The Depositional and Landscape Histories of Dungeness Foreland and the Port of Rye

Understanding Past Environments and Coastal Change

Introduction

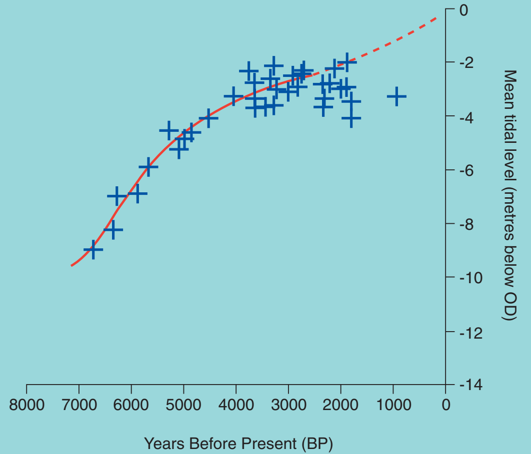
In 2002 research began on two projects in the Romney Marsh region funded by English Heritage through the Aggregates Levy Sustainability Fund (ALSF). The ALSF provides funds to help tackle a wide range of problems in areas affected by the extraction of aggregates (sands and gravels). The Department for Environment, Food & Rural Affairs (DEFRA) have made available resources, through the Fund, which have been distributed by English Heritage, English Nature and the Countryside Agency.

The programme of research on Dungeness Foreland and Rye Bay ran from November 2002 to March 2004, during which time research personnel from the universities of Durham, Liverpool, Kingston and Aberystwyth undertook a wide range of field- and laboratory-based analyses in order to understand the past development of this coastline. In this task, their work was supported by a number of local stakeholders, including the Romney Marsh Research Trust, Archaeology South-East, English Nature, Defence Estates, the RSPB, and Rye Harbour LNR. The outputs of the research aim to provide a thorough understanding of the area's landscape history, as well as coastal response to global environmental change, particularly climate, sea-level rise, storm events, and human activity, from which a strategy for future coastal management and conservation may be established.

This booklet provides an introduction to the two projects by explaining the background to the work, as well as the methods we have used to undertake our analyses. We also introduce and explain some of the many processes which have controlled the landscape development of the region through time. Our hope is that this information provides an accessible introduction to our work which stimulates further public and academic interest in the history of this very special coastal system.

The Research Projects

The Dungeness and Romney Marsh depositional complex is the third largest area of coastal lowland in the UK. Located in the east of the English Channel, the complex comprises a very large coastal barrier made of sand and gravel, behind which are extensive low-lying areas, former tidal flats and saltmarshes, now reclaimed from the sea. The two ALSF projects detailed in this booklet address different, but related aspects of the Dungeness and Romney Marsh depositional complex; one is focussed on the spectacular gravel and sand beach of Dungeness Foreland, and the other is based on the landscape history of the Port of Rye. By way of introduction, we begin by briefly outlining the aims and objectives of each project.

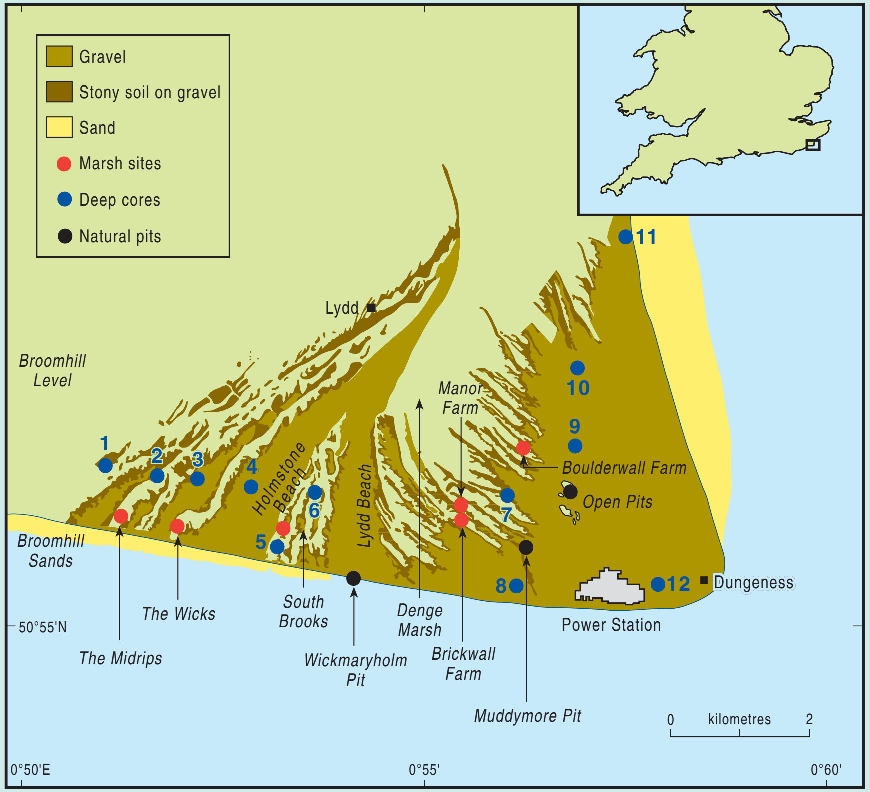


A graph showing the rise in sea level during the last 8000 years. Each data point is an observation on former sea-level collected from the Dungeness and Romney Marsh depositional complex. The crosses approximate the age and height uncertainties with each point. The dotted line is a suggested trend in long term sea level during the last 2000 years, during which time we have very few data points. The depths are expressed with respect to Ordnance Datum (OD) which approximates to mean sea level.

Project 1. The Evolution and Landscape History of Dungeness Foreland

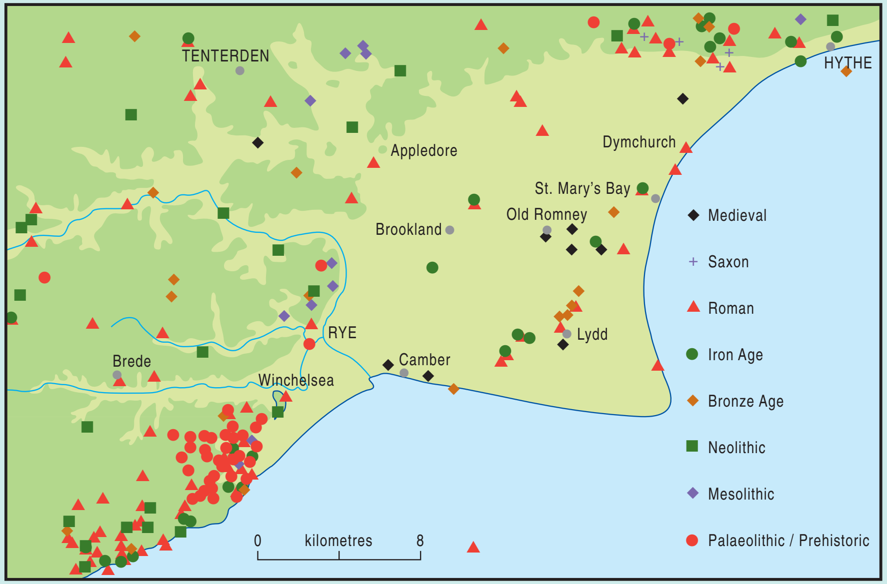
The extensive gravel beaches of Dungeness Foreland are a spectacular monument to the long-term effects of sea-level change, storms, coastal erosion and sediment deposition during the Holocene period (the last 10,000 years). This sequence of beaches is unparaleled in the UK and is acknowledged internationally as an

Location map showing the gravel beaches of Dungeness Foreland and the various sites investigated in this project

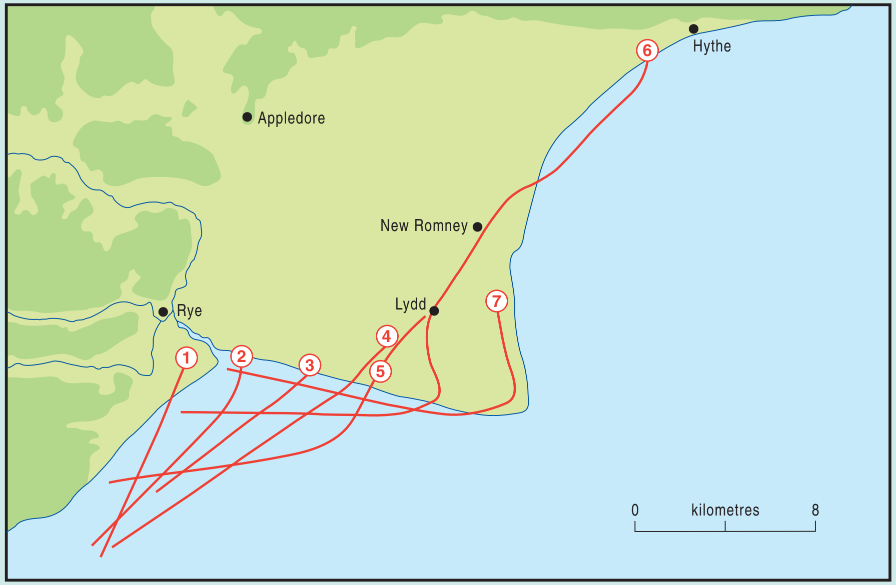


outstanding example of a cuspate gravel foreland. These beach deposits are attractive today as a major source of aggregate for UK industry, and a long history of sand and gravel extraction has resulted in the partial destruction of the beach ridges and, of course, the history of past depositional environments (palaeoenvironments) contained within.

The oldest evidence for human activity on the foreland is a group of five bronze low-flanged axes recovered from a Lydd quarry in 1985 (see distribution map overleaf). Fire-cracked and worked flints, as well as some Bronze Age pottery, have also been identified as surface scatters on the gravel. During the Romano-British period, saltworking developed as an important local industry, with saltwater trapped between the shingle beaches and evaporated over fires positioned on the higher beach crests.



The distribution of archaeological sites recorded in the National Sites and Monuments Record across the Romney Marsh - Dungeness region (redrawn from RomneyMarsh.net)



Hypothetical shoreline positions for Dungeness Foreland. During the earliest period, suggested by shorelines 1-4, a large sand and gravel barrier probably developed across much of Rye Bay. However, actual proof for the age of these shorelines has been lacking prior to this project

Remarkably little is known about the age and depositional history of the 500 or so beach ridges that make up Dungeness Foreland. Existing theories suggest that the earliest beaches were in place by at least 4000 years ago (see map bottom left), but thereafter our information on age has been reliant on the dating of organic matter deposited underneath or on the gravel surface (e.g. peat, wood, shell, bone), and archaeological finds on the gravel surface. In addition, this chronology of beach deposition may be supplemented by palaeoenvironmental and historical records relating to the age of marshland landscapes that abut the gravel. However because of the lack of direct dating of the gravel beaches we were still struggling to understand how the foreland developed, as well as the impacts which the development of Dungeness Foreland had on the wider landscape history of Romney Marsh.

The Dungeness project was based on a large-scale survey of the Dungeness Foreland. The overall aim of the work was to develop a depositional history for gravel beach formation, storms, sediment supply and landscape change during the last 5000 years or so. We believe that the work is locally important for informing models of coastal evolution and human activity, regionally significant by developing a chronology for sea-level change, storm incidence and sediment processing in the English Channel, and of wide international importance to the scientific community with an interest in the sedimentary response of cuspate gravel forelands to environmental changes.

Project 2. The Evolution of the Port of Rye, Romney Marsh, Sussex

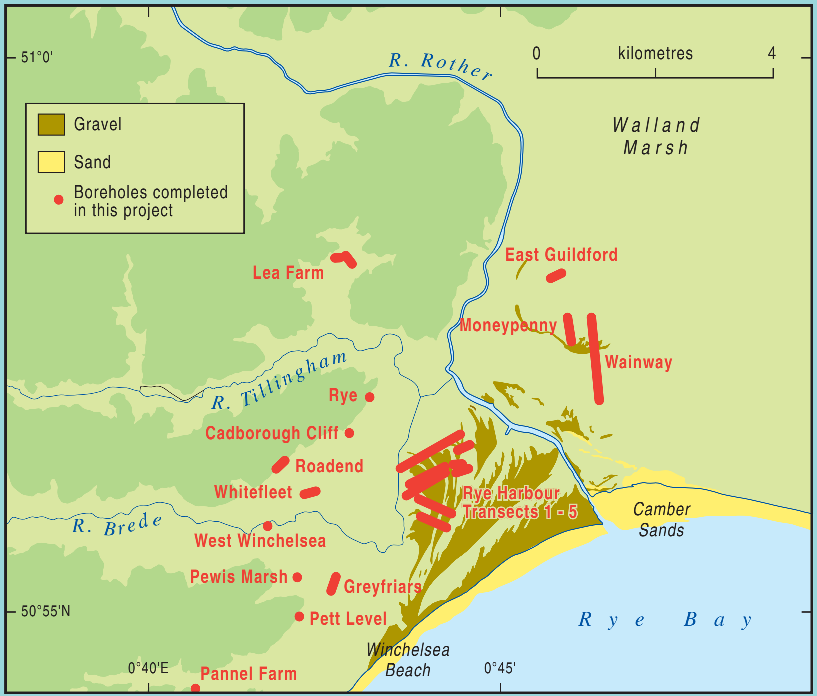
The Romney Marsh depositional environment is the third largest coastal lowland in the UK, and the most extensive in SE England. It contains a rich and varied record of environmental and landscape change from the prehistoric to the present.

A key control on the evolution and occupation of the marsh has been, and continues to be, the coastal gravel and sand beaches, which are most extensive at Dungeness but which also occur significantly at Hythe and Rye Harbour. These beaches have been subject to a long history of aggregate extraction which has impacted on the important geomorphological, archaeological and historic landscapes of the region.

Within the Rye area, the stability of the gravel and sand beaches and dunes has played a pivotal role in the growth and demise of first Winchelsea and then Rye as major ports in southern England (see map on facing page). Their interlinked histories tell a story of the shifting balance between natural and human processes as agents of landscape change. During the prehistoric period, natural processes controlled coastal evolution. Indeed, by about 6000-3000 years ago, valley and

Rye Harbour saltmarshes

Location map showing the Rye Bay study site and stratigraphic transects



marshland areas adjacent to Rye, lying in a protected position behind the gravel beach barrier, saw the extensive accumulation of peat deposits. Following this, the rate of peat accumulation seems to have declined, and then these areas were subject to inundation by the sea. The earliest attempts at reclamation pre-date a well-documented breach in the gravel barrier at about AD 1250. Thereafter, physical processes, such as variations in the supply of sand and gravel, and alterations in the magnitude and frequency of sea-level change and storminess, vied with human activity, i.e. land claim and sea defence works, as agents of landscape change.

The over-arching aim of the Rye project was to develop an environmental history for the evolution of the port of Rye during the last 3000 years, paying particular attention to the landscape changes associated with the development of the sand and gravel beaches of the area.

The Rye project examined the depositional history of the Rye area in three discrete time periods:

1000 BC to AD 1250: Emphasis for palaeoenvironmental reconstruction during this period was placed on the physical evolution of the area prior to the devastating storms of the thirteenth century. This included landscape change associated with the inundation of an extensive coastal peatland, which persisted from 6000 until approximately 3000 years ago before being submerged by tidal waters.

AD 1250 to 1500: The great storms which breached the gravel beach barrier in the thirteenth century resulted in the destruction of Old Winchelsea, but also the inlets that were formed created safe harbours. Geomorphological, palaeoecological and archaeological studies from this period helped to determine the impact of the initial breaching, and the location and extent of the major tidal inlets.

AD 1500 to 1850: This period saw major changes in coastline due to siltation, gravel beach barrier development, and land claim and sea defence, all of which contributed to the decline in the economic fortunes of the area. These changes were tracked using aerial photographic interpretation, as well as sediment analyses of tidal channel and port infilling.

The Rye project was based on the collection of sediment cores to determine the age of the end of peat formation across the region, mapping and surveying to determine the spatial extent of the 13th century barrier breach, as well as detailed analysis of the channel fill sediments from the former channels of the rivers Rother and Brede.

Research approach and techniques

A fundamental underpinning of palaeoenvironmental research is that it provides the capacity to understand past change as the baseline for future prediction. Indeed, whilst computer models are being used more and more for the prediction of future change in response to climate change and human impact, the relationships between process and response must be determined in the first instance for the predictions to have any degree of reliability. It is these relationships and linkages between cause and effect that are the primary focus of the research on Dungeness Foreland and in the Rye area.

Research into the nature and extent of past environments

Palaeoenvironmental research is based on the simple principle that the present is the key to understanding the past. Hence, the grain size distribution of the present-day shoreline can be used as an analogue by which to identify such an environment from the grain-size characteristics preserved in the sedimentary record. Similarly, wetland habitats are characterised by different plant and algal species assemblages. The preservation of the remains of these assemblages in the form of fossil pollen grains and diatoms can, therefore, provide information on changing wetness or changing salinity brought about as a consequence of climate change and/or sea-level rise. It is this simple approach which is the mainstay of our programme of palaeoenvironmental research, which includes:

Stratigraphy and Sediments

The primary investigative tool used to determine the spatial and depth distribution of different depositional environments, using the principle that sediment layers found at successively greater depths become progressively older. This technique is coupled with accurate surveying and positioning to determine the three-dimensional pattern of sediment deposition.

Grain-size

Here, the energy and flow characteristics of the environment in which a sediment layer was deposited can be determined from the distribution of different sized grains.

Palaeoecology

The visible fossils of plant remains and other biota provide detail on the environment of deposition if compared with their present-day distribution. However, many large fossils become broken or undergo decay. Hence, more robust microscopic remains may be used to reconstruct past environments in a similar manner. The most commonly used microfossils are pollen, diatoms and foraminifera.

Dating

In addition to the detail of palaeoenvironments, it is essential to know their age. Different techniques are available to determine the age of various sedimentary materials, but the most commonly used method during the Holocene is radiocarbon (^{14}C) dating. Other methods used in this programme of research include optically stimulated luminescence (OSL) and palaeomagnetic secular variation dating (PSV).

Sediment Provenance

Through comparison of the metal concentrations or the magnetic properties of the sediment layers preserved in a core with those of the potential source areas (soils, river deposits, sea bed sediments), the origin or 'provenance' of sediments may be determined.

Stratigraphy and Sediments

Coring

Determining the three-dimensional pattern of past depositional environments is a matter of hard, back-breaking work. Although there are geophysical techniques available to determine the sequence of sedimentation preserved underground, such techniques still need to be validated or 'ground-truthed' using coring. The coring of marsh sediments and peats can be done using hand-augers. These are relatively soft sediments, through which the corer can be driven and samples extracted at the required depth. Using this method, many thousands of borehole records have been obtained from the Romney Marsh area, providing the basis for our site selection. However, it has still proven necessary to confirm the sequence of sediments present at any given site before sampling for laboratory analysis. In such cases, a small

The percussion drilling rig used in the Dungeness and Port of Rye projects collecting sediment from close to Dungeness Power Station

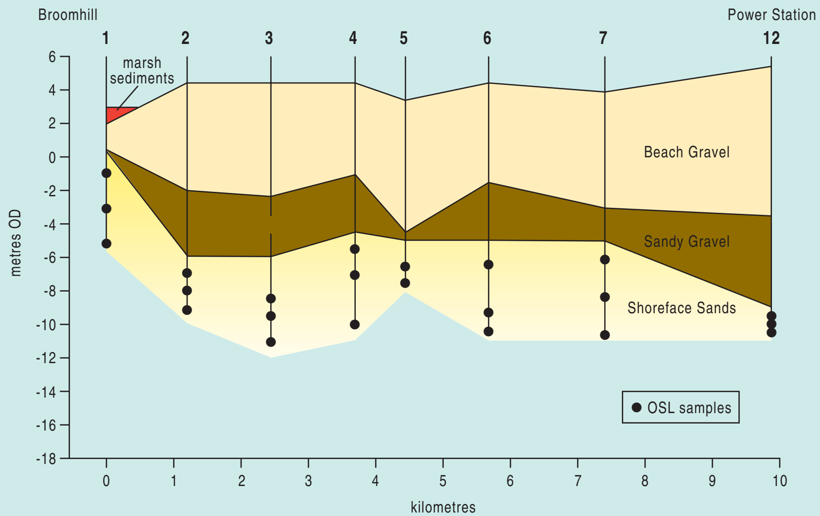
network of boreholes is sunk on a grid-based sampling strategy and the sediments from successive depths described and recorded. From these records, stratigraphic cross-sections may be drawn before deciding which is the best site to sample.

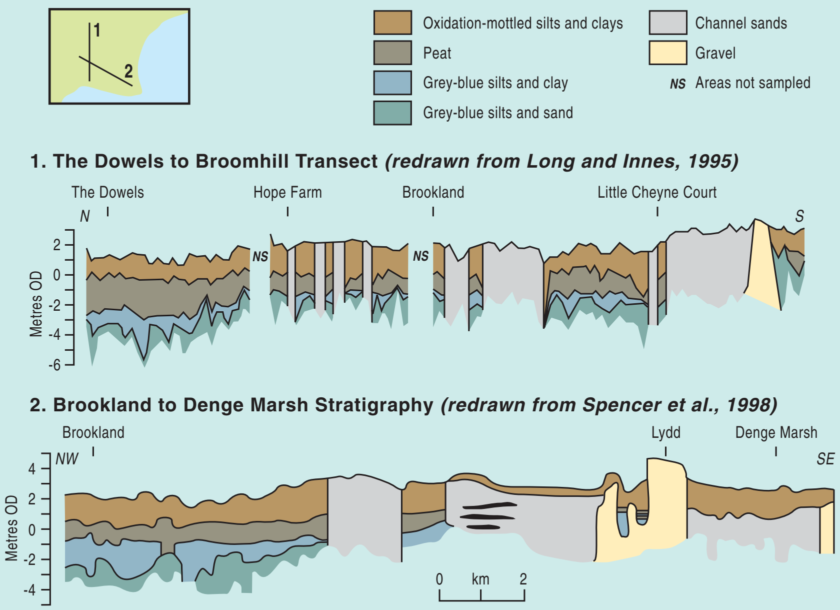
Coring the gravel beaches and the underlying sands is a more difficult affair. In this case, *Strata Investigation Services* were commissioned to drill a series of boreholes on Dungeness and Rye Harbour to retrieve gravel samples for particle size analysis in the field, and sand samples for subsequent laboratory analysis and dating (see photograph). Boreholes through the gravel were cased with a steel liner to prevent back-filling, and a 38 mm plastic-lined steel sampling chamber was then inserted into the sands using percussion. Successive 1 m sections were sampled, with each plastic liner being sealed, wrapped, and returned to the laboratory.

Stratigraphic cross-sections

The Dungeness sediments consist of a suite of sands and gravelly-sands that overlie bedrock at depth. These represent the open coast or shoreface environment prior to the deposition of the gravel beaches. The development of the shoreface was an essential precursor to the deposition of gravel beaches, with the gravel only deposited as the coastal environment became a sufficiently shallow sandflat.

A simplified stratigraphic cross-section across Dungeness Foreland. For location of boreholes see map on page 3



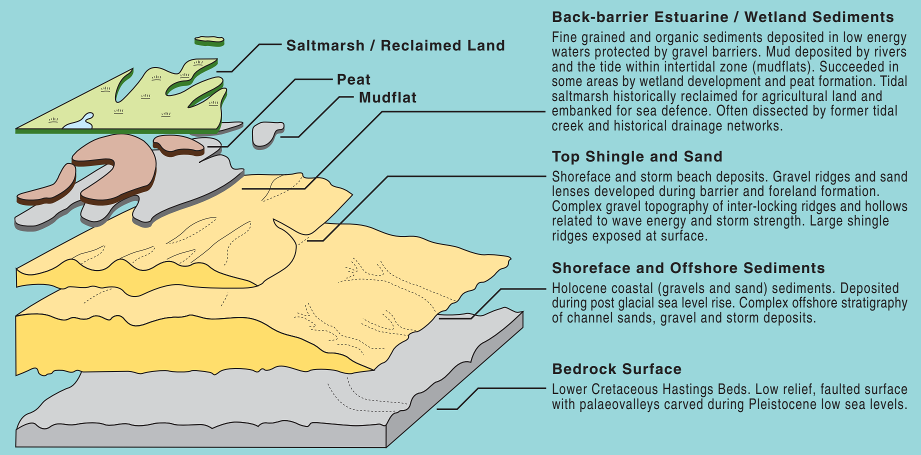


The marshland stratigraphy is characterised by a lower sequence of sands and silts (minerogenic sediments) overlain by an extensive peat deposit (see transects above). This peat formed between about 6000 and 3000 years ago as the marshland emerged above the highest tides in an estuarine setting and extended seaward. An upper sequence of silts and clays was then deposited as the peat was inundated by the sea sometime after 3000 years ago. The nature of this inundation was either sudden or erosional as the intervening period of saltmarsh sedimentation (as expected from gradual coastal change) is often absent.

Tidal rhythmites

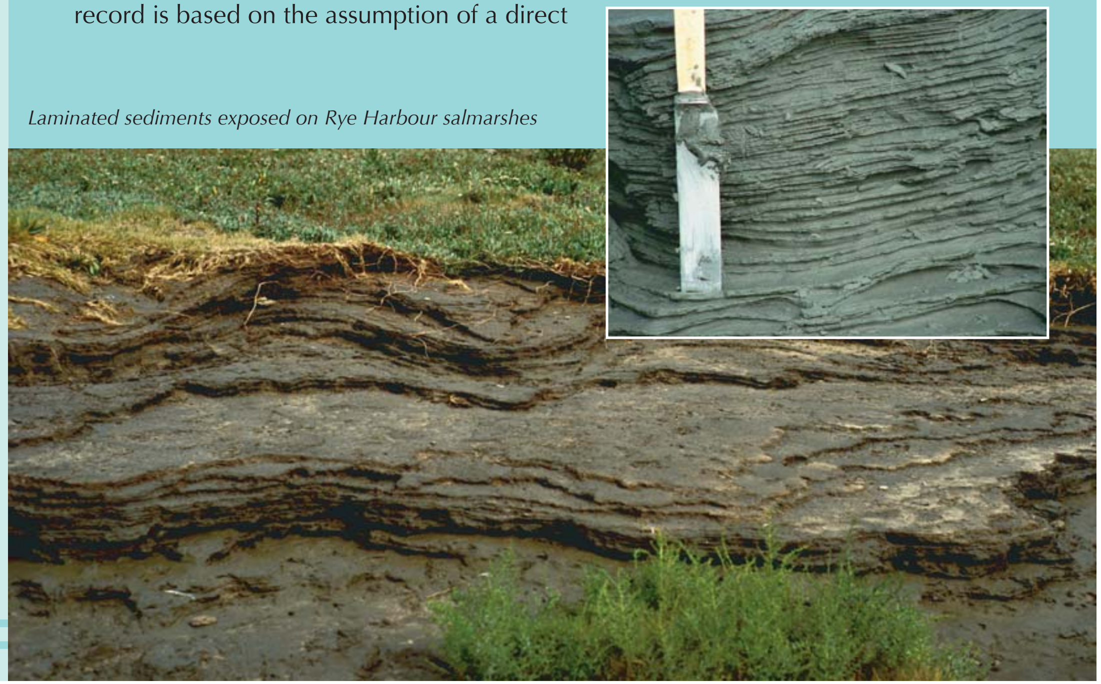
Sequences of up to several metres of alternating (laminated) sand and mud have been recovered from the marshland deposits that both interfinger with, and lie behind, the gravel beach ridges. These layered sediments, or tidal rhythmites, appear to record deposition from individual tides and this suggests that sedimentation was much more rapid than is considered to be typical in coastal settings (see photographs opposite).

In order to analyse the tidal cycles preserved by the marsh sediments, we carefully split the cores in the laboratory, and measured the thickness of the individual sand

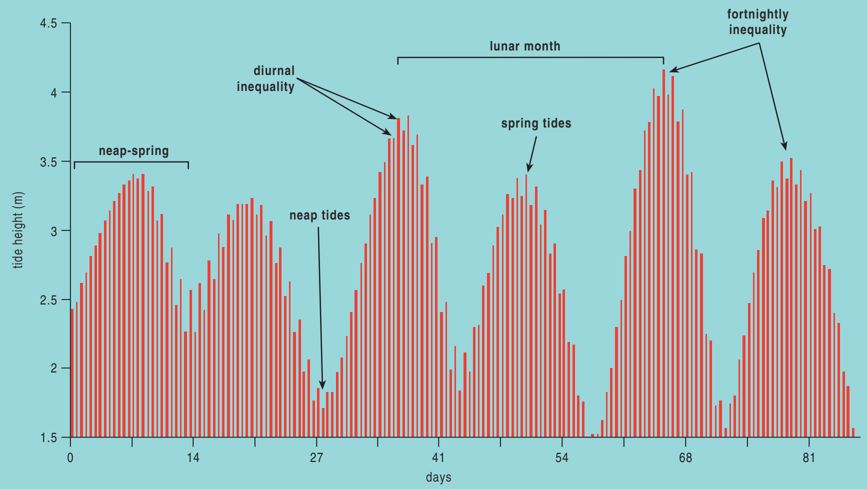


Exploded diagram showing the different depositional environments preserved in the Dungeness Foreland and back-barrier environments (redrawn from RomneyMarsh.net)

and mud layers under a microscope. Graphs of layer thickness reveal a sequence of nested and repeating cycles of thickening, then thinning, layers which resemble a series of overlapping sine waves. Such cycles are reminiscent of the regular progression of high tides recorded by tide gauges, over fortnightly neap-spring, lunar monthly and longer periods (see graph overleaf). Interpretation of the sedimentary record is based on the assumption of a direct



Laminated sediments exposed on Rye Harbour salmarshes



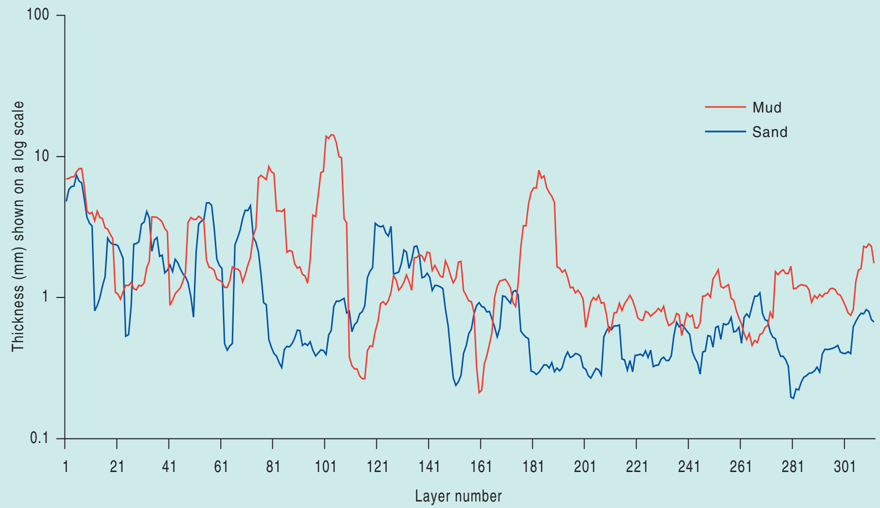
A plot of measured variations in tidal height over an 85 day period that shows the main tidal cycles recorded in the Dungeness and Rye areas

link between layer thickness and the regularly varying height and depositional energy of the tides.

Statistical analysis of the data breaks down the complex pattern into its constituent sine waves and estimates the amplitude, frequency and phase of each of the principal cyclical components of the tidal signature recorded in the sediments. This allows an estimation of the number of layers in each of the repeating cycles. The two most important cycles in these sequences repeat every four to eight layers and every 30 to 40 layers approximately. The shorter wavelength cycles, probably fortnightly neap-spring tyde deposits, combine to generate the longer wavelength, 30 to 40 layer, cycle which represents several months of deposition.

Deposition and preservation of these tidal rhythmites is related to the period of higher energy tides which occurs twice per year at the equinoxes. This period of higher tides last for about three months and deposits more sediment (i.e. thicker layers) facilitating the preservation of layers deposited by individual tides. At times of lower tides sedimentation rates are too low to preserve the tidal signature and only structureless muddy sediments remain.

This analysis provides an estimate of the periods of time over which the sediments accumulated. For example, at Boulderwall Farm, the deposition rates derived



Sequence of layer thickness through a laminated sediment core from Boulderwall Farm

from this approach are approximately 0.5 metres per year (see graph above). The widespread occurrence of these sediments on Romney Marsh is important in that it suggests that deposition was not always slow and gradual, but was more likely to have seen rapid accumulation of tidal sediments punctuated by periods of non-deposition, emergence or erosion.

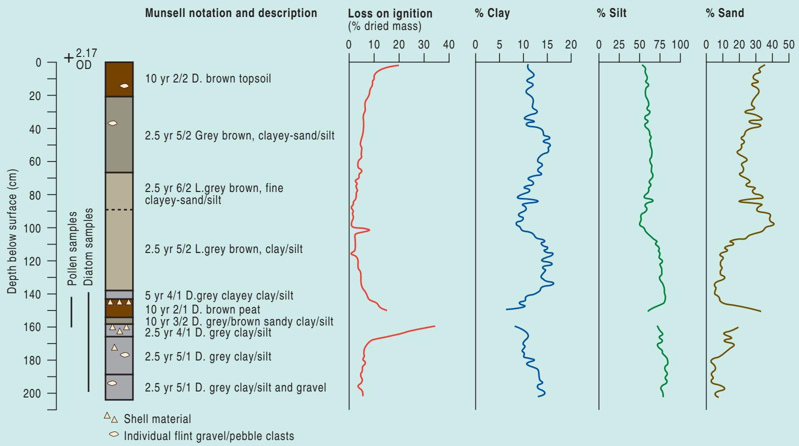
Grain-size analysis

This technique can be used to interpret the energy of the environment of deposition as well as the nature of sediment processing by tidal currents and waves. Fundamentally, the larger the mean grain size in a particle-size distribution, the higher the depositional energy, i.e. progressively larger grains are kept in suspension by the flow, thus increasing the mean size of the particles remaining on the bed. Similarly, the continual to-and-fro processing of sediment by waves tends to produce particle-size distributions that are well-sorted (a low standard deviation from the mean) and coarse-skewed (excess coarse particles due to the winnowing, or selective removal of fines). In contrast, tidal deposits are poorly-sorted and have an excess of fine particles due to their deposition from suspension at slack water at the turn of the tide, coupled with a process known as ‘flocculation’ where river-derived clay particles become stuck together and sink as larger grain-sizes.

Sieving different grain size fractions from the deep Dungeness cores.

Particle-size distributions were measured in the laboratory using the laser diffraction technique. Here, the range of grain-sizes in a sample is scanned by a laser, which is then diffracted to different extents according to the size of each particle. In order to retain all the detail in the full particle-size distribution determined by laser diffraction, down-core data are plotted as a contour plot of the percentage in each size class against depth.

By way of example, shown below is a grain size plot from the Scotney Marsh area near Lydd. The sedimentary record here is characterised by occasional thin peats, as shown by high loss on ignition values, in a thick sequence of clays, silts and sands. The sediments below the peat are clayey-silts, indicating deposition in a low energy lagoon. In contrast, the sediments above the peat have a higher sand content, which increases towards the top of the record and indicates higher depositional flow velocities.



Grain size plot from Scotney Marsh, near Lydd. The peat near the base of the core dates from approximately 3000 years ago

Palaeoecology

Pollen and plant macrofossils

A fossil hazel pollen grain (x400)

Wetland environments and habitats can be characterised by distinct groups or assemblages of plant species. Similarly, the preferred environmental conditions, or tolerance, of certain plant species (or assemblages) may be used as a direct indication of wetness, soil or water quality. For example, plants typically found in reedswamps are tolerant of long periods of waterlogging by freshwater. In contrast, saltmarsh plants can tolerate considerable periods of inundation by seawater. Hence, changes in wetland environments through time can be interpreted in the context of changing water levels and/or water quality. Unfortunately, the preservation of visible plant matter, or macrofossils, can be limited by oxidation or humification. However, flowering plants produce pollen which may also be used to characterise wetland environments and habitats. The advantage of pollen over plant macrofossils is that the pollen walls are made of an acid-resistant protein called sporopollenin. As a result, pollen is often well preserved, even after the decay of the cellulose plant matter.

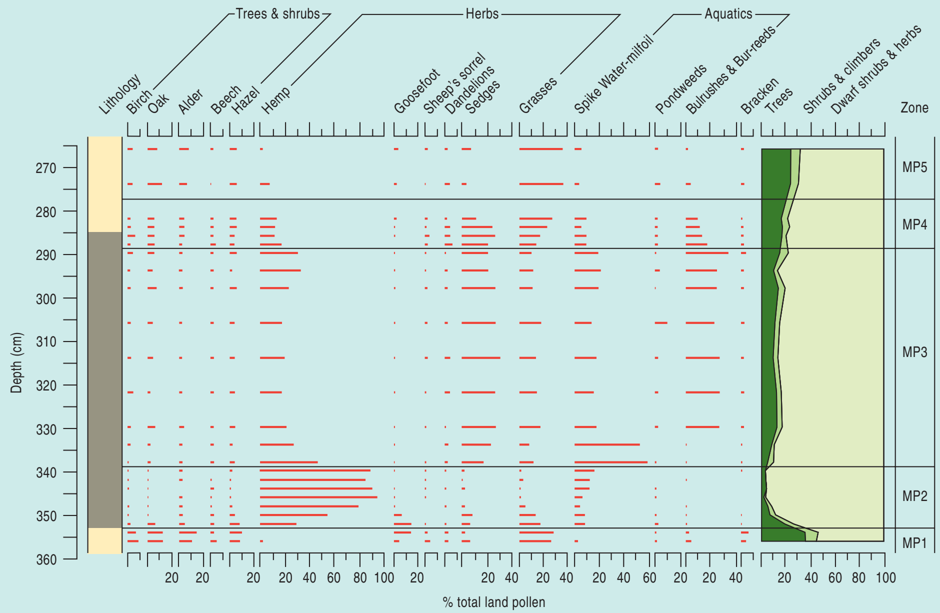
Analysis of down-core trends in pollen assemblages using optical microscopy can be used to reveal the nature and degree of palaeoenvironmental change brought about by changing climate or sea-level. Similarly, human activity on adjacent areas of dry land can be interpreted from characteristic changes in vegetation assemblage, perhaps due to clearance of the landscape for agriculture or industry, or alternatively the cultivation of characteristic plant species.

To illustrate the application of palaeoecology in the Dungeness project, outlined below is the past environmental history reconstructed from Muddymore Pit, one of the natural pits that exist on the surface of the Dungeness Foreland.

Muddymore Pit, Dengemarsh Sewer. The sample core from which the pollen and diatoms were extracted was collected from the middle of the reedbed

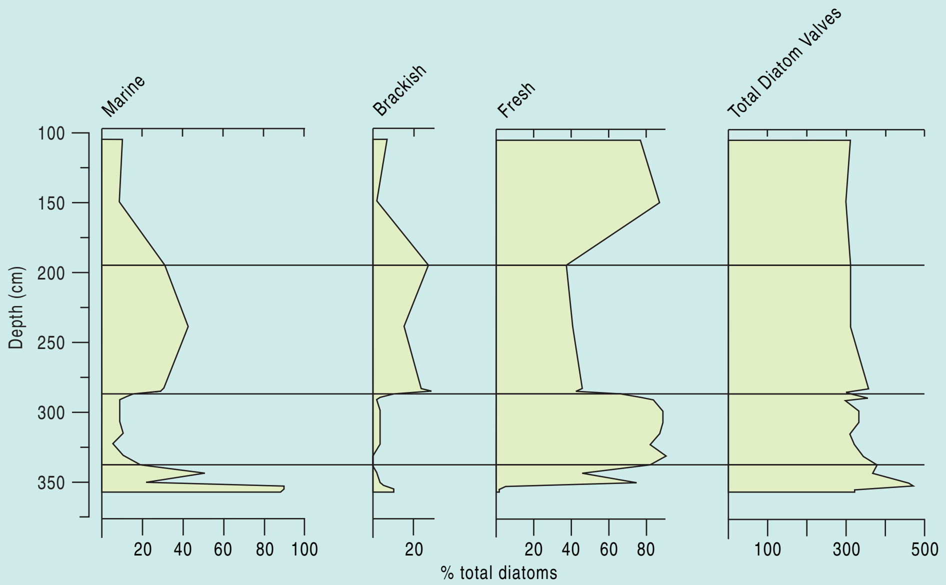
Muddymore Pit is an elongate pond, now largely infilled with sediment and supporting a healthy population of *Phragmites australis* (the common reed) (see photograph). The pit has been modified by the construction of the Dengemarsh Sewer which cuts across its western edge. Cores collected from the centre of the pit reveal about 3.5 m of sediment that lie above gravel. The sequence comprises a thin lower silty sand that passes upwards into an organic mud deposit which is, in turn, overlain above 285 cm by grey organic silts and clays that extend to present surface.

Pollen extracted from the organic mus record the development of a freshwater pond with submerged and floatign-leaved aquaatic plant (Water-Milfoil and Pondweeds) surrounded by fringing emergent vegetation (Bulrushes/Bur-reeds). Interestingly, there are also exceptionally high frequencies of hemp pollen (*Cannabis sativa*) at the base of the deposit. During the early Medieval period, hemp was cultivated in the area in large quantities for its fibres. The pollen data suggest that Muddymore Pit was used as a “Retting Pond” to break down the hemp fibres and make it more workable for rope manufacture. Production appears to have been on such a scale that making hemp rope must have been a commercial activity.



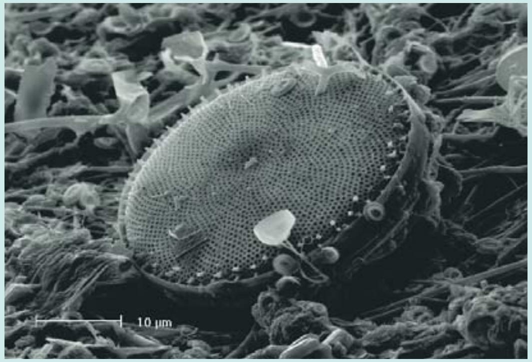
The Muddymore pollen diagram shows very high frequencies of hemp pollen in the lowermost sediments (zone MP2)

Sample core collected from the middle of Muddymore Pit. In the base of the core are grey silty sands that accumulated under marine tidal conditions. These sediments pass upwards into a largely freshwater organic mud



Muddymore Pit diatom diagram

The diatoms from Muddymore Pit (see diagram) show that the lowermost silt sand accumulated under marine tidal conditions, but that the pond then became largely freshwater between about 350 cm and 285 cm. Above this level, the organic lake deposit is overlain by brackish water silts, probably deposited by flooding following the construction of the Dengemarsh Sewer.



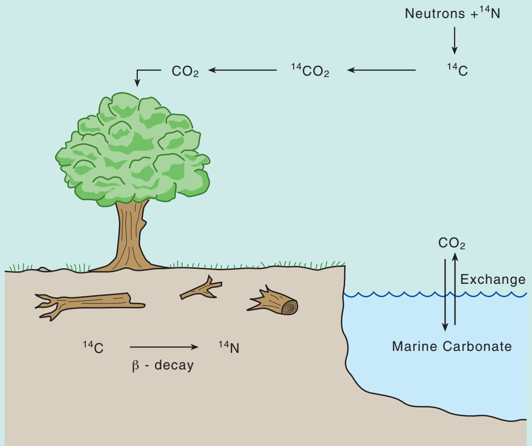
A scanning electron microscope image of a diatom. Diatoms are single-celled plants that have specific habitat and salinity tolerences. They are often abundant in the marsh deposits from Dungeness and Rye Harbour

*A dense freshwater reed swamp comprising the common reed (*Phragmites australis*). Pollen from these reeds are often recorded in sediments from the back-barrier indicating the former existance of communities such as this in the Romney Marsh and Rye areas*

Dating

Radiocarbon dating

Organic deposits such as peat, as well as organic remains preserved in the muds and sands, e.g. shells, wood and bone, can be dated using radiocarbon or ^{14}C dating. Whilst this provides accurate dates for the time of death of the organic matter, this does not necessarily reflect the time of sediment deposition. Hence, care must be taken in relating the radiocarbon date to the depositional history of the sediment sequence in question.



Radiocarbon or ^{14}C is produced in the upper atmosphere and is incorporated into living organic matter through photosynthesis. Once the plant dies, the amount of ^{14}C then decreases due to radioactive decay with a half life of approximately 5,700 years. Hence the time which has elapsed since deposition can be determined for organic matter

Radiocarbon dating works on the principle that organic matter takes up carbon dioxide during its lifetime, and that a proportion of this gas contains the radioactive isotope of carbon, ^{14}C, which is formed in the upper atmosphere when free neutrons interact with nitrogen (see diagram above). When the plant or animal dies, the contained ^{14}C decays with a half-life of approximately 5700 years by the loss of an electron, i.e. beta decay. Hence, as the production rate of ^{14}C is known – and the spatial and temporal variations in this production and storage within the carbon cycle can be constrained – the time since death can be determined by direct comparison of the number of atoms present, or the activity of ^{14}C, compared with original number or activity. This gives a potential dating range of about 40,000-50,000 years in terms of beta-counting (Conventional ^{14}C dating), or around 55,000 years if the number of atoms present is determined by accelerator mass spectrometry (AMS ^{14}C dating).

A section through back-barrier marsh sediments showing alternating bands of peat, which formed under wet freshwater conditions, and grey-blue silts and clays laid down in tidal environments. Large sections such as this are ideal for mapping distinct sedimentary units, but more commonly we had to rely on small core samples such as the one in the inset, which shows a lower part of the sediment infilling one of the Natural Pits on Dungeness Foreland

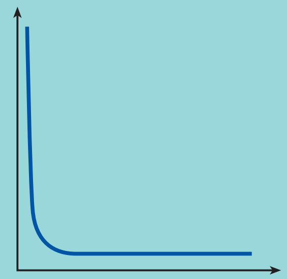
As indicated above, the dating of material where the carbon is originally derived from the sea, e.g. marine shells, requires some correction for the natural cycling and storage of ^{14}C. Similarly, radiocarbon dates need to be corrected for natural changes in ^{14}C production rate through time. This can be achieved accurately for the last 3,000 years by using a calibration curve established using ^{14}C-ages of dated tree-rings, which have a known calendar year age.

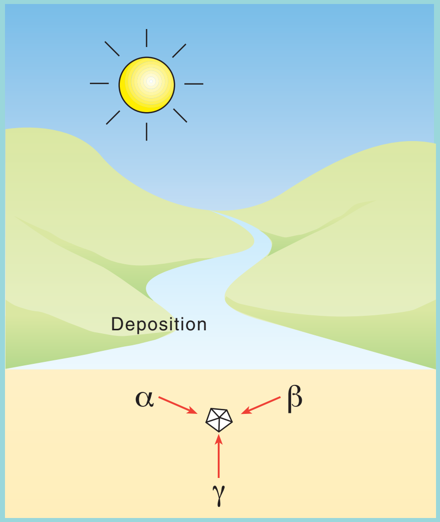
In our work we have used radiocarbon dates from a number of organic fractions to investigate the potential for contamination and anomalous age determinations. Crucial data on the minimum age for gravel deposition can be obtained through radiocarbon dating of the organic deposits found in the back-barrier marshland and in the small ponds found on Dungeness Foreland. In addition, the dating of peat deposits immediately underlying tidal rhythmite sequences or storm deposits reveals the timing of changing coastal configuration or sudden inundation by the sea.

Optically stimulated luminescence

Optically stimulated luminescence (OSL) dating can be applied directly to the mineral grains that make up sediment deposits. Here, the event being dated is the last time the mineral grains were exposed to sunlight i.e. the time the sediments were deposited. The technique is typically applied to mineral grains of quartz or feldspar, and examines the luminescence signal which builds up in these grains over time as a result of exposure to ionizing radiation in the natural environment. Any pre-existing luminescence signal contained in the sediment grains is lost on exposure to sunlight during transport, prior to deposition. Once the sediment grains are deposited and then buried by further sediments which shield them from light exposure, the luminescence signal re-accumulates over time with exposure to cosmic radiation, and to radiation from the decay of naturally occurring radioisotopes of uranium, thorium and potassium (see diagram above).

Sunlight during deposition bleaches the luminescence signal stored in sediment. After deposition, natural radiation from the surroundings then displaces electrons, which become trapped and build up as energy. This energy can then be measured in the laboratory by laser (OSL or optically-stimulated luminescence)





The luminescence signal is measured in the laboratory by stimulating small sub-samples of prepared mineral grains with light – hence the term 'optically stimulated luminescence' or OSL. The size or intensity of the OSL signal is proportional to the time elapsed since the mineral grains were last exposed to sunlight. The OSL age is determined by calibrating the intensity of the OSL signal to a laboratory-administered radiation dose in order to determine how much radiation the sample was exposed to during burial (termed the 'burial dose'). This value is divided by the radiation dose to which the sample has been exposed each year since deposition and burial (termed the 'annual dose rate'), to give the OSL age.

$$\text{OSL age (years)} = \frac{\text{Burial dose (grays)}}{\text{Annual dose rate (grays per year)}}$$

(1 gray = 1 Joule/kg)

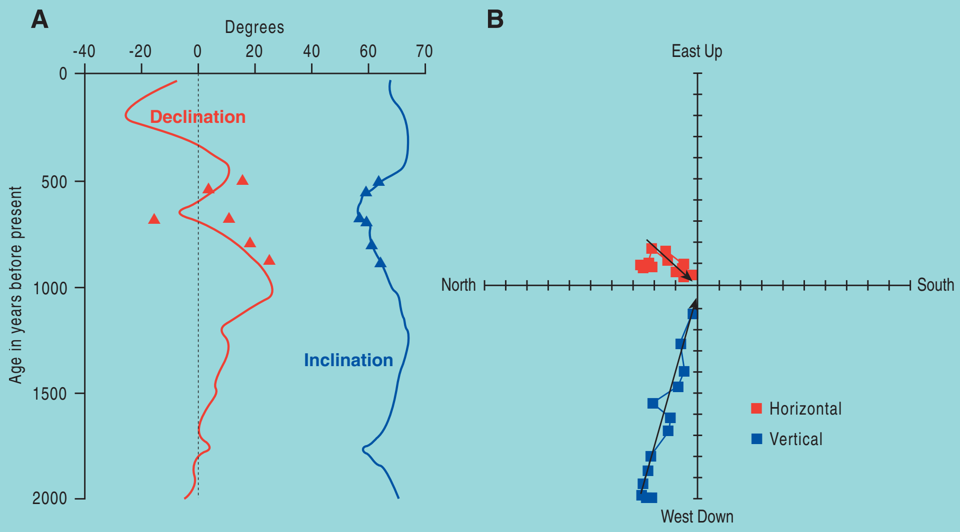
A Risø reader used for laboratory-based luminescence measurements

The sands underlying the gravel beach ridges of Dungeness and Rye Harbour were dated using OSL applied to sand-sized quartz grains. Samples of shoreface sand were taken by drilling to recover sediment cores, and the cores were sent to the luminescence laboratory at Aberystwyth for dating. The sand samples (for locations see core transect on page 7) proved sufficiently sensitive and responsive to enable well-resolved dating using OSL. The chronology for Dungeness places the early formation of the underlying shoreface at about 5000 years ago in the region of Broomhill, with progressively decreasing age to the east to approximately 2000 years ago beneath Denge Marsh, and 1000-600 years ago under the present ness. Similarly, the OSL age of the sands near Camber Castle at approximately AD 1400 compares well with documentary and cartographic evidence of coastal change.

Palaeomagnetic secular variation (PSV)

We also determined the ages of back-barrier marshland sequences of silt and clay using palaeomagnetic secular variation or PSV dating. Here, when fine-grained sediments are deposited in quiet-water or under low-energy conditions, the particles orientate themselves in the earth's magnetic field. This orientation, expressed in terms of inclination (azimuth) and declination (compass bearing), becomes locked into the sedimentary record so that sediments deposited 3000 years ago, for example, preserve the earth magnetic field around that time. Significantly, the earth's magnetic field has undergone changes in orientation and intensity through time, which is known as palaeomagnetic secular variation - PSV.

Figure A shows the PSV ages for marshland mud sequences in the topographic lows between the gravel beach ridges of Dungeness. These place the timing of marsh formation at 900-500 years ago. Figure B shows typical magnetic field orientation data for entire one metre long sections of marshland sediment, emphasising the rapid rate of deposition.



Carefully collecting an oriented sample core for PSV dating from Boulderwall Farm

By comparing the sequence of changing inclination and declination preserved in the sedimentary record with the known record of PSV during the Holocene, it is possible to determine when the marsh sediments were deposited. In our dating approach, the reference PSV record of the earth's magnetic field during the Holocene is that determined from pottery, hearths and lava flows, which is known as the archaeomagnetic record.

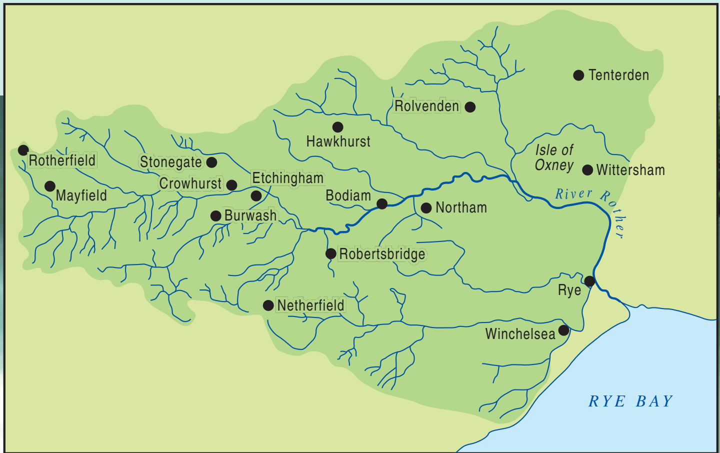
The PSV data from many of the marshland sediments from Dungeness show two important phenomena. First, values of inclination and declination change little down-core – thus confirming the rapid deposition rates determined from the sequence of tidal rhythmite thickness. Secondly, average values of inclination for marsh sediment sequences from different marshland sites provide an effective means for sediment dating by comparison with the archaeomagnetic record. Using this method, it appears that the marshland sediments interfingering with the gravel beach ridges in the region of Lydd ranges and Denge Marsh were deposited between 900 and 500 years ago, with sediments becoming younger in an easterly direction.

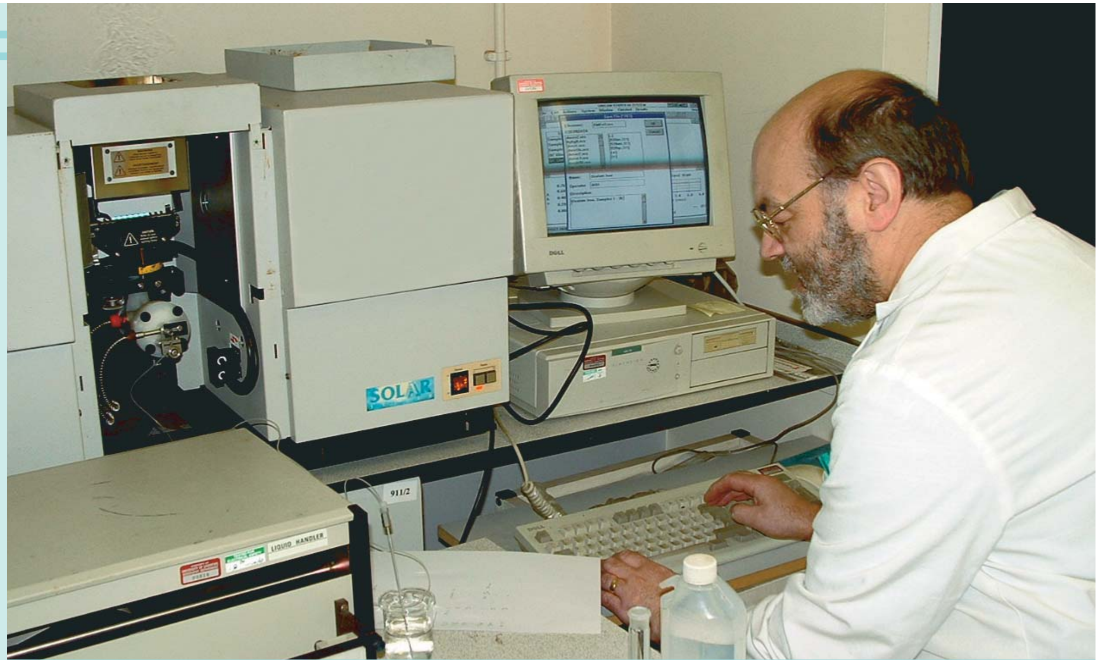
Sediment tracing

An important element of palaeoenvironmental reconstruction is to determine the causes of change. Whilst many stratigraphic, sedimentary and palaeoecological studies provide a wealth of information on the site and nature of deposition, the actual source of the sediment itself can remain undetermined. However, a number of techniques enable 'fingerprinting' of different sediment types, which may then be linked to corresponding properties in the potential source areas.

Two approaches used in this programme of research are X-ray fluorescence (XRF) and environmental magnetism. XRF enables the determination of metal concentrations. Hence, mineral matter can be categorized according to the concentration of various metals, such as Si, Zr, Ti, K, Ca, Pb and Zn. Similarly,

The catchment area of the River Rother. A significant proportion of the sediment that forms Dungeness Foreland and the back-barrier marshland may have originated from this area and been washed downstream to the coast

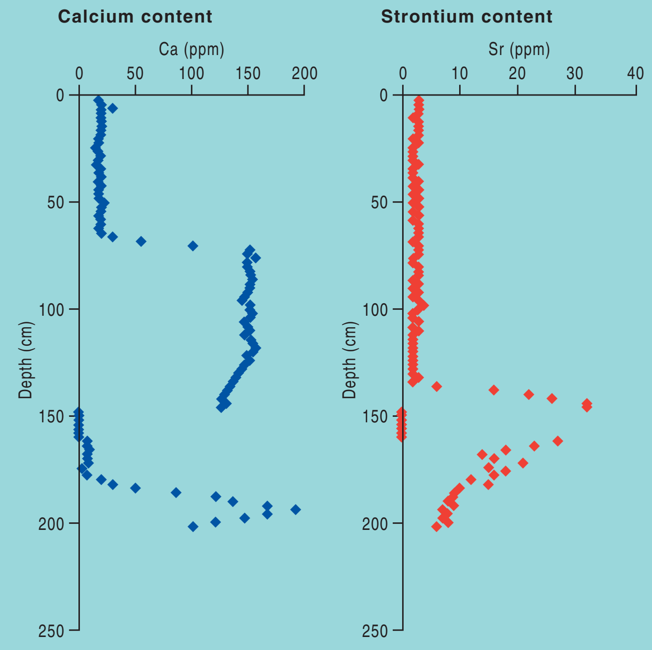




An x-ray fluorescence spectrophotometer, which is capable of measuring small quantities of different elements from sediment samples

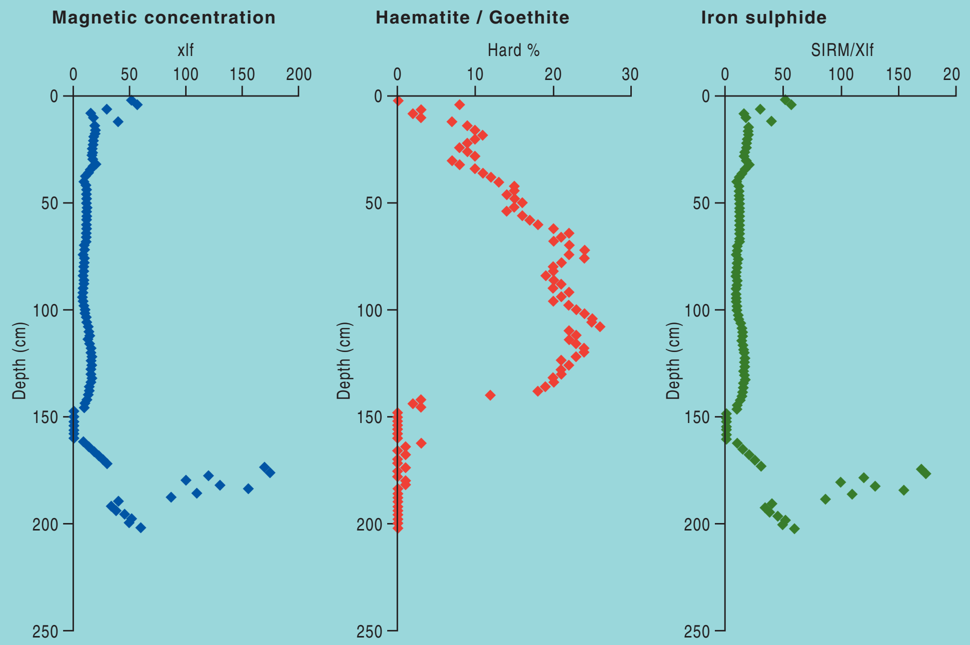
the magnetic properties of sediments, i.e. their magnetic concentration, magnetic mineralogy and magnetic grain-size, can also be used to identify suites of sediments that may then be traced to their sources through direct comparison. Changes in source area through time may then be related to human impact (e.g. clearance leaving the soil more susceptible to erosion), climate change (e.g. increasing river flow enhancing the supply of material from river bank erosion) or sea-level rise (e.g. catchment-derived material giving way to sediments supplied by the marine system).

We have applied both approaches in the studies of Dungeness and the Rye area. However, down-core changes in metal concentration and/or magnetic properties may not simply be a function of changing sediment source. For example, the plots overleaf show low concentrations of Ca and Sr beneath the present marsh surface, and indeed below the peat at about 150 cm depth in the region of Lydd. These changes can be linked to a process known as 'decalcification' where percolating groundwaters slowly dissolved the contained carbonate material, i.e. fossil marine shells trapped in the sediment. Similarly, the high magnetic concentration and change in magnetic mineralogy at the base of the same marshland sequence is due to the post-depositional formation of iron sulphide. These post-depositional factors are readily identified and, in fact, add to our palaeoenvironmental reconstructions of the back-barrier marshland environments.



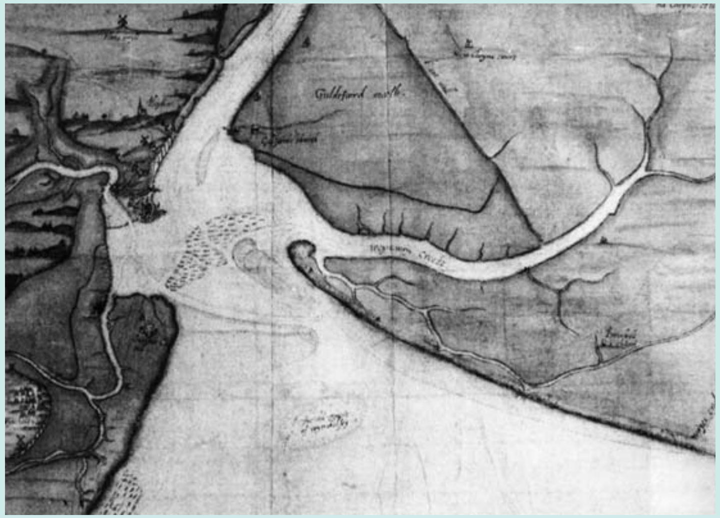
Calcium and strontium content is often linked to the proportion of shelly material in the sediment. Low concentrations of both Ca and Sr in the upper 60-70 cm of the sedimentary record is due to 'decalcification' where the shells have been dissolved by percolating water. The same phenomenon is illustrated below a thin peat layer at 150-160 cm depth.

The high magnetic concentration observed in the lower part of the sedimentary record is due to the presence of iron sulphide which forms after deposition in the presence of organic matter and low oxygen supply. In contrast, the high proportion of haematite and/or goethite in the upper metre or so is due to oxidation and marks the depth of the watertable during the summer (approx.140 cm).



Documents and maps

Although sediment-based investigations represented the main thrust of the reconstruction studies, the period of time under investigation was one of increasing human impact. As a result our palaeoenvironmental reconstructions were supplemented by archaeological and historical evidence – particularly charts, maps and documentary records of known events. These events include the nature and extent of human endeavour, such as the development of the Wealden iron industry, various phases of land claim and embankment works on the marshland and, of course, coastal erosion and flooding.



Inset of The Decayed Harbour of Rye *(Phillip Symondson, 1594). This shows the dramatic breach of the Rye barrier caused by the great storms of the 13th century. Camber Castle (see photograph overleaf) is located on the western entrance to the harbour. ESRO ACC 6364*

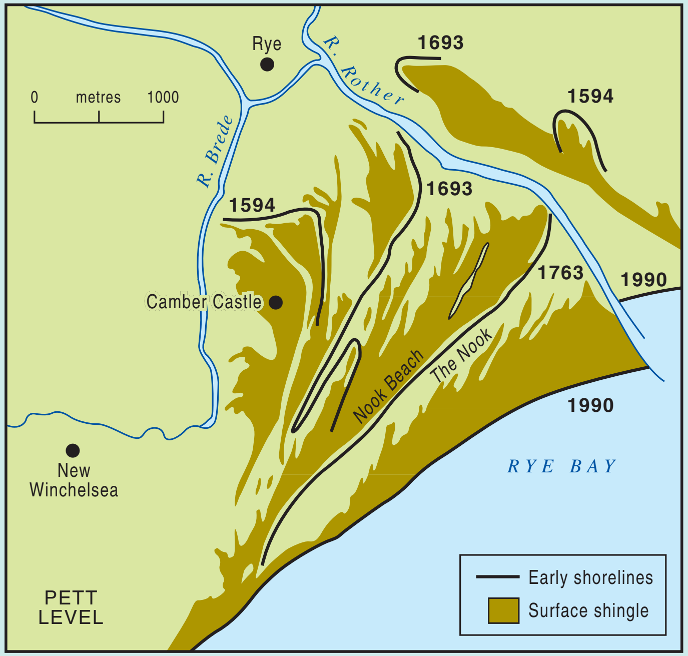
These different aspects are of crucial significance in the depositional history of Dungeness and, in particular, Rye. For example, the timing of clearance of the landscape for agriculture, or resource use for the iron industry may have had a significant impact on the supply of catchment-derived sediment to the coast. Similarly, the land claim and flood history are intimately entwined with the three-dimensional pattern of sedimentation in the back-barrier marshland, sudden changes in the nature and rate of sedimentation, and catastrophic changes in the shape of the coast and its tidal inlets.

A good example of the value of documentary records is provided by Matthew Paris in the Chronica Majora where the 13th Century storms are not only catalogued in terms of their occurrence, but also their extent and various impacts:

> *"At Winchelsea, a certain eastern port, besides saltcotes and the retreats of fishermen and bridges and mills, more than three hundred buildings were destroyed in that same district by the violent surge of the sea, as well as several churches. Holland in England, and Holland in the parts beyond the sea, suffered irreparable losses. The rivers issuing into the sea, were so throust back that they swelled, and destroyed meadows, bridges and crops which the barns had not received, and which were standing in the fields."*

The value of successive historical maps is also illustrated by the sequence of coastal change in the region of Camber Castle. Here, the early barriers on which Camber Castle was built can be seen extending into the newly-created Rye Bay between about AD 1400 and 1700. After this time, the direction of beach accretion switches to the formation of gravel beaches advancing to the south-east. As a result, the

Old shorelines and periods of gravel beach development near Camber Castle (after Lovegrove 1953)



Camber Castle (above) and abandoned saltmarsh creeks at Winchelsea (below)

sedimentary response to changing coastal shape and space for sedimentation can be determined, and the natural self-sustaining characteristics of the barrier beaches can be investigated.

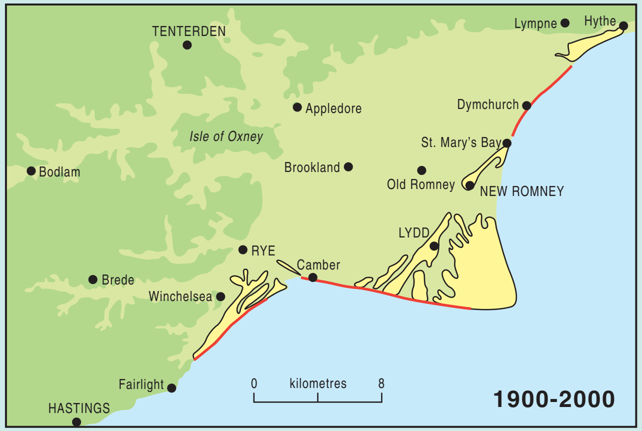
Palaeogeographic reconstruction

The pieces of the jigsaw provided by the research techniques and methodologies described above can be put together to provide not only the sequence of coastal change through time, but also to offer explanations. Such explanations, linked to causal factors such as climate change, sea-level rise, storm frequency and human activity, provide us with the means to understand and predict future coastal response. Too many decisions are made about our present coastal resources and living spaces based on short-term data. Indeed, we consider fifty years of coastal monitoring to be a short-term dataset, unable to capture the full consequences of changing sea-level or sediment supply, or temporal changes in the size and frequency of storms. Hence, our long-term data lay the foundation for appropriate, well-informed and sustainable management of the coast.

The nature and extent of change, as well as the factors and processes driving change, are best illustrated by maps of past environments and coastlines. In putting together a sequence of palaeoenvironmental maps, coastal change through time becomes tangible. An example of these maps illustrate the extent of gravel beach barrier breaching during the 13th Century storms and the growth of Dungeness into its present form.

Gravel beaches in Sussex

Historical shorelines of Rye Bay and Dungeness shown relative to the present (reproduced from RomnetMarsh.net, Eddison, 1998). The maps illustrate the formation of Rye Bay following breaching of the barrier by storms in the 13th Century. Since then, the deposition and redistribution of gravel has infilled Rye Bay and led to the growth of Dungeness Foreland. The red lines in the lowermost map shows the extent of sea defences



Main Project Findings

• *The age of Dungeness Foreland*

The deep boreholes drilled beneath Dungeness Foreland tell us the gravel beaches were deposited on a tidal sandflat that has extended eastward during the last 5000 years. The early beaches now lie buried by later marsh sediments beneath much of Broomhill Level, to the immediate east of Camber Sands. The first of the exposed gravel beaches at Jury's Gap, are dated to about 5000 years ago. These higher beaches have been flooded by occasional storms but never for long enough to be buried beneath marsh sediments. The wide swath of beaches between Jury's Gap and Brickwall Farm, that include Holestone and Lydd Beach (the current Ministry of Defence firing range), were deposited by about 2000 years ago. The most easterly beaches on Dungeness, including those on which the nuclear power station and lighthouses stand, formed in the last 1000 to 500 years. Much of the growth of Dungeness Foreland during the last 2000 years or so probably results from the erosion and reworking of a former complex of beaches that extended across Rye Bay. In particular, the storms of the 12th and 13th centuries resulted in widespread destruction and the transport of large volumes of sand and gravel in an easterly direction.

• *The marsh sediments on Dungeness Foreland*

Our work has also cast new light on the depositional history of the marsh sediments that are deposited between the gravel ridges and in the shelter of the gravel foreland. These sands, silts and clays were laid down rapidly by the tide, accumulating at about 50 cm per year in sheltered conditions as the gravel beaches built out in an easterly direction, or as a result of occasional breaching of the barrier by the sea. The age of these marsh sediments are oldest in the west and become younger in an easterly direction. Thus, in the Midrips and the Wicks, marsh sediments were deposited about 800 years ago, whilst those on Denge Marsh formed about 500 years ago. The geochemical and magnetic properties of the marsh sediments are characterised by significant overprinting following deposition and it is, therefore, difficult to use these properties to determine sediment source.

•*The Natural Pits*

The Natural Pits on Dungeness provide valuable information on past vegetation history and land-use practice on the foreland. The oldest of these (Wickmaryholm Pit) dates from about 1700 years ago when seawater percolated through the beaches and led to the formation of enclosed tidal ponds as the foreland extended eastward. The sediments preserved in these pits initially record a natural freshening trend as the marine influence receded and the lakes became wholly freshwater. The pollen records from pits of different age suggest that the foreland has largely been occupied by herbaceous vegetation with little evidence of the successional development of scrub. Our records from one site, Muddymore Pit, show that in early Medieval times rope manufacture was an important local industry.

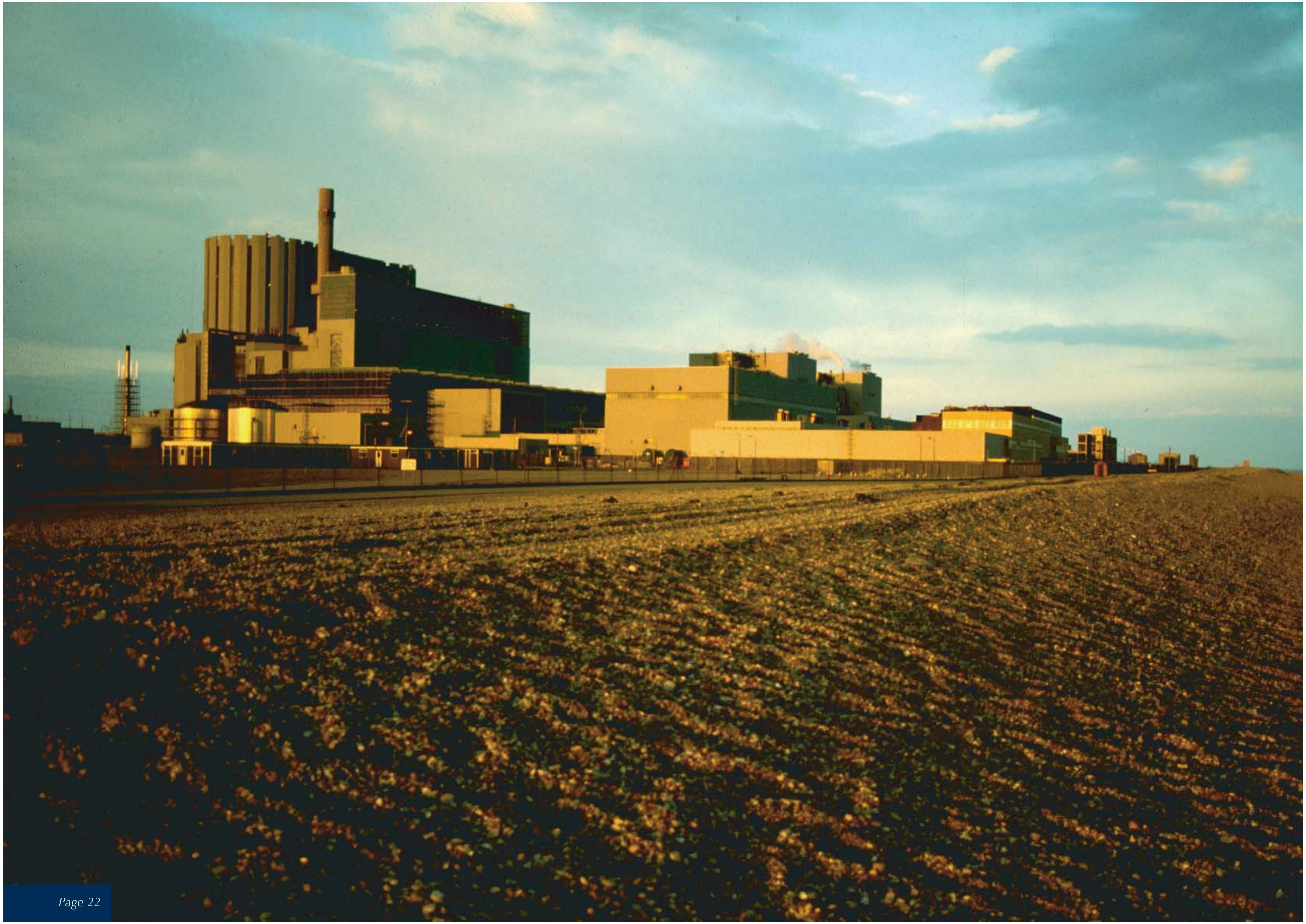
• *The flooding of Rye Harbour*

In the west of the study area, peat accumulation effectively ceased in the valleys and marshland adjacent to Rye by 3000 years ago, though a raised bog on Walland Marsh probably continued to grow into early Medieval times. In the former areas the upper surface of the peat is often truncated, either by erosion or peat cutting, and is overlain locally by slope-wash sediments. There is widespread evidence for flooding of these former freshwater wetlands by the sea during the last few thousand years.

A major effort has been made to date the timing of this inundation, and to see whether we could establish the impacts of the storms of the 12th and 13th centuries. Most radiocarbon dates from this peat surface range from 3400 to 1700 years ago due either to the slow rate of peat accumulation or the non-accumulation of peat in the period before marine flooding. Our ages from the peat surface, therefore, date the end of peat formation and not necessarily the timing of marine inundation. Despite this problem, we believe that most of the marine sediments were deposited as a consequence of breaching of the coastal barrier beaches in the Rye area. As flooding occurred, so the development of creek systems is likely to have promoted drainage of the peat, which, as it became dewatered, rapidly lost volume. This collapse of the peat provided the vertical space for 2-3 m or more of marine sediment to accumulate, often over only a very short period of time (a few decades to a few centuries).

Conclusions

Our work has demonstrated the highly dynamic nature of the Dungeness depositional complex. For at least the last 5000 years, the barrier beaches in the region have provided protection from the high energy of the open sea, creating protected environments in their lee where thick deposits of low energy organic and minerogenic sediments have accumulated. The work demonstrates the potential for major periods of instability and rapid shoreline change, most spectacularly that associated with the storms and coastal flooding of the 12th and 13th centuries. These changes have had profound impacts on the lives of people living on the coastal change as part of their daily lives. This work also has important implications for present and future management in the region. In particular, it highlights the comparative youth of the Dungeness Foreland, on which the nuclear power station sits, and underscores the propensity of this landscape to undergo major change. It also reminds us that as we increasingly seek to control, dominate and manage this landscape, so we underestimate the power of these natural processes at our peril.



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Further reading

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