Carl Pain

Regolith '98

Australian Regolith & Mineral Exploration

New Approaches to an Old Continent

Program & Abstracts

Edited by A.F. Britt and L. Bettenay

3rd Australian Regolith Conference

WMC Conference Centre, Kalgoorlie, Western Australia

2-9 May 1998

REGOLITH '98

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This Abstract Volume is proudly sponsored by

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ISBN 0 9586857 3 8

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Program and Contents

Saturday, 2 May

Workshop: Sampling Media in Various Australian Regolith Regimes

Sunday, 3 May

Workshop: Sampling Media in Various Australian Regolith Regimes
Workshop: Remote Techniques for Regolith Mapping and Characterisation

4.30 Registration Desk Opens

6.30 - 8.00 Welcome Drinks

Monday, 4 May

Wednesday, 5 May

Thursday, 7 May to Saturday, 9 May

Post-Conference Field Trip: Departs Kalgoorlie on Thursday after lunch at 1.00pm, arrives back in Kalgoorlie approximately 6.15pm Saturday evening.

Posters

Acknowledgement: The editors wish to acknowledge the work of Bernadette Kovacs and Nikita Sergeev and the useful comment from Charles Butt and Graham Taylor in the production of this volume.

Landscape evolution and mineral exploration into the future

Raymond E. Smith and Allison F. Britt

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The Australian land mass has been moving northwards over the last 65 million years since its separation from Antarctica. The resulting climate changes accompanying this northward migration have impacted on the landscapes, regolith and weathering processes, of which geochemical dispersion in an integral part. Furthermore, there have been substantial global changes in climate over this period. We need to know what the implications of these vastly differing climatic histories of the continent are for mineral exploration. What does this mean in terms of the weathering processes that result in enrichment of ores, of gold mobility and geochemical exploration methods?

Greater knowledge of these matters would give a major boost in confidence for transferring exploration experiences from a known area to like areas across the continent. Some of the implications include whether or not to expect gold depletion zones in upper saprolite, choice of elements in soil geochemistry for example, what thresholds to apply in geochemical surveys and what drilling depths are required to test anomalies. Current and future research on regolith mapping, regolith stratigraphy, reconstructions of landscape history, controls on chemical behaviour and the development of GIS and expert systems will continue to improve our knowledge of Australian landscape evolution and our ability to predict for exploration.

Regolith-landform mapping is a key step in the exploration process. Interpretation of air photography, Landsat TM imagery, airborne radiometrics and magnetics, and, importantly, ground traversing are all part of this process. Other techniques such as airborne and spaceborne radar and mineral mapping, and airborne electromagnetics (AEM) are of real benefit and offer potential breakthroughs in the future.

Our ability to predict the subsurface regolith geology is also based on the use of a wide range of technologies, knowledge and "know-how". These include drilling (with its required skills in sample logging), ground electromagnetics, detailed seismic, gravity and other surveys. Knowledge of the regolith stratigraphy, regolith facies variations, landscape models and regolith processes, coupled with regolith mapping of the ground surface, provide a powerful basis for prediction when exploring an area. The pressing need, however, is for three dimensional mapping of the regolith environment, say to a depth of 100 m, from the air. No single technology can provide the "magic bullet" for this, although AEM is making important inroads. Rather, we expect combinations of approaches will remain the predictive method over the next decade.

Regolith-landform mapping and defining regolith stratigraphy are two of the steps in reconstructing the history of an area. Other important information is contained in bedrock relationships, tectonic changes, ages of deposition of local and trunk drainage sediments, weathering processes, ages of weathering, palaeoclimates and changes in weathering styles. A comprehensive reconstruction will provide key information that will impact on deciding appropriate exploration approaches.

In terms of understanding a district or area, some of the most commonly missing information pertains to our lack of knowledge of the controls of chemical behaviour and quantitative ages of weathering profiles. These are a major areas of research opportunity, though advances will probably come slowly because of the nature of the work and because both aspects generally require that knowledge of regolith-landscape relationships have already been established. There are many areas of potential breakthrough, one example being those areas of Australia (and the world) covered by shallow basin sediments. Eventually, models of chemical behaviour should be tied to regolith-landform chemical-domain maps. GIS and expert systems will have an important role to play in this.

The importance of regolith geology is already widely recognised in Australia. For the subject to mature, we need to have more informed debate as happens in other disciplines, such as structural geology, igneous and metamorphic petrology.

In summary, we can expect three dimensional mapping of the regolith to remain multidisciplinary in approach, there is a real need to improve our knowledge of past climates and their impact on the Australian landscape and there are major opportunities for breakthroughs in our understanding of chemical behaviour.

Regolith '98 and beyond: a minerals exploration industry perspective

Leigh Bettenay

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The industry approach to regolith is pragmatic; we have to be able to cope with whatever regolith exists and we would prefer to use it to our advantage. In essence, we will support and adopt anything which gives us tools, techniques or insights that shorten the discovery process. Granted, no-one can predict all scientific breakthroughs, but research themes in which we cannot see a probable or possible contribution to exploration will not be supported by industry.

By far the greatest challenge, is exploring under cover because most of the world's undiscovered mineral deposits will be concealed within and beneath regolith materials. We all strive to be first to identify and harness the breakthrough technique which will "see through" cover materials to enable cheap first-pass surface exploration and direct drill-targeting. However, developments like calcrete sampling indicate that we don't need to know the underlying science; the simple empirical observation of an association will suffice to give us a tool. Natural optimism and a sniff of success will do the rest.

My perspective is that the battle for credibility for Regolith Science is largely won within most Australian exploration groups (and largely won elsewhere as well, if overseas demand for our regolith geochemists is any gauge). Exposure to regolith of many frontline Australian explorers via short courses was the decisive factor and represents a major benefit flowing to industry. Regolith-aware geoscientists and technicians are also graduating from some institutions, although this is not consistent. Perhaps there is a role here for CRC LEME in "teaching the teachers" and/or providing material for undergraduate practical studies in regolith materials and processes.

Industry has responded in disparate ways to the increased knowledge of the Australian weathering environment. Procedures in the Yilgarn gold search are tighter now overall than they were ten years ago: reconnaissance regolith mapping is common if not quite universal; there is more likely to be a multi-element approach rather than just Au-As; and full profile sampling via regolith-controlled composites is widespread. However, it should be noted that many successful exploration groups have responded to the regolith challenge by focussed deep drilling, suggesting a lack of faith in our collective ability to sample and interpret upper regolith. Only time will tell if the drill-focussed approach is superior, but one consequence is the requirement for much narrower geographic concentration, requiring precise targeting and project generation.

On the world scene, there is a rapidly developing awareness of the importance of regolith in exploration, and also that Australia is at the forefront in both research and exploration practises for deeply weathered terrain. Although the CRC LEME structure potentially brings synergy, continuity and substantial funding, the real key to our present success lies in the pragmatic, industry-focussed, CSIRO-AMIRA research outcomes of the '80s and early '90s. There is plenty of scope therefore to further exploit Australia's regolith advantage, but the gap will quickly narrow if we are inattentive.

With no shortage of worthy exploration challenges and scientific problems to address in future regolith study, what could possibly hold us back? Principal threats to our success are: our researchers not maintaining their strong focus on the "mission-critical" exploration problems (principally, cheap and rapid surface methods for exploring large areas under cover); lack of imagination in defining research themes which have the potential for breakthroughs; a failure of the industry and research groups to continue to cooperate and disseminate information; or a significant downturn in the minerals industry (potentially leading for example to reduced take-up of research outcomes, loss of continuity and a lessened desire to be innovative in exploration).

None of these is insurmountable, although the last is mostly outside our collective control. As well, there are some major challenges where improvement is required, including: significantly better data management and documentation, so that we can draw on the existing case study material in suitable digital formats; better preservation of the collective regolith "ground truth" represented by on-going exploration drill sampling by the industry at large; and improved access to regional and framework studies from regolith-dominated terrains elsewhere in the world, so that we can place our Australian experiences into a global context.

Acknowledgements: I would like to thank all my erstwhile colleagues at MIM Exploration for their encouragement and contributions in developing a perspective of regolith and how to respond to its challenge.

The regolith and environmental management

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The regolith is not only of major significance in exploration and the host of a wide range of mineral deposits in Australia, but also plays a major role in minesite environmental management. With the community, shareholders and regulatory authorities requiring ever increasing higher standards of environmental management, a better understanding of regolith characteristics is essential. This can be initiated during early drilling programs and developed during mining to ensure sustainable rehabilitation.

Information collected during the exploration and pre-feasibility stages can be used as environmental baseline data. Of particular use are geochemical and landscape function analyses.

Characterisation of geotechnical, hydrological, mineralogical and geochemical properties of the regolith (and fresh rock) samples in pre-mining activities can be incorporated into EIS and EMS documents. Application in the design of dam walls and bunds, inert covers for potentially acid-generating wastes and long-term stability and constructed landforms are dependent on these regolith properties. Characteristics of residual regolith can also provide insight into those of fresh rock as it weathers on waste dumps.

Revegetation and ecosystem reconstruction strategies are highly dependent on the properties of mine soils. These are usually significantly different from natural soils, being low in nutrients, micro-organisms and faunal activity. In the Bowen Basin, dragline spoil has many characteristics detrimental to regrowth of native grasses, shrubs and trees and long-term stability against erosion.

Rehabilitation of the bauxite mines south of Perth, Gove (NT) and Weipa (Qld) is dependent on a detailed knowledge of the laterite profiles and the top-soil which is returned to the mined areas. These bauxite mines together with areas which have been subjected to mining of heavy mineral sands have been successfully rehabilitated and sustainable ecosystems have been constructed.

Additional examples will be provided of the application of regolith characteristics to environmental management throughout Australia as well as the need to closely monitor weathering of fresh rock.

Regolith-landform evolution on Cape York Peninsula: lessons for mineral exploration

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A number of landform features on Cape York Peninsula (CYP) contain important clues for the development of landforms and regolith in the area. The Great Escarpment, up to 200 m high, separates old landforms and regolith on the western side from younger landforms and regolith on the eastern side. West of the Great Escarpment there are smaller less continuous scarps which also form important boundaries between different regolith. There is clear evidence for superimposed drainage, river capture and reversal, and inversion of relief on CYP.

Formation of the Carpentaria and Laura Basins during Middle to Late Jurassic and Early Cretaceous time covered the Palaeozoic and Proterozoic rocks of the Coen Inlier with a veneer of coarse terrestrial to fine marine sediment. The emergence of these basin sediments in the Late Cretaceous marks the beginning of landform and regolith evolution on CYP. The sediments probably covered most, if not all, of the Coen Inlier, and post-Mesozoic erosion subsequently uncovered the basement to form the Inlier.

Substantial erosion and surface lowering in the area followed emergence at the end of the Cretaceous, leaving the basement rocks high in the landscape. The breakup of the north eastern part of the Australian continent and the opening of the Coral Sea had a profound effect on landforms on CYP. Down warping to the east formed the Great Divide and resulted in drainage modifications and the formation of the Great Escarpment. Subsequent retreat of the Great Escarpment formed the lowlands to the east.

West of the Coen Inlier, on plains formed on Mesozoic sediments, there was erosion of several tens of metres of material, and inversion of relief. Further north, plateaus with a deep bauxitic weathering profile formed on Rolling Downs Group sediments.

The importance of this evolutionary sequence for mineral exploration is discussed.

The palaeoplain model for passive margins - does it really work for the SE Australian margin?

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The geomorphic evolution of high elevation passive continental margins has been the focus of numerous studies for over a century, and a wide range of landscape evolution models have been formulated in attempting to understand their development. These early models proposed that a pre-existing land surface, or "palaeoplain", was downwarped towards the axis of the subsiding rift basin to form a continuous, long wavelength flexure or monocline. Present-day topography was then formed by erosion of the monoclinal flexure by a process of escarpment retreat. The concept of a downwarped palaeosurface has recently been proposed as an explanation for the landforms, including preserved "coastal facets", observed along the SE margin of Australia

One method which can be used to test this model is apatite fission track (FT) analysis. This technique is widely recognised as being useful in constraining the low-temperature (<≈110°C) thermal history of rocks and identifying a thermal stratigraphy through any apatite-bearing sequence. In many cases, FT analysis is the only technique which is currently able to provide quantitative estimates of denudation over time scales of the order of 10^6-10^8 years. Previous apatite FT studies of the rifted margins of SE Australia, have suggested that ≈1.5-2 km of denudation occurred along the coast and as much as ≈2-4 km of denudation occurred within localised regions of the eastern highlands. Importantly, most of this denudation occurred in response to either the Hunter-Bowen Orogeny, or the middle Cretaceous rifting event associated with rifting and separation of Australia from Antarctica and the Lord Howe Rise. In general, there is little direct evidence from the apatite FT data for any ongoing large-scale Tertiary denudation.

Along the SE Australian margin, the palaeoplain model would predict, assuming a constant dip on the downwarped plain, and depending on the level of preservation of coastal facets, apatite FT ages to increase towards the coast when the escarpment is well inland, and to decrease towards the coast when the escarpment is located close to the shoreline. Throughout the SE margin, however, apatite FT ages consistently increase inland from the coast, a trend which occurs no matter how far inland the Great Escarpment is located. Further, across proposed coastal facets (eg. Bega, Port Macquarie) the apatite FT ages are substantially younger than those from rocks exposed on the top of the proposed inland palaeoplain. These findings indicate that the amount of denudation recorded by the FT data is significantly greater than that predicted by the palaeoplain model, even if extraordinarily high (c. 60°C/km) palaeogeothermal gradients are assumed.

The FT data from SE Australia are clearly incompatible with the palaeoplain model in general, and in particular the data from the Bega and Port Macquarie districts demonstrate unequivocally that landforms along this sector of the coastal plain are younger than landforms inland of the escarpment. In light of these findings we conclude that topographic features described as coastal facets along the SE margin, cannot be remnants of an older, downwarped "palaeoplain".

Palaeodrainage and its significance to mineral exploration in the Bathurst region, NSW

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Drainage evolution in the Bathurst region is complex and has been influenced by both external and local factors. These factors relate to convergent and passive plate margin tectonics, intraplate basins, bedrock lithology and structure, and volcanism, and are fundamental in explaining the geomorphic and regolith evolution of this region.

Drainage direction has shifted through time in an anticlockwise direction from northeast to southwest. Changes in direction relate to the development of the surrounding depositional centres of the Triassic Sydney Basin, the Jurassic to Cretaceous Surat Basin and the Tertiary Murray Basin.

Upwarping associated with rifting of Pacifica from southeast Australia in the Late Cretaceous formed the proto Great Divide and imprinted a northwest slope across the region. Initiation of the Murray Basin in the Tertiary led to the formation of westerly flowing watercourses and the Canobolas Divide separating the Lachlan and Darling drainage basins.

The onset of three periods of Tertiary volcanism and the formation of erosion bowls in incompetent lithologies have further deranged earlier drainage. Sea level fluctuations and climate change have influenced erosion and sedimentation in the Lachlan River system.

Recognition of buried palaeodrainage lines, which are often associated with deep weathering, will assist in the discrimination of hydrothermally altered bedrock from deeply weathered bedrock, and enable provenance of palaeochannel sediments to be determined. These sediments may have geochemical backgrounds quite different from those of the surrounding rocks, and this knowledge of their distribution and whether or not the sediments have themselves been eroded and dispersed will be important in interpretation of geochemical surveys.

Morphostructural analysis of digital topography in the study of landscape/regolith evolution of the Mt Lofty Ranges

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We have used image processing and visualisation as well as digital geomorphic techniques to analyse the morphostructural characteristics and evolution of the Mt Lofty Ranges landscape. A digital elevation model (DEM) with a 100 m grid was used in this analysis, which also incorporates regional geologic and tectonic data.

The Mt Lofty Ranges morphostructural evolution occurred in two stages. The first stage (Middle Eocene to Middle Miocene) was connected with low amplitude epeirogenic movements. The axis of maximum elevation (~100 m) was located in the eastern part of the Ranges while marine conditions prevailed in the flanking St Vincent and Murray basins. The second, more active stage (Pliocene to Holocene) resulted in the development of modern topography (~700 m) with maximum uplift in the western parts of the Ranges.

At the 10-100 km scale, landforms mostly reflect the neotectonic control of fault movements. Fluvial landsculpting plays a role at shorter length scales. The modern drainage pattern was established in the first stage. Second stage produced dramatically incised gorges along the western range front and increasing terrestrial deposition in flanking.

Pre-Middle Eocene remnants of regolith may be seen at summit surfaces of the major watershed of the Mt Lofty Ranges and buried beneath younger Tertiary deposits of the flanking basins. The regolith process in the Mt Lofty Ranges was dependent on Tertiary-Quaternary tectonic movements and landscape evolution and can be related to two stage development of the morphostructure.

The laterite profile: origins and variations

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Laterite is a word that has come to mean almost anything the user decides. Its application ranges from strict conformity to Schellman's original definition, to any outcrop of ferruginous surface rock. In this paper, we first consider the meanings of the word. We will then consider the ways through which deeply weathered profiles with an iron-rich upper region develop. So-called laterites from Weipa, central Queensland and south-western WA will be compared and contrasted with a view to discovering, not a universal law of laterite, but rather better laterite lore.

Paleomagnetic dating of weathered regolith at Northparkes Mine, NSW

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The ages of weathered, non-fossiliferous regolith materials are notoriously difficult to determine in Australia. Dating methods such as radiocarbon, luminescence and U-series disequilibrium are generally limited to the last few hundred thousand years, while techniques such as K/Ar and ESR are only applicable to mineral phases that are rare in regolith sequences. However, because of the common occurrence of secondary iron-rich minerals, the techniques of paleomagnetism have wide application in regolith studies. In this study, we have used paleomagnetism in an attempt to establish a chronological framework for weathered regolith materials at Northparkes Mine, NSW.

At Northparkes Mine the orebody is a porphyry copper-gold deposit related to Late Ordovician quartz monzonite intrusions. The orebody is overlain by up to 30 m of strongly weathered regolith, which is well exposed in two open-cast pits (E22 and E27). In both pits, transported sediments unconformably overlie in situ weathered bedrock saprolite. The transported sediments fill broad depressions (up to 400 m wide and 25 m deep) which have little or no expression in the modern landscape. They consist of mottled clay-rich materials composed dominantly of kaolinite, with secondary dolomite, silica and hematite. The high degree of weathering of the transported sediments makes interpretation of their depositional environment extremely difficult, but we tentatively refer to them as valley fill sediments, probably partly colluvial and partly alluvial.

Eighty five oriented paleomagnetic samples were collected in 6 cm^3 plastic boxes from each of nine sites: four sites in saprolite; and five sites in the valley fill sediments. Both thermal and alternating field demagnetisations were carried out on the samples to isolate the Characteristic Remanent Magnetisation (ChRM). From their strongly weathered appearance, we conclude that the ChRM is a chemical remanent magnetisation acquired during weathering of both the in situ and transported regolith materials. Natural Remanent Magnetisation (NRM) directions (i.e. prior to demagnetisation) were scattered, with a general tendency to cluster around the present field direction at the site, which in some of the samples suggests contemporary (e.g. mining-related) weathering. However, with progressive demagnetisation many of the samples revealed a reverse polarity component, indicating remanence acquisition during weathering prior to the Brunhes/Matuyama polarity transition (0.78 Ma). Samples from the weathered valley fill sediments yielded generally scattered directions, broadly consistent with remanence acquisition during Cainozoic weathering. Principal component analysis of forty four samples from Site 2, in pinkish weathered saprolite, yielded well defined intermediate and high temperature remanence components with a combined mean pole position of 51.2∞S, 81.4∞E (A_{95} = 3.6∞). This pole lies considerably west of the Australian Cainozoic Apparent Polar Wander Path (APWP) and appears to lie on the Carboniferous APWP.

From our paleomagnetic results we infer that weathering of regolith at Northparkes Mine has been an on-going process since at least late Paleozoic time.

Australian calcretes: classification systems and genesis interpretation

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In Australia, calcretes occur widely in the arid and semi-arid inland and coastal zones. Classification and genetic interpretation of a calcrete may provide clues for landform history and may have implications in mineral exploration, eg. uranium occurring in groundwater calcretes and gold anomalies being found in pedogenic calcretes.

There are three major types of calcrete classification system: (1) morphological classification; (2) genetic classification using hydrologic settings; and (3) classification based on calcrete development stage.

The morphological classification is easy to use and appears to be most objective, which is a basis, and the first step, for genetic interpretation and classification. Some morphological features are formed through certain depositional and diagenetic processes, which reveal the genetic history of a calcrete profile.

In the genetic classification system, there are two extreme types: phreatic (or groundwater) calcrete, which is formed by absolute accumulation of Ca and CO_3 from lateral transport by groundwater flow; and pedogenic calcrete resulting from relative accumulation of carbonate, eg. by eluviation/illuviation. However, between the two extremes there are many other types forming a series from more groundwater related types to more soil-water controlled ones.

According to development stages, calcretes can be classified from the least developed, with low carbonate content and simple morphology, to mature types, with high carbonate content and various morphological features.

In different areas, calcretes may form under different conditions of climate, geology and topography, and through different landform histories. This results in differences in the associations of calcrete and landforms in different areas. The examples include the valley calcrete along the ancient drainage lines in the northern Yilgarn Plateau, sheet and rhizocretionary calcretes in coastal dunes, discrete carbonate nodules in blanket-like aeolian clay (parna) deposits and cap-crust calcrete on some calcareous rocks. Although it is difficult to classify calcretes solely based on these landform-calcrete associations, these relationships may be used to map Australian calcretes, particularly at a small scale and covering large areas.

Regolith carbonates in eastern Australia: characteristics and potential as an exploration sampling medium

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Australian regolith carbonates are most abundant and widespread across the south of the continent, occurring in association with coastal calcarenite dune complexes, and further inland in association with a wide range of geological and landscape settings. Regolith carbonates are frequently used as indicators of semi-arid or arid palaeoclimates, in which the degree of carbonate leaching is limited. However their more restricted occurrence in semi-arid to arid central and northern Australia, and presence in more humid parts of southern Australia, suggests that the controls on their distribution are much more complex. Their regional distribution is largely controlled by a fundamental relationship between:

(i) the degree of leaching of carbonates, which is mainly proportional to the amount of rainfall, but also to landscape setting; and,

(ii) the availability of carbonate and appropriate cations, mostly derived from bedrock weathering (particularly of primary carbonates, and mafic lithologies), aeolian accessions, and rainfall chemistry, with some local landscape controls.

Rainfall chemistry, rather than amount, is a particularly significant control on regolith carbonate distribution. Areas in southern Australia with widespread pedogenic carbonates (such as south of the Menzies Line in WA and its equivalent across central SA and NSW) largely conform to the extent of calcium and magnesium-rich winter rains derived from the Southern Ocean. Coinciding with this regolith carbonate distribution are major geoecological associations, such as the regional association of mallee eucalypts, nelia (*Acacia loderi*), rosewood (*Heterodendrum oleifolium*) and some bluebushes (*Maireana spp.*) with regolith carbonates in south-western NSW, and the association of mulga (*Acacia aneura*) with neutral to acid regolith types in north-western NSW. The distribution of many bird, mammal, reptile, amphibian and crustacean species may also be related to the distribution of regolith carbonates.

Both pedogenic and groundwater carbonates occur in western and central NSW. The pedogenic types mostly consist of nodular, pisolitic and rhizomorphic facies within the top 1-2 m of the regolith, which in many cases overlay laminated, massive and silty carbonate facies. Groundwater types are mainly in the form of massive and tabular sheets formed in the phreatic zone, particularly within deep alluvial sequences, such as along palaeovalley systems. Studies of profiles and regolith-landform toposequences in the Broken Hill region reveals that regolith carbonate facies vary both vertically within a profile and laterally across the landscape.

Regolith carbonates in central and western NSW range from calcium-rich accumulations dominated by calcite through more magnesium-rich dolomites, to magnesite accumulations, especially in association with weathered ultramafics. The carbonate mineralogy and chemistry broadly corresponds to the origin and facies of the regolith carbonates. The Ca/Mg and associated calcite/dolomite ratios progressively decrease with increasing depth in most pedogenic carbonates, with a weak association between nodular carbonate facies and higher calcium and calcite contents. Groundwater carbonates typically have higher magnesium and dolomite contents, largely reflecting their precipitation from saline groundwaters. Towards the axis of many valley systems where regolith carbonates are often thickest, magnesium-rich carbonates of both pedogenic and underlying groundwater types predominate, whereas on valley margins, more calcium-rich, nodular and laminated pedogenic carbonates occur. This reflects the strong association between vadose and phreatic water chemistry with landscape setting.

Although pedogenic carbonates have been successfully used as a sampling medium in gold exploration programs in WA and SA, so far they have only had limited applications in eastern Australia. Preliminary results from NSW, reveal that with considerations for the origins, facies and landscape settings of regolith carbonates they may be a valuable sampling medium. In the Broken Hill and Cobar regions of NSW a strong affinity between Au and Ca has been found in many pedogenic carbonates. Carbonates with greater Mg contents, however contain much less Au, possibly reflecting greater mobility, and therefore leaching of Au, in saline solutions. As a result, the nodular, calcium-dominated, pedogenic regolith carbonates are often a good gold exploration sampling medium. Further to this, however, the lateral dispersion of carbonate solutions through the regolith towards the axis of valley systems may account for "false anomalies" in many situations.

Specialised regolith maps for mineral exploration

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Regolith maps describe and show the distribution of weathered materials in different landscapes. The surface expression of mineral deposits is typically highly modified, or, in places, completely obscured by the regolith. Therefore regolith maps form an integral part in any comprehensive exploration program, particularly in environments that have an extensive regolith cover.

In addition to the standard regolith-landform map, a series of specialised thematic regolith maps and modelled/processed raster datasets using geographic information system tools are now being generated to assist mineral exploration. An example of a specialised product is a geochemical sampling strategy map which reclassifies regolith-landforms units into major geochemical-regolith associations. Regolith-geochemical associations are regolith units which require similar sampling and interpretative approaches. Other thematic maps are generated by integrating regolith information with other complementary datasets. For example, major regolith-geochemical units and surface geochemistry can be superimposed over airborne magnetics imagery enabling those datasets to be readily interpreted and correlated with sub-surface structural features.

Modelled/processed raster datasets can also be generated that use regolith polygons as spatial limits to preform zonal mathematical functions on other datasets. These functions allow the user to take into account the effects of the regolith when interpreting geochemical or other imaged datasets like airborne gamma-ray spectrometrics. Zonal modelling allows the user to highlight subtle features or anomalies in the data which may of otherwise be missed. Several examples of specialised maps and modelled raster datasets specifically tailored for industry are presented.

The relevance to geochemical surveys of mapping the regolith with field portable spectrometers

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One of the characteristics of the regolith which sets it apart from most other geological environments is the abundance of clay and other fine grained phyllosilicate minerals concentrated in the near surface environment. Although difficult to study, there is a wealth of information that can be gained from analysing the composition and distribution of these minerals within the regolith. New techniques for analysing and presenting data from portable infrared spectrometers provide an ideal way of mapping these minerals.

This paper investigates the use of data from portable infrared spectrometers for mapping regolith profiles in a number of geological environments. The results presented show how these data can be used to recognise not only important mineral species but also compositional and crystallinity variations within these species. This has implications not only for logging regolith profiles but also for recognising and mapping alteration in weathered rocks.

Our work has shown that the integration of these data with other data sets (eg. geochemical results and field logs) can lead to a far greater understanding of the nature of the regolith in a project area in a short space of time. A number of case studies are used to demonstrate the usefulness of these data and the processing techniques which can be used to analyse them.

A summary of data from over 40 profiles though deeply weathered regolith is presented. These data show that in many regions there is a strong correlation between variations in kaolinite crystallinity, smectite proportions and the location of basement contacts beneath transported cover sequences.

Results of the analysis of spectral data from a palaeochannel in the NT is presented. These were used as an aid in trying to locate basal gravels in the channel and to correlate between drill holes in an environment where visual logging is difficult.

The integration of 'end of hole' sample spectral data with equivalent geochemical data is used to show how the reliability of geochemical results can be assessed using the infrared data. The same type of data is used to investigate relationships between mineralisation and alteration in a deeply weathered environment.

This type of analysis can be carried out on site as drilling is being undertaken, facilitating more effective geochemical sampling and more consistent logging in deeply weathered terrains. It can also be applied to pre-existing samples and the results used to reassess interpretations of geochemical data and to plan future drilling.

A new regolith-landform map of the Western Victorian Volcanic Plains

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The Western Victorian Volcanic Plains extend from north of Melbourne to near the SE South Australia border, and are linked by age and volcanic type to the nearby sub-province around Mt Gambier.

Geological and regolith-landform mapping by Honours students over the past decade has provided new data across most of the northern part of the Plains, which also covers the southern part of the Ballarat 1:250 000 mapsheet area. Some twelve Regolith-Landform Units have been distinguished, elaborating on the four major units presented on the Hamilton 1:1 000 000 regolith map (Ollier and Joyce, 1986) which were based in turn on earlier soil mapping by Gibbon and Gill (1964).

Mapping units are based on landforms and regolith development. The landforms range from young Stony Rise flows, through degraded Stony Rises and undulating clay plain on flows of 2 to 3 Ma, to dissected clay plateaux on the oldest flows of 4 to 5 Ma. The regolith ranges from almost-bare basaltic lava outcrop, through 1 to 2 m deep montmorillonitic clays with gilgai, to mottled and kaolinitic profiles many metres deep. Natural vegetation and current land use have also provided indications of regolith type, and the Honours mapping has been assisted by the use of air photos, photomaps and Landsat imagery. Airborne geophysics from the National Geoscience Mapping Accord now covers much of the area, and has been used to add further detail.

Available K/Ar and radiocarbon dates have been used to provide numerical ages for the parent materials of the Regolith-Landform Units on the lava flows, and the regolith map is unusual in that the units have maximum ages of only 5 Ma or less. The new regolith map allows a detailed landscape history to be developed, including the sequence of volcanic activity and related drainage changes.

Regolith - an ally to new mineral exploration in eastern Queensland

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Eastern Queensland between Marlborough and the New South Wales border is a prospective area for new mineral discoveries. The area is well credentialled historically, recording significant gold production at Mt Morgan (240 t), Gympie (106 t) and Cracow (19 t). The area contains numerous small occurrences of gold, silver and copper. Other minerals range from nickel and cobalt in lateritic environments, to magnesite and even diamonds. Exploration for VMS style deposits is continuing. The region contains a patchy distribution of regolith consisting of ferruginous duricrusts overlying mottled and bleached lateritic soil sequences. Silcretes are also present in some regions. Erosion has stripped the older regolith from many areas to contribute to Quaternary alluvial deposits. However, there are a number of locations where consolidated and semi-consolidated regolith profiles are partially or completely intact, obscuring prospective underlying geology. New data are now available to assist the study of these areas. The data include the Department of Mines & Energy's extensive program of aerial geophysics comprising magnetics and radiometrics. Revised geological data are also available from mapping programs now in progress. These new datasets, when integrated with Landsat TM information, provide an opportunity to revisit a prospective region in the search for new mineral discoveries.

Geoelectrochemical phenomena in placer deposits and the possible role of electrical fields in the overall formation of regoliths

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Besides Au and Pt, placer deposits sometimes contain other native metals, eg. Hg, Ag, Zn, Fe, Sn, Pb, Bi, Cu and As. With the exception of gold and metals of the Pt group, all these metals are less stable in surface environments. Nonetheless, metals in native form are found more often in surface environments than in primary rocks of deep-seated ore deposits.

In placer deposits, native metals sometimes join in mutual coalescence, such as Pt-Pb, Sn-Pt or Sn-Au. Such mineral associations are unknown in primary ore deposits.

A question arises: why (how) do metals in reduced forms occur in oxidised surface environments? We examine the above data from a geoelectrochemical perspective. Several types of natural electrical fields are widespread in surface environments, particularly filtration, diffusion and absorption electrical fields, which may be responsible for the above occurrences.

We modelled the filtration electrical field in laboratory conditions with water flowing through quartz under pressure equivalent to 1.6 m height of water. (Goldberg, 1972). As a result of water permeating through quartz, a -0.05 volt potential appeared in the system. Under such conditions, formation of secondary native metal deposition is possible when the primary native metal and mineral particular are present (a growth Au nuggets and other phenomena).

Electrical fields were also modelled based on geochemical potential (Alekseyev et al, 1989). Model laboratories showed an accumulation of component against the gradient of concentration, only because of diffusion potential.

A wide-ranging manifestation of various types of electrical fields in surface environments should lead to a polar redistribution of elements and their accumulation. The research cited above demonstrates this approach.

I believe it is important to conduct special geoelectrochemical research on the formation of the regolith in the broad sense of the term.

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Bronzewing – the role of regolith-landform control and regolith geochemistry in the discovery of a large gold deposit

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A brief assessment in 1992 of the geology, regolith systematics and exploration success in adjacent tenements pointed to suitable structural/lithological association for discovery of gold mineralisation in the Bronzewing/Alf Well Exploration Licences of the Great Central Mines/Mark Creasey Joint Venture. Some of the most prospective sites for Au are covered by thick transported overburden (up to 80 m) and the remainder amenable to surface sampling of regolith materials.

Regolith domains were outlined and a program of surface sampling was carried out (747 lag, 527 rock and 162 soil samples). Rotary Air Blast drilling was undertaken on areas of transported cover on a nominal 400 m spacing along tracks and selected transects.

Lag was hand-picked ferruginous materials, mostly heavily ferruginous saprolite and iron segregations in saprolite-dominated areas, with lesser areas of residual nodules and pisoliths in duricrust-dominated areas. Exposed weathered rock, ferruginous saprolite and potentially mineralised rock (e.g. quartz) were sampled separately. RAB drill holes were taken to refusal (reasonably fresh rock) in the depositional area. The holes were sampled by 4 m composites over the length of the hole and analysed for gold. Additional samples were hand picked from drilled intervals of lateritic residuum which commonly occur beneath variable thicknesses of colluvium-alluvium. Lateritic residuum consists of nodules and pisoliths merging to collapsed ferruginous saprolite with depth. These latter samples and the surface samples were submitted for ppb level gold analysis and a multi-element AAS suite (As, Bi, Cu, Pb, Zn, Ni, Ag, Mo, W, Sb, Sn, Mg, Cr).

Results were plotted by sample type on the map of regolith distribution and anomalous areas outlined. A high proportion of gold assays were anomalous; 5.5% of the lag samples were in excess of 100 ppb and 15% of the rock samples were greater than 100 ppb.

Strongly anomalous gold occurred in nodular pisolitc lateritic residuum under 5-30 m thick alluvial cover at the site of the Bronzewing pits, and in surface sampling at the Bob's Find and Sundowner localities.

Gold at Bronzewing was first reported in the routine four metre composites of hole BWRB 65 (12 m @ 1 g/t from 72 m) below 19 m of transported cover.

Synthetic Ni goethite and hematite: reproducing hosts for nickel mineralisation in Ni-laterites

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Incorporation of Ni within synthetic goethite and hematite was investigated by x-ray diffraction (XRD) and acid dissolution analysis. Goethites synthesised by the oxidation of mixed Fe^{2+}-Ni^{2+}-chloride solutions at room temperature and pH 6-7 uniformly incorporated up to 10 mole% Ni. Goethites prepared at ambient temperature and pH >12 incorporated 5-6 mole% Ni at the surface of crystals. Differences in the extent and homogeneity of Ni incorporation appear related to the different synthesis conditions and kinetics of goethite crystallisation. Incorporation of the larger Ni^{2+} ion resulted in anisotropic distortion of the goethite unit-cell. The unit-cell b-dimension increased linearly as Ni substitution increased whereas the a- and c-dimensions did not change.

Hematite prepared from coprecipitated Ni-ferrihydrite gels at pH 7-8 and 90°C, uniformly incorporated up to 6 mole% Ni. Unit-cell parameters increased linearly with increasing Ni substitution indicating the replacement of Fe by Ni within the hematite structure.

The prolonged weathering of iron and stony-iron meteorites and their anomalous contribution to the Australian regolith

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The surface of the Earth has continually been bombarded by meteorites since it first accreted 4.6 billion years ago. Australia's relative tectonic stability and prolonged aridity has provided an ideal site for the accumulation of meteorites over a long period of time, so much so that the Nullarbor Plain in southern Australia is considered one of the best collecting grounds for meteorites after Antarctica. Unlike those from Antarctica, portions of some ancient Australian iron meteorites have become so highly weathered (either in part or in whole) that fragmental material has come to resemble much of the ferruginous lag that blankets many parts of arid Australia. Herein lies the difficulty that mineral exploration companies searching for nickel and platinum group elements (PGE) face; is ferruginous material anomalously high in these economic minerals, derived from deep weathering of ore-bearing ultramafic rock or is it only the scattered remnants of highly weathered iron-nickel meteorites which is of virtually no economic value other than to academics and collectors? To address this confusion, highly weathered portions of the iron meteorites Mundrabilla and Youndegin, a completely weathered ball of iron shale from Wolf Creek and a weathered sample from the stony-iron meteorite Huckitta were investigated by X-ray diffraction (XRD), X-ray fluorescence (XRF) and scanning electron microscopy (SEM) to ascertain features which can be used to characterise highly weathered iron-nickel meteorites. This study will then allow comparison with on-going CRC LEME research into ultra-mafic weathering on the Yilgarn, WA and north of Rockhampton, QLD.

Regolith geology of the MKD5 nickel sulphide deposit, Western Australia

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The MKD5 nickel sulphide deposit is located 80 km south of Wiluna, 90 km north of Leinster. The deposit is situated within the Norseman-Wiluna Greenstone Belt of the Yilgarn Craton and represents the word's largest known dunite-hosted Archaean nickel sulphide deposit. The current resource of MKD5 is 460 Mt at 0.6% Ni.

The mineralogical and geochemical composition of the primary komatiitic rocks at MKD5 and their weathered equivalents and overlying exotic material have been studied in two cross-sections. The first section runs sub parallel to the regional strike of the komatiites and has allowed extensive regolith profile mapping. The second section, perpendicular to the regional strike of the komatiites, has provided extensive geochemical and mineralogical information through drill hole sampling.

The base of weathering extends below 120 m over the mineralised sequences and is much shallower over barren lithologies. The regolith has been broadly divided into three main units, in situ and residual, mixed zone and exotic cover. The in situ regolith is composed predominantly of degraded serpentine, neo-formed hydrated GM-silicates, carbonates, silica and minor Fe oxides. The top of the in situ regolith is marked by a sharp drop in GM content, referred to as the GM-disconformity. The most significant zone within the profile is the collapsed ferruginous saprolite, in which element abundance show a significant increase, due to residual concentration processes. The collapsed ferruginous saprolite overlies the Mg-disconformity.

The unconformity between weathered Archaean and overlying exotic cover is clearly visible in pit mapping but, in detail, there is a mixing zone, up to 15 m thick, with chemical and mineralogical characteristics of both the underlying and overlying regolith. Above this mixing zone, the exotic cover is up to 30 m thick, is characterised by elevated concentrations of olivine-incompatible elements and authigenic minerals of multiple provenance.

Regolith and geochemical evolution at Honeymoon Well and the dispersional response of nickel-associated elements

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The Honeymoon Well Ni-sulfide deposits lie beneath a featureless sheetwash sandplain, in the northern half of the Agnew-Wiluna greenstone belt, 40 km north of Mount Keith. Weathering processes have differentiated weathering profiles into residual regolith horizons, overlain by transported overburden, both modified by overprinting features. A change from humid to arid climates in the latter part of the Tertiary caused gross changes in profile hydrology and weathering solution chemistry, resulting in overprinting effects that acted to modify or replace existing mineralogical assemblages of residual regolith and transported overburden.

Weathering at Honeymoon Well has been accompanied by tectonic stability, a lack of glacial incision and regolith has evolved under humid and arid weathering styles. Lateritisation under humid weathering is generally characterised by high watertables, seasonal variations in climate, an open chemical system, where soluble products are partially or totally removed from weathering profiles, and a large throughflow of water.

Later, arid weathering occurred via three phases. Phase 1 occurred during the transition from humid to semi-arid climates. Here, the change in vegetation and decrease in throughflow of water acted to truncate residual regolith, lower watertables and Fe-redox zones and increase salt contents of groundwaters. Saprolite formed during lateritisation became differentiated into upper and lower saprolites. The chemical system became more closed resulting in the inception of carbonate overprinting layers at the base of lower saprolite and the modification of secondary sulphides, lizardite and secondary silicates by metal-bearing weathering solutions.

Phase 2 occurred with increased aridity. Residual regolith truncation ceased, the upper portion of residual regolith became indurated, alluvial sediments were deposited, horizontal, impermeable overprinting layers influenced the lateral flow of groundwaters, salinity increased and the chemical system continued to be more locally restricted. These features resulted in the formation of new Fe- and Mn-redox zones and associated silica overprinting layers, and further upgrade of silicate and secondary sulphides by metal-bearing solutions expelled during the transformation of goethite to hematite.

Phase 3 occurred with extended aridity and continues to the present day. This phase was characterised by: aeolian and colluvial sediments deposited at surface; further hydrological fluxes and stillstands; an increase in horizontal movement of groundwaters and evaporative processes; a generally closed chemical system; and variably saline weathering solutions. Further, the upper portion of residual regolith physically and chemically interacted with the base of transported overburden. These processes resulted in the following features: multiple Fe- and Mn-redox zones in residual regolith and transported overburden; multiple upper saprolitic silica overprinting layers; carbonate overprinting layers in lower and upper saprolite and at the base of transported overburden; a neoformed supergene sulfide layer near the basal Fe-redox zone; continued upgrade of secondary sulphides and silicates by metal-bearing solutions; and accumulation of a siliceous hardpan. Formation of overprinting layers further modified regolith permeability and hydrology.

Regolith expression in prospective areas of the central western Lachlan Fold Belt, NSW

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The central western area of New South Wales is a significant metallogenic province. Most deposits with surface expression have been discovered and present exploration is focussed on the search for deposits in areas obscured by surficial material. The most obvious expressions of an ore body in or beneath the regolith zone include gossan development and the formation of landforms (hills) in areas of resistant siliceous alteration. However, sometimes the physical traces of these ore bodies are more subtle, for example: geochemical haloes of tracer minerals; elevated concentrations of unusual secondary minerals in the soil zone; a characteristic radiometric signature; or, detectable magnetic properties of transported sediments. This study defines the range of physical expressions of regolith in the landscape, along five transects in central western New South Wales, in order to develop a better understanding of the mineralogical, topographical, microstructural and geophysical expression of regolith in areas of base metal mineralisation in this part of Lachlan Fold Belt. The transects are: Temora to West Wyalong; Lachlan River South; Lachlan River North; Canobolas Rise; and, Condobolin to Nyngan.

Studies of Australian terrestrial environments indicate a change toward warmer and moister conditions during the early Tertiary. This change in climate regime would have enhanced weathering, and it is possible that many of the deeply weathered profiles preserved in this area formed around the early Tertiary. There is still debate about whether there was a widespread deeply weathered profile developed in central western New South Wales, or whether the pre-Tertiary topography had such great variation in relief that deep weathering profiles only developed in some places. Preliminary reconnaissance in the Temora-West-Wyalong-Parkes-Condobolin-Nyngan area indicates that there has been a relatively extensive deeply weathered surface developed, however, it has subsequently been dissected and covered to varying degrees. This is consistent with backfilling of this area during periods of high-stand in the Murray Sea.

Weathering contrasts between the Yilgarn and Carlin gold provinces

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The Archaean greenstone belts of the Yilgarn Craton of Western Australia and the Carlin-type deposits within the Palaeozoic succession of northern Nevada are the two main sources of gold today after the Witwatersrand goldfields of South Africa. New data from Carlin, in particular, place an interesting perspective on weathering in major gold provinces.

The Yilgarn Craton is traditionally thought of as being deeply weathered, and it has been the birthplace of many techniques that characterise different components of the regolith. Strong to complete oxidation in the form of kaolinite and ferric oxide-rich material commonly extends to several tens of metres depth and to 100 m depth in rare cases. There are many examples where the base of oxidation is deeper near sulphide accumulations than it is in surrounding terrain, and this depression has been attributed to acid ground waters developed from the oxidation of sulphides. Below the zone of oxidation is a transitional zone in which rock textures are well-preserved, the rock is fragmented into clasts, sulphides are present and Fe is in the reduced state. The base of the transitional zone, i.e. the top of fresh rock, can be as deep as 200 m below the surface, but is more commonly 100 m deep or less. The transitional zone is characterised by the deposition of secondary minerals below the water table and the destruction or modification of primary mineral assemblages. The transition zone is commonly porous with open pore spaces from the leaching of carbonate and other minerals. Fluctuations in the level of the water table, in conjunction with local variations in rock type, can result in complex regolith patterns. Clay and oxide minerals on fractures and cracks indicate the passage of ground waters well into bedrock.

The Carlin-type deposits are characterised by a bleached upper interval dominated by kaolinite and ferric oxides, without pyrite or carbonaceous material. This zone of oxidation extends to 300 m depth in several pits, and 500 m depth in at least some areas. Drill core to 800 m depth locally contains ferric oxide and kaolinite lined clasts that appear relatively fresh in their centres. This zone of oxidation was originally attributed to the primary mineralising process, but is now well-established as a feature of weathering. This oxidised zone generally follows the topography (i.e. is present in every open pit operation for the top few 100 m regardless of elevation); this is after exhumation from their formational site at several km depth.

Below the oxidised zone in Carlin-type deposits the gold is refractory and needs different extraction methods to the cyanide-leachable gold in the oxidised zone. This deeper mineralised interval is characterised by the presence of carbonaceous material, introduced silica, arsenian pyrite, dolomite, 'illite' and/or kaolinite as well as local high orpiment and realgar content and a high proportion of voids (i.e. porosity). The porosity is due to the dissolution of calcite and is known in drill holes from 1.5-2 km depth. There are rare occurrences of calcareous gold mineralisation lacking excess porosity as well as silicified ores with local concentrations of stibnite. Outside mineralisation, calcite occurs in host rocks as matrix and veinlet material.

A substantial part of the porous mineralisation, which is virtually all the mineralisation in the Carlin-type deposits below the oxidised ores, is here interpreted as postdating the major gold and arsenical pyrite mineralisation and may in part be 'transition' zone material formed during the early stages of weathering. This weathering is likely to have been Tertiary in age although meteoric waters are still percolating to great depths today, as evidenced by the large crystal filled cavities at the Meikle Mine. Deuterium isotopes on kaolinite support the influx of meteoric waters to the deepest levels of mineralisation.

This interpretation defines the transition zone of weathering in the Carlin province as the interval in which weathering including the dissolution of calcite has begun but has not totally consumed sulphides and carbonaceous material through oxidation. The relatively late origin for this porosity helps overcome the paradoxical preservation of open spaces previously proposed to have been generated at initial formation depths of >4 km. This revised interpretation also strongly suggests a re-evaluation of hypothesising a meteoric influx during formation by deep H_2O-CO_2 fluids under lithostatic pressure.

We are forced to review our idea of the Yilgarn Craton as being deeply weathered. The differences in depth of weathering between the Yilgarn and Carlin provinces can, at least in part, be related to elevation differences.

The use of acid insoluble residue of rock powders as a sample medium in the recognition of primary wall rock alteration patterns of gold mineralisation in regolith

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During the last fifteen years, an integrated paramagnetic/lithogeochemical exploration technique was developed for the search of gold and massive sulphide deposits. The method is based on the interpretation of electron paramagnetic resonance (EPR) powder spectra and trace elemental composition of the acid insoluble residue of fresh rock or rock pulp samples. What remains of the rocks after hot nitric acid treatment consists essentially of quartz, with minor feldspar and sericite. If the residue is rich in certain elements like Au or Zn, for example, it is likely that mineralisation is nearby. Depending on the case, additional mineralisation indicators like Ba and Mn for massive sulphide deposits and As, Ge, Li, Rb and W for many gold deposits may be used. The very typical EPR spectra indicate lattice imperfections in the quartz and correlate well with the trace element distributions. Wallrock alteration patterns usually express themselves by increased K and Rb concentrations, high Rb/K and Rb/Al ratios (sericitic alteration), Na, Ca and Sr depletion and strong $[AlO_4]^\circ$ centres in the EPR spectra.

Use of the integrated paramagnetic/geochemical method has now been extended to highly weathered terrain. Sample treatment with hot hydrochloric, nitric and sulphuric acid removes secondary minerals like iron and manganese oxides and hydroxides, carbonates, sulphates, clay minerals etc. The acid insoluble residue of regolith samples consists essentially of quartz and chalcedony (together with some resistate minerals), which can be used to delineate primary mineralisation and wallrock alteration, just like the quartz concentrates derived from fresh rock. Case studies have been carried out for gold deposits in the Tanami Desert and in the Meekatharra, Kalgoorlie and Cobar regions. Pronounced EPR signals can be observed at the surface above mineralised areas, in the gold depletion zones below, and in the wallrock alteration zones around mineralisation. Trace elemental patterns are similar to those of quartz in fresh rocks. High Rb/K ratios in surface material above mineralisation may indicate remnants of original sericitic alteration and in some cases extensive surface anomalies of As, Cu, Pb and Zn occur.

Regolith effects and Au exploration in the Blayney district, NSW

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Au mineralisation in the Blayney district, 180 km west of Sydney in the Lachlan Fold Belt, may have significant associated As, Cu, Pb, Sb and Zn contents. Such potential pathfinders are retained in gossanous outcrop, where present, and may also be retained in residual soils. Indeed study of residual soil at Osborneville (10 km south of Blayney) suggests that the fine (<63 µm) fraction of the soil contains higher concentrations of Au and base metals than the coarser soil fractions. However aeolian material is also known to be deposited in the Lachlan Fold Belt during the last 300 000 years. Aeolian material successions produce red soils with > 80% of their weight having a grain size < 63(m and having consistent Ti/Zr ≈ 10-13. Furthermore, many soils of the region contain an aeolian component which is not immediately apparent except after sieving and chemical characterisation.

If a significant amount of an aeolian component is present in a soil, the magnitude of any Au or base metal anomaly (associated with residual material) could be substantially reduced. Thus sampling based on the use of the fine fraction of soils may not have fully tested the economic potential of the region. Instead, use of the coarse (>2 mm) fraction of the soils is recommended, preferably after inspection of such material for the degree of rounding of grains or other signs of transport. The use of pisoliths in the district is also briefly discussed.

seem to be derived/grown in aeolian component.

Lateritic weathering and gold enrichment in the Victorian gold province

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Although deep weathering and associated supergene enrichment of gold have not been considered features of the Victorian gold province, there is emerging evidence that these processes operated during the Tertiary, and that they should be considered during exploration in low-lying areas marginal to the Central Victorian Uplands. At least two periods of deep chemical weathering can be recognised, with strong development of ferricrete and silcrete duricrusts and thick pallid zones. Variations in gold/silver ratios, coarsening of gold, and colloform gold textures are suggestive of solution and redeposition of gold in the weathering zone.

Isolated remnants of red soil reported at 1 000 m a.s.l. in west-central Victoria, and evidence from Mesozoic sediments in the Gippsland Basin and from beneath Renmark Group sediments of the Murray Basin, might relate to weathering of a Mesozoic palaeoplain. However, the best-represented deep weathering surface is present at elevations below 500 m in highland areas and is referred to here as the Norval Surface. Younger weathering surfaces include the mid-late Miocene Mologa Surface of the Murray Basin, which reportedly does not have deep chemical weathering associated with it, and the Karoonda Surface and equivalents, developed on early Pliocene sediments and basalt.

The Norval Surface is confined to the floors of broad palaeovalleys and was apparently related to high water tables in such positions. Palaeosols within these valleys can be seen to be continuous from remnant White Hills Gravels onto adjacent Palaeozoic basement, where well-developed ferricretes are underlain by pallid zones up to tens of metres deep. Younger Calivil Formation deep lead gravels are partly sourced from these older gold-bearing gravels and contain ironstone clasts, but lack deep weathering profiles themselves. These younger gravels are overlain by previously dated basalt which indicates a minimum age of 6.07±0.11 Ma (Miocene), constraining the age of the Norval Surface between this and the Mesozoic palaeoplain. Deep weathering of overlying basalts may be related to the Karoonda Surface.

Acknowledgements: We thank Metex Resources NL, Forrestania Gold NL, Centaur Mining and Exploration Ltd and, in particular, Dr Neil Phillips for their support of and comments on this work.

Regolith study of the McKinnons gold deposit, near Cobar NSW

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At McKinnons, 37 km SW of Cobar, 4.5 mt at 1.2 g/t Au were held in oxides within weathered profiles to a depth of approximately 80 m. A study was carried out of weathered profiles, in particular, mineral dispersion by weathering and landscape and the gradients they created. Macroscopic analysis was used extensively on selected profiles as well as PIMA analysis, and some were analysed by chemistry and X-ray diffraction.

At 60-100 m depth sulphides are weathered; Zn disappears whilst Pb persists through to the surface. Sb and As become depleted at 30 m then reappear at the surface. Gold increases upward through the profile, dropping near the surface. Gold is most likely supergene, Pb occurs as hindsdalite and Sb and As are taken up by iron oxides formed after the pyrite. Kaolinite tends to be absent from the mineralised profiles, gradually increasing away from them through the barren profiles. PIMA analysis is a particularly effective tool in the identification of this gradient. The disappearance of kaolinite, Zn, Sb and As and the transformation of muscovite into a poorly crystallised illite are the result of the acid conditions created by the weathering of pyrite.

The acid conditions created by oxidation of pyrite mobilised part of the Fe, together with Zn, Co, Ni, Mn. As a result of Fe mobilisation, a bleached zone occurs in the upper part of the mineralised profiles and around it, whilst mustard colours occur in barren profiles. In the lower part of mineralised profiles, a pink-brown zone occurs, passing to mustard beige colours in barren profiles. The presence of pink purple colours in profiles around mineralisation is due to precipitation of iron oxides introduced mainly in the form of hematite and bearing the Fe, Zn, Co, Ni, Mn removed from mineralised profiles during weathering. This hydromorphic displacement of Fe, Zn, Co, Ni, Mn from mineralised profiles during weathering can be observed about 1 km from the deposit at a palaeo-watertable 40 m down. Through the history of the deposit, Fe oxides have accumulated at two paleo-watertables, at the surface and at 40 m. The surface accumulation led to (Sb-As) iron oxides over the mineralised area and (Zn) iron oxides further away. With the drop in water level, these anomalous iron oxides were left hanging above the deposit, floating at the surface.

As weathering progressed down below, a second accumulation was created at the next longstanding palaeo-watertable 40 m below the surface. The former accumulation was dismantled by concurrent erosion and is likely to occur as (Sb-As) iron oxides lag on the paleosurface above and around the deposit and (Zn) iron oxides lag on the palaeosurface around and away from the deposit. The palaeosurface and its anomalous lag now lie beneath the pile of transported overburden. Directly over the deposit, the palaeosurface raises from the plain of transported overburden and anomalous Fe lag occurs on the surface. Additional dispersion from this anomalous lag on the current surface around the deposit is bound to be restricted compared to the underlying palaeosurface. It has to be noted that the current surface is somewhat flatter than the palaeosurface below it. Calcretes occur on the paleosurface and are potentially useful in identifying this palaeosurface.

Regolith geology and geochemistry at the Birthday gold prospect, Gawler Craton, South Australia

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Regolith geological and geochemical studies were conducted at the Birthday Au Prospect in the Gawler Craton, South Australia (SA). The study locality occupies an area of low topographic relief and has an arid climate. Vegetation cover consists of an open woodland of mulga and sheoak, with a chenopod shrubland understorey. The regolith consists of erosional (residual) units with a veneer (<2 m) of locally transported material. Calcrete, is ubiquitous in the B horizon as pisoliths, nodules and plates. The lower regolith consists of variably weathered clay-rich saprolite (5-10 m thick) overlying saprolite (20-30 m thick) and then fresh rock. The calcrete was anomalous in Au over mineralisation (>5 ppb) but generally poor with respect to Au contents in the clay-rich and saprolite zones (<3 ppb). Drilling indicates a series of parallel zones with Au mineralisation at about 30-40 m depth. A sampling line was chosen for intense study to cross proven mineralisation and to best intersect the original regional calcrete-Au anomaly, a variety of landforms, soils and vegetation.

Drill cuttings, vegetation, surface lags, soil and calcrete were sampled. The results suggest that although high Au contents in calcrete can locate underlying mineralisation, caution is required because similar concentrations may occur where there is no apparent underlying source. This apparent false anomaly is located on relatively steeper sloping terrain and at the base of a slope well to the west of known mineralisation (400 m). The Au enrichment in calcrete may suggest (i) the presence of mineralisation further to the west and that the Au has been chemically or physically transported to this site or (ii) that mineralisation may occur at a greater depth than presently drill tested.

The authors wish to acknowledge the support provided by Minotaur Gold NL. Charles Butt is thanked for earlier comments. CRC LEME is supported by the Australian Cooperative Research Centres Program.

A complex regolith at the Harmony gold mine, Baxter mining district, WA

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The Harmony Au deposit is hidden beneath a broad depositional plain, near Peak Hill, 125 km north-northeast of Meekatharra in Western Australia. Drilling has revealed a complex regolith of weathered and partly lateritised Proterozoic basement, clay-rich valley-fill sediments and colluvium. Logging the main regolith units produced a 3D regolith model which provided a valuable guide to geochemical sampling and later interpretation.

The basement of mafic and ultramafic metavolcanics and fine-grained metasediments has been weathered and partly eroded. Higher parts of this basement consist of ferruginous saprolite but saprolite and mottled zone occurs beneath the deeply weathered axes of palaeovalleys. Lateritic residuum, including duricrust, occupies the flanks of the palaeovalleys and provides evidence of weathering under seasonally humid conditions.

The palaeovalleys have been infilled with up to 35 m of smectite-kaolinite sediments, derived from erosion of the surrounding saprolite and deposited in a low-energy environment, probably during the last stages of the humid weathering phase. Hematitic, manganiferous and dolomitic mega-mottles have developed in these sediments and the tops of some valley-fill sediments contain pisolitic structures and fossil wood detritus, indicating pre-existing primitive vegetation (cycad, fern or conifer). There has been intense post-depositional weathering both at the surface and at oxidation fronts within the sedimentary pile. The upper parts of some of these sediments were eroded prior to deposition of the colluvium.

The colluvium, which is strewn with polymictic lag, varies from 0.5 m over parts of the Harmony Au deposit to 20 m over the palaeovalleys; some of the deeper sediments are probably alluvial. The base of the colluvium is complex, in places, being a mixture of saprolite blocks included in what appears to have been a palaeosol.

Recognition of regolith units and mapping of regolith relationships and distributions, during exploration drilling, is necessary for effective geochemical sampling and data interpretation.

Unconformity-related weathered laterite profiles at Mt Gibson gold mine, Yilgarn Craton, Western Australia

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Over 500,000 oz of gold have been mined from weathering profiles at Mt Gibson. Previous workers (CSIRO/AMIRA Laterite Geochemistry Project 240) concluded on the basis of preservation of primary rock fabric and quartz veins in ferricrete, together with gold above or close to bedrock sources that the profiles were developed mainly in situ on Archaean bedrock due to strong vertical chemical fractionation. However, recent open pit and surface regolith mapping have revealed a more elegant history indicating the weathering profile is best viewed as a polyphase groundwater metasomatic system, controlled by an Archaean/Tertiary unconformity. The following paragenetic sequence is recognised:

Stage 1: Ferricrete Formation

Preserved ferricrete duricrusts have all formed at, and overprinted, the unconformity between Archaean basement and overlying Tertiary sediments. Within basement, the ferricrete preserves original textures and pisolitic structures are rare. Within sediments, the ferricrete is markedly vermiform to nodular-pisolitic, demonstrably formed in situ and two end-member types are recognised. The internal structure and mineralogy of which are controlled by original sedimentology. Type 1 contains detrital quartz grains and formed within sandy to conglomeratic beds. Type 2 has a fine-grained massive internal structure and formed by replacement of clay-rich sediments. Cementation was aided by tree/plant root systems. Ferricrete development is not spatially related to a mottled zone. Gold mobilisation occurred from the basement into the ferruginised sediments late in the history of ferricrete formation. Airborne radiometric data indicates significant introduction of U and Th into the ferricretes, presumably from a granitic source.

Stage 2: Silcrete Formation

Ferricrete zones are clearly overprinted by a later bleaching, caused predominantly by the precipitation of silica cement and silcrete. This metasomatism has both pseudomorphed and destroyed pre-existing ferricrete textures, producing a characteristic mottling texture and was also focussed along the unconformity. The fluid moved both upward into the sediments and downward into the basement. The bleached areas are commonly cylindrical and are always 'cored' by hollow tubes up to 1.5 cm in diameter. Widespread preservation of such tubes, presumably fossil root/solution cavity systems, attests to high permeability around the unconformity.

Stage 3: Later Events

Later events have had a significant influence on profile development, including in paragenetic order: near surface hardpan development, near surface carbonate development and general degradation of the whole profile by formation of clays by hydration. Such pedogenetic processes have had a different effect on the two types of ferricrete in the sediments: Type 1 shows complete progressive in situ degradation to form loose yellow sandy soils. Type 2 also degrades in situ except that the pisolites are more chemically inert and commonly remain as layers of black cutan-less gravels.

The features described are not compatible with vertical chemical fractionation models for both laterite profile formation or supergene gold enrichment (eg Lawrence, 1997). They require significant subterranean lateral fluid influx and migration firstly of iron-bearing fluids and later silica-bearing, iron and gold dissolving fluids along an unconformity, followed by an extended period of in situ weathering and soil formation. Major iron-rich palaeodrainage systems identified in magnetic data indicate such processes have occurred on a regional scale. They have significantly affected geochemical dispersion haloes.

Field mapping and remote sensing data indicate the profiles are for the most part developed on long-lived drainage systems which are now undergoing subtle but widespread topographic inversion in their upper reaches. This has restricted the use of the Relict-Erosional-Depositional model of landform mapping. It is genetically based and requires modification to accommodate the phenomena reported here which are being increasingly recognised as an important component of the Western Australian landscape.

Selective extraction techniques for the recognition of buried mineralisation, Curara Well, Western Australia

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At the Curara Well Au prospect, about 420 km NNE of Perth, WA, primary and lateritic gold mineralisation are overlain by up to 20 m of barren transported overburden. A previous study conducted for CRAE had suggested that mobile metal ion (MMI) extractions were successful in locating the buried mineralisation. The site was therefore selected for a series of investigations of this and other partial and selective extractions in delineating buried mineralisation. Samples were collected from one soil profile and three traverses in mineralised and background areas and were treated using various commercially available and in-house analytical extraction techniques. The selective extraction involved pH 5 acetate (carbonate and adsorbed metals), followed by 0.25 M hydroxylamine (Mn oxides and "amorphous" Fe oxides). Except for Mn, no element shows enhanced acetate solubility above Au-rich laterite. In contrast, hydroxylamine extracts more Fe, Mn, Cu, Zn and Pb above mineralisation. The best signal to noise contrast was obtained for Mn, which reaches extractable concentrations greater than 800 ppm.

The higher concentrations of extractable base metals above mineralisation are primarily due to association of these metals with Mn oxides and/or amorphous Fe oxides. Furthermore, examination of the MMI results suggested that those MMI-extractable metals showing high contents over mineralisation (eg. Cu and Cd) were also associated with these phases. There is no known association between these metals and primary or secondary mineralisation at Curara, suggesting that this spatial correlation of greater extractable (and, weakly, total) metals with the buried Au deposit is coincidental. Similarly, there is unlikely to be a direct link between the surface Mn anomaly and the Au mineralisation buried at 10-20 m depth. Surface phenomena unrelated to the presence of mineralisation, such as the present-day drainage, are possible causes. It is considered that partial extractions can only be understood and interpreted correctly if conducted in conjunction with determinations of critical soil phases such as Mn oxides, amorphous Fe oxides, carbonates and any other materials expected to adsorb or otherwise accumulate dissolved ions at the site under investigation.

Acknowledgement: This research has been the outcome of productive collaboration between CSIRO/CRC LEME and the mineral industry through AMIRA project 409 and the industry sponsors are thanked for their encouragement and support, with particular thanks to CRAE for logistical support and site information. CRC LEME is supported by the Australian Cooperative Research Centres Program.

Some Remarks on the Definition of Bounding Surfaces within the Regolith Using AEM Data

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The conductivity contrasts within the regolith, between transported cover and underlying materials, and at the irregular interface between the saprolite and saprock/ bedrock, should be well resolved by the new generation of Airborne Electromagnetic (AEM) systems, which have skin depths ranging between 5 to 150 m. Improvements in system bandwidth, instrument sensitivity and noise reduction, together with new techniques for data processing and display, now permit the generation of maps of physical property variations and sections of conductivity structure. In regolith dominated terrains, detail on the conductivity structure may provide the opportunity to examine the geometry of certain bounding surfaces, specifically surfaces defining the top of regolith materials developed in situ and the top of fresh rock (the "weathering front"). Knowledge of the nature and variability of these surfaces could provide important information on landscape evolution and has relevance to mineral exploration.

Relatively simple, though computationally intensive, inversion techniques permit the processing of AEM data using layered models. This approach assumes that the regolith, from the perspective of AEM systems, might adequately be represented as a layered earth. Saltmap AEM data processed using a 1D layered earth inversion, has been examined for two study areas located over granite-greenstone terrain in the Eastern Goldfields, WA, and over granite-gneiss in the south-west of WA. For these studies the inversion assumes that the regolith can be represented as a three-layer model comprising: a relatively resistive upper layer (considered to represent transported alluvium and colluvium); a conductive second layer (representing saprolitic materials); and a resistive lower layer (representing fresh rock).

In both studies, the depth to the surface approximating the weathering front shows a relationship with the interpreted bedrock geology as defined by airborne magnetics. The patterns identified by the inversion indicate that weathering style is strongly lithodependent. This is manifest as variations in physical properties (conductivity) and apparent thickness. Whilst we caution against the use of absolute values defined in the inversion, the observed trends appear consistent and believable. Similar observations are warranted for the surfaces that define the top of "in-situ" regolith. This surface is better defined as representing the "top of conductive regolith". Interestingly, this surface appears to mirror trends in the thickness and variability of transported cover and could assist in our understanding of landscape evolution where transported overburden forms a significant part of the regolith.

Further work is required to better constrain the veracity of AEM inversion methods. Consideration is also required of new, approximate, conductivity-depth imaging methods for resolving the variability of regolith materials in the third dimension.

WMC exploration successes in lake terrains - applications of element dispersion, Kambalda, WA

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Exploration for nickel and gold in the Yilgarn Craton is focusing increasingly in covered terrains, with one of the most challenging of these being salt lake systems. WMC Resources has been intensively exploring Lake Lefroy near Kambalda, WA, for the last five years. As a result, a significant geochemical database obtained from drilling now exists, and this has lead to a greater understanding of the distribution of elements within the regolith. This knowledge can be utilised in exploring for ore bodies in covered terrains. A majority of the discussion focuses on gold exploration, however, brief mention will be made on some of the methods being employed in exploring for nickel mineralisation.

The element dispersion database is used at a number of different scales in gold exploration including target generation, prospect selection, and extension of known prospects/trends. In this paper, Lake Lefroy will be examined at a regional scale, then two prospect/mine scale case studies will be discussed, namely the Santa Ana and Intrepide ore bodies. The two case studies illustrate some of the differences expected in gold dispersion patterns due to variability in regolith development. The paper will also investigate how aircore geochemical signatures can be interpreted.

Although for the most part the paper will discuss the uses of drill hole geochemistry dispersion signatures (particularly aircore) in exploration, some surface geochemical techniques have also been tested. One of these techniques which has returned some promising results is Enzyme Leach. Three orientation study sites have been selected for discussion: the Santa Ana gold deposit; the Intrepide gold deposit; and the Mariners nickel deposit.

Regional-scale regolith geochemistry: identification of metalloid anomalies and the extent of bedrock in the Archaean and Proterozoic of Western Australia

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Base metal, PGE, and ferroalloy metal anomalies, and the extent of bedrock can be identified using the chemistry of regolith sampled at low density (one sample per 16km^2) over Archaean and Proterozoic rocks of the Nabberu area of central Western Australia. A variety of transported regolith media have been sampled, as in-situ regolith comprises about 15% by area. At the regional scale, results are not biased according to sample medium, but meaningful interpretation of regolith chemistry requires knowledge of the nature and distribution of regolith, and integration of regolith chemistry with other data such as airborne geophysics.

In conjunction with airborne magnetics and gravity, a variety of trace elements at a range of concentrations in regolith (eg. from Sc at a maximum of 32 ppm, to In at a maximum of 1.4 ppm) show that mafic igneous rocks are more extensively developed at the southerly junction of the Nabberu and Peak Hill 1:250 000 map sheets, where Archaean granite and subordinate greenstone were previously mapped. These mafic rocks represent Proterozoic sills and extrusives which have anomalous regolith concentrations of Pt and Pd on Peak Hill. Elevated concentrations of some base metals and ferroalloy elements in regolith near the contact of two groups of Proterozoic sedimentary rocks in the central northern part of Nabberu coincide with (a) a gravity high marking the northern extent of the Yilgarn Craton, and (b) an area of structural complexity including reverse faulting and shearing.

Posters

Aspects of palaeodrainage in the north Lachlan Fold Belt region

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Evidence for palaeodrainage in the northern Lachlan Fold Belt is provided by field exposures, drillholes, seismic, magnetic and radiometric data, and analysis of drainage directions combined with regolith-landform mapping. Palaeodrainage may be indicated by aligned segments of modern drainage, buried and topographically inverted palaeoalluvium and basalt flows. Palaeodrainage deposits range in age from Mesozoic to Quaternary. In many cases, palaeodrainage directions are oblique to present day drainage, and indicate a dynamic palaeohydrological regime, affected by continental breakup, subsidence of basins and global sea levels.

Aligned north to northeast trending segments of present day drainage along the eastern margin of the Lachlan Fold Belt are evidence for a drainage system which has since been disrupted by incision, capture and reversal. This system is likely to have contributed sediment to the Sydney Basin in the Triassic.

Topographically inverted Late Jurassic to Early Cretaceous alluvial deposits, dated by plant macro- and microfossils, occur in the Cobar and Parkes areas. These were most probably deposited by watercourses draining northwards to the Surat and Eromanga Basins.

Early Miocene sediments are known from an aggraded palaeovalley beneath the Darling River, and Late Miocene to Pleistocene sediments from a now-buried 140 m deep gorge cut by the proto Lachlan River during the Middle Miocene global sea level minimum. Some north to northwest flowing modern tributaries of these rivers are also known to overlie aggraded palaeovalleys.

Closely spaced dendritic networks of buried alluvium have been recognised from magnetic data in many areas. Magnetic pisoliths, probably derived by erosion of weathering profiles, are present as detrital clasts. The infilled channels were formed at a time of lower base levels, possibly the Middle Miocene. These channels may be related to "deep leads" present in many historic gold mining areas.

Basalt from the 11-13 Ma Canobolas and older eruptions flowed along local valleys. The courses of some of these valleys are preserved both as strings of topographically inverted basalt residuals and as basalt buried beneath alluvium.

Palaeodrainage deposits in the region have been mined for tin and gold, and the possible presence of placer deposits, which could form important secondary resources, needs to be properly assessed during exploration for bedrock mineralisation.

Geoscientists in LEME: Rights and Responsibilities

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This poster addresses the rights and responsibilities of geoscientists operating at all levels of mineral exploration and landscape evolution. The phrase 'all care and no responsibility' may be a useful phrase in normal conversation but what status does it have in law? What if one were injured in the field? What if one were involved in an accident where property was damaged? At a different level, one might ask what rights might one have in the intellectual property of a map, a journal article or even the discovery of a new theory of landscape evolution. These legal issues are explored in a poster that reports on work-in-progress concerning the boundaries of liability and various issues of intellectual property rights.

Characteristics of the regolith at the Jundee Deposit, Wiluna Region, Western Australia

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Jundee gold mine is located in the northeast of the Eastern Goldfields Province of the Yilgarn Craton, within the northern part of the Yandal Greenstone Belt. The area lacks outcrop, being covered extensively by colluvium and alluvium. Small, undulating hills of exposed ferruginous saprolite and minor BIF ridges provide the only relief. Jundee gold mine is situated within a plain covered with thin (1-5 m) colluvium-alluvium, overlying the residual profile.

The regolith profiles on basalt, porphyry and gabbro were contrasted using petrology, mineralogy and geochemistry. The weathering depth was greatest over porphyry (~100 m) due to its fabric and mineralogy; gabbro was more resistant (~40 m) due to its massive, intergranular fabric and larger grain size. Regolith profiles on basalt were generally about 70 m thick. Structural features, such as shearing, increase the depth of weathering locally.

Weathered profiles on basalt and gabbro have a well developed ferruginous horizon consisting of mega-mottled saprolite, mottled saprolite and collapsed mottled saprolite. The ferruginous horizon over porphyry is poorly developed with thinner units and more diffuse mottles because of a lower Fe content in the underlying lithology. Hematite was more abundant in regolith over basalt and gabbro; goethite was more abundant within profiles over porphyry. Zones of carbonate were also present within the porphyry profile.

Hardpanisation has affected both the colluvium-alluvium and the upper parts of the residual regolith. A combination of petrology, mineralogy and geochemistry of regolith may assist in identification of underlying lithologies and stratigraphic variations in the profile.

Geochemical characteristics of the regolith at the Fender gold deposit, Murchison province, Western Australia

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The Fender deposit, about 2 km south of the Big Bell mine, near Cue, Western Australia, is a saprolite and laterite resource that produced 497 kg of gold. The deposit developed over low-grade, shear-hosted Au mineralisation, in a mid to upper amphibolite facies metamorphic sequence of the Big Bell greenstone belt. Fender is in a depositional regime and is concealed by 3 to 5 m of granite-derived sheetwash and clays. The residual regolith beneath the transported overburden varies over the short strike length of the deposit, from an essentially complete laterite profile in the south to a truncated profile in the north.

Primary gold mineralisation, with mean grades of about 1.85 ppm Au, occurs in two zones, namely the Main Lens (Au-Sb-W-Hg-Mo association) and the Hanging-wall Zone (Au-Fe-As-Cu-Zn association). These differences in primary composition are retained in the regolith. Overall, Au is enriched in the saprolite (mean 2.7 ppm) and, in the north, persists to the base of the transported overburden. In the south, Au is depleted (<0.1 ppm) in the upper 25 m of saprolite, but there is a widespread zone of Au enrichment (to 9 ppm) in the overlying lateritic material. Other elements associated with mineralisation (e.g., As, Sb, Cu, W±Hg) persist throughout the residual regolith, including zones where Au is depleted. The presence of high concentrations of Hg (to over 100 ppm), in such high grade metamorphic terrain is enigmatic, and its persistence in upper saprolite at concentrations exceeding 0.5 ppm is very unusual.

Soils (15-30 cm depth) and transported overburden contain <5 ppb Au. Partial analyses are ineffective at delineating the deposit. However, broad, low-order As+Sb±W anomalies are present in silty clay sediments and can be markedly enhanced by selective sampling of ferruginous nodules.

The results support the use of multi-element geochemistry in exploration. Both the primary and secondary mineralisation at Fender have 100 m-wide haloes of anomalous As, Sb, W and Hg, even where Au is depleted, and ferruginous nodules give haloes exceeding 300 m.

Acknowledgements: The support of the management and staff of Normandy (Murchison) Pty is gratefully acknowledged. Some of the research formed part of AMIRA Project 409. CRC LEME is supported by the Australian Cooperative Research Centres Program.

Palaeodrainage mapping using drillhole data and remote sensing techniques

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Integrated datasets (airborne magnetic and gamma-ray spectrometric imagery, processed Landsat Thematic Mapper imagery, a digital elevation model, and water-bore logs) have contributed to an investigation of the regolith of a ~2600 km^2 area of semi-arid central Australia in and around Uluru - Kata Tjuta (Ayers Rock - The Olgas) National Park in the Amadeus Basin. The investigation, conducted at the Australian Geological Survey Organisation for Uluru - Kata Tjuta National Park, reveals a heterogeneous basement topography of domes and basins with 100 m of vertical relief (a buried "mini-Kata Tjuta") underlying the Dune Plains, an extensive sand plain between Kata Tjuta, Uluru, and Yulara.

A significant feature of this buried landscape is a palaeodrainage valley, now the setting for an aquifer system, which is the major source of water supply to the inhabitants and tourists of the area. The palaeovalley was originally a closed valley with discrete depocentres, formed by dissolution of calcareous bedrock, in which early Tertiary lacustrine and alluvial fan sediments accumulated. Later, a river evolved and flowed north to Lake Amadeus, not eastward as previously mapped. North of Yulara the palaeoriver spread out in a broad deltaic braid plain to the lake.

Important regolith units in the region include groundwater calcrete (non-pedogenic or phreatic calcrete) bodies, reticulate dunefields and a sheetwash landscape unit composed of red earths. The sheetwash unit forms broad, gently sloping aprons around outcrops and supports banded mulga shrubland. It is underlain by a near-surface layer of distinctive "sheetwash calcrete"

Directed principal components analysis and ratios of Landsat TM data proved most useful for mapping the regolith in the study area where the spectral dominance of fire scars and sand dunes needed to be mitigated. This processing divided the landscape into predominant clay-, iron oxide- and quartz-rich components. The methodology utilised for this central Australian study is transferable to other regions where obscured palaeodrainage systems and diverse regolith units need to be mapped.

Marlborough nickel deposit – regolith characterisation of the Coorumburra prospect

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Preston Resources, a small Perth based mining company, are currently exploring and resource proving a large nickel mineralisation in the Marlborough district. The Marlborough nickel deposit is a residual lateritic enrichment developed on a series of ridges and hills of exposed serpentinite 20-30 km north of Rockhampton. Whilst the whole Marlborough nickel enrichment is developed on the ultramafics of the Marlborough block, there are several prospects that have economic potential. The Coorumburra prospect is one of the most significant of these enrichments with nickel grades as high as 5%. It is located on the ridge north and east of Coorumburra Station.

Coorumburra East characteristically has a thin 1-10 m thick laterite profile overlying a thick clay and/or a green saprolite profile that contains the nickel enrichment. The whole profile sits above the serpentinised ultramafic basement. There are seven main regolith lithologies identifiable at Coorumburra East: sediments; dolerite dykes; ferruginous ironstone; clay; siliceous regolith; saprolite; and serpentinised ultramafic. The weathering profile may be as deep as 100 m on some ridges. The valleys and creek lines lack any nickel enrichment because erosion and/or sediment accumulation rates are greater than that of weathering.

Regolith geology and geochemistry at Old Well gold prospect, Gawler Craton, South Australia

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Following the recent successes of calcrete sampling in discovering primary Au mineralisation, such as Challenger and Tunkillia in the Gawler Craton of South Australia, many companies have employed this sample medium as a primary exploration tool in this region. This study examined the morphology, geochemistry, mineralogy and position of calcrete and other units within the regolith at Old Well, approximately 45 km south-southeast of Tarcoola (Gawler Craton).

Detailed examination of drill cuttings, and a 70 km^2 mapping area, indicated the presence of eroding remnants of variably weathered granite within a larger area of thin to thick sequences of transported material. The relatively uniform distribution of calcrete throughout the area, and the lack of a recognisable source of the Ca in the granitic regolith, suggests that the Ca is externally derived. Macroscopic and microscopic examination of the calcrete horizon indicates pedogenesis involving cementation of sand and extensive reworking of the calcareous component.

A strong association between Au and calcrete was observed, with a high positive correlation between Au and Ca within individual profiles. However, there are multiple Au maxima throughout the entire regolith. In particular, anomalous Au is often associated with the deeper ferruginous consolidated sands of the transported overburden. This, together with the absence of any significant bedrock mineralisation, suggests that the anomalous Au in the upper regolith is attributable to primary mineralisation from outside the study area.

This study demonstrates the importance of orientation surveys. Calcrete sampling is of great value on the regional scale, but on the prospect scale it may be of reduced importance if the nature and origin of the regolith is not fully understood. If calcrete sampling is to be used to its full potential, detailed regolith studies are required.

Acknowledgements: MIM Exploration Ltd, in particular, Mr M. McGeough, are thanked for their support. Dr C.R.M. butt is thanked for earlier comments. CRC LEME is supported by the Australian Cooperative Research Centres Program.

Weathering crusts and placers of the Russian Far East

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Weathering crusts and placer deposits are one of the principal sources of precious, rare and rare earth metals in Russia. The eluvial and talus placers composed of slightly redeposited weathered materials are the important types of regolith-related deposits. They occur in various geomorphological positions: feet of tectonic scarps, planes and karst depressions.

The All-Russian Institute of Mineral Resources (VIMS) has carried out a long term study of the Russian Au, PGE, Sn, Ta, Nb and REE weathering crust and placer deposits. The most detailed works were in the territory of the Russian Far East. The work program included:

i. The study of geological structure, stratigraphy, geochemistry and mineralogy of the regolith, and the dating of the weathered products - to understand conditions of the regolith formation and preservation.
ii. The regolith-landform mapping - to reconstruct palaeo-landscapes and understand weathering history and modification of regolith, to determine the scale and directions of removal and deposition of weathered materials.
iii. The analysis of metallogeny of regolith-dominated areas.

As a result, high correlation between the majority of known large gold, platinum, columbite and monazite placers and regolith sources have been established in the region. The most significant correlation has been observed for old placers of long evolution.

Also, some data on ore components accumulation in the regolith have been obtained. Gold mainly concentrates in the deep weathered materials. Thus, at the Kyrov ore field (Amur region) Au values rise dramatically in the deeply weathered products, where Au grades are 10-12 times those in primary mineralisation. In contrast, vermiculite, used as insulator and chemical raw material concentrates in saprock and lower saprolite (Primorsk and Amur regions).

In conclusion, the analysis of the regolith-landform maps compiled for Amur region in the scale 1:500 000, and for all Russian Far East allows new appraisal of these territories for a range of useful regolith-related minerals.

Morphotectonic evolution of the Mundi Mundi Escarpment, Broken Hill Block, NSW

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Geomorphology, regolith geology and apatite fission track thermochronology (AFTT) have been used to further constrain the later tectonic history of the Mundi Mundi Escarpment in western NSW. The Mundi Mundi Escarpment is predominantly a NE-SW trending feature that divides the Mundi Mundi Plains to the west, from the Barrier Ranges to the east. It approximates the trend of the Mundi Mundi Fault, however erosion has led to the main escarpment being located up to several hundred metres east of the main fault line. The Mundi Mundi Fault appears to be of major regional landscape significance, marking the western, upthrown edge of a major tilted block. This tilted block is reflected in the morphology of the Barrier Ranges in the Broken Hill region and controls the distribution and preservation of regolith types. The Mundi Mundi Fault is an ancient structural feature, possibly dating back to the Proterozoic. Since then it has continued to be active up to recent times, making it difficult to precisely constrain the younger tectonic contribution of this feature within the context of the regional landscape evolution.

A pilot AFTT study clearly shows very different temperature-time paths for rocks on either side of the Mundi Mundi Fault. Samples from west of the fault record initial cooling from palaeotemperatures >~100-110°C during the Early Palaeozoic (Cambrian-Ordovician, suggesting an association with cooling following the Delamerian Orogeny), whereas samples from within the Barrier Ranges immediately east of the fault show significant cooling to have occurred during the late Palaeozoic (Carboniferous, suggesting an association with the Alice Springs Orogeny). Further cooling is also recorded during the Tertiary but the timing is less well constrained because it occurred from relatively shallow crustal levels. These results are consistent with geological and geomorphological interpretations of greater denudation east of the fault and suggest long term tectonic activity.

The sedimentary and geomorphological record further constrains the tectonic history of this fault. Cretaceous and Tertiary sediments are abundant and widespread west of the fault, particularly along northern sections. Their apparent absence immediately east of the fault suggests that they have either been eroded or were not extensive in these parts. The expression of the Barrier Ranges at least back into the Palaeozoic, and also the contribution of detritus derived from the Barrier Ranges in the Cretaceous and Tertiary sediments, suggests that the sedimentary cover was not extensive over the present area of the ranges near Broken Hill during those times. Neogene sediments are up to 100 m thick immediately west of the fault, suggesting further tectonism during this time. Recent movement is further indicated by the displacement of pediments and associated alluvial fans, the extensive incision, and a series of terraces downstream of knickpoints in stream channels crossing the fault.

SURFCHEM, a digital database of surface geochemical samples extracted from WAMEX open file reports, Western Australia

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A digital database containing spatial surface geochemical data recovered from the WAMEX open file report system of the Geological Survey of Western Australia, is available for the Davyhurst, Dunnsville, Bardoc and Kalgoorlie 1:100,000 sheets in the Eastern Goldfields of WA.

The WAMEX database is a valuable strategic resource and is used extensively by explorers, miners and entrepreneurs to generate new exploration targets and to evaluate the effectiveness of past exploration on specific tenements and prospects. However, the current format of WAMEX precludes the easy use modern data handling tools, specifically GIS software, which is rapidly becoming industry-standard. SURFCHEM is aimed at providing a seamless surface geochemical layer for prospect and regional GIS investigations.

Data in SURFCHEM are stored in a relational database using Microsoft Access. All samples are recovered to AMG coordinates and each is fully attributed with source details, sampling and assaying techniques, analytical detection limits and units, and grid conversion details, all pertinent to evaluating the usefulness of the data.

SURFCHEM presently contains more than 100,000 samples and over 350,000 assays and coverage is being progressively extended to other 1:100,000 sheets in the Kalgoorlie area.

The diverse sources of the data and the evolution in techniques (different sampling medium, assay techniques and detection limits) requires the data be normalised in some way to allow comparison and integration of data in overlapping and adjoining surveys. One method of allowing for these differences is the calculation of a response ratio (for example value/mean of first quartile) for each element in each survey in the database. This has been done for gold with startling results.

Landscape evolution, regolith development and gold mobility, Central Victoria, southeastern Australia

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The Palaeozoic succession of Victoria, southeastern Australia, which outcrops as subdued ranges that form the West Victorian Highlands and Southeastern Highlands, is one of the world's largest gold producers, to date having a total production of over 2,500 tonnes, or 2% of the world's gold production. Historic gold production has come from: (1) primary deposits within the Palaeozoic rocks, and (2) secondary placer and palaeoplacer deposits derived from erosion and weathering. The later deposits, in conjunction with regolith, and the sedimentary record of surrounding basins (Murray, Otway, Torquay and Gippsland) record a complex history of weathering, erosion and landscape evolution. This story is further complicated by Late Cainozoic re-activation of faults within the highlands, commonly thought to have been active only in the Palaeozoic.

Secondary mobility of gold in the near-surface environment occurs in both Palaeozoic bedrock and post-Palaeozoic rocks and is due to recently recognised supergene and hydromorphic processes. Secondary gold occurrences are widespread and occur in a number of surficial environments, from those associated with primary gold deposits to those that are distal from them. Surficial processes have also modified hypogene wall rock alteration haloes characterised by carbonatisation, sericitisation, sulphidation and chloritisation. These processes have had important implications for the economic viability of near-surface mining operations at Fosterville, Heathcote, Costerfield and Nagambie.

There is a distinctive morphology of secondary gold that is associated with different environments of precipitation, and preliminary investigations indicate unusual geochemical associations. Ferruginised veins associated with weathering typically host micro-colloform gold, whereas gold hosted within interstitial voids in clastics is well crystallised.

On-going research seeks to understand the relationship between landscape evolution, regolith development, oxidation of gold deposits, and the mobility of gold in the surficial environment of central Victoria.

Acknowledgement: The authors wish to acknowledge the financial support of the Bicentennial Gold 88 Endowment towards the presentation of this paper.

Inferring regolith variation using surface features

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The aim of this research is to investigate how the character of regolith may be inferred using surface information. Surface information is used because it is easy and simple to collect and is becoming increasingly available in digital form. If surface information can be used to infer regolith properties it will lead to better utilisation of the resource.

The field site is the Weipa bauxite mine in far north Queensland, Australia (12°30'S, 141°30'E). It is part of an extensive laterite plain that covers much of the western part of Cape York Peninsula.

A Geographic Information System (GIS) dataset of drill core assay data, topographic information and Landsat 5 Thematic Mapper (TM) data has been built. The drill core data contains assays of Al_2O_3, Fe_2O_3, SiO_2 and TiO_2, and the physical parameters depth of overburden and bauxite.

Relationships between the regolith parameters and surface features are analysed using a backpropagation neural network. A neural network is used because it is a reliable means of combining numerically dissimilar data sources like topography and vegetation. The results obtained from this method give an indication of the strength of the relationship between regolith and the landscape at Weipa.

Results, so far, show that regolith properties are difficult to separate using surface indices from the today's environment. The extent to which the regolith is approaching some form of quasi-equilibrium with the current environment regulates the effectiveness of this approach. This is not a new discovery, however these results suggest there exists the possibility of explaining at least 10% to 30% of the distribution of regolith properties in this way.

Case histories showing discrete airborne EM response associated with gold mineralisation, Eastern Goldfields, Western Australia

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Gold exploration often relies on extensive RAB and air-core drilling to map and sample regolith cover, basement lithology, alteration and mineralisation. High bandwidth airborne electromagnetic (AEM) techniques can be used for mapping the regolith, estimating depth to bedrock and isolating discrete anomalies potentially associated with alteration and gold mineralisation. QUESTEM100SW data was collected over several known gold deposits in the Laverton area, including Sunrise-Cleo, Keringal, Golden Delicious, Beasley Creek and Jupiter. The Lake Gidji gold resource and Eight Mile Dam project, northeast of Kalgoorlie and Lake Cowan, near Higginsville, both in salt lake environments, were also flown.

AEM interpretation relies on layered earth inversion techniques (Sattel, 1997). A three-layer model with a conductive layer sandwiched between two resistive layers proved useful in the Eastern Goldfields. Layer 1, a thin resistive surficial layer coincides with hardpan, alluvium and colluvium. Layer 2 corresponds with the intervening saprolite and layer 3 is the resistive basement. Systematic examination of selected data sets including layer 2 conductance (conductivity x thickness), basement topography, regolith thickness and conductivity-depth sections permits the interpretation of regolith relationships. Transported versus erosional and relict environments can be clearly differentiated thereby predicting drilling conditions, the depth of cover and the geochemical sampling environment.

Inversion models do not perform as well in areas of extreme (high or low) total conductance. However, using an integrated interpretation methodology, limitations of the models are easily recognised. Features such as inversion of topography, palaeochannels and palaeolacustrine environments can be recognised. Discrete basement highs, which may be caused by silicification, quartz veining, and carbonate alteration can be identified. Furthermore, thickening of the regolith due to preferential weathering along shear zones where argillic, chloritic, and potassic alteration may accompany gold mineralisation has also been identified. Contrasting conductivity of host rock and alteration lithologies with country rock is required for successful application of AEM.

Sattel, D., 1997. Conductivity information in three-dimensions. (In press).

Geochemical dispersion into transported overburden, Deep South gold deposit, Mount Gibson, Western Australia

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Geochemical surveys rely on the detection of a suite of ore-associated or pathfinder elements as vectors to mineralisation. In areas of transported overburden geochemical sampling techniques can be ineffective. However, the Deep South gold deposit at Mount Gibson, Western Australia, provides a case study where a surface soil anomaly of Au, Cu, Ni, Pb and Zn exists over a gold deposit covered by 15 - 20 m of transported sediments.

A two stage hydromorphic dispersion model is suggested to explain dispersion of ore-associated elements at Deep South. The stages in this model are closely linked with the morphological development of the profile under the influence of climate.

Stage one of the model assumes hydromorphic and mechanical processes of dispersion are active surrounding the ore body under the influence of a hot and wet climate. Gold mineralisation extending to the surface is mechanically concentrated in the ferruginous horizons through landform reduction. Hydromorphic dispersion occurs above the redox front in the ferruginous horizons as ore elements complex with organic and humic acids. Dispersion below the redox front is restricted to the immediate area surrounding the primary mineralisation via sulphur-complexes.

With the initial change in conditions to a more arid climate, the redox front moves down the profile with the lowering of the water table forming lateral accumulations of gold in the saprolite. Major erosion has taken place truncating the profile in the upper saprolite. Approximately 15 - 20 m of granitic derived sediments have been deposited over the truncated profile, probably via sheet wash.

Stage two of the model assumes that dispersion takes place in arid conditions where evaporation exceeds precipitation and the mass transfer of groundwater is towards the surface. The association of gold with weathering products in the hardpan indicates emplacement is by hydromorphic processes, probably via a chloride-complex.

The possibility that gold can be mobilised from saprolitic enrichment zones through transported overburden to the surface has major implications for exploration. By utilising sampling techniques to minimise dilution, geochemical soil sampling may provide an economic and effective exploration method in areas of transported overburden. This method of exploration, suitable for the Mount Gibson region, requires the development of a hardpan within the transported material and the sampling of weathering products, such as manganese oxides and carbonate, in that hardpan.

Cored concentric iron-rich mega-nodules from Wilpena Pound, Flinders Ranges, South Australia

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Cored concentric iron-rich mega-nodules up to 25 cm in diameter form part of a lag preserved at the modern land surface, south of Cooinda Camp, Wilpena Pound, South Australia. The core material of the nodules resembles clay-rich sandstone of the Cambrian Parachilna Formation. Concentrically laminated ferruginous material up to 8 cm thick encloses each core. This iron-rich material is dominantly goethitic with hematite becoming more enriched adjacent to the core. Petrographic studies indicate that the proportions of clastic quartz within the core and within the ferruginised zone are equivalent, implying that the nodules are formed wholly from the same parent lithology. Secondary goethite and hematite replace pre-existing layer silicate minerals in the matrix and infill voids. Preservation of etched feldspar clasts indicates that the sandstone was not intensely weathered at the time of ferruginisation. Therefore, the process of nodule formation is unlikely to be related to the formation of a kaolinised "lateritic" profile.

Crusts enriched in iron oxides and oxyhydroxides are presently preserved along joint planes in the stratiform sediments forming the Flinders Ranges, including Wilpena Pound. This suggests that contemporary groundwater is enriched with respect to iron as a result of weathering of the enclosing strata. The proposed mechanism for mega-nodule formation within Wilpena Pound, a natural structural depression, follows:

(i) Partially weathered clay-rich Parachilna sandstone was episodically infiltrated by iron-bearing ground waters as a result of perched water table fluctuation within the Wilpena Pound depression.

(ii) Weathering proceeded with hematitic mega-mottle formation in the zone of water table fluctuation.

(iii) Erosion removed unconsolidated weathered material and slowly excavated the iron-mottled zone.

(iv) Nearer the surface the mega-mottles became increasingly goethitic, following the transformation of initial hematite under contemporary weathering conditions.

(v) Progressive and selective removal of alumino-silicate minerals from the mottles during ferruginisation has lead to a net concentration of iron.

(vi) Induration of mottled material once reaching the land surface has resulted in mega-nodule formation.

Optical, geochemical and mineralogical analysis of alternations within the ferruginised zone allows a detailed interpretation of mega-nodule formation history to be constructed.

Regolith development in the Bulart area, southeastern Dundas Tableland

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Three principal weathering profiles developed on Rocklands Rhyolite and granodiorite in the Bulart area were characterised for detailed mineralogical, chemical and morphological studies. The profiles selected are comprised of parent rock, saprock, mottled saprolite, lateritic residuum and soil. Ferruginised sediments overlying mottled saprolite at the Boral Quarry were included in the study.

The development of lateritic residuum has involved the collapse and bioturbation of the underlying mottled saprolite and ferruginised sediment. Hematite, goethite and maghemite-rich pisoliths and nodules occur as clasts in a sandy clay matrix. Pisoliths and nodules commonly have yellow-brown goethitic cutans resulting from the hydration of hematite to goethite. The greater abundance of maghemite-rich pisoliths at the top of the lateritic residuum and particle size of the magnetic fraction suggests that surface heating is responsible for the conversion of goethite to maghemite.

Mottled saprolite underlies the lateritic residuum at two of the studied profiles and is subdivided into the lower mottled saprolite and upper mottled saprolite zones. Lower mottled saprolite is characterised by hematitic and goethitic mottles commonly occurring in the centre of pallid blocks separated by remnant jointing in the parent rock. Upper mottled saprolite typically consists of regularly alternating, subhorizontal goethitic/hematitic mottles in a pallid clay matrix. The evolution of the mottled saprolite is principally controlled by oxidation/reduction reactions along remnant jointing and root channels.

Ferruginised sediments overlying mottled saprolite, saprock and Rocklands Rhyolite at the Boral Quarry are subdivided into various units based on their morphology. The evolution of these sediments is thought to involve deposition in association with the evolution of the Wannon River and subsequent ferruginisation and bioturbation.

Three dimensional analysis of a "geophysical halo" in the regolith over Keringal gold deposit

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Electromagnetic geophysical exploration in Western Australia is traditionally difficult, as highly conductive regolith has a great influence on the measurements, reducing the depth of signal penetration and masking responses of deeper structures. Overprinting geological, geochemical, structural, alteration and mineralisation effects can further complicate rock conductivities.

A ground-based time domain electromagnetic survey over Keringal gold deposit (Eastern Gold Fields, Yilgarn Craton) resulted in a data set for which conventional interpretation methods did not work satisfactorily, due to the masking effect of the regolith and complex overprinting relationships of deeper structures. The research aim was to use a novel Artificial Intelligence-based method to decompose the data into statistically meaningful factors, than find the geological-geochemical meaning of those factors.

Here, the anomalous electromagnetic response of the regolith over Keringal gold deposit is explained. Three dimensional integration of geochemical, topographical, structural and geophysical data provides evidence that the anomalous response of regolith is a "geophysical halo", corresponding to mapped geochemical anomalies. This anomaly is caused by differential weathering of underlying ultramafic bodies.

Gold and tellurium redistribution in the stone line lateritic profile of the Posse deposit, central Brazil

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The Posse deposit is associated with the Mara Rosa volcano-sedimentary sequence of Proterozoic age in Central Brazil. It is located in a lateritic terrain in a seasonally humid tropical climate with average annual rainfall of 1500 mm.

The weathering profile consists of a 10 to 15 m thick saprolite zone overlain by a 1 to 2 m soil. The interface between the soil and saprolite is marked by a stone line horizon rich in quartz fragments and scattered ferruginous nodules. There are two types of nodules: hematitic nodules or pisoliths with goethitic cortex; and gibbsitic nodules. The pisoliths represent remnants of an ancient iron crust and show signs of having been reworked. The gibbsitic nodules have a microfabric directly inherited from the saprolite.

Primary gold occurs disseminated within sheared felsites in which it is strongly associated with Te. SEM examination shows that nearly 80% of the Au occurs intermixed with frohbergite ($FeTe_2$) and minor amounts of calaverite ($AuTe_2$).

The Au-Te association diminishes in the regolith due to telluride oxidation and residual concentration of Au. Nevertheless, despite leaching, there is a strong Te anomaly in the stone line due to the concentration of Te in pisoliths (up to 42 ppm). The Te anomaly peak in pisoliths is dislocated about 100 m downslope reflecting some lateral mechanical transport during stone line development. In contrast, Au abundances in pisoliths are low (150 ppb), but give widespread anomalies, reflecting low gold enrichment in the ancient crust but probably good dispersion. The Au concentration in gibbsitic nodules is higher (1 to 2 ppm), but show a more limited dispersion pattern and probably reflect residual Au in the saprolite.

Acknowledgement: C.G. Porto is on leave from Federal University of Rio de Janeiro, Brazil

An integrated regolith geochemical and paramagnetic exploration at the McKinnons gold deposit, Cobar, NSW

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A geochemical and paramagnetic study has been carried out at McKinnons gold mine to investigate the potential of acid insoluble residues from regolith samples as a sample medium in the search for buried gold deposits. Residues derived by sequential treatment with hot aqua regia, sulphuric acid and nitric acid are composed of quartz with a minor amount of sericite.

Zones of enrichment in Cu, Zn, Pb, Ag, As, and Sb (as indicators of mineralisation) and depletion in K, Al, Fe, Mg, Ca, Na, Ti and Sr (as indicators of wall-rock alteration) outline the gold deposit and also extend to the surface. The McKinnons gold deposit is associated with a geochemical zonality characterised by enrichment in Cu, Pb, Ag, As, Sb, Ba, Bi and W, and depletion in Zn and Ni at the upper level of the deposit. The geochemical indices of Zn x Pb x As, Cu x Pb x As, Zn x Pb, Ca x Na x Sr, (Zn x Pb x As)/(Ca x Na x Sr), (Zn x Pb)/(Na x Sr), (Cu x Pb x As)/(Zn x Ni) and (Pb x Ag x Sb)/(Zn x Ni) are useful indicators of mineralisation and associated hydrothermal alteration in the area studied. These indices define the gold mineralisation and clearly distinguish between gold mineralised and barren areas. Electron paramagnetic resonance (EPR) signatures of the acid insoluble residues also show significant difference between mineralised and barren areas. A strong paramagnetic halo outlines the gold mineralisation while barren areas have weak paramagnetism. The EPR spectra are considered to reflect lattice imperfections in the quartz, with mineralised quartz containing more imperfections.

Significant geochemical and paramagnetic expression at the surface above and adjacent to the gold deposit demonstrate that this integrated exploration method has a high potential in the search for buried gold deposits in highly weathered terrain.

Regolith of the Balmoral 1:100 000 mapsheet, Western Victoria

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The Balmoral 1:100 000 mapsheet area is in southwestern Victoria, to the west of the Grampians Range and near the border with SE South Australia, and includes parts of the Dundas Tablelands and the Wimmera Plains to the north.

A regolith-landform map was prepared in 1997 as part of an Honours project by Natalie Quinn and sponsored by the Geological Survey of Victoria, which provided map and image data, including airborne geophysics flown as part of the VIMPS initiative. The regolith-landform map will be used to assist in the preparation of a new bedrock geology map by the Survey during 1998.

Palaeozoic basement rocks of the Dundas Tablelands support tens of metres of kaolinitic regolith profiles with upper mottled zones, developed largely by continuous in situ weathering since the Permian. Transported materials of Tertiary and Quaternary ages mantle parts of the Tablelands and dominate the adjacent Wimmera Plains. Ferruginous induration including the development of in situ ferricrete on slope edges and along former valleys, and as lag deposits, is common, but the earlier concept for the area of a continuous lateritic capping is inaccurate.

Nineteen Regolith-Landform Units, including transported and in situ units, have been mapped and variations in profiles and landform associations described, and these allow a detailed landscape evolution sequence for the area to be deduced.

Radiometric data has been useful in differentiating regolith types, and in particular, areas of ferricrete can be mapped using high thorium response.

Both radiometric and magnetic imagery have been used to map, for the first time, a suite of regressive Pliocene shoreline ridges which extend onto the Tablelands from the adjacent Wimmera Plains. Deformation of these shoreline ridges can be used to date the formation of the Tablelands to less than 4 Ma, with an uplift of the order of 120 m, probably in the late Pliocene.

Mineralogical and chemical characterisation of ooidal iron ore (channel iron deposits) using field spectroscopy

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The channel iron deposits (CID) of the Hamersley Province (WA) are infillings of generally meandering palaeochannels and are genetically related to weathering processes. The average thickness of these important iron ore deposits is approximately 40 m and their lateral extent can be many tens of kilometres. In polished section, the texture of the CID is typically ooidal, with minor pisoids. These spheroids are characterised by hematitic nuclei and goethitic cortices cemented by a goethitic matrix. Electron-microprobe X-ray chemical maps of the distribution of Al and Si show that these components are typically associated with the goethite-rich cortices and matrix material.

The ore grade of the CID is positively correlated to its iron content and negatively correlated to deleterious minor components, including aluminium, silicon, phosphorus and water. As goethite typically contains more of these components than hematite, the hematite:goethite ratio is introduced as a new, useful measure of ore quality.

Field reflectance spectroscopy has recently emerged as a potential technique for the mineral analysis in the field with the development of portable, high spectral resolution spectrometers. The wavelength range between 400 and 1000 nm (visible to near infrared - VNIR) is particularly suitable for the measurement of iron oxides whereas the 1300-2500 nm range (short-wave infrared) is useful for clays.

In this study, the natural variations of the hematite:goethite ratio and the chemistry of the CID were modelled using laboratory mixtures of pure hematites and goethites. Spectral and mineralogical/chemical relationships were established and then applied to 300 CID samples. The success of these results was validated using laboratory techniques such as XRF, XRD and LOI. The results show that following mineralogical and chemical parameters can be measured: hematite:goethite ratio, Fe, Al, Si, P and LOI content.

Hence, field reflectance spectroscopy has the potential to provide quick, in situ quantitative measurements of a range of important parameters necessary for the characterisation of CID.

Regolith characteristics and element dispersion processes at the No 4 Tank prospect, Cobar, NSW

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The No 4 Tank prospect was identified as a multi-element (Cu, Pb, Zn, Au) geochemical anomaly by lag sampling and RAB drilling during a regional exploration program conducted by Pasminco in 1994-96. The prospect lies in an area of the Cobar landscape which is close to an old (probably Mesozoic) and partly dissected unconformity surface marked by silicification and areas of ironstone. Quartz-rich gravels defining remnant channels, now inverted in the landscape, overlie this surface. Deep weathering profiles beneath the surface have been generated during the late Mesozoic-Early Tertiary and subsequently modified through the Tertiary. This prolonged weathering history, combined with the landscape setting, has had important implications for secondary mineral development and element dispersion within the regolith of this region of the Cobar terrain.

No 4 Tank lies close to the boundary between metasediments of the pre-Devonian Giralambone Group and shelf sediments of the Kopyje Group within the Devonian Cobar basin. Bedrock/saprock intersected in drilling is mainly quartz-veined siltstones and fine-grained sandstones. Weathering is up to 130 m deep with regolith composed of a red, silty-loam soil mantling bleached and mottled clay-rich zones over saprolite. Other regolith elements in the area include patches of ferruginised saprolite/bedrock (ferricrete/ironstone), which form caps on some of the lower hills, silicified saprolite/transported regolith (silcrete), forming landscape highs, and a variety of transported and in situ lag materials. Surficial materials contain a significant parna component, and regolith carbonates are developed at the saprock interface where this is near surface.

Detailed XRD and PIMA analysis of the weathering profile indicate that the clay zones are predominantly kaolinite with quartz, lesser muscovite/illite and minor hematite, goethite, calcite, dolomite and anatase. The bedrock mineralogy is quartz, muscovite and chlorite. Lags include bleached lithic, ferruginised lithic, irregular ferruginous, pisoidal maghemitic, quartz-vein and silicified/silcreted materials.

Geochemical anomalies in the regolith at the No. 4 Tank prospect are very irregular and appear to reflect vein-style mineralisation developed along NNW-trending, fault-controlled fracture systems. Intersections in RAB drilling give patchy anomalies with discrete concentrations of Cu-As-Au and Pb-As-Zn, at least partly related to variations in regolith host mineralogy. Optical and SEM analysis of samples from anomalous zones has revealed that the majority of the indicator elements are hosted by Fe oxides/hydroxides (Cu, Zn) but are also present in secondary phosphates (e.g. plumbogummite hosting Pb, Cu, Zn) and Mn oxides (Cu, Ba). Sulphate minerals appear to be absent.

Although the No 4 prospect was initially detected as a lag anomaly of coincident base metal geochemistry, the wide distribution of transported lags, including from palaeosurfaces, means that caution should be exercised in the use of lag surveys in this area. Ironstones higher in the landscape are known to contain anomalous Cu concentrations. Discrimination of in situ from transported materials and awareness of the landscape context of sampling sites are critical to effective geochemical exploration in the area.

Geochemical dispersion in residual and transported regolith near the CSA Mine, Cobar, NSW

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Metal dispersion patterns near the CSA Mine, in partially stripped residual regolith and adjacent transported overburden, have been examined using total, enzyme leach and hydroxylamine.HCl extractions. Total analyses display three distinct geochemical associations, all of which are located in recent or palaeo-drainage channels.

Elevated concentrations of Zn±Mn±Au, in deeper parts of the saprolite, are coincident with extensive Zn+Cu anomalies in CSA Siltstone. The saprolite is overlain by varying thicknesses of transported silt with gravels lenses. Zinc is generally depleted in the upper part of the saprolite, except for weak but widespread enhancement near surface and at the interface with the transported overburden. A series of weak, irregular Au anomalies occur at the base of near-surface carbonate accumulations or in association Fe enrichment deeper in the saprolite. An As±Au±Sb association is observed in the residual regolith, especially along the faulted contact between the CSA Siltstone and Girilambone Group. Arsenic is depleted in the upper saprolite but total and selective extraction concentrations increase with depth. The gold component of this association is also most coherently associated with the zones of carbonate accumulation. The Pb+As+Fe±Sb±Bi feature is associated with interbedded gravels and silts in palaeochannels of Yanda Creek. Goethite rims on maghemite-dominant clasts and Fe cementing of gravel matrices indicate some in situ ferruginisation. Persistent Pb+As±Sb±Bi anomalies closely follow Fe concentrations and there is a significant correlation between total and selective extraction metal concentrations. The geochemical patterns for the Pb+As±Sb±Bi association suggest lateral transport of metals, stripped from the upper portions of the weathered profile, along palaeochannels extending from the CSA mine.

Whereas some metals are dispersing vertically from deep bedrock sources during the present cycle of weathering, selective extraction patterns for soils, overburden and saprolite indicate that a significant trace element component may be related to recent mobilisation of metals from more refractory residues of previously dispersed materials.

Palaeogeomorphology of ferricretes in Meredith, Victoria

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Regolith mapping was carried out as part of a study into aquifer development and salinisation. Although the recent Ballarat 1:100 000 Regolith-Exploration map, published by Geological Survey of Victoria, covers a portion of the study area, a wealth of additional information was gained by mapping at 1:25 000 scale. Groundwater and pedogenic duricrusts, particularly within Tertiary sediments (differentiated during the course of this project), are currently being investigated, along with the hillslope hydrological and pedomorphological processes that lead to their development, alteration and degradation. The aim of this presentation is to reflect on the value of large-scale regolith mapping and to describe the use of ferricrete as a palaeogeomorphic indicator.

Groundwater ferricrete is frequently found along the edges of the Tertiary marine Moorabool Viaduct Sand, where faulting and deep stream incision has exposed potential seepage faces. Exposure of seepage faces would have enhanced lateral groundwater flow, encouraging iron precipitation at the redox boundary in these areas. Much ferricrete is not, however, found adjacent to the margin of the host sediments but was probably deposited at break-of-slope positions.

The presence of subhorizontal slabs of groundwater ferricrete beneath several metres of noncemented sand with duplex soil suggests that the aquifer responsible was unconfined, or semiconfined in areas where the strata are capped by pedogenic ferricrete and contain silt-rich zones at depth. Since throughflow is the predominant type of groundwater flow within the Tertiary unit, iron transport was probably a near surface mechanism mostly unrelated to deep fractured bedrock aquifers, although minor leakage would have occurred.

The pedogenic ferricrete varies from homogenous red-coloured, internally massive, sandstone, to ferricrete with texture resembling tiger mottling due to bleaching by soil water along macropores through to true tiger mottled regolith. Tiger mottling is here believed to be the result of ferricrete fracturing, copious clay illuviation and local iron relocation in response to changes in the soil water regime in lower hillslope or frequently waterlogged positions, perhaps in a similar environment in which iron hardpan development occurs.

An approach to understanding the regolith-landform features of the Cobar region

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The Cobar Basin, in western NSW, is a thrusted, north-northwest - south-southeast trending, Devonian basin containing turbiditic metasediments and structurally controlled Cu, Pb, Zn, Ag and Au deposits. Many of the known deposits show some degree of silicification and therefore outcrop as topographic highs, making them a primary target for exploration. The remainder of the Cobar Basin has generally low relief and is commonly obscured by regolith of highly variable thickness. There is considerable potential for poorly exposed deposits in the Cobar area, for example a McKinnons style deposit. New techniques need to be developed to explore within the regolith, especially using low cost surface techniques. For this, it is necessary to understand the regolith materials that are being sampled, their landform setting and the regional landscape history.

The Problem

There has been a long and complex history of weathering and landscape change at Cobar. Previous work has included aspects on regolith at Cobar, but this has not been within a regional landscape framework. Studies of geochemical dispersion haloes for example, especially in transported ferruginous lag, are difficult to interpret because the provenance of the many different types of lag is not well understood. Some lag has been transported for significant distances, making surface and lag sampling in these areas ineffective when exploring for local anomalies. It is therefore essential to have an understanding of how the landscape has evolved and how materials may have been moved and from where. Climate change and tectonic movement may have played an influential role in the movement of surface materials.

The Cobar area is frequently cited as an area of long-term stability, the "Cobar Pedeplain", yet there are gravels developed within the Tertiary that have been incised to at least 35 m along deep narrow valleys. In other areas, there are Cretaceous gravels only 5 m above the present drainage which show the same current directions as the present drainage in that area indicating that very little landscape change has occurred since their deposition 100 Ma.

Some Preliminary Results

Cobar is an area of relatively low relief, with low residual hills of bedrock and extensive areas of regolith cover. Regolith materials include parna, silcrete, ferricrete, calcrete, a range of lag types, saprolite and palaeo-drainage deposits. Parna (aeolian material) of varying thicknesses blankets much of the Cobar area. The modern drainage divide between drainage flowing to the Darling or Lachlan is oriented in a north-westerly direction and occurs to the west of Yanda Creek. Present drainage consists of broad, extensive channels forming a dendritic pattern.

Aeromagnetic images show drainage channels that do not correspond with the modern drainage. A number of these older drainage systems have a different morphology from the present drainage. One type of palaeochannel deposit consists of pebbly sands and gravels with maghemite pisoliths as detrital clasts and formed in deep narrow valleys. Silcrete is present at intervals in these channels. Other palaeochannels are topographically inverted due to silicification and contain clasts ranging from sandstone and chert pebbles to boulders in a sandy matrix. At one location, forams indicate a Cretaceous age, although other deposits of these type may be younger. These gravels formed prior to maghemite development because they do not contain maghemite pisoliths. At one location to the west of Cobar, these gravels indicate southwest current directions (as does the modern drainage in that area), suggesting long term stability of the drainage since their deposition. Other gravels overlie a calcrete horizon but are slightly higher than the present drainage.

Conclusion

Investigation of the regolith and landscape history in the Cobar area will aid mineral exploration by incorporating surface materials into a landscape evolution context. With a regional landscape model, more effective sampling techniques can be applied to exploration within the regolith in the Cobar region.

Soil landscape association at the McKinnons gold deposit area, Cobar, New South Wales

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Soil sampling was used to define geochemical anomalies at the McKinnons gold deposit area situated 40 km south of Cobar. Soil samples were taken at 50 cm depth in the assumed B horizon of the soil profiles. To enhance the interpretation of the geochemical results an understanding of the distribution of soil types in the landscape is necessary. Soil landscape units have been used to classify the soil types across an area of 8 x 12 km^2 The soil profiles are found to associate with four types of landscape, they are: steep slopes (1-2°) with shallow soils (10-50 cm); gentle slopes (<1°) with moderately deep soils (≈1 m); alluvial flats (<0.5°) with deep soils (>1 m); and narrow drainage channels with moderately deep soils (≈ 1 m). The soil profiles in all landscape types essentially consist of: surficial lag materials in varying abundance and lithotypes; a red loam A horizon which may overlie either a stone line, a uniform red loam, a structured clay layer or weathered bedrock (for shallow soils). Carbonate is present at depth of some structured clay layers, commonly present in soils of narrow drainage channels, while alluvial sand is mainly present in soils of alluvial flats. Truncation of structured clay by stone line and the use of bivariate plots (skewness vs. sorting) indicate that the clay is a palaeosol formed under a wetter period. The red loam has significant abundance of coarse silt (4 - 6 f) interpreted as aeolian material deposited during later period of aridity, and has been subsequently reworked by both colluvial and alluvial processes. Weathering accompanying downcutting of the landscape produced hydromorphic surficial lag materials. Most recently, post-European clearing of vegetation caused accelerated surface erosion.

Secondary mineral distribution and element dispersion at the McKinnons gold deposit, Cobar, New South Wales

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The main aim of this study was to determine the mineralogy and element dispersion, including Au, Ag, Cu, Pb and Zn, within the oxidised zone over the McKinnons gold deposit. The primary sulphides consist of vein and disseminated pyrite, galena and sphalerite with minor aggregates of chalcopyrite. The pyrite hosts trace Ag-As-Cu-Zn with or without Pb.

Weathering of chalcopyrite produced supergene Cu as chalcocite, which also hosts trace Zn (0.17 %). Weathering of galena produced anglesite. In the partially oxidised zone, acid sulphide weathering conditions caused dissolution of muscovite and formation of alunite-jarosite minerals, particularly hinsdalite [$PbAl_3(PO_4)(SO_4)(OH)_6$]. Both goethite and hematite are abundant in the partially oxidised zone and host significant Pb with lesser Cu, Zn, As and probably Sb. Iron oxides in the completely oxidised zone also acted as a host for Cu, Pb and Zn. Near the surface in a ferruginous layer over mineralisation, hematite also hosts anomalous amounts of Cu-Pb-Zn-Ag-As-Sb. These elements are dispersed at the surface and are adsorbed by iron oxides in the soils and also by the surficial lag materials.

The presence of sulphates such as hinsdalite, jarosite and anglesite throughout the weathering profile indicates high levels of sulphate species in the ground water. However, secondary silver occurring as chlorargyrite suggests a high chloride concentration in the weathering solution possibly due to onset of aridity. The oxidising chloride solution separated Ag from the electrum to form high fineness gold. The presence of a small gold grain occurring in iron oxide pseudomorph further indicates supergene gold. Although no gold grains in the primary sulphide zone have been found, low fineness (683) gold in the completely oxidised zone associated with and enclosed by quartz could indicate that primary gold originally contained some Ag.

Regolith-exploration maps: interpreting the cover of the Victorian goldfields

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The Geological Survey of Victoria is producing regolith maps for the western Victorian goldfields. A 1:100 000 scale regolith map and accompanying report has been produced for Ballarat and others are in preparation or planned for the future. The primary purpose of the maps is to allow geochemical exploration programs and orientation surveys to be planned. Primary gold mineralisation is hosted in mesothermal quartz veins in the Palaeozoic bedrock. Large amounts of this gold have been transported across the landscape by several cycles of Cainozoic erosion. The resulting sedimentation, marine incursions and volcanism cover up to half of the goldfields area. The exposed bedrock is variably weathered from extremely leached to slightly ferruginised. Much of the low-lying bedrock has been exhumed from beneath the Cainozoic cover which has probably geochemically contaminated the regolith of these areas.

Understanding the landscape evolution and the regolith development of the goldfields is vital for modern geochemical exploration because the regolith controls the exploration sampling strategy. The nature of the media being sampled, areas of ferruginisation versus areas of leaching and the presence of transported overburden are delineated so that the right sampling technique, sampling density and assay technique can be determined early in the exploration program. Although the regolith is often viewed as an impediment to exploration, dispersed geochemical haloes within it and geochemical plumes in the groundwater may enhance the expression of small parent ore bodies and allow exploration beneath the cover.

A comparison of various configurations for powder diffractometry

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Comparison is made between data collected using Siemens D5005 XRD fitted with a Cobalt tube and Göbel mirrors producing parallel beam optics, with a position sensitive detector (PSD) and scintillation detector.

The data was collected from a side packed sample, in reflection mode using both scintillation and position sensitive detectors.

In transmission mode, the same sample was packed into a capillary and the data collected using Göbel mirrors and PSD.

The stratigraphy and evolution of regolith within palaeochannel environments at the Sundowner area, North Yilgarn Craton, Western Australia.

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The palaeodrainage systems in the north of the Yilgarn Craton in Western Australia have undergone a process of progressive burial producing a landscape with subdued relief and poor bedrock exposure. Exploration drilling has provided the opportunity to investigate the stratigraphic features of the buried drainages which are up to 120 m deep.

Sundowner Prospect is situated on a colluvial-alluvial plain adjacent to Bates Creek, 10 km north of the Bronzewing gold mine. Detailed investigation in the area has provided information on the several types of alluvium and colluvium and on the probable sources of the transported materials. Logging of drill spoil over an eight kilometre square area depicted a palaeosurface with considerable relief. A wide range of sediments, including those in the palaeochannels, overlie older residual regolith.

The palaeosurface has an extensive layer of lateritic residuum developed on basalt, which is truncated by the main channels of the drainage and by erosion on the upper slopes. The palaeochannels have been filled with kaolinitic clays derived from the erosion of pre-existing saprolite developed on granite and basalt. The forty-five metres of kaolinitic clays are divided into a lower grey-green puggy unit which contains small spherical pisoliths with multiple cutans, and an upper hematitic mega-mottled unit. Above the channel clays there are layers of recent colluvial-alluvial sediments. Ferruginous nodules and pisoliths occur at the base of these sediments and are overlain by fine clay-rich sediments. This stratigraphy indicates an inversion relative to the residual profile from which they were derived. Near the surface a poorly developed hardpan occurs below two metres of quartz-rich sandy clay soil.

Several methods were used to determine detailed characteristics of regolith materials which provide clues to the sources and processes of formation of the transported regolith.

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