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REGOLITH LANDFORMS OF THE GILMORE PROJECT AREA

Roslyn A. Chan and David L. Gibson

CRC LEME OPEN FILE REPORT 147

March 2003

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ABSTRACT

This report accompanies the Gilmore Regolith Landforms map, which was mostly compiled at 1:50 000 scale, and is available as a digital coverage. A 1:130 000 scale ARCVIEW generated hardcopy map covering the entire Gilmore Project area is included with this report. Regolith landform units were mapped primarily by photo interpretation, backed up by field checking. Thirty regolith landform units are mapped and described.

The Gilmore project area is well endowed with mineral resources, especially in the north. However, exploration is hampered by extensive sediment deposited in previously incised valleys and on hill slopes, and by complex weathering of both altered and unaltered bedrock. Much of the area is also characterised by saline ground water, hosted in both weathered bedrock and sediment.

Both mineral exploration and environmental concerns can be better managed with an understanding of the distribution, characteristics and processes (both present and past) of the various transported and *in-situ* regolith materials and their landform associations, as presented in this map. This understanding also underpins the formulation of mineral and land use models to help extrapolate this knowledge to other areas.

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1. BACKGROUND

Regolith landform units (see Pain et al. 2000) were mapped over the Gilmore Project area in central NSW (Fig. 1) to assist with the interpretation of data from Airborne Electromagnetic (AEM) surveys and drill holes. The area can be divided into five main geomorphic regions or regolith-landform provinces based on regolith landform characteristics (Fig.2):

1. Uplands of relatively unweathered bedrock in hills to mountains (90 m to >300 m relief) with covered upland basins, minor saprolite rises to low hills;
2. Low hills (30-90 m relief) and local higher peaks with minimal bedrock weathering and colluvial transfer slopes;
3. Weathered bedrock in rises to low hills (9-90 m relief), minor saprolite plains;
4. Undulating lowlands of plains to rises (< 30 m relief) with a cover of residual to colluvial sediments and major alluviated valleys, scattered saprolite in plains and rises;
5. Extensive low angle coalescing alluvial fans and plains (<9 m relief).

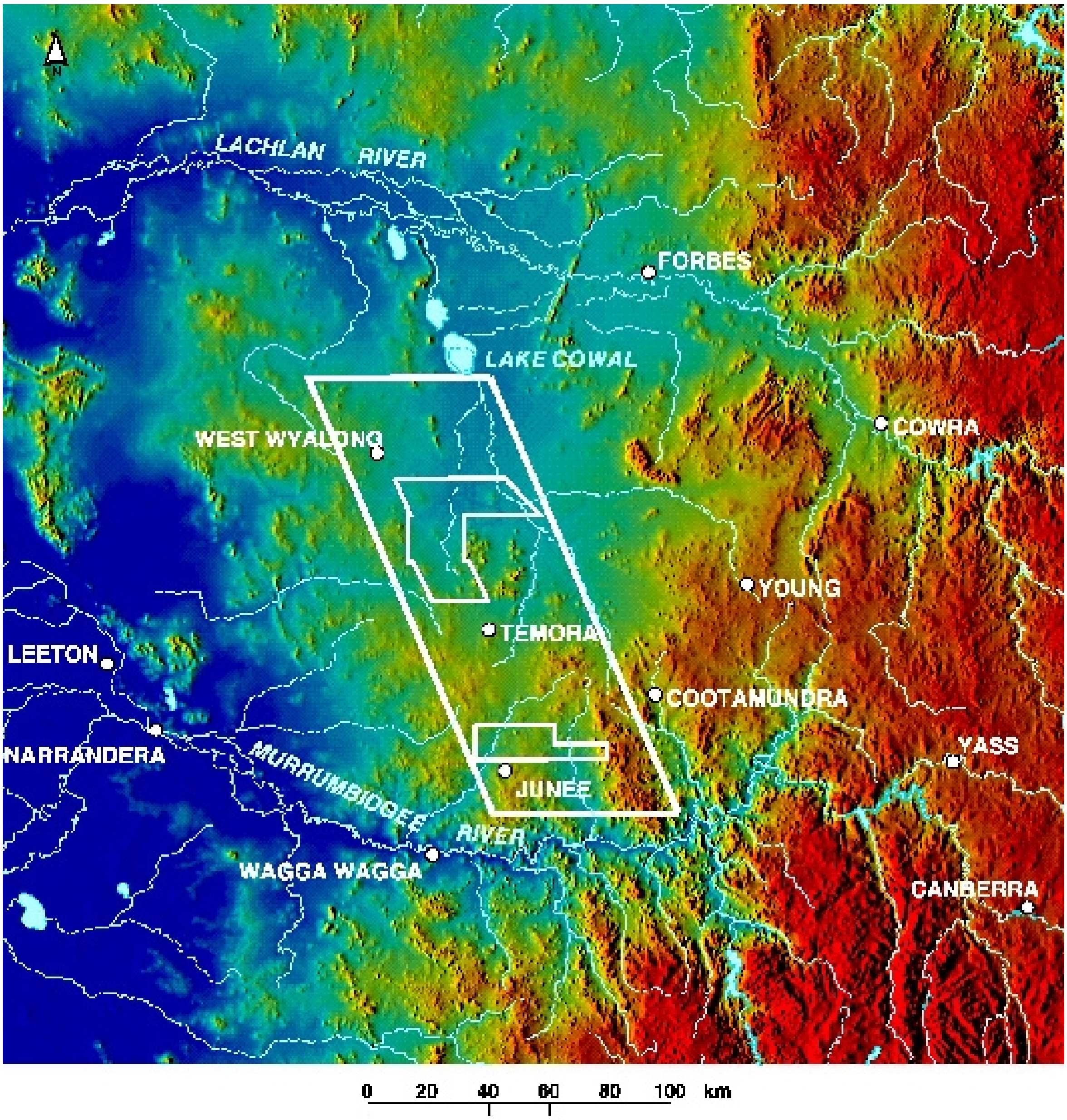

Figure 1. Location of Gilmore Project area and two Airborne Electromagnetic (AEM) areas with Digital Terrain Model (DTM) backdrop (oblique illumination, red ~ higher elevation, blue ~ lower elevation).

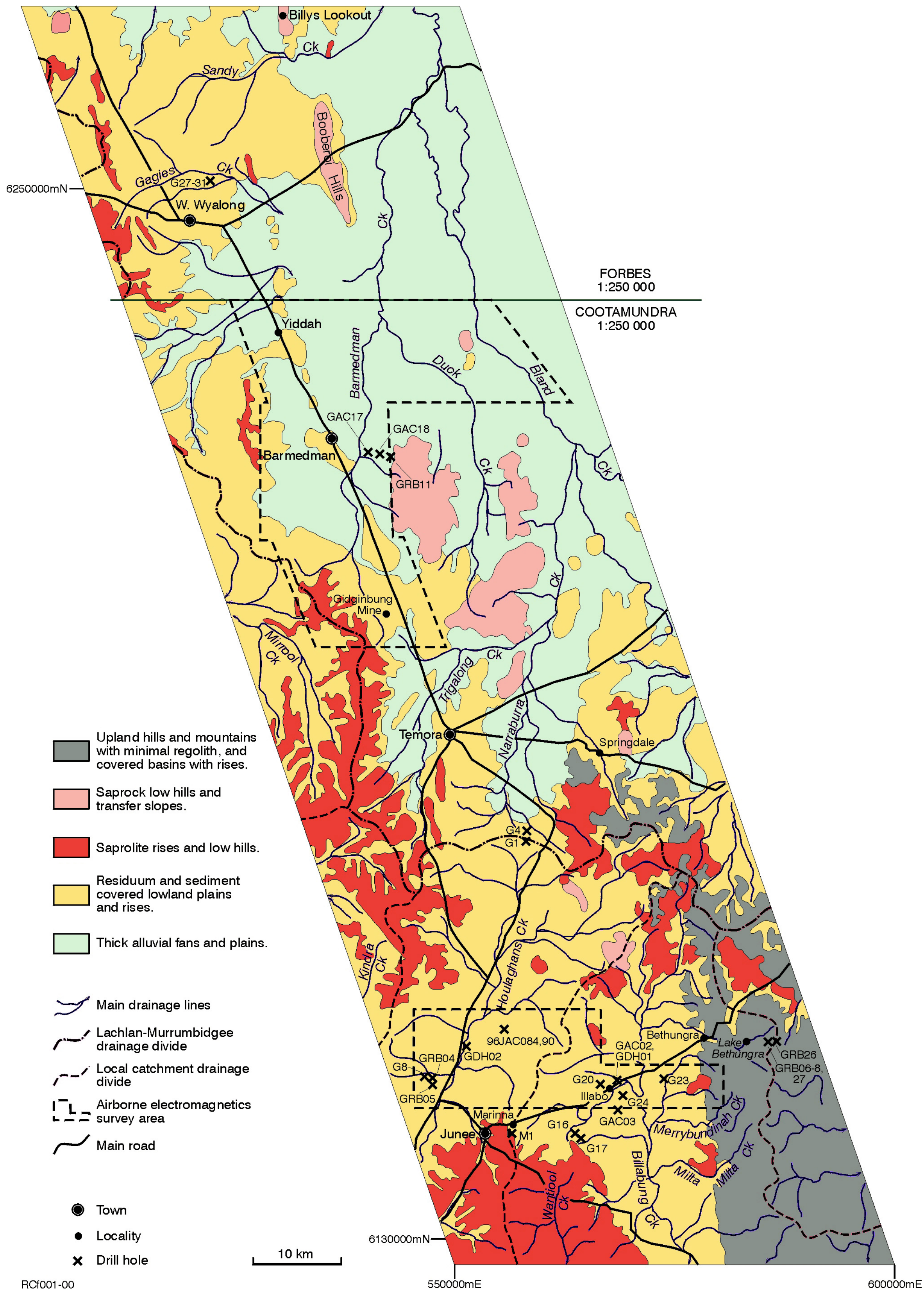

Figure 2. Gilmore Project area showing regolith landform provinces, drainage divides, AEM survey areas, and drilling locations mentioned in this report.

In the north of the project area most of the terrain has extremely low relief and low gradients which make it difficult to distinguish between areas dominated by transported or *in-situ* regolith. In the south most of the lowlands consists of undulating country which required detailed photo interpretation to distinguish subtle but important differences between alluvial, colluvial and erosional landforms.

The regolith and gross features of the landscape of the Gilmore Project area owe much of their character to incision of the area during the Cainozoic. Lowered local base levels resulted from incision of the Murrumbidgee and Lachlan Rivers into the surrounding landscape. Subsequently, alluviation occurred in the valleys, mostly in the period late Miocene to Pleistocene. Prior to alluviation, Bland Creek and its tributaries had eroded a broad valley, with local structurally controlled ridges separating some tributaries, whereas creeks draining south to the Murrumbidgee flowed in relatively narrow steep-sided valleys separated by more rounded interfluves. Deposition of up to 140 m of sediment in the Lachlan and 80 m in the Murrumbidgee valleys (Martin, 1991; Williamson, 1969, 1986; Anderson et al., 1993; staff of NSW Dept of Lands and Water Conservation, pers. comm.), raised local base levels, and resulted in deposition of sediment in the tributary valleys. Rising river base levels because of sedimentation in the Murray Basin, and cooler, drier climate probably triggered the alluviation. In the broad Bland palaeovalley in the north, only higher ridges and hilltops were not covered by sediment, resulting in a modern landscape of broad alluvial plains with residual rises to low hills forming isolated “islands”.

A large proportion of the total Bland Creek catchment has been buried, with large areas of thick sediment extending to within a few kilometres of and about 10 m below low parts of the Lachlan-Murrumbidgee divide in the area between the headwaters of Narraburra and Houlaghans Creeks. The narrower palaeovalleys in the south were filled to the extent that the steep slopes were buried, and broad valley floors separated by rises and low hills now predominate. Colluvial deposition of sheetwash from valley sides is now in many places dominant over alluvial deposition, especially in areas of low local relief, resulting in broad U shaped valley floors rather than flat-floored alluvial floodplains. However, Billabung Creek, which has many east bank tributaries in uplands along the southeast margin of the area, has a well formed alluvial plain, possibly reflecting increased runoff from the upland areas during heavy rain periods. There has been minor erosion of the alluvial valley-fill deposits, especially in the south of the area, both as incision of watercourses into a preserved alluvial plain, and probable sheetwash erosion of old alluvial deposits to form undulating landscapes.

AGSO/BRS drilling has shown that a low relief undulating, eroding area around Illabo is underlain by alluvial deposits up to 41 m thick, and some watercourses in the far south of the area have incised into their valley fill deposits by up to 8 metres. The modern drainage is generally still confined to the approximate location of previously incised palaeovalleys, although locally it may have been displaced by prograding alluvial fans or slope wash deposits. However, northeast of West Wyalong, the Wyalong Palaeochannel (recognised from short wavelength magnetic anomalies caused by maghemite-bearing gravels that were deposited as part of the valley fill; Lawrie et al., 1999; Gibson & Chan, 2000), has been blocked by aeolian deposits, creating a new drainage divide and diverting the modern Gagies Creek away from the palaeochannel.

Many rocks throughout the area have undergone extensive weathering, with saprolite thicknesses exceeding 50 m, especially in intermediate volcanic rocks and granite in the north. It is possible that the broad geometry of the Bland palaeovalley results from the widespread distribution of mechanically weak, highly weathered volcanic and sedimentary bedrock in the Bland catchment, whereas the southern catchments were eroded into more competent less weathered bedrock, resulting in more local incision along watercourses. This difference in weathering susceptibility between north and south of the Lachlan-Murrumbidgee drainage divide may be due to preferential structural deformation and associated hydrothermal alteration in the Bland catchment north of the divide. The most resistant, least weathered rocks, mostly acid volcanics and some granites, form areas of steeper and higher relief in the southeast of the area and north of Temora. Rock outcrop and thin residual soils predominate in these areas. Many slopes in areas of lower relief are covered with a layer of residual to colluvial (sheetwash) derived detritus, with the possibility of addition of aeolian dust (parna; Munday et al., 2000). AGSO drilling has shown that this cover may exceed 15m thickness, even on lower parts of local divides. Preservation of this material implies that the surface processes responsible for its removal (sheetwash, mass movement, wind erosion etc) have been unable to keep pace with supply. The veneer is probably a combination of local (e.g. generation of residual material through collapse of saprolite) and exotic (e.g. transport of detritus from adjoining steeper landforms, and accession of parna) material.

2. MAPPING METHODLOGY

Boundaries between regolith landform units were mostly compiled from interpretation of 1:50 000 to 1:80 000 scale panchromatic aerial photographs, detailed landform contours, and four weeks field work. Polygons were compiled at 1:50 000 scale for areas on the Cootamundra 1:250 000 Sheet and at 1:100 000 scale on the Forbes 1:250 000 Sheet. Subsidiary data were derived from analysis of cuttings and core from AGSO/BRS and company drill holes, down-hole geophysics, airborne gamma-ray spectrometrics, and company drill hole logs. Details of the lithology of cuttings have been entered into AGSO's Minerals Division database; logging of core is presently continuing.

Due to the complexity of the geomorphology, a systematic integration of the gamma-ray spectrometrics and bedrock geology with landforms was not attempted as the level of detail of ground truth required was outside the scope of this project. However, some regolith landform unit boundaries were defined using gamma-ray spectrometrics in conjunction with field data. Both geology and gamma-ray spectrometrics are separate and complementary coverages within the Gilmore project Geographic Information System (GIS). Determination of bedrock lithology for correlation with regolith landform units is based on a combination of field site data, and the 1:250 000 Cootamundra Interpreted Geology map (Bacchin et al, 1999), the 1:250 000 Cootamundra Geological map (Warren et al., 1996), and the preliminary 1:250 000 Forbes Geological map (Duggan et al., 1999).

Thirty regolith-landform units have been mapped, and are described in this report.

3. REGOLITH-LANDFORM UNITS

3.1 Units Dominated by Transported Regolith

Transported regolith is widespread throughout the study area and is present in alluvial plains (active and stagnant), alluvial fans (active with a range of gradients, and eroding), alluvial terraces, sheet wash plains and rises, aeolian sand dunes and lunettes, and swamps.

3.1.1 Alluvium

AGSO/BRS and company drilling show that valley-fill sediments, considered to be dominantly alluvial (i.e. deposited by water localised by channel flow; Pain et al., 2000), commonly reach 50 m thickness in valley floors both north and south of the Lachlan-Murrumbidgee divide. This resulted from infilling of a previously more deeply incised landscape. Alluvial areas have been subdivided into various mapping units, depending on the modern landform present. These landforms will reflect the depositional (and in some cases erosional) processes taking place today. However, it is possible that at any one location, alluvium in the subsurface was deposited in a variety of alluvial landscapes. Drilling and AEM suggest the presence of lacustrine sediments from a large palaeo-lake within the fill of part of the Bland palaeovalley, and have shown that alluvium is also locally present beneath modern inclined colluvial landscapes, i.e. colluvial (sheetwash) deposits have been deposited over prior alluvial landscapes.

Alluvial plains (Aap1)

Undifferentiated alluvial plains up to 2km wide have been mapped predominantly along the creeks flowing south into the Murrumbidgee River, notably Houlaghans and Billabung Creeks and their tributaries. Alluvial plains have also been mapped in the headwaters of north- and west-flowing creeks, particularly Bland, Duck and Mirrool Creeks. The alluvium variably consists of clay, sand and gravel, and is of variable thickness. For example, in an upper Billabung Creek headwater stream, AGSO Rotary Air Blast (RAB) drill hole G23 intersected 4m of alluvium consisting of clay to silt with magnetic pisoliths. However AGSO/BRS Diamond Core Hole GDH02 drilled in the electromagnetically conductive alluvium on the eastern banks of Houlaghans Creek intersected 53m of alluvial sand and gravel with minor clay overlying saprolite (BRS staff, pers. comm.). The maximum thicknesses of alluvium may be within incised palaeodrainage lines that have been laterally displaced from the present creeks. The palaeodrainage lines show as conductive zones on the AEM imagery. AGSO RAB drill holes G20 and G24 around Illabo in the southern AEM area intersected zones of calcrete and transported magnetic pisoliths in transported sandy clay within this unit.

Recent stream incision into alluvial deposits is at least 8m for Billabung Creek in the south of the study area, whereas in the upper reaches of Houlaghans Creek there is very little incision. In the headwaters of Duck Creek cross-bedded coarse sandstone and clay hardpanised sand is exposed by incision into the alluvial plain. The wide alluvial plains adjacent to the narrow incised parts of Billabung Creek are mapped as alluvial plains and not as terraces as they are intact, and are likely to have active sedimentation periodically during floods due to the steep headwaters of Billabung Creek.

The distribution of potassic-rich sediments and their provenance are depicted clearly by the gamma-ray spectrometrics. Sediments along Billabung Creek are derived mostly from tributaries draining the dominantly acid volcanic and granite uplands to the east; similarly an eastern tributary of Houlaghans Creek derives its sediments from the granite country around Junee.

Alluvial flood plains (Aaf1)

Incised modern alluvial floodplains occur as ribbons of alluvium, commonly less than 100m, but in places up to 1km wide, along Barmedman, Duck, Bland and Narraburra Creeks north of the Lachlan-Murrumbidgee drainage divide, and along Mirrool Creek southwest of the divide. Only a few short narrow ribbons of incised floodplains occur in the upper reaches of Houlaghan and Billabung Creeks south of the divide. In the north the modern floodplain is typically incised 1-2 m below the surrounding depositional plain, whereas in Mirrool Creek incision is at least 6m. At a locality in Mirrool Creek bedded granule alluvium overlies mottled cemented alluvium, sometimes known as “creek rock”. Minor terraces too small to be mapped and calcrete also occur along Mirrool Creek.

Terraced land (Aal1)

Terraces were noted only south of the divide. Minor terraces occur along the upland front on westerly flowing tributaries of Billabung Creek. The main area of terraced land occurs in an area dominated by unit *Ser1* southeast of Junee. Here the southerly flowing Wantiool Creek has deeply incised its prior alluvial plain leaving many stranded alluvial terraces (ie. detached terraces rather than intact alluvial plain) along the trunk stream as well as its tributaries. McConnell (1983) has described up to seven terraces in the catchments of Wantiool and nearby creeks in the area between the Gilmore study area and the Murrumbidgee River. She concludes that the terraces have developed in response to local rather than regional factors.

Stagnant alluvial plains (Aas1)

Barmedman and Bland Creeks bound a large area of stagnant alluvial plains with extremely low slopes (about 1m/km or 0.1%) to the west and east respectively in the north of the area. It is probable that these two creeks channel the runoff and sediment derived from the coalescing fans further west and east (see below) towards Lake Cowal to the north, leaving a stagnant, low gradient plain between the two creeks. This plain has little organised drainage, and would receive fine grained sediment only in major flood events when the ribbon floodplains of Barmedman and Bland Creeks could not contain the resulting floodwaters. This area is underlain by thick clayey alluvium (up to around 120 m deep; Anderson *et al.*, 1993), and there appears to be very little modern geomorphic activity other than leaching and formation of gilgai.

Alluvial fans (Afa1, Afa2, Afa3 and Afa4)

Areas of alluvial fans have been subdivided on the basis of gradient, and in some cases, granitic provenance (*Afa3*). By far the largest unit is *Afa1,* which is mapped north of the Lachlan-Murrumbidgee drainage divide, and forms most of the alluvial landscape of the Bland valley. Very low angle coalescing alluvial fans (2-4m/km or 0.2-0.4%) grade generally towards the trunk drainage lines of Barmedman Creek in the west and Bland-Narraburra-Trigalong Creeks in the east. These creeks act as gutter drainage for alluvial wash from *Afa1*. Analysis of drill chips, down-hole geophysical logging, electromagnetic and magnetic data indicates areas of buried clay within the transported cover that may be lacustrine in origin, and a complex sub-sediment topography on variably weathered and altered bedrock lithologies. The sediments are up to 120m thick (Anderson et al, 1993) and locally contain calcrete, detrital magnetic iron pisoliths, quartz and lithic pebbles, and ferruginised rock fragments. Gilgai and waterlogging are common at the surface (Fig. 3).

Figure 3. View to the north of waterlogged gilgai on alluvial fan plains. (Regolith Landform Province 5; 0559896E 6193385N, Horizontal Datum WGS84).

Regolith landform unit *Afa2* consists of undifferentiated low angle alluvial fans with gradients of 5-20 m/km, or 0.5-2%. These alluvial fans occur predominantly north of the Lachlan-Murrumbidgee drainage divide around colluvially-dominated bedrock terrain and grade into the very low angle more distal fans of *Afa1*. A few low angle alluvial fans of *Afa2* occur south of the divide at the junction of some tributaries and the trunk drainage lines of Houlaghans and Billabung Creeks. At one location in the more eastern of a pair of opposite fans in the headwaters of Houlaghans Creek the depth of alluvium is less than 6m with sandstone saprolite beneath. The undifferentiated alluvium in fans north of the divide may be much thicker than south of the divide, but no drill hole information is available.

To the south-east of Barmedman and around Billys Lookout Hill southwest of Lake Cowal, coalescing alluvial fans derived from low granite hills have been defined by the their high potassium gamma-ray spectrometrics signature and constitute unit *Afa3*. These fans generally have gradients of 10-20m/km, or 1-2%, and locally have a creek with natural levee banks in the middle and highest part of the fan. The alluvium is sandy and in places has layers of poorly cemented and poorly sorted clayey sandstone with sedimentary structures. Drill hole GRB11, in the proximal part of a fan to the west of the low granite hills east of Barmedman, intersected about 20m of granite-derived sandy sediments over sedimentary saprolite. Holes GRB 17 and 18, drilled further west on more distal parts of the fan, bottomed at about 60 m in sandy granite-derived sediment.

A few fans, mainly just north of the Lachlan-Murrumbidgee drainage divide, have gradients steeper than 20m/km (2%) and constitute unit *Afa4*. Some fans are sourced from non-granitic bedrock, but the steep fans in the low granite hills southeast of Barmedman have a high potassium signature, and are steeper versions of *Afa3*

Eroded alluvial plains (Aep1)

Old alluvial fans that are now being eroded and form erosional plains occur on both sides of Houlaghans and Billabung Creeks. Two major areas of old fans emanate from the upland front east of Billabung Creek. The most southern area may consist of a number of coalescing alluvial fans, and there appears to be an abandoned medial alluvial plain trending northwest: the present creek flows southwest, incising and cutting across the fan. This fan is relatively steep proximal to the upland front (>30m/km) and has convex lower slopes. A 2m exposure in the distal part of the fan shows well-bedded pebbly sand with detrital magnetic pisoliths, well to poorly-bedded pebbly conglomerate with mud matrix, and massive grey mottled clay. There is a lag of exhumed angular and some rounded clasts on the eroded surface of the fan.

The apparent proximal part of a large area of eroded palaeo-alluvium (*Aep1*) further north is separated from the distal part of the fan by a modern alluvial plain (*Aap1*) along Merrybundinah Creek. It is likely that old fan sediments have been covered by modern alluvium. A few smaller old alluvial fans rise within and on the edge of the upland front north of Bethungra. Sediments in the fan just northeast of Bethungra have been cemented.

AGSO/BRS drillhole GAC03, drilled through the eroded fan on the western side of Billabung Creek near Illabo, penetrated 41m of dominantly clayey to silty sediments with detrital magnetic pisoliths. At a site on an eroded alluvial fan on the eastern side of Houlaghans Creek, southwest of Junee, porous granite-derived poorly sorted and crudely bedded coarse sandstone is exposed in the walls of a farm dam. Similar palaeo-alluvium is found in and around the headwaters of Duck Creek, north of the Lachlan-Murrumbidgee drainage divide. Here, recent sediments, reflecting current geomorphic processes, largely mask the older indurated sediments.

Alluvial residual rise (Aeu1)

Alluvial plains west of Billabung Creek, at the southern edge of the Gilmore project area, surround one small residual rise partly draped with alluvial sediments (Aeu1). Here up to 2m of stony red clay loam soil overlies 0.5m of pebble conglomerate with detrital magnetic iron pisoliths and rounded quartz and lithic pebbles (<1cm diameter), and a clay matrix. The sediment has a very irregular disconformable contact with underlying Palaeozoic chert. This is an example of relief inversion with preserved palaeo-alluvium.

3.1.2 Sheet wash

Sheetwash deposits have been mapped over much of the area. Areas of sheetwash with gentle slopes (up to around 20 m/km) have been classed as depositional plains, and divided into three units on the basis of slope and presence of ferruginous material, mostly maghemite pisoliths, in soils and as lag. Steeper slopes with sheetwash are interpreted as transfer slopes and classified here as erosional rises. Locally, sheetwash deposits are known to overlie alluvium, and in many places drainage lines flow through broad U-shaped rather than flat-floored valleys, indicating that sheet flow deposition from valley sides rather than alluvial deposition now predominates on the valley floors.

Sheet wash depositional plains (CHpd1, CHpd2, CHpd3)

Low slope depositional plains (*CHpd1*) are widespread, both north and south of the Lachlan-Murrumbidgee drainage divide. They have gentle slopes of <10m/km, or 1%, and have smooth concave contact with upper slope units, rather than the angled contact of alluvial plains. This concave slope indicates that surface sediment is dominantly derived from up-slope rather than from upstream, as is the case with alluvial plains. However, secondary alluvial deposition from stream flow imperceptibly merges with the sheet wash forming a facies change. It is likely that buried alluvium occurs at depth in variable locations across this landform due to increased sheet wash from slopes covering palaeochannels.

Areas of *CHpd1* are especially prevalent in catchment headwaters, eg. Houlaghans, Kindra and Mirrool Creeks south of the divide, and Barmedman, Gagies and Sandy Creeks, as well as a north trending creek about 15km west of Barmedman, north of the divide. Further downstream tributary junctions are also a common location for this unit, eg along Houlaghans Creek. Mid-way along Houlaghans Creek sheet wash deposition from side slopes dominates and interrupts the alluvial plain further north along the creek. This change in valley cross-section occurs within a convex zone on the longitudinal thalweg profile along Houlaghans Creek: this contrasts with the classic concave “J” curve profile along Billabung Creek (Fig. 4).

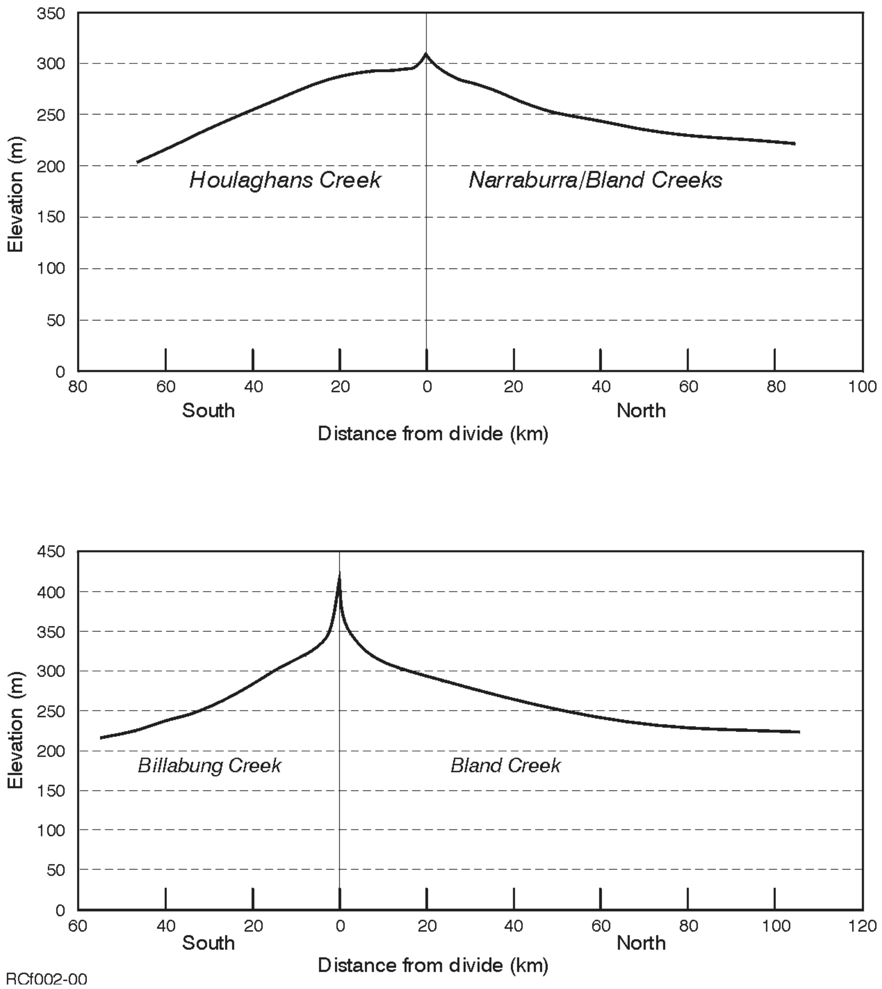

Figure 4. Longitudinal thalweg profiles on either side of the Lachlan-Murrumbidgee drainage divide:

a. Houlaghans/Narraburra, Bland Creeks (note the convex profile of Houlaghans Creek);
b. Billabung/Bland Creeks (note the classic “J” curve profile of Billabung Creek).

Areas of *CHpd1* have been mapped immediately adjacent to, and on either side of, unit *Rep1* on the Lachlan-Murrumbidgee drainage divide between Houlaghans Creek to the south, and Narraburra Creek to the north. Here, clayey soils commonly include magnetic iron pisoliths, angular quartz and ferruginised rock fragments, calcrete, and gypsum at 30cm depth to the south. AGSO RAB hole G4 just north of the divide intersected at least 10m of clayey sediments with a sand to gravel layer over possible clay saprolite. Gilgai are present immediately northwest of G4.

Northeast of West Wyalong *CHpd1* forms a modern valley floor over parts of the Wyalong Palaeochannel (Lawrie et al., 1999; Gibson and Chan, 2000), defined by the presence of sediments containing detrital maghemite that gives an intense short wave magnetic anomaly. AGSO RAB holes G27-31, drilled across the palaeovalley penetrated up to 7m of sediment with abundant detrital magnetic iron pisoliths, identified as maghemite (C. Leslie, CRC LEME Honours student, pers. comm.), over maghemite-free sediments reaching at least 8m thick in G28. The other four holes intercepted saprolite between 3 and 7m depth. Poorly cemented maghemite-bearing alluvium is also exposed in the bed of Sandy Creek within *CHpd1* to the north-northeast of the RAB drilling and downstream along the Wyalong palaeochannel

Moderately sloping (10-20m/km, or 1-2%) and slightly undulating sheet wash depositional plains (*CHpd2*) are prevalent both north and south of the Lachlan-Murrumbidgee drainage divide. They are especially common south of the divide, and between Temora and Yiddah as well as skirting the Booberoi Hills north of the divide. A variation of this unit, *CHpd3*, mapped to the west of Barmedman and Yiddah, has magnetic iron pisoliths (likely to be maghemite) and ferruginised rock fragments as a lag and within the soil, and has a thorium-dominant gamma-ray spectrometrics response. Unit *CHpd2* often occurs as an intermediate depositional slope unit between an upper steeper transfer slope unit (*CHer1*) and a lower gentler sheet wash slope unit (*CHpd1*) or low angle alluvial fans (*Afa1*).

The sheet wash covered slopes at least locally disguise a steeper palaeo-topography with modern drainage displaced laterally from palaeodrainage deposits buried beneath sheetwash slopes. For example, northwest of Junee on the western side of Houlaghans Creek, airborne electromagnetics indicates a narrow conductive zone approximately parallel to a modern easterly flowing tributary of Houlaghans Creek, beneath the north facing slope of a *CHpd2* area. AGSO RAB hole G8, drilled in the conductive zone, penetrated coarse alluvial sand with minor rounded quartz pebbles from 13m to 15 m (bottom of hole). AGSO/BRS drill hole GRB04, drilled down palaeo-stream and also within *CHpd2*, intersected dominantly clay with interbedded sand and calcrete nodules to 17m (bottom of hole). Hole GRB05, drilled up slope from GRB04 near the upper boundary of *CHpd2*, intersected 8 m of transported clay, silt and sand over granitic saprolite.

Soils in unit *CHpd2* in and around the western part of the southern AEM area generally have a significant clay component, along with goethite and calcrete nodules (cf. drill hole GRB04), and have a depleted potassium gamma-ray spectrometrics signal. Adjacent plains and rises with granitic residuum have a similar signal, so either the sheet wash which thickly coats this terrain is derived from leached residuum, or the sheet wash was deposited fresh and later leached at the same time as the residuum was leached. North of the southern AEM area some minor areas within this unit have magnetic pisoliths and fragments, and ferruginised fragments. Drill hole GAC02 near Illabo intersected 40m of transported clay to silt, and the adjacent drill hole GDH01 intersected 48m of transported material over saprolite to 72m (bottom of hole), (BRS staff, pers. comm.), low down the slope within *CHpd2*. In general, the sheetwash thickens down slope.

Sheet wash erosional rises (CHer1, CHer2)

Sheet wash slopes with gradients >20m/km, or 2%, (*CHer1*) are common as aprons around saprolite and saprock crests of rises and low hills, both north and south of the Lachlan-Murrumbidgee drainage divide. *CHer1* often grades into the less steep sheet wash slope units (*CHpd2 or CHpd3*) down slope. A striking example of this is the Booberoi Hills range northeast of West Wyalong. The upper slopes (*CHer1)* are transfer slopes between the eroding crests and the progressively lower slopes of units *CHpd2* and *CHpd1* on which much of the sediment is deposited.

Sediments overlie saprolite with occasional bedrock outcrops, and thicken down slope. Abundant lithic and ferruginised rock fragments, and in places fragments of vein quartz, are present in variably textured soils which vary in depth from less than 0.5m to >2m. Some poorly bedded coarse quartzo-feldspathic sandstone, which is poorly cemented with clay, occurs within *CHer1* in the granite hills southeast of Barmedman, and is interpreted to be cemented granite-derived colluvium.

Constricted basins (*CHer2*) have a narrow outlet, often with a knick point, and predominantly occur within uplands. Most constricted upland basins are present in the southeast of the Gilmore project area in headwater tributary catchments of Billabung Creek to the west and Muttama Creek to the east. A few basins occur in uplands north of the Lachlan-Murrumbidgee drainage divide to the south of Springdale. Within these basins sheet wash colluvium and *in-situ* residuum cover saprolite rises with local low hills of saprock outcrop. Minor alluvium is present along some creeks.

In a large upland basin draining west into the headwaters of Billabung Creek, in the vicinity of Lake Bethungra, RAB drilling intersected clayey sediments up to 4m thick overlying granitic saprolite and core stones (holes GRB6-8 and 27) in the upper part of the catchment. These sediments also coat the saddle of the Billabung-Muttama drainage divide to 1.5m depth, overlying very highly weathered microgranite to >18m depth (end of hole, GRB26). This contrasts with the sandy loam soils on the lee (eastern) side of this divide (D. Dent, BRS, pers. comm.) which are typical of soils derived from granitic and acid volcanic saprolite rises within the uplands. It is possible that this clay is exotic and is colluvially reworked aeolian clay, ie. parna, blown in from the western plains. Similar soils are locally preserved on granite just south of the Lachlan-Murrumbidgee drainage divide in the Young-Wombat area further to the east and outside the Gilmore project area.

Figure 5. Gully erosion since fence built in granite alluvium in upland basin near Lake Bethungra. (Regolith Landform Province 1; 0584742E 6152080N, Horizontal Datum WGS84).

Two major hazards are associated with these constricted basins. Firstly, erosion is common in physically dispersive soils, especially in gritty colluvium, residuum and alluvium on steep slopes (Fig. 5). Secondly, groundwater flow is constricted, resulting in high water tables and possible salinity problems. An example of such a case is at a site about 5km south of the southeastern corner of the southern AEM area, where an upland basin drains into the headwaters of Mitta Mitta Creek, a major eastern tributary of Billabung Creek. Salt crystals and piping are present at 1m depth on the face of a profile cut by the incised creek into the sandy loam alluvium with pebbly beds. This indication of shallow saline groundwater is supported by the presence of saline scalds on the surface nearby (Fig. 6).

Figure 6. View towards southeast of salt scalding in upland basin in headwaters of Mitta Mitta Creek. (Regolith Landform Province 1; 0581752E 6139142N, Horizontal Datum WGS84).

3.1.3 Aeolian sediments

Lunettes (Iuu1)

Lunettes are formed by wind blown sediment being deposited as a crescentic dune adjacent to and on the leeward (eastern) side of an ephemeral lake or swamp. Two small (less than 0.5km long) lunettes associated with swampy depressions occur on the broad alluvial plains in the north. In the south a larger (2km long) possible lunette is associated with a depression adjacent and to the west of upper Houlaghans Creek. The lunettes have not been field checked, and the nature of the sediment is not known.

Aeolian sand sheets and dunes (ISu1, ISud1)

Northeast of West Wyalong, quartzose aeolian sand sheets and dunes (*Isu1*) overlie magnetic alluvium of the Wyalong palaeochannel and, presumably, weathered bedrock. It is likely that these aeolian sediments were derived from Wyalong palaeochannel sediments upstream to the southwest, and that their accumulation blocked the northeast course of the palaeochannel. As a result drainage over the upstream part of the palaeochannel was diverted by the sand drifts to flow towards the southeast and become the modern Gagies Creek (Gibson and Chan, 2000).

To the northwest of Yiddah a series of small quartzose sand bodies (*ISud1*) form a linear northeast trend which parallels a modern creek. It is possible that these are the remnants of source bordering dunes from an older generation of the modern creek. At one location a roadside embankment has exposed 2m of yellow quartz sand. A hand auger hole shows that this grades down into well cemented white sand. Two small isolated dunes occur northeast and east of West Wyalong.

3.1.4 Lake and swamp sediments

Lake and swamp sediments may make up part of the valley fill sediment of the Bland palaeovalley. However, they are difficult to differentiate from fine-grained alluvial sediment in drill hole cuttings, and thus their distribution is not well known. Small modern swamps are present on the alluvial areas mainly in the north of the area.

Swamp sediments (Paw1)

Small swamps are scattered on the broad alluvial plains in the north of the area. Most of these swamps do not have associated lunettes. However, an isolated swamp, as mentioned previously, on the western edge of upper Houlaghans Creek in the south, may have a large lunette. In the far northeast of the area more extensive swamps are associated with Lake Cowal which is to the north of the area. The swamps are internal drainage depressions with sediments occasionally deposited in still-stand water.

3.2 Units Dominated by *In-situ* Regolith

Areas mapped as being dominated by *in-situ* regolith are extensive south of the Lachlan-Murrumbidgee drainage divide, and around the broad alluvial plains north of the divide. *In-situ* regolith materials consist of residual materials and saprolith.

3.2.1 Residual materials

Residual material is relatively *in-situ* regolith that has lost its isovolumetric character, eg. collapsed saprolite, or has moved only locally, eg. lag.

Residual materials on plains and rises (Rep1, Rer1)

Undifferentiated residual materials and locally transported colluvium mantle plains (*Rep1*) and rounded rises (*Rer1*) both north and south of the Lachlan-Murrumbidgee drainage divide. This cover is highly variable in depth and character as indicated by drilling and field data. Electromagnetic depth profiles, which contrast conductive and resistive layers, support this.

North of the divide unit Rep1 has been mapped to the northeast of West Wyalong, in the headwaters of Bland Creek and on the Lachlan-Murrumbidgee divide between the north flowing Narraburra Creek and the south flowing Houlaghans Creek. Rises with residual materials are mostly to the northwest of West Wyalong, southwest of Barmedman, and on and north of the Lachlan-Murrumbidgee divide between the north flowing headwaters of Narraburra and Trigalong Creeks.

South of the Lachlan-Murrumbidgee divide there are plains with residual materials on both sides of Houlaghans and Billabung Creeks, but especially adjacent to Billabung Creek downstream of the southern AEM area and over the Houlaghans-Billabung drainage divide within and south of the southern AEM area. Polygons of rises with residual materials are scattered from the Lachlan-Murrumbidgee divide to just south of the southern AEM area, and are on both sides of Houlaghans and Billabung Creeks, as well as across the drainage divide between them (Fig. 7).

There is a large variability in the characteristics of the cover and saprolite in *Rep1* and *Rer1* depending on the bedrock lithology, pedological and geomorphic processes, and possible inherited and exotic sediments. The grain size (eg. sand, clay) of the residuum and locally derived colluvium reflect the underlying bedrock, for example, sandy cover (residuum and colluvium) over granite on either side of Houlaghans Creek in and to the west of the southern AEM area. Another example is residual clay on highly weathered Palaeozoic shales on the Lachlan-Murrumbidgee drainage divide between Houlaghans and Narraburra Creeks. Abundant magnetic iron pisoliths and goethite nodules on residual clay plains with loamy soils bordering on Billabung Creek south of the southern AEM area may reflect the high iron content of the highly magnetic underlying Junawarra Volcanics.

Figure 7. View to east from the crest of a rise across covered plains and rises of the interfluve between Houlaghans Creek to the west and Billabung Creek to the east. The upland front can be seen in the distance. (Regolith Landform Province 4; 0548151E 6150012N, Horizontal Datum WGS84).

In some areas loamy topsoils have clayey subsoils, eg. on acid volcanics of the Junawarra Volcanics, which may be due to leaching of clays downwards (ie eluviation), resulting in texture contrast soils. Both pedological factors (eg. eluviation and bioturbation) and geomorphic processes (eg. sheetwash and saprolite collapse) often result in a mobile zone of locally transported cover.

Rounded quartz granules and magnetic iron pisoliths are scattered widely across residual plains and rises. We found rounded quartz granules on crests of rises and on drainage divides, such as at RAB hole G1 on the Houlaghans-Billabung divide, and on the Lachlan-Murrumbidgee divide between Mirrool and Barmedman Creeks. It is conceivable that these rounded quartz granules are inherited remnants of an older sediment cover, such as preserved in unit *Aeu1*. These quartzose sediments may have been originally derived from Late Jurassic to Early Cretaceous fluvial sediments that may have covered much of south-east Australia. (Chan, 1999; Gibson and Chan, 1999; Gibson et al., 1999).

Sediments in a railway cutting at Marinna within *Rep1*, about 3kms east of Junee at the top of the catchment draining immediately east of Houlaghans-Billabung drainage divide, are described as parna by Beattie, 1972, ie. exotic aeolian clay that may have been remobilised as colluvium or alluvium after initial deposition. Mineralogical and petrophysical characteristics of this material have been studied from an AGSO core hole (M1) drilled adjacent to Beattie's rail cut parna site (Munday et al, 2000). They conclude that an eroded palaeovalley has been filled with material from two sources – local and aeolian, and that these materials have been reworked by alluvial and colluvial processes. If aeolian derived silt and clay is incorporated within the cover in Marinna, parna is likely to be present in other parts of *Rep1*.

Most of the near surface material in *Rep1* in this general area is depleted in potassium, as indicated by gamma-ray spectrometrics. It is likely that much of the granite residuum and locally derived colluvium from the residuum in *Rep1* is leached. In *Rer1* the relatively high potassium signature on the crests of rises suggests that there is limited residual material or saprolite on the crests, or that the residuum is not as leached here. Further fieldwork is required to ascertain this.

We have not found it possible to distinguish between residuum and sheetwash colluvium from a granitic source by gamma-ray spectrometric response. Similarly, with drill cuttings the distinction is unclear, other than to differentiate cover (residuum and/or sheetwash) from saprolite. However, the residual units (*R*) have a gross landform (photo-interpretation) uniformity that is different from that of the sheet wash units (*CH*). This is supported by field observations indicating residuum up to 2m depth on crests. Away from crests company drill hole 96JAC084 east of Houlaghans Creek intersected 16m of clay to silt cover with minor sand and calcareous induration overlying 12m saprolite, then saprock. Drill hole 96JAC090 drilled on lower slopes of *Rep1* also intersected 14m of clay to silt cover over 30m of saprolite, then saprock. Calcrete nodules and clay hardpans, including poorly cemented conglomeratic sediments, and ferruginous fragments have been noted within the cover in places.

Bedrock within units *Rep1* and *Rer1* is variably weathered, but often highly weathered in granitic and recessive sedimentary bedrock terrain. Moderately weathered bedrock and granite corestones subcrop on some rises, and stony lag and outcrop occurs on the crests of other rises. A toposequence on sedimentary bedrock is indicated by RAB drill holes G16 and G17 about 10km east of Junee. Drill hole G17 drilled on the crest of a rise with lag of angular rock fragments penetrated 1m of residual soil over saprolite to 15m (bottom of hole). Drill hole G16 on the lower slope of the rise to the north intersected 7m of sediment with calcrete over saprolite to 15 m (bottom of hole).

Residual lags on plains and rises (RLep1, RLer1)

Most of the general comments for *Rep1* and *Rer1* apply to *RLep1* and *RLer1*. However, in addition there is a lag of abundant magnetic iron pisoliths (determined as maghemite from near West Wyalong tip) and ferruginous rock fragments. These ferruginous lag units (Fig. 8) have been mapped with the help of gamma-ray spectrometrics, which depict these areas as being dominated by thorium.

Figure 8. Ferruginous lag in the Wyalong area. (Regolith Landform Province 4; 0519213E 6248285N, Horizontal Datum WGS84).

The lag also includes lithic fragments (saprolite and rare sub-rounded allochthonous pebbles) and quartz. Rare rounded quartz granules to small pebbles (to 1.5cm diameter) are present on the crest of some rises. Mottled saprolite and some mottled indurated sediment pavement or subcrop with surface lag may occur on some crests. Such sediment has also been found on the lower slopes of a rise northeast of West Wyalong, as if it had once draped the landscape. It is extremely difficult to distinguish mottled granite saprolite from mottled granite-derived sediment, unless a rare rounded quartz granule to pebble is preserved within the sediment, so the extent of granite saprolite versus indurated granite derived sediment is unknown.

Goethitic nodules and ferruginous concretions within mottles in granite saprolite appear to be eroded out and then transported, becoming magnetic iron pisoliths containing maghemite, possibly due to goethite being transformed to maghemite by bushfire or microbial activity. In this form they are preferentially preserved as lag, or transported and deposited in colluvium or alluvium (cf. Wyalong magnetic palaeochannel).

The photo-interpreted units *Rep1* and *Rer1* include part of the Wyalong palaeochannel, which is only mappable using high-resolution magnetics. Its location is given by a separate digital coverage, along with other interpreted magnetic palaeochannels. The palaeo-alluvium is locally eroded and partially inverted in relief.

3.2.2 Saprolith

Saprolith landforms retain bedrock form, even though weathered, as opposed to residual materials and sediments that often mask the bedrock form. Saprolith regolith landforms have been distinguished on the basis of relief. Saprolith is weathered bedrock that retains its isovolumetric character, and is made up of saprolite and saprock. Saprolite has more than 20% of labile minerals weathered, saprock less than 20%.

Saprolith plains, rises and low hills (Sep1, Ser1, Sel1)

We have used the more general regolith type, saprolith, as there is insufficient information in these areas to distinguish saprock from saprolite as the dominant regolith material, or there is a mixture of saprolite and saprock dominated areas. Areas are considered to be saprolith dominated if any residual or transported cover is generally less than 2 m thick.

Saprolith erosional plains (*Sep1*) with low relief (<9m), low slopes and rounded crests are mapped in scattered patches on various bedrock lithologies both north and south of the Lachlan-Murrumbidgee drainage divide, though not in the West Wyalong area. Many polygons of *Sep1* are small in area (<1km diameter), especially in the north. However, in the headwaters of Kindra Creek flowing to the southwest, Billabung Creek flowing to the south, and Bland Creek flowing to the north, larger areas of saprolith erosional plains occur.

Sep1 regolith consists of sub-cropping and outcropping saprolith that may be ferruginised, residuum and possible locally derived colluvium in the form of sheetwash. Typically crest exposures studied in the field have up to 0.5m residual soil, with lag in places, overlying variably weathered bedrock.

Saprolith rises (*Ser1*) are the most extensive saprolith landform. This regolith landform unit occurs in two dominant areas and as scattered polygons, often with skirts of *CHer1*. An arc of *Ser1* borders saprolith low hills within the Wantabadgery Granite immediately south of Junee. Areas of *Ser1* over Wagga Group metasediments in the western part of the area are characterised by thin stony soils with lithic lag. Many of the Wagga Group rises have sharply defined saprock to fresh bedrock ridges of the more resistant sedimentary lithologies of quartzose sandstone and chert. The Lachlan-Murrumbidgee drainage divide follows these resistant ridges for much of its northwesterly course in the northern part of the Gilmore area. More rounded crests with upper slopes of about 2° on less resistant sedimentary lithologies also occur in these areas.

Scattered polygons of *Ser1* are mapped over sediments and felsic volcanics of Combaning, Stockingbingal and Bethungra Formations in the lowlands in the southeast of the Gilmore project area, and the felsic Frampton Volcanics in the uplands further to the southeast.

The arc of granitic rises south of Junee has dominantly subcropping granite saprolite up to at least 4m depth, with sporadic outcrop of corestones on crests and slopes. The soil is generally a sandy loam, and at one 2m profile sandy clay loam with abundant quartz sand grains overlies mottled clay with goethite nodules on an upper northwest-facing slope. Upper slopes are generally about 4°. At another site relief inversion is indicated by at least 4m of granitic colluvium, with possibly a 1m thick mottled clay parna layer draped over top, filling a palaeovalley in highly weathered granite on the crest of a rise. At still another site on a crest there is at least 2m of residual gritty loam soil. There are local indications of a salinity problem, as indicated by a saline scald just west of the

Houlaghans–Billabung drainage divide, and saltbush planting on a valley floor near the eastern edge of this unit.

Regolith on crests of *Ser1* on sedimentary and volcanic bedrock is variable, ranging from lithosols and sub-cropping saprock, to 25cm to 1m deep residual soils on saprolite. Rare rounded quartz clasts to 2cm diameter, ferruginous rock fragments and iron pisoliths are present on some crests. Minor colluvium occurs in pockets on some lower slopes. Well-rounded quartzite pebbles to cobbles often occur as a lag over conglomeratic bedrock of Combaning Formation, and similarly, shale lag occurs in places. Silicified bedrock associated with hydrothermal alteration, especially in Combaning Formation, forms low crests of *Ser1*, eg. near Yiddah.

A large area of saprolith low hills (*Sel1*) is present on the southern edge of the Gilmore area to the west (Fig. 9). As mentioned above, it has a skirt of *Ser1* to its north, and occurs predominantly on the Wantabadgery Granite. It also occurs on a band of schist of the Wagga Group on the eastern edge of this area. At one location in an upper slope profile on the schist, sandy loam soil overlies highly weathered bedrock to within 40cm of the surface. *Sel1* on the Wantabadgery Granite is generally dissected with outcrops on crests and local colluvial lower slopes. Much granitic detritus is being shed into the creeks, which are eroding into their own older bedload deposits to form terraces (cf. *Aal1*). Other smaller areas of *Sel1* occur mainly on sedimentary and volcanic bedrock, both in the north and central-east to southeast of the area.

Figure 9. Highly to moderately weathered granite with aplite dyke, and colluvium above stone line. Road cut near crest of rise southwest of Junee. (Regolith Landform Province 3; 0551530E 6137358N, Horizontal Datum WGS84).

Saprock rises and low hills (SSer1, SSel1)

Saprock rises (*SSer1*) and low hills (*SSel1*) occur mainly in the uplands in the southeast of the Gilmore project area, extending to Springdale north of the Lachlan-Murrumbidgee drainage divide, and in granite country southeast of Barmedman (Fig. 10) and northeast of Temora. Saprock low hills also occur around Junee and further southeast, as well as in the Booberoi Hills northeast of West Wyalong. Some local granite hills northeast of Temora with relief up to 180 m have been included in *SSel1*.

As well as slightly weathered bedrock to locally fresh bedrock, minor residuum and colluvium is present on rises and there is a partial veneer of colluvium on low hills. Skeletal soils are common, and thin stony soils to less than 0.5m occur locally. Minor more highly weathered bedrock occurs in places, eg. at Gidginbung Mine northwest of Temora, which is on the crest of a saprock rise, and minor phyllite interbeds in saprock low hills of the Booberoi Hills which form a linear north-northwest trending ridge.

Figure 10. View to the northeast towards the upland front (Regolith Landform Province 1); Alluvial plains and terraces in midground (Regolith Landform Province 4); (0580999E 6130499N, Horizontal Datum WGS84).

3.3 Units dominated by unweathered bedrock

Unweathered hills, mountains, escarpments and footslopes (BUeh1)

As regolith is minimal to non-existent in *BUeh1* areas, landforms have not been separately defined. The regolith landform symbol reflects the dominant landform, ie. hills. *BUeh1* has been mapped mostly on felsic volcanic and granitic terrain in the uplands south of and on the Lachlan-Murrumbidgee drainage divide in the east. A smaller area is on Billys Lookout Granite north of Sandy Creek to the southwest of Lake Cowal.

Most of *BUeh1* consists of hills, with local higher mountain peaks. Steep escarpments of variable relief are common along the upland front to the east of Billabung Creek (Fig. 10). Steep footslopes (>30m/km) occur along the upland front especially to the north of Bethungra. Minimal regolith occurs sporadically in this rocky steep terrain in the form of saprock and minor saprolite and colluvium, including scree. Locally there is banded outcrop pattern with minimal soils between outcrops.

3.4 Units dominated by anthropogenic regolith

Anthropogenic fill (Fm1)

A tailings dam at the now closed Gidginbung gold mine (Fig. 11), to the northwest of Temora, has been mapped as made land. Other areas of made land not mapped because of lack of detailed information at the time of compilation include overburden dumps at Gidginbung, and banks formed from excavated materials at the man-made Centenary Lake (north of Temora) and numerous farm dams. Unmapped made land is also associated with roads, railways, towns and small scale mining activities carried out in the past in many parts of the area.


Figure 11. Gidginbung gold mine pit on crest of rise (0542224E 6201310N, Horizontal Datum WGS84).

4. CONCLUSION

The regolith landforms of the Gilmore project area have been described here as an adjunct to the regolith landform GIS coverage, database descriptions of the mapping units, and the hardcopy regolith landform map included with this report. The results of this mapping will be integrated and synthesised with the three dimensional architecture gained from interpretation of drilling and electromagnetics. This will then become the basis for a description of the evolution of landforms and regolith in the Gilmore project area.

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