Kashima Industrial Area

Part 2
COASTAL SEDIMENT PROBLEMS

Shinano River Mouth, Niigata

CHAPTER 29

SEDIMENT TRANSPORT & ACCRETION AROUND THE COASTLINES OF JAPAN

Richard Silvester
Department of Civil Engineering,
University of Western Australia,
Nedlands, Western Australia.

ABSTRACT

The process of sedimentation can be traced from its initiation as weathering of base rock, transport to the ocean by rivers, and its distribution by waves. The sediment supplied by a river is dependent upon catchment characteristics - topography, precipitation, vegetation and geology. The grading of this sediment can change over geologic time.

The transport of material by waves is an important aspect of this overall movement, to a destination of either coastal plain or offshore shoal. The persistent occurrence and direction of ocean swell make this wave domain the most important in this process. In enclosed seas littoral drift is effected by storm type waves, per medium of a different beach profile from that on oceanic margins.

Accepting that the wave climate has not changed significantly over geologic time, it is possible to picture the geomorphology of river and coastal plains to the present continental outline. The coastlines of Japan are examined in this paper with such an emphasis.

Lowland so formed is of extreme economic importance. In order to promote accretion of further areas on a large scale, the character of the sediment and of the natural forces available at any location must be considered. Suitable structures and their siting within natural shoreline features are discussed.

SEDIMENT SUPPLY

The majority of sediment in the geologic process is formed by weathering of rock through chemical breakdown, temperature effects and the forces exerted by wind and rain. Abrasion by ice or waves provides an insignificant percentage of material from which river and coastal plains are constructed.

The distribution of stone, sand and silt is accomplished by run-off, river systems and finally by ocean waves. The current resting place of particles may have been dictated by any one of these transport phases, depending upon how many they have passed through. Since $\frac{3}{4}$ of the land area of the world is sedimentary of which $\frac{3}{4}$ shows indications of marine environment, the part played by waves appears paramount. Also, the volumes accreted at the ocean margins in the form of accreted continental shelves, being $\frac{1}{7}$ of the dry land area, must also be placed to the account of ocean waves.

The volume of sediment being fed annually to the ocean at any point will be determined by the area and type of river catchment, the annual precipitation, the geologic structure, and the degree of protection afforded by vegetation. The catchment of a river can change over geologic time due to the construction of its sedimentary plain, affecting as it does both the area and the topography. The rainfall and natural vegetation are dictated by geographical location as well as topography. The weathering and erosion of land structure is a function of source material and the intensity of elements producing this breakdown. In the case of sedimentary strata being elevated above sea level for redistribution some famous formations result, such as the Grand Canyon of Colorado.

The material being transmitted by a river will change as it grows in length and flattens its hydraulic gradient. Whilst it traverses rugged rock structure it will flow swiftly and so contain sufficient energy to transport coarse sediment or even large boulders. In fact most of the material will be of this character due to the extremes of weathering resulting from lack of protective cover by soil or vegetation. As the sedimentary plain is constructed, the river suffers reduced velocities and its capacity for carrying is restricted to the finer material. Although a catchment may be enlarged by the plain, the river flow becomes more uniform due to water infiltration into the porous basin. The higher velocities are reserved for the few occasions when energy is distributed over wide flood plains. Thus, where short steep rivers debouche on a coast sand should predominate. Longer rivers, on the other hand, should supply the finer elements of the sedimentary spectrum.

TRANSPORT BY WAVES

Once material reaches the coast its distribution is taken over by wind generated waves. Tidal currents may have a reasonable incluence over the dispersion of suspended matter, but the bed load is mainly moved by waves, together with their secondary effects. The oscillatory motion of the water particles, resulting from wave propagation, continaully picks up sediment and forms it into ripples. The major secondary effect of the waves, the mass transport of the water, causes a net movement forward as these seabed particles are temporarily suspended. Waves can thus sweep material towards the shore, out to the limit where there is incipient motion of the bed, which essentially is the deep-water limit for the waves. The other major force on the sediment particles is gravity, acting normal to the shore. Hence, where waves are arriving obliquely to the coast the resultant vector will have a longshore component, which will decrease as the shore is approached because of wave refraction.

The author has discussed elsewhere his contention that the important waves in coastal processes are those termed swell. These are generated somewhere in the ocean basin of which the coast under study is part of the boundary. Because of the magnitude of the oceans, swell will be arriving day after day, year after year, century after century. Also, because the major storm centres of the

world are repetitive in their locations, the swell is likely to originate from the same regions season after season. In spreading out circumferentially across the oceans these waves will arrive at the surrounding shorelines from some persistent direction, hence the author's notation of "persistent swell".(1) Although the energy content per unit area of ocean is decreased as swell waves spread out from their zone of generation, the total is not reduced significantly. In this sense swell waves are extremely efficient distributors of energy, from the major points of origin to the coastlines of the world.

Storm waves, defined for present purposes as those still being generated when they reach the coast, or having just left the fetch, have a very short duration compared to the incessant arrival of swell. For this reason, and because of the multidirectional nature of the waves and their shifting fetches, storm waves have little influence in the overall pattern of coastal sediment movement. This is so, in spite of the rapid and sometimes devastating changes they inflict on beaches and coastal structures.

Another factor relevant in storm situations, particularly those of the intensity which strike Japan two or three times a year, is the accompanying wind set-up of the sea surface. These high water levels are additional to the high tides, and cause flooding which can drastically alter the sedimentation process by breaking open lagoons and silting up specific sites. This aspect has been adequately discussed before by Japanese engineers.(2)

The above discussion refers to oceanic margins. Where a coastline bounds an enclosed sea, in which swell incidence from distant storms is partially or totally restricted, the waves are generated more-or-less locally and are therefore of storm character. This implies a wide spectrum of waves, which are moving at a variety of angles to the mean wind direction. In this case the longshore transport of sediment is solely effected by storm waves. These will operate with a permanent offshore bar, as distinct from ocean beaches where a transient bar is formed during storm sequences and then dissipated as material is returned to the shore by the swell.

LONG-TERM TRENDS

The wave climate at any location could be considered relatively constant over many thousands of years, in fact, over a significant proportion of geologic time. The global wind pattern would not have altered greatly whilst the present temperature ranges existed and the continents were in their present dispositions. It is reasonable, therefore, to envisage the present wave forces being applied to the original land masses, as evolved by some geologic mechanism. The development of river and coastal plains can thus be traced from their commencement to the present day and future trends might be forecast. Such an "astronautical" look at a landmass, with these major forces in mind, can augment the microscopic inspection of sediments on any beach and methods of measuring their movement over short periods of time.

In this comprehensive analysis it must be possible to determine the direction of the long-term sediment movement, or to know whether material will be retained near its source because the persistent swell is arriving normal to the coast. Although the general wave climate may be known for a locality, a more definite means must be sought for establishing net movement or lack of it right at the beachline. The author has discussed elsewhere[3] the use of half-heart or crenulate shaped bays to test longshore drift. These bays are oriented in such a manner, in respect to the persistent swell, that they indicate the direction sediment has moved, and will move if any is available for transport. As recorders of geologic events, they have integrated the results of wave action over hundreds of years. Ancient coastlines can be envisaged by applying the same forces.

By using such a "pointer", and others correlated to it, the author has surveyed the coastlines of the world[4] and derived a pattern of net sediment movement, which agrees favourably with the source of energy, the global wind system[5]. Davies has carried out a similar analysis[6] using only the major wave generating areas between the 40° and 50° latitudes of both northern and southern hemispheres. The results over vast lengths of continental margin are sensibly the same.

In this paper the coastlines of Japan will be analysed in greater detail. The physiography and climate of the four main islands will be discussed, following which will be an outline of the wave climate for the oceans and seas bordering Japan (Figure 1). Finally, each section of coastline will be considered and the mode of past and present accretion discussed (Figure 2).

PHYSIOGRAPHY AND CLIMATE OF JAPAN

Japan consists, in the main, of four islands, which, by any comparison, are extremely mountainous. The proportion of reasonably level plain being in the order of a quarter[7]. The coastal outline features prominent peninsulars and headlands, with many minor promontories making up an altogether rugged shoreline. However, along some stretches of coastline plains have been constructed, which vary in width from a kilometre or two to a hundred or so kilometres. These have provided valuable sites for road and rail communication as an alternative to the tortuous hinterland.

Due to the topography, the watersheds of Japan are, in general, numerous and diminutive but some of the embayments into which they have fed and, in some cases still feeding, are of a size commensurate with land masses of a much larger size. In forming coastal plain at the head of some of these basins much higher tidal ranges could have been experienced in previous geologic periods than at present, due to the co-oscillation set up in these bodies of water.[8] It is reasonable to expect, therefore, that these plains will vary in height above sea level as the reach of the waves has altered. This is plainly exhibited in Japan by the terraces

sculptured in the volcanic tephra and ash at levels[9] which are higher at what were the heads of bays. These higher level terraces do not appear to have formed on the open coast where the tidal range has remained sensibly constant. Lower terraces, however, occur at the extremities of peninsulars together with coastal plains, for which slumping might provide an explanation.

Maps generally show land elevations in steps of 100 metres for the lowest two ranges at least. Since sandy coasts at the present time can be built up into dunes two or three hundred metres high it should be expected that these lowland areas (at least to 100 metres) are sedimentary plains accreted by river and wave action. Within this height limitation will be zones provided by other geologic phenomena, but these will be minimal. In Figure 2 are depicted the major lowland zones of Japan, together with other information to be referred to later.

The steepness of the mainland structure of Japan generally continues below sealevel, resulting in extreme depths close inshore at many points. However, the zone known generally as the continental shelf deviates greatly in width and in many places rises above the water level to form islands. This type of structure has been termed "continental borderland", and implies submarine topography of equal ruggedness to that of the adjacent land, within the limit of 100 fathoms (200 metres approximately). Where sediment has been deposited on this underwater surface to smooth its profile the area may be termed a shelf. But only in one location (to be cited) is there evidence of accretion forcing the 100 fathom line out from the coast and therefore forming a complete shelf in this respect.

The rainfall of Japan varies from 1000 mms (40 inches) to 3000 mms (120 inches); it could therefore be considered a wet climate. To this run-off could be added the snow melt in the northern regions of Honshu and in Hokkaido, as well as on the higher mountain structures of all islands. A plentiful supply of energy exists, therefore, for the erosion and transport of sediment to the coastal margins. The lack of larger plains may be explained in part by the relative geologic youth of the country.

WAVE CLIMATE

The coastlines of Japan may be divided into three zones in respect to wave climate. The major one is that section bordering the Pacific Ocean, which comprises the southern and eastern shorelines of all four islands. The second in order of magnitude is that bounding the seas of Japan and Okhotsk, facing generally north or west. The third comprises the coastal margins of the Inland Sea, being the northern coastlines of Kyushu and Shikoku and approximately half the southern shoreline of Honshu.

PACIFIC

The waves reaching the Pacific shores of Japan are derived from

six distinct wind systems. These are:

(a) the south-east monsoons
(b) the north-east trades
(c) the south-east trades
(d) the tropical cyclones (typhoons)
(e) the north Pacific low-pressure system
(f) the Polar cyclonic centres.

In the following discussion reference should be made to Figure 1.

The S.E. monsoons occur during the Japanese summer months and consist of southerly winds extending from near the equator to north of Japan. They generate waves which arrive at the coast from a southerly to south-easterly direction.

The north-east and south-east trade winds blow throughout the year and commence from the west coasts of North and South America respectively, extending across most of the Pacific just north and south of the equator. The waves generated in the strong wind zones of this system spread westward across the Pacific and arrive almost continuously at the Japanese coast as swell from a south-east direction.

The typhoons form in the western Pacific at about 5°N and traverse paths to the 35° latitude, stretching from the Chinese mainland to east of Japan. They are a summer phenomenon. Because of the anticlockwise circulation of air in these low-pressure centres and their northward movement, the strongest waves are generated in a northerly direction. As typhoons reach the coast, however, the storm waves being generated at the time can hit the coast from the south-east, east and even north-east.

The low-pressure system of the north Pacific occurs during the winter months of Japan. Its anticlockwise circulation of air produces cold winds from the north across the Bering Sea and the northern Pacific. Their wave generating capacity may be limited by the formation of ice during these colder months.

The Polar system of cyclonic centres, occurring in summer, consists of low-pressure centres travelling from the north-Chinese and Manchurian land masses, in a north-easterly direction, across the Seas of Japan and of Okhotsk towards Bering Sea and Alaska. When they are so located as to affect the Pacific coast of Japan, the resultant waves will arrive from a northerly direction.

Considering Figure 1, where the above information is summarised, it would appear that the southern shores of Kyushu, Shikoku and Honshu will receive persistent swells whose resultant will be from a south-easterly direction. The eastern shores of Honshu and Hokkaido will be mainly influenced by waves from the north. Where parts of a land-mass intercept these waves and cause diffraction the approach direction could be changed significantly.

SEAS OF JAPAN AND OKHOTSK

Referring again to Figure 1 it is seen that the Sea of Japan experiences northerly winds during winter and southerlies during summer. The former appear to be of much greater significance to the Japanese coast[2]. The waves generated towards the north could only be influential on the west coast of Hokkaido, since the majority of the western shoreline of Honshu has greater fetch lengths for the southward directed waves. The Polar cyclonic centres traversing this body of water in a north-easterly direction would generate waves towards the Japanese coast from the north to west quadrant. The resultant from this system is therefore sensibly normal to the coast except for the northern tip of Honshu.

Hokkaido has a stretch of coast bounding the Sea of Okhotsk, which experiences similar winds to the Sea of Japan. The generation of waves by the winter northerlies, however, may be impeded by the ice cover over large tracts of this Sea for approximately three months. Waves of any consequence reaching this northern coast must necessarily arrive normal to the coast. In the western region, which runs NW-SE, the waves again arrive normally due to their diffraction around the southern tip of Sakhalin Island.

The waves on both these Seas are of storm type, lasting only as long as the winds generating them. Inspite of the confused nature of these waves, the longshore component would be fixed by the mean wind direction, or its "diffracted" value.

INLAND SEA

The Inland Sea, between Honshu and the northern coasts of Kyushu and Shikoku, is divided by island groups and promontories into five basins, whose major axes run in a NE-SW direction. The winds blowing across them being partly influenced by the surrounding mountain structure. The basins most likely to suffer the strongest winds are the two westerly ones, namely, the Suo Nada and the Iyo Nada, the latter even permitting the penetration of swell from the Pacific through Bungo Strait. The waves generated over these bodies of water are of a storm category. Their persistence cannot be compared with the shorelines discussed in the previous two sections, but could be sufficient to concentrate littoral drift in certain zones.

SEDIMENT MOVEMENT

For ease in presentation the coastlines of Japan have been divided into a number of sections, each of which has the same wave climate. This is not to imply that nearshore conditions are similar along the whole stretch of coast, but that the waves arriving in the open stretches of ocean away from the coast are sensibly the same. Locally the distribution of sediment will be greatly influenced by promontories, offshore islands and submarine features.

The subdivision is as follows:

(a) Southern Coastlines - consisting of the Pacific margins of Kyushu, Shikoku and the section of Honshu from Kii Strait to Uraga Strait, which forms the entrance to Tokyo Bay.

(b) Eastern Coastlines - containing the Pacific coast of Honshu from Nojima Cape (enclosing Uraga Strait) to its northern tip of Shiriya Cape.

(c) Hokkaido - encompassing all the coastlines of this uniquely shaped island, which bounds the Pacific Ocean and both the Sea of Japan and of Okhotsk.

(d) North-western Coastlines - containing the entire length of Honshu facing the Sea of Japan, plus the small section of Kyushu also adjoining this body of water.

(e) Inland Sea Coastlines - consisting of the southern shore of Honshu from the Shimonoseki Strait to Kii Strait and the northern boundaries of Kyushu and Shikoku.

The sections will be discussed in the above order, with the general pattern following the coasts in an anticlockwise direction. Reference should be made to Figure 2, where all place names are included, and where the figures represent the region being discussed in the paragraph of the same number.

SOUTHERN COASTLINES

1. The west coast of Kyushu could be considered open to the Pacific swell, but many sections of coast cannot receive it because of island protection. Sediment deposited by rivers in these deep indentations has formed tidal shoals, as exemplified in Ariakeno Gulf, which serves the city of Kumamoto. Where waves are able to penetrate, small pocket beaches exist, as between the peninsulars of Noma and Yoshiku. In the case of a dearth of sediment the indentation preserves its original rugged profile, as instanced by the extreme depths of Kagoshima Gulf.

2. At the southern tip of Kyushu the continental borderland rises to form several islands. No sediment is likely to be present in this offshore area since there is no notable supply point, and any available material would be swept northwards up the coast or into an embayment. The ruggedness of this southern region is interrupted only by a pocket beach within Ariake Bay. Further north, beyond To Cape the Oyoda River provides sufficient material for a modest coastal plain to have smoothed off the shoreline. Towards Bungo Strait the coast again becomes rugged, with little or no sediment in evidence.

3. The southern coast of Shikoku consists mainly of two

mountainous peninsulars, ending in the Capes of Ashizuri and Muroto. Between these a limited amount of sediment has been accreted to form a coastal plain, on which Kochi is located. East of Muroto Cape the submarine slopes are extremely steep, but inside Kii Strait (past Kamata Cape) an extensive water shed has brought material to the coast. Two deltas exist here, the major one being that of the Yoshima River. Sediment transport is necessarily into the Strait because of the penetration of southerly swell and as evidenced by the bay shapes and sand spits present.

4. Honshu provides the eastern boundary of Kii Strait, at the northern end of which the Kino River has filled a Vee shaped indentation. Further accretion is probable, with the shoreline being fashioned by the swell diffracting around headlands to the south. Otherwise the peninsular east of Kii Strait is rugged and depths of hundreds of fathoms are close inshore.

5. Further to the east this mountain structure almost seals off Ise Bay from the Pacific. Under the normally calm conditions ensuing a multiple river system has constructed a deltaic plain on which Nagoya is sited. A more modest delta exists in Mikawa Bay, which connects with the larger unit.

6. East of these bays the southern coast has been abundantly supplied with sediment by the Tenryu River, which also exhibits a deltaic mouth. The volume of sediment has exceeded the power of the waves to distribute it west and east, resulting in a slight protuberance of the coast. Mildly curved coasts extend either side, that to the west having formed an inlet known as Hamana Ko. The coastline further west, which was originally very rugged, has been silted to a smooth outline.

7. Sand is transported east from the Tenryu delta, but much is lost on the steeply sloping submarine shelf. The projection of the continental borderland southward causes refraction of the ocean swell so that Cape Omai has been constructed. Sediment is transmitted around this prominence with related shoaling. On the eastern side a curved beach has smoothed off a previously rugged shoreline.

8. Suruga Bay is extremely deep and but for its width might be termed a submarine canyon. But in spite of its precipitous underwater slopes the west coast of this bay has coastal plain. The Oi and Abe Rivers have been the major sources of sediment, which has been distributed by the southern swell. It is along one of these beachlines facing south that the accretion from this process has probably pushed the 100 fathom line seawards.

9. At the head of Suruga Bay a modest plain has been shaped by the southerly swell from material supplied by the Fuji River at the western extremity. This sediment has been deposited

into a deep ravine and the offshore shelf is extremely narrow. Since it follows the shoreline in a smooth curve, deposition to the 100 fathom limit is indicated. To the east Suruga Bay is bounded by the Idzu Peninsular, which is extremely mountainous. Because it has little watershed to its ocean margins the submarine slopes have retained their original precipitous character.

10. To the east of the Idzu Peninsular is the entrance to Tokyo Bay, through Sagami Bay and Uraga Strait. This bay is extremely deep and the strait itself contains the notable Tokyo submarine canyon. At the head of Sagami Bay an extensive coastal plain exists, which joins further north with the Tokyo plain. Most sediment in this region is presently supplied by the Sagami River. Unlike Suruga Bay, the 100 fathom line here deviates in such a manner as to preclude the possibility of accretion out to this limit. The eastern boundary of Uraga Strait is provided by the Awa Peninsular. Its mountainous structure and lack of watershed is reflected in its precipitous submarine slopes where several canyons have been recognised and mapped.

EASTERN COASTLINES

11. On the eastern side of Awa Peninsular the previously rugged coast has given way to narrow beaches, the material for which has been supplied from the Tokyo plain sources further north. This material has traversed the cliffed coastline of Toriyama Cape and formed crenulate shaped bays around the southern tip of the peninsular. The direction of transport is westward due to the waves from the south to east quadrant. Even swell from the north will be diffracted and refracted around Capes Inubo and Toriyama to force material westwards around Cape Nojima.

12. In Figure 2 is depicted a suggested development of the Tokyo plain over geologic time. Initially two embayments were filled until one large bay was formed. Further accretion caused this bay to protrude behind the Awa Peninsular, which at this time would have been an island. A relatively sudden addition of sediment caused the transfer of the coastline to the peninsular, with material feeding to Toriyama Cape. The presence of an island (Inubo), with its related shoaling of the continental borderland, caused the shoreline to attach itself to this fixed point and so form the present Cape. The Undulatory nature of the borderland and its weathered volcanoes is indicated by the lake system incorporated into the plain. Kasumiga Lake is extremely deep and yet Kita Lake system is shallow. The elongated form of the latter suggests its origin from a southward growing sandspit, material being mainly supplied from the Naka River. The progressive filling of the Tokyo Plain suggested above is exhibited by the concave nature of the sedimentary strata apparent in the basin[9].

13. Considering the present shoreline, sediment south of Inubo Cape

moves rapidly south-west, as evidenced by the deflection of the river mouths and the sand-spit formations. The deviations of the 100 fathom contour would indicate that saturation by sediment has not been reached.

14. North of Inubo Cape the coast has a straighter outline, indicating a slower movement of material in a southward direction. North of the Naka River is an extensive length of rugged country. Short steep rivers have supplied sufficient sand to form a narrow coastal plain, mainly in the form of pocket beaches, whose slight curvature indicates the near balance of wave energy from the north and the south.

15. Further north the coastline takes on a sudden new north-south alignment due to a mountain range projecting into the sea. This peninsular would formerly have been a series of islands and might still be considered separated from the mainland due to the double outlet of the Oppa River, into which the Kitakami flows. The elongated embayment formerly existing between this mountain structure and the mainland has been accreted by the Katikami River to the present shoreline limit of Ishinomaki Bay, which curves in equilibrium with the waves refracted from the south and those diffracted from the north. The Miyato Island group, which limits this beach, has on its southern side another coastal plain provided by the Abukuma River, which also is in equilibrium with the waves of this region. Sendai is situated on this plain and canal systems have been constructed in many places.

16. To the north the aforementioned mountain structure extends to the coast, resulting in rugged shoreline topography with deep water close inshore. There is practically no watershed to this coast until the Mabuchi River is reached, with its sundry smaller streams. These have constructed a coastal plain, together with a large lagoon known as Ogawara Numa. The beachline is in near equilibrium with the waves, there being only a slight trend northwards. It is seen from Figure 2 that Hokkaido causes waves from the north to be diffracted and to arrive at northern Honshu from the east. Southerly swell, on the other hand, will be slightly oblique at the shore, in spite of its refraction across the shelf.

17. The continental borderland in this region varies greatly in width and extends northward beyond Shiriya Cape. This shoal refracts the waves arriving from the east and south, so that in Ohata Bay, to the west of the cape, the available sediment has accumulated in a curved coastline and formed the isthmus linking this narrow stretch of land to the mountainous block to the west.

HOKKAIDO

18. There are strong indications from the topography that Hokkaido

originally consisted of a number of islands which, over geologic time, have been welded together by sedimentation, particularly in the western regions. Accretion is still taking place between the many prominent peninsulars, limited only by the modest nature of the watersheds and the prevalence of ice and snow.

19. The Oshima Peninsular, north of Tsugura Strait, is rugged and the limited volume of sediment available is swept westwards by the swell. On the southern side this has formed the isthmus or tombolo on which Hakodate is sited. On the northern side the sediment has formed a coastal plain around the head of Uchiura Bay, the shape of which has been sculptured by the swell.

20. Takarisho Peninsular, at the entrance to Uchiura Bay, supports a coastline to which the swell approaches almost normally. Sediment brought on to this ocean margin, by local rivers or from supply sources to the east, is thus accreted in a slightly curved beachline, with a moderate tendency for drift in a south-west direction.

21. The mountainous block culminating in Cape Erimo also provides an obstruction against which sediment is retained in equilibrium, by waves from east or south. A number of indentations of this originally rugged coastline have been enclosed by sand spits. To the east a submarine canyon is indicated by the deviation in the 100 fathom contour. This would have penetrated the present mainland and provided the embayment into which the Kushiro River flowed. This valley now exhibits extensive swamp land. The sediment has filled out to the 30 fathom line where the canyon head now commences.

22. From this river outlet, to the eastern limit of Hokkaido (Noshappu Cape), the coastline is rugged, with the small amount of sediment available being swept westwards into pockets formed by promontories. The continental borderland extends beyond Hokkaido to support island chains running north-east. A number of rivers shed water to this region, which experiences waves from the one possible direction of north-east. This provides specific littoral drift forces, which have resulted in lagoon formation and predominant sand spits.

23. The northern coast of Hokkaido faces the Sea of Okhotsk. The continental borderland varies from practically nothing at Cape Shiretoko in the east to a substantial width at the western extremity of Cape Soya. This is due to this submarine feature providing support for the southern regions of Sakhalin Island north of Hakkaido. It should be noted that the 50 fathom contour follows the coast of Hokkaido fairly uniformly. Waves generated across the Sea of Okhotsk would arrive at the shoreline normally, being diffracted around the southern tip of

Sakhalin Island in order to approach at right angles in the region of Cape Soya, where a NW-SE alignment exists. The whole sweep of shoreline is smoothed, with equilibrium being exhibited by such features as the double spit almost enclosing the lagoon of Saroma Ko.

24. The west coast of Hokkaido bounds the Sea of Japan and because of its position experiences strong wave action from both the northerly and southerly quadrants. The latter appears more influencial as shoreline features indicate a slight northerly drift on the main expanse of coast. At the northern tip a coastal plain has been constructed from sediment supplied mainly by the River Teshio. The shoreline protrudes in the lee of Rishiri Island.

25. To the south the coast becomes very rugged, with many promontories and indentations edged by steep submarine slopes. One notable feature is Ishikari Bay where a smooth beachline exists. The associated lowland appears to extend through the valley containing Sapporo to the Pacific Ocean shoreline. This together with an extensive plain has been built by the Ishikari River system. This initial sea passage appears, by the river pattern, to have been blocked near the Pacific margin and progressively accreted to the existing Ishikari Bay.

NORTH-WESTERN COASTLINES

26. The northern tip of Honshu is extremely rugged with no sediment in evidence. South of Cape Gongen, however, a substantial coastal plain exists, the beach shape indicating near equilibrium. The main supply of sediment has been the Iwaki River, which is at present feeding a delta within an estuary that is almost closed from the sea by sand spits.

27. Beyond a stretch of rugged coastline to the south, another zone of coastal plain exists. This is the northern boundary of a large tombolo that has formed in the lee of the former island of Oga. In so forming, this tombolo has entrapped a large body of water known as Hachiro Gata, which discharges to the sea south of the Oga Peninsular. Material for this massive sand-spit has emanated mainly from the Yoneshiro River. To the south the coastal plain has been furnished mainly by the Omono River and is limited in the south by another mountainous prominence. To the south of this the Mogami River has built a low level plain, the beachline of which protrudes slightly at the mouth. This indicates a surplus of sediment for the wave energy available to distribute it.

28. Further south, sheltered by Sado Island, the Shinano River has built a plain which is protruding. Silting has been in evidence at the river mouth, upon which the port of Niigata has been developed. Coastal problems with this port have been

discussed elsewhere[2]. The Shinano is among the longest rivers in Japan and is in a zone of high rainfall. Material brought down to the sea can only be spread southward as waves from the southerly quarter are blocked by Sado Island and Noto Peninsular to the south. A number of small rivers has provided coastal plain north of the present mouth of the Shinano.

29. From this river to the Noto Peninsular the mountain structure adjoins the sea and contains practically no submarine shelf. Small rivers in this high rainfall zone bring sediment into pockets, which is retained there by the normally approaching waves. In the hook formed by the Noto Peninsular sedimentation has taken place. The narrow continental shelf here indicates previous penetration of this marine depression into the present plain area.

30. On the south-western side of the Noto Peninsular, the watershed is sufficient to supply a coastal plain. Near equilibrium with the incoming waves is evidenced by the slightly curved outline and a number of lagoons. The slight southerly drift is contained by Cape Echizen.

31. At Wakasa Bay the general coastline turns westward. Its mountainous structure provides practically no beach material and hence the shoreline is rugged for some 100 kilometres. The continental borderland varies greatly in width. Towards the western limit two small plains exist with their east-west alignments indicating stability with respect to the waves approaching from the north.

32. A headland then occurs on the coast known as Takono Hana. This appears to have been an island originally, located fairly close to the mainland. It might still be considered an island, since it is separated by lakes, rivers, lagoons or deltas from the mainland. At the eastern end is a circular sand spit separating Miko Bay from a lagoon. The central accretion contains a lake known as Shinji Ko, into which a river is now discharging through a deltaic mouth.

33. From Takono Hana the coastline runs south-west with a rugged outline. Only minor beaches occur in embayments of this region. The northerly waves would be reflected from the cliffs and so create standing waves which would readily dispose of any sediment down the steeply graded submarine slopes. The western tip of Honshu is similar to the above.

34. The northern coast of Kyushu, across Shimonoseki Strait, is significantly different in that several rivers have formed pocket beaches, which, nevertheless, are still contained between the headlands. The north-western boundary of Kyushu consists of a complex of hundreds of islands. These rise steeply out of Korea Strait, with depths of 30 to 50 fathoms close inshore. Their deep indentations could be oonsidered

as miniature submarine canyons.

INLAND SEA COASTLINES

35. Five basins in essence constitute the Inland Sea, the major axes of which all run north-east. The strength and direction of waves in them is dictated mainly by the lengths of fetch and the control of wind direction by the surrounding mountain structure. There are indications that the more effective wave generators are the winds from the south-west.

36. The most westerly basin is the Suo Nada which has a wide connection to the adjacent Iyo Nada. Its southern coast consists of a wide bay stretching from Shimonoseki Strait to the Futago mountain structure to the east. Shoals are caused by a number of short rivers, mainly around the mouths. No particular direction of drift is apparent. The northern shore is deeply indented, except in the vicinity of the strait where a protruding plain has been provided on which Ube is now located.

37. The Iyo Nada has contact with the Pacific Ocean by means of Bungo Strait, through which swell penetrates to beaches in the vicinity. These mainly surround Beppu Bay, on the southern boundary of which a deltaic plain was formed. This material is swept westwards by the diffracted waves. The northern edge of Beppu Bay contains a modest coastal plain aligned with the crests of the incoming swell. A northward longshore drift is indicated around Futago Yo, but the rate would be meagre due to the lack of watershed. The south-eastern shore of the Iyo Nada has multiple indentations with steep underwater slopes. Material for transport is available from about one river and is swept eastwards towards the mouth of the Shigenoba River, which has constructed a plain from a formerly long embayment.

38. The Hiuchi Nada is a smaller basin than the two previously mentioned and has islands scattered around it, particularly on its northern boundaries. Shoaling can readily be correlated with the larger rivers bringing material down to the waterline. The only littoral drift evident from shoreline features is on the south-eastern region where a net movement to the north-east is indicated.

39. The Harima Nada has a fairly uniform depth of about 18 fathoms, with few islands to break up the fetches for wave generation. Only in the western region do islands provide calm conditions for in-situ sedimentation. The south-east boundary of the basin is Awazi Island, which displays pronounced longshore drift to the north-east. Because of steep underwater slopes and lack of material the associated coastal plain is very narrow.

40. The Izumi Nada, the eastern most basin, is the smallest in area of all five. It varies in depth from about 30 fathoms in

the south-west to around 5 fathoms in the north-east. This excessive shoaling is probably due to the silting of the Yodo River complex, which has also constructed the plain on which Osaka is cited. The basin is also called Osaka Bay as it has contact with the Pacific Ocean through the Kii and Kitan Straits. However, little swell enters the Nada because the entrance is blocked by two islands. If this were not the case much of the material from the Kino river would have been carried through and along the south-eastern shoreline of the Nada. Both this boundary and that to the north of the Nada have littoral drift towards Osaka. The construction of break-waters along these well developed coastal plains have been designed to cope with this net movement.

PROMOTION OF LOWLAND FORMATION

The islands of Japan exemplify the world wide tendency for population to be concentrated on the sedimentary plains built by rivers and ocean waves. To quote Hom-ma and Horikawa(2): "It is in these coastal plains that the cores of the Japanese industrial and other economical activities are deployed with swarming population". These relatively flat areas are the most useful to man, not only for production of food, but also for his industrial and commercial enterprises. In countries lacking alluvial plains, land reclamation becomes an economic necessity. It is essential in these circumstances to select sites that can be developed at minimal cost, but which can be guaranteed to withstand the forces of flooding and of wave erosion.

SEDIMENT AND WAVE CHARACTERISTICS

Where sediment is deposited by a river into a body of water with little or no wave occurrence, accretion takes the form of underwater shoals or swamps. Only in the event of flooding, when the water level rises above normal, can dry land be formed. Even this is subject to periodic flooding unless levees or other reclamation work is carried out. This type of coastal plain is therefore costly to develop.

On the other hand, shorelines which experience swell waves have their material thrown up into the form of a beach berm. These can accrete to 3 or 4 metres above mean sealevel. If the sediment is sandy and winds exist to dry it out, dunes may be constructed to heights of hundreds of metres. Silty material is not so readily formed into beaches and only vegetation can promote deposition, and even then not far above high tide level. If dried the mud cakes and cannot be blown into heaps.

It is submitted, therefore, that sites for the natural creation of land should be those where sand is predominant, dry seasons are experienced, winds are shorewards, and a persistent swell is present. With knowledge of net-sediment movement, if any, structures can then be devised which will produce accretion in desired areas.

Cognisance should continually be taken of erosion that will occur downcoast of any impediment to the longshore drift. These zones of degradation should be designed for areas of little consequence or where deepening of a channel may be desired.

STRUCTURES AND THEIR LOCATION

Since the land additions contemplated in this discussion are large in magnitude, the normal rockfill groyne or offshore breakwater would not appear an economic proposition for promoting deposition. Also, progressive aggradation is required, because any accretion takes place at the immediate expense of adjacent areas. For these reasons the author has suggested elsewhere[10] that mobile offshore breakwaters might warrant investigation. These could be moved seawards intermittently as tombolos formed and upshore silting had progressed sufficiently. It has been suggested that they might take the form of concrete shell structures which can be floated into position, dissipate waves when submerged, and be refloated by refilling the domes with air. These units would be of a size that they could be mass produced and several would be used in echelon fashion at any one offshore site.

The method of using such mobile offshore breakwaters for straight shorelines and crenulate shaped bays has been discussed elsewhere[3][10]. The choice of sites must be made with the same strict caution as for the usual groyne location. According to a recent resumé of continental practice such planning has not been extremely successful[11]. The remarks expressed elsewhere by the author on crenulate shaped bays may therefore warrant reiteration[3].

Figure 3 illustrates this half-heart shape, with the tangent section near normal to the direction of the persistent swell. The curved portion is sculptured by the waves diffracting and refracting around the upcoast headland. Yasso has shown these curves to resemble logarithmic spirals[12]. This is deserving of further study to relate the parameters of such a simple equation to conditions of sediment supply, shore profile and angle of wave approach.

If such a bay is suffering erosion, due to non-replenishment of sediment removed from it, the ad-hoc use of groynes around the perimeter will not prevent it. As observed in Figure 3a, accretion along the tangent section can be effected by a groyne at the downcoast headland. The nearer the bay is to equilibrium the longer will be the wedge of beach built up. To promote siltation in the lee of the upcoast headland (or to prevent erosion), the headland should be expanded as illustrated in Fig. 3b. This extends the pivot point around which the waves must diffract. When the intermediate zone in the body of the bay needs progradation a third headland might be established. (See Figure 3c). If the bay were approaching its equilibrium shape in respect to the persistent swell and hence the orientation of the tangent section remained constant, a reduction

in headland spacing by additions to both upcoast and downcoast outcrops could be effective. (Figure 3d).

Once a bay reaches complete equilibrium the littoral drift due to the persistent swell ceases altogether, and any wave crest arrives around the periphery of the bay simultaneously. It should not be inferred that erosion will not take place during a storm sequence, because sufficient beach material will be taken until the offshore bar can dissipate the incoming waves. But allowing adequate resources in the beach for the bar, the remaining coastal plain can be fully developed without fear of longterm encroachment by the sea. The prevention of longshore drift has obvious advantages in respect of harbour siting around the bay.

REFERENCES

(1) Silvester R. (1959) Engineering Aspects of Coastal Sediment Movement: Proc. A.S.C.E. Jr. Waterways and Harbors Divn. Vol. 85, No. WW3, pp.11-39.

(2) Hom-ma M. and Horikawa K. (1960) Coastal Protection Works and Related Problems in Japan: Coastal Engg., Vol.7, pp.904-930.

(3) Silvester R. (1960) Stabilization of Sedimentary Coastlines: Nature, Vol.188, No.4749, pp.467-469.

(4) Silvester R. (1962) Sediment Movement around the Coastlines of the World: Proc. Conf. on Civil Engg. Problems Overseas, I.C.E. pp.289-305.

(5) Silvester R. (1963) Design Waves for Littoral Drift Models: Proc. A.S.C.E., Jr. Waterways and Harbors Divn., Vol. 89, No. WW3, pp.37-47.

(6) Davies J.L. (1964) Morphogenic Approach to World Shorelines: Ann. Geomorph., Vol.8, pp.127-142.

(7) Smith G.H. and D. Good (1943) Japan - A Geographical Review: Am. Geogr. Soc. Spec. Pub. No.28, 104 pp.

(8) Dorrestein R. (1961) Amplification of Long Waves in Bays: Florida Eng. and Indust. Exp. Stn., Tech. Rep. No. 213.

(9) Minato M., M. Gorai and M. Hunahashi (1965) The Geologic Development of the Japanese Islands: Tsukiji Shokan Co. Ltd.

(10) Silvester R. (1965) Coastal Sediment Movement - Some Fundamental Problems with Discussion of Research Support: Jr. Insn. Engrs. Aust., Vol.37, pp.311-321.

(11) Petersen M.(1963) Review of German Experience on Coastal Protection by Groins: Beach Erosion Board, Annual Bulletin, Vol.17 pp.38-54 (Translation and Summary by O.W. Kabelae).

(12) Yasso W.E. (1965) Plan Geometry of Headland Bay Beaches: Jr. Geology, Vol. 73, pp.702-714.

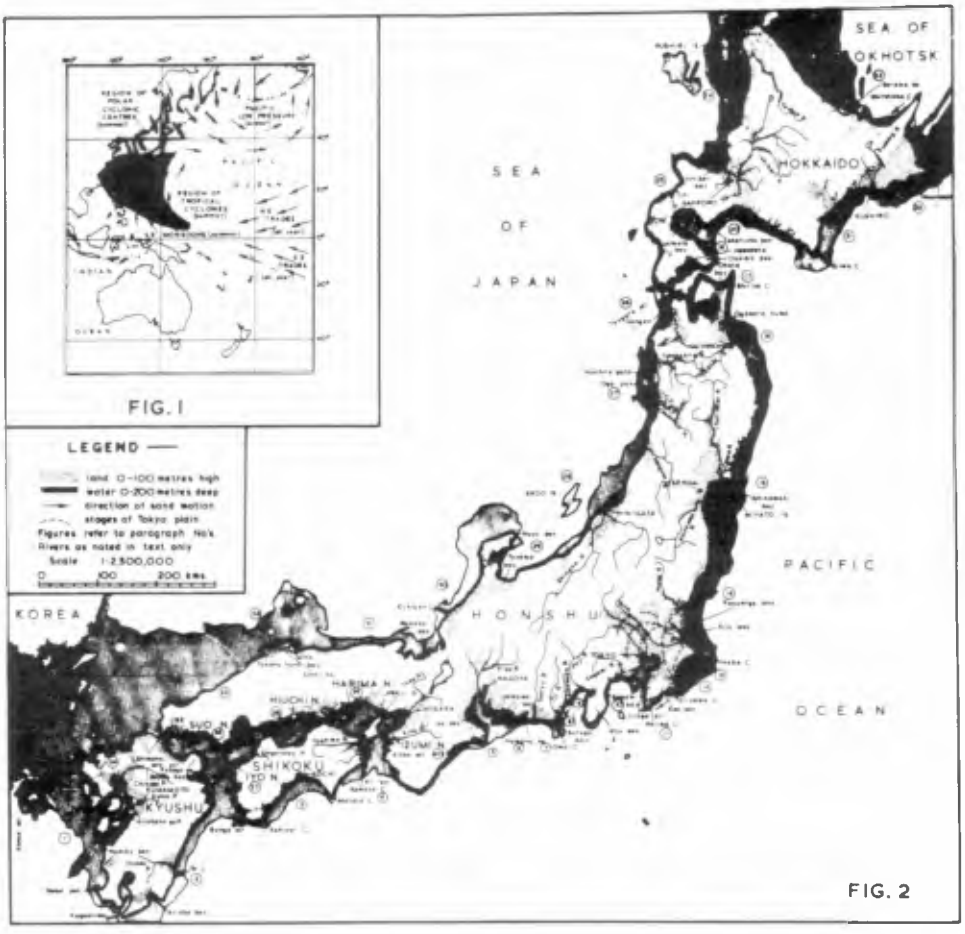

Fig. 1. Wave generating areas affecting Japan.

Fig. 2. Map of physiographic features discussed in text.

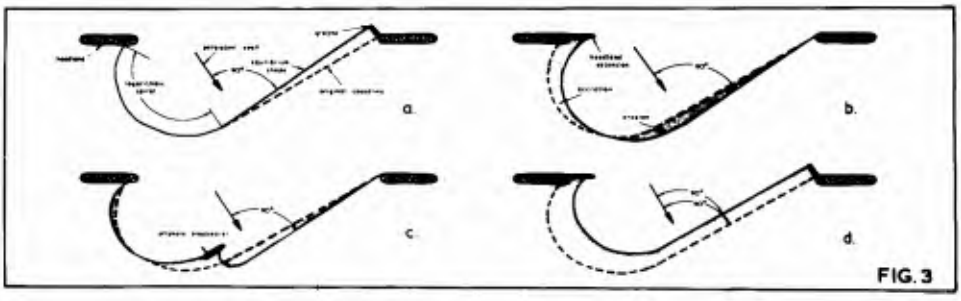

Fig. 3. Accretion promotion in crenulate shaped bays.