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EVOLUTION OF THE AUSTRALIAN COAST

Introduction

THIS BOOK PROVIDES a comprehensive overview of the more than 30 000-kilometre-long Australian coast (see Figure 1.1). It is based on the latest scientific investigations and thinking, and aims to leave you, the reader, with a clear understanding of the coastline, including its geological background and evolution, and the processes and ecosystems that operate around the coast. A major part of the book is devoted to describing each of the systems that make up the coast, starting with the rivers, estuaries and deltas, and followed by the thousands of beach systems and the dune systems that back most of the beaches. We describe the extensive rocky shores that separate many of the beaches, then the coral reef systems that fringe much of northern Australia. We conclude with an overview of human impact on the coast, including the potential impacts of climate change.

Defining the Australian coast

The length of the Australian coastline depends, first, upon how we define coastline. In this book, when we use the term 'coastline', we mean the broader coastal zone. We may also refer to the 'shoreline', by which we mean the point at which the ocean meets the land. The length of the coastline – or shoreline – also depends on the precision with which we measure it. For example, if we were to divide the coastline into segments, each 1 kilometre long, the length of the coastline around the mainland and Tasmania would

State/Territory	Mainland area (km²)	Island area (km²)	Total area (km²)	Mainland length (km)	Island length (km)	Total length (km)
Western Australia	2 526 786	3089	2 529 875	12 889	7892	20 781
Queensland	1 723 936	6712	1 730 648	6973	6374	13 347
Northern Territory	1 335 742	13 387	1 349 129	5437	5516	10 953
South Australia	978 810	4672	983 482	3816	1251	5067
Tasmania	64 519	3882	68 401	2833	2049	4882
Victoria	227 010	406	227 416	1868	644	2512
New South Wales	800 628	14	800 642	2007	130	2137
ACT*	2430	1	2431	54	3	57
Australia	7 659 861	32 163	7 692 024	35 877	23 859	59 736

Table 1.1 *Land area and length of coastline for Australia, by state/territory, as determined from digitisation of the 1:100 000 topographic maps*

* Australian Capital Territory: coastline relates to Jervis Bay Territory
Source: Geoscience Australia, www.ga.gov.au.

measure 30 270 kilometres. However, if we were to add Australia's islands of more than 12 hectares, the coastline would measure 47 070 kilometres.

If we were to measure the shoreline, which includes mangroves but excludes coral reefs, using 1:100 000 topographic maps (see Table 1.1), the length of the Australian shoreline would be 35 877 kilometres for the mainland alone, or 59 736 kilometres including Australia's islands. These estimates would increase if the shoreline were determined from larger-scale maps, and if we included the intricate perimeter of coastal waterways. They would also increase if the shorelines of Australia's island territories, including the Australian Antarctic Territory, were included.

As well as possessing one of the longest national coasts in the world, Australia claims the third-largest Exclusive Economic Zone (EEZ) in the world, with an area of 8.1 million square kilometres. This is equivalent to about 2.2 per cent of the world's ocean area and larger than Australia's land area (see Table 1.1). The EEZ adjacent to the Australian mainland covers more than 6 million square kilometres, and is augmented by the extensive EEZ around its small island territories such as the Cocos (Keeling) Islands, Christmas Island and Heard and McDonald Islands.

Structure of this book

The remainder of this book traces the nature of the Australian shoreline, its beaches, dunes and rocky coast, the intricate river mouth and estuary systems and the myriad coral reefs. In this chapter we outline the geological evolution of the Australian continent – the most ancient on the planet. We describe the continent when Australia lay 3000 kilometres further south, attached to the supercontinent known as Gondwanaland. The Australian landmass as we know it became recognisable after it detached from Antarctica and began its slow and continuous drift to the north. We conclude the chapter by describing the impact of global cooling, the beginning of the ice ages and associated major changes in sea level that helped to form the present coast and shoreline.

In Chapter 2 we look at the contemporary processes that form and rework the coast, beginning with the Australian climate, which delivers the rainfall needed to maintain our rivers and to distribute sediment to parts of the coast. Across the oceans, cyclones and strong winds generate wave climates that provide the energy to build beaches and erode rocky cliffs. The ocean also delivers the tides that range from very small on the south coast to some of the world's largest in the north. The oceanic and coastal wind systems also drive the major ocean currents and build the sand dunes along the coast. In total, these processes control the evolution of the coast.

Cambridge University Press
978-0-521-87398-7 - The Coast of Australia
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Figure 1.1 *Map of Australia, showing some of the major locations mentioned in this book*

Figure 1.2 *Arndani lagoon, in eastern Arnhem Land, exemplifies the diversity of the Australian coast. It is bordered on its seaward side by seagrass meadows, with beaches, dunes and low rocky sections forming the shoreline. An inlet and tidal channel connects the lagoon to the Gulf of Carpentaria, while the lagoonal shoreline has a fringe of green mangroves, backed by the white salt flats.* Photo: A.D. Short

In Chapter 3 we describe the variety of coastal ecosystems that are such a vital part of the coast. First, we examine the land-based, coastal dune vegetation and coastal freshwater wetlands, then the intertidal samphire (coastal herbs), salt marshes and mangroves, and the subtidal seagrasses and coral reefs. We conclude by looking at the rich ecology of the sandy beaches and rocky shore.

In the following five chapters we examine each of the major coastal systems, which together make up the Australian coast (see Figure 1.2).

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In Chapter 4 we discuss the estuaries and deltas associated with river mouths, streams and tidal creeks, and their distribution, habitats and evolution. Following this we take you on a tour of the coast, highlighting some of the major estuarine systems and their regional variability.

What makes a beach? In Chapter 5 we look at Australia's more than 10 000 beach systems that occupy half of the open coast. We describe the 15 different types of beaches around Australia, their nature and distribution. Australia is renowned for its beaches, and in this chapter we finish with an overview of beaches from around Australia, exploring why Australia has the world's best beaches. In Chapter 6 we describe the coastal sand dunes that back many of the beaches and the associated larger sand barrier systems, which fringe 40 per cent of the coast.

While approximately half the Australian coast consists of soft sandy shorelines – the beaches – much of the other half is composed of hard, resilient rock. We therefore begin Chapter 7 with a discussion of the types of rocks and their distribution around the coast, and then explore the dynamic interaction between waves, tides and rocks that leads to the erosion and evolution of our rocky coast. In this chapter we again conclude with a tour of the coast, highlighting some of the more spectacular sections of Australia's rocky coastline.

Australia's world-famous coral reef system is our focus in Chapter 8, which begins with a description of reef structure and the processes that control reef evolution. We then examine the types of reefs that occur around the coast, before looking at the distribution of reefs around northern Australia and some of its major offshore islands.

In the final chapter, Chapter 9, we reflect on the influence and impact of humans on the Australian coast. We start by describing the arrival of Indigenous Australians and, later, European explorers and the initial coastal settlements, which were all located in estuaries. We assess the increasing impact of humans on the coast, the way in which the coast is managed and some present-day threats to the coast. We conclude with a discussion of the coastal impact of climate change and the future prospects for the Australian coast.

Geological evolution

The Australian coast surrounds an ancient continent, and yet the coastline is also continually being renewed. In some places the coast is composed of some of the oldest rocks on Earth, while in others it is built from sediments that are reworked every day. The type of coast that forms is intimately related to the geology of the continent. In order to understand the nature of the present-day coast, we need to consider the evolution of the Australian continent, its northwards drift and fluctuating climates, and the changes in sea level it has experienced.

Understanding the 'flat' continent

The Australian continent has been exposed to weathering for so long, and with no recent mountain building, that it has eroded to become the world's oldest, lowest and flattest continent, with an average height of just 330 metres. Its latitude, centred at 30º South under the dry, subtropical high-pressure system, also makes it the driest inhabited continent,

Figure 1.3 *The heavily jointed and deeply dissected coast at Cone Bay in the western Kimberley is part of the ancient Australian Craton. The rocks are composed of 1800-million-year-old Proterozoic sandstones.* Photo: A.D. Short

Figure 1.4 *Australia is made up of the ancient Pilbara–Yilgarn cratons, which merged by 2200 million years ago, the uplifted Kimberley Basin and the Arunta–Gawler cratons, which were added by 1800 million years ago to form the Precambrian Australian craton. Successive episodes of mountain building associated with the Tasman Fold Belt (400 million years old) and later the New England Fold Belt (200 million years old) completed the geological evolution of the Australian continent, at that time still part of Gondwanaland.*

with an average rainfall of 465 millimetres, resulting in extensive arid regions both in the interior and along parts of the south and west coast.

The western core of the continent is composed of some of the oldest surviving rocks on the planet, 3500 million years in age, which form the vast Pilbara and Yilgarn cratons (ancient portions of the Earth's crust). These rocks form outcrops along much of the irregular Pilbara coast, and along the south and southwest Western Australian coast, where massive, sloping granite headlands dominate the shore. To the east, the continent is composed of rocks formed during periods of continental welding and mountain building over the past 2000 million years. In the south, the Gawler Craton, in central South Australia, formed and attached by 2000 million years ago, and the Northern Australian or Arunta Craton attached to the western cratons more than 1800 million years ago. These four giant cratons, the Pilbara, Yilgarn, Northern/Arunta and Gawler cratons, together with the uplifted Kimberley Basin (Figure 1.3), combined to form the Australian Craton, which occupies all of western and central Australia, including much of Cape York Peninsula (see Figure 1.4). Between 1800 and 650 million years ago, the eastern boundary of this craton buckled to form the Adelaide geosyncline (a major downwarp in the Earth's crust, in which great thicknesses of sedimentary sequences have accumulated), with the eastern side of the geosyncline, known as the Tasman Line, becoming the eastern boundary of the evolving 'Australia' (see Figure 1.4).

The formation of the third of Australia east of the Tasman Line commenced in the late Cambrian period (600 million years ago) and involved a series of orogens, or episodes of mountain building. Formation of the Adelaide Geosyncline (1400–560 million years ago) was followed 500–330 million years ago by development of the Kanmantoo Fold Belt, which borders eastern South Australia and extends south through western Victoria and across Bass Strait to include the western half of Tasmania. Then a broad zone, known as the Tasman Fold Belt, evolved extending to the present east coast. This includes the granite-rich Thompson-Lachlan Fold Belt, which extends north from eastern Tasmania, through the Snowy Mountains into western New South Wales and central Queensland. It formed 500–230 million years ago, and also includes the New England Fold Belt, which extends north from the Hunter region to eastern Cape York Peninsula and formed 400–230 million years ago. Wedged between these two mountain belts is the 1800-kilometre long Sydney–Bowen Basin, into which sediments hundreds of metres thick were deposited 270–180 million years ago, including the rich basal coal units. All the time this massive eastern landmass was being added to the continent, Australia was attached to Antarctica and formed the northern part of Gondwanaland.

During the formation of the Tasman Fold Belt, buckling along the western margin of the continent resulted in the formation of four major sedimentary basins, which today occupy much of the west coast and continue to fill (see Figure 1.5). In the northwest is the 500-million-year-old Bonaparte Basin, which today is occupied by Cambridge Gulf. The massive Canning Basin, which extends between Port Hedland and King Sound, reaching more than 1000 kilometres inland, was also initiated 500 million years ago. The elongate Carnarvon Basin, located between the Murchison River and Dampier Archipelago, has been filling with sediments for the past 400 million years. The narrow, 1000-kilometre-long Perth Basin extends south from the Murchison River to Augusta; it commenced filling 450 million years ago.

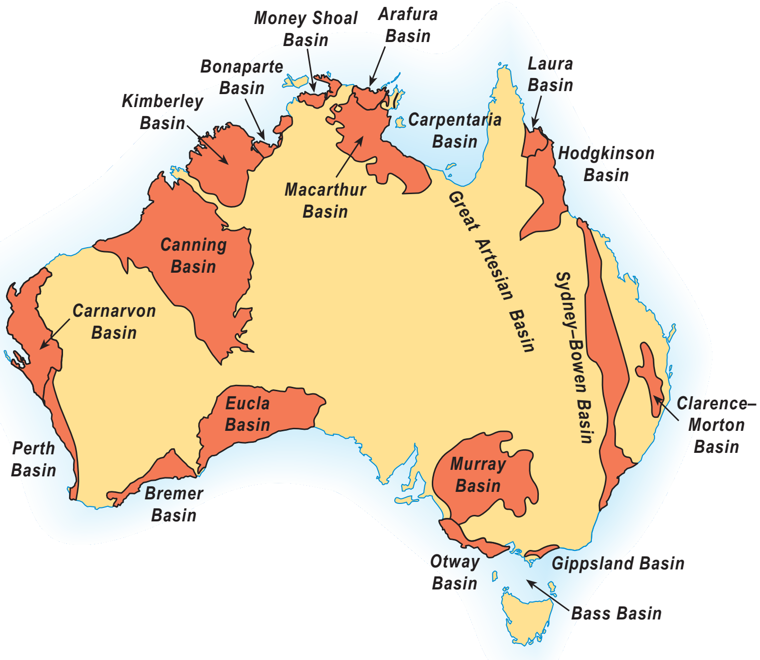

Figure 1.5 *Australia's coastal sedimentary basins occupy over half of the coastline. All were formed from buckling of the Earth's crust, and all continue to infill with sediments.*

Separating from Gondwanaland

The breaking up of Gondwanaland commenced in the northwest 180 million years ago, when India and Africa separated from Antarctica and Western Australia, opening up the Indian Ocean and forming the west Australian coast (see Figure 1.6). This rifting (gradual separation of two continental or oceanic plates) continued counter-clockwise around Australia, forming first the west coast, then the southern coast as Australia itself separated from Antarctica 120 million years ago and began its slow northward migration. This was followed by rifting in the southern Tasman Sea 85–60 million years ago, which separated New Zealand and the Chatham Rise from southeast Australia. As a result, the Tasman Sea opened and formed the coast along southeastern Queensland–New South Wales, eastern Victoria and eastern Tasmania. The rifting continued northward, opening the Coral Sea 55–50 million years ago and forming the rest of the Queensland coast. As the continent moved north, buckling, mountain building and volcanic activity on the northernmost margin formed the New Guinea highlands, which was also part of the Australian plate – uplift continues there to this day.

AUSTRALIA'S MOST RECENT VOLCANO

The most recent volcanic activity in Australia occurred at Tower Hill in western Victoria. The 'hill', an extinct volcano, last erupted 25000 years ago, building the ash cone that can be seen today, and sending a river of lava several kilometres south to the coast. The lava forms the low basalt points, rocks and reefs between Killarney Beach and Port Fairy, the youngest igneous (volcanic) rocks in Australia. Tower Hill was declared Victoria's first national park in 1892. It is now a State Game Reserve.

While the continent was rifting and moving it caused regional buckling around its perimeter (see Figure 1.5), which formed a series of shallow coastal basins, including the large Carpentaria Basin (180–100 million years old) in the north. Across the south coast the Eucla (Nullarbor) (160–0 million years old), Otway–Murray (170–40 million years old), Otway (50–20 million years old), Gippsland (35–2 million years old) and Bass basins (120–0 million years old) also formed. Each of the basins flooded, gradually filling with sediments and then subsequently uplifted, though parts of the Gippsland and the entire Bass Basin have been submerged by the recent postglacial sea-level rise, described later in this chapter.

Along the east coast, during the opening of the Tasman and Coral seas, there was subduction of the oceanic plate under the eastern seaboard's continental plate, which resulted in the gradual uplift of the eastern highlands between 85 and 60 million years ago. The net result was the formation of the Great Dividing Range, which extends for 3000 kilometres down the east coast, from Cape York to central Victoria. This event finalised the general outline of the Australian coast. It was now separated from Antarctica and the Tasman Rise (including New Zealand), surrounded by the southwest Pacific, Southern and Indian oceans, and drifting north at about 7.3 centimetres per year.

Australia's northward drift has had two additional major impacts on the continent and coast. First, beginning about 40 million years ago, it increasingly placed Australia under the influence of the great subtropical high-pressure systems, the source of the continent's aridity. Second, it opened up the Southern Ocean, enabling the strong westerly winds associated with the prevailing mid-latitude cyclones to blow across the longest fetch of ocean in the world. These westerlies were named 'the roaring forties' and 'raging fifties', after the latitudes at which seafarers encountered them. High waves and strong winds have battered the southern half of the continent ever since.

Climate change and sea-level fluctuations

Climatic changes and the associated adjustments of sea level that have occurred over the past few million years have exerted a major influence on how the Australian coast has evolved. Gradual global cooling commenced about 10 million years ago, primarily as a result of the opening of the Southern Ocean. Falls in global temperature triggered the accumulation of ice caps on Antarctica and Greenland. By 2 million years ago, both the cooling and accumulation of ice caps was sufficient for ice sheets to begin to form on Eurasia (centred on the Baltic Sea) and North America (centred on Hudson Bay). These cooler periods are termed 'glaciations'. They result in a lowering of sea level (up to 120 metres below the present sea level) because of the amount of water 'locked up' in the glacial ice sheets – this is known as a sea-level 'lowstand'. The warmer periods of these ice-age cycles are called 'interglacials'. As in the present interglacial, which is usually called the 'postglacial', the Eurasian and North American ice sheets melt completely, but the Greenland and Antarctic ice sheets do not. As a result, the sea level rises to what is called a sea-level 'highstand' – at or close to our present sea level.

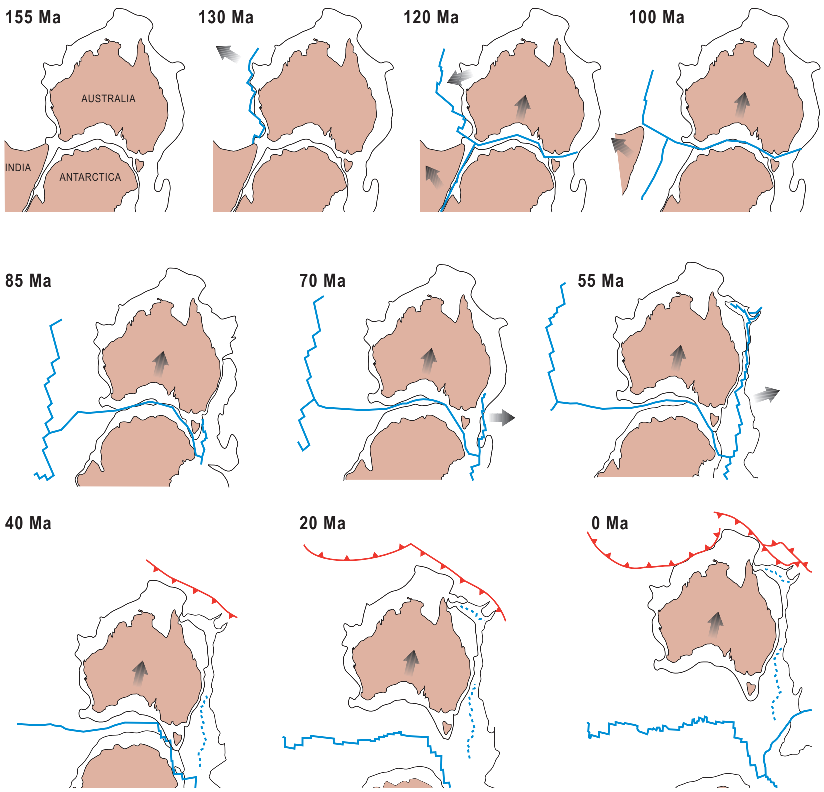

Figure 1.6 *The separation of Australia from the supercontinent Gondwanaland commenced in the northwest 155 million years ago, forming the Western Australian coast by 130 million years ago. The Indian subcontinent began separating around 120 million years ago. By 100 million years ago, both India and Australia were moving north (arrows) and Australia's southern coast was formed. By 40 million years ago the Australian continent began colliding with, and subducting beneath, the Pacific plate north of New Guinea. Australia has continued to move north at about 7 centimetres per year, opening up the Southern Ocean and colliding with the Indonesian Archipelago and oceanic plate north of New Guinea (red line). Blue lines indicate active submarine spreading; dashed blue lines inactive spreading; and black outlines the edge of the continental shelves and plates.*

Cycles of ice-sheet growth and decay

The past 2.5 million years represent the Quaternary Period, which consists of the Pleistocene and Holocene epochs (see box 'The Cenozoic era'). It is a period dominated by the ice ages, during which time the Eurasian and North American ice sheets accumulated during glaciations, followed by melting of the ice sheets and sea-level rise to interglacial highstands. The growth of these ice sheets has been gradual, but the decay is quicker, taking in the order of 10 000 years. The cause and timing of these cycles are linked to regular variations in the Earth's orbit: variation in its eccentricity (the shape of the Earth's elliptical orbit around the sun) at periods of 100 000 years; its obliquity (the angle of tilt of the Earth's axis) with a cycle of 41 000 years; and the precession of the equinoxes (the wobble, or rotation, of the orbital plane) that recurs every 22 000 years. These astronomical variations have effects on the balance of heat at different latitudes and, hence, global temperature. They result in the growth and decay of the Eurasian and North American ice sheets in a cyclical manner that reflects these 20 000, 40 000 and 100 000-year periodicities.

The record of successive interglacials and associated sea-level highstands is particularly well preserved as a series of coastal sand barriers located on the high-energy southeast coast of South Australia. The barriers parallel the present coast for over 200 kilometres and extend one after the other up to 300 kilometres inland. The age of each of these barriers – determined by luminescence dating, a technique that measures trapped electrons by releasing their energy in the form of light – can be correlated with successive sea-level highstands (see Figure 1.7). The Last Interglacial shoreline can also be clearly observed at several locations along the coast of Western Australia, where it remains as a raised coral reef. The best sequences of raised coral reefs, providing the most useful records of past sea-level changes, occur on shorelines that have been tectonically uplifted by earthquakes, as around the Indonesian island arc, on which there is a staircase-like series of raised reefs or terraces, which increase in height with age. A sea-level reconstruction has been undertaken based on the ages of such reefs on the Huon Peninsula in Papua New Guinea (determined by uranium-series dating). Dating of terraces from several sites at which there have been different rates of uplift has enabled a history of sea-level positions to be developed, and this has been linked with the record of global temperature analysed from deep-sea cores (determined by a geochemical technique called 'oxygen isotope analysis'). Figure 1.7a shows a reconstructed, sea-level curve derived from the Huon Peninsula which indicates the probable pattern of sea-level change over the past two glacial–interglacial cycles; that is the past 240 000 years.

THE CENOZOIC ERA

Tertiary Period	65–2.5 million years ago	period of gradual global cooling
Quaternary Period	2.5–0 million years ago	beginning of ice ages (glacials and interglacials)
Pleistocene Epoch	2.5 million years to 10 thousand years ago	(approximately 20 major ice ages)
Holocene Epoch	10 thousand years ago to present	(period of postglacial warming and present interglacial)

Patterns of sea-level fluctuation

The details of past sea-level fluctuations continue to be refined. Dating the time and depth of sea-level