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An Archive of Environmental and Global Sea-Level Changes

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Cover illustration: View looking south-east from Cape Dombey, Robe, southern South Australia, towards the actively eroding cliffs of Robe Range, an aeolianite coastal barrier complex of Late Pleistocene to Holocene age. The original dune crest of the Late Pleistocene landform is highlighted by the strongly indurated calcrete profile (light coloured band), which is overlain by vegetated Holocene dunes. The cliff is 20 m high. In the horizon, near-shore islands of Robe Range illustrate the active erosion of this coastal barrier. Similar erosional residuals occur up to 1.5 km offshore and illustrate the high rates of erosion along this coastline since the attainment of the Holocene sea-level highstand 7000 years ago. The Late Pleistocene components of Robe Range were deposited during Marine Isotope Substage 5c (105 ka; Robe III) and MIS 5a (82 ka; Robe II); only Robe III is visible in the photograph. The overlying Holocene dunes (Robe I) were deposited since the culmination of post-Last Glacial Maximum sea-level rise (Photograph: Murray-Wallace, 2017).

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For my darling daughter Deirdre

Preface

Besides being a region of fragile and subtle beauty, attracting the interests of artists, poets, novelists, naturalists (Theile and McKelvey 1972; Harris 1996; Paton 2010) and those with an interest in the aesthetics of landscapes and their preservation (Heyligers 1981), the Coorong Coastal Plain in Southern Australia is internationally significant for its long record of Quaternary sea-level changes and coastal landscape development. In particular, the region preserves a long record of temperate sedimentary carbonate deposition and evidence for sea-level highstands spanning at least the past 1 million years. The coastal plain is situated within the modern world's largest temperate carbonate realm (James and Bone 2011). An older succession of coastal barriers extends several hundred kilometres farther inland and awaits further developments in geochronological methods before their numeric ages can be satisfactorily resolved.

In a global context, the Coorong Coastal Plain and the more landward portion of the Murray Basin are unique for their preservation of coastal barrier shoreline successions in a terrestrial realm extending back in time some 7 million years. The coastal barrier landforms chronicle the latter stages of shallow marine-coastal deposition within the Murray Basin of Southern Australia. The coastal plain has attracted international interest from people with diverse research interests such as Quaternary geochronology, palaeopedology, palaeomagnetism, palaeontology in its various forms including megafaunal extinctions, volcanology, Quaternary sea-level changes, karst geomorphology, cool-water temperate carbonate deposition, as well as sedimentary facies models for hydrocarbon exploration.

This book provides an overview of the Quaternary geological and geomorphological evolution of the region and its significance in a global context, particularly in quantifying Pleistocene sea-level highstands. In its scope and coverage, the work seeks to complement the magisterial volume by Noel P. James and Yvonne Bone, *Neritic Carbonate Sediments in a Temperate Realm*, also published by Springer.

The rationale for writing this book is the firm conviction that the region examined needs even greater recognition on the international stage in terms of its long Quaternary record of relative sea-level changes and coastal landscape evolution, making it an important global reference site in investigations of interglacial sea-level highstand events.

There are several distinctive geomorphological attributes of the coastal plain that particularly leave an impression in the minds of international visitors to the region. First, the spatial scale of the landforms is striking, such as the uninterrupted coastal barrier dune complex of Younghusband Peninsula, which extends for 194 km and represents the longest beach in Australia. Similarly, the Coorong Lagoon, landward of Younghusband Peninsula extends over 150 km and was even larger in the mid-Holocene. In a similar manner, many of the relict coastal barrier landforms of the coastal plain can be traced along their strike length for up to 300 km, such as the last interglacial barrier Woakwine Range (Marine Isotope Substage 5e; 125 ka). Many visitors to the region have also been struck by the prolific bio-productivity of sedimentary carbonates and the seemingly ubiquitous development of calcretes (relict calcareous soil profiles), which blanket the landscape and effectively armour the ancient barrier dunes, thereby preserving much of their original morphology. Another remarkable attribute of the region is that it is situated within one of the modern world's highest wave energy settings of the Southern Ocean with a high capacity for coastal erosion, yet a remarkably long record of coastal barrier deposition is preserved.

My earliest introduction to the Coorong area was on a family holiday, camping at Policeman's Point. A few years later, the significance of the geomorphology of the Coorong Coastal Plain was clearly articulated in a first-year geography lecture given by Dr. Nick Harvey at the University of Adelaide. I was so impressed by the remarkable geomorphological character of the region that I scurried off to the South Australian Department of Mines and Energy to buy what turned out to be one of the few remaining copies of Bulletin No. 29 by Reg Sprigg on the *Geology of the South-East Province* which was published in 1952.

This book builds upon my collaborative research with several colleagues since 1989 on the long-term evolution of the coastal plain—Antonio Belperio, Amy Blakemore, Debebrata Banerjee, Alan Brenchley, Robert Bourman, Brendan Brooke, John Cann, Patrick De Deckker, Nick Harvey, Dave Huntley, Terry Lachlan, Jon Olley, the late John Prescott, David Price, Deirdre Ryan and Frances Williams. The book also builds upon many research field trips to the coastal plain as well as three previously 'road-tested' field guides (Belperio and Cann 1990; Belperio et al. 1996; Murray-Wallace and Cann 2007) produced under the auspices of the Geological Society of Australia (South Australia Division), the International Geological Correlation Program, IGCP Project 367 (*Late Quaternary Coastal Records of Rapid Change: Applications to Present and Future Conditions*) funded by the International Union of Geological Sciences and UNESCO, and a field trip associated with the XVII INQUA Congress (2007—the International Union for Quaternary Research). Two recently produced small format field guides will also assist visitors to the area (Cann 2013, 2014).

Other researchers who have influenced my thoughts about the geology and geomorphology of the region include Yvonne Bone, Jim Bowler, Steve Eggins, Victor Gostin, Rainer Grün, the late John Hutton, Noel James, Brian

Jones, Bernie Joyce, Fred Leaney; the late Orson van der Plassche, Jim Rose and Colin Woodroffe.

During the production of this book, numerous people have provided help and encouragement. I particularly thank Petra van Steenbergen, Executive Editor in Earth Sciences, Geography and Environment at Springer International in commissioning this project, and Ram Prasad Chandrasekar and Mohammed Ali with technical production of the book. I also thank Dr. Thomas Oliver for assistance with the manipulation of SRTM images, Peter Johnson, Cartographer *par excellence*, in preparing the line drawings, Sandra De La Fosse of Big Vision and Print for assistance in map reproduction, and Peter Waring of the Resources and Energy Division, Department of Premier and Cabinet (DPC), South Australia, for assistance in obtaining references that would have otherwise been more difficult to acquire. I also thank people for their assistance in granting permission to reproduce maps and photographs still covered by copyright including, Dr. Craig Williams, Editor of the Royal Society of South Australia, for permission to reproduce maps and figures published in the Transactions of the Society; Peta Abbot and Peter Waring, Resources Information, Resources and Energy Group, Department of the Premier and Cabinet, South Australia; CSIRO Land and Water Business Unit; Debbie Barrett, Elsevier Science, and Natasha Mangeruca, Mapland, Department of Environment, Water and Natural Resources. I thank Bob Bourman for reading a draft of the entire manuscript of this book.

I gratefully acknowledge research funding support from the Australian Research Council over many years, as well as the *GeoQuEST Research Centre* in the University of Wollongong.

Given the dynamic nature of many of the coastal environments examined in this book, the years that many of the photographs were taken are indicated, as this will serve to be of historical interest in subsequent investigations of the coastal landscapes. Since first visiting some field sites close to 30 years ago, with the passage of time they have become almost completely overgrown by *Acacia* (coastal wattle) such as a large borrow pit in Holocene coquina near Lake St Clair (see Fig. 3.13; field site SE#44 of Cann et al. 1999). Some of the exposed coastal localities such as portions of Robe Range have been eroded during this period, also highlighting the pace of coastal landscape change.

Wollongong, Australia Colin V. Murray-Wallace

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Contents

Abbreviations

AAR	Amino acid racemization
AHD	Australian Height Datum
APSL	Above present sea level
b2k	Before 2000 AD
BP	Before present (a radiocarbon term referring to years before 1950 AD)
BPSL	Below present sea level
cal BP	Calibrated years before present (sidereal years)
CMAT	Current Mean Annual Temperature
D/L	Ratio of D- to L-amino acids
De	Equivalent dose
DSDP	Deep Sea Drilling Project
EPICA	European Project for Ice Coring Antarctica
ESR	Electron spin resonance
FAA	Free amino acids
GRIP	Greenland Ice Core Project
GSSP	Global Stratotype Section and Point
Gy/ka	Gray/thousands of years (radiation dose)
h	Hour(s)
ha	Hectare(s)
IODP	International Ocean Discovery Program
IR-OSL	Infrared-optically stimulated luminescence dating
ka	Kilo-anna (thousands of years)
km	Kilometre(s)
m	Metre(s)
Ma	Mega-anna (millions of years)
MIS	Marine isotope stage
mm	Millimetre(s)
mol/L	Moles per litre
NGRIP	North Greenland Ice Core Project
$^{18}O/^{16}O$	Ratio of stable oxygen isotopes
ODP	Ocean Drilling Program
OSL	Optically stimulated luminescence
SRTM	Shuttle Radar Topography Mission
THAA	Total hydrolysable amino acids
TL	Thermoluminescence dating

About the Author

Colin V. Murray-Wallace is a Quaternary geologist and currently a Professor in the School of Earth and Environmental Sciences in the University of Wollongong, Australia. He completed his Ph.D. and D.Sc. degrees in Geology at the University of Adelaide. His long-standing research interests include investigations of Quaternary sea-level changes, coastal evolution, neotectonics, carbonate sedimentary environments and amino acid racemization dating. Professor Murray-Wallace was project leader of the International Geological Correlation Program Project 437 (1999–2003) 'Coastal environmental change during sea-level highstands', and leader of the INQUA (International Union for Quaternary Research) Coastal and Marine Commission (2004–2007). He served as Editor-in-Chief of the journal *Quaternary Science Reviews* from 2008 to 2016. His previous jointly written books include *Quaternary Sea-Level Changes: A global perspective* (Cambridge, 2014) and *Coastal Landscapes of South Australia* (Adelaide, 2016). He received the A. H. Voisey Medal from the Geological Society of Australia and the Mawson Medal from the Australian Academy of Science.

1 The Coorong Coastal Plain, Southern Australia—An Introduction

Abstract

The Coorong Coastal Plain is a distinct morphotectonic province in southern Australia covering an area of approximately 34,600 km^2. The coastal plain preserves a long Quaternary record of temperate carbonate sedimentation in the form of high wave energy barrier shoreline successions and associated back-barrier facies formed in low energy, estuarine-lagoon environments. The barriers occur sub-parallel to the modern coastline and to each other due to ongoing epeirogenic uplift. The coastal barriers (locally termed Dune Ranges), the principal focus of this book, formed during successive sea level highstands over the past 1 Ma and generally increase in age landwards. Some barriers, however, are composite structures having formed in more than one interglacial or interstadial. An older succession of Pliocene to possibly Early Pleistocene coastal barriers occur farther inland as part of the later stage progradational sequence of the Murray Basin and have been mapped as Loxton-Parilla Sands. The preservation of successive Quaternary shoreline features has resulted from slow epeirogenic uplift, calcareous cementation of dune limestone (aeolianite), and regional calcrete development. Across the coastal plain from Robe to Naracoorte, the mean uplift rate is approximately 70 mm/ka. In the region surrounding the Holocene and Pleistocene volcanic centres in the southern-most portion of the coastal plain, a higher rate of uplift of 130 mm/ka has been determined.

Keywords

Coorong Coastal Plain · Coastal barriers Bridgewater formation · Pleistocene interglacials

1.1 Introduction

The Coorong Coastal Plain in southern Australia is a natural laboratory for examining the response of coastal barrier landscapes and depositional systems to relative sea-level changes (Fig. 1.1). The region is also internationally significant for quantifying long records of ice-equivalent, glacio-eustatic sea-level changes during the Quaternary Period. The region provides direct evidence of coastal barrier sedimentation during successive interglacials and numerous interstadials over the past 1 million years, as well as geologically recent volcanism. The volcanic episodes are associated with widespread volcanism in

Photos by the author, if not indicated differently in the figure/photo legend.

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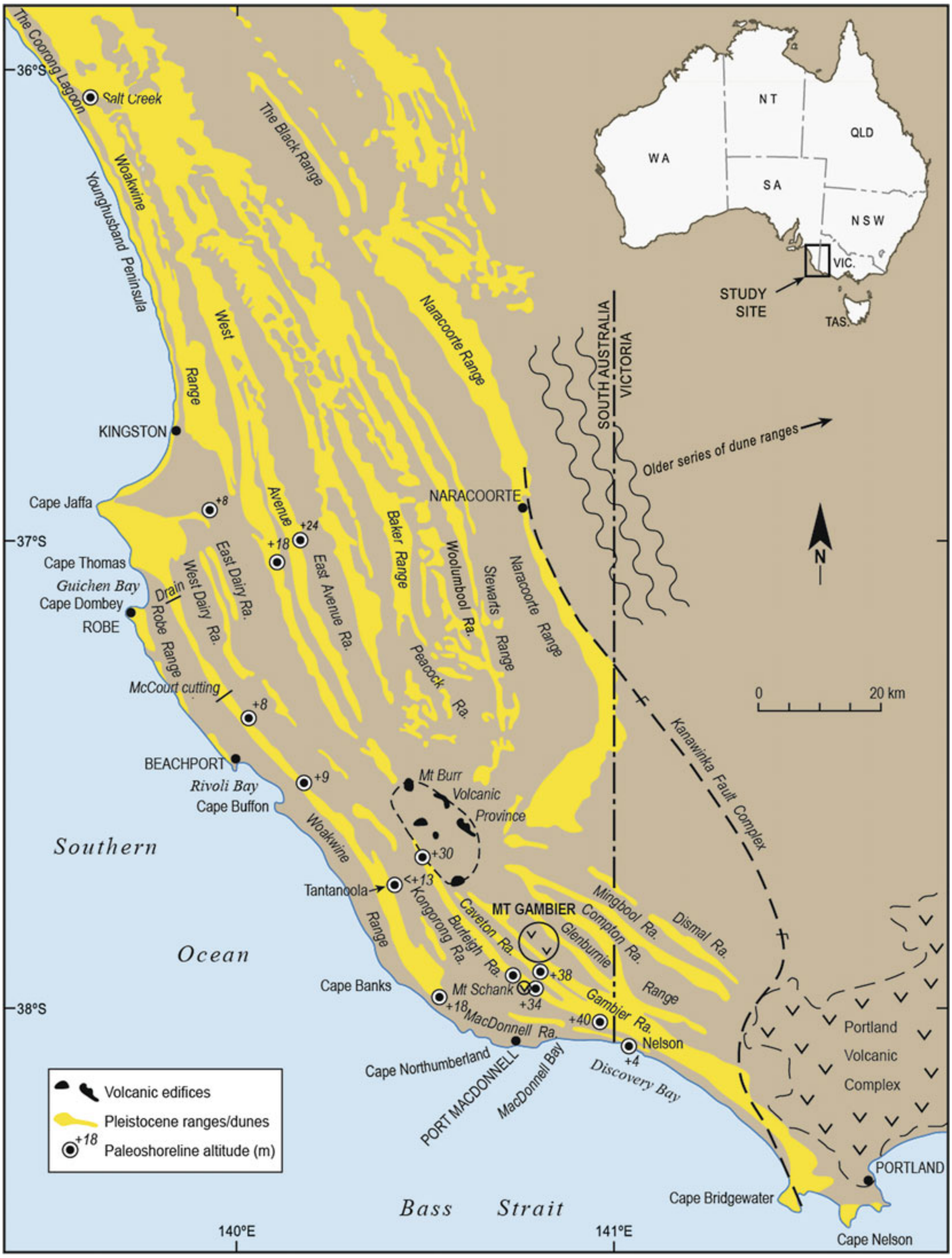

Fig. 1.1 Map of the Coorong Coastal Plain, southern Australia based on research by Hossfeld (1950), Sprigg (1952) and Murray-Wallace et al. (1996)

western Victoria, and the Pleistocene volcanic groups have directly influenced long-term coastal sedimentation.

One of the major challenges in understanding the longer record of Pleistocene global sea-level changes is the paucity of direct evidence from well-preserved shoreline successions to infer former sea levels. In a global context, the Quaternary stratigraphical record is highly fragmentary, particularly in marginal marine environments and few coastal regions around the world provide landform and stratigraphical evidence for Pleistocene sea levels before the Antepenultimate Interglacial (Marine Isotope Stage—MIS 9; c. 322 ka) leaving a gap of approximately 2.3 Ma or 89% of Quaternary time in which the record of palaeosea-level has not been directly defined from relict shoreline successions. This is due to the generally low preservation potential of relict shoreline deposits and coastal landforms resulting from erosion by terrestrial and marine processes. Although indirect inferences for palaeosea-level may be derived from oxygen isotope records of global ice volume change from deep sea and ice cores (Rohling et al. 2008; Masson-Delmotte et al. 2010), such records are enhanced by calibration, based on the dating and surveying of palaeosea-level indicators (i.e. direct measures of palaeosea-level). This is particularly important in view of local variations in ocean temperatures and salinity which may introduce variability in stable isotope records and increase the uncertainty in the magnitude of inferred former ice volumes and palaeosea-levels (Bradley 2015).

Oxygen isotope records from marine and ice cores reveal long records of climate changes of global significance. The time-series isotopic records reflect ice-volume changes associated with the waxing and waning of the continental ice sheets and valley glaciers, and as a corollary provide indirect insights into the nature of glacio-eustatic (ice-equivalent) sea-level changes during the Quaternary, in terms of their relative magnitude and timing (Murray-Wallace and Woodroffe 2014). The longest records span up to 800 ka for ice cores such as the European Project for Ice Coring (EPICA) Core from Dome C, Antarctica (Masson-Delmotte et al. 2010; Schilt et al. 2010) and longer time-series oxygen isotope records have been derived from deep sea sediments such as the LR04 compilation of 57 records that span the past 5.3 Ma (Lisiecki and Raymo 2005).

While the relative intensities of successive interglacials may be inferred from oxygen isotope records (Masson-Delmotte et al. 2010), how these data are expressed in a more quantitative manner for the magnitude of glacio-eustatic sea levels for different interglacial highstands and from different geographical realms, remains a challenging task. It is in this sense, that direct records of relative sea-level changes for long Quaternary timescales from terrestrial environments are so important despite their paucity.

The Coorong Coastal Plain in southern Australia is uniquely placed to address these issues. Situated within an intra-plate, tectonic setting and in the far-field of Pleistocene ice sheets and therefore characterised by a relative sea-level record dominated by glacio-eustatic change, and within a region not directly glaciated in the Quaternary, the coastal plain provides important stratigraphical and geomorphological evidence for glacio-eustatic sea-level changes, and in particular, interglacial and interstadial hightsands over the past 1 Ma. The relative sea-level record of the region is dominated by glacio-eustasy with a minor but quantifiable, locally-based hydro-isostatic contribution and an even smaller contribution from glacio-isostatic adjustments within near-field settings (Conrad 2013).

Given the low gradient of the coastal plain and in global terms, the slow rates of epeirogenic uplift (e.g. 70 mm/ka in the transect from Robe to Naracoorte; Fig. 1.1), modest differences in the height of sea level during successive highstands dramatically affected the geographical location of the barrier shorelines. The region can thus be described as having experienced a ‘Goldilocks tectonic regime’ during Quaternary time, as the rate of epeirogenic uplift is not too fast to cause erosion of the emergent shoreline complexes through substantial changes in base level, and just sufficient for many of the successive interglacial highstand events to be represented in the geological record. In addition, the absence of large river systems across the coastal plain has significantly curtailed rates of denudation and enhanced the preservation of the stratigraphical record.

The coastal plain is located within the modern world's largest temperate carbonate factory, a region characterised by very high calcium carbonate bio-productivity on the adjacent continental shelves of the southern and Western Australian margins (James and Bone 2011). The level of carbonate bio-productivity is also attested by the spatial scale of the coastal landforms. Individual coastal barriers, termed 'Dune Ranges' such as the last interglacial (MIS 5e; 125 ka) Woakwine Range can be traced along their strike lengths for over 300 km in largely uninterrupted form as low relief landforms, '… across the otherwise flat, featureless country' (Mawson and Dallwitz 1944, p. 192). Commonly the barriers are 1–3 km wide in cross-section and attain maximum heights of up to 40 m above the general surface of the coastal plain. The coastal barriers conform to the classical definition of these landforms, in being laterally-persistent sand accumulations formed by wave and wind action and backed on their landward side by an estuarine-lagoon system at the time of their formation (Otvos 2012).

The Coorong Coastal Plain is also globally significant in representing one of the few coastal barrier landscapes in which empirical evidence for the Early-Middle Pleistocene Transition is preserved. This is manifested by the onset of prolific sedimentary carbonate production during the sea level highstands following the end of Early Pleistocene time. The sediment of the Middle Pleistocene West Naracoorte Range for example, comprises up to 90% calcium carbonate (bioclastic, skeletal carbonate sand) in contrast to the older East Naracoorte Range (>781 ka) which comprises only 21% sedimentary carbonate (Murray-Wallace et al. 2001). From about 940 ka ago corresponding to MIS 22 (Head and Gibbard 2005), to the Last Glacial Maximum, substantially larger ice volumes are evident during glacial maxima in oxygen isotope records (Lisiecki and Raymo 2005). By implication, geographically more extensive subaerial exposure of the continental shelves and the landward entrainment of larger volumes of bioclastic sand is likely to have occurred at times of de-glacial sea-level rise to produce volumetrically larger coastal barrier landforms.

1.2 The Coorong Coastal Plain as a Morphotectonic Province

From the River Murray Mouth and its terminal lakes, Lakes Alexandrina and Albert, the Coorong Coastal Plain extends for some 300 km south-east along the modern coastline to the east of Mount Gambier and into western Victoria (Fig. 1.1). The coastal plain is a distinctive morphotectonic domain in southern Australia, and for the purposes of this book, is defined as extending from the modern coastline, landward to the Marmon Jabuk, Coonalpyn, Hynam and East Naracoorte Ranges covering an area of approximately 34,600 km^2 (Fig. 1.2).

Morphotectonic regions are characterised by distinctive landform assemblages that define a particular area, and which differ from adjacent regions. Tectonic processes commonly create a level of landscape uniformity within a morphotectonic region irrespective of whether a region is tectonically highly active or highly stable. Accordingly, morphotectonic regions show some uniformity in the scale and types of landforms present that confer an internal coherence to the regional landscape (Fenner 1930; Jennings and Mabbutt 1986). The presence of different morphotectonic regions at a continental-scale is a direct expression of contrasting modes of tectonic behaviour. In southern Australia, the Yilgarn Craton (Western Australia) and Gawler Craton (Eyre and Yorke Peninsulas, South Australia) are examples of morphotectonic regions of high tectonic stability. In contrast, the Mount Lofty Ranges (part of the Adelaide Foldbelt; also termed Adelaide Geosyncline) is a region that is more seismically active and shows evidence of neotectonic activity in the later Quaternary,

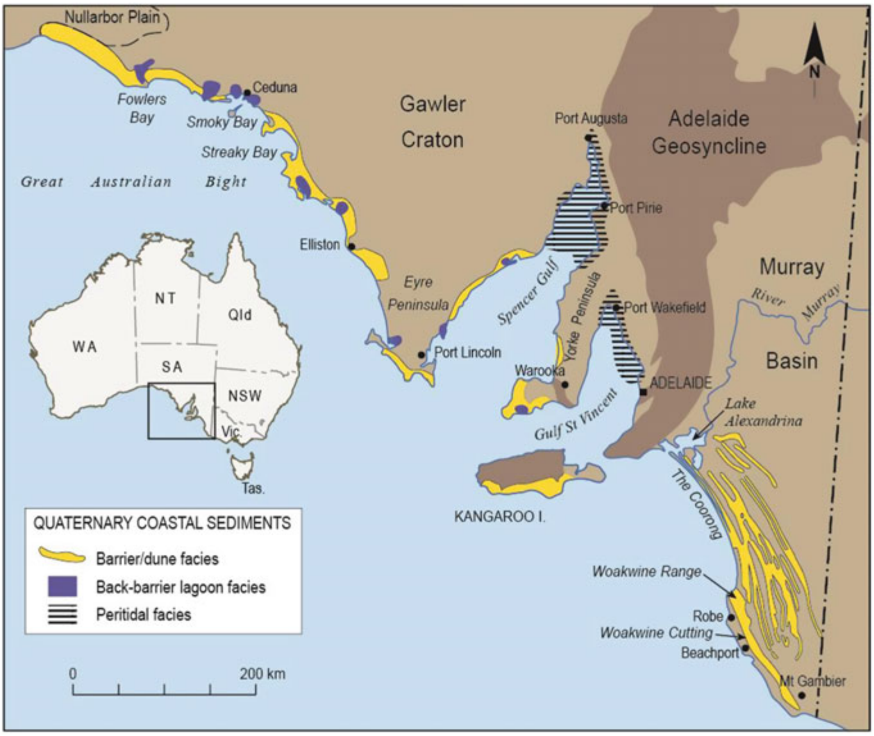

Fig. 1.2 Map of principal morphotectonic provinces of southern Australia illustrating the location of the Coorong Coastal Plain in southern South Australia

manifested by uplift of well-defined horst blocks along range-bounding faults (Bourman et al. 1999; Jayawardena 2013).

The Coorong Coastal Plain is a distinctive morphotectonic province distinguished by a sequence of coastal barriers that extend along the entire length of the coastal plain. The barrier landforms have been uplifted during the Quaternary by epeirogenic processes. The magnitude of uplift, although small in global terms (10s metres over 100s ka), is evident in transects landward across the coastal plain from the modern coastline, and along the shore parallel length of the coastal plain for individual barriers.

The coastal plain is a low relief seaward sloping landscape of 0.5° punctuated by a series of coastal barrier landforms in a transect between the towns of Naracoorte and Robe (Fig. 1.1). The coastal plain is bounded by Proterozoic and Cambrian strata of the Mount Lofty Ranges to the north-west, by an older succession of Pliocene to Early Pleistocene barriers (Loxton-Parilla Sands) of the Murray Basin to the north-east, and by the Pleistocene volcanic plains (Newer Volcanics) of western Victoria. The coastal plain represents the latest stage of progradational development of the Murray Basin following a major phase of deeper water marine inundation after the final separation of Australia and Antarctica some 43 Ma ago (Brown and Stephenson 1991). The earlier phase of deposition within the Murray Basin was characterised by deeper water marine limestones (Brown and Stephenson 1991; Lukasik and James 2006).

During the Quaternary the coastal plain has evolved progressively from the interplay of repetitive sea-level transgressions and regressions associated with a succession of Pleistocene interglacials and interstadials. The geomorphological evolution of the region has also been profoundly influenced by the prolific bio-productivity of sedimentary carbonates on the inner continental shelf (Lacepede and Bonney Shelves), high wave and wind energy to form substantial coastal barrier dune systems, and slow epeirogenic uplift associated with plate tectonic ridge push and localised volcanism and crustal doming of the Paleogene/Neogene bedrock.

The shoreline successions, representing the depositional product of successive sea level highstands, have been preserved by ongoing uplift to remove the relict coastal landforms from erosion by younger sea level highstands. Extensive subaerial calcrete development, an expression of regional aridity, has effectively blanketed the regional barrier beach landform complexes aiding the preservation of their original morphostratigraphic form. The Coorong Coastal Plain to the north and the Mount Gambier Coastal Plain (Gambier Sunklands of Sprigg 1952) to the south are separated by a region of localised upwarp termed the Mount Burr Peninsula (Sprigg 1952; Blakemore et al. 2015). This book adopts the term Coorong Coastal Plain for the entire region acknowledging the importance of the modern landscapes as an analogue for the Pleistocene coastal landscapes.

Modern and Holocene coastal sediments and sedimentary environments that have developed during the past 7000 years since the attainment of the Holocene highstand are of particular significance for interpreting the preserved sediment facies and for making inferences about palaeosea-levels from the Pleistocene successions. In south-eastern Australia, present sea level was attained by 7000 years ago, representing the cessation of sea-level rise following the post-Last Glacial Maximum transgression (Lewis et al. 2013). The coastal sedimentary successions and landforms that developed during this period provide a more recent analogue of the Pleistocene barrier shoreline successions.

1.3 Historical Background

Numerous studies have examined aspects of the Quaternary environmental history and record of past sea levels of the Coorong Coastal Plain. Some of the more significant earlier studies that have led to a more detailed understanding of the geological history of the region, particularly in terms of relative sea-level change as currently understood, include those of Hossfeld (1950), Sprigg (1952), Firman (1973), Cook et al. (1977), Schwebel (1978, 1983, 1984) and Huntley et al. (1993a, b, 1994).

Early impressions of the coastal landscapes of the region were documented by Nicolas Baudin and Matthew Flinders during their respective voyages in 1802 charting the coastline of Australia. The two met on Friday 9th April, 1802 at what Flinders would later term Encounter Bay, approximately 11 km SSE of the mouth of the River Murray (S 35° 44′; E 139° 28′), although they were too far offshore to identify this feature. Baudin in *Le Géographe* had sailed north along the coast from Lacepede Bay, while Flinders in HMS *Investigator* had sailed from Gulf St Vincent, through Backstairs Passage between Fleurieu Peninsula and Kangaroo Island, arriving at Encounter Bay. Baudin noted that;

> The entire stretch of coast that we have examined since yesterday consists solely of sand-hills and inspires nothing but gloom and disappointment. Quite apart from the unpleasant view that it offers, the sea breaks with extraordinary force all along the shore, and two or three swells preceding the breakers indicate that there is a bar there which must reach at least half a mile out to sea. (Baudin 2004, p. 379).

After their encounter exchanging information about the respective coastlines they had both charted, Flinders sailed south-east along the Lacepede Bay coastline (Younghusband Peninsula) noting that;

> From Encounter Bay to this slight projection [Cape Bernouilli of the French Navigators; south-west of Cape Jaffa], the coast is little else than a bank of sand with a few hummocks on the top, partially covered with small vegetation; nor could any thing (sic) in the interior country be distinguished above the bank. (Flinders 1814, p. 197).

The first detailed geological observations made in this region were reported by Reverend Julian Edmund Woods in 1862, resulting from his missionary travels from Penola to Naracoorte, Bordertown, Robe and Mount Gambier (note that he subsequently published under the name Tenison-Woods; Fig. 1.3). Woods made many astute observations about the nature of the regional geology and landscapes of the Coorong Coastal Plain, as well as more extensive regions of southern Australia. He noted the pronounced lateral extent of the coastal barriers over distances of tens of kilometres, locally termed 'dune ranges', that ongoing 'upheaval' of the coastal plain explained the origin of the raised beaches, that each range corresponded with a former coastline and that the flats on the landward side of each barrier represent former estuaries. The findings of Woods (1862) were published when little was known about the nature and complexity of Quaternary sea-level changes. Accordingly, glacio-eustatic sea-level changes were not distinguished from uplift of the coastal plain. He assumed that the succession of coastal barrier landforms resulted from periodic phases of quiescence in uplift rather than a series of eustatic-changes. Woods (1862) also described the marine fossils from the Paleogene—Neogene limestones representing the local basement to the Quaternary sedimentary successions as well as the volcanic landforms and cave and karst features of the region, providing detailed engravings made from photographs. This new-found appreciation of the physical landscape of the coastal plain was independently supplemented by the highly accurate renderings of the accomplished artist and landscape painter Eugene von Guérard (1811–1901) in his series of paintings of the Newer Volcanics (Pullin 2016).

Woods subsequently published a more detailed map of the coastal plain outlining the positions of eleven of the coastal barriers from Salt Creek to the Glenelg River area to the east of Mount Gambier and across to Naracoorte in the north (Woods 1866; Fig. 1.4). His map is significant in several respects particularly given that his observations were made on horse-back before an age of remote sensing technology. Woods completed much of his survey work with a compass on horseback before the residents of his home base in the Penola District donated funds to buy him a buggy (Press 1994). The broad shape of many of the ranges in plan-view is relatively accurately rendered in his map of 1866; Fig. 1.4). Woods correctly deduced the lateral continuity of what is now termed the Last Interglacial (125 ka) Woakwine Range along the entire length of the coastal plain. He also astutely depicted the curvature of some of the ranges in relation to the Mount Burr Volcanic Province and in broad view, correctly determined the relative spacing of many of the barriers across substantial parts of the coastal plain. Accounts of the early life of Tenison Woods are given by Press (1994) and Hamilton-Smith (2006).

Based on a short visit to the area of Robe and Guichen Bay, the Chief Justice of South Australia (1861–1876) Sir Richard Davies Hanson, set out to describe the landforms of the region (Hanson 1867) and to clarify some interpretations made by Tenison Woods in his book *Geological Observations in South Australia* (Woods 1862). Hanson described the sand hills of the region and mistakenly identified middens within pedogenically modified dune sands as natural shell accumulations, and invoked changes in elevation of the land to account for their preservation, as well as for other geological features. Hanson also made numerous other factually incorrect interpretations based on his field observations. Tenison Woods (1867) prepared a carefully crafted response outlining the short comings of many of Hanson's field observations and interpretations. Given the status of Hanson in Adelaide society, the exchange must have caused embarrassment in the early history of the Adelaide Philosophical Society (later to become the Royal Society of South Australia in 1880).

Crocker and Cotton (1946) described several raised beaches and associated fossil marine mollusc assemblages in the southern portion of the coastal plain, particularly in the Mount Gambier region of South Australia. They introduced the terms Burleigh and Caveton Ranges, correlatives of the Reedy Creek and West Avenue Ranges respectively, which occur within the region between Robe and Naracoorte some 120 km to the north-west. Another notable aspect of their paper is a time-slice map

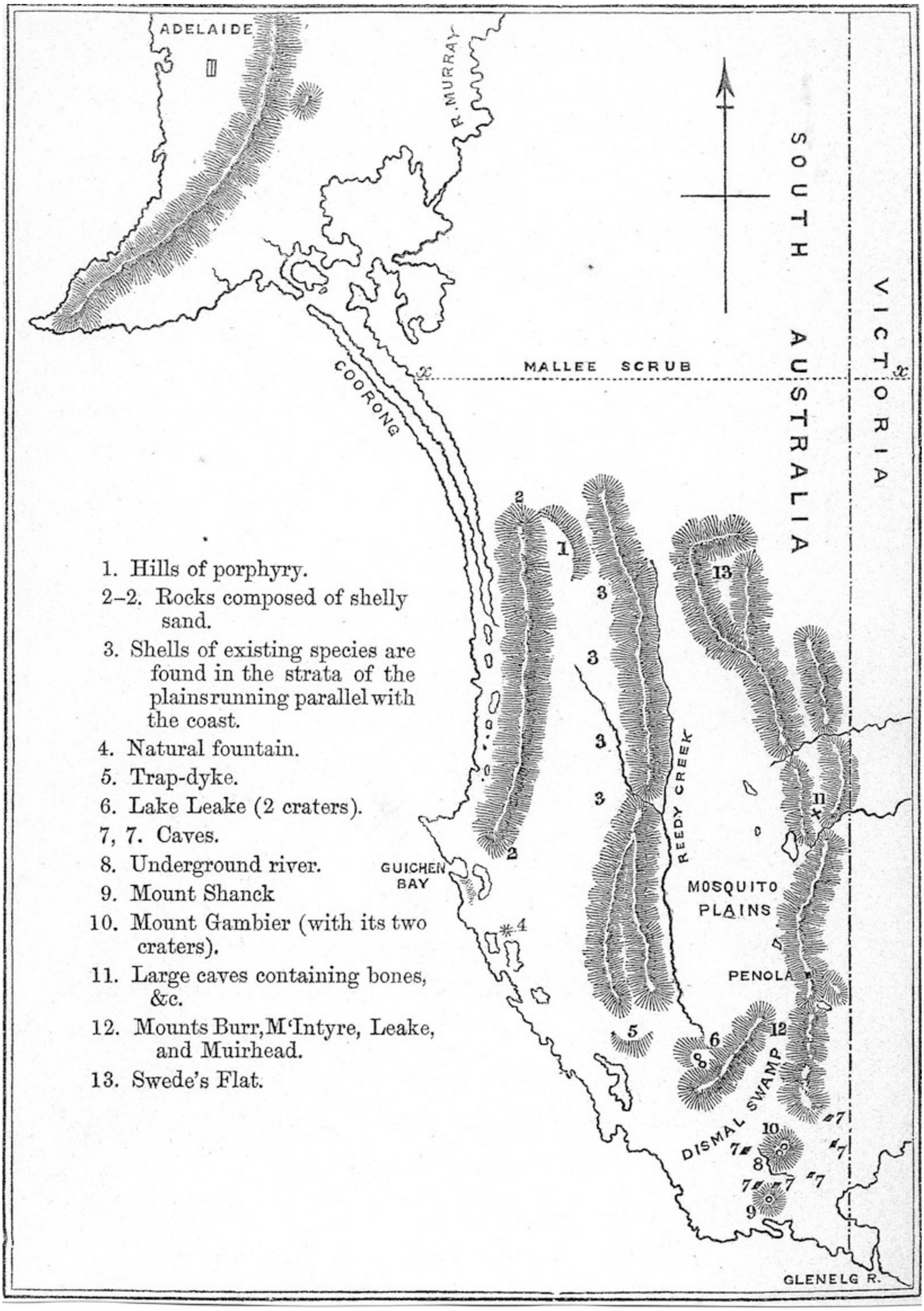

Fig. 1.3 Regional map of the Coorong Coastal Plain, southern Australia, compiled by Reverend Julian Edmund Tenison Woods, as published in 1862 in his book *Geological Observations in South Australia* (*Source* Woods 1862)

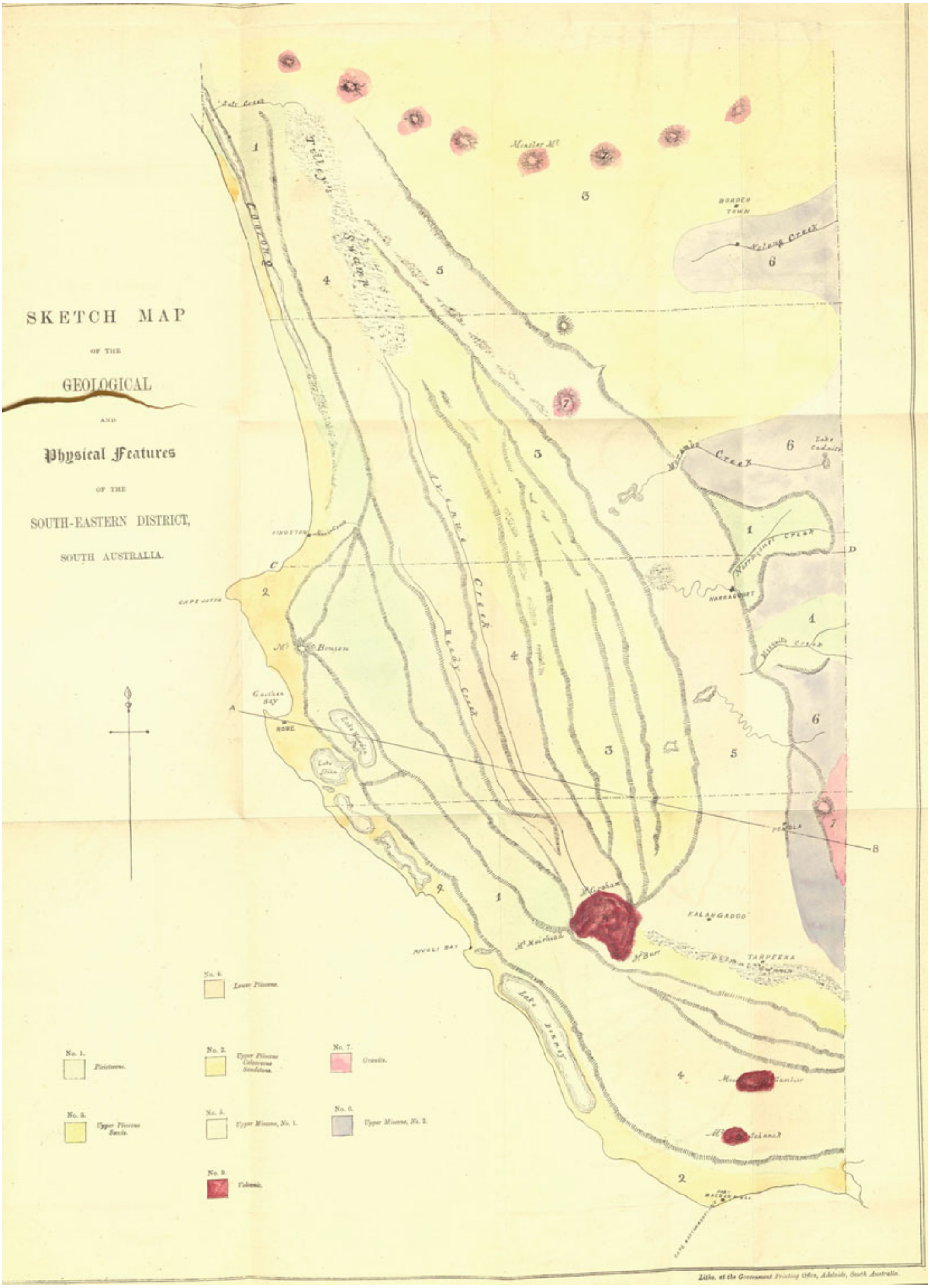

Fig. 1.4 Regional map of the Coorong Coastal Plain, southern Australia, compiled by Reverend Julian Edmund Tenison Woods in 1866. The map presents considerably greater detail on the spatial distribution of the relict coastal barrier landforms than his map published in *Geological Observations in South Australia* which was published four years earlier (cf. Fig. 1.3; *Source* Woods 1866)