SOME ISSUES AND CHALLENGES FOR REGOLITH-LANDFORM MAPPING WITH PARTICULAR REFERENCE TO THE BROKEN HILL REGION

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INTRODUCTION

Although a relatively new field of geoscience, regolith-landform mapping is beginning to be recognised and adopted as a valuable way of representing regolith materials and associated landforms. It is flexible and robust, and as such is able to combine a range of regolith and landscape attributes in multi-purpose maps but also provide a framework for special purpose maps and applications. The wide range of applications of these maps makes them especially valuable and popular, particularly for providing a framework and as a tool for mineral exploration, and landscape and environmental management and research.

A range of regolith and closely related maps are now being produced, in a wide range of landscapes, by an increasing range of geoscientists. As a result there is increasing scope for considerable variations, and in some cases inconsistencies, to occur between these maps. Some of the reasons for this may be that many regolith geoscientists have had little training or equivalent experience in this field, plus there are relatively few detailed and specific guidelines for regolith mapping that have been widely available. Although there are many exciting achievements and potential for regolith-landform mapping, some of its aspects typically challenge new regolith-landform geoscientists and users of these maps. Some of these challenges and issues are presented and discussed here, with particular reference to the regolith-landform mapping program that has evolved in the Broken Hill region within CRC LEME.

REGOLITH-LANDFORM MAPPING APPROACH

The regolith-landform mapping program in the Broken Hill region has used the Geoscience Australia Regolith-Landform Unit (RLU) approach (Pain *et al.* in prep.). This primarily represents units based on: (i) regolith materials; and (ii) landform expression. A standard set of alpha-numeric codes (using upper-case letters to represent regolith material, lower-case letters to represent landforms and subscript numbers to further subdivide RLUs) and polygon colours are used to represent the various RLUs on the map face (Pain *et al.* in prep.).

Further detailed unit and site-specific information is recorded in compilation notes and presented in reports or theses that accompany the maps, and in a distilled version within the text of the map's legend. The minimum amount of detailed information recorded for each field site and for each mapping unit includes descriptions of:

1. dominant regolith material;
2. dominant landform assemblage;
3. minor regolith and landform attributes (attributes too small to represent as distinct map units);
4. materials expressed at the landsurface (e.g. surface lags, soils, etc.)
5. the dominant vegetation community type and dominant species;
6. geohazards (such as erosion, anthropogenic land disturbance, rabbit warrens, etc.); and,
7. other attributes (such as photograph and sample numbers and any attributes not covered above).

Further details of this mapping approach at Broken Hill can be found in Hill (2002), Senior & Hill (2002) and Thomas *et al.* (2002).

MAPPING OBJECTIVES

It is important to have a clear appreciation of the objectives of the mapping program before regolith-landform mapping is commenced. Typical objectives may include multi-purpose or special purpose mapping and broad regional coverage or detailed local coverage. Mapping scale is discussed further below, and is closely linked with the overall objectives of the mapping.

Although interest and support for the regolith-landform mapping program in the Broken Hill region has so far mostly come from mineral exploration applications, the maps released are designed to not only meet these requirements but also to provide multi-purpose information. The multi-purpose mapping includes

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information that is of general interest to mineral explorers, and the range of data collected can also be used to produce special purpose maps specific to the needs of mineral explorers. Some special purpose applications of the regolith-landform maps relating to mineral exploration include: highlighting the distribution of specific sampling media such as regolith carbonate accumulations (RCAs); showing geochemical dispersion vectors; or presenting maps of regolith geochemistry. Similarly, for land management applications, these maps can be used to broadly delineate the nature of soil erosion, or local sedimentary depocentres that may be characterised by weed infestations and sediment burial, and are related to the distribution of rabbit burrows, or affect potential stocking rates, amongst many other things.

MAPPING SCALE CONSIDERATIONS

The scale of regolith-landform mapping mostly relates to the objectives of the mapping program. Regional scale maps best show broad patterns of regolith-landform assemblages that could be used to plan regional exploration programs, or decide upon the general approach of exploration programs (e.g. showing regolith- versus bedrock-dominated terrains; areas where drilling may be needed as opposed to surficial sampling, etc.). Detailed scale maps (at 1:25,000 scale or larger) are best able to show information relating to local dispersion pathways and the distribution of specific sampling media, and are ideal for use on the scale of most mineral exploration tenements in the Broken Hill region. Time and financial constrains are also a consideration for the choice of a suitable mapping scale. For example, although an extremely detailed map of a large area may be desirable, it would take considerable time and expense compared with regional scale mapping.

By influencing the detail that can be shown on a map face, the scale of the map also relates to the amount of heterogeneity or homogeneity of RLUs. Regional scale RLUs have greater heterogeneity and typical include an assemblage of several regolith and landform types, such as a particular toposequence. The compilation of maps at different scales therefore requires different approaches and ways of 'reading' the landscape. Table 1 shows the influence of mapping scale on the minimum size of mapping units and the resolution of polygon boundaries. For detailed scale maps, the density of polygons and field description sites across the landscape is generally greater than for regional scale maps. As a general guide, in the Broken Hill region field sites are taken along mapping traverses at intervals < 1 km for the production of 1:25,000 maps, whereas for 1:100,000 maps they are generally taken at intervals of < 5 km. This density of field sites also depends on the objectives and time constraints of the mapping, as well as the complexity and heterogeneity of regolith-landforms in particular areas. Ultimately however, all maps can only present a finite selection of an infinite number of possible observations. The challenge for the mapper is to best select the observation sites within the context of the objectives and constraints of the mapping program.

Table 1: Minimum recommended width of mapping polygons and cartographic precision of map unit boundaries at various scales.

Map Scale	Minimum width of mapping units if greater than 3 mm on map sheet	Line thickness at 0.3mm on the map sheet
1 : 500,000	1500 m	150 m
1 : 250,000	750 m	75 m
1 : 100,000	300 m	30 m
1 : 50,000	150 m	15 m
1 : 25,000	75 m	7.5 m
1 : 10,000	30 m	3 m

DESCRIPTIVE AND INTERPRETIVE MAPS

All regolith-landform maps are a constructed representation of the spatial pattern of regolith materials and associated landforms. Some mapping schemes however are strongly driven by interpretations. Typically, these interpretations are based on stratigraphical and chronological frameworks (e.g. Grimes 1984) and landscape evolution models (e.g. Anand *et al.* 1998). The validity of these approaches depends on the validity and reliability of the underlying interpretations.

The RLU approach has a degree of interpretation in its presentation. This is largely based on genetic interpretations for regolith materials and associated landforms. The potential problems with the interpretive basis for presentation have been greatly minimised in the more recent regolith-landform mapping in the Broken Hill region. This has been done by ensuring that the detailed legend descriptions keep interpretation to a minimum, therefore only using the interpretive presentation framework as a convenient and easy to read means of presentation. In particular, the legend descriptions should be free of repetition and direct translation of RLU codes, therefore making them somewhat independent of the interpretative label given. For example the regolith lithology of an IS unit should not be given in the legend as 'aeolian sands' but instead should describe the sediment lithology (e.g. colour, grain size and range, grain shape, composition. etc.). This also helps resolve the problem of units where the origin is uncertain, or if units include an even mixture of materials from different sources and a dominant material is not easily decided upon. If at a later date the interpreted polygon label is found to be incorrect then at least the RLU polygon and legend description should still stand.

Although standard definitions of regolith are widely cited (e.g. Taylor & Eggleton 2001, Eggleton 2001), putting them into practice is not always easy. For example, the exposures of the sediments associated with the Mesozoic sedimentary basins, particularly the marginal marine sediments of the Eromanga Basin, and to a lesser extent the Cainozoic sedimentary basins in western NSW, could be considered to be either bedrock or regolith. In the Tibooburra region these sediments have been mapped as 'saprolite' (S), with an unspecified weathering grade (Chamberlain & Hill 2002). Equivalent uncertainties also exist for Cainozoic volcanics in eastern Australia. Cainozoic basalts are considered as weathered bedrock and therefore could be mapped as saprolite or saprock with varying degrees of weathering (i.e. SS, SM or SH). They are also inherently a landscape feature and form in relation to the landscape. In many cases they are underlain by regolith units such as sub-basaltic gravels and weathering profiles. They could therefore be mapped as volcanic (V) regolith materials. Recent mapping in the upper Shoalhaven valley of southeastern NSW (Lewis *et al.* 2002), and student mapping exercises in the Cooma region of NSW, have shown Cainozoic basalt flows as Ver and Vep units with modifier numbers reflecting the degree of weathering.

Mappers and map readers need to also be aware of regolith mapping surrogates used both in their mapping and as the basis for later interpretations drawn from maps (Hill 1995). There is a risk of becoming entrenched in circular arguments if distribution patterns of landscape attributes are compared with regolith-landform map polygons. An example of this can be seen in some of the maps of Anand *et al.* (1997) where the underlying bedrock lithology was used as a basis for subdividing regolith units, yet this work uses mapping to support conclusions about the relationships between regolith materials and bedrock. Comparing regolith maps with vegetation, soil and remote sensing responses could have similar problems. As a general rule, surrogates can be a powerful tool and a great assistance to regolith mapping, but if not tested, acknowledged, or recognised they can limit the value of the mapping.

3D AND 4D REPRESENTATION

The traditional regolith-landform map is a graphical representation of observations and interpretations on a horizontal plane (a sheet of paper or a computer screen). In reality, however, regolith materials vary in at least three dimensions (4 if you consider temporal variations). It is a major challenge of regolith maps, and even geological maps, to present information beyond two-dimensions.

Regolith-landform maps have previously been able to show some three dimensional information by using cross sections, and presenting compilations of accessory data sets (such as drilling information, geophysics, 3D graphics of the regolith architecture), either on the map sheet or as derivative maps. Regolith-landform mapping representing the timeframe of the evolution of regolith and landscapes (4-dimensional mapping) has had little previous consideration. Recent work within CRC LEME at the University of Canberra has produced regolith-landform maps from over a 50 year period in the area of the Shoalhaven River Delta, south-eastern NSW (Christian & Hill 2002). The major limitation on being able to map 3D and 4D regolith information, however, is only in small part related to the possible methods of presentation. Instead, the difficulties in obtaining reliable data, in both the vertical scale and over the time scale of regolith and landscape evolution, are major limitations. The most reliable and useful maps are initially based on what can be directly described rather than what can be imagined or interpreted.

The subject of regolith mapping deals with material that extends from the fresh bedrock interface up to the landsurface. This may range from thicknesses of millimetres to 100's of metres. Two possible approaches for dealing with this material are therefore either from the 'top down' or the 'bottom up'. Many traditionally trained geologists are most interested and comfortable with a 'bottom up' approach to understanding and accounting for regolith. In this case the regolith is considered in the context of what is in many cases deeply buried bedrock and structures. The challenge for applying this approach to mapping the regolith across a map sheet area is the reliability and availability of information to compile the map. In contrast the RLU mapping approach is mostly a 'top down', where landforms are a strong basis for considering regolith materials. Some 3D information is gained by the topographic relief and cross-sections (typically in gullies, pits, drill holes or geophysics). The RLU approach is also flexible enough to show deeply buried regolith and bedrock geology information on derivative maps. The advantage of this approach is that:

- landform information required to define RLUs extends in infinite detail across the landscape;
- RLUs can be readily observed in the field and using remote sensing techniques; and,
- the presentation and understanding of landsurface and near surface settings can have important connections to more deeply buried features.

MAPPING REGOLITH IN BEDROCK-DOMINATED TERRAINS

Many people become confused about the concept of being to map regolith-landforms in areas that appear to be dominated by bedrock. In some cases they are at a loss to know what to do, while others may believe that regolith mapping need only show information from areas where bedrock is not exposed (i.e. just add detail to the sea of yellow around the islands of outcrop). The problems with showing regolith-related features on the same map sheet as detailed bedrock geology presentations include:

- the map sheet may be presenting too much information for clear presentation;
- the detail and nature of stratigraphic information traditionally used on bedrock geology maps may not be available for the regolith-dominated parts of the map sheet; and,
- the mapping representation may be inconsistent and in conflict across the map sheet.

In the Broken Hill region separate bedrock geology and regolith-landform maps have been produced for equivalent sheet areas. On the regolith-landform maps, bedrock-dominated terrains are represented by the weathering grade of the weathered bedrock (typically slightly weathered, moderately weathered or highly weathered) and the landform expression (typically erosional rises, hills, mountains and plains). The division of RLUs based on landform expression, and in some cases slope facets, is a successful way to further subdivide these units, especially if detailed topographical information is available. By viewing the bedrock geology and regolith-landform maps together, this provides flexible information that can form the basis for significant interpretations, such as bedrock lithological controls on regolith and landscape expression, and geochemical analyses of bedrock samples can be evaluated based on the weathering grade of bedrock exposures.

PERSONAL MAPPING STYLES

The presentation on a regolith-landform map sheet ultimately depends on how different people read, describe and interpret the regolith and its associated landscape. This will depend on many of the factors discussed above, although personal mapping style is also significant. Standard mapping schemes and mapping consistency, however, are ideal objectives. In reality there may be as many different styles of regolith mapping as there are regolith geoscientists. As the techniques and approaches evolve and become more standardised these differences may be minimised. Some of the main style differences that occur between regolith-landform geoscientists are outlined in Table 2.

CONCLUSIONS

Regolith-landform mapping has a lot to offer geoscience research and its applications, largely because of its ability and flexibility to represent regolith materials that are otherwise difficult to represent on more traditional geological maps. The approach to this mapping is an evolving process that will need to resolve the challenges of trying to represent regolith materials and associated landforms effectively and consistently.

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Table 2: Some typically encountered personal mapping styles

Mapping Style	Description	Advantages	Disadvantages
'complex wriggles'	Regolith polygon boundaries and shapes show great detail and irregularities	• may reflect true irregular nature of landscape • can appear detailed and thorough	• may extend beyond the detail of primary information and therefore become 'artistic'; • slow to compile and draft; • can reflect poor drafting technique
'sausage and donuts'	Regolith polygon boundaries and shapes are simple and smooth	• clear and simple presentation; • may show fundamental framework; • quick to compile and draft	• does not represent true inter-relationships and complexity of polygons
'lumpers'	Regolith heterogeneity grouped into single units	• clearly distilled representation of the landscape	• neglects important details and regolith complexity • may be too simple for scale of presentation
'splitters'	Regolith heterogeneity subdivided into multiple units	• represents detail and complexity of the landscape	• presentation may be difficult to read; • may be too detailed for scale of presentation
'idea driven explorer'	Organises mapping program to test ideas and hypotheses	• planned use of observations and descriptions; • May quickly develop an interpretive understanding	• may have closed mind and miss out on new discoveries
'blank minded explorer'	Enters mapping program with few pre-conceived ideas	• open mind for new discoveries	• may be more time consuming • may not develop any ideas

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