Customised regolith maps incorporate hydrologic modelled attributes for geochemical exploration

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Regolith-landform maps provide an important geomorphic and landscape evolution framework for developing more effective geochemical exploration strategies, and in the interpretation of geochemical datasets in highly weathered terrains. Recently, customised and more focused regolith-landform maps have been compiled to provide direct information for the exploration industry. These new maps show specific information for geochemical exploration including, for example, recommended sampling strategies, estimated thickness of transported cover, and modelled hydromorphic attributes to assist in metal dispersion studies.

Regolith is particularly well developed in Australia with more than 80 per cent of the continent's surface characterised by highly weathered bedrock and/or transported materials. The formation of an extensive blanket of transported regolith and weathered bedrock in Australia is largely due to:

- long exposure of most of the land surface to sub-aerial weathering;
- preservation due to the overall low relief and recent arid climate with associated low rates of geomorphic processes; and
- tectonic stability of the Australian landmass.

Mapping the regolith, understanding past and present geomorphic/geochemical processes and developing models of landscape evolution are key factors that underpin geochemical exploration in deeply weathered landscapes.[1]

Mapping regolith in Australia is largely based on a lands system approach. A lands system is defined by Christian and Stewart as an area of land throughout which recurring patterns of topography, soils and vegetation can be recognised.[2] The key to the land system approach is the recognition of the interrelationships between landforms, soils and vegetation. Soil scientists have long recognised these relationships and have used the term 'catena' to describe a repeating sequence of soils that are spatially associated with changes in topography. These relationships form the basis for regolith-landform mapping. Regolith-landform maps use landforms as the principal surrogate for mapping regolith materials and this is justified by the close spatial and genetic associations between regolith and topography. Landform attributes are derived from aerial photography and, where available at appropriate detail, digital elevation models. In areas of poor landform expression, other mapping surrogates such as gamma-ray spectrometry and enhanced Landsat TM imagery become the principal datasets from which regolith boundaries are derived.[3]

The first 1:250 000 regolith-landform map over the Ebagoola map sheet was compiled by AGSO in 1992.[4] The map was compiled from existing geological mapping, aerial photographs and gamma-ray spectrometric imagery. The use of gamma-ray imagery for mapping regolith including soils[5] and in understanding landscape processes was relatively new at the time, but the imagery is now used widely in regolith map compilation and more recently in soil/landscape modelling.[6]

The Ebagoola map and other similar maps[7,8] are generic products with equal application for mineral exploration and land-use assessment. Since the mid-90s a new generation of specialised and tailored regolith and thematic maps for the exploration industry have been developed—through the activities of the Cooperative Research Centre for Landscape Evolution and Mineral Exploration (CRC LEME). Examples from Leonora (WA), Tanami (NT), and Selwyn (Qld) are used to illustrate these new thematic maps (see locations in figure 1).

Geochemical sampling strategy maps

Geochemical sampling strategy maps are hybrid regolith-landform maps (figure 2) that have been specifically designed to aid interpretation of geochemical datasets and for developing geochemical sampling strategies. Geochemical sampling strategy maps build on the standard regolith maps that show in-situ and transported materials. They do this by incorporating additional information from detailed regolith-geochemical orientation studies.[9] These studies are usually undertaken at local district scales (e.g. a 5 x 5 km area or mine sites). They provide detailed descriptions on the composition and distribution of the regolith, and information on the physical and chemical dispersion processes that have occurred or are currently active within the regolith.

Knowledge gained from these studies, in particular metal dispersion processes and recommended sample

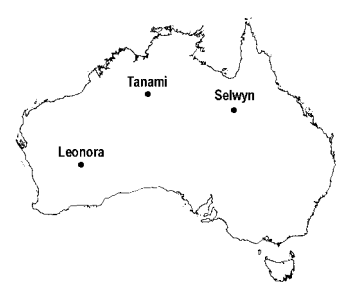

Figure 1. Location diagram of the study areas—Leonora, Tanami and Selwyn

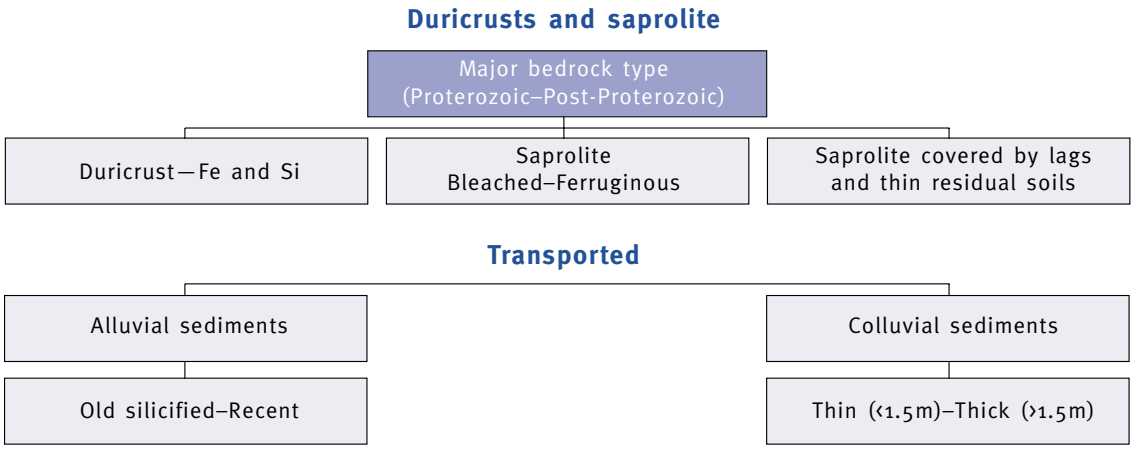

Figure 2 (above). Major geochemical sampling groups that are used in a geochemical sampling strategy compiled over the Selwyn area 140 kilometres south-east of Mount Isa.[9] Bedrock age is used first to separate the landscape into prospective and non-prospective terrains. Then major in-situ and transported regolith materials are identified and grouped into geochemical exploration domains. These major geochemical groups are specific to the Selwyn region; other areas are likely to show different associations reflecting their specific geologic and landscape histories.

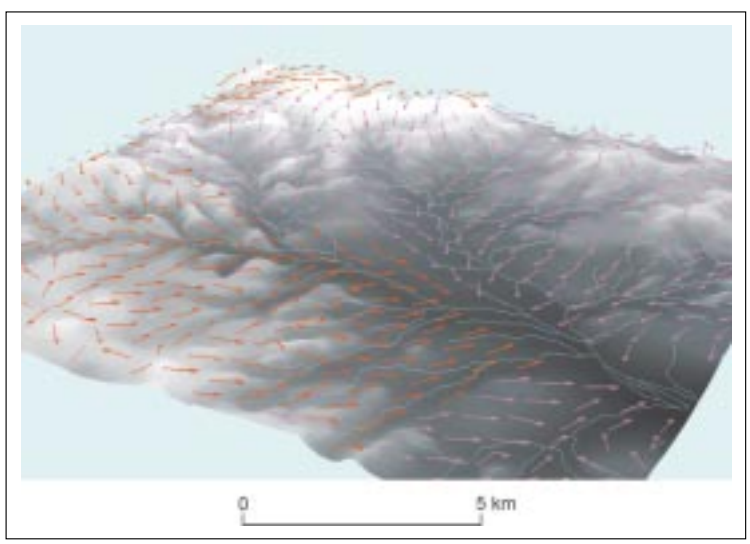

Figure 3 (left). Surface flow vectors draped over a digital elevation model. The length of the arrows generated by the algorithm can be proportionally scaled to the flow accumulation or slope of the DEM. Surface flow direction including areas of flow convergence and divergence is readily interpreted from the model.

types, are then incorporated and extrapolated to the wider area via geochemical sampling strategy maps. Units on a geochemical sampling strategy map are grouped by their regolith-geochemical characteristics and sampling approach—for example, lag (lithic, ferruginous, calcareous), soil or drilling. Although the units on a geochemical sampling map are largely based on the physical and chemical characteristics of the regolith, genetic landscape models are involved in the classification processes. The geochemical sampling strategy map is therefore an interpretive product that has more focus than the standard descriptive-based regolith-landform map. Primary descriptive regolith and landform attributes are also provided in the GIS from which the maps are generated, allowing the user to modify or develop new geochemical strategy classification schemes where necessary. The maps are further enhanced by incorporating hydrological attributes (see figure 3) derived from digital elevation models (DEMs).

Integrating hydrologic attributes

From a mineral exploration perspective, hydro-geomorphological processes are critical in understanding landscape geochemistry—particularly in element dispersion studies. Chemical weathering through hydrolysis, oxidation and reduction reactions, and movement of sediment and solute materials (both vertically and laterally in the landscape) are mainly controlled by surface and near-surface hydrologic pathways.

Water will move downslope in two ways: as overland flow and as through-flow. Overland flow or runoff consists of surface flow that occurs when rainfall exceeds the infiltration rate of the upper part of the regolith. Sheetflow is a common form of overland flow. Concentrated or channelled overland flow typically results in stream flow. Through-flow in contrast is the movement of water through the regolith. Water

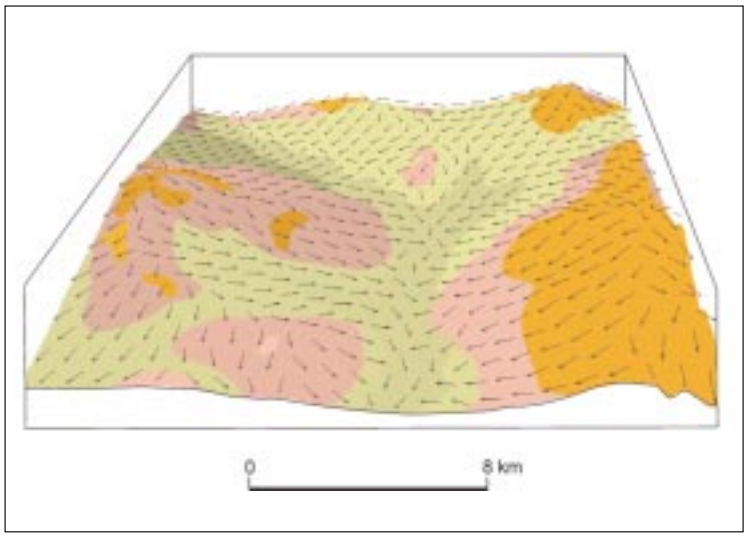

Figure 4 (left). Flow vectors superimposed on a regolith map over part of the Tanami region in the Northern Territory. Regolith units are classified according to thickness of sediments (orange-brown ‹1 m, green 1–10 m). The Tanami area has poorly defined drainage patterns and very low relief. Most sediment is being shed into lower parts of the landscape in the form of colluvial sheet flood fans, rather than in discrete channels. The surface flow vectors predict the likely movement of colluvial sediments in the landscape. As a consequence, flow vectors are important to understanding geomorphic dispersion processes—particularly in relation to soil or lag geochemical surveying.

movement as through-flow has an important control on the intensity and depth of weathering and the movement of solute materials in the regolith.

Although regolith map units imply past palaeo and present hydro-geomorphic processes (e.g. colluvial sheet flood fans, alluvial sediments), the direction of transport and provenance of sediments are generally not well shown. This is particularly true in areas with gentle slopes and poorly defined surface drainage, which typify large parts of central Australia (figure 4).

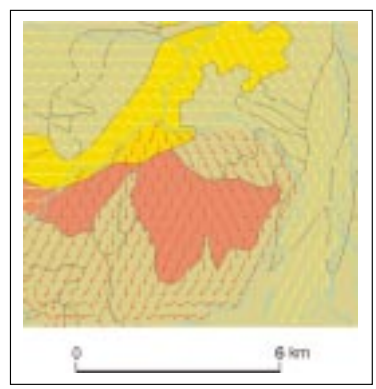

Figure 5 (above). Flow vectors superimposed on a DEM over part of the Leonora map sheet in the Eastern Goldfields of Western Australia. Sediments derived from granite and greenstone lithologies have been coloured red and yellow, respectively. Catchment boundaries are shown in blue.

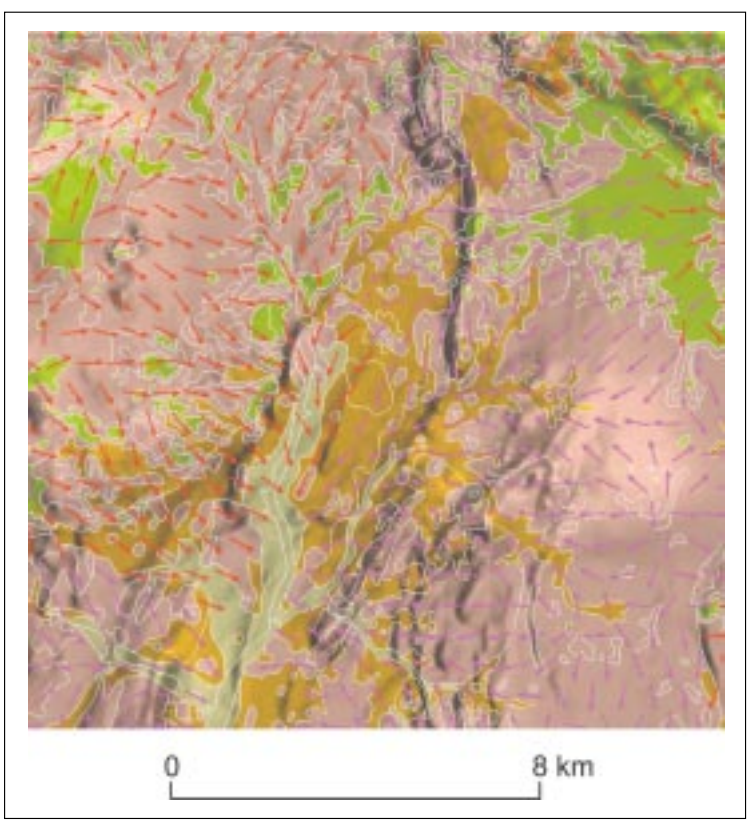

Figure 6 (left). An airborne magnetic image with a first vertical gradient (courtesy of Mount Isa Mines) has been embedded into the map to add a bedrock/structure dimension to the interpretative process. Flow vectors overlayed on a geochemical sampling strategy map over part of the Selwyn region 140 kilometres south-east of Mount Isa. This combination allows geochemical datasets to be interpreted in terms of the regolith materials, areas of active erosion, potential mechanical and chemical dispersion patterns, and provenance of sediments.

DEM-derived surfaces can complement regolith maps by providing information about hydrological and geomorphological processes in the landscape.[10] Holyland discusses the use of DEM for generating slope vectors maps for soil sampling and hydromorphic dispersion studies, and in generating drainage divides and stream intersections points for stream sediment surveys.[11] Building on Holyland's work, an algorithm has been developed that uses DEMs to generate overland (surface) flow vectors and then integrates the vectors with regolith and geological maps using stream catchment boundaries.

The first part of the algorithm generates surface flow vectors in the form of arrows that indicate the likely movement of sediments and solutes in the landscape.

Overlaying the flow vectors on regolith and geochemical maps allows surface flow directions, including areas of flow convergence and divergence, to be analysed with respect to regolith/lithological materials.

After the arrows have been generated, the second part of the algorithm uses drainage catchments to analyse these flow characteristics in association with regolith or geological units. Catchment boundaries are generated automatically from the DEM or imported as a polygon layer. The algorithm is capable of automated delineation of catchment boundaries at various scales. Catchment scaling is controlled by factors such as the minimum allowed catchment size (area), flow accumulation threshold at which drainage networks derived from the DEM begin to form, and the minimum stream order at which catchments may form. To prevent discontinuity in creation of drainage networks, and to ensure correct catchment delineation, all sinks that may be present in the DEM are filled before applying the algorithm.

Regolith types or lithologies likely to contribute to the greatest supply of sediment within each catchment are automatically identified. The arrows are then coloured to indicate sediments derived from different sources (figures 5 & 6). This is done by firstly identifying the active eroding parts of the catchment using a slope derived from the DEM. High slopes correspond to zones of active erosion. Intersecting the zones of high slope with the underlying geological or regolith map units is used to determine the predominant lithology or regolith material that is likely to be contributing the most sediment within each catchment.

Combining the datasets in this manner allows potential mechanical and chemical dispersion patterns to be linked directly to regolith and lithological materials. These DEM-derived surfaces are then overlayed on the geochemical sampling strategy map allowing geochemical datasets to be interpreted in a regolith, hydromorphic and geomorphic context. Further integration and customisation are achieved by combining these themes with other datasets such as airborne magnetics (figure 6). This integration is achieved using colour–space transformations where the intensity, hue and saturation components of colour are used to combine different datasets.

Limitations in interpretations

There are some important assumptions and limitations to consider when interpreting surface flow maps. Surface water flow maps generated by this technique are based exclusively on information presented in a DEM. They do not take into account variation in infiltration rates caused by factors such as soil depth, texture and vegetation cover. Flow patterns are likely to relate to present-day geomorphic processes or the last geomorphic event. If the present-day topography differs markedly from the palaeo-topography, the hydrological regime predicted by this technique is unlikely to correlate with the distribution of older regolith materials. In such cases, the surface flow maps will show the likely re-distribution of these older materials in the landscape by present-day processes. Also the flow grids are based on surface flow only; movement of deeper groundwater may have little correlation with the topography-derived water flow model, particularly in low-relief landforms.

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