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CONTRASTED MORPHOLOGIES OF THE WESTERN AND EASTERN PIEDMONTS OF THE MT LOFTY RANGES, SOUTH AUSTRALIA

[Diferencias morfológicas de los piedemontes occidental y oriental de la cadena montañosa del Monte Lofty, Australia del Sur]

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ABSTRACT: The Mt Lofty Ranges is a horst that evolved in two stages. The western margin developed as part of the South Australian Shatter Belt during the separation of Australia and Antarctica. Gulf St Vincent formed at this time. Though recurrently active the upland dates essentially from the Early Eocene with major uplift in the later Cenozoic. By contrast, the eastern faulted margin postdates the Middle Miocene. Also, whereas the western piedmont and upland were affected by Late Cenozoic sea level changes and all that those imply for river behaviour, the eastern sector was buttressed against such fluctuations by the massive Miocene limestone deposited in the Murray Basin immediately to the east. Consequently, the western piedmont is dominated by alluvial fans, but the eastern is complex, with well-developed scarp-foot depressions, exhumed landforms, and dunefields in some sectors.

Key words: Horst; piedmont; alluvial fan; desert dune; rain shadow; scarp-foot depression; exhumed forms.

RESUMEN: La cadena montañosa del Monte Lofty es un horst que se originó en dos etapas. Su margen oeste se desarrolló como parte del “Shatter Belt” de Australia del Sur durante la separación de Australia y la Antártida. El golfo de San

Vicente se originó en esa época. Aunque recurrentes en el tiempo, los levantamientos tectónicos se inician esencialmente al inicio del Eoceno y con el mayor ascenso al final del Cenozoico. Por el contrario, el margen fallado del este es al final el Mioceno Medio. Por otra parte, mientras el piedemonte y las zonas levantadas del oeste se vieron afectadas por los cambios del nivel del mar durante el Cenozoico tardío, y lo que ello implicó en el comportamiento de los ríos, el sector este fue protegido de esos cambios por la gran masa de calizas del Mioceno que rellenan la cuenca Murray, inmediatamente al este. Por tanto, el piedemonte oeste está dominado por abanicos aluviales mientras que el del este es complejo, con depresiones de pie de escarpe bien desarrolladas, formas exhumadas y campos de dunas en algunos sectores.

Palabras clave: Horst; piedemonte; abanico aluvial; desierto; duna; depresión; pie de escarpe; exhumación.

INTRODUCTION

The Mt Lofty Ranges (figure 1) is a horst block defined by faults developed in the Early Palaeozoic Delamerian Orogeny, but reactivated at various times in the later Phanerozoic (BENSON, 1911; PREISS, 1987). The upland is dominated by a lateritised summit bevel, which has been dated variously as Pliocene (NORTHCOTE, 1946), Cretaceous (e. g. MILES, 1952; CAMPANA, 1958; GLAESSNER & WADE, 1958) or early Mesozoic (DAILY *et al.*, 1974). Others assert that laterisation has been a continuing and continuous process (e. g. BOURMAN, 1995; see also MCFARLANE, 1986). The older laterite persists in the southern Ranges, i. e. Fleurieu Peninsula, and on Kangaroo Island, but occurs only in small isolated patches in the centre and north, with the erstwhile weathering front exposed as an etch surface.

The geological framework of the western Mt Lofty Ranges differs from that of the eastern (figure 1) and, together with the Cenozoic tectonic and climatic changes, has influenced drainage patterns that find expression in contrasted piedmont morphologies (figure 2). These factors are discussed with reference to the piedmonts in and about the latitude of Adelaide, though because of its relative complexity, a greater latitudinal range of the eastern flank is considered.

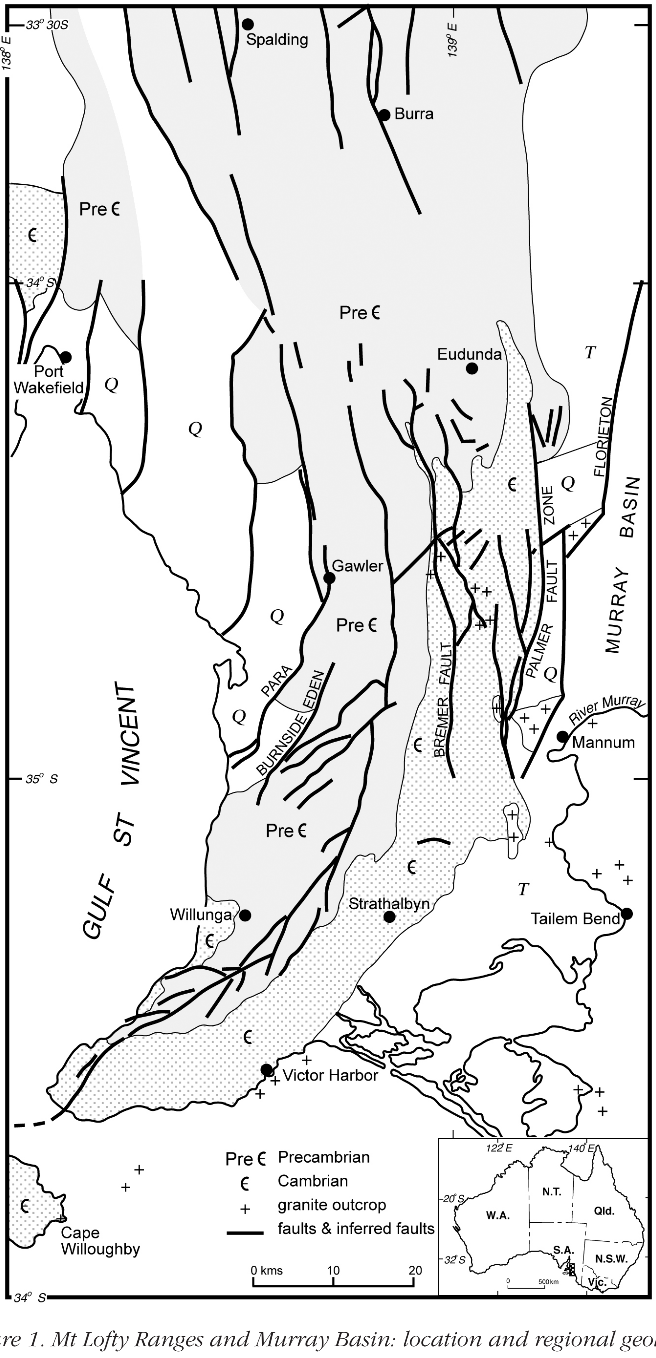

Figure 1. Mt Lofty Ranges and Murray Basin: location and regional geology.

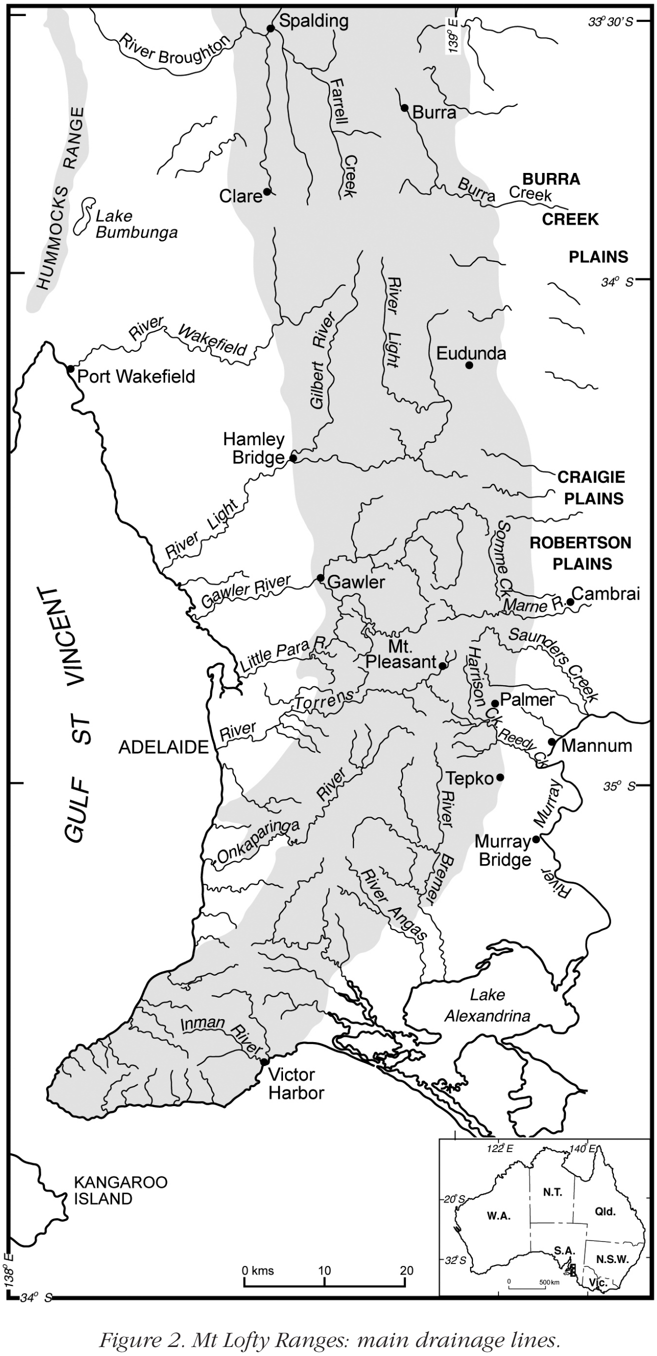

Figure 2. Mt Lofty Ranges: main drainage lines.

WESTERN PIEDMONT

FAULTING AND CONSEQUENCES

The scarps that define the western margin of the Mt Lofty Ranges, are associated with faults that form an *en echelon* pattern that is arcuate in the south (figure 1). The chronology of these tectonic events is indicated by stratigraphic sections preserved in adjacent down-faulted basins. For example, marine strata as old as Middle Eocene were deposited in the southernmost half-graben flanking the western Mt Lofty Ranges (REYNOLDS, 1953; GLAESSNER & WADE, 1958) showing that the lateritic surface had been disrupted and uplifted prior to the deposition of the basin sediments. The depression formed by the Burnside-Eden Scarp to the east and the back-slope of the Para Fault Block to the west, was occupied by a lake during the Eocene, as is evidenced by deposits of lacustrine and fluvial sand and clay. The various faults that define the western flank of the Mt Lofty Ranges have been revived as a result of recurrent and continuing dislocation along high-angle reverse faults. The Burnside-Eden Fault displays evidence of post-Eocene uplift (figure 3), and the Para Fault of post-Pliocene and Pleistocene dislocation (FENNER, 1930; GLAESSNER & WADE, 1958). This later Cenozoic activity involved uplift of scores of metres (TOKAREV *et al.*, 1999) and was critical to the formation of the topography. Contemporary earthquakes are common (e. g. GRANT, 1956; LOVE *et al.*, 1995).

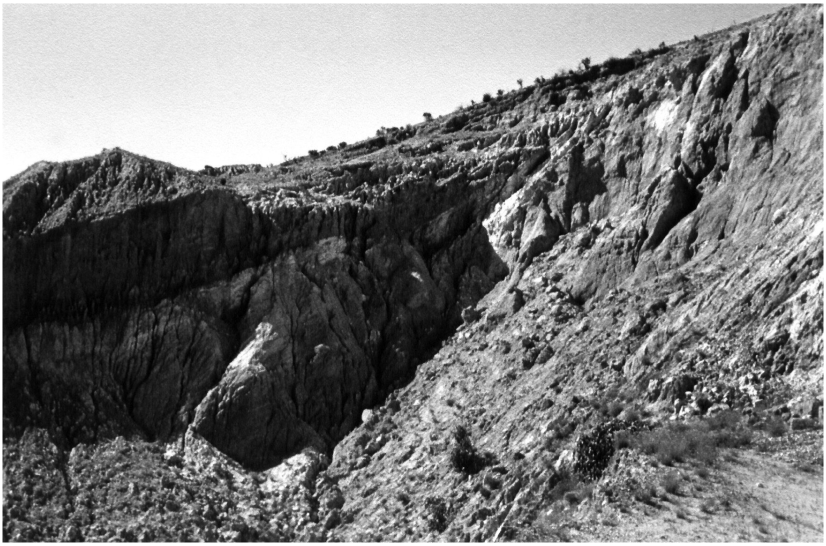

Figure 3. The Burnside-Eden Fault, indicated by drag in Eocene sand, and exposed in what was Duhne's Quarry near Highbury, in the northeastern suburbs of Adelaide. Proterozoic rocks are exposed in the back wall.

The faulted western margin of the Mt Lofty Ranges is a component of the South Australian Shatter Belt (Fenner, 1930), a landscape that was initiated as Australia and Antarctica separated. The disturbed zone includes Spencer and St Vincent gulfs, which are connected to the open ocean. This configuration allowed a widespread Miocene marine transgression that spread over the present gulfs and extended on to the margins of adjacent areas, for the Mt Lofty Ranges, Kangaroo Island and Yorke Peninsula were not inundated (Glaessner & Wade, 1958; Milnes *et al.*, 1983).

Thus, the major backing scarps defining the western flank of the horst were formed in earliest Tertiary or latest Cretaceous times. They have been revived at various times through the Cenozoic, and the rivers flowing to the west and Gulf St Vincent have responded to changes of this baselevel as well as to tectonic events.

DRAINAGE DEVELOPMENT

The chronology of tectonism in the western Mt Lofty Ranges determined river behaviour in that region. Contemporary rivers that drained the Mesozoic plain incised valleys into the lateritised landscape, for the uplift of the Ranges east of Adelaide caused rejuvenation of the river systems. The Torrens and other major rivers excavated deep gorges. As they lowered their channels the early rivers developed incised meanders and at one site an incised meander cut-off or ox-bow lake. These are autogenic fluvial forms and are not inherited from a former higher planate surface (Mahard, 1942; Twidale, 1955, 1964). How far these early west-flowing rivers extended their headwaters to the east is not known. They may have drained the pre-Miocene inselberg landscape that occupied the western Murray Basin, which is now buried by a thick sequence of sediments of that age (Barnett, 1989); however, that has not been demonstrated. What is clear is that the later Mesozoic-earliest Tertiary uplift of the western margin of the Ranges caused the west-flowing rivers to be rejuvenated and to extend far into the upland with the result that the drainage systems of the Mt Lofty Ranges and the Mid North region are asymmetrical (figure 2). Some of the longer west-flowing rivers such as the Onkaparinga, Torrens, Gawler, Light, and Broughton not only developed prominent strike tributaries but they rise much nearer the eastern than the western scarp. For instance, north of Mt Pleasant the headwaters of the west-flowing River Torrens penetrate to within 5-6 km of the eastern escarpment of the upland and the Murray Plains.

PIEDMONT ASSEMBLAGES

In early Tertiary times the Onkaparinga and Torrens rivers flowed to the then recently formed Gulf St Vincent. Water flowing from the uplands caused widespread and intense weathering in the scarp-foot zone. Scarp-foot depressions were probably developed, but only one example, northeast of Adelaide and located immediately north of Anstey Hill was exposed, prior to housing development. At the base of Anstey Hill, a piedmont platform, known as the Gun Emplacement, stands high in the local relief (FENNER, 1939), and appears to be the only remnant of its type that has survived. It consists of a ferruginous capping developed on Eocene lacustrine and fluvial strata. It is probably of Pliocene age (BOURMAN *et al.*, 2010a).

In addition, several of the fault scarps display bevelled spurs. On the Willunga Fault Scarp, for example, bevelled spurs stand at almost 160 m above sea level and still carry a scatter of rounded, mainly quartzitic, cobbles and gravels (W. T. WARD, pers. comm. 1962). They can be interpreted as uplifted former piedmont or shoreline forms and deposits of either Eocene, or more likely Miocene, age.

Overall, however, the western piedmont is dominated by coalesced alluvial fans generated by innumerable smaller streams that debouch from the uplands (figure 4). They drain extensive catchments in which are exposed various sedimentary strata that weather to provide plentiful loads of mixed calibre to be transported to the plains. On leaving the confines of the upland gorges, the streams in flood broke their banks, developed a distributary pattern and became hydraulically inefficient because the combined wetted perimeters of the channels increased while the volume of water carried remained the same. Energy was dissipated due to friction resulting in the deposition of fanglomerates that merged laterally to form the aprons or outwash plains (AITCHISON *et al.*, 1954), which buried most of the pre-existing bedrock forms and extended distally.

All the rivers display evidence of cut-and-fill and the River Torrens can be taken as an example (figure 4). By contrast with the smaller streams to north and south, the River Torrens had the volume to maintain its flow to the west, although immediately below its gorge mouth its course was diverted to the north by the alluvial fans building out from the Burnside-Eden Fault Scarp, which caused it to undercut and steepen the northern slope of the valley (GREAR *et al.*, 2006).

Below the Para Fault Scarp, immediately to the west of the Adelaide CBD ??, the River Torrens flowed northwest to the present Port Reach, depositing an alluvial fan on its lower outwash plain (AITCHISON *et al.*, 1954: 17). At some stage the river choked its own channel causing it to be diverted south to its present western course, which is partly man-made. The fanglomerates that form the bulk of the aprons located at the base of the Burnside-Eden and other fault scarps are a reddish-brown colour.

Thus, the rivers flowing to Gulf St Vincent responded to Late Cenozoic sea level changes that caused rejuvenation and extension. The valleys in the

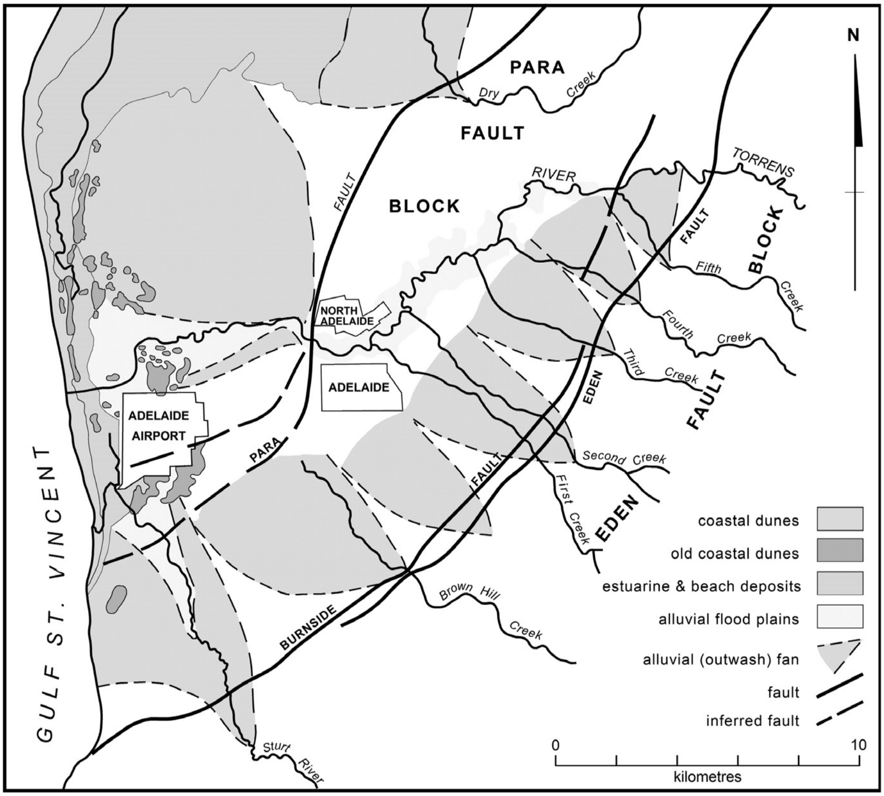

Figure 4. Adelaide Plains area of the western piedmont of Mount Lofty Ranges, including a diagrammatic representation of the alluvial fans associated with the major streams (after AITCHISON et al., *1954).*

reddish-brown fanglomerates were subjected to alternations of cut-and-fill during the Late Pleistocene (BOURMAN *et al.*, 2010b; figure 5). Tree trunks buried by this deposit and exposed in a sand quarry in the Torrens Valley some 4 kilometres northeast of the Adelaide CBD (FENNER, 1931: 260) gave a ^{14}C date of 5860 years BP (DSIR NZ R833/1), though this age has been challenged as too young (BOURMAN *et al.*, 2010b). The dissection of the younger, grey, valley fills postdates European settlement (TWIDALE, 1969).

The piedmont zone is succeeded to the west by the Adelaide Plains that extend between the upland and the sea coast as far north as Port Wakefield. They are underlain by several scores of metres of Pleistocene alluvia deposited by such rivers as the Gawler and Light, which like the Torrens and Onkaparinga drain substantial areas of the Mt Lofty upland. Toward the head of Gulf

Figure 5. Evidence of cut-and-fill exposed in gully in Pleistocene fanglomerate near Sellicks Hill, south of Adelaide. The terrace remnants (X) mark the upper limit of 'grey' alluvial deposits within a valley incised in the 'red', seen exposed in the river bank in left foreground. The most recent incision postdates European settlement.

St Vincent NW-SE trending linear dunes stabilised by vegetation are preserved. They attest to an extended phase of aridity in the Late Pleistocene, the consequences of which are discussed in connection with the eastern piedmont.

EASTERN PIEDMONT

FAULTING

The eastern flank of the Mt Lofty horst defines the western limit of the Murray Basin (figure 1), a framed or structural basin, part of which was occupied by the ocean during the Early Cretaceous, and identified as the Berri Basin, underlain by a down-faulted trough probably linked to the Eromanga Basin (ROGERS, 1995: 127). In Middle Miocene times it became a marine embayment in which a thick sedimentary sequence including the Mannum Limestone was laid down. The Miocene seas extended to the west of the fault zone and scarp but by how far is not known, for the old shoreline has not been identified. However, Mannum Limestone beds were disrupted by the faulting that produced the Milendella Scarp (figure 6), which with the Palmer Fault Scarp delimits the horst on its eastern side (MILLS, 1965; TWIDALE & BOURNE, 1975; BOURMAN & LINDSAY, 1989). This tectonic phase can be correlated with the phase of intense Late Cenozoic faulting and uplift on the western flank.

Figure 6. Milendella Fault (f-f) exposed in mouth of incised stream near Cambrai. The fault is obviously of reverse type with weathered folded Precambrian bedrock riding eastwards over younger alluvia. The white material (M) is Miocene limestone involved in the dislocation.

The Milendella Fault zone clearly throws down to the east. However, a southerly continuation of the structure evidently occurs in the shallow subsurface and is exposed just north of Summerfield HS, some 7 km SSE of Palmer, in a road-cutting best known for the evidence of granite intrusive into the Cambrian gneiss and schist (figure 7). It is one of several faults located adjacent to, and roughly in parallel with, the main scarp-generating Palmer and Milendella zones (e. g. NELSON, 1977; GIBSON, 2004) and with the fractures with which the course of the River Murray is associated (BOWLER *et al.*, 2006; TWIDALE & BOURNE, 2009; MCLAREN *et al.*, 2011). As in the west the faults remain active, though in lesser degree (LOVE *et al.*, 1995).

DRAINAGE DEVELOPMENT

The post Miocene age of the faulted eastern escarpment implies either that any major west-flowing streams that originally extended east of the present upland were truncated by the faulting, or that all the present east-flowing rivers that drain the eastern upland and debouch on to the eastern piedmont – the Bremer, the Marne, the Truro and the Burra, for instance, postdate the faulting.

Figure 7. Fault plane near Summerfield Homestead showing slickensides and steps indicating plucking or rucking by the now eroded block. Usually, this would indicate upthrow of the block to the west for the 'plucked' face of the faults steps face up (HILLS, 1963: 131). But laboratory experiments with marble subjected to shear produced steps and faces caused by downward pressure and the pushing up or rucking of miniature ridges or steps (PATERSON, 1958, his Plate 2).

Partly for this reason, but also because of the lower rainfall received in the eastern areas both at present and in the recent past, the streams of the eastern upland have developed smaller catchments than their western counterparts. As in the west uplift induced stream rejuvenation and incision. Within the Ranges streams such as the Marne, Milendella, Harrisons, and Bremer rivers and creeks, are structure-controlled, and though short have excavated deep gorges with well-developed incised meanders. However, what at first glance appears to be the largest and best-formed of these supposed meander loops is a structural feature, for the horseshoe-shaped valley just to the east of Rathjen Gap is due to a pattern of foliation that has caused strike stream valleys to converge and merge headwards.

These eastern streams flow to the Murray Basin the western part of which is dominated by plains shaped in and underlain by the clastic Mannum Limestone (TWIDALE, 2012). This, combined with climatic factors, prevented most of the streams that debouch from the eastern Ranges from reaching the local baselevel, the River Murray (figure 2). With the exception of Harrisons-Reedy Creek, the River Marne and Burra Creek, for example, no other of the many short streams that drain the eastern Mt Lofty Ranges cross the karst plain and reach the Murray. The fault-controlled Bremer Creek, the Angas and the Finniss flow to Lake Alexandrina but do so via natural tidal flats.

RIVER MURRAY AND ITS IMPACTS

The River Murray established its present general plan prior to the Pliocene (Twidale & Bourne, 2009). During periods of higher sea levels the River aggraded its bed (Firman, 1971). Following a rise in sea level during the Middle Pliocene, however, this valley became a marine estuary that served as the regional baselevel to which the adjacent karst plains were graded by a process of dissolution and collapse down to the then water table (Twidale, 2012). During Pleistocene low sea levels the River extended its course far to the south, to the edge of the continental shelf. During phases of low sea level the rejuvenated river regressed northward as it incised its bed, exposing pre Miocene granitic forms in and adjacent to it (figure 8). The present Gorge and valley-in-valley form typical of the lower Murray were thus developed.

Most of the eastern piedmont has been buttressed against the effects of the Late Cenozoic sea level changes that elsewhere had significant effects on river behaviour. The effects of the changing Pleistocene sea levels on the channel of the lower River Murray were not transmitted to most of its tributaries. Reedy Creek was an exception with the lower valley well represented in the valley below Mannum Falls (Twidale *et al.*, 1978; figure 9). On the southern side of the gorge a ferruginous regolith can plausibly be construed as a remnant of the surface graded to the River when that was part of the estuary (Twidale & Bourne, 1975), and may be of Pliocene age.

PIEDMONT ASSEMBLAGES

The many short rivers flowing from the eastern Ranges reached the piedmont. These waterways combined with wash from the ramparts dissolved the Mannum Limestone that clearly once extended at least as far west as the present escarpment. Thus, sectors of the piedmont are devoid of Tertiary sediments. The underlying Cambrian granite and gneiss and the forms developed on these basement rocks, either prior to the Miocene inundation or while buried beneath the Mannum Limestone, were exposed. These basement forms have also been modified since re-exposure.

Figure 8. Granite dome exposed a few kilometres upstream from Mannum from beneath Miocene limestone as a result of incision of River Murray. The granite, which is quarried at the eastern end of the outcrop, is overlain by the limestone in which the summit bevel is shaped.

Figure 9. Reedy Creek at Mannum Falls showing valley-in valley form.

These bedrock features include exhumed sub-Miocene surfaces in the form of mantled and rock pediments (TWIDALE, 1981) that are relics of the inselberg landscape. Thus, a pediment cone, now partly dissected but originally shaped by the fracture-controlled Milendella Creek prior to its capture and diversion, is preserved just north of Palmer. Resurrected gneiss plains as well as sundry exposures of boulders, large and small, also occur, and not only in the piedmont but also at various sites between the eastern scarp and the River Murray Gorge: the pre Miocene landscape is nowhere far below the surface in the western Murray Basin.

Granites exposed in the broader piedmont were formerly covered by limestone and occur in a moist environment. The deep erosion of Reedy Creek and its tributaries has exposed fields of granite boulders some of which display pans and short sectors of gutters as well as evidence of repeated subsurface weathering and erosion (figure 10). They are construed as remnants of a former domical hill the flanks and lower slopes of which have been disintegrated. The boulders also display undercutting caused by cavernous weathering. In the Caloote area, stepped bases exposed as a result of post-European settlement indicate soil erosion of about 25 cm over the hillslopes.

As on the western side of the Ranges, scarp-foot weathering has produced depressions. On the west almost all are covered by deposits, save one example that was formerly visible, before the encroachment of residential development, north of the footslopes of Anstey Hill. On the east, however, they are not only developed but exposed. For example, where Harrisons Creek emerges from the upland (to become Reedy Creek on the plains) near Hillydale HS ?? a broad topographic depression intervenes between the east-facing scarp of the upland and the limestone plains located immediately to the west of the River Murray Gorge (figure 11). Reedy Creek has exploited the broad zone of piedmont weathering developed along the Palmer Fault zone from north of Palmer to the vicinity of Tepko, a distance of some 15 km to form what is a major scarp-foot depression (e. g. THORBECKE, 1927; CLAYTON, 1956). Several other minor depressions have been noted. Unlike the Hillydale feature they lack surface drainage, but they can be attributed to the flushing of fines during heavy rains (RUXTON, 1958). Volume loss and compaction during weathering (e. g. TRENDALL, 1962) may also be invoked to account for some of the surface lowering,

As most of the east-flowing streams are comparatively short with drainage basins of limited area, the alluvial fans associated with them are of limited extent and thickness. This comparative lack of piedmont deposits has contributed to the exposure of the bedrock morphology.

Figure 10. Isolated anvil-shaped granite block located on the crest of a hill near Caloote. The rock basin etched on the upper surface and the short gutters preserved on remnants nearby together suggest that the isolated blocks were once part of a domical hill, which has been severely weathered and reduced by carbonated groundwaters seeping through the Mannum Limestone, when the latter extended up to and beyond the eastern scarp of the Ranges. Note the low platform or plinth indicating recent (post European settlement) lowering of the surface.

Figure 11. View west across the scarp-foot valley in the eastern piedmont to Hillydale Homestead (H) and its nearby historic cemetery (C) situated lower than the level of a perched pediment remnant (P). This is in turn located adjacent to Harrisons Creek where it emerges from the Mt Lofty Ranges to become Reedy Creek. Note prominent summit bevel, which is the sub-lateritic etch surface.

CLIMATIC FACTOR

RAINFALL PAST AND PRESENT

The Mt Lofty Ranges are situated in the Westerlies zone. Given a northward migration of 10 cm per annum or one km every 10,000 years and that a degree of latitude equals about 110 km, it follows that the upland and associated piedmonts stood within that zone throughout the later Cenozoic. Thus, the eastern areas were located in the rain shadow of the upland when their piedmonts developed: they are and have been more arid than their western counterparts.

The western Mt Lofty Ranges on average receives a much higher rainfall than the eastern: Mt Lofty averages 1050 mm per annum but can receive up to 1200 mm, and Stirling, also located in the western part of the upland, averages 1190 mm, but in the eastern sector of the Ranges Mt Pleasant and Tungkillo average 676 m, and 756 mm per annum, respectively, yet Palmer, in the eastern piedmont averages only 345 mm and Mannum, a few kilometres further east and located on the banks of the River Murray, 304 mm per annum.

Between 300-350 ka years and 25 ka years ago, however, a more arid climate prevailed. This is evidenced by fields of NW-SE trending longitudinal desert dunes, which extended over northern Eyre and Yorke peninsulas, and spread on to the northern Adelaide Plains. The field of sand ridges also occupied the western Murray Basin but these trend west-east (TWIDALE *et al.*, 2007; LOMAX *et al.*, 2007; HILGERS *et al.*, 2011).

Contrasts due to the rain shadow effect would have obtained as long as the area under review was situated in the zone of the Westerlies. It follows that the lithological desert created by the limestone plain that dominates the western Murray Basin is enhanced by local climatic factors.

DESERT DUNES

Though comparatively short, the rivers of much of the eastern Mt Lofty Ranges drain outcrops of granite and gneiss that have been weathered to produce quartz sand. This was deposited in the piedmont and was shaped into linear desert dunes. The dunes trend west-east under the influence of northwest and southwest winds and with a resultant easterly movement (*cf.* WOPFNER & TWIDALE, 1967, 1988). The dunes are initiated quite close under the eastern scarp of the Mt Lofty Ranges. In the vicinity of Cambrai, for example, dunes are initiated less than a kilometre from the scarp.

But there are gaps in the eastern piedmont dunefields. One is located where Harrisons Creek debouches on to the piedmont and where in consequence the Mannum Limestone has been eliminated. The piedmont plains north of the

River Marne are virtually free of relic desert dunes, save for a few that arguably are sourced from the sandy river channels, such as the Burra Creek, Craigie and Robertson plains (figure 2), in some of which Late Pleistocene alluvia were deposited (BOURMAN, 2010b).

Several reasons can be adduced for the absence of dunes in these areas but all are areas of water concentration, which has inhibited the work of wind. The broad piedmont zone north of the River Marne is a topographic depression. Like that excavated by Reedy Creek it may be tectonic – it can be construed as bounded by faults – or it may be due to weathering. Whatever, it is and has been a depocentre for streams issuing from the upland to the east. At present, the streams terminate in the depression so that the sediment load conveyed from the hills remains there, but in the past presumably before the recent subsidence of the piedmont, alluvium was spread also to the east of the Florieton scarp. It thins to the east and is absent in the sector adjacent to the River where the Tertiary strata are capped only by calcrete. Not only were there suitable soils but also intermittent supplies of surface water, so that a woodland cover was supported.

Thus, as in the western piedmont, rivers have played a significant role in the development of its eastern counterpart. That the wind regime in the lee of the upland barrier to the west is capable of shaping detritus into ridges is demonstrated by the presence of sand ridges in areas not well served by debouching streams. Furthermore, the higher plains that remain between the piedmont and the Murray Gorge are underlain by Miocene limestone. Calcrete is well developed but the A-horizon has been removed to expose the carbonate crust. Some has been washed underground, but most has been swept away by the wind. In many sectors the work of the wind is negated by weathering, erosion, and deposition by water flowing and seeping from the adjacent upland.

SUMMARY AND CONCLUSIONS

The contrasted piedmonts of the western and eastern flanks of the Mt Lofty Ranges can be attributed partly to the contrasted age and regimen of the rivers involved, which in turn reflects the different age of the major faulting responsible for the opposed flanks of the Mt Lofty horst, for it developed in two stages. The western scarp formed prior to the Middle Eocene and was enhanced in the Late Tertiary, whereas the eastern was not in place in any substantial form until at least 55 million years later, in post-Miocene times. Because the complex western scarps of the Mt Lofty horst block was developed earlier than the eastern, rivers and streams that had served the lateritised plain and flowed west developed larger catchments than east-flowing streams. They also received a higher and more reliable rainfall throughout the later Cenozoic, the period of piedmont development.

Moreover and significantly, the western flank was exposed to the effects of later Cenozoic sea level changes, whereas the eastern piedmont was largely protected against them. Thus, regardless of the pre Miocene geography, the west-flowing rivers effectively developed over a much longer period than their eastern counterparts. This resulted in longer streams, carrying greater volumes of sediment, including coarse debris. By contrast, the eastern streams are shorter, and though the River Murray undoubtedly responded to Pleistocene sea level changes, with the exception of the sectors adjacent to major tributaries the piedmont was buttressed by the limestone-clad plains between it and the River. The eastern piedmont generates dunes save where scarp-foot depressions act as local depocentres in which the availability of water inhibited any tendency to sand transport.

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