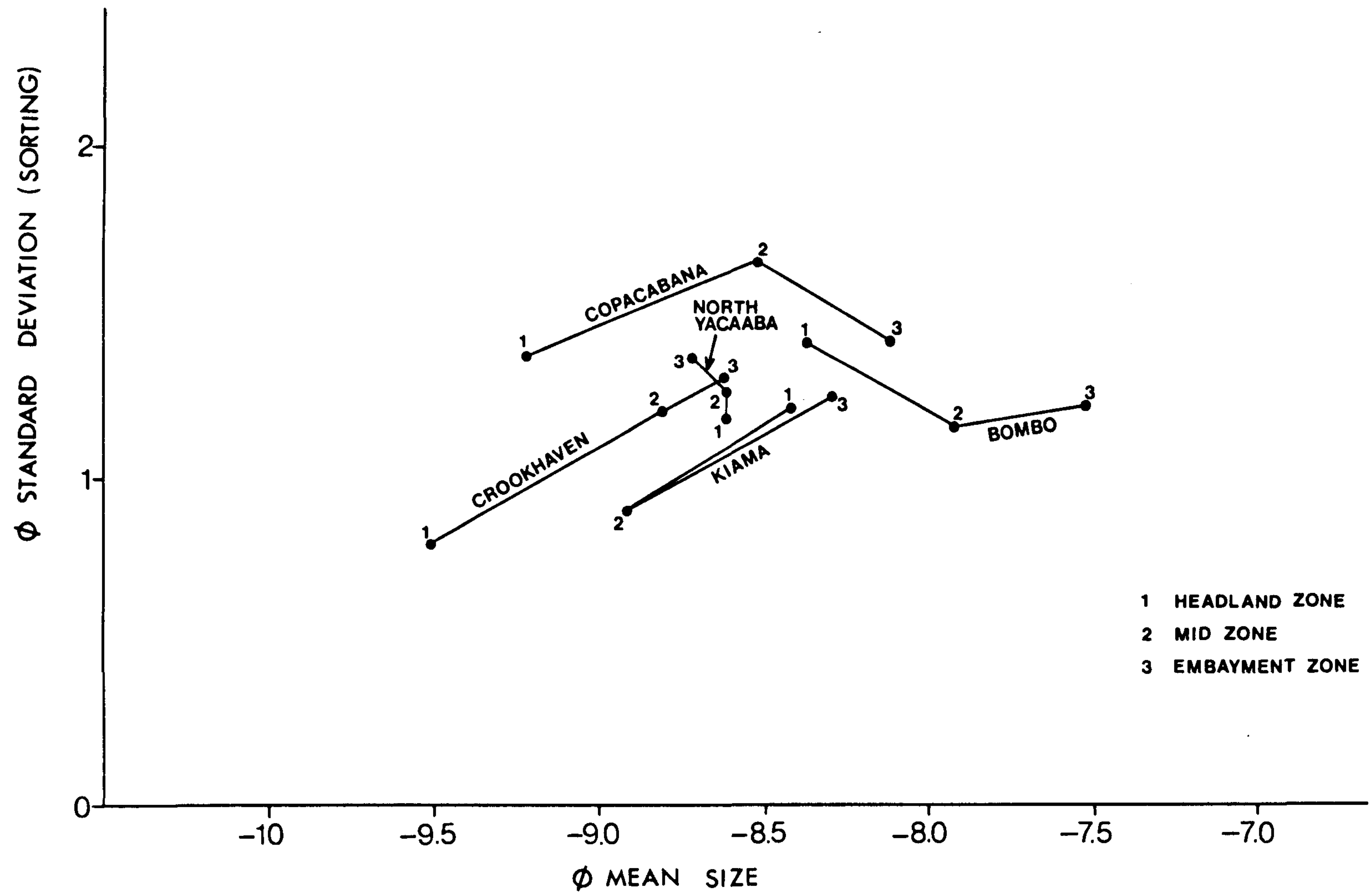


Figure 20. The relationship between sediment sorting and size on five boulder beaches.

sorting was found to be best in the mid zone, mean size showed no relationship to sorting on both Bombo and Kiama beaches.

Crookhaven beach is abundantly supplied with uniform-sized sandstone blocks, which produce the best size sorting found in a headland zone. As this uniformly sized sediment is transported, moderated by breakage and attrition, and deposited, size sorting deteriorates. Therefore, on this beach alone a relationship was found between size and size sorting - as size decreased along the beach, so did sorting.

On all beaches, mean size was found to decrease landward, but sediment supply may influence up-beach sorting. The four beaches with active sediment supply show little change in sorting (Table 9), hence no clear relationship between up-beach size grading and up-beach sorting. North Yacaaba beach (low rate of sediment supply), however, shows markedly poorer sorting in a landward direction. Thus as mean size decreases on this beach, sorting becomes poorer. Perhaps lack of sediment supply on this beach has allowed fines to be removed to lower energy areas without being replaced, thus minimizing size variation amongst the coarse material.

Mean Size *vs* Size Skewness

As shown in Figure 21, when all beaches are considered, there is a tendency for positive skewness to increase as size increases. This is because the fragments and chips tend, in real terms, to be of the same sizes no matter how large the mean size of the beach sediment may be. As the discrepancy between the mean size of the boulder population and the mean size of the fines increases, skewness increases. Geology may affect size skewness because the size of the initial joint blocks and the ease with

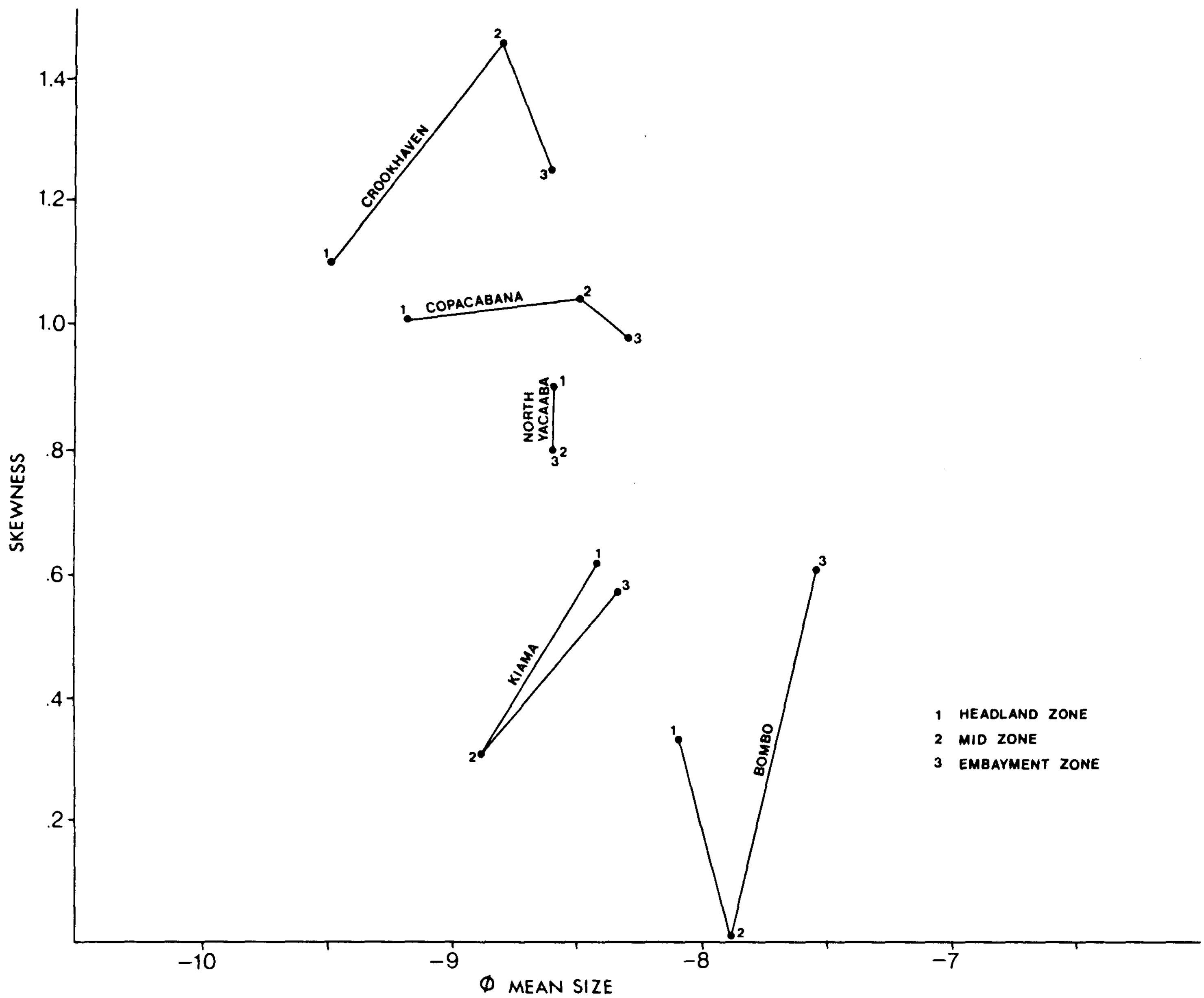


Figure 21. Skewness and size of sediment on five boulder beaches.

which they break down determines the difference between the means of the boulder and fines populations, and hence, the degree of skewness.

Within each beach, skewness and mean sediment size show no relationship (Figure 21), and skewness values appear to be sensitive to the particular conditions found on each beach. On poorly supplied North Yacaaba beach, skewness decreases only slightly and mean size also shows little change from headland to embayment. This uniformity may be due to the lack of coarse sediment input, while transport and diminution processes are still active.

Skewness changes little along Copacabana beach, while size was found to decrease. The fragile sandstone which comprises the beach may be responsible for this effect because large amounts of breakage over the entire beach could negate the tendency for transport to cause size sorting and a reduction in skewness.

On both Bombo and Kiama boulder beaches, skewness was found to be lowest in the mid zone. Skewness may be higher in the headland zone because it is there that the contrast between the mean size of the boulders and fines is greatest, while in the mid zone the contrast decreases and wave sorting lowers skewness. In the embayment zone, however, skewness rises again, possibly as a result of the previously discussed depository or "dump" effect (Figure 21).

Massive similar-sized sandstone blocks so dominate the headland zone of Crookhaven beach that skewness was found to be lower there than in the other two zones along the beach. Fines are produced through transport, and in the mid zones these fines contrast sharply with the still-large boulders and result in a peak in skewness. The contrast diminishes as mean size of the boulders diminishes in the embayment (Figure 21).

Table 9 shows that when mean size and skewness are examined up beach, there is a general association of decreasing size with decreasing positive skewness. The only negative size skewness value for any zone on any studied beach is that found for the landward zone of North Yacaaba. Because virtually no boulders are being added to North Yacaaba beach, well-worked chips and fragments so dominate the landward zone that the tail of the size distribution is formed by coarser sediment.

Overall, the studied boulder beaches showed similar mean sizes, poor sorting, positive skewness, and up-beach size grading. Within these similarities. each beach was found to have a dominant boulder population and subordinate fines population, with characteristics largely determined by the type of sediment and rate of supply at each beach.

CHAPTER IV

BOULDER MORPHOLOGY

BOULDER SHAPE

The study of particle shape on sand and gravel beaches has provided information fundamental to the understanding of sediment transport and deposition, mainly because particles of different shapes have different hydrodynamic characteristics (Albertson, 1953; Bluck, 1967; Dobkins and Folk, 1970; Cheng and Clyde, 1972). The shapes of the boulders forming the studied beaches were investigated using two shape classifications: the Williams (1965) classification; and the Zingg (1935) classification.

Williams Classification

It has been suggested that oblate fragments are preferentially developed by wave action in the coastal environment (Blatt, 1959). Some believe that mechanical wear caused by swash-induced movement produces flat particles (Cailleux, 1945; Dobkins and Folk, 1970), while others have suggested that oblate fragments are more abundant on beaches because of shape sorting (Landon, 1930). Still others suspect that there is no environmental shape preference, and that particle shape is mainly determined by geology (Wentworth, 1922c; Pettijohn, 1975, p.55).

In order to investigate the "flatness" of the boulders comprising the studied beaches, each measured boulder was classified as oblate or prolate according to the Williams (1965) shape classification. Table 10 displays the percentages of oblate boulders found in the six zones of each beach. As can be seen, the boulders were found to be generally more oblate than prolate.

TABLE 10

PERCENTAGE OF OBLATE BOULDERS (WILLIAMS, 1965) IN EACH BEACH ZONE

Beach	Zone*					
	1	2	3	4	5	6
North Yacaaba	52	44	52	42	50	55
Copacabana	78	81	77	86	72	80
Bombo	59	65	58	59	59	64
Kiama	61	55	59	60	59	54
Crookhaven	62	62	54	65	55	59

*Zone 1 = Headland Zone
2 = Mid Zone
3 = Embayment Zone
4 = Tidal Zone
5 = Supra-tidal Zone
6 = Landward Zone

If, in fact, marine processes are responsible for producing a majority of oblate boulders, some relationship between beach position and degree of "oblateness" could be expected because these processes are more intensive in the high-energy portions of each beach. However, as Table 10 shows, the percentage of oblate boulders in zones both parallel and normal to the shore remains relatively constant within each beach. In contrast, from beach to beach there do appear to be clear differences in the percentage of oblate boulders, but they seem to bear little relationship to marine processes. Since North Yacaaba beach has little fresh sediment supply, all the boulders are well worked, yet this beach possesses a low proportion of oblate boulders. Copacabana beach, on the other hand, has ample sediment supply and many fresh boulders as yet little affected by marine processes, but this beach has a relatively high percentage of oblate boulders.

Thus it appears that, on the beaches studied, the degree of oblateness of the boulders may be largely dependent upon their geology. For example, thinly bedded sandstone forms most of the Copacabana boulders, and readily splits along bedding planes into oblate shapes. On North Yacaaba beach, however, the andesite and toscanite boulders do not so readily produce flat shapes. Therefore, although the boulder beaches were found to be composed of a greater number of oblate- than prolate-shaped boulders, this tendency need not necessarily be a characteristic of boulder beaches. Marine processes may be less important than geological controls in determining boulder shape (*c.f.*, Brock, 1974), because the swash on boulder beaches does not have the competence, and hence the shaping capability, found on sand or pebble beaches.

Zingg Classification

Each measured boulder was classified as a sphere, disc, rod, or blade, according to the method developed by Zingg (1935). Discs are the most numerous shape on Copacabana, Bombo, and Kiama beaches; spheres on Crookhaven (sphere indicating equidimensionality not roundness); and rods on North Yacaaba beach.

Relative frequency distributions of Zingg shapes were prepared for each beach and are presented in Figure 22. These shape distributions show marked differences from one beach to another but vary little from zone to zone within each beach. This internal shape consistency within each beach is not found on pebble and cobble beaches, and will be discussed at greater length. (See Appendix III for more detailed sediment-shape data.)

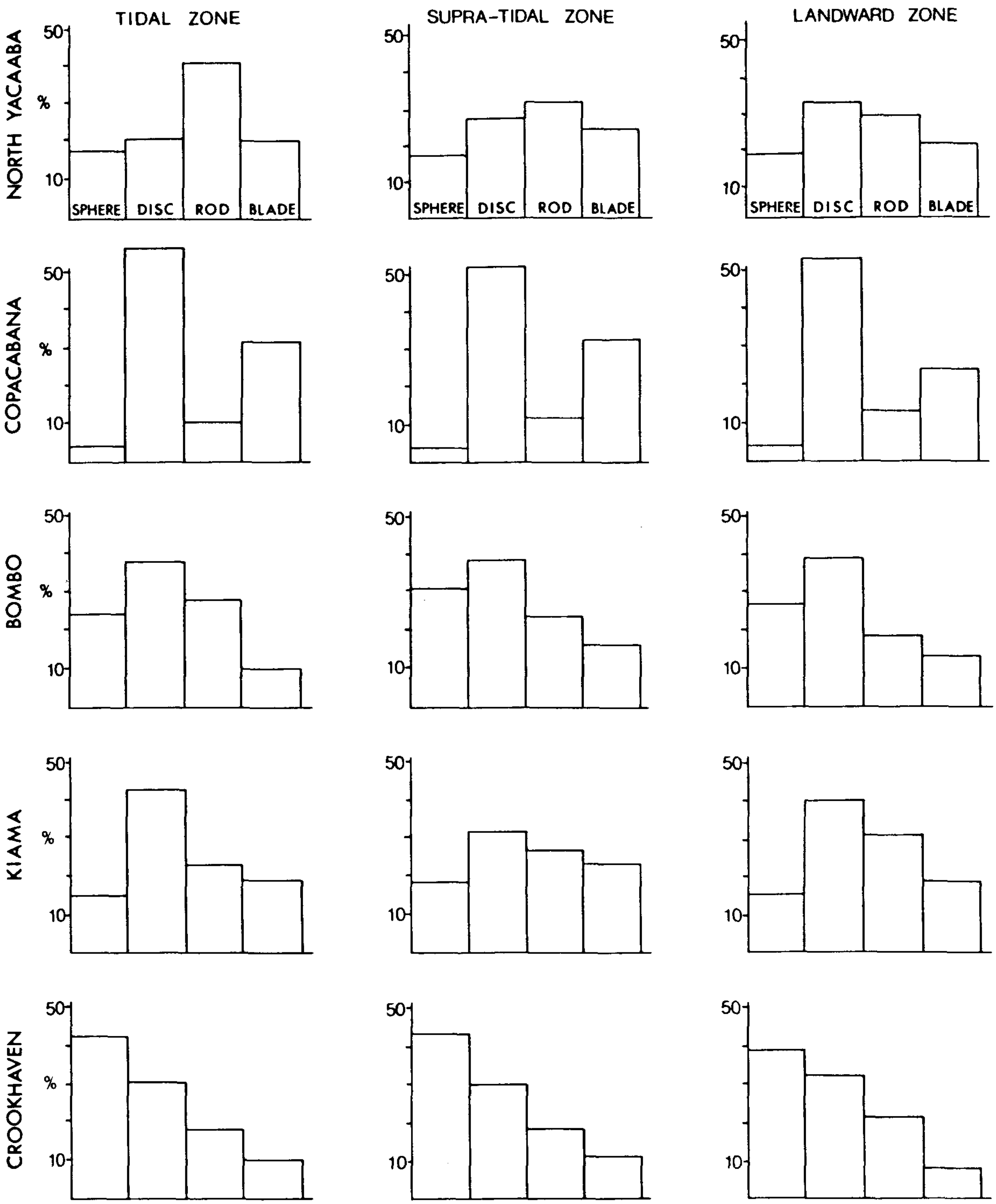


Figure 22. Up-beach distributions of Zingg shapes zone by zone.

SHAPE FORMATION

Transport of sediment on boulder beaches was observed to cause breakage and attrition of both the moved and stationary particles. In marked contrast, on pebble beaches, "despite the tremendous impact of pebbles against each other, broken pebbles were almost never seen" (Dobkins and Folk, 1970, p. 1178). On the studied beaches, however, boulder breakage is widespread, highly visible, and clearly exerts a significant influence on particle shape (Plate 17). Other forms of abrasion were also considered to aid in shape formation since in some cases entire boulders were observed to be pitted and chipped from contact with other beach sediment (Plate 18), while other boulders were rounded and worn from attrition. Generally, though, it was felt that attrition plays a minor rôle compared to breakage in shape creation.

Other factors influencing shape formation were considered. No clear examples of water-faceted boulders (Kuenen, 1947) were found, but fitting boulders (Shelley, 1968; Hills, 1970) were a feature noted on all studied beaches. The tightly fitting boulder to boulder and boulder to bedrock interfaces were found mainly in tidal zones, but some were situated where the interface was constantly wet. Salt crystallization, therefore, cannot be responsible for all observed fitting (Hills, 1970), as suggested by Shelley (1968).

It was observed that the fitted material in the swash zone was often trapped by boulders of a size too large to be readily transported. However, the combined forces of lift and drag cause coarse particles to vibrate *in situ* (Schumm and Stevens, 1973), and sufficient energy is available, especially in the tidal (swash) zone, to cause movement or rubbing of many boulders along their adjacent surfaces producing and promoting fitting.

Plate 17. Breakage on Kiama boulder beach. Boulder "23 C" was broken *in situ* by the impact of another boulder. The two portions, one marked "23", the other marked "C", are both more equidimensional than was the original boulder. (Book is 20 cm wide.)

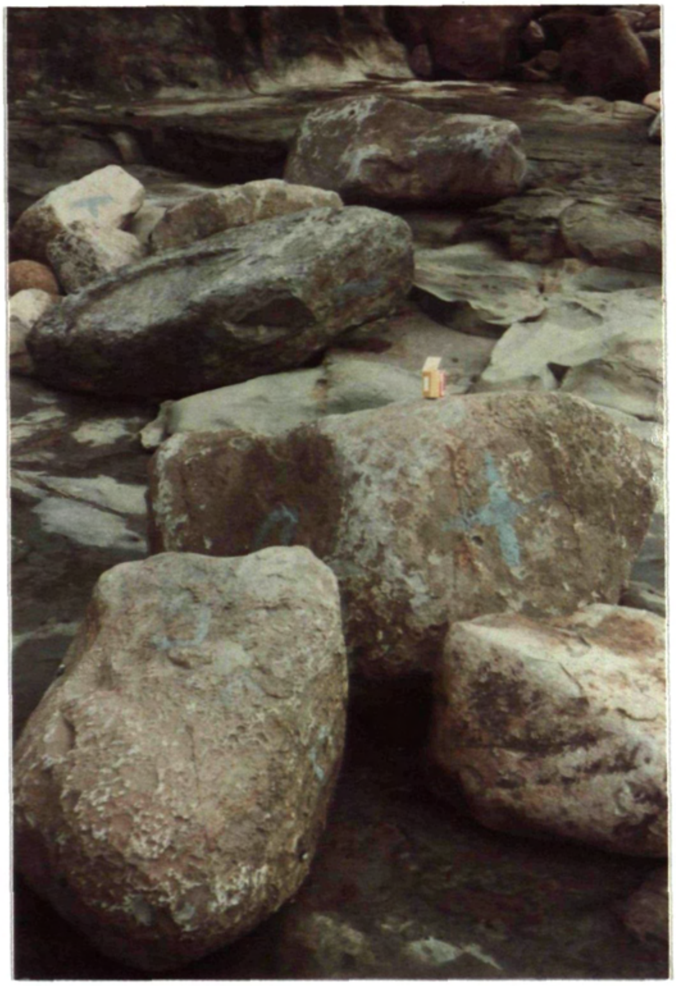


Plate 18. Frosting effect of numerous percussion marks on boulders on the platform adjacent to Kiama boulder beach. (Length of film box is approximately 6 cm.)

From field observations, this process of attrition appeared to affect the shape of some individual boulders, but generally it seemed to merely accentuate the pre-existing shape. Fitting, therefore, is not considered to be an important factor in shape development on the studied beaches. On the contrary, shape sometimes appeared to aid fitting, a condition that was especially noticeable on Copacabana beach. This beach has a high proportion of geologically determined disc-shaped boulders which are imbricated. The small swash-induced movements of the boulders appear to be responsible for accentuating the disc shapes, and fitting occurs through *in situ* attrition.

Random breakage was also investigated as a shape-determining mechanism. Smalley (1966) suggested that random breakage of sedimentary particles, especially large ones, not influenced by any particular preferential geological partings will yield Zingg shapes in the following proportions:

Spheres	11.1%;
Discs and Rods	66.7%;
Blades	22.2%.

The distribution of these shapes on each studied beach was compared to the above distribution developed by Smalley, and the significance of the resulting differences tested statistically by the F test ($\alpha = 0.05$) (Table 11). Copacabana, Bombo, and Crookhaven beaches have distributions of shape which differ significantly from Smalley's predicted distribution. These differences appear to be largely due to the structure of the bedrock cliffs supplying the sediment to each beach. The sandstone at Copacabana produces a higher than predicted proportion of blade-shaped boulders, while the latite forming Bombo beach tends to break down into blocks, yielding a beach with a higher proportion of spheres than would be expected to

TABLE 11

PERCENTAGE DEVIATION FROM SMALLEY DISTRIBUTION

	Beach				
Shape	North Yacaaba	Copacabana	Bombo	Kiama	Crookhaven
Sphere	7.0	-7.6	17.8	5.3	31.1
Disc & Rod	-4.3	1.2	-7.9	-3.6	-17.4
Blade	-2.7	6.2	-9.9	-1.7	-13.7
f test	NS	S*	S	NS	S

*S = f test showed that a significant difference exists between the shape distribution predicted by Smalley (1966) and the shape distribution found in this study ($\alpha = 0.05$). NS = no significant difference.

occur through random breakage. Crookhaven beach has an extreme deficit in discs, rods, and blades, and an abundance of spheres relative to Smalley's distribution because the sedimentary particles supplied to this beach are of a blocky nature. The results from these three boulder beaches support the proposition that shape can be largely determined by the geology of the particles forming each beach.

North Yacaaba and Kiama beaches show less effect of shape determination by geology. North Yacaaba receives very little fresh sediment, and the tendency of the volcanic lithology to produce prolate rather than oblate forms is obscured by Smalley's combining of discs and rods into one category. Kiama beach receives some boulders already shaped by transport, and the supplying cliffs do not exhibit rigid bedding forms. Thus, these two beaches are found to have shape distributions not significantly different from that produced by random breakage (Table 11); but only on Kiama beach is it reasonable to suggest that particle shapes are likely the result of random breakage.

Another indication of the control of geology over shape formation is the very strong positive correlation between number of observations of each shape and the mean size of that shape (*i.e.*, the larger the mean size of a particular shape, the more numerous are the boulders of that shape)(Table 12).

A particular shape may be found all along the beach as the most numerous shape because of the original lithological preference. This shape will have the greatest mean size of all the shape classes because the largest "new" material entering the beach sediment system will tend to consist of the preferred shape. Crookhaven beach provides an illustration of this idea. Large equidimensional blocks (sphere-shaped) from the degrading cliff accumulate at the high energy extremity of the beach. The sphere shape is found throughout the beach, but the initial input of large spheres results in a large average size for spheres (Plate 19). As the boulders break down into other shapes the size-shape characteristic may be carried into other shapes: the spheres of Crookhaven most readily cleave into discs, thus discs are the second largest and second most numerous shape found on this beach.

It is suggested, therefore, that most of the shape formation on the the studied boulder beaches is controlled by geology, and is not the product of wave processes or random breakage.

TABLE 12

RANK ORDER COMPARISON OF SIZE AND SHAPE-FREQUENCY

Shape	Beach									
	North Yacaaba		Copacabana		Bombo		Kiama		Crookhaven	
	Size Rank*	Frequency Rank+	Size Rank	Frequency Rank	Size Rank	Frequency Rank	Size Rank	Frequency Rank	Size Rank	Frequency Rank
Sphere	4	4	4	4	2	2	2	4	1	1
Disc	2	2	1	1	1	1	1	1	2	2
Rod	1	1	3	3	3	3	4	2	3	3
Blade	3	3	2	2	4	4	3	3	4	4

*Each shape is ranked by the magnitude of the mean ϕ size of that shape: 1 = Largest; 4 = Smallest

+Each shape is ranked by the frequency of boulders of that shape: 1 = Most numerous; 4 = Least numerous.

Plate 19. Equidimensional boulders of Crookhaven boulder beach.

The search for a relationship between size and shape was continued by using Spearman rank correlation to locate any size frequency trends for each shape. The only significant ($\alpha = 0.05$) correlations were found on Bombo beach where the number of discs decreased and the number of rods increased as boulder size decreased. The number of all other shapes on all beaches showed no significant increase or decrease in number with size.

Regardless of the mode of formation, the four Zingg shapes are found in varying proportions on all of the studied beaches (Figure 23). Since hydrodynamic properties of variously shaped particles are well known (*e.g.*, Bluck, 1967; Meland and Norrman, 1969; Dobkins and Folk, 1970), it was expected that behavioural characteristics could be identified for each shape on the boulder beaches. On pebble beaches, shape sorting occurs both longshore (Marshall, 1929; Grogan, 1945; Carr, 1969) and up the beach (van Andel *et al.*, 1954; Bluck, 1967; Orford, 1975). "Even the ancient Greeks recognized that waves sorted pebbles by shape on a beach" (Dobkins and Folk, 1970, p. 1168).

Because discs have the best suspension properties, pebbles so shaped tend to be thrown high onto a pebble beach where they are stranded because of their large contact surface. Since the prolate shapes present less surface area in relation to volume, they are more pivotable than the oblate shapes and are "rolled" downbeach to collect along the seaward margin. This differential wave sorting results in the development of shape zones on gravel beaches.

Bluck (1967) described regular shape zoning on gravel beaches and this zoning was later quantitatively substantiated by Orford (1975). In the field, the disc zone of a pebble beach is often the most easily identified area of shape preference because of its characteristic imbrication (Bluck, 1967;

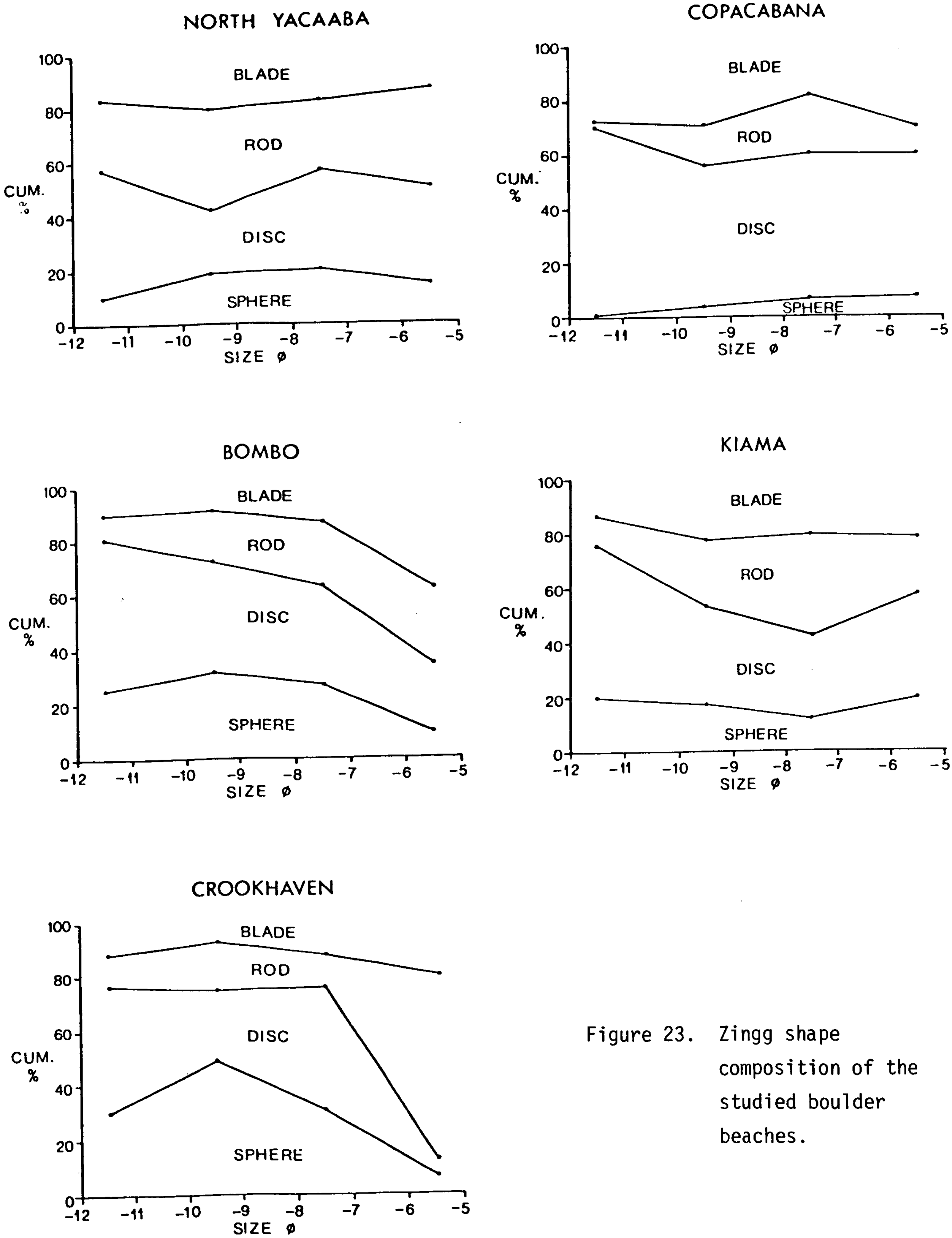


Figure 23. Zingg shape composition of the studied boulder beaches.

Orford (1977). However, the only boulder beach to show any consistent imbrication was Copacabana, a beach with a high proportion of discs. These discs, however, do not occur in zones but are found over the entire beach. In dramatic contrast with gravel or pebble beaches, no shape zoning could be found on any of the studied boulder beaches. As has been noted, shape distributions were internally consistent both along and up each beach. Kruskal-Wallis testing (see Appendix II) showed that the shape distributions for all six areal zones (three longshore and three up-beach) within each beach could have been drawn from the same shape population.

Shape selection on gravel beaches occurs because of suspension and pivotability differences amongst the four Zingg shapes, and the intact deposition of the transported particles. Boulders, however, are of such mass that their suspension is difficult. Boulder movement is most readily accomplished by sliding and rolling (Inman, 1949), and transport by these processes has been shown to be somewhat affected by differences in particle shape (Meland and Norrman, 1969). However, it is interesting to note that Meland and Norrman also found that maximum transport velocities occur in coarse natural materials and "the effect of particle shape on transport velocity decreases with increase in rate of transport" (Meland and Norrman, 1969, p. 127). Therefore, the influence of particle shape on transport of boulders may be minimal. Also, when a boulder is thrown high onto the beach, breakage often occurs, hence the shapes observed in the landward zone may have no relation to the shapes that were transported. For example, upon impact, a disc or rod may break into a more equidimensional shape. Thus, it is suggested that because bed-load transport is relatively insensitive to differences in particle shape, and breakage can destroy evidence of selective transport, the distinctive shape zones found on gravel beaches are absent on boulder beaches.

SPHERICITY

Maximum projection sphericity (ψ_p) (Folk, 1955; Sneed and Folk, 1958) was calculated for all measured boulders to prevent distortion of results which may occur if sphericity values are based on a sample from a pre-selected particle size range (see Bardecki, 1977). Since this measure is another manner of classifying sedimentary particles by shape, much information had already been found by investigating form using the Zingg (1935) and Williams (1965) methods.

Bluck (1969) observed on gravel beaches in South Wales an increase in sphericity towards the sea, and Cox (1973) also found this seaward sphericity trend on all eight studied pebble beaches along the coast of New South Wales. This seaward accumulation of spheres has been attributed to the tendency for more-spherical pebbles to migrate ("roll") to positions low on the beach, and to the fact that, because of their low surface-to-volume ratio, they are usually transported in traction and become trapped in the seaward portion of the beach (van Andel *et al.*, 1954; Sneed and Folk, 1958).

On the five boulder beaches, the mean sphericity remained virtually constant from one portion of each beach to another (see Appendix III). No significant correlation (α = 0.05) could be found between sphericity and position along any beach, and only on Copacabana was there found a significant up-beach relationship (Table 13). On this beach, boulders become more spherical up the beach, an effect directly opposite to that found by Bluck (1967) and Cox (1973) on pebble beaches. Thus, none of the boulder beaches shows the seaward increase in sphericity that is a common feature of pebble or gravel beaches.

TABLE 13

SPEARMAN RANK CORRELATION COEFFICIENTS FOR MAXIMUM PROJECTION SPHERICITY VS BEACH POSITION

	Beach				
	North Yacaaba N=298	Copacabana N=345	Bombo N=374	Kiama N=342	Crookhaven N=350
Sphericity vs Poslong+	.0899	.0533	.0609	.0239	.0754
Sphericity vs Posup≠	-.0020	-.1257*	-.0127	-.0013	.0568

+Poslong = Longshore beach position (profile by profile) with numerical increase from headland to embayment.

≠Posup = Up-beach position (grid point by grid point) with numerical increase from sea to land.

*once underlined values significant at the 0.05 level of probability

Sphericity, however, does vary from beach to beach, a likely result of the previously discussed geological controls. For example, at Copacabana beach, thinly bedded sandstone produces boulders of very low sphericity, while the massive near-cubic sandstone blocks of Crookhaven beach yield high sphericity values. This geological influence on sphericity has also been found in smaller sedimentary particles (Blatt, 1959).

Inasmuch as sphericity shows little fluctuation either along or up each beach, except on Copacabana, sphericity is also unrelated to sediment size on all studied beaches, except Copacabana where these two properties are negatively correlated (see Appendix III, Table A6). This decrease in size with increasing sphericity, and up-beach sphericity increase on Copacabana is most likely the result of the disc-shaped (low-sphericity) boulders which, when transported and fractured become both smaller and more equidimensional (spherical). This effect is illustrated by the trend surface map of sphericity prepared for Copacabana beach (Figure 24). The first-degree surface shows a sphericity increase in the low-energy landward portion of the beach where the smaller fragments accumulate. On all other studied beaches, no trend surfaces for sphericity explained a significant amount of the variation.

PARTICLE-SURFACE FEATURES

No attempt was made to quantitatively assess surface features or textures of individual sedimentary particles on boulder beaches. Folk (1974) suggests that in a particular environment the coarsest grains are frosted, the intermediate are polished, and the finest are dull. No clear relationship could be seen between particle size and surface features on the boulder beaches, and frosting caused by numerous percussion marks was the most common surface feature found on boulders of all sizes on all beaches (Plate 18). The abundance of frosted boulders on all beaches attests to the mobility of the sediment. Polished grains were found amongst the fine size fraction on all beaches, and amongst the large boulders on North Yacaaba beach where sand blasting (Kuenen, 1955, 1956) likely occurs (Plate 20). In Chapter VII, the cavernous weathering of boulders found on Crookhaven beach and the lichen-cover at Kiama are discussed in their rôle as stability indicators.

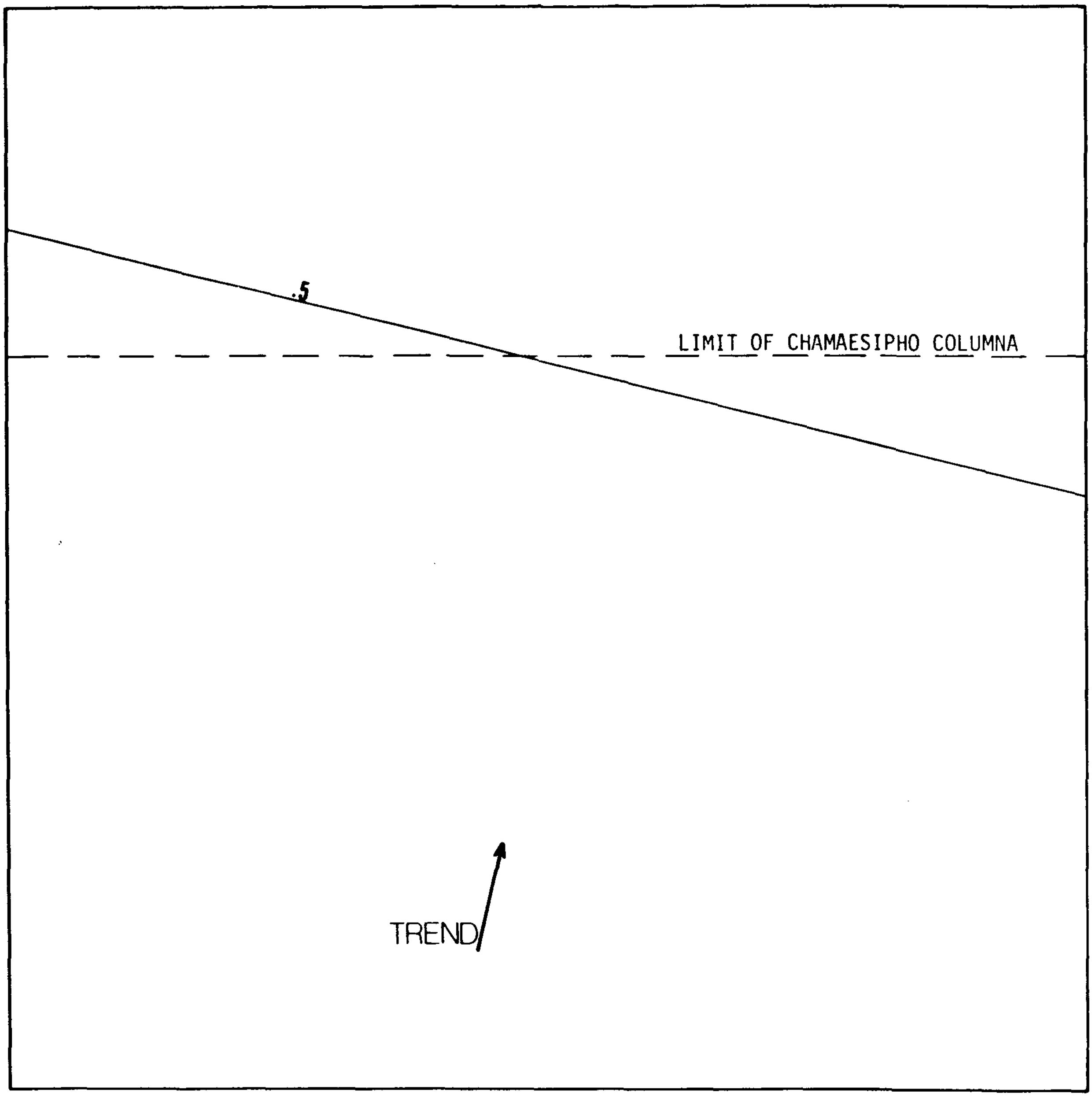


Figure 24. First degree trend surface map of Copacabana boulder beach: Maximum projection sphericity.
Explained variance = 2% Significant at the 0.05 level

Plate 20. North Yacaaba boulder beach showing sand associated with the boulders.

CHAPTER V

BOULDER ROUNDNESS

Along with size and shape, roundness is considered to be a fundamental sedimentary property. Attrition, which occurs during the transport of most sedimentary particles, tends to increase particle roundness, thus degree of roundness is sometimes viewed as an indication of the distance a particle has travelled. However, it has been found that breakage and lithology can complicate the relationship between distance travelled and particle roundness because breakage occurring during transport can decrease particle roundness (Sneed and Folk, 1958) and different rock types may round at unequal rates. Whether roundness increases or decreases, roundness is generally believed to be strongly influenced by the processes of abrasion (Krumbein, 1941), and on the studied beaches the roundness of the sediment might be expected to reflect its transport and geology.

The sediment supply determines the quantity and nature of the material found on each boulder beach. Copacabana, Bombo, Kiama, and Crookhaven beaches have been classified as open-system beaches, each receiving sediment at varying rates. Of these four beaches, Crookhaven receives the largest, most angular, and probably the greatest input of sediment. North Yacaaba, classified as a closed-system beach, receives little or no sediment. Therefore, the sediment present on this beach has presumably been there for some time and, consequently, the boulders and fragments are likely to be well worked.

Sediment transported from the headland zone to the embayment zone of a boulder beach is subject to much attrition. Up-beach transport occurs over a much shorter distance than long-beach transport, so attrition occurring during up-beach transport might be expected to be less effective. Where sand is present in the boulder-beach environment, rounding may be aided by "sand-blasting" since boulders can remain stationary in waves competent to carry sand (Kuenen, 1955, 1956).

Roundness may also reflect geology; jointing and bedding can determine the type of impact fracturing or splitting of a boulder, chipping can depend on texture, and rock texture and composition may influence attrition effectiveness (Bluck, 1969). These factors, however, are variable even within the same rock type, and are difficult to quantify. Consequently, only a few elementary observations were made regarding the effect of geology on boulder roundness on the studied beaches. For example, the dense and hard andesite of North Yacaaba appears to produce fewer fragments as a result of boulder impact than do the more fragile sandstones found on Copacabana, Kiama, and Crookhaven beaches. The massive, angular sandstone blocks supplied to Crookhaven beach, and the thinly-bedded, fragile sandstone of Copacabana beach give rise to low roundness values.

The influence of breakage on the rounding process is believed to be important because breakage can instantly negate the rounding effects of attrition. Thus, using roundness as a key to distance travelled by a boulder is most unreliable, for an angular boulder could be the result of transport fracture, while a well-rounded boulder could be the product of *in situ* abrasion (*e.g.*, Bartrum, 1947; Sneed and Folk, 1958).

Numerous studies have shown that, where little or no breakage occurs, rounding increases with particle transport. This rounding initially occurs rapidly and then slows as it asymtotically approaches a maximum value (*e.g.*, Wentworth, 1919; Krumbein, 1941; Cailleux, 1952; Pettijohn, 1975; Mills, 1979). Consequently, distributions of roundness for clastic sediments are typically right-skewed (log-normal) when values are determined by employing Wadell's (1932) method of assessing roundness (Folk, 1955; Sahu and Patro, 1970; *c.f.* Folk, 1972). Since the *rho* scale (Folk, 1955) presents roundness data already log transformed, distributions of roundness reported in *rho* units are usually symmetrical.

ROUNDNESS FREQUENCY DISTRIBUTIONS

Each boulder in the sample was visually assessed for roundness according to the Powers (1953) method, and *rho* values were assigned (see Chapter II). The frequency distributions of the *rho* values can be seen in Figure 25. North Yacaaba has a nearly symmetrical distribution, Copacabana, Bombo, and Kiama have distributions with slight negative skewness, while Crookhaven is markedly right-skewed (see Appendix III, Tables A1 to A5). The tail of the Crookhaven distribution is formed by the rounded population; thus angular particles dominate, suggesting an abundant supply of angular material and/or extremely active breakage. The high angularity of the abundant sediment supply on Crookhaven boulder beach is believed to be the cause of this anomalous distribution where the bulk of the sediment has very low roundness values. It should be remembered, however, that because the *rho* scale is logarithmic, a given proportion of well-rounded boulders does not produce the high-skewness values that the same proportion of angular boulders would.

On the other beaches where the rate of sediment supply is lower, newly arrived, angular boulders are less numerous, a greater proportion of boulders

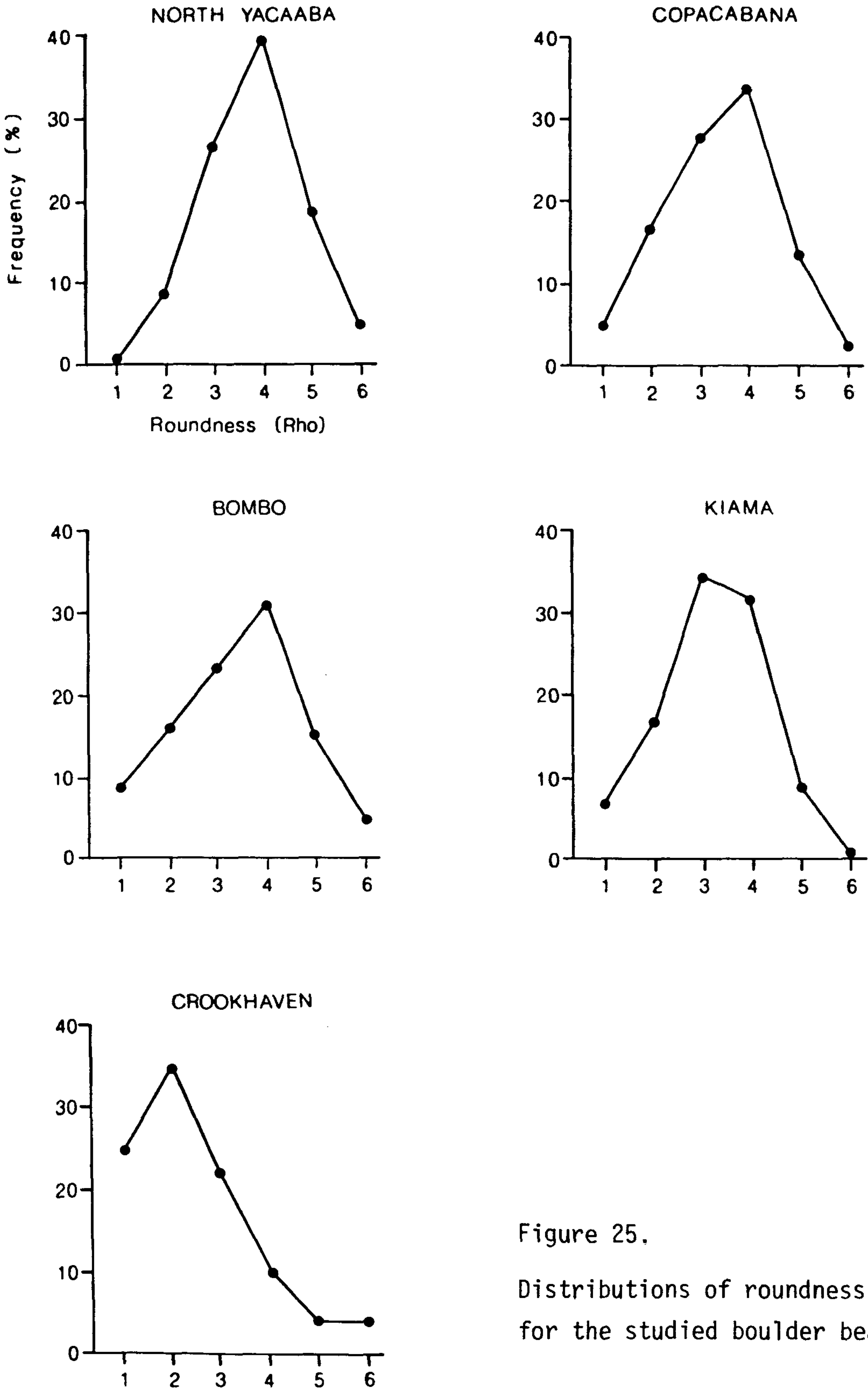


Figure 25.

Distributions of roundness for the studied boulder beaches.

have high roundness values, and the negative skewness tail is formed by angular fragments. The distribution for North Yacaaba (Figure 25) is the closest to a normal distribution of all the studied beaches, indicating that only a small proportion of sediment on this beach has not been rounded. Thus, the input of angular material must be low and there has been little recent breakage on this beach.

In situ attrition caused by the near constant bombardment of boulders by swash-borne particles is believed to occur on all of the studied beaches, and may contribute to boulder rounding in the tidal zone. This process was particularly evident on Kiama beach because boulders had been painted in order to monitor movement. Although paint impregnated the porous sandstone, the marked boulders located in the swash zone required monthly repainting, while the paint on boulders above the swash zone remained for many months. On North Yacaaba beach, which has a low rate of sediment supply, very few boulders are highly angular (Figure 25). This is possible because of the lack of fresh boulders and fragments, and the presence of sand which is an effective rounding agent (Plate 20). Thus, the proportion of fresh, hence angular, sediment found on each beach is reflected in the distribution of roundness.

ROUNDNESS AND SEDIMENT SUPPLY

The median roundness value for each beach was plotted against rate of sediment supply (Figure 26). The abundance of angular material entering Crookhaven beach was reflected in the low median roundness value of 2.2ρ. The three beaches with moderate sediment supply rates, Copacabana, Bombo, and Kiama, yielded median roundness values of 3.0ρ, 3.5ρ, and 3.2ρ;

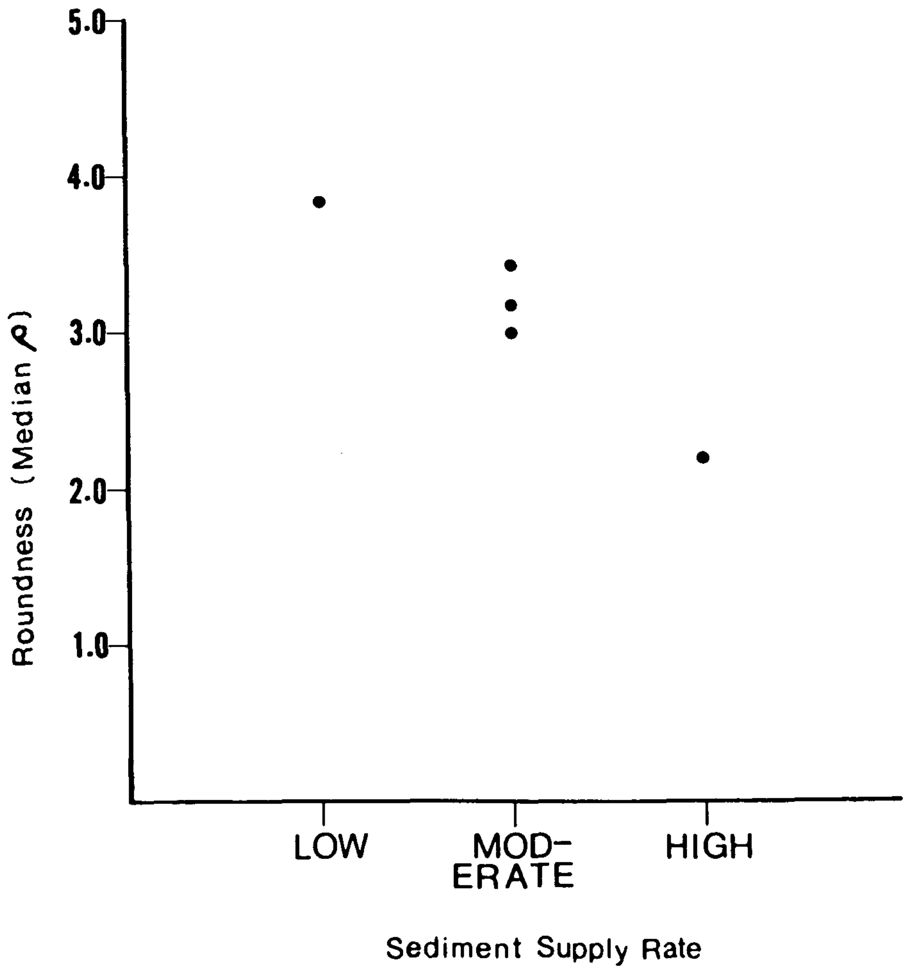


Figure 26. The relationship between sediment roundness and rate of sediment supply on the studied boulder beaches.

and poorly supplied North Yacaaba, composed of well-worked boulders, was found to have the highest median roundness of 3.8ρ.

Roundness sorting varied little from beach to beach (from 1.0 to 1.3 standard deviations), so no systematic variation in sorting of roundness with sediment supply or any other property could be discerned.

ROUNDNESS ALONG THE BEACH

Spearman rank correlation analyses showed that on all beaches except Copacabana, roundness increases in the direction of transport from headland to embayment (Table 14). This rounding of the boulders by attrition during movement along the beach appears to be an important process on four of the five studied beaches. It was observed on Copacabana beach that boulders split easily and there was a large number of freshly fractured boulders and fragments in the embayment zone. This geological predisposition towards breakage may have concealed any rounding produced by attrition during transport (see Sneed and Folk, 1958). The occurrence, to varying degrees, of both attrition and breakage with transport along all of the beaches gives rise to a tendency for roundness sorting to decrease from the headland zone to the embayment zone (Table 15).

ROUNDNESS UP THE BEACH

Spearman rank correlation analyses revealed that, with the exception of North Yacaaba, roundness decreases up each beach (Table 14). A combination of several factors may be responsible for the consistent up-beach decrease in roundness on the four beaches with active sediment input.

TABLE 14

SPEARMAN RANK CORRELATION COEFFICIENTS FOR ROUNDNESS VS BEACH POSITION, AND ROUDNESS VS SIZE

	Beach				
	North Yacaaba	Copacabana	Bombo	Kiama	Crookhaven
Roundness (ρ) vs Poslong+	.1545*	.0525	.1559	.1169	.4676
Roundness (ρ) vs Posup≠	-.0192	-.2061	-.4377	-.2950	-.2653
Roundness (ρ) vs Size	-.1449	.1789	.2970	.1928	-.2448

*once underlined values significant at the .05 level
twice underlined values significant at the .001 level

+Poslong = Longshore beach position (profile by profile) with numerical increase from headland to embayment.

≠Posup = Up-beach position (grid point by grid point) with numerical increase from sea to land.

TABLE 15

ROUNDNESS SORTING (ρ STANDARD DEVIATION) FOR EACH BEACH ZONE

Beach	Zone* 1	2	3	4	5	6
North Yacaaba	.939	1.036	1.146	.877	1.020	1.213
Copacabana	1.109	1.197	1.270	1.129	1.132	1.146
Bombo	1.353	1.375	1.198	.950	1.213	1.352
Kiama	1.010	1.078	1.164	.927	1.031	1.114
Crookhaven	.741	1.339	1.357	1.208	1.317	1.248

*1 = Headland Zone; 2 = Mid Zone; 3 = Embayment Zone; 4 = Tidal Zone; 5 = Supra-tidal Zone; 6 = Landward Zone

The boulders in the most seaward positions are subject to the rounding effects of attrition by swash-borne particles and small swash-induced boulder movements, while boulders high on the beach are affected only by infrequent storm waves and subaerial weathering. Probably more important to the up-beach decrease in roundness, however, is the effect of breakage on the boulder beaches. Chipping and crushing of newly supplied boulders provide many angular fragments which undergo minimal rounding when transported the short distance to the landward zone. Because sediment is continually supplied to these four beaches, fresh (angular) chips and fragments are present in the beach. In addition to the newly deposited angular fragments, many boulders which had been fractured or split *in situ* were found in the landward zones. These angular products of recent breakage are stranded high on the beach because the backwash is absorbed by the highly permeable beach. Thus, boulder roundness tends to decrease up the beach.

On North Yacaaba, however, roundness does not show any significant trend up the beach, and in the landward zone many well-rounded fragments were found. It is suggested that, because there is no fresh sediment input, there are few angular chips and fragments being formed. Through attrition and perhaps sub-aerial weathering, most fragments, which were produced when the beach had a more active sediment supply, have become rounded. The presence of rounded fragments high on North Yacaaba beach results in roundness exhibiting very little variation up the beach.

Generally, on the beaches where the suggested sediment supply rate is moderate or high, roundness decreases up the beach. However, some rounding may be occurring with up-beach transport because sorting becomes poorer from seaward to landward (Table 15) indicating the presence of some rounded material amongst the more angular of the landward zones.

BOULDER ROUNDNESS AND BOULDER SIZE

Spearman rank correlation analyses showed that there exists a significant relationship between roundness and size on all beaches (Table 14). On Crookhaven and North Yacaaba beaches, this relationship is negative, while on Copacabana, Bombo, and Kiama beaches, it is positive. These relationships are depicted in Figure 27.

Copacabana, Bombo, and Kiama beaches all show roundness increasing with size. On these beaches with moderate sediment supply, much breakage was observed to produce very angular fines and small boulders. The boulders supplied to these beaches are also angular, but not uniformly large, and not in sufficient quantity to balance the number of angular particles caused by breakage. It is believed that the angularity caused by breakage results in the positive relationship between size and roundness found on these three beaches.

On Crookhaven, chipping and fracturing with transport were observed, but the great number of large, fresh, angular boulders on this beach appears to overshadow the angularity produced by breakage, The dominant angular population is composed of very large, newly supplied boulders, while those boulders which have been subject to rounding processes tend to be relatively smaller. Therefore, roundness on Crookhaven beach decreases as size increases (Table 14).

Roundness was also found to decrease as size increases on North Yacaaba beach (Table 14), which, in contrast to Crookhaven, lacks sediment input.

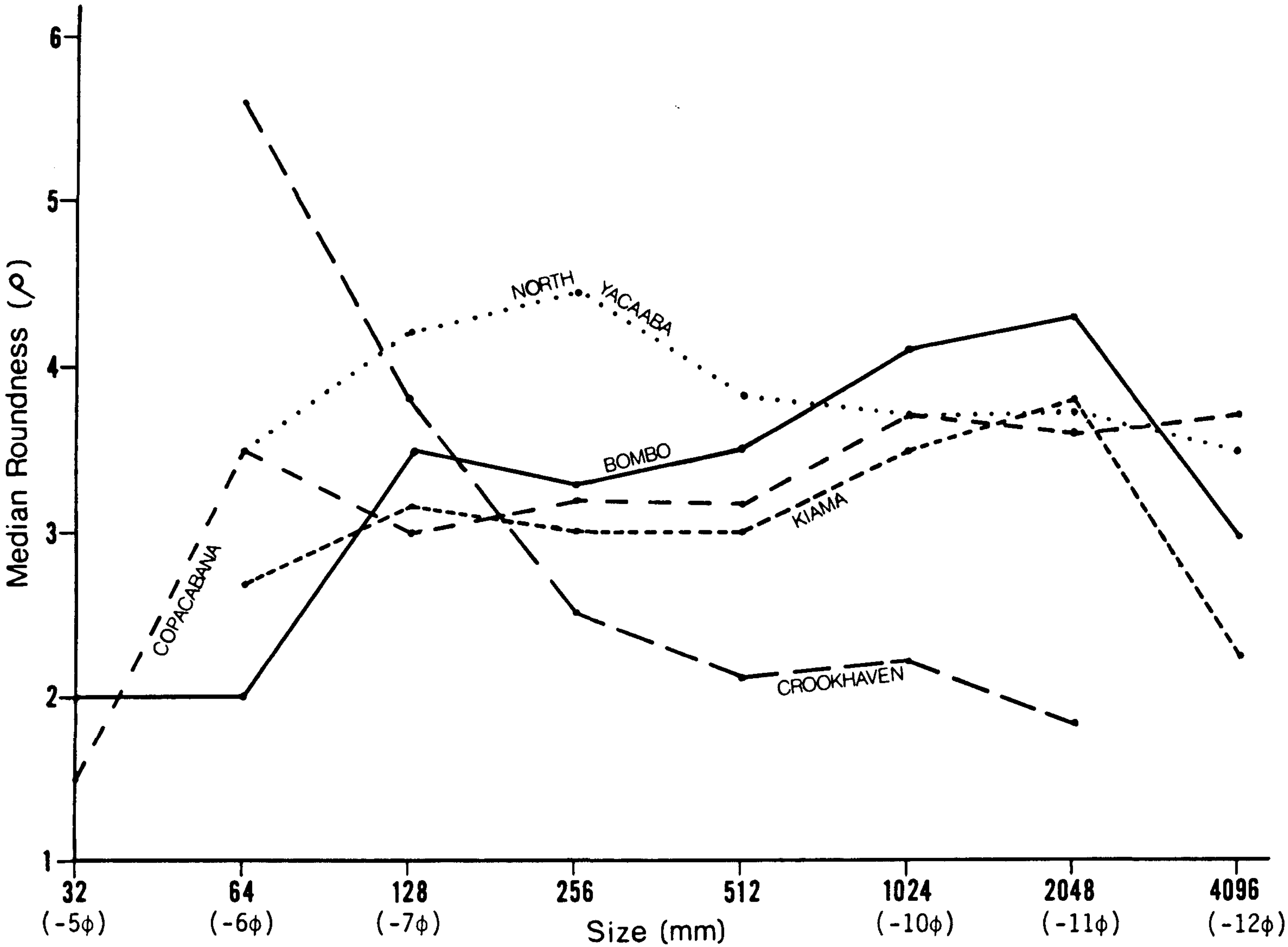


Figure 27. The relationship between roundness and size on the studied boulder beaches.

Since there is little fresh, angular material introduced, the sediment has presumably been present on this beach for some time and tends to be well worked, and roundness values are higher on this beach than on any of the other studied beaches. Because breakage does not appear to be an important process on this beach, the relatively high roundness of the small boulders and fines which are more easily moved and rounded by attrition, is not balanced by large numbers of very angular fragments. Therefore, although roundness varied little over the entire beach, there was a tendency for roundness to increase as size decreased. Although the direction of this relationship is the same as that for Crookhaven beach, the causes are quite different.

The relationship between boulder roundness and size was further examined by grouping sediment into the size groups shown in Table 16 and calculating the median roundness for each group. It is noteworthy that the median roundness which is nearest the overall median roundness of each beach always occurs in the size groups between -7ϕ and -10ϕ. In Table 17, the frequency of boulders for each size group is shown. When this table is examined in conjunction with Table 16, it can be seen that for each beach the size group which has the median roundness closest to the overall median roundness is also the modal size class. Thus, on each studied beach, boulders of the modal size group were found to have a median roundness value very close to the median roundness value found for the entire beach. It is suggested, therefore, that the median roundness of an entire boulder beach can be very closely approximated by examining the roundness of the modal size group.

TABLE 16

MEDIAN ROUNDNESS OF SIZE GROUPS

	Beach				
Size Group (ϕ)	North Yacaaba (ρ)	Copacabana (ρ)	Bombo (ρ)	Kiama (ρ)	Crookhaven (ρ)
> -4		1.500	2.000		
-4 to -6	3.500	3.500	2.045	2.500	5.667
-6 to -7	4.250	3.083	3.536	3.150	3.833
-7 to -8	4.444	3.192	<u>3.281</u>	3.000	2.500
-8 to -9	<u>3.818</u>*	3.175	3.515	<u>3.096</u>	2.120
-9 to -10	<u>3.725</u>	<u>3.744</u>	4.130	3.500	<u>2.254</u>
-10 to -11	3.700	3.587	4.300	3.833	1.826
< -11	3.500	3.750	3.000	2.250	

*Underlined ρ value is the median roundness value nearest to the median roundness for the entire beach.

TABLE 17

OBSERVATION FREQUENCY OF EACH SIZE GROUP

Size Group (ϕ)	Beach				
	North Yacaaba (%)	Copacabana (%)	Bombo (%)	Kiama (%)	Crookhaven (%)
> -4		1.16	.27		
-4 to -6	4.70	7.54	8.56	2.92	4.27
-6 to -7	7.72	4.93	15.24	7.31	4.56
-7 to -8	12.42	11.01	<u>28.88</u>	15.20	7.41
-8 to -9	26.51	24.64	28.61	<u>36.84</u>	19.09
-9 to -10	<u>38.59</u>*	<u>31.88</u>	15.51	29.82	<u>51.28</u>
-10 to -11	9.40	17.97	2.67	6.43	13.39
< -11	.67	.87	.27	.88	

*Underlined valued is modal size class.

TABLE 18

ROUNDNESS SORTING (STANDARD DEVIATION) FOR EACH SIZE GROUP

Size Group (ϕ)	Beach: North Yacaaba (ρ)	Copacabana (ρ)	Bombo (ρ)	Kiama (ρ)	Crookhaven (ρ)
> -4		2.062			
-4 to -6	1.342	1.164	1.281	1.636	1.464
-6 to -7	1.430	1.029	1.604	1.201	1.673
-7 to -8	1.127	1.000	1.187	1.066	1.392
-8 to -9	1.026	1.332	1.208	1.026	1.314
-9 to -10	.910	1.064	.923	.981	1.069
-10 to -11	.786	1.002	.675	.922	.702
< -11	.707	1.155		.577	

Roundness sorting also tends to vary with size, and as size increases, roundness sorting improves (Table 18). This effect may be due to the fact that, in most cases, the largest boulders on each beach have similar histories and are part of one roundness population. Whether the large boulders are highly angular, as at Crookhaven, or fairly well rounded, they tend to possess similar degrees of roundness within each beach. The smaller material, however, can be divided into two roundness populations: one composed of angular chips and fragments; and, the other composed of material which has been subject to attrition and is well rounded. Thus, both angular and rounded sediment may be found in the smaller sizes, resulting in poor roundness sorting.

In order to gain a better understanding of the operation of rounding processes on the largest boulders, these boulders were individually examined on each beach. Except on Crookhaven, where the large angular boulders dominate the roundness relationships, roundness was found to be quite high for some of the coarsest boulders. This field observation is reflected in the values of Table 16, and contradicts the belief that effectiveness of rounding processes diminishes in the largest sizes (Bluck, 1969), a supposition developed during the study of gravel beaches (Figure 28). The largest boulders encountered in this study are moved very rarely, and then most probably in traction, However, during storms many very large boulders are bombarded by smaller sediment, and hence rounded by attrition. Also, as has been previously noted, the large boulders are often positioned where they may be rounded by swash-borne particles.

Bluck (1969) found that the effectiveness of the processes which cause rounding on gravel beaches varies with particle size in the manner illustrated in Figure 28. The present study has examined larger particles than were investigated by Bluck. After analyzing the roundness and size data (Table 16) from the five boulder beaches and examining individual boulders in the field, an extension of Bluck's diagram (Figure 28) is proposed and illustrated in Figure 29.

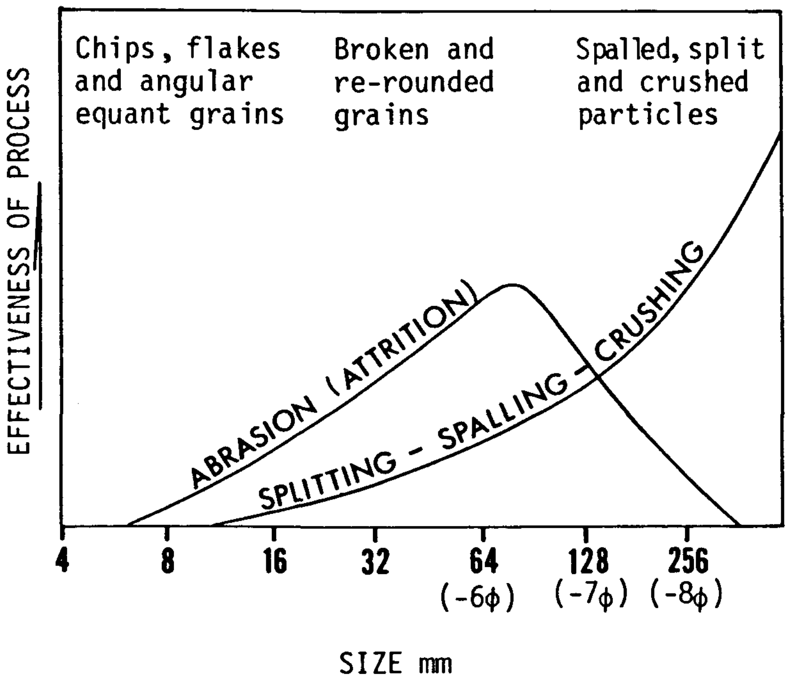


Figure 28. Diagrammatic illustration of the effectiveness of various processes in different sizes and the commonly occurring grain types. (after Bluck, 1969, p. 8)

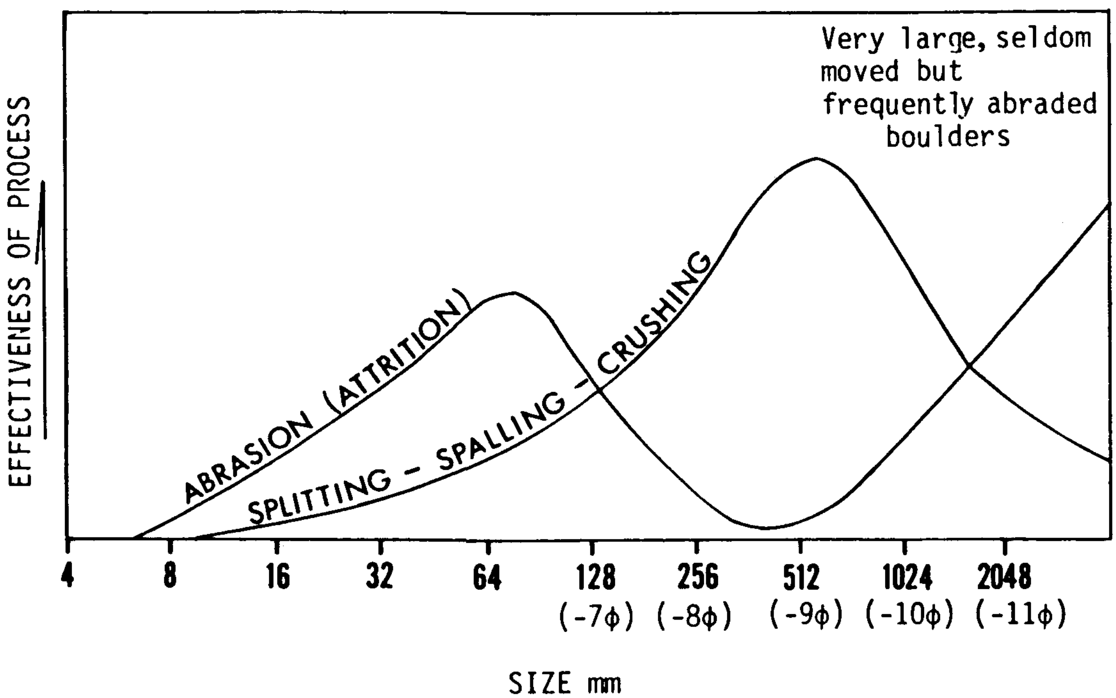


Figure 29. Extension of figure 28, illustrating the decline of splitting-spalling-crushing and the rise of attrition as a process effective on large boulders.

BOULDER ROUNDNESS AND BOULDER SHAPE

Boulder roundness and shape were investigated to determine if any relationship could be found between these sedimentary parameters. On each beach, Spearman rank correlation analyses were performed between maximum projection sphericity and roundness, but none of the derived correlation coefficients was statistically significant ($\alpha = 0.05$).

Although no general relationships between sphericity and roundness could be found, it is of interest to note that Crookhaven beach, the beach with the greatest mean sphericity was also the beach with the lowest median roundness. This is because sediment which is both equidimensional and angular is supplied at a high rate to this beach.

Roundness was also investigated for each Zingg shape on each beach. Kruskal-Wallis analyses of variance revealed no significant variation among the distributions of roundness for each shape except on Bombo beach where discs tended to be better rounded than the other shapes. The general weight of the evidence, however, suggests that boulder shape is unrelated to rounding.

Spearman rank correlation analysis was used to examine the relationship between size and roundness for each Zingg shape. The positive size *vs* roundness relationships reported for all sediment on Copacabana, Bombo, and Kiama boulder beaches, and the negative size *vs* roundness relationships obtained for North Yaccaba and Crookhaven beaches, were found to exist for each shape on those beaches. The size and roundness relationships for each shape on each beach are illustrated in Figure 30.

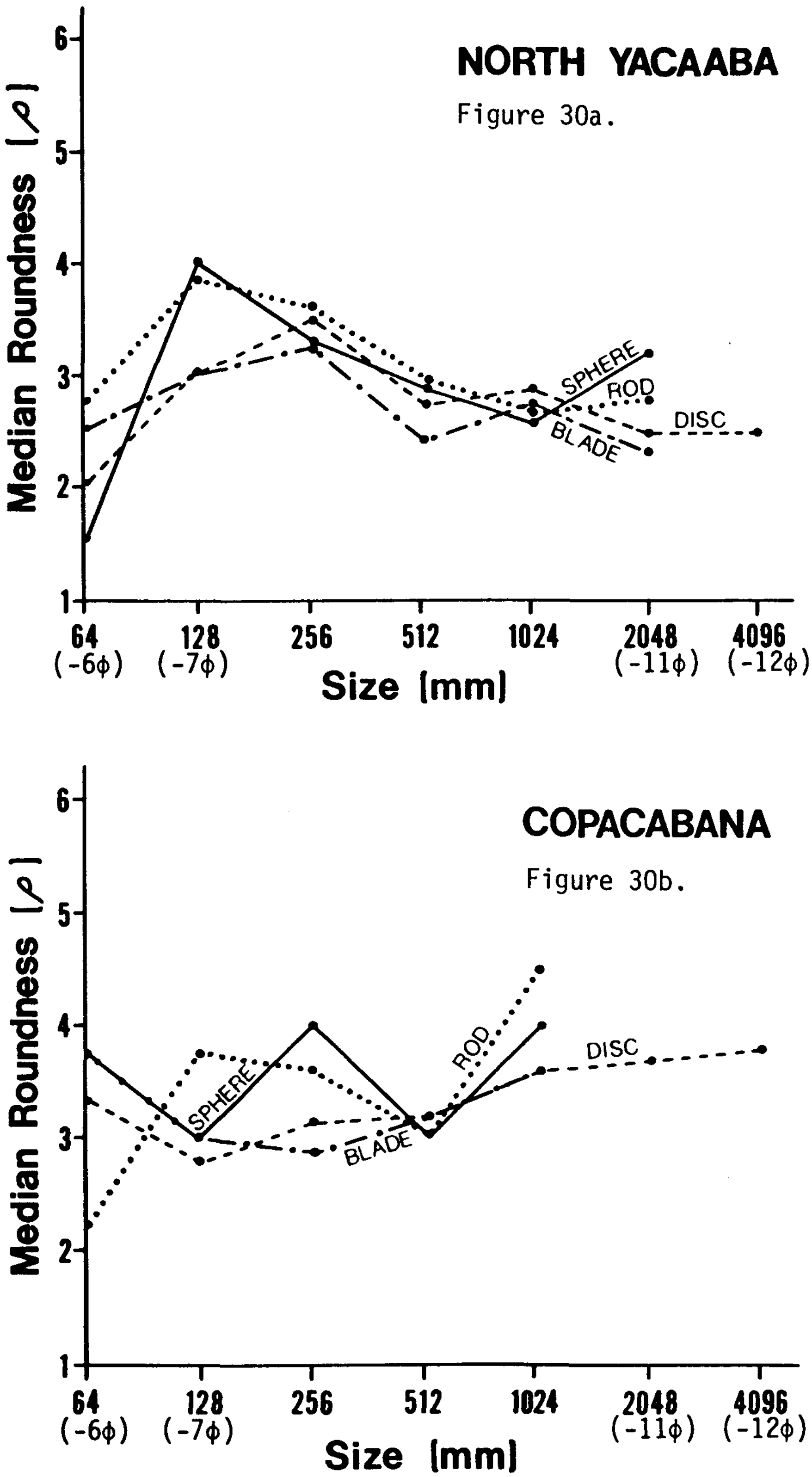


Figure 30. Relationship between roundness and size for each Zingg shape on each studied boulder beach.

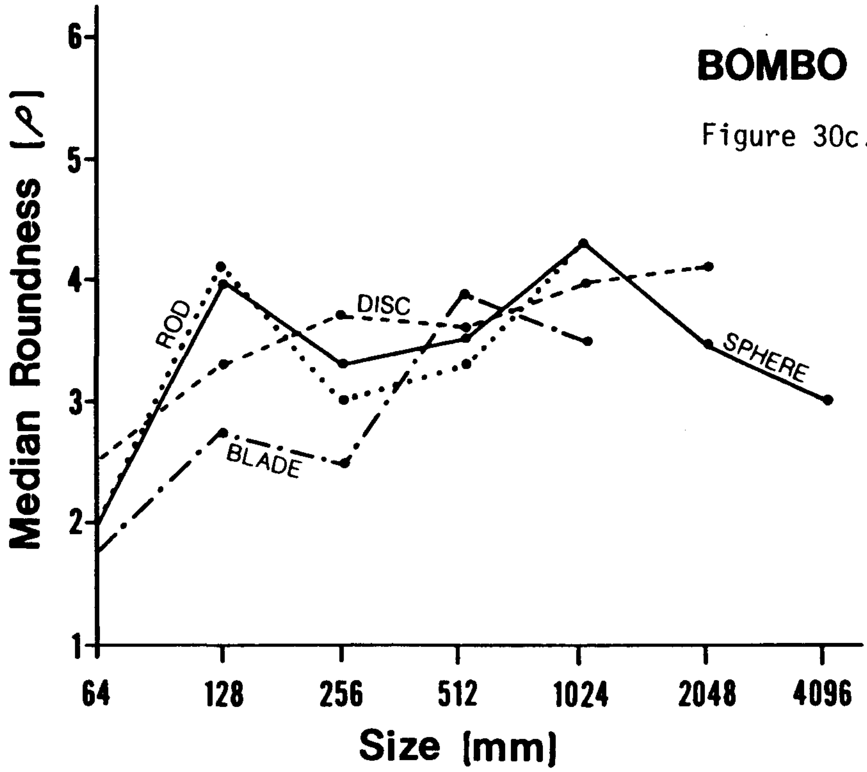


Figure 30c.

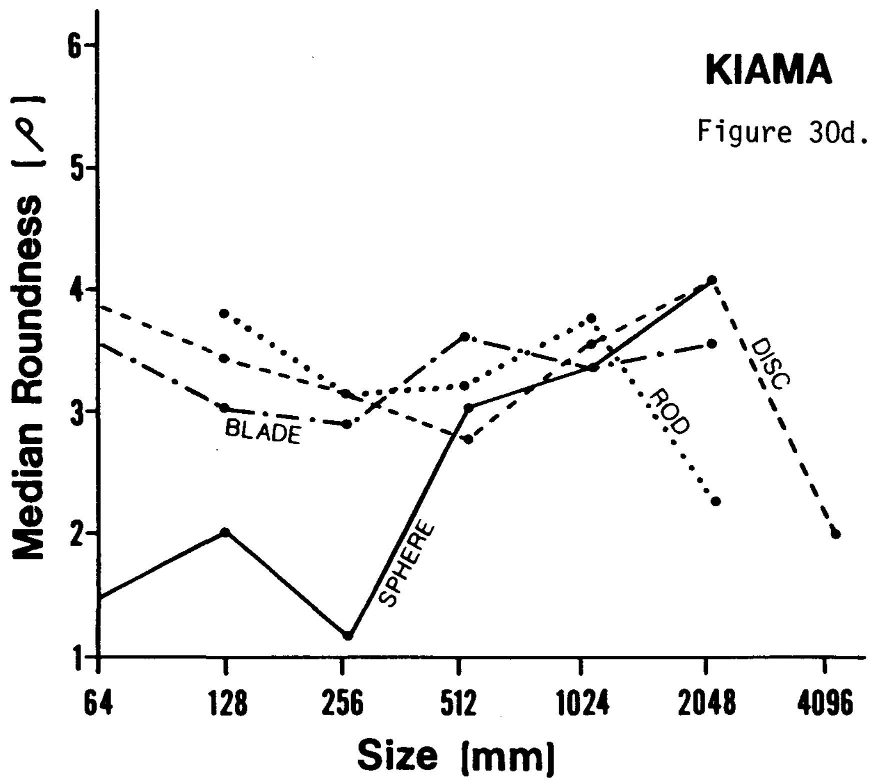


Figure 30d.

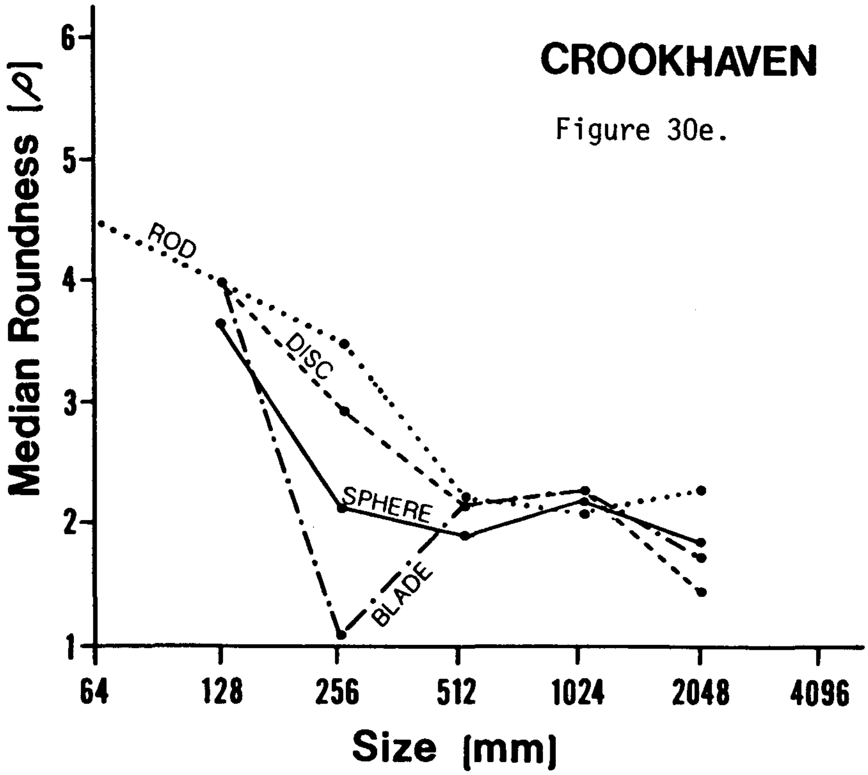

CROOKHAVEN
Median Roundness [ρ]
6
5
4
3
2
1
64
128
256
512
1024
2048
4096
Size [mm]
ROD
DISC
SPHERE
BLADE

Figure 30e.

TREND SURFACE ANALYSIS OF ROUNDNESS

The organization of roundness on each beach is shown by the trend surface maps in Figures 31 to 35.

On North Yacaaba beach, the first-degree, and only significant, trend surface (Figure 31) shows that although roundness increases towards the embayment, the trend is not a strong one. This trend is probably due to both the low rate of input of angular material and the effects of attrition (especially by sand) on the boulder population.

The two statistically significant surfaces presented for Copacabana beach (Figures 32a and 32b) show roundness decreasing both along the beach and up the beach. The second-degree surface (Figure 32b) shows roundness within the swash range increasing in the direction of longshore transport, while the portion of the beach above the swash shows a tendency for roundness to decrease alongshore. This suggests that the swash on Copacabana beach may affect the rounding process. The low roundness in the landward portion is most likely caused by the accumulation of large numbers of chips and fragments produced by the easily broken sediment of this beach.

The significant trend surfaces obtained for Bombo, Kiama, and Crookhaven beaches (Figures 33 to 35) are very similar in form and show no difference in trend above or below swash range. The longshore increase in roundness combines with the up-beach decrease in roundness to give the roundness coutours for Bombo, Kiama, and Crookhaven a diagonal pattern. On these three beaches, transport both along and up the beach appears to influence the roundness characteristics of the beach.

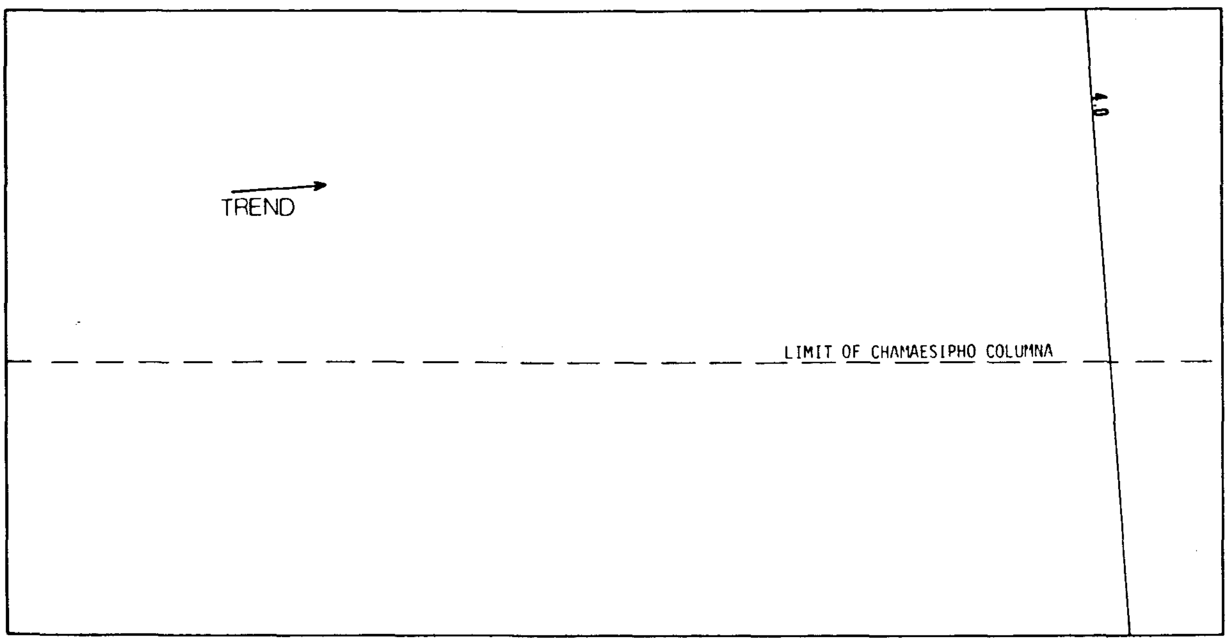


Figure 31. First degree trend surface map of North Yacaaba boulder beach: Roundness (*rho* values).
Explained variance = 2%   Significant at the 0.05 level

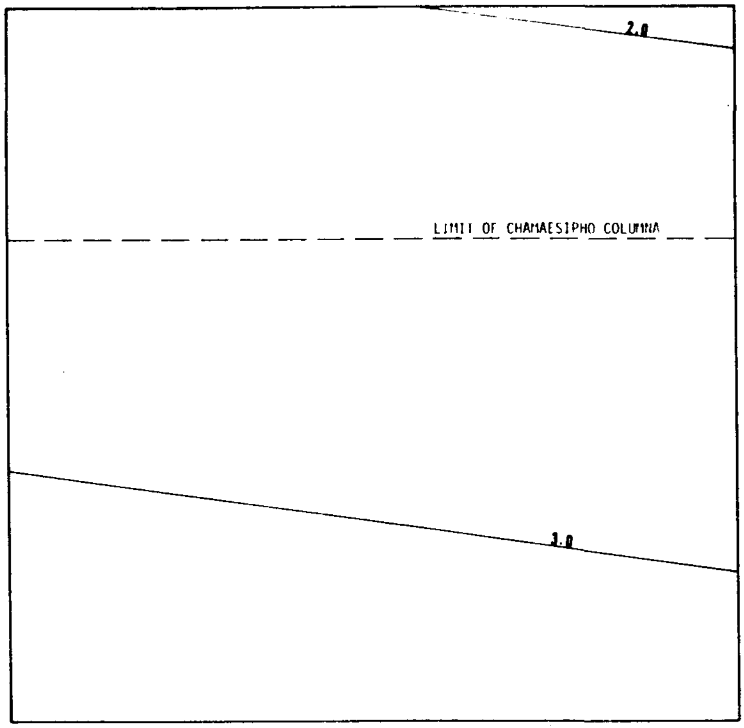


Figure 32a. First degree trend surface map of Copacabana boulder beach: Roundness (*rho* values).
Explained variance = 4% Significant at the 0.05 level

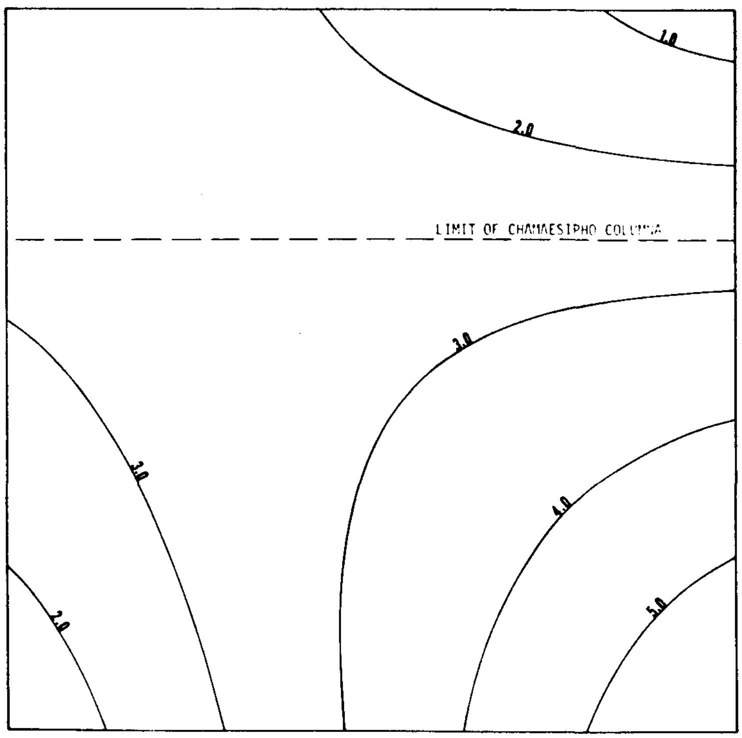


Figure 32b. Second degree trend surface map of Copacabana boulder beach: Roundness (*rho* values).
Explained variance = 9.5% Significant at the 0.05 level

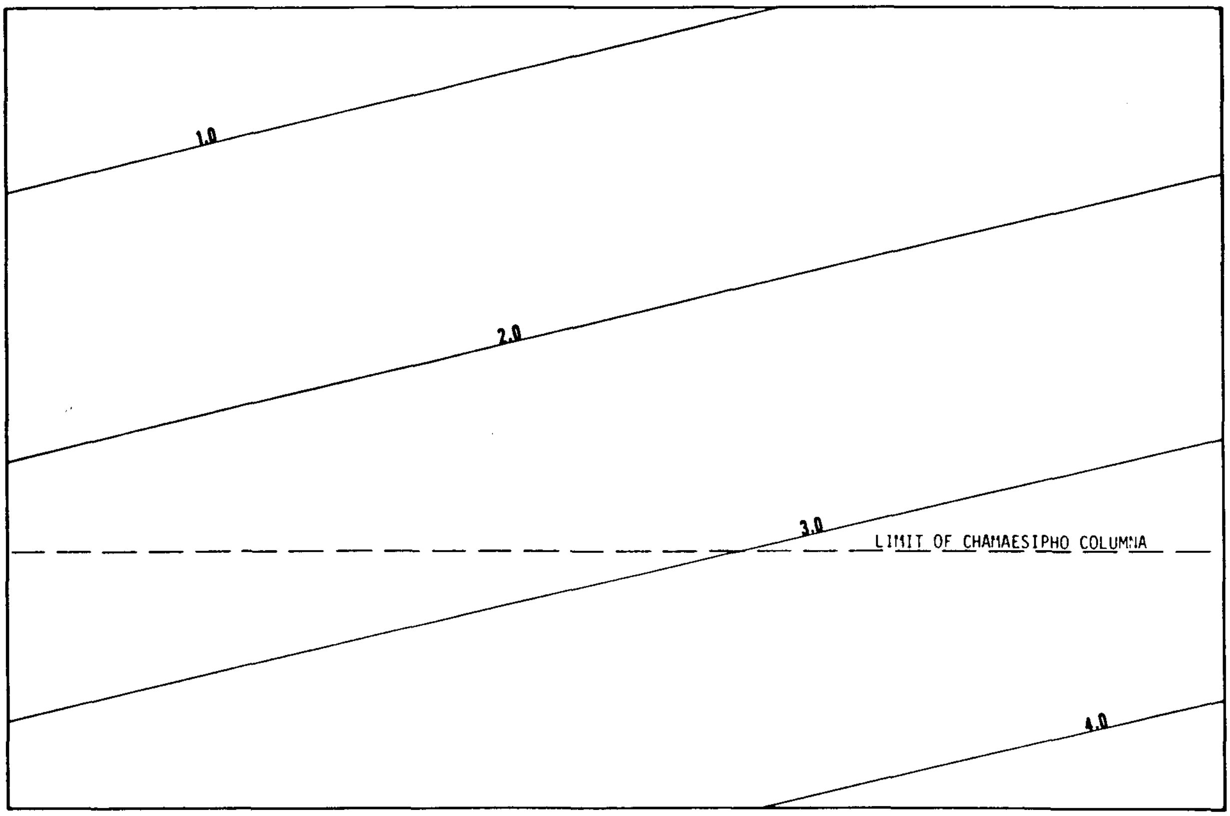


Figure 33. First degree trend surface map of Bombo boulder beach: Roundness (*rho* values).
Explained variance = 24% Significant at the 0.05 level

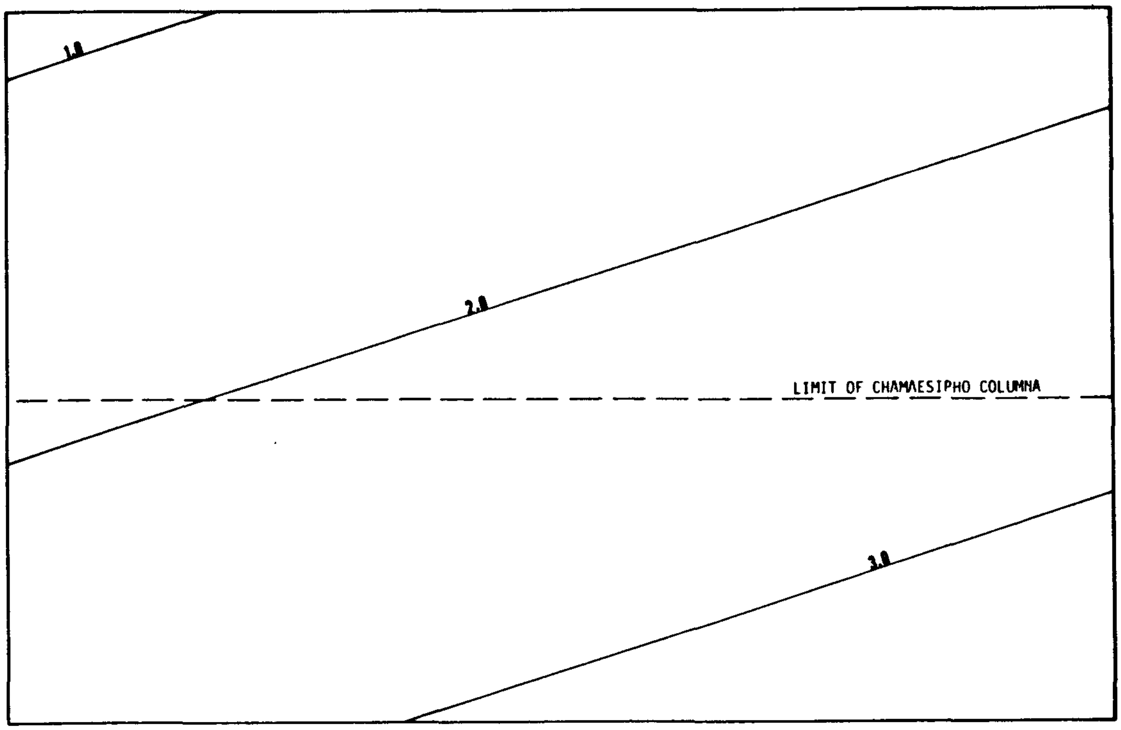


Figure 34a. First degree trend surface map of Kiama boulder beach: Roundness (*rho* values).
Explained variance = 13.5% Significant at the 0.05 level

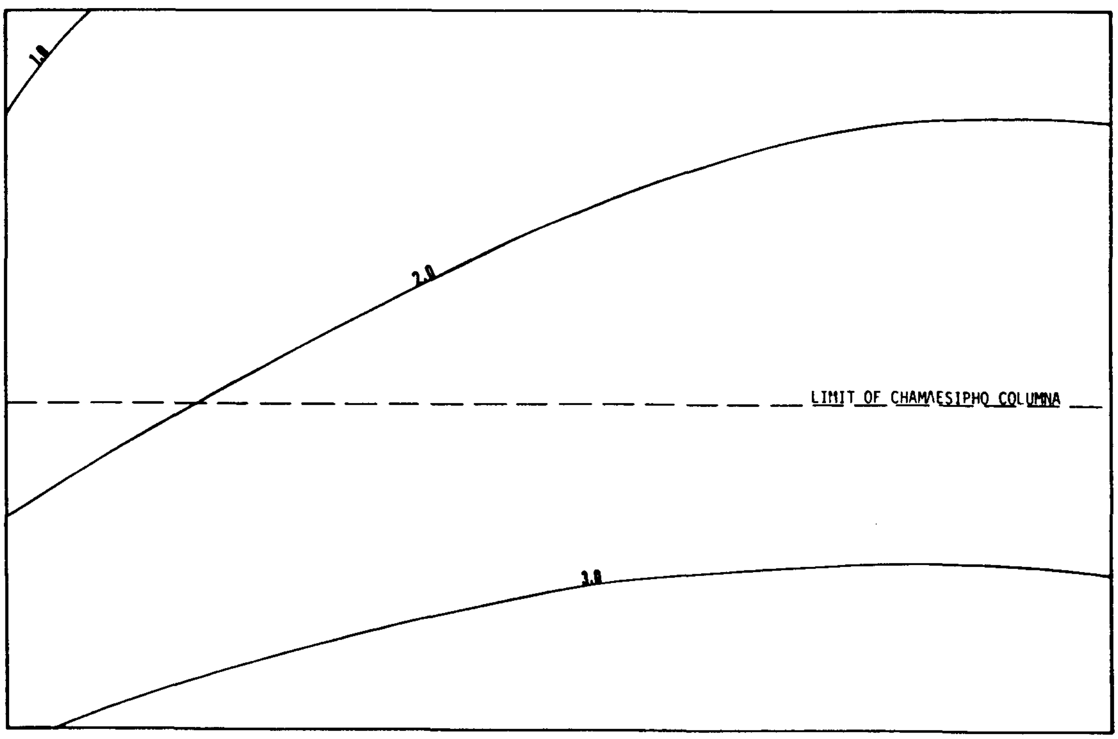


Figure 34b. Second degree trend surface map of Kiama boulder beach: Roundness (*rho* values).
Explained variance = 15.5% Significant at the 0.05 level

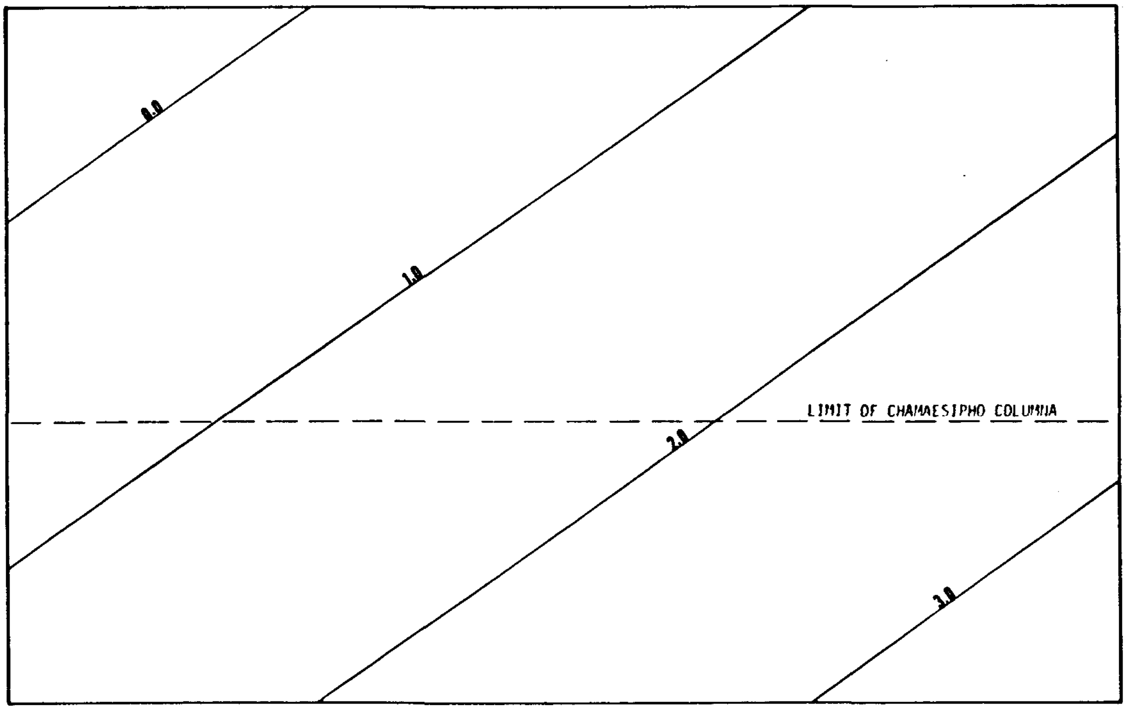


Figure 35a. First degree trend surface map of Crookhaven boulder beach: Roundness (*rho* values).
Explained variance = 28.5% Significant at the 0.05 level

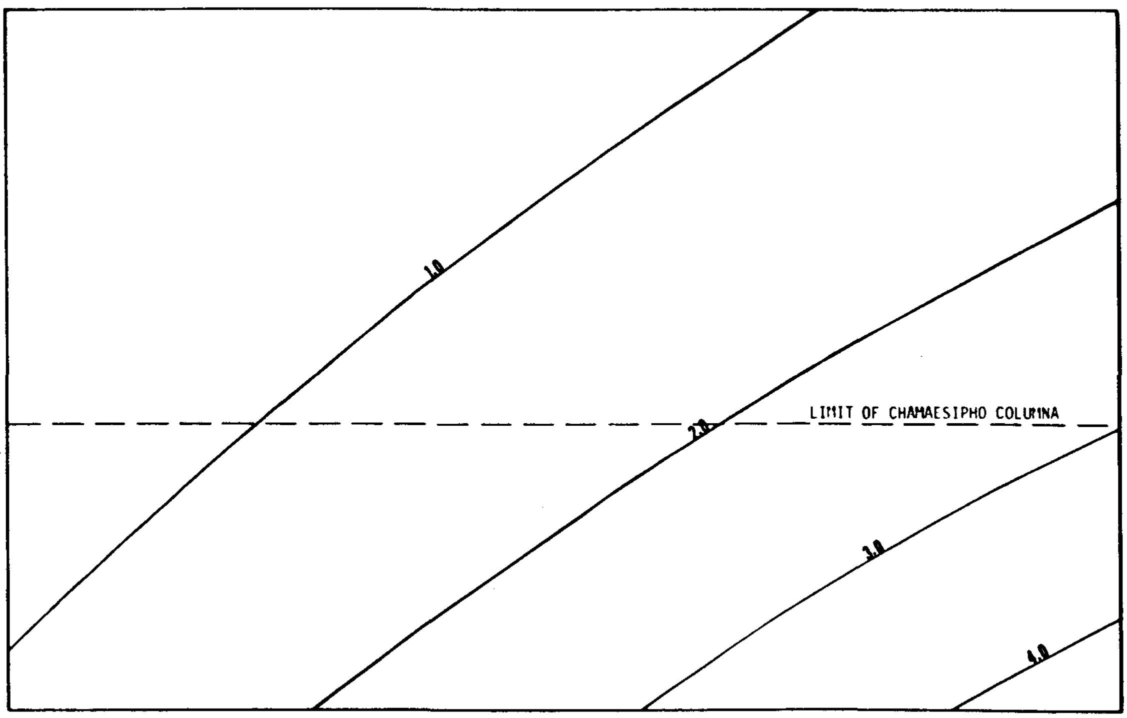


Figure 35b. Second degree trend surface map of Crookhaven boulder beach: Roundness (*rho* values).
Explained variance = 29% Significant at the 0.05 level

COMPARISON OF ROUNDNESS STATISTICS

Median Roundness *vs* Roundness Standard Deviation (Sorting)

Table 19 shows both the median roundness and the standard deviation of roundness for each beach. North Yacaaba has the highest roundness and best sorting, and Crookhaven the lowest roundness and poorest sorting. The roundness and sorting values for Copacabana, Bombo, and Kiama beaches fall between the values for North Yacaaba and Crookhaven.

The high median roundness and roundness sorting values found for North Yacaaba can probably be attributed to the dearth of fresh, angular sediment, the rounding by sand, and the lack of angular chips and fragments on the beach. In contrast, on Crookhaven, angular sediment dominates the beach, causing median roundness to be low. Some boulders, however, have been rounded, giving rise to the poor sorting of roundness on this beach. Rounding by attrition during transport as well as chipping and fracturing were noted on Copacabana, Bombo, and Kiama beaches, where neither angular nor rounded sediment appears to dominate the beach. Thus roundness and sorting values are moderate, and fall between the more extreme values found for North Yacaaba and Crookhaven.

Median roundness and roundness sorting were also examined to find if the relationship between these two sedimentary parameters varies either along or up the beach. During longshore transport, many boulders are rounded, but some breakage also occurs. The best rounded sediment, therefore, may often be found in conjunction with angular material, and the variation in degree of roundness may increase in the direction of longshore transport. In Table 20 it can be seen that roundness tends to increase while sorting

TABLE 19

MEDIAN ROUNDNESS AND ROUNDNESS SORTING (STANDARD DEVIATION) ON EACH BEACH

Roundness Statistics	Beach				
	North Yacaaba	Copacabana	Bombo	Kiama	Crookhaven
Median (ρ)	3.822	3.002	3.540	3.246	2.236
Standard Deviation (ρ)	1.045	1.153	1.303	1.065	1.304

TABLE 20

MEDIAN ROUNDNESS AND ROUNDNESS SORTING (STANDARD DEVIATION) ALONG EACH BEACH

Roundness Statistics	Beach and Zone*														
	North Yacaaba			Copacabana			Bombo			Kiama			Crookhaven		
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Median (ρ)	3.93	3.87	3.56	3.91	4.04	4.06	3.80	4.01	4.261	3.81	3.92	3.47	2.13	2.80	3.45
Standard Deviation (ρ)	.939	1.036	1.146	1.109	1.197	1.270	1.353	1.375	1.198	1.01	1.08	1.67	.741	1.339	1.357

*1 = Headland Zone
2 = Mid Zone
3 = Embayment Zone

decreases along each beach.

Table 21 shows that roundness and roundness sorting both tend to decrease up the beach. The boulders low on each beach are subject to attrition by swash-borne particles, and form a better rounded, more homogeneous group than do the boulders and fragments which have been deposited higher on the beach.

It can be seen from Tables 19, 20, and 21 that the relationship between median roundness and roundness sorting is highly variable on the five studied boulder beaches. The rate and angularity of sediment supply appears to influence this relationship, as does within-beach location. Generally, roundness sorting tends to decrease in the directions of transport (longshore and up-beach) as the two populations of rounded and angular boulders are mixed. Median roundness, however, tended to increase along the beach and decrease up the beach. Thus, rounding processes appear to be most effective during longshore transport.

The preceding analyses of boulder roundness suggest that the following roundness characteristics may be common to all bay-side boulder beaches:-

1) Roundness-size relationships are affected by rate of sediment supply. Specifically, a high rate of input of very angular, large-size sediment may result in roundness increasing as size decreases because the bulk of the angular population is comprised of large angular blocks. Alternatively, a low rate of input of angular, large-size sediment may result in roundness increasing as size increases because rounding of the sediment is more rapid than the rate of input, and it is small chips and fragments that dominate the angular population.
2) Roundness decreases up the beach.

TABLE 21

MEDIAN ROUNDNESS AND ROUNDNESS SORTING (STANDARD DEVIATION) UP EACH BEACH

Roundness Statistics	Beach and Zone*														
	North Yacaaba			Copacabana			Bombo			Kiama			Crookhaven		
	4	5	6	4	5	6	4	5	6	4	5	6	4	5	6
Median (ρ)	3.88	3.70	3.90	4.00	3.51	3.13	4.27	3.45	3.00	3.67	3.13	2.98	2.68	2.17	1.84
Standard Deviation (ρ)	.877	1.020	1.213	1.129	1.132	1.146	.950	1.213	1.352	.927	1.031	1.114	1.208	1.317	1.248

*4 = Tidal Zone
5 = Supra-tidal Zone
6 = Landward Zone

3) Roundness increases along the beach from headland to embayment because waves approach at an oblique angle, causing longshore transport which tends to round the moved sediment.
4) Roundness and shape are not related.
5) Rock type and structure of the beach sediment influence the rounding process by determining the likelihood of breakage and the effectiveness of attrition.

CHAPTER VI

BEACH FORM

The overall dimensions of the studied boulder beaches are remarkably similar (see Table 22). The consistent seaward to landward beach widths reflect the uniform wave climate and tidal range of the New South Wales coast, where it appears that storm waves are able to maintain active boulder beaches approximately 20 m wide.

BEACH-SURFACE FEATURES

Surface features vary from beach to beach and are often impracticable to assess. The massive size of individual grains makes measurement of gross beach angle difficult, and most finer measurements impossible.

The most easily recognized morphological feature of the studied beaches is the berm, which occupied the landward portion of some boulder beaches, well above the tidal or swash limit. Many fractured boulders were found on these berms, which appear to be formed during storms by the accumulation of wave-transported boulders and fragments which are often impact fractured. The berm is not a continuous feature on any of the studied beaches.

No rhythmic features could be positively identified on any of the five beaches, although cusps have been reported on another boulder beach along the New South Wales coast (Eliot and Bradshaw, 1975). It is generally believed that cusp formation is favoured when beaches are aligned parallel to the approaching wave fronts (Longuet-Higgins and Parkin, 1962; Komar, 1976, pp. 267-268). Therefore, the absence of cusping on the studied boulder beaches may reflect their oblique alignment to the approaching

TABLE 22

BEACH DIMENSIONS

	North Yacaaba	Copacabana	Bombo	Kiama	Crookhaven
Longshore Length (Metres)	300	150	175	150	150
Seaward to Landward Mean Width (Metres)	20	25	20	20	20

waves rather than any incapacity for boulder-sized sediment to form cusps.

Other than the berms, the only large-scale identifiable surface features were irregularly spaced mounds formed by the accumulation of boulders against bedrock outcrops, steps, and/or very large boulders. These mounds are ramp-shaped, and indicate direction of sediment movement along the beach because the ramp faces towards the sediment source (Figures 36a and 36b). A mound formed beside a large boulder is a temporary feature which will be destroyed when competent storm waves move the large boulder, while mounds associated with bedrock outcrops and shore platform steps are relatively permanent features. Both types of mound provide ramps over which other boulders are transported. These ramps thereby reduce the effectiveness of many beach-surface irregularities as obstacles to sediment transport.

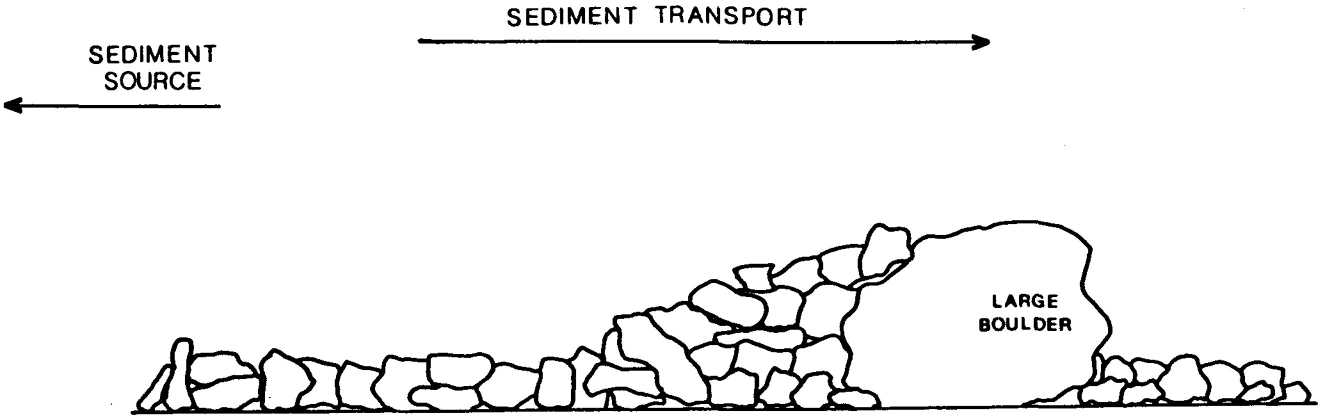


Figure 36a. Boulder ramp: Short-term feature.

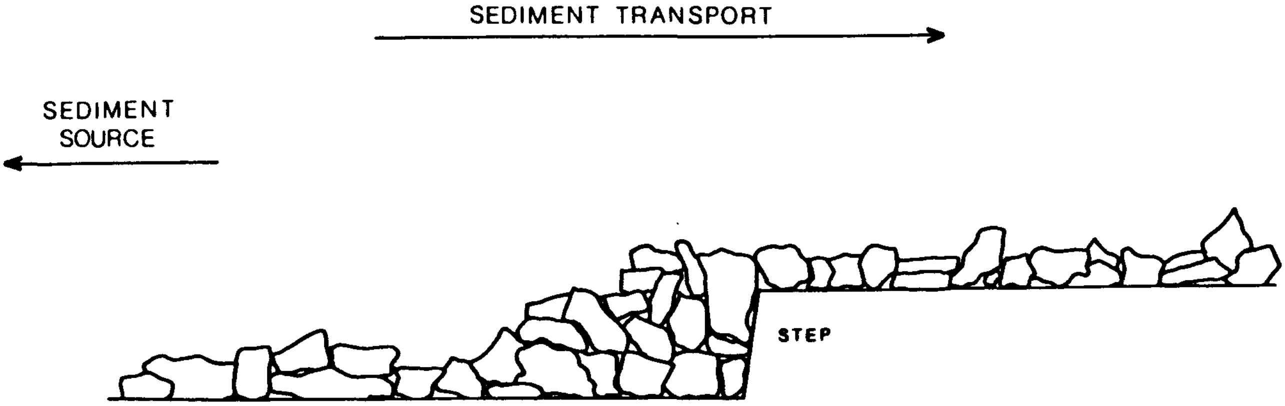


Figure 36b. Boulder ramp: Long-term feature.

Surface roughness is great in all study areas. However, where boulders are imbricated, the beach-surface roughness is decreased. Some imbrication was found on all beaches; Copacabana having the highest proportion of its surface area imbricated. Once again, geology can be seen to affect the characteristics of this beach. Copacabana has many boulders with planes of weakness parallel to the maximum projection plane, and thus fracture occurs parallel to this plane, forming discs which readily imbricate. Generally, however, beach-surface roughness was great and porosity high on the studied boulder beaches.

PACKING

Since there is often a long time period (months, sometimes years) between storms with waves sufficiently competent to re-arrange the boulder beaches, a considerable amount of settling can occur. The large-scale fitting of boulders has been discussed under "Boulder Shape" (Chapter IV), but there is also a less perceptible fitting or interlock of surface boulders.

The constant swash action between storms rotates and settles boulders *in situ* until a relatively compact surface is achieved, This effect can be readily observed by walking over a boulder beach which has been undisturbed for several months, and then walking over that same beach immediately after storm waves have altered boulder placement. In the former case, the boulders are generally stable, while in the latter, boulders are loose and unstable.

Surface particle packing structure has been described by Laronne and Carson (1976) and categorized as (1) *open structure*, where there is almost no contact between surface particles, or (2) *closed structure*, where there is close contact between surface particles. The boulder beaches in this study exhibit a closed structure. The simplest type of closed structure, the *infilled structure*, where the voids between the large particles are approximately half filled with finer material (Bluck, 1967), was the most common surface boulder arrangement observed on the five beaches. Another form of closed structure, the *imbricate structure*, was also found in many locations.

Whatever the type of closed structure, any packing of boulders may impede initial sediment transport because the constraining forces resulting from the confinement by neighbouring particles combine with the submerged boulder weight to oppose the transport inducing fluid forces of lift and drag. Thus, constraining forces are fundamentally important, but virtually impossible to quantify since each boulder is constrained to a different degree.

Lift and drag forces can cause particles in riprap shore protection structures to vibrate *in situ* (Schumm and Stevens, 1973). Therefore, it is reasonable to suggest that the same process occurs on boulder beaches, and that this vibration may aid in boulder fitting (as has been previously discussed) and settling, resulting in an armoured surface on natural boulder beaches. Thus, as Laronne and Carson (1976) and Schumm and Stevens (1973) found in coarse-bedded alluvial channels, the threshold forces for movement initiation are most likely larger than would be expected if only individual particles were considered. Since boulder packing was widely observed, the classical concept of competence may be of limited utility in the study of boulder beaches.

The dense packing of some of the boulders on the studied beaches probably makes them more difficult to entrain than would be expected on the basis of their size alone (see Novak, 1972). In fact, a few of the most stable boulders were found to be small sized, but trapped in niches which prevented their movement (Plate 21) (see Laronne and Carson, 1976).

When shore-protection structures are composed of rubble, they are constructed with layers of "armour units" which may be quarry stones or specially designed concrete units (tribars, dolosse, *etc.*). The stability of these armour units is partially dependent upon the degree of interlock achieved (Hudson, 1959; Muir Wood, 1969; U.S. Army, Corps of Engineers, 1977, chapter 7), and it is suggested that the natural armouring (packing and fitting) found on the studied boulder beaches provides a similar stabilizing effect.

The inhibition of movement by packing was especially evident where conditions were suitable for imbrication. Although the hydrodynamic properties of the disc shape facilitate entrainment, the tendency to imbricate appeared to inhibit much movement. As the voids between the large discs became infilled with boulder fragments and chips, structural rigidity most likely increased (see Laronne and Carson, 1976).

Because groups of adjacent boulders were found to move in the same storm, it is suggested that, once a boulder is dislodged from the packed beach surface, the armour breaks down, and the constraining forces are thereby decreased (see Font, 1970). Thus the surrounding boulders can be transported by waves of less competence than was required for initiation of movement. In this respect, armouring is analogous to cohesion, for once the bonds have been broken, the particles can more readily move about. On

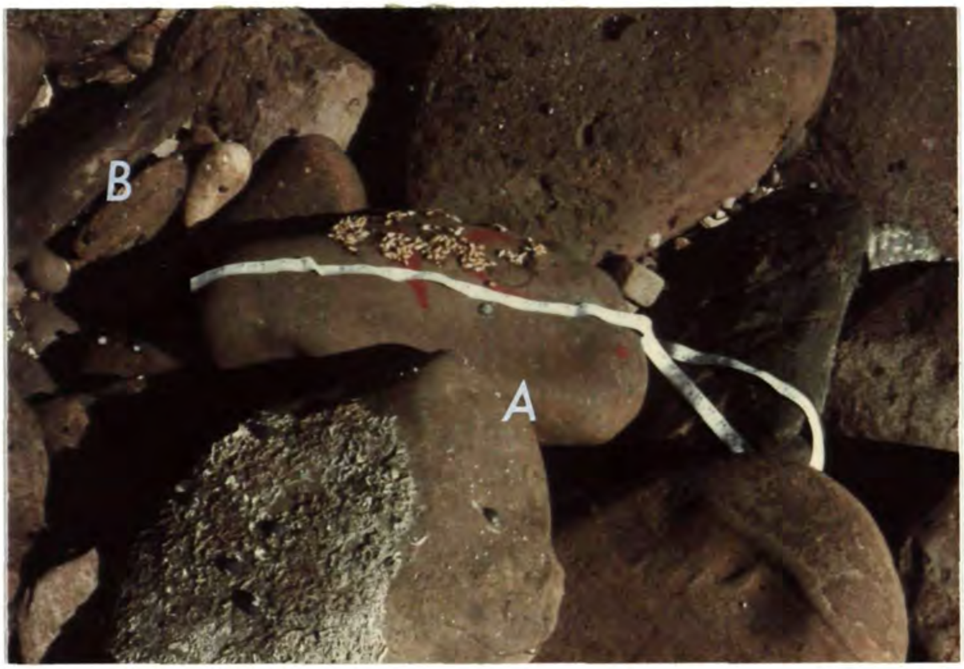


Plate 21. Dense packing of cobbles and boulders. In one storm the two boulders at A were moved while the sediment in the upper left corner (B) remained stationary because it was tightly wedged in position. (A axis of marked boulder is 58 cm.)

the studied beaches, the preferential movement of boulders in close proximity has caused shallow scour depressions to develop which increase the beach-surface irregularity. Schumm and Stephens (1973, p. 39) noted that similar scour holes developed in a cobble-bed flume.

The tendency for a boulder-beach surface to become armoured was observed in all study areas. Large and small particles are jostled *in situ* by waves not competent to entrain them (particularly swash) until they become trapped or locked into an armoured surface. Because of this mechanism, boulder beaches may require greater wave force to initiate transport as the time period increases from the most recent competent storm waves.

Fabric

"Although fabric and packing are closely related, they are not the same thing" (Pettijohn, 1975, p. 65). In sedimentology, fabric refers to dip and orientation of particles (Andrews, 1971, p. 4; Pettijohn, 1975, pp. 65-77; King, 1980, p. 61), while packing is the spacing and arrangement of these particles.

Fabric analysis is often employed in the study of palaeosediments because particles with dimensional inequalities respond to fluid flow, and analysis of preferred dip and orientation can yield information on the depositional environment and transport direction. "The commonest aims of fabric studies are therefore the distinction of deposits laid down in different environments, or the direction of movement of the sediments" (Briggs, 1977, p. 144).

Since in this study it is established that the beach boulders are transported by present-day wave action, the depositional environment, transport direction, and nature of the depositing medium can be directly observed, and fabric analysis was not undertaken. Where dip could be observed, it was clearly seaward (see Plate 7, p.26), which is usual for coastal deposits (Briggs, 1977, p. 145).

FORESHORE SLOPE

It is generally believed that beach-face slope is controlled by two factors: sediment size and wave intensity (Bascom, 1951). King (1972, p. 330; 1980, p. 81) suggested that size is the more important of these two variables. Indeed, "the coarser the material the steeper the beach" (Zenkovich, 1967, p. 267) is a virtual axiom of coastal geomorphology.

Coarse-sediment beaches are believed to form steep foreshores because the flattening component of the swash is reduced as the backwash is diminished by percolation. Since permeability varies directly with the square of the geometric mean grain diameter (Krumbein and Monk, 1942), the studied beaches are obviously highly permeable, allowing much percolation.

Various investigations have been conducted in which foreshore slope has been related to grain size (*e.g.*, Bascom, 1951; Shepard, 1963, p. 171; Wiegel, 1964, p. 359; King, 1972, p. 330; and 1980, pp. 80-81). In all of these studies, beach angle has been shown as increasing as sediment size increases. Continuing this trend into boulder-sized sediment results in predicted foreshore slopes $\geqslant 24^{0}$ for boulder beaches (Shepard, 1963, p. 171).

The foreshore slopes of the five boulder beaches under study were measured as outlined in Chapter II. Six profiles for each beach are illustrated in Chapter I, and the measured angles are reported here in the form of both cotangents and degrees of arc in Table 23. As is evident from this table, the steepest beach face was $12^{0}20'$. The measured foreshore slopes are therefore considerably lower than those predicted in the literature. Observations of boulder beaches by the author in Wales, Scotland, and Hawaii indicate that they too have low foreshore angles, similar to the five studied beaches.

Krumbein and Graybill (1965, pp. 351-353) and McLean and Kirk (1969) found poor size sorting of beach sediment to be associated with low foreshore slopes. They suggested that poor sorting decreases the permeability of the beach face and so permits a gentler foreshore to develop than otherwise would be the case. The gentle foreshore slopes of the studied boulder beaches, however, cannot be explained by their poor size sorting because, although sorting is poor, the voids between boulders are not wholly infilled by fines and the permeability remains high.

In an attempt to discover why the foreshore angles of the observed boulder beaches are well below those predicted, literature concerned with the slopes of artificial coastal protection boulder structures (riprap, rubble mound) was examined. Although boulder beaches are not exactly comparable to rubble-mound or riprap breakwaters, their common large constituent particle size and exposure to wave action provide useful slope-stability analogies. (This will be further discussed in Chapter VIII.)

TABLE 23

MEAN SLOPE OF LONGSHORE BEACH ZONES
(TWO PROFILES PER ZONE)

Beach	Headland Cotan θ	Headland Degrees from Horizontal	Mid Cotan θ	Mid Degrees from Horizontal	Embayment Cotan θ	Embayment Degrees from Horizontal
North Yacaaba	5.4	(10.49)	5.6	(10.12)	7.1	(8.02)
	8.4	(6.79)	7.8	(7.31)	8.2	(6.95)
Copacabana	7.6	(7.50)	5.9	(9.62)	4.6	(12.30)
	8.3	(6.87)	5.5	(10.30)	5.0	(11.30)
Bombo	6.2	(9.16)	5.7	(9.95)	4.9	(11.53)
	5.3	(10.68)	6.3	(9.02)	4.8	(11.77)
Kiama	9.7	(5.89)	5.7	(9.95)	7.1	(8.02)
	9.7	(5.89)	5.2	(10.89)	6.2	(9.16)
Crookhaven	8.0	(7.13)	8.6	(6.63)	6.3	(9.02)
	8.6	(6.63)	6.0	(9.46)	6.9	(8.25)

Rubble-mound breakwaters are usually built with slopes between 18^{o} and 33^{o}, but *only* because "the volume of material required for a breakwater flatter than 1:3 [18^{o}] is not usually economical" (Davidson, U.S. Army, Corps of Engineers, pers. comm., 1977). In high energy conditions these angles cannot be naturally preserved, so slopes are maintained by the use of concrete caps, mesh coverings, and other artificial means. Although economics constrain breakwater construction, it is recognized that flatter slopes are more stable (Hudson, 1953) and therefore more likely to be found in nature.

Iribarren's formula (Iribarren, 1953), modifications of which are widely used in the design of rubble shore protection structures, takes slope into account:

$$W = \frac{K \gamma r H^3}{(\gamma r - 1)^3 (\cos\alpha - \sin\alpha)^3}$$

W = weight of cap rock
K = coefficient (15 for natural rock)
γr = specific weight of cap rock
H = wave height
α = breakwater slope

As the breakwater slope increases, the denominator in this formula decreases, indicating an increase in structural instability (which may be countered by heavier cap rock). Moreover, Hudson (1961) showed in wave tank tests that the stability of both quarry-stone and armour units increased as breakwater slope decreased (Figure 37). In another wave tank investigation of rubble-mounds, the U.S. Army, Corps of Engineers (1953) found that stones were displaced in a manner such that slopes were flattened and, after thorough model testing, it was concluded that "flattening the seaside slopes increases the stability of a rubble-mound breakwater" (U.S. Army, Corps of Engineers, 1953, p. 23). Thus, a low angle would appear to be

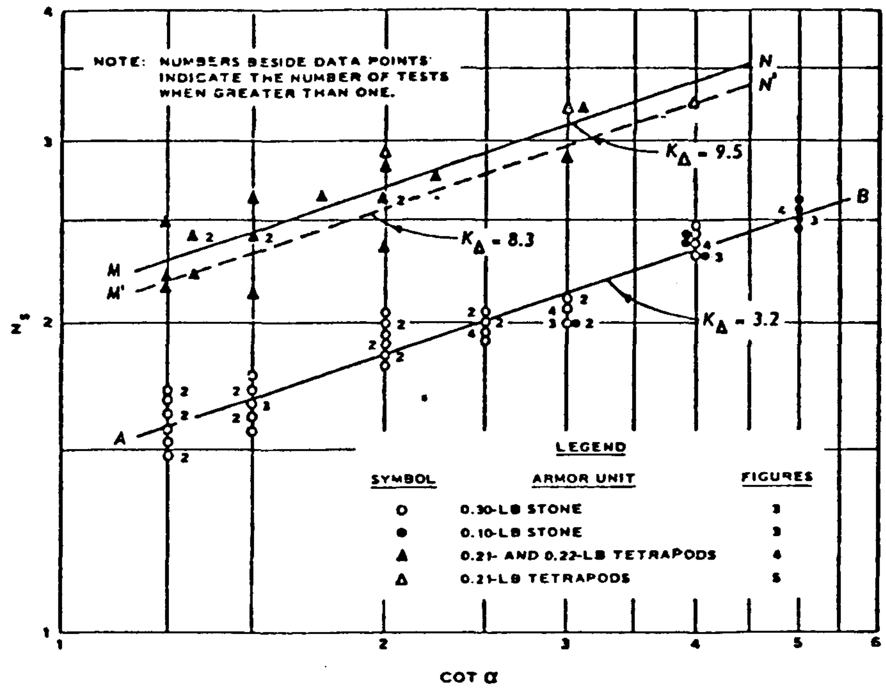


Figure 37. Stability of quarry-stone and tetrapod armour units: N_s represents stability and cot α is breakwater slope.

(after Hudson, 1969, p. 504)

the equilibrium foreshore angle for boulder-sized sediment, and since boulder beaches have no artificial constraints on their foreshore slope, a low, stable angle is developed.

Profile Shape

In addition to the low foreshore angle, profile shape may influence boulder-beach stability. In a model study by Priest, *et al.* (1965), it was found that the stability of a rubble slope was greatly improved when the material had been re-arranged by wave action to form a more "natural" slope (see Figure 38). Rogan (1968) also found that after wave attack on a rubble-mound breakwater, a new profile was formed (Figure 39). These slopes, formed after wave attack, more closely approximate the profiles of the studied boulder beaches (Figures 2-6) than do their initial rectilinear profiles.

FORESHORE SLOPE *vs* GRAIN SIZE

In the literature, high angles have been predicted for coarse-grained beaches because slope and grain size are generally believed to be positively related. The relationship between slope and grain size was investigated on the studied boulder beaches by performing Spearman rank correlation analyses between beach slope, cotan θ (30 transects, six per beach), and the mean grain size in *phi* (ϕ) units of the beach zone where each slope measurement had been taken. A correlation coefficient of -0.643 was obtained, and this is easily significant at the 0.05 level of probability ($P < 0.001$). Thus, not only are the boulder-beach slopes lower

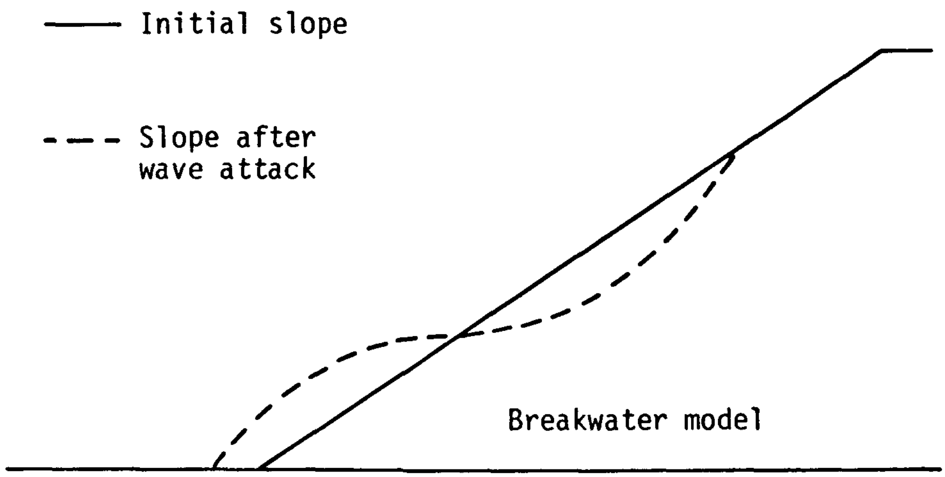


Figure 38. Slope of rubble-mound breakwater model before and after wave attack. (after Priest *et al.*, 1965, p. 557)

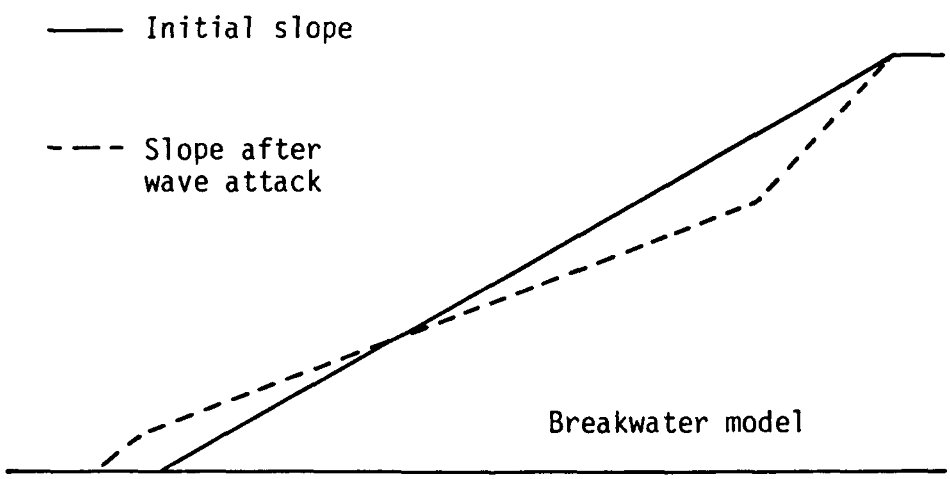


Figure 39. Slope of rubble-mound breakwater model before and after wave attack. (after Rogan, 1969, p. 774)

than those predicted in the literature, but they are *inversely* related to grain size.

High-energy waves are known to flatten sand and cobble beaches, while lower energy waves tend to steepen foreshore slopes of these beaches (Bascom, 1951; Shepard, 1963, pp. 170-180). Implicit in this statement is that both low-energy (swell) waves and high energy (storm) waves are competent to move sediment on these beaches. However, since high-energy conditions are relatively infrequent, very low-angled sand and cobble beaches are seldom observed and measurements of foreshore angles typically relate to low-energy conditions. In contrast to sand and cobble beaches, on boulder beaches only high-energy waves are competent. Consequently, boulder beaches are formed by, and adjusted to only these high-energy waves. These beaches, therefore, typically have low foreshore slopes (approximately 7^{o} to 12^{o}) which are entirely in keeping with the high-energy waves which produced them.

If sand or cobble beaches were exposed *only* to the high-energy waves which determine boulder-beach form, they would likely have gentler foreshore slopes than those observed for boulder beaches. Indeed, Zenkovich (1967, p. 277) reports that during storms and surges in the Baltic, sandy beaches are completely levelled; and the slope of Chesil Beach (a cobble beach) in England has been lowered to 6.3^{o} during severe storms (King, 1972, p. 328).

All beaches, whatever their sediment-size composition, reflect the most recently competent wave action. On beaches where not all waves are competent, the minimum competent wave energy increases as particle size increases. It follows that since beach slope varies inversely with wave energy, beach slope will vary inversely with particle size on boulder beaches.

Two main points emerge from this discussion of boulder beach foreshore slope and particle size:-

1) Boulder beaches probably never attain the steep slopes predicted for them in the literature because high-energy waves (the only competent waves) maintain a low equilibrium beach slope.
2) There is no reason to doubt that beach foreshore angle increases with grain size, but ONLY when waves are competent to transport all sizes of available beach sediment. As particle size increases, the range of competent waves decreases, and only the high-energy waves are competent. Since beach slope varies inversely with wave energy, on boulder beaches the beach slope DECREASES as particle size increases.

CHAPTER VII

BOULDER MOVEMENT

Because of the low beach angle which reduces down-beach gravity effects (Evans, 1939), and the high permeability, which diminishes the backwash, particle movement on the studied boulder beaches is probably almost entirely uprush induced. Thus, unlike beaches composed of steeper slopes and/or smaller, less permeable material, effective water flow is believed to be generally unidirectional. Fluvial studies, therefore, may be more applicable to boulder beaches than they are to other beaches with competent backwash.

As water flows past a boulder in a river or on a beach, the stream lines are deflected, with the force exerted resolved into two components: drag (parallel to main flow) and lift (normal to main flow) (Raudkivi, 1967). In a beach environment, however, the repeated impact of water striking a particle may also aid in initiating movement (Inman, 1949), while percolation of water produces upward pressures (Shepard, 1963), and variations in current velocities cause pressure differentials, also producing upward forces (Bernoulli's Principle) (Inman, 1949).

Opposing movement are the submerged boulder weight and the previously discussed constraining forces due to neighbouring particles. Because packing inhibits movement, hydraulic formulae generally underestimate the threshold forces for the initiation of movement of particles in closed structures (Schumm and Stevens, 1973; Laronne and Carson, 1976). Once a boulder is moved, however, the armour weakens allowing the adjacent boulders to be moved by waves of less competence than was required for the initiation of movement. Consequently, variations in boulder movement may be unrelated to size, shape, or position of the transported material.

Instantaneous hydrodynamic lift can, in theory, cause large-scale saltation movement of boulders with great surface-to-volume ratios. Thus, some boulders may be tossed high on the beach, break, and cause breakage, while others remain at the seaward margin. However, because of the great size of individual particles, most boulder movement probably occurs in traction where calibre is of primary importance in determining particle transport (Meland and Norrman, 1969; Laronne and Carson, 1976).

STABILITY INDICATORS

On all studied beaches, there is clear evidence of recent boulder mobility. Freshly fractured boulders, impact pitting, shell encrusted boulders above the tidal zone, and unstable placement can be observed on all beaches and clearly attest to recent boulder movement. However, on Crookhaven and Kiama boulder beaches, particle-surface features were observed which may indicate relative stability. Indicators of absolute stability, such as the kaolinization mentioned by Sussmilch and Clark (1928), are absent on all five studied beaches.

Crookhaven and Kiama Boulder Beaches

On Crookhaven boulder beach, lichen growth on (see Figure 6, pp. 39-40) and cavernous weathering of many landward boulders were observed. This type of weathering produces fragile structures which would most likely be destroyed during transport. Thus, the landward portions of the beach where the cavernous weathering and lichen growth have occurred are very probably the most stable areas of the beach.

On Kiama boulder beach, lichen is present on many boulders in the landward portion of the beach (see Figure 5, pp. 35-36). Kiama and Crookhaven are the only beaches studied where lichen growth was observed. It is possible that the landward portions of these two beaches are more stable than the landward zones of the other beaches, thus providing a more suitable environment for lichen colonization, but the variation in the presence of lichen amongst the studied beaches may be due to factors other than particle stability.

Perhaps the boulder lithology at Crookhaven and Kiama is suitable for lichen colonization, while the rock types found on the other beaches are not. Although studies of lichen and mineral interaction are limited, "it is clear that lichens have substrate 'preferences'"(Brodo, 1973, p.402). Mineral content, hardness, surface texture, porosity, water retention capacity, colour, and temperature of rocks have all been found to affect lichen (Wirth, 1972). However, the presence or absence of interstitial sand may well be an important factor in the lichen colonization of the studied beaches. Kiama and Crookhaven beaches are the only study areas where interstitial sand is totally absent, and the only beaches where lichen growth occurs. Thus, it is suggested that the abrasive effect of the sand (sand blasting, Kuenen, 1955, 1956) present at North Yacaaba, Copacabana, and Bombo prevents lichen growth on these beaches (J.L. Davies, personal communication, 1981).

Distribution of Lichen Colonization on Crookhaven and Kiama Beaches

On the boulder beach at Boat Harbour, New South Wales, described by Sussmilch and Clark (1928), a landward to seaward zonation of lichen from very heavy encrustation through discontinuous colonization, to lichen-free boulders can be observed (J.L. Davies, personal communication, 1980). In contrast, the lichen colonization on Kiama and Crookhaven beaches is restricted to the landward portion of each beach (Figures 5 and 6), and no zonation could be discerned. Within these areas of lichen colonization, there are many lichen-free boulders, and on Kiama, as can be seen in Plate 17, p.103, many fractured and impact scarred boulders.

Since lithology is consistent within each beach, and sand is absent, lichen growth may be restricted to the landward portions of Crookhaven and Kiama beaches because of the influence of seawater. In studies of lichen growth in littoral environments it has been found that the degree of wetness is an important limiting factor (Fletcher, 1976, p. 381). Under very wet conditions some lichen thalli have been found to break down because the symbionts (fungus and algae) become free living. Perhaps Kiama's prominent berm provides protection from ocean spray.

Whatever the causes of the landward restriction, the presence of a zone of lichen colonization indicates the relative stability of that portion of both boulder beaches. In order for lichen to have developed in one particular area, the colonized boulders must have remained in that portion of the beach for some time.

In addition to relative stability, another characteristic of boulder movement was noted from the study of lichen distribution on Kiama beach:

direction of boulder transport. After boulder movement had occurred during a storm, many lichen-free boulders were observed in the lichen zone, while no lichen-colonized boulders were observed outside of that zone. Also, many lichen-colonized boulders were found to have abrasion and impact markings. These observations suggest that boulder movement tends to be up-beach (*i.e.* uprush induced) and that there is little down-beach (*i.e.* backwash induced) transport. This interpretation is consistent with the results of the transport study to be discussed in this chapter, however, the distribution of lichen-colonized boulders may be readily observed in the field, while a transport study requires much measurement, marking, and a long period of observation.

TRANSPORT STUDY

When investigating boulder transport, it was useful to view the beaches as sediment compartments (Davies, 1974) or cells (Tanner, 1974). The beaches of this study are bounded by rocky headlands and shore platforms which both supply and confine sediment. North Yacaaba, Copacabana, Bombo, and Crookhaven beaches are simple (exclusive) compartments (Figure 40).

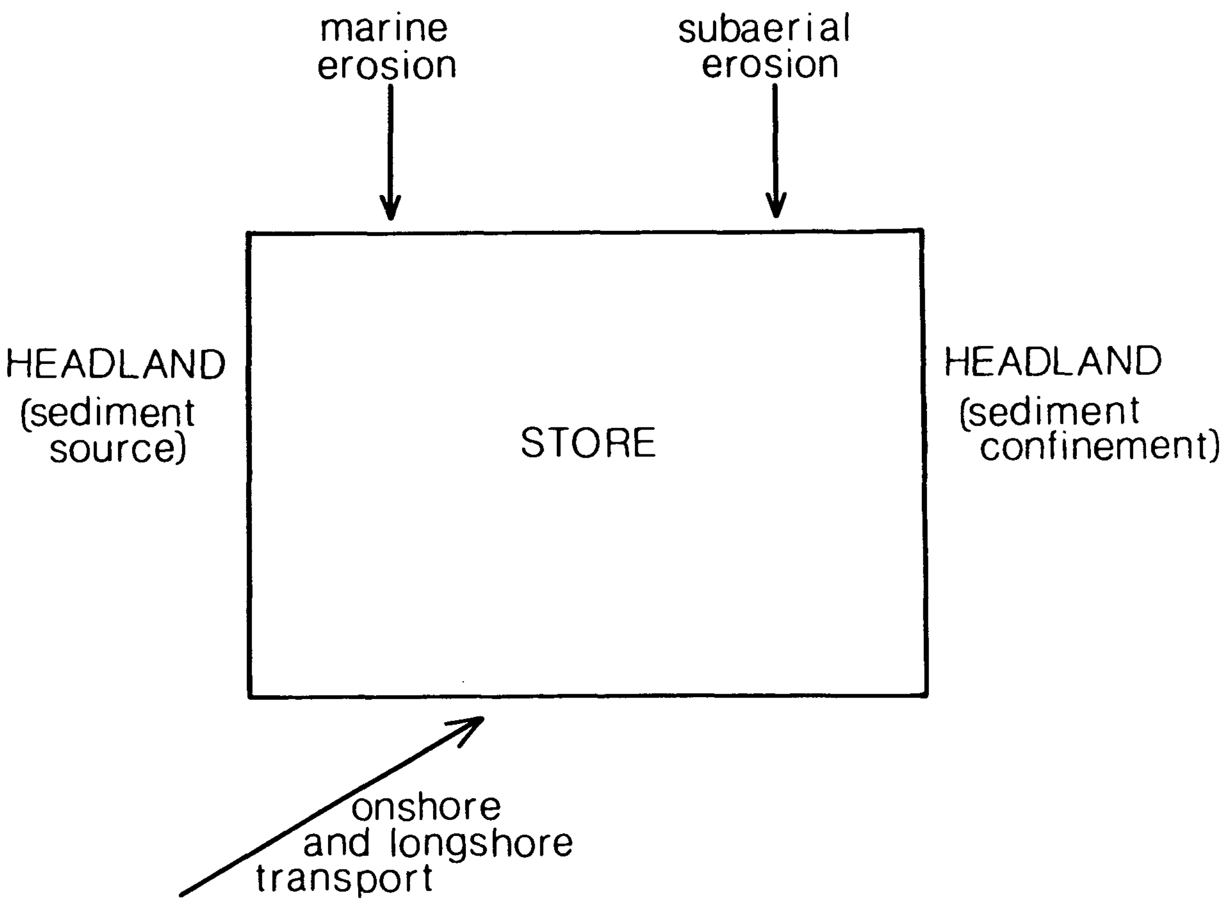


Figure 40. Simple (exclusive) sediment compartment.

Kiama beach, however, is part of an hierarchy of "compartments of varying size and varying degrees of exclusiveness" (Davies, 1974, p. 141) (see Figure 41). Boulder movement was investigated within this complex compartment which consists of three identifiable "areas".

Area 1 consists mainly of wide shore platforms and talus at the foot of actively eroding cliffs (Plate 22, Figure 41). It is believed that most of the sediment found in the beaches of areas 2 and 3 has been transported from area 1. In area 2 there is a small boulder beach, and in area 3 a much larger boulder beach - the Kiama study beach (Plate 23, Figure 41).

Areas 2 and 3 are separated by 75 m of shore platform backed by a cliff (Figure 11, p. 55). All boulders on this platform, and 30 boulders in the northern portion of the area 2 beach were marked with blue paint, a colour not used in the marking of Kiama beach (area 3). At any one time only a few boulders were observed on the platform and most of these were trapped behind bedrock steps or were extremely large (*e.g.* B axis of 1.5 m). The positions of these boulders (Figure 42) clearly indicated that the direction of transport was from area 2 to area 3. All boulders found on the platform were heavily abrasion scarred, indicating movement of other sediment over and around them, and/or their own movement (see Plate 24).

During the study period of two years, 17 area-2 boulders with vestiges of blue paint were found in the Kiama study beach (area 3). Seven of these boulders could be identified as having been marked while on the platform, six had been part of the area 2 beach, and 4 were so abraded that only the paint colour, not the location number, could be identified. The mean B axis of these 17 boulders was 49.2 cm (almost -9ϕ), and the largest was

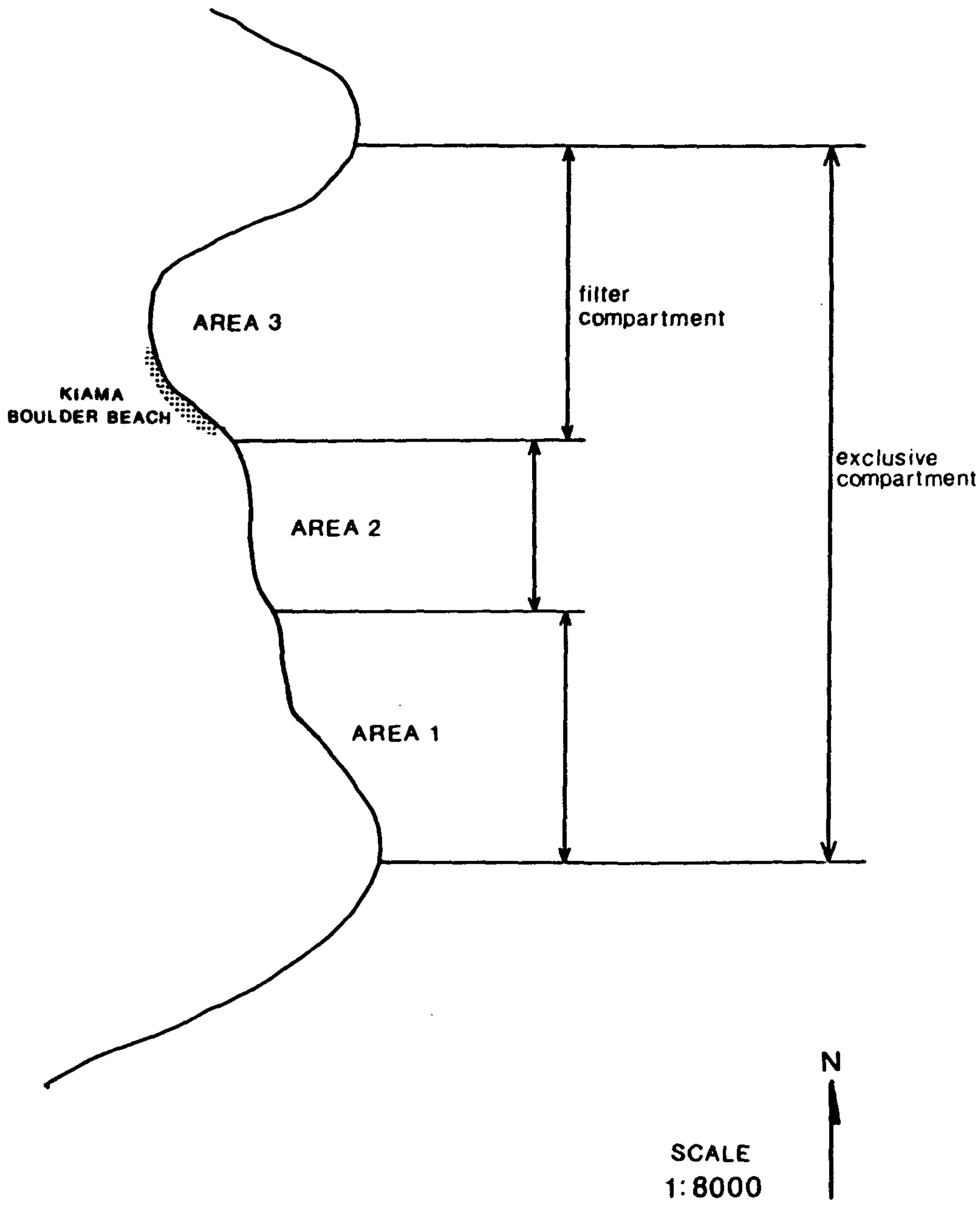


Figure 41. Hierarchy of compartments at Kiama boulder beach.

Plate 22. Actively eroding cliffs (area 1) south of Kiama boulder beach.

Plate 23. Kiama study area showing area 2 and area 3 separated by 75 m of shore platform.

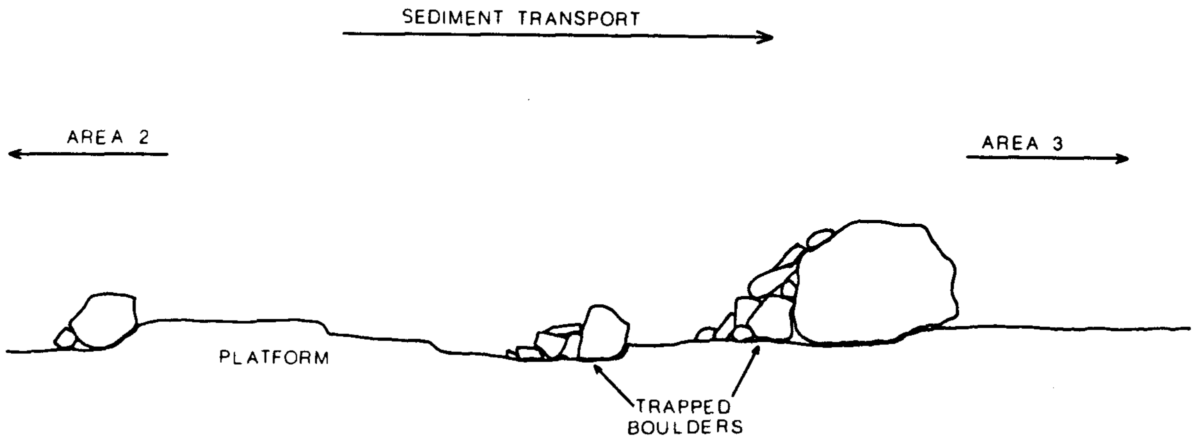


Figure 42. Boulders on platform surface separating area 2 and area 3.

Plate 24. Abrasion markings on large boulder located on platform separating area 2 and area 3.

close to -10ϕ. Larger boulders (< -10ϕ) originally marked on the platform did not move during the course of the study, suggesting that their movement depended upon waves of greater competence than had occurred during the two years between June, 1975 and July, 1977.

Movement Record of Kiama Boulder Beach (Area 3)

The method of marking and monitoring Kiama beach has been discussed in Chapter II, and the data on which the study of transport on Kiama beach is based were gathered after major storms and/or at monthly intervals from June, 1975 to July, 1977.

On June 6, 1975, 150 boulders were marked on Kiama beach, along 30 profiles, each 10 m long, beginning at low water. On June 21, 1975, a storm of great intensity occurred; the bureau of Meteorology (Australia) reported winds from the east-south-east at 100 km/hr at Port Kembla (25 km north of Kiama boulder beach), and the wave-rider buoy at Port Kembla recorded a significant wave height of 6.0 m. During this storm, 44.3 per cent of the marked boulders were moved. Of the transported boulders, 48 per cent were recovered, and virtually all of these had been carried both towards the embayment and up the beach (see Figure 11, p.55). Some boulders were found many metres from their pre-storm positions; for example, one boulder with an A axis of 51 cm, B axis of 36 cm, and a C axis of 33 cm was found to have been transported 25 m longshore. Although this beach was monitored for two years, movement of so great a proportion of the marked boulders did not occur again. That boulders tend to be transported from headland to embayment is also demonstrated by the form of the boulder "ramps" discussed in Chapter VI and illustrated in Figure 36 (p.151).

The size, shape, and sphericity distributions of all the marked boulders were compared with the same distributions of those boulders which were transported during the storm. The only distribution to differ significantly (Kolmogorov-Smirnov two-sample test, $\alpha = 0.05$) was size. As Figure 43 shows, the two size distributions have similar shapes, but the marked boulders (all sediment) have a larger maximum size than do the moved boulders (transported sediment). The mean size of all the marked boulders is close to -9ϕ, while the mean size of the transported boulders is -8ϕ.

The results of this investigation of boulder movement during one storm suggest that (1) boulder size, not shape, controls movement; (2) the storm on the 21st of June 1975 simply was not competent to transport those boulders having B axes larger than -10ϕ, yet boulders of this size are present on the beach; and (3) the beach must, therefore, be subject to storms of even greater magnitude when waves are competent to transport the largest material. This limited competence has been noted in the discussion of boulder movement between areas 2 and 3 of the complex Kiama sediment compartment.

On July 3, 1975, the marking of the boulders on Kiama beach was extended landward to include 150 more boulders, bringing the sample size to 300 grid points along 30 profiles.

Over the period of data collection it was noted that, for movement to occur, not only was boulder size important, but also boulder position on the beach. Boulders on 102 different grid points moved during the two years. Of these 102 points, only 26 were not adjacent to other moved boulder positions on the same profile, and only 13 were not adjacent to

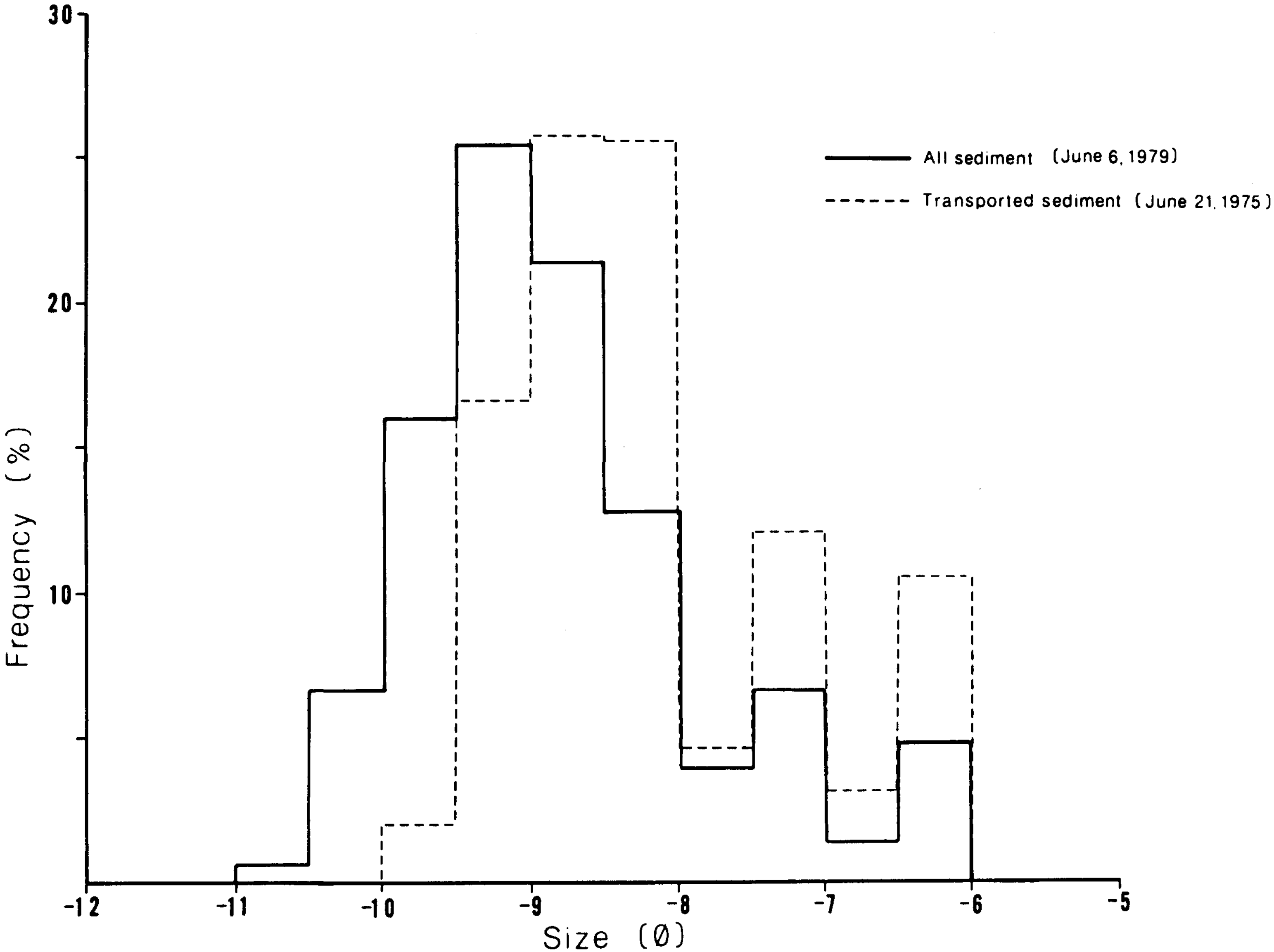


Figure 43. Comparison of the size frequency distribution of all sampled boulders on Kiama boulder beach and the size frequency of those boulders on Kiama beach which moved during the storm of 21 June 1975.

other moved boulder positions on the same profile or on one of the two neighbouring profiles (Figure 44). These data suggest that rather than individual boulders being independently transported, there is a tendency for groups of boulders to be moved. This interpretation is consistent with the scour depressions observed on the beach, and strongly supports the notion that surface packing or armouring is an important process on the boulder beach.

During the study period it was also observed that 45 positions (of the 102 where movement occurred) were subject to movement more than once, and 14 of those grid points experienced boulder movement three or more times (Figure 44). This locational preference for initiation of transport may be due to two factors. Firstly, boulder movement is more likely to occur where the packing has been disturbed by previous movement; and, secondly, waves of sufficient competence to cause boulder transport may strike the beach in a consistent pattern. It can be seen in Figure 44 that most positions where repeated boulder movement was recorded are located in the seaward portion of the boulder beach where wave energy is greatest.

Changes on Kiama Beach From 1975 to 1977

Kiama boulder beach was monitored for boulder movement by maintaining a fixed grid of 300 marked sample points on the beach for two years. Movement of the marked boulders at each grid point was recorded regularly, and the beach was divided into seaward and landward zones, each containing 150 sample points. In order to identify any changes in the beach sediment over the study period, Kolmogorov-Smirnov two-sample tests (Appendix II)

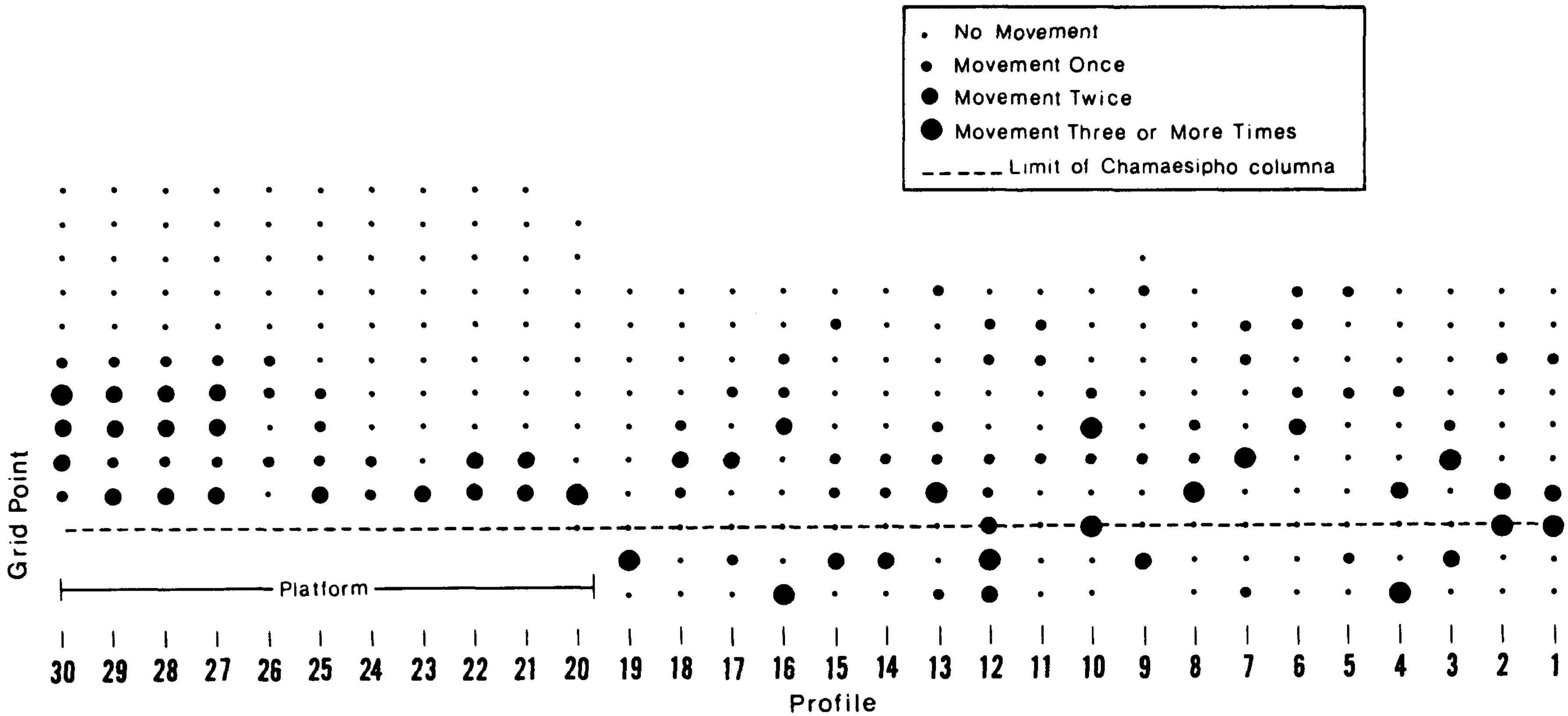


Figure 44. Grid points and movement frequency on Kiama boulder beach from June 1975 to July 1977.

were used to compare sedimentary characteristics of the beach at the beginning of the study period to those at the end, and to compare the characteristics of the transported sediment to those of the beach sediment in general (see Table 24).

Over the entire beach there was no significant change in the distributions of size, shape, or sphericity from June 1975 to July 1977 even though many of the actual boulders had moved (Table 24). Such consistency demonstrates the stability of the beach as a sedimentary assemblage which has overall characteristics that are maintained even though the individual sedimentary particles may change.

When size, shape, and spherecity of boulders comprising Kiama beach in 1975 or 1977 are compared with the same parameters of the boulders which moved during the study period, it can be seen that size is the only characteristic to show any consistently significant difference (Table 24). When the beach is divided into two sections (seaward and landward), only the seaward portion is found to have a size distribution for all boulders which is significantly different from the size distribution for the transported boulders. The seaward portion of the beach contains the largest sized boulders, many of which were not moved during the study period. Thus, the significant differences in the size distributions are most likely a reflection of the wave competence during the period of study. This is another indication that Kiama beach is affected by storm events of greater magnitude than occurred between June 1975 and July 1977.

None of the comparisons of shape distributions showed any significant change or difference over the two years (Table 24). It has been found that

TABLE 24

CHANGE IN KIAMA BEACH FROM JUNE 1975 TO JULY 1977 AS SHOWN BY THE KOLMOGOROV-SMIRNOV STATISTIC (D_{max}) FOR THE KOLMOGOROV-SMIRNOV TWO-SAMPLE (TWO-TAILED) TEST

Beach Area			Distribution			Comments
			Size (D_{max})	Zingg Shape (D_{max})	Maximum Projection Sphericity (D_{max})	
Entire Beach 1975	vs	Entire Beach 1977	.0613	.0264	.0551	No change.
Seaward Zone 1975	vs	Seaward Zone 1977	.1141	.0268	.0872	No change.
Landward Zone 1975	vs	Landward Zone 1977	.0403	.0267	.0372	No change.
Entire Beach 1975	vs	All Moved Boulders 1975-1977	.2206	.0417	.1364	Significant difference in size and sphericity
Seaward Zone 1975	vs	All Moved Boulders in Seaward Zone 1975 - 1977	.3096	.0601	.0953	Significant difference in size (effect of competence).
Landward Zone 1975	vs	All Moved Boulders in Landward Zone 1975 - 1977	.1865	.0855	.1480	No difference.

(continued)

TABLE 24 (CONTINUED)

Beach Area			Distribution: Size (D_{max})	Distribution: Zingg Shape (D_{max})	Distribution: Maximum Projection Sphericity (D_{max})	Comments
Entire Beach 1977	vs	All Moved Boulders 1975-1977	.2677	.0337	.1010	Significant difference in size (effect of competence)
Seaward Zone 1977	vs	All Moved Boulders in Seaward Zone 1977	.3991	.0471	.0584	Significant difference in size (effect of competence)
Landward Zone 1977	vs	All Moved Boulders in Landward Zone 1975-1977	.2027	.0588	.1556	No difference

*Once underlined values significant at the 0.05 level of probability.
Twice underlined values significant at the 0.001 level of probability.

shape characteristics are less important than size when fluvial sediment is transported as bed load (Meland and Norrman, 1969), which is probably the predominant mode of transport on boulder beaches. The effect of packing may also tend to negate the influence of shape upon transport because, in some instances, sections of the beach surface rather than individual boulders were moved during storms. In any case, other than particle size (which is limited by competence during the study), there appears to be little difference between the sediment on the beach and the moved particles. Thus the beach deposit appears to be a reflection of modern transport, an indication that the boulder beach is in equilibrium with present-day processes.

The statistically significant difference between the maximum projection sphericity of the sediment comprising the entire beach in 1975 and the sediment that moved during the study (Table 24) might indicate a tendency, not revealed by the investigation of Zingg shapes, for boulders of low sphericity to be entrained more readily than boulders of high sphericity. This suggestion of preferential movement according to shape, however, can be evaluated only by more documentation of the transport of boulders of known dimensions because on boulder beaches much breakage, hence shape change, occurs during transport. Meaningful measurements of transported must be made *before* they are moved.

WAVE COMPETENCE

Since size appeared to be a critical factor in determining boulder movement, wave competency in relation to sediment size was investigated.

Because of the difficulty involved in measuring uprush competent to move such large individual particles, no direct measurements of swash velocity were made. Uprush height (not depth) was calculated (Appendix V and Table 25) but could not be converted to uprush velocity for a boulder beach. However, wave-height recordings were available from the Maritime Services Board of New South Wales which maintains a wave-rider buoy off Botany Bay, and from the New South Wales Department of Public Works which maintains a wave-rider buoy at Port Kembla, 25 km north of the Kiama study area.

Between June 1975 and July 1977, 11 storm events caused widespread boulder movement on Kiama beach. The maximum significant wave height for each storm is recorded in Table 25. Information on recurrence intervals for these specific wave heights is not available, but wave duration data obtained from the wave-rider buoy positioned offshore from Port Kembla have recently been published (Hoffman *et al.*, 1980)(Table 25). Since the recurrence interval data were collected over only a three-year period, they must be interpreted with caution.

In Figure 45, the information obtained from the Port Kembla buoy is presented along with wave-duration probability data obtained from "Long Term Wave Statistics off Botany Bay" (Lawson and Abernethy, 1975). It is interesting to note that the Port Kembla data are generally consistent with the Botany Bay data. The major deviation occurs where the Port Kembla information gives too great a probability for a six metre wave; a reflection of the short period of data collection. The greatest wave heights considered in Figure 45 are in the 6.0 - 6.9 m range, no higher than those which occurred during the study of particle movement on Kiama boulder beach. Thus the duration probability for waves of greater competence can only be speculated upon.

TABLE 25

MAXIMUM SIGNIFICANT WAVE HEIGHT (H_S), PER CENT OF TIME H_S EQUALLED OR EXCEEDED, UPRUSH HEIGHT (R), AND THE SIZE (B AXIS) OF THE LARGEST MARKED BOULDER TRANSPORTED ON KIAMA BEACH DURING EACH STORM

H_S (m)	Time H_S equalled or exceeded (%)	R (m)	Size (cm)	Date of storm
6.0	.24	1.75	82	21-06-75
2.2	22.06	.85	40	04-08-75
3.2	5.87	1.16	25	13-08-75
3.3	5.87	1.13	28	05-09-75
2.2	22.06	.84	31	14-11-75
2.1	22.06	.78	24	25-12-75
5.1	.44	1.86	70	05-03-76
4.2	1.70	1.56	21	28-03-76
2.3	22.06	.88	26	12-05-76
5.4	.44	1.50	79	17-06-76
4.3	1.70	1.59	88	18-08-76

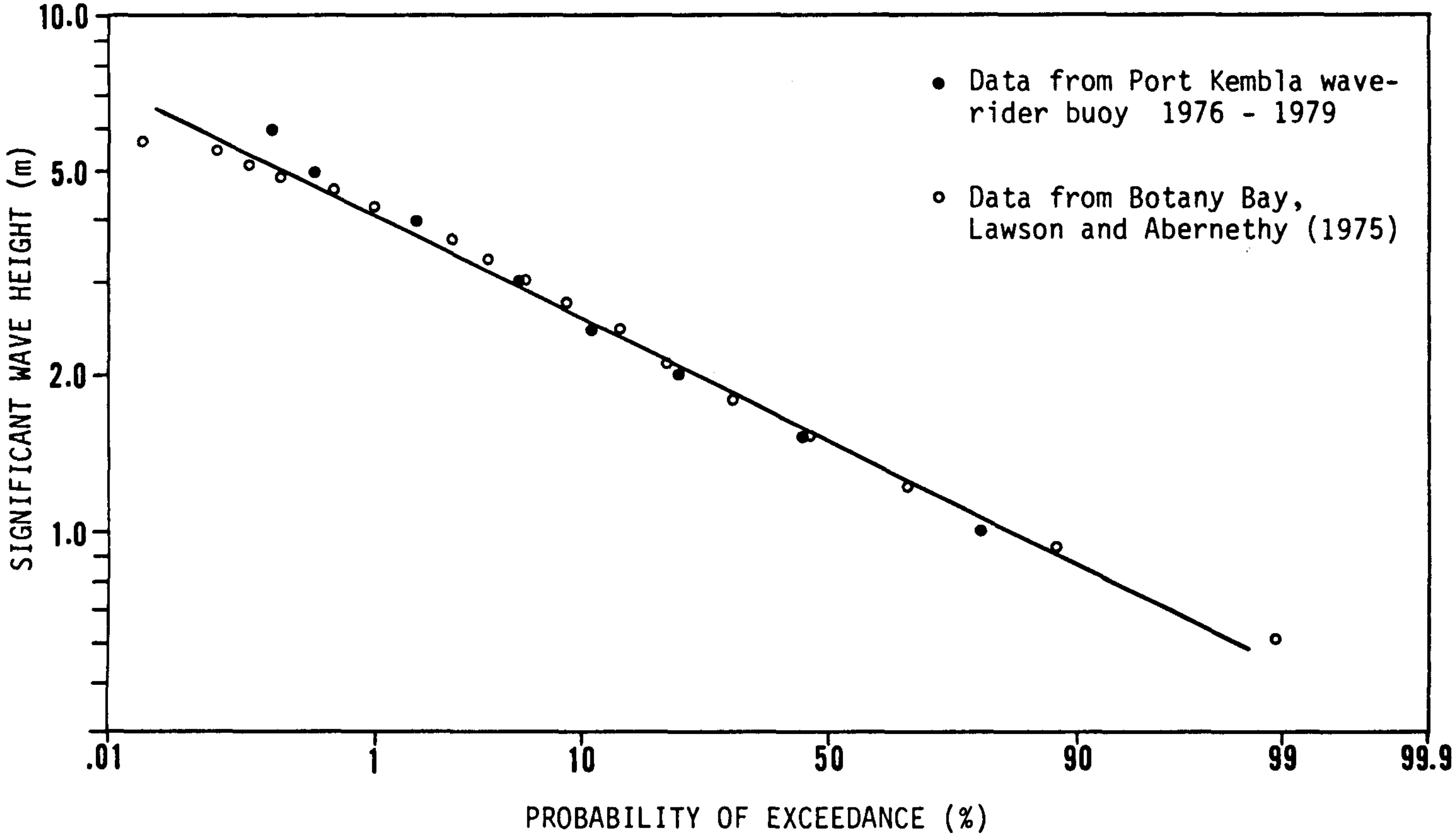


Figure 45. Comparison of Port Kembla and Botany Bay wave data.

(after Hoffman *et al.*, 1980, p. 85)

Competency Model

The packing or armouring of a boulder beach most likely affects initial movement. Thus, when threshold wave velocities are not greatly exceeded, transport is likely to be complex, so any predictive model must be viewed with caution. Bearing this point in mind, a theoretical competency equation for boulder beaches was developed, and the actual data from eleven storms then compared with the model.

Novak (1972) has shown that

$$F \propto H^2 \qquad (1)$$

where F = tractive force

and H = significant wave height.

It is also known that

$$V \propto F^{1/3} \qquad \text{(Novak, 1974)} \quad (2)$$

and

$$D \propto V^2 \qquad \text{(Novak, 1974)} \quad (3)$$

where D = intermediate particle diameter (B axis)

and V = swash velocity.

It follows that

$$D \propto V^2 \propto F^{2/3} \propto H^{4/3}$$

or

$$D \propto H^{1.33} \qquad (4)$$

Thus, this competency model predicts that there exists a power relationship with a slope of 1.33 between particle diameter (D) and significant wave height (H).

The theoretical competency relationship was compared with the empirical relationship between the log-transformed B axis of the largest boulder moved (D, the dependent variable) and the log-transformed maximum significant wave height (H, the independent variable) recorded by wave-rider buoys for the eleven individual storms experienced at Kiama boulder beach during the study period (Table 25). The *exact* empirical relationship between log D and log H is given by the structural relation between these two variables (Kendall and Stuart, 1973; Mark and Church, 1977). The slope coefficient of the structural relation must lie between the slope coefficients of the regressions of log D on log H, and log H on log D, which were found to be respectively 1.10 and 1.90 (Figure 46). The coefficient of determination for these regressions is 0.582.

Since log H has been observed with error, and the coefficient of determination between log D and log H is not close to 1, *the structural relation is different from both regression relationships* (Mark and Church, 1977, p. 64). The slope coefficient of the structural relation is dependent upon the error variances of log D and log H, about which little is known. It is reasonable to suggest, however, that since H is a mean, the error variance of log H is probably less than that of log D; hence the structural relation should have a slope closer to that for log D on log H (1.10) than to that for log H on log D (1.90). Although this reasoning does not suggest conclusively that the structural relation has a slope of 1.33, a relation with such a slope is entirely consistent with the available data (Figure 46). The reliability of the theoretical model can be assessed only by the collection of more field data, and by comparing the model with these additional data.

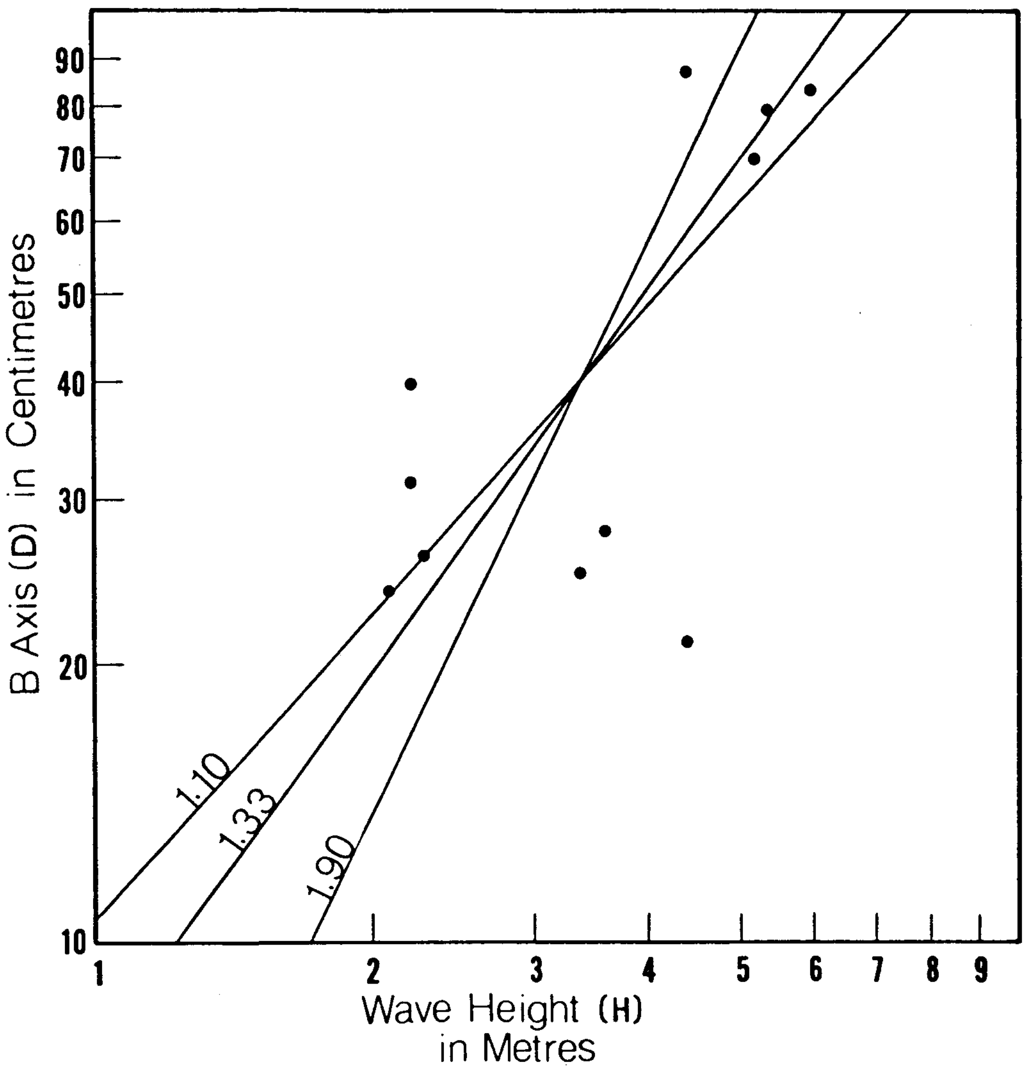


Figure 46. Graph of maximum size of sediment moved against maximum significant wave height for 11 storms at Kiama boulder beach. Regressions for log D *vs* log H and log H *vs* log D have slopes of 1.10 and 1.90, respectively. Predictive model has slope of 1.33.

The theoretical relation may be used to predict the deep-water wave heights which produce on-shore waves competent to transport boulders larger than were moved during the study period. This relation has the form

$$D = aH^{b} \qquad (5)$$

(a log D = log a + b log H) where the slope coefficient b = 1.33, The intercept (a) may be estimated by assuming that the relation passes through the grand mean ($\overline{\log H}$, $\overline{\log D}$) of the measured data. Substituting b = 1.33, H = antilog($\overline{\log H}$) = 3.41 m, and D = antilog($\overline{\log D}$) = 0.403 m into equation (5) yields

$$D = 0.079\, H^{1.33} \qquad (6)$$

Of the particles sampled on Kiama boulder beach, the largest B axis is 1.82 m. Substituting D = 1.82 into equation (6) yields H = 10.58 m. Thus, the theoretical model predicts that when waves are competent to move a boulder with a B axis of 1.82 m, the deep water wave height will be 10.58 m.

CHAPTER VIII
PROCESS INFERENCE FROM STUDIES OF COASTAL-PROTECTION STRUCTURES

Although little is known about the processes which form and maintain boulder beaches, there has been considerable engineering research on coastal-protection structures composed of rubble. Since these structures and boulder beaches are found in essentially the same environment and are composed of similar material, it seems logical to apply the available information on rubble-structure stability (movement) to the movement of boulders on boulder beaches.

This, however, must be done with extreme caution because there are fundamental differences between the research approach of engineers and sedimentologists, and between the form of rubble shore-protection structures and boulder beaches.

Research Approach

When investigating rubble protection structures, engineers are primarily concerned with minimizing construction and maintenance costs and maximizing the stability of the structure as a whole. Individual units are considered for their stability features, but how and why these units can be transported by waves are often of little importance. How and why boulders move on a boulder beach are, however, basic sedimentological questions. Thus, much information pertinent to the process of particle transport on boulder beaches cannot be found in the engineering literature.

The engineering research is largely based on laboratory models of rubble structures, which in many cases are site specific. From these models, empirical design formulae are developed (*e.g.*, Hudson, 1959, 1961 1975; Hudson and Jackson, 1962; Carstens *et al.*, 1966; Johnson *et al.*, 1966; and many others). "These design equations are not intended for general use in the manner of theoretical equations" (Pope, U.S. Army, Corps of Engineers, personal communication, 1981). Although the stability relations found for rubble shore-protection structures must relate in many ways to boulder beaches, their limitations as empirical formulae must be borne in mind.

Differences in Form

In order to make direct process inferences from rubble structures to boulder beaches, their basic forms should be similar. This, however, is not the case because the angle and shape of their seaward profiles differ greatly. As has been previously discussed, the studied boulder beaches tend to have concave foreshore slopes ranging from 6^{o} to 12^{o}, while rubble protection structures are usually constructed with rectilinear seaward slopes between 20^{o} and 35^{o}. The form of boulder beaches is established by waves acting on the available sediment, while the steep, straight slopes of most rubble coastal-protection structures are the result of "simplicity of construction, initial volume of material and insufficient knowledge of wave action. . ." (Priest *et al.*, 1965).

BOULDER MOVEMENT

Movement of units on rubble coastal-protection structures is viewed as damage and has been studied in regard to the stability of the structure as a whole. The direction of movement of individual units on rubble structures appears to be consistently downslope (Priest *et al.*, 1965; Font, 1968; Rogan, 1969; Markle and Davidson, 1979). Once the units have been dislodged, they tend to roll down the steep face. In contrast, the study of boulder movement on Kiama beach found boulder movement to be generally upslope. Thus, on rubble shore-protection structures, the transport of units seems to be greatly influenced by gravity and, perhaps, backwash, while on the studied boulder beach, uprush appeared to both initiate and accomplish transport.

Little is known about the actual mechanism of movement on boulder protection structures. However, because of their steep slopes, toe scour by waves and subsequent structural (gravity) failure appears to be important in cases where many units have moved (Machemehl, 1979). In a study by Markle and Davidson (1979, p. 30), "all of the test results showed that the stability of the placed-stone armor is very dependent upon the stability of the breakwater toe area."

Movement of boulders on the studied boulder beaches does not cause slope failure. Slope measurements of the beaches taken before and after large-scale boulder transport were virtually the same. Presumably, the low boulder-beach foreshore angle is adjusted to the environment, allowing individual particles to be moved with little change in slope form.

Although the direction and mode of particle movement on rubble structures appear to be different to those on boulder beaches, the forces which initiate movement may be similar. Whillock and Price (1976) suggested that the rubble assemblage is fluidized by the passage of water, thus weakening the frictional forces and allowing particle movement. Unfortunately, however, little research on this subject has been undertaken and knowledge of how movement is initiated (*i.e., cause* of failure) on boulder structures is extremely limited. For example:

> The investigating team traveled to the site soon after the failure [of a rubble breakwater] and began to assemble data on the accident. Their final report (in press) will provide most of the facts surrounding the failure but will not suggest the cause of failure (Edge and Magoon, 1979, p. 342).

Thus, no inference concerning the process of movement initiation can be made from rubble structures to boulder beaches.

Movement Threshold

Research concerning the point at which movement (damage) occurs on rubble coastal-protection structures is, however, abundant.

The practice of keeping a full-time maintenance crew or mobilizing plant for breakwater repair has virtually disappeared becasue of high labour costs (Wiegel, 1964, p. 290). Hence, modern rubble protection structures must be designed to withstand failure, and equations have been developed for this purpose. Because these "no damage" (0 per cent to 5 per cent movement) equations are supposedly extremely sensitive to a small amount of movement (damage), they may be useful in the prediction of movement initiation and wave competence on boulder beaches.

Design Formulae

When developing design criteria for rubble protection structures, "the problem is to find a law governing the size of the blocks and the gradient of the slopes in relation to certain wave characteristics" (Hedar. 1960, p.16). Even though rubble coastal-protection structures have been used since ancient times, no formulae to guide their design were developed until the 1930's -the most notable being the Iribarren (1938) formula, mentioned in Chapter VI. In this study, the unit sizes allowing zero to five per cent movement predicted from design formulae are compared with the recorded sizes of the largest moved boulders. It must be remembered that the largest boulder actually moved in each storm may not have been part of the marked sample. However, since the 300 marked boulders represented a great size range, including particles larger than were transported during this study, the recorded boulder transport is probably a reasonable indication of the transport occurring on Kiama boulder beach.

The Hedar Formula

Most design formulae can be adjusted, to a limited extent, to allow for varying seaward slope steepness of the structure. Hedar (1960, 1965), however, was aware of the importance of the seaward slope to the movement processes occurring on a rubble structure and formulated two stability equations: one was developed for slopes steeper than 14^{o} to 18^{o}, where gravity and backwash influence particle movement; and another equation was developed for flatter slopes where he found uprush to be dominant. Thus, the second equation may be useful in assessing the conditions under which movement is initiated on boulder beaches. By model testing, Hedar found the coefficients which allow the equation to be adjusted for slope permeability. The Hedar formula for low slopes is expressed as:

$$k = \frac{S_f}{S_s - S_f} \cdot \frac{K_{up}(d_b + 0.7\ H_b)}{(\log_{10} \frac{14.83\ H_b}{k})^2\ (1.1\ \cos\theta + \sin\theta)}$$

(Hedar, 1965, p. 203).

k = diameter of unit

S_f = unit weight of water

S_s = specific gravity of units (2.5 for Kiama beach boulders)

d_b = depth of water where design wave breaks

H_b = height of breaking design wave

K_{up} = coefficient for slope permeability (0.9 for permeable slope)

θ = angle of slope with the horizontal

Appendix IV explains the calculation of breaker height and the depth at breaking, while breaker wave length was found by using a standard table of functions of d/L for even increments of d/L_0.

Hedar (1960, p. 109) found "that the waves breaking at a distance of half the breaking wave length from the toe of the breakwater will cause maximum attacks on the seaside slope." Thus, the "design wave" values of H_b and d_b should be those found at $\frac{1}{2}L_b$ from the rubble structure.

The Hedar formula was calculated using the wave-height data for each of the eleven storms which caused boulder movement at Kiama beach (Table 26). The size of the largest measured particle actually moved during each storm is compared with the size predicted by the Hedar formula for the same wave conditions (Table 27 and Figure 47). It can be seen that the H_b and d_b values occurring at $\frac{1}{2}L_b$ (the design wave recommended by Hedar) consistently underpredict the size of boulder actually moved during the storms. This may be because the design formula is not developed for a beach situation and assumes some water depth at the toe of the structure. In any case, by experimenting with design waves at various

TABLE 26

LARGEST SAMPLED MOVED PARTICLE AND WAVE CHARACTERISTICS FOR ELEVEN STORMS AT KIAMA BOULDER BEACH

B axis (cm)	Particle volume (cc)	H_s (m)	T_s (sec)	H_b (m)	d_b (m)	L_b (m)	Date of storm
82	373,920	6.0	12	6.8	7.8	100.7	21-06-75
40	21,000	2.2	12	3.2	3.6	69.2	04-08-75
25	10,850	3.2	12	4.2	4.8	80.4	13-08-75
28	15,680	3.3	11	4.2	4.7	72.9	05-09-75
31	37,076	2.2	11	3.0	3.4	61.5	14-11-75
24	11,352	2.1	10	2.8	3.4	54.1	25-12-75
70	359,100	5.1	15	6.9	7.8	128.5	05-03-76
21	9,702	4.2	14	5.5	6.2	107.9	28-03-76
26	9,672	2.3	11	3.1	3.5	63.4	12-05-76
79	510,340	5.4	11	6.1	7.0	87.8	17-06-76
88	876,480	4.3	14	5.7	6.9	113.0	18-08-76

TABLE 27

INTERMEDIATE DIAMETER OF LARGEST MOVED PARTICLE RECORDED FOR ELEVEN STORMS AT KIAMA BEACH AND INTERMEDIATE DIAMETER PREDICTED BY HEDAR FORMULA

Recorded B axis (cm)	Predicted B axis design wave height at $1L_b$ (cm)	Predicted B axis design wave height at $\frac{1}{2}L_b$ (cm)
82	69	34
40	44	25
25	52	25
28	47	26
31	39	22
24	35	20
70	84	45
21	70	34
26	40	23
79	60	31
88	77	40

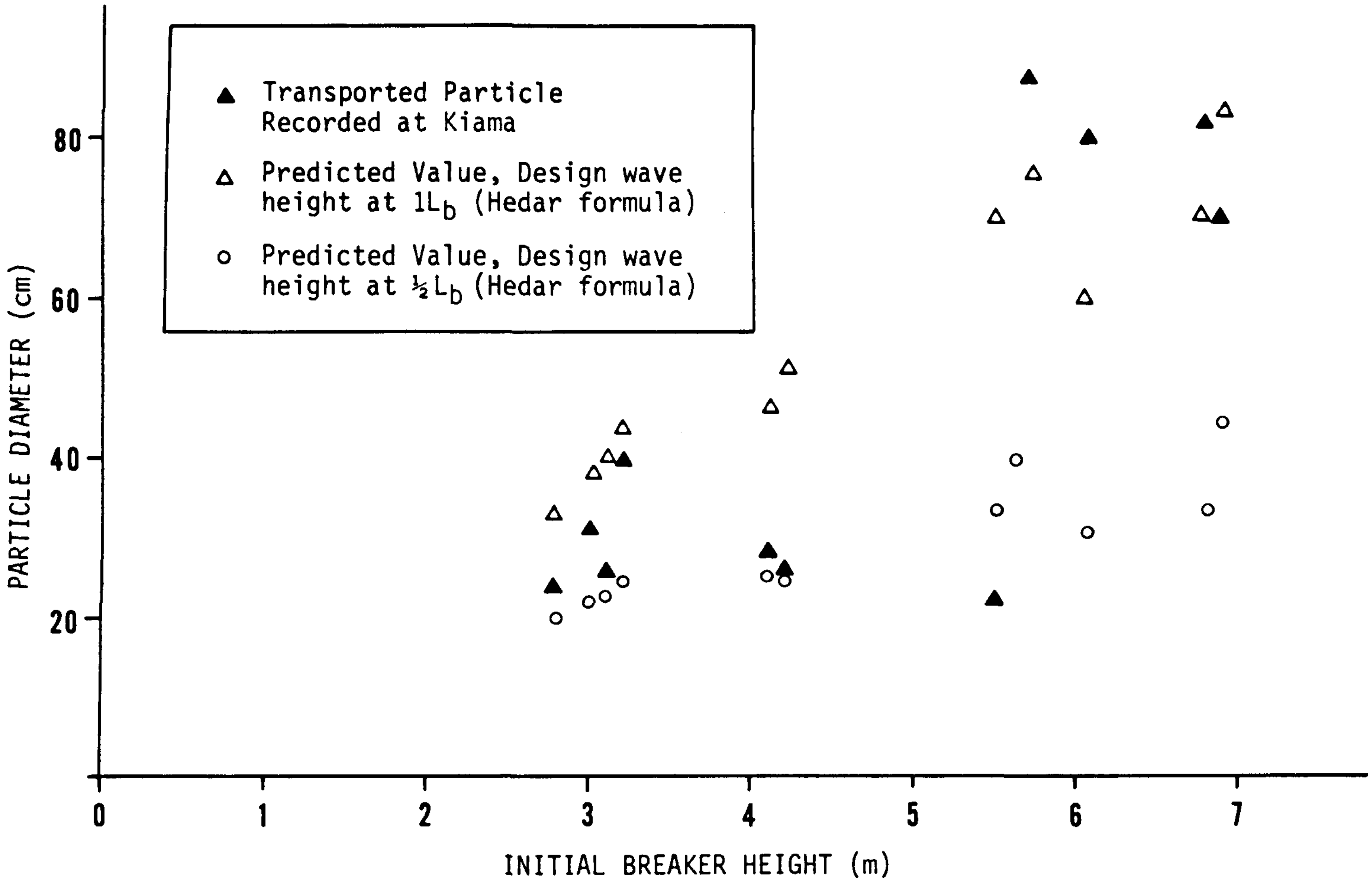


Figure 47. Comparison of the largest transported particle recorded for eleven storms at Kiama boulder beach with the values predicted by the Hedar formula to have one per cent movement under the same deep-water wave heights. Design wave heights at $1L_b$ and $\frac{1}{2}L_b$.

wave lengths from the boulder beach, it was found that the H_b and d_b values occurring $1L_b$ from the beach gave a more realistic indication of boulder movement than did the values at $\frac{1}{2}L_b$ (Figure 47).

The Hudson Formula

Since "it is now practically universal practice to determine the required size of armour [units] by reference to Hudson's equation" (Brown, 1979), in addition to Hedar's formula, the design equation developed by Hudson (1953, 1959, 1961) was used with the boulder-beach data. Hudson's formula follows the work by Iribarren (1938), is based on extensive small-scale and some large-scale model testing, and is expressed as:

$$W = \frac{w_r H^3}{K_D (S_r - 1)^3 \cot\theta}$$

(U.S. Army, Corps of Engineers, 1977, p. 7-180)

W = weight of individual armour unit (lb)

w_r = unit weight of armour unit (lb/ft^3)

H = design wave height (ft)

S_r = specific gravity of armour unit, relative to the water at the structure ($S_r = w_r/w_w$)

w_w = unit weight of water at structure (sea water = 64.0 lb/ft^3)

θ = angle of slope with the horizontal (degrees)

K_D = stability coefficient (2.3 = rough, angular quarry stone, randomly placed)

Many design-wave heights were used in the calculation of the Hudson formula, but the one which yielded the results nearest those obtained in the field was the wave height occurring $1L_b$ from the beach -the same design wave found to give the most reasonable results when using the Hedar formula. Table 28 and Figure 48 compare the calculated weights of the largest measured boulders moved during eleven storms to the weights predicted by the Hudson formula to have five per cent or less movement.

Discussion of the Results Obtained From the Hedar and Hudson Formulae

There are two main advantages of the Hudson equation over the formula developed by Hedar. These are:-

a)Wealth of experimental data:

A great range of empirically derived stability coefficients are available for the Hudson equation. The coefficients vary with the shape of units, roughness of unit surface, and method of placement.

b)Ease of calculation:

Solving the Hedar equation involves trial calculations and can be a lengthy process. The Hudson equation, however, can be solved quickly and easily.

The clear disadvantage of the Hudson formula is that stability coefficients have not been developed for slopes flatter than 18^{o}.

When figures 47 and 48 are viewed together, it can be seen that in both cases, the design formulae tend to over-predict the size required

TABLE 28

WEIGHT OF LARGEST MOVED PARTICLE RECORDED FOR ELEVEN STORMS AT KIAMA BEACH AND WEIGHT PREDICTED BY HUDSON FORMULA*

Recorded weight (kg)	Predicted weight design wave height at $1L_b$ (kg)
934.8	344.4
52.5	112.3
27.1	175.2
39.2	131.3
92.7	78.8
28.4	56.3
897.8	722.3
24.3	423.9
24.2	85.4
1275.9	265.3
2191.2	486.0

*K_D = 2.3 (rough, angular quarry stone, randomly placed)

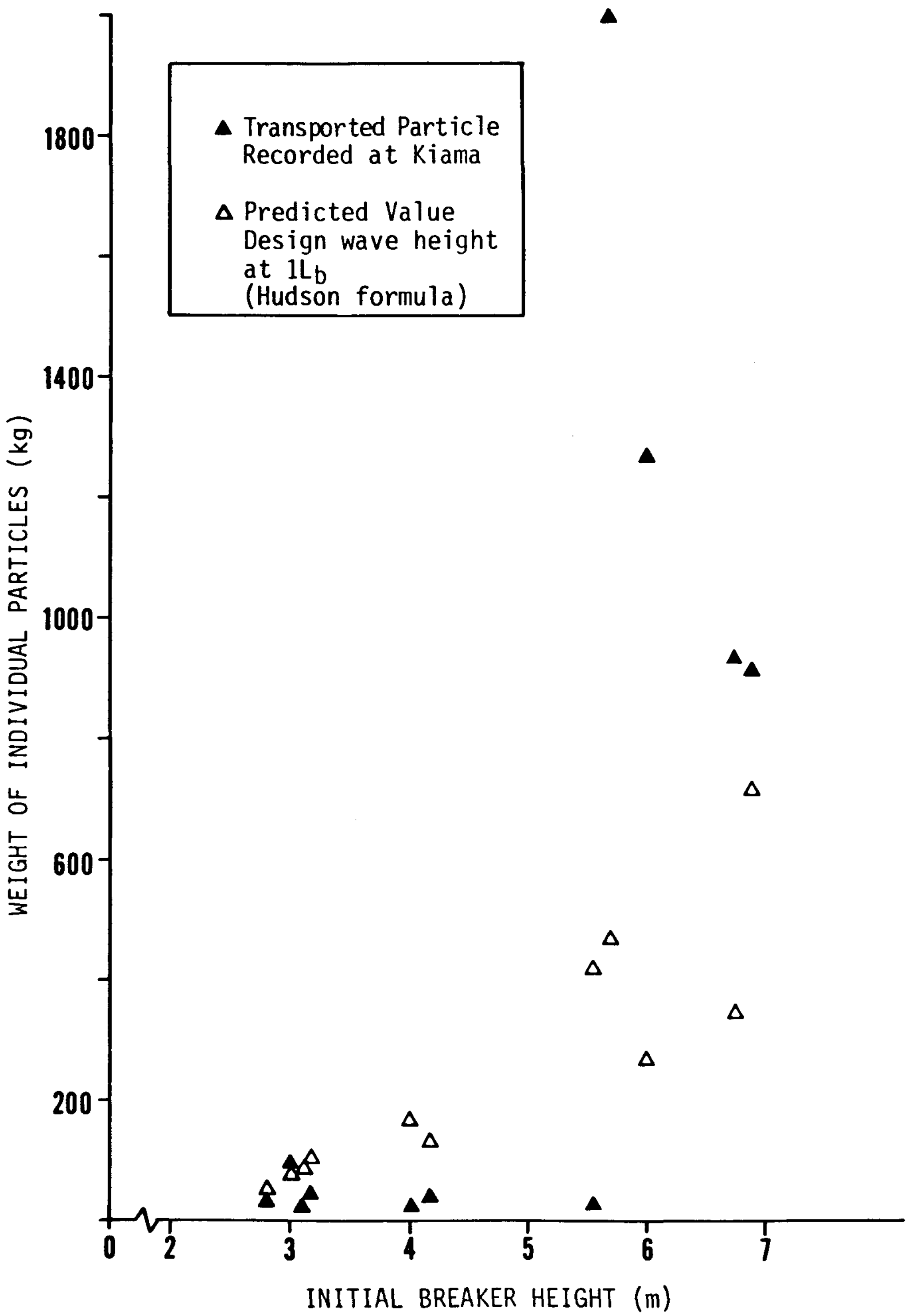


Figure 48. Comparison of the largest transported particle recorded for eleven storms at Kiama boulder beach with the values predicted by the Hudson formula (K_D= 2.3) to have zero to five per cent movement under the same deep-water wave heights.

for stability of the smaller boulders, and under-predict the required size for the larger boulders. This may be due to the packing of sediment on a boulder beach. The resistance to movement offered by the small boulders is increased because of packing (see p. 152). The clustering of the recorded moved particles in Figures 47 and 48 may be an indication of the effectiveness of packing in constraining movement of the smaller particles. When the wave energy is great enough to cause the larger boulders to move, much of the smaller material has already been transported and the stabilizing effect of packing has been removed. Also, as Whillock and Price (1976) suggested, fluidization of the boulder assemblage may occur, allowing high-energy waves to affect movement of boulders of greater size than is predicted by design formulae.

In Chapter VII, it was predicted that the largest measured boulder on Kiama beach (A axis = 183 cm, B axis = 182 cm, C axis = 90 cm; approximate weight = 7500 kg) would be transported by a wave with a deep-water wave height of 10.58 m. The Hedar equation predicted that the B axis of a stable particle on Kiama beach when the deep-water wave height is 10.58 m (design wave at $1L_b$ from the beach) would be 123 cm. The Hudson formula predicted a weight of 1937 kg. Once again, both design formulae underpredicted the size required for stability of a large boulder on Kiama boulder beach, but the Hedar equation yielded the more reasonable value. This, of course, does not confirm the prediction made in Chapter VII, it merely shows consistency.

In any case, it must be noted that in this study the Hedar formula, used with the design wave $1L_b$ from the beach, gave a more realistic wave competence prediction than did the Hudson formula. Perhaps this is because the Hedar formula was specifically designed for low-angle slopes.

Thus, in spite of numerous limitations, it would seem that the research on rubble coastal-protection structures may prove useful when boulder-movement thresholds on beaches are closely examined. Because of the low foreshore angles associated with boulder beaches, the Hedar design formula for slopes less than 14^o to 18^o appears to hold more promise for process inference to boulder beaches than does the widely used Hudson formula. However, the utility of design formulae in the study of beach-boulder movement cannot be assessed until more data from boulder beaches are available.

Since coastal engineers have recently begun investigating movement mechanisms and unit breakage on rubble structures (*e.g.*, Galvin and Alexander, 1981), in the future there will likely be more scope for process inference from rubble coastal-protection structures to boulder beaches.

CHAPTER IX

SUMMARY AND CONCLUSION

From the investigation of five boulder beaches and the observation of many more, it is suggested that the following characteristics are common to all boulder beaches - that is, bay-head and bay-side boulder beaches alike:-

1) HIGH WAVE-ENERGY ENVIRONMENT

   In order to construct and maintain a boulder beach, a high wave-energy environment is essential because only large waves are competent to transport the boulder-sized sediment forming these beaches.

2) UP-BEACH FINING OF SEDIMENT

   On all five studied boulder beaches, a significant up-beach fining trend was found. In contrast, pebble and cobble beaches generally coarsen up the beach.

3) ABUNDANT BREAKAGE OF SEDIMENT

   When boulders are transported, much breakage occurs, while on pebble and cobble beaches particle breakage is minimal. Breakage of boulders affects the distributions of both particle size and roundness.

4) POSITIVE SKEWNESS OF THE DISTRIBUTION OF PARTICLE SIZE

   During boulder transport, breakage and chipping diminish boulder size, and the products of these forms of abrasion give rise to a subordinate fine population. This fine population of chips and fragments mixed with the dominant population of boulders causes the distribution of particle size to be positively skewed. Unlike boulder beaches, most fine-sediment beaches exhibit negative size skewness.

5) UP-BEACH DECREASE IN ROUNDNESS

Roundness tends to decrease up the beach most likely because (a) small angular fragments are transported the short distance up the beach and then are stranded as the uprush percolates into the beach, and (b) fracturing from impact occurs high on the beach and the fragments are not subsequently removed.

6) NO SHAPE (SPHERE, DISC, ROD, BLADE) ZONATION

Because hydrodynamic properties vary with particle shape, cobbles and pebbles in beach environments tend to be deposited in zones according to their shapes. No evidence of shape zonation could be found on any of the studied boulder beaches. Particle breakage alters shapes and, therefore, may prevent the formation and maintenance of shape zones. But perhaps more important is the fact that most boulders are probably transported as bed load, and bed-load transport appears to be less sensitive than suspended-load transport to shape differences.

7) NO SPHERICITY GRADING

Sphericity, another measure of shape, varied little within each studied boulder beach, and nowhere did this property increase seaward as is common for pebble and cobble beaches.

8) LOW FORESHORE SLOPE WHICH DECREASES AS PARTICLE SIZE INCREASES

Foreshore slopes of the studied beaches were found to range between 7^{o} and 12^{o}. These angles are significantly lower than the angles of $\geq 24^{o}$ predicted in the literature for beaches composed of boulder-sized sediment. The observed low foreshore slopes and their tendency to decrease as particle size increases may perhaps be explained by the fact that high-energy waves produce low-angled beach slopes, and only high-energy waves are competent to transport boulders. The larger the sediment comprising a boulder beach, the greater the energy of the waves that are competent to affect movement, and the lower will be the foreshore slope produced by those waves.

The tendencies found in this study for particle size to decrease, and roundness to increase longshore in the direction of transport can occur only where there is longshore transport (*i.e.* on bay-side boulder beaches), and thus they cannot be considered as general features of all boulder beaches.

Up-beach fining, abundant breakage of sediment, positive skewness of the distribution of particle size, the absence of shape zoning, the absence of sphericity grading, and low foreshore slope are all characteristics of the studied boulder beaches which contrast strongly with the known sedimentary characteristics of pebble and cobble beaches. Thus, it is suggested that the findings of this study provide convincing evidence that boulder beaches have a distinct set of sedimentary properties, and hence must be distinguished from beaches composed of finer sediment.

SEDIMENT SUPPLY

Repeatedly in this study it has been observed that the five boulder beaches appear to group according to suggested rates (high, moderate, low) of sediment supply. These three categories again emerge when the signs of the Spearman rank correlations amongst boulder roundness, size, and longshore position are considered (Figure 49). It should be noted, however, that the presence of the longshore component (poslong) in the analyses probably restricts this indication of sediment supply to bay-side boulder beaches.

In category 1 (high sediment-supply rate) of Figure 49, the signs of the correlations show that roundness increases along the beach, roundness decreases with size, and size decreases along the beach from headland to embayment. These simple relationships are found for the beach with an abundant supply of large, angular material which is rounded through longshore transport. That the largest boulders are also the most angular is likely a reflection of the rapid rate of sediment supply.

In category 2 (moderate sediment-supply rate) of Figure 49, the positive relationship between roundness and size suggests that the angular population is dominated by chips and boulder fragments, while attrition and chipping have caused some rounding of the coarser sediment. The relationships found in this category characterize those beaches which appear to have moderate rates of sediment supply.

In category 3 (low sediment-supply rate) of Figure 49, size does not vary along the beach, although the beach is aligned obliquely to the approaching waves. This lack of longshore size trend may be indicative of a low rate of sediment supply which fails to maintain the mean size of the headland zone at a relatively high value by the input of fresh, large boulders. Few new angular fragments are produced and the negative relationship

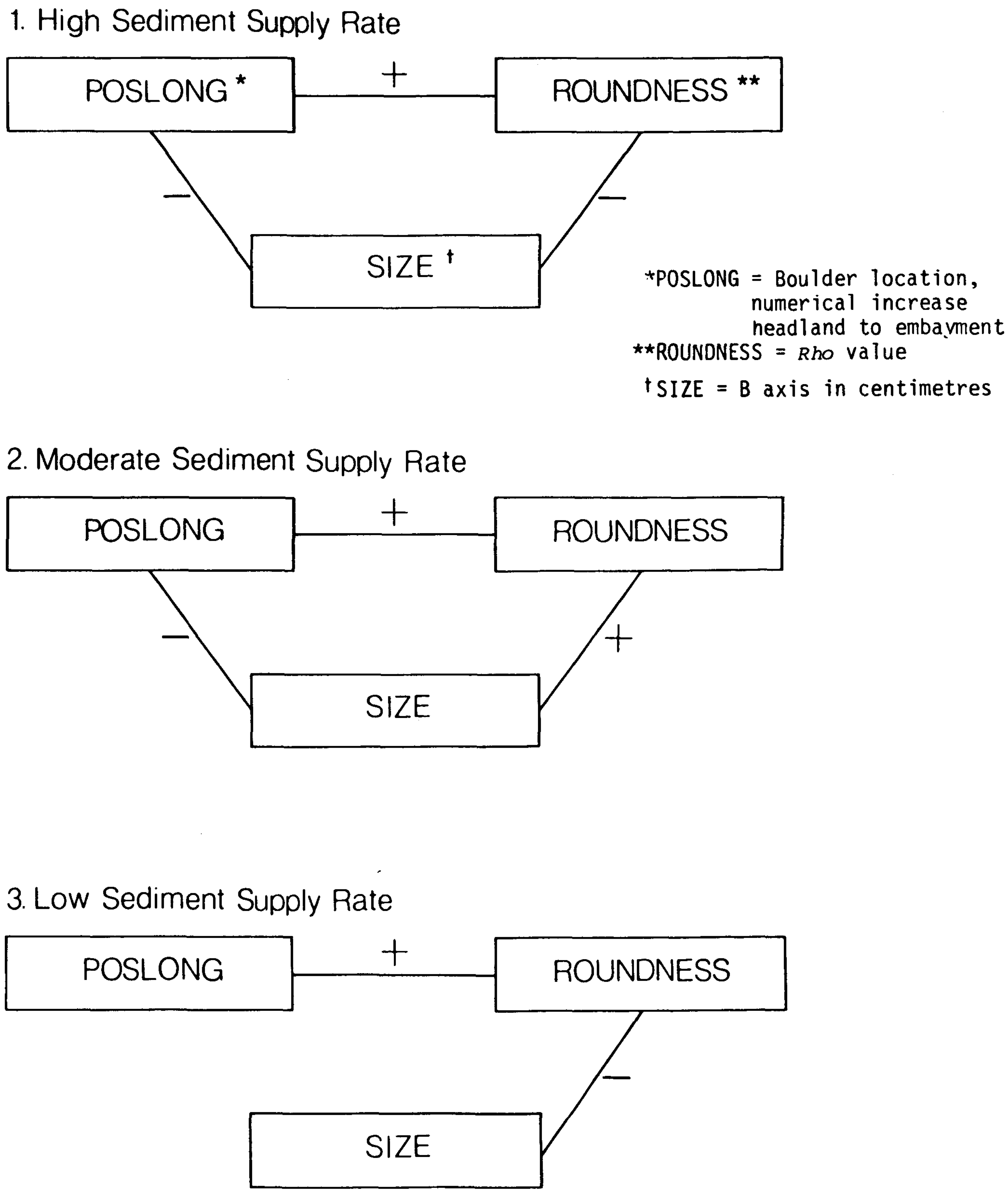


Figure 49. Rate of sediment supply categorized according to the signs of Spearman rank correlations amongst longshore boulder position, roundness, and size.

between size and roundness is probably a result of the rounding of chips and fragments which have been present on the beach for some time.

DEFINITION OF "BOULDER"

The research herein described suggests that beaches composed of boulders have sedimentological characteristics distinct from those composed of cobbles and finer particles. The question therefore arises: At what point does sediment begin to behave as "boulders" rather than as "cobbles"? Because the hydraulic behaviour of coarse sediment is dependent upon wave energy, a definition of a boulder cannot be based upon size alone since the boundary between "cobble" and "boulder" behaviour would vary with the wave environment. However, an approximate cobble-boulder size boundary may be found if the following factors are considered:-

1) Sediment forming a boulder beach must be of sufficient size that movement occurs only under high-energy conditions which produce low foreshore slopes.
2) Sediment forming a boulder beach must be of sufficient size that most transport occurs as traction load.
3) Sediment forming a boulder beach must be of sufficient size that breakage during transport is common. Abundant breakage produces chips and fragments and maintains the characteristic of up-beach decrease in sediment roundness. Breakage also may inhibit the formation of zones according to sediment shapes.

Since this study did not investigate a continuum of sediment sizes from cobble through boulder, no evidence has been presented that could provide a clear indication of the size at which sediment initially exhibits "boulder" behaviour. However, it has been noted that little or no particle breakage occurs in pebble and cobble beaches, while it is a significant process on the studied boulder beaches.

In a study of beach gravels where six different rock types were represented, Bluck (1969, p. 2) found that "when a wide range of sizes is studied a decrease in roundness takes place in sizes greater than the 64 - 128 mm [-6ϕ to -7ϕ] range." This represents a dramatic reversal in the trend of roundness with size and is illustrated in Figure 50. (See Figure 27, p. 127 for values found in the size range of the studied boulder beaches.) Bluck suggested that the processes of breakage dominate the processes of attrition when the particles are slightly larger than -7ϕ (Figure 28, p. 133). Thus, from Bluck's work, it appears that, in a variety of rock types, the lower size limit of significant breakage is near -7ϕ. It is of note that this value is slightly smaller than, but quite close to, the size of -8ϕ chosen by Wentworth to define the lower limit of boulder size.

The point at which particle breakage becomes an important process on a beach cannot, however, be the sole criterion for establishing the size threshold between cobbles and boulders. Further studies into suspension properties of large particles, and the porosity of coarse-sediment beaches may reveal other boundaries between cobbles and boulders. In any event, it is likely that no simple definition of "boulder" will be found for the beach environment. Since much boulder-beach structure is dependent on

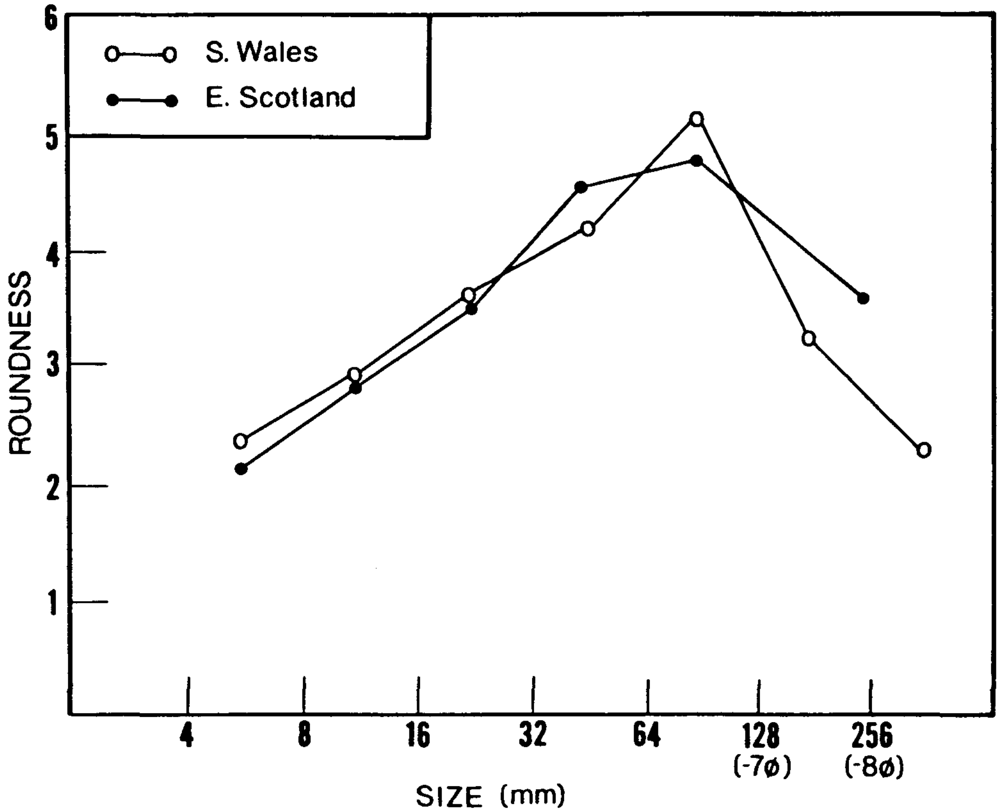


Figure 50. Relationship between roundness and size.

(after Bluck, 1969, p. 2)

available wave energy, it is possible that the same-sized sediment could form a beach with all the characteristics of a boulder beach in one energy environment and not in another. However, until further work on the behaviour of cobble- and boulder-sized sediment has been completed, there would seem to be insufficient cause to alter the cobble-boulder boundary from the presently accepted value of -8ϕ.

FUTURE RESEARCH

Because work on boulder beaches has been extremely limited, there are numerous opportunities for research in this area. Initially, boulder beaches in many locations must be investigated in order to test the general applicability of the results obtained during this study. Bay-head boulder beaches should be examined to determine if, in fact, the suggested differences between bay-head and bay-side boulder beaches do exist. As has been previously indicated, the analysis of a continuum of sediment sizes in various energy environments might aid in establishing a generally acceptable size boundary between the constituent particles of cobble and boulder beaches. Since this study was essentially limited to boulder-sized particles, no definitive boundary between cobbles and boulders could be found.

Although this work concentrated on the previously undocumented sedimentology and form of boulder beaches, it is clear that process investigations need to be undertaken. Research into individual behaviour of very coarse particles as well as group characteristics could prove most useful to the understanding of boulder movement. Determining transport threshold conditions and the relation, if any, between boulder shape and likelihood of entrainment are possibly suitable subjects for laboratory investigation. Packing of beach boulders, which appears to be important to boulder mobility, must be further examined.

Particularly needed are data from other boulder beaches on wave characteristics and sediment movement, which, in addition to providing more information on boulder transport, would allow evaluation of the predictive model for wave competency. More transport data would also aid in assessing the value of process inference from coastal-protection structures to boulder beaches.

Some means of measuring swash velocity needs to be developed before boulder transport can be thoroughly examined. This is a difficult task because the velocity must vary greatly on a beach with such large particles and high permeability. Also, as has been mentioned previously, particularly robust equipment would be needed to withstand the conditions under which boulders are mobilized.

In any case, it is clear that there is broad scope for future boulder-beach research. Such work could be beneficial to planners of coastal- and, in some cases, fluvial-protection structures. However, whether or not applications accrue from the investigation of boulder beaches, intrinsic value lies in furthering the understanding of our physical environment.

REFERENCES

Abrahams, A.D. and Melville, M.D., 1975. A source of error in surveying hillslopes by Abney level. *Area*, v.7, (4), pp.299-302.

Albertson, M.L., 1953. Effect of shape on the fall velocity of gravel particles. *Proc. Fifth Hydraulics Conf., Univ. Iowa*, pp.243-261.

American Geological Institute, 1962. *Dictionary of Geological Terms*. Doubleday & Co. (Dolphin) Garden City, New York, 545 pp.

van Andel, T.H., Wiggers, A.J., and Maarleveld, G., 1954. Roundness and shape of marine gravels from Urk (Netherlands): A comparison of several methods of investigation. *Jour. Sed. Petrology*, v.24, pp.100-116.

Andrews, F.C., 1954. Asymtotic behavior of some rank tests for analysis of variance. *Ann. Math. Statist.*, v.25, pp.724-736.

Andrews, J.T., 1971. Techniques of till fabric analysis. *British Geomorphological Research Group Tech. Bull.* No. 6 Geo Abstracts, Norwich, England, 43 pp.

Bardecki, M.J., 1977. Size selection: A source of error in sphericity determination. *Sedimentology*, v.24, pp.447-450.

Bartrum, J.A., 1947. The rate of rounding of beach boulders. *Jour. Geol.*, v.55, pp.514-515.

Bascom, W.N., 1951. The relationship between sand size and beach-face slope. *Trans. Amer. Geophys. Union*, v.32, (6), pp.866-874.

Battjes, J.A., 1974. *Wave Runup and Overtopping*, Technical Advisory Committee on Protection Against Inundation, Rijkswaterstaat, The Hague, Netherlands.

Bird, E.C.F., 1972. Beach gravels. *Victorian Naturalist*, v.89, (7), pp.180-185.

Blatt, H., 1959. Effect of size and genetic quartz type on sphericity and form of beach sediments, northern N.J.. *Jour. Sed. Petrology*, v.29, (2), pp.197-206.

Bluck, B.J., 1967. Sedimentation of beach gravels: Examples from South Wales. *Jour. Sed. Petrology*, v.37, (1), pp.128-156.

_____, 1969. Particle rounding in beach gravels. *Geol. Mag.*, v.106, pp.1-14.

Branagan, D.F. and Packham, G.H., 1970. *Field Geology of N.S.W.*. Science Press, Sydney, 191 pp.

Briggs, D., 1977. *Sources and Methods in Geography SEDIMENTS*. Butterworths, London, 190 pp.

Brock, E.J., 1974. Coarse sediment morphometry: A comparative study. *Jour. Sed. Petrology*, v.44, (3), pp.663-672.

Brodo, I.M., 1973. Substrate Ecology *in* Ahmadjian, V. and Hale, M.E., eds., *The Lichens*, Academic Press, New York, pp.401-441.

Cailleux, A., 1945. Distinctinction des galets marins et fluviatiles. *Bull. Soc. Geol. France*, 5 serie, v.15, pp.375-404.

_____, 1952. Morphoskopische analyse der geschiebe und sandkorner und ihre bedeutung fur die palaoklimatologie. *Geol. Rundschau*, v.40, pp.11-19.

Carr, A.P., 1969. Size grading along a pebble beach: Chesil Beach, England. *Jour. Sed. Petrology*, v.39, (1), pp.297-311.

Carstens, T., Torum, A., and Traetteberg, A., 1966. The stability of rubble-mound breakwaters against irregular waves. *Proc. 10th Conference on Coastal Engineering*, A.S.C.E., New York, pp.958-965.

Carver, R.E., ed., 1971. *Procedures in Sedimentary Petrology*. Wiley-Interscience, New York, 653 pp.

Chappell, J., 1967. Recognizing fossil strand lines from grain-size analysis. *Jour. Sed. Petrology*, v.37, (1), pp.157-165.

Chayes, F., 1970. On deciding whether trend surfaces of progressively higher order are meaningful. *Bull. Geol. Soc. Am.*, v.81, pp.1273-1278.

Cheng, E.D.C. and Clyde, C.G., 1972. Instantaneous hydrodynamic lift and drag forces on large roughness elements in turbulent open channel flow. *in* Shen, H.W., ed., *Sedimentation Symposium to Honor Prof. H.A. Einstein*. Fort Collins, Colorado, Water res. publ. 3-123-20.

Chissom, B.S., 1970. Interpretation of the kurtosis statistic. *Amer. Statistician*, v.24, (5), pp.19-22.

Chorley, R.J. and Haggett, M.A., 1965. Trend-surface mapping in geographical research. *Trans. Inst. Brit. Geogr.*, v.37, pp.47-67.

Corey, A.T., 1949. *Influence of Shape on Fall Velocity of Sand Grains*. M.S. dissertation, Colorado A & M College, 102 pp.

Cox, H.C., 1973. *Form and Process on Shingle Beaches in New South Wales*. B.A.(Hons) Thesis, School of Geography, The University of New South Wales, 47 pp.

Croxton, F.E., 1953. *Elementary Statistics With Applications in Medicine and the Biological Sciences*. Dover Publications, New York, 376 pp.

Dakin, W.J., 1973. *Australian Seashores*. Angus and Robertson, Sydney, 372 pp.

Darlington, R.B., 1970. Is kurtosis really "peakedness?" *Amer. Statistician*, v.24, (2), pp.19-22.

Davies, J.L., 1964. A morphogenetic approach to world shorelines. *Zeits. f. Geomorph.*, 8(Sp. No.), pp.127-142.

_____, 1974. The coastal sediment compartment. *Aust. Geogrl. Stud.*, v.12, pp.139-151.

Davis, M.W. and Ehrlich, R., 1970. Relationship between measures of sediment-size-frequency distributions and the nature of sediments. *Bull. Geol. Soc. Am.*, v.81, pp.3537-3548.

Dobkins, J.E. and Folk, R.L., 1970. Shape development on Tahiti-Nui. *Jour. Sed. Petrology*, v.40, (4), pp.1167-1203.

Dolan, R. and Ferm, J., 1966. Swash processes and beach characteristics. *The Professional Geographer*, v.18, (4), pp.210-213.

Doornkamp, J.C. and King, C.A.M., 1971. *Numerical Analysis in Geomorphology*. Edward Arnold, London, 372 pp.

Duane, D.B., 1964. Significance of skewness in recent sediments, Western Pamlico Sound, North Carolina. *Jour. Sed. Petrology*, v.34, (4), pp.864-874.

Edge, B.T. and Magoon, O.T., 1979. A review of recent damages to coastal structures *in Coastal Structures '79*, Amer. Soc. of Civil Eng., New York, pp.333-348.

Eliot, I. and Bradshaw, M., 1975. Rhythmic forms in a boulder field on a rock platform skirting Point Upright, Durras, N.S.W.. unpubl. *abstract, Wollongong Meeting, Inst. Aust. Geogr..*

Engel, B.A., 1962. Geology of the Bulahdelah-Port Stephens District, N.S.W.. *Jour. Proc. Roy. Soc. N.S.W.*, v.95, pp.197-215.

Engel, B.A., McKelvey, B.C., and Campbell, K.S.W., 1969. Stroud-Gloucester and Myall Synclines. *in* Packham, G.H., ed. The Geology of New South Wales. *Jour. Geol. Soc. Aust.*, v.16, (1), pp.253-261.

Evans, O.F., 1939. Sorting and transportation of material in the swash and backwash. *Jour. Sed. Petrology*, v.9, (1), pp.28-31.

Fletcher, A., 1976. Nutritional Aspects of marine lichen ecology *in* Brown, D.H., Hawksworth, D.L., and Bailey, R.H., eds. *Lichenology: Progress and Problems*. Academic Press, London, pp.359-384.

Folk, R.L., 1955. Student operator error in determination of roundness, sphericity, and grain size. *Jour. Sed. Petrology*, v.25, (4), pp.297-301.

_____, 1966. A review of grain-size parameters. *Sedimentology*, v.6, pp.73-93.

_____, 1968. *Petrology of Sedimentary Rocks (with Powers visual roundness chart)*. Hemphill Publishing Co., Austin, Texas, 182 pp.

_____, 1972. Experimental error in pebble roundness determination by the modified Wentworth method. *Jour. Sed. Petrology*, v.42, (4), pp.973-974.

_____, 1974. *Petrology of Sedimentary Rocks*. Hemphill Publishing Co., Austin, Texas, 182 pp.

Folk, R.L. and Ward, W.C., 1957. Brazos River bar: A study in the significance of grain size parameters. *Jour. Sed. Petrology*, v.27, (1), pp.3-26.

Font, J.B., 1970. Damage functions for a rubble-mound breakwater under the effect of swells. *Proc. 12th Conference on Coastal Engineering*, A.S.C.E., Washington, D.C., pp.1567-1585.

Friedman, G.M., 1961. Distinction between dune, beach, and river sands from their textural characteristics. *Jour. Sed. Petrology*, v.31, (4), pp.514-529.

_____, 1962. On sorting, sorting coefficients, and the lognormality of the grain-size distribution of sandstones. *Jour. Geol.*, v.70, pp.737-753.

_____, 1967. Dynamic processes and statistical parameters compared for size frequency distributions of beach and river sands. *Jour. Sed. Petrology*, v.37, (2), pp.327-354.

Galvin, C.J., Jr., 1969. Breaker travel and choice of design wave height. *Journal of Waterways and Harbors Div.* A.S.C.E., WW2, No. 6569, pp.175-200.

Galvin, C. and Alexander, D.F., 1981. Armor unit abrasion and dolos breakage by wave-induced stress concentrations. *Amer. Soc. Civil Eng., Preprint*, New York, 20 pp.

Gill, E.A., 1971. Rocks plucked by the sea. *Victorian Naturalist*, v.88, (10), pp.287-290.

Goda, Y., 1970. A synthesis of breaker indices. *Trans. Japanese Soc. of Civil Eng.*, v.2, part 2, 1970.

Gostin, V.A. and Herbert, C., 1973. Stratigraphy of the upper Carboniferous and lower Permian sequence, southern Sydney Basin. *Jour. Geol. Soc. Aust.*, v.20, (1), pp.49-70.

Grogan, R.M., 1945. Shape variation of some Lake Superior beach pebbles. *Jour. Sed. Petrology*, v.15, (1), pp.3-10.

Hedar, P.A., 1960. *Stability of Rock-fill Breakwaters*. Doktorsavhandlingar, Chalmers Tekniska Högskola, Göteborg, Sweden, No. 26, 119 pp.

_____, 1965. Rules for the design of rock-fill breakwaters and revetments. *21st International Navigation Congress*, Stockholm, Section II, pp.203-210.

Hildebrand, D.K., 1971. Kurtosis measures bimodality? *Amer. Statistician*, v.25, (1), pp.42-43.

Hills, E.S., 1970. Fitting, fretting and imprisoned boulders. *Nature*, v.226, (5243), pp.345-347.

Hoffman, J.G., Gordon, A.D., Nielsen, A.F., and Lord, D.B., 1980. Assessment of environmental impact marine aggregate project Broken Bay NSW. *Dept Pub. Works NSW, Report* no PWD 80022.

Hotelling, H. and Pabst, M.R., 1936. Rank correlation and tests of significance involving no assumption of normality. *Ann. Math. Statist.*, v.7, pp.29-43.

Hudson, R.Y., 1953. Wave forces on breakwaters. *Trans. Amer. Soc. Civil Eng.*, v.118, pp.653-685.

_____, 1959. Laboratory investigation of rubble-mound breakwaters. *Jour. of Waterways and Harbors Div., Proc. A.S.C.E.*, v.85, (Sept.), pp.93-121.

_____, 1961. Laboratory investigation of rubble-mound breakwaters. *Trans. A.S.C.E.*, v.126, (4), pp.492-520.

_____, 1975. Reliability of rubble-mound breakwater stability models. *U.S. Army Engineering Waterways Experiment Station, Vicksburg, Mississippi*, Misc. paper H-75-5.

Hudson, R.Y. and Jackson, R.A., 1966. Stability tests of proposed rubble-mound breakwaters, Nassau Harbor, Bahamas. *U.S. Army, Corps of Eng., Waterways Experiment Station.*, Misc. Paper No. 2-799.

Inman, D.L., 1949. Sorting of sediments in the light of fluid mechanics. *Jour. Sed. Petrology*, v.19, pp.51-70.

Iribarren, R., 1938. Una formula para el calculo de los diques de escollera. *Revista de Obras Publicas*, Madrid, (or see: A Formula for the calculation of rock-fill dykes, by Ramon Iribarren Cavanilles, translated by D. Heinrick, University of California, Dept. of Engineering TR-He-116-295, Berkeley, California, 1948).

Iversen, H.W., 1952. Laboratory study of breakers *in Gravity Waves*, National Bureau of Standards, Washington, D.C., Circ. No. 521.

_____, 1953. Waves and breakers in shoaling water. *Proc. of 3rd Conference on Coastal Engineering*, A.S.C.E., Cambridge, Mass.

Johnson, J.W., Kondo, H., and Wallihan, R. 1966. Scale effects in wave action through porous structures. *Proc. 10th Conference on Coastal Engineering*, A.S.C.E., New York, pp.1022-1024.

Johnson, J.W., O'Brien, M.P., and Isaacs, J.D., 1948. *Graphical Construction of Wave Refraction Diagrams*. U.S. Naval Oceanographic Office, Washington, D.C., HO No. 605, TR-2.

Kellerhals, R. and Bray, D., 1971a. Comments on "An improved method for size distribution of stream bed gravel" by Luna B. Leopold. *Wat. Resour. Res.*, v.7, (4), pp.1045-1047.

_____, 1971b. Sampling procedures for coarse fluvial sediments. *Jour. Hydraulics Div., Proc. A.S.C.E.*, v.97, (HY8), pp.1165-1179.

Kendall, M.G. and Stuart, A., 1973. *The Advanced Theory of Statistics, 3rd ed. vol. 2*. Charles Griffin & Co., London, 723 pp.

King, C.A.M., 1972. *Beaches and Coasts, 2nd ed.*. Edward Arnold, London, 570 pp.

_____, 1980. *Physical Geography*. Barnes & Noble, Totowa, New Jersey, 332 pp.

Kirk, R.M., 1980. Mixed sand and gravel beaches: morphology, processes and sediments. *Prog. in Physical Geog.*, v.4, pp.189-210.

Komar, P.D., 1976. *Beach Processes and Sedimentation*. Prentice-Hall, Englewood Cliffs, New Jersey, 429 pp.

Krumbein, W.C., 1934. Size frequency distributions of sediments. *Jour. Sed. Petrology*, v.4, pp.65-77.

_____, 1936. Applications of logarithmic moments to size frequency distribution of sediments. *Jour. Sed. Petrology*, v.6, pp.35-47.

_____, 1938. Size frequency distributions of sediments and the normal phi curve. *Jour. Sed. Petrology*, v.8, (3), pp.84-90.

Krumbein, W.C., 1939. Tidal lagoon sediments on the Mississippi delta. *in* Trask, P.D., ed. *Recent Marine Sediments: A Symposium.* Soc. Eco. Paleontologists and Mineralogists Spec. Publ. No. 4, Tulsa, Oklahoma, pp.178-194.

_____, 1941. Measurement and geological significance of shape and roundness of sedimentary particles. *Jour. Sed. Petrology*, v.11, (2), pp.64-72.

_____,1953. Statistical designs for sampling beach sand. *Trans. Amer. Geophys. Union*, v.34, (6), pp.857-868.

Krumbein, W.C. and Graybill, F.A., 1965. *An Introduction to Statistical Models in Geography.* McGraw-Hill, New York, 574 pp.

Krumbein, W.C. and Monk, G.D., 1942. Permeability as a function of the size parameters of unconsolidated sand. Am. Inst. Mining and Metallurg. Engrs. Tech. Publ. No. 1492. *Petroleum Technology*, July, pp.1-11.

Kruskal, W.H., 1952. A nonparametric test for the several sample problem. *Ann. Math. Statist.*, v.23, pp.525-540.

Kruskal, W.H. and Wallis, W.A., 1952. Use of ranks in one-criterion variance analysis. *Jour. Amer. Stat. Assoc.*, v.47, (260), pp.583-621.

Kuenen, Ph.H., 1947. Water faceted boulders. *Amer. Jour. Sci.*, v.245, (12), pp.779-783.

_____, 1955. Experimental abrasion of pebbles 1. Wet sand blasting. *Leidsche Geol. Meded.*, v.20, pp.131-137.

_____, 1956. Experimental abrasion of pebbles 2. Rolling by current. *Jour. Geol.*, v.64, pp.336-368.

Landon, R.E., 1930. An analysis of beach pebble abrasion and transportation. *Jour. Geol.*, v.38, pp.437-446.

Langford-Smith T. and Hails, J.R., 1966. New evidence of Quaternary Sea Levels from the north coast of New South Wales. *Aust. Jour. Sci.*, v.28, (9), p.353.

Langford-Smith, T. and Thom, B.G., 1969. N.S.W. coastal morphology. *in* Packham, G.H., ed., The Geology of New South Wales. *Jour. Geol. Soc. Aust.*, v.16, (1), pp.572-580.

Laronne, J.B. and Carson, M.A., 1976. Interrelationships between bed morphology and bed-material transport for a small, gravel-bed channel. *Sedimentology*, v.23, pp.67-85.

Lawson, N.V. and Abernethy, C.L., 1975. Long term wave statistics off Botany Bay. *Papers, 2nd Aust. Conf. on Coastal and Ocean Eng.*, 75/2, pp.167-176.

Leopold, L.B., Wolman, M.G., and Miller, J.P., 1964. *Fluvial Processes in Geomorphology*. W.H. Freeman, San Francisco, 522 pp.

Longuet-Higgins, M.S. and Parkin, D.W., 1962. Sea waves and beach cusps. *Geog. Jour.*, v.128, pp.194-201.

Machemehl, M., 1979. Damage and repairs to coastal structures *in Coastal Structures* '79, Amer. Soc. of Civil Eng., New York, pp.314-332.

Mark, D.M. and Church, M., 1977. On the misuse of regression in earth science. *Math. Geol.*, v.9, (1), pp.63-75.

Markle, D.G. and Davidson, D.D., 1979. Placed-stone stability tests, Tillamook, Oregon. *U.S. Army Waterways Experiment Station Hydraulics Lab. Technical Report* HL-79-16, 36 pp.

Marshall, P., 1929. Beach gravels and sands. *Trans. & Proc., New Zealand Inst.*, v.60, (2), pp.324-365.

Mason, C.C. and Folk, R.L., 1958. Differentiation of beach, dune and aeolian flat environments by size analysis, Mustang Island, Texas. *Jour. Sed. Petrology*, v.28, (2), pp.211-226.

McElroy, C.T., Branagan, D.F., Raam, A., and Campbell, K.S.W., 1969. Shoalhaven Group. *in* Packham, G.H., ed., The Geology of New South Wales. *Jour. Geol. Soc. Aust.*, v.16, (1), pp.357-366.

McLean, R.F. and Kirk, R.M., 1969. Relationships between grain size, size sorting, and foreshore slope on mixed sand-shingle beaches. *New Zealand Jour. Geol. & Geophys.*, v.12, (1), pp.138-155.

Meland, N. and Norrman, J.O., 1969. Transport velocities of individual size fractions in heterogeneous bed load. *Geograf. Ann.*, v.51A, (3), pp.127-144.

Michell, J.H., 1893. On the highest waves in water. *Philosophical Magazine*, 5th Series, v.36, pp.107-109.

Mills, H.H., 1979. Downstream rounding of pebbles - A quantitative review. *Jour. Sed. Petrology*, v.49, (1), pp.295-302.

Moss, A.J., 1962. The physical nature of common sandy and pebbly deposits, Part I. *Amer. Jour. Sci.*, v.260, pp.337-373.

Muir Wood, A.M., 1969. *Coastal Hydraulics*. Macmillan, London, 187 pp.

_____, 1970. Characteristics of shingle beaches: The solution to some practical problems. *Proc. 12th Conference on Coastal Engineering*, A.S.C.E., Washington, D.C., pp.1059-1075.

Munk, W.H., 1949. The solitary wave theory and its application to surf problems. *Annals of the New York Academy of Sciences*, v.51, pp.376-462.

Nashar, B., 1967. *Geology of the Sydney Basin*. Jacaranda Press, Brisbane, 119 pp.

Nie, N.H., Hull, C.H., Jenkins, J.G., Steinbrenner, K., and Bent, D.H., 1975. *Statistical Package for the Social Sciences (SPSS), 2nd ed.*. McGraw-Hill, New York, 675 pp.

Norcliffe, G.B., 1969. On the use and limitations of trend surface models. *Can. Geogr.*, v.13, (4), pp.338-348.

Novak, I.D., 1972. Swash-zone competency of gravel-size sediment. *Marine Geol.*, v.13, (5), pp.335-346.

_____, 1974. Predicting coarse sediment transport: The Hjulstrom curve revisited. *in* Morisawa, M., ed., Fluvial Geomorphology. *Proc. 4th Annual Binghamton Symposium.* Binghamton, New York, pp.13-25.

O'Leary, M., Lippert, R.H., and Spitz, O.T., 1966. Fortran IV and map program for computation and plotting of trend surfaces for degrees 1 through 6. *State Geol. Surv. Kansas, Computer Contribution* No. 3, Univ. Kansas, Lawrence, 48 pp.

Orford, J.D., 1975. Discrimination of particle zonation on a pebble beach. *Sedimentology*, v.22, pp.441-463.

_____, 1977. A proposed mechanism for storm beach sedimentation. *Earth Surf. Proc.*, v.2, pp.381-400.

Pettijohn, F.J., 1975. *Sedimentary Rocks, 3rd ed.*. Harper & Row, New York, 628 pp.

Pettijohn, F.J., Potter, P.E., and Siever, R., 1972. *Sand and Sandstone.* Springer-Verlag, New York, 618 pp.

Powers, M.C., 1953. A new roundness scale for sedimentary particles. *Jour. Sed. Petrology*, v.23, (2), pp.117-119.

Priest, M.S., Pugh, J.W., and Singh, R., 1965. Seaward profile for rubble-mound breakwaters. *Proc. 9th Conference on Coastal Engineering*, A.S.C.E., Lisbon, pp.553-559.

Raam, A., 1969. Geringong volcanics. *in* Packham, G.H., ed., The Geology of New South Wales. *Jour. Geol. Soc. Aust.*, v.16, (1), pp.366-368.

Raudkivi, A.J., 1967. *Loose Boundary Hydraulics.* Pergamon Press, Oxford, 331 pp.

Robinson, G., 1970. Some comments on trend-surface analysis. *Area*, v.2, (3), pp.31-36.

Rogan, A.J., 1969. Destruction criteria for rubble-mound breakwaters. *Proc. 11th Conference on Coastal Engineering*, A.S.C.E., London, pp.761-778.

Russell, R.D., 1939. Effects of transportation on sedimentary particles. *in* Trask, P.D., ed. *Recent Marine Sediments: A Symposium.* Soc. Eco. Paleontologists and Mineralogists Spec. Publ. No. 4, Tulsa, Oklahoma, pp.32-47.

Russell, R.D. and Taylor, R.E., 1937. Roundness and shape of Mississippi River sands. *Jour. Geol.*, v.45, pp.225-267.

Sahu, B.K. and Patro, B.C., 1970. Treatment of sphericity and roundness data of quartz grains of clastic sediments. *Sedimentology*, v.14, pp.51-66.

Schumm, S.A. and Stevens, M.A., 1973. Abrasion in place: A mechanism for rounding and size reduction of coarse sediments in rivers. *Geology*, v.1, (1), pp.37-40.

Shelley, D., 1968. Fitting boulders: The result of an important shore process. *Nature*, v.220, pp.1020-1021.

Shepard, F.P., 1963. *Submarine Geology.* Harper & Row, New York, 557 pp.

Short, A.D., 1967. *A Selective Regional Study of the Coastal Geomorphology of the Copacabana-McMasters Beach Area.* B.A.(Hons) Thesis, Department of Geography, The University of Sydney.

Siegel, S., 1956. *Nonparametric Statistics For the Behavioral Sciences.* McGraw-Hill, New York, 312 pp.

Smalley, I.J., 1966. The expected shapes of blocks and grains. *Jour. Sed. Petrology*, v.36, pp.626-629.

Sneed, E.D. and Folk, R.L., 1958. Pebbles in the lower Colorado River, Texas: A Study in particle morphogenesis. *Jour. Geol.*, v.66, pp.114-150.

Spencer, D.W., 1963. The interpretation of grain size distribution curves of clastic sediments. *Jour. Sed. Petrology*, v.33, (1), pp.180-190.

Stone, D.M., 1969. A wave recording network for Australia. *Univ. N.S.W. Water Res. Lab. Report*, No. 115.

Stone, D.M. and Foster, D.N., 1967. Data provided for N.S.W. coastal engineering works. *Aust. Civil Eng. & Construction*, v.8, (4), pp.33-39.

Stone, P.B. and Gordon, A.D., 1970. Wave climate at Bombo. *Univ. N.S.W. Water Res. Lab. Technical Report*, 70/13.

Strahler, A.N. and Strahler, A.H., 1978. *Modern Physical Geography.* John Wiley & Sons, New York, 502 pp.

Sussmilch, C.A. and Clark, W., 1928. The geology of Port Stephens: Part 1, Physiography and General Geology. *Proc. Roy. Soc. N.S.W.*, v.62, pp.168-181.

Swan, B., 1975. Depositional evidence for higher sea levels in coastal New South Wales. *Aust. Geog. Studies*, v.13, pp.62-76.

Tanner, W.F., 1974. The "a-b-c. . ." model. *in* Tanner, W.F., ed. *Sediment Transport in the Near-shore Zone.* Florida State Univ., pp.12-21.

Tuccy, J., 1977. SPSS Subprogram NPAR TESTS: Nonparametric Statistical Tests. *in SPSS 7.0 Update Manual*, Northwestern University, Illinois.

Udden, J.A., 1914. The mechanical composition of clastic sediments. *Bull. Geol. Soc. Am.*, v.25, pp.655-744.

U.S. Army, Corps of Engineers, 1953. Stability of rubble-mound breakwaters: Hydraulic model investigation. *U.S. Army Corps of Eng. Tech. Memo.*, No. 2-365, 80 pp.

_____, 1977. *Shore Protection Manual, 3 Vols.* U.S. Army Coastal Engineering Research Center, Fort Belvoir, Virginia.

Valia, H.S. and Cameron, B., 1977. Skewness of size frequency distributions as a paleo-environmental indicator. *Jour. Sed. Petrology*, v.47, pp.784-793.

Wadell, H., 1932. Volume, shape, and roundness of rock particles. *Jour. Geol.*, v.40, pp.443-451.

_____, 1934. Shape determinations of large sedimental rock fragments. *Pan-Amer. Geol.*, v.61, pp.187-220.

Wentworth, C.K., 1919. A laboratory and field study of cobble abrasion. *Jour. Geol.*, v.27, pp.507-521.

_____, 1922a. A scale of grade and class terms for clastic sediments. *Jour. Geol.*, v.30, pp.377-392.

_____, 1922b. A method of measuring and plotting the shapes of pebbles. *Bull. Geol. Soc. Am.*, v.730-C, pp.91-102.

_____, 1922c. The shapes of beach pebbles. *U.S. Geol. Survey Prof. Paper* No. 131 C, pp.75-83.

Whalley, W.B., 1972. The description and measurement of sedimentary particles and the concept of form. *Jour. Sed. Petrology*, v.42, (4), pp.961-965.

Whillock, A.F. and Price, W.A., 1976. Armour blocks as slope protection. *Proc. 15th Conference on Coastal Engineering*, A.S.C.E., New York, pp.2564-2571.

Wiegel, R.L., 1964. *Oceanographical Engineering.* Prentice-Hall, Englewood Cliffs, New Jersey, 532 pp.

Williams, C.M., 1965. A method of indicating pebble shape with one parameter. *Jour. Sed. Petrology*, v.35, pp.993-996.

Wirth, V., 1972. Die Silikatflechten-Gemeinschaften in ausseralpinen Zentraleuropa. *Dissert. Bot.*, v.17, pp.1-306.

Wolman, M.G., 1954. A method of sampling coarse river-bed material. *Trans. Amer. Geophys. Union*, v.35, (6), pp.951-955.

Wright, L.D., 1976. Nearshore wave-power dissipation and the coastal energy regime of the Sydney-Jervis Bay region, New South Wales: A comparison. *Aust. Jour. Marine and Freshwater Research*, v.27, pp.633-640.

Young, A., 1972. *Slopes.* Longman, London, 288 pp.

Zenkovich, V.P., 1967. *Processes of Coastal Development.* Oliver & Boyd, Edinburgh, 738 pp.

Zingg, Th., 1935. Beitrag zur Schotteranalyse. *Min. Petrog. Mitt. Schweiz.*, v.15, pp.39-140.

APPENDIX I

WAVE-REFRACTION DIAGRAMS

"Fundamentally, all methods of refraction analysis are based on Snell's law" (U.S. Army, Corps of Engineers, 1977, p. 2-65), that is: when a wave crosses a boundary, the wave normal changes direction so that the sine of the incident angle between wave normal and boundary normal divided by the wave velocity in the first medium equals the sine of the angle of refraction divided by the velocity in the second medium (American Geological Institute, 1962, pp. 283-284). Thus, accurate depth data are crucial to the construction of meaningful wave-refraction diagrams.

Since accurate shallow-water bathymetry was not available for most study areas, sophisticated analysis of wave refraction was not warranted. Wave-refraction diagrams were constructed by the wave-front method (see Johnson *et al.*, 1948; Wiegel, 1964, pp. 150-179) because the wave crests were actually drawn, and could be compared with field observations and air photographs. This comparison with the field situation was not possible with the other construction methods for wave-refraction diagrams. Thus, because whatever construction method was chosen, poor depth data would be used, the control afforded by the wave-front method made it the most suitable means for constructing wave-refraction diagrams in this study.

All deep-water bottom configurations were obtained from Royal Australian Navy Hydrographic charts numbers 808 and 809. The data sources for shallow water will be discussed for each beach. For all five study areas, wave crests were first drawn in deep water with the waves approaching from the north-east, east, and south-east; and, when data permitted, crests were then extended into shallow water. The refraction diagrams were constructed to obtain an indication of the *relative* energy expenditure along the boulder beaches for different directions of deep-water wave approach. The lack of shallow-water data prevents precise calculation of refraction coefficients, but the relative energy expenditure from headland to embayment can be visually assessed in Figures A1 to A12. Wave crests are presented as dashed lines, orthogonals as solid lines.

North Yacaaba Boulder Beach

Only for North Yacaaba beach were there available deep- and shallow-water Naval Hydrographic charts (#809 and #1070, respectively) from which the bottom configuration was obtained. Figures A1 to A3 present the portion of the refraction diagrams in shallow water.

It can be readily observed that, regardless of the direction of deep-water wave approach, refraction causes the waves to strike the beach in a similar pattern, and the energy expenditure is greater near the headland than near the embayment. The wave-crest configuration illustrated in Figures A2 and A3 agrees well with field observations (see Plate A1). The north-easterly wave approach depicted in Figure A1 was not observed. Figure A3 shows similar refractive qualities to those found on an aerial photograph where waves were approaching from a southerly direction (N.S.W. Coastline misc. 730, 2035/5013). Unfortunately, a cross pattern of secondary waves appears more dominant in Plate 1 (p.18), and comparisons with the wave-refraction pattern presented in this appendix cannot be made.

Copacabana Boulder Beach

No shallow-water hydrographic charts were available for the Copacabana area. The most detailed information was found to be contained in an Honours thesis by A. Short (1967). The wave-refraction diagrams prepared for that thesis are presented in Figures A4, A5, and A6. Since only the shallow-water portions of the diagrams were presented by Short, refraction coefficients could not be calculated, nor could orthogonals comparable to those constructed for North Yacaaba and Bombo boulder beaches be presented. However, these figures do illustrate the relative energy expenditure from headland to embayment.

Comparisons of these wave-refraction diagrams with aerial photographs provided little information because wave crests on the photographs were difficult to discern (*e.g.* see Plate 2, p. 19). Field observations of waves approaching from the south-east were reasonably consistent with Figure A6, however the near-perfect alignment of wave crests and embayment was not as clear in the field as it is in Figure A6. In any case, at all times, waves were observed to first strike the headland portion of the beach, and sweep along the beach toward the embayment (Plate A2).

Bombo Boulder Beach

North Yacaaba and Bombo boulder beaches were the only study areas for which deep- and shallow-water bottom-configuration data were available. In the case of Bombo, shallow-water data were available because a study had been undertaken to determine the feasibility of constructing a breakwater and ship-loading facility on the north side of the headland. The University of New South Wales Water Research Laboratory was engaged by Maunsell and Partners to study the wave climate in the locality of the proposed breakwater (Stone and Gordon, 1970).

Manusell and Partners made available detailed sounding information to the Water Research Laboratory and the Laboratory staff performed additional sounding of the area adjacent to Bombo headland. The nearshore bottom contours used in the feasibility study are published by Stone and Gordon (1970) and provided the shallow-water data used in this work to construct wave-refraction diagrams of the Bombo beach area. Royal Australian Navy Hydrographic Chart #808 provided the offshore data.

Figures A7, A8, and A9 show the near-shore portions of these wave-refraction diagrams. It can be seen that, regardless of the direction of deep-water wave approach, energy expenditure decreases from the headland zone to the embayment zone of Bombo boulder beach. In the field, it was clear that the greatest wave energy was expended on the portion of the boulder beach nearest the headland, with energy expenditure decreasing towards the embayment (Plate A3). The wave crests presented in Figures A8 and A9 agreed with field observations and aerial photographs (see Plate 3, p.20). The north-easterly approach illustrated in Figure A7 was not observed in the field or on aerial photographs.

<u>Kiama and Crookhaven Boulder Beaches</u>

No nearshore bottom-configuration data were available for the areas of Kiama and Crookhaven boulder beaches. The information used to construct

Figures A10, A11, and A12 was obtained from Royal Australian Navy Hydrographic Chart number 808, which provides only offshore bathymetry. Since the scale of this chart is 1:150,000, the two boulder beaches could be merely pinpointed. The long-beach zonal divisions which were possible at larger scales (*e.g.*, Bombo, Figures A7, A8, and A9 at 1:1,600) could not be shown. Because of the small scale of available charts and lack of nearshore bathymetry, orthogonals showing energy expenditure along Kiama and Crookhaven boulder beaches could not be drawn. However, the headlands adjacent to both boulder beaches are clearly presented and it can be observed in Figures A10, A11, and A12 that, regardless of the direction of wave approach, waves first strike the headlands.

Repeated field observations of both beaches under many wave conditions found waves first striking the headland and then washing along the boulder beach toward the embayment (Plates A4 and A5). Aerial photographs also showed this situation: on Plate 4, p. 21, wave crests can be seen to first strike the headland adjacent to Kiama boulder beach. Wave crests are not so clearly defined in Plate 5, p. 22, the aerial photograph of the Crookhaven boulder beach area, but it can be observed that on this beach too, the waves are first striking the headland and then sweeping along the boulder beach.

CONCLUSION

Because data were obtained from different sources, strictly comparable wave refraction diagrams could not be constructed for the five study areas. Nearshore data were available for North Yacaaba because it is adjacent to

Port Stephens and the Navy has made detailed soundings of the area. A feasibility study for a ship-loading facility yielded nearshore bottom information for the Bombo area. These two areas were "special cases" in terms of data availability, and the only ones for which refraction coefficients could be calculated (see Tables 2 and 3). Large-scale nearshore refraction diagrams for Copacabana boulder beach were available in Short (1967), however, no deep-water continuity was possible.

Although the method of construction of the wave-refraction diagrams is crude and the data generally meagre, these diagrams illustrate that regardless of direction of wave approach, there is similar relative energy expenditure along each beach. That waves first strike the headland portion and sweep toward the embayment is a characteristic common to all five studied boulder beaches.

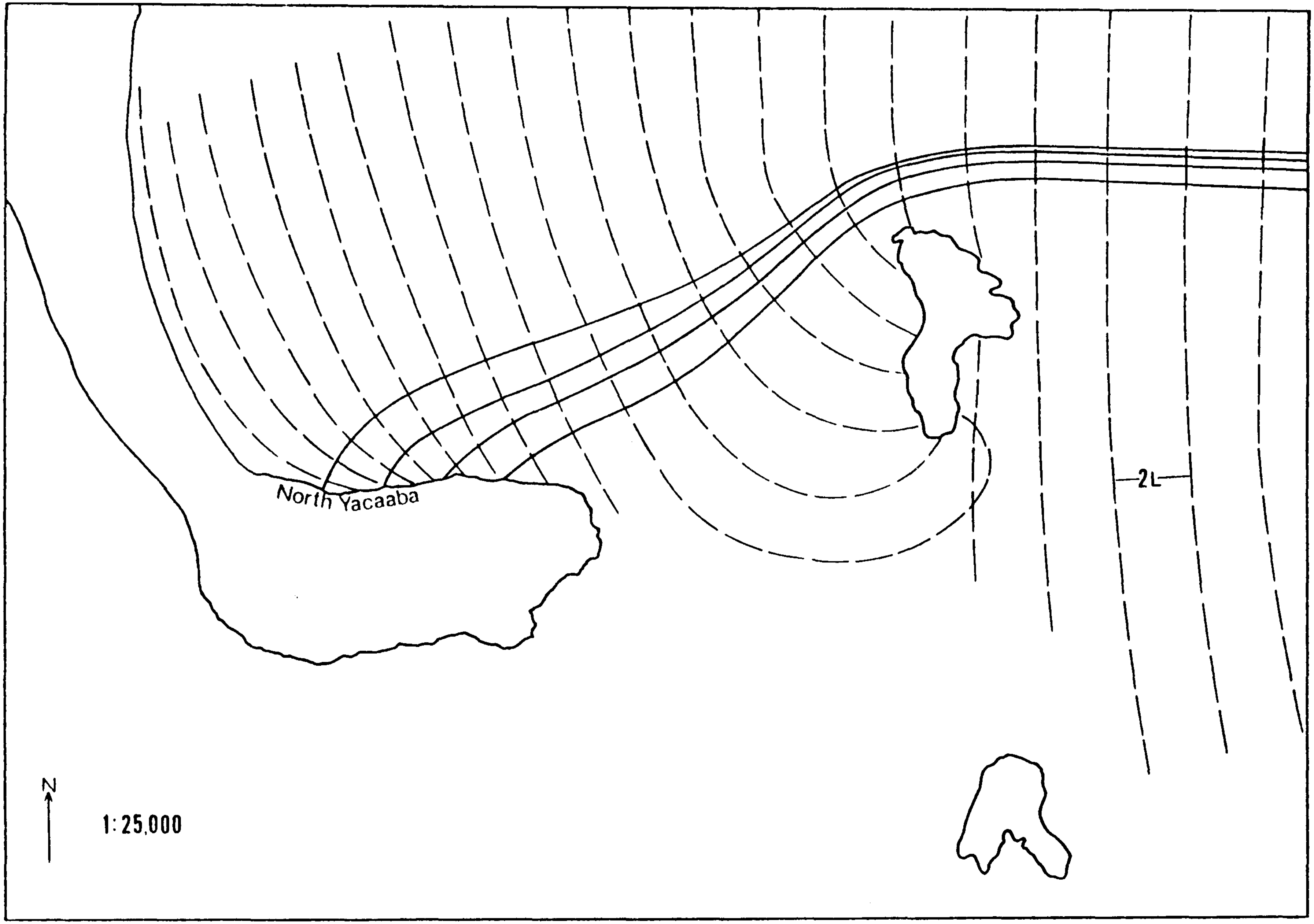


Figure A1. North-east wave approach for North Yacaaba boulder beach. Wave period = 12 sec.
(Deep water: Royal Australian Navy Hydrographic Chart #809. Shallow water: Chart #1070.)

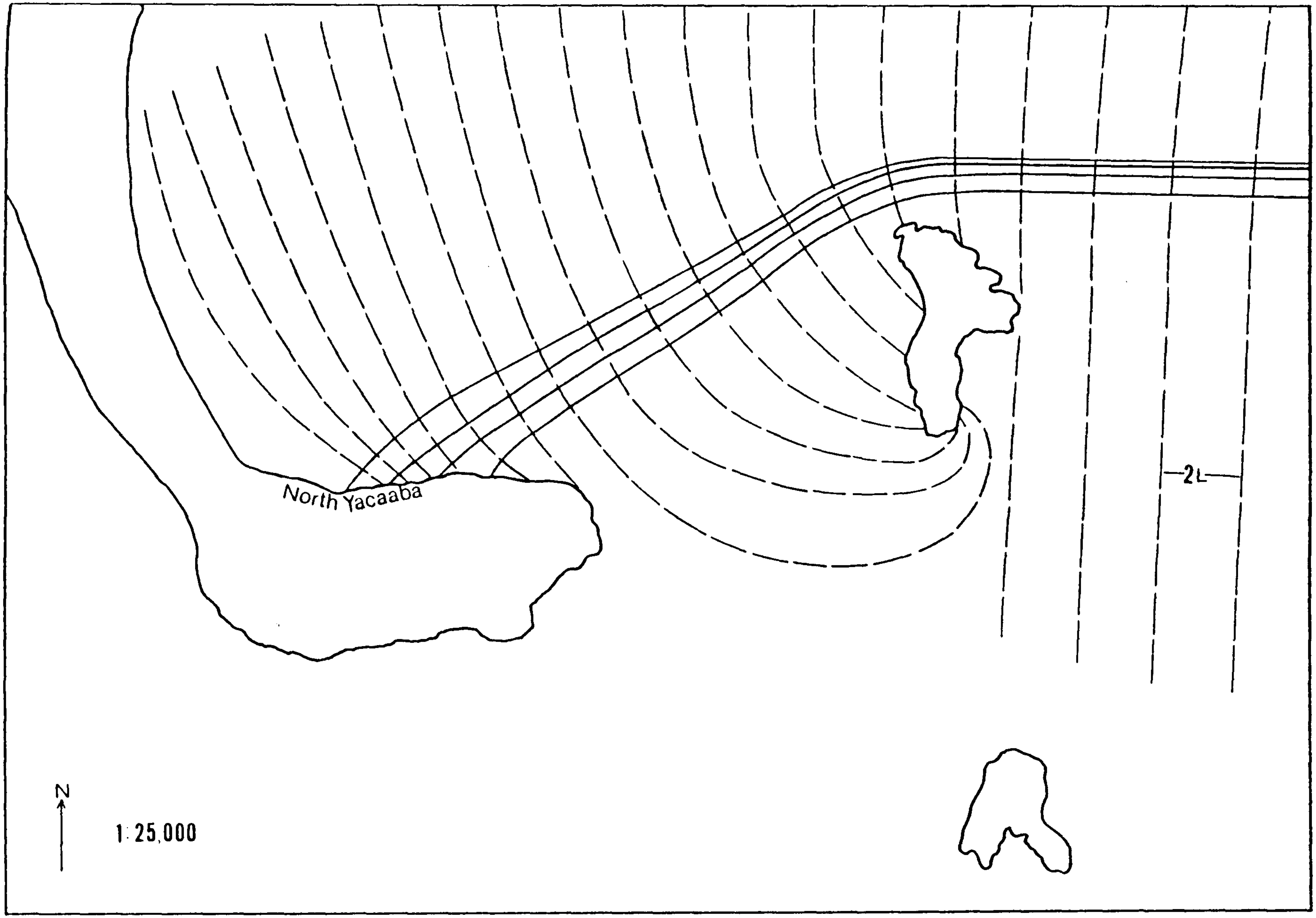


Figure A2. East wave approach for North Yacaaba boulder beach. Wave period = 12 sec.
(Deep water: Royal Australian Navy Hydrographic Chart #809. Shallow water: Chart #1070.)

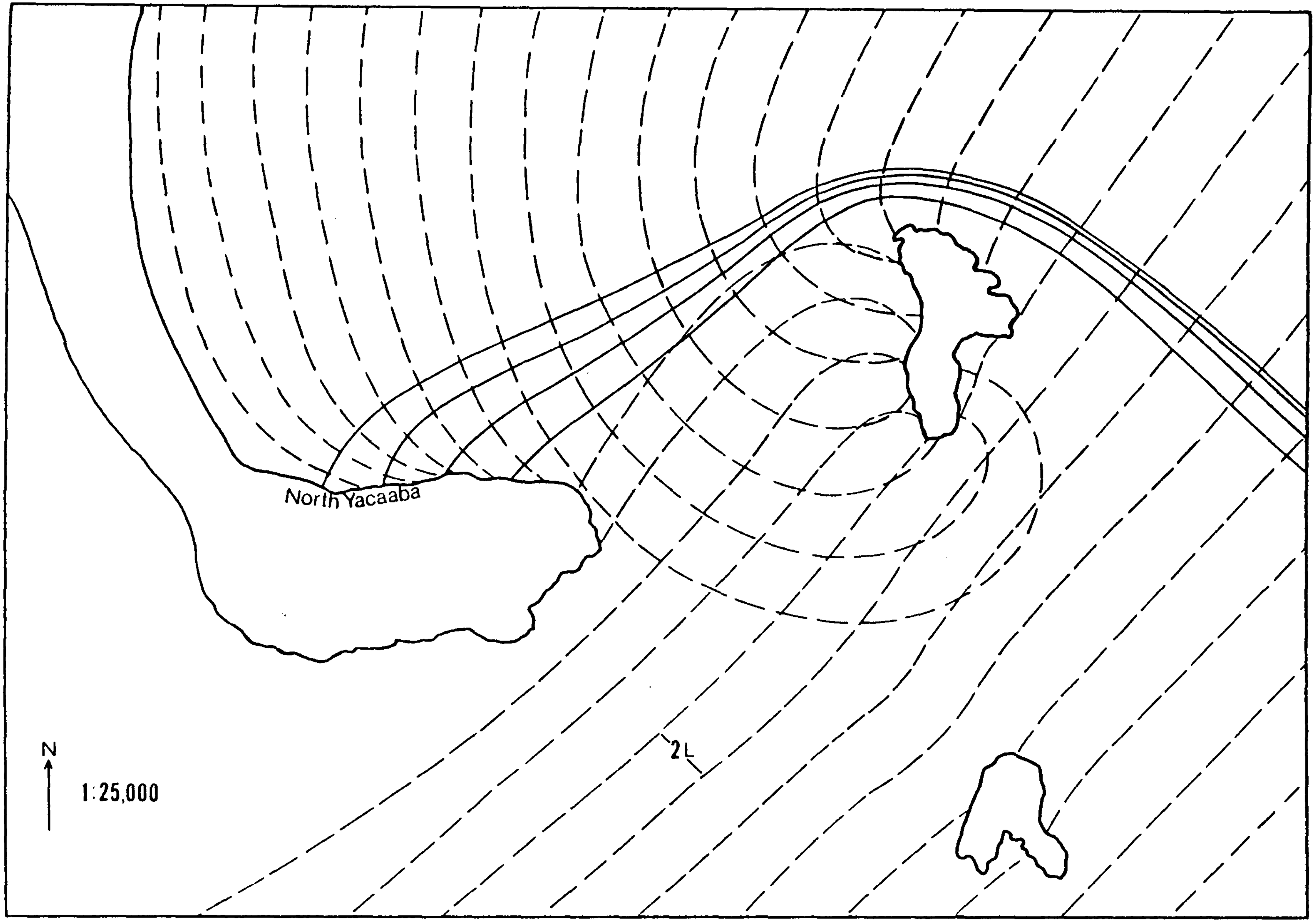


Figure A3. South-east wave approach for North Yaccaba boulder beach. Wave period = 12 sec.
(Deep water: Royal Australian Navy Hydrographic Chart #809. Shallow water: Chart #1070.)

COPACABANA BOULDER BEACH WAVE REFRACTION DIAGRAMS

The refraction coefficients for the large-scale refraction diagrams of Copacabana beach (after Short, 1967) cannot be calculated because these diagrams do not extend into deep water. They do, however, illustrate that the waves first break on the headland with the direction of drift from the headland to the embayment, regardless of the deep-water wave approach.

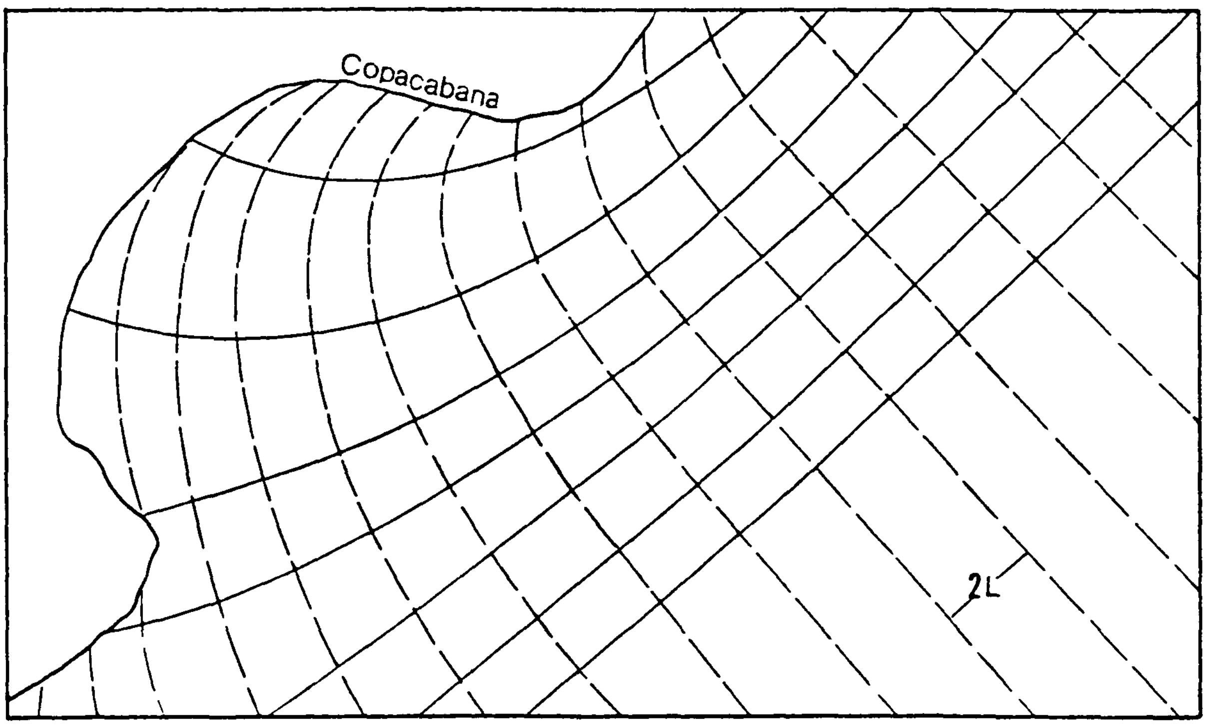


Figure A4. North-east wave approach for Copacabana boulder beach. Wave period = 10 sec. (after Short, 1967, p.19)

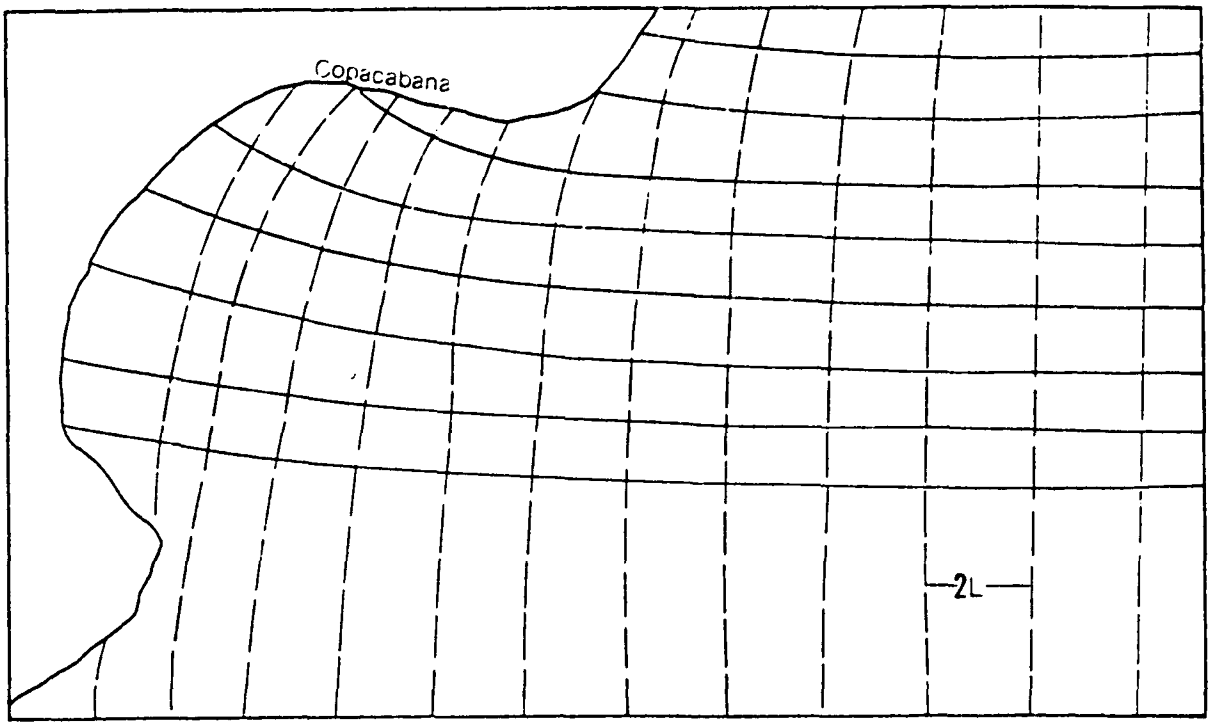


Figure A5. East wave approach for Copacabana boulder beach.
Wave period = 10 sec. (after Short, 1967, p. 19)

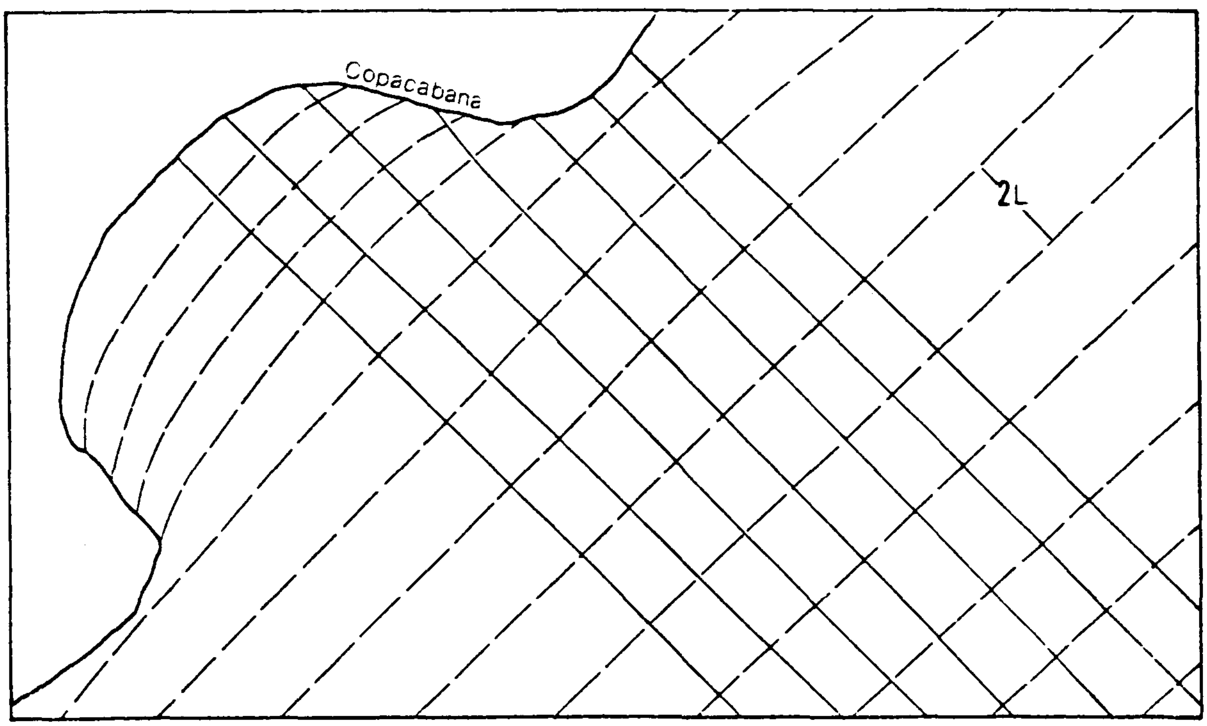


Figure A6. South-east wave approach for Copacabana boulder beach.
Wave period = 10 sec. (after Short, 1967, p. 20)

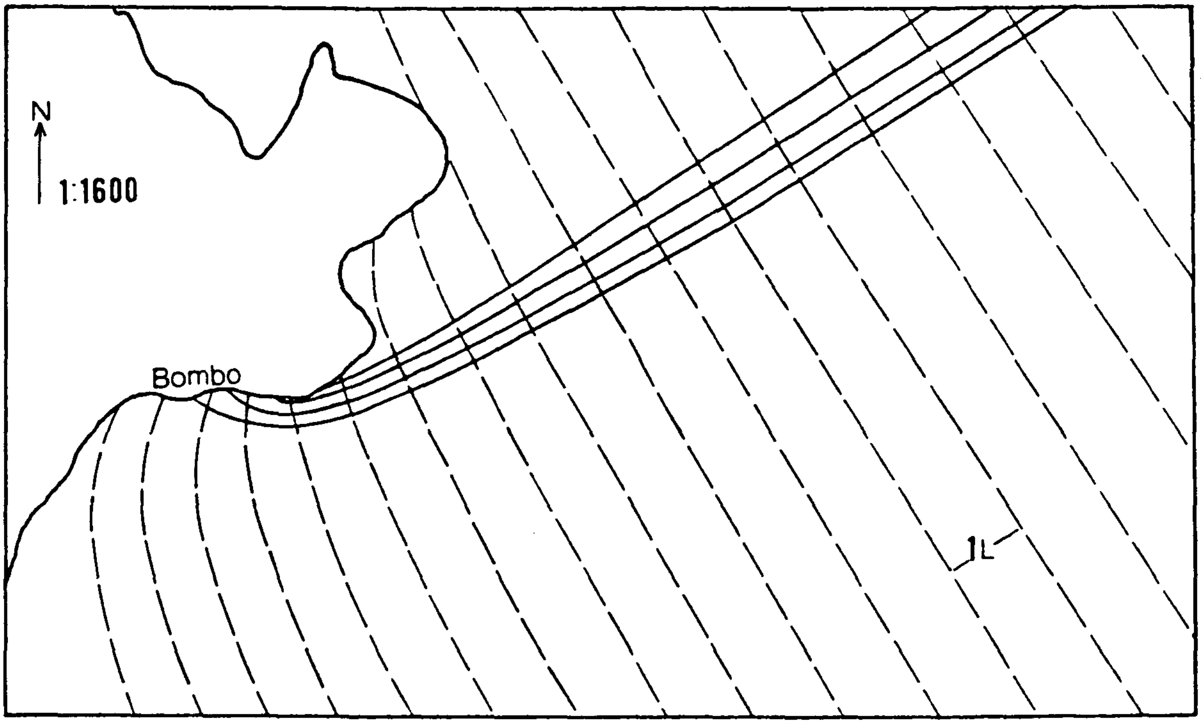


Figure A7. North-east wave approach for Bombo boulder beach.
Wave period = 12 sec. (Stone and Gordon, 1970)

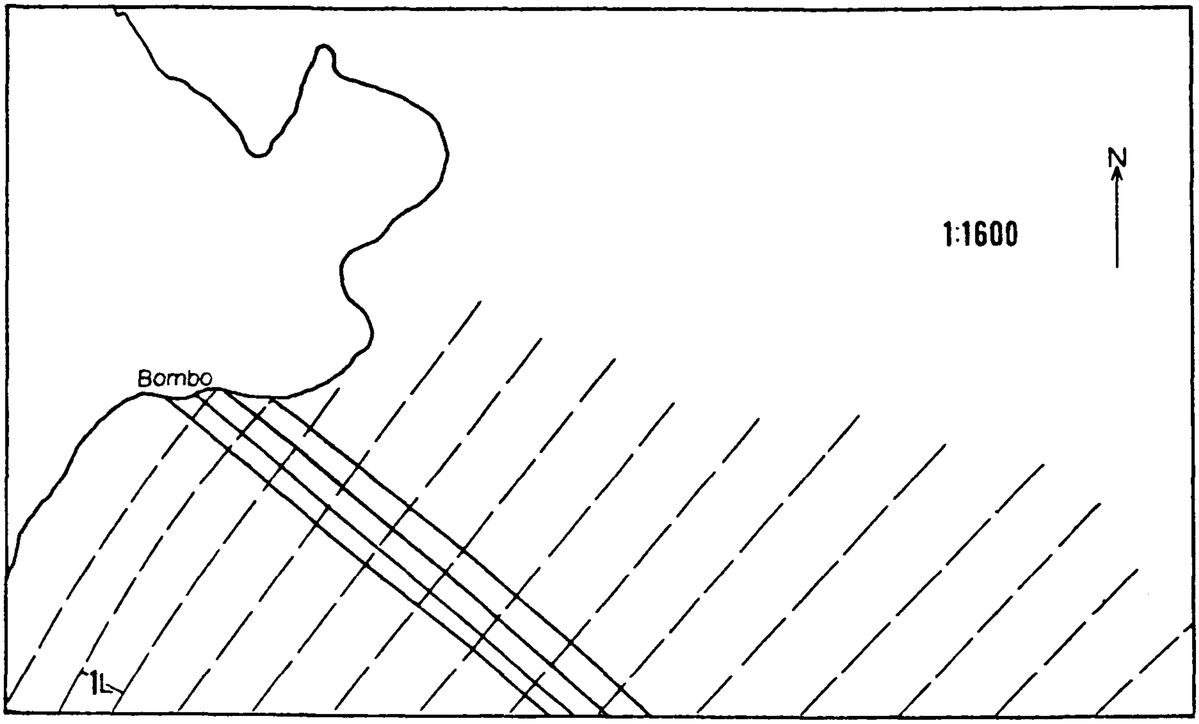


Figure A8. South-east wave approach for Bombo boulder beach.
Wave period = 12 sec. (Stone and Gordon, 1970)

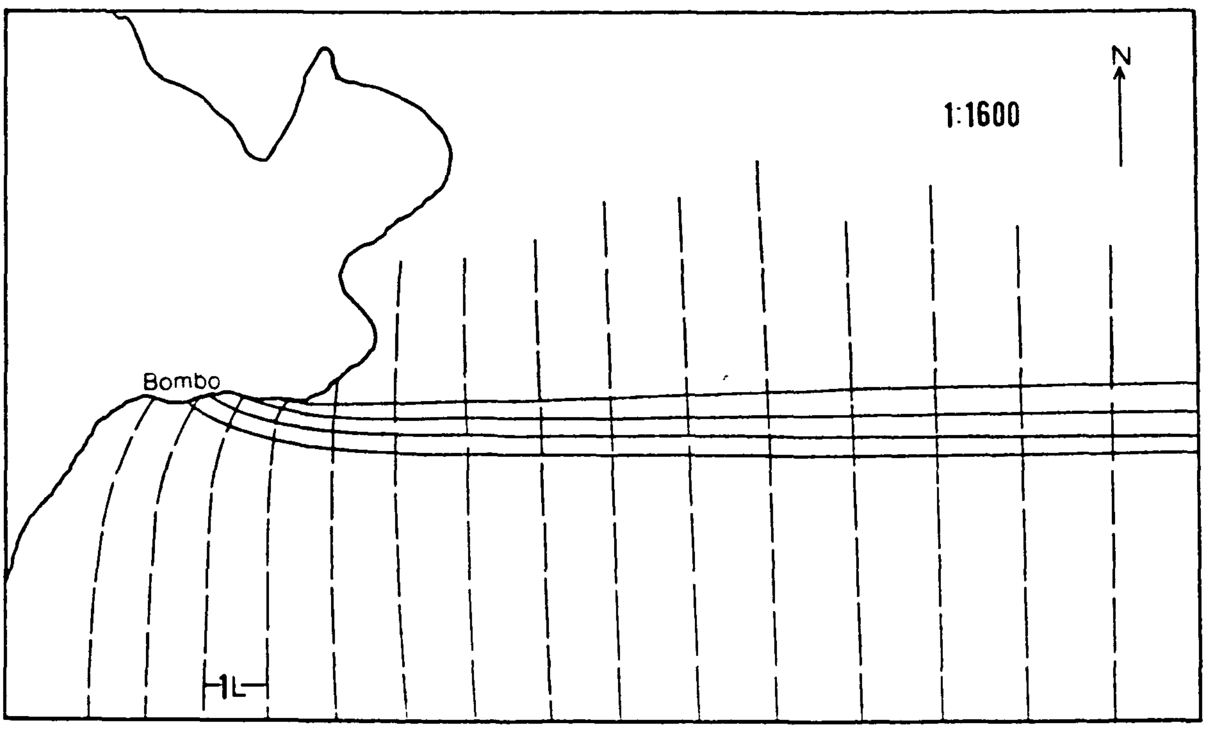


Figure A9. East wave approach for Bombo boulder beach.
Wave period = 12 sec. (Stone and Gordon, 1970)

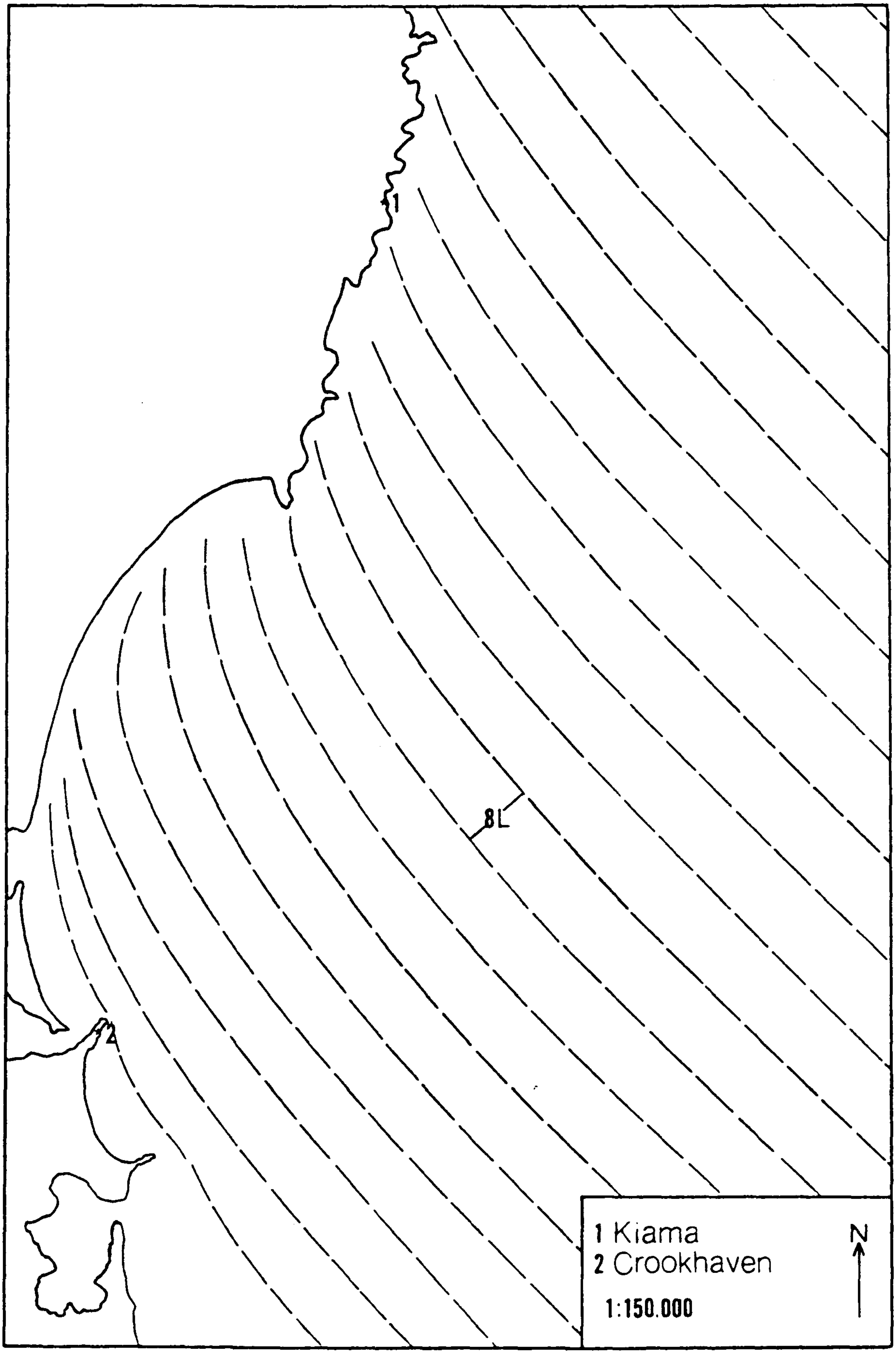


Figure A10. North-east wave approach for Kiama and Crookhaven beaches. Wave period = 12 sec. (Royal Australian Navy Hydrographic Chart #808)

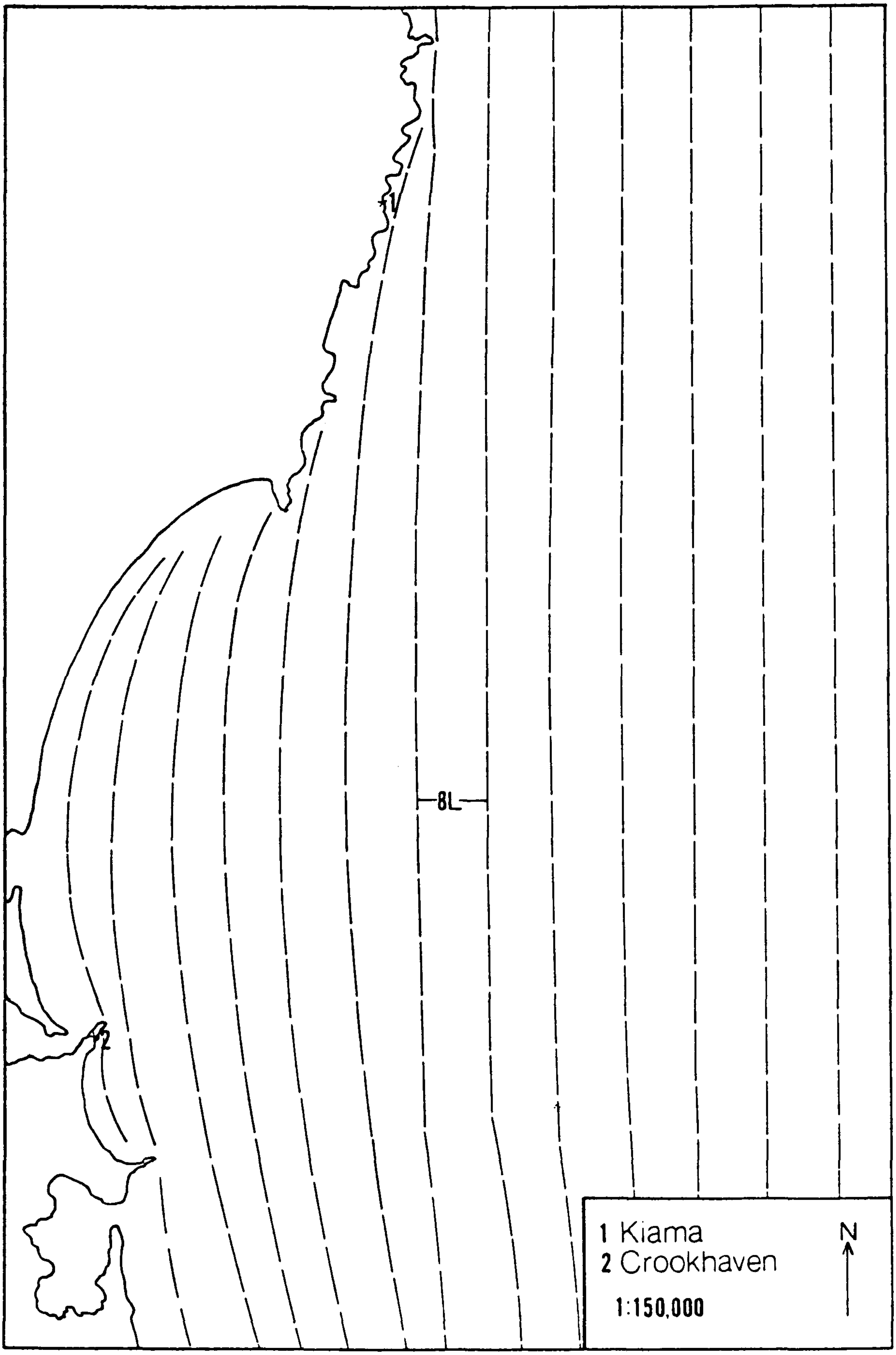


Figure A11. East wave approach for Kiama and Crookhaven boulder beaches. Wave period = 12 sec. (Royal Australian Navy Hydrographic Chart #808)

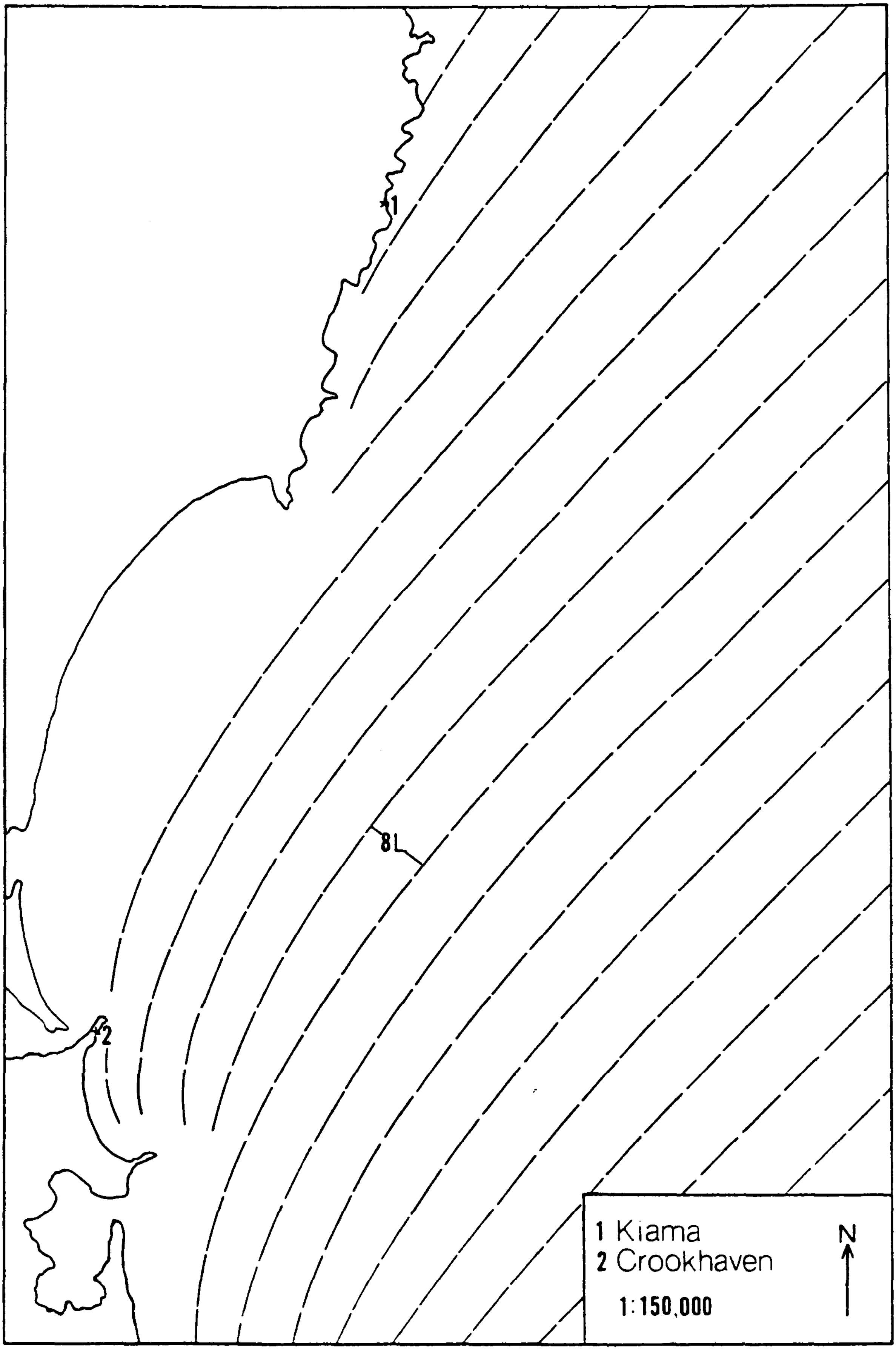


Figure A12. South-east wave approach for Kiama and Crookhaven beaches.
Wave period = 12 sec. (Royal Australian Navy Hydrographic Chart #808)

Plate A1. Nearshore wave approach at North Yacaaba boulder beach.

Plate A2. Nearshore wave approach at Copacabana boulder beach.

Plate A3. Nearshore wave approach at Bombo boulder beach.

Plate A4. Nearshore wave approach at Kiama boulder beach.

Plate A5. Nearshore wave approach at Crookhaven boulder beach.

APPENDIX II

NON-PARAMETRIC STATISTICAL TESTS: METHOD AND USE

SPEARMAN RANK CORRELATION

Since the Spearman rank correlation is a measure of direction as well as significance of a relationship, this test was particularly useful in the investigation of relationships between basic sedimentary measures (size, roundness, sphericity) and between these measures and beach position. For example, not only did this test demonstrate that particle size and position up the beach were significantly related, but the negative direction of this relationship indicated that on the studied boulder beaches, particle size decreases up the beach. This characteristic is opposite to the up-beach size trend found on cobble beaches. The results of these tests are discussed in the appropriate chapters throughout the study, but are compiled in a condensed form in Appendix III, Table A6.

In all cases, correction was made for ties and the two-tailed test was used. For this test, the null hypothesis is that there is no association between two variables. Although non-parametric tests tend to be less powerful than their parametric counterparts, the results of these tests should be viewed with reasonable confidence since the Spearman rank correlation is close to 91 per cent as efficient as the product-moment correlation (Hotelling and Pabst, 1936). Siegel (1956, pp. 202-213) details the method and formula for computing the Spearman rank correlation.

The computer package, SPSS (Nie *et. al.*, 1965, pp. 288-292), was used in this study to calculate the Spearman rank correlation.

KRUSKAL-WALLIS ONE-WAY ANALYSIS OF VARIANCE

The Kruskal-Wallis one-way analysis of variance (Kruskal and Wallis, 1952) was chosen for use in this study because it determines whether a number of samples are drawn from the same population. Because the five studied beaches were divided into three longshore and three up-beach zones, this test was used in the attempt to discern any particle-shape zoning by beach position. Because this test could show that on all five beaches, regardless of the areal zone, shape distributions within each beach could have been drawn from the same population, it was concluded that areal zoning by shape was not present. The Kruskal-Wallis one-way analysis of variance was also useful in investigating whether there was a significant variation among the distributions of particle roundness when the boulders were classified according to the five Zingg shapes.

The test was corrected for ties and the null hypothesis is that K samples are drawn from the same population. The Kruskal-Wallis one-way analysis of variance is 95.5 per cent as effective as the F test (Andrews, 1954) and is "more powerful than k-sample Median test since it uses the rank value of each case, not just its location relative to the median" (Tuccy, 1977, p. 324/40). The method outlined by Siegel (1956, pp. 184-194) for performing this test is that used by the SPSS computer package update (Tuccy, 1977). For more detailed information about the Kruskal-

Wallis one-way analysis of variance, see Kruskal (1952), Kruskal and Wallis (1952), and Doornkamp and King (1971, pp.343-344).

KOLMOGOROV-SMIRNOV TWO-SAMPLE TEST

The Kolmogorov-Smirnov two-sample test is a non-parametric goodness-of-fit test. In this study, the two-tailed test has been employed because it is "sensitive to any kind of difference in the distributions from which the two samples were drawn —differences in location, in dispersion, in skewness, etc" (Siegel, 1956, p. 127) (see also Doornkamp and King, 1971, p. 333). This test was useful in the investigation of beach change over time. The distributions of size, shape, and sphericity on Kiama boulder beach as measured in June 1975 were compared, using the Kolmogorov-Smirnov two-sample test, to those distributions as measured (in the same grid) in July 1977. Although much boulder movement had occurred during this period, the Kolmogorov-Smirnov two-sample test was able to determine that there had been no significant change in the distributions of the measured sedimentological characteristics. This test was also used to compare the sedimentological characteristics of the entire beach with the sedimentological characteristics of the boulders which moved during the study period.

The null hypothesis for this test is that there is no difference between the initial and subsequent distributions. Because the Kolmogorov-Smirnov two-sample test is sensitive to any type of difference in the two distributions being compared, it is more powerful than the X^2 or the Median test, and it has close to 96 per cent power-efficiency when compared with the t test (Siegel, 1956, p. 136). Again, the SPSS computer package update (Tuccy, 1977, pp. 324/32-33) was used to calculate the test on a computer, employing the method described by Siegel (1956, pp. 127-136).

APPENDIX III

DATA FOR THE STUDIED BOULDER BEACHES SUMMARIZED IN TABLES

TABLE A1

NORTH YACAABA BEACH: GENERAL DATA

	Beach Zone* 1	2	3	4	5	6	Entire Beach
Size (ϕ)							
Mean	-8.608	-8.668	-8.709	-9.257	-9.008	-7.685	-8.660
Median	-8.912	-8.994	-9.073	-9.363	-9.148	-7.837	-8.921
Standard Deviation	1.174	1.252	1.359	.828	.900	1.360	1.253
Skewness	.859	.805	.794	.993	.848	- .100	.808
Roundness (ρ)							
Mean	3.929	3.869	3.556	3.880	3.695	3.903	3.822
Standard Deviation	.939	1.036	1.146	.877	1.020	1.213	1.045
Skewness	- .309	.047	.046	.074	.049	- .244	- .095
Shape (%)							
Sphere	22.5	19.0	12.1	17.4	17.8	19.1	18.1
Disc	27.5	26.7	31.9	20.4	29.3	33.0	28.5
Rod	29.4	36.2	36.3	41.8	30.2	27.8	33.9
Blade	20.6	18.1	19.8	20.4	22.6	20.1	19.5
Maximum Projection Sphericity (ψ_p)							
Mean	.670	.677	.654	.678	.655	.671	.668
Standard Deviation	.138	.125	.107	.119	.124	.132	.125

Beach Zone:
1 = Headland
2 = Mid
3 = Embayment
4 = Tidal
5 = Supra-tidal
6 = Landward

TABLE A2

COPACABANA BEACH: GENERAL DATA

	Beach Zone* 1	2	3	4	5	6	Entire Beach
Size (ϕ)							
Mean	-9.236	-8.536	-8.350	-9.033	-8.787	-8.277	-8.674
Median	-9.513	-8.994	-8.814	-9.345	-9.074	-8.811	-9.022
Standard Deviation	1.371	1.664	1.383	- .488	1.386	1.643	1.605
Skewness	1.060	1.136	.948	.988	1.172	.973	1.325
Roundness (ρ)							
Median	3.913	4.043	4.056	3.999	3.512	3.132	3.002
Standard Deviation	1.109	1.197	1.270	1.129	1.132	1.146	1.153
Skewness	- .330	- .164	- .224	- .279	- .089	.042	- .108
Shape (%)							
Sphere	2.9	3.6	4.0	3.4	3.2	3.6	3.5
Disc	54.1	55.5	55.5	55.8	50.9	58.7	55.7
Rod	13.0	10.9	12.9	9.5	12.2	14.8	12.2
Blade	30.0	30.0	27.9	31.3	33.6	22.9	28.5
Maximum Projection Sphericity (ψ_p)							
Mean	.503	.497	.517	.480	.523	.510	.505
Standard Deviation	.125	.143	.135	.130	.139	.134	.135

*Beach Zone: 1 = Headland
2 = Mid
3 = Embayment
4 = Tidal
5 = Supra-tidal
6 = Landward

TABLE A3

BOMBO BEACH: GENERAL DATA

	Beach Zone* 1	2	3	4	5	6	Entire Beach
Size (ϕ)							
Mean	-8.108	-7.852	-7.534	-8.707	-7.884	-7.111	-7.830
Median	-8.180	-7.901	-7.717	-8.933	-7.969	-7.236	-7.910
Standard Deviation	1.392	1.142	1.206	1.132	1.119	1.119	1.266
Skewness	.336	- .029	.594	.354	.374	.467	.248
Roundness (ρ)							
Median	3.799	4.011	4.261	4.265	3.451	3.000	3.540
Standard Deviation	1.353	1.375	1.198	.950	1.213	1.352	1.303
Skewness	- .167	- .129	- .077	- .192	.045	.218	- .117
Shape (%)							
Sphere	24.2	36.6	24.8	24.0	32.8	27.5	28.9
Disc	30.5	37.6	40.8	37.7	34.5	39.1	36.6
Rod	28.8	16.4	22.4	28.2	20.2	20.2	22.2
Blade	16.5	9.4	12.0	10.1	12.5	14.2	12.3
Maximum Projection Sphericity (ψ_p)							
Mean	.672	.701	.687	.673	.685	.692	.687
Standard Deviation	.132	.124	.122	.131	.130	.133	.126

*Beach Zone:
1 = Headland
2 = Mid
3 = Embayment
4 = Tidal
5 = Supra-tidal
6 = Landward

TABLE A4

KIAMA BEACH: GENERAL DATA

	Beach Zone* 1	2	3	4	5	6	Entire Beach
Size (ϕ)							
Mean	-8.448	-8.906	-8.300	-9.338	-8.312	-8.147	-8.557
Median	-8.649	-8.904	-8.495	-9.565	-8.526	-8.234	-8.711
Standard Deviation	1.212	.894	1.256	1.100	1.062	.952	1.153
Skewness	.636	.292	.489	1.157	1.204	.703	.658
Roundness (ρ)							
Mean	3.814	3.924	3.468	3.667	3.134	2.983	3.246
Standard Deviation	1.010	1.078	1.164	.927	1.031	1.114	1.065
Skewness	- .223	- .457	- .190	.015	- .236	- .169	- .227
Shape (%)							
Sphere	14.1	21.4	13.1	14.1	19.0	13.4	16.4
Disc	28.2	30.6	41.2	42.6	31.2	39.3	36.5
Rod	27.0	24.8	27.2	23.8	26.0	31.5	26.6
Blade	20.6	23.1	18.4	19.5	23.7	15.6	20.5
Maximum Projection Sphericity (ψ_p)							
Mean	.623	.648	.637	.632	.635	.640	.636
Standard Deviation	.132	.130	.136	.122	.136	.138	.133

*Beach Zone: 1 = Headland
2 = Mid
3 = Embayment
4 = Tidal
5 = Surpa-tidal
6 = Landward

TABLE A5

CROOKHAVEN BEACH: GENERAL DATA

	1	2	3	4	5	6	Entire Beach
Size (ϕ)							
Mean	-9.484	-8.818	-8.640	-9.242	-8.999	-8.684	-8.970
Median	-9.589	-9.155	-9.176	-9.588	-9.318	-9.107	-9.300
Standard Deviation	.814	1.203	1.310	1.108	1.164	1.244	1.191
Skewness	1.115	1.464	1.248	2.101	1.573	.962	1.453
Roundness (ρ)							
Median	2.127	2.794	3.449	2.677	2.170	1.838	2.236
Standard Deviation	.741	1.339	1.357	1.208	1.317	1.248	1.304
Skewness	.576	.804	.519	1.072	1.022	1.105	.944
Shape (%)							
Sphere	43.5	41.2	42.6	43.5	43.4	39.3	42.2
Disc	32.1	31.2	28.3	30.2	28.8	33.1	30.2
Rod	16.4	19.0	20.5	17.2	17.4	22.1	19.1
Blade	8.0	9.5	8.3	9.1	10.4	5.5	8.5
Maximum Projection Sphericity (ψp)							
Mean	.706	.700	.734	.712	.711	.721	.715
Standard Deviation	.134	.145	.119	.137	.138	.123	.133

*Beach Zone: 1 = Headland
2 = Mid
3 = Embayment
4 = Tidal
5 = Supra-tidal
6 = Landward

TABLE A6

SPEARMAN RANK CORRELATION COEFFICIENTS

	Beach				
	North Yacaaba N=298	Copacabana N=345	Bombo N=374	Kiama N=342	Crookhaven N=350
Size vs Roundness	-.1449*	.1789	.2970	.1928	-.2448
Size vs Sphericity	-.0441	-.3166	-.0821	-.0274	.0266
Size vs Poslong+	.0382	-.2976	-.2157	-.0041 (-.2802)[1]	-.2802
Size vs Posup≠	-.5177	-.2528	-.5078	-.5539	-.2127
Roundness vs Sphericity	.0848	-.0070	.0723	.0120	-.0306
Roundness vs Poslong	.1545	.0525	.1559	.1169	.4676
Roundness vs Posup	-.0192	-.2061	-.4377	-.2950	-.2653
Sphericity vs Poslong	-.0899	.0533	-.0609	.0239	.0754
Sphericity vs Posup	.0020	.1257	-.0127	-.0013	.0568

*Once underlined values significant at the 0.05 level of probability.
Twice underlined values significant at the 0.001 level of probability.

+Poslong = Longshore beach position (profile by profile) with numerical increase from headland to embayment.

≠Posup = Up-beach position (grid point by grid point) with numerical increase from sea to land.

[1]Removal of profiles located on shore platform.

TABLE A7

SIZE SORTING (STANDARD DEVIATION) FOR EACH SHAPE
(ZINGG CLASSIFICATION)

Shape	Standard Deviation (cm)				
	North Yacaaba	Copacabana	Bombo	Kiama	Crookhaven
Sphere	33.351	19.378	30.114	32.776	30.045
Disc	49.973	52.699	33.845	42.168	38.515
Rod	31.213	29.658	25.250	28.213	34.306
Blade	33.500	42.786	26.910	40.723	43.811

TABLE A8

ROUNDNESS SORTING (STANDARD DEVIATION) FOR EACH SHAPE
(ZINGG CLASSIFICATION)

Shape	Standard Deviation (ρ)				
	North Yacaaba	Copacabana	Bombo	Kiama	Crookhaven
Sphere	1.077	1.371	1.264	1.175	1.138
Disc	1.120	1.141	1.306	1.078	1.330
Rod	.953	1.265	1.254	.987	1.453
Blade	1.076	1.082	1.389	1.055	1.520

TABLE A9

PERCENTAGE OF BOULDERS IN EACH ZONE

Zone	North Yacaaba (%)	Copacabana (%)	Bombo (%)	Kiama (%)	Crookhaven (%)
Headland	30.5	31.0	32.4	31.3	32.9
Mid	34.2	39.7	34.2	35.4	30.0
Embayment	35.3	29.3	33.4	33.3	37.1
Tidal	33.2	33.3	23.5	28.1	28.0
Supra-Tidal	34.2	33.3	44.4	45.9	40.9
Landward	32.6	33.3	32.1	26.0	31.1

APPENDIX IV

CALCULATION OF BREAKER HEIGHT (H_b) AND DEPTH AT BREAKING (d_b)

When using equations developed by coastal engineers to assess stability of protection structures composed of rubble, it is often necessary to know the breaker height and the depth of water at breaking. Since the only wave-height data available to this study was for deep water (provided by wave-rider buoys), it was necessary to calculate breaker height and breaking depth.

In deep water, the maximum possible height of a wave is limited only by the steepness at which the wave can remain stable. When the limiting steepness is reached, the wave will begin to break. From theoretical work, Michell (1893) expressed limiting steepness as:

$$\frac{H_o}{L_o} = 0.142 \simeq \frac{1}{7} \quad .$$

At this point, wave celerity and water particle velocity at the wave crest are equal; greater steepness would cause the wave celerity to be less than the particle velocities at the wave crest, thus resulting in instability.

When waves move into shoaling water, however, wave steepness is limited by depth and beach slope. Using modified solitary wave theory, Munk (1949) related breaker height, breaking depth, unrefracted deep-water wave height, and deep-water wave length as follows:

$$\frac{H_b}{L_o} = \frac{1}{3.3(H_o/L_o)^{1/3}} \quad \text{(breaker height index)},$$

$$\frac{d_b}{H_b} = 1.28.$$

More recent work (Iverson, 1952, 1953; Galvin, 1969; and Goda, 1970) has shown that H_b/H_o and d_b/H_b are dependent upon incident wave steepness and beach slope. For several beach slopes, Goda (1970) presented empirically derived relationships between H_b/H_o and H_o/L_o. The U.S. Army, Corps of Engineers recommends that this empirical information, as presented in Figures A13 and A14, be used rather than Munk's equations when finding breaker heights and breaking depths "since the figures take into consideration the observed dependence of d_b/H_b and H_b/H_o on slope" (U.S. Army, Corps of Engineers, 1977, p. 2-124). Therefore, in this study, Figure A13 was used to calculate breaker heights and Figure A14 to calculate breaking depth.

NOTE: Imperial units must be used with Figures A13 and A14.

EXAMPLES OF CALCULATIONS

1. Breaker Height (H_b)

   H_o = 6 m = 19.69 ft (obtained from buoy)

   T = 12 sec (obtained from buoy)

   m = 1:52 (obtained from hydrographic chart)

   L_o = 5.12 x T^2 = 737.28

$$\frac{H_o}{L_o} = 0.027$$

Consult Figure A13.

Where $\frac{H_o}{L_o} = 0.027$, $\frac{H_b}{H_o} = 1.126$

Therefore, H_b = 22.17 ft = 6.76 m

2. Depth at Breaking (d_b)

H_b = 6.76 m = 22.17 ft (calculated above)

T = 12 sec

m = 1:52

g = 980.6 cm/sec^2 = 32.17 ft/sec^2

$$\frac{H_b}{gT^2} = 0.0048$$

Consult Figure A14.

Where $\frac{H_b}{gT^2} = 0.0048$, $\frac{d_b}{H_b} = 1.16$

Therefore, d_b = 25.7 ft = 7.8 m

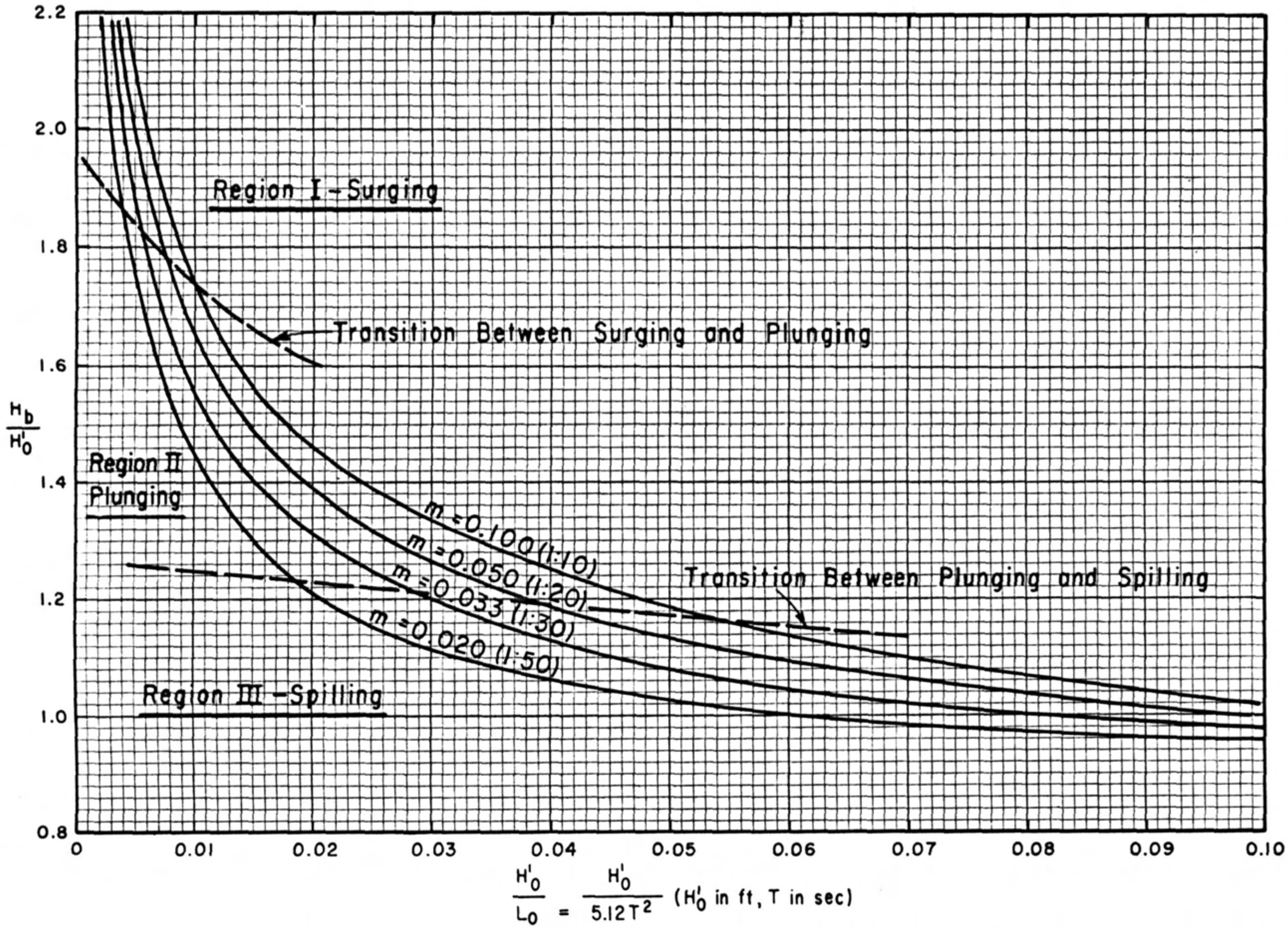


Figure A13. **Breaker Height Index Versus Deep Water Wave Steepness**

(after U.S. Army, Corps of Engineers, 1977, p. 2-122)

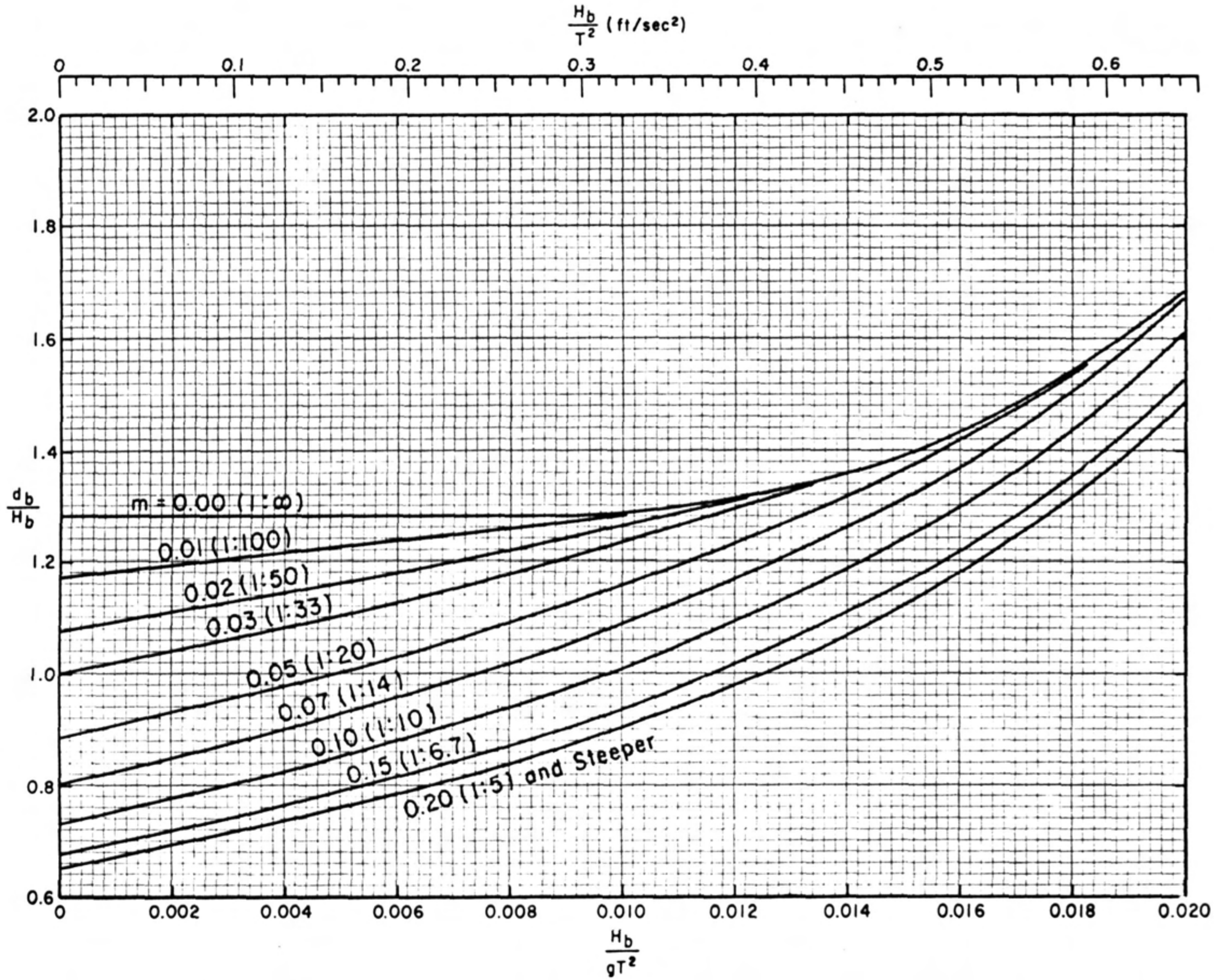


Figure A14. Dimensionless Depth at Breaking Versus Breaker Steepness
(after U.S. Army, Corps of Engineers, 1977, p. 2-123)

APPENDIX V

CALCULATION OF UPRUSH (RUNUP) HEIGHT (R)

The steps in the calculation of uprush height are as follows:

1. H_o and T are known
2. Find $\frac{H_o}{gT^2}$
3. Use Figure A15 to estimate $\frac{R}{H_o}$ from $\frac{H_o}{gT^2}$
4. Correct R for scale dffects using Figure A16. (R x k = corrected R)
5. Multiply corrected R by the roughness and porosity correction factor (r) found in Table A10.

   corrected R x r = R_{riprap}
6. R_{riprap} should approximate uprush height on a boulder beach.

NOTE: Imperial units must be used with figures A15, A16, and Table A10.

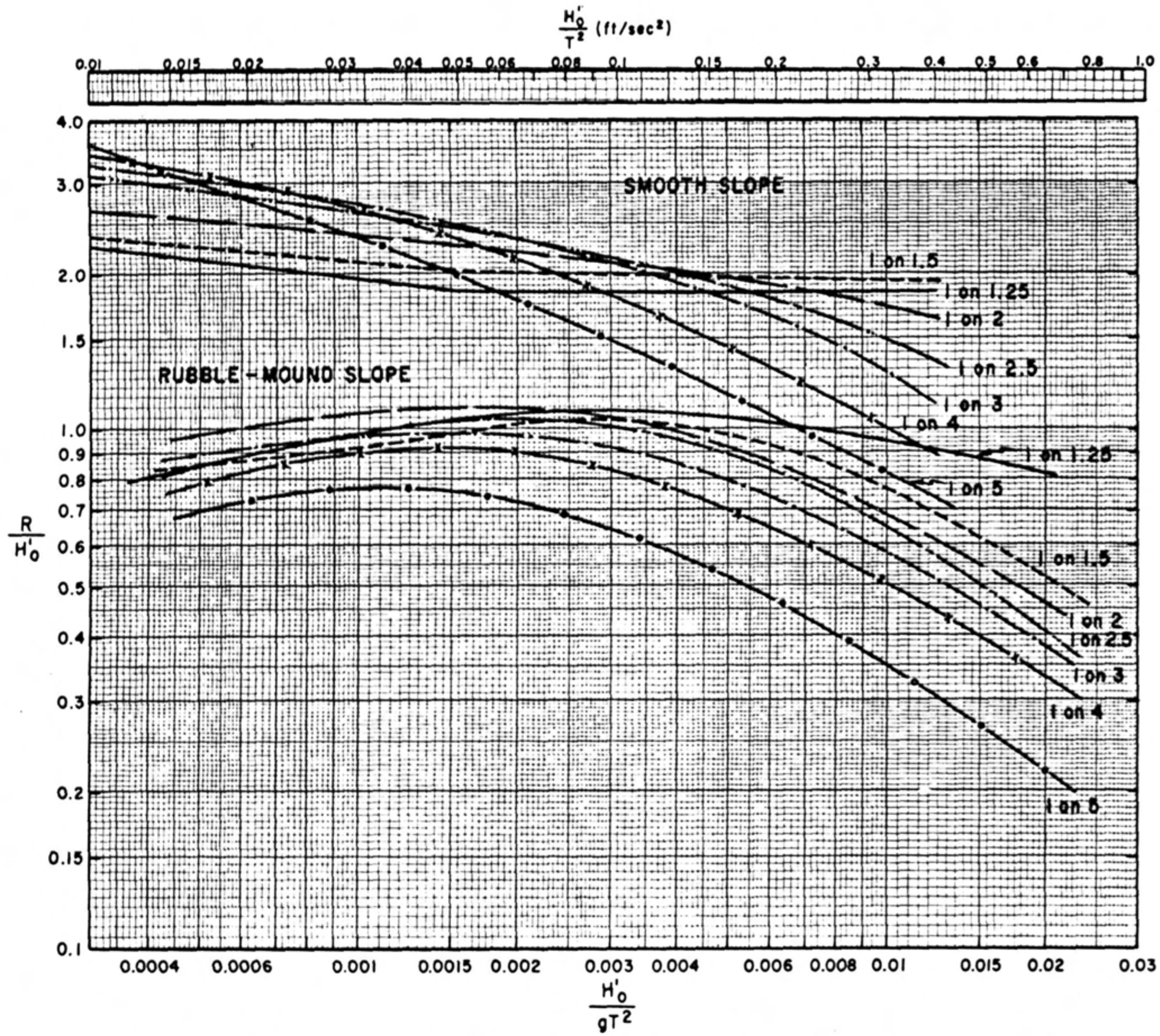


Figure A15. Comparison of Wave Runup on Smooth Slopes with Runup on Permeable Rubble Slopes (data for $d_s/H'_o > 3.0$)
(after U.S. Army, Corps of Engineers, 1977, p. 7-31)

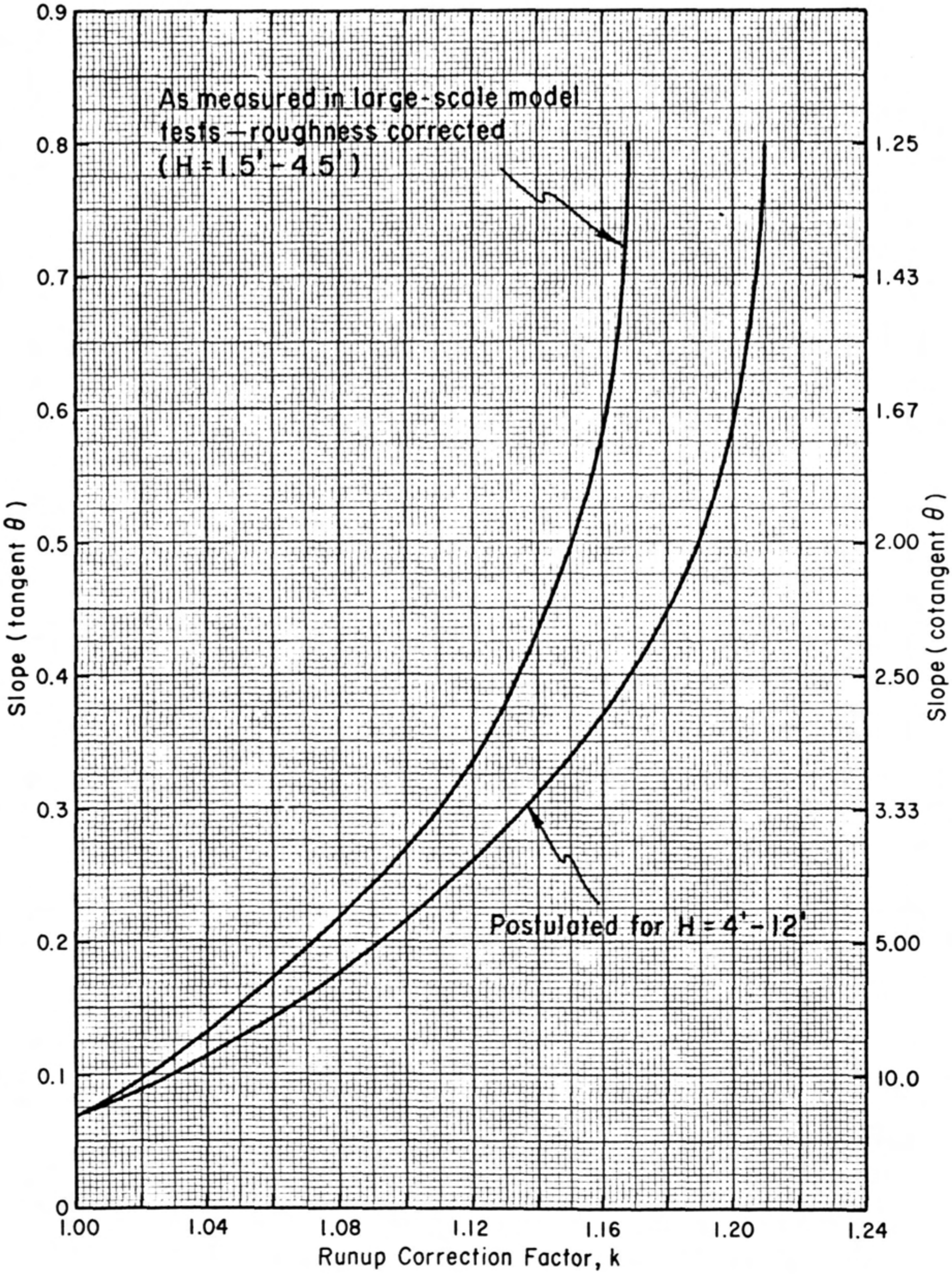


Figure A16. Runup Correction for Scale Effects

(after U.S. Army, Corps of Engineers, 1977, p. 7-23)

Table A10. Values of r for Various Slope Surface Characteristics (after Battjes, 1974).

Slope Surface Characteristics	Placement	r
Smooth, impermeable	------	1.00
Concrete blocks	Fitted	0.90
Basalt blocks	Fitted	0.85 to 0.90
Gobi blocks	Fitted	0.85 to 0.90
Grass	------	0.85 to 0.90
One layer of quarrystone (impermeable foundation)	Random	0.80
Quarrystone	Fitted	0.75 to 0.80
Rounded quarrystone	Random	0.60 to 0.65
Three layers of quarrystone (impermeable foundation)	Random	0.60 to 0.65
Quarrystone	Random	0.50 to 0.55
Concrete armor units (~50 percent void ratio)	Random	0.45 to 0.50

(after U.S. Army, Corps of Engineers, 1977, p. 7-32)

APPENDIX VI

BASIC DATA FOR

EACH STUDIED BOULDER BEACH

SYMBOLS USED IN APPENDIX VI

X = profile number from headland zone to embayment zone

Y = sampling point up profile in landward direction

A = A axis of measured boulder (cm)

PHI B = B axis of measured boulder expressed in *phi* (ϕ) units

C = C axis of measured boulder (cm)

R = boulder roundness according to the *rho* (ρ) scale

SH = shape according to the Zingg classification

1 = sphere

2 = disc

3 = rod

4 = blade

SPHER = maximum projection sphericity (ψ_p)

LONG = zone along the beach

1 = headland zone

2 = mid zone

3 = embayment zone

UP = zone up the beach

4 = tidal zone

5 = supra-tidal zone

6 = landward zone

NORTH YACAABA BOULDER BEACH

X	Y	A	PHI B	C	R	SH	SPHER	LONG	UP
1	2	61.0	-8.3663	31.0	4.0	3	.7820	3	4
1	3	56.0	-8.7142	23.0	2.0	2	.6080	3	4
1	4	147.0	-9.7977	50.0	5.0	4	.5760	3	4
1	6	33.0	-7.3219	10.0	5.0	4	.5750	3	4
1	7	111.0	-9.0768	49.0	3.0	3	.7370	3	5
1	8	165.0	-10.0901	55.0	3.0	4	.5520	3	5
1	9	83.0	-9.4512	52.0	4.0	1	.7750	3	5
1	10	84.0	-9.0768	30.0	3.0	4	.5840	3	6
1	11	78.0	-8.6795	32.0	2.0	3	.6840	3	6
2	2	125.0	-9.4305	65.0	4.0	3	.7880	3	4
2	6	128.0	-9.0498	47.0	3.0	3	.6880	3	4
2	7	132.0	-9.5887	56.0	2.0	3	.6760	3	5
2	8	55.0	-8.2761	24.0	2.0	3	.6970	3	5
2	9	54.0	-8.1799	23.0	4.0	3	.6970	3	6
2	10	101.0	-9.1293	36.0	2.0	4	.6120	3	6
3	4	108.0	-9.5699	30.0	3.0	2	.4790	3	4
3	5	128.0	-9.4305	57.0	3.0	3	.7170	3	4
3	6	116.0	-9.2527	28.0	4.0	4	.4810	3	4
3	7	91.0	-9.1799	31.0	3.0	4	.5670	3	5
3	8	20.0	-6.1293	4.0	3.0	4	.4860	3	5
3	9	200.0	-9.7313	83.0	2.0	3	.7400	3	5
3	10	30.0	-7.3219	14.0	6.0	3	.7420	3	6
3	11	35.0	-8.1799	26.0	5.0	1	.8730	3	6
4	4	93.0	-9.2046	53.0	3.0	3	.8000	3	4
4	6	37.0	-7.2288	14.0	6.0	3	.7070	3	4
4	7	45.0	-8.3219	18.0	2.0	2	.6090	3	5
4	9	85.0	-8.8138	25.0	3.0	4	.5470	3	5
4	10	49.0	-8.4094	20.0	4.0	2	.6220	3	5
4	11	79.0	-7.7142	18.0	3.0	3	.5810	3	6
4	12	8.0	-6.0224	4.5	5.0	1	.7300	3	6
4	13	6.5	-5.6439	2.5	4.0	2	.5780	3	6
5	3	112.0	-9.3880	66.0	5.0	3	.8340	3	4
5	5	270.0	-11.3718	138.0	4.0	2	.6440	3	4
5	6	165.0	-10.1033	88.0	3.0	3	.7530	3	4
5	7	170.0	-9.7977	67.0	3.0	3	.6670	3	5
5	8	136.0	-10.1799	50.0	4.0	2	.5410	3	5
5	9	74.0	-8.9944	27.0	4.0	2	.5780	3	5
5	10	54.0	-8.6795	17.0	3.0	2	.5080	3	6
5	11	50.0	-8.9366	37.0	2.0	1	.8240	3	6
5	12	81.0	-9.2046	29.0	5.0	2	.5610	3	6
6	3	227.0	-10.6439	97.0	3.0	2	.6380	3	4
6	4	67.0	-9.1548	35.0	4.0	2	.6850	3	4
6	5	65.0	-9.2761	30.0	4.0	2	.6070	3	4
6	6	112.0	-9.6439	76.0	3.0	1	.8640	3	4
6	7	92.0	-8.6439	26.0	5.0	3	.5690	3	5
6	8	75.0	-8.8765	35.0	4.0	3	.7030	3	5
6	9	107.0	-9.8611	70.0	2.0	1	.7900	3	5
6	10	13.0	-6.7814	8.0	6.0	1	.7650	3	6
6	11	10.0	-5.9069	4.0	4.0	3	.6440	3	6
6	12	11.0	-6.6439	5.5	2.0	2	.6510	3	6
7	4	130.0	-10.1674	105.0	5.0	1	.9040	3	4
7	5	219.0	-10.2167	72.0	4.0	4	.5840	3	4
7	6	36.0	-8.0224	11.0	3.0	2	.5060	3	4

NORTH YACAABA

X	Y	A	PHI B	C	R	SH	SPHER	LONG	UP
7	7	69.0	-8.8455	18.0	3.0	4	.4680	3	5
7	8	72.0	-8.9069	43.0	5.0	3	.8120	3	5
7	9	52.0	-8.9944	20.0	2.0	2	.5330	3	5
7	10	84.0	-9.2761	36.0	5.0	2	.6290	3	5
7	11	82.0	-8.9944	42.0	4.0	3	.7500	3	6
7	12	10.0	-5.4919	3.5	1.0	3	.6480	3	6
7	13	7.0	-5.6439	3.0	2.0	2	.6360	3	6
8	3	64.0	-9.1033	28.0	4.0	2	.6060	3	4
8	4	24.0	-7.3219	14.0	4.0	3	.7990	3	4
8	5	93.0	-9.6618	44.0	5.0	2	.6360	3	4
8	6	8.5	-5.7814	3.0	5.0	4	.5780	3	4
8	7	11.0	-6.6439	4.5	4.0	2	.5690	3	5
8	8	91.0	-9.1293	29.0	3.0	4	.5490	3	5
8	9	33.0	-8.0768	18.0	5.0	2	.7140	3	5
8	10	55.0	-7.9658	24.0	5.0	3	.7480	3	6
8	11	103.0	-9.3443	61.0	3.0	3	.8220	3	6
8	12	12.0	-6.6439	6.5	3.0	2	.7060	3	6
9	4	72.0	-8.8455	33.0	4.0	3	.6900	3	4
9	5	265.0	-10.1674	68.0	3.0	4	.5340	3	4
9	6	270.0	-11.1033	70.0	3.0	2	.4360	3	4
9	7	129.0	-9.2761	40.0	3.0	4	.5850	3	5
9	8	104.0	-9.2288	40.0	4.0	4	.6360	3	5
9	9	160.0	-10.5216	55.0	4.0	2	.5050	3	5
9	10	42.0	-8.6439	29.0	3.0	1	.7940	3	6
9	11	280.0	-10.8533	89.0	4.0	4	.5350	3	6
9	12	69.0	-9.3880	49.0	2.0	1	.8040	3	6
9	13	12.0	-6.4919	4.5	3.0	2	.5730	3	6
10	3	205.0	-9.7482	65.0	4.0	3	.6210	3	4
10	4	280.0	-10.3554	97.0	4.0	3	.6360	3	4
10	5	62.0	-9.0768	25.0	4.0	2	.5720	3	4
10	6	125.0	-8.8138	41.0	5.0	3	.6690	3	4
10	7	94.0	-9.2761	39.0	2.0	4	.6390	3	5
10	8	160.0	-9.6970	78.0	3.0	3	.7710	3	5
10	9	141.0	-10.0362	42.0	1.0	2	.4920	3	5
10	10	105.0	-9.3663	54.0	4.0	3	.7500	3	5
10	11	87.0	-8.8455	44.0	3.0	3	.7850	3	6
10	12	7.0	-5.6439	3.5	5.0	1	.7050	3	6
10	13	11.5	-6.4094	3.5	6.0	2	.5010	3	6
11	3	270.0	-10.2761	77.0	3.0	4	.5620	2	4
11	4	85.0	-8.9658	42.0	5.0	3	.7460	2	4
11	5	145.0	-9.6439	62.0	4.0	3	.6920	2	4
11	6	93.0	-8.8138	25.0	3.0	4	.5310	2	4
11	7	98.0	-9.4094	65.0	2.0	1	.8590	2	5
11	8	77.0	-8.3663	27.0	4.0	3	.6600	2	5
11	9	18.0	-6.9069	5.0	5.0	4	.4880	2	5
11	10	135.0	-9.7814	86.0	4.0	3	.8540	2	6
11	11	72.0	-8.4919	20.0	3.0	4	.5370	2	6
11	12	76.0	-8.7142	26.0	3.0	4	.5960	2	6
12	3	220.0	-9.4512	60.0	5.0	3	.6160	2	4
12	4	17.0	-7.1293	9.0	2.0	2	.6980	2	4
12	6	118.0	-9.4919	52.0	5.0	3	.6830	2	4
12	7	59.0	-8.3219	14.0	4.0	4	.4700	2	5
12	8	115.0	-9.6618	40.0	3.0	2	.5560	2	5

X	Y	A	PHI B	C	R	SH	SPHER	LONG	UP
12	9	34.0	-7.2288	8.0	3.0	4	.5010	2	5
12	10	100.0	-9.4919	45.0	2.0	2	.6550	2	5
12	11	101.0	-9.4512	15.0	2.0	2	.3170	2	6
12	12	31.0	-7.4919	15.0	3.0	3	.7390	2	6
12	13	53.0	-8.4094	17.0	4.0	4	.5440	2	6
13	3	51.0	-8.8455	19.0	5.0	2	.5360	2	4
13	4	226.0	-10.5507	100.0	3.0	2	.6660	2	4
13	5	94.0	-9.2527	51.0	4.0	3	.7690	2	4
13	6	109.0	-9.4717	70.0	4.0	3	.8590	2	4
13	8	24.0	-7.4094	10.0	6.0	2	.6260	2	5
13	9	120.0	-9.5314	26.0	3.0	4	.4240	2	5
13	10	250.0	-10.1293	90.0	3.0	3	.6620	2	5
13	11	29.0	-7.8455	15.0	5.0	2	.6960	2	6
13	13	7.5	-5.9069	3.5	5.0	2	.6480	2	6
14	3	63.0	-8.5314	23.0	6.0	4	.6100	2	4
14	4	78.0	-8.4919	23.0	5.0	4	.5740	2	4
14	5	61.0	-9.2046	34.0	3.0	2	.6850	2	4
14	6	143.0	-10.1033	66.0	4.0	2	.6520	2	4
14	7	165.0	-9.5699	48.0	2.0	4	.5690	2	5
14	8	53.0	-8.4094	24.0	4.0	3	.6840	2	5
14	9	93.0	-9.3443	63.0	3.0	1	.8690	2	5
14	10	33.0	-8.0224	20.0	4.0	1	.7760	2	5
14	11	150.0	-10.3987	78.0	5.0	2	.6700	2	6
14	12	53.0	-8.3663	28.0	6.0	3	.7660	2	6
14	13	7.0	-5.6439	2.5	2.0	2	.5630	2	6
15	1	165.0	-9.6073	59.0	2.0	3	.6470	2	4
15	2	230.0	-10.2527	84.0	4.0	3	.6310	2	4
15	3	92.0	-9.3880	45.0	4.0	1	.6900	2	4
15	4	84.0	-8.9658	26.0	4.0	4	.5440	2	4
15	6	150.0	-9.5314	52.0	2.0	3	.6250	2	4
15	7	113.0	-9.6618	75.0	4.0	1	.8500	2	5
15	8	310.0	-10.8138	137.0	4.0	3	.6960	2	5
15	9	95.0	-8.9366	32.0	2.0	4	.6040	2	5
15	10	66.0	-9.1033	34.0	2.0	2	.6830	2	5
15	12	55.0	-8.6073	37.0	4.0	1	.8610	2	6
15	13	23.0	-7.0768	9.0	4.0	4	.6390	2	6
15	14	40.0	-8.3219	22.0	6.0	1	.7230	2	6
15	15	9.5	-5.9069	4.5	3.0	3	.7080	2	6
16	1	141.0	-9.0768	51.0	2.0	3	.6990	2	4
16	2	150.0	-9.0498	50.0	3.0	3	.6800	2	4
16	3	128.0	-9.6618	49.0	3.0	4	.6140	2	4
16	6	98.0	-9.0224	45.0	4.0	3	.7350	2	4
16	7	90.0	-9.3880	33.0	4.0	2	.5660	2	5
16	8	160.0	-9.9069	73.0	3.0	3	.7030	2	5
16	9	84.0	-8.7142	35.0	4.0	3	.7030	2	5
16	10	112.0	-9.2288	43.0	3.0	3	.6510	2	5
16	11	68.0	-8.7482	30.0	4.0	3	.6750	2	5
16	12	102.0	-9.9513	71.0	5.0	1	.7930	2	6
16	13	180.0	-10.3443	78.0	4.0	2	.6390	2	6
16	14	5.5	-5.1293	3.0	5.0	3	.7760	2	6
16	15	20.5	-7.2288	5.0	4.0	2	.4340	2	6
17	1	140.0	-10.1799	96.0	4.0	1	.8280	2	4
17	5	90.0	-8.8765	43.0	3.0	3	.7590	2	4

X	Y	A	PHI B	C	R	SH	SPHER	LONG	UP
17	7	97.0	-9.6439	47.0	5.0	2	.6580	2	5
17	8	142.0	-9.5699	36.0	4.0	4	.4940	2	5
17	9	39.0	-8.2761	21.0	3.0	1	.7150	2	5
17	10	91.0	-9.0498	49.0	3.0	3	.7930	2	5
17	11	165.0	-10.4512	73.0	3.0	2	.6140	2	6
17	12	29.0	-8.0224	14.0	4.0	2	.6380	2	6
17	13	15.5	-6.3219	7.5	5.0	3	.7690	2	6
17	14	13.5	-6.4919	6.0	5.0	4	.6670	2	6
18	2	137.0	-9.1799	57.0	4.0	3	.7420	2	4
18	4	49.0	-8.3663	32.0	4.0	1	.8590	2	4
18	6	89.0	-9.7814	42.0	4.0	2	.6090	2	4
18	7	160.0	-10.2288	54.0	3.0	2	.5340	2	5
18	8	105.0	-9.1293	34.0	5.0	4	.5820	2	5
18	9	25.0	-7.3219	15.9	3.0	3	.8580	2	5
18	10	34.0	-8.0224	25.0	4.0	1	.8910	2	5
18	11	107.0	-9.0498	41.0	4.0	3	.6670	2	6
18	12	18.0	-7.3219	15.0	5.0	1	.9210	2	6
18	13	105.5	-6.0224	3.5	4.0	3	.2620	2	6
18	14	16.0	-6.7814	10.0	3.0	1	.8280	2	6
18	15	26.0	-7.9069	16.0	4.0	2	.7430	2	6
19	6	112.0	-9.5118	64.0	4.0	3	.7940	2	4
19	7	88.0	-9.7313	65.0	3.0	1	.8270	2	5
19	8	100.0	-9.8297	40.0	5.0	2	.5610	2	5
19	10	71.0	-9.4512	48.0	4.0	1	.7740	2	5
19	11	46.0	-8.2288	28.0	4.0	3	.8280	2	6
19	12	11.0	-6.4919	7.0	6.0	1	.7910	2	6
19	13	10.5	-6.1293	6.0	5.0	3	.7880	2	6
19	14	35.0	-8.0224	19.0	4.0	1	.7350	2	6
20	5	82.0	-9.6073	70.0	4.0	1	.9150	2	4
20	8	85.0	-8.9944	39.0	4.0	3	.7060	2	5
20	9	86.0	-9.0498	45.0	4.0	3	.7630	2	5
20	10	43.0	-8.4919	24.0	6.0	2	.7190	2	5
20	11	55.0	-8.8138	37.0	4.0	1	.8210	2	6
20	12	57.0	-9.0224	25.0	3.0	2	.5960	2	6
20	13	24.0	-7.3219	15.0	5.0	3	.8370	2	6
20	14	12.5	-6.7814	3.5	5.0	2	.4470	2	6
20	15	9.5	-6.4919	4.5	4.0	2	.6190	2	6
21	6	89.0	-8.4512	31.0	4.0	3	.6760	1	4
21	7	49.0	-8.3219	17.0	3.0	4	.5690	1	5
21	8	117.0	-9.4512	51.0	4.0	3	.6830	1	5
21	9	20.0	-7.0768	12.0	5.0	1	.8110	1	5
21	10	52.0	-8.4094	33.0	3.0	3	.8510	1	6
21	11	10.5	-5.9069	4.0	3.0	4	.6340	1	6
21	12	26.0	-7.8455	13.0	5.0	2	.6570	1	6
22	3	110.0	-9.3663	58.0	4.0	3	.7740	1	4
22	4	102.0	-9.5699	55.0	3.0	1	.7310	1	4
22	5	63.0	-9.2527	50.0	5.0	1	.8670	1	4
22	6	89.0	-8.9366	35.0	4.0	3	.6550	1	4
22	7	67.0	-8.9069	43.0	4.0	1	.8320	1	5
22	8	91.0	-8.5314	33.0	6.0	3	.6870	1	5
22	9	81.0	-9.5507	38.0	4.0	2	.6200	1	5
22	10	113.0	-9.7142	35.0	5.0	2	.5060	1	5
22	11	67.0	-9.1548	40.0	4.0	1	.7480	1	5

X	Y	A	PHI B	C	R	SH	SPHER	LONG	UP
22	12	10.5	-6.6439	3.5	4.0	2	.4890	1	6
22	13	43.0	-8.5699	11.0	5.0	2	.4200	1	6
22	14	47.0	-7.8455	20.0	3.0	3	.7180	1	6
22	15	5.5	-5.6439	3.5	2.0	1	.7640	1	6
23	3	82.0	-9.4919	41.0	4.0	2	.6580	1	4
23	4	75.0	-9.5314	64.0	3.0	1	.9040	1	4
23	5	95.0	-9.2046	37.0	6.0	4	.6250	1	4
23	6	150.0	-9.6970	75.0	4.0	3	.7680	1	4
23	7	82.0	-8.9069	27.0	5.0	4	.5700	1	5
23	8	85.0	-9.1293	55.0	4.0	3	.8600	1	5
23	9	98.0	-9.6795	37.0	5.0	2	.5550	1	5
23	10	43.0	-8.4919	16.0	3.0	2	.5490	1	5
23	11	9.5	-6.3219	5.0	5.0	2	.6910	1	6
23	12	36.0	-7.9069	17.0	4.0	3	.6940	1	6
23	13	5.0	-5.4919	3.0	3.0	2	.7370	1	6
23	14	14.0	-6.4919	5.0	4.0	4	.5840	1	6
24	2	54.0	-8.9944	38.0	3.0	1	.8070	1	4
24	4	91.0	-9.7977	86.0	4.0	1	.9700	1	4
24	5	170.0	-9.5314	68.0	4.0	3	.7170	1	4
24	6	112.0	-9.4919	30.0	4.0	4	.4820	1	4
24	7	118.0	-9.9218	7.0	4.0	2	.1630	1	5
24	8	23.0	-7.7814	8.5	3.0	2	.5230	1	5
24	9	61.0	-8.9069	47.0	4.0	1	.9100	1	5
24	10	22.0	-7.3219	15.0	4.0	1	.8620	1	6
24	11	25.0	-7.4919	10.0	2.0	2	.6060	1	6
24	12	18.0	-7.4094	11.0	5.0	2	.7340	1	6
25	3	71.0	-8.8765	15.0	3.0	4	.4070	1	4
25	4	56.0	-7.9069	17.0	5.0	3	.5990	1	4
25	5	103.0	-9.2527	49.0	4.0	3	.7260	1	4
25	6	109.0	-9.0498	36.0	3.0	3	.6080	1	4
25	7	103.0	-8.9366	34.0	3.0	3	.6120	1	5
25	8	76.0	-8.8138	23.0	4.0	4	.5370	1	5
25	9	135.0	-9.2288	34.0	4.0	4	.5230	1	5
25	10	138.0	-9.3443	42.0	4.0	4	.5820	1	6
25	11	7.0	-6.0224	2.5	4.0	2	.4150	1	6
25	12	71.0	-8.7814	26.0	2.0	4	.6010	1	6
26	3	200.0	-10.0224	73.0	4.0	3	.6350	1	4
26	4	44.0	-8.5699	36.0	4.0	1	.9190	1	4
26	5	116.0	-9.8138	62.0	3.0	1	.7170	1	4
26	6	140.0	-9.9658	53.0	3.0	2	.5860	1	4
26	7	16.0	-7.1293	9.0	6.0	2	.7130	1	5
26	8	222.0	-10.1548	85.0	4.0	3	.6590	1	5
26	9	130.0	-9.9513	60.0	4.0	2	.6540	1	5
26	10	38.0	-8.2288	17.0	4.0	2	.6330	1	6
26	12	9.0	-6.0224	6.0	1.0	1	.8510	1	6
26	12	17.0	-6.7814	6.0	1.0	4	.5780	1	6
27	2	63.0	-9.1293	42.0	4.0	1	.7940	1	4
27	3	128.0	-9.3663	30.0	4.0	4	.4740	1	4
27	4	270.0	-10.0084	98.0	4.0	3	.7020	1	4
27	6	94.0	-8.9069	28.0	4.0	4	.5580	1	4
27	7	200.0	-10.5507	123.0	4.0	1	.7960	1	5
27	8	120.0	-9.9658	50.0	3.0	2	.5930	1	5
27	9	57.0	-8.5314	33.0	3.0	3	.8020	1	6

X	Y	A	PHI B	C	R	SH	SPHER	LONG	UP
27	10	70.0	-8.7142	41.0	5.0	3	.8300	1	6
27	11	30.0	-7.7142	12.0	3.0	2	.6120	1	6
27	12	10.0	-5.7814	4.5	4.0	3	.7170	1	6
28	2	108.0	-9.9366	67.0	3.0	1	.7520	1	4
28	3	70.0	-9.0224	44.0	4.0	1	.8100	1	4
28	4	73.0	-8.9069	28.0	5.0	2	.6070	1	4
28	5	47.0	-7.7814	17.0	5.0	3	.6540	1	4
28	6	160.0	-10.1293	64.0	3.0	2	.6120	1	4
28	7	114.0	-9.1548	36.0	5.0	4	.5850	1	5
28	8	110.0	-9.1799	41.0	4.0	3	.6410	1	5
28	9	28.0	-7.8455	16.0	5.0	1	.7360	1	5
28	10	113.0	-9.8138	60.0	4.0	2	.7080	1	6
28	11	61.0	-9.0768	32.0	3.0	2	.6780	1	6
29	2	64.0	-8.6795	35.0	4.0	3	.7760	1	4
29	3	133.0	-9.6439	38.0	5.0	4	.5140	1	4
29	5	128.0	-9.5314	50.0	4.0	3	.6420	1	4
29	6	33.0	-8.2761	11.0	3.0	2	.4910	1	4
29	7	75.0	-8.9069	22.0	3.0	4	.5130	1	5
29	8	149.0	-9.7313	68.0	4.0	3	.7150	1	5
29	9	136.0	-10.0768	44.0	4.0	2	.5090	1	5
29	10	180.0	-9.8138	60.0	4.0	4	.6060	1	5
29	11	82.0	-8.9658	18.0	4.0	4	.4290	1	6
29	12	18.0	-7.1293	8.0	5.0	2	.6340	1	6
29	13	27.0	-7.4919	8.0	4.0	4	.5090	1	6
30	5	79.0	-9.1799	55.0	5.0	1	.8710	1	4
30	6	138.0	-9.5118	70.0	4.0	3	.7870	1	4
30	7	57.0	-8.2288	29.0	3.0	3	.7900	1	5
30	8	89.0	-9.2046	58.0	4.0	3	.8620	1	5
30	9	17.0	-7.0224	10.0	4.0	1	.7680	1	5
30	10	22.0	-7.5699	15.0	3.0	1	.8140	1	5
3C	11	33.0	-7.4919	10.0	6.0	4	.5520	1	6
30	12	24.0	-7.1293	12.0	5.0	3	.7540	1	6
30	13	26.0	-7.9658	24.0	4.0	1	.9610	1	6

COPACABANA BOULDER BEACH

X	Y	A	PHI B	C	R	SH	SPHER	LONG	UP
1	17	148.0	-9.9218	68.0	4.0	3	.6860	1	4
1	18	230.0	-10.9658	46.0	3.0	2	.3590	1	4
1	19	214.0	-10.0498	73.0	5.0	3	.6170	1	4
1	20	109.0	-9.2046	17.0	3.0	4	.3560	1	5
1	21	55.0	-8.2288	19.0	4.0	4	.6030	1	5
1	22	98.0	-9.1033	27.0	3.0	4	.5140	1	5
1	23	12.0	-6.3219	7.0	4.0	3	.7990	1	5
1	24	57.0	-8.5314	14.0	4.0	2	.4530	1	6
1	25	111.0	-9.1293	38.0	5.0	3	.6150	1	6
1	26	21.0	-7.3219	8.0	3.0	2	.5760	1	6
2	18	361.0	-10.8533	86.0	5.0	4	.4810	1	4
2	19	134.0	-9.8765	51.0	5.0	2	.5910	1	4
2	20	33.0	-8.0224	8.0	3.0	2	.4210	1	5
2	21	308.0	-10.4919	85.0	4.0	4	.5460	1	5
2	22	109.0	-10.0498	34.0	5.0	2	.4650	1	5
2	23	148.0	-9.8138	55.0	4.0	4	.6100	1	5
2	24	42.0	-8.3219	9.0	3.0	2	.3920	1	6
2	25	93.0	-9.0224	23.0	4.0	4	.4790	1	6
2	26	117.0	-10.0084	32.0	4.0	2	.4400	1	6
3	18	82.0	-9.6618	23.0	2.0	2	.4310	1	4
3	19	37.0	-8.3663	9.0	2.0	2	.4050	1	4
3	20	28.0	-7.9658	10.0	4.0	2	.5230	1	5
3	21	214.0	-9.9801	42.0	3.0	4	.4340	1	5
3	22	280.0	-10.1674	61.0	2.0	4	.4870	1	5
3	25	34.0	-8.0224	15.0	3.0	2	.6340	1	6
3	26	68.0	-8.7482	20.0	4.0	4	.5160	1	6
4	18	73.0	-8.6073	15.0	2.0	4	.4300	1	4
4	19	95.0	-9.6439	37.0	4.0	2	.5650	1	4
4	20	8.0	-5.9069	3.5	4.0	2	.6350	1	5
4	21	165.0	-10.1421	21.0	3.0	2	.2870	1	5
4	22	66.0	-8.6795	21.0	2.0	4	.5470	1	5
4	23	120.0	-9.2761	44.0	5.0	3	.6390	1	5
4	24	109.0	-9.5118	42.0	2.0	2	.6060	1	5
4	25	119.0	-8.2288	25.0	6.0	3	.5600	1	6
4	26	204.0	-10.9218	62.0	3.0	2	.4600	1	6
4	27	63.0	-8.5699	29.0	2.0	3	.7060	1	6
5	18	326.0	-11.3826	72.0	4.0	2	.3910	1	4
5	19	268.0	-10.6883	65.0	3.0	4	.4580	1	4
5	20	207.0	-10.8218	70.0	4.0	2	.5080	1	5
5	21	259.0	-10.3880	80.0	2.0	4	.5700	1	5
5	22	49.0	-8.7482	13.0	4.0	2	.4320	1	5
5	23	49.0	-8.6439	30.0	3.0	1	.7720	1	5
5	24	192.0	-10.3880	42.0	3.0	2	.4100	1	6
5	25	266.0	-10.0901	54.0	4.0	4	.4650	1	6
5	26	107.0	-9.4305	25.0	5.0	4	.4390	1	6
5	27	86.0	-9.3663	44.0	3.0	2	.6990	1	6
5	28	31.0	-7.3219	9.0	2.0	4	.5470	1	6
5	29	197.0	-10.7313	41.0	4.0	2	.3690	1	6
6	15	174.0	-10.5699	54.0	1.0	2	.4800	1	4
6	17	48.0	-8.4512	17.0	4.0	2	.5560	1	4
6	18	195.0	-10.8765	65.0	4.0	2	.4870	1	4
6	19	186.0	-9.9944	27.0	4.0	4	.3380	1	4
6	20	138.0	-10.2761	36.0	4.0	2	.4230	1	5

X	Y	A	PHI B	C	R	SH	SPHER	LONG	UP
6	22	30.0	-7.4919	8.0	3.0	4	.4920	1	5
6	23	58.0	-8.7142	24.0	4.0	2	.6190	1	5
6	24	127.0	-10.2761	42.0	5.0	2	.4820	1	6
6	25	160.0	-10.5981	22.0	5.0	2	.2700	1	6
6	26	144.0	-10.1674	45.0	3.0	2	.4970	1	6
6	27	70.0	-8.9944	30.0	2.0	2	.6320	1	6
6	28	9.0	-5.3219	3.0	2.0	3	.6300	1	6
7	16	237.0	-10.0634	40.0	2.0	4	.3980	1	4
7	17	185.0	-10.8376	31.0	3.0	2	.3050	1	4
7	18	326.0	-10.8611	69.0	3.0	4	.4290	1	4
7	20	212.0	-10.3663	83.0	4.0	4	.6270	1	5
7	21	181.0	-10.6707	52.0	5.0	2	.4510	1	5
7	22	98.0	-9.6073	44.0	4.0	2	.6330	1	5
7	23	178.0	-9.7649	66.0	4.0	3	.6550	1	6
7	24	58.0	-8.8455	18.0	1.0	2	.4960	1	6
7	25	140.0	-9.6970	25.0	4.0	4	.3780	1	6
7	26	107.0	-9.5314	25.0	5.0	2	.4290	1	6
7	27	79.0	-9.2288	24.0	4.0	2	.4960	1	6
7	28	214.0	-10.3106	19.0	3.0	2	.2370	1	6
8	15	45.0	-8.0224	17.0	3.0	4	.6280	1	4
8	16	270.0	-10.4512	47.0	4.0	4	.3880	1	4
8	17	76.0	-9.5118	32.0	4.0	2	.5700	1	4
8	18	267.0	-10.1421	40.0	3.0	4	.3760	1	4
8	19	183.0	-10.4512	26.0	3.0	2	.2980	1	4
8	20	63.0	-8.9658	27.0	5.0	2	.6140	1	5
8	21	190.0	-10.6439	35.0	3.0	2	.3430	1	5
8	22	90.0	-8.6795	18.0	3.0	4	.4450	1	5
8	23	73.0	-9.0498	38.0	4.0	1	.7200	1	6
8	24	215.0	-10.6439	50.0	3.0	2	.4180	1	6
8	25	175.0	-9.9366	72.0	3.0	3	.6710	1	6
8	26	92.0	-9.2527	27.0	4.0	4	.5070	1	6
8	27	10.0	-6.1293	1.5	4.0	2	.3180	1	6
8	28	115.0	-9.6795	43.0	5.0	2	.5810	1	6
8	29	33.0	-8.3219	15.0	3.0	2	.5980	1	6
9	16	210.0	-11.0293	44.0	2.0	2	.3540	1	4
9	17	72.0	-9.2761	20.0	3.0	2	.4480	1	4
9	20	150.0	-10.4094	47.0	3.0	2	.4770	1	5
9	23	122.0	-9.3880	55.0	5.0	3	.7180	1	5
9	24	72.0	-9.2992	25.0	3.0	2	.5170	1	6
9	25	98.0	-9.6795	19.0	2.0	2	.3560	1	6
9	26	68.0	-9.1033	20.0	4.0	2	.4750	1	6
9	27	11.5	-6.1293	5.5	3.0	3	.7220	1	6
9	28	66.0	-8.8138	15.0	3.0	2	.4230	1	6
10	13	54.0	-7.9658	17.0	1.0	3	.5990	1	4
10	14	155.0	-10.4094	25.0	2.0	2	.3100	1	4
10	16	25.0	-7.3219	8.0	3.0	4	.5430	1	4
10	19	10.0	-6.1293	6.0	1.0	1	.8010	1	4
10	20	158.0	-10.2046	61.0	3.0	2	.5850	1	5
10	21	160.0	-10.3106	34.0	4.0	2	.3850	1	5
10	22	35.0	-7.7814	5.0	2.0	4	.3190	1	5
10	23	36.0	-7.4919	17.0	4.0	3	.7640	1	5
10	24	152.0	-10.1548	25.0	4.0	2	.3310	1	6
10	25	5.5	-5.3219	1.5	2.0	2	.4680	1	6

X	Y	A	PHI B	C	R	SH	SPHER	LONG	UP
10	26	114.0	-9.5887	24.0	3.0	2	.4040	1	6
11	15	256.0	-10.0362	36.0	3.0	4	.3640	2	4
11	16	65.0	-8.6795	17.0	4.0	4	.4770	2	4
11	17	235.0	-10.5699	41.0	3.0	4	.3610	2	4
11	18	159.0	-9.9366	37.0	5.0	4	.4450	2	4
11	19	46.0	-8.4512	21.0	3.0	2	.6500	2	4
11	20	179.0	-10.5887	9.0	4.0	2	.1440	2	5
11	22	171.0	-10.1674	40.0	4.0	2	.4340	2	5
11	23	78.0	-8.5699	22.0	4.0	3	.5470	2	5
11	24	99.0	-9.7482	25.0	5.0	2	.4190	2	6
11	25	79.0	-9.5118	20.0	2.0	2	.4110	2	6
11	26	73.0	-8.5699	25.0	5.0	4	.6090	2	6
11	27	54.0	-8.7482	12.0	2.0	2	.3960	2	6
12	13	232.0	-10.8218	50.0	4.0	2	.3910	2	4
12	14	163.0	-10.0362	49.0	5.0	4	.5200	2	4
12	19	114.0	-9.9944	17.0	3.0	2	.2920	2	4
12	20	42.0	-8.3219	11.0	2.0	2	.4490	2	5
12	21	141.0	-9.9944	43.0	4.0	2	.5050	2	5
12	22	112.0	-9.8455	13.0	4.0	2	.2540	2	5
12	23	114.0	-9.5887	50.0	4.0	2	.6580	2	6
12	24	122.0	-9.6618	19.0	3.0	4	.3320	2	6
12	25	105.0	-9.0224	38.0	4.0	3	.6420	2	6
12	26	30.0	-7.9658	9.0	2.0	2	.4770	2	6
12	27	35.0	-7.8455	8.0	5.0	4	.4300	2	6
13	1	70.0	-8.9366	22.0	5.0	2	.5210	2	4
13	2	155.0	-10.3106	28.0	4.0	2	.3420	2	4
13	3	25.0	-7.6439	10.0	4.0	2	.5850	2	4
13	4	146.0	-9.8918	41.0	3.0	4	.4950	2	4
13	5	301.0	-11.1923	50.0	4.0	2	.3290	2	4
13	6	152.0	-10.3554	27.0	3.0	2	.3320	2	4
13	7	7.0	-5.3219	1.0	4.0	4	.3300	2	4
13	8	28.0	-7.6439	5.0	4.0	2	.3550	2	4
13	9	80.0	-9.4305	20.0	6.0	2	.4170	2	4
13	10	85.0	-8.8765	11.0	3.0	4	.3120	2	4
13	12	124.0	-9.2046	24.0	4.0	4	.4290	2	4
13	13	48.0	-8.6073	7.0	4.0	2	.2970	2	4
13	14	54.0	-8.5699	36.0	5.0	1	.8580	2	4
13	19	48.0	-8.1293	7.0	3.0	4	.3320	2	4
13	20	19.0	-7.1293	3.0	3.0	2	.3240	2	4
13	21	97.0	-9.0224	40.0	5.0	3	.6820	2	5
13	22	138.0	-10.0224	31.0	4.0	2	.4060	2	5
13	23	150.0	-10.3332	49.0	2.0	2	.4990	2	5
13	24	87.0	-9.1548	13.0	4.0	4	.3250	2	5
13	25	2.5	-3.9069	1.0	1.0	4	.6440	2	6
13	26	22.0	-6.4919	7.0	2.0	3	.6280	2	6
13	27	6.0	-5.3219	.7	5.0	4	.2740	2	6
13	28	8.0	-5.9069	1.0	3.0	2	.2760	2	6
14	15	130.0	-9.9069	47.0	4.0	2	.5620	2	4
14	16	19.0	-7.2288	6.0	3.0	2	.5020	2	4
14	17	122.0	-9.9218	33.0	4.0	2	.4520	2	4
14	18	41.0	-8.3219	10.0	5.0	2	.4240	2	4
14	19	120.0	-9.5314	30.0	3.0	4	.4670	2	4
14	20	85.0	-9.0768	27.0	4.0	4	.5420	2	5

X	Y	A	PHI B	C	R	SH	SPHER	LONG	UP
14	22	46.0	-7.7814	19.0	4.0	3	.7090	2	5
14	23	125.0	-9.7977	52.0	4.0	2	.6240	2	5
14	24	116.0	-9.6257	21.0	3.0	2	.3640	2	6
14	25	72.0	-8.9944	48.0	5.0	1	.8560	2	6
14	26	125.0	-9.5507	55.0	5.0	3	.6860	2	6
14	27	3.0	-4.7549	1.0	4.0	2	.4980	2	6
14	28	84.0	-8.8138	35.0	3.0	3	.6870	2	6
15	16	186.0	-10.3880	40.0	4.0	2	.4010	2	4
15	17	109.0	-9.2761	54.0	3.0	3	.7560	2	4
15	18	38.0	-7.7814	13.0	3.0	4	.5870	2	4
15	19	215.0	-10.9293	70.0	6.0	2	.4890	2	4
15	20	122.0	-9.7313	45.0	6.0	2	.5800	2	5
15	21	150.0	-10.1293	37.0	3.0	2	.4340	2	5
15	22	115.0	-9.2761	35.0	3.0	4	.5560	2	5
15	23	95.0	-8.9944	49.0	3.0	3	.7920	2	5
15	24	13.0	-6.7814	10.0	4.0	1	.8880	2	5
15	25	86.0	-9.5118	28.0	1.0	2	.5000	2	6
15	26	43.0	-8.2288	16.0	2.0	2	.5840	2	6
15	27	30.0	-7.9069	12.0	3.0	2	.5850	2	6
15	28	1.7	-3.7004	.5	1.0	2	.4840	2	6
16	14	22.0	-7.2288	10.0	3.0	2	.6720	2	4
16	15	185.0	-10.0634	27.0	3.0	4	.3330	2	4
16	16	4.5	-5.3219	1.5	6.0	2	.5000	2	4
16	17	11.0	-6.6439	5.0	2.0	2	.6110	2	4
16	18	247.0	-10.6883	70.0	4.0	2	.4940	2	4
16	19	190.0	-9.9658	50.0	5.0	4	.5090	2	4
16	20	106.0	-9.6439	22.0	3.0	2	.3850	2	5
16	21	165.0	-10.0634	50.0	3.0	4	.5220	2	5
16	22	85.0	-9.4305	23.0	2.0	2	.4490	2	5
16	23	1.7	-3.9069	.5	5.0	2	.4610	2	5
16	24	78.0	-8.9944	21.0	1.0	4	.4810	2	5
16	25	28.0	-7.5699	8.0	2.0	2	.4940	2	6
16	26	69.0	-8.1293	27.0	2.0	3	.7230	2	6
16	27	40.0	-8.0224	14.0	2.0	4	.5740	2	6
17	14	19.0	-7.3219	12.0	4.0	1	.7800	2	4
17	15	96.0	-9.7482	22.0	3.0	2	.3890	2	4
17	16	26.0	-7.9069	12.0	5.0	2	.6140	2	4
17	17	55.0	-8.4094	10.0	4.0	4	.3770	2	4
17	18	51.0	-8.1799	14.0	4.0	4	.5100	2	4
17	19	130.0	-9.3443	50.0	6.0	3	.6670	2	4
17	20	83.0	-9.6439	25.0	4.0	2	.4550	2	5
17	22	37.0	-7.8455	18.0	3.0	3	.7250	2	5
17	23	58.0	-8.8138	26.0	1.0	2	.6380	2	5
17	24	113.0	-9.4919	29.0	3.0	4	.4700	2	6
17	21	121.0	-9.8765	17.0	3.0	2	.2940	2	5
17	25	57.0	-9.0768	20.0	2.0	2	.5070	2	6
17	26	80.0	-9.2288	27.0	4.0	2	.5340	2	6
17	27	3.5	-4.9069	1.3	2.0	2	.5440	2	6
18	14	15.0	-6.3219	7.0	4.0	3	.7420	2	4
18	16	25.0	-7.7142	11.0	4.0	2	.6130	2	4
18	17	215.0	-10.1033	33.0	1.0	4	.3590	2	4
18	18	160.0	-9.9801	33.0	5.0	4	.4070	2	4
18	20	83.0	-9.5699	22.0	2.0	2	.4250	2	5

X	Y	A	PHI B	C	R	SH	SPHER	LONG	UP
18	21	7.5	-5.9069	2.5	3.0	2	.5180	2	5
18	22	5.5	-5.2095	2.5	4.0	1	.6750	2	5
18	23	109.0	-9.3880	24.0	4.0	4	.4290	2	5
18	24	94.0	-8.0768	22.0	2.0	3	.5760	2	5
18	25	6.5	-5.6439	2.0	3.0	2	.4980	2	6
18	26	93.0	-9.0768	14.0	3.0	4	.3400	2	6
18	27	4.5	-5.1293	.5	4.0	2	.2520	2	6
19	15	120.0	-9.6439	28.0	3.0	4	.4340	2	4
19	16	30.0	-7.9658	6.0	2.0	2	.3640	2	4
19	17	66.0	-8.8765	20.0	5.0	2	.5060	2	4
19	19	34.0	-7.1293	10.0	4.0	3	.5950	2	4
19	20	150.0	-9.7142	53.0	3.0	4	.6070	2	5
19	21	95.0	-9.6439	27.0	5.0	2	.4580	2	5
19	22	54.0	-8.4094	32.0	2.0	2	.8230	2	5
19	23	6.0	-5.3219	1.0	4.0	4	.3470	2	5
19	24	78.0	-8.8455	29.0	4.0	4	.6170	2	6
19	25	28.0	-7.8455	15.0	4.0	2	.7050	2	6
19	26	102.0	-9.3663	26.0	2.0	4	.4650	2	6
19	27	87.0	-9.4305	17.0	3.0	2	.3640	2	6
19	28	49.0	-8.8765	11.0	3.0	2	.3750	2	6
20	16	65.0	-9.1293	13.0	2.0	2	.3600	2	4
20	17	160.0	-10.1548	30.0	4.0	2	.3670	2	4
20	18	43.0	-8.2288	13.0	4.0	2	.5080	2	4
20	19	160.0	-10.3443	28.0	5.0	2	.3360	2	4
20	20	71.0	-8.6073	13.0	3.0	4	.3940	2	5
20	21	57.0	-8.6795	25.0	5.0	2	.6450	2	5
20	22	69.0	-9.3443	37.0	3.0	2	.6740	2	5
20	23	110.0	-9.4919	40.0	2.0	4	.5870	2	5
20	24	13.0	-6.7814	2.5	4.0	2	.3530	2	6
20	25	3.0	-4.6439	.7	3.0	2	.4030	2	6
20	26	2.2	-3.8074	.6	4.0	4	.4890	2	6
20	27	23.0	-7.4919	8.0	2.0	2	.5370	2	6
21	16	100.0	-9.3219	25.0	5.0	4	.4610	3	4
21	18	150.0	-10.4512	52.0	4.0	2	.5050	3	4
21	19	63.0	-9.1293	38.0	4.0	1	.7430	3	4
21	20	128.0	-9.8297	31.0	6.0	2	.4360	3	5
21	21	113.0	-9.9218	21.0	4.0	2	.3430	3	5
21	22	52.0	-7.4919	12.0	4.0	4	.5360	3	5
21	23	83.0	-8.9069	41.0	5.0	3	.7500	3	5
21	24	13.0	-6.6439	4.5	2.0	2	.5380	3	6
21	25	32.0	-7.9069	14.0	1.0	2	.6350	3	6
21	26	20.0	-7.4919	6.5	3.0	2	.4900	3	6
21	27	27.0	-7.3219	8.0	3.0	4	.5290	3	6
22	13	31.0	-7.1293	13.0	4.0	3	.7300	3	4
22	14	155.0	-9.9658	18.0	4.0	4	.2760	3	4
22	15	94.0	-9.3663	13.0	4.0	2	.3010	3	4
22	16	6.5	-5.9069	1.5	4.0	2	.3870	3	4
22	17	115.0	-9.7814	54.0	4.0	2	.6610	3	4
22	18	3.5	-4.0875	.5	2.0	4	.3480	3	4
22	19	67.0	-9.0224	21.0	2.0	2	.5020	3	4
22	20	29.0	-8.0224	15.0	2.0	2	.6690	3	5
22	21	170.0	-10.4200	52.0	4.0	2	.4880	3	5
22	22	13.0	-6.7814	2.0	3.0	2	.3040	3	5

X	Y	A	PHI B	C	R	SH	SPHER	LONG	UP
22	23	5.0	-5.1293	.7	4.0	2	.3040	3	5
22	24	7.5	-5.6439	1.3	4.0	4	.3560	3	6
22	25	46.0	-8.0224	23.0	2.0	3	.7620	3	6
22	26	67.0	-8.8455	18.0	2.0	2	.4720	3	6
23	16	13.0	-6.7142	2.5	3.0	2	.3580	3	4
23	18	56.0	-8.6073	14.0	6.0	2	.4480	3	4
23	19	88.0	-9.4305	37.0	4.0	2	.6090	3	4
23	20	73.0	-8.6073	17.0	5.0	4	.4670	3	5
23	21	85.0	-9.7142	20.0	3.0	2	.3830	3	5
23	22	80.0	-9.4512	25.0	5.0	2	.4820	3	5
23	23	128.0	-9.2527	25.0	2.0	4	.4310	3	5
23	24	176.0	-10.3443	38.0	4.0	2	.3990	3	6
23	25	44.0	-8.4919	20.0	1.0	2	.6320	3	6
23	26	44.0	-7.8455	18.0	3.0	3	.6840	3	6
24	16	190.0	-10.0498	35.0	4.0	4	.3940	3	4
24	17	126.0	-9.3443	30.0	4.0	4	.4790	3	4
24	18	77.0	-9.5314	33.0	5.0	2	.5760	3	4
24	19	140.0	-9.2527	49.0	5.0	3	.6550	3	4
24	20	53.0	-8.8765	25.0	6.0	2	.6310	3	5
24	21	160.0	-9.2046	35.0	4.0	4	.5070	3	5
24	22	29.0	-7.9658	13.0	4.0	2	.6160	3	5
24	23	10.5	-5.9069	3.5	3.0	4	.5800	3	5
24	24	7.5	-6.0224	4.5	3.0	1	.7460	3	6
24	25	76.0	-8.8455	14.0	4.0	4	.3830	3	6
24	26	96.0	-9.6439	11.0	2.0	2	.2510	3	6
25	17	7.5	-5.4919	3.0	3.0	4	.6440	3	4
25	18	65.0	-8.8138	15.0	4.0	2	.4260	3	4
25	19	93.0	-9.2992	36.0	5.0	2	.6050	3	4
25	20	8.5	-5.7814	2.0	5.0	4	.4410	3	5
25	21	58.0	-8.1293	10.0	5.0	4	.3950	3	5
25	22	90.0	-8.6073	25.0	2.0	4	.5630	3	5
25	23	112.0	-9.5887	17.0	3.0	2	.3230	3	5
25	24	56.0	-8.9069	16.0	5.0	2	.4570	3	6
25	25	10.0	-5.9069	5.0	2.0	3	.7470	3	6
25	26	68.0	-8.8765	22.0	4.0	2	.5330	3	6
26	18	81.0	-8.4919	13.0	3.0	4	.3870	3	4
26	19	67.0	-8.8455	22.0	4.0	2	.5400	3	4
26	20	62.0	-8.1293	26.0	4.0	3	.7300	3	5
26	21	145.0	-9.1033	35.0	3.0	4	.5360	3	5
26	22	28.0	-7.7142	14.0	2.0	2	.6940	3	5
26	23	20.0	-6.9069	5.0	3.0	4	.4710	3	5
26	24	71.0	-9.1799	13.0	4.0	2	.3450	3	6
26	25	6.0	-4.9069	2.5	4.0	3	.7030	3	6
26	26	28.0	-7.5699	7.0	4.0	2	.4520	3	6
26	27	37.0	-7.4094	9.0	2.0	4	.5050	3	6
27	18	145.0	-9.6795	58.0	4.0	3	.6570	3	4
27	19	122.0	-9.7649	32.0	4.0	2	.4590	3	4
27	20	225.0	-9.9513	75.0	3.0	3	.6320	3	5
27	21	42.0	-8.4512	14.0	2.0	2	.5110	3	5
27	22	68.0	-8.9658	23.0	3.0	2	.5380	3	5
27	23	43.0	-8.0224	17.0	1.0	4	.6370	3	5
27	24	77.0	-9.2288	17.0	2.0	2	.3970	3	6
27	25	38.0	-8.2288	7.5	2.0	2	.3670	3	6

X	Y	A	PHI B	C	R	SH	SPHER	LONG	UP
27	26	55.0	-8.6439	14.0	4.0	2	.4470	3	6
28	17	122.0	-10.1421	40.0	3.0	2	.4880	3	4
28	18	80.0	-9.1033	20.0	4.0	2	.4500	3	4
28	19	77.0	-9.5507	25.0	4.0	2	.4770	3	4
28	20	87.0	-9.0498	17.0	3.0	4	.3980	3	5
28	21	84.0	-9.2288	23.0	4.0	2	.4720	3	5
28	22	5.0	-5.6147	1.7	2.0	2	.4910	3	5
28	23	102.0	-8.9069	21.0	4.0	4	.4490	3	5
28	24	26.0	-7.9658	16.0	3.0	2	.7330	3	6
28	25	52.0	-8.1293	25.0	1.0	3	.7550	3	6
29	18	110.0	-10.0224	25.0	5.0	2	.3800	3	4
29	19	75.0	-9.0224	19.0	5.0	2	.4530	3	4
29	20	45.0	-8.0768	17.0	1.0	4	.6200	3	5
29	21	38.0	-8.3663	13.0	3.0	2	.5130	3	5
29	22	87.0	-9.3663	20.0	2.0	2	.4120	3	5
29	23	90.0	-9.6795	9.0	4.0	2	.2230	3	5
29	24	43.0	-8.3663	23.0	2.0	1	.7200	3	6
29	25	55.0	-8.8455	18.0	3.0	2	.5040	3	6
29	26	61.0	-8.5699	10.0	3.0	4	.3510	3	6
30	19	11.5	-6.1293	5.0	5.0	3	.6770	3	4
30	20	82.0	-9.0768	33.0	5.0	4	.6270	3	5
30	21	41.0	-8.2288	23.0	1.0	1	.7550	3	5
30	22	10.0	-6.1293	2.0	2.0	2	.3860	3	5
30	23	49.0	-8.2761	24.0	4.0	3	.7240	3	5
30	24	42.0	-8.2288	16.0	2.0	2	.5880	3	6
30	25	10.0	-6.2288	4.0	3.0	2	.5980	3	6
30	26	70.0	-8.8455	23.0	1.0	4	.5480	3	6

BOMBO BOULDER BEACH

X	Y	A	PHI B	C	R	SH	SPHER	LONG	UP
1	1	180.0	-10.5507	100.0	4.0	2	.7180	1	4
1	2	120.0	-9.5507	59.0	3.0	3	.7290	1	4
1	3	8.0	-5.9069	2.0	2.0	2	.4370	1	4
1	4	128.0	-9.5507	74.0	4.0	3	.8290	1	4
1	5	42.0	-8.6439	20.0	4.0	2	.6200	1	4
1	6	165.0	-10.4512	75.0	4.0	2	.6250	1	4
1	7	112.0	-9.4512	48.0	5.0	3	.6650	1	5
2	3	95.0	-9.4512	38.0	3.0	2	.6010	1	4
2	4	150.0	-9.7142	43.0	4.0	4	.5280	1	4
2	5	50.0	-8.6073	30.0	2.0	1	.7730	1	4
2	6	17.0	-6.4919	7.0	5.0	3	.6840	1	4
2	7	33.0	-8.0224	13.0	3.0	2	.5820	1	5
2	8	68.0	-8.8765	37.0	3.0	1	.7540	1	5
2	9	43.0	-8.4094	26.0	2.0	1	.7730	1	5
2	10	26.0	-7.7814	17.0	5.0	1	.7970	1	5
3	5	91.0	-8.0224	25.0	3.0	3	.6420	1	4
3	6	106.0	-9.8765	59.0	4.0	2	.7050	1	4
3	7	79.0	-9.5118	72.0	4.0	1	.9650	1	5
3	8	69.0	-8.5314	36.9	2.0	3	.8110	1	5
3	9	10.0	-6.3219	6.0	2.0	1	.7670	1	5
3	10	80.0	-9.0768	47.0	4.0	1	.8000	1	5
3	11	48.0	-8.5314	20.0	4.0	2	.6090	1	5
3	12	28.0	-7.6439	11.0	5.0	2	.6000	1	5
3	13	34.0	-7.9069	22.0	5.0	1	.8400	1	5
4	4	53.0	-8.4094	27.0	4.0	3	.7400	1	4
4	5	72.0	-9.4094	45.0	3.0	2	.7450	1	4
4	6	14.0	-6.3219	6.0	4.0	3	.6850	1	4
4	7	200.0	-10.2288	90.0	5.0	3	.6960	1	5
4	8	27.0	-7.9658	8.0	2.0	2	.4560	1	5
4	9	47.0	-8.6073	32.0	4.0	1	.8240	1	5
4	10	25.0	-7.9069	12.0	3.0	2	.6220	1	5
4	11	21.0	-7.5699	6.0	5.0	2	.4490	1	5
4	12	33.0	-8.2761	20.0	3.0	2	.7310	1	5
4	13	15.0	-6.6439	6.0	2.0	4	.6220	1	5
5	3	150.0	-9.6618	58.0	5.0	3	.6520	1	4
5	4	75.0	-8.7482	30.0	2.0	3	.6540	1	4
5	5	230.0	-9.9658	70.0	4.0	3	.5980	1	4
5	6	100.0	-9.9513	68.0	5.0	1	.7760	1	4
5	7	62.0	-8.7482	38.0	1.0	1	.8150	1	5
5	8	33.0	-8.1293	27.0	2.0	1	.9240	1	5
5	9	43.0	-8.2288	25.0	3.0	1	.7860	1	5
5	10	67.0	-8.6795	24.0	2.0	4	.5940	1	5
5	11	21.0	-7.4919	14.0	4.0	1	.8040	1	5
5	12	24.0	-7.8455	11.0	4.0	2	.6030	1	5
6	3	123.0	-9.6795	64.0	5.0	3	.7410	1	4
6	4	83.0	-8.9366	41.0	3.0	3	.7450	1	4
6	5	59.0	-9.1033	25.0	3.0	2	.5780	1	4
6	6	124.0	-9.5887	42.0	4.0	2	.5700	1	4
6	7	77.0	-9.1293	21.0	2.0	2	.4680	1	5
6	8	78.0	-9.3443	38.0	5.0	2	.6580	1	5
6	9	39.0	-8.0224	15.0	2.0	4	.6060	1	5
6	10	12.0	-6.1293	3.0	3.0	4	.4750	1	5
6	11	15.0	-6.4919	4.0	2.0	4	.4920	1	5

X	Y	A	PHI B	C	R	SH	SPHER	LONG	UP
6	12	91.0	-9.2288	32.0	2.0	4	.5730	1	5
6	13	35.0	-7.9658	7.0	2.0	2	.3830	1	5
6	14	17.0	-6.4919	8.9	4.0	3	.8030	1	5
6	15	9.0	-5.6439	4.0	2.0	3	.7090	1	6
6	16	4.0	-4.9069	1.5	1.0	2	.5730	1	6
7	4	61.0	-9.0224	28.0	5.0	2	.6280	1	4
7	5	231.0	-10.5507	60.0	5.0	4	.4700	1	4
7	6	41.0	-8.4094	23.0	4.0	1	.7240	1	4
7	7	34.0	-7.5699	14.0	3.0	3	.6720	1	5
7	8	43.0	-8.6439	23.0	1.0	2	.6750	1	5
7	9	6.0	-5.1293	3.0	1.0	3	.7540	1	5
7	10	200.0	-10.8918	100.0	4.0	2	.6410	1	5
7	11	35.0	-7.5699	10.0	3.0	4	.5320	1	5
7	12	20.0	-6.6439	7.0	5.0	3	.6260	1	5
7	13	9.0	-5.9069	4.0	1.0	4	.6670	1	5
7	14	25.0	-7.4094	9.0	3.0	2	.5760	1	5
7	15	118.0	-9.6439	44.0	4.0	2	.5900	1	5
7	16	20.0	-6.6439	5.0	3.0	4	.5000	1	6
7	17	49.0	-8.8765	41.0	3.0	1	.9000	1	6
7	18	54.0	-8.5314	18.0	3.0	2	.5460	1	6
8	4	88.0	-9.1033	47.0	4.0	1	.7700	1	4
8	5	92.0	-9.4512	60.0	4.0	1	.8240	1	4
8	6	216.0	-10.9218	100.0	4.0	2	.6210	1	4
8	7	34.0	-8.0224	18.0	3.0	1	.7160	1	5
8	8	58.0	-8.6795	36.0	5.0	1	.8170	1	5
8	9	56.0	-8.6795	37.0	2.0	1	.8420	1	5
8	10	54.0	-8.4919	29.0	2.0	3	.7570	1	5
8	11	59.0	-9.1548	30.0	4.0	2	.6450	1	5
8	12	44.0	-7.9069	20.0	3.0	3	.7240	1	5
8	13	29.0	-7.2288	14.0	3.0	3	.7670	1	5
8	14	46.0	-8.4919	35.0	4.0	1	.9040	1	5
8	15	20.0	-6.7814	7.0	2.0	4	.6060	1	5
8	16	29.0	-7.1293	12.0	2.0	3	.7080	1	5
8	17	12.0	-6.3219	7.0	6.0	3	.7990	1	6
8	18	13.0	-6.9069	6.5	1.0	2	.6470	1	6
8	19	110.0	-9.3443	40.0	3.0	4	.6070	1	6
8	20	50.0	-8.6073	26.0	2.0	2	.7030	1	6
9	4	32.0	-7.5699	15.0	5.0	3	.7180	1	4
9	5	117.0	-9.8611	50.0	5.0	2	.6130	1	4
9	6	68.0	-9.3443	45.0	5.0	1	.7710	1	4
9	7	29.0	-7.4919	16.0	3.0	3	.7890	1	5
9	8	25.0	-7.5699	13.0	4.0	1	.7090	1	5
9	9	33.0	-8.1293	10.0	3.0	2	.4770	1	5
9	10	87.0	-9.2527	14.0	4.0	2	.3330	1	5
9	11	40.0	-8.1799	17.0	4.0	2	.6300	1	5
9	12	4.5	-4.6439	.5	1.0	4	.2820	1	5
9	13	9.0	-5.4919	2.5	2.0	4	.5370	1	5
9	14	9.0	-5.7814	5.0	2.0	3	.7970	1	6
9	15	10.0	-5.7814	2.5	1.0	4	.4850	1	6
9	16	4.0	-5.1293	3.0	1.0	1	.8630	1	6
9	17	16.0	-6.6439	2.5	1.0	4	.3400	1	6
9	18	14.5	-6.4919	5.5	4.0	4	.6150	1	6
9	19	15.5	-7.2288	14.0	1.0	1	.9450	1	6

X	Y	A	PHI B	C	R	SH	SPHER	LONG	UP
10	3	69.0	-9.1548	46.0	5.0	1	.8130	1	4
10	4	116.0	-9.5314	59.0	4.0	3	.7400	1	4
10	5	142.0	-9.8297	70.0	5.0	3	.7240	1	4
10	6	17.0	-6.7814	8.0	4.0	3	.7000	1	4
10	7	23.0	-7.5699	12.0	5.0	2	.6910	1	5
10	8	27.0	-7.1293	12.0	4.0	3	.7250	1	5
10	9	174.0	-9.4717	62.0	4.0	3	.6780	1	5
10	10	17.0	-7.3219	13.0	3.0	1	.8530	1	5
10	11	21.0	-7.4919	7.0	2.0	2	.5060	1	5
10	12	9.0	-5.4919	3.5	2.0	3	.6720	1	5
10	13	35.0	-8.1799	14.0	1.0	2	.5780	1	6
10	14	16.0	-7.1293	10.0	1.0	1	.7640	1	6
10	15	41.0	-7.7814	19.0	1.0	3	.7370	1	6
10	16	41.0	-7.9069	9.0	1.0	4	.4350	1	6
10	17	20.0	-7.1293	12.0	1.0	1	.8010	1	6
11	3	18.0	-6.9069	6.0	4.0	4	.5510	2	4
11	4	243.0	-11.1293	150.0	3.0	1	.7450	2	4
11	5	46.0	-8.2288	18.0	4.0	4	.6170	2	4
11	6	92.0	-9.3443	58.0	6.0	1	.8260	2	4
11	7	88.0	-9.6795	38.0	4.0	2	.5850	2	5
11	8	121.0	-9.1799	45.0	4.0	3	.6610	2	5
11	9	13.0	-6.4919	5.0	2.0	2	.5980	2	5
11	10	150.0	-10.5118	67.0	4.0	2	.5900	2	5
11	11	10.0	-6.1293	3.0	3.0	2	.5050	2	6
11	12	5.0	-4.9069	2.0	1.0	4	.6440	2	6
11	13	11.0	-6.6439	6.0	2.0	2	.6890	2	6
11	14	19.0	-7.2288	13.0	4.0	1	.8400	2	6
11	15	21.0	-7.3219	4.0	2.0	2	.3630	2	6
12	5	46.0	-8.5314	33.0	6.0	1	.8620	2	4
12	6	88.0	-9.3219	40.0	5.0	2	.6580	2	4
12	7	64.0	-8.8455	20.0	4.0	2	.5140	2	5
12	8	33.0	-8.2761	26.0	4.0	1	.8710	2	5
12	9	19.0	-7.4919	16.0	3.0	1	.9080	2	5
12	10	73.0	-8.9944	28.0	4.0	2	.5950	2	5
12	11	18.0	-6.7814	6.0	2.0	4	.5670	2	5
12	12	13.0	-6.3219	7.0	1.0	3	.7780	2	5
12	13	32.0	-8.0768	21.0	2.0	1	.7990	2	5
12	14	54.0	-8.6795	23.0	2.0	2	.6210	2	6
12	15	33.0	-7.7142	19.0	2.0	3	.8050	2	6
12	16	18.0	-6.7814	8.0	1.0	3	.6870	2	6
13	5	170.0	-10.5507	140.0	5.0	1	.9160	2	4
13	6	63.0	-9.1293	28.0	4.0	2	.6060	2	4
13	7	22.0	-7.0224	11.0	4.0	3	.7510	2	5
13	8	75.0	-9.4919	44.0	2.0	2	.7110	2	5
13	9	53.0	-8.3219	20.0	2.0	4	.6180	2	5
13	10	45.0	-7.9069	17.0	3.0	3	.6450	2	5
13	11	25.0	-7.7142	15.0	5.0	1	.7540	2	5
13	12	70.0	-8.5314	31.0	3.0	3	.7190	2	5
13	13	23.0	-7.2288	13.0	2.0	3	.7880	2	5
13	14	11.0	-6.4919	2.5	1.0	2	.3990	2	5
13	15	9.0	-6.4094	7.5	4.0	1	.9030	2	6
13	16	21.0	-6.9069	7.0	2.0	4	.5800	2	6
14	4	49.0	-8.3219	17.0	4.0	4	.5690	2	4

X	Y	A	PHI B	C	R	SH	SPHER	LONG	UP
14	5	23.0	-7.6439	14.0	4.0	1	.7530	2	4
14	6	39.0	-7.3219	14.0	4.0	3	.6800	2	4
14	7	59.0	-8.6439	32.0	5.0	1	.7570	2	5
14	8	64.0	-9.1033	28.0	2.0	2	.6060	2	5
14	9	9.0	-6.1293	6.0	2.0	1	.8300	2	5
14	10	26.0	-7.5699	12.0	4.0	2	.6630	2	5
14	11	32.0	-7.9069	23.0	3.0	1	.8830	2	5
14	12	7.0	-5.6439	3.0	4.0	2	.6360	2	5
14	13	5.0	-5.1293	1.5	1.0	2	.5050	2	5
14	14	35.0	-8.0224	13.0	1.0	2	.5710	2	6
14	15	26.0	-7.8455	22.0	3.0	1	.9320	2	6
14	16	29.0	-7.4919	17.0	2.0	3	.8210	2	6
15	4	68.0	-8.8455	28.0	5.0	2	.6310	2	4
15	5	21.0	-7.3219	15.0	4.0	1	.8750	2	4
15	6	26.0	-7.5699	15.0	4.0	1	.7700	2	4
15	7	59.0	-9.0498	20.0	6.0	2	.5040	2	5
15	8	90.0	-9.2761	42.0	3.0	1	.6810	2	5
15	9	39.0	-8.3663	26.0	4.0	1	.8070	2	5
15	10	77.0	-9.1033	31.0	4.0	2	.6100	2	5
15	11	13.0	-6.4919	4.0	4.0	2	.5160	2	5
15	12	38.0	-8.0224	17.0	3.0	2	.6640	2	5
15	13	9.0	-5.9069	4.0	2.0	4	.6670	2	5
15	14	9.0	-6.3219	2.5	1.0	2	.4430	2	6
15	15	11.0	-6.3219	7.0	1.0	1	.8230	2	6
15	16	16.0	-6.7814	6.0	4.0	2	.5900	2	6
15	17	59.0	-8.4094	23.0	4.0	3	.6420	2	6
16	3	20.0	-7.1293	9.0	5.0	2	.6620	2	4
16	4	40.0	-8.4512	16.0	6.0	2	.5680	2	4
16	5	14.0	-6.7814	7.0	5.0	2	.6830	2	4
16	6	63.0	-9.0498	28.0	3.0	2	.6170	2	4
16	7	51.0	-8.1293	20.0	3.0	3	.6550	2	5
16	8	26.0	-7.7814	8.0	2.0	2	.4820	2	5
16	9	27.0	-7.9069	11.0	2.0	2	.5720	2	5
16	10	37.0	-7.8455	17.0	1.0	3	.6980	2	5
16	11	11.0	-5.7814	4.5	2.0	3	.6950	2	6
16	12	19.0	-7.2288	6.5	1.0	2	.5300	2	6
16	13	32.0	-8.1799	14.0	3.0	2	.5960	2	6
16	14	24.0	-7.7814	17.0	2.0	1	.8180	2	6
16	15	33.0	-8.0224	22.0	2.0	1	.8260	2	6
16	16	34.0	-7.9069	19.0	3.0	1	.7620	2	6
17	4	81.0	-8.9366	46.0	5.0	3	.8110	2	4
17	5	54.0	-8.9366	23.0	3.0	2	.5850	2	4
17	6	26.0	-7.6439	9.0	4.0	2	.5380	2	4
17	7	49.0	-8.8765	26.0	3.0	2	.6650	2	5
17	8	6.0	-5.6439	3.0	4.0	2	.6700	2	5
17	9	30.0	-8.0224	21.0	3.0	1	.8270	2	5
17	10	9.5	-5.9069	4.5	1.0	3	.7080	2	6
17	11	28.0	-8.0768	20.0	3.0	1	.8090	2	6
17	12	41.0	-7.8455	21.0	4.0	3	.7760	2	6
17	13	39.0	-7.9658	14.0	2.0	4	.5860	2	6
17	14	36.0	-8.2761	22.0	4.0	1	.7570	2	6
17	15	28.0	-7.8455	12.0	1.0	2	.6070	2	6
17	16	39.0	-8.2761	19.0	1.0	2	.6690	2	6

X	Y	A	PHI B	C	R	SH	SPHER	LONG	UP
18	4	24.0	-7.7142	12.0	6.0	2	.6590	2	4
18	5	180.0	-10.3880	85.0	5.0	2	.6690	2	4
18	6	30.0	-8.1293	15.0	5.0	2	.6450	2	4
18	7	71.0	-9.0768	33.0	4.0	2	.6580	2	5
18	8	30.0	-8.0768	20.0	3.0	1	.7910	2	5
18	9	55.0	-8.6795	40.0	4.0	1	.8920	2	5
18	10	17.0	-7.3219	12.0	4.0	1	.8090	2	5
18	11	22.0	-7.2288	10.0	3.0	2	.6720	2	6
18	12	26.0	-7.9658	12.0	5.0	2	.6050	2	6
18	13	22.0	-7.5699	18.0	1.0	1	.9190	2	6
18	14	16.0	-7.0224	9.0	4.0	1	.7300	2	6
18	15	29.0	-7.6439	15.0	3.0	1	.7300	2	6
18	16	61.0	-8.8765	26.0	3.0	2	.6180	2	6
19	3	63.0	-9.2046	57.0	4.0	1	.9560	2	4
19	4	44.0	-8.2288	21.0	5.0	1	.6940	2	4
19	5	13.0	-6.3219	4.0	6.0	4	.5360	2	4
19	6	150.0	-10.5118	140.0	3.0	1	.9640	2	4
19	7	38.0	-8.3663	23.0	4.0	1	.7500	2	5
19	8	22.0	-7.4094	15.0	2.0	1	.8440	2	5
19	9	79.0	-8.4094	30.0	4.0	3	.6950	2	6
19	10	11.5	-6.4919	8.5	5.0	1	.8870	2	6
19	11	34.0	-8.3219	24.0	3.0	1	.8090	2	6
19	12	24.0	-7.2288	14.0	4.0	3	.8170	2	6
19	13	19.0	-7.4919	12.0	4.0	2	.7500	2	6
19	14	27.0	-8.0224	21.0	5.0	1	.8570	2	6
19	15	26.0	-7.9658	18.0	3.0	1	.7930	2	6
20	4	86.0	-9.3880	46.0	5.0	1	.7160	2	4
20	5	42.0	-7.5699	17.0	4.0	3	.7130	2	4
20	6	48.0	-8.2288	23.0	3.0	3	.7160	2	4
20	7	24.0	-7.3219	10.0	4.0	4	.6390	2	5
20	8	24.0	-7.4919	13.5	2.0	1	.7500	2	5
20	9	60.0	-9.1033	40.0	4.0	1	.7860	2	5
20	10	20.0	-7.5699	15.0	5.0	1	.8400	2	5
20	11	24.0	-7.4919	14.0	4.0	1	.7690	2	5
20	12	28.0	-7.7142	14.0	4.0	2	.6940	2	6
20	13	30.0	-8.2046	29.0	3.0	1	.9830	2	6
20	14	6.0	-5.3219	2.0	1.0	4	.5510	2	6
21	4	83.0	-9.3880	45.0	5.0	1	.7140	3	4
21	5	71.0	-9.0224	41.0	3.0	1	.7700	3	4
21	6	39.0	-8.0768	13.0	4.0	2	.5440	3	4
21	7	102.0	-9.6257	40.0	5.0	2	.5840	3	5
21	8	10.0	-6.0224	4.5	4.0	3	.6780	3	5
21	9	120.0	-9.3880	41.0	5.0	4	.5940	3	5
21	10	43.0	-8.5314	15.0	6.0	2	.5210	3	5
21	11	62.0	-8.8138	33.0	2.0	1	.7310	3	5
21	12	63.0	-8.9069	30.0	4.0	2	.6680	3	6
21	13	15.0	-6.7814	6.0	4.0	2	.6020	3	6
21	14	30.0	-7.3219	14.0	3.0	3	.7420	3	6
21	15	25.5	-7.7142	11.0	4.0	2	.6090	3	6
21	16	21.0	-7.2761	15.0	3.0	1	.8840	3	6
22	4	70.0	-9.2288	26.0	5.0	2	.5440	3	4
22	5	33.0	-8.0224	12.0	4.0	2	.5520	3	4
22	6	47.0	-8.5314	22.0	4.0	2	.6530	3	4

X	Y	A	PHI B	C	R	SH	SPHER	LONG	UP
22	7	62.0	-9.2527	36.0	4.0	2	.7000	3	5
22	8	54.0	-8.6795	26.0	3.0	2	.6740	3	5
22	9	28.0	-7.4094	12.0	3.0	3	.6720	3	5
22	10	44.0	-8.1799	17.0	5.0	4	.6100	3	5
22	11	16.0	-6.1293	4.5	4.0	4	.5660	3	5
22	12	94.0	-9.3880	44.0	4.0	2	.6750	3	6
22	13	23.0	-7.4919	14.0	4.0	1	.7800	3	6
22	14	43.0	-7.7814	18.0	1.0	3	.7000	3	6
22	15	30.0	-7.7814	21.0	5.0	1	.8740	3	6
22	16	18.0	-7.3219	9.0	3.0	2	.6550	3	6
23	6	67.0	-8.7142	36.0	5.0	3	.7720	3	4
23	7	41.0	-8.0768	16.0	4.0	4	.6140	3	5
23	8	88.0	-9.1799	55.0	4.0	3	.8400	3	5
23	9	35.0	-8.1293	15.0	4.0	2	.6130	3	5
23	10	13.0	-6.6439	9.0	6.0	1	.8540	3	5
23	11	27.0	-7.9658	23.0	3.0	1	.9220	3	6
23	12	22.0	-7.0224	8.0	2.0	4	.6070	3	6
23	13	49.0	-8.8765	33.0	5.0	1	.7790	3	6
23	14	34.0	-8.2761	15.0	4.0	2	.5980	3	6
24	5	72.0	-8.8138	38.0	3.0	3	.7640	3	4
24	6	57.0	-8.9366	17.0	4.0	2	.4700	3	4
24	7	19.0	-7.1293	4.0	3.0	2	.3920	3	5
24	8	25.0	-7.6439	12.0	4.0	2	.6610	3	5
24	9	92.0	-9.1033	41.0	4.0	3	.6930	3	5
24	10	37.0	-7.5699	12.0	3.0	4	.5900	3	5
24	11	18.0	-6.4919	8.0	6.0	3	.7340	3	5
24	12	14.0	-6.7814	6.5	5.0	2	.6500	3	6
24	13	5.0	-5.3219	2.5	3.0	2	.6790	3	6
24	14	3.2	-4.3923	1.2	2.0	4	.5990	3	6
24	15	36.0	-7.8455	22.0	3.0	3	.8360	3	6
25	5	31.0	-7.9069	21.0	5.0	1	.8400	3	4
25	6	48.0	-7.7142	16.0	4.0	3	.6340	3	4
25	7	25.0	-7.8455	13.0	5.0	2	.6650	3	5
25	8	22.0	-6.4919	8.0	3.0	3	.6870	3	5
25	9	55.0	-8.2761	23.0	4.0	3	.6770	3	5
25	10	19.0	-7.2288	4.5	4.0	2	.4150	3	5
25	11	8.0	-4.9069	2.0	6.0	4	.5510	3	6
25	12	6.0	-5.1293	2.0	4.0	4	.5760	3	6
25	13	37.0	-7.5699	16.0	3.0	3	.7140	3	6
25	14	2.5	-4.5850	1.6	2.0	2	.7530	3	6
25	15	8.5	-5.7814	4.0	2.0	3	.7000	3	6
25	16	14.0	-6.5699	6.0	6.0	2	.6470	3	6
26	5	104.0	-9.2761	45.0	5.0	3	.6800	3	4
26	6	100.0	-8.9944	43.0	3.0	3	.7130	3	4
26	7	37.0	-8.1293	16.0	5.0	2	.6280	3	5
26	8	18.0	-7.2288	8.5	4.0	2	.6450	3	5
26	9	33.0	-8.0224	25.0	3.0	1	.9000	3	5
26	10	7.5	-6.0224	6.0	6.0	1	.9040	3	5
26	11	11.5	-6.4919	4.5	3.0	2	.5810	3	6
26	12	13.5	-6.8455	4.0	2.0	2	.4690	3	6
26	13	14.0	-6.7814	6.5	5.0	2	.6500	3	6
26	14	40.0	-8.2288	11.0	3.0	2	.4660	3	6
26	15	5.5	-5.6439	4.5	2.0	1	.9030	3	6

X	Y	A	PHI B	C	R	SH	SPHER	LONG	UP
26	16	3.0	-3.9069	1.3	2.0	3	.7220	3	6
27	5	31.0	-8.0224	17.0	5.0	2	.7110	3	4
27	6	68.0	-9.2046	29.0	4.0	2	.5940	3	4
27	7	49.0	-8.8138	38.0	4.0	1	.8690	3	5
27	8	28.0	-7.7814	15.0	3.0	1	.7150	3	5
27	9	29.0	-7.7814	11.0	4.0	2	.5750	3	5
27	10	18.0	-7.3219	10.0	4.0	2	.7030	3	6
27	11	15.0	-6.4919	8.0	4.0	3	.7800	3	6
27	12	14.0	-6.5699	6.0	4.0	2	.6470	3	6
27	13	22.0	-7.7142	13.0	4.0	2	.7150	3	6
27	14	12.0	-5.3923	3.7	3.0	3	.6480	3	6
27	15	13.5	-6.7142	10.0	3.0	1	.8900	3	6
27	16	15.0	-6.6439	4.5	3.0	4	.5130	3	6
27	17	16.0	-7.0224	4.5	2.0	2	.4600	3	6
28	6	63.0	-9.0498	42.0	4.0	1	.8090	3	4
28	7	81.0	-8.7814	43.0	4.0	3	.8040	3	5
28	8	7.5	-5.6439	3.0	3.0	4	.6220	3	5
28	9	18.0	-7.2288	13.0	3.0	1	.8560	3	5
28	10	51.0	-8.5699	37.0	3.0	1	.8910	3	5
28	11	18.5	-7.1293	10.0	2.0	1	.7280	3	5
28	12	17.0	-7.3663	16.0	3.0	1	.9700	3	6
28	13	30.0	-8.1799	18.0	5.0	2	.7200	3	6
28	14	7.0	-5.4919	2.5	4.0	4	.5840	3	6
28	15	9.0	-6.4094	4.0	1.0	2	.5940	3	6
29	5	53.0	-8.2288	17.0	5.0	4	.5670	3	4
29	6	41.0	-8.3219	20.0	6.0	2	.6730	3	4
29	7	140.0	-8.8455	40.0	6.0	3	.6290	3	5
29	8	38.0	-8.2288	18.0	4.0	2	.6580	3	5
29	9	20.0	-7.4919	11.0	4.0	2	.6960	3	5
29	10	23.0	-7.7142	16.0	3.0	1	.8090	3	5
29	11	54.0	-8.4919	32.0	3.0	3	.8080	3	5
29	12	10.0	-6.1293	5.5	6.0	1	.7560	3	6
29	13	14.0	-6.7814	9.0	4.0	1	.8070	3	6
29	14	11.0	-6.3219	4.5	3.0	2	.6130	3	6
29	15	32.0	-7.8455	21.0	3.0	1	.8430	3	6
30	5	34.0	-8.2761	28.0	6.0	1	.9060	3	4
30	6	9.0	-6.0224	2.5	3.0	2	.4750	3	4
30	7	46.0	-8.6439	31.0	3.0	1	.8050	3	5
30	8	58.0	-8.8455	45.0	4.0	1	.9120	3	5
30	9	52.0	-8.6073	33.0	4.0	1	.8130	3	5
30	10	16.0	-6.7814	5.0	6.0	2	.5220	3	5
30	11	38.0	-7.5699	16.0	2.0	3	.7080	3	5
30	12	7.5	-5.7814	3.5	4.0	2	.6670	3	6
30	13	31.0	-8.2288	14.0	2.0	2	.5950	3	6
30	14	9.5	-5.7814	5.0	4.0	3	.7820	3	6
30	15	10.5	-6.0224	3.5	3.0	4	.5640	3	6
31	6	26.0	-7.5699	7.0	5.0	2	.4630	3	4
31	7	55.0	-8.6073	37.0	5.0	1	.8610	3	5
31	8	49.0	-8.0768	13.0	4.0	4	.5040	3	5
31	9	35.0	-7.8455	18.0	3.0	3	.7390	3	5
31	10	39.0	-7.9658	22.0	3.0	3	.7920	3	5
31	11	8.5	-5.9069	5.0	3.0	1	.7890	3	5
31	12	49.0	-8.7142	19.0	3.0	2	.5600	3	6

X	Y	A	PHI B	C	R	SH	SPHER	LONG	UP
31	13	13.0	-6.9069	7.0	5.0	2	.6800	3	6
31	14	23.0	-7.6439	10.0	2.0	2	.6020	3	6
31	15	42.0	-7.6439	19.0	4.0	3	.7550	3	6

KIAMA BOULDER BEACH

X	Y	A	PHI B	C	R	SH	SPHER	LONG	UP
1	8	137.0	-8.2761	31.0	4.0	4	.4260	1	4
1	9	66.0	-8.7482	23.0	4.0	4	.5720	1	5
1	10	88.0	-8.6073	33.0	3.0	3	.6820	1	5
1	11	8.0	-5.9069	4.5	1.0	1	.7500	1	5
1	12	3.0	-4.3923	1.5	2.0	1	.7100	1	5
1	13	8.5	-5.5850	2.7	4.0	4	.5640	1	5
1	14	33.0	-8.0224	10.0	1.0	2	.4890	1	6
2	7	150.0	-9.1548	53.0	4.0	3	.6900	1	4
2	8	42.0	-8.0224	12.0	2.0	4	.5090	1	4
2	9	26.0	-7.4919	11.5	3.0	2	.6560	1	5
2	10	60.0	-8.1293	20.0	4.0	3	.6200	1	5
2	11	7.0	-4.3923	1.8	1.0	3	.6040	1	5
2	12	83.0	-9.0768	29.0	4.0	4	.5730	1	5
2	13	52.0	-8.5699	8.5	2.0	2	.3320	1	5
2	14	29.0	-7.9069	5.5	3.0	2	.3520	1	5
2	15	26.0	-7.7814	12.0	3.0	2	.6320	1	6
3	7	75.0	-9.2761	21.0	4.0	2	.4560	1	4
3	8	11.5	-6.6439	7.0	2.0	1	.7530	1	4
3	9	23.0	-7.1799	14.0	2.0	3	.8380	1	5
3	10	79.0	-8.9366	21.5	1.0	4	.4930	1	5
3	11	65.0	-8.6073	24.0	1.0	4	.6110	1	5
3	12	22.0	-7.6073	5.5	1.0	2	.4130	1	5
3	13	35.0	-7.4512	17.0	4.0	3	.7790	1	6
4	8	54.0	-8.3219	17.5	3.0	4	.5620	1	4
4	9	67.0	-9.1033	39.0	3.0	1	.7450	1	5
4	10	16.0	-6.7814	8.5	3.0	1	.7430	1	5
4	11	21.5	-7.3663	5.0	4.0	2	.4130	1	5
4	12	18.0	-6.8455	7.0	3.0	4	.6190	1	5
4	13	41.0	-8.0224	23.0	4.0	3	.7920	1	6
4	14	14.0	-6.7814	5.0	3.0	2	.5460	1	6
5	8	88.0	-8.8138	24.0	4.0	4	.5260	1	4
5	9	43.0	-8.4512	29.0	2.0	1	.8240	1	5
5	10	15.0	-7.0224	6.0	1.0	2	.5700	1	5
5	11	41.0	-8.0224	16.0	2.0	4	.6220	1	6
5	12	23.0	-7.4094	10.0	3.0	2	.6350	1	6
5	13	57.0	-8.6795	26.0	4.0	2	.6620	1	6
5	14	27.0	-7.2288	13.5	3.0	3	.7670	1	6
5	15	53.0	-8.9944	32.0	3.0	2	.7240	1	6
6	8	44.0	-8.4512	22.0	2.0	2	.6800	1	4
6	9	71.0	-9.2288	19.0	1.0	2	.4400	1	5
6	10	76.0	-9.4094	23.0	1.0	2	.4680	1	6
6	11	8.5	-5.8580	2.3	1.0	2	.4760	1	6
6	12	38.0	-7.4094	14.0	2.0	3	.6720	1	6
6	13	22.0	-7.5699	10.5	1.0	2	.6420	1	6
6	14	104.0	-8.9366	47.0	4.0	3	.7570	1	6
6	15	11.5	-6.3219	7.5	1.0	1	.8490	1	6
7	8	26.0	-7.2288	12.0	3.0	3	.7180	1	4
7	9	67.0	-8.7482	33.0	3.0	3	.7230	1	5
7	10	52.0	-8.3663	25.0	4.0	3	.7140	1	5
7	11	101.0	-9.0224	36.0	2.0	3	.6280	1	6
7	12	64.0	-8.4512	32.0	3.0	3	.7710	1	6
7	13	25.0	-7.7482	9.0	2.0	2	.5320	1	6
7	14	33.0	-8.1799	14.5	2.0	2	.6040	1	6

X	Y	A	PHI B	C	R	SH	SPHER	LONG	UP
8	8	93.0	-9.4717	42.0	4.0	2	.6440	1	4
8	9	69.0	-8.7142	26.0	4.0	4	.6160	1	5
8	10	53.0	-8.9366	36.0	5.0	1	.7930	1	6
8	11	137.0	-8.8455	27.0	4.0	4	.4880	1	6
8	12	81.0	-9.4512	24.0	4.0	2	.4670	1	6
8	13	85.0	-8.9944	22.0	2.0	4	.4820	1	6
8	14	154.0	-9.7649	22.0	1.0	4	.3310	1	6
9	8	89.0	-9.2288	41.0	4.0	1	.6810	1	4
9	9	59.0	-8.7814	23.0	2.0	2	.5890	1	5
9	10	112.0	-9.7142	62.0	4.0	1	.7420	1	6
9	11	86.0	-8.9658	44.0	4.0	3	.7670	1	6
9	12	76.0	-9.0498	33.0	2.0	2	.6470	1	6
9	13	60.0	-8.4512	34.0	3.0	3	.8200	1	6
9	14	69.0	-9.1293	14.0	3.0	2	.3710	1	6
10	1	70.0	-8.6795	37.0	3.0	3	.7820	1	4
10	2	11.0	-6.2288	4.0	3.0	2	.5790	1	4
10	3	33.0	-7.9658	11.0	4.0	2	.5280	1	4
10	4	117.0	-9.6439	43.0	4.0	2	.5830	1	4
10	5	86.0	-9.5118	52.0	4.0	1	.7550	1	4
10	6	88.0	-9.3663	52.0	4.0	1	.7750	1	4
10	7	69.0	-8.7482	32.0	3.0	3	.7020	1	4
10	8	66.0	-8.9944	31.0	4.0	2	.6590	1	4
10	9	70.0	-9.2046	40.0	2.0	1	.7290	1	5
10	10	45.0	-8.0224	25.9	3.0	3	.8310	1	6
10	11	2.0	-8.6073	37.0	3.0	3	.7010	1	6
10	12	36.0	-7.8455	7.0	2.0	4	.3900	1	6
10	13	49.0	-8.6439	13.0	3.0	2	.4420	1	6
11	2	66.0	-8.7814	22.0	5.0	4	.5510	1	4
11	3	64.0	-8.2288	29.9	5.0	3	.7750	1	4
11	4	56.0	-8.7482	11.0	5.0	2	.3690	1	4
11	5	358.0	-11.2288	96.0	2.0	2	.4750	1	4
11	6	358.0	-11.2288	96.0	2.0	2	.4750	1	4
11	7	48.0	-8.8765	23.0	3.0	2	.6170	1	4
11	8	120.0	-9.1293	43.0	3.0	3	.6510	1	4
11	9	33.0	-7.9069	14.0	4.0	2	.6280	1	5
11	10	45.0	-7.7142	19.0	2.0	3	.7260	1	5
11	11	30.0	-7.6439	19.0	2.0	3	.8440	1	5
11	12	89.0	-9.2992	32.0	3.0	2	.5680	1	6
11	13	105.0	-9.4305	60.0	3.0	3	.7920	1	6
11	14	43.0	-8.6439	14.0	2.0	2	.4850	1	6
12	3	576.0	-11.5216	159.0	3.0	4	.5310	1	4
12	4	133.0	-9.9944	70.0	5.0	1	.7120	1	4
12	5	250.0	-10.4818	125.0	2.0	3	.7590	1	4
12	6	74.0	-8.8138	29.0	4.0	4	.6320	1	4
12	7	204.0	-10.8918	92.0	3.0	2	.6020	1	4
12	8	155.0	-10.3219	72.0	4.0	2	.6400	1	4
12	9	82.0	-8.3663	28.0	5.0	3	.6620	1	5
12	10	82.0	-8.9366	29.0	1.0	4	.5940	1	5
12	11	135.0	-9.2761	53.0	4.0	3	.6950	1	5
12	12	93.0	-9.0768	26.0	3.0	2	.5130	1	5
12	13	48.0	-8.8455	28.0	3.0	2	.7080	1	5
12	14	60.0	-8.6073	17.0	3.0	4	.4980	1	6
12	15	48.0	-8.5314	36.0	2.0	1	.9000	1	6

X	Y	A	PHI B	C	R	SH	SPHER	LONG	UP
12	16	62.0	-8.8455	14.0	1.0	2	.4100	1	6
13	4	132.0	-9.2288	46.0	4.0	3	.6440	2	4
13	5	78.0	-8.9069	46.0	3.0	3	.8270	2	4
13	6	135.0	-9.8765	86.0	3.0	1	.8350	2	4
13	7	50.0	-8.8455	17.0	5.0	2	.5010	2	4
13	8	64.0	-9.2046	25.0	2.0	2	.5490	2	4
13	9	95.0	-9.6073	63.0	4.0	1	.8120	2	5
13	10	80.0	-8.8455	23.0	4.0	4	.5240	2	5
13	11	94.0	-9.1548	33.0	3.0	4	.5880	2	5
13	12	54.0	-9.0498	37.0	2.0	1	.7820	2	5
13	13	94.0	-9.8138	58.0	5.0	2	.7360	2	6
13	14	41.0	-8.3219	28.0	3.0	1	.8420	2	6
13	15	81.0	-9.2527	25.0	2.0	2	.5020	2	6
14	5	104.0	-9.3880	65.0	4.0	3	.8470	2	4
14	6	234.0	-10.3106	46.0	2.0	3	.4150	2	4
14	7	38.0	-8.0768	12.0	4.0	4	.5200	2	4
14	8	80.0	-9.3443	38.0	4.0	2	.6530	2	4
14	9	83.0	-9.6257	45.0	4.0	2	.6760	2	5
14	10	49.0	-8.6439	18.0	4.0	2	.5490	2	5
14	11	64.0	-8.0768	21.0	3.0	3	.6350	2	5
14	12	72.0	-9.2046	30.0	5.0	2	.5960	2	5
14	13	67.0	-8.4512	29.0	2.0	3	.7110	2	5
14	14	89.0	-9.6439	24.0	4.0	2	.4330	2	6
14	15	73.0	-8.9658	48.0	5.0	1	.8580	2	6
14	16	51.0	-8.5699	25.0	3.0	2	.6860	2	6
14	17	24.0	-7.4094	15.0	1.0	1	.8200	2	6
15	4	102.0	-9.1293	36.0	4.0	4	.6100	2	4
15	5	69.0	-8.6439	26.0	4.0	4	.6260	2	4
15	6	154.0	-10.4200	49.0	5.0	2	.4850	2	4
15	7	62.0	-8.4919	28.0	3.0	3	.7060	2	4
15	8	92.0	-9.7977	44.0	4.0	2	.6190	2	4
15	9	69.0	-9.2527	28.0	5.0	2	.5710	2	5
15	10	75.0	-9.3443	32.0	4.0	2	.5950	2	5
15	11	60.0	-8.4094	25.0	5.0	3	.6740	2	5
15	12	82.0	-9.0224	12.0	4.0	4	.3240	2	5
15	13	49.0	-8.1799	14.0	4.0	4	.5170	2	6
15	14	13.0	-6.6439	8.0	1.0	1	.7900	2	6
15	15	89.0	-8.8765	46.0	4.0	3	.7970	2	6
15	16	41.0	-8.4919	22.0	2.0	2	.6900	2	6
15	17	73.0	-8.4094	22.0	5.0	4	.5800	2	6
16	2	140.0	-9.9801	55.0	5.0	2	.5980	2	4
16	3	110.0	-9.9218	70.0	5.0	1	.7720	2	4
16	4	64.0	-8.8765	27.0	3.0	2	.6240	2	4
16	5	170.0	-10.1799	95.0	4.0	1	.7710	2	4
16	6	159.0	-9.9366	82.0	5.0	3	.7560	2	4
16	7	42.0	-7.9658	22.0	4.0	3	.7730	2	4
16	8	155.0	-9.7649	45.0	3.0	4	.5320	2	4
16	9	92.0	-8.4919	21.0	3.0	4	.5110	2	5
16	10	125.0	-9.7977	62.0	1.0	1	.7020	2	5
16	11	62.0	-9.2288	47.0	3.0	1	.8410	2	5
16	12	32.0	-8.2761	20.0	3.0	2	.7390	2	5
16	13	29.0	-8.0224	20.0	3.0	1	.8100	2	6
16	14	36.0	-8.4512	12.0	1.0	2	.4860	2	6

X	Y	A	PHI B	C	R	SH	SPHER	LONG	UP
16	15	42.0	-7.7142	14.0	3.0	4	.6060	2	6
16	16	44.0	-8.4919	20.0	4.0	2	.6320	2	6
16	17	26.0	-7.3219	13.0	3.0	3	.7410	2	6
17	5	152.0	-9.5699	56.0	5.0	3	.6480	2	4
17	6	280.0	-10.4512	107.0	4.0	3	.6640	2	4
17	7	158.0	-10.3443	67.0	4.0	2	.6030	2	4
17	8	150.0	-9.4919	37.0	4.0	4	.5030	2	4
17	9	93.0	-9.3443	50.0	4.0	1	.7450	2	5
17	10	128.0	-9.4512	29.0	4.0	4	.4550	2	5
17	11	44.0	-8.7142	25.0	3.0	2	.6970	2	5
17	12	51.0	-7.4919	17.0	4.0	3	.6810	2	5
17	13	42.0	-8.2761	22.0	2.0	1	.7190	2	5
17	14	63.0	-9.0768	47.0	1.0	1	.8660	2	5
17	15	76.0	-8.7814	38.0	3.0	3	.7560	2	6
17	16	43.0	-8.2288	11.0	3.0	2	.4550	2	6
17	17	45.0	-8.1799	20.0	4.0	3	.6750	2	6
17	18	73.0	-8.9069	39.0	3.0	3	.7570	2	6
18	5	142.0	-10.1548	60.0	3.0	2	.6060	2	4
18	6	152.0	-10.4409	94.0	5.0	1	.7480	2	4
18	7	310.0	-10.4512	84.0	3.0	4	.5460	2	4
18	8	80.0	-9.0768	33.0	4.0	2	.6320	2	4
18	9	45.0	-7.4919	17.0	4.0	3	.7100	2	5
18	10	94.0	-9.1799	27.0	4.0	4	.5120	2	5
18	11	49.0	-8.2761	30.0	2.0	3	.8400	2	5
18	12	80.0	-8.5314	22.0	2.0	4	.5470	2	5
18	13	73.0	-8.0768	16.0	2.0	4	.5070	2	5
18	14	62.0	-8.7814	42.0	3.0	1	.8650	2	5
18	15	0.0	-8.9366	24.0	3.0	2	.5810	2	5
18	16	42.0	-8.1799	20.0	3.0	1	.6900	2	6
18	17	83.0	-8.5314	30.0	2.0	3	.6650	2	6
18	18	62.0	-8.9658	18.0	2.0	2	.4710	2	6
18	19	64.0	-8.7814	36.0	3.0	1	.7720	2	6
19	6	128.0	-10.1548	72.0	5.0	2	.7080	2	4
19	7	304.0	-10.6348	59.0	4.0	4	.4160	2	4
19	8	108.0	-10.0362	89.0	3.0	1	.8870	2	4
19	9	112.0	-9.6439	53.0	4.0	2	.6800	2	5
19	10	86.0	-8.7142	34.0	3.0	3	.6840	2	5
19	11	62.0	-9.2046	46.0	3.0	1	.8330	2	5
19	12	52.0	-8.4094	15.0	3.0	4	.5030	2	5
19	13	45.0	-8.2288	26.0	4.0	3	.7940	2	5
19	14	65.0	-8.9658	39.0	3.0	1	.7770	2	5
19	15	62.0	-7.6439	19.0	2.0	3	.6630	2	5
19	16	32.0	-8.0768	8.0	4.0	2	.4200	2	6
19	17	32.0	-7.4094	14.0	3.0	3	.7120	2	6
19	18	67.0	-8.6439	21.0	4.0	4	.5480	2	6
20	4	130.0	-10.0084	90.0	5.0	1	.8460	2	4
20	5	152.0	-9.9218	68.0	4.0	3	.6800	2	4
20	6	184.0	-9.9801	37.0	4.0	4	.4200	2	4
20	7	127.0	-9.9069	53.0	3.0	2	.6130	2	4
20	8	13.0	-6.9658	10.0	3.0	1	.8510	2	4
20	9	105.0	-9.6439	54.0	3.0	1	.7030	2	5
20	10	123.0	-9.3880	65.0	4.0	3	.8010	2	5
20	11	39.0	-7.7814	8.0	3.0	4	.4330	2	5

X	Y	A	PHI B	C	R	SH	SPHER	LONG	UP
20	12	44.0	-8.4512	24.0	2.0	1	.7210	2	5
20	13	95.0	-9.1799	19.0	3.0	4	.4040	2	5
20	14	44.0	-8.1799	23.0	3.0	3	.7460	2	5
20	15	46.0	-7.4094	8.0	2.0	4	.4350	2	5
20	16	13.0	-6.1293	5.0	1.0	3	.6500	2	6
21	6	160.0	-10.5699	46.0	4.0	2	.4430	2	4
21	7	118.0	-10.0634	55.0	4.0	2	.6210	2	4
21	8	109.0	-9.7142	32.0	3.0	2	.4820	2	4
21	9	67.0	-9.3663	25.0	4.0	2	.5210	2	5
21	10	62.0	-8.4094	19.0	4.0	4	.5560	2	5
21	11	75.0	-8.8765	41.0	2.0	3	.7810	2	5
21	12	65.0	-8.7142	25.0	4.0	4	.6120	2	5
21	13	61.0	-8.4512	18.0	3.0	4	.5340	2	5
21	14	27.0	-7.2288	10.0	2.0	4	.6280	2	5
21	15	32.0	-7.9658	16.0	3.0	2	.6840	2	5
21	16	56.0	-8.0224	20.0	2.0	3	.6500	2	6
22	7	112.0	-9.9513	66.0	3.0	2	.7330	3	4
22	8	150.0	-10.2761	56.0	4.0	2	.5530	3	4
22	9	119.0	-9.9944	97.0	4.0	1	.9190	3	5
22	10	75.0	-8.1799	22.0	5.0	3	.6060	3	5
22	11	80.0	-9.4512	28.0	3.0	2	.5200	3	5
22	12	47.0	-7.7142	19.0	4.0	3	.7150	3	5
22	13	39.0	-8.1293	20.0	3.0	1	.7160	3	5
22	14	11.0	-6.0224	5.0	5.0	3	.7050	3	5
22	15	61.0	-9.1033	26.0	3.0	2	.5870	3	6
22	16	33.0	-7.7142	15.0	3.0	3	.6880	3	6
22	17	24.0	-6.9069	7.0	2.0	4	.5540	3	6
23	6	120.0	-9.6795	80.0	3.0	1	.8670	3	4
23	7	136.0	-10.2761	64.0	5.0	2	.6240	3	4
23	8	120.0	-9.2527	55.0	4.0	3	.7450	3	4
23	9	107.0	-8.9069	43.0	5.0	3	.7120	3	5
23	10	116.0	-9.7649	75.0	3.0	1	.8230	3	5
23	11	49.0	-8.5314	11.0	3.0	2	.4060	3	5
23	12	17.0	-6.7814	6.0	3.0	4	.5780	3	5
23	13	82.0	-9.4512	35.0	4.0	2	.5980	3	5
23	14	78.0	-9.4094	38.0	4.0	2	.6480	3	5
23	15	51.0	-8.7142	24.0	1.0	2	.6460	3	5
23	16	10.0	-6.5699	3.5	3.0	2	.5060	3	5
23	17	29.0	-7.4919	17.0	4.0	3	.8210	3	6
24	5	114.0	-9.8611	57.0	5.0	2	.6740	3	4
24	6	158.0	-9.5887	76.0	3.0	3	.7800	3	4
24	7	135.0	-10.3443	85.0	4.0	2	.7440	3	4
24	8	110.0	-10.0362	45.0	3.0	2	.5600	3	4
24	9	57.0	-8.2288	18.0	4.0	4	.5750	3	5
24	10	150.0	-9.2046	52.0	5.0	3	.6740	3	5
24	11	78.0	-8.5314	26.0	4.0	3	.6170	3	5
24	12	44.0	-8.4094	13.0	3.0	2	.4840	3	5
24	13	48.0	-8.8138	32.0	3.0	1	.7800	3	5
24	14	61.0	-8.4919	29.0	3.0	3	.7260	3	5
24	15	40.0	-8.3219	11.0	2.0	2	.4560	3	5
24	16	31.0	-6.4919	8.9	3.0	3	.6580	3	5
24	17	29.0	-6.9069	10.0	3.0	3	.6600	3	6
25	7	108.0	-9.4094	67.0	4.0	3	.8490	3	4

X	Y	A	PHI B	C	R	SH	SPHER	LONG	UP
25	8	122.0	-9.2288	34.0	3.0	4	.5410	3	4
25	9	123.0	-9.5314	36.0	3.0	4	.5230	3	5
25	10	10.0	-6.3219	5.0	4.0	2	.6790	3	5
25	11	26.0	-7.6439	8.0	5.0	2	.4980	3	5
25	12	40.0	-8.0768	24.0	4.0	1	.8110	3	5
25	13	38.0	-8.4919	20.0	4.0	2	.6640	3	5
25	14	54.0	-8.6795	20.0	2.0	2	.5660	3	5
25	15	43.0	-8.4919	9.0	2.0	2	.3740	3	5
25	16	27.0	-7.4094	11.0	3.0	4	.6410	3	5
25	17	30.0	-7.0224	11.0	2.0	3	.6770	3	5
25	18	54.0	-8.0224	17.0	4.0	4	.5910	3	6
26	7	129.0	-10.1548	84.0	3.0	1	.7830	3	4
26	8	26.0	-7.0224	7.0	5.0	4	.5260	3	4
26	9	81.0	-9.2761	17.0	4.0	2	.3860	3	5
26	10	72.0	-9.1293	52.0	3.0	1	.8750	3	5
26	11	25.0	-7.3219	8.0	4.0	4	.5430	3	5
26	12	17.0	-6.9069	2.0	4.0	2	.2700	3	5
26	13	72.0	-9.1548	45.0	3.0	1	.7900	3	5
26	14	72.0	-8.6795	19.0	3.0	4	.4970	3	5
26	15	27.0	-7.8455	9.0	4.0	2	.5070	3	5
26	16	36.0	-7.4919	9.0	2.0	4	.5000	3	5
26	17	30.0	-7.7142	17.0	5.0	1	.7710	3	6
26	18	29.0	-7.4919	9.0	4.0	4	.5380	3	6
26	19	34.0	-7.7814	20.0	4.0	3	.8120	3	6
27	6	143.0	-9.7977	87.0	3.0	3	.8410	3	4
27	7	148.0	-9.8138	83.0	2.0	3	.8030	3	4
27	8	6.0	-5.1293	1.5	5.0	4	.4750	3	4
27	9	114.0	-9.8138	60.0	3.0	2	.7060	3	5
27	10	100.0	-9.2046	51.0	3.0	3	.7610	3	5
27	11	81.0	-9.0498	16.0	4.0	4	.3910	3	5
27	12	75.0	-9.1033	40.0	3.0	1	.7300	3	5
27	13	78.0	-9.1548	22.0	3.0	2	.4780	3	5
27	14	48.0	-8.4512	30.0	4.0	1	.8120	3	5
27	15	26.0	-7.9658	23.0	1.0	1	.9340	3	5
27	16	57.0	-8.6073	26.0	2.0	2	.6730	3	5
27	17	16.0	-6.6439	9.0	4.0	3	.7970	3	6
27	18	36.0	-8.2288	19.0	3.0	2	.6940	3	6
28	6	136.0	-9.9658	49.0	4.0	2	.5610	3	4
28	7	77.0	-9.5699	26.0	3.0	2	.4870	3	4
28	8	24.0	-7.4919	8.0	3.0	2	.5290	3	4
28	9	91.0	-9.2761	23.0	4.0	2	.4550	3	5
28	10	130.0	-9.4512	49.0	2.0	3	.6420	3	5
28	11	115.0	-9.4717	43.0	2.0	4	.6100	3	5
28	12	101.0	-9.0224	34.0	3.0	4	.6040	3	5
28	13	105.0	-9.2527	28.0	2.0	4	.4970	3	5
28	14	7.0	-5.6439	3.0	4.0	2	.6360	3	5
28	15	39.0	-7.6439	19.0	3.0	3	.7740	3	5
28	16	6.0	-5.6439	2.0	4.0	2	.5110	3	5
28	17	16.0	-7.0224	7.0	4.0	2	.6180	3	6
28	18	7.0	-6.1085	2.5	4.0	2	.5060	3	6
29	6	116.0	-9.7313	36.0	3.0	2	.5090	3	4
29	7	97.0	-9.2527	37.0	3.0	4	.6140	3	4
29	8	72.0	-9.3880	35.0	3.0	2	.6340	3	4

X	Y	A	PHI B	C	R	SH	SPHER	LONG	UP
29	9	57.0	-9.0224	34.0	3.0	2	.7310	3	5
29	10	78.0	-9.2761	24.0	5.0	2	.4920	3	5
29	11	9.0	-6.3219	5.0	3.0	2	.7030	3	5
29	12	88.0	-8.3219	29.0	3.0	3	.6690	3	5
29	13	56.0	-8.4919	32.0	3.0	3	.7980	3	5
29	14	84.0	-8.0768	23.0	2.0	3	.6160	3	5
29	15	52.0	-8.9069	28.0	2.0	2	.6800	3	5
29	16	17.0	-6.4919	7.0	4.0	3	.6840	3	5
29	17	39.0	-7.7142	17.0	3.0	3	.7070	3	6
29	18	70.0	-8.5314	16.0	2.0	4	.4630	3	6
29	19	10.0	-5.6439	4.9	1.0	3	.7830	3	6
30	7	95.0	-9.8611	33.0	2.0	2	.4980	3	4
30	8	22.0	-6.9069	8.0	6.0	4	.6240	3	4
30	9	75.0	-9.1799	55.0	4.0	1	.8860	3	5
30	10	55.0	-8.7814	8.0	3.0	2	.2980	3	5
30	11	20.0	-7.2288	10.0	3.0	2	.6940	3	5
30	12	13.0	-6.3219	7.0	4.0	3	.7780	3	5
30	13	15.0	-6.6439	7.0	4.0	3	.6890	3	5
30	14	11.0	-6.6439	7.0	2.0	1	.7640	3	5
30	15	28.0	-7.4919	7.0	3.0	4	.4600	3	5
30	16	39.0	-8.0224	22.0	3.0	3	.7820	3	5
30	17	49.0	-8.6795	16.0	4.0	2	.5040	3	6
30	18	5.0	-5.4919	1.5	4.0	2	.4650	3	6
30	19	19.0	-7.4094	10.0	2.0	2	.6770	3	6

CROOKHAVEN BOULDER BEACH

X	Y	A	PHI B	C	R	SH	SPHER	LONG	UP
1	5	95.0	-9.4094	67.0	2.0	1	.8860	1	4
1	6	117.0	-9.9069	79.0	2.0	1	.8220	1	4
1	7	71.0	-9.4305	49.0	2.0	1	.7890	1	4
1	8	66.0	-9.2761	46.0	2.0	1	.8030	1	5
1	9	59.0	-8.8765	28.0	1.0	2	.6570	1	5
1	10	82.0	-9.1799	37.0	1.0	2	.6610	1	5
1	11	40.0	-8.1293	8.0	1.0	2	.3860	1	6
1	12	140.0	-9.8611	72.0	3.0	3	.7360	1	6
2	4	145.0	-10.0084	101.0	1.0	4	.8810	1	4
2	5	165.0	-9.7814	42.0	2.0	2	.4960	1	4
2	6	26.0	-7.6439	8.0	3.0	1	.4980	1	4
2	7	93.0	-9.2992	44.0	2.0	3	.6920	1	4
2	9	257.0	-10.3332	101.0	1.0	1	.6750	1	5
2	10	94.0	-9.4717	56.0	1.0	2	.7780	1	5
2	11	54.0	-8.9944	27.0	2.0	1	.6420	1	5
2	12	102.0	-9.6795	55.0	3.0	2	.7130	1	5
2	13	106.0	-9.7313	28.0	2.0	1	.4430	1	6
2	14	9.5	-6.1293	4.5	1.0	2	.6730	1	6
2	15	116.0	-9.9069	64.0	2.0	2	.7170	1	6
3	4	225.0	-10.5507	114.0	3.0	3	.7280	1	4
3	5	68.0	-9.2992	46.0	2.0	1	.7910	1	4
3	6	107.0	-10.0498	99.0	2.0	1	.9530	1	4
3	7	124.0	-9.9218	78.0	3.0	1	.7970	1	4
3	8	180.0	-10.3219	77.0	1.0	2	.6360	1	5
3	9	66.0	-8.9366	25.0	1.0	2	.5780	1	5
3	10	112.0	-10.1163	52.0	1.0	2	.6020	1	5
3	11	73.0	-9.2992	53.0	1.0	1	.8490	1	5
3	12	22.0	-7.4512	13.0	2.0	1	.7600	1	5
3	13	28.0	-8.0768	25.0	1.0	1	.9390	1	6
3	14	58.0	-8.4512	31.0	1.0	3	.7800	1	6
3	15	92.0	-9.1548	51.0	2.0	3	.7920	1	6
3	16	61.0	-8.8765	29.0	1.0	2	.6650	1	6
4	5	109.0	-9.7649	18.0	2.0	2	.3250	1	4
4	8	250.0	-10.8138	160.0	2.0	1	.8290	1	4
4	9	160.0	-10.3443	87.0	3.0	1	.7140	1	5
4	10	35.0	-8.3663	25.0	1.0	1	.8150	1	5
4	11	120.0	-9.9069	54.0	1.0	2	.6330	1	5
4	12	136.0	-10.1674	47.0	1.0	2	.5210	1	5
4	13	182.0	-10.4094	83.0	1.0	2	.6530	1	5
4	14	67.0	-9.0498	51.0	1.0	1	.9020	1	6
4	15	65.0	-8.9658	43.0	1.0	1	.8290	1	6
4	16	110.0	-9.8918	67.0	1.0	1	.7550	1	6
4	17	192.0	-9.8765	39.0	2.0	4	.4390	1	6
4	18	113.0	-9.8138	67.0	2.0	1	.7620	1	6
5	2	172.0	-9.9658	80.0	2.0	3	.7190	1	4
5	3	57.0	-8.7814	20.0	2.0	2	.5430	1	4
5	4	123.0	-9.8455	76.0	3.0	1	.7990	1	4
5	5	180.0	-10.5018	84.0	2.0	2	.6470	1	4
5	6	99.0	-9.6257	60.0	2.0	1	.7720	1	4
5	7	100.0	-9.7649	50.0	2.0	2	.6600	1	4
5	8	239.0	-10.3987	108.0	2.0	3	.7130	1	5
5	9	106.0	-10.0084	101.0	1.0	1	.9780	1	5
5	10	204.0	-10.2877	45.0	1.0	4	.4300	1	5

X	Y	A	PHI B	C	R	SH	SPHER	LONG	UP
5	11	202.0	-10.5314	100.0	2.0	1	.6940	1	5
5	12	140.0	-9.9658	80.0	3.0	1	.7710	1	6
5	13	51.0	-8.9658	26.0	1.0	2	.6430	1	6
5	14	141.0	-9.9658	90.0	1.0	1	.8310	1	6
6	2	59.0	-8.9069	31.0	2.0	2	.6980	1	4
6	3	133.0	-10.2527	80.0	3.0	2	.7340	1	4
6	4	120.0	-10.0498	65.0	2.0	2	.6930	1	4
6	5	160.0	-9.9218	47.0	3.0	4	.5220	1	4
6	6	186.0	-10.2288	100.0	2.0	3	.7650	1	4
6	7	94.0	-9.1548	45.0	2.0	3	.7230	1	4
6	8	127.0	-10.2046	50.0	1.0	2	.5510	1	5
6	9	165.0	-10.1421	97.0	2.0	1	.7960	1	5
6	10	140.0	-10.1923	98.0	1.0	1	.8370	1	5
6	11	152.0	-10.0901	99.0	1.0	1	.8400	1	5
6	12	32.0	-7.5699	14.0	3.0	3	.6860	1	6
6	13	41.0	-7.9069	13.0	1.0	4	.5560	1	6
6	14	102.0	-9.3443	52.0	1.0	3	.7420	1	6
6	15	72.0	-9.2761	45.0	1.0	1	.7690	1	6
7	4	160.0	-10.0634	82.0	3.0	1	.7330	1	4
7	7	190.0	-10.2761	80.0	2.0	4	.6480	1	4
7	8	89.0	-9.6439	23.0	2.0	2	.4210	1	5
7	9	64.0	-8.9658	43.0	1.0	1	.8330	1	5
7	10	84.0	-9.5887	63.0	1.0	1	.8500	1	5
7	11	69.0	-9.0768	24.0	1.0	2	.5370	1	5
7	12	140.0	-10.0768	63.0	1.0	2	.6410	1	5
7	13	24.0	-7.7814	15.0	1.0	1	.7530	1	6
7	14	80.0	-9.2046	43.0	1.0	1	.7320	1	6
7	15	105.0	-9.3219	45.0	1.0	3	.6710	1	6
8	1	138.0	-10.3443	109.0	2.0	1	.8720	1	4
8	7	150.0	-9.8138	70.0	2.0	3	.7140	1	4
8	8	130.0	-9.5507	60.0	1.0	3	.7180	1	5
8	9	104.0	-9.4512	40.0	2.0	2	.6040	1	5
8	10	115.0	-9.4512	53.0	2.0	3	.7040	1	5
8	11	82.0	-9.2761	56.0	1.0	1	.8510	1	6
8	12	102.0	-9.5507	68.0	1.0	1	.8460	1	6
8	13	100.0	-9.2288	50.0	1.0	3	.7470	1	6
9	3	107.0	-10.0362	80.0	2.0	1	.8290	1	4
9	4	31.0	-8.0224	15.0	4.0	2	.6540	1	4
9	5	160.0	-10.6348	88.0	2.0	2	.6730	1	4
9	6	39.0	-8.4919	10.0	2.0	2	.4150	1	4
9	7	78.0	-9.5314	56.0	3.0	1	.8160	1	4
9	8	81.0	-9.1033	44.0	1.0	1	.7580	1	5
9	9	59.0	-9.1033	37.0	2.0	1	.7500	1	5
9	10	72.0	-9.3219	43.0	1.0	1	.7380	1	5
9	11	55.0	-8.8455	45.0	2.0	1	.9290	1	5
9	12	106.0	-9.9658	70.0	2.0	1	.7730	1	5
9	13	150.0	-10.4512	59.0	1.0	2	.5500	1	6
9	14	23.0	-7.6439	7.0	1.0	2	.4740	1	6
9	15	90.0	-9.1548	54.0	1.0	3	.8290	1	6
9	16	50.0	-8.9366	40.0	1.0	1	.8680	1	6
10	2	160.0	-10.0498	97.0	3.0	3	.8220	1	4
10	3	140.0	-10.2992	57.0	3.0	2	.5690	1	4
10	5	50.0	-8.6439	25.0	2.0	2	.6790	1	4

X	Y	A	PHI B	C	R	SH	SPHER	LONG	UP
10	6	34.0	-8.3663	22.0	2.0	2	.7560	1	4
10	7	92.0	-9.7977	73.0	2.0	1	.8670	1	4
10	8	61.0	-8.5314	22.0	2.0	4	.5990	1	5
10	9	360.0	-10.6439	75.0	2.0	4	.4610	1	5
10	10	360.0	-10.6439	75.0	2.0	4	.4610	1	5
10	11	140.0	-9.5507	73.0	1.0	3	.7980	1	5
10	12	177.0	-10.5216	63.0	1.0	2	.5350	1	6
10	13	96.0	-9.5314	65.0	1.0	1	.8410	1	6
10	14	74.0	-9.3443	47.0	1.0	1	.7720	1	6
11	2	60.0	-9.0224	39.0	3.0	1	.7870	2	4
11	4	79.0	-9.2288	42.0	3.0	1	.7200	2	4
11	5	124.0	-10.1163	52.0	2.0	2	.5820	2	4
11	6	109.0	-9.4512	65.0	3.0	3	.8210	2	4
11	7	44.0	-8.1293	13.0	2.0	4	.5160	2	4
11	8	55.0	-8.8455	39.0	2.0	1	.8440	2	5
11	9	25.0	-7.7814	5.5	1.0	2	.3810	2	5
11	10	105.0	-9.4512	65.0	1.0	3	.8320	2	5
11	11	81.0	-9.5699	45.0	2.0	2	.6910	2	5
11	12	155.0	-10.0901	96.0	2.0	1	.8170	2	6
11	13	9.0	-5.9069	5.0	4.0	3	.7740	2	6
11	14	20.0	-7.3219	9.0	3.0	2	.6330	2	6
12	2	97.0	-9.8455	68.0	2.0	1	.8030	2	4
12	3	116.0	-9.8611	70.0	2.0	1	.7690	2	4
12	4	40.0	-8.4094	27.0	5.0	1	.8120	2	4
12	5	85.0	-9.2992	33.0	2.0	2	.5880	2	4
12	6	105.0	-9.8918	40.0	4.0	2	.5440	2	4
12	7	65.0	-9.1799	54.0	3.0	1	.9180	2	4
12	8	34.0	-8.1799	8.0	3.0	2	.4020	2	5
12	9	48.0	-8.3219	25.0	5.0	3	.7410	2	5
12	10	91.0	-9.7977	81.0	1.0	1	.9320	2	5
12	11	70.0	-9.2527	55.0	1.0	1	.8920	2	5
12	12	107.0	-9.7482	68.0	2.0	1	.7950	2	6
12	13	170.0	-10.1033	85.0	2.0	3	.7260	2	6
12	14	9.5	-6.2288	3.0	6.0	2	.5020	2	6
12	15	42.0	-8.6439	27.0	4.0	1	.7570	2	6
13	3	155.0	-10.0362	62.0	3.0	4	.6180	2	4
13	4	76.0	-9.3219	30.0	2.0	2	.5700	2	4
13	5	90.0	-9.0768	37.0	3.0	3	.6560	2	4
13	7	100.0	-9.8297	76.0	2.0	1	.8600	2	4
13	8	106.0	-9.5314	61.0	2.0	1	.7800	2	5
13	9	109.0	-9.4919	41.0	2.0	4	.5990	2	5
13	10	87.0	-9.2761	48.0	1.0	1	.7530	2	5
13	11	6.7	-5.3219	2.0	6.0	4	.5310	2	5
13	12	50.0	-8.7814	39.0	1.0	1	.8840	2	5
13	13	114.0	-9.6795	67.0	2.0	1	.7830	2	6
13	14	71.0	-9.2046	40.0	1.0	1	.7260	2	6
13	15	116.0	-9.4094	63.0	2.0	3	.7960	2	6
14	4	153.0	-10.0224	63.0	2.0	2	.6300	2	4
14	5	94.0	-9.5118	52.0	3.0	1	.7330	2	4
14	7	68.0	-9.4073	67.8	2.0	1	.9990	2	4
14	8	145.0	-9.7142	68.0	2.0	3	.7240	2	5
14	9	125.0	-9.7313	58.0	1.0	1	.6820	2	5
14	10	24.0	-7.7482	5.5	3.0	2	.3890	2	5

X	Y	A	PHI B	C	R	SH	SPHER	LONG	UP
14	11	61.0	-8.8765	28.0	2.0	2	.6490	2	5
14	12	162.0	-9.4919	42.0	1.0	4	.5330	2	5
14	13	116.0	-10.0362	65.0	1.0	2	.7030	2	6
14	14	9.5	-5.7814	5.0	6.0	3	.7820	2	6
14	15	102.0	-9.9658	67.0	1.0	1	.7610	2	6
15	6	91.0	-9.7313	61.0	5.0	1	.7840	2	4
15	7	80.0	-9.0224	20.0	5.0	4	.4580	2	4
15	8	147.0	-10.2408	49.0	2.0	2	.5130	2	5
15	9	124.0	-9.4512	65.0	2.0	3	.7870	2	5
15	10	120.0	-9.7814	58.0	2.0	2	.6830	2	5
15	11	25.0	-7.8455	17.0	3.0	1	.7950	2	5
15	12	33.0	-7.7142	13.0	2.0	4	.6250	2	5
15	13	48.0	-8.7814	35.0	2.0	1	.8340	2	6
15	14	33.0	-8.2288	22.0	1.0	1	.7880	2	6
15	15	50.0	-8.9069	30.0	2.0	2	.7210	2	6
15	16	55.0	-8.9366	21.0	1.0	2	.5470	2	6
16	6	74.0	-9.0224	43.0	3.0	1	.7830	2	4
16	7	77.0	-9.1033	44.0	3.0	1	.7710	2	4
16	8	154.0	-9.1293	37.0	2.0	4	.5420	2	5
16	9	145.0	-10.3987	67.0	2.0	2	.6120	2	5
16	10	118.0	-9.8765	75.0	1.0	1	.7980	2	5
16	11	88.0	-9.1293	33.0	4.0	4	.6050	2	5
16	12	39.0	-8.3663	32.0	2.0	1	.9270	2	6
16	13	18.0	-6.7814	7.0	4.0	4	.6280	2	6
16	14	56.0	-8.8138	41.0	1.0	1	.8740	2	6
16	15	11.0	-6.4919	3.0	1.0	2	.4500	2	6
17	6	120.0	-9.9944	76.0	4.0	1	.7790	2	4
17	7	21.0	-7.1293	4.0	1.0	4	.3790	2	4
17	8	35.0	-8.0768	26.0	4.0	1	.8940	2	5
17	9	102.0	-9.1548	41.0	3.0	3	.6620	2	5
17	10	43.0	-8.3663	21.0	3.0	2	.6780	2	6
17	11	66.0	-9.1033	31.0	2.0	2	.6420	2	6
17	12	49.0	-8.1799	27.0	2.0	3	.8010	2	6
17	13	6.5	-5.3219	3.9	4.0	3	.8360	2	6
18	5	94.0	-9.5887	71.0	3.0	1	.8870	2	4
18	6	83.0	-9.5887	60.0	3.0	1	.8260	2	4
18	8	70.0	-8.7814	42.0	2.0	3	.8310	2	5
18	9	5.0	-4.7549	2.0	6.0	3	.6670	2	5
18	10	103.0	-9.4305	35.0	2.0	2	.5570	2	6
18	11	18.5	-7.1293	7.0	5.0	2	.5740	2	6
18	12	72.0	-9.3443	48.0	2.0	1	.7900	2	6
19	6	85.0	-9.5887	69.0	2.0	1	.8990	2	4
19	7	51.0	-8.5314	18.0	3.0	2	.5560	2	4
19	8	144.0	-9.7814	68.0	2.0	3	.7150	2	5
19	9	63.0	-9.0224	35.0	3.0	1	.7210	2	5
19	10	83.0	-9.4094	32.0	2.0	2	.5660	2	5
19	11	93.0	-9.2992	52.0	1.0	1	.7730	2	5
19	12	25.0	-7.8455	17.0	1.0	1	.7950	2	5
19	13	78.0	-9.5118	46.0	5.0	2	.7190	2	6
19	14	75.0	-9.4305	52.0	1.0	1	.8060	2	6
19	15	13.5	-6.4919	7.0	4.0	3	.7390	2	6
20	5	65.0	-8.9366	25.0	4.0	2	.5810	2	4
20	6	14.0	-7.0224	4.0	3.0	2	.4450	2	4

X	Y	A	PHI B	C	R	SH	SPHER	LONG	UP
20	7	85.0	-9.0224	48.0	2.0	3	.8050	2	4
20	8	90.0	-8.9069	47.0	3.0	3	.8000	2	5
20	9	69.0	-9.3663	33.0	4.0	2	.6210	2	5
20	10	54.0	-8.7142	30.0	2.0	1	.7350	2	5
20	11	110.0	-9.9801	74.0	1.0	2	.1700	2	5
20	12	72.0	-8.6439	39.0	3.0	3	.8080	2	6
20	13	7.0	-5.9069	3.5	1.0	2	.6630	2	6
20	14	135.0	-9.9069	39.0	5.0	2	.4900	2	6
21	3	160.0	-9.7313	42.0	3.0	4	.5070	3	4
21	4	70.0	-9.2288	50.0	2.0	1	.8410	3	4
21	5	113.0	-9.1293	19.0	2.0	4	.3850	3	4
21	6	140.0	-9.9801	77.0	3.0	1	.7490	3	4
21	7	107.0	-9.5887	72.0	5.0	1	.8570	3	4
21	8	83.0	-9.2992	37.0	3.0	2	.6400	3	5
21	9	10.0	-5.9773	2.2	6.0	4	.4250	3	5
21	10	107.0	-9.8138	77.0	2.0	1	.8510	3	6
21	11	48.0	-8.0768	23.0	3.0	3	.7420	3	6
21	12	104.0	-9.6073	56.0	2.0	1	.7290	3	6
21	13	12.0	-6.1293	6.9	1.0	3	.8280	3	6
21	14	34.0	-7.7814	14.0	1.0	4	.6400	3	6
22	3	127.0	-10.1421	67.0	2.0	2	.6790	3	4
22	4	150.0	-9.5887	65.0	4.0	3	.7150	3	4
22	5	110.0	-9.0768	45.0	3.0	3	.6990	3	4
22	6	59.0	-9.0768	35.0	3.0	2	.7270	3	4
22	7	43.0	-7.5699	18.0	4.0	3	.7350	3	4
22	8	65.0	-9.3219	35.0	4.0	2	.6660	3	5
22	9	30.0	-7.7814	15.0	2.0	1	.6990	3	5
22	10	82.0	-9.3219	62.0	2.0	1	.9020	3	5
22	11	16.0	-6.7814	5.5	6.0	2	.5560	3	5
22	12	63.0	-9.1033	37.0	2.0	1	.7340	3	6
22	13	46.0	-8.2288	28.0	1.0	3	.8280	3	6
22	14	97.0	-9.7814	45.0	3.0	2	.6190	3	6
22	15	45.0	-8.3663	30.0	2.0	1	.8460	3	6
23	4	34.0	-8.3663	18.0	6.0	2	.6610	3	4
23	5	56.0	-8.8455	35.0	3.0	1	.7810	3	4
23	6	7.5	-5.4263	4.0	6.0	3	.7920	3	4
23	7	6.0	-5.3219	2.5	6.0	4	.6390	3	4
23	8	140.0	-10.0498	52.0	3.0	2	.5670	3	5
23	9	101.0	-9.6257	64.0	4.0	1	.8010	3	5
23	10	6.0	-5.6439	4.0	6.0	1	.8110	3	5
23	12	53.0	-8.4919	21.0	2.0	2	.6140	3	6
23	13	58.0	-8.5314	30.0	2.0	3	.7490	3	6
23	14	25.0	-7.9069	12.0	1.0	2	.6220	3	6
23	15	104.0	-9.0768	49.0	2.0	3	.7540	3	6
24	5	55.0	-8.2288	22.0	6.0	3	.6650	3	4
24	6	47.0	-8.8138	34.0	4.0	1	.8180	3	4
24	7	7.3	-4.9069	2.7	6.0	3	.6930	3	4
24	8	42.0	-8.2288	11.0	3.0	2	.4580	3	5
24	9	29.0	-8.1293	21.0	6.0	1	.8160	3	5
24	10	105.0	-9.8918	89.0	2.0	1	.9260	3	5
24	11	60.0	-9.1033	45.0	3.0	1	.8500	3	5
24	12	8.0	-5.6439	4.9	4.0	3	.8440	3	5
24	13	130.0	-9.4717	55.0	2.0	3	.6900	3	5

X	Y	A	PHI B	C	R	SH	SPHER	LONG	UP
24	14	137.0	-9.7313	72.0	2.0	3	.7640	3	6
24	15	119.0	-9.8455	73.0	1.0	1	.7870	3	6
24	16	86.0	-9.4305	55.0	2.0	1	.7990	3	6
24	17	137.0	-10.3106	94.0	2.0	1	.7980	3	6
24	18	87.0	-9.3443	48.0	3.0	1	.7420	3	6
24	19	64.0	-9.2046	55.0	3.0	1	.9290	3	6
25	5	113.0	-9.8611	50.0	3.0	2	.6200	3	4
25	6	77.0	-9.0498	25.0	4.0	2	.5350	3	4
25	7	110.0	-9.6970	63.0	3.0	1	.7580	3	4
25	8	6.5	-5.3219	3.0	6.0	3	.7020	3	5
25	9	86.0	-9.2527	54.0	4.0	1	.8220	3	5
25	10	67.0	-9.2288	55.0	4.0	1	.9100	3	5
25	11	36.0	-8.4512	25.0	2.0	1	.7920	3	5
25	12	71.0	-8.7142	23.0	3.0	4	.5620	3	5
25	13	100.0	-9.7313	52.0	1.0	2	.6830	3	5
25	14	18.0	-7.1293	13.0	3.0	1	.8750	3	6
25	15	11.0	-6.6439	8.0	2.0	1	.8350	3	6
25	16	21.0	-7.6439	12.0	3.0	2	.7000	3	6
25	17	116.0	-10.1421	56.0	1.0	2	.6210	3	6
25	18	24.0	-7.7142	13.0	1.0	2	.6950	3	6
26	5	8.0	-5.1293	3.0	4.0	3	.6850	3	4
26	6	64.0	-9.2288	48.0	4.0	1	.8440	3	4
26	7	92.0	-9.6795	74.0	2.0	1	.8990	3	4
26	8	135.0	-9.4305	43.0	2.0	4	.5840	3	5
26	9	102.0	-9.4094	56.0	2.0	3	.7680	3	5
26	10	40.0	-8.3663	32.0	4.0	1	.9190	3	5
26	11	71.0	-9.0768	26.0	3.0	2	.5610	3	5
26	12	80.0	-9.5507	72.0	3.0	1	.9520	3	5
26	13	92.0	-9.5699	62.0	3.0	1	.8190	3	5
26	14	81.0	-9.5699	43.0	2.0	2	.6700	3	5
26	15	10.5	-6.0224	4.5	5.0	3	.6670	3	5
26	16	63.0	-8.4919	35.9	2.0	3	.8280	3	5
26	17	16.0	-6.9069	6.0	2.0	2	.5730	3	6
26	18	93.0	-9.3219	40.0	2.0	2	.6460	3	6
26	19	38.0	-8.4512	34.0	1.0	1	.9540	3	6
27	6	120.0	-9.8138	89.0	5.0	1	.9020	3	4
27	7	34.0	-7.8455	13.0	6.0	2	.6000	3	4
27	8	94.0	-9.6795	54.0	3.0	2	.7230	3	5
27	9	81.0	-9.5887	59.0	3.0	1	.8230	3	5
27	10	129.0	-9.4919	42.0	2.0	4	.5750	3	5
27	11	84.0	-9.4305	65.0	2.0	1	.9000	3	5
27	12	68.0	-9.3880	46.0	1.0	1	.7750	3	5
27	13	103.0	-9.3663	59.0	3.0	3	.8000	3	5
27	14	96.0	-9.0224	36.0	4.0	3	.6380	3	6
27	15	84.0	-9.4717	69.0	3.0	1	.9280	3	6
28	7	134.0	-9.2992	55.0	4.0	3	.7110	3	4
28	8	80.0	-8.6795	40.0	2.0	3	.7870	3	5
28	9	74.0	-9.1799	41.0	3.0	1	.7320	3	5
28	10	15.0	-6.9069	10.0	3.0	1	.8220	3	5
28	11	55.0	-8.9069	27.0	1.0	2	.6510	3	5
28	12	21.0	-7.6439	14.0	2.0	1	.7760	3	5
28	13	44.0	-8.6073	24.0	3.0	2	.6950	3	5
28	14	7.5	-6.1293	4.5	5.0	2	.7280	3	6

X	Y	A	PHI B	C	R	SH	SPHER	LONG	UP
29	7	103.0	-9.8455	65.0	3.0	1	.7640	3	4
29	8	57.0	-8.8765	25.0	4.0	2	.6160	3	5
29	9	17.0	-7.2288	8.0	4.0	2	.6310	3	5
29	10	89.0	-9.1799	56.0	5.0	3	.8470	3	5
29	11	64.0	-8.6073	37.0	2.0	3	.8190	3	5
29	12	36.0	-8.0768	23.0	3.0	1	.8170	3	5
29	13	130.0	-9.7814	65.0	2.0	1	.7180	3	5
29	14	10.0	-6.2288	5.5	4.0	1	.7390	3	5
29	15	90.0	-9.3219	36.0	4.0	2	.6090	3	6
29	16	30.0	-7.9069	12.0	4.0	2	.5850	3	6
29	17	114.0	-9.5314	36.0	2.0	4	.5360	3	6
30	7	81.0	-9.6439	44.0	5.0	2	.6690	3	4
30	8	16.0	-6.7814	10.5	4.0	1	.8560	3	5
30	9	78.0	-9.3219	57.0	3.0	1	.8670	3	5
30	10	88.0	-9.3663	47.0	3.0	1	.7250	3	5
30	11	7.0	-6.1085	4.0	4.0	2	.6920	3	5
30	12	102.0	-9.8765	93.0	3.0	1	.9660	3	5
30	13	123.0	-9.7482	77.0	3.0	1	.8250	3	5
30	14	73.0	-9.1293	31.0	2.0	2	.6170	3	6
30	15	165.0	-10.2046	45.0	2.0	2	.4710	3	6
30	16	91.0	-9.2527	56.0	3.0	1	.8270	3	6
30	17	107.0	-9.4717	51.0	3.0	3	.7000	3	6
31	7	96.0	-9.6618	77.0	5.0	1	.9140	3	4
31	8	76.0	-9.3219	49.0	3.0	1	.7900	3	5
31	9	122.0	-9.8918	57.0	3.0	2	.6550	3	5
31	10	132.0	-9.5507	56.0	3.0	3	.6820	3	5
31	11	57.0	-8.9069	46.0	2.0	1	.9180	3	5
31	12	109.0	-9.4919	46.0	4.0	4	.6460	3	5
31	13	66.0	-8.8765	29.0	3.0	2	.6480	3	5
31	14	13.0	-6.7814	9.0	4.0	1	.8280	3	6
31	16	80.0	-9.5507	65.0	4.0	1	.8900	3	6
31	17	9.5	-5.6439	3.0	4.0	3	.5750	3	6
31	18	69.0	-9.4094	44.0	2.0	2	.7450	3	6