LAKE LEWIS, NORTHERN TERRITORY

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INTRODUCTION

Lake Lewis is a 250 km^2 salt lake, or playa, situated within an internally draining basin about 200 km west-northwest of Alice Springs in the Northern Territory (Figure 1). The drainage basin has an area of 14 075 km^2 and occupies contiguous halves of the NAPPERBY (SF53-09) and HERMANNSBURG (SF53-13) 1:250 000 map sheets. Little previous work on the regolith and landforms of the region has been carried out. Regolith characterisation of the Lake Lewis area is based on an investigation of playa landforms by Chen *et al*. (1995) and recent multi-disciplinary PhD research by English (2001a,b) and English *et al*. (2001).

PHYSICAL SETTING

Geology

The Cenozoic Lake Lewis basin overlies igneous and metamorphic rocks of the Proterozoic Arunta Craton (Figure 2), and also drains well-exposed sedimentary successions of the late Proterozoic–Palaeozoic Amadeus and Ngalia basins, to the south and north, respectively. Tectonism during the Devonian–Carboniferous Alice Springs Orogeny resulted in major thrusting and folding of the Precambrian and Palaeozoic rocks to produce an elevated landscape of steep, rugged mountain ranges, termed the Central Australian Uplands. The bedrock geology within the two 1: 250 000 map sheet areas has been described by Stewart (1982) and Warren and Shaw (1995). A palaeo-elevation of above 430 m AHD (Figure 2) precluded Cretaceous marine incursions, and no Mesozoic sediments have been identified in the area. Cenozoic basin infill comprises up to 170 metres of terrestrial sediments overlying weathered Arunta Complex basement (Figure 2).

Geomorphology

The structural and geomorphic grain of the region is dominated by folded and faulted east–west striking ridges and broad, flat-floored valleys (Figures 1, 2). These were initially formed during the Alice Springs Orogeny, but have been modified by subaerial weathering and erosion from the Late Palaeozoic onwards. Major relief contrasts are represented in this Cenozoic basin-and-range province. The fault-bounded mountains rise steeply several hundred metres (to a maximum of 1 531 m AHD at Mt Zeil — the highest peak in the Northern Territory) above the piedmont plains (Figures 1, 2).

The present land surface across the basin can be sub-divided into a

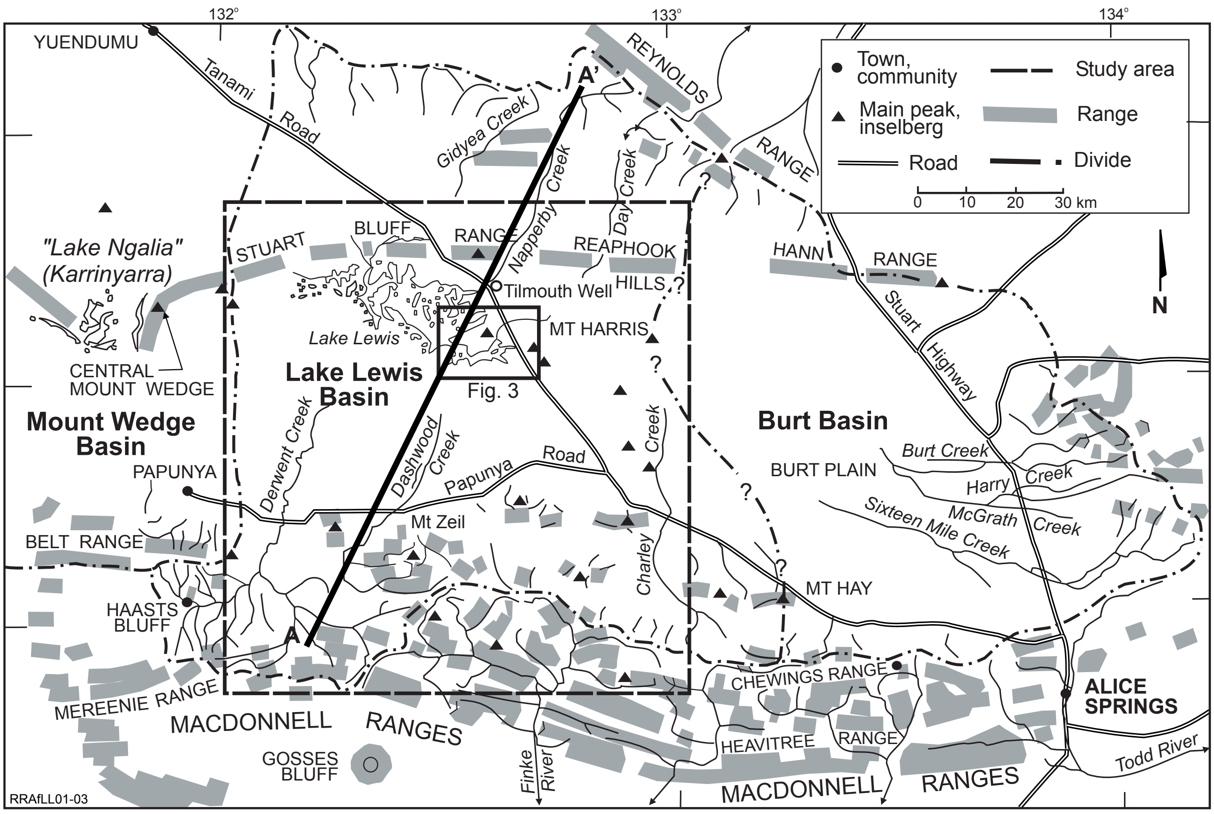

Figure 1. Location of the Lake Lewis, Burt and Mount Wedge basins; part of a Cenozoic basin-and-range province in the Northern Territory. The basins are separated by basement highs (outcropping and subsurface) and are hydrologically separate. The main study area, outlined, is centred on Latitude 23º S and lies between Longitudes 132º and 133º E. The Tropic of Capricorn crosses the southern part of the basin. The small inset box outlines the area shown in Figure 3 and the section line A–A' is shown in Figure 2.

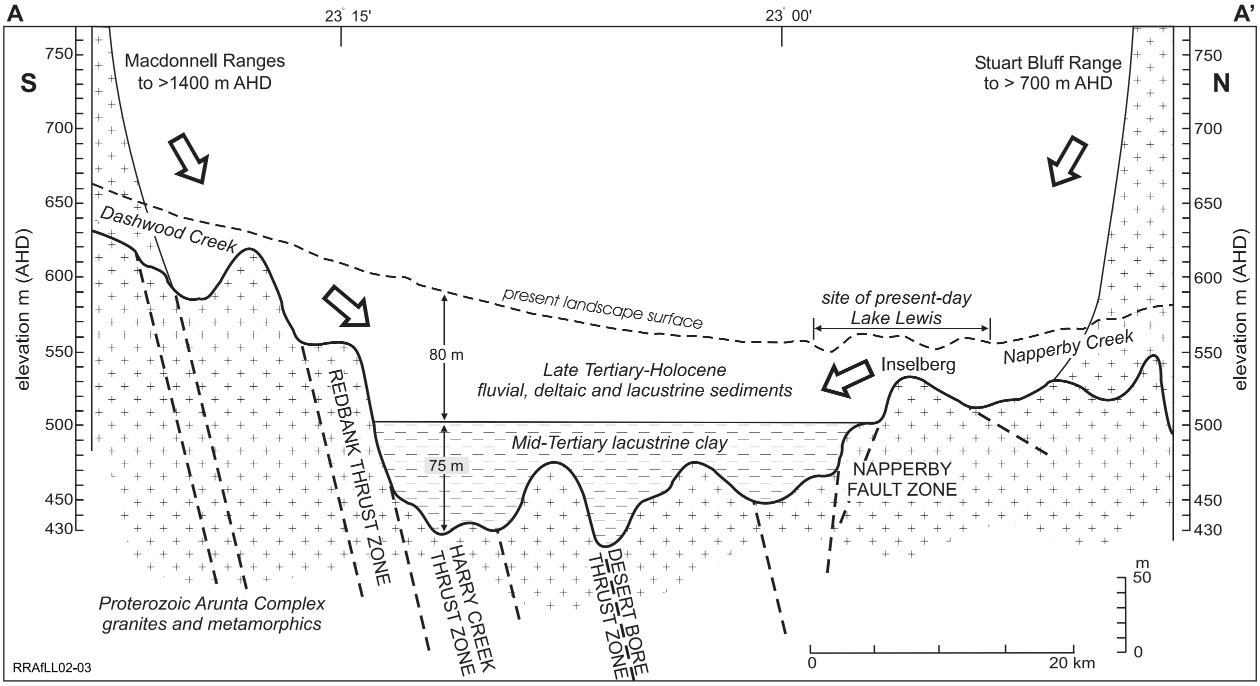

Figure 2. South–north section through the Lake Lewis basin along part of the BMR 1985 seismic line (A–A' in Figure 1), showing the subsurface relief of the Arunta Complex granitic and metamorphic basement, based on seismic reflection, airborne magnetic and drill-hole data. Cenozoic basin evolution was structurally controlled and resulted in initial infill of the depocentre with Palaeogene lacustrine clay (arrows denote surface water and sediment flow directions). Subsequent Neogene to Pleistocene sedimentation involved up to 100 m of piedmont alluvial fan, lacustrine and palaeochannel deposits.

low-gradient alluvial plain and a flat lacustrine plain. Lake Lewis, situated at 550 m AHD, forms the present depocentre of the basin (Figure 2). Scattered granite and gneiss inselbergs rise 50–100 m above the plains. Chalcedonic mesas are present in intermontane areas amongst outlier bedrock ranges of the MacDonnell Ranges.

The geomorphology of the Lake Lewis playa environment is complex (Figure 3). The playa is set within lacustrine clays (Figures 2, 4) that were deposited in greatly expanded palaeo-lakes. The playa is currently a groundwater discharge zone and its highly irregular shape reflects the dominant influence of groundwater processes on landform development, although many features relate to ancient and modern ephemeral surface water processes. Regional linear dunefields overlie the basin axis south of Lake Lewis.

Climate and vegetation

Lake Lewis lies at the southern limit of influence of the Australian monsoon regime that originates in coastal regions to the north. The location of Lake Lewis in the centre of the continent, over 1 000 km from the coast in all directions, results in a low and highly variable rainfall, although the MacDonnell Ranges intercept sporadic moist air masses crossing the region and efficiently deliver water and sediment to the lake and its surrounding alluvial plain. The climate is semi-arid to arid with an annual rainfall of 280 mm and an annual potential evaporation of 3 065 mm.

Vegetation assemblages correlate strongly with regolith–landscape units within the drainage basin. Playa shore terraces support halophytic Chenopodiaceae, such as samphire and saltbush species. Playa-fringing dunes support inland tea-tree (*Melaleuca glomerata*). Calcrete ground surrounding the playa is vegetated with blue mallee (*Eucalyptus gamophylla*). Where shallow calcrete aquifers can be accessed, particularly in karstic depressions, coolibah (*Eucalyptus intertexta* or *E. microtheca*) occur. Elsewhere across the lacustrine plain, where saline water tables are moderately shallow, low stature *Melaleuca*, *Grevillea* and *Acacia* species shrubs are widespread. Dense dunefields at the western, downwind end of the basin are vegetated with tall desert oak (*Allocasuarina deciasneana*). Mulga (*Acacia aneara*) dominates the interfluvial areas of the alluvial plain, particularly where sheetflow drainage is typical. The major creeks are lined with river red gum (*Eucalyptus camaldulensis*) and scattered ghost gum (*E. papuana*). White cyprus pine (*Callitris glaucophylla*), cycad (*Macrozamia macdonnellii*) and native fig (*Ficus platypoda*) grow in crevices on rocky outcrops, elevated above the bushfire-prone plains. Spinifex (*Triodia*) is common in most environments of the basin. Thus, despite having nutrient-deficient soils (typically lithosols, red earths, quartz sands and saline soils), the region is well vegetated. This reflects a combination of good runoff from the ranges, high or perched water tables in some regolith–landscape units, and the efficient use of water by the desert-adapted flora.

REGOLITH–LANDFORM RELATIONSHIPS

Regolith–landform mapping in the Lake Lewis basin was only conducted at a reconnaissance level because of the large size of the study area (>10 000 km^2) and the virtual absence of existing information upon which such a study could be based. Impediments associated with the remoteness and scale of the area were largely circumvented by using high-resolution remotely

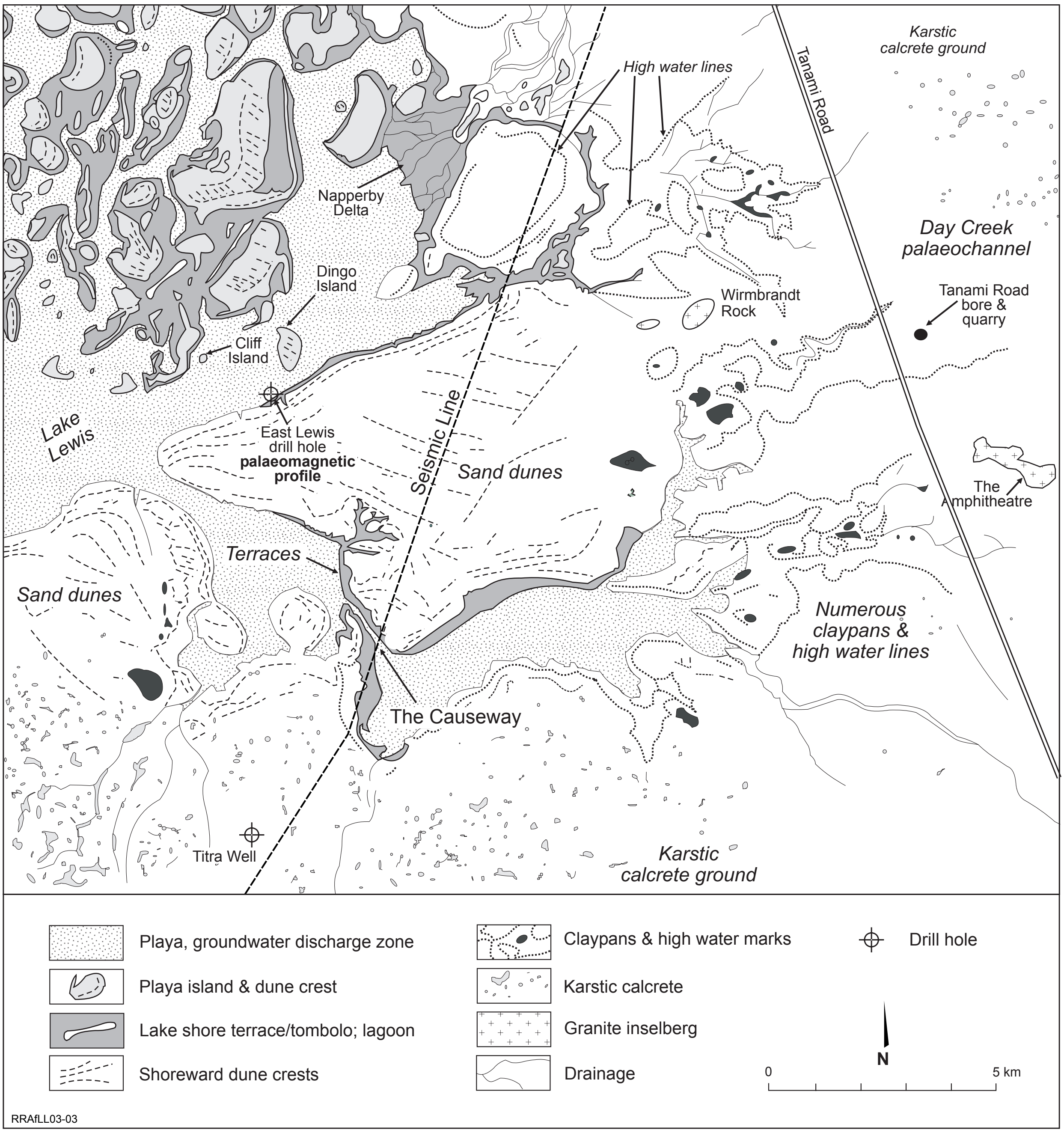

Figure 3. Geomorphology map of the eastern part of Lake Lewis (area outlined in Figure 1) showing the irregular playa outline, granite inselbergs, and the distribution of diverse regolith–landscape units. The latter include: an ephemerally active delta, playa islands, terraces, strandlines formed during episodic inundations, calcrete, and quartz sand and gypseous dunes.

sensed data sets that were combined with conventional approaches of aerial photograph interpretation and field and laboratory techniques.

Many of the regolith–landform units are obscured by calcrete and aeolian sand. However, drilling and shallow excavation elucidated the nature of key subsurface regolith units. Airborne gamma-ray spectrometry, Landsat TM and digital elevation models provided information of the areal distribution of the main units, which greatly assisted in palaeoenvironmental reconstructions (English, 2001a,b).

Prominent landforms, particularly the ranges, inselbergs and deeply-incised headwater catchments, are relict from a subaerial landscape that may have a Gondwanan (Jurassic–Cretaceous) origin. Well-developed weathering profiles on high-grade metamorphic rocks are exposed in pediment and piedmont zones in the east of the drainage basin. These may reflect intense weathering episodes during the Late Cretaceous–Early Palaeocene and Eocene as identified east of Alice Springs by Senior *et al.* (1995). Apart from the ancient bedrock ranges and the eastern ferricrete and associated shallow saprolite exposures, most of the study area comprises depositional environments, with both clastic and chemical sediments well represented. Four major regolith–landform units have been identified on the basis of their environmental setting. These are described below.

1. *Lacustrine plain.* The lacustrine plain is composed of two distinctive lacustrine facies, the Anmatyerre Clay and the

Tilmouth beds (Figure 4). The Anmatyerre Clay is red-brown, homogeneous clay that was deposited in standing water during perennial high lakewater conditions, possibly in a well-flushed lake that overflowed to the west. The clay is at least 28 m thick and may extend to 80 m depth beneath some parts of Lake Lewis. Detrital minerals include quartz, feldspar, mica–illite and kaolinite ± smectite; the unit is non-calcareous. Authigenic analcime has been identified in the Anmatyerre Clay and its genesis has been documented by English (2001a).

The overlying Tilmouth beds of olive–grey clay with gypsum laminae, represent fluctuating lake conditions, high levels of salinity and chemically reducing conditions in bottom muds. The detrital mineralogy is similar to that of the underlying Anmatyerre Clay, although smectite is more common and analcime is absent. Abundant gypsum occurs displacively within surrounding clay layers, and calcite is present as microfossils. The Tilmouth beds were deposited in a hydrologically closed palaeolake that was much smaller than the antecedent Anmatyerre palaeolake, but still much larger than the present-day playa.

The Anmatyerre Clay and Tilmouth beds are exposed as pedestals in playa islands (Figure 4) and together form the very flat landscape covering >3 000 km^2 of the lacustrine plain. Much of the near-surface lacustrine sediment has been calcretised and a 10 km wide zone of phreatic and vadose calcrete surrounds Lake Lewis (Figure 3). The calcrete is several metres thick, highly karstic and silicified.

2. *Alluvial plain.* The broad, low-gradient alluvial plain across the southern half of the basin (Figure 2) is underlain by alluvial fans of sands, clays and subordinate gravels, with pedogenic overprints and disseminated calcium carbonate nodules. Near-surface units are unweathered flood deposits of the modern hydrologic regime which spread out laterally from the main creek channels over very large floodplains. The sands are commonly micaceous, reflecting their derivation from granites and gneisses. Interfluve areas are characterised by red earth sheetwash, generally supporting mulga vegetation and termite mounds.

3. *Aeolian dunes.* Regional quartzose linear dunes trend WNW–ESE to E–W, indicative of the trajectories of the formative Trade winds. The main dunefields within the basin have a hybrid status of being both source-bordering dunes and regional linear dunes, oriented at right angles to the trend of the creeks. The mineralogic composition of the dunes, coupled with airborne gamma-ray imagery, indicates that aeolian sand is sourced from piedmont alluvial fans located upwind from each dunefield, which, in turn, were derived from distinctive igneous and metamorphic rock types in individual headwater catchments. The dunes are typical ‘red desert sands’ with hematitic argillan patinas on the grains. Since their formation, the dunes have been severely disrupted by floodwaters debouched from the mountain catchments. The dunes are now largely stabilised by vegetation with only the crests of larger dunes, particularly those near playas, remaining mobile in the present climatic conditions.

4. *Playa landforms.* Major regolith–landform units in the playa environment include playa islands composed of aeolian gypsum units, terraces, tombolos, arroyos, transverse and linear sand dunes, and the surrounding zone of silicified calcrete, described above (Figure 3). The gypseous playa islands and playa-fringing dunes have been described by Chen *et al*. (1995); the gypsum

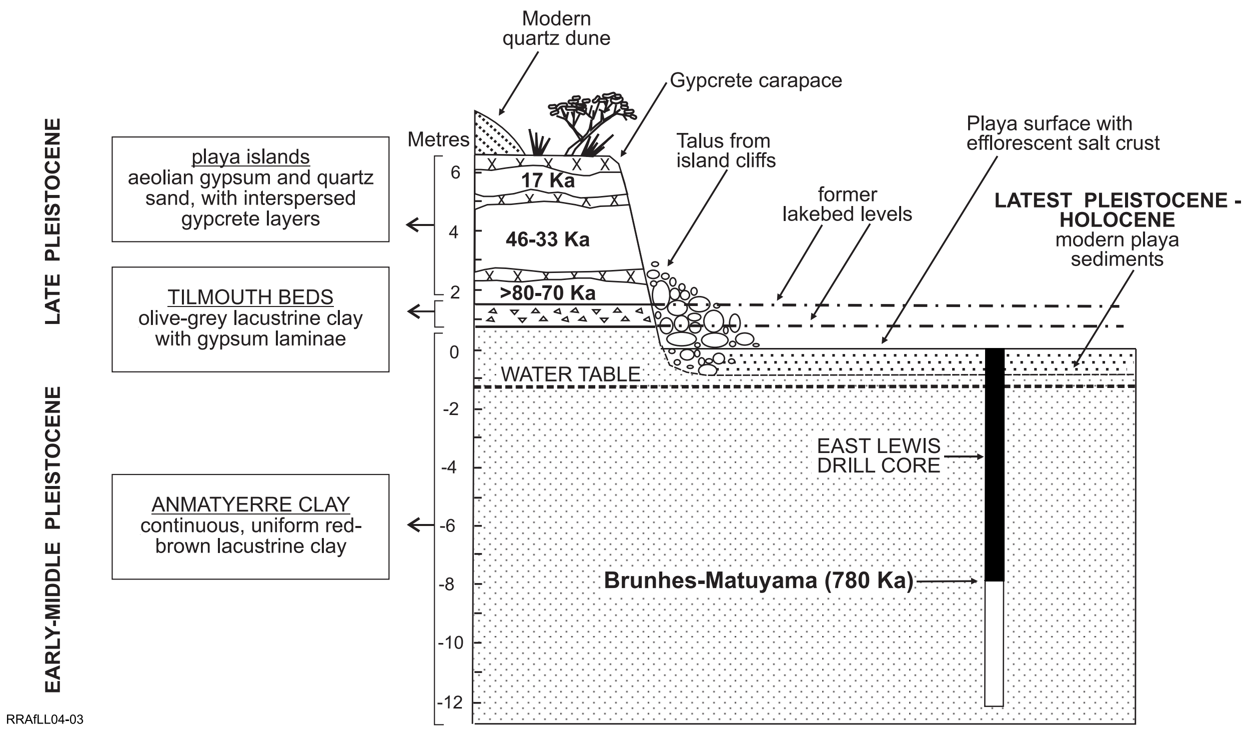

Figure 4. Generalised stratigraphic relationships of the main Lake Lewis playa units. Location of the East Lewis drill hole shown in Figure 3. Thermoluminescence ages for gypseous aeolian units from Chen *et al*. (1995); palaeomagnetic data from English (2001b).

sand units are interspersed with gypcrete layers and capped with gypcrete carapaces (Figure 4). Up to one metre of 'modern playa sediments', deposited during episodic floods of the modern hydrologic regime, overlies the lacustrine clay strata in the playa. The playa is underlain by a brine pool with salinity levels of >200 000 mg/L Total Dissolved Solids. Gypsum has crystallised within sediment in the capillary fringe above the brine pool and efflorescent halite has precipitated on the playa surface.

REGOLITH CHARACTERISATION

The Lake Lewis basin comprises regolith bearing imprints from past climatic and hydrologic regimes that were both much wetter and drier than present, and regolith–landforms that reflect the present semi-arid desert regime.

Ferricrete overlying Arunta Complex bedrock is either deeply buried beneath Cenozoic cover or, where exposed, largely eroded. The Cenozoic regolith is dominated by sediments, including lacustrine, fluvial, aeolian and playa facies. Thick lacustrine clay strata attest to the former presence of large perennial lakes and chains of swamps occupying troughs and depressions in the pre-existing heterogeneous crystalline basement topography. Thick alluvial fan sediments were also deposited in very wet periods during which runoff and sediment supply from the adjacent mountain ranges were high. Down-gradient, lacustrine clay was deposited, representing, firstly, open hydrologic conditions, and then a closed system during more recent lacustrine phases. Contractional lake stages and the onset of interaction between shallow lakewater and saline groundwater resulted in the crystallisation of gypsum in chemically reduced clays.

Dunefields across the basin are part of the northern arm of the continent-scale anti-clockwise dunefield whorl that embraces the Australian deserts and that was established during the Pleistocene.

The alluvial fan sediments are overlain by palaeochannel sands and associated finer-grained floodplain deposits, and toward the basin centre by deltaic successions composed of interdigitating fluvial and lacustrine beds. Widespread calcrete characterises the topographically low, flat parts of the landscape, surrounding the playa. Secondary silica overprints the karstic calcrete in the form of opal-CT and chalcedony. Silica precipitates from shallowing groundwaters as they approach the discharge zone; silicification processes in the basin are described by English (2001a).

Regolith within the playa is dominated by groundwater-influenced units. These include gypseous aeolian deposits in the form of playa islands and lake-shore dunes, and intrasedimentary gypsum and efflorescent halite, precipitating in the capillary fringe over the shallow brine pool. Units relating to episodic ephemeral surface waters in and around the playa include 'modern playa sediments' deposited during rare flood events, terraces, arroyos, and erosional high water marks.

DATING

Deposition of lacustrine sediments on weathered gneiss in the central Australian region had commenced by the Middle–Late Eocene and continued through the Oligocene–Miocene (Macphail, 1996). In the Lake Lewis basin, basal lacustrine clay infilling a deep trough north of the MacDonnell Ranges is thought to be related to this middle Tertiary (Eocene) lacustrine phase (Figure 2). The thick overlying sequence of lacustrine Anmatyerre Clay beneath Lake Lewis is interpreted as late Tertiary to Pleistocene in age. The Brunhes-Matuyama palaeomagnetic polarity reversal (0.78 Ma) has been identified at 9 m depth in the Anmatyerre Clay from the eastern part of Lake Lewis (English, 2001b; Figures 3, 4). The Anmatyerre Clay was probably deposited continuously during the Early and Middle Pleistocene, without any erosional breaks. The cessation of perennial standing water in Lake Lewis probably resulted from climatic oscillations associated with glacial and interglacial periods in the later part of the Middle Pleistocene.

The Tilmouth beds lacustrine facies is tentatively assigned to the Last Interglacial period of around 130–110 ka, based on extrapolation from well-dated records from comparable Australian inland lake systems (English *et al*., 2001).

Regolith–landform units relating to more arid conditions and the influence of saline groundwater are therefore attributed to approximately the past 100 000 years. Optically stimulated luminescence (OSL) dates indicate that dune building in Lake Lewis basin commenced before 95 ka (English *et al*., 2001), when salinity at the depocentre was high. Thermoluminescence (TL) ages for gypsum sand units in Dingo and Cliff islands (Figure 3) have been obtained by Chen *et al*. (1995). As shown in Figure 4 these are >80–70 ka for the lowermost unit, 46–33 ka for the thick middle unit and 17 ka for the top unit. Additional TL dates from Chen *et al*. (1995) indicate that dune building in the basin peaked around 23–21 ka. OSL ages of fluvial deposits in the alluvial plain show that episodic floods have occurred during the last 19 000 years, following the last phase of maximum aridity in the region (English *et al*., 2001). The latter fluvial activity, associated with monsoonal rainfall following the Last Glacial Maximum, corresponds with ^{14}C ages for basin groundwaters of 20 000 years to the present (English, 2001b).

REGOLITH EVOLUTION

Subsidence north of the Redbank Thrust Zone (Figure 2) initiated Tertiary basin development (Beekman *et al*., 1997). This resulted in the formation of a large lake and the deposition of up to 75 m of lacustrine sediments over the irregular weathered basement palaeotopography. Crustal subsidence is also likely to have occurred during sedimentation. The depocentre switched further north to its present site in the late Tertiary as pre-existing depressions became infilled. The northwards migration of the depocentre may also have occurred in response to minor neotectonic activity involving uplift of the fault-bounded MacDonnell Ranges to the south and/or further subsidence of the northern bedrock fault slices. Alluvial fan sediments to

100 m thick accumulated in the piedmont zone, and toward the basin centre the lacustrine Anmatyerre Clay infilled topographic depressions. Both the alluvial fans and the lacustrine clay attest to a very wet climate and to abundant sediment supplies from the catchment.

A change to much drier climate and the onset of groundwater influence at Lake Lewis are indicated by the gypseous clay laminae in the Tilmouth beds. Hydrologic closure of the basin and intensified aridity resulted in lake contraction, precipitation of calcrete around the progressively receding lake margin, and precipitation of large volumes of gypsum on the lake floor and within the underlying near-surface sediments. Aeolian reworking of gypsum and beach sands, and the formation of playa islands and lake-shore dunes, represent a distinctive stage in regolith–landscape evolution in the basin, characteristic of a major aridification trend. This stage is correlated with the establishment of regional linear quartz dunes elsewhere across the basin.

The influence of saline groundwater, precipitation of evaporites and aeolian processes dominated regolith evolution at Lake Lewis from approximately 100 000 to 20 000 years ago. The current evolutionary phase is characterised by the renewed input of surface water to the basin (although the volumes of water involved are very small compared to those of the palaeolake times), with ephemeral floods in the alluvial plain and shallow inundations of the playa leaving marked impressions on the characteristic semi-arid desert landscape.

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