TOMINGLEY PROJECT, CENTRAL WESTERN NSW, 1: REGOLITH-LANDFORM MAPPING TECHNIQUES AND IMPLICATIONS FOR LANDSCAPE EVOLUTION

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INTRODUCTION

The Tomingley area is situated within the northern Macquarie Arc, part of the Lachlan Fold Belt, in central western NSW. Ordovician volcanic rocks of the Macquarie Arc host some of Australia's largest gold and copper-gold deposits including the > 1.3 M oz Northparkes deposit, the > 3 M oz Cowal deposit and the > 30 M oz Cadia-Ridgeway deposits. Recent work by Alkane Exploration Ltd. (Alkane) has proven a resource of > 600,000 oz of gold in the Wyoming One and Three deposits (Alkane 2005) at Tomingley, north of the company's Peak Hill gold mine (Figure 1).

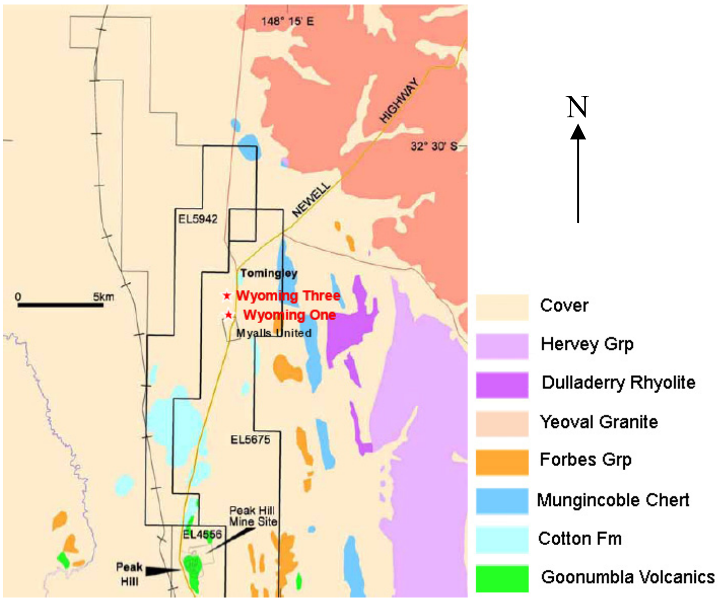

Figure 1: Regional geology of the Tomingley-Peak Hill area including the Wyoming gold deposit (Alkane 2004).

This manuscript describes some of the methods used for 1:25,000 scale regolith-landform unit (RLU) mapping around the Tomingley area, including the Wyoming gold deposits, conducted during 2004 and 2005 (described in Roach 2006; this volume). The sources and sinks and 4-dimensional distribution of transported materials and implications for landscape evolution are then discussed in a mineral exploration context.

PREVIOUS WORK

The Tomingley region has been the subject of mineral exploration activities since before 1889, at which time production records commenced (Clarke 1983), focussed on a narrow belt of Ordovician volcanics between Forbes and Tomingley. Oxide zone and hard rock sulphide zone workings in the region until 1981 yielded an estimated 2185.7 kg (ca. 70,270 oz) from the Tomingley area, the bulk from the Myalls United mine, about 500 m south of the Wyoming deposits. An estimated 2703.4 kg (ca. 86,900 oz) was also mined from around Peak Hill pre-1981, mostly as alluvial gold (Clarke 1983). Further gold extraction by Alkane using cyanide heap-leach on the oxide zone at Peak Hill, ceasing in 2005, yielded ca. 153,000 oz. An estimated 467,000 oz remains below the weathering front as sulphide ore (Alkane 2005).

Chalmers *et al.* (2003) comprehensively describe the recent mineral exploration history, however, regolith interest commenced in the late 1990s when Bruce Cruikshank and Keith Scott conducted a partial leach soil survey over the Wyoming deposits for Sipa Resources, described in Cruikshank *et al.* (1999) and Scott *et al.* (2005). Alkane took over the lease and evaluated the Wyoming deposits using a combination of reverse-circulation and diamond core drilling, revealing a palaeochannel over the site, leading to an Honours project by Peter Bamford in 2004. Bamford refined a three-dimensional model of regolith distribution and pathfinder element distribution in the regolith around the deposits (Bamford 2004; Bamford *et al.* 2004). A biogeochemical survey of a large windrow of mature native trees, running almost directly across strike, commenced during January 2005, to determine whether the trees could be used to penetrate the significant transported cover to detect the Wyoming gold deposits. Preliminary results were published in Roach (2004) and Roach & Walker (2005) and will be fully detailed in later publications, e.g. Roach (in prep.). Regolith-landform mapping commenced in 2005, together with repeat biogeochemical sampling to determine possible seasonality effects. The resulting regolith-landform mapping procedure and map is described in this paper and in Roach (2006, this volume).

REGIONAL AND REGOLITH GEOLOGY

Seven main groups of basement rocks are mapped on the Narromine 1:250,000 geological sheet (Sherwin 1996) and these are also visible on aerial photography and radiometric imagery:

1. Ordovician-Silurian Cotton Formation (O-Sc), comprising coarse- to fine-grained sandstones and siltstones, with conspicuous quartz veining;
2. Mugincoble Chert (Om). The Mugincoble Chert is believed to be silicified Cotton Fm. These are both apparently contemporaneous with the Goonumbla Volcanics;
3. Ordovician Goonumbla Volcanics (Obv), comprising shoshonitic (K-rich mafic to andesitic) lavas and volcanoclastics with significant vein gold mineralisation;
4. Silurian Mumbidgle Formation (Sfm, Sfv), comprising mudstone, siltstone and minor sandstone;
5. Middle Devonian Dulladerry Volcanics (Dds, Ddr, Ddc), comprising rhyolite lava, ignimbrite, porphyry and minor volcanoclastic sediments;
6. Obley Granite (Dog) of the Middle Devonian Yeoval Granite Complex, which intrudes the Dulladerry Volcanics;
7. Late Devonian Hervey Group (Dh), comprising quartz sandstones and reddish mudstones of the Clagger Sandstone, Kadina Formation, Mandagery Sandstone, Pipe Formation and Caloma Sandstone.

Sherwin (1996) also mapped various alluvium as Cz, Cza, Qa and Qr. These comprise older, slightly more consolidated, more deeply red-coloured sediments (Cz) and, younger more greyish-brown sediments with noticeable meanders (Cza). Qa comprises recent alluvium in drainage systems and Qr comprises "elluvium" (*in situ* regolith) and colluvium. Basement rocks are generally slightly to moderately weathered and weakly ferruginised, forming plains and rises throughout the mapping area, rarely forming low hills. These have prominent colluvial mantles blending into the alluvial plains that dominate the landscape. It is only rarely that the boundaries between these regolith landforms are preserved undisturbed because of disturbance by agriculture. Many of the alluvial RLUs have been modified by cultivation or drain digging. More detail of the regolith geology and detailed descriptions of individual RLUs can be found in Roach (2006).

MAPPING TECHNIQUE

Regolith-landform unit descriptions follow the RTMAP scheme of Pain *et al.* (2000). The scheme labels RLUs using a flexible range of alphanumeric codes, for instance, "SSer1" representing slightly weathered saprolith (saprock) "SS" on an erosional rise "er" with a dominant regolith lithology of type "1", in this case Cotton Fm rocks. Regolith-landform units have been given a numerical modifier of 1 to 7 in keeping with the regional geological stratigraphy of the mapping area described above. The RTMAP scheme was also modified to include the prominent gilgai plains, which are included as "Aag" RLUs (alluvial sediments "A" on alluvial gilgai plains "ag") with appropriate numerical modifiers related to the dominant source materials.

Site descriptions and ground control points were collected during fieldwork in 2005 and 2006 using a Garmin hand-held GPS receiver with coordinates in the Universal Transverse Mercator Zone 55 projection using the Australian Geodetic Datum of 1966, in keeping with Alkane's GIS data. Preliminary RLUs were mapped onto stereo pairs of 1:50,000 colour aerial photographs using RLU site descriptions to extrapolate before further field checking. Completed RLUs were transferred onto overlays on orthorectified aerial photograph base maps. Orthophotos were prepared using camera parameters supplied by the NSW Land Information Centre, the Shuttle Radar Topography Mission 2nd release (SRTM2) digital elevation model from the National Aeronautics and Space Administration (NASA) and ground control points collected earlier. Completed RLU overlays were then scanned, raster-to-vector converted using Vextractor ver. 2.95 software and edited using MapInfo ver. 8 GIS software at the Department of Earth and Marine Sciences, ANU. Regolith-landform units mapped on the aerial photography were cross-checked against airborne radiometric data from the Northern Parkes Discovery 2000 dataset (Discovery 2000) and the included digital Narromine 1:250,000 geological sheet (Sherwin 1996) polygons and were modified where necessary to better reflect the dominant source materials.

PHOTOGRAPHIC AND RADIOMETRIC CHARACTERISTICS OF WEATHERED BEDROCKS

Colour aerial photography is the primary basis for the RLU map described in Roach (2006). This is extremely useful because of the stereo effect, enabling mapping of subtle landforms. Unfortunately, the aerial photography is of limited use in distinguishing different regolith materials because different basement rock types may release similar-looking light- or dark-toned sediments when weathered. Land use practices also make it difficult to distinguish subtle regolith-landforms, especially in areas that have been extensively cropped. However, the stereo photography is very useful for locating drainage channels, identifying subtle landforms such as drainage depressions, which appear lighter- or darker-toned than the surrounding plains, and for separating alluvial plains from depositional plains within the mapping area. This knowledge is instrumental for determining sediment migration pathways across the otherwise apparently "featureless" plains. Radiometric imagery from the Northern Parkes Discovery 2000 data release has been used to interpret the distribution of *in situ* and transported regolith on a regional scale and to separate regolith materials that appear similar on the aerial photographs. Imagery has 135 m pixels and is presented in a variety of formats, including a RBG image with potassium (K), thorium (Th) and uranium (U) represented as red, green and blue respectively, separate channels (K, Th and Total Counts) and K/Th ratio. The most useful image for this study was found to be the RGB image, used both to separate *in situ* regolith material from transported regolith and to estimate weathering grades. Another useful interpretation image was prepared by intensifying the radiometric RGB image with Total Counts as an intensity layer using ERMapper 6.4 software. This modified RGB image highlights the bedrock geology and weathering products and better separates strong and weak gamma-ray emitters, providing important clues to the sources and distribution of weathered materials.

A range of observations or empirical rules were developed from the RGB and intensified RGB radiometric images, such as:

1. Cotton Formation (O-Sc; Late Ordovician-Early Silurian) tends to be dull pink to white in the RGB images (moderate to high K, Th and U but with K in excess of Th and U). Colluvium tends to be darker pinks (low to moderate K, Th and U, but with K in excess of Th and U) through to green (low Th only). This latter colour may represent *in situ* leaching of K leaving Th-rich residue, or, mixing of colluvium with alluvium derived from the Dulladerry Volcanics, which onlaps;
2. Mugincoble Chert (Om; Ordovician) tends to display dark brown colours signifying overall low K, Th and U, but with K in excess of Th and U in the RGB image. This unit is black in the intensified RGB image, signifying low overall gamma-ray emission;
3. Goonumbla Volcanics (Obv; Late Ordovician-Early Silurian) is deep red in both images, indicating moderate to low K content;
4. Mumbidgle Formation (Sfm, Sfv; Late Silurian) is dull pink (moderate K, Th and U but with K in excess of Th and U) in both images. Colluvium tends to be dark pink (low K, Th and U but with K in excess of Th and U) through dark green (Th only). This too may be a mixture of colluvium and alluvium derived from the Dulladerry Volcanics, which onlaps;
5. Dulladerry Volcanics (Dds, Ddr, Ddc; Middle Devonian) is bright pink-white in both images where fresh (high K, Th and U in equal amounts), quickly fading to green (high Th), the green colour deepening along alluvial tracts leading to the west signifying additional leaching of Th. These sediments onlap Ordovician-Silurian saprolith outcrops, possibly mixing and resulting in blends from pink to green colours around outcrops of Cotton Fm and Mumbidgle Fm rocks;
6. Obley Granite (Dog; Yeoval Batholith, Middle Devonian) rocks tend to be bright pink to white where freshest (high K, Th and U, with K in excess of Th and U where pink coloured) in both images. Alluvium varies from white to dark pink in a large alluvial fan system leading westwards from the source. Colours signify K leaching in overlapping deposits of different ages: white youngest; pink oldest. This alluvial system appears to be sharply separated from green-coloured (Th-bearing) sediments derived from weathering and leaching of Ordovician-Silurian-Late Devonian basement rocks.
7. Hervey Group (Dh; Late Devonian) rocks tend to have dark green-blue colours (low Th and U only) in the RGB image, except for the dark red coloured Beargamil Subgroup (low K in excess of Th and U) that is visible in both images as a moderately strong emitter. Alluvium derived from these tends to be black-dark blue speckled in the RGB image or black in the intensified RGB image and is visible as dark leads trailing away from the Hervey Group outcrops and possibly on the Bogan River floodplain in the far west of the mapping area.

These observations have been used to label polygons in the RLU map described in Roach (2006) and to split polygons in a few situations where they have been shown to appear similar on aerial photography, but are actually composed of regolith materials from different sources.

IMPLICATIONS FOR LANDSCAPE EVOLUTION

The Tomingley area is bordered to the north and west by the Mesozoic Surat Basin (or Great Australian Basin; Sherwin 1996) and has a variety of variable-thickness transported regolith materials already noted, e.g., Chalmers *et al.* (2003), Bamford (2004), Bamford *et al.* (2004), Roach (2004), Roach & Walker (2005) Scott *et al.* (2005) and Roach (2006). These range in age from Recent to potentially Mesozoic, perhaps older. *In situ* and transported regolith materials from a number of different sources are visible on aerial photography, airborne geophysics and satellite imagery. These form a complex surface of overlapping and inter-mixed materials that may have different background geochemical values depending on their original rock type and weathering grade. Pattern drilling by Alkane gives an insight into the three dimensional structure of the regolith over the Wyoming deposit. A limited regional landscape evolution model has been developed using this 3D information, together with a new RLU map (Roach 2006). This review is limited to the post-Mesozoic development of the mapping area. A reasonable pre-Mesozoic geological history was presented by Sherwin (1996).

Drilling over the Wyoming deposits reveals a relatively simple stratigraphy in this area, consisting of saprolith overlain by mottled clay-rich alluvium, sandy alluvium with gravel lenses and finally loamy soil. Transported regolith is of variable thickness and ranges from 0 to > 60 m over the top of the Wyoming 1 deposit (Bamford 2004; Bamford *et al.* 2004). Further pattern drilling and high-resolution aeromagnetics by Alkane has revealed a complex palaeochannel system over the deposits with drainage predominantly to the north and northwest (Rimas Kairaitis, Alkane, *pers. comm.* 2005). The maximum age of these palaeochannels is not known, because there has been no dating. It is possible that these are feeder drainage systems into the Mesozoic Surat Basin (Great Australian Basin), which lies to the northwest of the Tomingley area. More likely, they are Tertiary valley-fills.

Sediments were deposited in a landscape with at least 60 m, but possibly several hundreds of metres, of relief, in the Mesozoic or Tertiary. The landscape was already subaerially exposed and deeply weathered perhaps by the mid-Carboniferous (at least Late Palaeozoic), as shown by palaeomagnetic dating of mottles in weathered Goonumbla Volcanics at the Northparkes mine by Pillans *et al.* (1998) south of Tomingley. There is evidence of widespread denudation in the Northparkes and Bathurst areas during the Middle Palaeozoic (Devonian-Carboniferous) and again, if apatite fission track thermochronology (AFTT) data are to be believed, during the Late Permian-Early Triassic and the Late Cretaceous-Early Tertiary (O'Sullivan *et al.* 1995, 2000).

The post-Carboniferous regional stratigraphy would therefore consist of the weathering products of subaerially exposed local rocks consisting of Goonumbla Volcanics but principally Hervey Range Group, Dulladerry Volcanics and Yeoval Batholith rocks, which would have been eroded in that order. Conjecturally, the lower, mottled clay-rich layer in the palaeochannel above the Wyoming deposits consists of a mixture of weathered Goonumbla Volcanics and possible Dulladerry Volcanics. Thin quartzose gravelly interbeds in the mottled clay-rich unit noted by Bamford (2004) could represent small amounts of quartzose material from the Goonumbla Volcanics, Dulladerry Volcanics and potentially Hervey Group sediments, carried along channel bottoms and point bars. Above this, the thick sandy unit with prominent gravely interbeds mostly likely indicates the lateral migration and vertical accession of the large quartzose and granite-lithic gravel-rich alluvial fan that crosses east to west across the north of the Tomingley regolith-landforms map. This fan originates from the Yeoval Batholith that lies to the east and spreads from a gap between the Herveys Range and the Sappa Bulga Range through which Tomingley Creek and Gundong Creek run. The sandy units represent alluvial plains and the gravely interbeds represent channel deposits. Finally, the loamy soil over the top of the Wyoming deposit represents the recent aeolian accession of red-brown fine sand and silt (parna) and its mixture, by bioturbation, with the underlying sediments derived from all bedrock sources. Bamford (2004) and Bamford *et al.* (2004) noted increased calcium levels in the top 1 m of the soil profile, possibly signifying powdery regolith carbonate accumulations derived from calcium-rich parna.

Unfortunately, there has not been regolith dating of any kind performed successfully in the Tomingley area, the closest being the Northparkes mine, which yielded hematite fixation palaeomagnetic ages of Middle Carboniferous and Cainozoic (Pillans *et al.* 1999), and Peak Hill, which yielded hematite fixation ages of 12-15 Ma (Smith & Pillans 2005; Smith 2006). There were attempts to date the transported sediments above the Wyoming deposits using palynology, however, these samples were either contaminated with modern pollens or were barren (L. Stoian *pers. comm.* to K.G. McQueen 2004). Therefore, we can say only with certainty that the transported sediments are younger than Middle Carboniferous and older than present day.

CONCLUSION

It is now possible to make educated guesses regarding the relative ages of materials in the modern landscape, their sources and their sinks. There is no evidence for neotectonic activity in the Tomingley regolith-landforms mapping area, although the Yeoval Batholith alluvial fan is abruptly terminated in a NNW-striking line to the west of the area, which removes any complicating factors from within the map sheet. The data present in Roach (2006) and this paper are intended primarily for the use of mineral explorers regionally, however, they may also be adapted to address the numerous land management issues that are also faced within the region.

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