Chesil Beach, Dorset

[SY 462 903]

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Introduction

Chesil Beach has been described as 'unique' — and is of considerable international renown and scientific significance. Its sheer size (over 18 km in length and exceeding 14 m in height), the systematic longshore size-grading of beach material, the evidence for the south-westerly provenance of its pebbles, the availability of historical records, and the sedimentary record in the adjacent lagoon ('The Fleet'), each contribute to the geomorphological importance of the site and help to explain why there is a vast scientific literature about it. In recognition of the importance of the site for coastal geomorphology, it is one of the GCR sites that form the Dorset and East Devon Coast World Heritage site.

Chesil Beach is one of five major gravel/shingle features along the British coast, together with Dungeness, Orfordness, Spey Bay and Culbin (see GCR site reports). It has been described as a 'prodigious accumulation of gravel', 'probably the most extensive and extraordinary accumulation of shingle in the world', 'an heroic piece of natural engineering' and 'unique' (quoted by Carr, 1983a). Only one coastal feature in the British Isles — Scolt Head Island — has been written about more than Chesil Beach. There have been a number of reviews of the literature, which currently totals over 75 published accounts, e.g. by Coode (1853), Strahan (1898), Arkell (1947) and Carr and Blacidey (1974b). Many other writers have concentrated on specific aspects of the site including de Luc, 1811; de la Beche, 1830; Austen, 1851; Coode, 1853; Rennie, 1853; Bristow and Walker, 1869; Codrington, 1870; Fisher, 1873; Groves, 1875; Prestwich, 1875; Black, 1879; Cornish, 1898a,b; 1912; Reid, 1898; Strahan, 1898; Richardson, 1902; Johnson, 1919; Prior, 1919; Ward, 1922; Baden-Powell, 1930; Lewis, 1931, 1938; Steers, 1946a, 1962, 1964a; Bond, 1951; Rimmer, 1953; Arkell, 1954; Adlam, 1961; Jolliffe, 1964, 1979, 1983; Neate, 1967; Carr, 1969a, 1971a, 1974, 1981, 1983a, 1999; Carr and Blackley, 1969, 1973, 1974b; House, 1969; Carr *et al.,* 1970; Bird, 1972, 1989; Carr and Gleason, 1972; Hardcastle and King, 1972; Hydraulics Research, 1979, 1985, 1991a,b; Brunsden and Goudie, 1981, 1997a; Ladle, 1981; Carr *et al.,* 1982; Draper and Bownass, 1983; Goudie and Gardner, 1985; Bray, 1986, 1990a,b, 1992, 1996, 1999; Hannah, 1986; Carr and Seaward, 1990, 1991; Heijne and West, 1991; Hook and Kemble, 1991; Brunsden, 1999). In addition, The Fleet's origins have been investigated by Ladle (1981), Whittaker (1980), Robinson *et al.* (1983) and The Fleet Study Group (including Coombe, 1996; Goudie pers. comm., Whittaker, pers. comm.).

Description

Chesil Beach is a simple, linear, pebble and cobble storm beach, which, because it links the so-called 'Isle of Portland' with land farther west at Abbotsbury, is frequently quoted as an example of a tombolo (e.g. Holmes, 1944; Monkhouse, 1965; Twidale, 1968). The mean spring tidal range at Bridport is 3.5 m with mean high-water spring tides (MHWS) at +1.8 m OD and mean low-water spring tides (MLWS) at –1.7 m OD (Nunny, 1995). Waves from the south-west have a fetch in excess of 4000 km and surges have produced wave heights in excess of 6.5 m (return period = 1 in 5 years) and 9 m (return period = 1 in 50 years). The beach extends at least 18 km from Chesilton in the east, where it ends against a sea-wall and the cliffs of the Isle of Portland, to an arbitrary boundary in the west. This limit depends upon the criteria used to define it and may, as Prior (1919) first suggested, have changed over time. Bird (1989) discussed the possibility that the beach extended farther west to a cliffed boundary at Eype, and Brunsden and Goudie (1997a) speculate that it may have reached Golden Cap. This part of the shoreline has been separated from the modern Chesil Beach since at least 1742 when the first harbour breakwaters were built at West Bay (Hannah, 1986). The western limit of the GCR site has been taken as West Bay to ensure that it includes the full range of features and sediment grading characteristics of the Chesil Beach.

The pebble and cobble feature is joined to the mainland at Abbotsbury and Chesilton, and is backed over the intervening 13 km by the shallow tidal Fleet lagoon (Ladle, 1981). Opposite The Fleet, Chesil Beach is between 150 m and 200 m wide, but it is narrower both adjacent to the cliffs in the west (e.g. 35–60 m at Burton Bradstock, [SY 485 890]) and between 40 and 54 m at its extreme eastern end. The beach crest is intermittent at the western end, but becomes continuous from midway between West Bexington [SY 530 865] and Abbotsbury [SY 570 837]. Ridge height increases progressively from about 7 m at Abbotsbury to a maximum some 14 m above mean sea level at Chesilton [SY 680 735]. Offshore the beach drops at a broadly similar gradient to that of the seaward face above low-water mark before shelving gradually to about –18 m OD some 270 m offshore at Wyke Regis and –11 m at a similar distance off West Bexington. The offshore slope between –25 and –50 m is almost linear and steepens to about 1 in 20 off the eastern end of Chesil Beach between –25 and 0 m OD (Nunny, 1995). Boreholes (Carr and Blackleg, 1969) show that only in the vicinity of Wyke Regis is bedrock anywhere near the surface, contrary to suggestions earlier in the literature (Figure 6.15).

Although it has been suggested by a number of writers that little gravel-sized material now appears to be available to nourish the beach from offshore and maintain the present-day characteristics of its clasts, more than 50% of the sediments in depths of less than 25 m between Abbotsbury and Burton Bradstock are gravel formed into wave-oriented mega-ripples. There are also extensive areas of bare rock (Nunny, 1995). Opposite The Fleet there are a number of rock outcrops broadly at right angles to the beach. At lower sea levels these outcrops may have affected wave refraction and thus sediment transport in a different way from the present-day shore-parallel wave approach. Borehole samples suggest that flint and chert pebbles become more angular with depth (Carr and Blackley, 1969). However, at these lower horizons, samples are largely derived from more local, less resistant, Jurassic strata. This implies that attrition is of some importance as a cause of loss of volume of the beach, at any rate in the long term. The boreholes also indicate that the massive pebble and cobble deposits are concentrated in the exposed, i.e. subaerial, part of Chesil Beach. Although shingle is present below low-water mark, it occurs as limited, discontinuous horizons. Estimates for shingle volume range between 15 and 60 million m^3, mainly because the volume of deposits below sea level is not adequately known from borehole evidence.

Like Chesil Beach itself, much has been written concerning the origin of The Fleet tidal lagoon. Carr and Blackley (1973) provide information on the form of the bedrock underlying Chesil Beach and The Fleet, and the material with which The Fleet is 'riffled, which mainly comprises silt, sand, pebbles and peat (some of which has been dated, (Figure 6.15)). They clarify some of the earlier ideas about its origin. The slope of the former coastal platform, largely planed-off bedrock, continues underneath the Chesil barrier to meet the hills inland. The break of slope, where the two join, and an associated ancient pebble and cobble storm beach (Carr and Blackley, 1973) are found at a depth of about –15 m OD opposite East Fleet, and at comparable depths elsewhere, as far west as Abbotsbury.

The Fleet is recognized as a marine Special Area of Conservation (SAC).

Interpretation

Although Chesil Beach and the associated Fleet lagoon have considerable botanical and zoological interest and importance, it is for their physical features that they are best known. There is a continuing debate about the origins and development of the features. The key issues under debate are:

1. the sources of the material forming Chesil Beach
2. the cause and extent of the distinct gradation in the size of clasts
3. the role of longshore sediment transport
4. the role of extreme events in the formation and present-day development of the feature
5. the origins of The Fleet, and
6. the origins and development of Chesil Beach itself.

The presence of beach pebbles of similar lithology to the cliffs to the west in Devon suggested to many authors that transport was eastward from the source areas by littoral drift along former shorelines (de la Beche, 1830; Fitzroy, 1853; Rennie, 1853; Pengelly, 1870; Baden-Powell, 1930; Arkell, 1947) or crossed Lyme Bay (Strahan, 1898). Prestwich (1875), however, suggested that sediments were transported north-west from a precursor of the Portland emerged ('raised') beach [SY 675 684], situated south of the Isle of Portland. Prior (1919) suggested three possible sources: an earlier Chesil-like beach from Start Point in Devon to Portland, erosion of the east Devon coast or river gravels deposited in Lyme Bay by a river of which The Fleet was once part. Bond (1951) argued for an ancient Exe–Teign river, flowing up to 10 km offshore from the present-day coast to a mouth south-east of Portland. Arkell (1947) thought shingle rafting by ice could account for some of the more exotic pebbles. The geological evidence indicates that there have been various potential sources of the pebbles and cobbles, including fluvial as well as marine deposits, and that the relative significance of these sources is likely to have varied over the long term. About 98% of the material is flint and chert that could have been derived from a number of primary (and secondary) local sources, but the remaining 2% (including Triassic quartzites) probably was derived from the south-west. 95% of the quartzite material is derived from the Budliegh Salterton Pebble Beds (Carr and Blackley (1969). Opposite The Fleet, there was a higher percentage of pebbles other than flint or chert, but Carr and Blackley (1969) could not explain this; they concluded (1969, 1974b) that all lithologies represented in the Chesil Beach could be derived from either local sources or older sources in south-west England.

The way in which the mean size of the pebbles forming Chesil Beach broadly increases towards the eastern, Chesilton, end has attracted considerable attention in the literature, but few quantitative measurements have been published. De Luc (1811) described the range from that of a 'hen's egg' at Chesilton, through 'horse beans' near Abbotsbury, to coarse sand at Burton Cliff. The mean long-axis of pebbles at Chesilton is of the order of 50 mm, falling to 35 mm opposite Portland Harbour and rather under 25 mm seawards of Herbury Point (Carr, 1969a). Thereafter, the exponential fall continues slowly as far as West Bexington. West of West Bexington, longshore grading is less systematic and varies locally, as does beach crest height. These variations may reflect minor changes in beach orientation, commercial exploitation of beach material, and/or local sources of supply from the cliff to landward. Reid (1898, 1907) explained the higher proportion of Budleigh Salterton quartzites at Chesilton by their greater resistance to abrasion. Arkell (1947) thought that their greater durability or later replenishment could account for their increased frequency here relative to the Portland emerged beach. Carr and Blackley (1969) stated that the percentage of quartzites did increase towards Chesilton but was less than appeared to be the case in the field. The quartzite pebbles tend to be flatter with a larger surface area that may make them more conspicuous (Carr and Blackley, 1969).

Carr (1965) took samples at 27 locations, 1.6 km apart (0.8 km apart at the eastern end), with between 3 and 11 samples per section at crest, high and low water. During 1965–1966 pebble samples were taken along a series of transects across Chesil Beach, as part of a wider research programme (Carr, 1969a). The results showed that on surface profiles between Smallmouth and the Bridging Camp, there were areas near The Fleet where pebble size was smaller, and degree of sorting greater, than nearer the beach crest. It was suggested that these samples might represent the legacy of a different beach relationship from the present-day one (a similar point is made by Brunsden, 1999). Borehole samples along the beach, covering the area between approximately Smallmouth and Herbury showed angular, local limestone pebbles at depth, reaching as much as 47% just west of the Bridging Camp, and 33% farther east. Both these maximum values occurred at about –15 OD. In the case of Carr's core (see (Figure 6.15)), this limestone-dominated material was separated from the present-day beach by sand, suggesting a different regime at a different depth level, and hence time (even if equal height does not always imply contemporaneity). Brunsden (1999) comments that graphical data compiled by Babtie from a survey in 1996 in which sediment was sampled at 1 km intervals reveals important facts about the sediment wave hypothesis. The printed Babtie data link only as a line graph those points that show the trend and similarities of size. Points that deviate from the overall trend are left as major outliers, revealing large variation from the otherwise westward decreasing trend. Thus there are areas where sediments are distinctively larger than would be expected from the normal trend.

Studies over very short periods of time using brickbats (Richardson, 1902) and painted pebbles (Adlam, 1961) showed net eastward wave-induced transport and preferential movement of larger materials. Carr's (1971a) experiments using clasts of a foreign or exotic lithology confirmed that larger material moved more rapidly eastwards, showing particularly strong eastward drift at Wyke Regis [SY 660 760], becoming more variable and random nearer Portland. Carr concluded that there was no consistent drift near Portland, thus explaining the absence of a large accumulation at Chesilton. Both pebble measurements and tracer experiments (Carr, 1971a) have shown that thickness (B axis) appears to be the most significant dimension affecting pebble transport alongshore by waves. Although movement seems predominantly to the east, negative correlations have also been recorded. Near Portland, travel eastwards is reduced by the more random nature of longshore movement as compared with sites farther west, where waves usually approach the shoreline more obliquely. The length of burial time of particles also varies between the two areas. These factors, coupled with the absence of sizeable amounts of new material, probably account for the lack of any permanent drift and thus of the absence of large quantities of pebbles being deposited at the eastern end. Rejection onto the surface of clasts larger than the general population is most marked under conditions of long-period swell. Thus material that is unduly coarse for a particular part of the beach would be given more opportunity for lateral transport than the remainder. Small pebbles would work their way down into the beach matrix. Together, these processes and effects, according to Carr, produce the longshore grading pattern. However, the lateral sorting could simply be related to the ability of the most powerful waves to produce eastwards drift offset only by westward movement as far as the smaller cobbles and shingle are concerned.

Experiments by Gleason and Hardcastle (1973) using the indigenous material show vertical sorting to be dependent on the wave frequency and square root of the significant wave height (highest third of all waves). Longshore sorting was dependent upon the angle of swell approach. Carr and Blackley (1974b) argued that fresh sediment inputs would tend to diminish size grading, although Bray (1990b) considered that new inputs of larger pebble sizes may be necessary to counter the continuous reduction by attrition. Carr and Blackley (1969) showed how limestone clasts derived from quarry waste from the western Isle of Portland were virtually unrepresented in the natural beach population at a distance of some 3–4 km northwest of Chesilton (a reflection of both attrition and net longshore transport).

Most explanations for the sorting concentrate on the commonly held view that:

- there is a continuous size change along the beach,
- sorting occurs by size and shape,
- rates of pebble movement depend on pebble thickness (B-axis dimension),
- different wave energy of storms from the south-west and the south-east cause the sorting, and
- different depths of water offshore and therefore differences in available energy are a fundamental cause of the clast distribution and sorting.

However, the above model may be based on simplistic notions of sediment transport with pebbles moving singly by longshore drift that assumes an open system with a continuous supply of material for drift (Brunsden, 1999). He argues first that the present-day beach cannot be regarded as an open system, for it is closed at the western end by the harbour walls at West Bay. Even before they were constructed, restriction of longshore movement by headlands to the west existed. Brunsden suggests that on Chesil Beach, groups of pebbles move both west and east as the wave approach varies but with a net westward movement. Groups dominated by small sizes move over groups of bigger ones and along different storm ridges, forming and reforming as conditions dictate. Such a process has also been observed on the shingle beaches at Ringstead (May, 1999) and at Spey Bay, where 'slugs' of gravel move alongshore (Gemmell *et al.,* 2001b). As pebbles are eroded from each beach ridge, remnants of pebble groups are left at different beach levels according to the severity and sequence of storms. When major storms washover the beach, surface beach material is moved over the crest regardless of the size and composition of pebbles that occur on the beach at that place at that time. As the beach moves landwards this sediment may re-emerge on the beach face many years later. As a result, Brunsden argues that any sorting model must be a complex, episodic spiral of individual movement and movement of gravel groups.

On the cuffed coast to the west, gravel inputs of approximately 5000 m^3 a^{-1} have occurred over the past 4000 to 5000 years (Bray, 1990a,b). Assuming that losses by attrition and entrapment have remained constant through time at approximately 1500 m^3 a^{-1}, Bray estimates that between 14 million and 18 million m^3 of sediment has been supplied to the coast by landslides since 5000 years BP The beaches between Lyme Regis and West Bay store slightly less than 1 million m^3 of shingle at present. Since the long-term mean rate is similar to present-day figures, Bray argues that current shingle budgets support the hypothesis that erosion of the west Dorset coast provided a major sediment source for the creation and replenishment of Chesil Beach. Today, however, a continuous supply of material no longer exists. Shoreline transport is regulated by landslide activity occurring at the main headlands of Golden Cap and Doghouse Hill. Bray's (1990b) model envisaged intermittent pulses of gravelbypassing these headlands at intervals of 30–50 years, most recently at Golden Cap between 1949 and 1962. Relict landslide deposits (boulder aprons) identified some 2–3 km offshore from Golden Cap (Brunsden and Chandler, 1996) may indicate the extent of past cliff erosion (Figure 6.17)b.

Bray (1990a) estimated that about 32 million m3 of gravel would be supplied to the retreating shore. Some materials would also have been contributed from the East Devon coast, giving a combined total of 58 million m^3. Chesil Beach is the only significant gravel accumulation within this part of the Lyme Bay cell.

According to Bray, the hypothesis is supported by a variety of evidence. Surveys in Lyme Bay have failed to reveal alternative offshore shingle sinks. Analysis of the size and lithology of cliff-top gravels in the Charmouth area indicate that the material is comparable with Chesil Beach shingle, and the size, shape and lithology of pebbles on Charmouth, Seatown, Eype and Chesil beaches support the hypothesis that the beaches were formerly contiguous (Bray, 1990b). The contemporary pattern of eastward littoral drift has probably existed over the last 5000 years. There is no evidence that the coastal orientation was significantly different in the past or that the frequency of west and south-west storms was less (Bray, 1996).

The present-day volume of Chesil Beach is estimated at 15 to 60 million m^3 (Carr, 1980). The estimated surplus by coastal landsliding is 14 to 18 million m^3 over the past 4000 to 5000 years. Although potential shingle supply from landslides is significant by comparison with the present-day volume of Chesil Beach, it is unlikely to have been the main supply (Carr, 1980). Chesil Beach had already formed by 7000 years BP (Carr and Blacldey, 1973). It is therefore suggested (Bray, 1990b) that sediment supply from terrestrial sources, such as coastal cliffs, updrift or feeder bluffs/cliffs) was a mechanism by which Chesil Beach has been nourished and enlarged. The original gravel source was probably fluvial and periglacial deposits on the floor of Lyme Bay, which gradually decreased in importance as the rate of sea-level rise slowed down. Subsequent erosion of the cliffs provided a supply of flint and chert that helped to maintain Chesil Beach. Shingle supply from the west by littoral drift was possible until as recently as the mid-1860s when longshore transport was halted by the construction of the piers at West Bay. The supply process up to 1860 may have offset attrition losses and assisted in the maintenance of the unique Chesil Beach size grading (Carr, 1969a) because it ensured that a wide range of clast sizes was always available. However, mineral extraction has been important in the past, especially at Seatown and West Bay. Material has been removed from the beach at West Bay for over 700 years, with about 1 million tonnes of gravel removed between the mid-1930s and 1977 (Hydraulics Research Station, 1979). Of this, more than 470 000 tonnes were taken from East Beach, Bridport Harbour, and 370 000 tonnes from Cogden Beach. At one time, pebbles were removed from other locations, e.g. during 1905–1907 from the back-slopes of Chesil Beach. Perhaps the most significant of these activities was the selective pebble picking carried out nearby, not because of the absolute quantities, varying between approximately 100 and 350 tonnes per year from 1944 to 1972, with a recorded total of some 9400 tonnes, but rather because of the removal of particular sizes and shapes. This may well have produced a disproportionate weakness in the beach as well as affecting locally the longshore grading pattern and distorting the geomorphogical processes.

Changes in crest height of Chesil Beach over the last 300 to 400 years and that at one time the crest may have been lower over most of the length between Abbotsbury and Portland. Although the total volume of beach material appeared to change very little between 1852 and 1968–1969 (Carr and Gleason, 1972), the crest height between Abbotsbury and Wyke Regis showed a substantial increase. This was of the order of 2 m at Langton Herring [SY 605 810]. Between Langton Herring and east of Wyke Regis [SY 650 770] there was a rise, typically, of 1.5 m. However, near Chesilton, a drop of 0.5 m, reaching an extreme fall of 3.5 m at one point, was recorded. Carr and Gleason (1972) found difficulty in explaining this phenomenon although it gave credence to early 19th century reports that the beach used to be overtopped more frequently. A comparison of the 1968–1969 profile and associated data with that of March 1979 shows that the single winter of 1978–1979 was capable of producing the same order of change at the south-east end of Chesil Beach as that indicated between 1852 and 1968–1969. Thus at one location there was a maximum fall of 2.7 m in crest height between September 1978 and March 1979 surveys. Coupled with the known stability of the crest between 1955 and September 1978, it suggests that one event could be enough to produce the scale of change observed over the period from 1852 to 1968–1969. Such an event appears to have occurred in 1904 under similar long-period swell conditions to those recorded on 13 February 1979. A possible mechanism to account for these height changes is that where atypically large swell waves arrive parallel to the beach, the crest is overtopped, lowered, and rolled inshore (i.e. towards Portland Harbour). Farther west, towards Abbotsbury, the same swell would arrive more obliquely so that instead of clasts moving from low-water mark, over the crest, and down the backslope, the material would simply be transferred from the face to the crest, by which time the wave energy would be expended. During this process, the crest would become higher than before and there would be some net longshore transport of clasts towards the east.

The western end of Chesil Beach shows considerable variation, which is related not only to the construction of the piers and mineral extraction, but also the reaction of the beach to prolonged periods of different wind direction. Between 1901 and 1984, based on comparisons between maps and field survey, accretion on the eastern side of the West Bay piers was not continuous. There were brief periods of erosion as for example between 1961 and 1964 (Hydraulics Research, 1979, 1985; Jolliffe, 1979). Littoral drift between West Bay [SY 462 904] and Cogden Beach [SY 504 880] was investigated using a mathematical beach transport model, and a hindcast wave climate model based on Portland wave data covering the period from 1974 to 1984 indicated mean net eastward transport at 8000 m^3 a^{-1}, similar to the documented trend for accretion against the east pier at West Bay (Hydraulics Research, 1985). The analysis is open to question, however, because it ignored swell waves and waves under 1 m and used shingle transport equations that had been calibrated on other beaches. Analysis of beach profiles and aerial photographs covering the period 1977 to 1990 showed that there was a marked switch from previously recognized patterns of accretion immediately east of the pier at West Bay in about 1982, to erosion, which resulted in retreat at mean high-water level by 40 m by March 1990 (Hydraulics Research, 1991a). The wave climate changed after 1982, with fewer south-east storm waves and an increase in westerly waves, i.c. a return to the generally accepted historical prevailing pattern. Littoral drift calculations confirmed net westward drift before 1982 and net eastward drift of up to 14 000 m^3 a^{-1} after 1982 (Hydraulics Research, 1991a). It appears from these studies that net littoral drift is very delicately balanced at both ends of Chesil Beach, especially at the western end where slight wave climate and storm frequency variations may produce major reversals of drift. Beach morphometry may react relatively slowly to changes in drfit regime because of the large volume of Chesil Beach, and so trends may be identifiable only at the ends of the beach. They contribute therefore, little to an understanding of the mechanisms along the whole beach.

The environmental history of The Fleet is critical to an understanding of the origins and subsequent development of Chesil Beach. Within The Fleet, sedimentation of clays, silts and sands is evident above the –15 m level to about –3 m OD where commonly thick common-reed *Phragmites* peat layers (dated at *c.* 5000 years BP) occurred (Carr and Blackley, 1973). As peat becomes exposed it is eroded and thrown up on the beach between Abbotsbury and West Bexington. The pollen from a sample at –13.4 m OD in Carr and Blackley's Langton Herring (E) borehole (Figure 6.14) at the boundary between sand and bedrock was tentatively dated as early Pollen Zone VI. They interpreted this as showing that both the peat formation and the sedimentary infill above bedrock must have been very rapid. At the eastern end of the Narrows [SY 650 772], peat deposits, with a high pine-pollen content, were found underlying the landward side of Chesil Beach at a depth of *c.* –5.3 m and dated at *c.* 6200 years BP Bedrock at this locality, occurred at –13.1 m OD, although it was as shallow as –7.8 m OD at a neighbouring location. It is unclear how these data fit into the evolutionary picture — does it imply, for example, that the relatively deep, narrow channel between the army Bridging Camp and Chesil Beach was cut as some sort of overflow feature? (Carr, 1999).

The detailed investigation of the sediments within The Fleet shows that its evolution has been a complex one (Goudie, pers. COMM.; Whitaker, pers. comm.). Coombe (1996) provides details of 26 boreholes that include lagoonal and pre-lagoonal phases. A series of radiocarbon dates in peats at depths of –3.00 m OD, –3.60 m OD and –4.32 m OD have been dated between 4540 ± 70 and 4840 ± 70 years BP (Figure 6.15), indicating rapid accumulation such as Carr and Blackley (1973) had inferred. Two samples in the East Fleet (cores 25 and 29) at –3.00 m OD and –3.15 m OD were dated at 3820 ± 70 and 4110 ± 60 years BP respectively. Mean grain size in Coombe's cores decreased westwards, indicating that energy lessened along The Fleet, supporting the hypothesis that the infill was derived mainly from the south-east in Weymouth Bay. The pollen in a sand sample beneath the lagoonal sequence included a high frequency of pine *Pinus,* together with oak *Quercus,* hazel *Corylus* and birch *Betula.* These are similar to the Carr and Bladdey (1973) findings that placed these basal sediments in Pollen Zone VI. This suggests that these sands found below the lagoonal sequence may be older than 6000–6500 years BP In all the cores, there is evidence of saltmarsh above the sands. This predates the brackish-marine lagoonal phase, which is not older than 5000 years, and is the dominant feature today. Throughout The Fleet narrow shell beds rest on top of each peat bed. Goudie *et al*. (pers. comm.) consider that the peats either represent stillstands or slight falls in the rising Holocene sea level or indicate that The Fleet was closed by a barrier and became a freshwater lake or a reed swamp cut off from the sea. West Fleet was behaving more like an estuary than a lagoon. At West Bexington, foramifera and ostracods show that a tidal, near-marine, water body existed well to the west of the modern Fleet around 4000–5000 years BP (Whitaker, pers. comm.). However, in order to allow for such a body to exist, it is necessary to have a barrier well seaward of the solifluction slope between Abbotsbury and West Bexington.

Although there is at present insufficient evidence for this to be more than conjecture, it would help explain the nature of the West Bexington and Burton Mere environments, both of which appear to be extensions of The Fleet. A further complication in identifying the origins of The Fleet and Chesil Beach comes from the solifluction slope itself, which extends the alignment of Chesil Beach towards West Bexington. If, as Brunsden and Goudie (1997a) have suggested, the solifluction materials overlie evidence of the Portland emerged beach, the western part of an extended Fleet could be a very old feature. To the west of West Bexington, present-day cliffs probably extended farther seawards and would have acted as an early headland from which sandy materials could supply a low sandy barrier beach, it also provides a basis for some re-interpretation of the classic transgression model for the development of Chesil Beach.

The longer term evolution of Chesil Beach is still not completely understood, but the chronological sequence compiled by Carr and Blackley (1973), modified by Bray (1990b) makes it possible to put forward the following scenario for the initiation and development of Chesil Beach.

1. Around 210 000 years BE the Portland emerged beach is formed and the slopes between Abbotsbury and the Narrows are trimmed. The beach is re-occupied about 125 000 years BP Westwards from Abbots-bury, there is also an emerged beach and so a coastline very dose to the present-day extended at least between Smallmouth and West Bexington. A forerunner of Chesil Beach may have existed as a bank well offshore of the present beach some 120 000 years BP (Carr and Blackley, 1973), contemporaneous with the development of the Portland emerged beach.
2. From the emerged beach level of between +7 and +15 m OD, sea level fell to about –120 m. The seabed is weathered by periglacial processes and a series of gravel-rich deposits, probably comprising material from the Portland emerged beach, solifluction deposits, river gravels and fluvioglacial deposits were deposited on the floor of Lyme Bay. Degraded landslides and solifluction deposits extend 2 to 3 km seawards of the modern shoreline position and mantle the former coastal cliffs.
3. From about 20 000 years BP sea level rose by 1 mm a–1, and by about 10 000' years BP sea level was at approximately –45 m. The proto-Chesil Beach approaches the former shore of Lyme Bay. The sea level then rose rapidly increasing by an average of 1.5 m every 100 years.
4. About 7000–6500 years BP the model suggests that closer to the modern coastline, the transgressing Chesil Beach overrode existing sediments as sea level rose. A shallow lagoon that became The Fleet was rapidly filled with silt, sand, pebbles and peat from 7000 to 5000 years BE About 7000 to 6500 years BP, with sea level between –12 and –4 m OD, a low sand and gravel beach developed at about 1 km offshore (Figure 6.17)a. Relict cliffs farther to the west, abandoned by falling early Devensian sea levels, were re-activated by marine erosion (Figure 6.17)b and large quantities of gravel were transported eastwards, to feed and enlarge the new Chesil Beach (Bray, 1990b). The Fleet forms behind this barrier beach. West of Abbotsbury, wave-energy distributions are modified by refraction and higher energies occur much closer to the eastern end. Solifluction deposits and landslide toes begin to be trimmed by the rising sea and gravels begin to travel eastwards.
5. Between 6500 and 4000 years BP, the lagoon is closed and a freshwater lake forms in the East and West Fleets. There was probably dry land between Weymouth and Portland, and The Fleet extended farther west to Burton Mere. The implicit shelter needed for peat deposition is taken as an indication that by 4000 to 5000 years BP, Chesil Beach had formed dose to, or a short distance seaward of, its present position (Bray, 1990b)
6. As sea level rose, between 4000 and 2000 years BP, tidal conditions developed in The Fleet. There was now a continuous beach to Portland from Abbotsbury and also a separate beach facing eastwards into Weymouth Bay.
7. From about 2000 years BP to 1850 AD, marine erosion to the west supplies increasingly large volumes of lasts to the beach, which therefore grows in volume and height to establish the current form. The beach became a shingle ridge overlying a finer-grained, impermeable core. This continued until the mid–19th century.
8. From the mid-19th century, the building of the Cobb and West Bay harbours cut off long-shore sediment transport at the same time as the beaches became more fragmented by the gradually emerging headlands at locations such as Golden Cap. Combined with the effects of beach mining and attrition, this leaves Chesil Beach as a relict feature

suffering slow decline in volume.

This scenario implies that the classic model of a transgressing gravel beach could be replaced by a two-phase model in which the early Chesil Beach is a low sand and gravel barrier that provided a base upon which the more massive gravel and cobble structure was constructed as large supplies of these materials became available. Better understanding of the wave climate of Lyme Bay still leaves questions about the effect over many centuries of major events, such as those of 13 December 1978 (a 1 in 50 year event with 9 m swell) and 13 February 1979 (when 18-second period waves arrived without warning out of a moderate sea).

Despite its magnitude, it is likely that in common with many other coastal features Chesil Beach at a comparatively late stage in its evolution. Carr and Blackley (1973) suggest that during the last interglacial, any proto-Chesil Beach must have been entirely reworked by marine action. Such may well be the ultimate fate of the present-day structure.

Screening of coarse indigenous shingle for gabion and mattress-fill for the trial length completed in November 1981 could also have had an effect. It is difficult to determine the proportion of beach volume lost by extraction, but Carr (1981) estimated that between the mid-1930s and 1977, something of the order of 2% was likely to have been removed overall. Although more research needs to be carried out to determine how losses through attrition compare with this, it is very unlikely that the latter are as great on this essentially flint and chert beach.

Most anthropogenic pressures on the beach have been concentrated at the extremities (Carr, 1983a). Those at the Portland end are most critical because it is there that the beach is subject to maximum fetch from the Atlantic Ocean, and, of scientific importance, the beach crest is at its highest and the rate of change in grading is greatest along the most easterly 2 km.

There can be little doubt that Chesil Beach is in a fragile state and is finite in amount. No more material is being supplied and loss continues through attrition and removal offshore. The logical prediction must be that Chesil Beach will now steadily move onshore and break up into separate beaches and bays. It may rotate at Weymouth, breach at several places, allowing The Fleet to become saline and disappear or develop into lakes like those behind Cogden and West Bexington. The main new headland may be at the Narrows. Severe erosion will take place at East Cliff and Burton Bradstock, where the next bays will develop. The processes that happen when a barrier beach comes onshore, already seen between Lyme Regis and West Bay, will be the model for the rest of the beach.

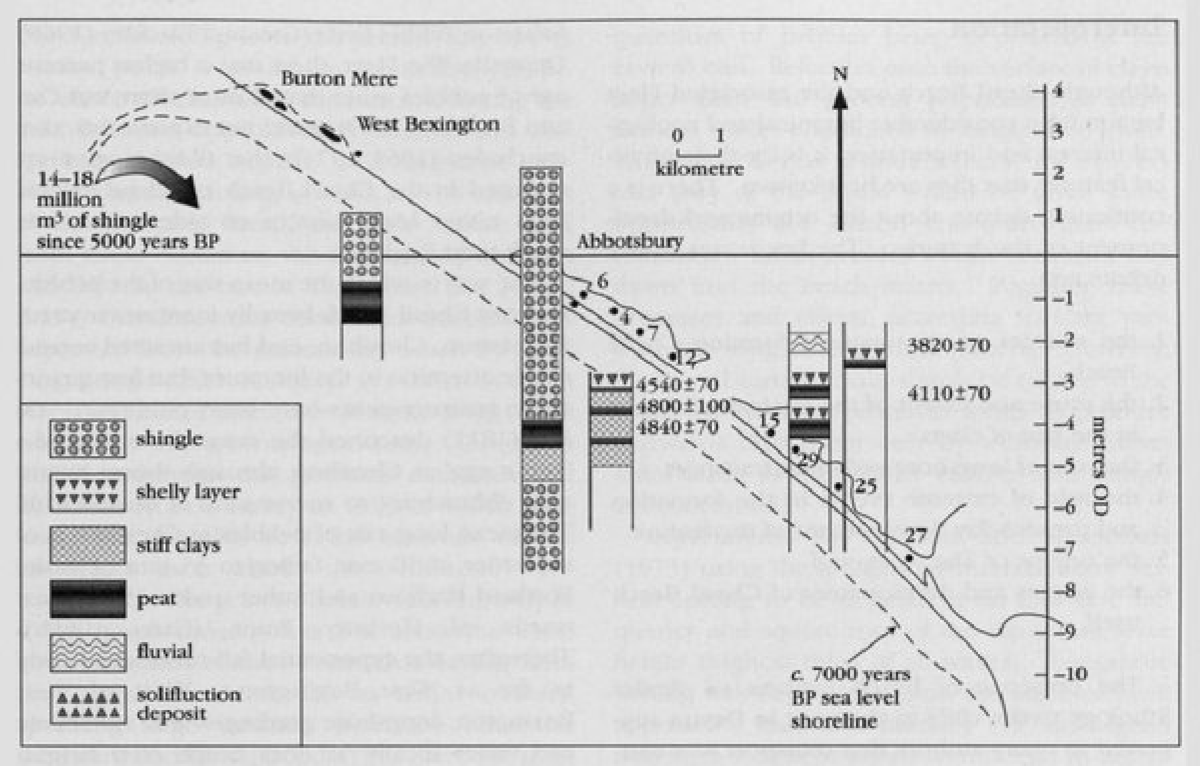
Conclusions

Chesil Beach is a massive, linear pebble and cobble coastal barrier/tombolo backed by cliffs at its western end and a lagoon, The Fleet, in its central and eastern parts. The beach ties the Isle of Portland to the mainland of Dorset. It is renowned worldwide especially for the size grading of its constituent clasts. There are four British gravel structures that rival Chesil Beach in scale, Culbin, Spey Bay, Dungeness and Orfordness, but none displays the simplicity of form or the simple barrier shape evident at Chesil Beach. Chesil Beach is very unusual in lacking any development of recurves, even within the lagoon between Abbotsbury and Wyke Regis. The fact that it is simple in form offers enormous scope as a baseline exemplar for studying many other more complex structures.

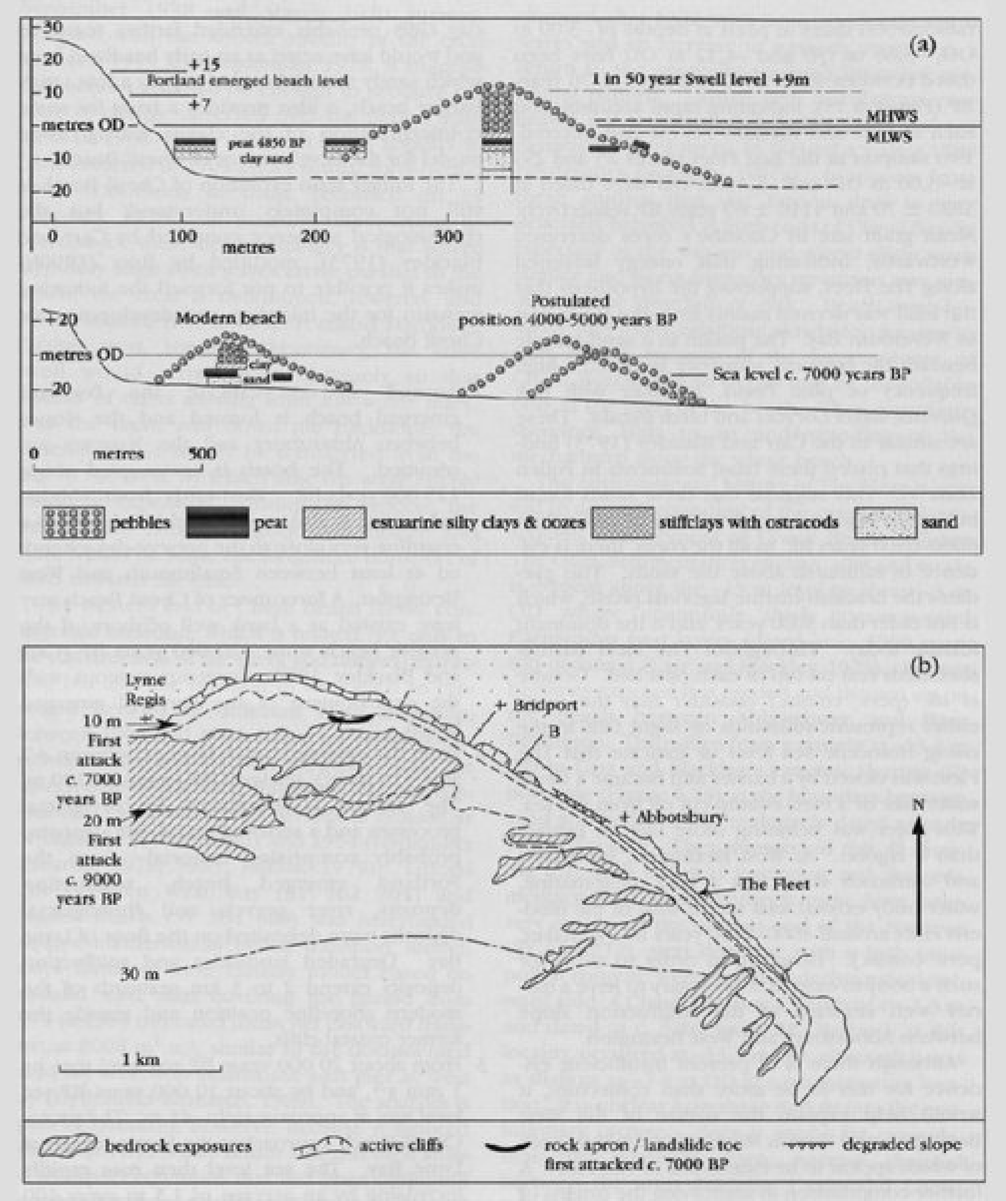
Despite the number of cores taken through the beach and The Fleet, the internal structures remain speculative. Furthermore, the three-dimensional form of the beach, the surfaces on which it rests, the nearshore seabed and the processes that produced and maintain the beach also warrant more detailed investigation.

The origins of the beach are open to debate, but can be summarized as follows (Bray, 1990b). With sea level at the end of the Devensian about 100 m below its present-day position, a barrier beach formed as a result of the erosion of river gravels and other offshore sediments. About 7000 years *BP,* infilling of the Fleet began and was virtually complete by 5000 years BP (Carr, 1974). According to Bray (1990b), Chesil Beach was thus formed before there was significant erosion of the west Dorset coastline. It was then maintained by longshore sediment transport from west Dorset. An alternative view suggests a two-phase development with a sand-dominated barrier offshore upon which the cobble ridge was then established.

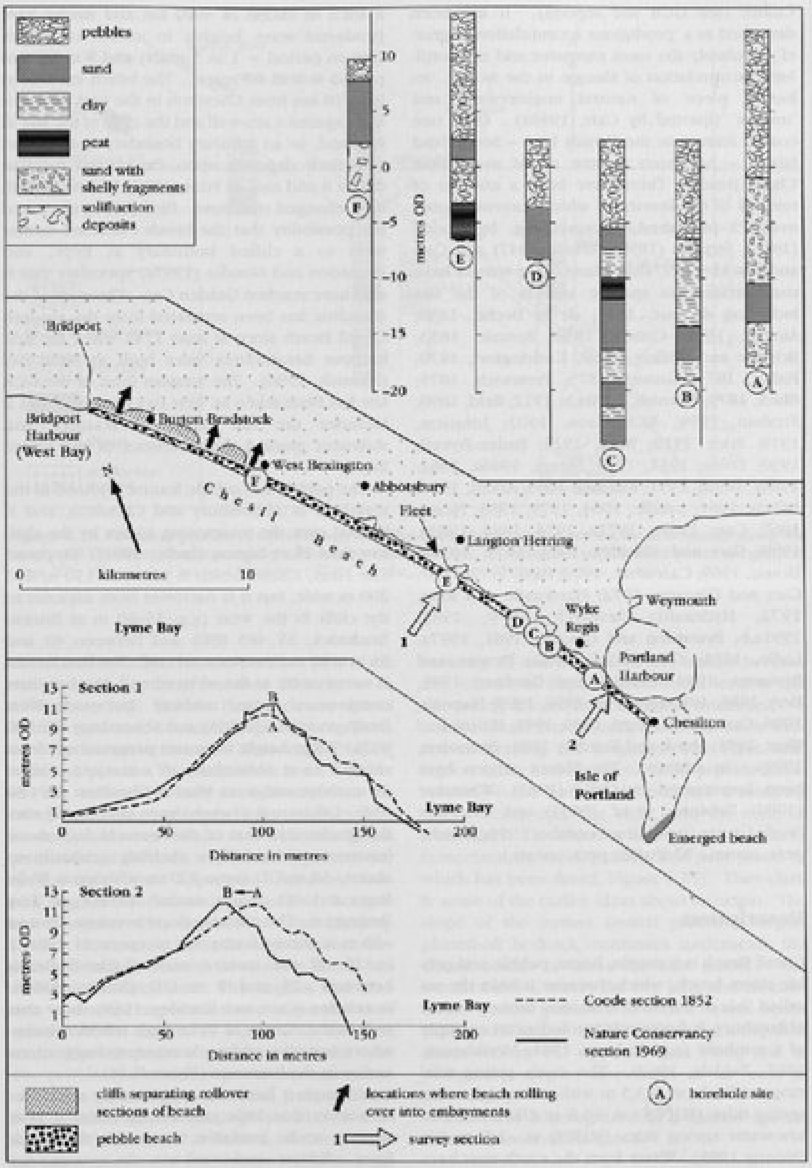
Even so its origins are still a matter of debate. Despite the local modifications to the beach, Chesil Beach remains a remarkable coastal land-form that is regarded worldwide as having extremely high scientific value because of its form, size, composition and documentary record. Chesil Beach is included in its entirety in the Dorset and East Devon Coast World Heritage Site, declared in December 2001. Few other sites are more cited or visited by coastal scientists.



(Figure 6.15) Sediment profiles of Chesil Beach and The Fleet. Sample cores are shown in sequence along the beach and The Fleet. Some peat layers have been dated in cores from the bed of The Fleet (dates are given in years BP). (Based on Carr and Blackley, 1973; Coombe, 1996 and Whittaker, pers. comm.)



(Figure 6.17) Chesil Beach (a) relationships between modern beach and dated peats and water levels (mean high-water springs and mean low-water springs, MHWS and MLWS, are shown). By c. 5000 years BP, the supply of flint was able to create a barrier beach atop an earlier sand ridge and estuarine peats. (b) Seabed features of eastern Lyme Bay and their relationship to Chesil Beach. Note the relation of bedrock exposures and seabed contours to the present shore, which probably affected the development of the earlier beach form. 'First attack' indicates the bathymetric contour representing the shoreline first attacked by the sea at the date shown.



(Figure 6.14) Map and sections of Chesil Beach. For general location see Figure 6.2. (Based on borehole information in Carr and Blackleg, 1969, 1973; and Carr and Seaward, 1990.)