The Physical Environment
A New Zealand Perspective

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16 Marine Processes and Coastal Landforms

Bob Kirk

As most (86%) of the New Zealand population is urban and no part of the country is more than 130 km from the sea, most New Zealanders live, work, and play in the coastal zone and its resources are exploited in manifold ways. It is therefore surprising that scientific studies aimed at understanding coastal resources and underpinning sustainable management of the coastal zone are quite recent (Hume et al. 1992), although the volume of research and the coverage of the coastal zone has increased dramatically in the last decade. The shape of the islands results in a long (11 000 km), varied coastline in relation to land area, and our 3.3 million population enjoys a comparatively long 3.3 metres of shore per person (Kirk 1987).

These simple statistics suggest that the coastal zone has high importance for the community (not to mention the fact that the bulk of national commerce depends upon our ports). Yet in contrast to other sectors of the environment (e.g. rivers, rocks, soils, plants, and the atmosphere) New Zealand has never had any agency or organisational structure formally tasked to provide knowledge about our coast. Though ocean waves are the single most important factor in coastal change on all types of coast in the country, New Zealand has no national or regional wave measuring or recording programme. Concern about climate change and the possible adverse effects of sea-level rise notwithstanding, no agency has a responsibility or maintains a national network for the measurement and recording of sea-level change (though the National Institute of Water and Atmospheric Research—NIWA—is attempting to develop one).

This chapter presents an overview of what is presently known about the principal landform systems in the New Zealand coastal zone and the processes that mould them.

The long view

Our coastal zone is, and long has been, physically the most changeable part of our landscape. The shape of New Zealand has continually altered as the result of several sets of processes (Figure 16.1; Fleming 1979). First, ancient New Zealand underwent **continental drift**, during which its location at the boundary of two great continental plates was squeezed, sheared, and buckled. Mountains have grown and been eroded, while basins marginal to them have been filled by many of our 7500 rivers. The jumble of earth blocks and volcanic piles that form the country have been variably lifted, tilted, or dropped, while climate has changed (sometimes colder and drier, sometimes warmer and wetter), and world sea levels have risen and fallen (by more than 100 m several times in the last 1–2 million years). These large-scale, long-term processes of coastal change are always present, so our coasts are good places to appreciate the adage that in nature nothing is constant except change.

Although New Zealand has long been isolated from other continental-type landmasses, so that much of the native flora and fauna is evolved from ancient forms, rather paradoxically these 'old' elements of the environment are hosted by a physical landscape that is extremely young and dynamic. The landscape, especially in the coastal zone, can be characterised by four words: instability, recency, diversity, and distinctiveness.

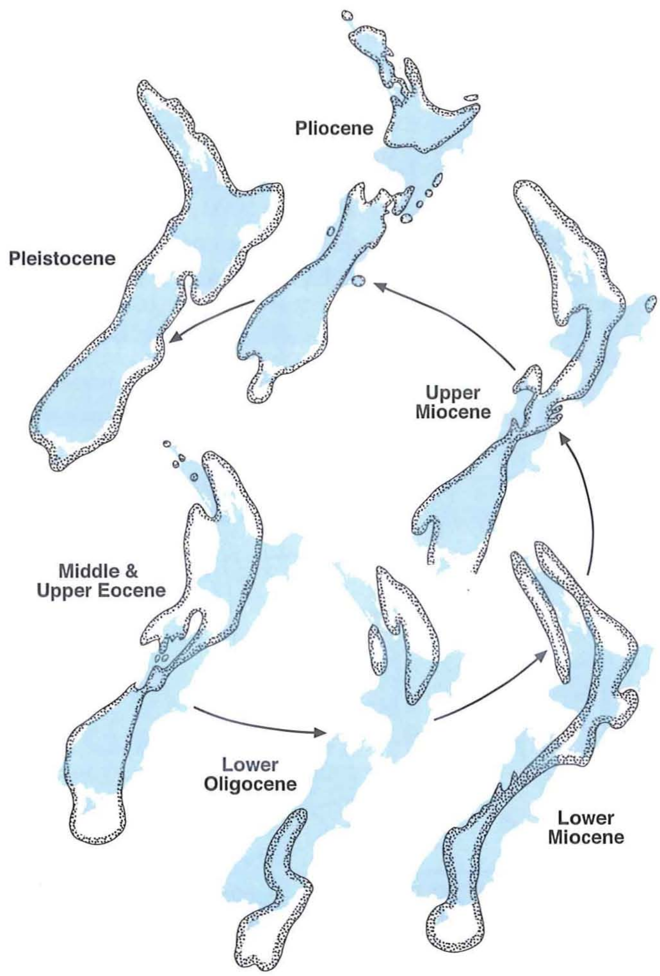

Figure 16.1 The changing form and length of the coast as New Zealand has changed its area, shape and position over geological time. The maps relate to only the last 50 million years. (Fleming 1979)

Instability

None of the major factors that control formation and change in coastal landforms has been stable for long (the land being disturbed often both tectonically and volcanically, the climate and sea level varying more or less continuously). Sea level is not presently stable and has risen by between 15 and 20 cm in most parts of New Zealand since 1900. Both the climate and sea-level rise are projected to change in the future in consequence of global warming postulated from the 'enhanced greenhouse effect'. Sea-level rise is believed to be a factor conducive to **coastal erosion**, though it is by no means the dominating factor in coastal instability. In a contrasting example, sea level fell 1.8 m in a few minutes as the land was heaved up in the catastrophic 1931 Napier earthquake. Widespread changes, both upward and downward, occurred to the Wellington coast and the shores of the Wairau Valley near Blenheim in an earthquake in 1855. The New Zealand coast presents a great many sites where beaches now high above the sea and/or tilted testify to but two kinds of these past instabilities and provide a good guide to future conditions.

Recency

Major changes of sea level and climate have occurred very recently (sea level reaching its present levels only between 5000 and 7000 years ago). In what is now Christchurch, some 6500 years ago the coast was 10 km inland of its present position (on the western edge of Hagley Park), and it has since built out in a series of stages each marked by a sandy beach and dune ridge with intervening ancient estuaries and swamps (Figure 16.2; Brown & Weeber 1992). Though it occurred in stages, having pauses marked by ridges in the central city (e.g. under the Law Courts on the Avon River and in Linwood), progradation averaged 1.5 m per year. Intriguingly, maps made

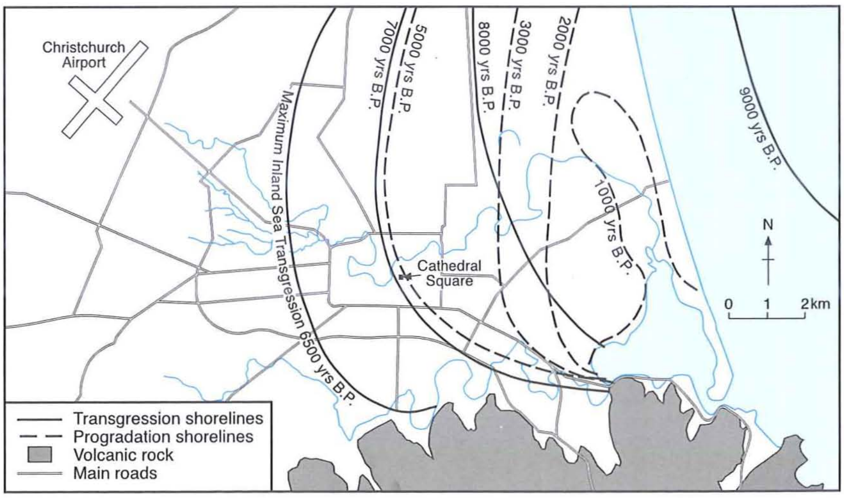

Figure 16.2 Transgression shorelines formed as the sea rose (solid lines), and progradation (regression) shorelines formed as sand accumulated and the shore prograded (dashed lines) over the last 6500 years in the Christchurch area. The coast is now 10 km seaward of its position at 6500 years BP. (Brown & Weeber 1992)

since the 1850s show that this has ceased and the coast has held much the same position since then.

Many other places in New Zealand show similar rapid and recent **accretional** histories. For example, Pullar and Selby (1971) demonstrate that the Rangitaiki Plains, north of Whakatane in the Bay of Plenty, contain a suite of prograded beach ridges, dunes, and associated deposits more than 9.75 km wide that have accumulated in the last 8000 years. Again, historical rates of change are much less.

Diversity

The 11 000 km of New Zealand's coast is extremely varied, ranging from long sweeps of sandy beach on the west coasts of the main islands, to numerous pocket beaches on headlands everywhere. The variety includes the drowned river valleys (ria) of the Marlborough Sounds and the glacially carved fiords of the southwest, as well as the vast sweeps of mixed sand and gravel beaches on the east coasts of both islands between Napier and Oamaru. There are also more than 300 harbours, estuaries, coastal lakes, and river mouths of a great range of forms and origins. Every major type of coastal landform system, short of tropical reefs and actively glaciated shores, occurs somewhere in New Zealand or its associated islands in the subtropics and subantarctic (Healy & Kirk 1992).

Distinctiveness

As well as being diverse, elements of the New Zealand coast are also highly distinctive. **Mixed sand and gravel beaches** are common in eastern New Zealand, where they are associated with sediments derived from greywackes, especially with fluvial outwash deposits derived from glaciated areas of the Southern Alps. This beach type is rare globally, so that most scientific knowledge needed to understand and manage land and port uses on this type of coast has had to be 'home grown' (Kirk 1980). This type of shore also presents our most severe coastal erosion and flooding problems (e.g. in South Canterbury and North Otago, and in Hawke's Bay) whether these problems are measured by rates of coastal retreat (up to 8 m per year), or the dollar value of developed assets, land, and infrastructure that are at risk (Figure 16.3).

Hapua comprise another distinctive coastal system, commonly referred to as a 'river mouth lagoon' (Kirk 1991). Since these features are not lagoons in any of the accepted scientific uses of that term, the author has proposed that they be known by the Maori name 'hapua'. These systems are extremely important culturally, and are important in wildlife, fisheries (e.g. searun trout and salmon), and recreational terms. They are typically associated with steeply sloping braided rivers delivering mixed sand and gravels derived from greywackes. There is negligible tidal inflow and outflow from them, and they comprise a narrow sand and gravel spit typically offset by 1–3 km (and as much as 6 km in the case of the Ashley River in Canterbury) by wave-induced longshore drift of sediments. The water body (the 'lagoon') is the deflected section of the river channel running parallel to the coast. In extreme cases, as when flows are very low, the mouth may close. In times of flood the enclosing spit breaches opposite the

Figure 16.3 Erosion damage to a house built on a foredune subject to storm wave erosion at Raumati, 1978. (D. Hayman, Coastal Photos)

river channel, the 'lagoon' drains, and a submerged fan of gravels is dumped in the surf seaward of the breach and later dispersed by wave action. This sequence of changes both terminates and re-initiates the **downdrift** displacement of the river mouth, since after the flood downdrift migration and reformation of a shore-parallel section of the river channel begins anew.

Shorter time scales—the human influence

It is easily seen that our coasts are in constant change as they respond to natural forces such as storm waves, tsunamis, and sea-level change at shorter than geological time scales. The time frame corresponds to the duration of human settlement in New Zealand, including coastal processes we observe during our lifetimes, and variations in them from day to day, season to season, or year to year. However, over the last millennium an additional and powerful set of factors transforming the coast has been introduced.

The character of a very high proportion of the New Zealand coast cannot be accurately described solely in terms of the effects of dramatic, sometimes even spectacular, natural forces. It is necessary to also appreciate the effects, often dominant, that human actions have had on the coastline of New Zealand, because the coastal zone is often as much (or more) a cultural than a natural landscape.

Within the last 1000 years, and especially within the last 200, much of the coast has been transformed through human use of land and water. Often described in pristine terms, the environment of much of New Zealand is remarkable for having had several kinds of 'natural character' in the past 200 years, and for both the rapid pace and widespread nature of cultural changes to the landscape.

Direct transformations

On coasts the changes have often been direct; for example, through widespread replacement of native sand dune plant communities with introduced near-monocultures. In the Christchurch area, marram grass (*Ammophila arenaria*), first introduced in 1890, has replaced the native pingao (*Desmoschoenus spiralis*) and is now dominant. At present, and as part of an extensive programme of bulldozing and lowering **foredunes** along the urban foreshore, yet another type of vegetation cover, dominated by iceplant (*Carpobrotus edulis*), is being planted. Together these activities, among other changes, are further transforming the character of the coastal landscape from a coastal wilderness to that of a manicured series of 'coastal parks'. In contrast to these presently occurring species-impoverished 'built' plant communities and dune landforms, Armstrong (1869) listed a much greater pre-urban biodiversity in the Christchurch dunes, having a total of 78 species of native plants including 11 shrubs, 59 herbs, 4 ferns and 2 mosses.

Coastal foredunes act as a very effective 'buffer' against storm-wave erosion of beaches, and a barrier to inundation by the runup of broken waves acting at water levels super-elevated by low air pressures and strong onshore winds. Bulldozing and wholesale removal of sand from protective coastal dunes is therefore an extremely hazardous, and therefore unwise, activity that has been widely carried out in New Zealand in order to form a surface on which to build or to obtain a view of the sea.

Other direct impacts on the coastal landscape include the extraction of sediments from beaches and dunes for a range of uses including construction aggregate, glass making, and sandblasting. At many sites a range of 'seawalls' (bulkheads and revetments) have been built in frequently vain attempts to prevent storm erosion hazard to inappropriately located assets and infrastructure in storms. Since it is the natural function of dunes to act as a store of sand that can be given up to the waves and used in building an energy-dissipating beach profile in time of storm, and because the artificial structures built are commonly incompetent in a variety of ways, this type of modification to beaches is muddle-headed and self-defeating. Such works often fail, and not infrequently they lead to magnified erosional effects in their vicinities.

Indirect transformations—big and small rivers

A variety of significant indirect human effects also occur throughout New Zealand. Beaches are commonly nourished by sediments supplied from the hinterland by rivers. Zenkovich (1967) introduced the notion of a distinction between 'big' and 'small' rivers. Relative to its coastline, a 'big' river is one that supplies sufficient or more than sufficient sediments to offset erosion of the coast. Such a river is associated with a stable or accreting shore. In contrast, a 'small' river is one that supplies insufficient sediment to maintain its associated coast against erosion and the shore retreats.

Kirk (1991) added the significant modification that whether a river is large or small relative to its coast depends not on the total river-borne sediment load, but on the fraction of it that is coarse enough to build and nourish beaches. This is important because some of New Zealand's largest rivers are 'small'. In Canterbury, as elsewhere in eastern New Zealand, large, braided rivers with apparently abundant sediment supplies in their beds debouch onto coasts that are chronically eroding. For example, the Rakaia with a mean flow of 200 $m^3 s^{-1}$ and a maximum flood flow of over 3000 $m^3 s^{-1}$, and which delivers an estimated 4 million tonnes of sediment to the sea each year, nevertheless has a coast that is eroding in the long term at rates of around a metre per year (Kirk 1991). This is because only about 3–5% of its total load is sand and gravel capable of building beaches. The vast proportion of the load is silt and fine sand dispersed at sea.

As distinct from the 'natural' relations that have existed between rivers and their coasts (and which varied as climate and other conditions such as sea level changed over time), human influences have also altered the relationships, sometimes to render rivers hydrologically 'big' and sometimes to make them 'small'. Historically, human changes in land-use practice first made many rivers 'big', as reflected in an associated phase of coastal sedimentation, and then made them 'small', rendering the coasts erosional.

Widespread burning of catchments and conversion of forest to grassland is an activity known to have been widespread in both pre- and post-European contact New Zealand. It affected the river–coast relationship in favour of a 'big' (or bigger) status and is known to have significantly increased sediment yields for a time in many catchments. Hicks and Griffith (1992) report experimental results from burned catchments showing 100-fold increases in sedimentation. Hume and Gibb (1987) report high rates of sedimentation (averaging 6 mm per year) after the 1930s in Tairua Estuary, Coromandel, and they relate this to logging and associated accelerated soil erosion in the catchment. On the west coast of the South Island extensive sluicing for alluvial gold also transformed large areas and greatly increased the sediment yields of rivers and streams. Similar effects have also been reported from estuaries adjacent to developing urban areas. Hicks (1993) reviews a series of studies that describe a large influx of muddy sediments to the Avon–Heathcote Estuary consequent on the early development of Christchurch city and lasting until the 1950s. Since then the mudflats have gradually 'deflated' at rates of 2–6 mm per year, and the main changes have been associated with migration of the tidal channels and bars.

According to Hicks and Griffith (1992), the instigation of soil conservation legislation and measures in the 1930s and 1940s largely offset historically elevated sediment yields, and since then most New Zealand rivers probably have maintained a stable (and smaller) sediment-load regime.

However, on several of the major rivers construction of dams for purposes of hydroelectric power generation has altered river-flow regimes and impounded huge amounts of sediment that would otherwise have reached the coast and nourished beaches. Most such dams have been constructed since the 1930s, so that a 'big' phase has been followed by a hydrologically 'small' one in respect of stability of the associated coasts. For example, Kirk and Hewson (1978) examined the consequences for coastal stability of accumulation of 9.5 million m^3 of sediment 60 km inland behind the Waitaki Dam over the period 1935–60. On the Clutha River, an average of 2 million m^3 per year accumulated in Lake Roxburgh after commissioning of the Roxburgh Dam in 1963. Most of this material is now being deposited in the Kawarau Arm of Lake Dunstan, upstream of the Clyde High Dam.

In such cases beaches, many of them already eroding, have been subjected to accelerations of erosion in proportion to the degree of sediment starvation. Kirk and Hewson (1978) demonstrated that prior to 1935 the Waitaki River was the dominant source of sediments for the beaches between Oamaru and Timaru. Since then erosion of coastal cliffs has become the principal source, and it has taken between 40 and 50 years for the starvation effect to spread throughout the coast to the downdrift end of the beach system 65 km north at the Port of Timaru.

In some rivers, extraction of sediments for construction aggregate has also adversely affected stability of the adjacent coasts. Other changes to river hydrology also affect coastal systems, especially the size and functioning of hapua, including incidence of mouth closure, water temperature in the 'lagoon', the duration of the 'lagoon' morphological sequence, and the magnitudes and effects of floods (e.g. when the mouth is closed). These have occurred through extensive utilisation of river water for irrigation.

Many coastal lakes, most of them culturally significant, and equally important for wildlife, fisheries, and recreation values, have also been significantly altered. For example, Hemmingsen (1997) demonstrated that the largest coastal lake in Canterbury, Lake Ellesmere/Waihora (24 km long, 11 km wide, 24 000 ha in area, and having an average depth of 2.1 m), is very much smaller than in pre-European times, owing to artificial drainage and control of its levels. Prior to European control the lake was 29 km long, 15 km wide, and had an area 1.7 times greater, at 40 600 ha. Depths averaged 5.0–5.5 m and much larger waves occurred, creating much larger beaches on its shores. These beaches are now stranded in farmland more than 4 m above the modern, shrunken lake.

Sources of beach sediments

Rivers

As previously mentioned, in temperate climates like that of New Zealand, rivers are the predominant source of sediments from which beaches are constructed. The small portions of their total loads (almost always less than 20%) that comprise sand and gravel are the prime building materials of ocean beaches.

As demonstrated by Griffiths (1981), catchment precipitation is the main factor affecting specific sediment yield, and New Zealand specific yields are among the highest in the world (see Chapter 13). From this it is concluded that beach nourishment from rivers in New Zealand roughly conforms to the distribution of rainfall (i.e. higher on the west coast than in the east, especially in the South Island).

Griffiths and Glasby (1985) estimated the total river-derived sediment load delivered to the coast and **continental shelf** around New Zealand at 389 million tonnes per year. Of this, 284 ± 40 million tonnes (73%) occurs around the South Island, while 105 ± 9 million tonnes (27%) is delivered from the North Island. In further contrast, some 75% of South Island sediment load is delivered by the numerous short, steep rivers of the west coast (though little from the hard rocks and glaciated basins of Fiordland), while in the North Island some 69% is transported to the east coast between Gisborne and East Cape, and the Manawatu River is important in sediment supply to the coast of the Taranaki Bight.

Ancient rivers

Some coasts, once abundantly supplied by rivers, no longer receive materials from this source. Figure 16.4 shows New Zealand at the end of the last glacial period (the Otiran) with sea level over 100 m lower than at present and the islands joined by land bridges. At that time the Waikato flowed not to the Tasman Sea but northeast toward the area now occupied by Whangarei. As discussed by Schofield (1970), river-borne sediments and airfall sediments from volcanic ash showers nourished what is now the continental shelf. During sea-level rise and its comparative **still-stand** over the last 5000–7000 years, these sediments have been swept off the seafloor into embayments to form the east coast beaches from the outer Firth of Thames to Whangarei. At the geological time scale the sediment supply is thus finite. Since half of New Zealand's population lives within 50 km of central Auckland, and demand for construction aggregate must be met increasingly from coastal sites, it can be seen that sustainable management both of aggregate sources and of beaches for scenic, recreation, and conservation values must be carefully planned in this region.

Seabed sediment supply

Several other sections of the New Zealand coast are nourished by beach sediments transported along the continental shelf. Perhaps the best example is the formation of Farewell Spit, on the northwestern corner of the South Island, the sediments being ultimately sourced in the high yields of the Westland rivers. Elsewhere, the beaches of Dunedin city (and north of the peninsula in Blueskin Bay) are nourished by large seabed sand transports, much of it sourced from the Clutha River (Bardsley 1977). Purakanui, Murdering Beach and Kaikai Beach in Blueskin Bay all display high historical rates of accumulation from north-going sand deposited in the 'lee' of Otago Peninsula (Nicholson 1979).

Similarly, Dingwall (1974) demonstrated that sand transported along the outer continental shelf in Canterbury has been deposited on a 'banner bank' in the northeastern lee of volcanic Banks Peninsula, from where it is then worked landward into some of its bays. The peninsula rocks contain little quartz, yet Okains Bay, for example,

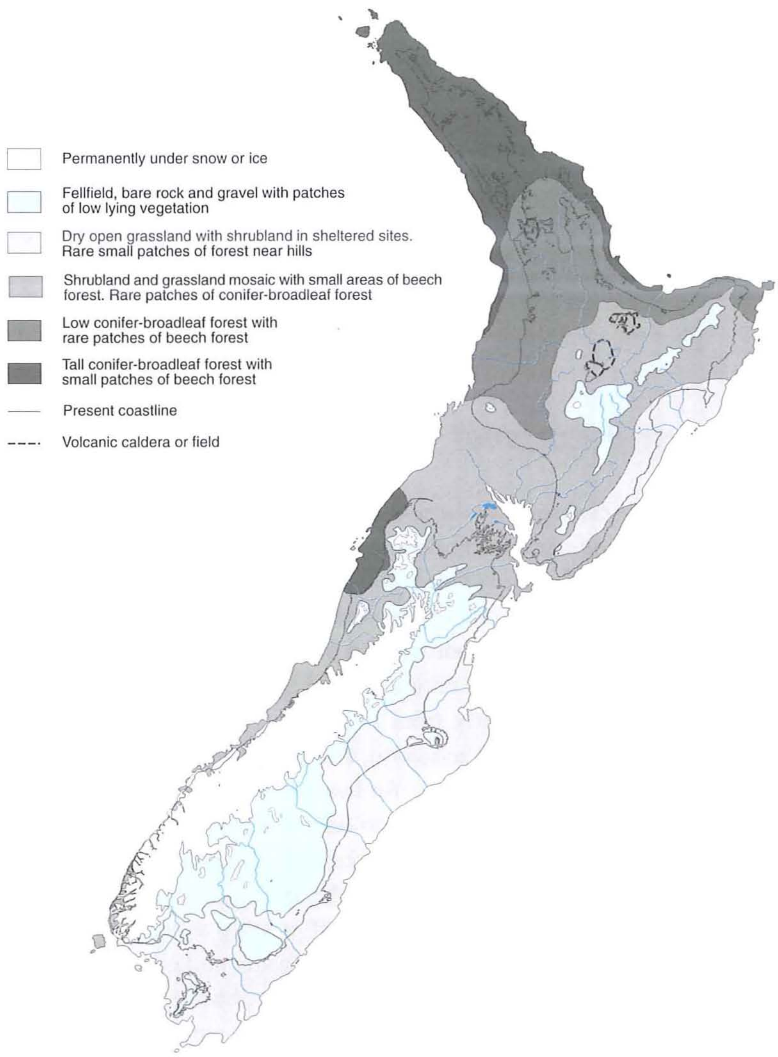

Figure 16.4 New Zealand during the last glaciation (the Otiran), perhaps 20 000 years ago, with world sea levels more than 100 m lower than now. The present continental shelf was land, the islands were tied together, and the coast was much less indented. (Fleming 1979)

is rapidly prograding (at 2.4 m per year) with quartz-rich 'exotic' sands derived from the greywackes of the southern river catchments.

Cliff erosion

The intertidal shore platforms that characterise hardrock shores (sometimes with overhanging notches at the base of the coastal cliff) are wholly erosional in origin. However, erosion of hardrock cliffs supplies little sediment to beaches. Nevertheless, the New Zealand coast presents long stretches of river fans and terraces or hillslope talus that has been cliffed by the sea. As already noted, in Canterbury there are over

100 km of such coast that is chronically eroding and constitutes the major source of sediments for mainly mixed sand and gravel beaches.

Flatman (1997) investigated a 32 km section of the Canterbury coast between the Ashburton and Rangitata River mouths, comprising cliffs cut in weakly consolidated outwash gravels broken only by numerous dry gullies known locally as 'dongas'. The cliffs, up to 20 m high, are persistently eroding at rates ranging up to 0.7 m per year. Sediment budget analysis revealed that cliff erosion supplies 70% of the sediments in the mixed sand and gravel beaches that fringe the cliffs, while the two substantial Main Divide rivers supply only 17%, and longshore transport from further south supplies the remaining 13%.

Beaches and coastal erosion

In New Zealand wave action is oceanic, persistent, perennial, strong, and sometimes devastating. At ocean beaches it is rare to see breaking waves less than a metre high. Beaches 'buffer' and convert the perennially high and ever-changing energies of ocean wind waves using one of the weakest geotechnical materials known—a mixture of sand and water. The combination of strong forces and weak materials is responsible for the highly changeable nature of our beaches. Sand is in motion, by the hour, with the tidal cycle, fortnightly from neap to spring tides, from storm to subsequent swell episodes, from season to season, and year to year (e.g. in response to El Niño/La Niña variations in the weather). Yet beaches are durable. Their changing forms are few in number and repeated over and again. Sandy beaches have 'equilibrium' forms and constantly adjust toward a balance with the prevailing wave conditions. Two extreme forms are well known. In storms, the foreshore becomes narrow and flat, and the foredune may develop a prominent cliff or scarp as it is eroded. Sand is transported offshore to widen the beach beneath the water and construct one or more bars on which waves break, so limiting the penetration of wave energy to the dune. Because storm wave energies are high, these changes occur rapidly over just a few hours or days.

In gentler swell conditions, energies are low and so beach change is slow. The offshore bars are broken down and sand is progressively returned to the shore. The foreshore is built up steeply and it widens. Sand is dried out and blown inland to restore the dune, so recharging it in preparation for the next occasion on which it will give up sand to buffer storm-wave effects. Thus the foreshore accretes in swells and erodes in storms.

Over the longer term, whether a coast erodes or accretes depends upon broader-scale sediment supply, loss, and budget state considerations. As in the discussion of river-supplied sediments, if waves transport more material out of a coastal system over some defined period than can be renewed from sources of supply, the coast will be in a deficit budget state and it will experience underlying chronic erosion superimposed on the short-term onshore–offshore, swell/storm sequence of changes. Where overall supply and loss are roughly equal, the beach system will fluctuate about a more-or-less constant position. Where gains exceed losses, net accretion will occur and the shore will advance seaward while the beach fluctuates with storms and swells.

Gibb (1978) examined maps, air photographs, and other documents showing shoreline positions during the post-European period in New Zealand. Well over half of our coast was found to be eroding. Historical erosion and accretion occurred at rates in the range 0.5–4.0 m per year, with maximum erosion of 25.4 m per year at North Kaipara Head, and maximum accretion of 68.9 m per year at Farewell Spit.

McLean (1978) examined the incidence of coastal accretion in New Zealand. While massive accretion (as described earlier in examples from Christchurch and Bay of Plenty) occurred in the late Quaternary in response to worldwide changes of climate and sea level, it was concluded that 'evidently the main phase is over'. This is in spite of evidence of considerable recent but mostly local progradation from several parts of the country.

Sea-level rise

It can be said that the trouble with sea level is that it is not! It is neither level nor still; one simple demonstration of which is the rise and fall of the tides, which must be averaged to find mean sea level. Coastal landform development is affected by changes of base level. These may come about through changes in the level of the land (e.g. by tectonics or subsidence) and/or by changes in sea level. Thus, it is relative sea level (RSL) rather than movements of ocean level that are significant for coastal stability.

Considerable concern has been expressed that global warming might lead to accelerated sea-level rise and to inundation of low-lying coastal areas, as well as to greater extent and severity of coastal erosion (Gibb 1991). However, international projections for the amount of rise in global mean sea level over the next century have been revised downward twice, and no one has shown how global mean sea level relates to relative sea level in the New Zealand region. Also, the notion that sea-level rise is a cause of shoreline erosion is grossly oversimple.

As noted earlier, while it is not the responsibility of any agency to monitor sea levels throughout the country, some work has been done on the historical patterns of RSL by Hannah (1990) from the tide gauge records at the ports of the four main cities. These are shown in Figure 16.5, from which three features should be noted. First, sea-level behaviour is very variable from year to year. Second, it has a different character at each place; and third, RSL has been rising at all four ports through this century at average rates ranging from 1.3 to 2.3 mm per year. It is not known how these rises relate to beaches on open ocean coasts in the regions of each of the four ports. Thus, sea-level rise has been a background factor present for all of this century and is as yet unevaluated for its role, if any, in coastal stability, land use, and land management. Examination of any adverse effects would be a good guide to possible impacts to be expected under accelerated rise of sea level.

Waves

Wind waves are the prime agents of coastal change, yet comparatively little is known about the wave climate of the New Zealand coast. New Zealand lies generally northeast–southwest, with its main ranges perpendicular to predominantly westerly wind

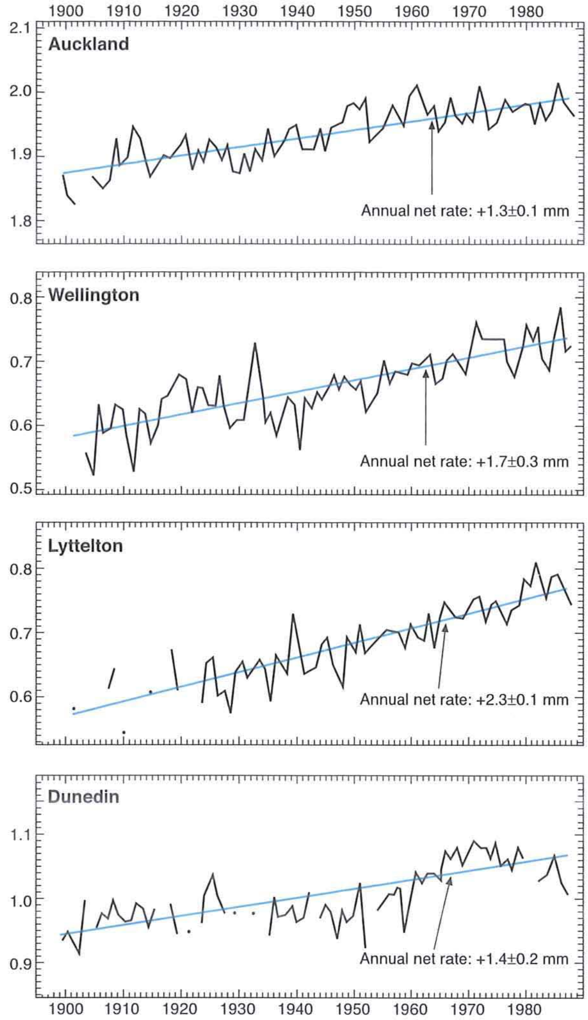

Figure 16.5 Changes in mean sea level and average rates of change since 1900 derived from tide gauges at the ports of the four main centres. Note the extreme variations from year to year superimposed on a general rise. The vertical scale is mean sea level (m) above chart datum. (From Hannah, 1990, adapted by Gibb, 1991.)

circulation. According to Davies (1972) and Pickrill and Mitchell (1979), the wave environment is dominated by west and southwest swell and storm waves generated by westerly winds. The west and south coasts are very exposed high-energy shores, the east coasts are high-energy lee shores, and the northern coast from North Cape to East Cape is a comparatively sheltered low-energy lee shore.

Wave energies are extremely high south of New Zealand, the prevailing waves being 3.5–4.5 m high with periods of 10–12 seconds. The west coast wave environment is mixed with locally generated westerly and southerly storm waves and swell waves from the south. The prevailing waves are 1.0–3.0 m high and 6–8 seconds period. There are no seasonal rhythms, but there is a strong five-day pattern associated with passage of fronts. The east coast also has a mixed wave climate, with southerly swells from south of New Zealand plus locally generated southerly and northerly waves. The prevailing waves are 0.5–2.0 m and 7–11 seconds period. A short weather 'cycle' like that of the west coast occurs, as does a weak seasonal pattern, with northerly waves more common in summer. On the north coast the prevailing waves are northeasterlies, 0.5–1.5 m high and 5–7 seconds period. Major storms occur in the form of subtropical disturbances (e.g. cyclones like the 'Wahine' storm of April 1968 and 'Bola' of March 1988). The wave environment is again a mix of ocean swell, storms, and locally generated smaller waves, and there is a tendency for greater storminess in winter.

New Zealand is also isolated in the vast mass of the Pacific, so that the fetches for wave generation are effectively unlimited in most directions (Davies 1972). Watching waves breaking at the beach is to view the past, because the waves are the remnants of stormy weather perhaps hundreds or thousands of kilometres away, which occurred days or even weeks ago. It is common for 'mixed sea states' to occur, with waves of varying ages travelling different distances and all arriving from different directions at the beach at the same time.

In addition to creating large waves that erode the shore, storms also raise sea level by creating **storm surge**. Surge combines the **inverse barometer effect**, by which sea level is drawn up by low air pressures (about 1 cm per hPa of pressure fall); **wind set-up**, by which strong winds cause a downwind drift and pile-up of water; and **wave set-up**, which is a further elevation of water levels produced as the waves break at the shore. Since these effects are weather-related and have nothing to do with the tide (which is created by the gravitational interaction of the Sun, Moon and Earth), storm surge is additive on the tide and it allows large, high-energy storm waves to erode and inundate areas to much greater elevations on the land. Heath (1979) examined the air pressure and wind set-up components of three damaging storm-wave systems and found that these two components raised local sea levels by as much as 0.6 m. Adding wave set-up at the beach could bring the total storm-induced rise to more than a metre (Kirk 1979).

Tides

Tidal systems on the New Zealand coast are shown in Figure 16.6. The coast is unusual in that all stages of the tide are continuously present, so that it is always high tide somewhere, and low tide somewhere else. Another feature shown on the diagram is that different tidal systems occur for the east, northeast and west coasts. On the west coast the flood (rising tide) sets south (so that southerly places have high tide later than more northerly sites), while on the east coast the opposite occurs. Mixed tides occur on the northeast coast. It can also be seen that a 4–5-hour inequality exists in the stages of the tide between the west and east coasts. It is this that accounts for the extremely strong tidal currents occurring back and forth through Cook Strait (and French Pass), Foveaux Strait and around North Cape.

Tidal currents are not important in coastal sediment transport except where they are accelerated by passage around headlands (such as Banks and Otago Peninsulas) or constricted in the inlets to estuaries and harbours. In the latter case, tidal circulation is thought to dominate stability of most estuary mouths.

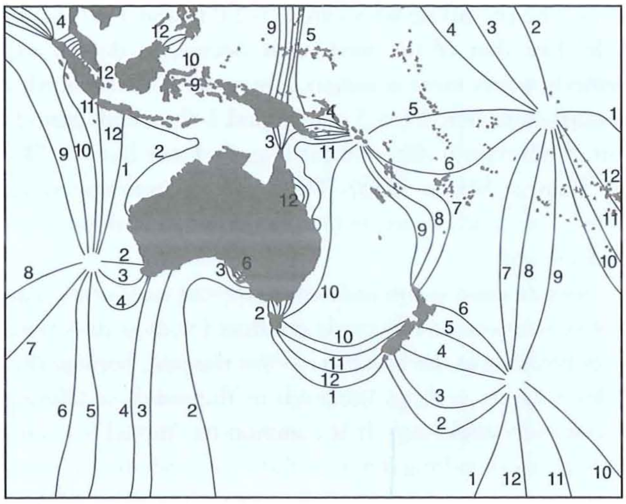

Figure 16.6 Tidal systems in the New Zealand region of the Pacifc Ocean. Three systems are apparent: one to the northeast, one to the southeast, and a complex system in the Tasman and centred east of New Guinea in the Coral Sea. The lines are co-tidal (i.e. they join places having the same stages of the tide at the same time). The numbers are stages of the tide in hours after the transit of the Moon in Universal Co-ordinated Time. Since a full tidal cycle occurs in 12 hours and 54 minutes, it can be seen that all phases of the tide are continuously present on our coast. (Adapted from Miller & Batt, 1973)

Tidal range is also variable around the New Zealand coast. It is related to the character of each tidal system, but is also significantly correlated with the width of the continental shelf (tidal ranges in deep water being less than in shallow water) and distance away from the open sea up harbours and inlets. Tidal range (and thus mean sea level) has been altered at some ports through actions such as channel dredging and sea-wall construction (as distinct from changes due to climatic oceanic factors). Most of the New Zealand coast is 'microtidal' (Davies 1972) in that tidal ranges are less than 2 m, but some areas (e.g. Nelson–Golden Bay) have 2–4 m ('mesotidal') ranges.

Much of the New Zealand coast experiences a fortnightly alternation of spring tides (larger range with higher high and lower low tides) and neap tides (smaller range with smaller extremes). However, although the Resource Management Act (1991) defines the boundary between 'land' and 'sea' as mean high-water spring tide, parts of the coast, particularly in Canterbury, do not experience spring tides (Goring 1991).

Tsunamis

Tsunamis are seismic sea waves. Often mistakenly called 'tidal waves', they have no connection with the ordinary astronomical tides. None of the world's oceans are tsunami-free, and the tectonically and volcanically active margins of the Pacific have been particularly prone to them. De Lange and Healy (1986) list 32 tsunami events reported in New Zealand between 1840 and 1982. They have a surprisingly high average recurrence interval of one about every 4.5 years (a 22% risk of occurrence in a given year). As hazards, tsunamis have three characteristics: extreme unpredictability of occurrence, short warning times, and potentially disastrous consequences.

Tsunamis are capable of trans-oceanic travel and are usually characterised as two main types. **Far-field tsunamis** are those for which the source of generation is remote from the 'target' coast of interest. There are nine of these in the New Zealand record, which is about a third of all reported tsunamis (de Lange & Healy 1986). Because tsunamis travel at up to 700 km per hour in the Pacific Ocean, a maximum warning time of little more than 12 hours is possible for far-field tsunamis, and neither the weather nor the sea state in the target area will give any inkling of the imminent arrival of seismic sea waves. The International Tsunami Warning Centre in Hawaii serves Pacific nations through seismographs and water-level recorders located throughout the Pacific.

Notwithstanding their frequency of occurrence in New Zealand, the most recent far-field tsunami was received from a magnitude 8 earthquake in Chile on 22 May 1960. In this event the waves crossed the Pacific to New Zealand in 12 hours and caused loss of human life in Japan. At Lyttelton a 7 m excursion of water level occurred, with the maximum level reached being 3.3–3.5 m above high-water mark. In Christchurch the Avon–Heathcote Estuary (which has a tidal range of 1.7 m) filled from low water to a metre higher than high water in 3.5 minutes.

Near-field tsunamis are those generated in or near the target area, commonly by earthquakes, but also by landslides above, into, or below the surface of the sea, and by volcanic activity. Two-thirds of reported tsunamis in the New Zealand record were of this type (de Lange & Healy 1986). Travel time is very short for these events, perhaps just a few minutes, and no effective warning is possible. The largest tsunami reported in New Zealand occurred on the Wellington coast in 1855. Another event was locally generated off Gisborne in March 1947. Two waves more than 10 m high reached the shore at Tatapouri, and waves more than 4 m high occurred in the harbour. The most recent near-field tsunami occurred as a result of a rock fall at Deep Cove, Doubtful Sound, in June 1988. The travel time to a wharf and moorings on the other side of the sound was about two minutes. A 40-tonne boat was lifted 4 m onto the wharf by waves at least 2.5 m high.

Summary

This chapter has presented an overview of coastal processes and landforms of the New Zealand coastline. It began with the 'long view' which assessed longer-term processes influencing the New Zealand coastline. This involved consideration of instability of sea level, recency (changes over the last 8000 years), diversity of coastal landforms, and the distinctiveness of the New Zealand coast such as mixed sand and gravel beaches and hapua. The chapter then examined shorter time scales and described the human influence on coastal landforms. First, direct transformations were discussed, including human alteration of plant communities on sand dunes, removal of sand from protective coastal dunes, removal of sediment from beaches and the building of sea walls. Second, indirect transformations were considered. Actions such as burning of catchments and conversion from forest to grassland, sluicing for alluvial gold, and urbanisation have all resulted in increased sediment yields to rivers and hence increased supply of sediment to the coastline. In contrast, the building of dams for hydroelectric purposes has altered river-flow regimes and substantially decreased the supply of sediment to the coast, resulting in accelerated coastal erosion.

The chapter continued with a description of beaches and coastal erosion. The influence of sea-level rise on coastal stability was discussed, followed by the wave climate of New Zealand. Although wind waves are the main agents of coastal change, comparatively little is known about the wave climate of the New Zealand coast, indicating an area requiring more research. Finally, the chapter focused on tidal systems of the New Zealand coast and the tsunami hazard.

Further reading

Davies, J.L. 1972, *Geographical Variation in Coastal Development*, Oliver and Boyd, Edinburgh.

Mosley, M.P. 1992, *Waters of New Zealand*, New Zealand Hydrological Society, Wellington.

Zenkovich, V.P. 1967, *Processes of Coastal Development*, ed. J.A. Steers, Oliver & Boyd, London.