DUNGENESS

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Introduction

Dungeness is the largest cuspate foreland in Britain, and globally very unusual because it is formed predominantly of flint shingle. Beaches ridges date from about 5500 years BP and the best-preserved sequence can be traced from the 8th century AD. In addition to exposed shingle covering about 2158 ha, there are also buried shingle banks, which underlie a further 1150 ha. Other large shingle structures such as Chesil Beach, Spey Bay and Orfordness are comparable in terms of the length of coastline that they occupy, but they do not contain the enormous volume of shingle stored in the shingle ridges at Dungeness. The feature is often regarded as an integral part of a system of former barrier beaches that extend about 40 km from Fairlight in the west to Hythe in the east. Other well-known cuspate forelands, such as the Darss peninsula on the German Baltic coast, Cape Kennedy in Florida, Cabo Santa Maria on the Portuguese Algarve coast and Cabo Rojo on the Mexican coast, rival and exceed Dungeness for size, but Dungeness is unique globally because it has a number of features that are absent or less well developed elsewhere.

Dungeness is formed almost entirely of flint shingle and is a relatively advanced form of cuspate foreland, much of the shingle having been re-distributed from barrier beaches to form a ness with a particularly acute angle between its two main shorelines. It has long been recognized internationally as a major example of its type. For instance, as early as 1913, de Martonne described it as ‘le type le plus connu: la pointe de Dungeness'. Standard texts from all parts of the world refer to Dungeness as the best-known example of a cuspate foreland (e.g. Holmes, 1944, 1965; Zenkovich, 1967; Bird, 1968, 1984; Paskoff, 1985).

No area inland of beaches to have been occupied and land-claimed over so long a period of time (about 1200 years) has been documented so intensively as Dungeness, and the documentary record extends over a far longer period than for any comparable site.

Finally, in contrast to many similar features, it lacks an offshore shoal that might extend its form seawards.

The Soil Survey of England and Wales (Green, 1968) has shown that shingle ridges often extend many hundreds of metres beyond the area of exposed shingle, the Beach Bank soil series representing the distal parts of successive beach ridges. Parts of the Lydd soil series also lie above shingle, while the Lydd series itself and parts of the Greatstone series are dominated by sand and loamy sand, which may be derived from sandy beaches associated with the shingle beaches in much the same way as sandy beaches are found today on the eastern shoreline of Dungeness. Recent archaeological and geomorphological studies have built on the work of the Soil Survey.

Large areas have been damaged by gravel extraction, vehicle tracks, military training areas and the construction of the Dungeness group of nuclear power stations. Detailed assessments of the damage have been made by Fuller (1985) and Green and McGregor (1986), both reports being drawn upon extensively in the assessment of this GCR site.

Description

The present-day shoreline at Dungeness is formed by a southern beach that faces SSW and is gradually moving north and inland over older relict beach ridges, the acute bend of the ness itself, which is migrating SSE, and an eastern beach, which has gradually migrated eastwards as the ness has grown. Much of this eastern beach is fronted by a wide intertidal sand beach. Landward of the present-day beach, there is a sequence of buried and exposed shingle ridges, which become both younger and more curved towards the east. Waller (1993, 1994) suggests that peat dating from 1100 to 2000 years BP helps date the development of both Romney

Marsh and Dungeness. The oldest beaches, buried at Broomhill and Sandylands, have been tentatively dated between 5500 and 4000 years BP (Eddison, 1983a). Between Jury's Gap (TQ 993 180) and Dungeness itself, about 500 individual ridges form four main groups, Jury's Gap beach, the Forelands, Holmstone and West Ripe–Wickmaryholm (Figure 6.48) with a change in ridge alignment of about 10° towards the north-west between each group. Eastwards of Galloway's Lookout (TR 045 172), the ridges become more curved and preserve earlier ness forms. At their seaward (southern) edge, the ridges are truncated by a single continuous ridge that forms the present-day shoreline. Inland, many of these curved ridges are buried, but represented by the Beach Bank soil series, which is described as associated with 'old inland pebble banks and beaches' (Green, 1968). The mapped distribution of these old beaches portrays them as having relatively straight seaward boundaries (Figure 6.49), whereas their landward edges are marked by lateral features at angles of between 30° and 40° to the main ridges, probably representing recurves in the distal part of the beaches. Only in the area around Open Pits (TR 073 180 and TR 074 185) are distal recurves completely preserved in the bare shingle. To the north of the Open Pits and the present-day ness, the shingle is found in over 100 sub-parallel south–north-trending ridges that extend northwards to very short, buried, distal forms. Although parts of this area have been disturbed by gravel extraction, the undisturbed parts remain the finest example of a gravel strandplain on the coastline of Britain, and have few rivals elsewhere in Europe.

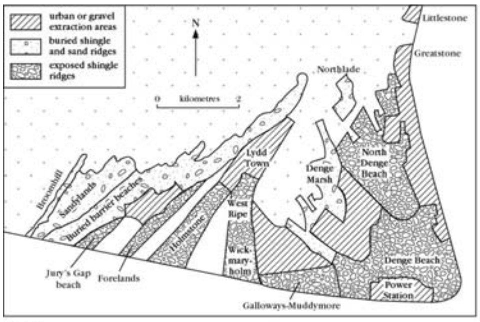

Fig 05.40

Figure 6.48: Major zones of shingle at Dungeness. a

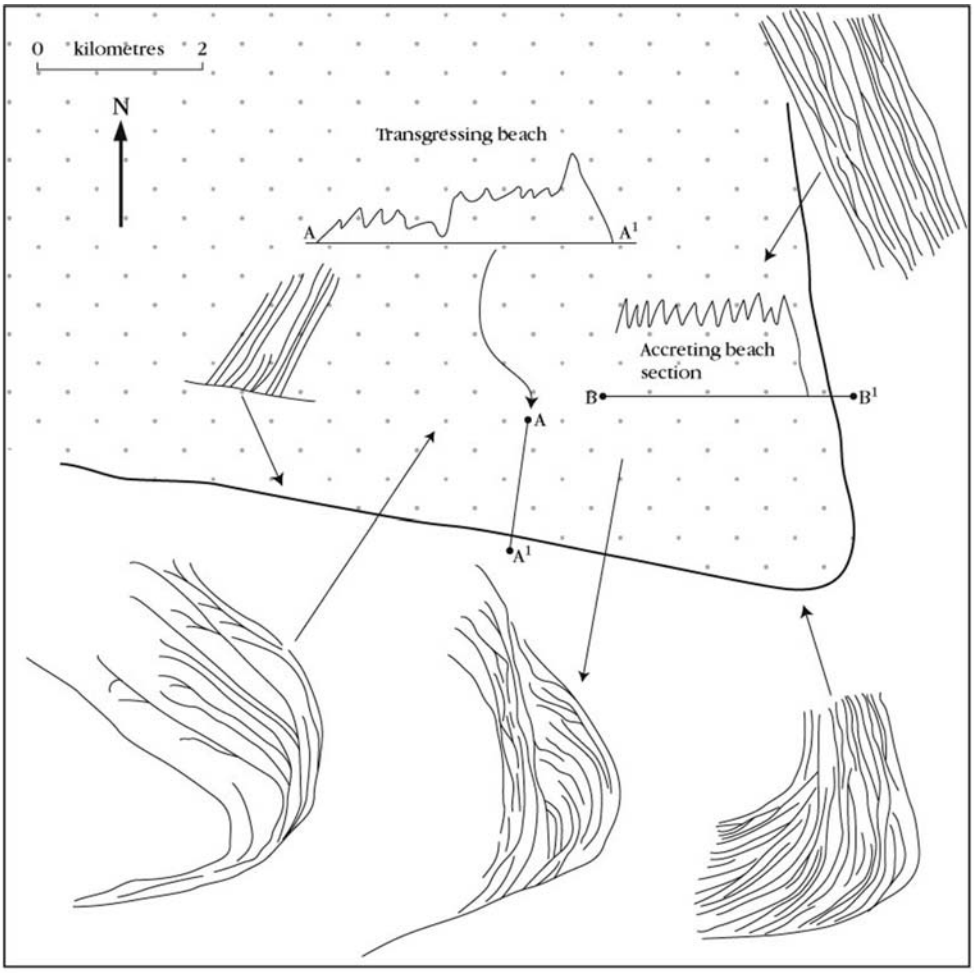

Fig 05.43

Figure 6.49: Schematic representation of the characteristic shingle ridge patterns and profiles at Dungeness. The vertical variation in ridge altitude is typically about 3m.

The shingle is almost entirely (over 98%) rounded flint shingle (Steers, 1946a), with pebbles of cherty sandstones derived from the Upper Greensand, fine-grained sandstones from the Hastings Beds, and red, grey and liver-coloured quartzites, including examples of the Triassic Budleigh Salterton Pebble Beds. Some of the latter may have been brought here as ballast. The Soil Survey (Green, 1968) recorded, unusually, subangular gravels as well as rounded pebbles at Northlade where a large distal complex is buried north of Lydd Airport. The material forming the ridges (known locally as 'fulls') is often smaller in size (down to 8 mm) than in the troughs between them ('lows' or 'swales' (Lewis and Balchin, 1940). Green and McGregor (1986) noted concentrations of coarser material (up to 150 mm maximum diameter). There is no published explanation of this phenomenon.

Lewis and Balchin (1940) showed that there are considerable differences in the heights of the ridges, which vary between 3.7 m and 6.3 m OD, and that there are differences between groups of ridges (Figure 6.49). In contrast the buried ridges are at much lower altitudes, for example, ridges west of Hythe reach between +0.6 m and –1.0 m OD, at St Mary's Bay +1.0 m OD and at Broomhill +1.5 m OD.

Individual ridges are normally defined by a ridge–swale relief of between 0.5 m and 2.0 m. A ridge frequency of 60 to 100 per mile (32–62 per km) is characteristic (Lewis and Balchin, 1940; Eddison, 1983a). Typical ridge widths are estimated at between 16 m and 28 m (Green and McGregor, 1986). Relief frequently deepens towards the edge of individual ridge systems, particularly towards the distal ends of ridges, which feather out into alluvial areas and where ridge-swale relief may reach 3 m (Green and McGregor, 1986). In some parts of the area, individual ridges are rarely continuous over long distances (Lewis and Balchin, 1940). Parasitic ridges are common, inter-ridge recurves also occur in many sectors, and natural pits have often formed where shingle-branching or recurve patterns give rise to enclosed hollows. Irregular, anastomosing ridge patterns also occur (Green and McGregor, 1986). These features increase in frequency towards the distal end of individual ridge systems. Natural pits whose formation is encouraged by the deepening of relief often observed in such situations contain an infilling of fine-grained alluvium varying in thickness from 0.5 m in the smaller pits to 3.5 m in the larger ones. The basal alluvium (0.3 m) contains evidence of marine conditions, but there is a transition upwards into freshwater deposits (Waters, 1985). Green and McGregor (1986) examined the ridges in more detail in a sample area of 0.3 km, concluding that ridge length may be bimodal. Long continuous ridges are separated by one or more subsidiary ridges of not more than a few hundred metres in length. Ridge–swale relief varied between 0.5 m and 1.75 m, but ridge crest elevation, even on the longer ridges, rarely varied by more than 0.5 m.

The most detailed accounts of the sedimentology of the Dungeness shingle are by Hey (1967) and Greensmith and Gutmanis (1990). Borehole data, the lack of mention of sub-shingle conditions in the literature and the trenched exposures observed by Hey all indicate that the shingle in the vicinity of the power station commonly varies in thickness between 3 m and 7 m, has a locally irregular base, and generally overlies sand. The sub-shingle surface was almost a plane surface with some irregularities caused by shallow channels and it fell by about 2 m from north to south in the excavations (Hey, 1967). The shingle was in beds from 7.5 cm to 75 cm in thickness, with beds sharply defined by changes of average particle size. Average bed thickness was about 15 cm and the beds dipped uniformly to the south-east at an average angle of 8° to 10°. The strike of the bedding planes was exactly parallel to the alignment of the shingle ridges in the immediate vicinity. Average particle diameters for individual beds varied between 8 mm and 40 mm (Hey, 1967). Much of the shingle includes impermeable beds of sand which give rise to a locally important freshwater aquifer.

The Soil Survey of England and Wales (Green, 1968) has shown that shingle ridges often extend many hundreds of metres beyond the exposed shingle, the Beach Bank soil series representing the distal parts of successive beach ridges. Parts of the Lydd soil series also lie above shingle, while the Lydd series itself and parts of the Greatstone series are dominated by sand and loamy sand, which may be derived from sandy beaches associated with the shingle beaches in much the same way as sandy beaches are found today on the eastern shoreline of Dungeness. The ridges often display outlines that indicate clearly patterns of primary depositional morphology (Green and McGregor, 1986). There is a broader tract of buried shingle on the western side of the GCR area, where both aerial photographs and Green's (1968) soil mapping indicate patterns of primary depositional morphology, similar to the exposed shingle. To the north-east of Broomhill, the shingle is replaced by the Midley Sand, but an outlying buried ridge close to the western boundary of the GCR area forms the most westerly identifiable element of the Dungeness shingle system. The buried shingle at Scotney Court and north of Lydd varies in thickness from 2 m to over 5 m increasing in thickness northwards. The shingle increases in thickness towards the south and attains depths in excess of 15 m in the area of the power station. Some boreholes (Green, 1968) reported 'sand with gravel', which continued for another 12 m. A series of mounds in Green's Newer Marsh between Lydd and New Romney have been identified by Vollans (1995) as accumulated remains of the spent sediments cleaned out from filter pits or troughs used in 11th century salt-making. At Belgar, one such ridge extends for almost 2 km in front of the distal end of the Lydd spit.

Dating of the shingle relies on cartographic sources and organic deposits; very few dates have been measured for the areas outside the exposed shingle. Tooley and Switsur (1988) date a marsh infilling of a shingle low at 3410±60 years BP. Peat overlying gravel at Broomhill has been dated at about 3600 years BP and in Scotney Marsh at around about 4000 years BP. Within the shingle-bank complex near Scotney Court (TR 023 202), Callow *et al*. (1966) dated in-situ woody roots lying above shingle at 2740 ± 400 years BP: this occurred beneath silty clay loam overlain by peat. This places the Early Barrier Beach at a date earlier than between 3100 and 2300 years BP.

The development of the foreland has been described (Lewis and Balchin, 1940; Eddison, 1983a,b) by using the trend patterns of the shingle ridges, assuming that each ridge is a former storm beach and so represents a former position of the shoreline. The rate of progradation of Dungeness has been estimated at between 4.1 m a^{-1} and 5.5 m a^{-1}, both

Redman (1852) and Hey (1967) estimating the higher value for the period from the early 17th century to the early 19th century. The lower value was estimated for the period 1878 to 1938 by Swallow (Lewis and Balchin, 1940). The morphological patterns of the shingle indicate different modes of deposition associated with different positions in the coastal system at the time of deposition and/or variations in the rate or direction of progradation (Eddison, 1983a,b). Within the area known as 'Denge Beach' (Figure 6.48), the full sequence of ness forms, from their early development to the present-day, is preserved. Few areas anywhere preserve such a complete sequence of beach ridges known to have been formed over at least 2000 years. Many of the ridges can be traced almost without break from this area northwards to their distal ends around Lydd Airport. North of the Dungeness power station, Hey (1967) reported thicknesses of about 10 m, whereas the Soil Survey noted that as much as 17 m depth of shingle had been found in the vicinity of the power station. The clean shingle forms only the upper 1–1.5 m (Hey, 1967), being composed beneath this depth of 'closely-packed pebbles with interstices filled with sand'. Sandy deposits beneath the shingle contained a few scattered pebbles and some marine shells. The sandy gravel is described by Hey as being in beds of between 0.1 m and 1 m in thickness. Each bed was composed of similar mixed material, but each bedding-plane was marked by a distinct change in pebble diameter. The bedding planes had a constant dip of 8° –10° towards SSE, the strike being almost the same as the alignment of the surface ridges. Greensmith and Gutmanis (1990) show, following analysis of 80 boreholes in the vicinity of the power stations, that the 40 m-thick marine Holocene succession can be divided into basal gravels, middle sands and upper gravels that rest directly on a pre-Holocene erosion surface cut across the Lower Cretaceous Hastings Beds between –32 and –35 m OD.

Dix *et al*. (1998) show that high resolution seismic (Chirp) surveys in Rye Bay indicate a dominant seaward-prograding shelf sand body (SSB) with only minor amounts of gravel. The presence of buried gravel beaches at Broomhill dating from the mid-Holocene (Tooley and Switsur, 1988; Long and Innes, 1995b) and studies of drowned Holocene barriers elsewhere (e.g. Forbes and Boyd, 1987; Oldale, 1985; Browne, 1994; Forbes *et al*., 1995) pointed to the possible preservation of early Holocene barrier structures in Rye Bay. The bedrock surface undulates between –25 m and –35 m OD (Lake and Shepherd-Thorn, 1987; Greensmith and Gutmanis, 1990; Long *et al*., 1996). NW–SE-trending channels with maximum depths of *c*. –45 m OD may be offshore extensions of the former valleys of the Rother, Tillingham, Brede and Pannel (Dix *et al*., 1998).

At Dungeness point, Greensmith and Gutmanis (1990) and Basa *et al*. (1997) describe a basal gravel (0.5 to 1.0 m thick) overlain by very fine- to fine-grained, moderately well-sorted sands (20–30 m). Their upper surface is channelled. These 'Middle Sands' are capped by gravel up to 5 m in thickness. At the Open Pits (TR 073 180 and TR 074 185), the ridges are very short and are truncated by a single south–north ridge suggesting that spit extension was more important here than the formation of individual storm beach ridges. There is no other part of the Dungeness beach-complex where distal features occur other than at the landward end of the very long linear ridges (Fuller, 1985; Green and McGregor, 1986).

The area of North Denge Beach broadly occupies the area between the former Southern Railway line from Lydd to New Romney, Lydd Airport and the residential buildings along the coast. It is a fine example of a shingle beach-plain, comprising over 100 sub-parallel shingle ridges, which run northwards to end in very short buried distal features. Some parts of this landform have been excavated for gravel, but a complete set of the ridges straddles the track from the Water Tower (TR 068 202) to Lade (TR 083 208), with only the most recent ridges being obscured by housing and the coastal road. Most of the ridges post-date the mid-8th century shoreline postulated by Lewis and Balchin (1940), the distal features south of Greatstone having marked historically the south side of the gradually silted and reclaimed area known as 'Romney Sands'.

Interpretation

The general interpretative context for this site is described above in the previous section (p. 310 ff).

There are three major issues to be addressed at Dungeness: the description and interpretation of the pattern of shingle ridges, the age of the features and their relationship to the development of the beaches, and the relationship between marsh sediments and the shingle structures.

A summary of the phases of development of Dungeness is presented in Table 6.4.

The earliest discussion of the formation of Dungeness (Elliott, 1847; Gulliver, 1897; and Lewis, 1932, 1937) regarded the ness as having evolved from barrier beaches crossing Rye Bay. These beaches were regarded as having aligned towards the dominant south-west waves and grown by redistribution of sediment from proximal and seaward areas to the recent locations straddling the mouth of the River Rother. Lewis's (1931) conceptual model has provided the basis for the early evolution of the beaches. However, Dix *et al*. (1998) argued that there is little evidence offshore to support Lewis' view.

The western shingle structures described above appear to represent the barrier spit extending towards Lydd and Hythe. The change in growth direction of the ness towards the south-east has not been explained adequately, and some of the western exposed shingle (for example, Jury's Beach, The Forelands and Holmstone) probably represents recurved sections of the early ness form. Green and McGregor (1986) show that these shingle areas are separated by alluvium, which often attains depths of more than 2 m within 10 m of the shingle margin. They consider that these areas of alluvium imply rapid eastwards growth of the ness, which would not have allowed sufficient time for closely spaced recurves to develop. The former southern shore of the ness is first identifiable where it is intersected by the modern southern shoreline about 1 km east of the Galloways Lookout. Northern parts of the sharply curved shingle ridges represent proximal areas of recurves, with, in several places, deep natural pits separating the curved ridges at the point of greatest inflection. This probably indicates shorter periods of rapid eastward growth of the ness (Green and McGregor, 1986), but it may also reflect reduced supplies of shingle from the west and reduced wave energy inputs to the southern shore. Most of the northern extremities of the recurves forming Denge Beach appear to have ended in deep water. The distal parts of the recurves gradually changed alignment towards the north from an early orientation of about 310° to 320° to a modern beach alignment of about 340° to 350° (Figure 6.50). The Holocene sediments in the vicinity of the power stations are consistent with a prograding, upwards-coarsening, barred shoreline, laid down under mixed wave-tidal conditions and predominantly rising sea levels (Greensmith and Gutmanis, 1990). The basal gravels and middle sands were deposited over a period at least 1900 years, a process that began at least 3270 years BP. Radiocarbon dates (1370–3270 years BP) from levels between –32 and –34 m OD are regarded as anomalously young and interpreted as arising from intertidal and high subtidal shells being swept, probably during prolonged stormy period, into depths greater than 20 m.

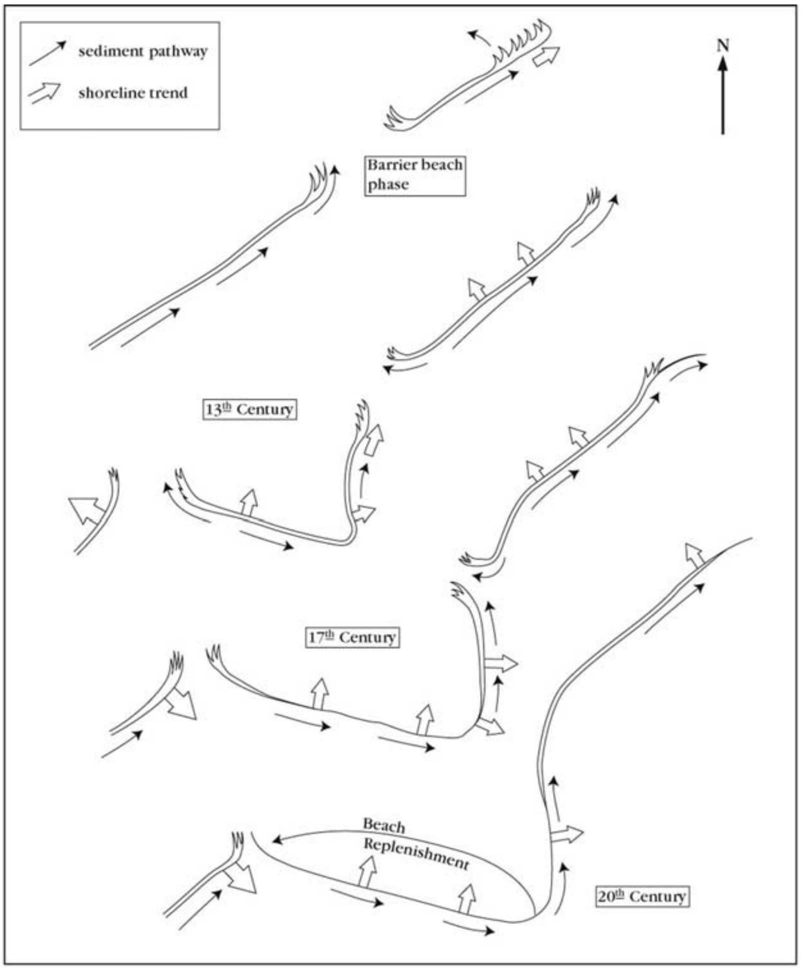

Fig 05.42

Figure 6.50: Historical sediment pathways and development at Dungeness. Each schematic map shows the probable sediment movements associated with the erosional and accretional trends in the shoreline.

The processes of longshore transport at Dungeness have been modified, first by a system of beach replenishment and second by coastal prorection structures defending the power station site. The replenishment programme, where shingle near the ness is returned to the western end of the beach near Brommhill, has been operating since the 1950s (Thorn, 1960) and is one of the longest running schemes anywhere. Figure 6.50 offers an interpretation of the probable sediment pathways both now and at earlier stages of beach development. They warrant further investigation to evaluate the effects of wave climate, storm events, different sea levels, and changes in sediment supply.

The preservation of so many beach ridges has tempted a number of writers (Gilbert, 1930; Lewis, 1932; Lewis and Balchin, 1940) to invoke changes in sea level as the cause of their varying height. Surveys of ridge altitudes by Plater and Long (1995) largely confirm the variations in altitude reported by Lewis and Balchin (1940). Plater and Long do not, however, agree with the earlier interpretation. They recognized that the altitude of the ness could be as much as 1.2 m below both the adjacent west–east (proximal) ridges and the south-east–north-west (distal) ridges. The latter also fell towards their north-western ends. Plater and Long (1995) observed an overall rise in ridge-swale altitude of about 1.5 m, between Galloway's Lookout and Denge Marsh Sewer, which they explain as a function of sampling location rather than real altitudinal change. Having taken measurements from a consistent point beyond the ness of the mapped ridges, they found an overall rise in ridge height of about 1 m (from *c*. 4.0 m on the Roman shoreline to 5.0 m OD on the AD 750 shoreline of Lewis and Balchin (1940)). In the central part of their transect there is evidence for a fall from *c*. 4.5 m to 3.9 m OD followed by a rise to *c*. 5.1 m OD. Plater and Long (1995) emphasized that because shingle ridge morphology and sedimentation are controlled by a number of interdependent variables (Carter *et al*., 1989; Jennings and Smyth, 1990), temporal variation in any single parameter is unlikely to explain the altitudinal trends.

Although the roughly 1 m increase from west to east in ridge altitude in Denge Marsh may be interpreted as related to sea-level rise and storm event magnitude between the Roman period and the mid-8th century, along-profile morphology accounts for much of the variability in ridge altitude (Plater and Long, 1995). Their stratigraphical, magnetic and diatom evidence indicates relatively uniform and widespread phase of marsh sedimentation. They propose that sedimentation took place on a surface extending from lower marsh to intertidal mudflat. Coarser laminations resulted from increased wave energy or velocities of tidal flow. At Galloway's Lookout–Greenwall and Brickwall Farm, marsh sedimentation was preceded by shingle emplacement, but later phases of ridge construction took place towards the end of the sedimentation phase. A high sediment supply from the Romney Marsh catchment during the mid-to late-Holocene provided much of the marsh sediments (Plater and Long, 1995). The intertidal flat then provided a surface upon which subsequent ness development could occur. The shingle-marsh interface in Denge Marsh appears to have moved eastward with the prograding shingle foreland as a series of advancing depositional environments (Plater and Long, 1995). Comparison of the altitude of the marsh surface and the base of a mottled facies with present-day mean high-water springs (MHWS) indicates that these sedimentary markers were close to MHWS about the times of the AD 774 charter and the great storms of AD 1287–1288. The uppermost mottled facies may have been deposited by the 13th century storms onto 8th century marsh surfaces (Plater and Long, 1995). This, according to them, contradicts the north-easterly younging trends at Brickwall Farm and Denge Marsh.

Thus long-term sea-level rise may have driven progressive tidal sedimentation (Plater and Long, 1995), taking advantage of storm-induced recurve emplacement and consequent back-barrier deposition. The intertidal flat seaward of the ness provided a base for this recurve formation. Others (Hey, 1967; Greensmith and Gutmanis, 1990; Plater, 1992; Long and Hughes, 1995) investigated the frequency and patterns of the ridges in terms of sedimentation rates and storminess. Shingle deposition is influenced by sediment composition and supply, prevailing wave climate and tidal dynamics, basement controls and inheritance controls such as influence of headlands on wave refraction and the need for back-barrier lagoon drainage (Lewis and Balchin, 1940; Carr and Blackley, 1973; Carter and Orford, 1981, 1993; Carter *et al*., 1987, 1989; Jennings and Smyth, 1990; Orford *et al*., 1991). In contrast, ridge morphology is controlled mainly by storm event magnitude and frequency (King, 1973; Orford *et al*., 1991). Ridge orientation is largely affected by sediment budget and transfers alongshore and wave climate (Lewis, 1931, 1933).

Marsh accretion results from incremental deposition of tidal lag sediments (settling at high tide) (Pethick, 1981; Allen, 1990a). Development of the marsh-shingle complex thus depends on processes at different ends of magnitude–frequency scales. Long and Hughes (1995), for example, argue that alternating gravel and marsh sediments result from changes in storm incidence and rates of gravel supply. Plater (1992) suggests that argillaceous and arenaceous sediments above buried shingle ridges in Denge Marsh result from storm breaching of the shingle complex. Most ridges (in their final form) are the result of major storms and so may indicate changing patterns of storminess, but changes in sea level have undoubtedly also been involved. Wass (1995) considers, on the basis of an investigation of sediments and microfauna, that the channel mapped by Green (1968) was a sheltered arm of a tidal inlet in which low-energy conditions prevailed. He concludes that this is inconsistent with the Rother (or any major distributary) crossing the northern part of Romney Marsh since the peat formed there about 3000 years BP. Plater and Long (1995) coupled stratigraphical investigation of Denge Marsh with diatom, mineral magnetic and radionuclide analyses to attempt to establish a chronology of marsh development, the nature of the palaeoenvironments and the primary sediment sources. Spencer *et al*. (1998a) utilized 3400 boreholes and pollen, diatom and radiocarbon dating to interpret the sedimentary record of Walland Marsh. Gravel lies beneath much of Scotney Marsh, and peat directly above the gravel accumulated between *c*. 3900 and 2400 years BP.

Boreholes near Rye show a pronounced coarsening-upwards sequence between –12 and –4 m OD, which pre-dates the main marsh peat in Walland and Romney Marsh, which formed after 6000 years BP (Long *et al*., 1996, 1998). Long *et al*. (1996) propose three hypotheses for this coarsening-upwards sequence:

1. a rapid rise in relative sea level;

2. landward migration of a coastal barrier or dune;

3. initiation of large-scale sand movement from the west after the opening of the Strait of Dover.

Dix *et al*. (1998) argue that the Rye Bay sand body has many similar characteristics to shelf sand bodies (SSBs) of south-east Australia (Roy *et al*., 1994). Rye Bay lies in a similar high-energy environment, has a steeper (more than 1°) shoreface and was affected by stable relative sea-level rise and may have had large-scale sand transport: all features of SSBs. Dix *et al*. (1998) argue that there is no evidence from their Chirp survey to suggest landward-migrating barriers in the early Holocene Rye Bay. Rather the evidence points to seaward progradation, with gravel largely absent. Thus Lewis' (1932) former extrapolated positions of the shoreline may not have existed. Dix *et al*. (1998) argue that any barriers probably existed much closer to the present-day shoreline. They identify a need for further work on the processes that allowed SSB progradation during a marine transgression and in-situ examination of the buried intertidal and subtidal stratigraphy of Rye Bay. They consider that an early Holocene complex could have been reworked by relative sea-level rise during the mid- and late Holocene and that this stopped close to the upper depositional surface of the underlying sandy body. A second possibility is that Rye Bay was too deep to allow early Holocene inter- and supertidal gravel deposits to accumulate. Such barriers would only form much closer to shore and rapid SSB progradation occurred with the slowing of relative sea-level rise after about 6000 years BP. A third hypothesis suggests that the early Holocene barrier was sand not gravel and that this is represented by the Midley Sand. Long and Innes (1993) have shown, however, that the Midley Sand is one of the youngest elements of the stratigraphical sequence of the marsh. Any such sand ridge would also have to be rapidly reworked to account for the absence of landward-inclined reflections in the Chirp profiles.

Evidence of a linkage between barrier formation and early marsh deposition is provided by the infilling of a shingle low at Broomhill (dated 3410 ± 60 ^{14}C years BP (Tooley and Switsur, 1988) and by recent stratigraphical evidence from Midley (Long and Innes, 1993; Plater and Long, 1995).

Litho-, bio- and chrono-stratigraphical investigation of the Midley Church bank (Innes and Long, 1992; Long and Innes, 1995a) show that the near-surface and surface outcrop of sand (Green's (1968) 'Midley Sand') must have accumulated after deposition of the lower sand and the younger marsh sediments. Peat began to accumulate beneath the Midley Church bank as marine influence declined from about 3700 years BP until about 2700 years BP, after which there was a gradual return to marine conditions; peat accumulation had ceased by *c*. 2200 years BP. Cereal-type pollen, other herbs and ruderal pollen types within the peat may indicate local Bronze Age farming. Long and Innes (1995a) suggest that the Midley Church bank was either an aeolian deposit or a water-lain sandbank (possibly within a former course of the Rother).

According to Eddison's (1983a,b) model, the first of the high-level shingle ridges were emplaced by about 3000 years BP with appromately 500 ridges over 10 km deposited owing to the co-incidence of storms and high tides. Discrete populations of ridges with similar orientation can be identified within the Dungeness complex. These might be the result of extended periods of high storm-frequency rather than individual events. Greensmith and Gutmanis (1990) also note this phase of shingle deposition on the seaward flanks of the ephemeral Midley Sound barrier complex from *c*. 3400 years BP. This could be linked to a more regional scale control on shingle deposition via changes in wave climate between 5000–300 years BP (Jennings and Smyth, 1990). Eddison (1983b) implies progressive or pulsed development, other authors have proposed much shorter periods of time for upper shoreface and storm beach deposits near the ness (i.e. 750 years – Greensmith and Gutmanis, 1990, and *c*. 350 years – Hey, 1967).

The more recent (eastern) ridges can be dated from cartographic evidence, but the accuracy and precision of the chronology of the western (older) ridges is more problematical (Plater and Long, 1995). Although documentary and archaeological evidence provides reasonable indications of age, linking this to particular ridges or groups is also problematical, the broad similarity between sediments of Denge Marsh (Long and Fox, 1988; Plater, 1992) and the 'post-peat' deposits of Romney and Walland marshes (Green, 1968; Burrin, 1988; Waller *et al*., 1988) suggests that marsh sedimentation may have taken place in the lee of the shingle foreland following the phase of peat deposition in much of Romney Marsh which culminated about 2000 years BP. Brooks (1988) suggests that Denge Marsh (which lies entirely with Green's (1968) 'New Marshland') was emplaced by Saxon times. However, Bronze Age axes in shingle north of Lydd (Needham, 1988) and evidence of Roman occupation of shingle west of Lydd (Cunliffe, 1988: Green, 1988) imply earlier marsh deposition. An alternative view (Cunliffe, 1980, Lamb in Eddison, 1983b) is that the most recent sediments of Denge Marsh were deposited during a series of storms in the 13th century. This largely confirms the view of Lewis and Balchin (1940) and Steers (1946a) that the marsh at Denge was largely deposited around AD 744 (Table 6.4).

Understanding of the development of the Dungeness foreland over time has a very practical application today. At the Public Inquiry held in 1958 into the proposed siting of a nuclear power station, it was pointedout that the new construction would be on an eroding shore. In spite of this the construction proceeded and, together with subsequent development, now requires to be protected from frontal erosion of the beach by the annual addition of up to 30 000 m^3 of gravel (Summers, 1985). The gravel is sourced from the accreting east side of Dungeness and transported artifically to nourish the south side where the reactors are sited (Figure6.46).

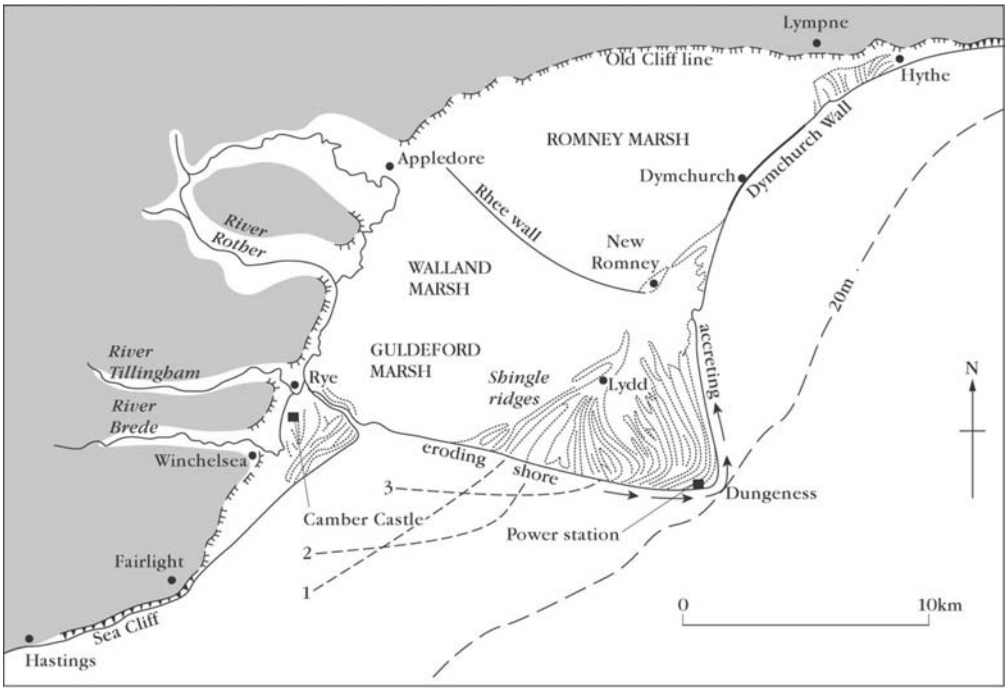

Figure 6.46: The cuspate foreland, Dungeness, Kent. The pecked lines 1 to 3 indicate former positions of the original spit over time, showing the downdrift extension of the spit across the bay. Saltmarsh has formed behind the outer shingle barrier. Over time, updrift erosion and downdrift deposition led to rotation of the feature from position 1 to 3. Land-claim of the marsh occurred in two phases – in the north it was drained in the Roman period, and in the 13th century diversion of the River Rother from its course north of Lydd to its new exit at Camber Castle led to the draining of the southern marshes. (After Bird, 1984, p. 159.)

Conclusions

Dungeness is a large, complex and geomorphologically important site, first because of the shingle ridges, and second for the shingle foreland. Beach ridges such as those found at Dungeness are not confined only to cuspate forelands, shingle ridges with recurved distal ends being found at many scales around the British Isles (for example, Blakeney Point, Orfordness, Hurst Castle Spit, and Pagham). The complex overlapping – and associated truncation – of sets of ridges that can be dated is extremely well-developed at Dungeness, where it occurs on a large scale over a known timescale.

Shingle structures of such complexity are unusual globally. Dungeness is a cuspate foreland of intermediate size in global terms, but features the size of Dungeness are rare on the coasts of Britain. Although none of the individual geomorphological features of Dungeness is unique, their association together gives the site its special interest. The considerable damage to much of the original feature (Fuller, 1985) has not obliterated the most important features and every part of the sequence of ridges is still preserved at some point. The as yet little-analysed archival and archaeological evidence provides a potentially rich field for further interpretation of the development of this large and complex feature.

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