Chapter 2
Causes of Beach Erosion

Abstract Before renourishing an eroded beach it is necessary to know why it has been eroded and where the sediment has gone: landward, seaward or alongshore. This chapter deals with the causes of beach erosion, including alterations in processes and sediment supply, along with anthropogenic influences.

Before renourishing an eroded beach it is necessary to know why it has been eroded and where the sediment has gone: landward, seaward or alongshore (Fig. 2.1).

Beach erosion is usually marked by the evolution of a concave-upward shore profile, whereas accreting (prograding) beaches typically have convex-upward shore profiles. There is sometimes a receding microcliff (an erosional scarp), a metre or more in height, where an upper convex beach is being undercut as a lower concave profile becomes established (Fig. 2.2). Backshore dunes are often cliffed behind beaches that have been lowered and cut back by erosion, as are backshore terraces, and in both cases vegetated land surfaces are truncated as erosion proceeds.

Erosion can be temporary, reversed by a following period of accretion, or long-term, resulting in a net retreat of the coastline (recession). The retreat of the coastline can be traced by comparing dated sequences of maps and charts, or air and ground photographs. Average annual rates of coastline recession are usually small (a few centimetres each year), but there have been instances of recession rates of more than 40 m per year, as on beaches fringing rapidly eroding delta shores, or on beaches fronting relatively less resistant cliffs, such as those comprising glacial deposits for example.

Beach erosion can be caused by natural or anthropogenic alterations to the sediment budget (including both the sources and sinks of beach sediment) or the processes that work on them. The main causes of beach erosion are as follows:

1. Reduction in sediment supply from eroding cliffs
2. Reduction of fluvial sediment supply to the coast
3. Reduction of sediment supply from the sea floor

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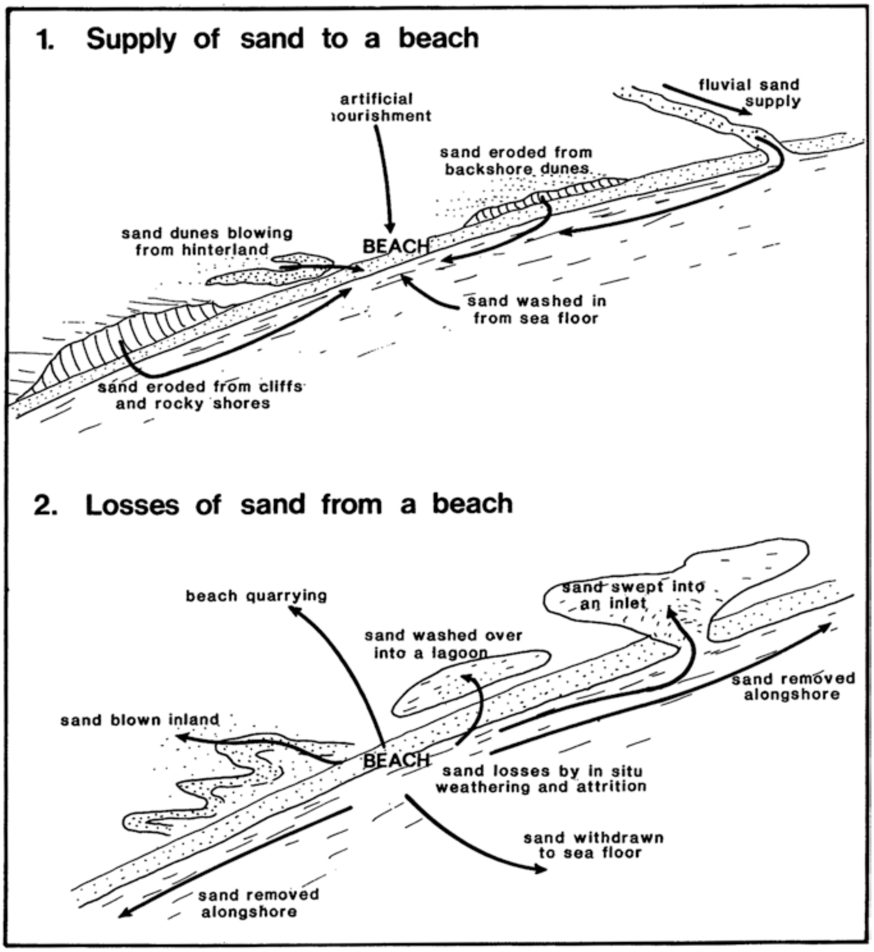

Fig. 2.1 The various ways in which sand can be supplied by and removed from a beach. © Geostudies

4. Reduction of sand supply from inland dunes
5. Submergence and increased wave attack
6. Increased wave energy because of increased storminess
7. Losses of beach sediment alongshore
8. A change in the angle of incidence of waves
9. Interception of longshore drift by breakwaters
10. Increased losses of beach sediment to the backshore
11. Beach weathering, including attrition of beach sediment
12. A rise in the beach water table
13. Removal of beach sediment by runoff

Fig. 2.2 Microcliff (erosional scarp) on Collaroy-Narrabeen Beach, NSW, Australia, cut by a number of late summer storms in 2013. © Nick Lewis

14. Increased scour by wave reflection from an artificial structure
15. Extraction of sand and shingle from the beach

Erosion on a particular beach is generally due to more than one of these causes, although one cause is often dominant.

2.1 Reduction in Sediment Supply from Eroding Cliffs

A common cause of beach erosion is the reduction of the supply of sand or gravel from erosion of nearby cliffs. Stabilisation of a cliff to halt erosion usually takes the form of building a solid wall or boulder rampart along the base of a cliff to prevent wave attack. Beach erosion also occurs when the sediment supply from an eroding cliff by runoff, seepage and slumping is reduced by inserting drains or introducing vegetation or a geotextile carpet.

As cliffs are stabilised their sediment yield to the shore diminishes, and may cease altogether. Beach erosion ensues as sediment lost offshore (mainly during storms) or alongshore (when waves arriving at an angle to the shore generate longshore drift) is no longer replenished from an eroding cliff. This happened on the

Fig. 2.3 Canford Cliff, Bournemouth, Dorset cut in Tertiary sandstones capped by Pleistocene gravel, as it was in 1950. Sand and gravel eroded from the cliff by runoff and marine erosion was then being delivered to adjacent beaches. See Fig. 2.4. © Geostudies

Fig. 2.4 Canford Cliff after the construction of a concrete esplanade along the base of the cliff. This halted marine erosion, but also reduced the supply of sand and gravel to adjacent beaches, which became depleted by marine erosion. © Geostudies

coast of Bournemouth in southern England after a concrete promenade built along the base of eroding cliffs cut in soft sandstone and gravel (Figs. 2.3, 2.4) cut off the supply of sand and gravel to the beach, which then gradually diminished. The promenade was built partly for the benefit of seaside holidaymakers, but it was also intended to halt cliff recession and preserve coastal properties. The coastal slope was artificially landscaped and planted with vegetation, but by the 1970s Bournemouth beach was severely depleted, and it was decided that it should be renourished (Sect. 4.2.7, p. 49).

2.2 Reduction of Fluvial Sediment Supply to the Coast

Beach erosion occurs where beaches that have been supplied with sediment carried down to the coast by rivers are depleted following a reduction in sediment yield to river mouths as a result of reduced runoff. In Southern California diminished river flow during droughts resulted in beach erosion, but the beaches were restored during intervening wet years when the fluvial sediment supply revived (Orme 1985). Reduction of fluvial sediment supply commonly results from the construction of dams to impound water upstream. These intercept fluvial sediment discharge and so cut off the supply of sand and gravel to beaches at and near the river mouth. This leads to the onset of erosion on beaches that were formerly maintained or prograded by the arrival of this fluvial sediment. Erosion develops more quickly, and becomes more severe, where there is strong longshore drift of sediment away from the river mouth.

The best known example of such erosion is on the shores of the Nile delta, where sandy beaches that had been prograding for many centuries as the result of the delivery of sediment to the mouths of Nile distributaries and its distribution by longshore drift became depleted after the construction of dams upstream. Erosion of beaches near the mouths of the Rosetta and Damietta distributaries started soon after barrage construction began in 1902, and became much more rapid and extensive after the completion of the Aswan High Dam in 1964, which impounded Lake Nasser and resulted in large-scale sediment entrapment. During the next few years beach erosion on parts of the deltaic coastline attained annual rates of up to 120 m (Sestini 1992). Some of the sediment removed from these beaches was carried away eastward by longshore drift along the coast towards Port Said, but much has been lost offshore (Lotfy and Frihy 1993).

Similar beach erosion has occurred on the shores of other deltas following dam construction upstream: for example on the Rhône delta in France, the Dnieper and Dniester deltas in the Ukraine, the Citarum delta in Indonesia and the Barron delta in Australia.

Diversion of a river mouth, either naturally or artificially, halts the fluvial sediment supply to the coast and leads to erosion of adjacent beaches, as on the shores of the Cimanuk delta in Java after a distributary changed its course during a flood in 1947, and on the Hwang Ho delta in China after the river mouth was diverted to another part of the coast during a flood in 1852.

Beach erosion near river mouths can follow the dredging of sand from river channels, which occurred on the River Rhine during the Second World War, or the reduction of fluvial sediment supply by soil conservation works in the hinterland, as exemplified by the rivers draining to the Gulf of Taranto in southern Italy. The same effect has been produced where long-continued soil erosion in river catchments has removed unconsolidated surface sediment, exposing extensive areas of bare rock, as in Turkey and Greece, where consequent reductions in fluvial sediment yield have resulted in beach erosion.

2.3 Reduction of Sediment Supply from the Sea Floor

On many coasts beaches were deposited and prograded when sand was swept in from the sea floor by wave action during and since the Late Quaternary (Pleistocene and Holocene) marine transgression. As sea level rose across the continental shelf waves collected sediment that had previously been deposited by rivers or wind action and sediment from weathered rock outcrops and carried it shoreward, and as the Late Quaternary marine transgression came to an end continuing shoreward drift from shoals prograded these beaches, often forming successive backing beach ridges and parallel dunes (Fig. 2.5a–d).

On many of these coasts shoreward drift has come to an end, with the reshaping of the sea floor profile to a transverse concave profile across which wave action no longer moves sediment on to the shore. If there is no compensating input of sediment from other sources (such as cliff erosion or supply from rivers) beach progradation stops, and with continued input of wave energy the transverse nearshore profile migrates landward, so that the beaches are eroded. This explains why many beaches that prograded earlier in Holocene times are now being cut back by erosion, continuing wave action driving the transverse concave landward (Fig. 2.5d). The onset of erosion comes at different times in different places because the development of the concave profile and the cessation of shoreward drift has occurred at various times on various beaches, and has not yet been attained on coasts where there is still shoreward drift from nearshore shoals.

The sequence portrayed in Fig. 2.6 is illustrated on the Ninety Mile Beach in south-eastern Australia, which borders a sandy coast that formerly prograded by accretion of sand supplied from the adjacent floor of Bass Strait, and is now being cut back by marine erosion, except in a sector of continuing accretion alongside breakwaters at Lakes Entrance (Fig. 2.6). There is still plenty of sand in the nearshore area, but the transverse profile has become smooth and concave, and there is no longer shoreward drift of sand to this beach, except at the SW end, sheltered by the granitic upland of Wilsons Promontory, where there are still nearshore sand shoals.

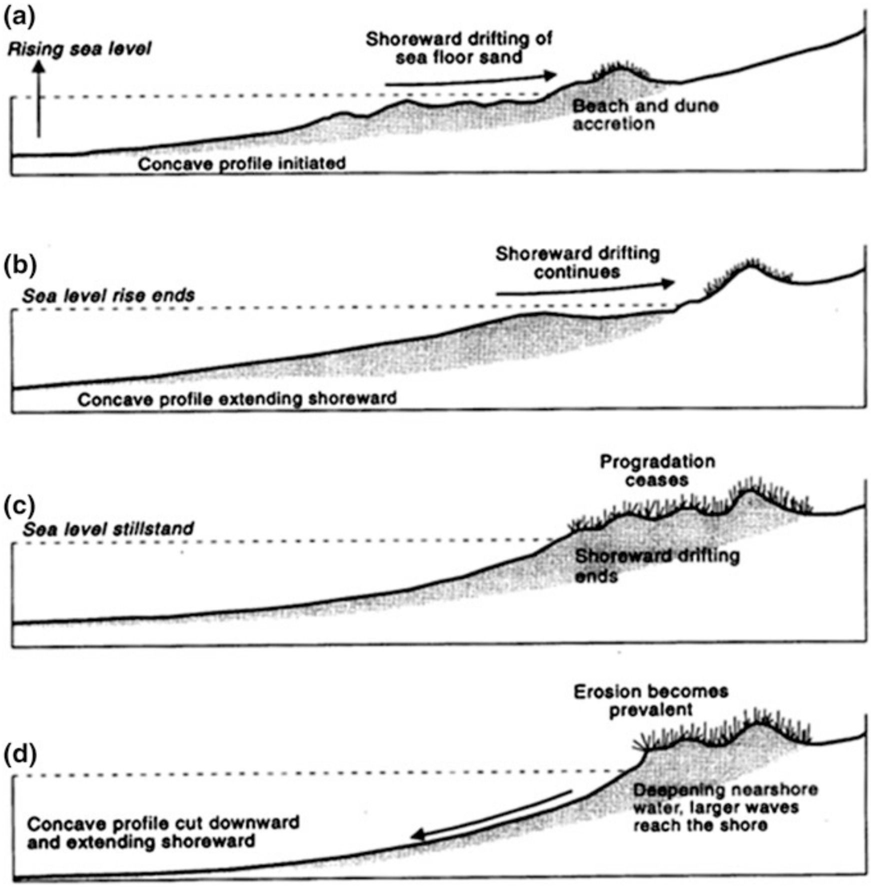

Fig. 2.5 On many coasts sand drifted shoreward from sea floor shoals during the Late Quaternary marine transgression (**a**), and for a time after this transgression ended (**b**), so that beaches prograded. With the attainment of a smooth concave sea floor profile progradation ceased (**c**), and the landward migration of this profile resulted in beach erosion and coastline retreat (**d**). © Geostudies

Sediment supply from the sea floor is also seen where shells, or other biogenic particles derived from sea floor organisms, become calcareous sand and gravel that drifts shoreward to be added to beaches. Several beaches on the west coast of Western Australia are still maintained in this way, supplied with calcareous sand and gravel from disintegrating nearshore reefs of dune calcarenite (which consists of sand, usually mainly calcareous, cemented by precipitated carbonates to form a coherent sandstone).

Such beaches prograde, or are maintained, as long as there is a supply of sea floor sediment, but beach erosion develops if the sediment supply is reduced

Fig. 2.6 Erosion (*arrowed*) of the Ninety Mile Beach, on the outer barrier of the Gippsland Lakes in SE Australia, with accretion (+) on either side of the Lakes Entrance breakwaters. © Geostudies

because of ecological changes such as the destruction of shell fauna by pollution, or because increased growth of seagrasses or other marine vegetation has impeded shoreward drift and trapped sediment offshore.

2.4 Reduction of Sand Supply from Inland Dunes

Some beaches have been supplied with sand blown from dunes spilling from the land on to the shore. If the sand supply runs out, or the backshore dunes become stabilised, either by the natural spread of vegetation, or from the planting of grasses or shrubs, the spraying of bitumen or rubber compounds, or sealing of the dune surface by built structures, these beaches may start to erode. On the south-facing Cape Coast of South Africa, where the prevailing westerly winds are driving dunes over headlands to supply beaches on the lee shore, dune stabilisation has resulted in beach erosion, as at Port Elizabeth.

Where beach erosion is due to the reduction of sand supply from inland dunes this could be the result of successful conservation measures, such as the

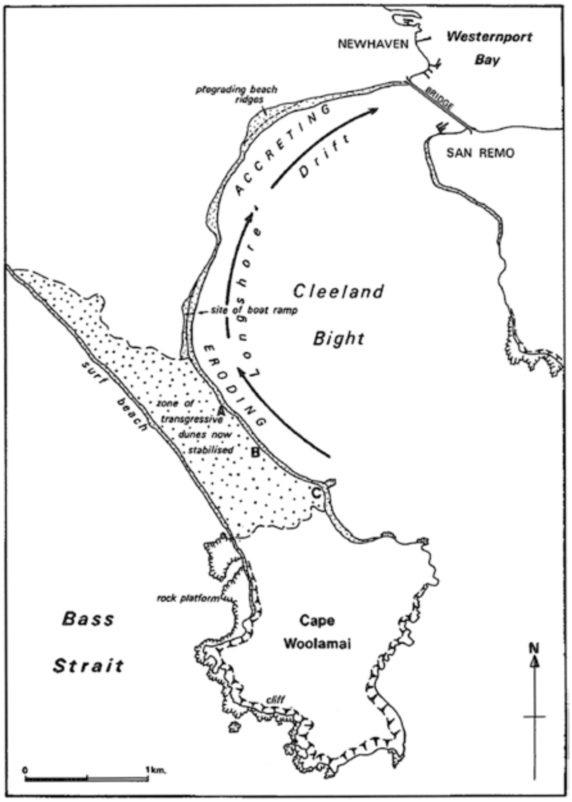

Fig. 2.7 Cleeland Bight on Phillip Island, Australia, showing the northward drift of sand towards Newhaven. When dunes were spilling on to the shore the beach was built upward and outward, but after the dunes were stabilised in the 1980s by planting marram grass this supply was reduced, and beach erosion ensued. © Geostudies

establishment of a vegetation cover on formerly drifting dunes, or the extinction of the dunes that had been drifting to the coast. On Phillip Island, Australia, partial stabilisation of dunes that had been spilling eastward across the Woolamai isthmus to renourish the beach in Cleeland Bight (Fig. 2.7) was followed by beach erosion (Fig. 2.8).

On Balneario Camboriu Beach in southern Brazil intensive urbanization of the coastal zone since the 1960s has resulted in the building of a sea wall, a road and several tall buildings. This process has reduced the amount of sediment exchange between the beach and dune and resulted in erosion during storms and a reduction in beach width (Temme et al. 1997). To minimise the loss of beach area 50,000 m^3 of sand was dredged from the sea floor and placed on an 800 m stretch of the beach in 2002 (Pezzuto et al. 2006). Periodic beach replenishment is required to widen the dry-beach and add height to the berm (Finkl and Walker 2004).

Fig. 2.8 Depleted beach and backshore erosion on the shore of Cleeland Bight, Phillip Island, following the stabilisation of dunes that previously supplied sand to this beach. © Geostudies

2.5 Submergence and Increased Wave Attack

Deepening of nearshore waters allows larger waves to reach the shore and erode the beach, withdrawing sand or gravel to the sea floor. Such deepening occurs briefly during storms, when strong onshore winds raise sea level along the coast and larger-than-usual waves break on the shore, eroding beaches. Longer-term deepening occurs as the result of coastal submergence, produced either by land subsidence, an actual rise of sea level, or some combination of land and sea movement that results in the sea standing higher relative to the land. Larger waves then reach the shore, causing erosion and the re-shaping of the nearshore profile: erosion of the upper beach and transference of sand or gravel from the beach to the adjacent sea floor causes the transverse shore profile to migrate upward and landward.

Beach erosion has become widespread on coasts where the sea has been rising because land subsidence is in progress, as on the Gulf and Atlantic coasts of the United States. Coastal land subsidence resulting from extraction of groundwater has resulted in beach erosion on the northern Adriatic coast of Italy, as at Ravenna, and beaches were cut back suddenly on sectors of the Alaskan coastline that subsided during the 1964 earthquake.

There is evidence from tide gauge records of a sea level rise of 1–2 mm/year during the past few decades, offset on some coasts by equal or greater land uplift, and varying also in relation to the geophysical factors that complicate the surface topography of the oceans. Coastal submergence has been widespread, and may provide at least a partial explanation for the modern prevalence of beach erosion (Bird 1996), although it is often cited as the primary cause of beach erosion (Douglas et al. 2000).

2.6 Increased Wave Energy

As has been noted, beach erosion occurs where wave energy increases (i.e. larger and higher waves approach the shore) because nearshore water is deepened by coastal submergence, due to a rise in sea level or subsidence of coastal land. Nearshore water can also be deepened where a shoal or reef is removed, either by natural erosion or by dredging, or where nearshore seagrass meadows disappear, so that sediment that had been retained is dispersed. On the coast at Benacre Ness, Suffolk, United Kingdom, a sector of beach that had been protected from wave attack by a nearshore shoal began to erode as the shoal moved away alongshore, while in Botany Bay, Australia, beach erosion accelerated at Brighton-le-Sands after the bay floor was dredged to provide sediment for the extension of a runway at Sydney International Airport. In the 1930s deepening of nearshore water following the disappearance of seagrasses (which had retained sediment in the sea floor shoals) led to beach erosion on the shores of Danish islands such as Kyholm (Christiansen et al. 1981). On the Arctic coast of Russia increased beach erosion has been attributed to larger waves arriving as the result of nearshore deepening due to downwarping of the adjacent sea floor.

Some beaches that had been stable or prograding began to erode as the result of an increase in the frequency and severity of storms in coastal waters. A series of storms in quick succession is particularly destructive because the second and subsequent events occur on beaches already reduced to a concave eroded profile. An example of this has been documented from Estonia, where the climate has become stormier during the past few decades, with sea level more frequently raised by storm surges, so that coastline erosion became more rapid and more extensive, notably on the west coast of Saaremaa Island (Orviku et al. 2003).

2.7 Losses of Beach Sediment Alongshore

Beaches are depleted when sand or gravel are carried away by longshore drift (due to the arrival of waves at an angle to the shore), unless these losses are compensated by the arrival of more sediment from updrift. Beach erosion will occur if the losses downdrift exceed the supply from updrift, for example where the source of sediment updrift is a cliff that has been stabilised, or a river where fluvial sediment yield has diminished. Some beaches develop lobes of sand or gravel that migrate along the coast in the predominant direction of longshore drift, and at any particular point there is accretion as each lobe arrives, and erosion as it moves on. At Somers, on the coast of Western Port Bay, Australia, a yacht clubhouse was built on one such lobe in the 1970s, and was threatened by beach erosion that developed as that lobe moved on (Fig. 2.9).

Portsea, on the southern shore of Port Phillip Bay, Australia, has had recurrent beach erosion because of eastward longshore drift (Fig. 2.10). Sand moving along the coast accumulates alongside headlands, and then is swept at intervals round them as a series of migrating lobes. As each lobe arrives at Portsea the beach widens, but as it moves on this beach diminishes. Segments of sea wall have been constructed successively on sectors where beach erosion was severe.

Attempts to blame the erosion of Portsea Beach in 2010 on the dredging of a deeper and straighter entrance to Port Phillip Bay in 2008 failed because of evidence that episodes of beach erosion occurred at several times prior to entrance deepening, and because wave refraction diagrams drawn for configurations before and after dredging showed no change in the pattern of waves or wave energy at Portsea (Cardno 2011). The beach was renourished, but the deposited sand quickly drifted away to the east, and the coast at Portsea was then armoured with sandbags to halt recession (Fig. 2.11).

Fig. 2.9 The yacht club at Somers, Western Port Bay, Australia, was built on a sand lobe (outline: *dotted line*) that had migrated to this position, and then moved on along the coast. A boulder rampart has been inserted to halt erosion here. © Geostudies

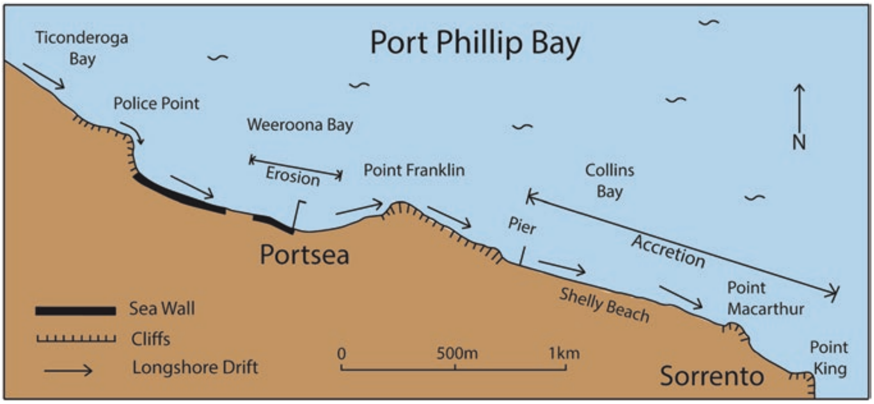

Fig. 2.10 At Portsea, on the north-facing coast of Port Phillip Bay, the predominant direction of longshore drift is from west to east. Lobes of sand form on the shore of Triconderoga Bay, to the w, and drift intermittently round police point into Weeroona Bay. As each sand lobe arrives, the beach widens in Weeroona Bay, but when it moves on the beach is depleated. Successive episodes of beach erosion have resulted in the building of sea walls along the shore. In 2010 there was severe beach erosion at Portsea Pier, with sand drifting away round point Franklin and along the coast to Shelly Beach and Point Macarthur, where there has been beach accretion. A sandbag rampart has been built on the eroded sector (Fig. 2.11), but the beach has not yet revived. © Geostudies

Fig. 2.11 A sandbag rampart marks the site of beach erosion at Portsea, Port Phillip Bay, Australia, in 2013. © Geostudies

2.8 A Change in the Angle of Incidence of Waves

Beaches tend to become adjusted to the prevailing wave regime, and then to respond to short-term changes in the direction of incident waves and the angle at which they arrive at the coast. A persistent change in the angle of incidence of waves can result in alteration or intensification of longshore drift, leading to beach erosion. Such a change followed the construction of the Portland Harbour breakwater in Victoria, Australia in 1957, when the onset of beach erosion on the adjacent coast at Dutton Way resulted from intensified longshore drift in response to the change in wave approach. Beach erosion then spread eastward along the coast of Portland Bay.

Oblique waves generated by passing ships (boat swash) can modify the incident wave regime. This has led to erosion on Point King Beach at Sorrento on Port Phillip Bay, Australia, where the beach was re-shaped as intensified longshore drift depleted the eastern end and led to accretion at the western end (Bird 2011).

Refraction of waves over the ebb shoal at the entrance to John's Pass, West coast of Florida causes a local reversal in longshore sediment transport contributing to severe erosion on Sunshine Beach (Wang et al. 2011).

Wave attack on a beach sector may intensify as a result of the lowering of the beach profile on the neighbouring sector, allowing stronger waves to arrive obliquely, and thus accelerate longshore drift. A beach profile may be lowered as the result of sea wall construction and scour by reflected storm waves on one sector, so that larger oblique waves can then move through the deepened water to

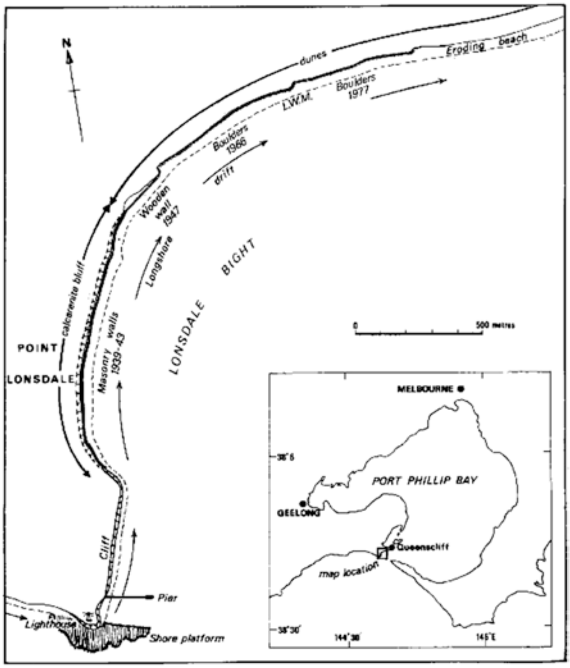

Fig. 2.12 In response to coastal erosion a sea wall was built at Point Lonsdale in 1900. This resulted in beach depletion by reflected waves (cf Fig. 2.15), and also the lowering of the beach to the north, followed by accelerated erosion there. The sea wall was extended northward in the 1930s, with a similar result, and further set-back extensions were made in 1947, 1966 and 1977. © Geostudies

attack the neighbouring sector, causing beach erosion there. If the sea wall is then extended along the coast to counter this beach erosion, a 'domino sequence' may ensue, with beach erosion beyond each limit of the extended sea wall. This happened at Point Lonsdale in Victoria, Australia, where each new sector of sea wall has been built on a set-back alignment on the eroded shore (Fig. 2.12).

2.9 Interception of Longshore Drift by Breakwaters

Breakwaters have been built to stabilise river mouths or lagoon entrances in order to improve their navigation, or create boat harbours. Where beach sediment is drifting alongshore there is interception on the updrift side of the breakwaters, and beach erosion on the downdrift side as the sediment supply is cut off. The downdrift erosion caused by breakwaters may spread for several tens of kilometres (Bruun 1995) and can prove irreversible (El-Asmar and White 2002). On the east coast of Florida breakwaters have been built to stabilise several tidal entrances through sand barriers, and in each case southward longshore drift has been intercepted to prograde the beach on the northern side, and beach erosion has ensued on the southern side, deprived of a longshore sand supply. The erosion at Upham on the west coast of Florida is caused by a significant deficit in the southward longshore sediment transport, due to the structures at the Blind Pass inlet (Elko and Davis 2006, Elko et al. 2005). Practically, no sand bypasses Blind Pass to reach Upham Beach (Roberts and Wang 2012). Finkl and Esteves (1998) estimated that structures blocking littoral drift accounted for 72 % of Florida's beach erosion.

The seaport at Chennai (formerly Madras) on the south east coast of India underwent massive expansion programmes in the last two decades, which resulted in substantial changes in the geomorphology of the down-drift side of the port (Ramana Murthy et al. 2008). Nearly 400 ha of beach was lost as a result of erosion, which resulted in the construction of a seawall.

Until about a century ago there was a shingle beach, maintained by eastward drift, beneath the Chalk cliffs between Dover and Deal in the United Kingdom but this has almost disappeared as the result of the interception of shingle drifting alongshore by the breakwaters at Dover Harbour, west of which the beach has prograded. In Lyme Bay on the south coast of England the dominant eastward longshore drift of shingle has been intercepted by landslide lobes and rock falls, each of which act as breakwaters, causing beach erosion downdrift.

2.10 Increased Losses of Beach Sediment to the Backshore

Sand is swept from the beach to the backshore by strong onshore winds (Fig. 2.13), or when storms wash beach sediment beyond the back of the beach, or over into lagoons, swales or swamps, or the mouths of rivers. If losses from the

Fig. 2.13 Sand is moving inland from a beach as drifting (transgressive) dunes on the shore of Encounter Bay, South Australia. The lowered backshore is then cut back quickly because of the diminished volume of sand to be removed by wave attack. © Geostudies

beach are not compensated by the arrival of fresh supplies of beach sediment from offshore, alongshore or hinterland sources the beach profile is lowered and the coastline recedes. Overwash during successive storm surges has eroded beaches on sandy barrier islands on the Atlantic coast of the United States. At Rockaway and Long Beach on the New York coast overwash during Hurricane Sandy in 2012 swept large amounts of beach sediment shoreward into residential areas.

2.11 Beach Weathering, Including Attrition of Beach Sediment

Beaches no longer receiving a sediment supply lose volume as the result of weathering, which reduces the size of beach particles and hence the volume of the beach, beach profile and so allowing larger waves to attack the shore and further erode the beach. Chemical weathering includes the decay and removal of ferromagnesian minerals from sediments of volcanic origin and the dissolving of carbonate beach sand grains or limestone gravels in rainwater, stream seepage or sea spray. Physical weathering occurs as the result of agitation of the beach by wave action and consequent gradual attrition of sediment particles.

Four Mile Beach, in North Queensland, Australia, has been eroded because its fluvial sand supply from the adjacent Mowbray River was cut off by coral reef growth. Without natural sand replenishment the beach has been reduced to very fine sand by attrition, and has become low and flat: it is now firm enough to land an aircraft, drive a bus or car, or ride a bicycle. As sediment calibre is reduced the lowered beach has been further eroded as the increasingly fine sediment is removed by winnowing, either landward into backshore dunes or seaward to bars and sea floor deposits.

2.12 A Rise in the Beach Water Table

A wet sandy beach is eroded more rapidly by wave action than a dry one because wet sand is more coherent, and erodes like a soft sandstone, whereas dry sand is disturbed but not removed by wave swash. Field studies conducted by Grant (1984) demonstrated the considerable impact of beach groundwater level on swash sediment transport. Seawater infiltration under a low water table was found to enhance onshore sediment transport, whereas groundwater exfiltration under high water table promoted offshore sediment transport. On Stanwell Park Beach, near Sydney, Australia, beach erosion increased with rises in the level of the beach water table during wet weather, due to the ponding or diversion of river or lagoon outlets, or to increased river or groundwater discharge following land use changes in the hinterland (Bryant 1985). This process has led to the practice of beach dewatering (artificially lowering the beach water table) for combating beach erosion, typically utilising drainage systems (Turner and Leatherman 1997, Loannidis and Karambas 2007).

2.13 Removal of Beach Sediment by Runoff

During periods of heavy rainfall beach erosion can result from runoff, particularly where water flows down a backing cliff or steep slope and beach sediment is swept into the sea. Examples of this are seen during the wet summer season in NW Australia, notably near Cape Leveque, where runoff cuts gullies across the beach and builds fans of sediment into the sea. Beach sediment removal by runoff after rainfall occurs at the mouth of a storm water outfall sited within a beach. On Collaroy-Narrabeen Beach, north of Sydney, Australia (Fig. 2.14) beach sediment has been washed away at a number of storm water outfalls. At Mission Bay and Kohimarama on the east coast of Auckland, New Zealand, sand was sluiced from beaches by storm water from outlets until these were extended seaward, beyond the foot of the beach (Papps and Priestley 2005).

The effects of runoff are stronger on sandy beaches, especially if they are already wet, than on gravel where runoff disappears more quickly by percolation. Increased runoff is often due to urbanisation and the construction of roads and other sealed surfaces from which water runs off quickly, instead of percolating into the subsoil, as it did before these structures were built.

Fig. 2.14 A channel cut through the beach and dune on Collaroy-Narrabeen beach, Sydney, Australia caused by storm water discharging from a drainage outfall. © Nick Lewis

2.14 Increased Scour by Wave Reflection from an Artificial Structure

Waves breaking against a solid shore structure, such as a sea wall built of concrete, stone blocks, boulder ramparts, steel sheeting or timber, are reflected, and generate seaward currents that carry sediment away from the foot of the wall (Fig. 2.15). This reflection scour is prevented as long as a beach is high and wide enough to stop waves reaching and reflecting from the solid structure, but beach erosion occurs rapidly once waves reach the backing wall (Fig. 2.16).

2.15 Extraction of Sand and Shingle from the Beach

Sand or gravel has been quarried from many beaches for use in road and building construction (Fig. 2.17), and the result of lowering the shore profile is to allow larger waves to attack the beach more strongly during storms. Beaches in Jersey and Guernsey were much reduced by the extraction of sand from beaches by the German occupying forces during the Second World War for use to build bunkers

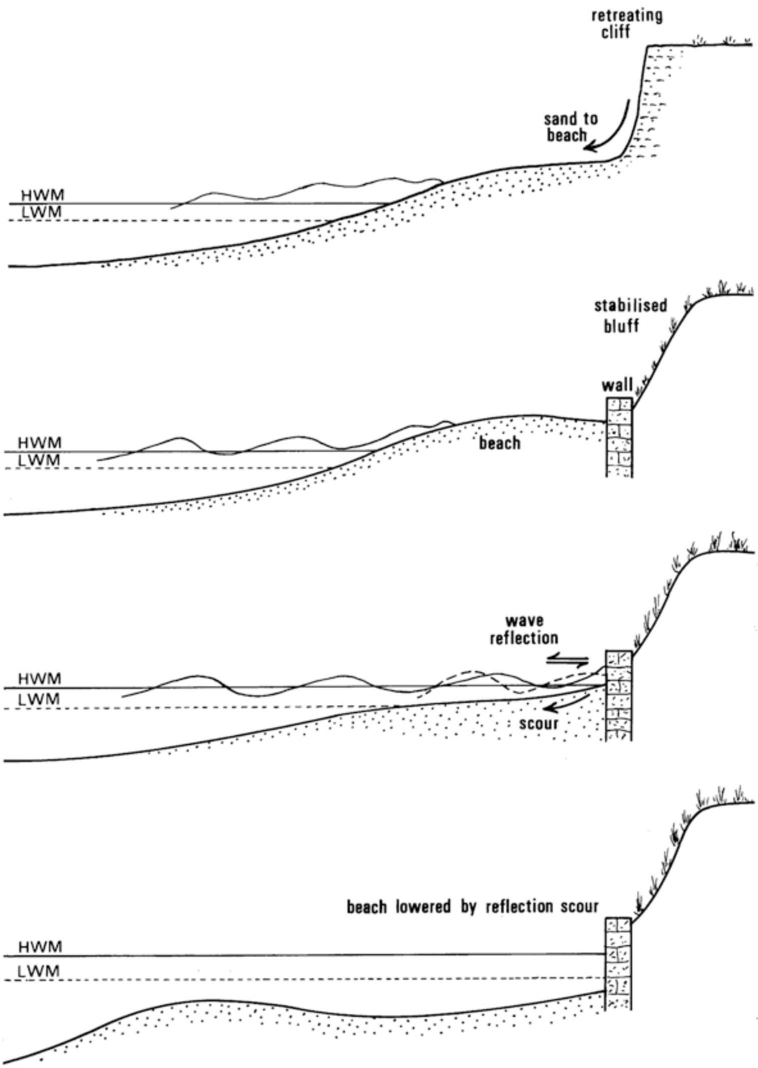

Fig. 2.15 Sequence where a beach fed with sediment from a receding cliff which is stabilised by building a basal sea wall. Waves reflected from the sea wall then withdraw sediment from the beach, which is lowered by reflection scour. © Geostudies

and gun emplacements, and massive sea walls were then constructed. These resulted in reflection scour, eroding the remaining beach, which is now completely submerged at high tide in St Ouen's Bay, Jersey (Fig. 2.18).

Calcareous beaches on the coast of Cornwall have been depleted by the extraction of shell sand and gravel for agricultural use as lime on farmland. Such extraction has traditionally been on a small scale (50–100 t/year) from several beaches, notably at Bude, where Summerleaze Beach has been depleted. Again,

Fig. 2.16 Beach at Surfers Paradise, Queensland, lowered by large waves reflected from a boulder wall during a tropical cyclone. © Geostudies

Fig. 2.17 Extraction of *sand* and *gravel* from the beach at Klim in Denmark. © Geostudies

Fig. 2.18 The sea wall at St Ouen's Bay, Jersey, with the beach lowered by reflection scour. © Geostudies

the artificial lowering of the shore profile has led to larger waves breaking on the shore, and increased beach erosion.

Erosion has developed on intensively used beaches at seaside resorts, which gradually lose sand as it is removed by visitors, adhering to their skin, clothes or towels, or trapped in their shoes. The losses are small, but cumulative, and no one brings sand to the beach. Pebbles and shells are also collected and carried away as souvenirs by beach visitors.

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