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Shore platform morphology and tidal duration distributions.

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SHORE PLATFORM MORPHOLOGY AND TIDAL DURATION DISTRIBUTIONS

by

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ABSTRACT

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Shore platform existence is related to the concentration of wave energy within the intertidal zone. The development and morphology of platforms is determined to a large extent by the tidally-controlled vertical distribution of wave attack. This study is an appraisal of a simulation model of shore platform morphogenesis. The parameters of the model are expressed in a single formula, and include: time, a water level duration factor; an erodibility constant; and platform slope. Using these and other variables, simulated platform profiles were generated for six areas of the world. Comparison of the simulated with the actual platform profiles for these areas, show the simulations to be fair models of reality, particularly in storm-wave areas. The model's ability to predict platform morphology in selected areas strongly suggests that existing surfaces are in close adjustment to present sea level. Further, the model helps to explain many of the morphogenic relationships found by previous workers, but in a simple, quantitative framework.

DEDICATED TO:

To Mary, my wife; and my mother and father,

for all their help and encouragement.

ACKNOWLEDGEMENTS

I would like to express my sincere thanks to my advisor, Professor Alan Trenhaile, for his unfailing support and advice throughout the year.

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CHAPTER ONE

INTRODUCTION

The existence of shore platforms[1] has, for a considerable time, been attributed to the concentration of wave energy within a narrow vertical range. Factors such as tidal range, geology, wave enviroment, and the possibility of inheritance have, however, clouded the nature of this relationship. Workers have frequently studied structural influences on coastal morphological and process variables, but there has been little effort to understand the effects attributable to the vertical distribution of wave attack along a bevelled coastline. The specific problem considered here is the nature of the relationship between the tidally-controlled vertical distribution of still water level for a given area and the geometry of that area's shore platforms.

The vertical distribution of wave energy will be of prime importance in determining whether a platform will develop and what form that surface assumes. This study is specifically concerned with the latter problem. Whether

1The term 'shore platform' is used here in preference to 'marine bench' or 'wave-cut platform'. It is purely a morphological term and should not suggest any mode of formation or any of the processes acting on the platform.

initiation is due more to hydrodynamic than structural factors is a problem large enough to warrant a separate study, but is not the concern of this thesis.

The particular approach adopted for the study was an investigation of the efficiency, characteristics, and future applicability of a mathematical simulation model of shore platform morphogenesis (Trenhaile, 1978; Trenhaile and Layzell, 1978, in press). In order to obtain the widest possible appraisal of the model, data were analysed from six contrasting areas: The Isle of Man, U.K.; The Isle of Thanet in S.E. England; the Gaspé Peninsula, Eastern Canada; Auckland, New Zealand; and Tasmania, Australia. The sampling design and characteristics of the areas is discussed fully in Chapter Three. The main aim of the study, then, was to shed some light on the association between characteristics of the distribution of wave energy and selected variables of shore platform morphology.

CHAPTER TWO

SHORE PLATFORM STUDIES: 1900–1978

During this century, recognizable trends have emerged in the approach of geomorphologists to the problems of shore platform development: cyclic modelling; a search for processes for platform genesis; a gestalt approach attempting to draw together the various morphological relations on shore platforms; and quantitative process studies. These stages should not be interpreted as being discrete, successive periods, but as a classification of existing literature and ongoing research. The relevant points of each stage will be discussed in turn.

Johnson's (1938) classic work represented the application of Davisian cyclic principles to shoreline development. His model was strictly bound to the ceaseless progression of time, showing the evolution of the coastline from an initial to a final stage of maximum entropy. The shore platform was described by Johnson as the development to maturity of an initial wave-cut notch. A roughly sigmoid shape was attributed to the platform profile. Growth continued, producing a wider and wider feature which, below sea level, was assumed to be a marine abrasion terrace. The final stage does not arrive until the whole landmass is planated to form an ultimate abrasion platform at the wave base, assumed at

220 metres below sea level. The Strandflat of Norway's west coast was offered as evidence for the plausibility of unlimited lateral erosion. In opposition to Johnson's uniformitarian view were De Martonne and von Richtofen who assumed the need for a continuously rising base level to produce the Strandflat.

The second era in the development of shore platform theory concentrated less on cyclic modelling and more on a search for the specific factors pertinent to their evolution. An early distinction by Bartrum (1926) is between the "Old Hat" platforms of Australasian swell wave conditions and intertidal storm wave platforms: Within swell wave environments, however, other platforms may also be discerned (fig. 1). Old Hat platforms were considered to form by sub-aerial disintegration of the rock followed by weak wave action which removes the fine debris (Bartrum, 1926, 1935). The base level of erosion was understood to be the level of permanent saturation, "... a little below mean high-water level" (Bartrum, 1926, pp. 796). Bartrum perceived the sea as continually eroding the platform in an attempt to produce a compound curve which is concave near the shore passing through a line of little or no curvature to a convex front. This he termed the "normal shore profile". The ultimate form in these environments existed at lower elevations than those produced by storm waves. To what extent Australasian storm wave and Old Hat platforms differ in their degree of adjustment to

SHORE PLATFORMS

Storm Wave Environments

Most common in Northern Hemisphere, esp. in exposed locations. Generally plats. are intertidal in extent with possibility of low-tide cliffs and mid-tide bevelling. Dominant type of erosion is mechanical (wave corrasion, quarrying) some pitting of plat. surface by chemical and biological agents. Profiles may be complex, related to Pleistocene or Holocene sea levels. Examples: the Vale of Glamorgan, Wales; Yorks. coast, Eng.; Isle of Thanet, Kent, Eng.; Gaspe, E. Canada.

Swell Wave Environments

Solution: Most common in tropical and sub-tropical coasts of Southern Hemisphere. No requirement of an exposed location Plats are narrow (5-10 m) and are located at or above MHWMOST with rampart and cliff at seaward edge. Rampart represents the zone almost constantly wet and so disallowing rapid rock destruction. Examples: Oahu, Hawaii and New Zeal.

Old Hat: Termed so because of distinctive two-angle profile. Formed by subaerial disintegration of rock then wave action to remove debris (see text). Examples: Auckland, N.Z. Tasmania, Aus.

Storm: Found in exposed locations. Generally recognizable by being sloping, intertidal, and poss. backed by wave-cut notch. Poss. of low-tide cliff.

Fig.1: Simple classification of shore platforms based on early research.

present sea level is dependent to a large extent on the vertical distribution of wave attack; as Bartrum (1938, p. 267) notes,

> "In deciding whether or not wave-carved shore platforms were developed with respect to modern sea level, it seems necessary to place special emphasis on tidal range and degree of storminess of the adjacent sea."

Edwards (1941), writing on Australian storm wave platforms, summarizes several relationships which are particularly germane to the present investigation. He found that the cliff-platform consistently occurs at high tide level. Secondly, he noted that a "low tide nip" or "low tide cliff" occurs at the platform's seaward edges. Further, platform width is dependent on the rates of erosion at low and high tides: low tide erosion pushes back the nip face; high tide erosion destroys the cliff face. Thirdly, he considered that, for a given rock type, platform width and gradient varied with the distribution and amount of wave attack.

These two relations may be summarized by the following diagram:

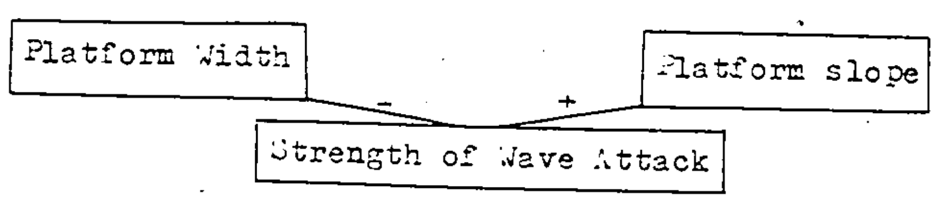


Fig. 2: Two morphological associations on shore platforms (based on Edwards, 1941).

It is interesting to note that Edwards found that stronger wave attack would produce a narrower platform by erosion of the nip.

Gill (1967) discussed the various factors of relevance to platform genesis and geometry, and, in particular, the height of the platform. Five specific factors are listed; it is suggested that shore platform height represents a balance between them. The five influences are:

(i) Oscillations of sea level.

(ii) Nature of the rocks forming the shore.

(iii) Effectiveness of marine erosion.

(iv) Climate.

(v) "Other factors", including the water table.

Gill's list represents little more than a barely adequate summary of the pertinent environmental conditions to be considered. Not only do his "five principles" appear to be overtly simplistic but, in the light of other evidence, incorrect. A similar discussion in many ways to Gill's was that by King (1963). Her list of relevant factors included all those of Gill plus offshore relief, exposure, beach cover, and wind action. King considered the effect of sea level rising at an intermittent rate in producing a stepped submarine abrasion surface.

Wentworth (1938) described in great detail the process of water level weathering and in a follow-up paper (1939) analysed solution benching. Two further 'bench forming processes were recognized: ramp abrasion and wave quarrying. Water level weathering was described as the progressive lowering of a marine platform by alternate wetting and drying of the surface. Cotton (1963) considered this process to be responsible for "secondary lowering".

King (1963) and Zenkovich (1967) are amongst the few workers to have recognized the importance of the tidal distribution of wave energy (see also Kirk, 1977), although make more than a passing reference to its relevance. Wright (1967) compared British with New Zealand platforms, the former having a macro-tidal storm wave environment, the latter, a meso-tidal, swell wave environment.[1]

Paralleling the development of geomorphometry and the application of systems theory to geomorphology has been the growth of a more gestalt approach to shore platform studies. The objective of these studies has been to gain insight into the network of inter-relationships controlling platform morphology, whereas previous work tended to be limited to a few interactions in one location. The first study to attempt a comparison of platforms in swell and storm wave environments was that by Wright (1967). Further extensive work has been accomplished by Trenhaile (1969, 1971, 1972, 1974a, 1974b, 1978). The network of

[1]Macro-tidal refers to a tidal range larger than 4m, meso-tidal to ranges from 2 to 4m (Davies, 1964). See also footnote 1, p. 20 (Ch. 3).

morphological relationships described by these writers is discussed below.

Although the early workers on shore platforms uncovered most of the important factors in their development, the lack of statistical analysis left questions concerning the relative contributions of these influences unanswered. Beginning at the cliff platform junction, both Wright (1967, 1970) and Trenhaile (1972) found this to occur frequently in conjunction with high tide level. Wright also found cliff-platform junctions to be higher on headlands than in embayments, as did So (1965) and Hills (1972). The question of differences in platform morphology between headland and embayment sites has been stressed by many researchers, however, as Trenhaile (1974) points out, too many contradictions exist at the moment to justify the making of simplistic generalisations.

Platform slope has repeatedly been the central character of morphometric analysis. The most important single influence on this, according to Trenhaile (1972, 1974a and 1974b), is tidal range. As he points out in a later paper (1978), this factor should more correctly be called: tidally-controlled expenditure of wave energy. Correlation coefficients for tidal range and platform slope were found to be as high as +0.86 and +0.92. Dietz and Menard (1951) and Bradley (1958) considered the offshore slope to be of importance. Trenhaile (1974b), working along the South Wales coast, found length of fetch to be slightly

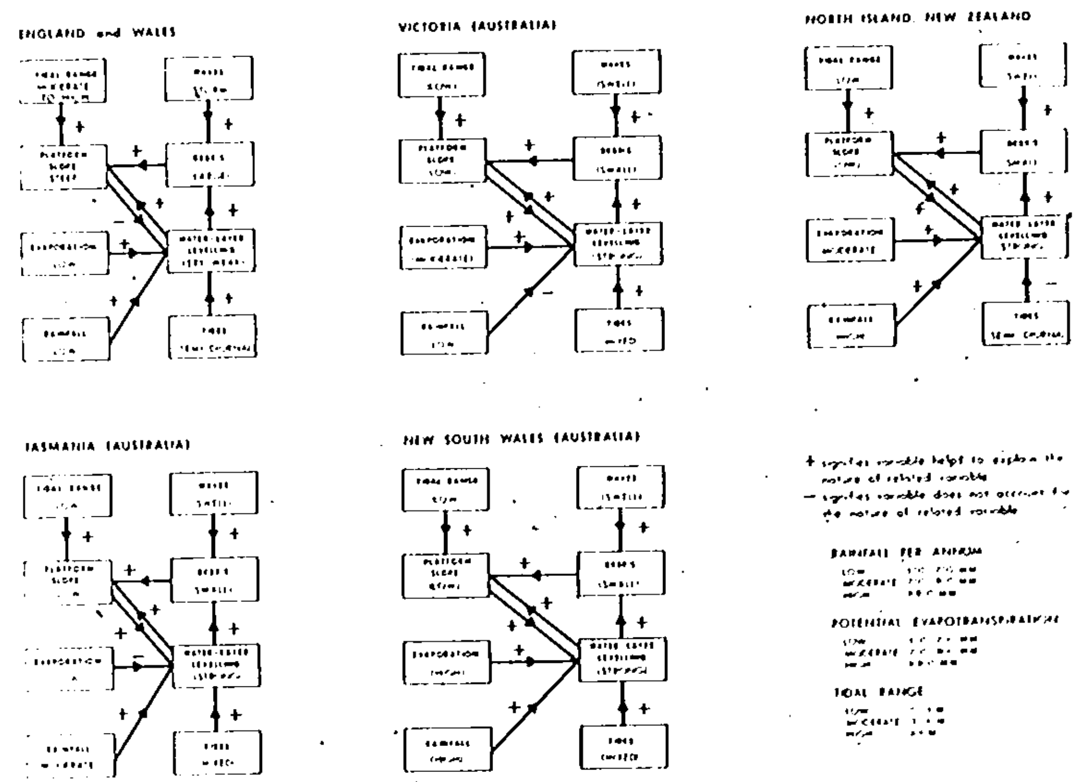


Fig. 3: The morphogenic control of platform slope in Australasia and in England and Wales. Source: Trenhaile (1974a)

negatively correlated with platform slope. Other factors which were found to influence platform gradient included lithology, exposure and, to a lesser extent, cliff height. The role of cliff height is a somewhat confused one. Edwards (1941) established a negative relationship between platform width and cliff height. If this is correct high cliffs will lead to narrow platforms, and since the cliff-platform junction is associated with high tide level, it would be expected that high cliffs would give steep platforms. Wave characteristics may, indirectly, be a factor in controlling platform slope. Trenhaile (1974a) argued that the storm waves of the British coast are responsible for high erosion rates, producing debris of greater size than that produced by weathering and swell waves in Australasia. The relationship between debris size and platform slope may be explained by the fact that larger debris requires greater slopes for its removal than the finer material produced by the processes of water-layer levelling. The network of inter-relationships between these factors makes the identification of causality very difficult. Platform slope assumes a central role in the network of morphometric variables (Fig. 3). Perhaps the largest single independent variable is 'tidal characteristics'. Both the nature (mixed / semi-diurnal) and size (range) are powerful controls on platform morphology (fig. 4).

The network of relationships shown assumes contemporaneity of process and observed form. Several

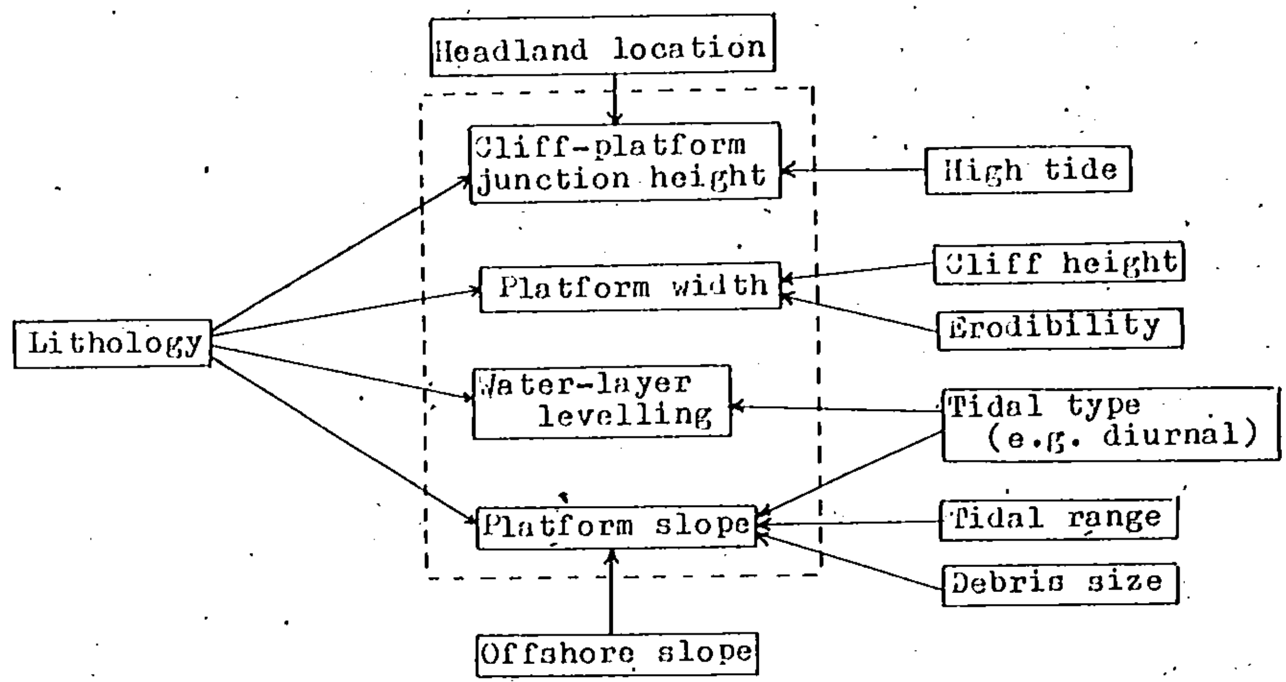


Fig. 4: A digrammatic summary of the morphological relationships on shore platforms (not necessarily statistically verified).

workers, however, have inclined towards an explanation of inter-tidal platforms in terms of their inheritance from a period during the Pleistocene when sea level was similar to today's, (e.g. Stephens, 1957; Agar, 1960; Orme, 1962; Hopley, 1963; Synge, 1964; Whittow, 1965; and Phillips, 1970a and 1970b). In such cases the high degree of correlation between morphological variables observed by many other workers cannot be expected to exist. In short, no dynamic equilibrium can be expected to occur on a recently inherited shore platform. That many platforms are well adjusted to present processes is shown by the amount of evidence held in support of existing morphometric relationships (figs. 3 and 4). The question of inheritance obviously merits careful investigation, but as the amount of statistical evidence supporting significant morphometric correlations grows, the possibility of recent inheritance must decrease in like proportion.

Several workers have noticed the existence of mid-tide bevelling (eg. Bartrum, 1938; So, 1965; and Trenhaile, 1972). Although only slight in relation to overall platform slope, such bevelling may be explained by the vertical distribution of wave activity.

Finally, Takahashi (1973a, 1973b, 1974a, 1974b, 1974c, 1975) has discussed the distribution, development, and the age of shore platforms in southern Kyūshū, Japan. Two of his conclusions are worthy of note here. Firstly, Takahashi (1973b, p. 120) states that the "... development of shore platforms requires a delicate balance between rock resistance and intensity of wave attack." Secondly, Takahashi (1974b) identified three shore platform elevations, the lowest of which was related to present sea level. The method employed was graphical, superimposing the eustatic and isostatic uplift curves. A height-time relation was arrived at to determine the age of supra-tidal shore platforms.

In addition to morphometric analysis, the past few years has seen the emergence of process studies. Attempts have been made to measure, classify, and model processes. Perhaps the earliest of these was the wave tank experiment of Sanders (1968b), who attempted to observe the platform-forming process in a controlled environment. His experimental results are of a very limited relevance, however, since erosive processes were limited to wave corrasion and the effect of tidal range was not considered. Sunamura (1973) classified erosion process studies according to their measuring technique. Four techniques are common: horizontal photographs taken in different years (Trenhaile, 1969); old maps and recent surveying (e.g. Steers, 1964); old and recent maps; and surveying conducted at different times (e.g. Robinson, 1976a et seq). Sunamura's (1973 and 1975) studies investigated rates of cliff recession using a two dimensional wave flume and a three dimensional wave tank. He concluded that erodibility along any stretch of coastline is related to the angle of the coast with the incident waves.

Quantitatively, this was expressed by

$$p = p_o \cos^2\theta$$

where p= pressure of breaking waves at angle θ to the normal,

and p_o= pressure of breaking waves normal to the cliff.

The amount of erosion at the base of the cliff is unlikely to be an exact indicator of the shore platform growth rate, although, within an order of magnitude, it should give an aproximation of this rate. Cliff recession rates have been summarized for three countries, USSR, G.B. and Japan (Table 1). The eroded distance at the cliff base was given by Horikawa and Sunamura (1966) as

$$dX = \emptyset\ (F, dt)$$

where dX = the eroded distance,

F = relative strength of eroding force (erodibility),

and dt = duration of wave attack.

F is a compound variable consisting of two factors: rock strength and wave intensity.

Sunamura (1975) once again used a wave flume in a simulation of shore platform formation. He found no erosion to occur with standing waves but considerable erosion with breaking and broken waves (fig. 5). Two kinds of force were exerted on the shore platform: normal force (=pressure) and tangential force (=shearing). The cliff and beach profile changes due to broken waves reflected very closely the vertical distribution of dynamic pressure exerted on the artificial coastline. In addition, Sunamura plotted the relationship between eroded distance and time

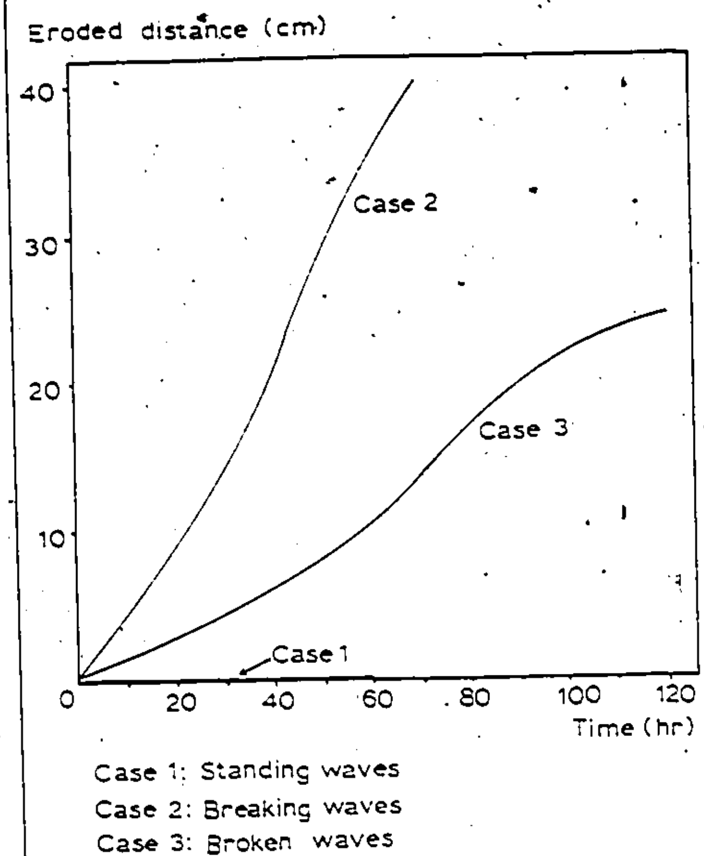


Fig. 5: Relationship between eroded distance and time for an artificial cliff.
(after Sunamura, 1973)

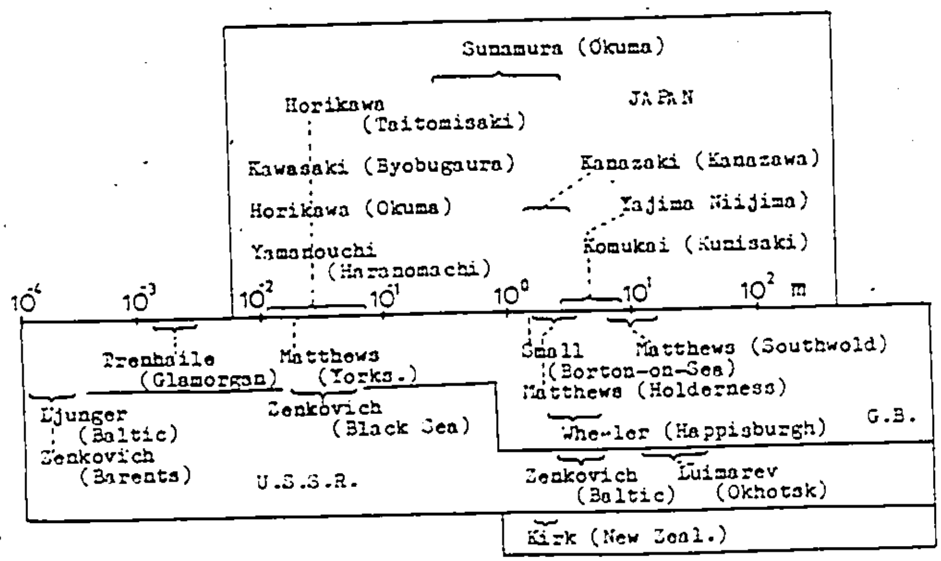


Table 1: Cliff recession rates for selected countries. Sources: Sunamura (1973), Kirk (1977), and Trenhaile (1972).

(fig. 5). Maximum wave erosion has long been known to occur above still water level (e.g. Zenkovich, 1967). The exact distribution of dynamic pressure about still water level, however, is not agreed upon (Sunamura, 1975).

Finally, a technique originally devised for use by engineers has recently been directed towards problems in coastal geomorphology (Robinson, 1976a, 1976b, 1977a, 1977b, 1977c; and Kirk, 1977). The micro-erosion meter (MEM) accurately measures small amounts of erosion at any selected site. Its principal limitation, however, is that it must stand freely on its own base, so that only downward erosion may be measured. Results have been significant though, and Robinson (1977a, 1977c) succeeded in plotting the spatial variations in amount and type of erosion over a shore platform surface. Expansion and contraction were found to be dominant on the horizontal parts of the platform, whereas corrasion proved dominant on the cliff-platform ramp.

Kirk (1977) derived data on intertidal platform lowering rates from thirty one MEM sites on seven profiles around the Kaikoura Peninsula, South Island, New Zealand. Mean lowering rate for two years was 1.53 $mm.yr^{-1}$ with rates generally higher on mudstone than on limestone. Backwasting rates were estimated from analysis of air photographs over the period 1942-1974 and ranged up to 1.49 $mm.yr^{-1}$. No rates were obtained on either recession of the low water cliff or block disintegration of platform rock.

Analysis of variation in lowering rates across the shore revealed upper and lower zones of relatively more intense erosion separated by a central zone of lesser intensity. "There is thus a gradient from sub-aerial processes to true marine processes across the shore so that it is unlikely that a single dominant mode controls platform development and morphology." (Kirk, 1977, p.571).

A four-fold classification has been used to describe the nature of shore platform research. Recent work has become increasingly analytical and numerical, and consequently less descriptive. Considerable effort has been put into modelling or simulation procedures along with the application of systems theory to morphometry. Gradually, a picture is being assembled of the relevant process-response relations, their characteristics, and long-term effects.

CHAPTER THREE

THE STUDY AREAS

The strong correlation between platform gradient and tidal range (Trenhaile, 1972; 1974a; 1978), and between the elevation of cliff-platform junctions and high tide levels (Wright, 1970; Trenhaile, 1972), suggest that morphogenic environments largely determine the gross morphometry of shore platforms. Geological factors are largely responsible for local deviations about morphological means that are determined by morphogenic environments. Until recently, differences in the morphogenic environments of southern and northern hemisphere coastlines had not been fully recognized (Davies, 1964). Many texts assumed the morphology of shore platforms in northern Europe, and northern North America to be essentially compatible with those around the Pacific rim.

Davies (1964) contended that the global diversity of coastal environments is explained by variations in morphogenic factors, such as wave and tidal regimes. More specifically, Trenhaile (1974b), proposed that the morphology of the quasi-horizontal platforms, terminating abruptly in low tide cliffs in the southern hemisphere is controlled by weaker, swell wave activity and smaller tidal range than in the storm wave environments of the north.

Shore platforms and aspects of their morphogenic environments were examined in six contrasting locations (figs. 6 ad 7), (Davies, 1964).[1]

Fig. 6: Classification of study locations by wave and tidal characteristics.[2]

Tidal Range \ Wave Regime	Storm Wave	Swell Wave
Micro-tidal	Gaspé Peninsula	
Meso-tidal		Auckland Tasmania
Macro-tidal	Vale of Glamorgan, Isle of Man, Isle of Thanet.	

The selected British platforms are located in macro-tidal environments receiving locally-generated storm waves, as well as occasional swell conditions. Extensive platform development has taken place in all three areas. The Vale of Glamorgan platforms selected for this study

1 Davies' classification of tidal ranges involved three categories: micro-tidal (less than 2m); meso-tidal (2 to 4m); and macro-tidal (greater than 4m).

2 The storm/swell wave distinction separates the short period, high amplitude, high energy waves associated with storms and waves in their generation zone from the less frequent, low energy waves which have travelled away from the generation zone (swell).

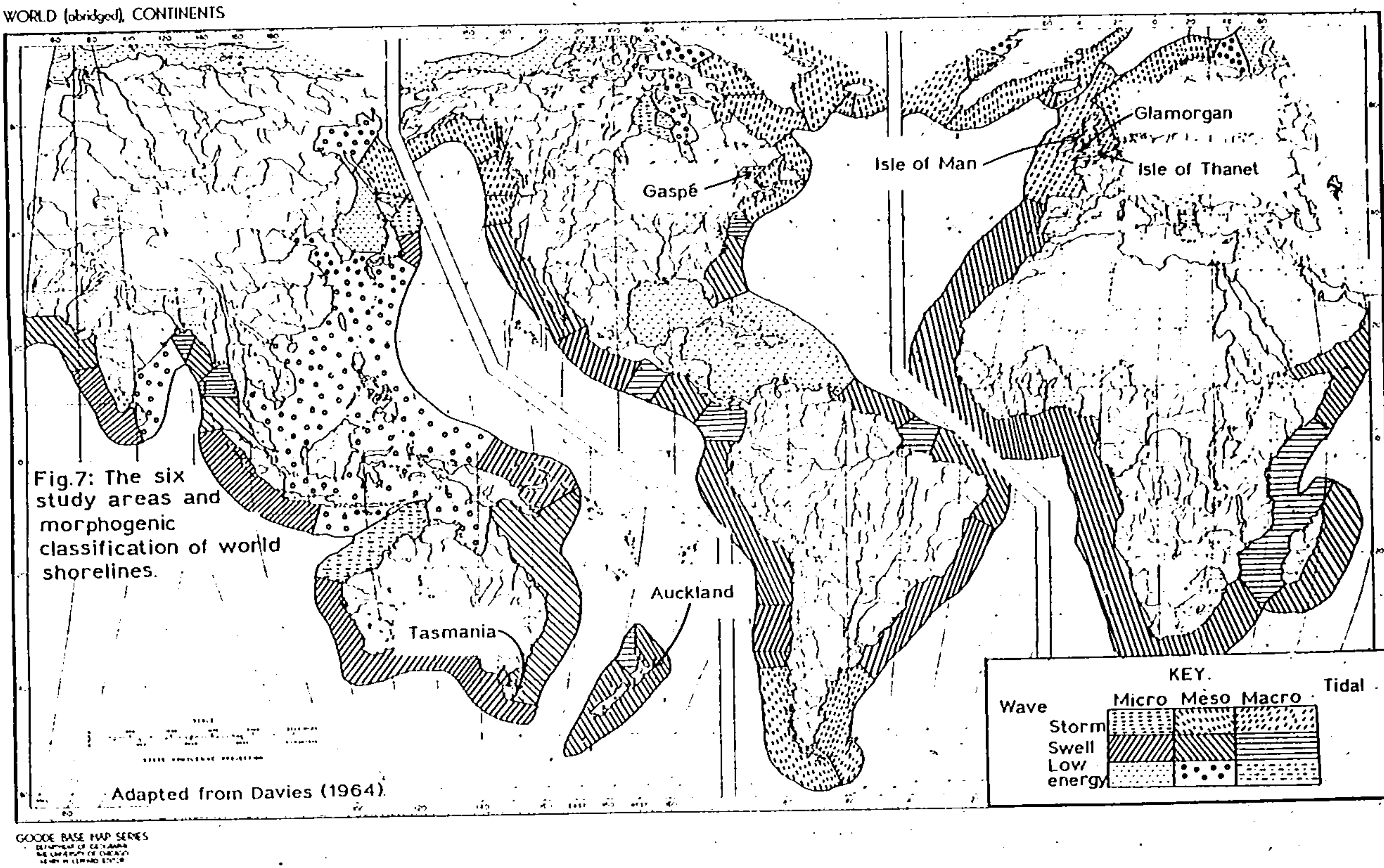


Fig.7: The six study areas and morphogenic classification of world shorelines.

have developed in thinly interbedded Liassic limestones and shales (Trenhaile,1972). The dominant process is one of joint-block removal, whereby the waves erode the shales producing overhanging limestone 'scarps'. At a critical point fracture occurs revealing a fresh limestone surface and renewed exposure of the underlying shales (Trenhaile, 1972). The platform profiles for this study have been selected from the exposed western shore (Trenhaile, 1969) which may receive waves generated by winds with a maximum fetch of over 5000km. Typical erosion rates have been estimated to be in the range 0.92 to 2.44 $cm.yr^{-1}$ (Trenhaile, 1969). Shore platforms occur along most of this coastline, attaining widths commonly greater than 250m (Trenhaile, 1972).

The shore platforms on the Isle of Thanet are cut in a shallow monocline of Upper Chalk, the eastern end of the North Downs range of S.E. England. Generally, platforms are 200 to 300m wide at low water (So, 1965). Pitting of the platforms by solution is extensive, and patches of freshly exposed chalk indicate mechanical wave action. Block loosening occurs, effected through wave force and pressure changes. Boulders, chalk fragments, and flints all point to storm wave action in platform formation. Low tide cliffs do exist in some areas and their continual recession suggests platforms are narrower in areas of less resistant material. Platform elevation was found to be linked with the tidal curve and some flattening of the platform profile was noticed at mid-tide level. However, no further numerical analysis was undertaken. So's conclusions are relevant to the present analysis of the Isle of Thanet platforms:

> "Thus, platforms, conforming so intimately with existing conditions of marine planation at a defined level, must have been formed at the present sea level." (So, 1965, p.155).

Close associations were also observed between location and height of platforms.

The Isle of Man is situated in the Irish Sea within the part of Britain glaciated during the last two advances of the Pleistocene Ice Age. The whole island is composed of a very resistant Cambrian grit and slate series. The shore platforms of the island are very complex in form, each profile having many recognizable units (Phillips, 1970b). This has been attributed to the inheritance, by the present sea level, of older surfaces interglacial in origin. Phillips (1970b, p.238) concludes that, "...interpretation of coastal histories within areas experiencing repeated changes in relative heights of land and sea, must be carried out with care, present practices of correlation and M.S.L. associations being ill-founded except on a most general scale." The contrast with So's conclusion is striking, and to what extent Phillips's assertion is correct will be the subject of much of the following chapters.

The Australasian areas selected for study both receive swell as the predominant wave type and both are classified as meso-tidal (fig. 6). Sanders (1968a) considered that the two dominant categories of shore platforms in Tasmania are: horizontal platforms near the level of mean high water, spring tide; and sloping, intertidal surfaces with gradients of between 3 and 45°. Most effective processes were breaking wave shock, water hammering, and air compression in joints. High shock pressures occurred in a narrow zone, approximately between still water level and the height of the wave crest. Water layer weathering was found to be a secondary process. Like So (1965), Sanders considered that the tidal regime was of great importance in determining platform elevation. Regardless of tidal range, horizontal platform height was about 0.6 to 1.0ft above mean high water, spring tides. Widths varied from 10 to 40m.

The tidal range for Auckland, New Zealand is almost identical to that of Hobart, Tasmania. In addition, the wave regime, climate, geology, fetch and other aspects of the morphogenic environment are similar between the two locations (Ferrar et al, 1925; Bartrum, 1935; and Healy, 1968). The platform-forming processes are a combination of wave action and sub-aerial weathering, controlled by the level of permanent rock saturation (Cotton, 1963; and Healy, 1968). Widths of the platforms on the Whangaparaoa Peninsula average between 60 and 70m.

The six study areas represent six different morphogenic environments, each varying according to lithology, shoreline orientation, wave regime and other factors. From the complete array of process and form variables along these coastlines two have been selected for study. In each case the form variable is the geometry of the shore platform profile, while the process variable is the duration of still water level at all elevations from low to high tide. Published profiles and tide tables were analysed to obtain the data. Ideally one would like to collect all the profile data personally, but for obvious reasons this is impossible. However, to ensure that maximum accuracy has been attained only carefully surveyed and clearly published profiles have been used. In fact, in two cases (the Vale of Glamorgan and the Gaspé Peninsula), access was available to original data.

CHAPTER FOUR

THE MODEL

The effects of tidal range on shore platform development are considerable. It has been suggested that platform width is determined by tidal range (Edwards, 1941; Flemming, 1965), but recent work has suggested that, whereas platform gradient is directly related to tidal range, width is largely a function of the erosion rate (Trenhaile 1972, 1974a, 1978). Other aspects of platform morphometry are also intimately related to tidal parameters, such as mean elevation, the elevation of the cliff-platform junction, profile shape and the presence, height, and slope of the low tide cliff (Trenhaile, 1978). It is not, however, the tides which are responsible for coastal erosion but wave energy and possibly some chemical processes. The role of the tidal pattern is to distribute the wave energy in a characteristic, repeating manner in the vertical plane. Exactly where a wave breaks is determined, then, by the height of the water surface, and to what extent the waves break more frequently at one level than any other is a function of the tidal curve. Several attempts have been made to consider the total control of wave activity. Some approaches have involved plotting the heights of high and low tides for a given location (Takahashi, 1974a). However, this produces a bimodal curve and ignores the heights of still water levels during ebb and flood. Other analyses, have considered the period during which any elevation is completely covered during the tidal cycle (Robinson, 1977a; Kirk, 1977). Since the effects of waves on hard rock are greatest at or just above still water level (Sanders, 1968), the usefullness of this approach is severely restricted. To determine the tidal role in directing the expenditure of wave energy within the tidal range, it is necessary to consider the fluctuation of still water level. The distribution of wave energy (storm or swell) is determined by this fluctuation.

I CONSTRUCTION OF THE CURVES OF STILL WATER LEVEL DURATION IN THE INTERTIDAL ZONE.

The first stage in modelling shore platform development was the construction of curves of the relationship between duration of still water level and height. These curves may be thought of as probability graphs of the likelihood of still water level being at any given height from low to high spring tide. Unless otherwise specified, the present method is that of Trenhaile (1978).

The total time still water level occupies a particular intertidal level consists of two components: one when high or low tides coincide with this elevation, and the other when the level is briefly, but frequently occupied at the ebb and flow stages at intermediate points on tidal cycles. The duration of still water level (F) therefore, at an elevation (n) is given by:

$$F_n = (De.\ Ne) + (2\overline{Di}.\ Ni) \qquad (1)$$

Where,

De is the duration of water level at that elevation when it coincides with either a high tide tide or low tide mark.

Ne is the number of high or low tides at that elevation.

Di is the duration of the tide at that elevation when it is an intermediate point on a tidal cycle. Each intermediate point is occupied twice on a tidal cycle. $\overline{Di}$ is explained below.

Ni is the number of high or low tides above or below a particular elevation.

The first stage involved plotting the occurrences of each high and low tide on a graph to give one histogram per location (figs. 8 to 10). Each distribution is clearly bimodal. Other characteristics of the tidal curves, however, vary greatly from one location to the other. Tasmania and Auckland have similar distributions with each mode being symmetrical. One exception does exist however. The low tide distribution for Tasmania is itself bimodal and has considerably more spread than the distribution of highs for the same port. This is a reflection of the location of Devonport Tasmania, which affects the complexity of the Fourier series used in the compilation of the tidal tables. Ramsey, Isle of Man, and Nash Point, Glamorganshire are west coast ports in the British Isles. The tidal

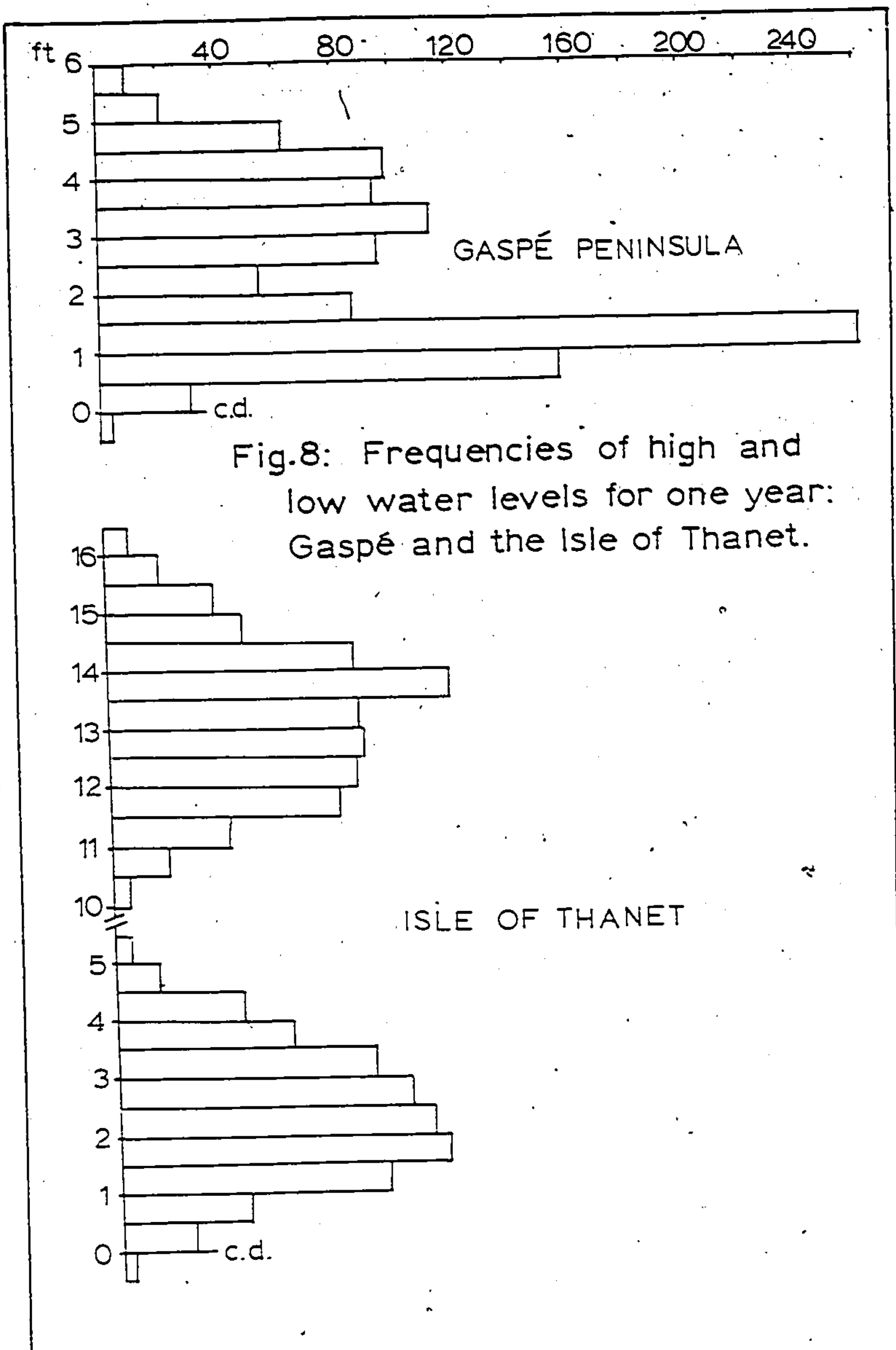


Fig.8: Frequencies of high and low water levels for one year: Gaspé and the Isle of Thanet.

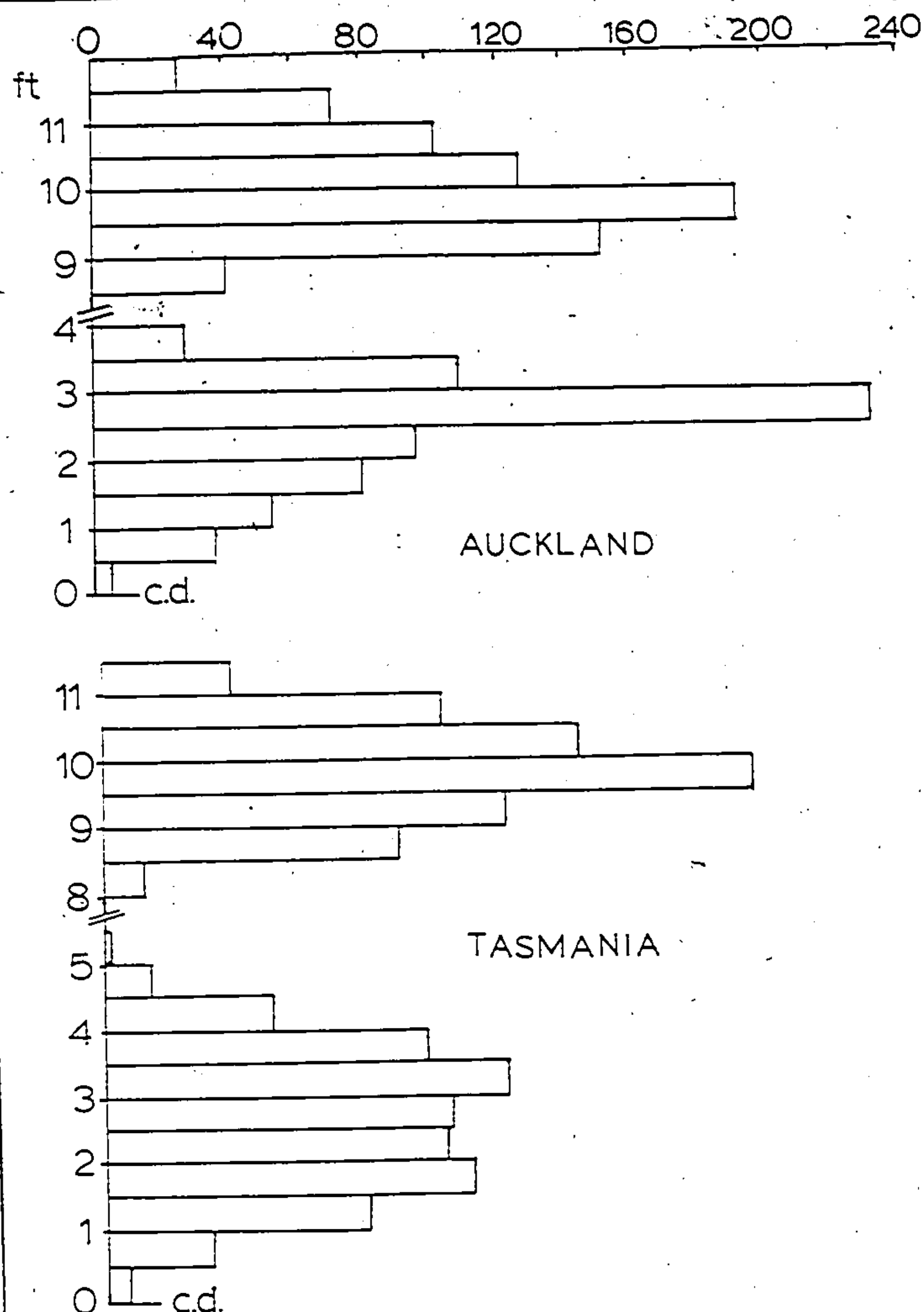


Fig. 9: Frequencies of high and low water levels for one year: Auckland and Tasmania. (c.d.: chart datum)

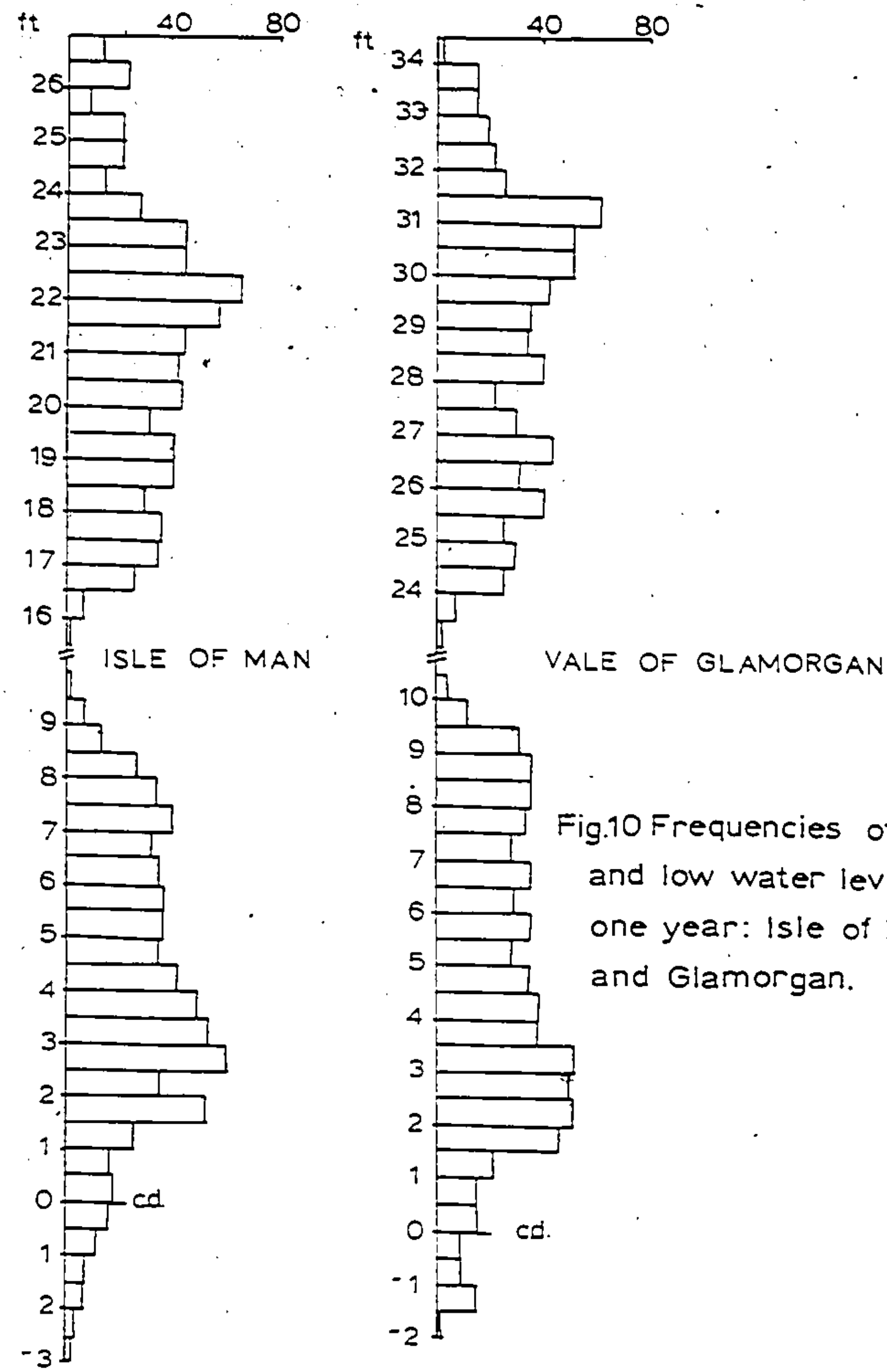


Fig.10 Frequencies of high and low water levels for one year: Isle of Man and Glamorgan.

ranges are large and the resulting histograms are spread out and somewhat complex. No clear symmetrical pattern exists within any of the modes. This, once again, reflects the complexity of the tidal curve. Pointe St. Pierre, Gaspe Peninsula is decidedly micro-tidal and no intertidal zone exists which does not experience a high or low tide sometime during the year. The pattern is a much simpler one than for the British and represents a fairly simple mixed, semi-diurnal tide (fig. 11).

A decision had to be made at this point concerning the time span to be taken into account. For this study one year was selected for each suite of platforms. That the tidal curves are not significantly different from each other over yearly cycles was tested by applying the χ^2 statistic in the form of an n x m contingency table for three consecutive years. No significant differences were found between any of the years.

After drawing the histogram of Ne against elevation, a curve of $\overline{Di}$ against tidal range was drawn (fig. 12). This involved the use of interpolation tables published alongside the tidal predictions. Since Di must be calculated for a height range, rather than for points, one of 15cm was selected. This interval was found by Trenhaile to produce curves of sufficient smoothness without excessive manual calculation.

Explanation of $\overline{Di}$: The present writer's method for finding Di differed somewhat from that suggested by

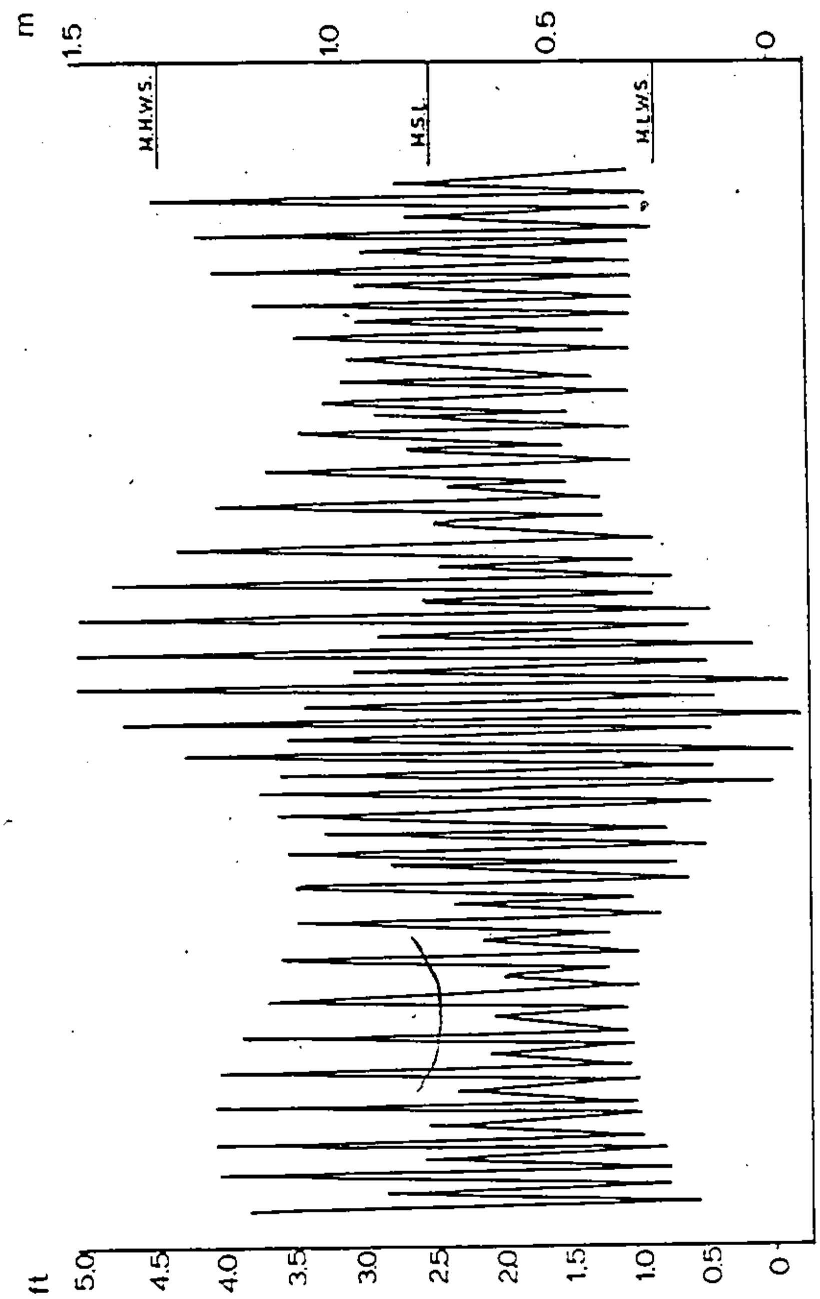


Fig.11:Tidal Curve for Pointe St. Pierre, Quebec: April, 1976.

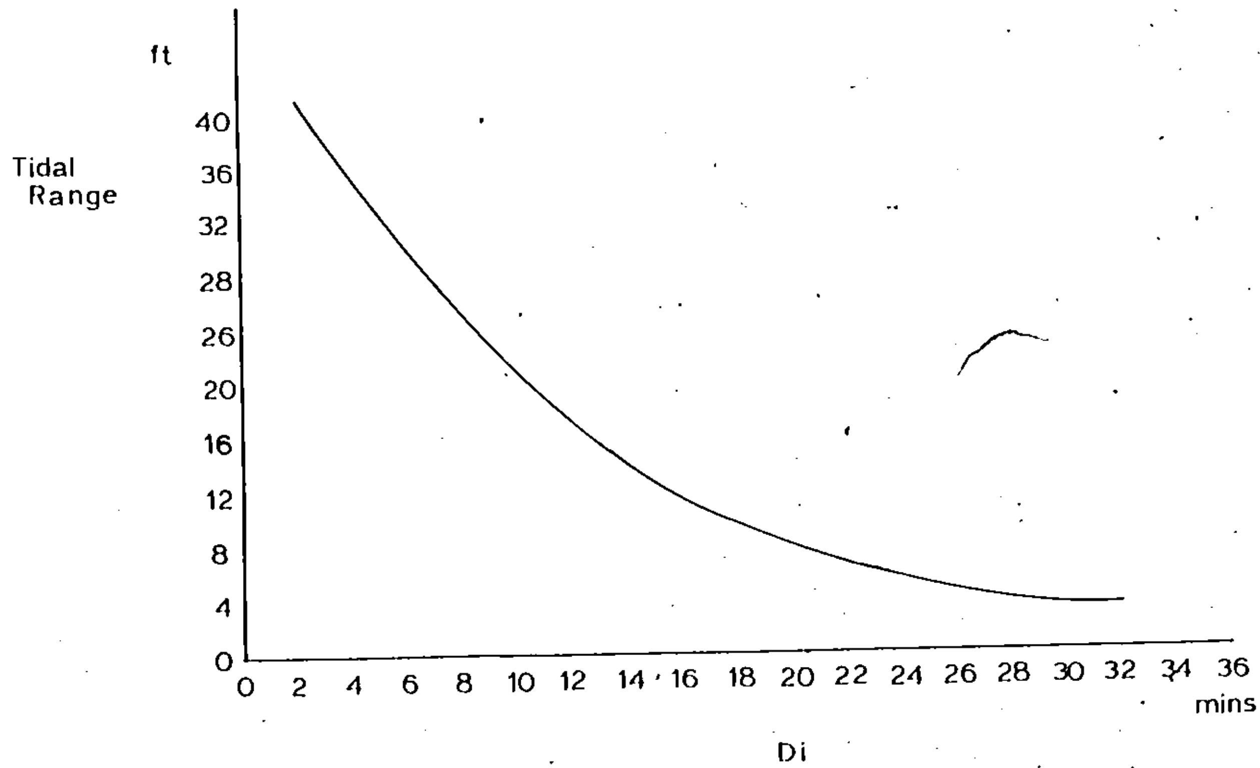


Fig.12: Actual Graph of Tidal Range/Di

Trenhaile (1978), hence the use of superscript bar to denote that used here (and in Trenhaile and Layzell, in press).

Assuming symmetry of the tidal curve about mid-tide level, it is true to say that the range of tidal ranges experienced by any points from mean low water (MLW) to mean high water (MHW) will decrease with increasing vertical distance above and below mean sea level (fig. 13a). Thus, points two and four receive a tidal range that just reaches those points and also all ranges larger than that, in this diagram, up to the range from zero to six, which is a spring tide. A Di value for point two or four must, then, be an average of some sort of the whole spectrum of ranges that encompasses these points. Mean sea level will, theoretically, receive Di values from all ranges including the highest spring to the lowest neap.

Assuming the tidal curves to be symmetrical about mean sea level, so too will all calculated values of Di, decreasing on average above and below this mark.

Since mean sea level will receive all tidal ranges from neap upwards, and since point x on fig. 13b represents neap tides, a new scale may be added to this graph. Mean sea level will receive the complete spectrum of Di from a to b; a good estimation of this would be the median point, c. This is the value of $\overline{Di}$ for mean tide level.

The points two units above and below mean sea level will receive the spectrum of tidal curves and their

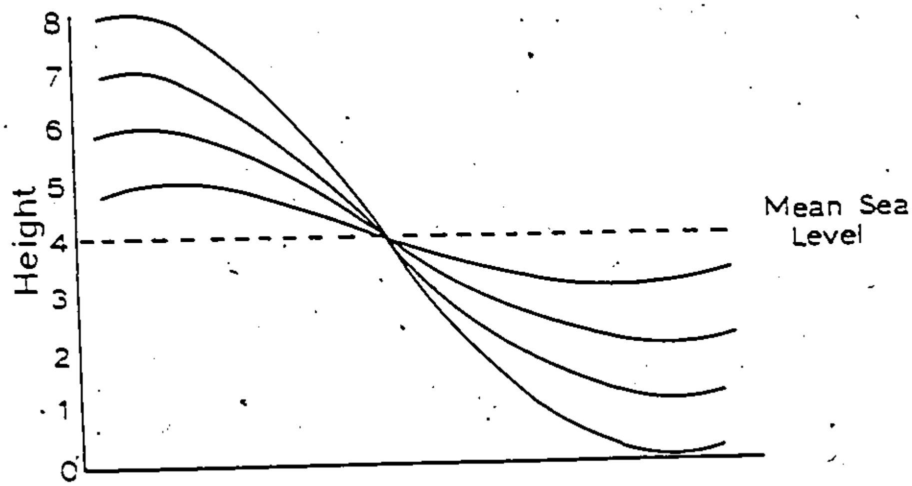
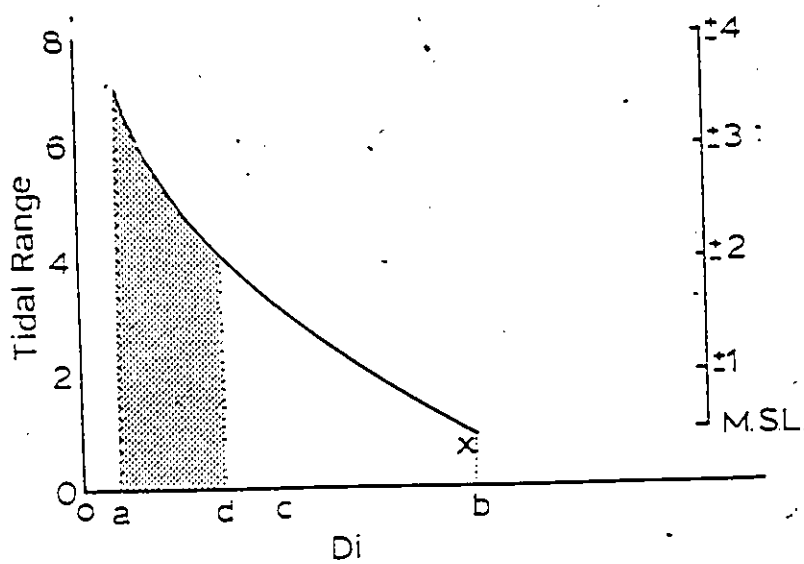


Fig.13a: Spectrum of Tidal Curves

Fig.13b: Tidal Range/Di Graph



For explanation see text

respective Di values from a to d (shaded). The median of this will represent the $\overline{Di}$ for these two points. This may be expressed as,

$$\frac{Od - Oa}{2} + Oa$$

$\overline{Di}$, then, is represented by,

$$\frac{Di(p) - Di(min)}{2} + Di(min).$$

$$= \tfrac{1}{2} (Di_{(p)} + Di_{(min)}) \qquad \text{———————} \qquad (2)$$

Where,

Di(p) is the maximum Di value for a particular height

Di(min) is the minimum Di value at one location defined by the range of the highest spring tide.

Following these graphic and numeric operations curves for each tidal range may be devised showing the value of $\overline{Di}$ for particular heights above MLW (fig. 14).

The only other two variables used in Trenhaile's original formula are Ni and De. The former may be obtained from the histograms (figs. 8 to 10). The latter was taken over a 15cm interval for all tidal ranges from interpolated tidal curves (fig. 15).

Having devised the various steps needed to calculate F, curves were drawn of F against height for each port (fig. 16). The vertical sampling interval in all cases for these graphs was every 15cm (6") from low water

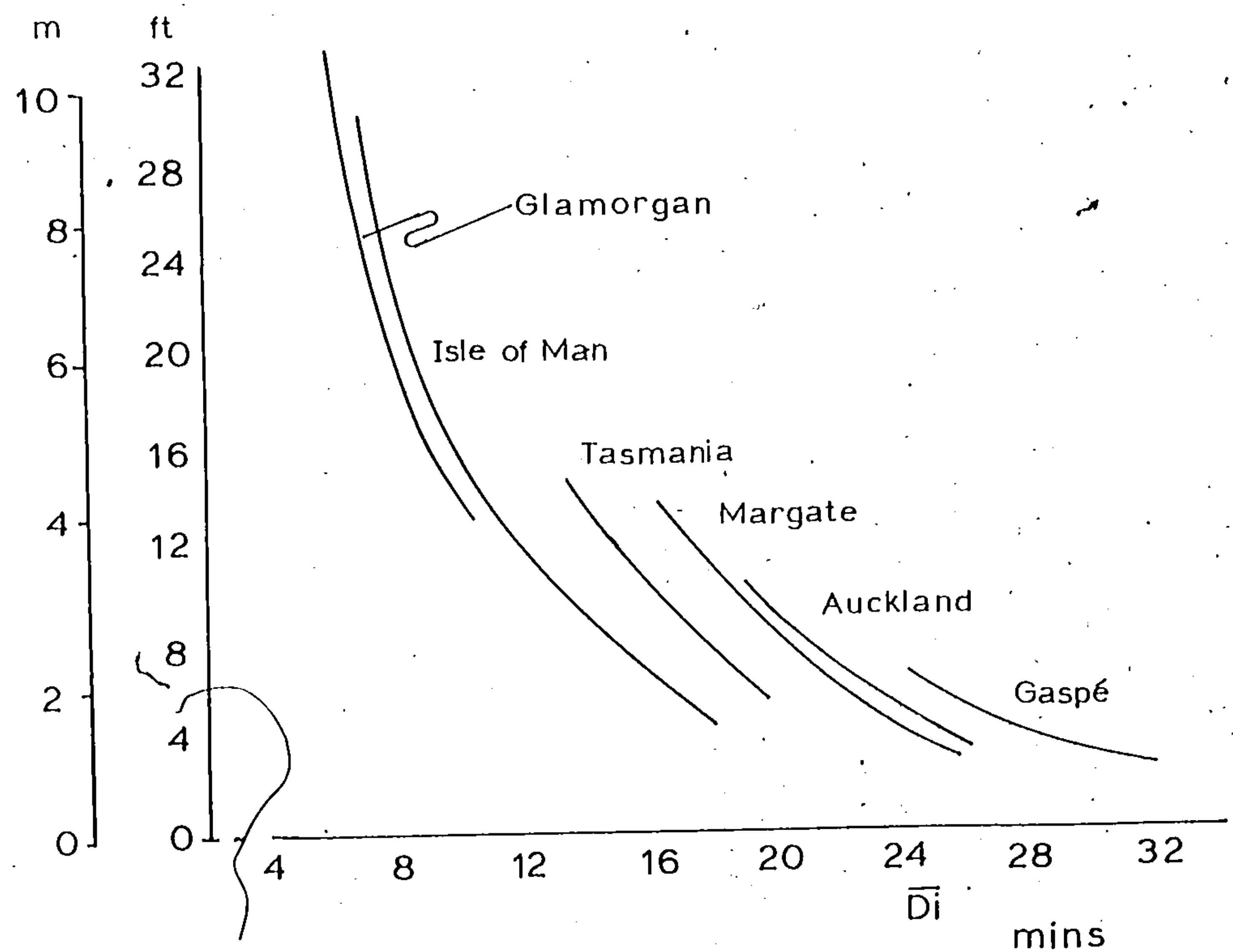


Fig.14: Graph of Height (above chart datum) against $\overline{\text{DI}}$ for the Sampled Areas

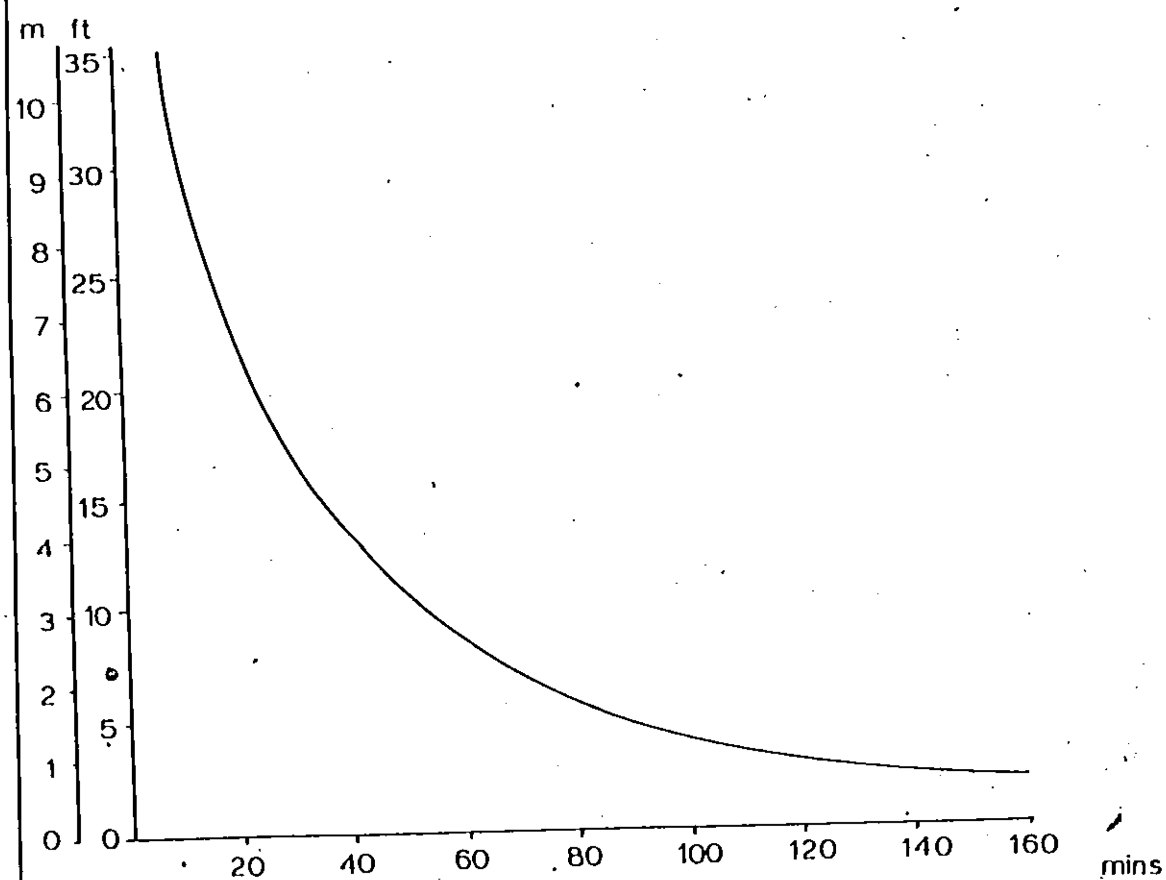


Fig.15: Actual Graph of Tidal Range/ De

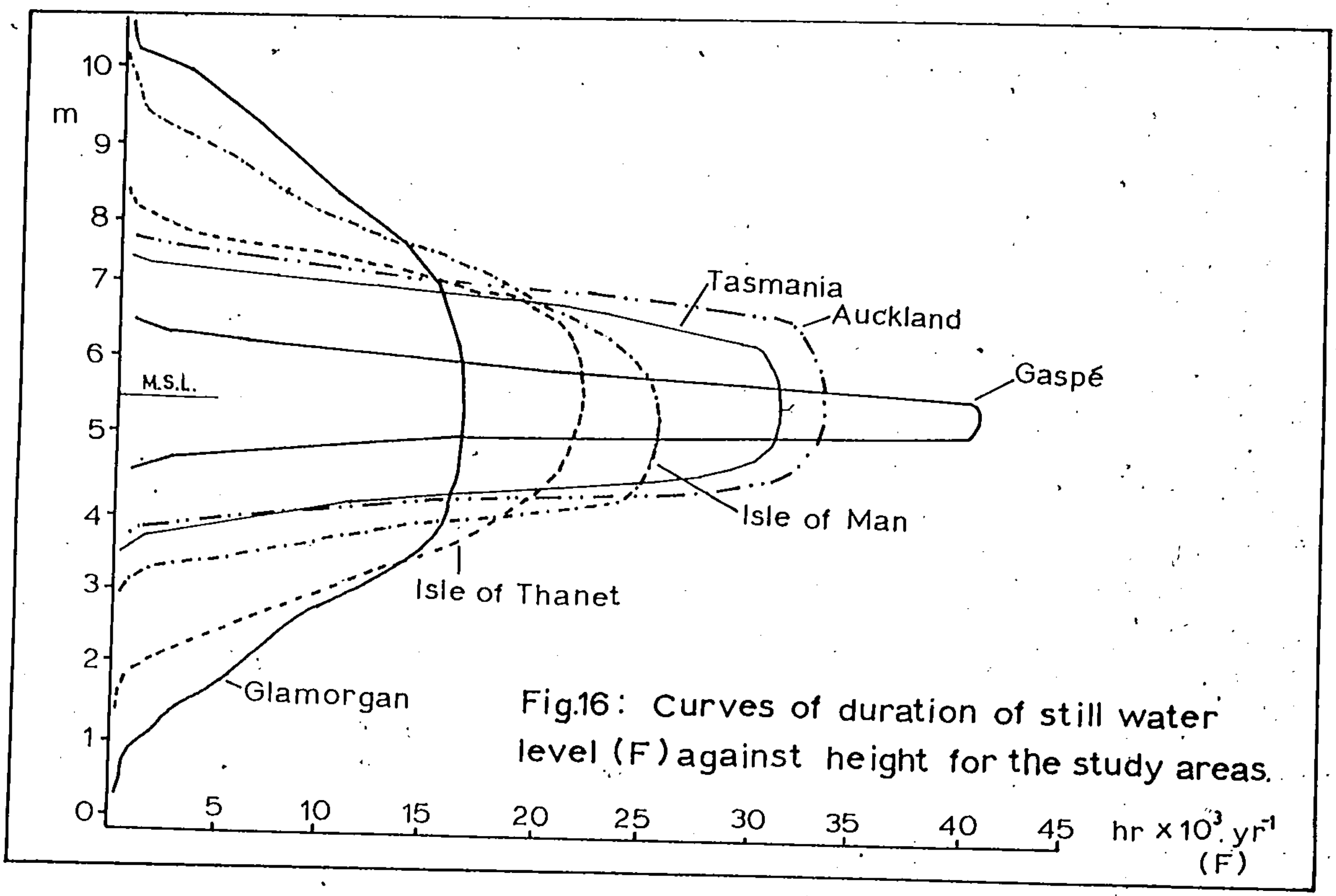


Fig.16: Curves of duration of still water level (F) against height for the study areas.

mark (spring tide) to high water mark (spring tide).

II MATHEMATICAL DESCRIPTION OF THE MODEL.

The model of shore platform morphogenesis has been described by Trenhaile (1978), and Trenhaile and Layzell (1978, in press). Full mathematical description is also given here.

The amount of erosion taking place at any particular level is proportional to the quantity of wave energy expended at that level, and the strength of the rock (Takahashi, 1974c; Kirk, 1977). Deep water wave energy is a function of the morphogenic environment, but in shallow water, wave energy declines according to that used in overcoming friction with the bottom (Putnam and Johnson, 1949); this is proportional to the slope of the bottom. Taking into account the frequency with which still water level coincides with any elevation, the amount of erosion (E) which occurs at an intertidal level (n), in a time t_1 (years), therfore, is approximated by: [1]

$$E_{n,t_1} = t_1 A F_n \tan \alpha_{n-1,\, t_0} \qquad (3)$$

where A is a constant related to the energy of the waves in deep water and the strength of the rocks (the erodibility factor);

1 It is interesting to note the similarity of this formula to one by Horikawa and Sunamura (1966) for the eroded distance of coastal cliffs at the base:

$$\Delta X = (F, \Delta t)$$

where ΔX is the eroded distance

F is an erodibility ratio

Δt is duration of wave attack. The differences between the formulae are that Trenhaile's has two expressions for time (F and t) and it also includes bottom angle ($\tan_x$).

F_n is the amount of time still water level is at elevation level n each year, as given by (1); and x_{n-1, t_o} is the slope of the platform extending downwards from level n to level n-1 before erosion (fig. 17). Consideration of the effect of bottom gradient on incoming wave-energy is limited in the model to slopes at depths down to only 91.44cm (3ft.) below still water level. Although the effect in nature is exerted over much greater depths, for the relatively short, locally derived waves which are primarily responsible for erosion in the study areas, only relatively shallow depths cause much adjustment in wave length and height, and this effect is strongest in very shallow water.

The model is also dependent on the rate of submarine erosion occurring immediately below the level of the lowest tides. Submarine erosion may:

a) decline significantly as the submarine slope declines;

b) be so slow that little change could have occurred in the roughly 2,500 years since the sea reached its present level; or

c) remain essentially constant, dependent only on water depth.

The destruction of rock on the submarine slope is a function of bottom wave energy, which may be taken to be proportional to the square of maximum orbital velocity

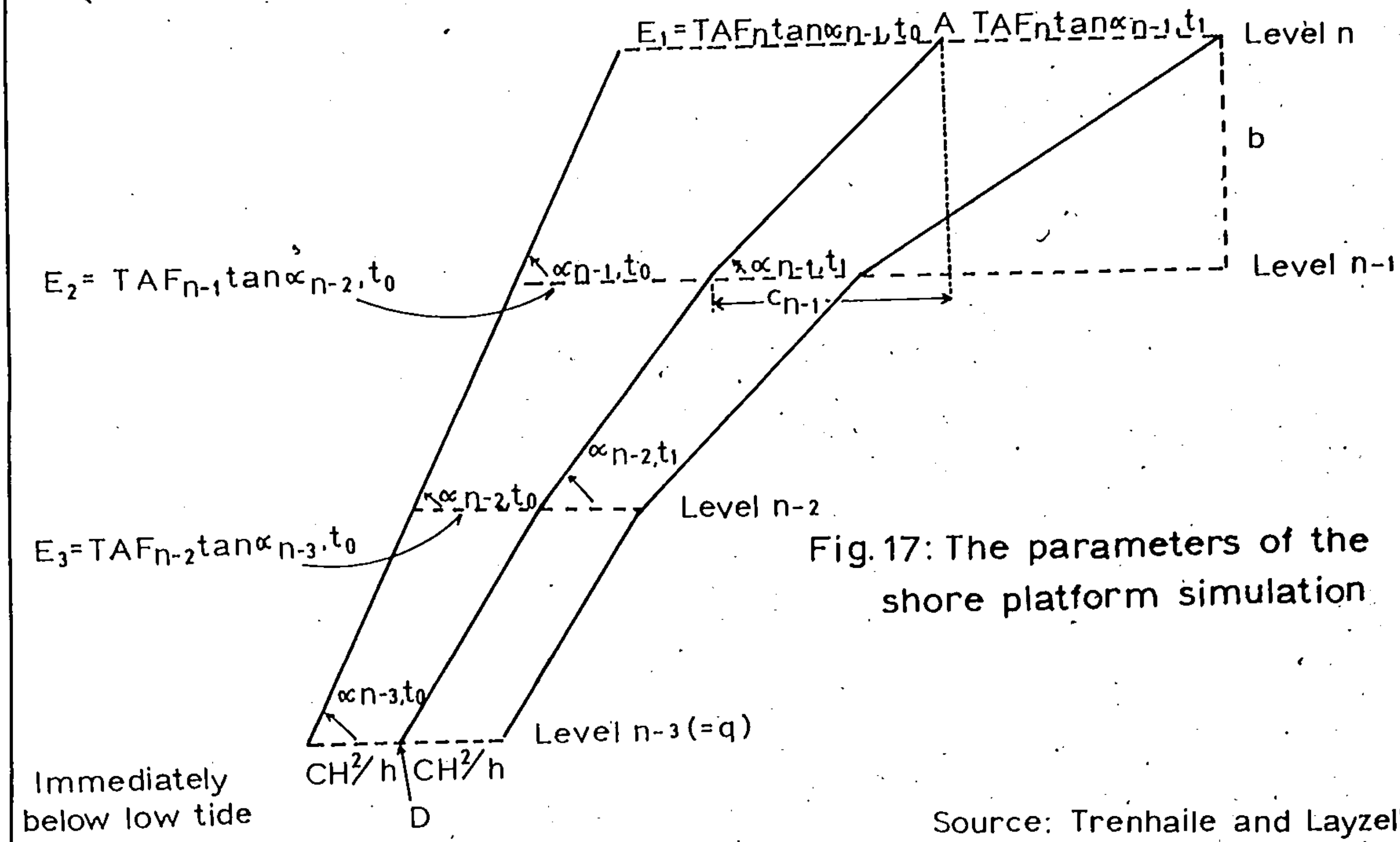


Fig. 17: The parameters of the shore platform simulation

Source: Trenhaile and Layzell (1978, in press) on the bottom (Zenkovitch, 1967).

ie. $E = kV^2$ ——————— (4)

where: E is the bedrock erosion rate;

k is a constant related to, amongst other things, rock hardness; and

V is the maximum orbital veloctiy on the bottom.

If water depth is greater than half the wavelength, or if wave height is greater than 0.04 to 0.06 water depth, waves consist of isolated crests with flat intervening troughs. Isolated wave theory indicates that (Bagnold, 1963):

$V = H\sqrt{gh}/2h$ ——————— (5)

where: H is wave height;

g is the force due to gravity; and

h is the water depth.

Substituting in (4):

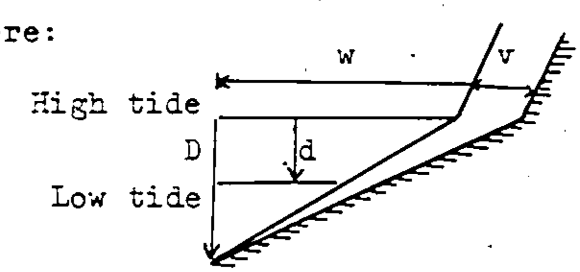
$E = CH^2/h$ ——————— (6)

where: $C = kg/4$

When a wave first encounters shallow water, wave height declines, its height in deep water being regained only when the ratio of water depth to wavelength is about 0.06. Although wave height may increase rapidly towards the breakpoint, the effect is greatest for long flat waves, and may be relatively small for very steep storm waves (Bigelow and Edmonson, 1947). For a wavelength of 15m (50ft), the deep water height is regained when water depth declines to 0.9m (3 ft). Although strictly incorrect therefore, it may be acceptable to assume that wave height is independent of the changing water depth or slope below low tide level which may occur as the model progresses. If, however, wave height does change significantly with relatively small changes in water depth and submarine slope, the effect is probably quite small, since the rate of submarine erosion in shallow areas close to hardrock coastlines appears to be very low. The rate of lowering of a linear profile is given by V$\tan\alpha$, where V is the cliff recession rate and α is the submarine gradient (Zenkovitch, 1967). Applied to the shore platform coastlines of southern Britain, this suggests that submarine downwearing is less than one millimetre per annum, and only 0.06 mm in the Vale of Glamorgan. Although Zenkovitch's formula is valid only for the cliff base, a related expression of somewhat greater complexity that considers submarine erosion immediately below the level of the lowest tides (z), confirms that erosion rates are very low:

$$z = \frac{v(D + d)}{w + v}$$

where:



These low values are similar to rates of downwearing of only a few tenths of a millimetre per annum in the calcareous rocks of the Black Sea, where abrasion is reported to be active and pronounced (Zenkovitch, 1967). Cliff recession rates have not been assessed for eastern Gaspé, but consideration of the morphogenic environment and the structure and lithology of the rocks, suggests that rates of submarine downwearing are probably similar to those in Britain. The only accurately determined rates available for the Australasian study areas show downwearing to be in the order of 1mm. yr^{-1} (Kirk, 1977).

Wave height at low tide level, therefore, is unlikely to have varied significantly in response to changes in water depth or slope related to submarine erosion, since the sea reached its present level. Accordingly, for modelling purposes, the submarine erosion rate immediately below low tide level was assumed to be constant through time, and equal to CH^2/h (eq. 6).

Modelling of shore platform development was done by calculating En,t_1 through various time intervals to En,t_{4200} (the amount of erosion 4,200 years after inheriting an initial slope). Values of E were calculated at 91.44cm (3 ft) intervals from low tide through to high tide. The figure of 91.44 cm or 3 ft. was selected by Trenhaile (1978) and was found to be fine enough to allow for variations in platform morphometry, and yet not too fine as to attempt the modelling of platform microrelief..

The inital surface was assumed to be one of uniform slope, subsequent stages being dependent on the frequency of wave action, the strength of wave erosion in relation to rock hardness ('erodibility'), and the gradient of the segment below each point being considered.

A Fortran IV computer program was used to run the model (fig. 18). Any number up to 200 runs (= t_{200}) with variable time intervals could be produced. A limit of thirty vertical intervals (q= 30) was built into the program. This was adequate for all tidal ranges encountered in the study.

In addition to the F values, values for erodibility (A), initial cliff angle (α_{n-1,t_0}) and low tide erosion ($E_L = CH^2/h$) had to be selected for each simulation. No data exist in any of the six areas to be able to rely on recorded information. Values for these constants had to be obtained by estimation and experimentation. Erodibility was calculated from intertidal erosion rates. Since $TAF_N \tan\alpha_{n-1}$ = Erosion, and erosion on any part of the platform is known to be X $cm.yr^{-1}$, A may be calculated from:

$$A = \frac{X}{F_n \tan\alpha_{n-1}}$$

The units of A are $cm.hr^{-1}$, representing the amount of erosion possible at an elevation with <u>constant</u> wave

Fig. 18: Computer program (FORTRAN IV) for simulating shore platform morphogenesis.

20

```
$JOB     LIST      KKKKKKKKKK
      DIMENSION ANGLES(  ,5 ), EROS(2  ,5 ),F(5 ),XAXIS(5 ),YAXIS(5 )
      REAL LEROS(  ,2  )
      INTEGER R, Y
      COMMON /BLOCK1/ ANGLE, EROS,F, LEROS
      WRITE (6,1 )
      R=1
      L=1
      READ (5,1  ,END=9  ) MAXR, MAXL
  1   FORMAT (2I5)
      READ (5,1 1) (F(I),I=1,MAXL)
  1 1 FORMAT (4(10F8. ,/))
      READ (5,1 2) ANGLE, HARD
  1 2 FORMAT (2F1  .3)
      READ (5,1 4) IOPT
  1 4 FORMAT (I1)
      READ (5,1 3) Z,TIME
      Y=IFIX(TIME)
  1 3 FORMAT (2F1  .5)
      WRITE (6,11) MAXR, MAXL
      WRITE (6,12) (F(I),I=1,MAXL)
      WRITE (6,13) ANGLE , HARD
      IF (IOPT.EQ.1) WRITE (6,1 6)
      WRITE (6,1  )
      WRITE (6,15) R
      WRITE (6,14) Z, TIME
    1 IF(R.EQ.1.AND.L.EQ.1)CALL FIRST(MAXR,MAXL,R,L,ANGLE,HARD,Z,TIME)
      IF(R.EQ.1.AND.L.GT.1)CALL SCOND(MAXR,MAXL,R,L,ANGLE,HARD,Z,TIME)
      IF(R.GT.1.AND.L.EQ.1)CALL THIRD(MAXR,MAXL,R,L,ANGLE,HARD,Z,TIME,Y,
     1IOPT)
      IF(R.GT.1.AND.L.GT.1)CALL FOUR(MAXR,MAXL,R,L,ANGLE,HARD,Z,TIME)
      GO TO 1
  9   STOP
  1   FORMAT (1H1,3 X,'S H O R E   P L A T F O R M   S I M U L A T I O N
     1P R O G R A M',//,3 X,'BY',//,31X,'RICHARD A. DUMALA',/,
     22 X,'DEPARTMENT OF GEOGRAPHY',/,4 X,'UNIVERSITY OF WINDSOR',///)
  11  FORMAT (5X,'CONTROL PARAMETERS FOR THIS JOB',//,5X,'MAXIMUM NUMBER
     1 OF RUNS REQUESTED',I6,/,5X,'MAXIMUM NUMBER OF LEVELS REQUESTED',
     2I4,/)
  12  FORMAT (5X,'TIDAL DURATION FACTOR      ',/,5(11F1 . ,/),/)
  13  FORMAT (5X,'INITIAL PLATFORM SLOPE ',F1  .5,/,5X,'ERODABILITY    FAC
     1TOR ',F12.5,///)
  14  FORMAT (5X,'EROSION AT BASE LEVEL ',F11.5,/,5X,'TIME (YEARS FROM S
     1TART)',F1  . ,/)
  15  FORMAT (5X,'RUN NUMBER ',I3)
  1 5 FORMAT (5X,'NO GRAPHS WILL BE PRODUCED.',///)
  1 6 FORMAT (5X,'PLOTS OF CUMULATIVE EROSION BY LEVELS VS. HEIGHT WILL
     1BE PRODUCED.',///)
      END
      FUNCTION CEX(EROS,R,L)
      DIMENSION EROS(2  ,5 )
      INTEGER R
      CEX= .
      DO 1   I=1,L
      CEX=CEX+EROS(R,I)
    1 CONTINUE
      RETURN
      END
      FUNCTION RADIAN(X)
      RADIAN= (X / 18 . ) * 3.14159
      RETURN
      END
      FUNCTION DEGREE(X)
      DEGREE= (X * 18 . ) / 3.14159
      RETURN
      END
      SUBROUTINE GRAPH (ML,R)
      DIMENSION EROS(2  ,5 ), XAXIS(5 ), YAXIS(5 )
      DIMENSION ANGLES(2  ,5 ), F(5 )
      REAL LEROS(  ,2  )
      INTEGER R
      COMMON /BLOCK1/ ANGLE, EROS, F, LEROS
      XAXIS(1)= .
      DO 1    I=2,ML
    1 XAXIS(I)=XAXIS(I-1)+LEROS(I,R)
      YAXIS(1)= .
      DO 2    I=2,ML
    2 YAXIS(I)=YAXIS(I-1)+ 1.44
      CALL PLOTS(XAXIS,YAXIS,ML)
      WRITE (6,1  ) R
```

Fig. 18 cont.

```
      WRITE (6,101)
      RETURN
100   FORMAT (5X,'PLOT OF CUMULATIVE EROSION (X-AXIS) VS. HEIGHT (Y-AXIS
     1) FOR RUN',I4)
101   FORMAT (1H1)
      END
      SUBROUTINE FIRST (MR,ML,R,L,A,H,Z,T)
      DIMENSION ANGLES(20,50),EROS(20,50), F(50)
      REAL LEROS(50,20)
      INTEGER R
      COMMON /BLOCK1/ ANGLES, EROS, F, LEROS
      RAD=RADIAN(A)
      EROS(R,L)=T*H*F(L)*TAN(RAD)
      LEROS(L,R)=EROS(R,L)
      ANGLES(R,L)=DEGREE (ATAN(91.44/(EROS(R,L)-(Z*T)+(91.44/(TAN(RAD)))
     1      )))
      HT=91.44 * L
      WRITE (6,100)
      WRITE (6,200) L,F(L),T,H,HT,EROS(R,L),EROS(R,L),ANGLES(R,L)
      L=L+1
      RETURN
100   FORMAT (//,5X,'LEVEL              F        TIME          HARD       HEIGHT
     1 EROSION          CUM. EROS       ANGLE',/)
200   FORMAT (5X,I5,4F10.2,2F15.2,F10.2,/)
      END
      SUBROUTINE SECND (MR,ML,R,L,A,H,Z,T)
      DIMENSION ANGLES (20,50), EROS(20,50), F(50)
      REAL LEROS(50,20)
      INTEGER R
      COMMON /BLOCK1/ ANGLES,EROS,F, LEROS
      RAD=RADIAN(A)
      EROS(R,L)=T*H*F(L)*TAN(RAD)
      LEROS(L,R)= EROS(R,L)
      ANGLES(R,L)=DEGREE(ATAN(91.44/(EROS(R,L)-EROS(R,L-1)+(91.44/(TAN(
     1               RAD))))))
      HT=91.44 * L
      CE=CEX(EROS,R,L)
      WRITE (6,200) L,F(L),T,H,HT,EROS(R,L),LEROS(L,R),ANGLES(R,L)
      L=L+1
      IF (L.GT.ML) GO TO 1
      RETURN
    1 IF (IOPT.EQ.1)  CALL GRAPH(ML,R)
      R=R+1
      L=1
      RETURN
200   FORMAT (5X,I5,4F10.2,2F15.2,F10.2,/)
      END
      SUBROUTINE THIRD (MR,ML,R,L,A,H,Z,T,Y,IOPT)
      DIMENSION ANGLES(20,50), EROS(20,50), F(50)
      REAL LEROS(50,20)
      INTEGER R, Y
      COMMON /BLOCK1/ ANGLES, EROS, F,LEROS
      READ (5,300) Z,T
      Y=Y+IFIX(T)
      IF (IOPT.EQ.1) GO TO 1
      WRITE (6,500)
    1 WRITE (6,400) R,Z,Y
      RAD=RADIAN(ANGLES(R-1,L))
      EROS(R,L)=T*H*F(L)*TAN(RAD)
      LEROS(L,R)=LEROS(L,R-1) + EROS(R,L)
      ANGLES(R,L)=DEGREE(ATAN(91.44/(EROS(R,L) -(Z*T)+(91.44/(TAN(RAD)))
     1    )))
      HT=91.44 * L
      CE=CEX(EROS,R,L)
      WRITE (6,100)
      WRITE (6,200) L,F(L),T,H,HT,EROS(R,L),LEROS(L,R),ANGLES(R,L)
      L=L+1
      RETURN
100   FORMAT (//,5X,'LEVEL              F INCREMENT         HARD       HEIGHT
     1   EROSION          CUM. EROS       ANGLE',/)
200   FORMAT (5X,I5,4F10.2,2F15.2,F10.2,/)
300   FORMAT (2F10.5)
400   FORMAT (5X,'RUN NUMBER ',I3,/,5X,'EROSION AT LOW TIDE',F13.5,/,
     15X,'TIME (YEARS FROM START)',I7,/)
500   FORMAT (1H1)
      END
      SUBROUTINE FOUR (MR,ML,R,L,A,H,Z,T)
      DIMENSION ANGLES(20,50),EROS(20,50),F(50)
      REAL LEROS(50,20)
      INTEGER R
```

Fig. 18: cont.

```
      COMMON /BLOCK1/ ANGLES, EROS, F,LEROS
      RAD=RADIAN(ANGLES(R-1,L))
      EROS(R,L)=T*H*F(L)*TAN(RAD)
      LEROS(L,R)=LEROS(L,R-1) + EROS(R,L)
      ANGLES(R,L)=DEGREE(ATAN(91.44/(EROS(R,L)- EROS(R,L-1)+(91.44/(TAN(
     1              RAD))))))
      HT=91.44 * L
      CE=CEX(EROS,R,L)
      WRITE (6,20 ) L,F(L),T,H,HT,EROS(R,L),LEROS(L,R),ANGLES(R,L)
      L=L+1
      IF (L.GT.ML) GC TO 1
      RETURN
    1 IF (IOPT.EQ.1)  CALL GRAPH(ML,R)
      R=R+1
      L=1
      IF (R.GT.MR) STOP
      RETURN
   20 FORMAT (5X,I5,4F10.2,2F15.2,F10.2,/)
      END
//
//
```

attack. From eq. (3) it is possible to see how this is derived:

$$E = AF \tan$$

For the purposes of defining units this may be reduced to,

$$E = AF,$$

where E is in cm and F is in hours. A must, therefore, be in cm. hr^{-1}. Appendix One gives a fuller derivation of this formula.

III SUMMARY

To simulate shore platform formation and morphology a mathematical model, devised by Trenhaile (1978), was employed. The computer program for the model calculates successive stages in the evolution of a shore platform from an initial cliff surface. Each stage influences the succeeding stage by varying the amount of erosion which takes place according to the angle of the platform. The angle of the platform segment connecting levels n and n-1 after time t_1, is given by:

$$\alpha_{n-1, t_1} = \tan^{-1} \left((91.44) / (E_{n1t1} - E_{n-1,t1} + 91.44 \cot \alpha_{n-1,t_o}) \right) \qquad (7)$$

where $E_{n1,t1}$ and $E_{n-1,t1}$ are the amounts of erosion at levels n and n-1 respectively, in time t_1, as given by (3) and

α_{n-1,t_o} is the initial slope at that level. For derivation of this formula see Appendix Two.

CHAPTER FIVE

TESTING THE MODEL : PART ONE

I PROCEDURE

II PROBLEMS

I PROCEDURE

Two levels of analysis were performed to assess the usefullness of the simulation model described in chapter three. Firstly, profiles were generated by insertion of the relevant Fn values and constants into the computer program. Comparison was then made between the actual and the simulated profiles for all six studys areas. Secondly, a graphical and statistical analysis was made of other properties of the model. This included studies of the model's ability to simulate the attainment of equilibrium in shore platform morphology, its efficiency in predicting the amount of erosion per unit time, and an analysis of the relationship between width and gradient among the simulated profiles.

Surveyed profiles from all the study areas were collected by referring to published material in the form of cross-sections or contour maps of the shore platforms. The particular sources used were: Trenhaile (1969) for

The Vale of Glamorgan; Phillips (1970) for The Isle of Man; So (1965) for The Isle of Thanet; Trenhaile (1978) for the Gaspé Peninsula; Sanders (1968a) for Tasmania; and Healy (1968) for the Whangaparoa Peninsula, Auckland, New Zealand. In each case the profiles had been constructed from surveyed data. From each suite of profiles a mean profile was constructed to represent the general pattern of shore platform morphology in the area. To construct a mean profile, all the surveyed profiles were superimposed on graph paper and average heights calculated at equal distances along the profiles. Within each group of profiles it was possible to align them to a common tidal datum, usually mean tide level (Admiralty, 1948). The actual and mean profiles have been drawn at suitable scales to allow for comparison with the simulated platforms (figs. 19 to 28).

Initially, the values for the constants E_L and A were estimated from a range of possible and typical values. After a few trial runs at the programs, however, a new and more accurate method was devised (Ch. 6, I).

The computer program was run many times for each study location, the E /A ratio being changed between runs. To assess the individual influences of low tide erosion and erodibility, these values were sometimes changed to maintain the same E /A ratio. The effect of this on the simulated profiles is discussed in Ch. 6.

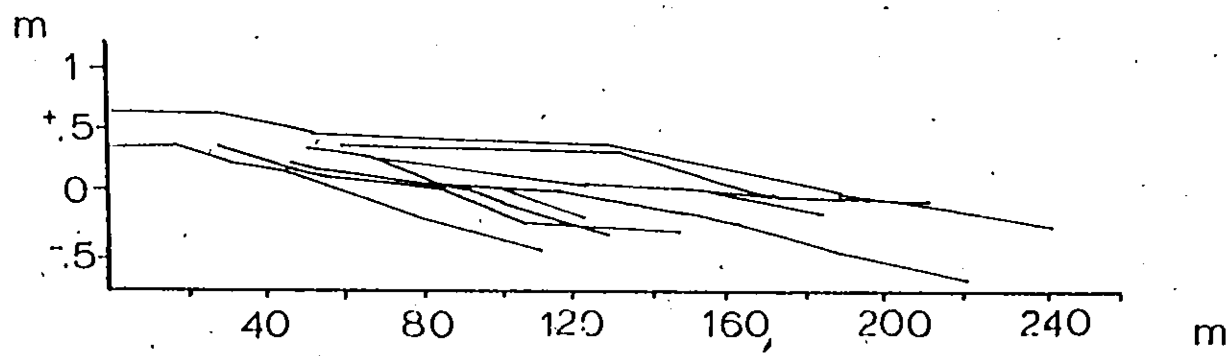


Fig.19: Superimposed shore platform profiles:
Isle of Thanet, G.B.

Source: So (1965)

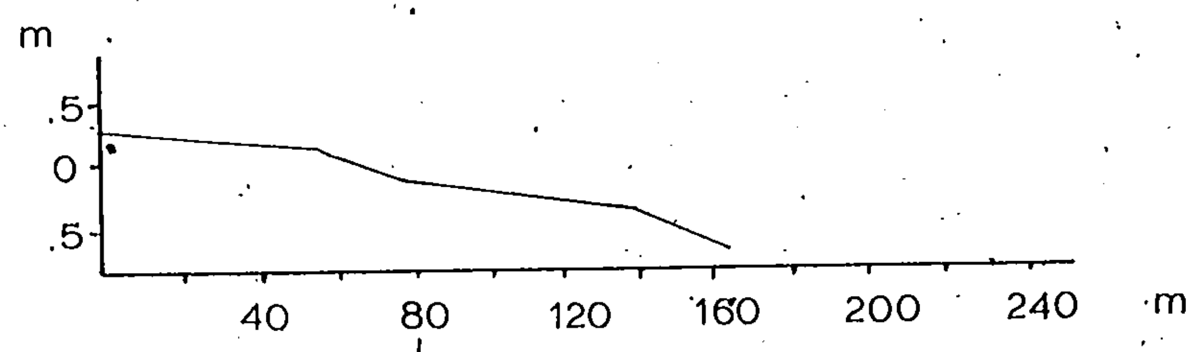


Fig. 20: Mean shore platform profile: Isle of Thanet, G.B.

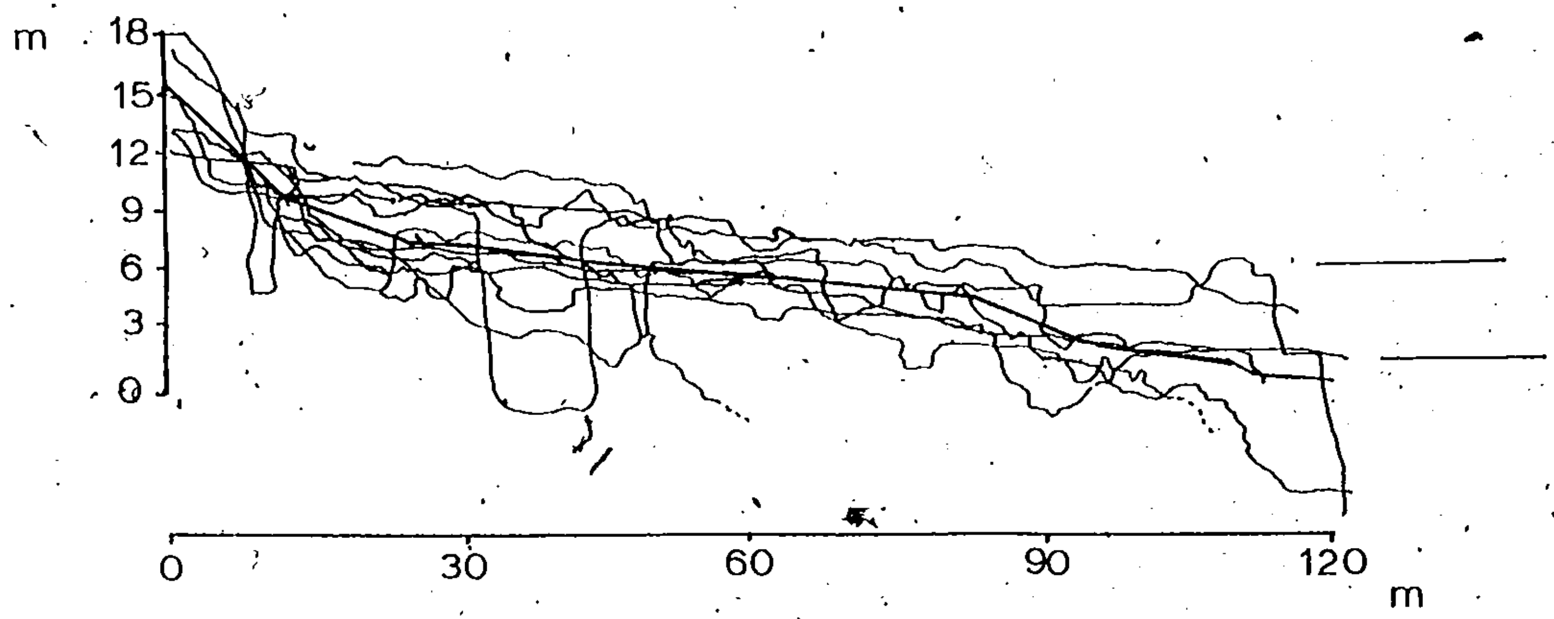


Fig. 21: Superimposed shore platform profiles:
Isle of Man, G.B.

(Source: Phillips 1970a)

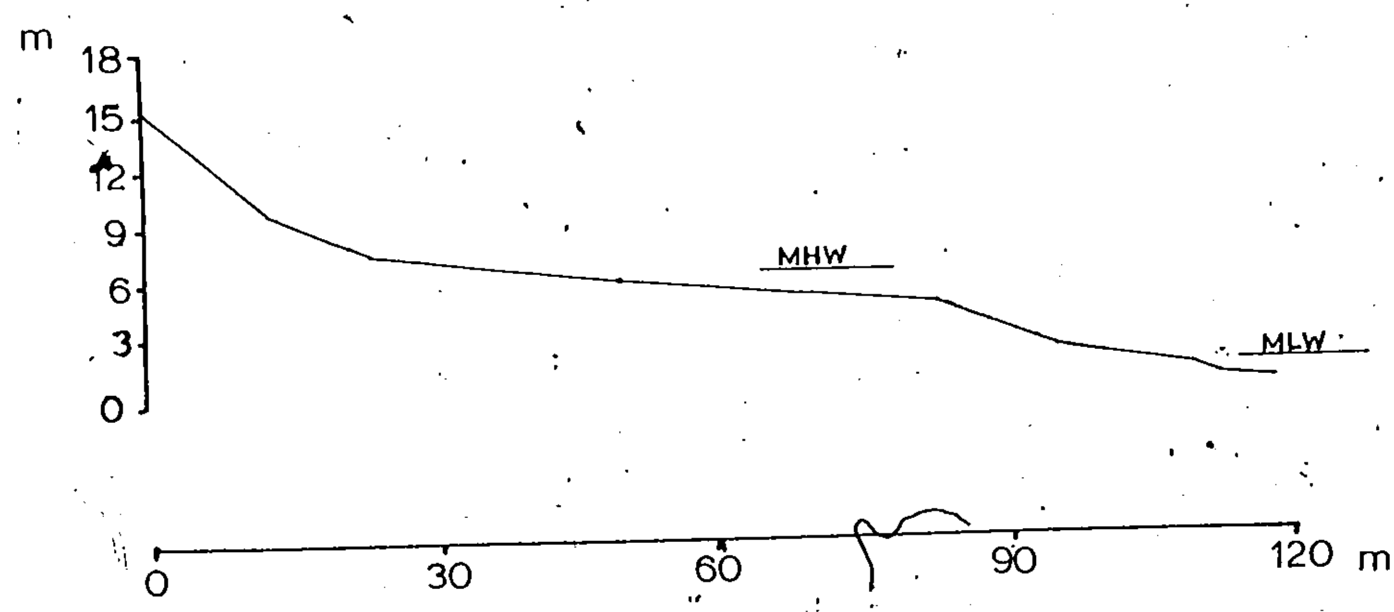


Fig.22: Mean shore platform profile: Isle of Man.

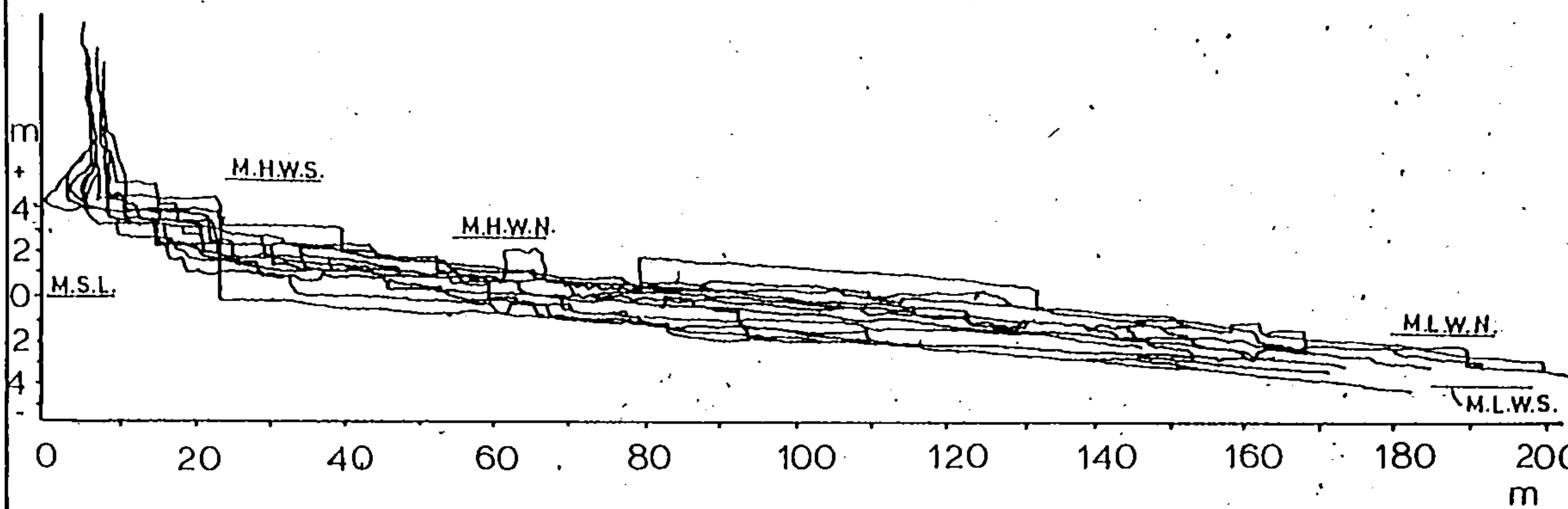


Fig.23: Superimposed shore platform profiles: Vale of Glamorgan, Wales.

Source: Trenhaile (1969).

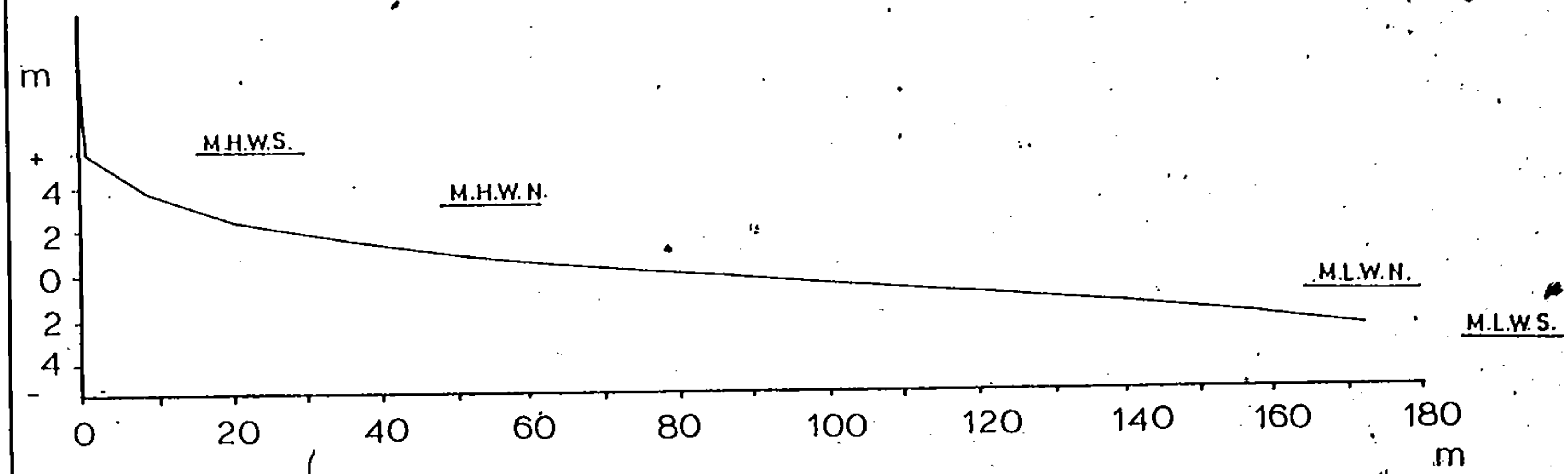


Fig.24: Mean shore platform profile: Vale of Glamorgan, Wales.

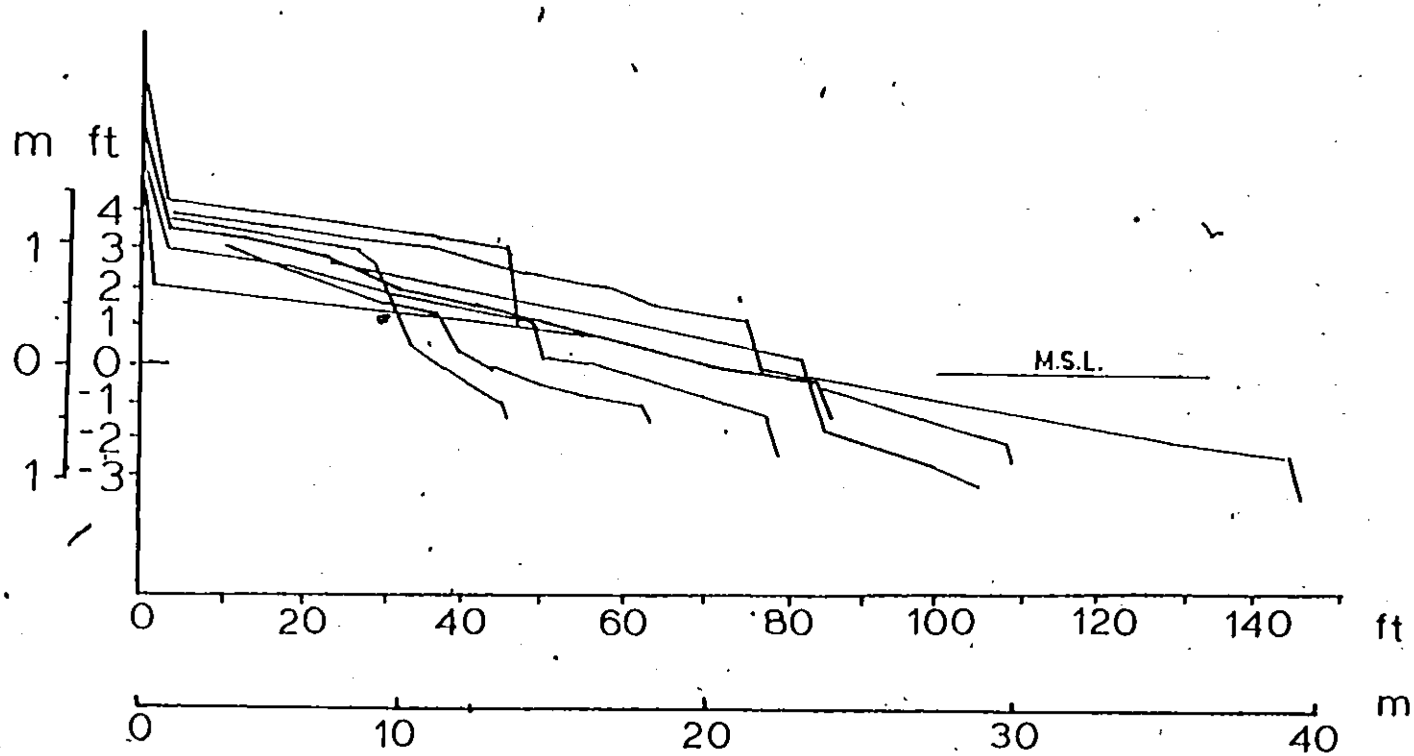


Fig. 25 Superimposed shore platform profiles: Tasmania

Source: Sanders (1968a)

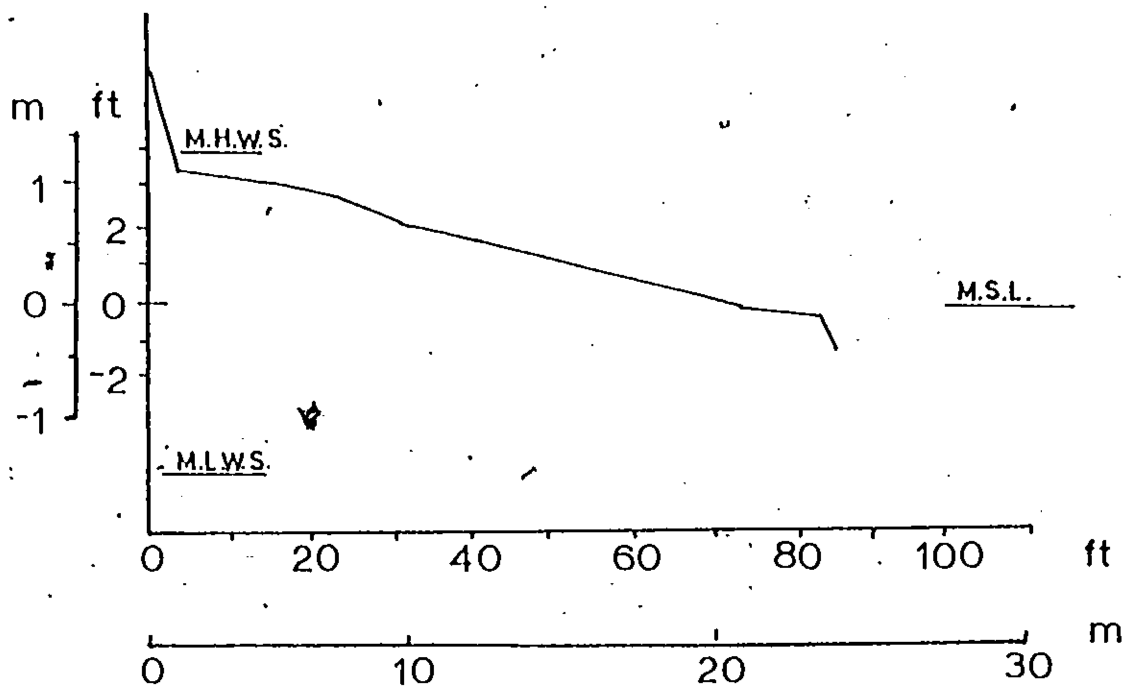


Fig.26: Mean shore platform profile: Tasmania

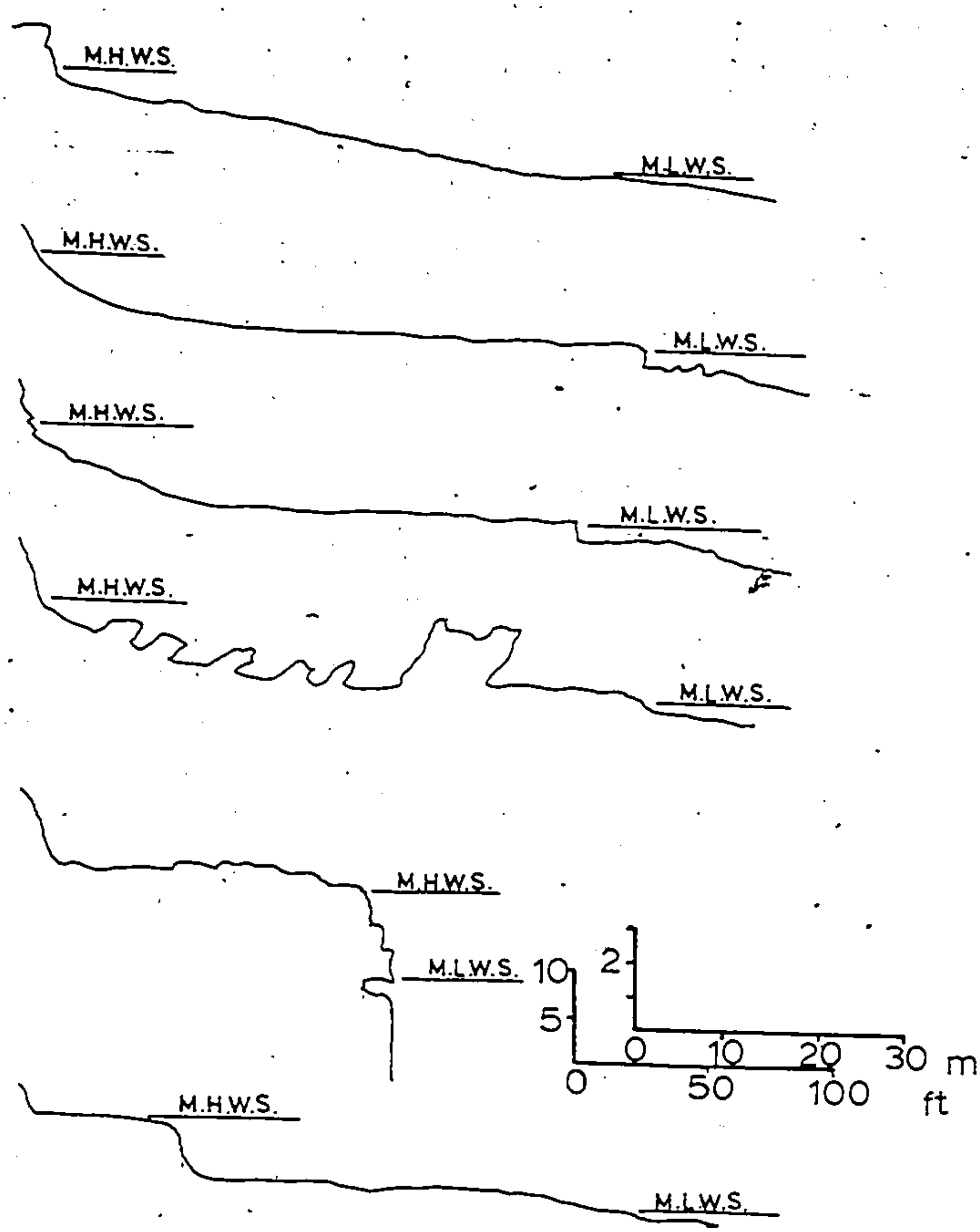


Fig. 27: Platform Profile Types for Auckland, N.Z.

Source: Healey (1968)

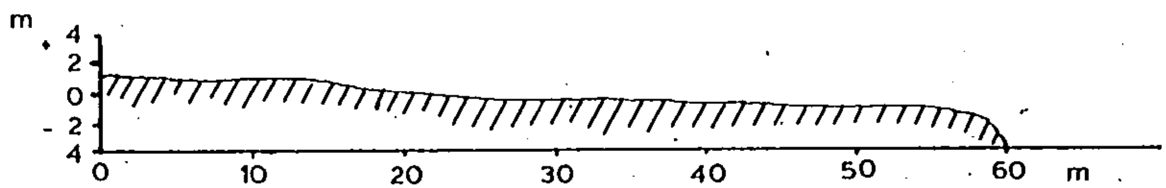


Fig. 28: Mean shore platform profile: Gaspé.

Source: Trenhaile (1978)

Computer output gave a listing of profile angles (in degrees) for each level and for any specified point in time, up to 4,200 years (fig. 29).

II PROBLEMS

Comparison of actual and simulated platform profiles presented a number of difficulties, mostly due to the dependence of segment gradient and width on the erodibility and submarine erosion constants. Six groups of difficulties were recognized:

(i) The influence of lithology on shore platform morphology.

(ii) The possibility of relative land/sea level changes within the recent past (Holocene).

(iii) The difference between still water level and the level of maximum wave attack, possibly influencing platform elevation.

(iv) Other morphogenic factors, which may include: fetch, platform location (headland or bay) (So, 1965; Takahashi, 1975); and cliff height (1974b) (figs. 3 and 4).

(v) Technical problems, including the possible invalidity of comparing the simulated profiles with the 'mean' profiles.

(vi) The many effects of changing either the submarine erosion constant or the erodability value, or

Fig. 29: SHORE PLATFORM SIMULATION PROGRAM

BY

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CONTROL PARAMETERS FOR THIS JOB

MAXIMUM NUMBER OF RUNS REQUESTED 200
MAXIMUM NUMBER OF LEVELS REQUESTED 11

TIDAL DURATION FACTOR
17. 81. 146. 243. 244. 245. 243. 241. 173. 54. 42.

INITIAL PLATFORM SLOPE 30.00000
ERODABILITY FACTOR 0.70000

PLOTS OF CUMULATIVE EROSION BY LEVELS VS. HEIGHT WILL BE PRODUCED.

NO GRAPHS WILL BE PRODUCED.

RUN NUMBER 1
EROSION AT BASE LEVEL 5.00000
TIME (YEARS FROM START) 1.00000

LEVEL	F	TIME	HARD	HEIGHT	EROSION	CUM. EROS	ANGLE
1	17.00	1.00	0.70	91.44	6.67	6.67	29.71
2	81.00	1.00	0.70	182.88	32.74	32.74	26.40
3	146.45	1.00	0.70	274.32	59.19	59.19	26.32
4	242.90	1.00	0.70	365.76	98.17	98.17	24.66
5	243.95	1.00	0.70	457.20	98.59	98.59	26.93
6	245.00	1.00	0.70	548.64	99.02	99.02	29.93
7	242.80	1.00	0.70	640.08	98.13	98.13	30.14
8	240.66	1.00	0.70	731.52	97.26	97.26	30.14
9	172.76	1.00	0.70	822.96	69.82	69.82	34.93
10	53.53	1.00	0.70	914.40	21.63	21.63	39.69
11	41.88	1.00	0.70	1005.84	16.93	16.93	30.75

RUN NUMBER 2
EROSION AT LOW TIDE 5.00000
TIME (YEARS FROM START) 2

LEVEL	F	INCREMENT	HARD	HEIGHT	EROSION	CUM. EROS	ANGLE
1	17.00	1.00	0.70	91.44	6.79	13.66	29.44
2	81.00	1.00	0.70	182.88	28.14	60.88	23.98
3	146.45	1.00	0.70	274.32	50.72	109.90	23.79
4	242.90	1.00	0.70	365.76	78.78	176.94	22.08
5	243.95	1.00	0.70	457.20	98.33	196.92	27.14
6	245.00	1.00	0.70	548.64	98.75	197.77	29.87
7	242.80	1.00	0.70	640.08	98.68	196.81	30.15
8	240.66	1.00	0.70	731.52	97.80	195.06	30.28
9	172.76	1.00	0.70	822.96	84.45	154.27	37.87
10	53.53	1.00	0.70	914.40	31.09	52.73	58.14
11	41.88	1.00	0.70	1005.84	17.44	34.37	33.15

RUN NUMBER 3
EROSION AT LOW TIDE 5.00000
TIME (YEARS FROM START) 3

LEVEL	F	INCREMENT	HARD	HEIGHT	EROSION	CUM. EROS	ANGLE
1	17.00	1.00	0.70	91.44	6.72	20.38	29.16
2	81.00	1.00	0.70	182.88	25.22	86.09	22.20
3	146.45	1.00	0.70	274.32	45.20	155.10	21.91
4	242.90	1.00	0.70	365.76	68.97	245.92	20.15
5	243.95	1.00	0.70	457.20	87.55	284.47	24.91
6	245.00	1.00	0.70	548.64	98.49	296.25	28.25
7	242.80	1.00	0.70	640.08	98.72	295.53	30.11
8	240.66	1.00	0.70	731.52	98.35	293.40	30.34
9	172.76	1.00	0.70	822.96	94.03	248.31	36.91
10	53.53	1.00	0.70	914.40	60.29	113.01	75.83
11	41.88	1.00	0.70	1005.84	19.14	53.51	42.76

both. This is expanded upon later.

(i) Lithology

This is not the place to attempt a full discussion of the influence of lithology on shore platform morphogenesis, since it is topic on which many workers have concentrated (for example: Ferrar et al., 1925; Edwards, 1941; Everard et al., 1964; Gill, 1967; and Trenhaile, 1972). Some, such as Trenhaile, have considered its influence to be fairly small, whilst others, including Everard, have stressed the geological influence on width, microrelief and slope of shore platforms. Geology is not ignored however, by the present simulation model. As has already been mentioned, erodibility is a factor of two components, one of which is rock resistance. Assuming uniform rock type then, the present model accounts for differences in geological resistance to attack, even if no precise data exist for this factor from each of the study locations. However, changes in geology, faults, planes of weakness and joints all, to a certain extent, play their role in shaping a shore platform. These factors, however, while significant at the local, single profile level, are less influential when consideration is made of regional (mean) platform morphometry (Trenhaile, 1969 et seq). Repeatedly, significant correlations have been found (figs. 3 and 4) between morphogenic variables, suggesting that many platforms are in, or are approaching, a state of dynamic equilibrium. Lithological breaks, such as joints, tend in these cases to explain the exceptions from the rule, or the residuals in a correlation analysis. In the case of the Vale of Glamorgan, "...residuals from regression for the platform gradient against tidal range ... change from a maximum negative value in the west, to a maximum positive value in the east... In the west, low platform gradients are often related to the presence of weak beds, characterized by thin limestones and thick, interbedded shales". (Trenhaile, 1974b, p. 137). The role of such geological changes is assumed to be one of imposing "noise upon the signal"; of upsetting the pattern of morphometric relationships by giving each platform its own distinctive micro-morphology. Two methods were employed to reduce the influence of lithological control: each level in the model was set at 91.44cm (3 ft) apart in the vertical plane; and mean profiles were drawn for comparison with the simulated ones. Both should minimize the interference of micro-relief.

(ii) Land/Sea Level Changes.

This topic has been investigated in both the isostatically and eustatically influenced coasts of Japan (Takahashi, 1964 et seq) and Britain (Phillips, 1970a and 1970b). All areas for the present study may be considered to have had a sea level within a metre or two of the present level over the past 4,200 years. Areas of greatest possible isostatic change are the Vale of Glamorgan, Wales, Gaspé Peninsula, and the Isle of Man. The first two of these three areas are also the areas which have given the strongest morphogenic correlations. Many curves of relative land/sea level movement have been drawn for the Holocene period (Jelgersma, 1966). Following from the work of Trenhaile (1969 et seq.) and the theories reviewed by Jelgersma (1966) it is fairly safe to assume that the present sea level was reached at least 2,500 to 3,000 years B.P. Indeed, the results of the present study may be used to support or attack this assumption, depending on whether or not close correlations are found between simulated and actual profiles. The closer the correspondence between real and modelled profiles, the greater the support for the view that present inter-tidal platforms are 'adjusted' to present sea level. Time and the simulation model are discussed later.

(iii) Elevation of water level during wave passage.

Sunamura (1973) has presented an overview of theories regarding the raising of the level of effective wave attack above still water level (see also, Sanders, 1968b). This phenomenon may raise the elevation of the platform, a few centimetres above that predicted in the model, but does not affect the other morphological characteristics of the simulated platforms (Sunamura, 1973). This is due to the random vertical distribution of the occurrence of storm waves. Storms occur independently of the factors determining the tidal curve, which are predominantly celestial. The randomness of this factor allows it to be ignoredas far as modelling shore platform geometry is concerned.

(iv) Other morphogenic factors.

As far as the variables of erodibility, angle, time and so on may be quantified they were included in the model formula. The precise role of other factors is less clear, however, and their quantification is consequently less viable. As morphometric research progresses it is likely that more and more variables maybe be quantified for the general model of shore platform evolution. The exclusion, then, of the many other factors which have been reported to influence shore platform morphology is justified on two related counts. Firstly, recent research has shown that the factors included here are the most important ones concerning the development of platform profiles. Secondly, because of their repeated appearance in multivariate studies, the factors included here are easier to quantify than the less important influences.

(v) Technical problems.

Undoubtedly, certain degrees of inaccuracy were both introduced but, hopefully, reduced by the drawing of mean profiles. It is possible that the mean profile for an area, instead of reducing variation, actually introduces more than would the use of a single surveyed profile, since it is composed of more data. Thus, the mean profiles may not even exist in the areas selected. Certainly, as the diversity of surveyed profiles increases the amount of error introduced into the mean profiles also increases. Compare, for example, the Vale of Glamorgan (figs. 23 and 24) with the Isle of Man (figs. 21 and 22). When comparing the simulated profiles with those for the relevant locations all profiles are considered, including the mean.

(vi) The effects of varying E and/or A.

It was found that both segment gradient and width are dependent on the values chosen for the constants in the basic formula. This obviously complicated the process of comparing actual with simulated profiles. The precise effects of varying E and/or A cannot be discussed without recourse to actual results (Chs. 6 and 7).

This chapter began by outlining the procedure for simulating shore platform profile development, and concluded with a discussion of the problems concerning the comparison of the modelled forms with the actual cases. These constraints upon the model are important and should be borne in mind whilst reading the later chapters.

CHAPTER SIX

TESTING THE MODEL : PART TWO

I EQUILIBRIUM

II THE E_L /A RATIO

III COMPARISON OF MODEL WITH A PARALLEL RETREAT APPROACH.

I EQUILIBRIUM

The tidal duration (F) values are initially responsible for great differences in erosion rates across the platform profiles. Steep slopes permit high rates of erosion, providing rapid changes in the width and gradient of each platform segment. Gradients decline quickly in most cases, but when relatively high rates of low tide erosion are combined with low erodibility, slopes near high and low tide level decline more slowly than those at midtide, or even increase once the steep inherited surface has been reduced. As the simulated profiles progress through time, platform segments attempt to attain gradients which compensate for the differences in the F-values across the profiles. The erosion rates at each level, in response to changes in platform slope, slowly converge towards equality. If sufficient time is available, a state of dynamic equilibrium is attained, in which the erosion rate at each level is equal to the constant rate occurring below low tide level. Once equilibrium has been achieved, platform slope, shape, and size remain constant, although the slow landward shift of the platform continues. Platform gradients have now adjusted to the intertidal distribution of wave energy (fig. 16).

The equilibrium form of platforms may be calculated without recourse to their intermediate stages. Equilibrium is attained at time T when the rate of erosion at each level is equal to that occurring immediately below low tide level.

Thus:

$$TAF_n \tan\alpha_{n-1,T} = TAF_{n-1} \tan\alpha_{n-2,T} = \ldots TE_L$$

therfore, $\tan\alpha_{n-1,T} = E_L / AF_n$

therfore, $\alpha_{n-1,T} = \tan^{-1}(E_L / AF_n)$. ____________(8)

In this way a range of E_L / A ratios for each location could be calculated, rather than obtained by trial and error with the computer programs.

The influence of the submarine erosion and erodibility constants on the simulated profiles is discussed in section II of this chapter. However , equilibrium profile shape is independent of these factors, since:

$\tan\alpha_{n-1,t_0} = E_L / AF_n$, and

$\tan\alpha_{n-2,t_0} = E_L / AF_{n-1}$ therefore

$$\tan\alpha_{n-1,t_0} / \tan\alpha_{n-2,t_0} = F_{n-1} / F_n \quad \text{(9)}$$

Therefore, whatever erodibility and submarine erosion values are considered, the ratio of the tans of the gradients of one platform segment to that of the segment below is constant. This indicates that, irrespective of the tidal range, declining duration values about the midtide maximum, causes platforms to be concave near high tide, linear over much of their length, and convex at their seaward termini. In actuality, however, a number of factors may serve to obscure this ideal form. The gradient of the concave ramp at the cliff base or the convex low tide 'cliff' depends upon the value of E_L / ΔF_n, as derived in eq.(8). If the rate of submarine erosion is low and erodibility is high, then both slopes may be so gentle that they grade almost imperceptibly into the main platform slope. Variation of the erodibility value caused by structural and lithological factors may also serve to emphasize or obscure these non-linear segments. If weak strata overlie more resistant beds, platforms may develop that have much lower gradients than those in more homogeneous outcrops in the same morphogenic environment. These platforms will have imperceptible ramps at the cliff base and a steep low tide cliff at their seaward termini. These platforms are typified by Breaksea Point in Glamorgan, where the erosion of weak upper bucklandi shales has exumed a platform cut in more resistant limestones Trenhaile, 1969). Breaksea Point is more than 550m wide, has a gradient of less than one degree and the only abrupt seaward terminus in Glamorgan. Alternatively, resistant strata overlying weaker beds provides steeper platforms than their neighbours, and gentler seaward termini. This explains platform gradients of more than a degree, and an ill-defined low tide break of slope near Grande Vallée Gaspé (Trenhaile, 1978). The occurrence of ramps is often related to beds of resistant strata at the cliff base (Trenhaile, 1978), or to sheltered environments (Trenhaile, 1969; Hills, 1972), where erodibility is also low. Ramps, therefore, may be associated with narrow, steep platforms in sheltered locations where erodibility is low across the platform, or may be the expression of low erodibility values at the cliff base, related to geological factors. In the latter case, prominent ramps may be found on profiles which lack the marked convex slopes of the seaward termini. In Gaspé, where steeply dipping strata determine that low tide erosion must eventually encounter relatively resistant beds of rocks, low tide cliffs are common, in contrast to areas where strata are quasi-horizontal, as at Riviere à Claude Gaspé, or throughout the Vale of Glamorgan.

II The E_L / A Ratio

That a change in the ratio between submarine erosion rate and the erodibility influenced gradient and width of the simulated profile, was first noticed for the ports of Gaspé and Glamorgan (Trenhaile and Layzell, 1978, in press). The simulated Gaspésian profiles consist of very low gradients and a marked break at their seaward termini, whereas those in Glamorgan are generally steeper, with a long, linear segment extending for some distance above and below midtide level (fig. 30). Simulated equilibrium profiles were closest to their real counterparts when the ratio E_L / A was between 12 and 6 in Glamorgan, producing platforms between 132 to 264m in width, and between 10 to 5 in Gaspé with associated widths between 69 and 138m, respectively. Optimum values of E_L / A = 8 for Glamorgan produced a platform 198m wide with a generally linear slope of about 2°, with one ramp of about 5° at the cliff base, and another of about 8° at absolute low tide level. When E_L / A is between 5 and 10, simulated profiles that are very similar to those in Gaspé were produced, with gradients between 24 and 48' and low tide cliffs with slopes between 8 and 16'.

The other two British areas, Thanet and the Isle of Man, show rather less correspondence than that for Glamorgan. The Isle of Man platforms have been described by Phillips (1970a) as largely inherited features. Formed on very resistant rock, the platforms assume a wide variety of shapes and widths. The mean profile is probably least reliable in this location. Bearing in mind the geology and location of the island, Phillips's hypothesis of 'inheritance' for the platforms seems quite feasible. Despite the weight of evidence that is held in favour of inheritance, the simulated profile with an E_L / A ratio of 10 has a width (13m) close to that

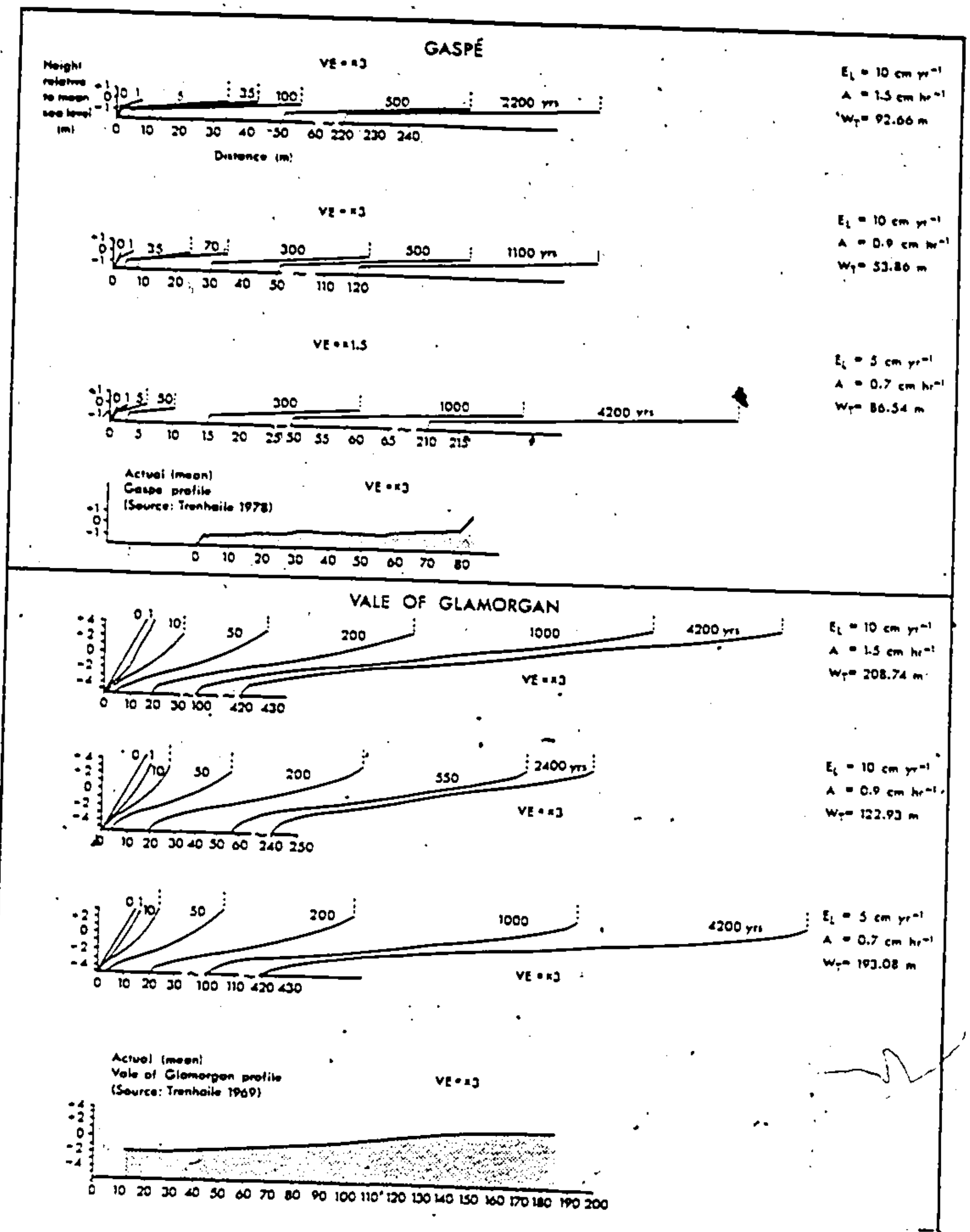


Fig. 30: Simulated and actual shore platform profiles: Gaspé and the Vale of Glamorgan.

of the widest surveyed profile (122m) (figs. 21 and 31). An E_L / A ratio of 25 provided a platform width (55m) similar to that of the narrowest surveyed profile (55m) (fig. 21). This range of acceptable E_L / A ratios for the Isle of Man is due to the diversity of platform morphology on the island. Over the central portion of the simulated platform, angles ranged from 2.51 to 3.22 degrees with a clear mid-tide bevel. Gradients increased at the seaward end to 28.35° and at the cliff-platform ramp to 6.68°. These are very close to the actual angles which average 2.0° over the central plane, 7.59° at the cliff-platform ramp, and range from 0 to 90° at the low-tide cliff.

The Isle of Thanet had a narrower band of acceptable E_L / A ratios, from 10 to 14. An E_L / A value of 11.1 produced a platform 106.3m in width with a mean angle of 1.52°, which is close to that surveyed by So (1965) of 1.2°. No low tide cliffs were produced within the range of 10 to 14 (fig. 32).

The Australasian study areas (Tasmania and Auckland) had similar platform profiles, a similar range of acceptable E_L / A ratios and almost identical simulated profiles (figs. 33 and 34). The Auckland simulations show quite clearly the controlling effect of the erodibility factor over platform width. With an E_L / A ratio of 12.5 the equilibrium platform profile is wider than that produced with an E_L / A = 25. The smaller

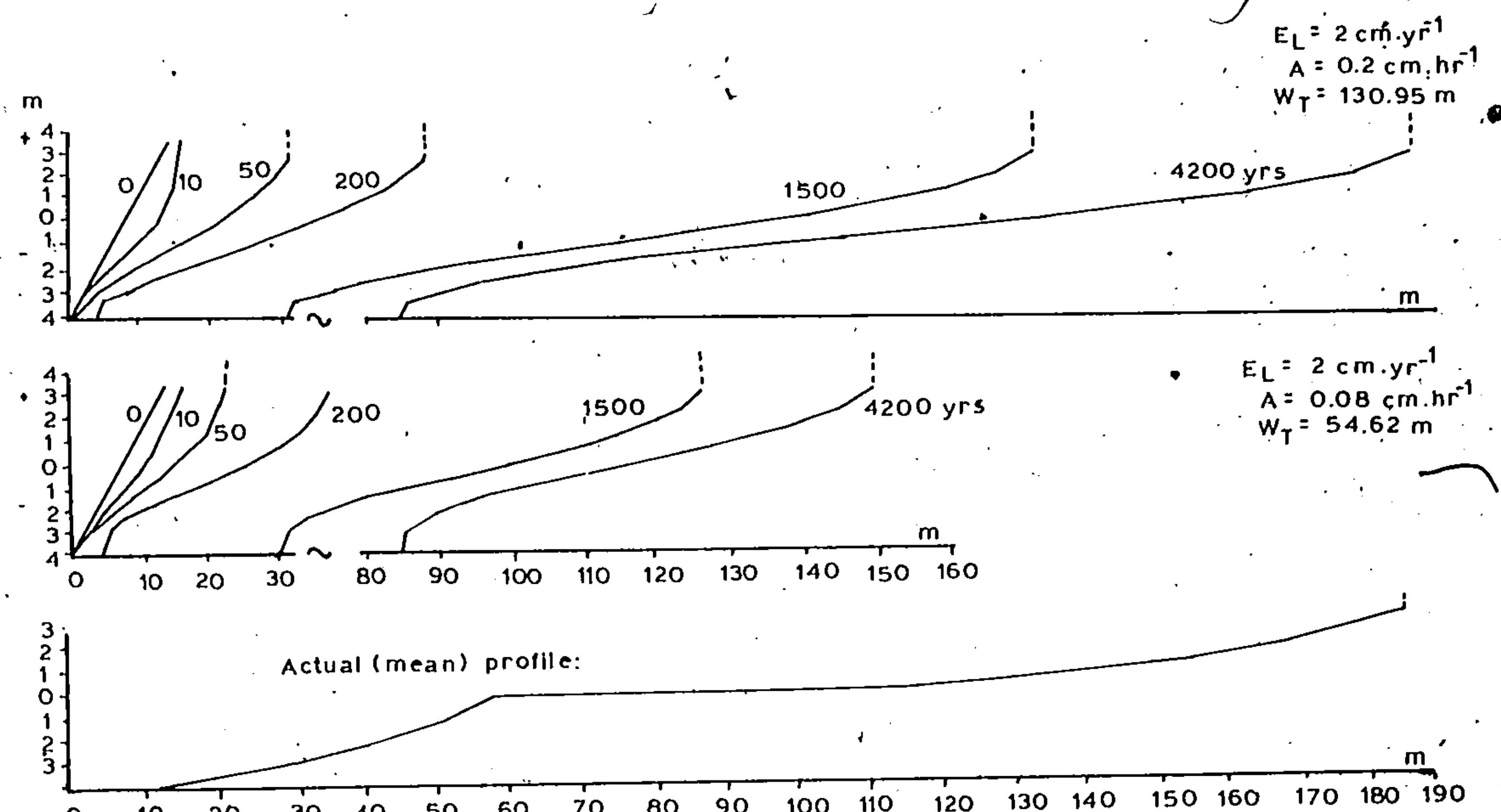


Fig.31: Simulated–and actual shore platform profiles: Isle of Man

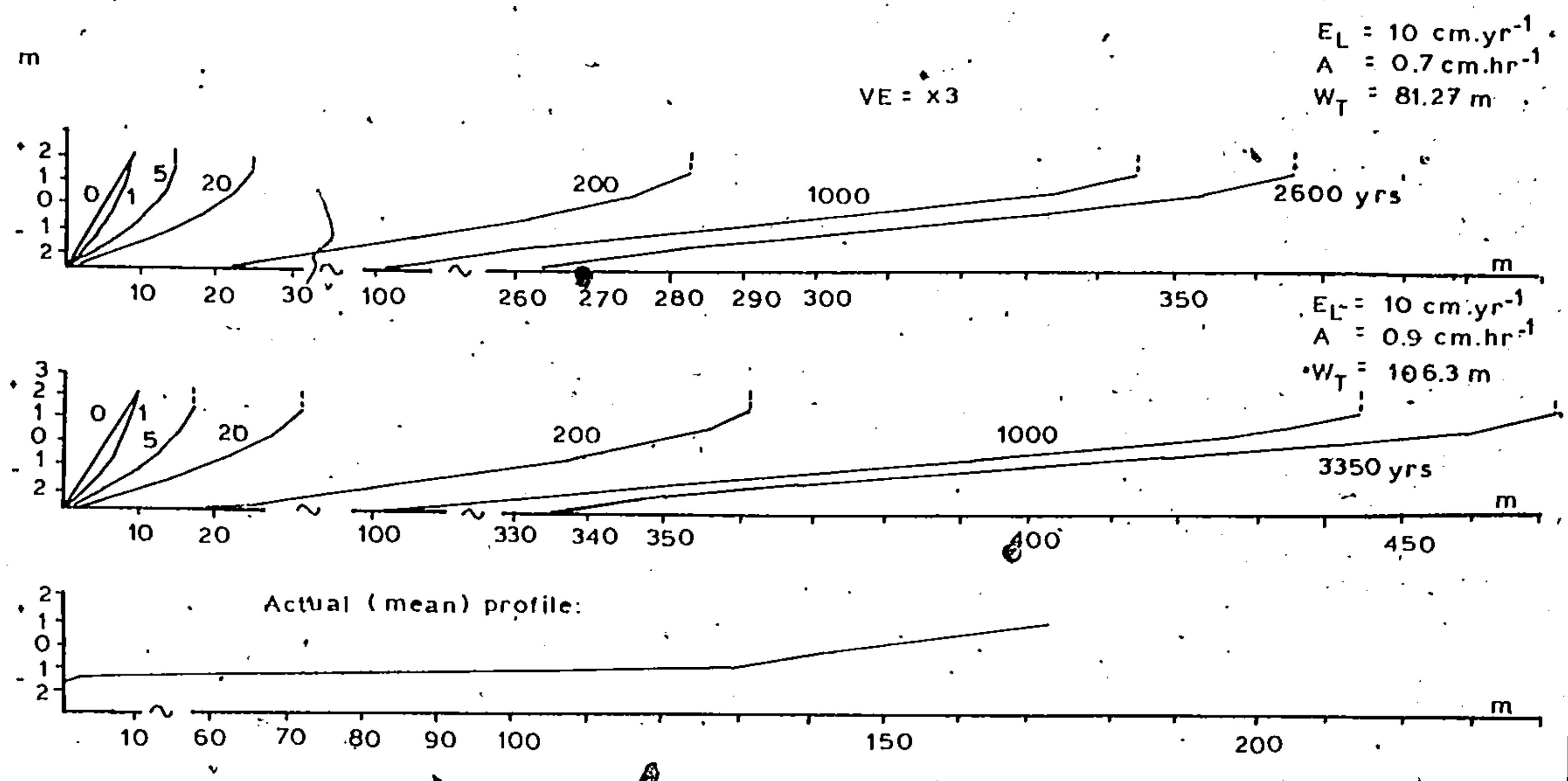


Fig.32: Simulated and actual shore platform profiles: Isle of Thanet.

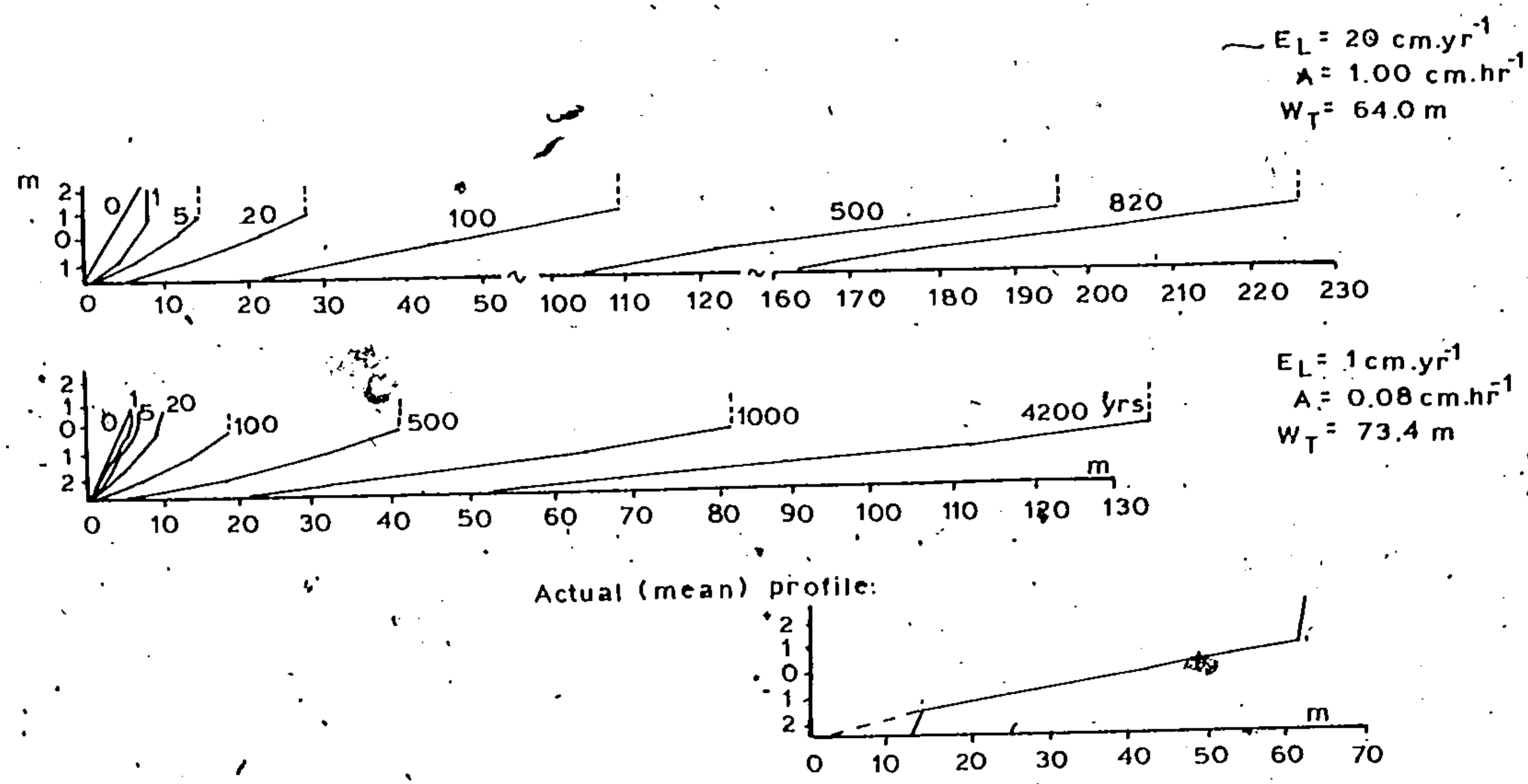


Fig.33: Simulated and actual shore platform profiles: Tasmania.

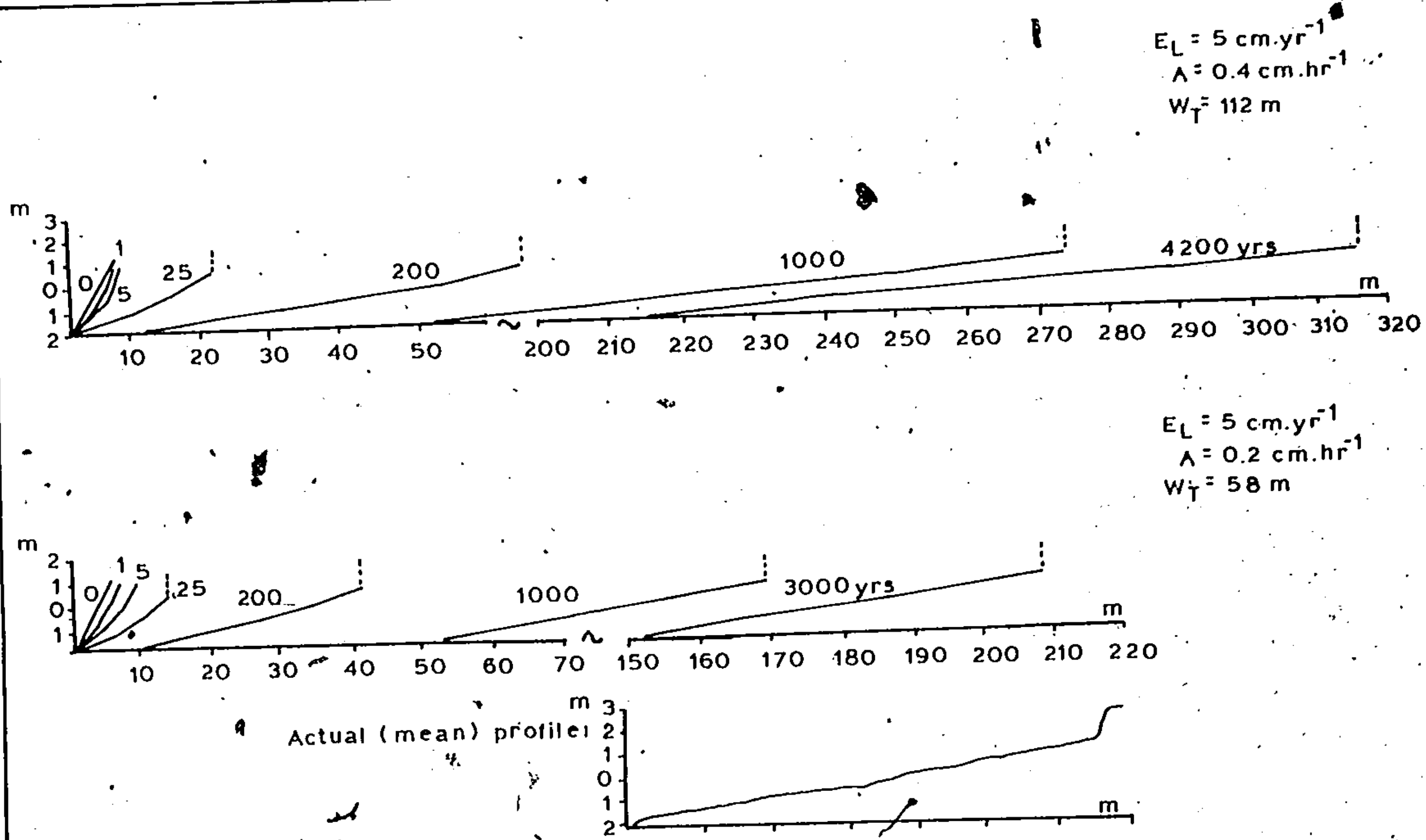


Fig.34 Simulated and actual shore platform profiles: Auckland.

ratio also results in a lower overall platform slope. In this instance then, a reduction by 0.2cm. hr^{-1} in the erodibility factor has reduced the platform width by almost one half.

Varying the absolute of E_L and A, while maintaining the same ratio, does not affect either equilibrium gradient or width. The time taken to reach equilibrium is, however, reduced by an increase in the values of E_L and A. A Vale of Glamorgan simulation with E_L / A values of 20/2 reached equilibrium after 930 years. Reducing the values of the constants to 10/1 delayed equilibrium until 1950 years. More will be said of the role of time in the simulation model in section I of chapter seven. The effect of increasing or decreasing the submarine erosion rate is to alter the platform's position relative to the location of the initial surface (figs. 30 to 34). Thus, a simulated platform with an E_L of 10cm yr^{-1} will have its low tide cliff or ramp 10m back from its initial position after a time period of 100 years. In actuality, submarine erosion rates probably are very low since they receive only the effects of chemical and biological erosion and the pressure changes induced beneath waves. This fact does not affect the validity of the model since, in determining platform width and gradients, it is the E_L / A ratio which is important, not merely the individual contribution of E_L.

Variations produced in the simulated shore platform profiles (figs. 30 to 34) by altering the ratio between submarine erosion rate and erodibility may be summarized as follows (fig. 35):

(i) Reducing the E_L / A ratio has the effect of:

(a) delaying the time needed to reach equilibrium;

(b) reducing the equilibrium platform angles;

(c) increasing width at equilibrium.

(ii) E_L determines the rate of platform retreat once equilibrium has been reached.

III COMPARISON OF MODEL WITH A PARALLEL RETREAT APPROACH.

From any of the simulated profiles (figs. 30 to 34), it is clear that the initial surface of 30° does not retreat parallel to itself. Indeed, parallel slope retreat does not appear until the state of dynamic equilibrium is reached. This section considers the reasons for the development of non-linear profiles in the simulated platform profile.

Since $\tan\alpha_{n-1,t1} = \frac{b}{c}$ (fig. 17), for AD to be rectilinear it must be shown that:

$$\frac{b}{c_{n-1}} = \frac{b}{c_{n-2}} = \frac{b}{c_{n-3}} = \ldots,$$

or

$$\frac{1}{c_{n-1}} = \frac{1}{c_{n-2}} = \frac{1}{c_{n-3}} = \ldots$$

If so, then parallel rectilinear recession is taking place.

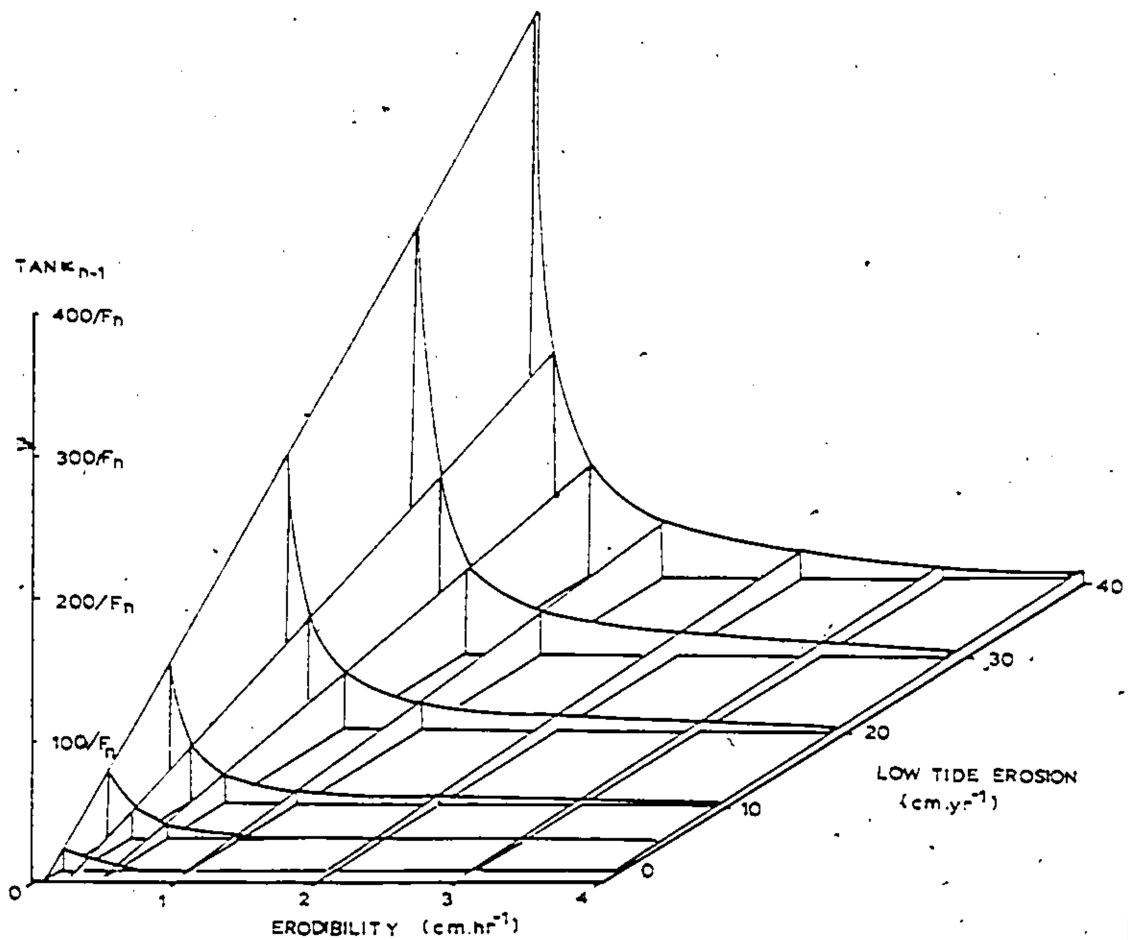


Fig. 35: Platform gradient at equilibrium, erodibility and submarine erosion rate.

It follows that (fig. 17),

$$c_{n-1} = E_1 - (E_2 - b\cot\alpha_{n-1,t_0})$$
$$= E_1 - E_2 + b\cot\alpha_{n-1,t_0}.$$

Therefore,

$$\frac{1}{E_1-E_2+b\cot\alpha_{n-1,t_0}} = \frac{1}{E_2-E_3+b\cot\alpha_{n-1,t_0}} =$$

$$= \frac{1}{E_{n-1}-E_n+b\cot\alpha_{n-(n-1),t_0}}$$

The numerators of this equation may be eliminated giving the formula for a linear slope:

$$E_1-E_2+b\cot\alpha_{n-1,t_0} = E_2-E_3+b\cot\alpha_{n-2,t_0} = \dots =$$
$$E_{n-1}-E_n+b\cot\alpha_{n-(n-1),t_0}.$$

Since $\cot\alpha_{n-1,t_0} = \cot\alpha_{n-2,t_0}$ etc. then, $E_1-E_2 = E_2-E_3 = E_n-E_{n+1}$. Expanding on E_n from eq.(3), and assuming homogeneous rock resistance along the profile, the situation of rectilinear recession with changing slope may be represented by:

$$F_n\tan\alpha_{n-1,t_0} - F_{n-1}\tan\alpha_{n-2,t_0}$$
$$= F_{n-1}\tan\alpha_{n-2,t_0} - F_{n-2}\tan\alpha_{n-3,t_0} \qquad (10)$$

Therefore, since $\tan\alpha_{n-1,t_0} = \tan\alpha_{n-2,t_0} = \tan\alpha_{n-n,t_0}$

(since α_{t_0} is linear),

$$F_n = F_{n-1} = F_{n-2} = \dots = F_{n-(n-1)}.$$

For a non-linear slope, in which $\tan\alpha_{n-1,t_0} \neq \tan\alpha_{n-2,t_0}$, equation 10 may be satisfied at all levels, but cannot be on a rectilinear surface, since the vertical distribution of wave attack is tidally controlled. Slope must, therefore, change as the platform develops such that differences in $\tan\alpha$ may eventually compensate for differences in the F values at each level. Assuming erodibility to be constant, the platform will become nearest to horizontal where F is greatest: at midtide level (fig. 16).

Several workers have argued for an initial decline in angles followed by some form of equilibrium between slope and width (Edwards, 1941; Challinor, 1949). Challinor believed that platforms would suffer sufficient lowering to allow incoming waves to attack the cliff base, unaffected by the development of an increasingly wide platform. Platforms were, therefore, considered to undergo parallel retreat, maintaining both slope and width in dynamic equilibrium. A state of dynamic equilibrium may also result from a balance between the rates of erosion at low and high tide, whether or not a low tide cliff is present (Bartrum, 1926; Jutson, 1939; Edwards, 1941, 1951; Hills, 1949; Cotton, 1963; and So, 1965).

Trenhaile (1974b) explored the possibility of dynamic equilibrium of platform angles within a parallel slope retreat model. Close relationships were found to exist between platform slope and various morphogenic factors, such as tidal range, 'normal' fetch, and cliff height.

> "Since there seems to be no reason to expect inevitable or predictable change with time of any of these factors, it is difficult to reconcile such results with the concept of declining platform gradient."
> (Trenhaile, 1974b, p.139).

On this basis, a parallel rectilinear slope retreat model was suggested which was found to fit reasonably well to data from the Vale of Glamorgan, at least within one order of magnitude.

At first, the two models described here may seem contradictory: one suggesting that the mode of shore platform growth is by declining gradients; the other suggesting parallel rectilinear slope retreat. They are not, however incompatible. The present model (eq.3, Ch. 3) produces a shore platform profile declining in gradient through time from an initial angle. After a period of time (T) a state of equilibrium is reached between erodibility, water level frequency, gradient and the constant low tide erosion rate. Thus, the shore platform profiles in the present simulation develop from an initial cliff with decliningslope angles until equilibrium is attained, after which parallel recession occurs.

This chapter discussed the results of simulating shore platforms in the six study areas with respect to three aspects: equilibrium; the E_L / A ratio; and the validity of a parallel retreat model in shore platform development. The next chapter will consider the aspects of time, and compare the overall morphology of observed and simulated profiles.

CHAPTER SEVEN

TESTING THE MODEL: PART THREE

I TIME

II COMPARISON OF OVERALL FORMS

III SUMMARY

I TIME

Absolute time predicted in the model cannot be accepted, if only because of the uncertainty regarding the values of the constants. The model may, however, be capable of suggesting the approximate time necessary to reach equilibrium. The relationship between equilibrium time and erodibility and submarine erosion values is complex. The time required to reach equilibrium increases with these values. High rates of submarine erosion cause the platform to steepen, thereby frustrating its efforts to reach a low gradient equilibrium state. Although rapid rates of erosion are associated with high erodibility, the equilibrium profiles are lower than those with low erodibility. Inspection of model runs demonstrated that slope reduction is much more rapid when erodibility is high, but most time is expended, in any run, in reducing profiles which already have low gradients, by the one or two degrees necessary to attain equilibrium. Despite their rapid erosion rates, therefore, high erodibility platforms require more time to achieve their gentle equilibrium gradients than do platforms with low erodibility, where equilibrium gradients are steeper. In the case of Auckland, for example, the higher erodibility value of 0.4 $cm.hr^{-1}$ has delayed equilibrium until 4200 years, over 100 years later than the simulation with an A value of 0.2 $cm.hr^{-1}$. Equilibrium angle is also less where erodibility is higher, the bulk of the time being spent in reducing the platform gradient by one or two degrees. Although the time necessary for equilibrium varies according to the constant values, simulated platforms achieved comparable gradients and widths to those in the field within 2500 years in most cases, and within 5000 years for all but those with the highest erodibility and submarine erosion values. This suggests that sufficient time has been available since the sea reached its present level for platforms to have attained their present dimensions, without recourse to inheritance.

Each simulation produced its own patterns of slope angle change with time. Whether these reflect reality can only be argued on a theoretical basis since no data exist with which to verify the simulated patterns. As far as one accepts the mathematical model one must accept the likelihood that intermediate stages, aswell as final stages, are accurately represented by the model. In spite of the fact that every program run produced different sequences of slope angle change with time, a crude pattern is discernible (fig. 36). The graph for the Isle of Man

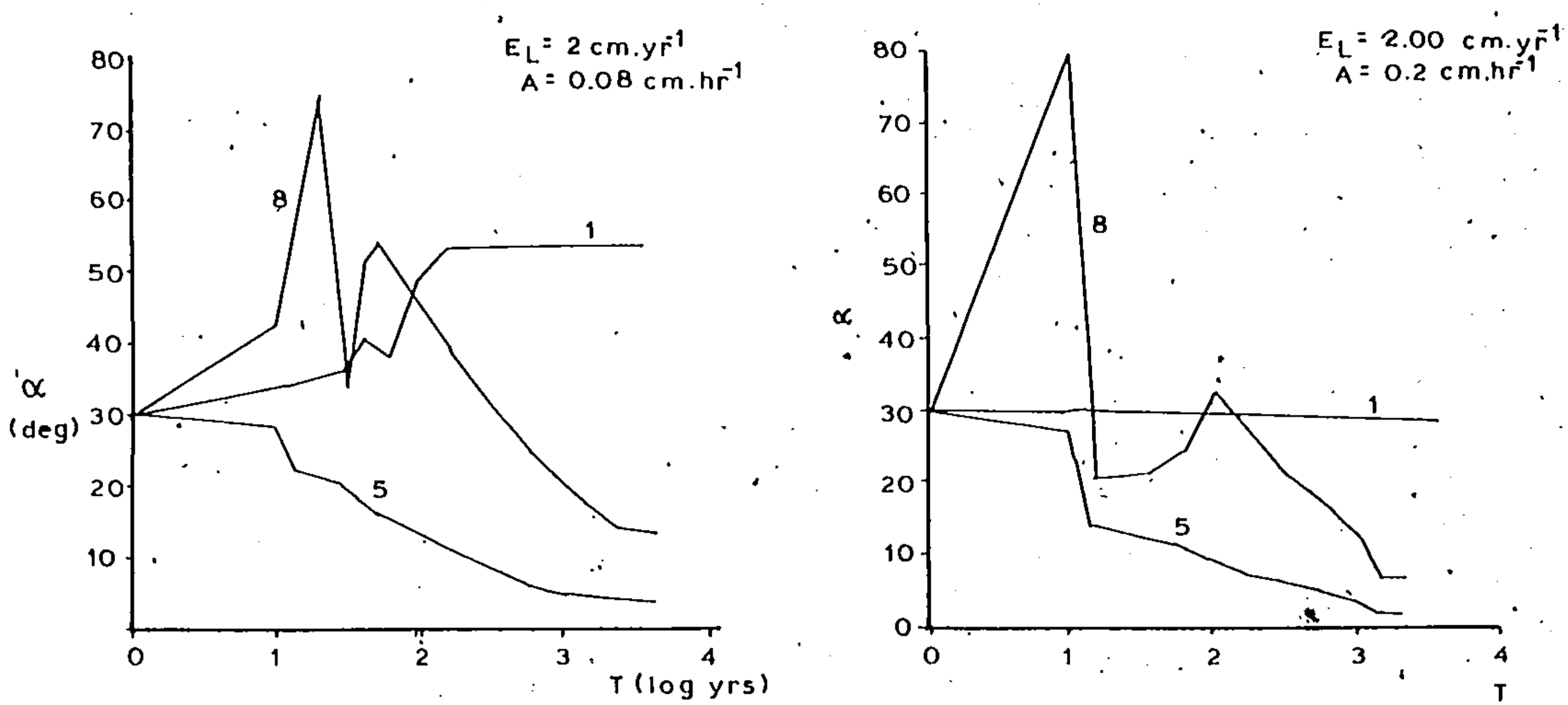


Fig.36 Simulated platform slope angles against time for three intertidal levels: Isle of Man.

reveals some of these patterns. About midtide level (no. 5) the trend was for a constant decline in gradient. This is presumably due to the concentration of wave energy at that level. Because of this concentration, or more accurately, because of the general dissipation of energy at higher levels, the platform near high tide initially increases in slope, declining after stabilization of lower slope angles. Thus, equilibrium exists first at the lower levels, progressing level by level to high tide. The stabilization of slope angles near low tide allows those in the upper part of the platform to decline. The micro-tidal environment of Gaspé gives rise to the concentration of wave energy so that the gradient of mid-tide levels quickly decline, while the low tide zone undergoes a gentle increase in slope angles.

These platforms are all intimately linked with values of the parameters in the model, thus it would be unwise to attempt to generalise the developmental sequences of shore platforms from this simulation in anything other than an approximate manner. However, several conclusions may be drawn:

(i) Platform gradients decline quickly at first, taking longer to reduce in gradient as time progresses (see chapter six).

(ii) Stabilization of angles (and hence, of widths) is attained in sequence from the lowest to the highest level.

(iii) The higher levels often increase in angle at first (for example, fig. 30) due to rapid erosion about midtide level.

(iv) Slope angles for the upper levels begin to decrease after stabilization of the lower levels.

II COMPARISON OF OVERALL FORMS

Comparing the actual and simulated groups of profiles involves, firstly, recognizing the large amounts of error that must exist within both groups (see chapter five, section two). The data sets involve one group derived from sample populations (the observed profiles), which may have included a mixture of sampling designs, and another group derived from a single mathematical model. The two are not incompatible but elude simple statistical analysis, since no common assumptions exist (for example, homoscedasity, normality, similar parent populations etc.).

Comparisons may be made, however, because of the nature of shore platform morphology. We are concerned here with the generalised form of platforms, rather than with micro-relief. Platforms are composed of commonly recurring slope units (low tide cliff; midtide bevel; the plane etc.), the existence of which is fairly easy to verify or dispute. Angles, too, often fall within a narrow range of ±1° and so allow for better comparison with simulated profiles.

(a) Gaspé Peninsula.

The range of angles simulated for Gaspé closely resembled almost all the profiles recorded by Trenhaile (1978). Broadly, the Gaspésian shore platform consists of two units: a quasi-horizontal plane and a steep low tide cliff. The high tide level lies at or just above the cliff-platform junction. This two-unit form was clearly simulated by the present method (fig. 30). Whatever the values for the constants, the 30° initial slope rapidly declined in its upper levels and increased, or remained nearly the same, about low tide. Over the plane angles ranged from 0.40 to 0.79° in the simulation, 0.53 to 0.82° in reality. Simulated widths were as equally close (Table 2). The difference between the actual and simulated ranges of widths, expressed as a percentage of the actual range yields a value of 74%. This may be interpreted as an index of similarity.

The elevation of the Gaspé platforms was also well represented by the simulation, there being a fairly narrow margin of possible error within such a small tidal range (less than two metres). The low tide cliff of Gaspé has been discussed (chapter six, section two) in relation to the E_L / A ratio. The existence of low tide cliffs appears to be due to two relationships: the dependence of platform gradient on tidal range; and the control of width by erodibility. When tidal range is small, resulting in a low platform gradient, and erodibility is fairly high, a low tide cliff results, its gradient being dependent on the rate of erosion at its base. This is the situation in Gaspé. The low tidal range is represented in the model by a very narrow distribution of F values. This distribution is so concentrated that, almost regardless of E_L and A, a gently sloping platform and low tide cliff result.

(b) Vale of Glamorgan.

In contrast to Gaspé, the southwest coast of Wales has a macro-tidal environment with wave activity experienced over a vertical range of eleven metres. Overall platform gradients are consequently much higher (fig. 30). Over the central portion of the profile actual gradients range from 1.5 to 3.0°. With E_L / A ratios from 6 to 12 simulated angles were 1.56 to 3.01°. In many cases a small low-tide cliff was produced, a product of the drop in F values as absolute low tide is approached. The elevation was, in many instances, over a wider range among the simulations than among the actual profiles. This limiting of the actual profiles is probably due to structural influences on the location of the cliff-platform junction. Simulated Glamorgan platform widths were similar to their actual counterparts. (Table 2).

(c) Isle of Thanet.

The Isle of Thanet platforms, surveyed by So (1965), are notably level with gradients from 0.6 to 1.7° being common over the central part of the profiles. The Isle of Thanet represents a good example where a restriction exists on the choice of E_L / A ratios to be used for the simulation. A range of E_L / A from 10 to 14 was found to give rise to profiles close in width to the actual form (fig. 32). However, this also produced platforms that were too steep at equilibrium (Table 2) to match So's surveys. A reduction in the ratio would have given more

	Range of E_L / A ratios	Gradient (°)*		Width (m)*	
		Observed	Simulated	Observed	Simulated
Gaspe Peninsula	5 to 10	0.4-0.79	0.55-0.82	120-80	138-69
Vale of Glamorgan	6 to 12	1.5-3.00	1.56-3.01	200-140	264-132
Isle of Thanet	10 to 14	0.6-1.70	1.52-1.96	240-85	106-81
Tasmania	15 to 20	1.85-2.2	1.70-2.50	40-15	73-64
Auckland	12 to 25	1.24-2.4	1.60-2.60	90-70	112-58
Isle of Man	7 to 27	2.1-3.90	2.10-3.90	120-50	130-54

* Over central portion of platform.

Table 2: Range of acceptable E_L / A ratios with observed and simulated gradients and widths for all six study areas.

realistic slope angles, and yet platforms that are wider than those in reality.

(d) Isle of Man.

The superimposed profiles for the Isle of Man (fig. 21) clearly show the diversity of platform morphologies in the area. The forms vary according to slope, width, elevation, and shape. The main profile is extremely unlikely, therefore, to be representative of the area's platforms in any of these aspects. This enormous variation in morphology within a small area has been attributed to inheritance (Phillips, 1970a), a discussion of which is given in the final chapter. The simulated platforms for this area (fig. 31) show little correspondence with the mean profile. In spite of the models poor predictive qualities for this group of platforms, two points are worth noting. Firstly, the simulated profiles are within a similar range of widths as the surveyed group: 54 to 130m, and 50 to 120m, respectively. This was made possible by using a wide range of E_L / A ratios (from 7 to 27) to counteract the great variation among the actual platforms. Secondly, over the central portion of the profile angles matched quite well, the model giving a range from 1.71 to 3.61° corresponding to one of 2.1 to 3.9° along the mean. Without further extensive field investigation no additional hypotheses concerning the origin of the Isle of Man platforms can be made. One returns, therefore, to Phillips's argument concerning inheritance.

(e) Tasmania.

The Tasmanian platform samples were all intertidal, sloping features from north Pirates Bay on the Tasman Peninsula. Tidal range is about 3.5m and the predominant wave type is ocean swell. Sanders (1968a) classified the platforms of the area, separating sloping, intertidal features from the horizontal rock ledges at higher high water. However, many of the superimposed profiles are composite features revealing a high water horizontal section with a steep ramp at the seaward end leading to a sloping surface to low water level. In some cases, platforms possess two or three of these marked breaks in slope reminiscent of a terrace-like feature. Low tide cliffs occur in many of these locations. Elevation of the Tasmanian platforms varies from 0.6 to 1.5m above mean tide level at the cliff-platform junction. All have a common base level at low tide. Slope angles are generally in the narrow range of 1.8 to 2.2°, excluding the bluffs which may have angles up to 90°. The simulations generated profiles very close to the actual with regard to gradient (1.7 to 2.5°). In each case though, platform width was overestimated by the model and, further, none of the bluffs on the surveyed profiles, or horizontal high tide units, were produced by the model.

It is generally accepted that the horizontal high water platforms of Australasia are predominantly features of chemical action, wave action serving only to remove the debris. In the upper parts of the Tasmanian platforms, horizontal sections exist over which this process may be dominant. However, the lower levels of the platforms receive more and more wave action, with a peak at mid-tide level (fig. 16). Corrasion and wave quarrying become of great significance, then, as one progresses down the platform from high to low tide levels. Secondary bluffs along the platform may well represent the influence of chemical and weathering processes in the intertidal zone, coupled with geological factors (Sanders, 1968a). If gradient is determined by tidal range, width may be affected by the existence of bluffs related to the presence of chemical action and water layer levelling, alongside mechanical wave action. The present model does not account for downward erosion by the former processes. This may explain why the simulation reproduced only the sloping, intertidal sections of the Tasmanian platforms giving a wider platform than occurs in reality.

(f) Auckland.

The mean profile for Auckland, N.Z. was selected from Healey's(1969) profiles. Healey, like Sanders, differentiated the sloping, intertidal platform from the high water solution/water-levelled feature. As for Tasmania, the present simulation reproduced only those platforms slopingfrom 2.5m above low water to the low water mark (the intertidal zone). Slope angles were in a similar range: 1.24 to 2.46° for the actual; 1.6 to 2.6° for the simulated. Actual widths fell well within the range generated by the program for Auckland (Table 2).

III SUMMARY

The time factor in this simulation of shore platform morphogenesis must be treated with caution. Absolute time cannot be accepted, if only because of the uncertainty regarding values of the constants. The time taken to reach equilibrium was generally in the field 2500 to 5000 years, strongly suggesting that sufficient time has been available since the sea reached its present level for platforms to have attained their present morphologies, without recourse to inheritance. Comparisons of the simulated and actual profile shapes, elevations and widths supported this argument.

For each of the six areas surveyed profiles were compared with simulated profiles. The following points summarize the results:

(i) In a general sense, both gradients and widths were simulated fairly accurately by the model. In no location did the modelled platform gradients differ by more than 1° from the actual range of angles, in many cases the error was less than 0.3°. In most locations gradients were simulated to a greater degree of accuracy than were the widths. Simulated platform widths were, consequently, more diverseand included more errors.

(ii) The simpler the actual profile, the more accurate was the simulation (for example, Gaspe and Auckland).

(iii) Processes other than wave abrasion are of importance in Australasia. These processes generally give rise to horizontal, high level platforms or bluffs. Neither of these were reproduced in the present simulation model. Low tide cliffs were, however, generated for the storm wave areas of the Northern Hemisphere.

CHAPTER EIGHT

CONCLUSIONS

The model described here is a mathematically simple attempt to simulate the development of platform profiles. The significance of tidal duration curves was developed initially by Trenhaile (1978) and later incorporated in a simulation model (Trenhaile and Layzell, 1978, in press). The simplicity of the model design is deliberate, since it is suggested that platform development and form bear a relatively simple relationship to the tidal distribution of wave energy. Nevertheless, several potential sources of error may be noted. The model is concerned with the distribution of still water level within the tidal range, but storm waves operate some distance above this level. This may influence platform elevation to some degree but is largely irrelevant to investigations of slope and width. Secondly, submarine erosion rates were considered to be low and constant through time. If submarine gradients do decline significantly within the life of a model run, the submarine erosion rate, and consequently the erosion rate at each intertidal level may also decline. Equilibrium profiles, therefore, may decline slowly in slope while increasing in width in a continual attempt to adjust to the decline in the submarine gradient. Relative land/sea level changes would also necessitate similar adjustments in platform gradient. With continual retreat of the platform and cliff other changes may take place, such as an increase in cliff height which may reduce the rate of cliff recession, or a change in lithology affecting the erodibility in either the horizontal or vertical plane. Climatic changes are also possible, but almost impossible to model. The present model might possibly consider the effect of submarine erosion in the intertidal zone, which is related to the duration of tidal inundation at each level (Robinson, 1977a; Kirk, 1977).

Alterations could possibly be made to the program to allow for the inheritance, by a rising sea level, of a previously formed platform. In this way complex profiles, such as those of the Isle of Man, could be modelled and a more accurate chronology assembled of such features. The lack of association between the simulated and actual platforms for the Isle of Man strongly suggests that equilibrium does not yet exist between wave action and platform morphology. In this way, the present model may be used to assess to what extent storm wave platforms are adjusted to the various erosive processes.

The model appears to be of limited value in areas where water-layer levelling and chemical weathering are dominant, such as in Tasmania, New Zealand and Hawaii. In such areas wave quarrying does occur, but often as a secondary process. The model may be used in this case to assess the relative extent of mechanical, as opposed to chemical and biotic, erosion.

Although this model may be made a good deal more complex, it is doubtful whether a more sophisticated program could improve significantly on the much simpler model described here. One of the strong merits of this model is that it allows for interactions between process and form. In the longterm it is the processes which govern the landforms, however, on a short-term basis forms are often seen to be influencing processes. An example of the latter would be the breaking of waves by friction with the bottom. In the model used here both types of interaction take place: the F values influence slope angles by erosion, slope angles in turn influence the erosion that takes place.

Perhaps the greatest improvement to the model could be made in the technique for obtaining the F values. The method used here is time-consuming and, being manual, is open to errors. F values are a function of the tidal curve and a plot of the reciprocal of the peak F_n for each station against tidal range shows just how strong the association is (fig. 37).[1] From such graphs it would be possible to predict F_{max} given any tidal range. Other F values could be derived from the mathematical functions

[1] There has been found to be very high correlations between gradient and tidal range (Ch. 2), a plot of $1/F_n$ against tidal range shows why. At equilibrium, $\tan\alpha_{n-1} \doteq E_L/A \cdot 1/F_n$ (from eq. 8) thus, gradient is an inverse function of the degree of wave concentration.

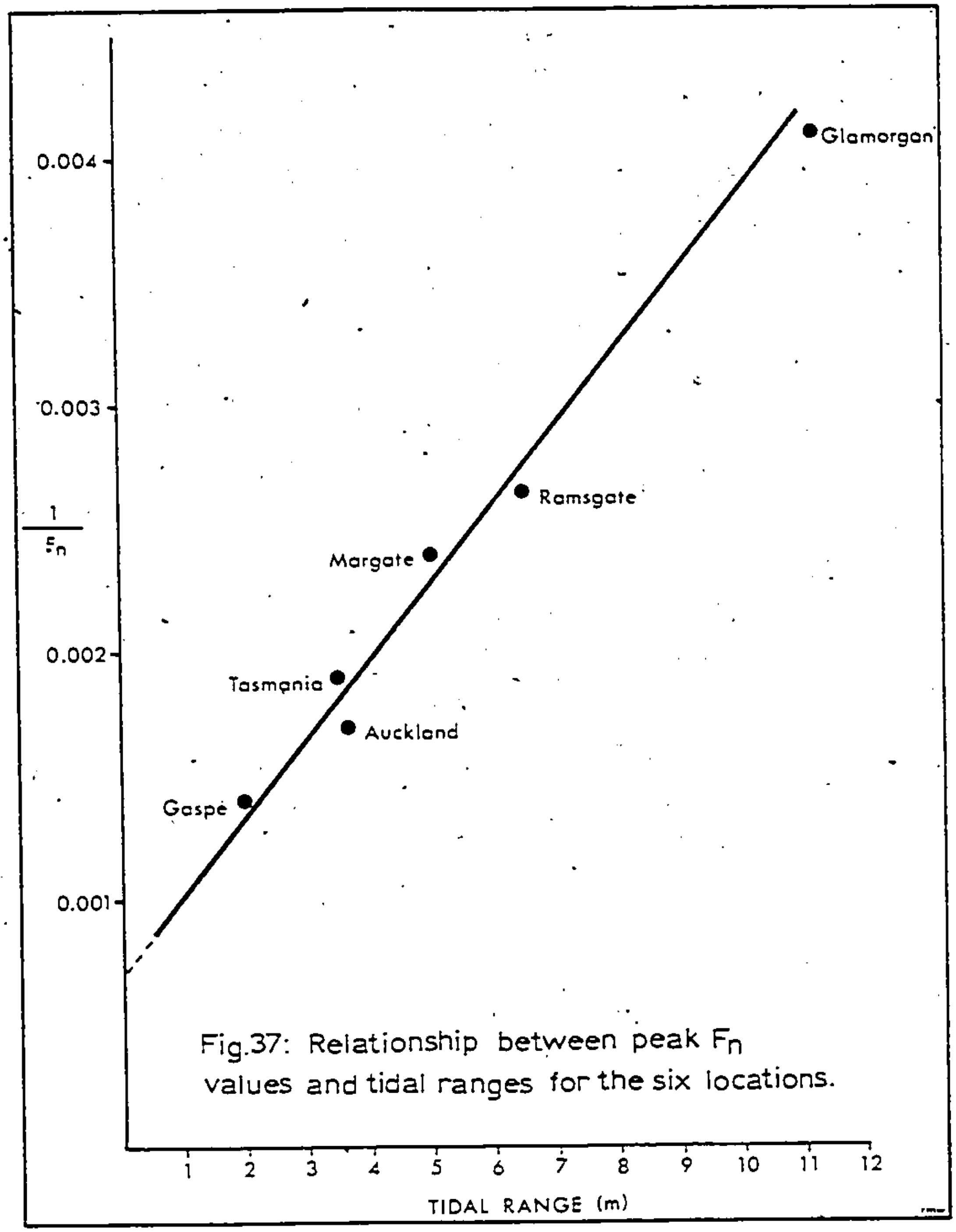


Fig.37: Relationship between peak F_n values and tidal ranges for the six locations.

describing the tidal curves (Fourier series).

This thesis is mainly concerned with the equilibrium form of shore platforms. Classical literature and some of more recent vintage, would maintain that the topic is esoteric, that platform geometry is constantly changing (Johnson, 1938; Flemming, 1965), that they contain elements inherited from a period when sea level was similar to today's, or that sufficient time has not been available for equilibrium to be attained, since the sea reached its present level. Strong correlations between a number of morphological and morphogenic factors, however, deny these claims, suggesting that platforms have already achieved a high degree of adjustment to the forces acting on them. The thesis presented here offers an explanation for these empirical relationships.

The values of E_L / A which produce simulated profiles which are most like those in the field were found to lie within fairly narrow ranges. This, and the apparently small effect of variation in either E_L or A other than on the local level, as evidenced by the very close relationship between platform gradient and the reciprocal of maximum (midtide) tidal duration, suggest that very restrictive conditions govern the occurrence of shore platforms. This provides support for the general observation that platforms are absent where rock is particularly resistant, or where wave activity is comparatively weak, but suggests that the range of suitable conditions for platform development is much narrower than has previously been assumed. These restrictive conditions appear to be satisfied in certain areas of the swell wave and storm wave environments of the world. The existence of platforms in sheltered locations in storm wave environments and their abundance in some of the very sheltered zones of swell wave areas suggests that exposure plays a subordinate role to geology in determining the occurrence of platforms.

Simulation programs should help to define the relative contributions of factors determining shore platform morphogenesis. It is only by building simple models, such as that described here, that insight can be gained into the complexities of shore platform geomorphology.

APPENDIX ONE

Derivation of the units of the erodibility constant, A.

Erodibility is composed of two components:

W = Deep water wave energy delivered per hour.

R = The amount of energy required to cause 1cm of erosion.

α = Platform or submarine gradient.

Therefore,

$$A = \frac{W\tan\alpha}{R}$$

$$= \frac{\text{energy.hr}^{-1}}{\text{energy.cm}^{-1}}$$

$$= \text{cm.hr}^{-1}.$$

Alternatively, erosion is given by $TAF_n\tan\alpha_{n-1}$

therefore,

$$E = \frac{F(W\tan\alpha)}{R} \quad \text{if } T = 1 \text{ yr.}$$

$$\text{cm} = \text{hrs} \frac{(\text{energy/hr.}\tan\alpha)}{\text{energy/cm}}$$

therefore,

$$\frac{\text{cm}}{\text{hr}} = \frac{\text{cm}}{\text{hr}}.$$

APPENDIX TWO

Derivation of the formula for each subsequent slope angle:

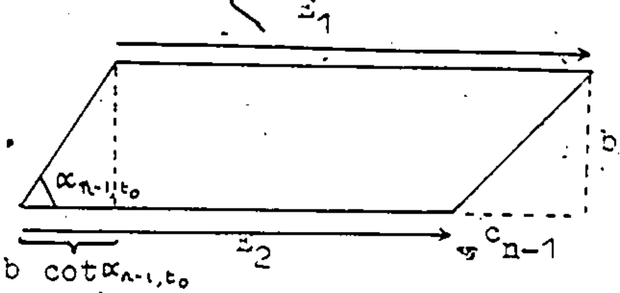
$$\tan\alpha_{n-1,t_1} = b/c_{n-1} \quad \text{(fig. 17)}.$$

Since b is constant and equals 91.44cm, this may be rewritten,

$$\alpha_{n-1,t_1} = \tan^{-1} 91.44/c_{n-1} \quad \text{(see equation 8)}.$$

Since,

$$c_{n-1} = E_1 - (E_2 - b\cot\alpha_{n-1,t_0})$$



this may be rewritten,

$$c_{n-1} = E_1 - E_2 + b\cot\alpha_{n-1,t_0}.$$

Therefore, from equation 8,

$$\alpha_{n-1,t_1} = \tan^{-1}((91.44)/(E_1 - E_2 + 91.44\cot\alpha_{n-1,t_0})).$$

The ramifications of this formula and equation 3 are dealt with in chapter five.

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