REGOLITH AND LANDSCAPE EVOLUTION OF FAR WESTERN NEW SOUTH WALES

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INTRODUCTION

The western New South Wales landscape contains many of the elements that have been important to the study of Australian landscapes including ancient, indurated and weathered landscape remnants, as well as young and dynamic, erosive and sedimentary landforms. It includes a complex landscape history closely related to the weathering, sedimentation and denudation histories of major Mesozoic and Cainozoic sedimentary basins and their hinterlands, as well as the impacts of climate change, eustacy, tectonics, and anthropogenic activities. All this has taken place across a vast array of bedrock types, including regolith-dominated areas extremely prospective for mineral exploration.

PHYSICAL SETTINGS

Location

This region contains the landscape within New South Wales, west of the Darling River and north of Menindee Lakes, including the city of Broken Hill and the towns of Menindee, Wilcannia, White Cliffs and Tibooburra (Figure 1). It is included on the Menindee, Manara, Broken Hill, Wilcannia, Cobham Lake, White Cliffs, Milparinka and Urisino 1:250,000 map sheets in the NATMAP series.

Geology

Palaeoproterozoic metasediments and meta-igneous rocks of the Willyama Supergroup (Stevens, 1986; Stevens *et al.*., 1988; Scheibner and Basden, 1998) are exposed as inliers of the Broken Hill Domain and Euriowie Domain and smaller inliers in the northern Barrier Range (e.g. Nardoo and Poolamacca Inliers) and Woowoolahra Range. These rocks are intruded by the Mesoproterozoic, Mundi Mundi Granites. Neoproterozoic to early Palaeozoic metasediments and minor metavolcanics from the Adelaidean sequence unconformably overlie or are in faulted contact with the Willyama Supergroup (Stevens, 1986; Scheibner and Basden, 1998). Palaeozoic metasediments, meta-igneous, and intrusive rocks of the Tasman Fold Belt occur in the eastern and northern part of the region (Mills, 1992; Scheibner and Basden, 1998).

Since the end of the Palaeozoic the region has hosted the development of major sedimentary basins. The northern part of the region is included within the Early Jurassic to Late Cretaceous, Eromanga Basin (Krieg *et al.*, 1995), while areas to the south may have been part of the Mesozoic, Berri Basin (Rogers, 1995). There is no major sedimentary record from the middle to late Cretaceous in the region, and this interval has been linked with a period of deep weathering and an erosional and sedimentary hiatus (Idnurm and Senior, 1978), or alternatively denudation and sedimentation outside of the region I areas such as the Ceduna Depocentre (O'Sullivan *et al*., 1998). Sedimentary basin development resumed in the Cainozoic with the formation of the Lake Eyre Basin in the north (Callen *et al.*, 1995) and the Murray Basin in the south (Brown and Stephenson, 1991; Rogers *et al.*, 1995). Mesozoic sediments in the area of the Bancannia Basin (Trough) have been traditionally considered as part of the Eromanga Basin, which may have been joined to the Berri Basin through this area. Cainozoic sediments in the Bancannia Basin have been previously described within the framework of the Lake Eyre Basin (Neef *et al.,* 1995; Gibson, this volume), but probably warrant a separate framework.

Geomorphology

The region mostly consists of undulating broad plains between 60 and 200 m above sea level, with a few areas of higher relief hills and mountains rising up to 473 m in the Barrier Ranges at Mt Robe.

The far west of NSW includes three main drainage basins (Figure 1):

1. The Murray-Darling Basin in the south and east of the region, including the Darling River, the Darling Anabranch and the Talyawalka Creek anabranch, and tributaries such as Pine Creek, Stephens Creek, Yancowinna Creek and Grassmere Creek. In the east of the region the Paroo Overflow and east flowing drainage such as Bunker Creek and Wannara Creek, occasionally flow into the Darling River (Thoms *et al.*, 2004).
2. The Lake Eyre Basin in the west of the region, with drainage mostly flowing towards the Lake Frome depocentre and mostly terminating in the Strzelecki Desert dunefields or on the Mundi Mundi Plain. Local stream systems such as Thackaringa Creek, Umberumberka Creek, Campbells Creek, Morphetts Creek, Teilta Creek, Floods Creek, Packsaddle Creek, Lake Wallace Creek, Yandama Creek, Stewarts Camp Creek and Fromes Creek are included in this basin.
3. The Bulloo – Bancannia Basin in the central north of the region, and including the Bulloo Overflow systems and the local depocentres of Bancannia Lake, Nuchea Lake, Cobham Lake, Salt Lake and Caryapundy Swamp, and locally fed by streams such as Gairdners Creek, Caloola

Creek, Noonthorangee Creek, Fowlers Creek, Yancannia Creek, Berawinnia Creek, and Twelve Mile Creek.

Most of the upland areas in the region broadly trend north-south. The Barrier Ranges in the far west of the region, are the area of greatest relief, and includes the Thackaringa Hills, Mt Darling Range, Mundi Mundi Range, Coonbaralba Range, Robe Range, Floods Range and Coko Range. The Woowoolahra Range forms a lower relief area to the west of the Barrier Ranges between Campbells Creek and Joulnie, rising to 204 m at Mt Woowoolahra. The southern Barrier Ranges includes the drainage divide between the Murray-Darling Basin and Lake Eyre Basin (an eastern continuation of the "Olary Spur", here called the Broken Hill - Olary Divide), and the northern Barrier Ranges includes the divide between the Bulloo – Bancannia Basin and Lake Eyre Basin (here named the Barrier – Grey Divide). Further north, the Grey Range includes Mt Arrowsmith (292 m), Mt Shannon (332 m), Mt Browne (332 m), and the Whittabrenah Ranges and Warratta Hills near Tibooburra, where the drainage divide between the Lake Eyre and Bulloo – Bancannia basins (Barrier – Grey Divide) continues to the north. Further east a group of ranges including the Scropes Range, Gap Range, Byngano Range, Turkaro Range, Koonenberry Mountain, Coturaundee Range and Yancannia Range form a broad north-south trending upland area that includes the drainage divide between the Bulloo – Bancannia Basin and the Murray – Darling Basin (here named the Koonenberry Divide). These regional drainage divides are shown in Figure 1.

Climate

The region presently experiences a semi-arid to arid climate. Daily temperatures in summer are frequently over 30^{o}C and in winter may fall as low as -6 ^{o}C. The annual rainfall is about 250 mm at Broken Hill, with a high degree of yearly variability and no predictable seasonal pattern. Further north in the region the rainfall, whilst still highly variable, is slightly summer-dominated and it is slightly more arid (rainfall is about 170 mm per year at Tibooburra). Annual evaporation typically exceeds rainfall in the entire region. Prevailing wind directions are variable, although tend to be mostly from the south and south-west.

Vegetation

There are some strong associations between vegetation communities and regolith-landform settings. Mulga (*Acacia aneura*) woodlands, mostly occur in areas with bedrock exposure or subcrop, and in the north of the region it also occurs in stands on aeolian sandplains. Belah (*Casuarina pauper*) and rosewood (*Alectryon oleifolius*) occur near the margins of bedrock-dominated terrains especially where the regolith is calcareous. Major drainage lines and associated depositional areas host eucalypt-dominated woodlands, including the widespread river red gum (*Eucalyptus camaldulensis*), with black box (*Eucalyptus largiflorens*) in alluvial swamps and floodplains, and coolabah (*Eucalyptus microtheca*) along drainage lines and alluvial swamps in low lying areas mostly in the north of the area. Bloodwood (*Eucalyptus terminalis*) dominated open woodlands mostly occurs on weathered granite in the Tibooburra Inlier. Mallee (including *Eucalyptus oleosa*, and *E.dumosa*) occur on aeolian regolith in the Murray Basin that tend to be dominated by sandy soils with regolith carbonate accumulations. Isolated stands of curly mallee (*E.* gillii) occur in areas with abundant regolith regolith carbonate accumulations at Corona, Fowlers Gap, Thackaringa, and near K-Tank and Avondale. White Cypress Pine (*Callitris columellaris*) woodlands mostly colonise sandy aeolian deposits such as dune ridges in the Strzelecki Desert, sandy alluvial deposits, and on well drained rocky and colluvial slopes near Mutawintji.

Chenopod shrublands are the most widespread vegetation community in the region (Eldridge, 1988). Shrubs of *Atriplex spp*. and *Maireana spp*. are dominant. Bladder saltbush (*Atriplex vesicaria*) is abundant in areas with clay-rich regolith such as within alluvial plains and low rises and highly weathered rises, and *Maireana pyramidata* and *Maireana sedifolia* mostly occur in areas with friable and calcareous regolith. Grasslands mostly dominated by mitchell grass (*Astrebla spp.*) occur in some of the lowland areas, such as southeast of Broken Hill and north of Fowlers Gap.

Since the late 1800s the vegetation cover has been greatly modified due to herbivore grazing, including rabbits, kangaroos, sheep and cattle, as well as tree clearance for fuel and construction (Kenny, 1936; Fanning, 1999; Lord, 1999).

REGOLITH-LANDFORMS

Weathered Bedrock

The area contains a vast array of bedrock lithologies and structures which have variable responses to weathering, and therefore different weathering morphologies and landscape expressions. Bedrock lithologies such as micaceous schists tend to be moderately to highly weathered in surface exposures, largely as a result of their abundance of relatively labile mineral and their extensive fracturing and sheared fabrics that facilitate the access and throughflow of weathering solutions. These bedrock types tend to have a more subdued landscape expression. More resistant bedrock lithologies such as quartz veins, quartzite and quartz-magnetite rock (such as at the Pinnacles, the Tors, and the Sentinel) have a more prominent landscape expression. In many settings adjacent to sulphide mineralisation, such as the Broken Hill Line of Lode, there is a deep zone of highly weathered bedrock largely resulting from enhanced weathering and the production of acidic solutions and more porous and permeable materials. Although highly weathered, the Broken Hill Line of Lode was originally associated with a prominent ridge mainly because of ferruginisation and silicification of the weathered

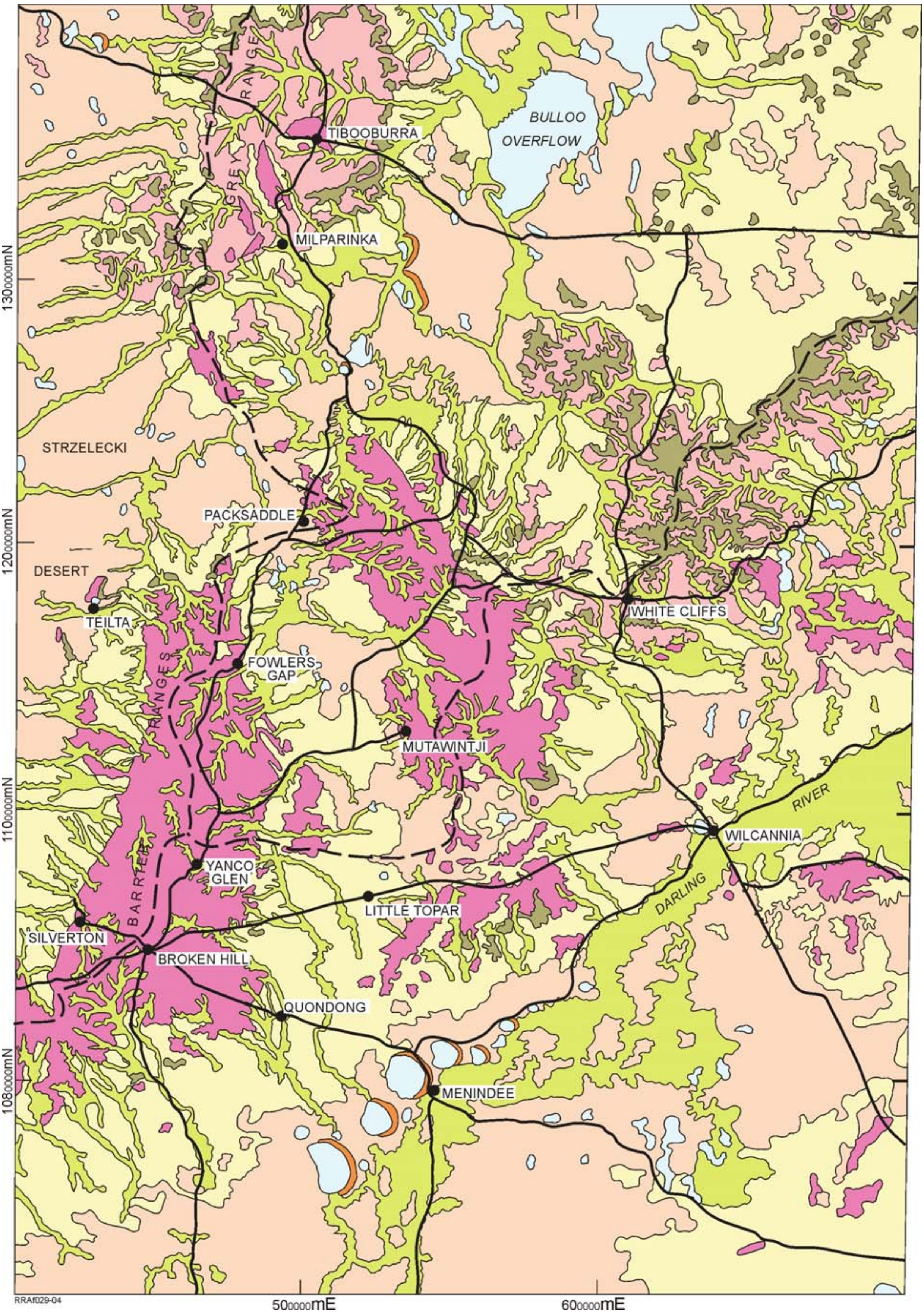
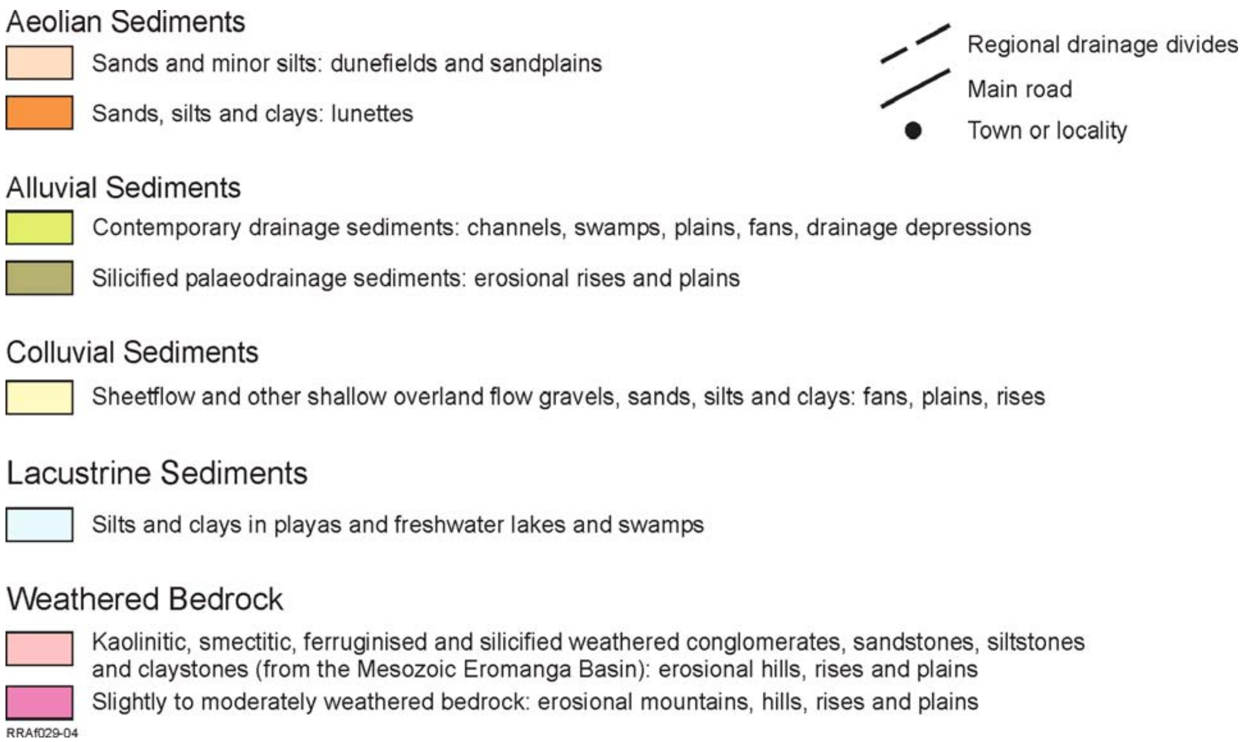


Figure 1. A regional regolith map of the study area also showing regional drainage divides.



bedrock (Plimer, 1984). Geological structures have also been important in controlling the extent of weathering and erosion, and the resulting landscape expression. Tectonic activity during landscape evolution has also had a major impact on the denudation and preservation of weathered materials, and their subsequent landscape expression. Range-fronts associated with the Mundi Mundi, Mulculca, Kantappa, Western Boundary, Koonenberry, Mt Browne and Warratta faults (Figure 2) show evidence of relatively young (at most post-Mesozoic) tectonism (Hill and Kohn, 1998; Gibson, 1997; Hill, 2000; Hill *et al.*, 2003; Anderson *et al.*, 2004).

Differences in landscape setting influence the formation and preservation of weathered bedrock. High relief areas, such as the central Barrier Ranges mostly consist of slightly weathered bedrock. Moderately to highly weathered bedrock is mostly exposed on the flanks of high relief areas, underlying plateaux capped by indurated regolith, or in low relief areas either with subdued landscape expression (such as low rises of erosional plains) or buried by transported regolith (such as underlying many valley systems).

Where weathered bedrock is well developed and preserved in the landscape it mostly consists of kaolinitic and siliceous saprolite with variable degrees and morphologies of ferruginous induration, including massive, slabby and mottled ferruginisations with well preserved saprolitic fabrics. In low lying areas such as south of Broken Hill and at the Mundi Mundi Plain west of Broken Hill, many weathering profiles underlying transported regolith may be over 50 m thick, although they are generally less than ten metres thick. The weathering front is typically highly irregular, largely relating to bedrock lithological and structural heterogeneities. In places (e.g. the southern margins of the Barrier Ranges), exposed, slightly weathered quartz veins may be adjacent to highly weathered bedrock extending for thickness up to 100 metres.

Alluvial Sediments

A wide range of alluvial sediments occur in the region, associated with both the modern and ancient drainage systems. They represent the preserved remnants of deposition associated with drainage systems from throughout the region's landscape history. The main alluvial sediment landform assemblages include channels, plains, swamps, outwash fans and drainage depressions, with more ancient sediments occupying erosional rises and erosional plains or are deeply buried (Figure 3).

The alluvial sediments contain a mixture of clays, silts, sands and gravels, with younger deposits mostly including a mixture of quartzose and lithic clasts, and more ancient deposits mostly dominated by quartzose clasts. Some of the younger sediments contain glass, wire and other anthropogenic derived materials indicating a significant post-settlement alluvial deposition (Fanning, 1999). Modern streams in the region are ephemeral. Larger streams mostly originate in bedrock-dominated uplands and flow towards flanking regolith-dominated terrains where they typically terminate as broad alluvial swamps, sheetflood fans, and lacustrine depressions. The dominant channel morphologies are

(a)

(b)

Figure 2. Range-fronts that have facilitated relatively recent tectonism in the region. a) Mundi Mundi range-front; b) Wahratta range-front.

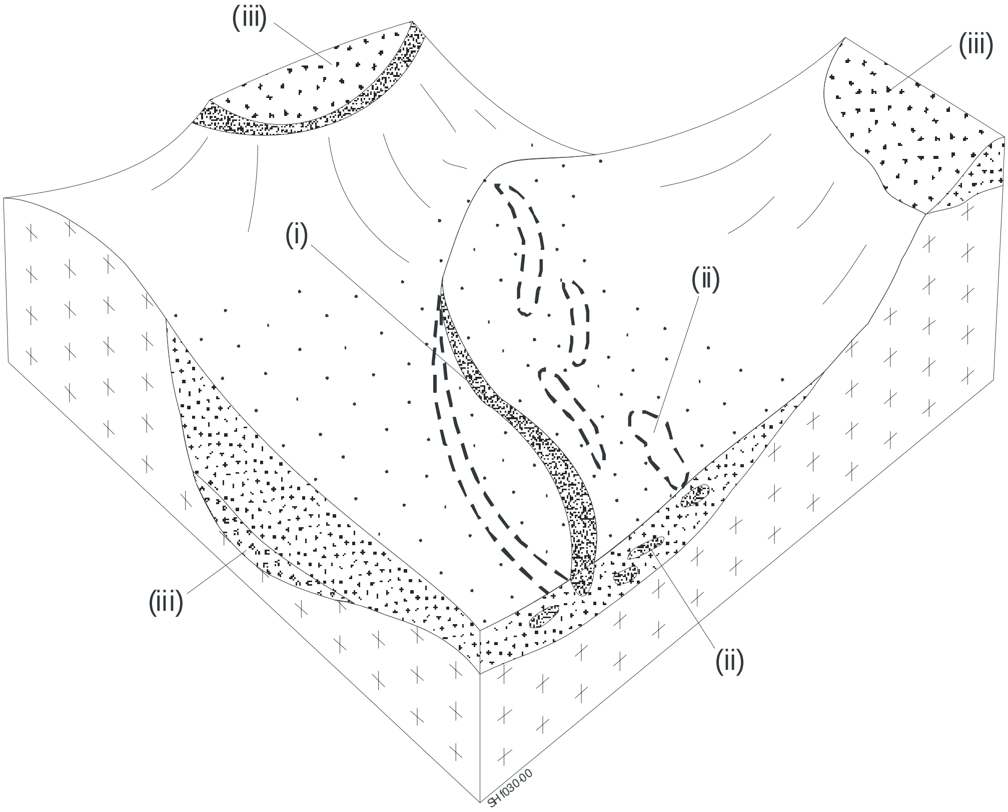


Figure 3. A diagrammatic representation of the landscape settings of major drainage systems from within the western NSW landscape. (i) Contemporary alluvial deposits associated with ephemeral stream systems; (ii) Alluvial sediments associated with contemporary valley systems that are either buried or slightly elevated so that they no longer carry stream flow; (iii) Channel deposits isolated from contemporary drainage systems through deep burial or elevation associated with inversion of relief (from Hill, 2000).

sandy meandering and braided channels. The middle reaches of many streams are entrenched within arroyos. Many of the ancient alluvial sediments are indurated by silica (e.g. silcretes) and occupy landscape settings isolated from modern drainage systems, either by burial or on erosional rises and erosional plains. These remnants were associated with sandy meandering to braided palaeovalley systems that were once linked to sedimentary basin depocentres such as in the Mesozoic Eromanga Basin and Berri Basin and the Cainozoic Murray Basin, Lake Eyre Basin and Bulloo-Bancannia Basin (Hill *et al.*, 1997; Hill, 2000).

Colluvial Sediments

Colluvial sediments in the region are derived from rockfalls, creep, slides, and debris flows, and sheetwash (Hill, 2000). Sheetwash sediments are extremely widespread across the region, typically extending from the upper slopes of rises down towards the axes of adjacent valley systems where they then typically contribute to alluvial sediments. Many of the features previously described as 'alluvial fans', largely consist of lobes of sheetwash deposits. They include a wide range of locally derived lithologies (clays, silts, sands and pebbles), and the composition of clasts is highly variable and depends on the nature of the local substrate. Vertical sections in many cases reveal alternating pebbly gravel and sand laminations, typically with pebbly gravel concentrated at the landsurface to form gravel surface lags. Most sheetwash deposits are contained within broad, low relief fans and lobes that mantle slopes over scales of 10s of metres to 10s of kilometres. Many have a prominent 'contour band' or 'tiger bush' surface pattern (Figure 4a), where surface lags conform to transverse bands of alternating sparsely vegetated pebbly bands and more densely vegetated bands of silty sand (Dunkerley and Brown, 1995; Wakelin-King, 1999).

Creep is a component of colluvial transport on most slopes in the region and is most apparent in surface exposures and cuttings into weathered pelitic schists, where steeply dipping cleavage planes are disrupted in accordance with the attitude of the landsurface. Rockfalls contribute to the development of talus deposits at the base of steep slopes, particularly adjacent to prominent exposures of slightly weathered bedrock, such as at the Pinnacles. Debris flows are rare in the region however they may have contributed to the development of many of the alluvial fans in the region, such as along the Mundi Mundi range-front, and debris flow deposits are also exposed in the railway cutting between Silverton and the Umberumberka Mine (Hill *et al.*, 1994; Hill, 2000).

(a)

(b)

Figure 4. a) 'Contour band' or 'tiger stripe' landsurface patterns defined by 'bands' of mitchell grass (*Astrebla spp.*) colonising fine red-brown sands and silts, alternating with sparsely vegetated pebble 'bands', Avondale Station, approximately 30 km southeast of Broken Hill; b) red-brown quartzose sands within linear dunes near Teilta on the southeastern margins of the Strzelecki Desert, northwest of Broken Hill.

Many hills and rises capped with silicified regolith are flanked by colluvial slopes with pebbly surface lags. These lags serve as an 'armour' to erosion of the underlying regolith and in many cases account for the development of 'ring-like' rises, surrounding and detached from a silica-capped hill or rise, such as at Peak Hill at Wonnaminta (Gibson and Wilford, 1996; Hill, 2000; Gibson, 2001), and Mt Wood northeast of Tibooburra.

Aeolian Sediments

Landforms dominated by aeolian sediments include longitudinal linear dunes, sand plains and lunettes. Aeolian sediments are widespread throughout the region and are at least a component of most surficial regolith materials. Linear dune fields consisting of low, WSW-ENE trending, elongate sand ridges are best developed in low lying areas such as the Strzelecki Desert in the northwest of the region (Figure 4b) (Wasson, 1983a; 1983b; Stevens, 1991), parts of the Mallee region in the south (Bowler and Magee, 1978), and across much of the Bulloo – Bancannia Basin. Sandplains and irregular, hummocky dunes are also typically developed on the margins of alluvial channel systems and lacustrine depressions. Aeolian materials are mostly composed of fine sand and silt size particles, typically consisting of clay mineral pellets, quartz and minor iron oxides, and calcium carbonate (Chartres, 1982; 1983; Hallsworth *et al.*, 1982). In most cases these sediments have a red to red-brown colour although these colours are lighter, tending towards white, nearer alluvial channels and lacustrine depressions. Lunettes (smooth, cresentic, transverse dunes) are well developed on the eastern shores of most ephemeral lakes in the region, such as the Menindee Lakes (Bowler and Magee, 1978; Chen, 1992), where they are typically extensively eroded with rills and gullies.

Lacustrine Sediments

Lacustrine basins are common in low-lying parts of the region, typically associated with the terminal or overflow systems of alluvial drainage. Water in most basins is ephemeral, although some of the Menindee Lakes system, Stephens Creek Reservoir and Umberumberka Reservoir are filled artificially for use as water storage basins. Lacustrine sediments are clays and silts, including clay minerals, quartz, salts (including halite and gypsum), and organic material.

Indurated Regolith

A range of regolith induration styles with different chemical compositions occur in the region within both *in situ* and transported regolith host materials. The main types include:

- Regolith Carbonate Accumulations (RCAs) respectively include 'calcrete', 'dolocrete', and 'magnecrete' for $CaCO_3$, (Ca, Mg)CO_3, and $MgCO_3$ end-members. They are extensively developed across the landscape in the south of the region and include nodular, hardpan, powder, rhizomorphic and tabular morphologies (Figure 5) (Hill *et al.*, 1998; McQueen *et al.*, 2000). Magnesite occurrences are restricted to sites with weathered serpentinites, such as at Thackaringa, Little Broken Hill and Macs Tank. In the north they mostly include hardpan morphologies restricted to bedrock-regolith and other hydromorphic interfaces, with powder and nodular facies in the swales of dunefields.
- Ferruginous regolith, also referred to as 'ferricrete' or 'laterite', is widespread in the region, but is mostly exposed on the margins of upland areas. This includes ferruginised saprolite, typically expressed as ferruginous surface lags derived from the exposure of mottled saprolite, as well as various morphological facies developed in transported regolith, such as ferruginised sediment, nodular ferruginisations consisting of detrital ferruginous clasts within a ferruginous matrix, and slabby ferruginisations (Figure 6) (Hill *et al.*, 1996; Hill, 2000; Hill *et al.*, 2003).
- Silica indurated regolith, has a wide range of morphological facies, such as silicified sediments with columnar, nodular, and tabular morphologies (Watts, 1978; Hill, 2000; Hill *et al.*, 2003), silicified hardpans (red-brown hardpans, Chartres, 1985), and silicified saprolite (Figure 7) (Hill *et al.*, 1996; 1997; Hill, 2000). The most abundant silica cement consists of micro-crystalline quartz, although opaline and chalcedonic varieties also occur in the region (Wopfner, 1978; Alexandre *et al.* 2004), and also include anatase and hematite in the cement.
- Gypseous regolith is a component of many regolith types, either as disseminated crystals or polycrystalline aggregates, particularly in low-lying landscape settings. Extensive zones of polycrystalline gypsum aggregates are well-developed in saprolite on erosional rises near Broken Hill at Balaclava (Figure 8a) and south of Cockburn and may relate to the weathering of sulphides (Shirtliff, 1998; Hill, 2000), while other polycrystalline gypsums aggregates are widely developed in low-lying sedimentary plains, such as near Teilta, Mulculca, and Yanco Glen and are probably mostly related to hydromorphic ponding of surface and groundwaters (Hill *et al.*, 2003). Gypsum is a major component of the regolith derived from the weathering of Mesozoic silts and clays, where it co-exists with kaolinitic and hematitic regolith. In this case the gypsum is probably derived from the weathering of pyrite originally within these marine sediments.
- Manganiferous regolith is limited in distribution in the region and mainly occurs adjacent to weathered Mn-rich bedrock lithologies including spessartine garnets and rhodonite (e.g. Line of Lode gossan (Figure 8b), and Melbourne Rockwell Mine). Morphologies include laminated, coralline, and botryoidal types (Hill, 2000), and desert varnish surface coatings (Dragovich, 1988).

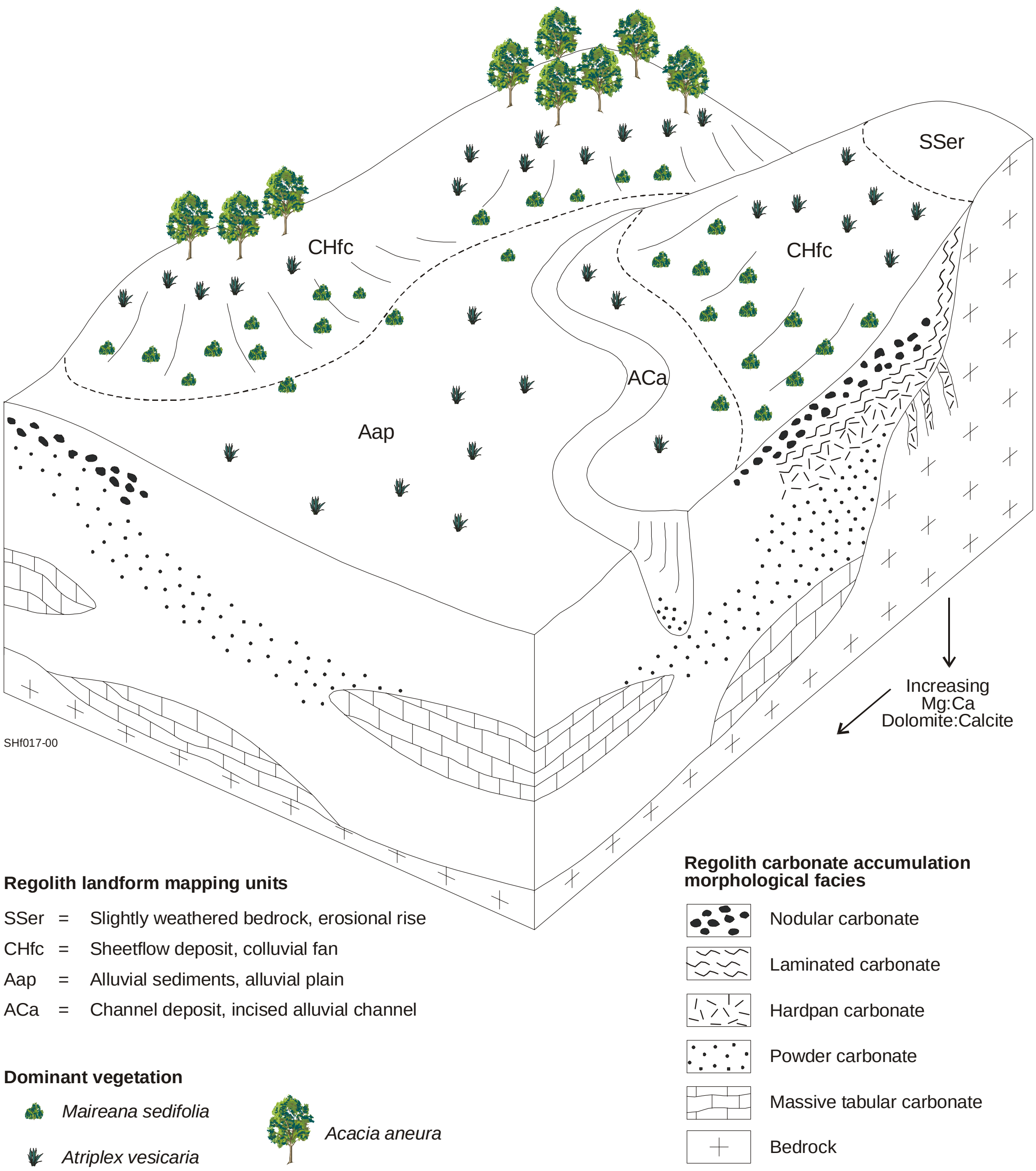


Figure 5. Landscape settings of major regolith carbonate accumulation (RCA) morphological facies, based on the upper Umberumberka Creek catchment, Limestone Station (from Hill, 2000).

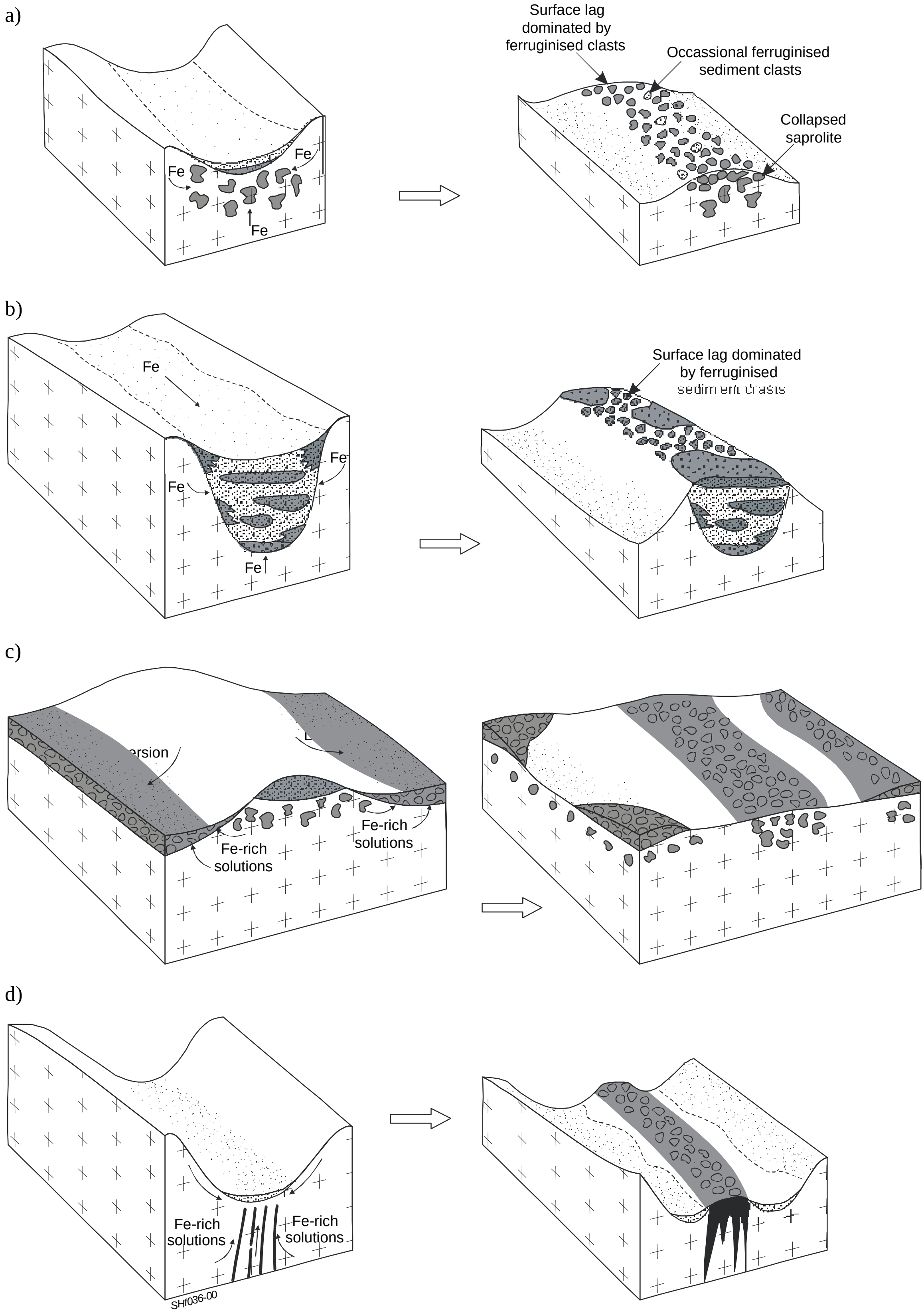


Figure 6. Landscape settings for the development and contemporary surface expression of ferruginised regolith in western NSW (from Hill, 2000).

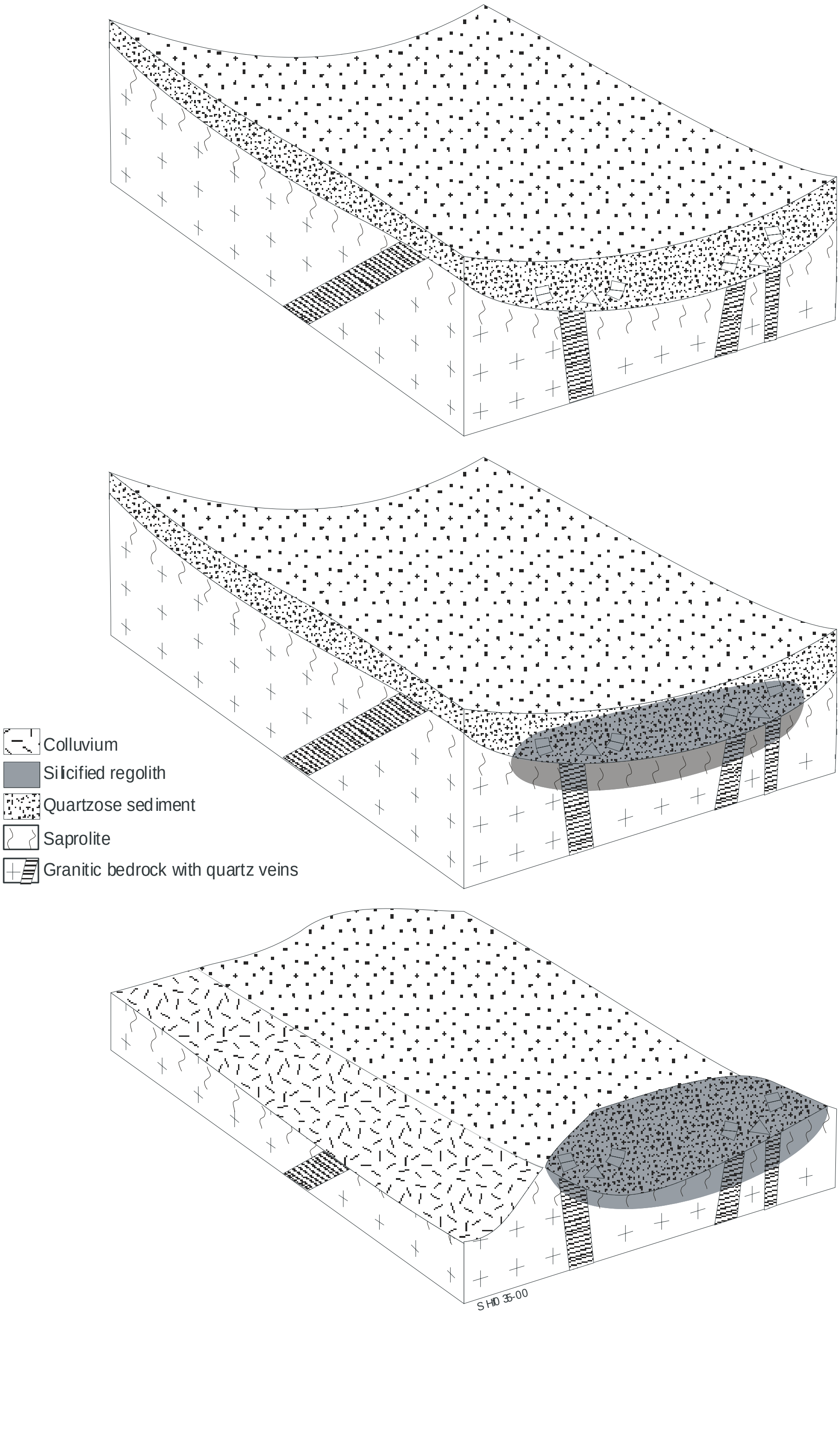


Figure 7. Landscape settings for the development and the contemporary surface expression of silicified sediments and underlying silicified saprolite near Boulder Tank, McDougalls Well station, northwest of Broken Hill (from Hill, 2000).

(a)

(b)

Figure 8. a) Polycrystalline gypseous regolith at Balaclava station, south of Broken Hill; b) Manganese oxide and hydroxide indurated regolith along the Broken Hill Line of Lode, near the Junction Mine.

REGOLITH AND LANDSCAPE EVOLUTION

Many of the controls on regolith and landscape evolution are shown diagrammatically in Figure 9.

Weathering and Induration

The bedrock of the region has continued to weather during its exposure to surface and near-surface processes and conditions.

Pre-Mesozoic weathering profiles and palaeosurfaces have been partly exhumed from beneath Mesozoic sediments along the margins of the Eromanga Basin, such as at Wonnaminta (Gibson, this volume) and Tibooburra (Hill *et al.*, this volume). The quartzose with very minor lithic composition of many of the basal Mesozoic sediments, support the interpretation that the landscape was highly weathered immediately prior to much of the Mesozoic sedimentation. Remnants of weathering profiles associated with the late Cretaceous 'Mornay Profile' (Idnurm and Senior, 1978) are also likely to occur in the region, and is also supported by the deposition of quartz and kaolin-rich sediments (e.g. Eyre Formation and other equivalent sediments) derived from the erosion of a highly weathered landscape that had developed by Palaeogene times.

Previous interpretations of weathering and induration during the Cainozoic mostly highlight a mid-Cainozoic event (e.g. Wopfner and Twidale, 1967; Idnurm and Senior, 1978; Callen, 1983; Alley, 1998). For example, this has been associated with the development of the Late Eocene to Oligocene 'Cordillo Silcrete' and 'Cordillo Surface' in parts of the Lake Eyre Basin (Wopfner and Twidale, 1967; Alley, 1998), and probably also the Late Oligocene Canaway Profile in western Queensland (Idnurm and Senior, 1978). A silicified Eocene flora assemblage within partially topographically inverted palaeovalley sediments at Fowlers Gap (Greenwood *et al.,* 1997; Hill and Roach, 2003) are consistent with Eocene silicification in at least this part of the landscape in western NSW. It is not clear whether this period represents a time of enhanced weathering and induration in the region, or instead an extensively developed and preserved weathering feature (Hill, 2000). Landscape settings hosting sediment accumulation and induration (such as the 'Cordillo Silcrete' overprinting the Eyre Formation) have a relatively high preservation potential, and therefore have a tendency towards its emphasis within the landscape and stratigraphic record. The Lake Eyre Basin sediments also provide some of the few stratigraphic benchmarks used for determining the age of induration, and as such they are an incomplete stratigraphic context for induration, especially considering that in some circumstances the presence of silicification has been used to establish a stratigraphic context. Later Cainozoic weathering and induration events have also been interpreted, such as Plio-Pleistocene silicification associated with gypsum development (e.g. Wopfner, 1978).

Previous interpretations of the weathering and induration histories derived from the stratigraphy of the sedimentary fill in the Lake Eyre Basin propose an episodic framework. This includes weathering and induration immediately preceding the Cainozoic, and again in the mid-Cainozoic and the later Cainozoic (e.g. Firman, 1994; Alley, 1998). Further work is needed to better constrain weathering and induration development in the Lake Eyre Basin in western NSW. Recent interpretations, suggest that the evolution of weathered and indurated materials has been more complex than many of the previous region models suggest, with weathering and many types of induration having taken place throughout much of the history of landscape development (Hill, 2000). By comparison, interpretations of the landscape history of western NSW derived from the study of the sedimentary fill of the Murray Basin have been poorly developed, and instead this basin has been mostly considered in the context of landscape evolution in the Eastern Highlands. The sedimentary fill of the Bancannia Basin has received no attention in this respect.

The development of regolith carbonate accumulations (RCAs) has occurred in the later part of landscape evolution in the region. This is reflected by its development within relatively young regolith host materials (e.g. aeolian, alluvial and colluvial materials closely related to the contemporary landscape) and its overprinting (such as hardpan coatings) of ancient regolith materials. This development is partly related to reduced leaching associated with increasing aridity during the Cainozoic, but also the increased input of marine derived dust and dissolved components in rainfall, particularly in the south of the region (Hill, 2000; L. Hill, 2004; Dart *et al*., 2004).

Denudation

The sedimentary record of the sedimentary basins in western NSW has been very broadly used to develop denudation histories of the region. One of the major limitations here is the poorly constrained Mesozoic and Cainozoic stratigraphy of the region, plus the very general mapping and irregularity of the three-dimensional information needed to determine sediment volumes and palaeogeographic context. The sedimentary fill of the Murray Basin in the south of the region has been mostly considered in relation to the evolution and denudation of the Eastern Highlands. Recent studies in the Broken Hill region however suggest that the erosion of the Barrier Ranges have also been supplying sediment into this basin since at least the early Cainozoic (possible Renmark Group and younger equivalents) (Hill *et al.,* 2003). Landscape evolution and more specifically denudation histories of the region in relation to the sedimentary fill of the Lake Eyre Basin propose episodic models of denudation and landscape evolution. For example, the Palaeogene sediments of the Eyre Formation are widely interpreted to be derived from the stripping of highly weathered regolith in hinterland areas, such as the Barrier Ranges, with subsequent development of a low relief, indurated landsurface in the mid-Cainozoic (e.g. Wopfner *et al.*, 1974; Alley, 1998).

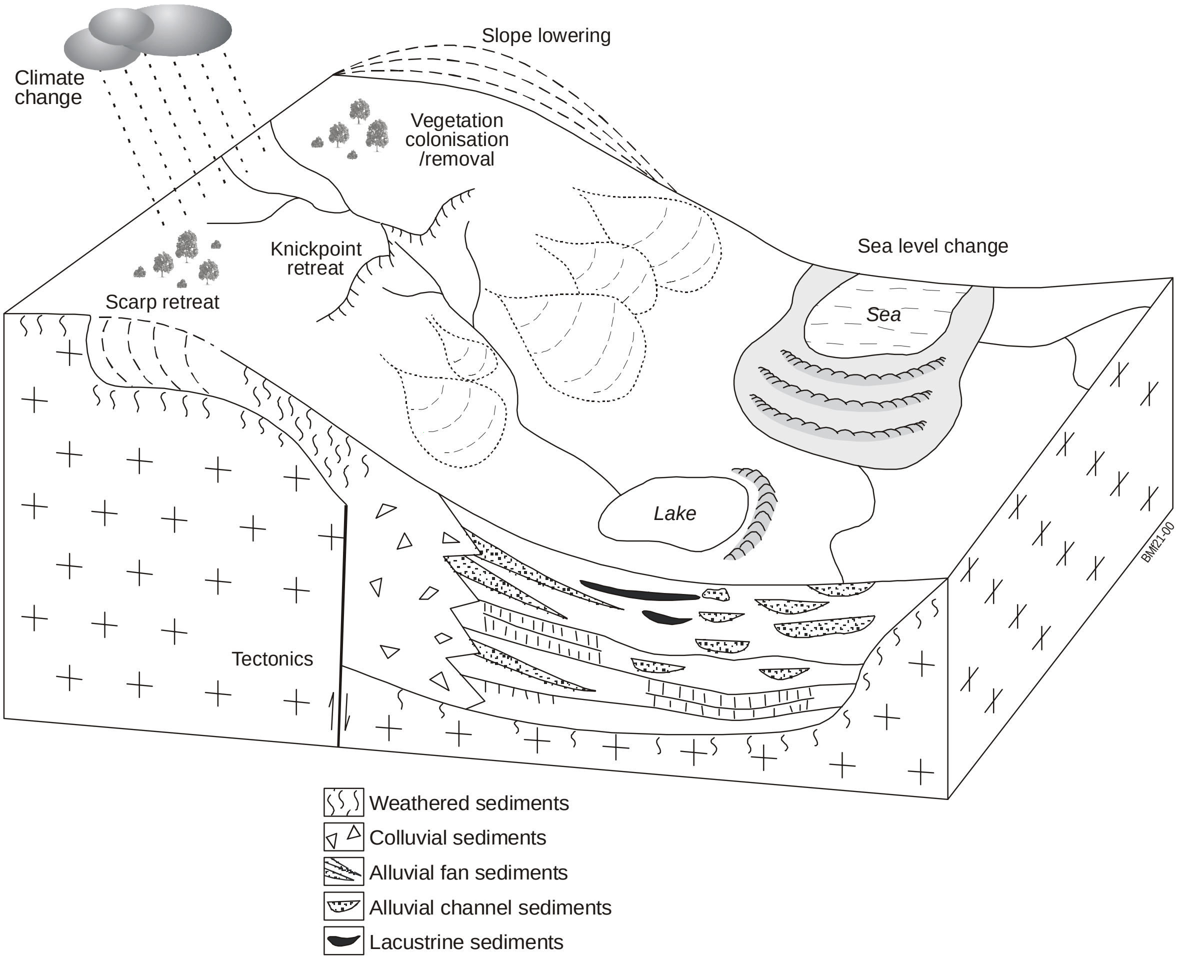


Figure 9: Diagrammatic representation of some of the major controls on regolith and landscape evolution in western NSW.

An Apatite Fission Track Thermochronology (AFTT) study of the Mundi Mundi range-front by Hill and Kohn (1999) shows a period of Late Palaeozoic cooling perhaps due to denudational cooling associated with the Lachlan Orogeny. Mesozoic and Cainozoic denudation has also been proposed from AFTT studies, with the Darling Lineament appearing to be an important structure controlling the denudation (e.g. O'Sullivan *et al.*, 1998), although further sampling across the region is needed to better constrain this in time and space.

Tectonism

Tectonic processes have had a major expression in the landscapes and the development of regolith materials in western NSW (Gibson, 1996; this volume; Hill and Kohn, 1999; Hill, 2000; Hill *et al.*, 2003; Hill, this volume; Hill *et al.*, this volume). Many of the range-fronts in the region reflect ongoing tectonic processes, such as along the Mundi Mundi, Kantappa, Mulculca, Warratta and many other faults near Tibooburra. Much of this tectonic activity is related to the evolution of Mesozoic and Cainozoic sedimentary basins in the region, and reflects the evolution of continental-scale stress regimes within this region. The younger (mid to late Cainozoic) tectonism appears to be associated with reverse-faulting, which is consistent with the contemporary compressive stress field. It is likely that older (early Cainozoic and Mesozoic) tectonism was associated with extensional tectonism associated with sedimentary basin evolution. Importantly, the expression of tectonism within the regional long-term landscape evolution model is in contrast to many previous suggestions of the region's, and much of Australia's, long-term, intraplate, tectonic stability.

Climate

Morphoclimatic models for regolith and landscape development have been widely cited for the region. The development of ferruginous regolith materials has been widely attributed to wetter and more 'tropical' conditions in the past (Stephens, 1971; Langford-Smith and Watts, 1978). Ferruginous materials however appear to have developed at many times throughout the landscape evolution of the region, and may still be forming in the present conditions (Hill *et al.*, 1996; Hill, 2000). Silcretes have been both attributed to either wetter conditions than present (e.g. Alley, 1998) as well as to aridity, such as presently experienced in the region (e.g. Langford-Smith and Watts, 1978), or to both climatic extremes (e.g. Wopfner, 1978). The development of silcretes is poorly understood, largely because of the lack of recognised modern analogues for their development. Hill (2000) suggests that there development could be due to acidic weathering conditions associated with organic acids and pyrite weathering within Mesozoic and Cainozoic sedimentary sequences. This would lead to de-alumification of the regolith, leading to local redistribution of silica-rich byproducts. Regolith Carbonate Accumulations (RCAs) have been previously interpreted as an indicator of climatic aridity and as such reduced leaching of their chemical constituents. Although this is partly true, it is an over-simplification and overlooks the importance of variations in the supply of chemical constituents for their initial development. Simply attributing RCA development to climatic aridity does not account for the present distribution of RCAs in this region, which are less widespread towards the more arid northwest of the region. Chemical inputs associated with atmospheric contributions (rain and dust) have instead been suggested as an important control on the widespread development of RCAs in the winter-rainfall dominated areas to the south that are more proximal to marine Ca and Mg sources that the summer-dominated rainfall areas to the north that are more distal to marine Ca and Mg sources (Hill *et al.*, 1998; McQueen *et al.*, 1999; Hill, 2000; L .Hill, 2004).

Quaternary climate changes have been an important control on the development of regolith and landforms, particularly associated with the surficial alluvial, colluvial, aeolian and lacustrine sediments (Chen, 1992; Bowler and Magee, 1978; Wasson, 1979). Wasson's (1979) morphoclimatic model for alluvial fan development along the Mundi Mundi range-front however is in need of further refinement. Recent tectonism along the range-front and its potential contribution to fan development (Hill and Kohn, 1998; Hill, 2000) was not recognised by Wasson. The sedimentary architecture of the fans also consists of irregular and laterally discontinuous fan lobes (Hill, 2000), rather than the broad "layered" alluvial fan architecture proposed by Wasson (1979). This not only has implications for better understanding the evolution and dispersion processes with the fans, but also in developing models for pre-1800s erosion and sedimentation within the landscape.

Eustacy

For an inland area like western NSW it may seem surprising that eustacy could be considered in models of landscape evolution, however because the development of this landscape extends at least beyond the Mesozoic, implications for marine transgressions with the Eromanga Basin and the Murray Basin may be significant. Many of the landscape changes outlined by Gibson (this volume) in the Wonnaminta area, and similarly by Hill *et al.* (this volume) in the Tibooburra region, are driven by the initial deposition and later stripping of marine sediments since the Mesozoic. The influence of the mid-Cainozoic marine transgression into the Murray Basin is not clear for this region. A similar transgression did not occur within the continental Lake Eyre Basin.

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