

Playas of inland Australia

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Abstract

Playas, mostly in the form of salinas, are characteristic of the Australian arid zone. Many are associated with lunettes in sebkha complexes or assemblages and can be attributed to the deflation of bare alluvial flats. Many playas are structurally controlled. Lake Eyre, for example, occupies a downfaulted segment of the crust, and many other playas large and small are associated with faults. Lakes Frome, Callabonna, Blanche, and Gregory each displays a linear shoreline, but also and arguably, all are located on a regional structural arc. Lake Gairdner occupies a valley probably blocked by faulting. Others may be caused by preferential weathering along fracture zones, some linear but others arcuate. Many salinas are developed in dismembered rivers channels, the position and pattern of which are structurally determined. But many owe their existence to the interaction of several of these factors. The various salts precipitated in playas constitute a significant resource, regional and local, past, present and future.

Key words: playa, salina, sebkha, lunette, Australia

INTRODUCTION

As LAMPLUGH (1917, p. 434) pointed out, anyone not knowing better could be misled by a physical map of Australia, for 'lakes', large and small, appear to be widely distributed over the interior of the continent. 'Lakes' imply water and a humid climate. FOREL (1892), for example, defined a lake as a body of water with no connection with the sea; except, presumably, for a possible overflow stream that reaches the coast. He also took no account of swamps, marshes and lagoons. But on the one hand, if the volume of water entering the lake depression is greater than the capacity of the topographic basin, the waters overflow and drain away, breaching the barrier that contains them as they do so. Alternatively, if water supply is less than losses resulting from evaporation and seepage either into the subsurface or via underflows, the erstwhile lakes become dry depressions. Also, lakes may gradually become filled with sediment and organic debris. Such changes in time account for the relationship of lakes, marshes, swamps, lagoons, and other types of 'water body'.

PLAYAS

The 'lakes' of inland Australia rarely hold water. They are playas or dry, bare vegetation-free areas standing in the lowest points of desert basins and are underlain by stratified sediments and commonly by soluble salts (BATES and JACKSON, 1987, p. 511). They carry water either rarely, spasmodically, and unpredictably; or they are intermittently wet, filling seasonally, in northern Australia during the summer monsoon, in the south during winter, when they are fed by rains associated with midlatitude lows. Some are flooded

by clastic sediments (hence 'claypan', even though the fill may consist mostly of sand) but all the muds are saline and many carry a crust of salts of various compositions. These playas are known as salt pans or salinas. In Australia, the central and western interiors are the driest parts of the continent, yet are replete with so-called lakes (figure 1). Lack of regular runoff inhibits the development of a coordinated exogenetic stream system that penetrates deep into the interior of the continent. This is particularly true of a compact land mass such as Australia. But no desert is rainless, and though such falls are no more intense than are experienced elsewhere, they fall on surfaces that are unprotected by vegetation and in many areas carry a sun-baked crust that induces short-lived but high runoff rates, so that even small amounts of precipitation can cause local flooding. They also transform the arid wastes for a few days or weeks, when the desert plants bloom as dormant seeds burst into life and aestivating animals awaken (see, e.g., various chapters in TYLER et al., 1990; also CLOUDSLEY-THOMPSON, 1965). But such events are infrequent and the temporary lakes soon revert to their arid status and again become playas.

Thus playa basins are a prominent feature of the Australian deserts (e.g. BOWLER, 1981, p. 432), but names like 'Lake Disappointment' signal a warning and suggest that despite the apparent abundance of water bodies, there are no lush meadows, but rather a wasteland. Lake Eyre is the best known, as well as the largest, of the Australian 'lakes'. Its periods of flood are well documented. It received the early attention of South Australian scientists. Yet, and ironically, it is situated in a hyperarid zone, so confirming the anomaly of 'lakes' existing in extreme aridity.

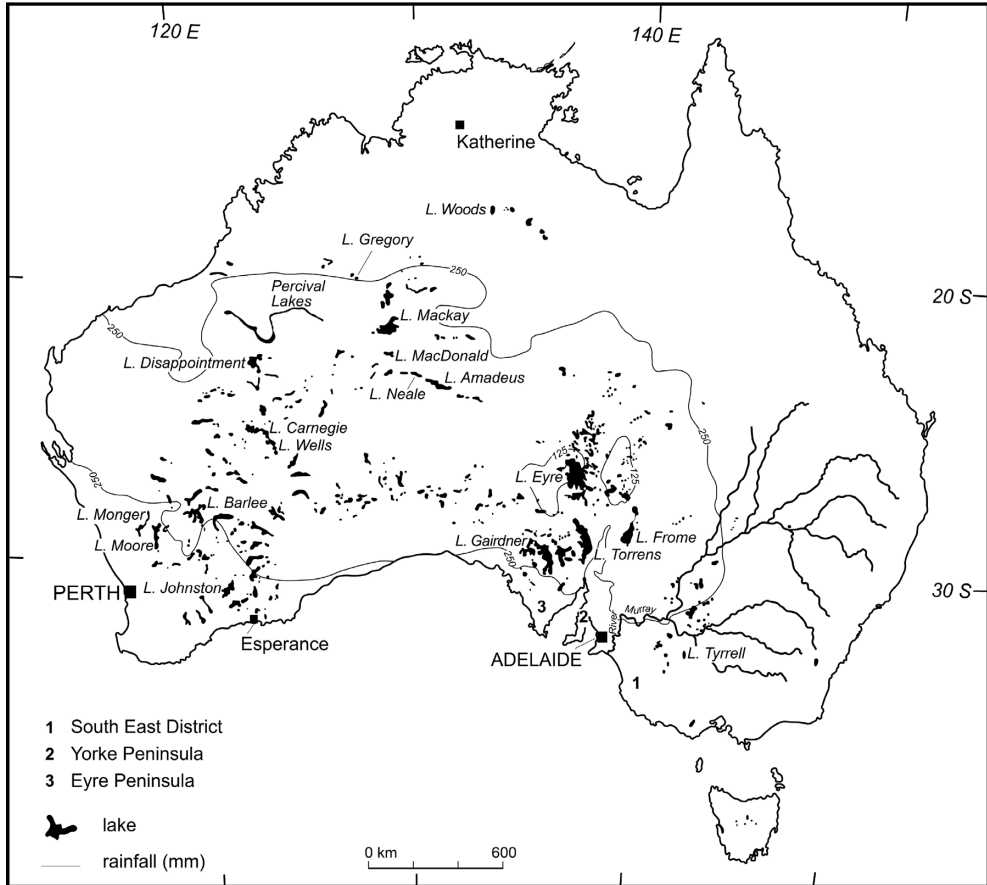


Fig. 1. Map of Australia showing the larger inland ‘lakes’ in relation to the semi-arid and hyperarid zones (after BOWLER, 1981; DE DECKKER, 1983).

Playas and exploration

Salinas and associated forms have influenced the exploration of the interior of Australia. For instance, during his inland travels of 1839 E.J. Eyre observed parts of the several salinas that encircle the northern Flinders Ranges – what are now known to be lakes Torrens, Eyre, and Frome (figure 2). In his mind’s eye, however, and his judgement possibly affected by mirages, he con-

nected the areas of white and thus came to believe that the uplands were enclosed by a single horseshoe-shaped lake (EYRE, 1845), an idea that was dispelled by G.W. Goyder some twelve years later when he surveyed part of the area in what was a very wet year. Even so, later explorers (e.g. H. Freeling) took boats to the interior in order better to breach the barrier and reach what they hoped were the green pastures beyond (see e.g. MINCHAM, 1964).

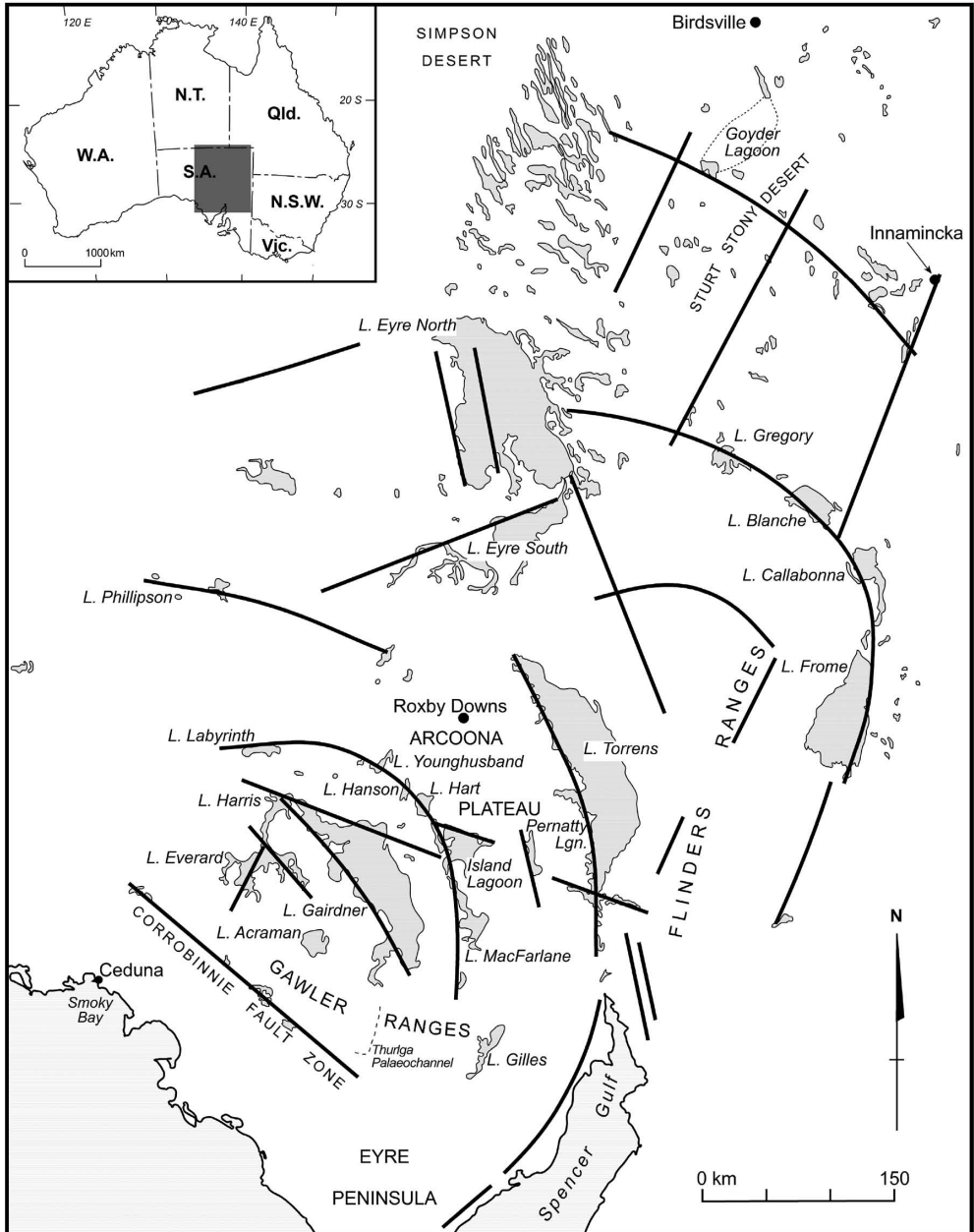


Fig. 2. Map of playas in relation to major fracture zones in central and northern South Australia.

Origins and classifications

Lakes and playas in general and Australian occurrences in particular have been classified in various ways and using various criteria (see e.g. HOLMES, 1965, pp. 672-675; DE DECKKER, 1983; for review, see TIMMS, 1993, pp. 2-10). De Deckker, for instance, distinguished inland playas according to catchment size. In this overview they are defined on the basis of their geological and geomorphological settings. All are located at low points in the regional or local relief and many owe their origin to a combination of factors. For this reason, possible playa origins are considered under a few simple headings that indicate the primary factor involved and apply to a number of examples. By contrast, Lake Acraman (WILLIAMS, 1994) occupies all that remains of the depression formed by a bolide impact of some 600 m.y. ago and as far as is known, is unique in Australia.

Deflation

In a desert setting, deflation, or the scouring and transport by the wind of clays, sands and other weak, unconsolidated materials unprotected by vegetation, readily comes to mind as a possible formative process for topographic lows that become depocentres and then playas. This led TIMMS (1993, p. 127 et seq.) to claim that deflation hollows "... are usually the commonest type of lake basin in deserts", a conclusion that finds support in the field evidence. The vast majority of the small playas located in interdune corridors in the Australian dunefields are deflation hollows (figure 3), the depth of which is limited by the local water table. Thus, Charles Sturt, exploring in what is now known as Sturts Stony Desert in 1845, noted that: "...the space between the ridges" [was] "occupied by the white and dry beds of salt lagoons" (STURT, 1849, II, p. 33). Lengthy periods between rains may allow vegetation to colonise the playa bed and thus inhibit further erosion, but most remain active.



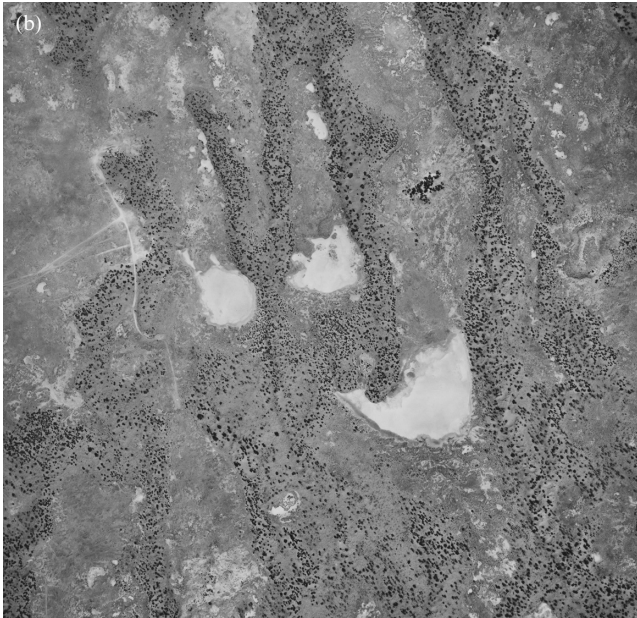


Fig. 3

(a) View from linear dune crest looking SSW, of interdune corridor occupied by salinas and source-bordering and transverse dunes, 95 km north of Innamincka, South Australia.

(b) Vertical air photograph of area near Roxby Downs showing linear sand dunes and corridors, the latter with playas where water occasionally accumulates facilitating growth of vegetation (Ma-pland, DEH, 1980: Survey 2545, Photograph 132).

Because of the absence or scarcity of the vegetation cover, and apart from coastal areas, wind has its maximum impact in desert regions, resulting most notably in the formation of the dunefields that occupy some 70% of desert areas world-wide. Yet, the power of wind abrasion has been overestimated at times in the past. Thus, regional planation briefly was attributed to deflation and abrasion by saltating sand grains propelled by the wind (PASSARGE, e.g. 1904; KEYES, 1912; JUTSON, 1914), but weathering and fluvial corrosion are now considered more likely to be responsible. Weak unconsolidated sediments certainly have been eroded by turbulent vortices to produce yardangs, or smooth, elongate, streamlined ridges separated by wind-eroded corridors (e.g. BLACKWELDER, 1934; BOBECK, 1969). But the shaping of hard rocks, though spectacular, is limited to minor features such as Dreikanter (three-sided stones) and flutings (e.g. HUME,

1925), particularly where local conditions have caused airflow to be confined. Thus in the San Gorgonio Pass, near Palm Springs in southern California, wind is funneled along a graben floored with sand derived from the weathering and erosion of the bordering uplands. It is further restricted, and its velocity increased, as it passes over a col, resulting in an assemblage of minor but spectacular pitting of wooden posts carrying powerlines, and fluting in gneiss (RUSSELL, 1932).

Notwithstanding the limitations inherent in the deflative process, BREED et al. (1989) presented sound evidence and argument to suggest that large playas in the north of Iran are shallow hollows scoured in unconsolidated fine sediments down to the local water table. In addition, exposures of recently deposited fine alluvia unprotected by vegetation are undoubtedly susceptible to airflows armed with sand or salt (cf. DERRUAU, 1956; see also KING, 1956; NICHOLS,

1969). Sand-sized particles form a surface that is rough in detail. Wind passing over such a surface becomes turbulent and erosive, and as COFFEY (1909) pointed out, the dried mud that underlies the floors of some playas tends to form platelets the edges of which curl upwards, again creating a rough surface. Salts are a common component of the clays exposed in the floors of many playas and their crystallisation causes micro-scale disturbances of the surface, so that instead of a smooth packed surface, the wind acts on one that is rough and induces turbulence and erosion (TRICART, 1954a). Lengthy periods between rains, however, may allow vegetation to colonise the playa bed and inhibit further erosion.

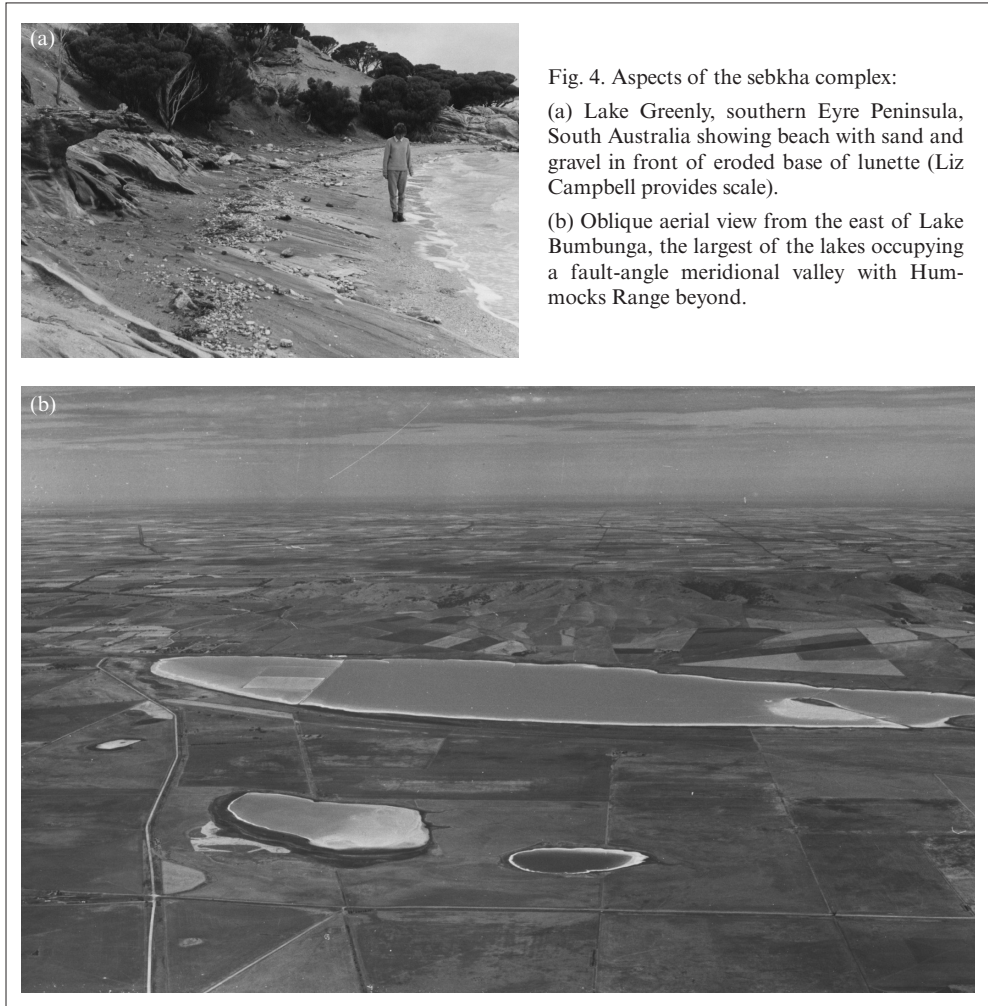
Deflation is of major significance in the formation of playas and in the evacuation of dust, millions of tonnes of which are set in motion every year with central Australian dust exported not only to the eastern states but to New Zealand, that from the Sahara to the Antilles and to the United Kingdom, and so on (see e.g. EGAN, 2006). Deflation also has been an important issue in the debate concerning the origin of lunettes and the assemblage of landforms of which they are part, i.e. the *sebkha* (*sabkha*) complex.

Lunettes and the *sebkha* complex

Early explorers and scientists referred to mounds, banks or ridges bordering salinas, pans, lagoons and marshes (e.g. MITCHELL, 1839; EYRE, 1845, p. 58; JACK, 1921, 1931, p. 8) but these terms are general and vague. The 'clay dunes' described by COFFEY (1909) from Texas are similar to the 'loam ridges' (HARRIS, 1939; HILLS, 1939) or 'lunettes' studied and so named by HILLS (1940) in northwestern Victoria. Terms such

as lee-side mounds, and source-bordering dunes also have been used to denote these fixed dunes. Later it became clear that the compositional range of these dunes is greater than was indicated by the examples chanced upon and reported by these early investigators (see e.g. JACK, 1921; STEPHENS and CROCKER, 1946). Moreover, the dunes were recognised as part of the pan-dune, or *sebkha*, assemblage (BOULAINÉ, 1954; TRICART, 1954b).

Lunettes are crescentic stationary dunes located adjacent to playas (figure 4), some small and unnamed, as well as some of moderate size, such as lakes Fowler and Bumbunga and Bool Lagoon, and yet others of considerable extent. Thus such features are found bordering, for example, the northern margins of Goyders Lagoon, and Lake Eyre, and the eastern shores of lakes Torrens and Gairdner. They are found also in the lee of deeper sections of river channels, like the dry billabong depressions in the bed of Goyders Lagoon. Some lunettes are several kilometres long, others just a few tens of metres. Similarly they vary in height, from a few metres to those located on the northern margin of Lake Eyre that are 50-60 m high (DULHUNTY, 1983). Some are built of silt or clay, and others of sand, but many consist of seed or flour gypsum, colloquially known as 'kopi'. Thus in South Australia, JACK (1921) and CRAWFORD (1965) provided accounts of the kopi dune bordering Lake Fowler in southern Yorke Peninsula, JOHNS (1968) described such forms bordering Lake Torrens, and BLISSETT (1985) cited gypsiferous dunes in the lee of lakes Acraman, Harris, and Everard further to the west, as did COWLEY and MARTIN (1991) from the Kingoonya area, and MAJOR (1993) and BENBOW (1982, 1993) from areas to the north.



In southern Australia lunettes typically are located on the eastern margins of depressions (e.g. BOWLER, 1968; CAMPBELL, 1968; PAGE et al., 1993), though there are exceptions. For instance, the lunette bordering Kappakoola Swamp on northern Eyre Peninsula stands adjacent to the southern shore (SMITH et al., 1975). As mentioned, a major lunette stands adjacent to the northern shore of Lake Eyre North

(DULHUNTY, 1983), but elsewhere in central Australia, for instance around Lake Amadeus they are located on the southern sides of the playas or river channels (CHEN et al., 1991). In the far north, as for instance at Lake Woods, lunettes border the western shore. Similarly they stand on the western side of playas in the Lake Gregory complex of northern Western Australia (BOWLER, 1990, p. 6) but north of Esperance, on the

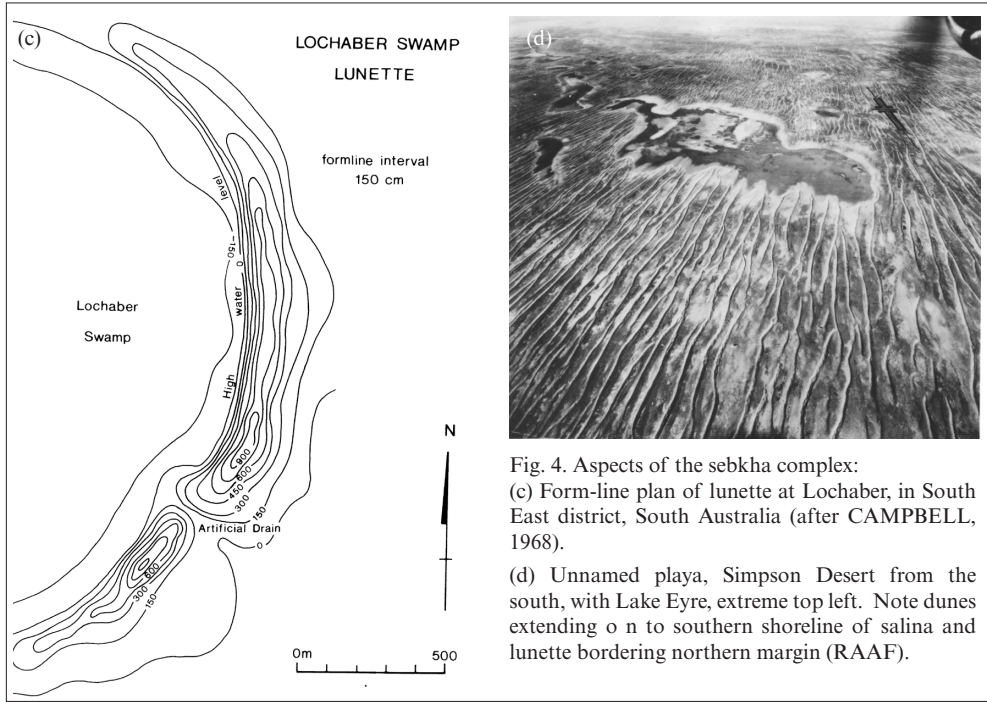


Fig. 4. Aspects of the sebkha complex: (c) Form-line plan of lunette at Lochaber, in South East district, South Australia (after CAMPBELL, 1968).

(d) Unnamed playa, Simpson Desert from the south, with Lake Eyre, extreme top left. Note dunes extending on to southern shoreline of salina and lunette bordering northern margin (RAAF).

south coast of Western Australia, lunettes occur on the eastern side of depressions.

COFFEY (1909) attributed the dunes to the deflation of lake beds located immediately upwind, but HILLS (1940) envisaged that lunettes formed when the lake depressions carried water. All the lunettes he studied were fine-grained (silty) and he suggested that air passing over the lake picked up moisture. Dust in suspension coagulated as a result of contact with moisture and halite, and was deposited on the lee shore (see also HILLS, 1939). This explanation became known as the 'wet' hypothesis because it involved a true lake, with water. Like Coffey, Hills offered no explanation for the lake depressions. Also the 'wet' hypothesis could not account for the many lunettes composed of sand or seed gypsum. Considering these mounds composed of coarser sediments,

STEPHENS and CROCKER (1946) returned to Coffey's deflation hypothesis, arguing that silt and clay particles coagulated on the dry lake bed to form pellets subject to wind transport by saltation as well as deflation.

The deflation or erosional hypothesis has the great advantage of simultaneously accounting for the lake depressions and the lunette. As would be expected if deflation had occurred, the composition of the lunette closely matches that of whatever sediments are found in the particular lake bed, with the exception of some fines lost to winnowing and preferential wind transport.

But difficulties remained. First, comparison of the position of lunettes adjacent to playas in southern South Australia with local seasonal wind regimes, suggests that the mounds were deposited by winter winds (cf.

KILLIGREW and GILKES, 1974), when the playas of southern Australia, for example, most likely were covered by water, and not summer winds, as might be anticipated if airborne dust or the lake bed were the immediate source of the lunette deposits (CAMPBELL, 1968). That many playas carry an encrustation of salt (gypsum, halite) also poses problems, for it was difficult to understand how sand or silt (or of whatever sediment the local lunette is built) could have been deflated from beneath such a cover.

A solution was suggested by CAMPBELL (1968) and BOWLER (1968) and, it transpired, and incidentally, by WOODS (1862, pp. 27-28). Working in the South East District of South Australia, Woods noted that flotsam was carried by wind-driven waves to the lee shores of lakes. Campbell made similar observations in the region around her childhood home, near Naracorte, also in the South East. When the playa carried water the salt crust was dissolved. Thus the underlying sediment could be drifted by waves to the lee shore. Bowler's discovery of gravel in lunettes also pointed to wave transport. The sediments deposited on the lee shore formed beaches from which the wind winnowed material of suitable size and carried it a short distance into vegetated areas where it was trapped and built up into immobile dunes or lunettes. Thus lunettes were interpreted as analogous to coastal foredunes. In this respect it is salutary to recall that when approaching the salina in July 1840, Eyre "found Lake Torrens completely girded by a steep sandy ridge, exactly like the sandy ridges bounding the sea shore..." (EYRE, 1845, I, p. 58)!

Sebkha complexes like that at Lake Greenly (figure 4) on southern Eyre Peninsula fully conform to this hypothesis for a

beach rich in sand and gravel stands as the source from which the sandy lunette is derived. The multiple lunettes formed on some lee shores mark stages in the shrinkage of the particular lakes. The Campbell-Bowler hypothesis comparing lunettes to coastal foredunes explains the major characteristics of lunettes, but anomalies remain. For instance, not all playas in a given locality are bordered by lunettes. Some are, but others are not. It might be expected that a large lunette would be associated with a large playa but it is not necessarily so, for some small playas are bordered by large lunettes, and vice versa. But the coastal foredune comparison explains many of the field characteristics.

Lunettes are widely represented in Australia and though best known from southern regions they occur in abundance also in the arid lands of the centre where they are associated with dry river channels as well as with playas. They play an important role in the generation of the linear sand dunes characteristic of the region (WOPFNER and TWIDALE, 1967, 1988; TWIDALE, 1972, 1981). Lunettes interfere with airflow causing deflection and turbulence, leading to the deposition in the lee of the topographic obstacle of ribbons of sand which coalesce downwind to form the linear sand ridges or dunes that dominate the Australian, and indeed the world's, deserts.

Working in the arid interior of Western Australia, JUTSON (1914, 1917) attributed 'billiard table' bedrock surfaces associated with salinas to the work of wind, waves and salt. He thought that salt from the salinas ate into and disrupted the rocks exposed at the western margin of the deflation hollows. The wind not only removed the debris but also caused the westerly migration of the

playas. In addition to such deflationary features, Jutson recognised that some playas occupied deformational hollows – salinas caused by minor, local faulting or warping, by structural effects.

The structural factor

JENNINGS and MABBUTT (1977, p. 39) claimed that the larger playas of the Australian interior owe their origins to geologically-young faulting. Active faulting (tectonism) can form depressions such as rift valleys, graben or sunklands, fault angle valleys or half-graben and sag ponds, all of which are potential sites for playas. Faults can be passive, first, because they can be zones of weakness exploited by weathering and erosion, and second, by bringing into juxtaposition rocks of contrasted susceptibility to weathering and erosion, again causing the development of topographic depressions that become playas. Faults influence the formation of river patterns some of which again have become the sites of playa development. Thus, the relationship between faults and playas is widespread but varied, frequently indirect, and commonly difficult to ascertain with certainty. But whatever their origin, the playas are depocentres and areas of salt accumulation and precipitation.

At one end of the scale a small sag pond is occupied by a dry marsh on the Ash Reef Fault, on northeastern Eyre Peninsula (MILES, 1952; HUTTON et al., 1994). At the other extreme is Lake Eyre (JOHNS, 1963), a salina some 3600 km² in extent and underlain by some 80 metres of Cenozoic

beds overlying a thick sequence of Cretaceous strata.

TIMMS (1993, pp. 45-46) cites Lake Eyre North as of tectonic origin, but attributes it to warping in the crust. This is incorrect. It is downfaulted and has resulted in the bed of Lake Eyre South being some 15-16 m below sea level (DULHUNTY, 1987). The precise location and value of the lowest point varies according to the most recent cycle of flooding, solution, desiccation, and salt precipitation and crystallisation. Whether the downfaulted block is a graben or half-graben (fault-angle depression) remains unclear, but certain it is that the salina is delimited on its western side by a fault scarp (figures 2 and 5). The evidence is varied (JOHNS, 1963; WOPFNER and TWIDALE, 1967; TWIDALE 1972). Though intricately dissected the scarp is linear. The scarp is capped by a 2 m-thick bed of coarsely crystalline gypsum underlain by friable gypsiferous silts, a sequence that is intersected at shallow depth beneath the adjacent salt bed. The mound springs that emerge on the bed are not randomly distributed but occur in rows. The so-called Warburton Groove is not winding, as depicted on some early maps (presumably because the Warburton River there debouches on the lake bed and as rivers are winding, so must the channel also be sinuous!) but straight and in parallel not only with the western scarp (figure 5b), but also with known faults to the west (REYNER, 1955; WOPFNER, 1968; AMBROSE et al., 1993). The area is seismically active (e.g. YOUNGS and WOPFNER, 1972; GREENHALGH et al., 1994).



Fig. 5

(a) Warburton Groove in the northwest corner of Lake Eyre, South Australia (RAAF). Note this is a linear feature, probably fault-controlled.

(b) Cliffs of gypsiferous silts capped by gypcrete, western shore of Lake Eyre (photograph courtesy The Advertiser, Advertiser Newspapers)



The nature of the eastern edge of the salina is uncertain. In an immediate sense it is depositional with the detritus of several large rivers deposited to form a flat and irregular shore. Whether these rivers have partly eroded and partly blanketed a cliff-line comparable to that exposed to the west is not known. Lake Eyre occupies a depocentre and is the focus of a drainage system that occupies about 1.4 million km² of central and northern Australia. The catchment includes such rivers as the Georgina and Diamantina that rise in the monsoonal north. Evidently the lake fills in whole or in part if the rivers run in two or more successive years, and this occurs three or four times a century (see e.g. LAKE EYRE COMMITTEE, 1955; BONYTHON and MASON, 1953; KOTWICKI, 1986). The first rains and flood clears the channels of rivers flowing to the Lake, and bring soils to field capacity. The second spate may reach the bed of the Lake. Taking a longer temporal perspective, a chronology of full and dry phases has been recorded extending over the past 150,000 years (MAGEE et al., 2004).

Lake Frome, some 2330 km² and occurring some 20 m above sea level, is a down-faulted embayment developed along a fault zone that coincides with its eastern shore. It is underlain by some 160 m of Cenozoic beds. Lake Torrens, some 5830 km² and about 34 m above sea level, occupies a depression that was initiated by subsidence along the Torrens Fault or Lineament in the Early Eocene or Late Cretaceous. Originally occupied by lake sediments, it was later a depocentre for alluvium from the Arcoona Plateau and the Flinders Ranges. Recent aridity has produced a crust of gypsum and halite, but some 16 m below the

surface and 5 km from the eastern shoreline there is a bed of gypsum some 12 m thick (JOHNS, 1968). The salina is bordered on its western side by a major fault zone known as the Torrens Lineament, which is gently arcuate and abruptly defines the Arcoona Plateau which is a dissected region developed on a sequence of very gently-dipping Neoproterozoic quartzites and siltstones. A series of springs occur in a line on the bed of the salina running southeast of Andamooka Island. The abrupt and rocky western shore of the gypseous salina stands in marked contrast with the depositional eastern shore, which is bordered by a kopi dune and a number of deltaic deposits associated with several episodic streams draining the Flinders Ranges. Silcrete is preserved in valleys draining to the salina from the Arcoona Plateau (TWIDALE et al., 1970).

More moderate in extent but significant for the area east of The Hummocks Ranges, Lake Bumbunga, some 25–35 km NNE of the head of Gulf St Vincent, and a series of associated unnamed small salinas are of similar origin for they are developed in a half graben. The Lake is bordered on its western shore by an Eocene fault zone characterised by springs as well as linearity, and on the east by a kopi dune. On the other hand, the salina carries a crust of halite which is commercially harvested from evaporation fields or pans at the southern end of the playa. Flat-topped islands stand some 4–5m above the present lake bed and indicate the minimum amount of detritus that has been eroded and reworked into the lunette (see below). Lakes Frome and Gilles also are partly defined by linear shorelines which may be coincident with and underlain by fault zones.

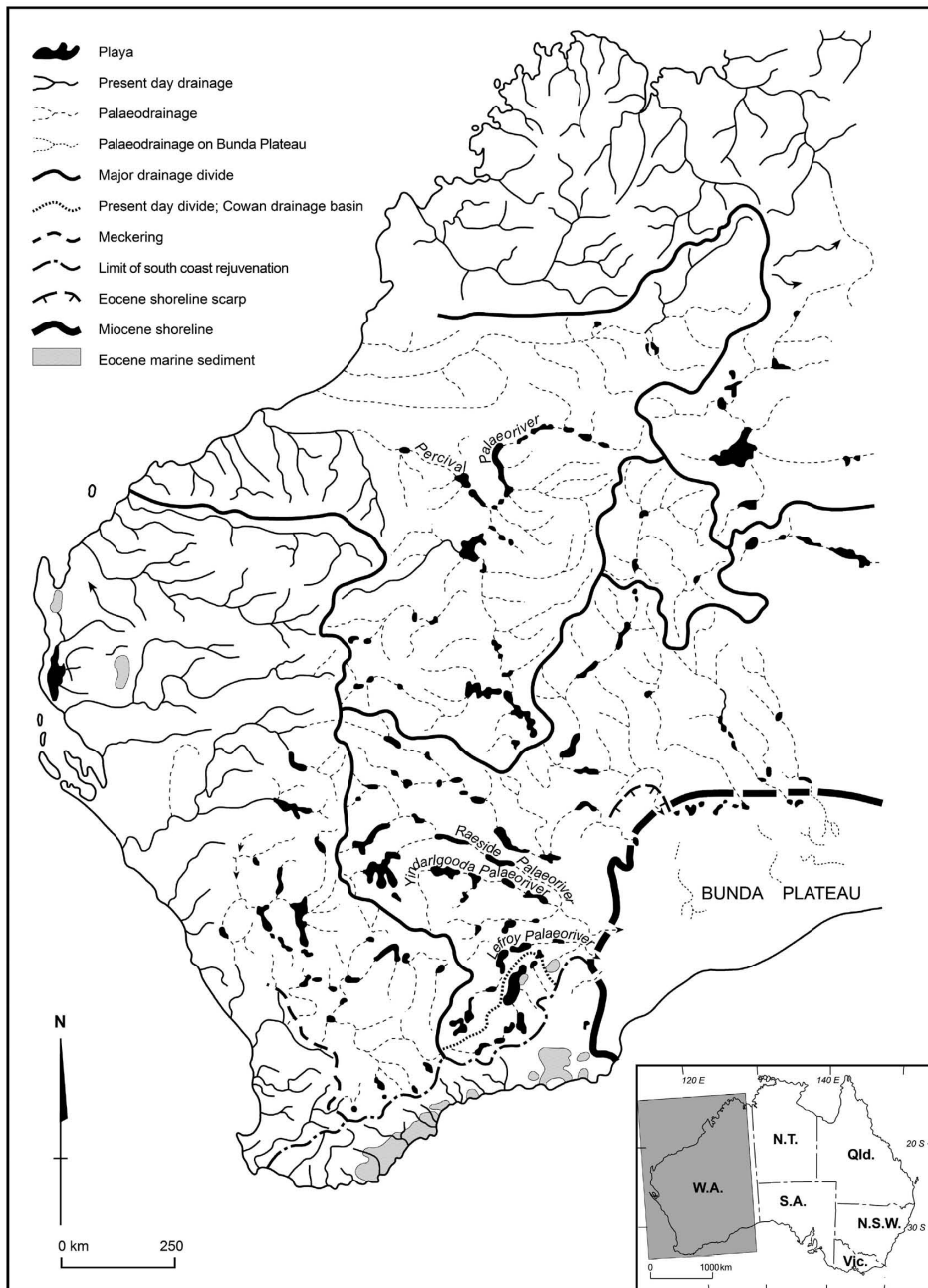


Fig. 6. Map of Western Australia, showing palaeochannels of Eocene age and major playas (after VAN DE GRAAFF et al., 1977).

Several large salinas such as Lake MacFarlane, Pernatty Lagoon, and Island Lagoon are suspected of having developed along faults because each has one shoreline that is linear or gently arcuate and aligned in concordance with known regional fractures, in this instance the Torrens Lineament (figure 2). The eastern shoreline of Lake Gairdner also falls into this category (but it also provides an example of another aspect of faulting that is considered later). But whether they occupy half grabens or are simply depressions caused by preferential weathering and erosion along fault zones is not known. In addition to a depression forming during dislocation, however, the accumulation of water must cause weathering of the strata, possibly resulting in volume decrease, compaction and surface subsidence (TRENDALL, 1962), so that the initial depression is enhanced.

Earth movements have also caused blocked drainage and playa development. In the southwest of Western Australia, uplift of the southern coastal zone consequent on the separation of Australia and Antarctica in the later Mesozoic and earliest Cenozoic caused rivers that had flowed southwards to be diverted to the north. Later, aridity caused their courses to be blocked and dismembered with many salinas, large and small, forming in the previous channels and valleys. Examples include the Lefroy palaeoriver and the Johnston Lakes systems, and lakes Monger, Moore and Barlee from the arid interior (figures 1 and 6).

The major river channels of the Yilgarn Block or Craton are of earliest Cenozoic age, for sediments of Eocene age are preserved in some (VAN DE GRAAFF et al., 1977; CLARKE, 1994; see also SALAMA, 1997). Many of these and other river pat-

terns are structurally controlled. Some like the arms of the zigzag Percival lakes system are linear and are associated with essentially straight fractures (figure 6). Others, however, are arcuate and are thought to be related to arcuate or circular (ring) structures in the crust (O'DRISCOLL and CAMPBELL, 1997; WOODALL, 1994; also KAMININE and RICHTER, 1956). Thus in the southwest of Western Australia the Lefroy, Yindarlgooda and Raeside palaeorivers describe a concentric pattern. In South Australia, the string of 'paternoster' lakes between lakes Labyrinth and Younghusband, to the north of Kingoonya is another example, and lakes Frome, Callabonna, Blanche and Gregory can be construed as occurring on an arcuate structure.

Mound springs mark the upwelling of artesian waters along fault zones and some sinkholes or dolines developed in lateritic terrains on the Sturt Plateau, south of Katherine in the north of the Northern Territory, are developed in valley floors and along minor fractures: hence the aligned pattern of many of the circular depressions. Many, like Frews Water Hole located some 300 km southeast of Katherine (STUART, 1863, p. 25), carry water during and following the summer monsoon season but some are converted to claypans during the winter dry season.

Blocked and dismembered drainage depressions

Lake Gairdner is a salina about 160 km long that occupies an area of almost 9000 km² in an old fracture-controlled valley in the Mesoproterozoic silicic volcanic rocks of the Gawler Ranges massif (JOHNS, 1968; figure 2). There was a major uplift of the

linear southern and southwestern margin of the massif during the Cretaceous when Australia separated from Antarctica. The orientation of the tributary valleys suggest the Gairdner palaeoriver first drained north but it was blocked by faulting (WNW-ESE trend), indicated by linear structures and dislocations near its northern extremity, and the river was diverted southwards and ran via the Thurlga palaeochannel to the Corrobinnie Depression. They have been reactivated when minor uplift, as evidenced by an observed dislocation (TURNER, 1975) and exposed platforms and flared slopes, some 3-4 m above present piedmont plain level, caused blockage and the formation of the salina with a halite crust (figure 7a; see also frontispiece) underlain by up to 20 m of gypsiferous silts. Silcrete, which is commonly found in and adjacent to lake basins (OPIK, 1954), occurs on the western shore. Sandy lunettes have been constructed on the eastern shore and the lake bed and shores provide fine examples of haloclastic forms and particularly etched and bevelled cobbles and blocks (figures 7b and 7c).



Fig. 7.

Lake Gairdner, northern Eyre Peninsula, South Australia: (a) pressure ridges in halite on bed of salina, (b) part of eastern shoreline showing salt-encrusted beach in embayment between rocky promontories, and undercut blocks of Gawler Range Volcanics, and (c) boulder transported to the lake bed, presumably by stream in flood, showing marked undercutting by haloclasty, or salt crystal precipitation and expansion (E.M. Campbell).

Playas associated with dismembered drainage systems are common in the Australian interior. River systems developed during past humid climatic periods were revived during the infrequent and brief but effective periods of rainfall and runoff of arid climatic regimes. With the onset of aridity, however, the rivers ceased to flow at the surface. The rivers broke down into a series of pools and shoals, and with the cessation of surface flow pools became isolated and eventually came to be bordered by lunettes.

The pools also filled during rains and short-lived phases of runoff. Many fine examples of salinas derived from the dismemberment of former rivers are found in the Yilgarn Block of southwestern Western Australia, and in the Menindee and Willandra systems of southwestern New South Wales. The latter includes Lake Mungo and its associated lunette (figure 8), which is well-known for its ancient human remains (see e.g. BOWLER et al., 2003).

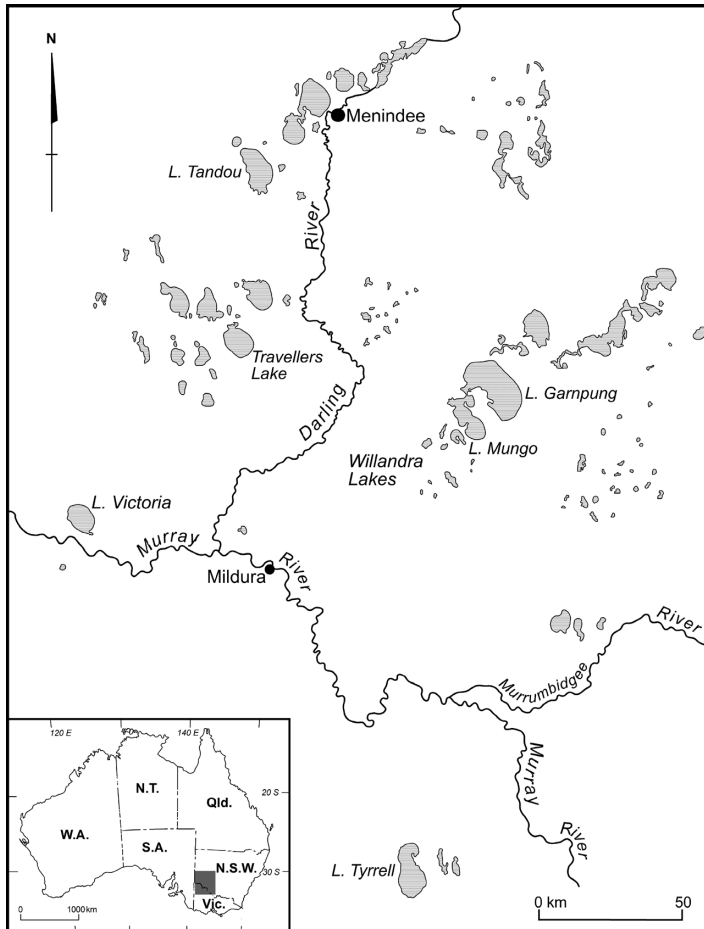


Fig. 8. (a) Map of Willandra and Menindee palaeodrainage.



Fig. 8. (b) Oblique air photograph of portion of The Wall of China, the lunette, bordering Lake Mungo on the east (J.M. Bowler).

Many dismembered river channels and valleys were blocked as sebkha complexes formed but blockages also arose in other ways. For instance, the Corrobinnie Fault Zone that delimits the Gawler Ranges massif on its southern side, was exploited by weathering and erosion forming the Corrobinnie Depression (BOURNE et al., 1974). It was drained by the Narlabby stream system during the Eocene and Pliocene (BINKS and HOOPER, 1984). The Narlabby palaeoriver reached the southern ocean via what is now Smoky Bay, on the northwest coast of Eyre Peninsula. A channel is still discernible in the floor of the Bay. But during glacial phases of low sea level in the Middle and Late Pleistocene (WILSON, 1991),

a thick and extensive sequence of calcareous coastal foredunes was deposited along the west coast of Eyre Peninsula. This blocked the Narlabby drainage, which however continued to receive runoff and sediments from the Gawler Ranges to the north and the granitic terrains of northern Eyre Peninsula to the south. With the onset of aridity the streams were dismembered and the remnants now form the many salinas found in the Depression while the sands of the broad flood plain were blown into complex parabolic dunes. The west coast field of coastal foredunes also blocked drainage further south on Eyre Peninsula to produce lakes Wangary, Greenly and Malata as well as numerous smaller salinas (e.g. DUTKIEWICZ

and VON DER BORCH, 1995; DUTKIEWICZ et al., 2002).

As many stream patterns are determined by local structure, and especially fracture patterns, many of the playas derived from the break-up of stream systems also are structurally determined. Thus Lake Amadeus stands in a former valley that ran NW-SE from the Lake MacDonald and Lake Neale area to the Lake Eyre Basin (CHEN et al., 1991). It may be fault-controlled. Lakes Everard and Harris also appear to occupy former valley systems. In the north of Western Australia, Lake Gregory appears to be a relic of another complex fracture-controlled drainage system (e.g. ALLEN, 1990), whereas lakes Carnegie and Wells are remnants of what were rivers following or underprinted from arcuate fractures.

HUMAN ASPECTS

Obviously what salts precipitate out of solution depends on what were in solution, and this varies to some extent with local and regional geology, and the products of rock weathering released into groundwaters. Beds of halite and gypsum are obvious sources but many soluble salts are released by the alteration of lithified materials. At a regional scale the lakes and salinas of southwestern United States and the African Rift Valley, for example, contain salts of great and unusual variety as a result of recent and active volcanicity. Moreover, salts originating in sea spray or scoured from existing salt pans and recycled are carried long distances on the wind – cyclic salt (e.g. JACK, 1921; HUTTON, 1976). Artesian waters also vary in composition. In particular, those of the western Great Australian or Artesian Basin are relatively rich in sulphate (HABER-

MEHL, 1980) so that the waters of mound springs that originate in this source may also be expected to be rich in sulphate and emit ‘bad egg’ odours (see BOYD, 1990). But superimposed on and overriding such considerations, most salts originate in the oceans and are carried inland on the wind, though gypsum is highly soluble and sulphites are found in commonly-occurring minerals such as pyrite (FeS₂) to react with carbonates to form gypsum.

Thus, the nature of salts in solution in seawater is crucial to any consideration of terrestrial salts and salinas. In enclosed basins (either natural or man-made) subject to evaporation the order of precipitation and crystallisation is well known, and is in reverse order of solubility. Carbonates of iron and calcium are first precipitated followed by calcium sulphate (when 20% of the brine remains), and sodium chloride (10%), with salts of magnesium and potassium remaining as an extremely alkaline solution known as bittern. Given that both gypsum and halite are widely distributed over the landscape, that both are soluble, and that groundwaters gravitate to low points in the topography resulting in gypsum precipitating out first. The less dense halite (SG 2.2; as compared to gypsum, 2.3) remains as brine, which after further evaporation precipitates to form a crust of halite.

But there is a wide window (between 20% and 10% of original solute volume) in which gypsum precipitates. Hence the wide distribution of the sulphate for it forms at the margins even of playas dominated by halite. It is weathered and the crystalline form is reduced to seed and flour gypsum by attrition of the corners and edges of the crystals (JACK, 1921, p. 90).

Salinas are also of considerable economic importance. DE DECKKER (1983, p. 235) stated that by contrast with the salinas of other continents Australian salt lakes are uniformly sodium-chloride-rich. Certainly most carry a crust dominated by, and even overwhelmingly composed of, sodium chloride or common salt (e.g. SALAMA et al., 1992), but these surficial deposits are underlain by gypsum. In some, like the playas that are strewn along the axis of what might be called the Amadeus corridor of central Australia (JACOBSON and LAU, 1987), gypsum and carbonate (gypcrete and calcrete) occur at the surface, and many other salinas, such as Lake Gilles on northern Eyre Peninsula, also are noted for their gypsum crystals. Many halite flats such as Lake Bumbunga (Mid North of South Australia) and Lake Fowler (southern Yorke Peninsula) are bordered by lunettes or kopi dunes composed of flour or seed gypsum. The kopi dunes worked at Cooke Plains are associated with past stands of Lake Alexandrina. Thus, though halite is a commonplace, gypsum is quantitatively dominant. For instance, BONYTHON (1956) estimated that in and beneath the bed of Lake Eyre there is ten times as much gypsum as there is halite - 4000 million tons [3800 tonnes] as compared with 400 million tons (plus some 7 million tons of magnesium and potassium salts). Similarly, JOHNS (1968) was of the opinion that South Australian playas are predominantly gypsiferous with only small areas of halite crust.

For humans, common salt, sodium chloride, is one of the most important of all minerals. It is an essential ingredient of human diet and for this reason has throughout recorded history and earlier been transported long distances to regions lacking a local supply. So valuable was it that it has taken its place in

our language, as in the word 'salary', and 'He is the salt of the Earth' (Matthew 5:13), an expression used if a person is favoured, but 'not worth his salt' if not. Common salt was widely used as a preservative until the widespread availability of refrigeration and is still utilised where modern technology is not accessible. It is used in the manufacture of a wide variety of products from glass to plastics. But salts other than halite also are useful. Gypsum, in particular, is used for the manufacture of Plaster of Paris, and Portland cement, but also and widely in agriculture and gardening, for it flocculates clays and thus improves soil texture.

The sea is the main source of both halite and gypsum, with many coastal sites either exploited, adapted or constructed for the trapping of sea water and allowing evaporation to bring the salts out of solution. South Australia is responsible for some 80% of Australia's salt production, and most of it is obtained from coastal pans at sites like Dry Creek (near Adelaide) and Price on northern Yorke Peninsula. Lake MacDonnell, west of Ceduna on western Eyre Peninsula, is the main source of gypsum for that area, as is the locally exploited Lake Gilles for northeastern Eyre Peninsula. Gypsum in commercial quantities is excavated from Cooke Plains near the Lakes at the mouth of the River Murray. Many small salinas have been exploited in the interior semiarid regions of the southern States of Australia. The Merredin area of Western Australia, the Griffith area of N.S.W., Mildura in Victoria, and lakes Fowler and Bumbunga in South Australia are examples of sources with accessible supplies close enough to users for harvesting to be economically viable, but there are numerous small deposits that are farmed to satisfy local needs. There are huge reserves in major

interior salinas though they are located at sites too remote to warrant exploitation at present.

Again, at the local level, lunettes bordering salinas in the South East district of South Australia are dry sites in a winter wetland, so that pastoral homesteads frequently are sited on such slight but significant topographic rises.

PLAYAS IN FLOOD

On many maps these Australian 'lakes' are coloured not blue for water but, and appropriately, white, for salt; for most of the 'lakes' are playas and most of these are salinas. But from time to time even in the present arid climatic regime the rivers run and the lakes fill and live up to their name. It is true that the 'lakes' are water bodies only for a few days, weeks or months after heavy rains in the locality of the playa or within the catchment of which the playa is the focus. Lacustrine plants and animals miraculously come to life and for a short time the lakes bloom. Even more astonishing are the coastal changes, for as was shown during the well documented 1974 filling of the Lake (KOTWICKI, 1986), depositional features such as beaches, spits, and bars, develop and change markedly and with surprising rapidity. This observation is germane to the interpretation of landscape and climatic chronology. For instance, DULHUNTY (1975, 1990) has recorded the presence of shingle beaches standing 280, 160 and 70 cm above the maximum level of the 1974 filling, but they may attest brief lake fillings following heavy rains somewhere in the catchment (which includes monsoonal northern Australia) rather than a secular or long-term humid climatic phase.

Regattas were held during the 1974 flooding of Lake Eyre. On the other hand, in 1964 an attempt was made to set the world land speed record using the flat, dry surface of Lake Eyre, and Lake Gairdner is similarly utilised annually since 1990 for motor cycle speed races and record attempts.

CONCLUSION

All lakes are ephemeral but these Australian playas are more ephemeral than most. Surely rather than call the various playas 'lakes', as is the present cartographic practice, it would be more realistic to call them all playas. Attempts to differentiate salinas and claypans might at this stage of our knowledge be too late and hence too difficult. But however they are labelled Australian playas clearly vary in origin and multiple causations can be cited for many. Such an analysis is highly appropriate to this memorial volume. Not only was Liz Campbell's family home at Binnun near Naracoorte, in the South East district of South Australia, located on a lunette, as part of a sebkha complex, but playas in general, and the Lake Gairdner salina in particular, were her principal research interests over the last 15-20 years of her life.

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