THE GEOLOGY, PHYSIOGRAPHY AND SOILS OF WHEATBELT VALLEYS

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ABSTRACT

Wheatbelt valleys lie in an ancient landscape in which drainage is largely internal and characterised by discontinuous chains of salt lakes. The crystalline rocks, eroded to a plateau maybe some hundreds of millions of years ago, preserve remnants of river systems originating when Australia was joined to Antarctica. These rocks, now deeply weathered beneath the valleys, are incised by old river courses (palaeochannels). The palaeochannels are infilled with up to 60 m of sediments either of Eocene (c 43 million years) or Pliocene (c 5 My) age, and lie within flat bottomed valley floors. The widened out valleys contain up to 20 m of more recent sediments, and soils of colluvial, alluvial, lacustrine and aeolian origin. Digital elevation models derived from the Land Monitor program now give the opportunity to map surface drainage pathways and areas of inundation in detail, and integrate with soils and radiometric data. The flat valley floors, and lack of either surface or subsurface drainage, present a challenge for water management.

INTRODUCTION

Wheatbelt valleys are now the focus of considerable attention from a water management perspective. The flat-bottomed, largely internally-draining valleys which form a significant proportion of the Wheatbelt were settled and cleared early as they are highly productive. However, the valley floors are subject to waterlogging, rising water tables and dryland salinity, with the likely soil structure decline, loss of productive farmland, and threat to native vegetation in reserves and infrastructure.

The southwest of Western Australia has some unique geological and physiographic features which have a bearing on the land use management in the valleys. The region has not only some of the oldest rocks in the world, but also one of its more ancient landscapes. The valleys, now occupied by discontinuous chains of salt lakes, are parts of palaeodrainage systems tens of millions of years old.

Modelling of hydrological processes in wheatbelt valleys has emphasised the importance of understanding the slope of the land surface in order to control surface water, allow drainage, and model groundwater table rise. The distinction between management of valley floors and uplands requires a definition of valleys, which is made possible by the availability of accurate digital terrain models (DEM) derived from the Land Monitor Project.

The purpose of this paper is to provide a brief background to the geology, physiography and soils of wheatbelt valleys, with a comprehensive and up to date bibliography of previous work. Details of palaeochannel sediments are discussed in some depth as this information is not collated elsewhere. It is convenient in this review to cover the whole of the southwest part of WA, while focussing on the valleys in the Wheatbelt Region which are contained within the zone of ancient drainage (Figure 1).

PREVIOUS WORK

The Darling Plateau had been recognised as a peneplain by Woolnough (1918) and Jutson (1934), who also distinguished an old plateau (the hills) and a new plateau (the valleys). The valleys were studied in detail by Bettenay (1962) who mapped the ancient drainage system, and by Bettenay *et al.* (1964) from the point of view of salinity. Detailed geomorphic descriptions of the landforms in the south west were made by Bettenay & Mulcahy (1972), Mulcahy & Bettenay (1972), Mulcahy (1973), and by Finkl & Churchward (1973), who put forward the concept of

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etch plains – the formation of the landscape from deeply weathered regolith. More recent authors have concentrated on specific aspects of landscape e.g. Twidale (1994); Glassford & Semeniuk (1995); Twidale & Bourne (1998); and Beard (1999) has recently made a comprehensive analysis of the drainage history.

Figure 1: Drainage pattern in the southwest of Western Australia

The impetus to understanding the bedrock geology was the systematic geological mapping carried out in the 1970s, together with isotopic age dating (Geological Survey 1990). The Cainozoic (younger than 65 million years old) geology of the sediments overlying the bedrock is less well known. Quilty (1974) reviewed the Tertiary stratigraphy, and Wilde & Backhouse (1977) described the existence of outcropping Tertiary (Eocene) sediments in the Darling Range area. The ancient drainages, termed palaeodrainages, were mapped and described by van de Graaff *et al.* (1977), but only in the last ten years have Eocene or Pliocene sediments been described from palaeochannels in wheatbelt valleys away from the south coast (Waterhouse *et al.* 1995; Salama 1997; De Silva 1999; Yesertener *et al.* 2000). These investigations in the Wheatbelt and adjacent areas followed the recognition of an integrated Eocene drainage system in the Eastern Goldfields (Kern & Commander 1993; Clarke 1994b). The palynological dating (from pollen) is hindered by lack of subsurface samples; as the groundwater in the region is almost invariably saline, there has been little deep drilling for water supply, and only some exploration for coal and kaolin. Only in the last ten years also have the full thickness of Quaternary sediments and regolith in the valleys been described in detail (e.g. George & Frantom 1990a,b,c; George, 1992; Salama *et al.* 1993) as part of land salinisation studies.

Wyrwoll (1988) has commented on the inordinate length of time during which the geomorphology has developed, but the acceptance that the landscape itself is of great antiquity is comparatively recent (Twidale 1998), a theme popularised by White (2000).

Definition of the valleys in a systematic way throughout the Wheatbelt has only been possible since the completion of the 1:2,500,000 geological mapping in the 1970s (Commander 1989, Fig. 1), through soils mapping and, since 2000, by remotely sensed digital elevation modelling carried out under the Land Monitor Project (Caccetta 1999a,b).

BASEMENT GEOLOGY

The southwest of Western Australia is divided into two major tectonic units: the Archaean (pre-2500 million years) Yilgarn Craton, and the Proterozoic (2500-600 My) Albany-Fraser Orogen. The evolution of the crystalline bedrock in these provinces is summarised in Table 1 from Geological Survey (1990).

Table 1: Geological timescale of basement rocks

Tectonic unit	Age range (millions of years)	Rock unit	Event
	550-750	Boyagin Dyke Swarm Muggamugga Dyke Swarm	Intrusion of dolerite dykes NW trending NE trending
Pinjarra Orogen	1000-1300	Moora and Yandanooka Groups	Deposition of dolomite, basalt, sandstone, siltstone
	1150		Metamorphism of Stirling Range Formation
Albany Fraser Orogen	1100-1300	Biranup and Nornalup Complexes	Metamorphism and granite intrusions
	1200-1800	Gnowangerup dyke swarm	EW trending dolerite dykes
	2400	Widgiemooltha dyke suite	EW trending dolerite dykes
Yilgarn Craton	2600-2700	Granite	Granite intrusions, metamorphism and folding
	2700-2900	Greenstone	Sediments and volcanic lava
	3000-3300	Western Gneiss	Metamorphism, sedimentation
	4500	Formation of the Earth	

The oldest rocks are remnants of early sedimentary crust thought to have been deposited around 3300 million years (My) and metamorphosed around 3000 My into what is now the Western Gneiss (Figure 2). A period of sedimentation and eruption of volcanic lava followed between 2900 and 2700 My, culminating in the intrusion of granite plutons, with folding and metamorphism of the sedimentary and volcanic rocks, the remnants of which are known as greenstone belts. Two major phases of dolerite dyke intrusions at 2400 My and 1800 My or later completed the crystalline bedrock distribution that we observe today in the Yilgarn Craton (Figure 3).

On the southern and south eastern margins of the craton, renewed orogenic activity around 1300 to 1100 My metamorphosed sediments (such as the Stirling Range Formation), whose age is currently unknown, and formed the Biranup and Nornalup gneiss and migmatite complexes. Further sedimentation took place on the western margin of the craton with deposition of the 2 km thick Moora and 5 km thick Yandanooka Groups. All these rocks were then further intruded by dolerite dykes between 750 and 550 My.

The basement rocks are generally exposed only in the hills, but isolated outcrops occur sporadically within the valleys. The crystalline basement is now mostly weathered to clay or clayey sand beneath the valleys to depths of generally 40 m below the surface, but exceeding 70 m in the vicinity of palaeochannels.

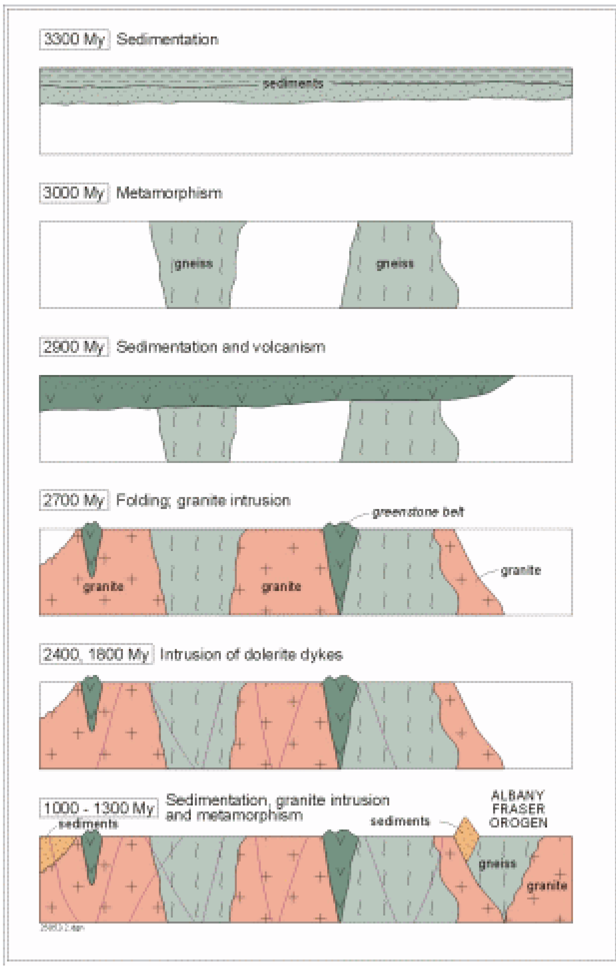

Figure 2: Diagrammatic sections illustrating the geological evolution of the basement rocks (age in millions of years, My)

EROSION, DRAINAGE AND SEDIMENTATION

Peneplanation

Erosion of the Archaean crystalline basement in the north east of the Yilgarn Craton to a subdued peneplain (the present Darling Plateau) certainly took place in the Middle Proterozoic, as evidenced by the exhumation of the unconformity beneath flat lying 1800 My old sediments. The unconformity being exhumed is a peneplain with slightly elevated greenstone belts, remarkably similar to the granite-greenstone topography of today's north east Yilgarn Craton.

In the south west of the Yilgarn Craton there may have been significant uplift and erosion during the Late Proterozoic. This is demonstrated by the higher grade metamorphic rocks at the surface, and by folding and faulting in the Albany-Fraser Orogen, and of the Moora and Yandanooka Groups.

The whole region was glaciated during the Carboniferous-Early Permian (about 280 My) when a continental ice sheet covering Gondwana (Figure 4), likely to have been 3-5 km thick, moving to the NNW, planed off the pre-existing land surface. Possibly, valleys would have been created beneath the ice sheet from melt waters (P E Playford, *pers. comm*. 2001), which may also have trended NNW. These valleys may have filled with glacial till and outwash gravels, as in the Collie, Wilga and Boyup Basins. In the extreme south west, there must have been a significant coverage of sand and coal measures immediately following glaciation, evidenced by the sediments now preserved only in the coal basins and in the Perth Basin to the west (Figure 3).

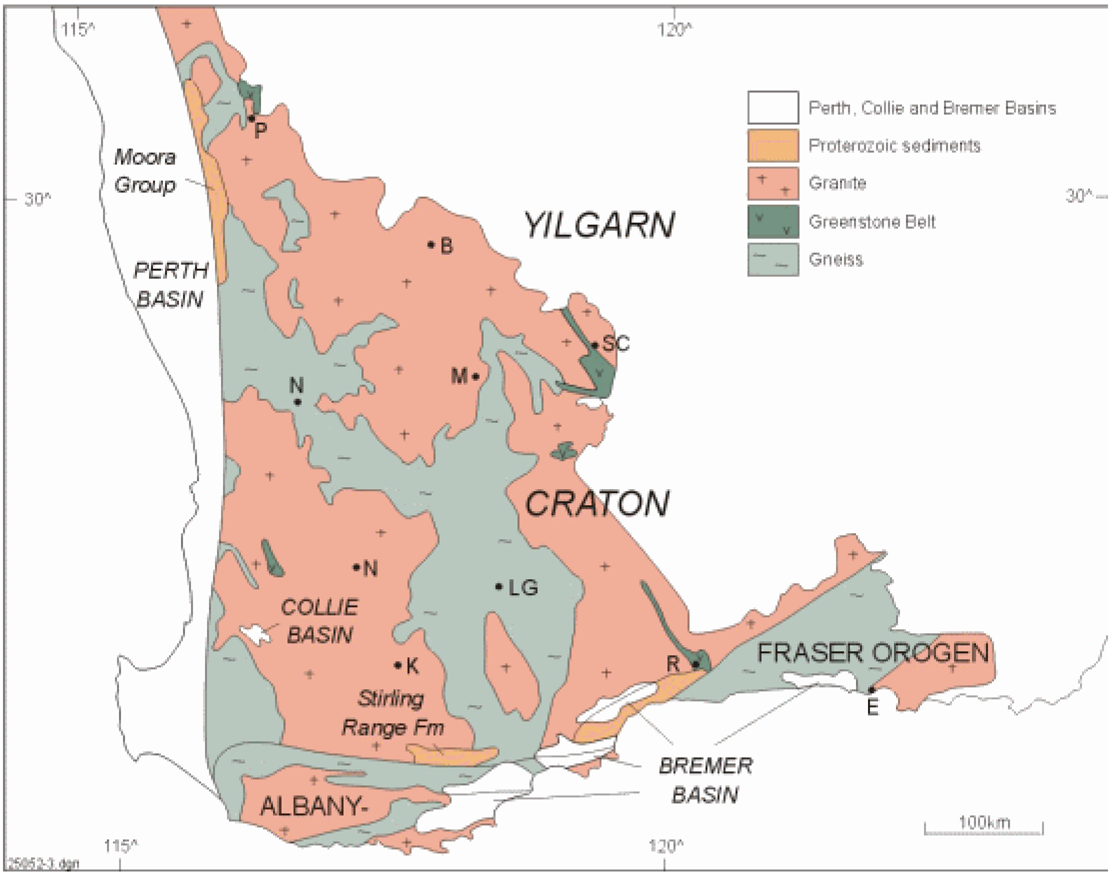

Figure 3: Solid geology of the Agricultural Area (after Myers and Hocking 1998)

Finkl & Fairbridge (1979) have suggested that peneplanation of the Yilgarn Craton was completed in the Proterozoic, and that denudation rates were minimal ever since. They argued for a western source for the Permian-Cretaceous Perth Basin sediments (Fairbridge & Finkl, 1978), though this was challenged by van de Graaff (1981) who argued for removal of some 500 m of rock from the Yilgarn Craton since the Jurassic. However, it has recently been found that the Archaean provides only a minor source of detrital zircons to Quaternary mineral sand deposits in the Perth Basin (Sircombe & Freeman 1999). This strongly implies a western source for Perth Basin sediments from Proterozoic rocks, and supports the suggestion of minimal erosion of the Yilgarn Craton at least since the Jurassic/Cretaceous. Thus the landscape appears to have been moderately stable since the age of the dinosaurs.

Most authors now agree that peneplanation was complete by the end of the Createceous. Twidale (1994) postulates that the 'new plateau' of Jutson (1934) in the eastern Yilgarn must also be of Eocene age, on the basis of the Eocene sediments there, and that the 'older plateau' is even older.

Drainage

The oldest drainage systems now preserved are likely to be in the zone of ancient drainage (Figure 1) containing the Pingrup, Lockhart and Camm valleys, between the median and the central watersheds, recently recognised by Beard (1998; 1999). The region may have been traversed by palaeoriver systems draining Antarctica when the continents were joined (Figure 4), and Beard (1999) has suggested that these rivers may have originally drained southwards (Figure 5), following the opening of a seaway between Australia and Antarctica in the Jurassic 150 million years ago (Table 2). It may be significant that these valleys follow the NNW structural trend in the basement rocks.

Figure 4: Reconstruction of Gondwana (GSWA 1990)

These palaeodrainages are analogous with the Eastern Goldfields where an integrated palaeodrainage system, at least in existence by the start of the Middle Eocene (50 My) has palaeochannels infilled with mid to late Eocene sediments (Kern & Commander 1993; Clarke, 1994b). These palaeodrainages, however, cross the geological structure and direction appears determined by drainage to the Eucla Basin. No age dating has apparently been carried out on the palaeochannel sediments in the zone of ancient drainage (Yilgarn System of Beard 1999), though they have been correlated with the Eocene Bremer Basin sediments (Dodson 1999).

Westward draining Eocene sediment-filled valleys (Figure 5) have been identified in the current Blackwood and Beaufort catchment (Waterhouse *et al.* 1995) and in the North Stirlings (Appleyard 1994), Mobrup catchment (Hundi *et al.* 2000) and at Wilgarup near Manjimup (Thorpe 1994). However, farther north, Eocene sediments have been identified only in dissected uplands (eg Westdale, Brookton), so the drainage pattern is currently unknown. The Perth Canyon, infilled onshore with Palaeocene (65-55 My) sediments (Davidson 1995), and correlated with the Avon palaeochannel (Salama 1997) indicates the presence of a large westward flowing river system, but no sediments of that age are preserved on the Darling Plateau.

The existence of Eocene sediments in palaeochannels confirms a minimum age for these palaeodrainages of about 45 My, Early Cretaceous sediments preserved only in the Collie basin (Nakina Formation) could have been much more extensive, but cannot be linked with current drainage systems. Twidale (1994) postulated a Gondwana landscape of low relief, with low domes rising from duricrusted plains in the southwest Yilgarn Craton, which could be similar to other pre-Cretaceous land surfaces currently being exhumed elsewhere in Gondwana.

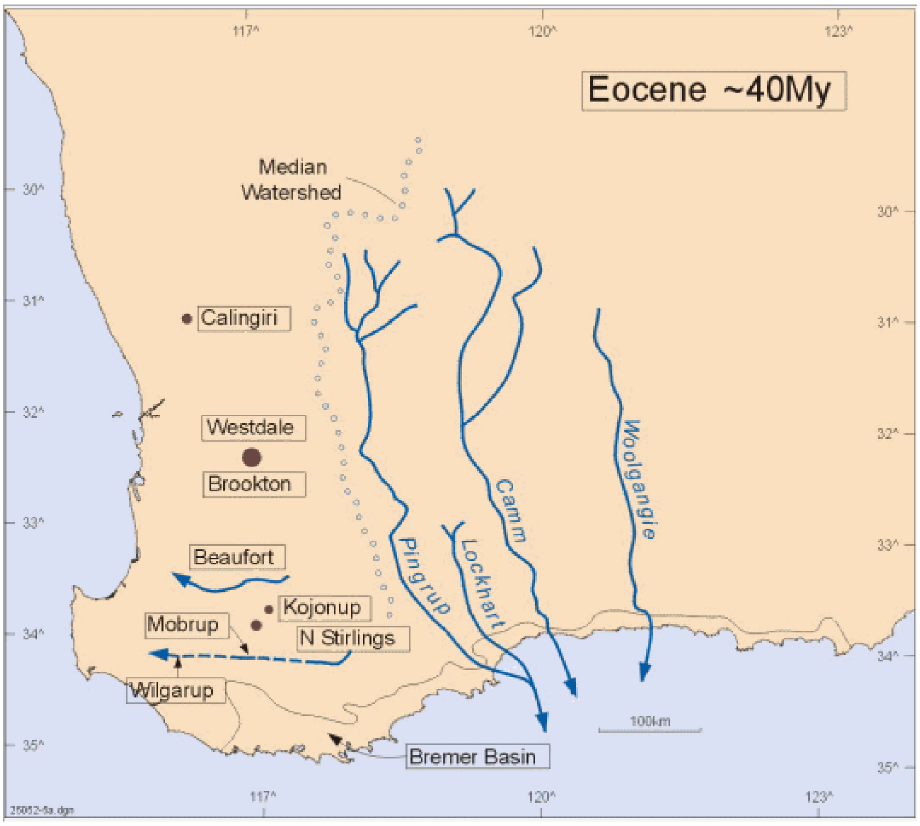

Figure 5: Eocene sediment localities and possible drainage pattern (after Beard 1999)

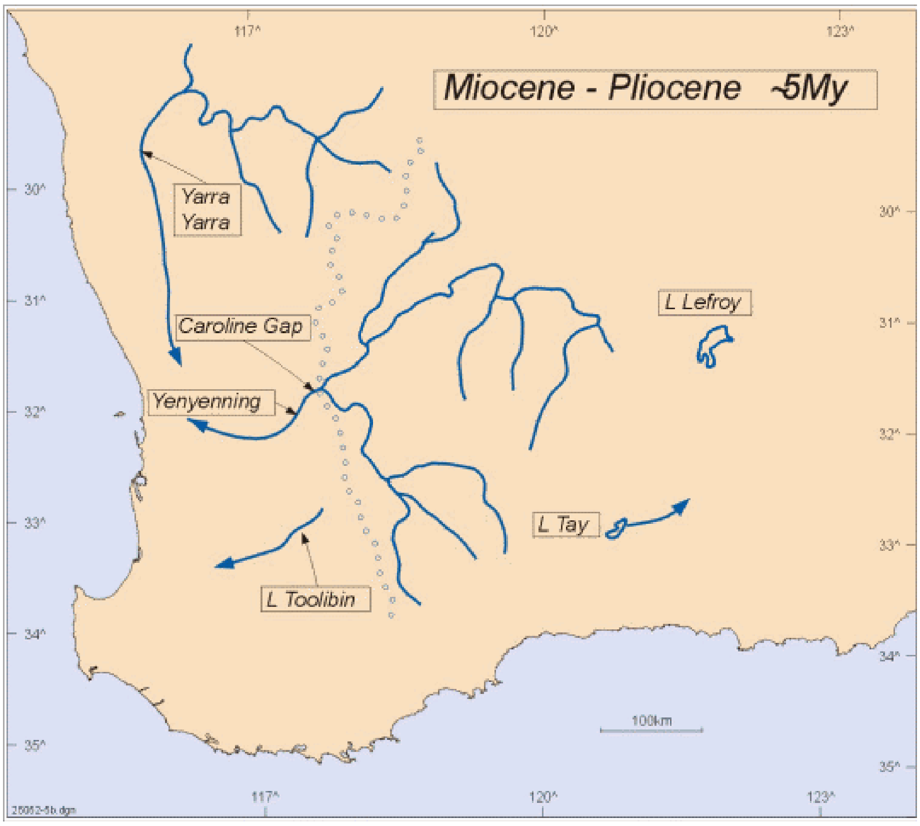

Figure 6: Late Miocene-Pliocene sediment localities and drainage pattern

Table 2: Evolution of the western part of the Australian continent (modified after Middleton 1991)

Age (millions of years)	Event
0-2	Quaternary – Late Pliocene sediments across wheatbelt valleys
5-2	Late Miocene - Early Pliocene sediments in palaeochannels
?	Uplift and rejuvenation of Darling Range, west of Meckering Line
25-11	Miocene chemogenic sediments in Eucla and Perth Basins
38-25	Main period of lateritisation in Oligocene?
43	Final separation of Australia from Antarctica
50-38	Eocene Bremer Basin and palaeochannel sediments
50	Rejuvenation of rifting with Antarctica
105	Spreading ceased along south coast– deposition of Late Cretaceous sediments in the offshore Bremer Basin
119	Opening of rift with Antarctica
	Separation of India, and widening of Perth Basin
150	Beginning of separation from Antarctica
280	Glaciation
280	Formation of Perth Basin

Separation of Antarctica after 43 My (Table 2) was accompanied by uplift along the Ravensthorpe Ramp (Cope 1975), about the Jarrahwood Axis, with the likely development of short incised south flowing streams. At this stage the Camm, Lockhart and Pingrup valleys may have been beheaded, or reversed. The westward trend of the North Stirlings-Mobrup-Wilgarup drainages was dissected, and the Beaufort Palaeoriver (Waterhouse *et al.* 1995) diverted south.

In the north, uplift of the craton, with tilting to the south, reduced the erosive power of north flowing drainages. Beard (1999) concluded that the Lockhart/Camm/Yilgarn Rivers were captured at Caroline Gap, the one prominent gap in the median watershed. While it is attractive to consider that this expanded catchment may be associated with the cutting of the Perth Canyon, and Kings Park Shale (Salama 1997), the presence of Pliocene sediments in the palaeochannel downstream of Yenyenning (Figure 6), and the dissection of high level Eocene sediments in the Darling Range suggests a post-Eocene capture.

By the Late Miocene-Early Pliocene there appears to have been substantial modification of the Eocene drainage pattern by uplift along the Darling Range, with dissection of lateritised bedrock and Eocene sediments. The Meckering Line marks the eastern extent of this rejuvenation, west of which current river valleys are generally youthful and incised (Mulcahy 1973). This line of rejuvenation also partly coincidesd with the South West Seismic Zone (Beard 1999). Unlike the Eocene drainages, river systems in the Pliocene may have been able to cut more easily through deeply weathered crystalline bedrock (saprolite).

Continued uplift of the whole continent to the north (Beard 1998) has contributed to the internal drainage and development of salt lakes in the north flowing valleys. The south tilt is evident from diversion of rivers to the south, such as the capture of Beaufort by the Blackwood at Duranillin, the south diversion of the Yarra Yarra Palaeodrainage (Figure 6) through the Moore-Brockman valleys, as well as the south coast rivers off the Ravensthorpe Ramp (the area of rejuvenated drainage along the south coast, Figure 1).

Sedimentation

Lack of widespread coarse land derived sediments in surrounding basins (Perth, Bremer, Eucla) after the Early Cretaceous (120 My) suggests that erosion of the Darling Plateau had been essentially completed by then. Rejuvenation after the late Cretaceous is indicated by the Palaeocene age Kings Park Shale filled Perth Canyon, implying that a precursor to the Yilgarn River – Avon Palaeodrainage existed at that time through the Darling Range.

Eocene Sediments occur both in palaeochannels (e.g. Waterhouse *et al.* 1995), and as dissected remnants on drainage divides (Wilde & Backhouse 1977).

The Eocene sediments have been lateritised and deep weathered. There is no unanimity on the date of laterite formation and Twidale (1994) noted that the age of the high plain surface and duricrust of Darling Range is controversial. van de Graaff *et al.* (1977) suggested an Oligocene (38-25 My) age on the basis that Eocene sediments are lateritised on the margins of the Eucla Basin, whereas Miocene (25-5 My) sediments were not, and a Late-Oligocene to Early Miocene date was supported by Schmidt & Embleton (1976) from palaeomagnetic work on laterite in the Perth Basin. Bird & Chivas (1993) also suggested a post mid-Tertiary age for deep weathering in Western Australia, based on oxygen isotope values in two samples of clay. A post-Eocene age for weathering is indicated by the deeper regolith paralleling Eocene infilled palaeochannels (Kern & Commander 1993). However, recent work (Pate *et al.* in press) suggests that laterite may have been forming continuously since the late Cretaceous, associated with iron fixing in the root zone of Proteaceae.

The time period of Oligocene-Middle Miocene (38-11 My) is not represented by sediments on the craton. The presence of Early – Middle Miocene carbonates in the Eucla and Perth Basins suggests a lack of erosion and sediment transport from the craton, consistent with deep weathering on the Darling Plateau (Finkl & Churchward 1973).

A later phase of sedimentation in palaeochannels appears to have taken place in the Late Miocene-Early Pliocene. Currently sediments of this age are known only from Yarra Yarra Lakes, Yenyenning, Lake Toolibin, Lake Tay and Lake Lefroy (Figure 6), though many areas are yet to be investigated.

It is not clear whether the valleys floors were incised by the Eocene and Pliocene palaeochannels or whether widening out of valleys took place subsequently. In places, as Twidale (1994) noted from the Eastern Goldfields, the valley floors may be of Eocene age, but valley widening may have been a continuing process. The mechanism for widening the valleys has not been extensively discussed by previous authors. Jutson (1934) illustrated sideways retreat of valley sides forming the new plateau from the remnants of the old plateau, and Finkl & Churchward (1973) discuss the processes of peneplanation and parallel scarp retreat.

The removal of stripped regolith has probably contributed both to the Pliocene palaeochannel sediments and to the surficial valley sediments (assumed to be Late Pliocene - Quaternary in age). Quaternary (< 1 My) aridity contributed to the development of salt lakes, and associated gypsum dunes and lunettes. The contribution of aeolian processes is discussed by Glassford & Semeniuk (1995) who propose a desert aeolian origin for much of the surficial material.

VALLEY SEDIMENTS

The valley sediments fall into two broad types, the thick (up to 70 m) Eocene, and Pliocene alluvial or lacustrine palaeochannel sediments, which occur in deeply incised narrow palaeochannels in the centres of the valleys, and the thinner (up to 20 m) Quaternary colluvial alluvial and lacustrine (salt lake) sediments which cover the full width of the valleys.

Permian sediments occur in valleys in the Eastern Goldfields and Pilbara, but do not seem to have been preserved in the Wheatbelt. Higher level Cretaceous and Eocene sediments also occur in the Darling Range. Palaeochannel sediments in the zone of ancient drainage have yet to be dated.

Cretaceous (130-120 My)

Cretaceous sediments have only been identified in the Collie Basin where the alluvial Nakina Formation is preserved as a thin covering on Permian coal measures (GSWA 1990). The sediments may have had a wider distribution, although alternatively they may be restricted to overlying Permian Collie Basin sediments, from which they may be derived.

Middle – Late Eocene (50-38 My)

Eocene sediments are preserved as high level remnants in the Darling Range, and in palaeochannels. To the south, the Eocene palaeochannel sediments become more or less continuous with the Plantagenet Group (42-38 My) in the Bremer Basin (GSWA 1990) where sand and lignite with basal gravel of the Werrilup Formation are overlain by siltsone and clay of the Pallinup Formation (formerly Pallinup Siltstone).

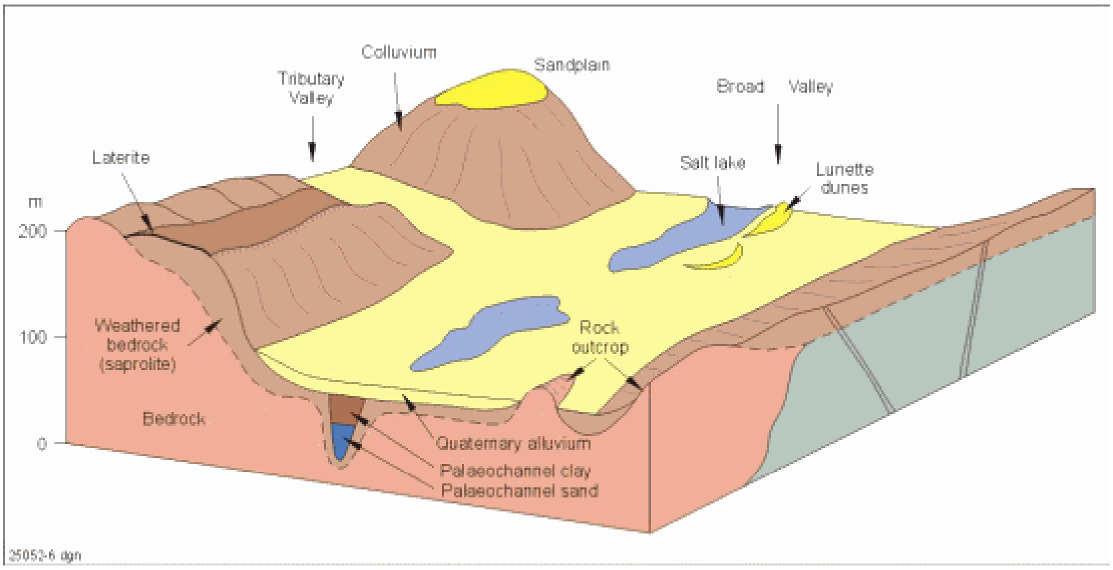

Figure 7: Block diagram showing schematic geology of a wheatbelt valley

North Stirlings (Appleyard 1994): This is the thickest and most extensive deposit of Eocene sediments away from the south coast Bremer Basin. There are 60 m of Eocene sands, lignites and clay, and this appears to continue westward to the Mobrup Catchment (Hundi *et al.* 2000). Farther west still, there is a remnant east-west trending palaeochannel preserved on the drainage divide between Donnelly and Wilgarup Rivers 12 km north of Manjimup (Thorpe 1994).

Beaufort (George *et al.* 1994; Waterhouse *et al.* 1995): This palaeochannel is 65 m thick in the Boscabel area, south of the current Beaufort River channel, and consists of basal sands and overlying clay with a degree of interbedding. The palaeochannel sands are about 1 km at their widest, whereas the overlying clays extend several kilometres across the valley floor.

Darling Range: High-level remnants are mainly preserved on drainage divides, e.g. Kojonup Sandstone, demonstrating younger (post Eocene) physiography west of the Meckering Line (Wilde & Backhouse 1977). A sequence of basal sand overlain by kaolinitic clay has been recently identified in a seemingly isolated high level basin 5 km north west of Brookton.

Oligocene - Middle Miocene (38-11 My)

As discussed above, there appears to have been no sedimentation on the Yilgarn Craton, other than those associated with lateritic duricrust.

Late Miocene - Pliocene (11-2 My)

Early Pliocene sediments on the Yilgarn Craton were first described from Lake Tay (Bint 1981), but remained isolated until discovery in the Yilgarn River valley at Yenyenning (Salama 1997). Subsequently, Pliocene palaeochannel sediments have also been identified at Lake Toolibin in the current Arthur River (de Silva 1999; Milne, 1998), and in the Yarra Yarra Lakes/Coonderoo palaeodrainage on the margin of the craton (Yesertener *et al.* 2000). Clarke (1993, 1994a) also documented shallow Late Miocene – Early Pliocene sediments from Lake Lefroy near Kambalda. The samples analysed from wheatbelt paleochannels are all from low in the profiles, and therefore suggest that all of the profile in each of these palaeochannels is Pliocene. By contrast, similar aged sediments in Lake Lefroy overlie Eocene sediments.

Yenyenning (Salama 1997): The sediments consist of greenish clay and sand with gravel and lignite, and are a maximum of 72 m thick.

Yarra Yarra Lakes (Yesertener *et al.* 2000): The sediments consist of clays and sands, with some calcrete development, and are a maximum of 30 m thick.

Lake Toolibin (de Silva 1999): Two bores contained Late Miocene-Early Pliocene flora from lignite layers (Milne 1998), within sand clay and silt. The sediments extend from 8-34 m and 12-31 m below surface.

Lake Tay (Bint 1981): These sediments extend to at least 39 m, and are described as predominantly clay.

Lakes Cowan and Lefroy (Clarke 1994a): These are described as up to 9 m of sandy silt and clay, with gypsum and carbonate, and interpreted to be deposited in an evaporitic environment similar to today.

Quaternary (<2 My)

The Quaternary is characterised by cyclic aridity, coinciding with glacial and interglacial periods. Periods of dune building are likely in a climate drier than today's current climate, but it is also likely that a wetter climate contributed to lakes and external run off. Silcrete horizons are evidence of past climatic changes through fluctuating water tables. Estimates of salt storage suggest that around 50 000 years is all that is required for salt to accumulate, implying cyclic periods of flushing have taken place. George & Coleman (this volume) suggest that salt lakes may have occupied an area 50% greater than today. Howevr, little research has been done on inland Quaternary climate in inland south western WA, and inferences drawn from studies in south eastern Australia may not be applicable.

Quaternary sediments are relatively thin, apparently ranging up to a maximum of about 20 m, though they are difficult to distinguish from Tertiary sediments and weathered basement (Figure 7), especially in rotary drill cuttings. The sediments are colluvial (slopewash), alluvial (water deposited), and in the centre of the valleys are characterised by aeolian and salt lake deposits, lunettes, and kopi dunes. Glassford & Semeniuk (1995) believe much of the valley fill sediments to be desert eolian in origin.

Bettenay & Hingston (1964) described some 10-20 m of sediments overlying weathered bedrock as clays and sandy clays. Similar descriptions are made by George & Frantom (1990 a,b,c) and George (1992) who investigated the valley sediments along traverses in the eastern Wheatbelt at Brennands, Merredin, Welbungin and Beacon River Catchments.

Salama *et al.* (1993) described relict channels, shallow sand seams which probably represent the last phase of alluvial sedimentation. These near surface features are also apparent on aerial electro-magnetic (AEM) surveys and radiometric data (see Figure19 below), and may be important in designing drainage works.

Characteristics of valley floors

In the zone of ancient drainage, the broad valleys are flat bottomed, and commonly range from 5 to 15 km wide. They contain large salt lakes, for instance Lake Grace North, which is 5 km wide, 17 km long and covers an area of about 75km^2.

Locally, there are outcrops of unweathered bedrock which protrude through the valley floor sediments, and the aeolian dunes are slightly elevated.

The upper parts of the wheatbelt valleys have a very low gradient in the direction of flow. Beard (1999) has measured a fall of 200 m in 525 km in the Yilgarn River, a grade of 0.38m/km, but in the Pingrup valley, between Lakes Grace and Chinocup, the gradient is only 0.037m/km. This contrasts with the gradient lower down the Avon of 0.58m/km between York and Beverley, and 1.9m/km through the Darling Range. Beard also quotes a gradient of 0.17m/km for the Coblinine River upstream of Lake Dumbleyung.

The broad valley floors are some 100 to 150 m below the level of the plateau surface, separated by comparatively steep valley sides (Figure 7).

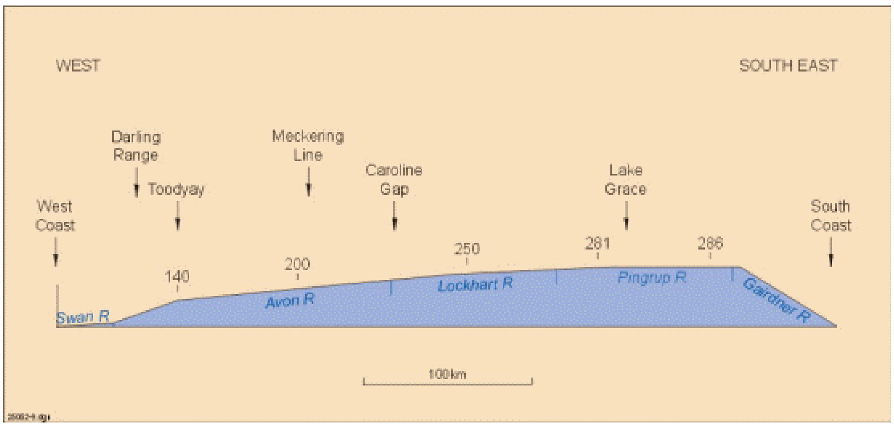

Figure 8: Physiographic profile along the Pingrup-Lockhart-Avon (after Beard 1999)

WHEATBELT VALLEY SOILS

General distribution of Soils

The Northern and Southern Zones of Ancient Drainage (Figure 9), as defined by the soil-landscape mapping conducted by the Western Australian Department of Agriculture, are characterised by a gently undulating plateau, wide divides, long gentle hillslopes, and broad valley floors 2 – 10 km wide which have been in-filled by alluvium and colluvium. Drainage is into chains of salt lakes on valley floors which are a remnant of an ancient drainage system that flows only in very wet years. The valley floors have very low gradients, often 1:500 or less. The western boundary of the zone is the Meckering Line (Mulcahy 1967, Moore 1998).

The Northern zone of Ancient Drainage is, in essence, characterised by yellow sandy earths on interfluves (Figure 10a) and red calcareous clays and loams in the valleys (Figure 10b). By contrast, the Southern zone of Ancient Drainage contains more Sandy Duplexes (Figure 10c).

The valley floors of the zones of ancient drainage have been simplified and divided into three broad landscape categories, idealised in Figure 11. The general distribution of each landscape category is discussed and described in terms of the Soil Groups of Western Australia (Schoknecht 1999) and the original soil series described in the several soil-landscape and soil mapping publications covering the Wheatbelt.

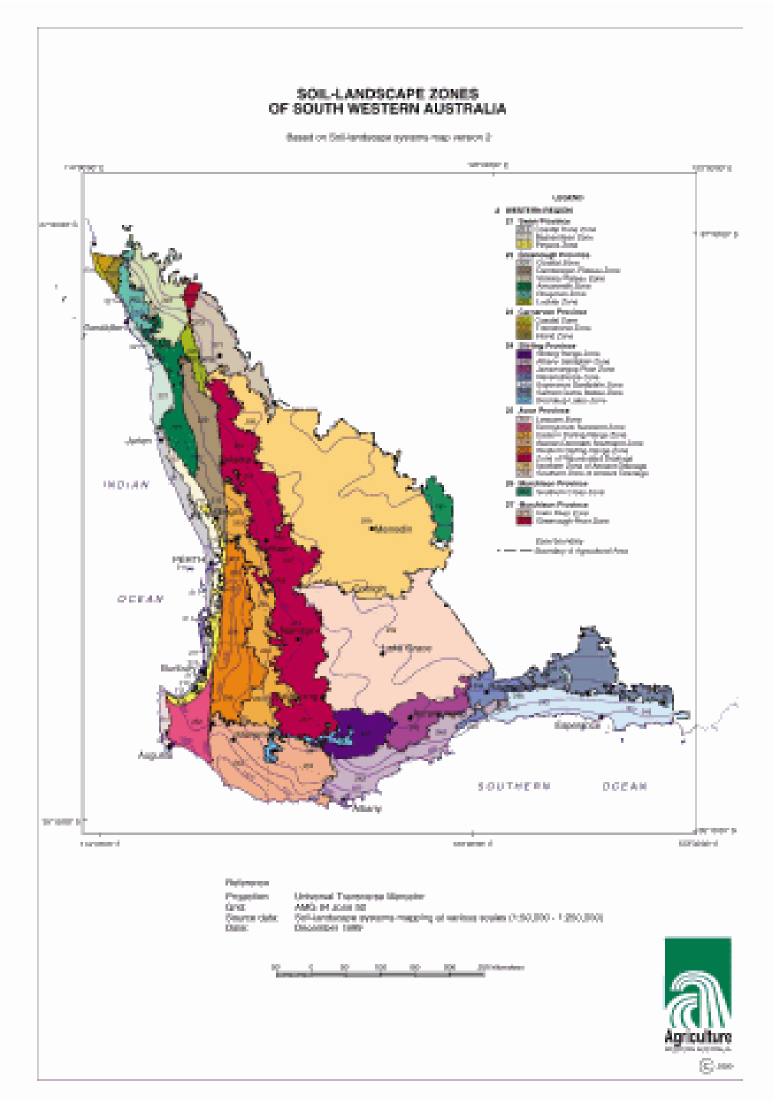

Figure 9: Soil-landscape zones of South Western Australia

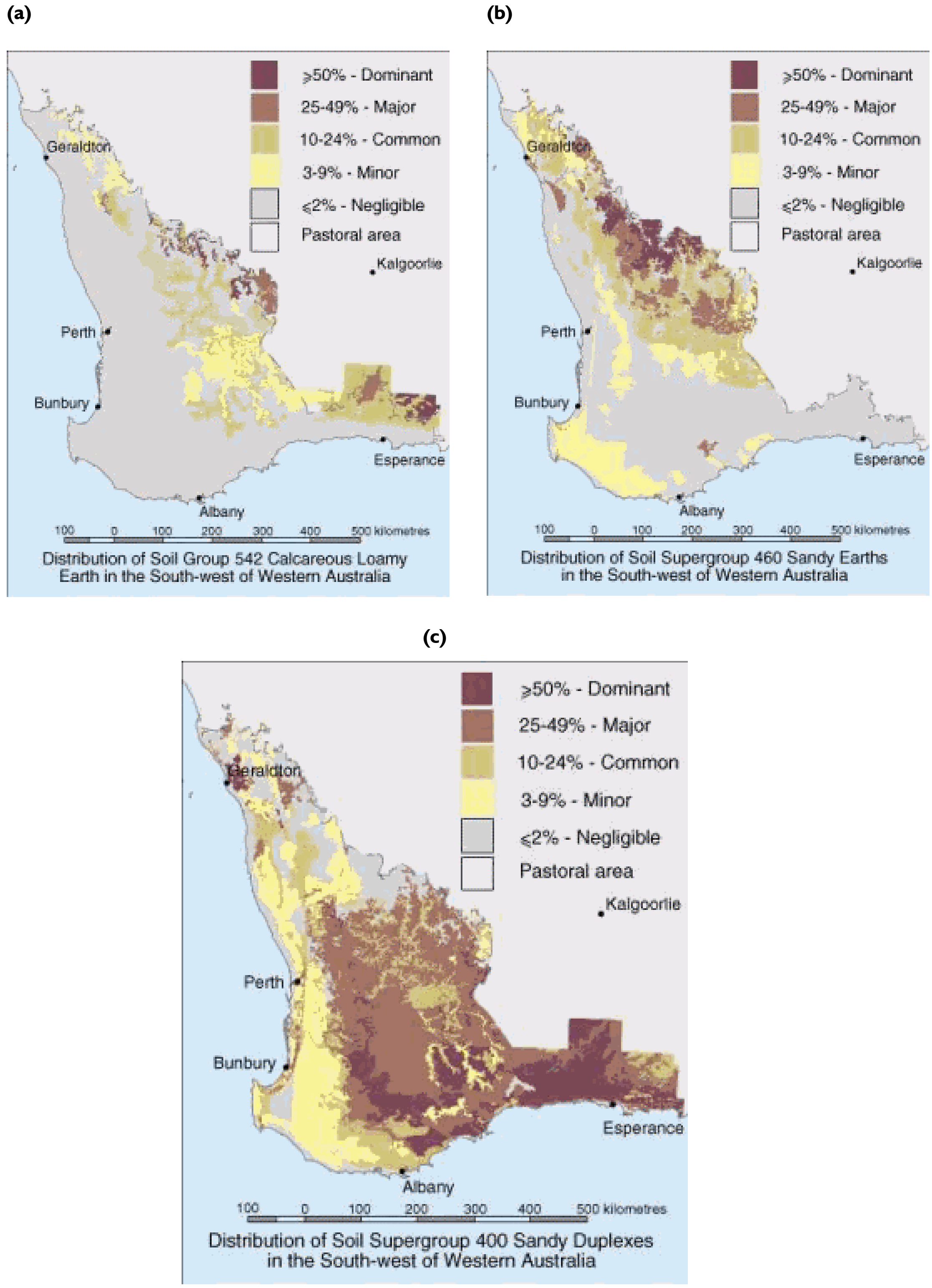

Figure 10: Distribution of selected soil groups

HYDRO-AEOLIAN LANDSCAPES

The hydro-aeolian "lakes and lunettes" landscape of the lower parts of the broad valleys has been formed by action of both wind and water. It is characterised by salt lakes and channels, source-bordering and relict lunettes and flat to undulating plains of clayey aeolian sediments sourced from salt lakes. This landscape corresponds to the Baandee and Nangeenan surfaces (Bettenay & Hingston 1961; Lantzke & Fulton 1993).

Salt lakes, playas and channels

The soils of the salt lakes are very variable, and have not been described in any detail across the zone. The lakes have shallow saline watertables, and may fill with surface water in wet years. The lakes are filled with fine and coarse alluvium, plus significant quantities of mobile salts. Sodium chloride is the dominant salt, but significant quantities of gypsum ($CaSO_4$) may also occur.

Soil groups: Salt lake soils, Saline wet soils

Vegetation: Usually bare of vegetation, with halophytic species such as samphire (*Halosarcia* spp.), saltbush (*Atriplex* spp.) and bluebush (*Maireana brevifolia*) on fringing areas.

Lunettes

Lunettes, composed of saline alluvium, occur on the lee side of the present or ancient salt lakes. The composition of the lunettes varies considerably, from gypsum, sand or even clays flocculated to sandy particle size by the saline conditions.

Soils: variable deposits of sands, clays and gypsum

Vegetation: Variable.

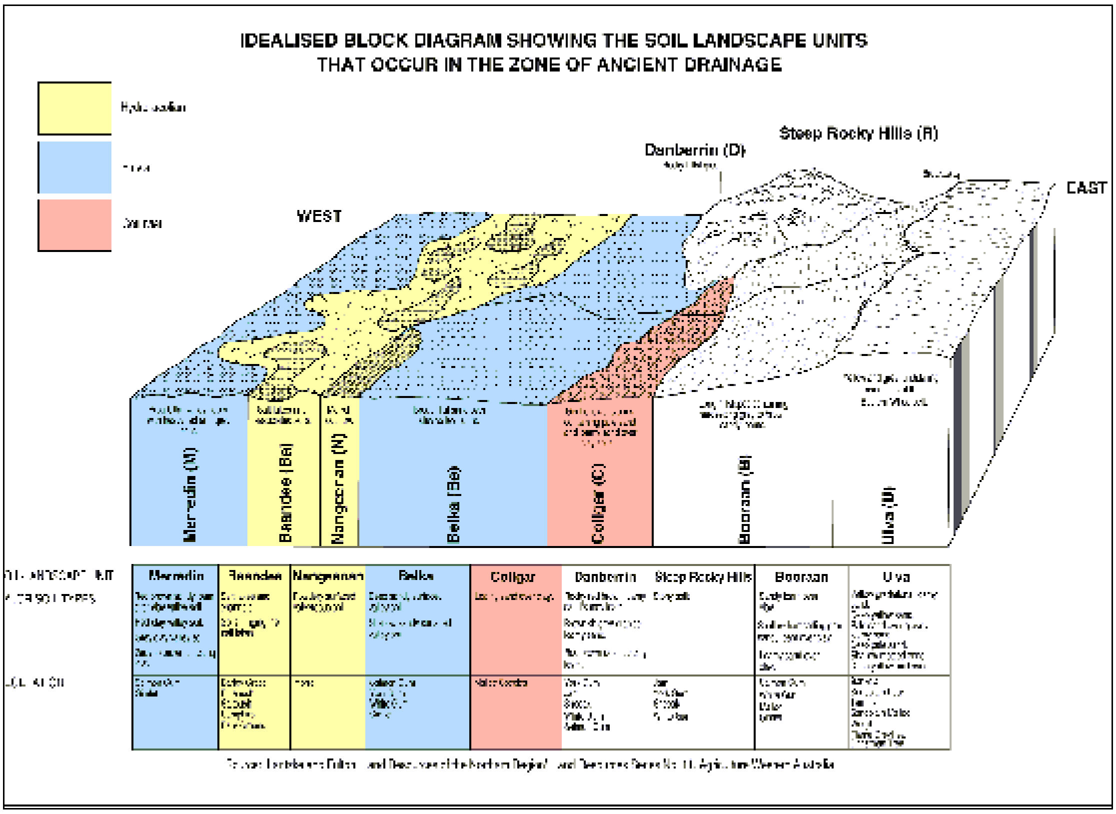

Figure 11: Block diagram showing soil-landscape units in wheatbelt valleys

Flat to gently undulating plains of clayey aeolian sediments derived from the lakes (parna)

These undulating plains are derived from fine textured and usually saline and calcareous dust derived from the salt lakes during dry periods (McArthur 1991). The soils are invariably brown to reddish brown, calcareous and often saline. Soils high in salt and carbonates at the surface have a fluffy or powdery surface condition. The soils are loamy to clayey at the surface, and clayey at depth.

Soils:

Brown calcareous loamy earths with powdery, calcareous surfaced soils, often saline (commonly referred to as Morrell soils).

Alkaline (and calcareous) red shallow loamy duplexes

Calcareous brown or reddish-brown non-cracking clays

Vegetation: Morrell (*Eucalyptus longicornis*) woodland dominant

FLUVIAL LANDSCAPES

The fluvial landscape of the broad, flat valleys of the Wheatbelt is derived from sediments moved and deposited by water.

Major valley floors in the eastern and northern areas are up to 3 km wide with gradients of 1:250 to 1:500. The soils in this area tend to be heavier textured, and more calcareous, with red or grey calcareous clays or loamy duplexes common. Crabholes (gilgais) sometimes occur.

The valley floors in the western and southern areas are of a similar width, but slightly steeper, with gradients of about 1:700 to 1:500. Natural drainage lines are ill defined, and old stream channels or sand seams mark the surface of this unit. Common soils are sandy duplexes, which are usually calcareous and alkaline at depth.

This landscape corresponds to the Merredin and Belka surfaces (Bettenay & Hingston 1961, Lantzke & Fulton 1993).

Soils in western and southern areas:

(Alkaline grey) shallow sandy duplexes

(Alkaline grey) deep sandy duplexes

Hard cracking clays

Saline wet soil

Soils in eastern and northern areas:

Calcareous loamy earths (neutral surface)

Alkaline red shallow loamy duplex

Hard cracking clay

Grey non-cracking clay

Red/brown non-cracking clay

Vegetation: Salmon gum (*Eucalyptus salmonphloia*) and gimlet (*Eucalyptus salubris*) woodland.

COLLUVIAL LANDSCAPES

A colluvial landscape of very gentle slopes fringing the broad alluvial plains occurs at heads of drainage lines and on the edge of the broad valleys. Sandy surfaced duplex "mallee soils" dominate. The depth of sand over the clays tending to increase with distance down the slope. This landscape corresponds to the Collgar surface (Bettenay and Hingston 1961, Lantzke 1993).

Soils:

Grey deep sandy duplex

Grey shallow sandy duplex

SOIL-LANDSCAPE EVOLUTION

Soil distribution in wheatbelt valleys broadly associates with the timing and degree of landscape rejuvenation and the inheritance of up slope materials (Jutson 1934; Mulcahy & Hingston 1961; NRAG mapping 2001). However, the notion that ancient lateritic soils are stripped away and replaced by non-lateritic soils derived from fresher crystalline basement may stem from the idea that laterite formed extensively on a pre-existing peneplain during hot humid interludes in the Tertiary (Jutson 1934; Butt & Zeegers 1992). Some subscribe to the idea that ferruginous horizons at and near regolith surfaces once developed in response to import of iron from underlying hydromorphic pallid zones by capillarity (Campbell 1917) or to seasonal rises in water tables (Prescott & Pendleton 1952). A modern refinement of these concepts is the relief inversion model of Pain & Ollier (1995). The essence is that lateritic mesas result from the prolonged erosion of resistant lateritic deposits that originally formed on valley flanks and its arguments hinging on the arrangement of lateritic components on mesa edges.

The problem is that lateritic bauxites and duricrusts are particularly common in incised systems towards the coast and laterites can develop on considerable slopes (Playford 1954; Mulcahy 1960). Furthermore existing valleys retain Tertiary sediments which clashes with the idea that laterites now on uplands formed in valleys during the Tertiary.

Verboom & Galloway (2000) and Pate *et al.* (2001) also point out that the relief inversion model cannot explain the remarkable regularity of the mesa edge effect, the circularity of mesa embayments and the development of a second front of duricrust formation in the fine pisolitic colluvium that is sometimes encountered.

The latter authors have offered a counter explanation that differs from conventional theories of old peneplain erosion or relief inversion while still in accordance with the concept that edge hardening and kaolinite preservation causes the landscape to evolve as surrounding superficial materials erode (Eggleton & Taylor 1998) and regolith materials dissolve (McFarlane 1995). This new hypothesis rests on evidence that laterites and related oligotrophic soils may have been partly derived biotically from soluble iron-rich complexes generated following secretion of low molecular weight organic acids by phosphate-absorbing specialised proteoid (cluster) roots of proteaceous plants. Gibbsitisation and induration may simply be a geochemical outcome of aggressive leaching following organic anion release by proteoid roots and concomitant mobilisation of ferric iron, and microbial precipitation where soil solutions bearing citrate-metal complexes would be attracted and concentrated. In addition, duricrust formation and bauxitisation may serve a biological function in countering headward incision and surface stripping of habitat soil and in certain situations combating Al toxicity.

We briefly examine competing claims of the above theories by considering a portion of the Avon valley system in the geophysics section below.

SOIL DEVELOPMENT

It is all very well talking about the broad geographical differences in wheatbelt valley soils or individual pedogenetic processes. Understanding how a multitude of poorly understood contemporaneous processes express themselves in soil morphology and distribution is another matter. It requires considerable field experience and intellectual sifting and disseminating that field wisdom then requires sweeping categorical statements and specific case studies as examples. To this end, we group soil forming mechanisms into three broad classes, and deal with each of these, in turn, below, before going on to newly acquired geophysical data and the pedogenetic insights and soil information that these data provide. The following statements and interpretations may of course have some fault, but at least the concepts can be tested or at least compared with the field experience of others.

Epimorphism

The genesis of a valley soil starts with epimorphism, that is the adjustment of near surface geological materials on the uplands to the superficial environment. Work on feldspars by Anand *et al.* (1985) and biotites by Gilkes & Suddiprakarn (1979) casts doubt on macro climate being the direct determinant of epimorphic change. These works show that controls over new mineral formation vary dramatically over extremely short distances, which might imply a role for micro-organisms and in this regard the emphasis may have to shift to bioclimate (see above). Indeed, understanding of rhizosphere chemistry is improving rapidly, to the extent that the importance of macro climate *per se* as a determinant of the World's soil zones is now openly questioned.

MOVEMENT OF SOIL MATERIALS

The detachment, transport, sorting and deposition of soil materials by the action of water and wind are also profoundly affected by the biosphere. Fauna are largely responsible for turning over soil materials and making them susceptible to rain and wind while vegetation has a mainly protective role. The combined action on the biomantle of rainsplash, slopewash and sediment rafting are collectively referred to as rainwash. The erosive power of a rainfall event is principally determined by kinetic energy delivered to the bare soil surface after it has become saturated and this obviously depends on vegetation cover at the time. Management practices which remove vegetation have of course contributed to accelerated erosion and caused deteriorating hydrologic conditions around the world. However, under more natural conditions, the protection afforded by vegetation, particularly in seasonally dry climates, varies from year to year and is periodically destroyed by fire.

The materials that leave the hill slopes are not representative of the soil as a whole. Soluble materials tend to enter groundwater systems while solid particles detached by rainsplash are entrained by sheet and rill flow and sorted down slope, often in quite complex ways with debris transported and organised into litter dams playing a major part (Paton *et al*.1995, Chapter 4). The big picture however is one in which solutes and suspended silts and clays move faster and further down slope than the rolling and saltating sands. The general model of soil formation on hillslopes thus involves epimorphism of bed rock to saprolite and saprolite to soil with the principal motivators of the latter being biochemical change in the rhizosphere, mining by fauna, mainly in the topsoil, clay eluviation (Chittlebrough 1992) and differential downslope movement of bioturbated topsoil by rain wash.

One outcome is a mobile, light textured, biomantle often expressing as a texture contrast soil. Reduced mobility on lower slopes, where the slope starts to wane, results in congestion and hence thickening of the mobile sandy layer. As deposition progresses, underlying soil starts to fall outside the influence of bioturbation, and clays coming in from upslope start to accumulate. In other words, there comes a point at which topsoil differentiation over-rides faunal mixing. Further down slope, old differentiation becomes buried by new differentiation and at this point we start to get a historical record of soil formation reflecting changes in surface hydrology, climate and vegetation (Figure 12). One thus encounters more and more colluvial/pedogenetic history in vertical sections as one progresses down waning cross valley slopes towards the oldest buried river channels.

The situation in flat-floored valleys is somewhat different. Their catchments are large enough to sustain planating flows that are tempered by the very low down valley gradients mentioned above. Indeed, the erosive power of contemporaneous flows may be so subtle and ineffective that their impact is more pedogenetic than topographic. In these situations, clay winnowing and sand saltation generates 'rivers' of deep sandy duplexes with shallow sandy and loamy duplexes on the 'interfluves'.

HYDRO-AEOLIAN ACTIVITY

Hydro-aeolian activity is important whenever there is a plentiful supply of loose fine material and little vegetation. The latter condition was particularly evident during last episode of aridity (25000 – 13000 B.P.) (Bowler 1976) and is caused by rising and lateral flows of salt in lower parts of the landscape. The obvious expression of hydro-aeolian activity is the playa lake systems and associated depressions.

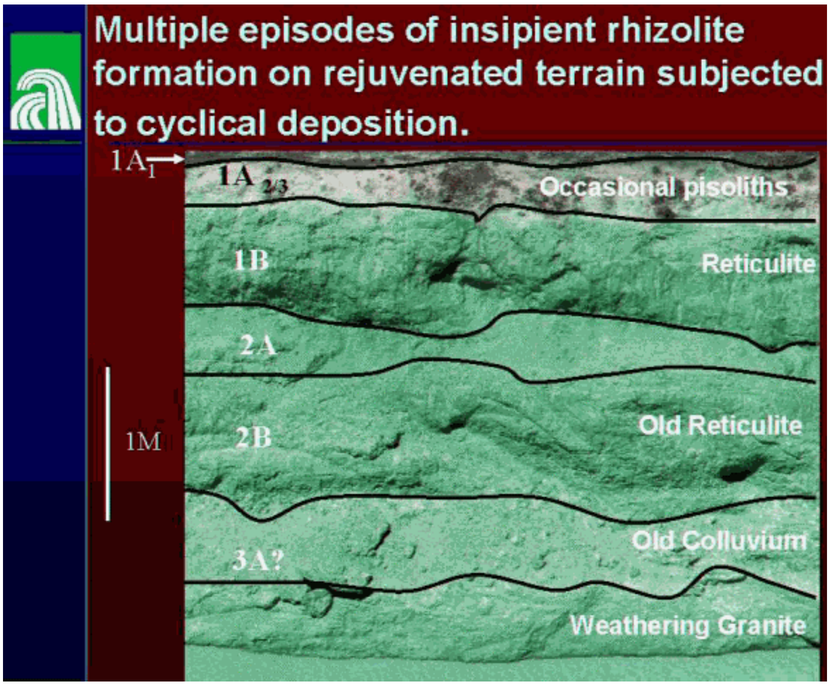

Figure 12: This profile, on a lower mid slope west of the town of Narrogin, records at least two cycles of soil formation in which iron and clay differentiation has been active with the most recent (uppermost) episode apparently contemporaneous. The sandy A-horizons appear intact and remain so 50 m down slope in two other exposures. They have similar sequences: red crystalline ferric oxides, principally hematite, can be seen along the margins of vertical root channels in horizon 1B, with their older, yellow hydrated counterparts in the buried 2B. Root channel precipitation does not extend into the sandy horizons below both B-horizons and so the contemporary process is limited to uppermost B-horizon. Contemporary precipitation tends to be confirmed by the observation of haematitic precipitates surrounding living Banksia roots.

Here, ground level winds entrained sand size particles (2.0 - 0.05 mm in diameter) which moved by rolling and saltation while finer particles moved in suspension after dislodgment by the saltating particles. The particles may themselves be quartz grains or aggregates of minerals detached from mud curls and salt/mud efflorescences. Lunettes on the south eastern side of playas betray old north westerly winds. Lunette composition depends on provenance which in turn depends on hydrologic regimes. In other words, playas producing loose quartz sand generate sandy lunettes while those producing pelleted clayey aggregates generate clayey lunettes. Finer particles blow and saltate out greater distances forming discontinuous sheets of parna (locally referred to as morrel soils) which may over print hillslope soils.

NEW GEOPHYSICAL PERSPECTIVES

At the end of the day, the above described pedogenetic processes have to be consistent with newly acquired data. Airborne geophysical mapping provides such data, offering pedologists a new and penetrating perspective of soil landscapes. Below we first briefly describe these techniques and then use them to examine the relationship between radiometric and elevation data and the occurrence of salts and soils in parts of the Avon, Lake Toolibin and Elashgin catchments.

DIGITAL ELEVATION MODELS (DEM)

A DEM is a digital representation of the earths' surface where, with the use of a computer, the elevation of a location on the ground (measured in Eastings and Northings, say) can easily be obtained by a simple click of a mouse button.

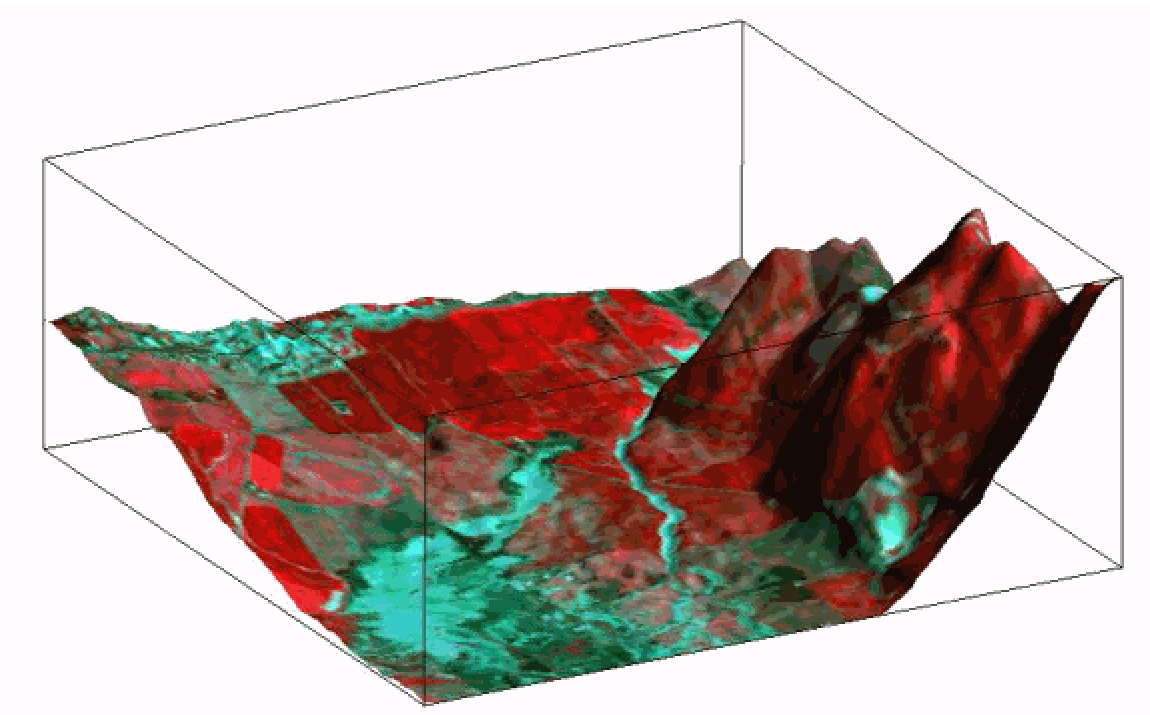

Figure 13: An example of landscape visualisation using Landsat TM

Figure 13 is an example of landscape visualisation using Landsat TM satellite information (visible and infrared) and digital elevation models. In this perspective view, the town of Merredin appears in the top left of the image as a blue/green colour. Paddocks with vigorous crop and pasture cover appear red, and saline areas in the lower left appear as hews of blue and green. Terrain has been exaggerated. From the figure we observe that the salinity is largely confined to the lower parts of the landscape.

DEMs may be combined with data such as Landsat TM, or aerial photography in digital form, to provide a powerful visualisation tool, an example of which is given in Figure 13. Further, computer algorithms and simulations may be applied to DEMs to produce estimates of land surface characteristics such as slope, curvature and sizes of catchment areas, which may be used in environmental assessments and risk analysis.

For the Western Australian Wheatbelt, the advent of relatively high-resolution DEMs (elevations accurate to 1-2 m sampled on a 10 m easting/northing grid) from the Land Monitor project, allows a great variety of variables to be accurately derived, e.g. Caccetta 1999b.

Here we outline an approach for extracting broad-valleys from DEMs:

A sample of digital elevation data generated by the Landmonitor project was used in the experiments. The data has an accuracy of approximately 1-2 m in elevation and is specified on a 10 m grid. The data were processed in a manner consistent with that currently being used for the salinity mapping component of the Land Monitor Project:

1. the data are smoothed to remove small discontinuities (Caccetta 1999a),
2. the data are resampled to 25 m, reducing the data volume and making the data consistent with landsat TM,
3. spurious depressions are filled to ensure surface flow (Caccetta 1999b),
4. an estimate of *upslope* area and *flowslope* is calculated, from which `flat' *flowpaths* are extracted,
5. the height above the nearest flat *flowpath* is derived,
6. all pixels having an elevation within 2 m of the nearest flat *flowpath* are classed as valley floors,
7. all remaining pixels are given a landform label based on stratifying the upslope area image into hilltops, ridges and upper slopes, upper valleys and lower valleys.

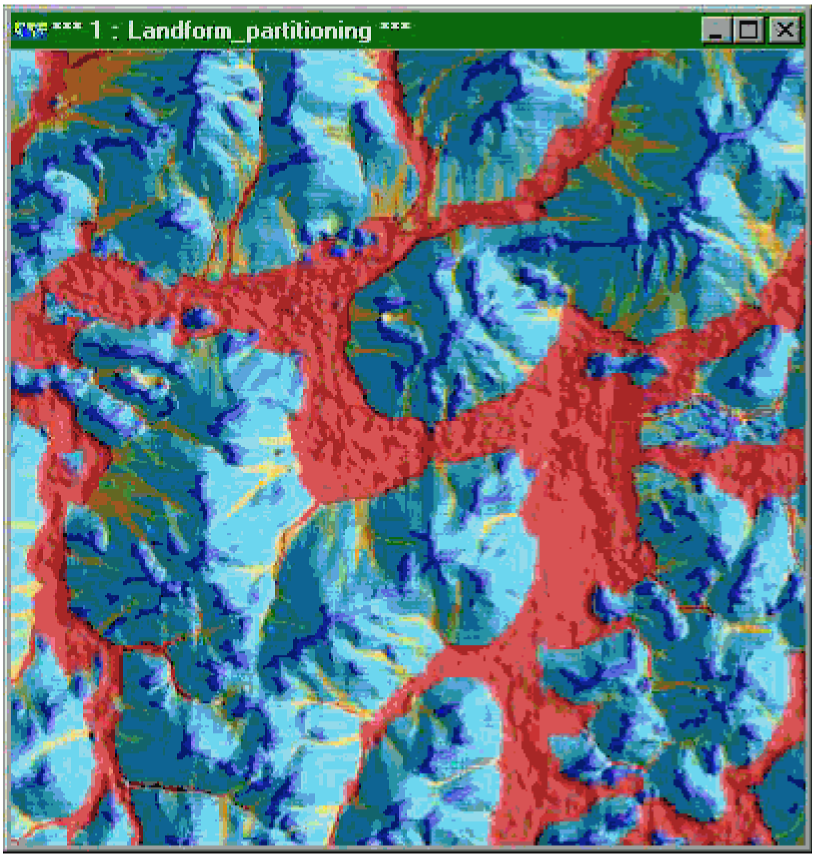

Figure 14: An example of a landform classification derived from a DEM. Hilltops are depicted as dark blue, ridges and upper slopes as cyan, upper valleys as green, lower valleys as orange and broad valleys as red. For visual purposes, the classification has been enhanced with sun shading

This process results in a landform classification having the following classes: hilltops, ridges and upper slopes, upper valleys, lower valleys, and broad valleys. An example of this partitioning is given in Figures 14 and 15. Here we note that the procedure may be applied with relative ease to extract broad valleys over large areas, and thus provides an accurate and consistent way of mapping valleys over large areas.

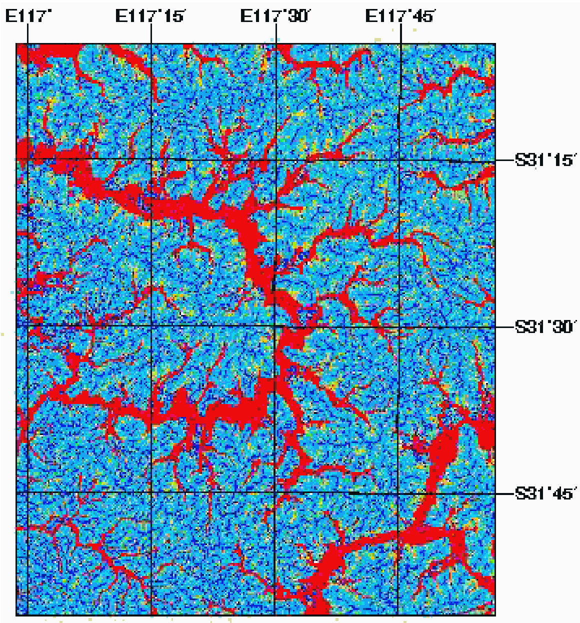

Figure 15: The landform partitioning may be applied over large areas to extract classes of interest. As in Figure 14, hilltops are depicted as dark blue, ridges and upper slopes as cyan, upper valleys as green, lower valleys as orange and broad valleys as red.

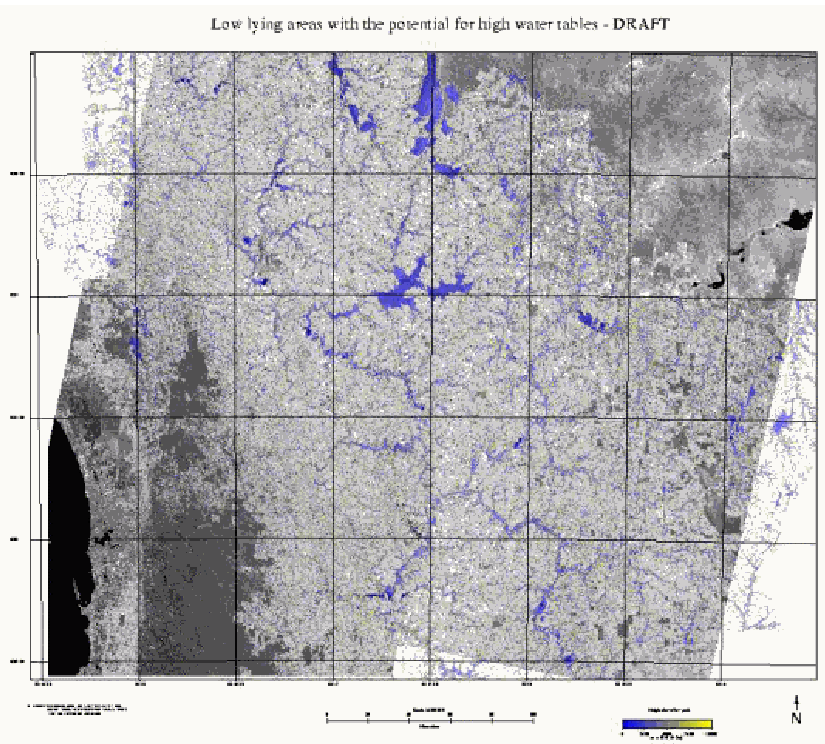

Figure 16: This figure depicts low lying areas with the potential for high water tables. In this figure areas with the potential for high water tables are coloured blue to yellow, as indicated by the colour bar in the figure. A grey-scale Landsat TM mosaic, along with a 1:100 000 map-sheet grid, is provided for reference. The region is approximately 400 x 400km, with the Swan River visible in the lower left

From the point of view of mapping and monitoring salinity, the landform partitioning provides strong prior evidence of which parts of the terrain are likely to be/become saline (the red and orange areas) and which parts are not (the blue areas) (Caccetta 1997; Hojsgaard *et al.* 1997). Observations from satellite imagery provide further information on the status of the land.

An extension to the above idea is to predict which of the valleys will experience high, saline water tables in the future, which serves as a tool for land management and planning. This concept forms the basis for Land Monitor salinity prediction, a preliminary result which is shown in Figure 16. Here we note that the DEM provides some morphological information (in practice about a dozen morphological variables are derived (Caccetta 1999b), and geological information is required to place the morphological information in context. The third piece of information required is expert knowledge, provided by Department of Agriculture hydrologists in this instance, presented as samples of areas that are likely to (and not to) go saline in the future. This information is used to form a relationship between terrain and potential salinity for each significant geological region (e.g. Evans *et al.* 1995; Evans & Caccetta 2000).

Giving Traditional Soil Mapping a New Perspective

As an example we return to the prediction by Pain & Ollier (1995) that rejuvenation exposes laterites that originally formed on valley flank, and the prediction by Verboom & Galloway (2000) that lateritisation requires leaching conditions and particular types of vegetation. These competing ideas might be tested by examining the association between rejuvenation and soil distribution in valleys on the margins of the Yilgarn block. We consider the tectonically affected areas near Brookton. Figure 17 gives the soil systems mapping of this area an exaggerated topographic context.

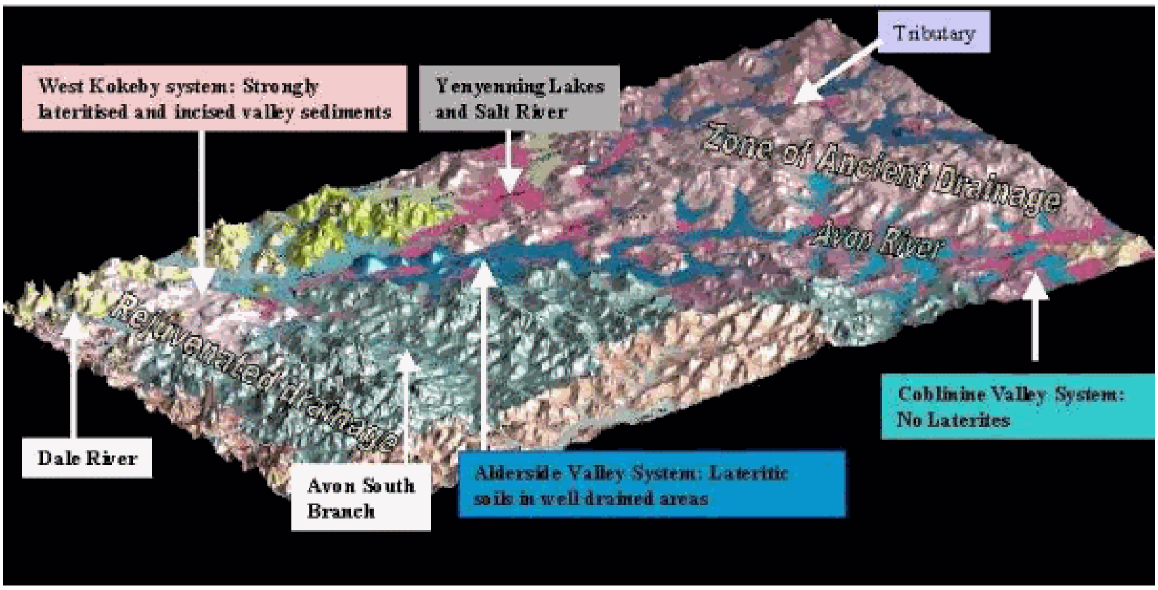

Figure 17: Soils mapping in the Avon River Valley, draped over DEM, viewed from the south

Salinity in the valleys is mapped by red and is used as a surrogate for down-channel gradient and drainage. For instance, the more sluggish the drainage, the more widespread the red. The usual scenario is increasing salinity down stream as seen in the tributary river running into the Avon from the east. In the case of the main Avon branch, salinity is much reduced in the rejuvenated lower reaches because of steeper down stream gradients.

Lantzke & Fulton's (1993) Kokeby system appears in the lower reaches as the light pink area towards the top left hand side of the image in the Zone of Rejuvenated Drainage. It is characterised by smooth rounded interfluves bearing proteaceous vegetation on lateritised palaeo-valley sediments. Of course, such occurrence favours both theories inasmuch as relief inversion is beginning where valley sediments become incised, drained and leached. However, further east, where rejuvenation is less substantial, flat valley sediments of the dark blue Alderside System are weakly lateritised and vegetated by Proteaceae. Conversely, lateritisation and associated Proteaceae are absent upstream in the light blue Coblinine System where salinity and sluggish drainage become dominant. The above hypotheses can of course be tested elsewhere but we leave that for now.

AIRBORNE GAMMA-RAY SPECTROMETRY (RADIOMETRICS)

This geophysical technique relies on an airborne instrument containing a thallium doped sodium iodide crystal. It measures the intensity and energy of gamma radiation emitted from naturally occurring radioactive isotopes of potassium (K), Bismuth (Bi) and Thallium (Tl). Emission peaks from isotopes of the last two elements are used to estimate the abundance of uranium (U) thorium (Th). Ninety percent of these emitted gamma-rays come from the top 30 - 45 cm of soil if it is dry and less than this if it is wet. An aircraft flying a series of transects at say 100 m spacings can thus map the abundance of the above elements if the data that it collects is geo-referenced. Since each element has its own peculiar soil chemistry and mobility, levels of radioactivity from each element, or combination of elements betray soil properties and geomorphic processes.

COMBINING DEM AND RADIOMETRIC DATA

We have already seen that relationship between topography and soil depends, in large measure, on the way in which water interacts with and moves over the surface and percolates downward. These interactions determine the outcome of rainwash and sub-aerial dissolution which of course depends on substrate and biological influences such as bioturbation, vegetative cover, exudates and bio-precipitates. Furthermore, soil landscape processes also reflect past macro and bioclimates. Not surprisingly relationships between topography and soils are not always straight-forward but certain associations stand out when radiometric images are draped over the DEMs.

In the image of Lake Toolibin Catchment (Figure 18), interfluve crests to the right (east) of the line A-B are of similar elevation to those in the western area but the main trunk valleys are longer and down stream gradients are less. This expresses itself in the landforms and soils. The irregularly undulating rocky hills to the left of the line A-B speak of active erosion and geological controls on interfluve topography. This usually goes hand in hand with exposed bedrock and weakly developed soils and, indeed, the east's geochemical inheritance is evidenced by higher concentrations of potassium (reds and pinks).

The smoothly undulating terrain to the right of the line A-B (Figure18) speaks of an old deeply weathered regolith. The soil materials are generally residual or colluvial and the radio element concentrations bear little resemblance to the underlying granites and gneisses. The top of the regolith is very leaky, K feldspars in the sand fraction have weathered away and clay minerals in these highly leached oligotrophic soils contain little K. However, chelatable metals such as uranium (blue) and thorium (green) concentrate to considerable degree in the biogenic ferricretes and emissions are strong where these soil materials are not blanketed by radiometrically barren quartz sand. Thick sand mantles (> 30cm) shows up as black.

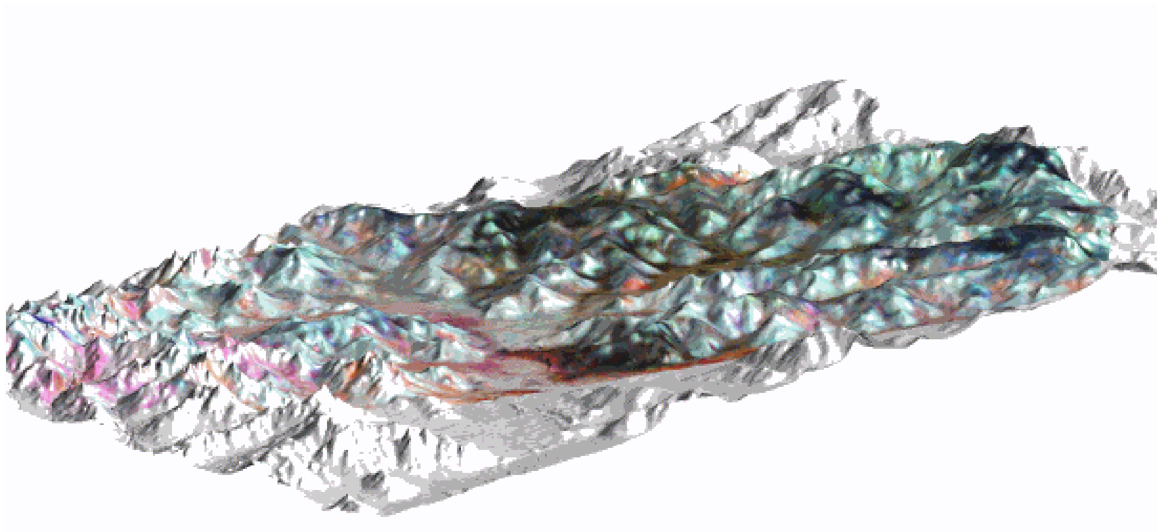

Figure 18: Ternary radiometric image of Lake Toolibin catchment draped over a sun-shaded DEM viewed from the south west

The alluvial materials that collect in the valleys reflect soil textures and provenance. The eastern valleys have inherited K deficient sands and clays from the uplands and these materials are differentiated according to fluvial and soil processes described above. Duplexes with deep sandy mantles (>30cm) develop in small braided channels and are only distinguishable on good contrast 1:25000 colour photos or high-resolution radiometrics. The duplex soils between these channels are comparable to over bank sediments as they receive slower flows and so accumulate more clay. This generates shallower sandy and loamy mantles on the 'interfluves'. More clayey K, Th and U material (pinkish-greenish white areas at lower ends of valleys) occur in zones where surface waters laden with clays accumulate. The ternary radiometric image shows very nicely how the valleys in the west have inherited K feldspars and K rich clays from shallow granitic soils on uplands vegetated by york gums, jams and casuarinas.

Evidence for contemporaneous formation of laterite is provided by radiometric images of smooth, upland south east of the Toolibin playa. The imagery in Figure 6 reveals a blanket of sand that blew out from the Toolibin playa in response to the wet season winds from the north-west. Such aeolian deposits are thought to have formed during the Pleistocene, but soil survey shows that the sands that deposited on the uplands have since differentiated to form various laterites, each vegetated by the characteristic Proteaceae community. To the north of this sand sheet one encounters a hydro-aeolian system with a clayey plume generated at about the same time. It is betrayed by the bright white radiometric signature (high in U, Th and K) and the perspective shows that it also encroaches upon upland. Soil profiles in these locations reveal lateritic profiles overprinted by calcareous red loamy parna.

HIGH RESOLUTION RADIOMETRICS

The radiometric data for Elashgin Catchment (Figure 19) reveals many of the processes referred to in the soil development section. As in the Toolibin area, Greeny-blue areas betray lateritic gravels (High U and Th and low K) and black areas show up the lateritic yellow sands. Granite outcrops (GO/C, pinkish white) emit strongly in the K window and moderately in the U and Th windows. Granitic soils are dominated by K emissions and show up as red.

The image unveils details of the downslope movement of the above soil materials to and along valley floors. Granitic colluvial fan deposits (GCF) differentiated as sandy duplexes, are evident on the waning southern slopes of the valley designated CGV. Associated finer materials (brighter whiter signature) can be seen beyond that, in the lowest positions towards the valleys northern margin. These soils are predominantly grey cracking and non-cracking clays. CVS locates another colluvial valley. In this case its sandy duplex soils have inherited K depleted materials from the adjacent lateritic uplands.

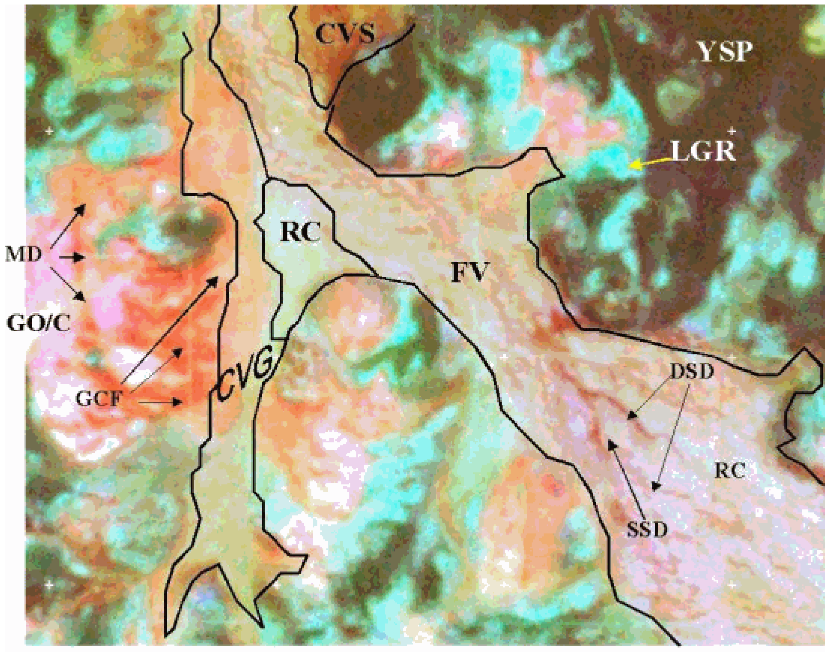

Figure 19: Ternary radiometric image of a portion of the Elashgin catchment. West is at the top, line spacings of 25 m and altitude approximately 20 m

Down valley migration also stands out in the flat trunk valley (FV) that has been planated by fluvial activity. In this, one encounters the 'rivers' of deep sandy duplexes (DSDs) referred to in the soil development section. An example of where shallow sandy and loamy duplexes occur on the 'interfluves' is designated by SSD. The bright white areas designated RC represent ferruginous loams and clays that tend to be removed from areas of active flow.

CONCLUSIONS

The landscape of the wheatbelt valleys is of considerable antiquity, originating at least some 50 million years ago, and modified since. The north flowing rivers in the zone of ancient drainage are broad and depositional in their upper reaches, which may reflect reversal of drainage direction. Valley floors are now flat, with very slight gradients.

Knowledge of the age of the palaeochannel sediments has emerged in the last decade with the recognition of two distinct phases of sedimentation, in the Eocene, and in the Late Miocene – Early Pliocene. Palaeochannel sediments, with their sandy basal layers, occupy only a small proportion of the broad valley floors. Elsewhere the valley sediments are composed mainly of sandy clay, overlying crystalline bedrock which is also weathered to form a sandy clay (saprolite).

Valley soils fall into three distinct landscape associations, a hydro-aeolian zone, a fluvial zone and a colluvial zone. The role of biochemical processes is being seen as increasingly important in soil formation. Combining digital elevation models with soil and radiometric data allows new insights into soil genesis and distribution.

The availability of digital elevation models allows an analysis of valley shape on a local scale, and a definition of valley forms using water accumulation models. This has the potential to greatly assist land and water management.

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