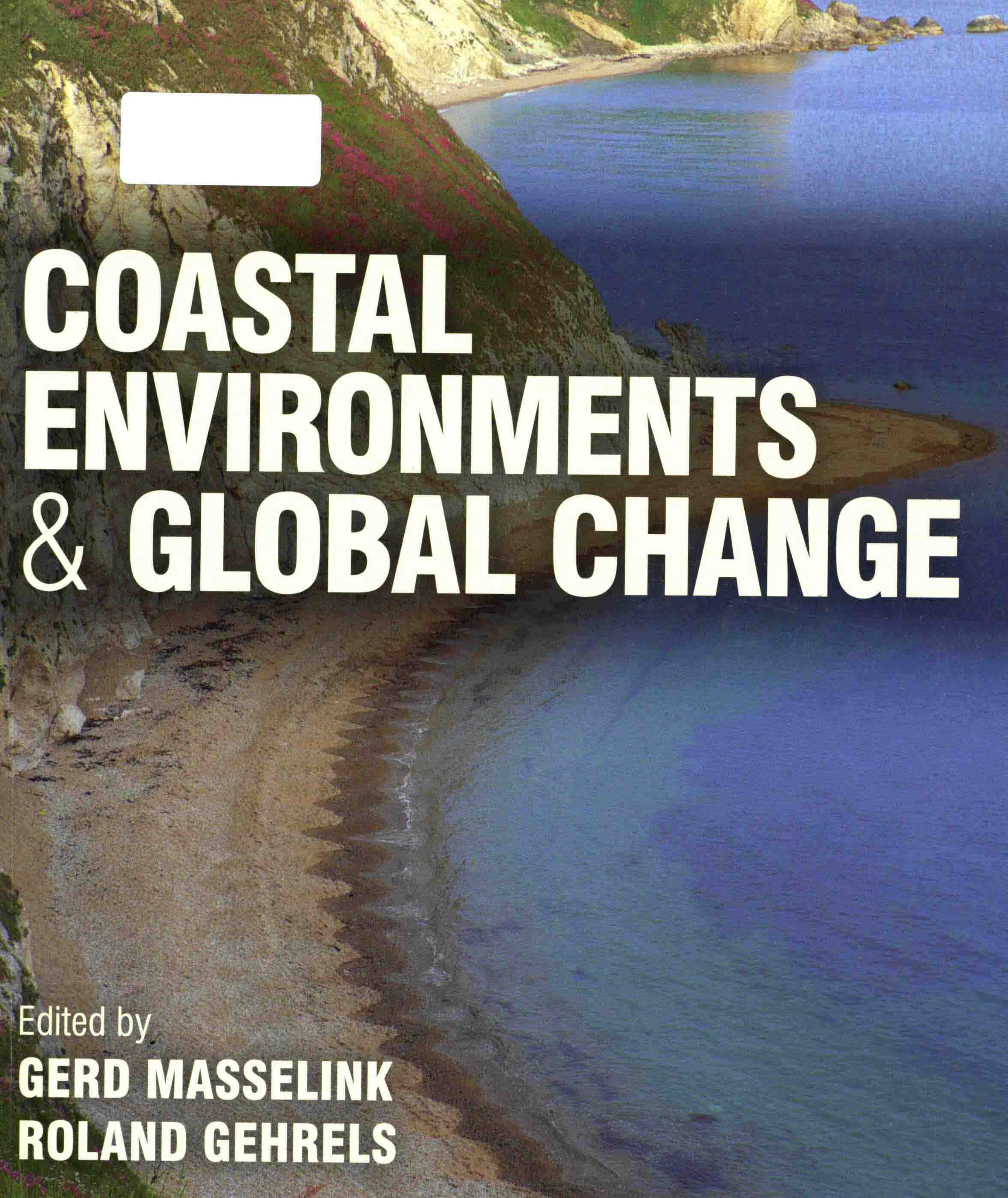

COASTAL ENVIRONMENTS & GLOBAL CHANGE

Edited by

GERD MASSELINK
ROLAND GEHRELS

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Coastal Environments and Global Change

Edited by

Gerd Masselink

School of Marine Science and Engineering
Plymouth University
Plymouth
UK

and

Roland Gehrels

Environment Department
University of York
York
UK

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COASTAL ENVIRONMENTS AND GLOBAL CHANGE

Contributors

WILLIAM P. ANDERSON, JR. *Department of Geology, Appalachian State University, Boone, NC, USA*

EDWARD J. ANTHONY *Aix Marseille Université, Institut Universitaire de France, Europôle Méditerranéen de l'Arbois, Aix en Provence Cedex, France*

DANIEL C. CONLEY *School Marine Science and Engineering, University of Plymouth, Plymouth, UK*

DUNCAN FITZGERALD *Department of Earth and Environment, Boston University, Boston, MA, USA*

ROLAND GEHRELS *Environment Department, University of York, York, UK*

IOANNIS GEORGIOU *Department of Earth and Environmental Sciences, University of New Orleans, New Orleans, LA, USA*

SYTZE VAN HETEREN *Geological Survey of the Netherlands, Utrecht, The Netherlands*

PAUL KENCH *School of Environment, The University of Auckland, Auckland, New Zealand*

AART KROON *Center for Permafrost (CENPERM), Department of Geosciences and Natural Resource Management, University of Copenhagen, Copenhagen, Denmark*

CATHERINE E. LOVELOCK *The School of Biological Sciences, The University of Queensland, St Lucia, QLD, Australia*

GERD MASSELINK *School of Marine Science and Engineering, Plymouth University, Plymouth, UK*

GLENN A. MILNE *Department of Earth Sciences, University of Ottawa, Ottawa, Canada*

MICHAEL MINER *Marine Minerals Program, Bureau of Ocean Energy Management, Gulf of Mexico Region, New Orleans, LA, USA*

ROBERT J. NICHOLLS *Faculty of Engineering and the Environment and Tyndall for Climate Change Research, University of Southampton, Southampton, UK*

KARL F. NORDSTROM *Institute of Marine and Coastal Sciences, Rutgers – the State University of New Jersey, New Brunswick, NJ, USA*

ROSHANKA RANASINGHE *Department of Water Science Engineering, UNESCO-IHE, Delft, The Netherlands*

KERRYLEE ROGERS *School of Earth and Environmental Sciences, University of Wollongong, Wollongong, NSW, Australia*

GERBEN RUESSINK *Department of Physical Geography, Faculty of Geosciences, Institute for Marine and Atmospheric Research Utrecht, Utrecht University, Utrecht, The Netherlands*

WAYNE STEPHENSON *Department of Geography, University of Otago, Dunedin, New Zealand*

MARCEL J.F. STIVE *Faculty of Civil Engineering and Geosciences, Delft University of Technology, Delft, The Netherlands*

ADAM D. SWITZER *Earth Observatory of Singapore, Nanyang Technological University, Nanyang Avenue, Singapore*

RICHARD S.J. TOL *School of Economics, University of Sussex, Brighton, UK*

COLIN D. WOODROFFE *School of Earth and Environmental Sciences, University of Wollongong, Wollongong, NSW, Australia*

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The website includes:

- Powerpoints of all figures from the book for downloading
- PDFs of tables from the book

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1 Introduction to Coastal Environments and Global Change

GERD MASSELINK[1] AND ROLAND GEHRELS[2]

[1]*School of Marine Science and Engineering, Plymouth University, Plymouth, UK*
[2]*Environment Department, University of York, York, UK*

1.1 Setting the scene

1.1.1 What is the coastal zone?

At the outset of this book, it is important to articulate clearly what we mean by 'coast', because the term means different things to different people. For most holidaymakers, the coast is synonymous with the beach. For birdwatchers, the coast generally refers to the intertidal zone; while for cartographers, the coast is simply a line on the map separating the land from the sea. Coastal scientists and managers tend to take a broader view.

According to our perspective, the coast represents that region of the Earth's surface that has been affected by coastal processes, i.e. waves and tides, during the Quaternary geological period (the last 2.6 M years). The coastal zone thus defined includes the coastal plain, the contemporary estuarine, dune and beach area, the shoreface (the underwater part of the beach), and part of the continental shelf and, in areas of isostatic or tectonic uplift, fossil raised shorelines (Fig. 1.1). At a first glance, it seems rather arbitrary and perhaps odd to take such a long-term view of the timescale involved with coastal processes and geomorphology. However, as we will see later (Chapter 2), the Quaternary was a period characterized by significant changes in sea level. In the past, eustatic, or global, sea level has been considerably lower than at present (>100 m) during cold glacial periods, but also somewhat higher (up to 10 m) during some of the warm interglacial periods. This implies that coastal sediments and landforms have the potential to extend considerably beyond the zone of contemporary coastal processes. In areas of former glaciations, where isostatic processes have caused crustal uplift, fossil coastal landforms can be found far above the present shoreline (Fig. 1.2a). Similarly, in tectonically active coastal areas, fossil shorelines can also be significantly displaced (Fig. 1.2b). In a lateral sense our definition means that the coastal zone can span hundreds of kilometres, especially

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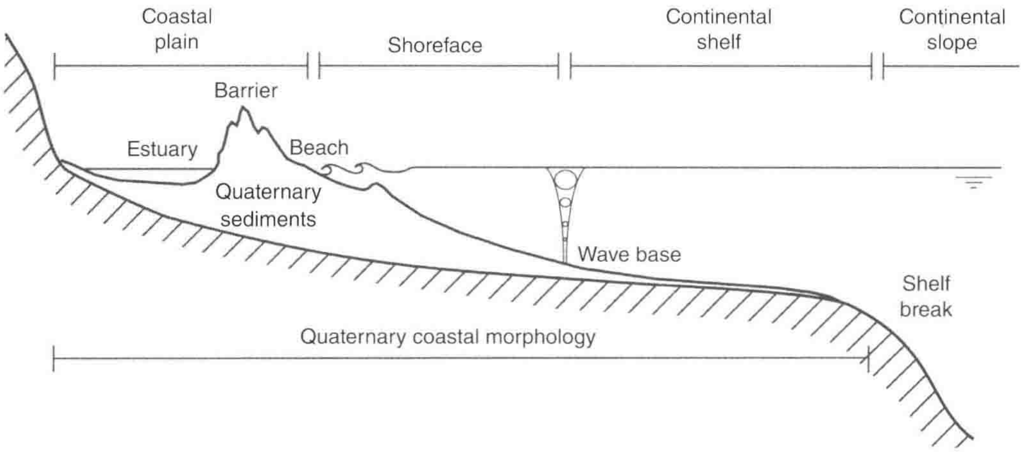

Fig. 1.1 Spatial extent of the coastal zone, including the coastal plain, shoreface and continental shelf. Note that the widths of these zones are globally highly variable. (Source: Masselink et al. 2011. Reproduced with permission of Hodder & Stoughton Ltd.)

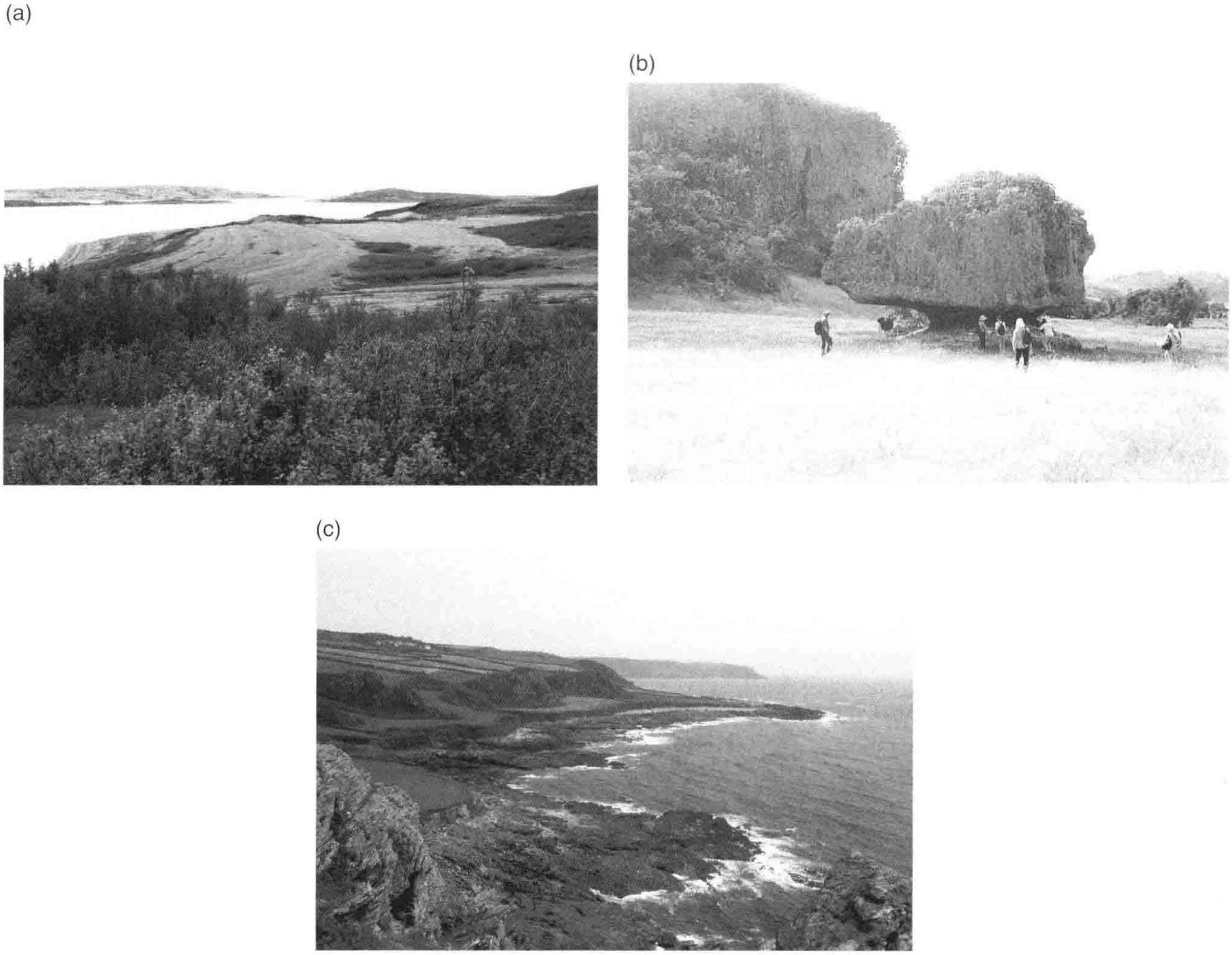

Fig. 1.2 (a) Postglacial raised beaches at Porsangerfjord, Finnmark, Norway; (b) fossil coastal notch in Barbados formed in the last interglacial (c. 125,000 years ago) and raised above sea level by tectonic processes; and (c) view from Prawle Point (south Devon, UK) looking east, showing an apron of periglacial solifluction deposits emplaced on a raised shore platform presumed to date to the last interglacial. The fossil interglacial sea cliff is also visible. (Source: Photographs by Roland Gehrels.)

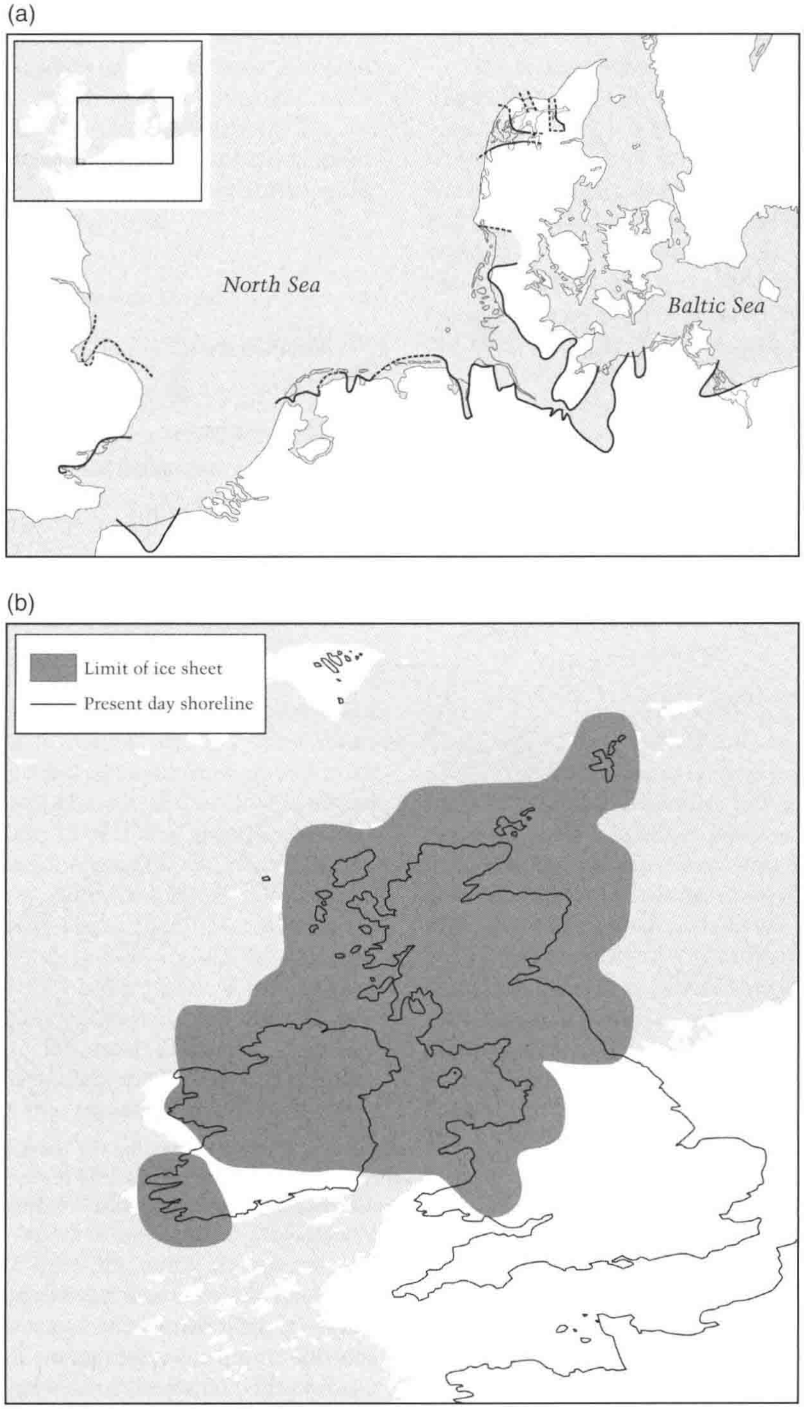

Fig. 1.3 (a) Coastline around the North Sea during the last interglacial, around 125,000 years ago (Source: Adapted from Streif 2004. Reproduced with permission of Elsevier); and (b) land area (in white) around the British Isles during the Late Glacial Maximum, around 20,000 years ago (Source: Adapted from Brooks et al. 2011).

in areas with broad continental shelves and shallow seas. For example, Fig. 1.3a shows the position of the coastline in northwest Europe during the last interglacial when sea level was several metres higher than today. During the Last Glacial Maximum the shoreline was close to the present-day continental shelf edge (Fig. 1.3b). Because coastal evolution is cumulative, i.e. the contemporary coastal landscape is partly a product of coastal processes and landforms in the past (Cowell and Thom, 1994), we need to take this long-term perspective.

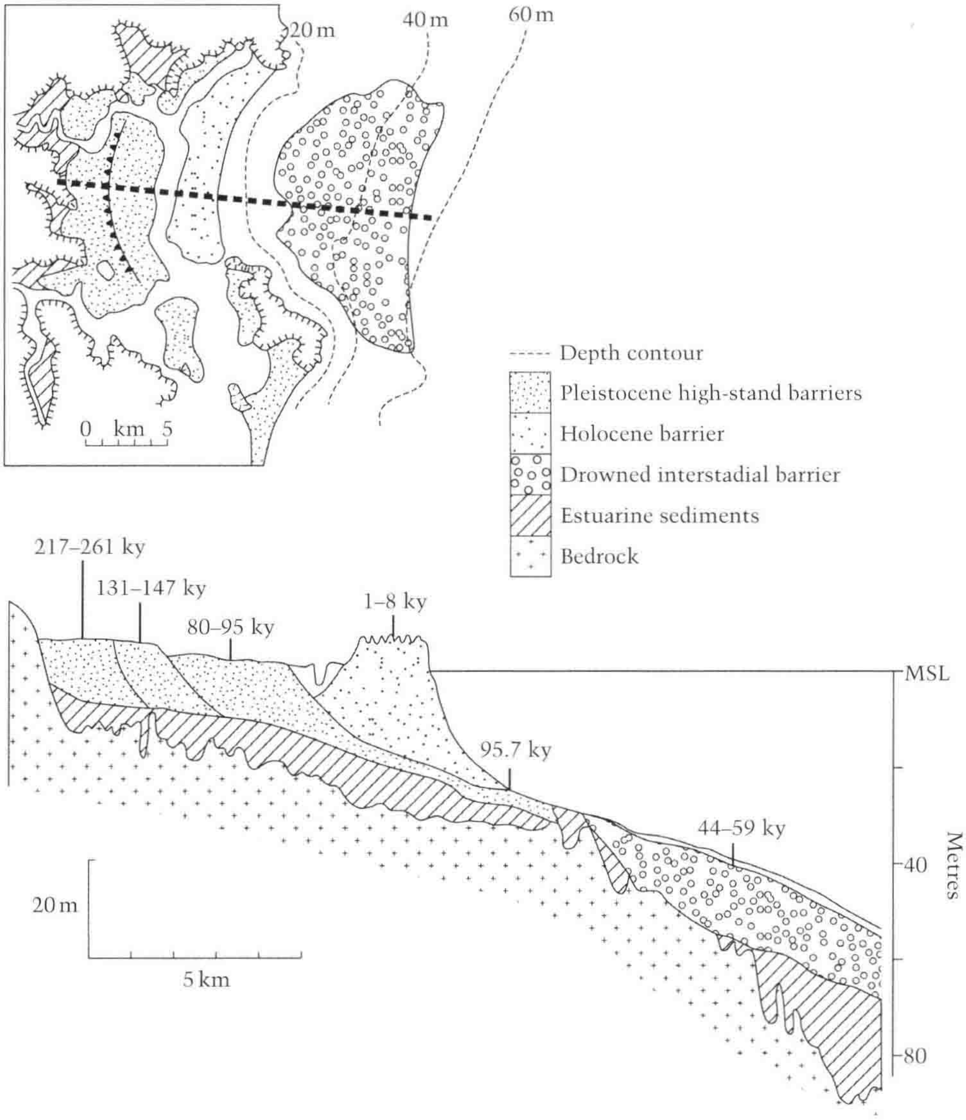

Fig. 1.4 Coastal morphology of the Tuncurry embayment, New South Wales, Australia, showing the presence of five barrier systems: the contemporary barrier, a drowned barrier on the inner shelf, and three high-stand barriers. Each of these barriers is of a different age and formed at a different relative sea level. MSL, mean sea level. (Source: Adapted from Roy et al. 1994. Reproduced with permission from Cambridge University Press and Masselink et al. 2011.)

Figure 1.4 shows an interpretive map and cross-section of the Tuncurry embayment in New South Wales, Australia. Here, research has demonstrated the presence of at least five coastal barrier systems of various ages (see Chapter 8), each of which is associated with a different sea level (Roy et al., 1994). In addition to the contemporary barrier system, there are three so-called highstand barriers to the landward (ages c. 240ky, 140ky and 90ky BP) and one drowned barrier system to the seaward on the continental shelf (age c. 50ky BP). To understand fully the dynamics of the present barrier system, in addition to contemporary coastal processes and sea level, the evolution and configuration of these older barriers also have to be taken into account. For example, the drowned barrier system can supply (and probably has supplied) sediment to the contemporary barrier, whereas the highstand barriers have provided the substrate on which the present-day barrier has developed.

Figure 1.2c shows a scenic view from Prawle Point in Devon, UK. At this location, periglacial solifluction deposits (locally known as 'head') were emplaced during the last glacial period on a raised shore platform that formed during the preceding interglacial when sea level was several metres higher than present. The 'head' is an important sediment source for contemporary beaches, while rocky shore platforms are re-occupied during consecutive interglacial highstands. So here also, present-day coastal geomorphology is significantly affected by past coastal processes and landforms. In fact, erosional coastal features, especially when carved into resistant rocks, are often polygenetic (i.e. the product of more than one sea level) and rocky coast morphology can rarely be explained solely in terms of contemporary processes and sea level (Trenhaile, 2010).

1.1.2 Coastal zone and society

The coastal zone, representing the interface between the land and the sea, is of interest to a range of coastal scientists, including geographers, geologists, oceanographers and engineers. Societal concern and interest are, however, concentrated on that area in which human activities are interlinked with both the land and the sea. This area of overlap is referred to as the 'coastal resource system' and is of great societal importance, often serving as the source or backbone of the economy of coastal nations. The most obvious use of the coastal zone is providing living space, and the coast is clearly a preferred site for urbanization. For example, 23% of the global population currently live within 100 km of the coast and less than 100 m above sea level. Population density in coastal areas is three times larger than average, and projected population growth rates in the coastal zone are the highest in the world (Small and Nicholls, 2003). In addition, 21 of the 33 megacities (cities with more than eight million people; the projected top five for 2015 are Tokyo, Mumbai, Lagos, Dhaka and Karachi) can be considered coastal cities (Martinez et al., 2007). It is worth pointing out, however, that the dynamic definition of the coastal zone at the start of this section (based on sediments, sea-level history and coastal processes) is different from the static definition generally used by planners and demographers, based on some arbitrary distance from the coastline and/or elevation above sea level.

Human occupation is, however, but one of many uses of the coastal resource system and an extraordinarily wide range of resources and activities essential to our society take place in the coastal zone, including navigation and communication, living marine resources, mineral and energy resources, tourism and recreation, coastal infrastructure development, waste disposal and pollution, coastal environmental quality protection, beach and shoreline management, military activities and research (Cicin-Sain and Knecht, 1998). Unfortunately, there can be fierce competition for coastal resources by various users (or stakeholders) and these may result in conflicts, and possible severe disruption, or even destruction, of the functional integrity of the coastal resource system. Such conflicts are especially prevalent in the case of incompatible uses of the coastal zone (e.g. land reclamation versus nature conservation; coastal protection versus tourism; waste disposal versus fisheries).

The dramatic growth in coastal population and uses has placed increased pressure on the coastal resource system and has led, in many cases, to severely damaged coastal ecosystems and depleted resources. In addition, overdevelopment of the coast in terms of urbanization and infrastructure has significantly increased our vulnerability to coastal erosion and flooding, whilst at the same time the increased reliance on hard coastal engineering structures for coastal protection has reduced our resilience. To make matters worse, global climate change resulting in a rise in sea level and potentially an increase in storminess (or at least a change in wave climate) will provide additional pressure on the coastal zone. An integrated approach is required for the management of activities and conflicts in the coastal zone (Integrated Coastal Zone Management, ICZM; see section 7.4 and Chapter 17), but what is also essential, is a thorough understanding of the key processes driving and controlling coastal environments.

1.1.3 Scope of this book and chapter outline

The focus of this book, therefore, is to provide a description of the various coastal environments, including their functioning and governing processes, and also to evaluate how they might be affected by global change and how coastal management may assist in dealing with coastal problems arising from climate change. To provide the theoretical framework and the scope of this book, this chapter will first discuss the dominant paradigm for coastal research ('morphodynamics'). This is followed by a summary of the dominant elements of climate change relevant to the coastal zone and finally a description of the various approaches used for modelling coastal change.

1.2 Coastal morphodynamics

1.2.1 Research paradigm

In science, the term 'paradigm' refers to the 'set of practices that defines a scientific discipline at any particular period of time' (Kuhn, 1996). It relates to the overall research approach adhered to by the majority of the researchers in a certain scientific discipline and encompasses a large number of elements, including methods of observation and analysis, the types of questions asked and the topics studied, the theoretical framework of the discipline, and even mundane issues such as the key scientific journal(s) of the discipline. In the vernacular, it can simply be translated as the most common way to study a subject or, even, the way a subject should be studied ('exemplar'). As a

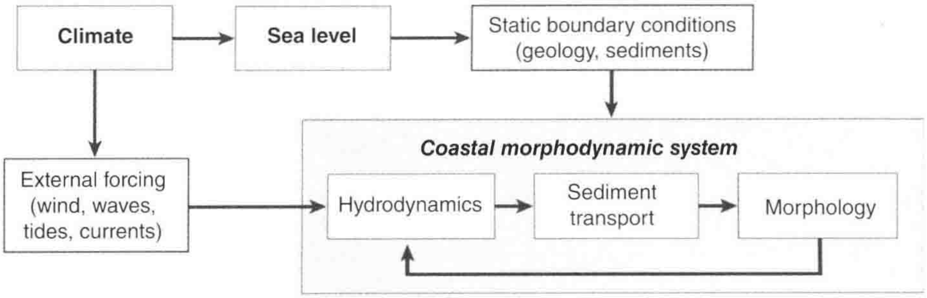

Fig. 1.5 Conceptual diagram illustrating the morphodynamic approach, showing the coastal morphodynamic systems and the environmental boundary conditions (sea level, climate, external forcing and static boundary conditions). (Source: Masselink 2012. Reproduced with permission from Pearson Education Ltd.)

discipline evolves over time, it is imperative that our knowledge and understanding thereof increases, concurrent with an increased sophistication of the research tools and analysis methods. As this happens, the relevant questions and methods of addressing these are likely to change as well; in other words, the paradigm changes. Thomas Kuhn (1922–1996), a leading philosopher of science, argued that science progresses by means of abrupt paradigm shifts, generally initiated by key scientific discoveries and/or novel research tools shedding new light on hitherto unobservable phenomena.

The dominant paradigm in coastal research up to World War II was observation and classification of coastal landforms, mainly in the context of geology and sea-level change, with coastal scientists primarily being concerned with describing and mapping the coast. During the 1950s and 1960s, the emphasis changed from observation to explanation, and this required a better understanding of the actual processes involved in driving and controlling coastal landforms and evolution. This development occurred right across the disciplines of geomorphology and physical geography, and is referred to as the process revolution (Gregory, 2000). A key tool of this paradigm was conducting actual measurements of (coastal) processes, either in the laboratory or in the field, and formulating empirical models and theories to explain these observations. Coastal landforms were very much considered the mere product of the processes, but it quickly became apparent that not only is the morphology shaped by processes, but it also provides feedback to these processes. In other words, the geomorphology is an active player, rather than a passive responder to the forcing, and has some degree of control over its own development. This notion initiated a new paradigm, referred to as the 'morphodynamic approach', and this approach was eloquently and comprehensively introduced to coastal geomorphologists by Wright and Thom (1977) in a benchmark paper in *Progress in Physical Geography* (ironically, a journal now rarely used as an outlet for coastal research).

There have been subsequent developments in geomorphology and physical geography that have contributed to a refining of the morphodynamic paradigm, involving concepts such as chaos theory and non-linear dynamics (Richards, 2003). However, these are all directly reliant on the key notion of mutual feedback between process and form, and are therefore not fundamentally different from the morphodynamic approach. It has been argued that the most current paradigm involves interactions between physical and socio-economic systems, and has materialized in a new scientific field: Earth System Science. Others maintain that this is merely a rebranding of the old discipline of Geography (Pitman, 2005). We leave such musings behind and focus on what the morphodynamic paradigm represents.

1.2.2 Coastal morphodynamic systems

According to the coastal morphodynamic paradigm, conceptualized in Fig. 1.5, coastal systems (e.g. salt marsh, beach, tidal basin) comprise three linked elements (morphology, processes and sediment transport) that exhibit a certain degree of autonomy in their behaviour, but are ultimately driven and controlled by environmental factors (Wright and Thom, 1977). These environmental factors are referred to as 'boundary conditions', and include the solid boundary (geology and sediments; Chapter 3), climate (section 1.3) and external forcing (wind, waves, storms, tides and tsunami; Chapters 4 and 5), with sea level (Chapter 2) serving as a meta-control by determining where coastal processes operate. When contemporary coastal systems and processes are considered, human activity should also be taken into account. In fact, along many of our coastlines human activities, such as beach nourishment, construction of coastal defences, dredging and land reclamation, are more important in driving and controlling coastal dynamics than the natural boundary conditions and can therefore not be ignored

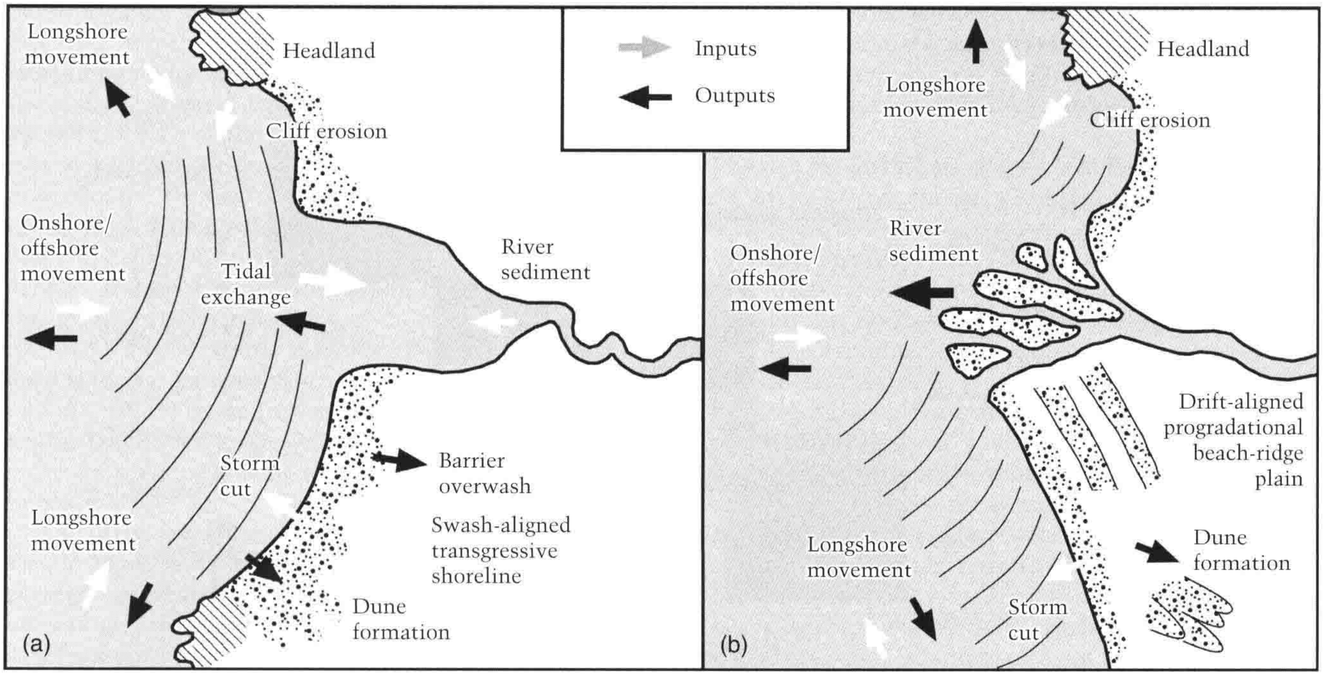

Fig. 1.6 Sediment budgets on: (a) estuarine; and (b) deltaic coasts. (Source: Masselink et al. 2011. Reproduced with permission of Hodder & Stoughton Ltd and adapted from Carter and Woodroffe 1994 with permission from Cambridge University Press.)

(Chapter 17). Moreover, through climate change, humans are altering the boundary conditions themselves (sea-level rise and changes to the wave climate).

Unless long-term coastal change (centuries to millennia) is considered, the boundary conditions can be viewed as given and constant, although it should be borne in mind that external forcing is stochastic (random), and the dynamics of coastal systems arise from the interactions between the three linked elements:

(1) Processes: This component includes all processes occurring in coastal environments that generate and affect the movement of sediment, resulting ultimately in morphological change. The most important of these are hydrodynamic (waves, tides and currents) and aerodynamic (wind) processes. Along rocky coasts, weathering is an additional process that contributes significantly to sediment transport, either directly through solution of minerals, or indirectly by weakening the rock surface to facilitate mobilization by hydrodynamic processes (Chapter 15). In addition, biological, biophysical and biochemical processes are important in salt marsh (Chapter 10), mangrove (Chapter 11) and coral reef (Chapter 16) environments. River outflow processes are important in deltas (Chapter 13).

(2) Sediment transport: A moving fluid imparts a stress on the bed, referred to as 'bed shear stress', and if the bed is mobile this may result in the entrainment and subsequent transport of sediment. The ensuing pattern of erosion and deposition can be assessed using the sediment budget (Fig. 1.6). If the sediment balance is positive (i.e. more sediment is entering a coastal region than exiting), deposition will occur and the coastline may advance, while a negative sediment balance (i.e. more sediment is exiting a coastal region than entering) results in erosion and possibly coastline retreat. This makes quantifying the sediment budget a fundamental means for understanding coastal dynamics, as well as providing a tool for assessing and predicting future coastal change.

(3) Morphology: The three-dimensional surface of a landform or assemblage of landforms (e.g. coastal dunes, deltas, estuaries, beaches, coral reefs, shore platforms) is referred to as the morphology. Changes in the morphology are brought about by erosion and deposition, and are, in part, recorded in the stratigraphy (section 1.2.4).

It is worth emphasizing that the morphodynamic approach is scale-invariant, i.e. the approach can be applied regardless of the spatial scale of the coastal feature under investigation. For example, at the smallest scale, the approach can be applied to wave and tidal bed forms; at the largest scale, to tidal basins or entire delta systems. Importantly, the spatial and temporal scales of coastal morphodynamic systems are related (Fig. 1.7): the larger the spatial scale of the coastal system, the longer the timescale associated with the dominant process(es) and the associated coastal morphodynamics. The spatio-temporal relationship is, however, not linear: some coastal systems respond faster than one would expect on the basis of their

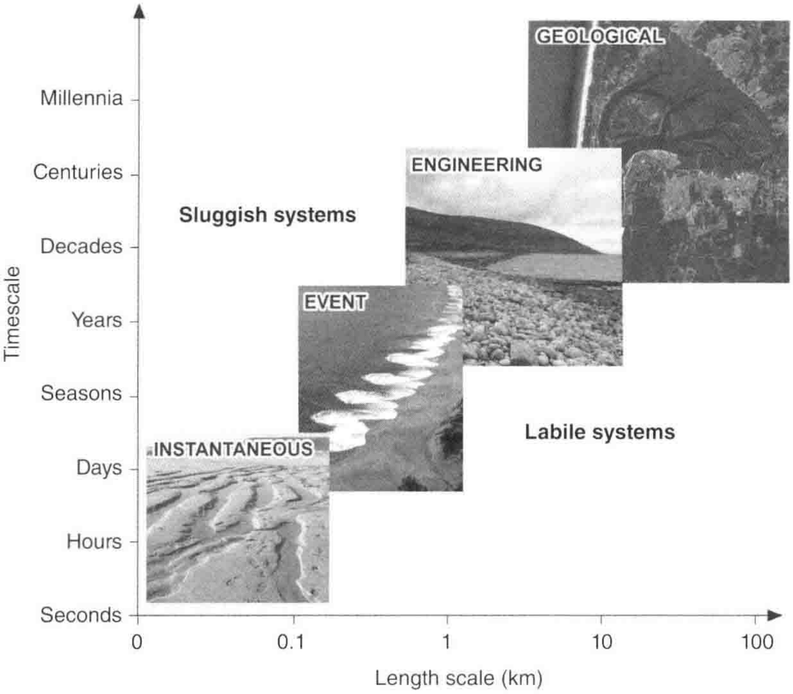

Fig. 1.7 Relationship between spatial and temporal scales of coastal systems. Sluggish and labile systems are those that respond relatively slow and fast, respectively. (Source: Adapted from Cowell and Thom 1994. Imagery © 2013 Terrametrics. Map data © 2013 Google.) For colour details, please see Plate 1.

size (labile systems; e.g. sandy barriers without dunes), whereas other coastal systems exhibit a relatively slow response (sluggish systems; e.g. rocky coasts). The timescale of the response of a coastal system also depends, of course, on the magnitude of the forcing, and the classic magnitude-frequency concept (Wolfman and Miller, 1960) is as relevant now as it was when it was introduced in geomorphology.

1.2.3 Morphodynamic feedback

A characteristic of coastal morphodynamic systems is the presence of strong links between form and process (Cowell and Thom, 1994). The coupling mechanism between processes and morphology is provided by sediment transport and is relatively easy to comprehend. There is, however, also a link between morphology and processes to complete the morphodynamic feedback loop.

As an example, under calm wave conditions sand is transported on a beach in the onshore direction resulting in beach accretion and the construction of a feature known as the 'berm' (Fig. 1.8). During berm construction, the seaward slope of the beach progressively steepens and the top of the berm increases in elevation relative to sea level through accretion; both morphological developments

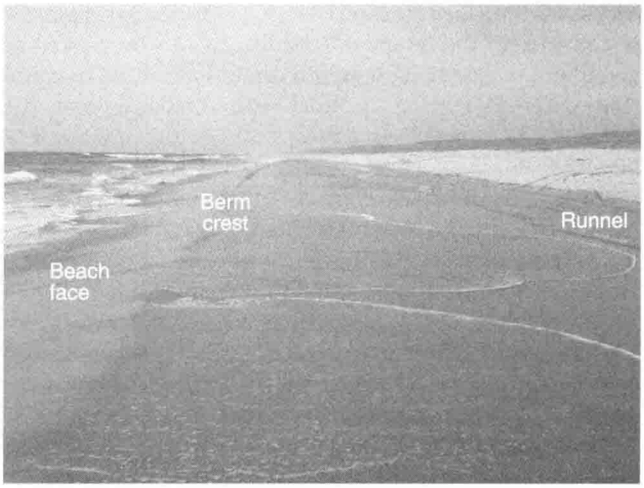

Fig. 1.8 Photograph of a developing berm on a sandy beach. Berms are swash-formed features that usually develop as part of beach recovery following storm erosion. On tidal beaches they are found just above the high-tide level. This particular berm formed after a period of energetic waves and is well defined with a small runnel located to the landward. The photo was taken at high tide and the berm is still being overtopped by swash action and is therefore still being constructed. (Source: Photograph by Gerd Masselink.)