SOUTHERN BARRIER RANGES – NORTHERN MURRAY BASIN, NEW SOUTH WALES

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INTRODUCTION

The southern margin of the Barrier Ranges and the adjacent northern Murray Basin is one of the most prospective landscapes for mineral explorers in the world. The region hosts the Broken Line of Lode Ag–Pb–Zn deposit within a landscape with a complex history reflecting the evolution of cratonic, intraplate uplands and adjacent sedimentary basins.

PHYSICAL SETTING

Location

The southern Barrier Ranges – northern Murray Basin region includes the landscape drained by mostly southerly flowing streams from the Barrier Ranges into the area of the Murray Basin (Figure 1). The city of Broken Hill is included on the northern boundary of this area, approximately 1200 km west of Sydney.

Geology

The oldest rocks in the area are Palaeoproterozoic complexly deformed and metamorphosed meta-sedimentary and meta-igneous rocks of the Willyama Supergroup (Stevens, 1980; 1986; Willis *et al.,* 1983; Page and Lang, 1990; Stevens and Corbett, 1993). In this area these rocks form part of the southern Broken Hill Domain and the southeastern Euriowie Domain. Major schist zones cut across the Willyama Supergroup rocks and have facilitated tectonic activity since the Proterozoic. Neoproterozoic meta-sedimentary and minor meta-igneous rocks of the Adelaide geosyncline (Adelaidean sequence) unconformably overlie and flank the Willyama sequence, and rocks of the Tasman Fold Belt occur to the south and east.

Mesozoic, marine and minor fluvial sediments of the Berri Basin (Rogers, 1995) occur to the south and are overlain by Cenozoic alluvial, aeolian, lacustrine and marine sediments of the Murray Basin (Brown and Stephenson, 1991), which laps onto the southern margins of the Broken Hill and Euriowie Domains.

Geomorphology

The dominant physiographic features of the area are the Barrier Ranges and adjacent plains. The Barrier Ranges can be subdivided into smaller range systems including the Mount Darling Range and the Mulga Springs area, and lower hills in the Farmcote–Redan area in the southeast, and the Balaclava–Oakdale area west of Pine Creek in the southwest. Range systems such as in the Mulga Springs and Farmcote–Redan areas have prominent sub-linear range-fronts, with relief more gradually decreasing behind the range-fronts to the south-east. The plains flanking the ranges to the south include the Langwell Plain, which gently slopes towards the Darling River system near the Menindee Lakes.

Stephens Creek, Pine Creek, and Yalcowinna Creek are the main drainage systems. These ephemeral creeks all rise in the Barrier Ranges, where they mostly occupy broad, low-lying alluvial tracts separating small ranges of hills. Depending on the variable level of discharge they either terminate in extensive swampy depressions flanking the ranges or continue into the Darling River system at the Menindee Lakes. A major southwest–northeast trending regional drainage divide marks the northern and western extents of these drainage systems and as such the boundary for the area covered by this case study. Drainage rearrangement, mainly in the form of stream diversion, has resulted in some migration of this drainage divide to the north during later parts of the landscape evolution (Hill, 2000a; Barratt and Hill, 2003).

Climate

The Broken Hill region presently experiences an 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, with a high degree of yearly variability and no predictable seasonal pattern. Annual evaporation typically exceeds rainfall. Prevailing wind directions are variable, although tend to be mostly from the south and southwest.

Vegetation

The dominant vegetation communities in the area include:

- mulga (*Acacia anuera*) woodlands and shrublands, which are mostly restricted to rises and hills with slightly weathered bedrock and lithosols;
- chenopod shrublands dominated by saltbush (mostly *Atriplex vesicaria*) and bluebush (mostly *Maireana pyramidata* and *Maireana sedifolia*) with occasional trees mostly including belah (*Casuarina pauper*) and rosewood (*Alectryon oleifolius*), which are widespread across the region but particularly on the plains flanking the ranges;
- river red gum (*Eucalyptus camaldulensis*) woodlands along major ephemeral drainage systems;
- black box (*Eucalyptus largiflorens*) woodlands in swampy stream discharge areas in the far south; and,
- minor mallee (*Eucalyptus oleosa* and *Eucalyptus gillii*) shrublands and woodlands, mostly restricted to some areas with sandy calcareous soils.

Large areas of mulga woodland have been cleared with further vegetation removal associated with increased herbivore grazing (rabbits, sheep, goats, cattle and macropods) since the late 1800s.

REGOLITH–LANDFORM RELATIONSHIPS

The regolith–landforms of the region have been mapped regionally at 1:500,000 (Gibson and Wilford, 1996) and 1:100,000 (Hill, 2000a; 2000b; 2002). Detailed regolith–landform mapping has also been undertaken of some areas at 1:25,000 scale (Foster, 1998; Holzapfel, 1998; Shirtliff, 1998; West, 1998; Jones, 1999; Brachmanis, 2000; Debenham, 2000; Maly, 2000; Senior, 2000; Foster *et al.*, 2000; Debenham *et al.*, 2001; Brachmanis *et al.*, 2001a; 2001b; Senior *et al.*, 2002; Foster *et al.*, 2003). The main regolith–landform units can be broadly subdivided into: weathered bedrock (*in situ* regolith); transported regolith, and indurated regolith (both *in situ* and transported regolith hosts).

Weathered bedrock

Variably weathered bedrock is most extensively exposed on the rises, hills and mountains of the Barrier Ranges (Figure 1). The original bedrock lithology has an strong influence on the landform expression and extent of weathering. For example, the micaceous schists related to shear zones are typically more weathered than most adjacent lithologies and tend to have more subdued landscape expressions. Lithologies more resistant to weathering such as quartz veins, quartz–magnetite rocks and felsic pegmatites and granites typically form prominent landscape expressions such as rise and hill crests. Some weathered bedrock may also form localised exposures within drainage channels and drainage depressions, where they are important controls on defining localised groundwater sub-basins (Dann, 2001). Elsewhere, weathered bedrock is covered by variable thicknesses of transported regolith, particularly within alluvial and colluvial systems such as along major drainage systems and in the east and south of the area towards the Murray Basin.

Transported regolith

Assorted alluvial, colluvial, aeolian and minor lacustrine sediments are widespread across the region, particularly towards the Murray Basin in the south (Figure 1). These sediments are most extensive in low-lying landscape positions, although they may also occur on the upper parts of some rises and hills.

Alluvial sediments are associated with the contemporary drainage network, as eroded exposures in elevated landscape positions, and deeply buried within the Murray Basin sequence and smaller depocentres near the basin margins. Contemporary alluvial deposition is mostly restricted to alluvial channel deposits and depositional plains and fans downstream of the intersection points of channels. Alluvial plains flank most channel systems and largely host active deposition following low frequency, high discharge flood events. Some alluvial sediments may be associated with modern valley systems, but are either buried or restricted to erosional rises and as a result no longer carry stream flow. Other alluvial sediments are isolated from modern drainage systems through deep burial or topographic inversion to form discontinuous interfluve rises.

Colluvial sediments are widespread across the area, particularly flanking hills and rises, and extending across the adjacent lowlands. The most widespread colluvial deposits are associated with shallow overland flow (including sheetflow) and may form a thin cover on erosional hills and rises or extensive sheetflow fans. Many areas characterised by sheetflow have a distinctive 'contour-band' surface pattern defined by the surficial organisation of pebbly surface lags with sparse vegetation cover and more densely vegetated areas composed of fine red–brown sands. Minor colluvial deposits derived from slope creep and rockfall are limited to steep slopes typically flanking bedrock exposures or indurated regolith.

Aeolian sediments are very extensive across the area. In many places they mantle most of the landscape ranging from forming a minor component of the regolith on rise and hill crests to forming extensive sand plains and linear dunefields in lower lying settings. Small transverse dunes flank the northeastern margins of most ephemeral channel systems.

Lacustrine and swamp sediments are limited to mostly buried exposures in low-lying settings to the west of the Mulculca Range-front near Mulculca homestead (Hill *et al.* in press). Minor clay pans occur on the depositional plains flanking many of the larger drainage channels, where some of these occupy circular collapse structures related to soil B-horizon dispersion and tunnelling.

Indurated regolith may occupy a wide range of landscape settings. Regolith carbonate accumulations are extensive across much of the landscape, especially on valley margins and rise crests composed of amphibolite bedrock. Ferruginised regolith is largely buried, either within ancient alluvial sediments or highly weathered bedrock, and its limited exposures are mostly characterised by a ferruginous surface lag on erosional rises composed of ferruginised highly weathered bedrock and ferruginised sediment. Silicified regolith is most prominent where it caps rises composed of ancient, topographically-inverted alluvial sediments, although it also occurs in low-lying landscape settings where it may be deeply buried within sedimentary sequences. Minor manganiferrous regolith is mostly restricted to small rises composed of weathered manganese-rich bedrock, such as along the Broken Hill Line of Lode, and near the Melbourne Rockwell and Angus Mines, southeast and southwest of Broken Hill, respectively.

REGOLITH CHARACTERISATION

Weathered bedrock

The bedrock of the region is highly variable and the development of weathering profiles is similarly highly variable. Most rock types develop surficial ferruginous staining and the opening up of fractures when slightly weathered. Many of the amphibolite rocks develop prominent hardpan coatings of regolith carbonates when slightly weathered. More highly weathered bedrock is typically dominated by kaolinitic saprolite, with variable preservation of more resistant minerals such as quartz, plus variable induration by siliceous, ferruginous, carbonate-rich and manganiferrous minerals. Thick weathering profiles may contain zones of ferruginous mottles the morphology of which is controlled by the hydromorphic characteristics of the host saprolite (Hill *et*

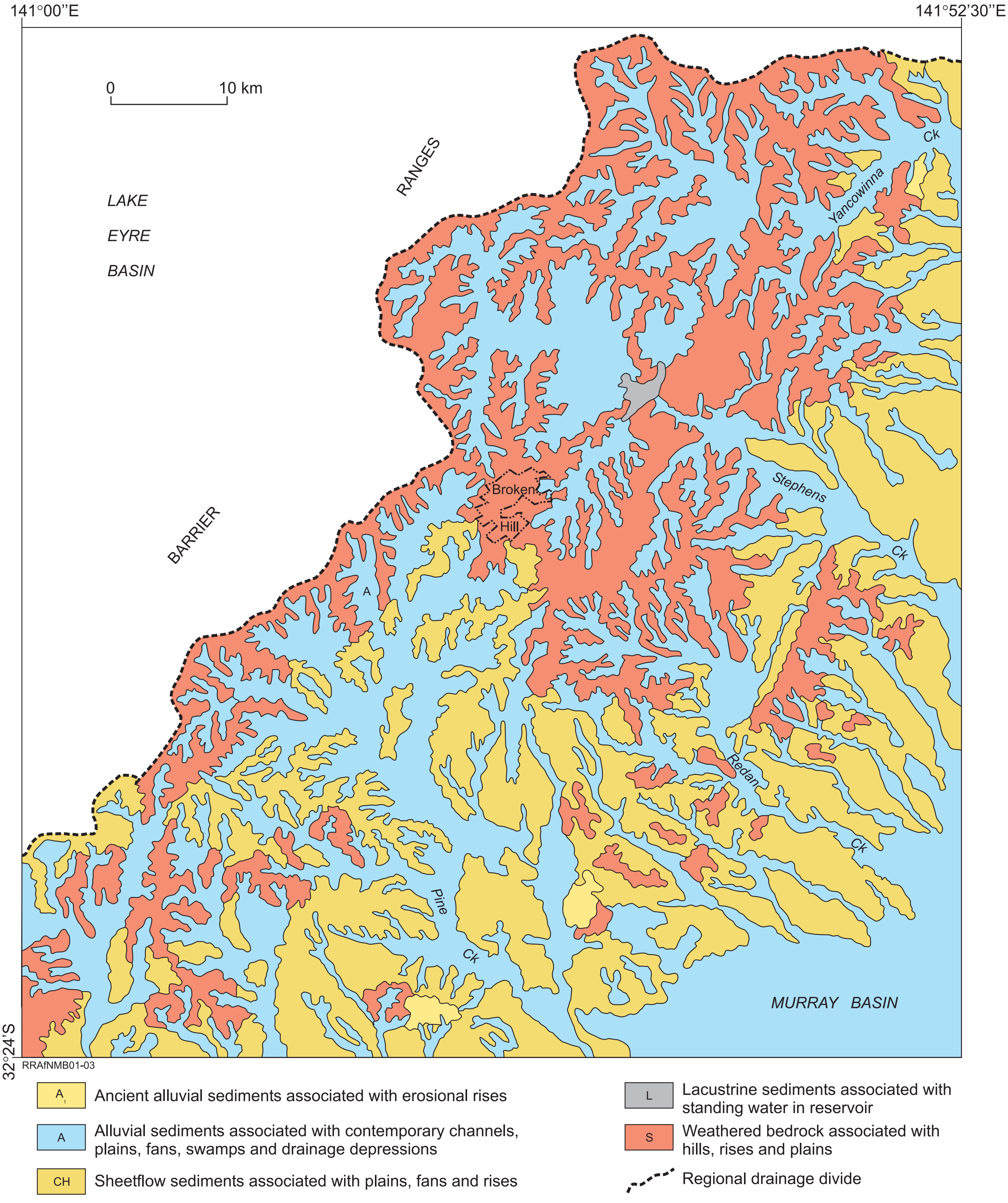

Figure 1. Simplified regolith–landforms of the southern Barrier Ranges – northern Murray Basin. (After Hill, 2000a and b)

al., 1996). Localised occurrences of polycrystalline gypsum accumulations in highly weathered saprolite occur at several sites, such as west of Balaclava homestead, south of Mulculca homestead (Hill *et al.* in press), and near Ophara Tank, some of which may be related to the weathering of sulphides (Shirtliff, 1998).

Transported regolith

Alluvial sediments associated with modern streams contain a mixture of red–brown and white quartzose sand, kaolinitic clays and lithic fragments. Alluvial sediments associated with contemporary drainage systems but no longer carrying streamflow are lithologically similar to the active alluvium, except for some buried channel deposits that are dominated by ferruginous clasts mostly consisting of maghemite. Older (high-level and deeply buried) deposits isolated from modern drainage systems predominantly consist of quartzose sands and gravels, with minor kaolinitic clay, and micaceous silt. Silicification and ferruginisation are widely developed in the older sediments, such as topographically-inverted alluvial sediments isolated from modern drainage systems, but they also occur in some younger sediments associated with contemporary valley systems.

Aeolian sediments are widespread in the region and mostly consist of rounded, red–brown quartzose fine sands. Weakly developed powdery and rhizomorphic regolith carbonate accumulations occur in many of these materials. Localised source-bordering aeolian deposits, flanking ephemeral stream channels mostly consist of pale red–brown quartzose sands with minor micaceous and lithic clasts.

Lacustrine sediments partly concealed beneath alluvial, colluvial and aeolian sediments consist of grey clayey silts dominated by quartz and kaolinite, with some goethitic ferruginous mottles and polycrystalline gypseous accumulations (Hill *et al.* in press). Minor lacustrine sediments in clay pans typically consist of kaolinitic clays with minor hematite and goethite, and quartz sand.

Colluvial sediments mainly consist of locally-derived lithic, quartzose and indurated regolith pebbles, with red–brown quartzose sands. Regolith carbonate accumulations are rare on sheetflow deposits with prominent 'contour banding', however powdery and rhizomorphic regolith carbonate accumulations are well-developed in other colluvial deposits.

Indurated regolith

Regolith carbonate accumulations occur in a range of morphologies, including nodular, hardpan, powdery, rhizomorphic, and massive tabular forms (Hill *et al.*, 1999). Their mineralogy is dominated by calcite, although dolomite-rich varieties also occur. A limited occurrence of magnesite occurs in association with the weathering of the Little Broken Hill Gabbro.

Ferruginous regolith is typically indurated by hematite and goethite, and minerals such as quartz and kaolin related to the lithology of the regolith material hosting induration. The main morphologies are ferruginised saprolite, ferruginised sediments and detrital ferruginisations (Hill *et al.* in press).

Silicified regolith is most extensively developed in quartzose alluvial sediments, where it may form massive tabular silicifications, glaebular (both sperical and elongate glaebules) silicifications and columnar silicifications typically restricted to 'pod-like' lenses within sediment bodies (Hill *et al.* in press). Some silicification is also hosted by saprolite, such as east of the Farmcote homestead, where granite bedrock fabrics and quartz veins are preserved in the silicified material. Rare red–brown hardpans also occur in the far south east of the area, however limited study has been made of these materials.

The rare manganiferrous indurations are mostly of massive, botryoidal and coralline morhologies. Coronadite and goethite is the dominant mineralogical assemblage.

DATING

The dating of regolith materials has been limited in the region. Most chronological constraints of regolith and landform features are restricted to comparison of field settings and inter-relationships and possible stratigraphic correlations of sediments in the adjacent Murray Basin.

The older alluvial, quartzose sands and gravels isolated from modern drainage systems are likely to be feeder channels to the Cenozoic Murray Basin (Hill *et al.*, 1997; Hill, 2000a). These could possibly be associated with the Palaeogene Renmark Group or the Neogene Calivil Formation. Stratigraphic correlations, however, are not clearly constrained mainly because a complex reworking of alluvial sediments of similar lithologies appears to have taken place throughout much of the history of landscape development. Similarly, the silicification and ferruginisation histories of these sediments is complex and likely to have taken place throughout much of the landscape history. At the very least, multiple 'generations' of induration have taken place, as demonstrated by the resilicification of the matrix surrounding silicified detrital clasts (Hill, 2000a; Hill *et al.* in press). Despite an abundance of ferruginised regolith materials there is yet to be a palaeomagnetic sampling program across this region to further refine chronological models for ferruginisation in this region.

The lacustrine grey, clayey silts described from the Mulculca Fault angle depression (Hill, 2000a) are lithologically similar to the Pleistocene Blanchetown Clay from the Murray Basin (Brown and Stephenson, 1991). Palynological investigation of these sediments from this region, however, suggests that they are too weathered to provide further support to stratigraphic correlations. It is unlikely that a continuation of the palaeo-Lake Bungunnia and the associated Blanchetown Clay extended continuously into this region, but instead this may be a localised lacustrine sediment accummulation.

REGOLITH EVOLUTION

Some of the important features of the history of regolith and landscape evolution in the southern Broken Hill Domain–northern Murray Basin margins include:

1. continual evolution of weathering products and regolith induration (Hill *et al.*, 1997; Hill, 2000a). This is in contrast to previous regional models emphasising perceived episodes or cycles of development;
2. complex sedimentary history. Maly (2000) showed that previous 'layer cake' stratigraphic approaches for the transported regolith have been over-simplistic, particularly on the Murray Basin–Broken Hill Domain margins;
3. the presence of palaeovalley systems probably feeding into the Murray Basin. These would be an important contributor to the Murray Basin sedimentary fill. They may also provide important geochemical vectors to mineralisation within geochemical sampling programs in mineral exploration (e.g. Brachmanis, 2000), or mineral sand sources;

4. significant contributions of neotectonics in a cratonic, intra-plate landscape setting. For example the Mulculca Range-front and associated regolith landform features are largely related to recent tectonic activity (Hill *et al.* in press). Neotectonics here are not mutually exclusive of expressions of landscape antiquity such as the exposure of offset palaeovalley sediments across range-fronts. Neotectonic activity also appears to be responsible for the deposition of lacustrine sediments in the area of the fault-angle depression adjacent to the Mulculca Rangefront (Hill, 2000a; Hill *et al.* in press)
5. differential weathering and erosion of a wide variety of bedrock lithologies are important controls on the landscape development;
6. complex evolution of gypseous regolith accumulations derived from possible regional rainwater / groundwater processes but in many cases from sulphide weathering. This suggests that gypsum in weathering profiles could in some cases reflect the presence of weathered sulphides (Shirtliff, 1998; Hill, 2000a);
7. widespread development of regolith carbonate accumulations, partially related to bedrock weathering (e.g. amphibolite weathering) but also largely related to rainfall inputs (Hill, *et al.,* 1999; Hill, 2000a).
8. post-settlement sedimentation has been extensive across much of the landscape. This can be demonstrated by the abundance of artefacts such as wire and glass mixed within upper sediment layers, such as along many of the major drainage systems.

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