BEACH PLAINS: FORMATION, EVOLUTION AND ECOLOGICAL SIGNIFICANCE

Edward J. Anthony
Coastal Geomorphology and Shoreline Management Unit, Université du Littoral Côte d'Opale, France

Keywords: coastal plains, progradation, beach ridges, swales, beach-plain hydrology, aquifer, weathering, beach-plain soils, beach-plain ecology.

Contents

Summary

Beach plains are coastal deposits, commonly of sand, and sometimes of gravel, forming flat or ridged accumulations whose crests generally lie a few metres above sea level. They occur in all types of wave, tidal and climatic settings wherever inherited environmental conditions have enabled the shoreward accumulation of wave-worked sediments.

Major beach plains generally form under conditions of abundant sediment availability that leads to progradation or seaward advance of the shoreline. Changes in the factors influencing the processes, patterns and rates of progradation of beach plains may be recorded in the morphology and depositional history of these deposits.

Beach-plain deposits, when cautiously analysed, may thus serve as valuable indicators of past environmental changes. This is especially the case of plains composed of beach

ridges, which, apart from serving as natural indicators of past shoreline positions, have been widely used as proxies for highlighting changes in various environmental conditions such as sea level, climate, sediment supply and wave directions and energy.

Beach-plain soils are generally poor in quality, because the parent sediments, composed predominantly of quartz sand, or gravel derived from various rock types, are subject to little weathering. These sediments commonly constitute remarkable life-supporting aquifers, and beach plains are thus biotopes for a wide range of plant and animal species.

The flat-lying lands of beach plains have attracted human settlements, and favoured subsistent and commercial agriculture, as well as industrial development in many areas. Beach plains are often associated with lagoons and marshes and thus offer higher-lying land for settlement in wetland areas. Because beach plains may also comprise linear beach ridges over long distances, they constitute suitable terrain for the establishment of routes in coastal wetland areas.

1. Introduction

Beach plains are accumulations of wave-deposited sand and/or gravel. They occur as flat or ridged deposits whose crests commonly lie a few metres above sea level. They form coastal barriers that impound lagoons, or plains that directly fringe land (see Figure 1). Beach plains differ from the beach itself (see *Sandy Beaches*), which is a component of still actively forming beach plains.

Beach plains occur on many coasts of the world wherever inherited environmental conditions have enabled the shoreward accumulation of sand or gravel derived from offshore sources, from rivers, and to a lesser extent, from eroding coastal cliffs. The largest beach plains commonly exhibit linear ridges alternating with linear depressions called swales (see Figure 2).

Beach ridges generally signify progradation, or advance, of the coast, under conditions of abundant sediment supply. While beach plains are commonly of Holocene to modern age, examples of Pleistocene beach plains may coexist on some coasts with Holocene plains, as in south-eastern Australia, Brazil and the southeast Alabama and northwest Florida coasts in USA. Gravel beach plains are less common than sandy plains but may form significant accumulations on mid- to high-latitude coasts.

They develop where loose heterogeneous sediments rich in gravel, cobbles or boulders, and derived from rivers with steep catchments, or from poorly consolidated coastal deposits, notably glacial material, have been abundantly available. The gravel in these beach plains is also commonly referred to as ‘shingle’.

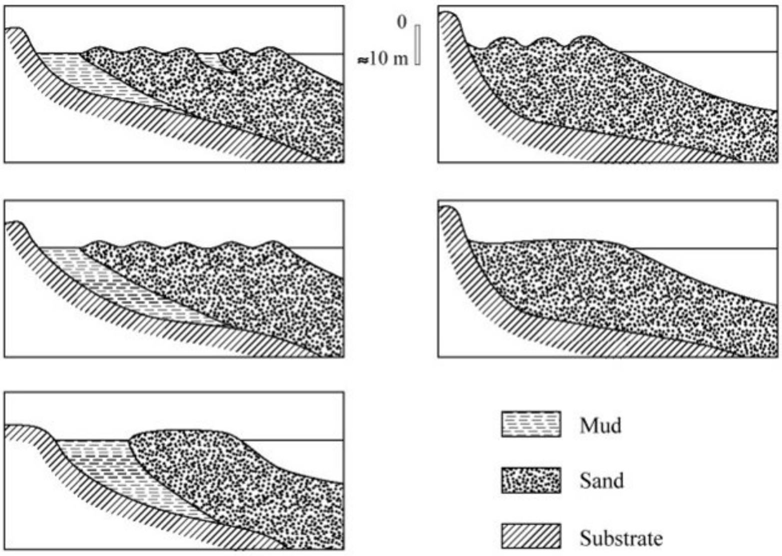

Figure 1. Idealized cross-sections of sandy beach plains. These low-lying deposits are either flat or ridged. They may or may not impound lagoons, the latter condition being much less common than that of beach plains associated with lagoons. Their width ranges from hundreds of metres to tens of kilometres.

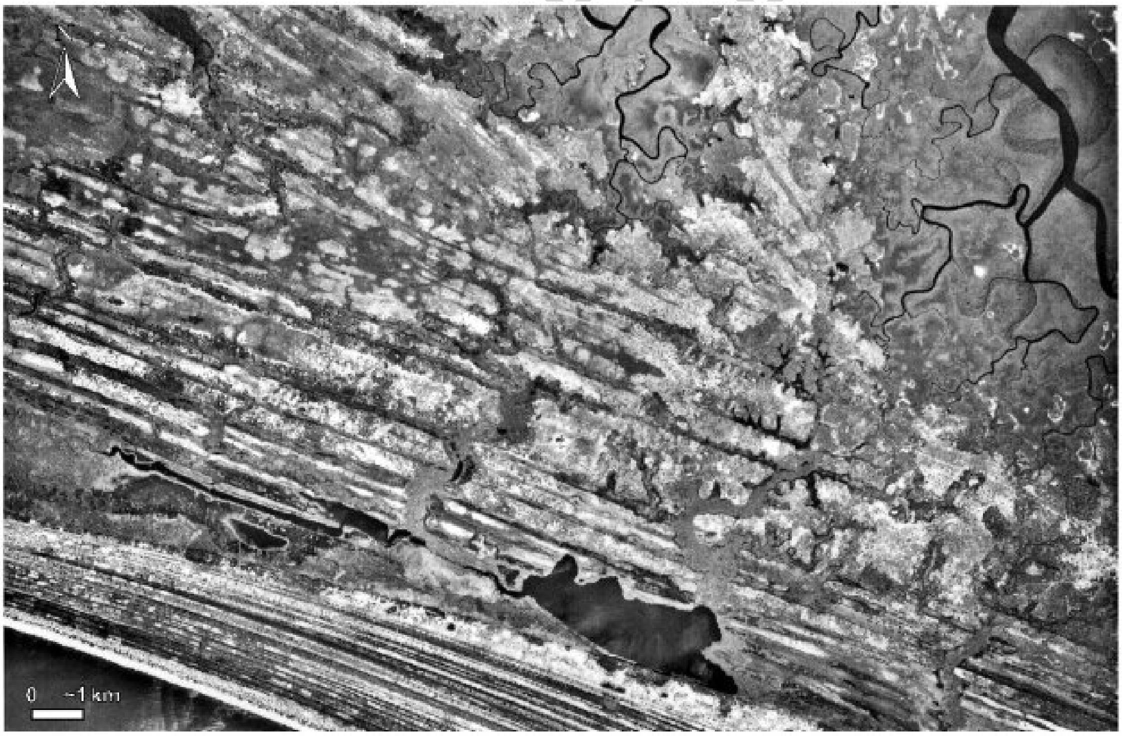

Figure 2. A sandy beach plain in Sierra Leone, West Africa, showing several sets of ridges and swales. The older sets inland have been considerably eroded by tidal channels and by post-formational modifications related to processes such as rain wash, rill wash and gullying.

Beach-plain sediments are deposited by waves. Beach plains are thus found on wave-dominated coasts, in all tidal range environments, from low to high. These plains are also sensitive to any environmental changes likely to induce variations in sediment supply. Changes in the factors influencing the processes, patterns and rates of progradation of beach plains may be recorded by variations in the morphology, internal structures and depositional history of these forms. These factors include sea level, climate, wave energy, wave direction, and sediment supply. Although beach-plain morphological variations may serve as valuable indicators of past environmental changes, they need to be cautiously analysed in order to avoid erroneous interpretations of such changes.

Beach plains may comprise aeolian dune systems wherein the sand deposited by waves is reworked by winds to form distinct accumulations. The morphology, dynamics and ecological status of dunes are not treated in this contribution. Beach plains may also be associated with barrier islands, which are linear deposits of sand cut by tidal inlets that are linked to a back-barrier lagoon. Barrier islands, which are treated in a separate contribution (see *Coastal Barriers*) support some of the most developed coasts in the world, especially along the east seaboard of USA. Beach plains differ from ‘chenier plains’. These are plains that develop on shores that receive large volumes of muddy sediments on which are periodically built individual ridges or ridge bands of sand, shells or gravel. These ridges are thus fronted and backed by mudflats and marshes. Examples abound on many muddy coasts fed by high-discharge deltas such as the Amazon, the Huang Ho, the Mississippi, and the Mekong. Chenier plains also occur on humid tropical coasts with low wave energy such as the Guinea coasts of West Africa. Transitions from beach to chenier plains are rare. Examples are found on the northeast coast of Brazil and in Australia.

Beach plains generally consist of quartz-rich sand, or gravel commonly derived from a wide variety of source rocks. The most common are limestone, chalk, sandstones, slates and shale. Beach plains may display acid soils subject to high infiltration rates. Some beach plains may involve significant fractions of whole or comminuted shells that mitigate soil acidity. Soil forming processes on these beach plains may also be conditioned strongly by the depth to the water table which depends on topography and on rates and patterns of drainage. In spite of their generally poor soil quality, beach-plain deposits are commonly remarkable aquifers and thus constitute biotopes for a wide range of plant and animal species.

Since time immemorial, beach plains have attracted human settlements, as the numerous kitchen middens of Holocene age found on beach plains world-wide attest. Beach plains are often associated with river floodplain, lagoon and marsh systems (see Figure 2) and thus offer higher-lying flat land for settlement in areas surrounded by wetlands. They are advantageous sites in terms of activities related to sea resources, notably fishing and maritime transport. Changes in shoreline positions related to the retreat or progradation of beach plains have correlatively resulted in abandonment of villages and in threats to modern settlements. The increasing attractiveness of coastal zones world-wide has also meant that beach plains have come under considerable pressure from both settlements and exploitation of their resources as well as those of the sea. In addition to settlements and routes, beach plains offer space for various activities such as farming, plantations, and recreation. Beach-plain sediments are commonly exploited for ballast, various industrial uses and construction. Several big cities and ports, and numerous villages, are located on prograded sandy beach plains. The most remarkable examples are the string of ports and capital cities in the Gulf of Guinea in West Africa. These include Grand Bassam and part of Abidjan (Ivory Coast), Lomé (Togo), Cotonou (Benin) and Lagos (Nigeria). In such cities, the enormous pressure on beach plains is expressed by the development of sprawling suburban zones that may impinge on low-lying marshy areas, resulting in insalubrious conditions and precarious hygiene (see Figure 3). The linear beach ridges that are commonly associated with beach plains (Figure 2) also serve as lines for the establishment of routes in such marshy coastal areas. However, highly pronounced topographic variations involving narrow beach ridges and low-lying humid swales may hinder large-scale human exploitation of beach plains. In many areas, the excellent aquifers in beach plains are the main sources of water supplies for many big cities, such as those mentioned above, as well as for numerous villages surrounded by brackish-water lagoons. These aquiferous qualities are a major condition that explains the life-support value of beach plains. Gravel beach plains also contain significant aquifers. A fine example is Dungeness foreland in southeast England (see Figure 4), one of the world's largest accumulations of beach gravel (35 km^2), and an important aquifer used for public water supply.

Figure 3. Precarious habitat and insalubrious conditions related to suburban sprawl on a beach plain in Cotonou, the capital city of Benin, West Africa.

Figure 4. The gravel beach plain of Dungeness in south-eastern England. The linear ridges are highlighted by the sparse vegetation of prostrate broom (*Cystis scoparius spp. maritimus*). In the background can be seen a fishing village and the outline of the Dungeness nuclear power station shrouded in mist.

Understanding the way beach plains form and how their morphology, hydrology, soils and vegetation interact are thus important with regard to the life-support value of these coastal plains. These relationships are examined following a review of the morphology, the sediment composition, the sediment supply conditions and the modes of progradation of beach plains.

2. Beach-plain stratigraphy and morphology

Beach plains are commonly referred to as 'strand plains' because their progradation results in the formation of a flat, low-lying coastal or 'strand' plain. These plains may range in width from hundreds of metres to several tens of kilometres, depending on the importance of past progradation. It is useful to distinguish between small beach plains, generally a few tens of metres to a few kilometres long, commonly niched in small coastal bays, and large, 'open-coast' beach plains which prograde in large embayments, re-entrants or rectilinear coasts and which may be in the range of tens of kilometres to several hundreds of kilometres long. The former generally constitute bay-fill deposits or occur adjacent to estuaries. Such small beach plains may commonly lack back-plain lagoons or marsh systems and are quite common on all types of coasts and in all types of wave and climatic settings wherever abundant sand or gravel-sized material can be trapped in small bays. Wide 'open-coast' beach plains may also represent bay-fill deposits in large coastal embayments or re-entrants, and usually impound back-plain lagoons and marshes. They also commonly represent net seaward advance of the coast and are limited to the world's coastlines where massive sand supply has been available over long stretches of coast. This condition is most likely to be met on tectonically stable, tropical, wave-dominated coasts subject to low rates of falling sea level since the middle Holocene. These include the coasts of Brazil and West Africa, which comprise several hundreds of kilometres of prograded beach plains.

Beach plains may range in thickness from less than a metre to several tens of metres, depending on the morphological setting in which they accumulate and the rates of sediment supply. Stratigraphically, these plains form sandy or sandy/gravelly units typical of so-called ‘prograding barriers’. However, the processes of initial sediment translation towards the coast responsible for their subsequent progradation may be associated with coastal retreat under sea-level rise, a condition referred to as ‘transgressive’. Beach plains may overlie the inherited terrestrial basement. More commonly, they overlie sand and mud (see Figure 1) that generally accumulated in lagoon environments behind migrating sand and gravel barriers in some coastal systems as sea level rose during the Holocene. In rare cases, the beach plain may form over a shallow carbonate platform. Beach plains up to 35 m thick have been reported from some of the barrier systems in Australia where high wave energy levels have driven massive amounts of sand onshore for coastal progradation. Lower wave energy systems on the West African coast exhibit less thick (10 to 15 m) beach plains.

Beach plains generally have elevations a few metres above mean high tide in areas where sea level has been relatively stable. Although the surface expression of these plains may vary from flat to ridged, totally flat beach plains are relatively rare, because of the specific hydrodynamic processes, briefly discussed below, involved in adding new sediment to an existing prograding beach face. Most often, beach plains show very mild to pronounced ridging. Pronounced ridge-and-swale morphology, quite distinct on aerial photographs (Figure 2), may limit large-scale occupation of beach plains, because of the topographic variations and stagnant water or humid conditions that sometimes prevail in the swales.

Each ridge-and-swale couplet represents a former beach and its immediate foreshore stranded by coastal progradation. Beach ridges form the most widespread and most commonly described type of beach-plain morphology. The ridge-and-swale morphology may become progressively obliterated by rain and rill wash processes in humid areas. Beach plains may undergo reworking and recycling of their sediment into estuaries, lagoons and rivers (Figure 2) by associated drainage networks and channel meandering. Ridge-and-swale morphology, and morphological variations, either related to formational differences in height and beach-ridge sets, or to post-formational erosion and dissection by channels or runoff drains, are of importance in soil development and heterogeneity in beach plains.

Beach plains in small embayed settings may occur as monotonous deposits in terms of their plan-view morphology. Often, however, such plains typically comprise set(s) of ridges. Each set may exhibit a distinct plan-view pattern or distinctive morphological and sediment characteristics that imply medium (order of tens to hundreds of years) to long-term (order of thousands of years) coastal changes, and notably variations in the loci of accumulation and erosion due to changes in sediment balance. These aspects are discussed in the next section.

-
-
-

TO ACCESS ALL THE **23 PAGES** OF THIS CHAPTER,
Visit: http://www.eolss.net/Eolss-sampleAllChapter.aspx

Bibliography

Anthony E.J. (1985). Geomorphology, water table and soil relationships in Holocene beach ridges in southern Sierra Leone. *Catena* 12, 167-178. [This is a rare case study of the influence of beach-plain topography and drainage conditions on beach-plain soils in a humid tropical setting].

Anthony E.J. (1995). Beach-ridge progradation in response to sediment supply: examples from West Africa. *Marine Geology* 129, 175-186. [This gives good coverage of beach plains in West Africa and the fundamental influence of sediment supply on their development].

Dominguez J.M.L., Bittencourt A.C.S.P. & Martin L. (1992). Controls on Quaternary coastal evolution of the east-northeastern coast of Brazil: roles of sea-level history, trade winds and climate. *Sedimentary Geology* 80, 213-232. [This is an interesting synthesis on the geological development of the beach plains that cover long stretches of the north coast of Brazil].

Mason O.K. (1993). The geoarchaeology of beach-ridges and cheniers: studies of coastal evolution using archaeological data. *Journal of Coastal Research* 9, 126-146. [This represents a critical survey of the use of beach ridges in interpreting archaeological data and environmental change]

Orford J.D. Carter R.W.G. & Jennings S.C. (1996). Control domains and morphological phases in gravel-dominated coastal barriers of Nova Scotia. *Journal of Coastal Research*) 12, 589-604. [This is a good synthesis on the morphological development of gravel beach plains].

Packham, J.R., Randall, R.E., Barnes, R.S.K. & Neal, A. (editors), (2001). *Ecology and Geomorphology of Coastal Shingle*. Westbury Academic and Scientific Publishing, Otley, West Yorkshire. [This volume contains useful case studies (including on Dungeness) of the geomorphology and ecology of temperate gravel beach plains, and of vegetation adaptations to the specific environmental conditions].

Short, A.D. (editor), 1999. *Beach and Shoreface Morphodynamics*. Chichester: Wiley and Sons. [This is a useful volume with chapters related to relationships between beach morphodynamics and aspects of long-term beach-plain development].

Taylor, M. & Stone, G.W., 1996. Beach-ridges: a review. *Journal of Coastal Research* 12, 612-621. [This represents a treatment of various aspects relating to the interpretation of beach ridges].

Thom, B.G., 1984. Transgressive and regressive stratigraphies of coastal sand barriers in southeast Australia. *Marine Geology* 56, 137-158. [This represents a synthesis on the geological development of the beach plains that form significant accumulations on the southeast coast of Australia].

Biographical Sketch

Edward Anthony is Professor of Physical Geography, leader of the Coastal Geomorphology and Shoreline Management Unit, and head of Post-Graduate Studies at the Université du Littoral Côte d'Opale in France. He has done extensive research on coastal geomorphology, sediment dynamics and shoreline management in various areas, notably northern France, the French Riviera, West Africa and most recently French Guiana. He has a record of national and international publications on sand and gravel beaches, beach ridges, estuaries, sediment transfers and sediment cell dynamics. He is a member of the editorial board of the *Journal of Coastal Research* and has reviewed many articles for various international and national journals. He has obtained various regional and national research grants, is involved in several research networks in Europe, and has successfully directed several PhD candidates since 1993.