REGOLITH-LANDFORMS OF NORTHERN LAKE PADDOCK, FOWLERS GAP ARID ZONE RESEARCH STATION, WESTERN NSW

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INTRODUCTION

The northern part of the Lake Paddock at the University of New South Wales' Fowlers Gap Arid Zone Research Station (Fowlers Gap) (Figure 1) contains a diversity of regolith materials and associated landforms that represent some of the significant processes in the regolith and landscape evolution of this part of the Barrier Ranges, western NSW. This landscape is the culmination of the interaction between many different landscape controls such as bedrock lithology and structure, Cainozoic tectonism, climate change and Mesozoic eustacy. This manuscript provides an account of the regolith and landforms of the northern Lake Paddock area, as well as outlining some of the aspects of the broader northern Barrier Ranges regolith and landscape evolution that can be determined from this area.

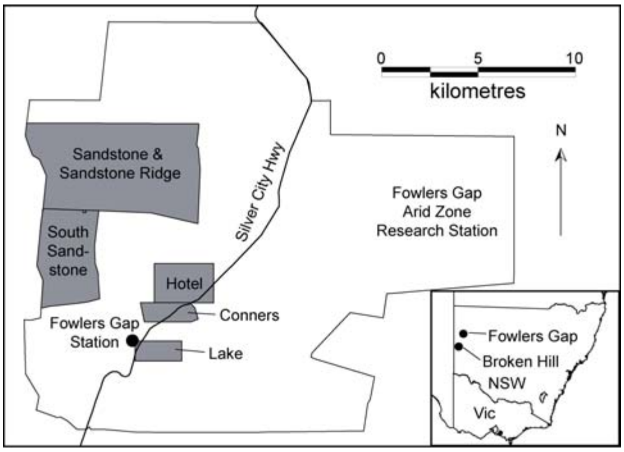

Figure 1: Location map of the Fowlers Gap Arid Zone Research Station. Boundaries of the Station and paddocks mapped to date (greyed-out) are shown. Lake Paddock is indicated in the south of the Station.

SETTING

The study area is approximately 2.3 km x 1 km, along the northern edge of Lake Paddock (Figure 1, 3). The homestead buildings of Fowlers Gap Station are just beyond the northwestern corner of the study area, which makes access to the study site within easy walking distance. The study area includes part of the channel of Fowlers Creek in its northwestern corner. The remainder of the area is dominated by rises and low hills of the Barrier Range (culminating in the 'Lake Ridge' in the east), with minor erosional and depositional plains, particularly in the west of the area. The Silver City Highway passes through the western edge of the area and station tracks traverse other parts, mostly along the NNW-SSE trending ridge crests.

Geology

The bedrock geology of the area was mapped by Cooper *et al.* (1975) and is dominated by Adelaidean metasediments including quartzite, shales, dolomitic shales and minor dolomite of the Caloola Synclinorial Zone. These have been included within the Fowlers Gap Formation, which includes thick beds of massive quartzite, underlain by the Faraway Hills Quartzite and the Sturts Meadows Siltstone. The Devonian Coco Range Sandstone (Neef *et al.* 1995) occurs in the far east of the area. The Adelaidean and Devonian are separated by the Nundooka Creek Fault, which trends NNW-SSE in the east of the area. Mesozoic fluvial and marginal marine gravels are interpreted as capping many of the rises in the far east of the area and are part of the basal units of the Telephone Creek Formation (Beavis & Beavis 1984), which is equivalent to sediments of the Eromanga Basin (possibly equivalent to parts of the Cadna-owie Formation and the Bulldog Shale). These include clasts of local bedrock (Adelaidean, Devonian) plus medium-high grade metamorphic rocks (schists, gneisses) that are presumed to be derived from the Palaeoproterozoic, transported from the Euriowie Inlier or possibly parts of the Broken Hill Inlier further south. The Cainozoic geology units are described as a part of the transported regolith-landform units of this manuscript.

Vegetation

Chenopod shrublands dominated by bluebushes (*Maireana spp.*) and saltbushes (*Atriplex spp.)* extend across much of the study area through most of the regolith-landform units. Riparian woodlands are dominated by river red gums (*Eucalyptus camaldulensis*) along Fowlers Creek and the tributary flowing from the "Lake" reservoir—Gum Creek. Smaller streams (mapped here as drainage depressions) are mostly colonised by prickly wattle (*Acacia victoriae*) shrubs. A mallee shrubland-woodland dominated by curly mallee

(*Eucalyptus gillii*) occurs in the east of the study area. Slopes and upper drainage depressions are mostly colonised by belah (*Casuarina cristata*), dead finish (*Acacia tetragonophylla*) and rosewoods (*Alectryon oleifolium*) and quartzite ridges are dominated by mulga (*Acacia aneura*).

Climate
The climate at Fowlers Gap is semi-arid with average rainfall is ca. 220 mm, occurring principally as low frequency, high magnitude falls.

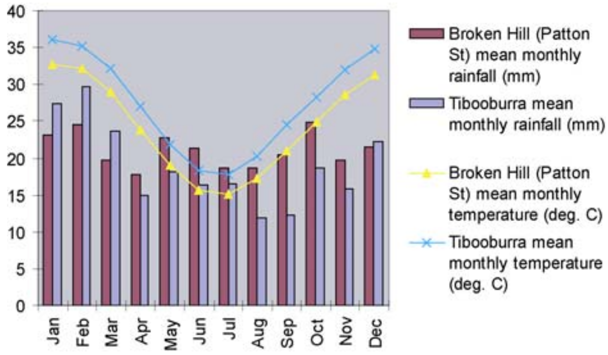

Figure 2: Climate averages for Broken Hill (Patton St) and Tibooburra. BOM (2005).

Landuse
The area has hosted pastoral grazing since the 1860s. Until 1949 it was a part of the 'Corona' run, and since 1966 the university of New South Wales has managed the area as an arid zone research station that includes some sheep, goat and cattle grazing. Rabbits arrived in the region in 1885 and have been a very significant herbivore grazer since that time.

MAPPING METHODS
The field mapping of this area was conducted as a part of an undergraduate regolith geology field trip jointly run within CRC LEME between the Australian National University and the University of Adelaide. This included two days of field mapping with one half day dedicated to biogeochemistry and soil sampling in the mapping area. To assist with the mapping a range of remote sensing data were used, including:

- A georectified aerial photo mosaic (Qascophoto 1981 1:10,000 colour infra-red aerial photos) (Figure 3);
- Landsat 5 TM;
- Radiometrics (NSW DPI Koonenberry version 1 dataset);
- First Vertical Derivative (1VD) aeromagnetics (NSW DPI Koonenberry version 1 dataset);
- Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) bands 3N21 image;
- Topographic map (Fowlers Gap 1:25,000) and Digital Elevation Model (DEM, developed from 5 m contours of the Fowlers Gap 1:25,000 topographic sheet and Shuttle Radar Topography mission—SRTM—90 m pixels); and,
- Torowangee-Fowlers Gap 1:100,000 geology sheet (Cooper *et al.* 1975).

Students mapped onto the aerial photo mosaic basemap and used the geophysical and remotely-sensed images to compare and contrast different regolith materials in their different landscape settings. Students worked in groups, each also being issued with a GPS receiver to more accurately record their observations for each regolith-landform unit (RLU).

RESULTS: REGOLITH-LANDFORMS
A total of 24 RLUs have been mapped and described from the area (Figure 4). The polygon codes and presentation style is compatible with the Geoscience Australia RTMAP scheme (Pain *et al.* in press), as this provides a universally applicable mapping standard for regolith materials and landforms and has been shown to be adaptable to a range of applications including landscape research, mineral exploration frameworks and land management. The RLU nomenclature scheme applied to this area is based on the scheme developed for the Sandstone and Sandstone Ridge Paddocks 1:25,000 regolith-landform map (Hill & Roach 2005), based on earlier work by Hill & Roach (2003). Note that not all of the same RLUs appear on this map, therefore RLUs may not be numbered sequentially.

TRANSPORTED REGOLITH

Alluvial Sediments
Alluvial sediments are mostly associated with the channel and tributaries of Fowlers Creek and Gum Creek, with minor occurrences in small pools and levees along alluvial depressions.

Aap1: Red-brown clays and silts and sub-rounded to sub-angular quartzose and lithic sands, granules, pebbles and cobbles associated with a low-relief, relatively smooth land surface with some minor incised channels. Vegetation consists of a chenopod shrubland dominated by bladder saltbush (*Atriplex vesicaria*), bluebushes (*Maireana* spp., principally *M. pyramidata*), prickly wattle (*Acacia* *victoriae*), belah (*Casuarina cristata*) on the east, forbs and grasses. River red gum (*Eucalyptus camaldulensis*) also occurs adjacent to Aap1 on Gum Creek.

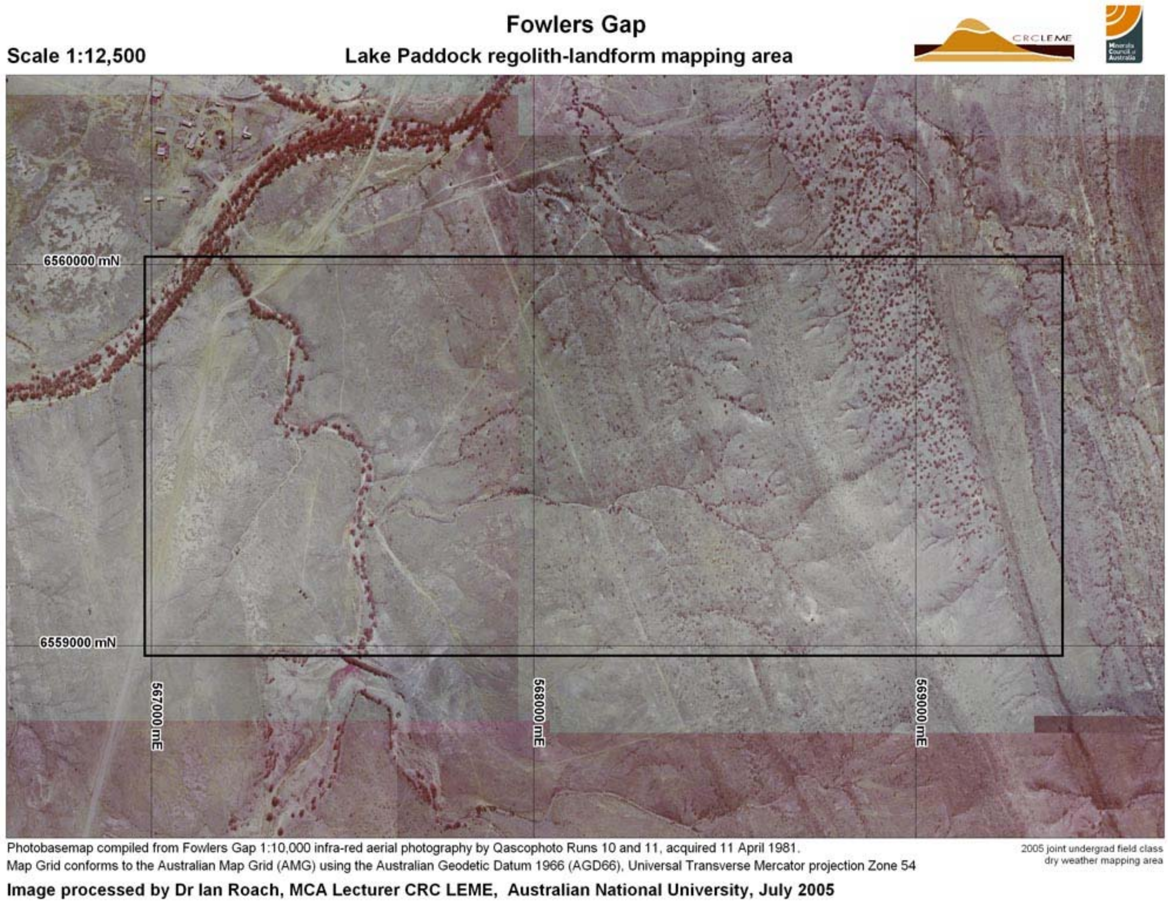

Figure 3: photo mosaic basemap.

Aaw2: Red-brown clayey and silty sediments associated with "The Lake". Fringed by a riparian woodland of river red gum (*Eucalyptus camaldulensis*), with an understorey consisting of chenopods, predominantly bladder saltbush (*Atriplex vesicaria*) and bluebushes (*Maireana* spp., principally *M. pyramidata*), forbs and grasses.

ACah1: Red-brown silts and sub-rounded to sub-angular quartzose and lithic sands, granules, pebbles and cobbles in channels and chutes incised < 3 m into the surrounding land surface. Vegetation in the channel of Fowlers Creek and Gum Creek is dominated by a riparian woodland consisting of river red gum (*Eucalyptus camaldulensis*), prickly wattle (*Acacia victoriae*) and some boobiala (*Myoporum montanum*) with an understorey consisting of chenopods including bladder saltbush (*Atriplex vesicaria*), bluebushes (*Maireana* spp., principally *M. pyramidata* and *M. astrotricha* but also some *M. sedifolia*), thorny saltbush (*Rhagodia spinescens*), emubushes (*Eremophila ssp*.), forbs and grasses.

Aed1: Red-brown silts and sub-rounded to sub-angular quartzose and lithic sands, gravels, pebbles and cobbles with locally exposed weathered bedrock in incised channels and gullies. Vegetation consists of rare river red gum (*Eucalyptus camaldulensis*) in the lower reaches, prickly wattle (*Acacia victoriae*) and dead finish (*Acacia tetragonophylla*) in the central to upper reaches and belah (*Casuarina cristata*) and rosewood (*Alectryon oleifolius*) in the upper reaches. A ubiquitous chenopod shrubland includes bladder saltbush (*Atriplex vesicaria*), black bluebush (*Maireana pyramidata*), southern bluebush (*M. astrotricha*), pearl bluebush (*M. sedifolia*) and rare old man saltbush (*Atriplex nummularia*). Lemon-scented grass (*Cymbopogon ambiguus*) and groundsel (*Senecio sp.*) are common within and immediately adjacent to channels, plus forbs and grasses.

Apd1: Red-brown, subrounded to subangular quartzose and lithic sands, granules and silts associated with smooth, low relief landforms (< 9 m), typically associated with intersection point floodouts of alluvial channels and drainage depressions. Colonised by chenopod shrublands dominated by *Maireana spp*., *Atriplex spp*., and *Sclerolaena spp*., with *Xanthum spp.*

Colluvial Sediments

Cel1: Weakly ferruginised angular, blocky quartzite rubble of coarse sand to cobble size with minor red-brown fines sand and silt associated with the edges of a high relief quartzite ridge. Vegetation consists of scattered belah (*Casuarina cristata*) on the lower slope and mulga (*Acacia aneura*) on the upper slope, chenopod shrubland (principally pearl bluebush *Maireana sedifolia*), forbs and grasses.

Cep1: Angular lithic (mostly quartzite) and quartzose granules with minor red-brown quartzose sands, associated with areas of low topographic relief (< 9 m). Colonised by chenopod shrublands dominated by *Atriplex vesicaria*.

Cer1: Angular lithic (mostly quartzite) and quartzose gravels with minor red-brown quartzose sands, associated with areas of slight topographic relief (9-30 m). Colonised by chenopod shrublands dominated by *Atriplex vesicaria*.

Sheetwash Sediments

CHep1: Angular lithic and quartzose gravels and red-brown quartzose sands on a low-relief (< 9 m), low gradient landform with shallow bedrock sub-crop that is locally shedding sediment. Colonised by open chenopod shrublands dominated by *Atriplex vesicaria, Maireana spp.* and grasses.

CHep2: Rounded and minor sub-angular quartzose and silicified sediment clast gravels and red-brown quartzose sands on a low-relief (< 9 m), low gradient landform that is locally shedding sediment. Colonised by open chenopod shrublands dominated by *Atriplex vesicaria*.

CHep4: Rounded to minor sub-angular quartzose, silicified sediment clast gravels and red-brown quartzose sands on a low-relief (< 9 m), low gradient landform with shallow bedrock sub-crop that is locally shedding sediment. Colonised by open chenopod shrublands dominated by *Atriplex vesicaria,* and *Maireana spp.* and occasional *Casuarina pauper* trees.

CHer1: Angular lithic and quartzose gravels and red-brown quartzose sands on a moderate-relief (9-30 m), moderate gradient landform with shallow bedrock sub-crop that is locally shedding sediment. Colonised by open chenopod shrublands dominated by *Atriplex vesicaria* and *Maireana spp*.

CHer4: Rounded to minor sub-angular quartzose, silicified sediment clast gravels and red-brown quartzose sands on a moderate-relief (9-30 m), moderate gradient landform with shallow bedrock sub-crop that is locally shedding sediment. Colonised by open chenopod shrublands dominated by *Atriplex vesicaria* and *Maireana spp.* and occasional *Casuarina pauper* trees.

CHpd1: Angular lithic (mostly quartzite) and quartzose gravels with minor red-brown quartzose sands associated with areas of low topographic relief (< 9 m) with prominent 'contour band' surface lag patterns. Colonised by chenopod shrublands dominated by *Atriplex vesicaria* and *Maireana spp.*

***IN SITU* REGOLITH**

Slightly Weathered Bedrock

SSel1: Outcrop and angular float of weakly ferruginised Adelaidean quartzite, clasts ranging from coarse sand to boulder size, with minor red-brown fine sand and silt in a high relief landform. Dominant vegetation consists of mulga (*Acacia aneura*), chenopod shrubland, dominated by pearl bluebush (*Marieana sedifolia*) and minor ruby saltbush (*Enchylaena tomemtosa*) plus forbs and grasses.

SSep1: Outcrop and angular float of weakly ferruginised quartzite, clasts ranging from coarse sand to boulders, with minor red-brown fine sand and silt in a low relief landform. Vegetation consists of belah (*Casuarina cristata*) and rosewood (*Alectryon oleifolium*) with chenopod shrubland, forbs and grasses.

SSer1: Blocky, weakly ferruginised Adelaidean quartzite outcrop with angular lithic lag up to cobble size and minor red-brown fine sand and silt on a moderate relief landform. Vegetation consists of western boobialla (*Pittosporum spp*.), prickly wattle (*Acacia victoriae*), chenopods, forbs and grasses.

SSer2: Weakly ferruginised Adelaidean quartzite and interbedded green dolomitic shale outcrop with angular lithic lag up to pebble size and minor red-brown fine sand and silt on a moderate relief landform. Hardpan RCA is associated with the shale, coating joint surfaces and the soil-saprolite interface. Dominant vegetation consists of mulga (*Acacia aneura*) and chenopod shrubland, principally bluebush (*Maireana spp*.), grasses and forbs.

Moderately Weathered Bedrock

SMep1: Kaolinitic, ferruginous quartzose and micaceous shales with minor quartz veins, sandstones and dolomite. Low-relief landform (< 9 m) associated with angular gravel surface lags. Sparsely colonised chenopod shrublands typically dominated by *Atriplex vesicaria* and *Sclerolaena spp.* with occasional *Casuarina pauper* trees.

SMep3: Kaolinitic and dolomitic shales with minor quartz veins and dolomite. Abundant powder and hardpan (fracture fill and bedrock interface) regolith carbonates. Low-relief landform (< 9 m) associated with angular gravel surface lags. Sparsely colonised chenopod shrublands typically dominated by *Eucalyptus gillii*, *Maireana spp.* and *Sclerolaena spp.* with occasional *Casuarina pauper* trees.

SMer1: Kaolinitic, ferruginous quartzose and micaceous shales with minor quartz veins, sandstones and dolomite. Moderate-relief landform (9-30 m) associated with angular gravel surface lags. Sparsely colonised chenopod shrublands typically dominated by *Atriplex vesicaria* and *Sclerolaena spp.* with occasional *Casuarina pauper* trees.

Highly Weathered Bedrock

SHer1: Kaolinitic, highly ferruginous sandstones and micaceous shales with minor quartz veins, sandstones and dolomite. Moderate-relief landform (9-30 m) associated with angular pebbly and granule surface lags. Sparsely colonised chenopod shrublands typically dominated by *Atriplex vesicaria* and *Sclerolaena spp.* with *Casuarina pauper* trees.

INDURATED REGOLITH

Ferruginised regolith

The occurrences of ferruginised regolith in the area are mostly restricted to ferruginised saprolite exposures along the eastern footslope of 'Lake Ridge'. Hematitic saprolite derived from the weathering of a fine sandstone and adjacent shales conforms with the strike of the weathered metasediments. This suggests that there is a strong lithological control on the occurrences of these materials, probably due to the weathering of sulphides in the original sedimentary rocks. Minor, rounded maghemite pebbles occur within the CHep2 RLUs flanking Fowlers Creek in the east of the area.

Regolith carbonate accumulations (RCAs)

Hardpan and powdery RCA morphologies are associated with the Adelaidean dolomitic shales (SSer1, SSer2, Aed1) and Devonian sandstones (SSer2) in the mapping area. Hardpan carbonates also occur as bedrock fracture fill and coating the hydromorphic boundary along the bedrock/transported regolith interface.

DISCUSSION: REGOLITH AND LANDSCAPE EVOLUTION

Lithological Controls

Bedrock lithology and structure has a major influence on the expression of regolith and landforms in the area. The positive relief along strike ridges associated with Adelaidean quartzite is most prominent in the area. The structural-grain (mostly N-S trending) of the area also has a major influence on the drainage pattern of lower order stream tributaries in the area. In contrast, larger streams, such as Fowlers Creek, appear to cut across this structural grain and may reflect the inherited pattern of these streams derived from palaeodrainage. The mineralogy and chemical characteristics of bedrock lithologies also strongly influences the nature of regolith materials derived from different bedrock types. The ferruginous saprolite occurrences are likely to be mostly related to the presence of bedrock lithologies that previously contain sulphides, while regolith carbonates are most abundant overlying calcareous and dolomitic Adelaidean rocks.

Tectonic Controls

The Western Boundary Fault, and possibly the Nundooka Creek Fault, have facilitated active tectonism during the landscape evolution of the area. This is demonstrated along the range front associated with the Western Boundary Fault to the north of the area, where Mesozoic sediments have been tilted, and a series of stream terraces are closely associated with this fault system. This tectonism is related to the relative uplift of the Barrier Ranges and subsidence of the Lake Bancannia Basin area. Other than confidently ascribing this tectonism to post-Mesozoic times, further resolution of its timing is poorly constrained from this area. Strath terraces (here mapped as $CHep_2$ RLUs) flanking Fowlers Creek in the area represent a graded valley profile associated with relative drainage stability in the area. The incision that subsequently elevated these terraces extends upstream from the location of the Western Boundary Fault and therefore most likely reflects tectonic influences on drainage evolution in the area. The discovery of rare, rounded silcrete clasts that are lithologically similar to the Sandstone Tank silcretes (Hill & Roach 2003) suggest that these terraces post-date the late Eocene.

Climatic Controls
The area has experienced considerable climatic change since the Mesozoic. A detailed synthesis and study of this has so far not been undertaken in this study. Generally, one of the greatest climatic influences on the landscape evolution would be the increasing climatic aridity that developed towards the later part of the Cainozoic.

Eustatic Controls
For an intra-continental setting such as Fowlers Gap, it may at first seem surprising that changes in sea-level could have a significant influence of the region's regolith and landscape evolution. A major marine transgression and regression in the Cretaceous had a major influence on the regolith and landscape evolution of the area. The marine transgression towards shallow marine conditions in the east of the area is best expressed in the deposition and micro-fossil content of the Telephone Creek Beds, exposed along the Western Boundary Fault range front (Beavis & Beavis 1984, Gibson 2005). Rounded pebbles and boulders expressed on erosional plains capping rises (mapped here as $CHep_4$) underlie Telephone Creek Beds to the east and northeast of the area. These gravels contain a mixture of locally derived Adelaidean quartzite and Devonian sandstone, but also amphibolite and gneiss typical of Willyama Supergroup rocks, suggesting derivation from the south (Nundoo Inlier, Euriowie Block and possibly Broken Hill Block source). These gravels maybe basal fluvial and most probably cobble beach deposits associated with basin subsidence and marine transgression.

CONCLUSION
This relatively small area contains an important variety of easily accessible regolith-landform features that express some of the important regional features in the regolith and landscape evolution of the northern Barrier Ranges near Fowlers Gap.

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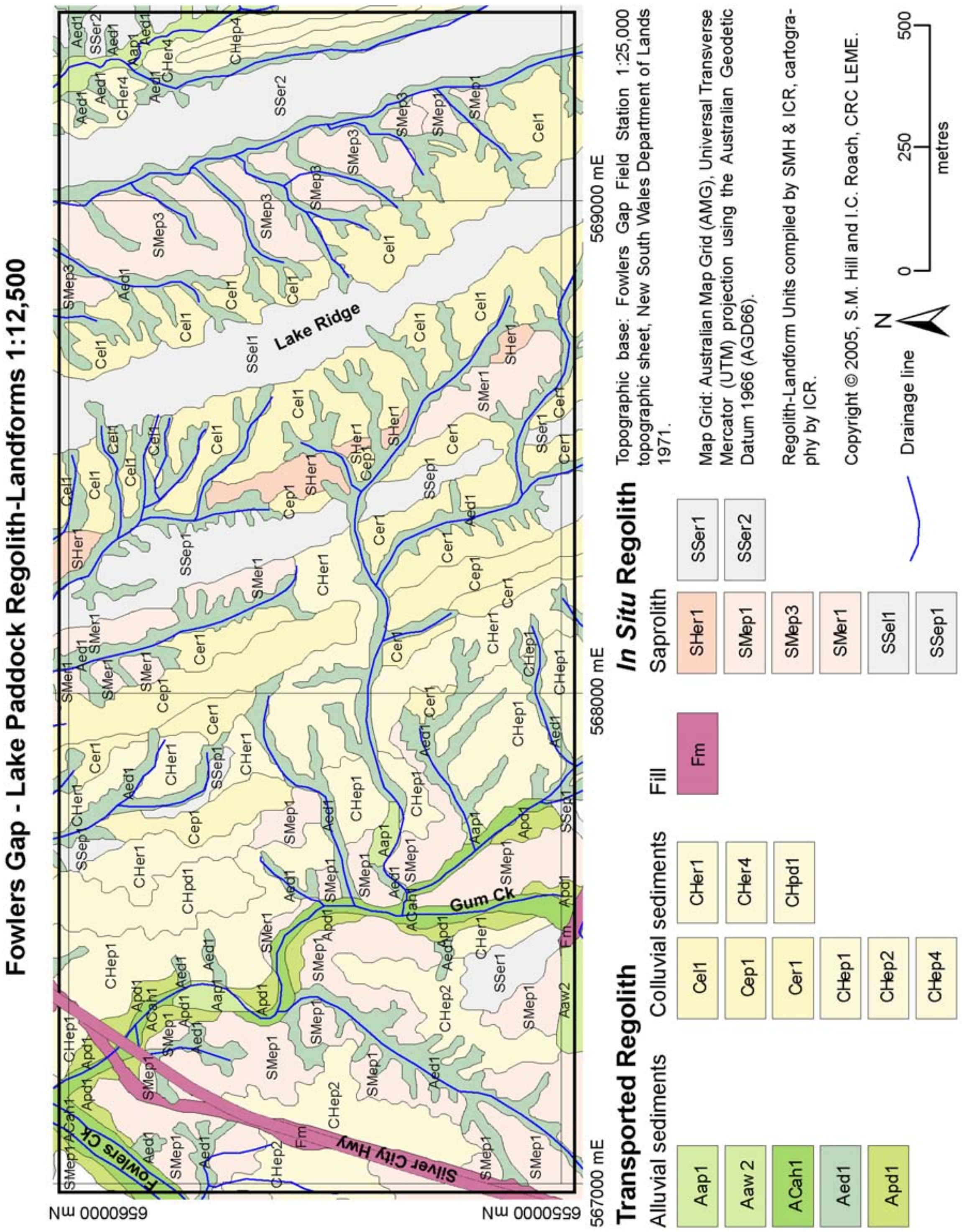

Figure 4: Lake Paddock regolith-landform map.