The southern edge of the Great Sandy Desert, Western Australia, part of the arid continental core.
WELDON TRANNIES

CHAPTER 2

WATER AND SAND:
CLIMATE IN ANCIENT AUSTRALIA

J. M. BOWLER

A HISTORY OF AUSTRALIA could well centre on water resources. The distribution of water over the continent controls the nature of the plants, animals and humans. The quantity, which has varied over time, has helped form the landscape and allowed changes in the pattern of human settlement. Daily and yearly fluctuations also have affected human lives.

Today most of the country is arid or semiarid, but that was not so in ancient times. Over the last 2 500 000 years there have been many major climatic cycles. The latest of these cycles spans the last 120 000 years; and evidence of changes in the quantity of water during this period has been preserved in a wide array of Australian landscapes. The glaciated mountain regions of the south, the dune fields and rivers of the inland and a series of lakes whose filling and drying have deposited rich evidence all reflect different phases in the continental water balance.

The environmental historian can read these landscapes as other scholars read documents in archives, finding new understanding of the continent both before people inhabited it and in its early stages of human occupation. Even within the period of human occupation we can discern changes in water balance that greatly influenced the lives of Aboriginal societies.

During the past 120 000 years there have been, broadly speaking, three phases of climatic history. From 120 000 to about 60 000 years ago climates were fairly similar to those of today. From 60 000 to 10 000 years ago, major changes in temperature, rainfall and wind systems occurred everywhere, associated with worldwide climate shifts towards generally colder and drier conditions. This period—known as the last glacial era—ended about 10 000 years ago, when climatic conditions began to return to what they had been before about 60 000 years ago, creating the kinds of environments which persist in modern times. The fluctuations that occurred during the last 60 000 years shaped Australia's human history, because they spanned the colonisation of the continent. Human societies therefore experienced contrasting environmental challenges, including intense aridity, glacial cold and expanding rain forests.

Glacial Lake Dove lies in a valley evacuated by ice of the last ice age. Frost-shattered columnar dolerite of Cradle Mountain and Barn Bluff in the Lake St Clair National Park, Tas, stand above the glacially scoured metamorphic rocks. This is the view looking south.

D. HOOLEY

GLACIAL LANDFORMS

The mountains of Tasmania, known for their spectacular scenery, also preserve the best record of the glacial period. Then, as now, most rain and snow came from the west, the direction of the strongest winds. The result was a lee side or 'fence' effect, with snow and ice accumulating mainly on eastern, more protected slopes and affecting climatic conditions there to lower altitudes than on more exposed, relatively snow-free western slopes. On Mount Wellington near Hobart, the mantle of slope deposits produced by frost action and snow during the last glacial period occurs down to sea level. In this period between 60 000 and 10 000 years ago, dunes and sand sheets formed in the exposed central and lowland regions of the island, and during the relatively dry period of maximum glaciation between 25 000 and 15 000 years ago they extended almost to the site of Hobart.

In areas such as the Franklin River the present-day rainforests did not exist during the period of maximum glaciation. Cold, windswept grasslands extended over large regions of what was then an extension of the Australian continent into a southern ocean cooled several degrees by the expansion of the Antarctic ice cap. About 15 000 years ago, however, glacial conditions began to moderate and 12 000 years ago the colder period ended. No permanent ice remained, even on the highest mountains.

The peaks of the Snowy Mountains, lacking the high rainfall and snow of the west coast of Tasmania, collected enough snow to produce only a small ice cap, even during the coldest periods. About 20 000 years ago, the Kosciusko ice cap covered about fifty square kilometres at its maximum. The chronology of the Snowy Mountain glaciation is still not well known. A stump of beech (*Nothofagus*) that grows only in rainforests, dated by radiocarbon analysis to about 34 000 years ago, has been discovered under a block stream, a type of rock river formed only under very cold conditions and not active in the Snowy regions today. The ice-forming conditions that buried and preserved the stump must have set in soon after that date.

We know more about when the ice retreated. Peats began to grow again about 15 000 years ago at the highest levels of the Snowy Mountains; permanent ice disappeared from Blue Lake 13 000 years ago, and the lake began to accumulate a mixture of mineral- and organic-rich sediments from the surrounding landscape. The glacial episode had ended.

PERIGLACIAL PROCESSES

While the extent of ice cap glaciation was restricted, the secondary or periglacial effects of glaciation extended widely throughout the southeastern highlands 25 000 to 15 000 years ago. The climate that controlled the ice cap produced intense frost action over the whole of the southeastern highlands, and the environment was shaped by the prevalence of freezing conditions below the soil surface. Today similar conditions exist only near the summit of Mount Kosciusko.

Throughout a wide region of the southeastern highlands from about 35 000 to 15 000 years ago, there were extended sparse grasslands where woodland cover later developed and unstable slopes deposited large quantities of debris and fine sand outwash along the margins of the lower foothills.

The Lake George area provides particularly good evidence of such developments. Lake George is an enclosed body of water in the southern tablelands of New South Wales. Having no outlet, it responds sensitively to changes in water balance induced by variations of climate. For a very long time, as now, the lake has grown

Winter snow blankets glaciated quartzites in the Frenchmans Cap area, Franklin–Lower Gordon Wild Rivers National Park, Tas. Frenchmans Cap rises to 1445 m on the right. Glaciers of the last ice age melted away in this region about 9000 years ago.
J. ENGLAND

Typically rugged topography of an alpine glaciated terrain, looking west-northwest across the Gwendolen Valley (in shadow) from above Frenchmans Cap (1445 m above sea level) in the highlands of Tasmania. A glacier of the last ice age melted from this typical U-shaped valley about 10 000 years ago.
J. ENGLAND

Lake George near Canberra has provided the longest record of hydrologic and vegetation changes in southeastern Australia. The lake is shown here drying in 1972. An exposed clay flat leads west towards the foot of the north–south range against which the lake is dammed.
J.M. BOWLER

larger after high rainfall and dried up after drought. Its catchment area has remained constant. Lake George can serve as a rain gauge for at least one million years of Australia's history.

The evidence from Lake George indicates that throughout the last 500 000 years, there have probably been cyclical oscillations in the water balance similar to those identified within the last 120 000 years. Although Lake George is shallow and sometimes dry under modern climatic conditions, about 30 000 to 25 000 years ago it was deep, overflowing westwards across the route of the present Federal Highway through Geary's Gap into the Yass River. Then followed a series of changes, with the lake level generally falling. It reached its lowest level between about 20 000 and 17 000 years ago, and, with the possible exception of a wet phase around 10 000 years ago, remained relatively low from that time onwards.

The episodes of glaciation and the development of periglacial environments are almost certainly connected with the high lake levels of about 30 000 to 25 000 years ago. Lower temperatures, loss of vegetation from highland slopes and seasonally frozen ground contributed to high runoff and reduced evaporation. The high lake levels registered these changes, which also affected water levels in rivers flowing into the interior. The drying of Lake George between about 23 000 and 17 000 years ago matched the maximum extent of glacial cold conditions in Tasmania, and fitted more general patterns of climatic change across the continent.

SOUTHERN AND WESTERN VICTORIA

Lying seaward of the dividing ranges, the plains of central and western Victoria were not influenced directly by glacial processes, though minor periglacial effects might have occurred on the summits of the divide. But the advance and retreat of ice on the highlands influenced rainfall patterns and wind systems across these extended coastal plains, and their environment changed accordingly. In the period of most intense cold, about 20 000 to 17 000 years ago, the sea level fell to about one hundred and fifty metres below present coastlines. This fall connected

Lake Keilambete, a circular crater lake in western Victoria, retains a clear record of climatically controlled changes of water level. The eastern shore has concentric high-water marks on the rim of the crater, representing periods wetter than today.
J.M. BOWLER

Tasmania to mainland Australia and increased a general trend towards drier conditions. Areas near Melbourne, which now receive relatively high rainfall, became as arid as today's climates near Naracoorte or Horsham further inland. Sand dunes aligned west to east near Moorabbin, Cranbourne and in east Gippsland near Seaspray, were created by the extension of dune building conditions from the continental interior into these regions that are quite wet today. The dryness that accompanied glacial environments was accentuated by stronger winds. Cooler, drier, windier conditions produced a number of changes across southern Victoria.

The Maribyrnong River, rising on the southern flanks of the divide near Mount Macedon, carried large quantities of yellow silt. Like the fine-grained silt from glacial and periglacial environments in Europe, China and New Zealand, this material was formed by frosts shattering rock on the highland slopes. The resulting fine silt was washed into valley floors. Some was then blown across the land during droughts and the rest was swept away by rivers to be deposited further downstream. The thick silt deposits near Keilor originated in this way between 25 000 and 14 000 years ago. Humans were attracted by the resources of the river and the protection provided by its valley. Artefacts, hearths and human remains found in the Keilor silts show that people lived in the region throughout the coldest glacial period. The conditions that deposited the silts at Keilor also contributed to the thick silt of the Werribee River delta and spread a veneer of quartz over the otherwise quartz-free basaltic plains of western Victoria.

Throughout the extensive lava plains of western Victoria, volcanoes were intermittently active from 130 000 to less than 12 000 years ago, as they had been during the previous four million years. Volcanic cones and craters such as Tower Hill, Mount Eccles and the *maars* (large explosion craters) near Camperdown and Terang, Gnotuk, Bullenmerri, Keilambete and elsewhere, were among those still active. The lakes within them provide much information about climatic changes.

Like Lake George, the crater lakes of Bullenmerri, Gnotuk and Keilambete are controlled by rainfall and evaporation and respond sensitively to slight changes in water balance. Their saucer-shaped depressions act as rain gauges. Phases of deep water corresponding to wetter climates are preserved as high notches or terrace-like water marks around the basin perimeter. Shallow or even dry phases are recorded in the sediments within the lakes. They remain as sandy deposits typical of shallow water, as high salinity sediments or as soils after the lake dries completely. At Keilambete the crater collected water rapidly after its formation by a volcanic explosion about 30 000 years ago. It appears to have remained full until about 23 000 to 20 000 years ago, then dried out. As it dried, plants colonised the lake floor and soil began to form. The crater remained relatively dry from 20 000 to 11 000 years ago, reflecting the lower rainfall conditions then prevailing throughout southern Victoria.

THE MURRAY–DARLING BASIN

Although glacial process and resulting landforms contributed much to the Australian landscape, their importance is surpassed by events in the vast inland plains. In southeastern Australia, these plains form the surface of the Murray basin, an area that lay under the sea until four or five million years ago. As the sea then retreated slowly towards its present coastline from an ancient shore near Balranald and Kerang, it left a legacy of ancient shorelines and sandy deposits. Its retreat extended the plains and created the landscape of the last 4 000 000 years, with its diversity of rivers, lakes and dunes.

Drying lakes, shifting river channels and advancing dunes all imposed new conditions on the human inhabitants. In the semiarid landscape of the Murray–Darling basin, the lakes attracted people to their fish, game and plants. These people also used the lake shores as burial grounds. This post-mortem evidence was then preserved by the natural advance of shoreline dunes over campsites or ritual burials. As a result, the names of Kow Swamp and lakes Mungo, Menindee and Victoria have become landmarks in the discovery of Australia's earliest human history.

The Murray basin provides a panorama of people in a changing landscape. It is divided into two natural regions, the riverine plain on the east, characterised by the channels and alluvial deposits of the complex river systems, and the mallee on the west, with its sandy dune fields, red calcareous [limey] soils and typical mallee eucalypt scrub.

The Murray–Darling river system is greatly affected by the climatic conditions through which the rivers flow. Rising on the wet western slopes of the highlands, the streams run inland for long distances, entering increasingly arid regions on their journey to the sea. Evaporation and river salinity increase. But while water has been the dominant influence shaping the landforms of the riverine plains, the mallee landforms consist of wind-constructed dunes partly modified by lake basins and occasional river channels.

The modern river channels of the Goulburn, Lachlan, Murrumbidgee, Darling and even the Murray appear sluggish and narrow, winding their way through tree-lined terraced depressions. All were larger some 40 000 years ago. The Goulburn, for example, flowed north of Shepparton in a wide sandy channel that cut a meander belt 2500 metres wide, more than twice the size that of the present river system.

About 30 000 years ago, this system changed. Along the Goulburn a younger channel, the Kotupna system, split away from the older one, but nevertheless retained a meander belt much larger than that of the Goulburn River today. Along the traces of both ancient channel systems, sands blown from channel floors onto the northern or eastern margins during low river levels built up sand dunes, which are now vegetated and stabilised. These dunes could not have formed if river woodlands such as those found today had existed. The protective canopy would have reduced wind velocity. Thus evidence of earlier landforms helps us reconstruct earlier landscapes.

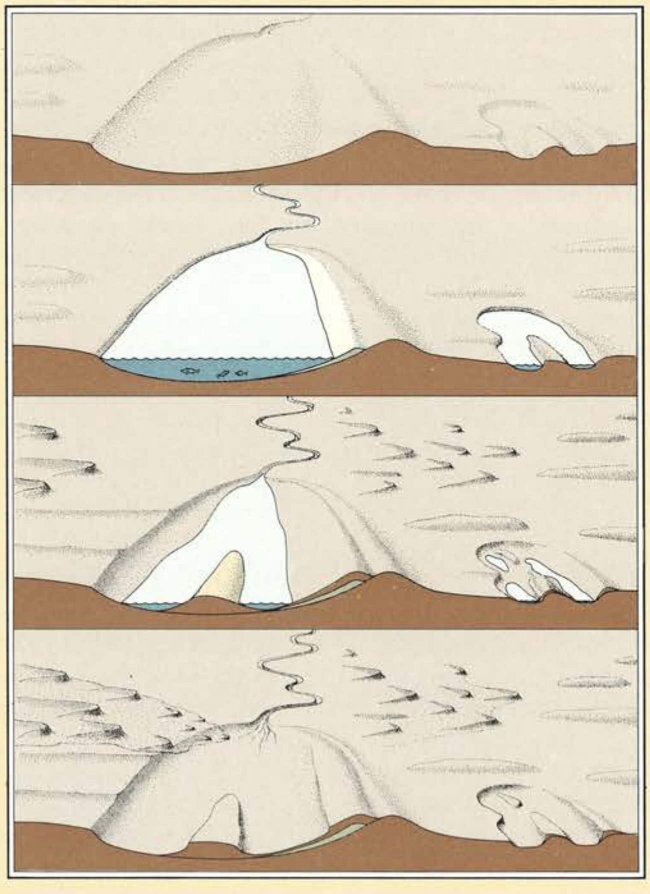
LANDFORM EVOLUTION

Across the semiarid zone, shallow basins left from wet periods remained dry. Ancient dune forms were already present but remained fairly stable.

Water returned to the land, flooding the lakes and causing water tables throughout the inland to rise. In the larger water bodies, wave action produced smooth beaches and shoreline dunes, as seen on beaches today. Fish and other aquatic fauna abounded in what had been dry, inhospitable country.

As the climate began to dry yet again, the lakes became saline, fish died and salts began to crystallise on exposed mudflats. These in turn disrupted drying clays and permitted wind action to transport large quantities of drifting clay pellets. Some accumulated within the basin to resemble islands as at Lake Tyrrell, but most travelled to the lake shores to produce *lunette* dunes. At the same time, the west-to-east dunes characteristic of the Mallee region were reactivated; a new layer of windblown sand covered their older forms.

Once ground waters, now saline, had fallen, vegetation returned. The dunes became stabilised and the landscape took on an appearance that has changed little over the past 14 000 years, except where erosion has reactivated older dunes.



Landform evolution typical of the semiarid landscape of southern Australia through the past 60 000 years.
J. JEFFREY

The shape of the ancient channels and the sandy nature of the sediments they carried also reveal the presence of relatively fast-flowing streams carrying much more water than the same rivers today. The modern channels are narrower and carry little sandy sediment. They have become muddy, sluggish streams. Radiocarbon dates from charcoal and shell in the banks of the Goulburn and Murray rivers indicate that the change to narrow sinuous channels typical of the present system happened between 12 000 and 10 000 years ago. Although they are less well documented, similar transitions occurred in the Murrumbidgee and the Lachlan rivers.

The landscape around the river port of Echuca is one of the few places in the world where a complete chronology of river evolution can be documented and related to changes in geological formations and climatic conditions. This is made possible because earth movements uplifted the block to the north of the Murray and Goulburn rivers, diverting their channels, and thus preserving the ancient ones.

The ancient channel morphology that evolved through a complex sequence of events described in the box Landform evolution still affects the behaviour of the modern river. The most recent Murray channel from Mathoura to Echuca is the product of a new diversion formed only about 8000 years ago. Water can flow through it in either direction. During floods, the peak arrives first from the Goulburn River, and at the Goulburn–Murray junction the flood backs up the Murray until it meets the Edward River in the Barmah depressions. Until artificial control was established, two-thirds of the Murray waters during flood peaks went down the Edward River and only one-third down the main Murray channel.

The anabranch (alternative channel) system, although well developed on the Murray, is best known on the Darling. There the Great Anabranch is an alternative channel. During high floods, water is carried through both channel systems instead of one. In the Darling system, the modern channel developed about 10 000 years ago, when it split from its older sinuous ancestor, leaving the abandoned course that now forms the anabranch. The changes that caused this diversion affected the lifestyles of Aborigines whose campsites have been found along the anabranch.

The Willandra and Other Lake Systems

The entire Murray basin is dotted with numerous shallow depressions of diverse shape and size. These are mainly dry, inactive lakes, whose beds are covered with vegetation. At times over the last 40 000 years, many were brimful of fresh water and areas where no surface water lies today for more than a few weeks were rich with fish or mussels. Around the edges of fossil lakes near Hatfield in Victoria, for example, far removed from any flowing streams, are shell middens of the mussel *Velesunio*, indicating the presence of permanent fresh water late in the last glacial period. Just as the history of rivers reflects changes in large catchments, many lakes on the plains fluctuate according to the volume of water in small catchments. Because such changes are controlled by processes simpler than those affecting stream systems, their causes can be identified more directly and reliably.

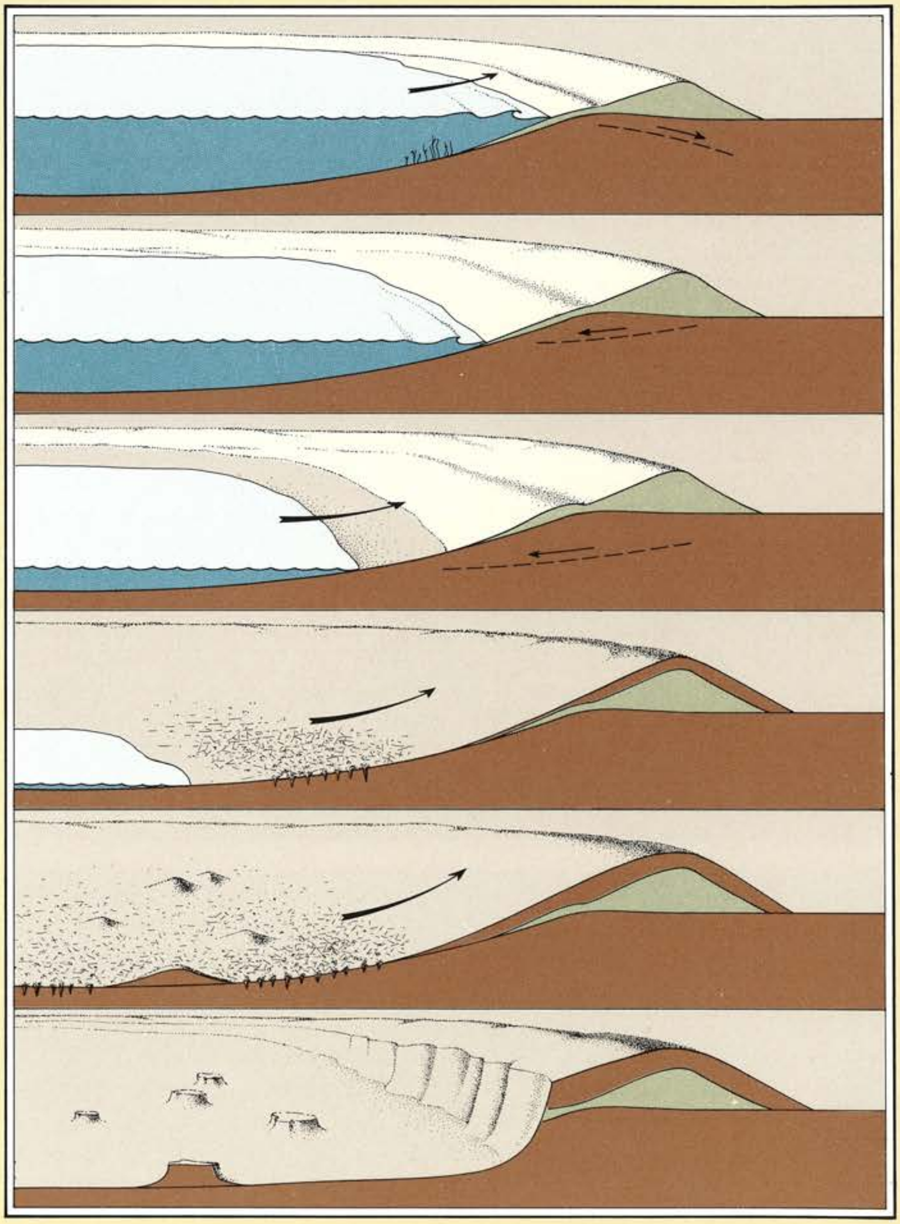
In the simplest system, rises or falls in the level of a lake are caused by changes in the relationship between precipitation and evaporation, which arise directly from variations in climate. Not all lakes are terminal systems with small catchments, however. Many in the mallee and the riverine plain were fed by through-flowing rivers, such as in the Willandra Lakes, which left the Lachlan and joined the Murrumbidgee. Others, such as the Darling River lakes near Menindee, were fed by overflow channels from major rivers. Another case was Lake Victoria, fed by the Rufus River, a Murray overflow channel. Lake Tyrrell, on the other hand, was a terminal lake fed by Tyrrell Creek, an overflow distributary of the Avoca River.

A chain of lakes in the southwest near Lake Grace, where ancient river valleys have dried up. Similar elliptical basins are found throughout southern Australia. The pink is caused by algal growth in highly saline waters. This view is from the south.

J.M. BOWLER

Horseshoe-shaped dunes (lunettes) near Hatfield in western NSW mark the outlines of former lakes. This view, looking south, shows how westerly winds have made ridges on the dunes on the eastern margins of the basins (left). The system of four small lake–lunette outlines is nested within the outlines of a larger system registering the progressive reduction of surface waters.

J.M. BOWLER



J. JEFFREY

LAKE EVOLUTION SEQUENCE

In the study of environmental changes over southern Australia, much evidence is obtained from analysis of sediments and landforms associated with shorelines of ancient lakes. Because they respond sensitively to changes of water level and salinity within the basin, they enable us to reconstruct sequences of wetter and drier climates. The diagrams show changes in dune building, with successive variations of water in lake basins. The sequence begins with a full lake and moves to dry conditions, using a vertical cross-section through the eastern side of a typical basin in southern Australia, where winds blow from left to right and determine where and how dunes form.

Full lake. Salinity is low; water may be fresh. Aquatic plants may grow in shallow marginal zones. Wave action generated by westerly winds produces sandy beaches on eastern shores. Strong winds may blow sand from the beach to form a foreshore quartz dune. Sand may contain shell fragments of freshwater fauna from the lake.

Water level falling, salinity increasing. The water table begins to drain back into the lake, returning salts to the surface. Fauna adjust to more saline conditions.

Continued drying. Saline mudflats are exposed around the margins of the lake. Salinity rises because of water loss and inflow of saline ground waters. During seasonally dry periods, the exposed mudflats become affected by crystallising salts.

More drying. Mudflats crack, more water is lost and more salts crystallise by evaporative loss through the capillary fringe above the saline water table. Salt crystallising cracks during the dry breaks up clays, forming a soft and fluffy layer. Strong westerly winds transport clays to the shoreline margin, covering the older quartz dune with a new layer of windblown material, rich in clay and containing large quantities of salts, in contrast to clean quartz dunes formed when the lake was full. Shells of salt-tolerant fauna may be incorporated into the saline dune.

Still more drying. Some clays transported from farther out on the basin floor accumulate as hummocky topography. After dune formation has ceased, the basin floor is smoothed, levelled and extended by cutting into dune margins. This may be done by return of water, with wave action cutting cliffs in earlier windblown materials, or by progressive erosion along the top of the water table, producing shoreline retreat and cliffing as shown. Hummocky materials on the basin floor become cliffed, resembling islands, now surrounded by mudflats.

On the eastern or downwind margins of nearly all the shallow basins of the riverine plain, a crescent-shaped dune follows the eastern shorelines. First described in detail by Thomas Mitchell in 1836 and known as lunettes, these dunes contain a variety of materials. Unlike most desert dunes, they are rich in clay and often contain much gypsum. Their formation involved a delicate balance between ground water beneath dry lake floors, and occasional surface inundations.

Lunettes in the Murray basin appeared when water tables much higher than those of the present combined with intermittent surface flooding to produce pellets of clay on dry lake floors that were later eroded by strong westerly winds. Today most lunettes in western New South Wales are inactive features or fossils with their adjacent lake floors often vegetated. Water tables had to be at or near the surface for the clay dunes to form, but present water tables are often ten to thirty metres below the surface. The special conditions necessary for the formation of such features throughout a wide region of southeastern Australia enable us to construct a detailed picture of its climatic evolution.

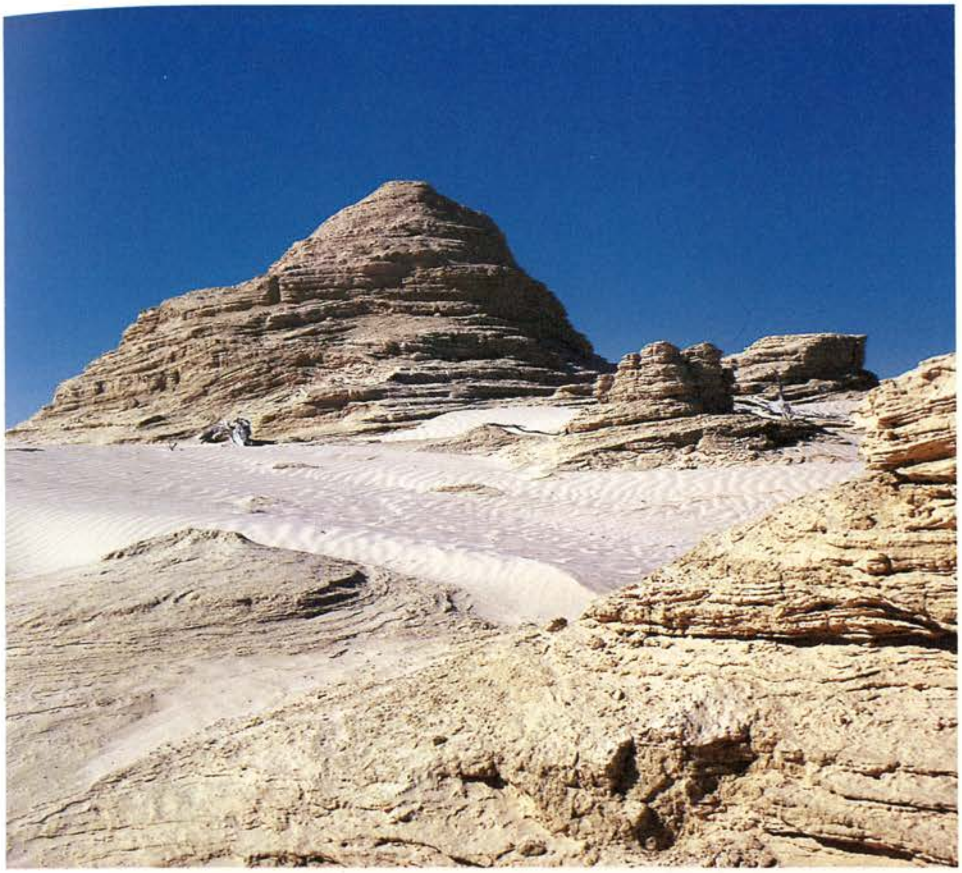
The Willandra Lakes have been preserved for posterity by inclusion in a United Nations World Heritage list. Today, even after very heavy rains, only small pools of water collect on the basin floors. Yet the beaches, fish remains and abundant mussel shells provide clear evidence of dramatic changes. The system, covering about a thousand square kilometres, has been filled and overflowing with fresh water for long intervals during the past 120 000 years.

The evidence from dunes and soils indicates that this region has undergone three cyclical changes in which periods of filling were followed by drying, dune formation and the development of soils across the landscape. The last such episode

Lake Mungo series

Aerial view looking north along the Walls of China, the eroding shoreline dune on the eastern side of Lake Mungo. On the shores of this lake much evidence of early human occupation has been found. Men and women were attracted to camp here up to 40 000 years ago by the abundant supply of fresh water. The lake dried out as the climate became more arid, and disappeared about 17 000 years ago.
J.M. BOWLER

Red soil on the shores of ancient Lake Mungo is all that remains of a dune more than 100 000 years old. The soil is overlain by grey sandy clays blown from the lake floor during a later climatic cycle of wetting and drying.
J.M. BOWLER



Winds today cut into the layered sediments to expose the internal anatomy of the ancient dune.
J.M. BOWLER

A pillar of layered sands sticks out from the eroding surface of the Walls of China. These layers, formed by wind action 17 000 years ago when the lake was drying, are now being destroyed by winds.
J.M. BOWLER

spans the period of the last interglacial–glacial cycle from 120 000 to 15 000 ago.

From about 120 000 to 60 000 years ago, the lakes were dry, much as they are today, with vegetation cover and soil formation on the lake floors. By about 50 000 years ago, the climate had changed. Increased runoff from the Lachlan catchment flowed down Willandra Creek, filling the lakes. Sandy beaches formed on the eastern shores under the influence of waves driven by westerly winds. Many trees grew around the water's edge and the branching traces of their root systems are preserved in fossil outline by calcium carbonate. Freshwater shellfish (*Velesunio ambiguus*, *Coriculina* and *Sphaerium*) abounded and so did other aquatic fauna.

About 36 000 years ago water levels fell in both Lake Mungo and outer Lake Arumpo. Both systems dried enough to permit exposure of saline mud, which was slowly blown away by the winds. The first clay-rich dunes of the last glacial cycle were formed at this time. This reduction in lake levels, accompanied by diminished surface water in the catchments of lakes and streams, marks the beginning of large-scale and apparently systematic harvesting of aquatic resources by human occupants of the region. Shell middens appeared in numbers on the shores of outer Lake Arumpo; many fish were cooked and eaten on the shores of Lake Mungo. At one site, along a single level representing one season's occupation, several hundred golden perch bones and cod bones have been recovered. The presence of this fish deposit in salty, windblown clay sediments suggests that the fish were dying or weakened by increased salt levels in the basin. They were easy prey to the foragers on the exposed shores.

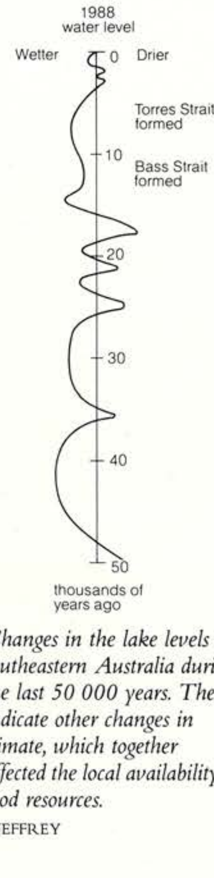
This phase of relatively dry conditions was short-lived. The lakes filled again and water overflowed south into Lake Prungle and beyond to join the Murrumbidgee. The next major change appeared about 25 000 years ago when evidence from lunettes and lake sediments indicates another large fall in water levels and another phase of lunette building that covered earlier beach deposits. For the next 4000 years there was less surface water (except during several intervals when lakes rose), but settlers still had a much easier livelihood than their successors in the very dry conditions that began about 21 000 years ago.

During this later period the lakes and their associated surface water resources within the surrounding dune fields disappeared. Wind built up lakeshore dunes of saline clay and gypsum on the shores of dozens of basins throughout the Murray catchment area, from Albacutya to Hatfield and from Menindee to Mungo, especially in the interval between 17 000 and 16 500 years ago. The hydrological and ecological implications of this climatic change towards more arid conditions were to be momentous for human settlement, chiefly in the way people used the landscape. Near this time, the first appearance of grindstones suggests an adaptation to food scarcity. The development of seed grinding was a new form of harvest insurance against the seasonal and longer-term scarcity, which became normal rather than exceptional in this landscape.

Shell middens dated to 14 000–13 000 years ago indicate a brief resurgence of water flow at the northern end of the Willandra system. Water might have reached Lake Mungo, but not enough to overflow, and the interlude of abundant water passed, never to return. Lake Tyrrell and the lakes of the Darling system have been studied less fully than the Willandra system, but a similar pattern of landscape changes appears to have occurred.

While the lakes were responding to changes in water balance, dune fields far removed from the direct influence of lakes were themselves undergoing related change. During the drying phases, ancient longitudinal and irregular quartz-rich dunes in western New South Wales and northern Victoria entered a new period of development. In areas of deep quartz sands, irregular dunes coalesced and

Islands in the centre of Lake Tyrrell, a large salt lake in northwestern Victoria. These were formed as ridges on the drying lake floor about 17 000 years ago. Water has returned to the lake under the wetter climates of today. Waves have trimmed the ridges and built up the smooth beach-like feature in the foreground. Algae produce the pink colours as the brines approach salt saturation. Salt is harvested from Lake Tyrrell each summer.
J.M. BOWLER



Changes in the lake levels in southeastern Australia during the last 50 000 years. They indicate other changes in climate, which together affected the local availability of food resources.
J. JEFFREY

advanced eastwards, some with lobes descending across the western shores of lake basins, as at Garnpung and outer Arumpo in the Willandra system. Elsewhere, as in the Wimmera River near Albacutya and Pine Plain, occasional flooding through the system trimmed back the dunes and prevented channels from becoming completely blocked.

The reactivation of dunes through the mallee region appears to have coincided with the final drying and main phase of clay dune building on lakes 25 000 to 16 000 years ago. At this time the lakes, and the human and animal occupants of surrounding regions, were subject to severe conditions known only during intense droughts in the subsequent 15 000 years. The disappearance of surface water, the construction of clay-rich lunettes with large quantities of airborne dust and salts generated from the hundreds of eroding depressions combined with the new phase of longitudinal dune movement to produce a most inhospitable landscape. People and animals had to look to the more permanent channels of the Murray–Darling and other rivers. These became lifelines.

THE ARID INTERIOR

The arid inland region encompassing the Flinders Ranges and the Lake Frome and the Lake Eyre basins extends over a large part of the continent. Its catchments, reaching far into north Queensland, are influenced more by summer rainfall than are regions elsewhere in the arid centre of the continent. Consequently, despite the different climatic settings, the arid centre has certain parallels with the wetter southeast in the nature and sequence of the major climatic changes recorded in the lake systems.

Lake Frome and Lake Eyre are remnants of larger systems that once existed around the northern end of the Flinders Ranges. Both have changed greatly in size during the last 120 000 years. Frome, which now rarely carries water for more than a few months at a time, was once a brimming freshwater lake. Around the western shore of the present dry, salt-encrusted surface, a gravel ridge rising 20 metres above the lake floor was formed by wave action during a long period of relatively

Overleaf.
Lake Mackay, NT-WA border. The desert dunes have advanced from the east with the arms of the salt lake now extending along dune corridors.
J. M. BOWLER

deep water. We do not know when this began to happen. It ended with the onset of shallow water and saline deposits estimated to be about 36 000 years old. This was a most significant change. Although in later times water returned to the lake, it never rose again to the level of the 20-metre shoreline.

Lake Eyre records changes similar to those at Lake Frome, spreading far to the northeast and east of the present shorelines and laying down sediments that contain fish remains and the brackish water gastropod *Coxiella gilesii.* These shell beds and deepwater sediments on the southern shores of the present lake stand in marked contrast to the gypseous saline muds of the salt lake itself. As in Lake Frome, sand dunes were mobilised and extended over the lake floor when the lake contracted. Large areas north and east of Lake Eyre and smaller areas east of Lake Frome were transformed in relatively recent times from large water bodies into a network of longitudinal desert dunes.

When these dunes began to form is unclear. It may have been 36 000 years ago or even earlier. We do know that in the Simpson and Strzelecki deserts dune activity continued until about 14 000 years ago, and that in Lake Frome wind action constructed gypseous dunes from 20 000 to 16 000 years ago. Thus the contraction of the lakes and the trend towards drier conditions culminated in widespread expansion of deserts over what was previously an environment of lakes and streams. What these changes meant for humans and animals is only now being evaluated. The abundance of large marsupials, especially *Diprotodon*, at Lake Callabonna just north of Frome, has been known since the end of the last century. The floor of Callabonna is a graveyard for many of these large marsupials that died, trapped in the mud of the receding lake.

While scientists still argue whether climatic stress was more important than the hunting activities of early Australians in making giant fauna disappear, changes in the water balance certainly contributed to the death of the diprotodons at Callabonna, where these browsing animals came in from the shrublands searching for water, only to be bogged in the shallow muds of the shrinking lake.

NORTHERN AUSTRALIA

The record from the northern, monsoon-dominated half of the continent is less well known than that of southern Australia. Tropical climates produce deep and rapid weathering which destroys much of the evidence, and little research has been done on the evidence that has survived. But there are exceptions, notably in the detailed evidence available from lake cores on the Atherton Tableland; and we have less detailed information from Lake Woods in the Northern Territory, the Gregory Lake system in the north of Western Australia and the Fitzroy estuary.

Vegetation records from the Atherton Tableland indicate that long dry periods persisted for much of the past 70 000 years. Throughout this time, the region was dominated by dry sclerophyll woodlands. The greatest aridity was about 20 000 years ago, when the sea was at its lowest in the offshore Great Barrier Reef region. Only in the past 10 000 years did wetter conditions return and rainforests expand.

On the other hand, both Lake Woods and the Gregory system have ancient expanded shorelines, evidence of much more water than in modern times. Dating these periods is difficult. Preliminary dates, from the shorelines of Lake Woods, are of 18 000 years ago and earlier than 23 000 years ago. They are almost certainly older than the peak period of expansion. At Gregory Lakes, radiocarbon dating indicates that the lakes were larger more than 30 000 years ago.

At both sites, contraction of the lakes was followed by dune building on the exposed lake floors, in areas where dunes do not form today. Again, dating is

In the Tanami Desert near the border of Western Australia and Northern Territory, parallel east–west dune systems stabilised by spinifex grass testify to a period of aridity when the dunes were built. In this view looking east, dunes controlled by easterly trade winds have grown towards the foreground, crossing the drainage line formed in earlier and wetter times, running from north to south.

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imprecise. Tentative correlations with dune building about 20 000 to 16 000 years ago in the south have been suggested.

In the Fitzroy estuary, longitudinal dunes of the desert type have been drowned by rising seas after the glacial period. The base of the dunes has been traced some seven metres below present sea level, so the dunes are certainly 8000 years old—probably more. The correlation between dune building and the arid environments of the glacial age is strengthened by such evidence.

Until about 50 000 years ago, the picture is patchy and blurred. We do know that from about 120 000 to about 60 000 years ago, the Willandra Lakes remained dry and that on the southeastern tablelands Lake George fluctuated rather as it does today, amid country mantled by grasslands and herb fields, not by trees.

About 60 000 years ago, drastic changes became apparent. The forest returned to the slopes of the southeast and warm sclerophyll forest was present in Lake George catchments, mixed with rainforest species. The Willandra Lakes filled. Widespread evidence of surface waters in Lake Eyre and Lake Frome suggests similar changes in interior Australia, although the dating is still tentative. In northern Australia, Lake Woods and the Gregory Lake system were greatly enlarged. Like Eyre and Frome, these lakes depended on summer rainfall, so the evidence of greatly increased runoff suggests that rainfall was substantially greater than it is in these arid zones today.

These conditions probably occurred within the last 40 000 to 60 000 years, coinciding with an early stage of human occupation. But finding traces of this occupation on the ancient shorelines of Lake Woods, Lake Eyre and Lake Frome presents a challenge. If people did live in these regions, they would scarcely be out of sight of surface water; droughts and all the stresses associated with present climates would have been almost unknown. Rivers such as the Finke, Diamantina and Cooper, which rarely flow today, would have been either permanent or seasonally reliable streams.

This period of abundance would have required frequent rainfall of the kind experienced during the wet of 1974–75, when Lake Eyre filled. But whereas such rains might now occur less than once a century, to keep Eyre and Frome filled would have required a similar rainfall at least every decade—a climatic situation very different from that of the past two hundred years.

While lakes Woods, Frome and Eyre may have begun to dry before 35 000 years ago, the evidence from further south—the Willandra Lakes and Lake George—indicates that relatively wet conditions persisted there for some time. But by about 35 000 years ago, falling temperatures in the southern highlands and the onset of cold, stormy winters—the precursors of glacial conditions—imposed a new set of seasonal stresses. High runoff and seasonal flooding in the streams draining the eastern divide maintained high flows in the Murray–Darling system, and human occupation along the Darling anabranch shows that early inhabitants depended on this ancient waterway.

If these distant periods of abundant surface waters were years of plenty, the time between almost 17 000 and 15 000 years ago was an age of prolonged famine. By comparison with today's climate, it represents a long run of droughts. Many rivers ceased to flow; lakes, previously abounding in fish and game, dried out. The shady shoreline beaches of previous years were now blanketed by layers of salty, gypsum-rich clays, repelling plants, animals and people. The inhabitants retreated to the seasonal flows of the arterial waterways on the better watered margins of the interior.

Within the desert regions, the full effects of these events are difficult to conceive. For the dunes to be reactivated over large regions and even to extend into southern Victoria and Tasmania, the soil had to be so lacking in moisture that any occupation by nomadic people dependent on a diverse range of seasonal resources might have been impossible over much of the inland.

At present occupation of central Australia is confirmed only as far back as about 12 000 years ago, although one would think that the earlier, wetter conditions must have encouraged settlement throughout the inland. During the driest period, people must have abandoned many habitats. Climatic change must have induced migrations and new mixtures of linguistic and cultural groups. Such innovations, obscured by the passage of time, invite exploration by students of Australian human and environmental history.

If the arid stresses were prolonged and drastic, the return to wetter conditions about 12 000 to 10 000 years ago was widespread and permanent. As rainfall increased, the ancient streams, partly choked by sand and with winding, low-gradient channels, proved inadequate. New channels split off from the older ones to carry increased volumes of water. Through the low-gradient plains they often ran parallel to older channels, leaving them as remnants,such as the anabranches of the Murray–Darling system.

Lakes from Lynch's Crater in northern Queensland to Keilambete in southern Victoria also filled as rainfall increased, and the rising sea, slowly advancing landwards, eventually flooded Bass Strait and isolated Tasmania and its inhabitants from the mainland. Rising sea levels, more moderate summer winds, stabilisation of dunes and more regular rainfall introduced climatic conditions about 10 000 years ago which have persisted with only minor changes until the present. Following the long, dry, glacial phase, vegetation patterns adjusted to the more genial environment. Dry sclerophyll woodlands returned to the southeastern slopes. Rainforest, previously reduced to the wettest, most sheltered habitats, expanded across the Atherton Tableland, Tasmania and the far southwest of Western Australia. The landscape took on the aspect that greeted Europeans.