REGOLITH SCIENCE – FROM INTERPRETING FOSSILS TO WATCHING IT HAPPEN – A PROPOSAL

Greg Shirtliff

CRC LEME, Geology Department, Australian National University, Canberra, ACT 0200

Regolith dating clearly shows that most of the weathering profiles found on the Australian continent have existed since the Tertiary. This is a fundamental problem for determining and understanding the processes that may have contributed to weathering profile formation because it introduces the possibility that the profiles being studied are fossils, preserved remnants of once more active systems. Even in tropical climates, which have long been advocated as the environments most likely to be responsible for 'laterite' formation, the possible antiquity of the weathering profiles (e.g. Twidale 1994, Nott 1994 and Dammer *et al.* 1996) could make it difficult to distinguish between what are products of current weathering processes and what are products of weathering that has occurred in the past.

One obvious, but costly, way to solve this problem would be to set up multiple large-scale in-field experiments, where weathering processes could be compared across different climatic environments and where weathering rates could be accurately defined. This may seem a near-impossible undertaking but it does not need to be, as it is argued here, because similar experiments already exist. These are more commonly known as mine waste-rock stockpiles and post-mine final landforms. Waste-rock stockpile research currently being undertaken at Ranger Uranium Mine (RUM) in Australia's Northern Territory is revealing the potential for such structures to be used for large scale weathering studies in the natural environment. It is also revealing that the ability to treat the stockpile as a relatively confined microcosm allows for the identification of all the parameters that may be influencing weathering within a certain environment. At RUM, environmental characteristics have been identified which are unique to the tropical savanna climate of the Northern Territory, characteristics that have yet to be considered in regolith formation

LARGE SCALE REGOLITH EXPERIMENTS

Waste-rock stockpiles are storage piles of the barren and uneconomic rock and regolith that is removed during the process of extracting an ore body from the earth. At RUM these piles represent over 60 Mt of material or about 60% of the total weight of material so far mined from the two open pits. They cover an area of approximately 60,000 m^2 and some of the piles are over 50 m in height. Whilst upon mine closure these dimensions will be different, the piles will still represent a body of material significant enough to begin to be considered as a potential analogue for regolith research.

In studying the weathering of waste-rock piles, there are inherent complications that may cause some difficulties. These centre on the fact that waste-rock stockpiles can have complex construction histories, which result in heterogeneous internal composition and structure. Two methods of construction are employed at RUM to build the waste-rock piles—free dumping and push dumping. Free dumping entails the dumping of discrete piles of approximately 1.5-2 m height across a level surface before being graded. This technique is used at RUM to start new lifts on the stockpiles before trucks can begin to work. Push dumping is then used to extend these levels laterally, where trucks dump loads close to the edge of the pile which are then pushed over the edge by a bulldozer. To ensure stability and ease of operation during lift extension the working platform is graded often with the intention of breaking rocks down to a smaller size, effectively creating a road base. Due to the fact that different rocks are being mined at different times, these techniques are reflected clearly on the internal structure and lithology of the stockpiles, which can be observed on the walls of fresh excavations into them. A further complication at RUM is that mining occurs on two platforms within the pit—an upper and a lower—so that during the wet season mining can continue unimpeded on the dry upper platform. This means that the waste-rock piles receive less weathered rock in the dry season followed by more weathered rock from the upper platform in the wet. Overprinting all of this is a vertical trend from weathered to fresher material, an inverse reflection of the pit, as mining has progressed from the surface to depth over time. This, of course, is disregarding the complexities associated with the six major rock types found at RUM.

It is believed, however, that the complexity at RUM can, to a large extent, be accounted for and the current study is attempting to do this. Using multiple-stringed geological cross-sections of both ore bodies (i.e. east-west sections at regular intervals covering the ore bodies from north to south), combined with annual pit outlines for the same sections and yearly waste extraction and utilisation figures, an estimate can be made of how much of each type of rock went to the waste-rock piles each year. Then, using 3D models of the stock piles generated for each year of mine operation via digital elevation models as well as colour aerial photographs flown annually, it is possible to gain an idea of exactly where in the waste-rock piles this material went.

If these problems can be solved then a complete-system approach to studying the piles becomes possible. Rainwater can be monitored, as can various mine waters, to assess both input to and output from the system. Rock and regolith mineralogy and geochemistry can be assessed, as can their total volume and, to an extent, their location in the pile. Internal structures can at least be identified and thus hydrological characteristics estimated. Using all of this information, complete hydrogeochemical modelling can then be attempted. Added to this, observations can be made regarding weathering at the surface and, like any other regolith profile study, mineralogical and geochemical changes through the pile can also be examined if excavations into them are available. In fact, the waste-rock stock pile becomes a relatively well confined and well controlled large scale microcosm set out in the field to weather in the 'real' environment. In mines that are currently active, the piles do change dramatically as material is added to them or removed for construction purposes but, with the excavations made by the latter, the working mine provides the best chance to sample and observe waste rock piles internally. Abandoned waste-rock piles, on the other hand, and post-mine final landforms built with waste, are even more analogous to the natural system, with soil and vegetation development often well advanced. At RUM vegetation is already established on one of the waste-rock piles that has been positioned ready for the final post-rehabilitation landform structure. Of course to ensure complete control over the microcosm, waste-rock piles can be set up for monitoring from the outset as has recently been attempted at the University of British Columbia (see: http://www.eos.ubc.ca/research/hydrogeology/).

LEARNING FROM NATURAL ENVIRONMENT MICROCOSMS - AN EXAMPLE

In a reasonably well constrained microcosm, one is forced to look at every parameter that has the potential to affect the system. If this microcosm is exposed to the natural environment then one is also identifying the parameters that influence this natural environment. In the case of RUM, those factors identified as possibly affecting the weathering of the waste-rock may also be factors influencing the weathering occurring in the surrounding tropical savanna environment.

A case in point was the analysis of rainfall at Ranger, the major input into the weathering system, and the subsequent identification that at the beginning of the wet season rainfall is acidic (pH 3.6-4.5) whilst at the end, it is closer to neutral (approximately pH 5.6). Research revealed that this phenomenon is well documented in the area, and that in fact the acidity corresponded to a period called 'the transition' in the northern monsoon climate, where rain has begun falling but the monsoon winds have yet to arrive. It has been shown previously by others (Noller *et al.* 1990, Likens *et al.* 1987, Gillett *et al*. 1990, 1994) that the low pH is being controlled by increases in the concentrations of the carboxylic acids, formic acid (HCOOH) and acetic acid (CH_3COOH). They concluded that these acids are derived from direct emission into the atmosphere, either by plant combustion during annual burning-off practices and/or through normal plant-atmosphere interactions, or from photochemical oxidation of precursor organic compounds from the same sources, or possibly from both. However, an examination of climatic data shows that other factors may also be involved.

Whatever the case, the key point is that the acid rain seems to be ultimately produced by a natural source, whether it be forest fires or biogenic emission. It has been documented in Darwin (Ayers *et al.* 1993) and as far south as Katherine (Likens *et al.* 1987), hence it appears prevalent over almost the entire 'top end' of the Northern Territory. The two carboxylic acids seem to be ubiquitous in rainfall and the atmosphere but in remote vegetated areas they can become important or dominating acid species (Ayers *et al.* 1993, Keene *et al.* 1988). Unless neutralisers such as ammonia or calcium carbonate (in dust) are present in the atmosphere, like that of many drier less vegetated landscapes, the incident rainfall may commonly have pH values < 5.0 (Gillet *et al.* 1994, Seinfeld & Pandis 1998).

This raises important questions for regolith science. What effect does the input of high concentrations of organic acids have on the soil chemistry of Australia's tropical savanna? Is the rain effectively neutralised? What effect, if any, does such rain have on the mobilisation of elements within the regolith in this region? If weathering is being affected then other questions arise. If the extraordinary concentrations of these acids are due to annual fire management practices, have current or even traditional human inhabitants changed weathering rates and solute transport to the rivers? If so, can we see this in sedimentary records? If natural acid rain would prevail, even without annual burning practices, and thus it is a phenomenon that would have been occurring before human habitation of the planet, then should this be considered another important factor in regolith formation and landscape evolution? Do large, remote, well vegetated landscapes, under the influence of higher rainfall climates, upwind of dust sources, have yet another 'weapon' for weathering—natural acid rain?

CONCLUSION: AN OPPORTUNITY FOR REGOLITH SCIENCE?

Waste-rock piles and post-mine final landforms are not natural landscapes, but they are exposed to almost the same environmental conditions as the natural landscapes that surround them. Therefore, discoveries in research into their weathering can be directly applicable to the natural weathering environment as is beginning to be revealed at RUM. Whilst complex, the waste pile still has structures, compositions and textures that reflect its source and the way in which it was formed, just as in any other geological regime. It is not a complete unknown; published material does exist on waste-rock piles although not in the context of regolith. Almost all mines have documented histories, so waste piles are time-delineated and in Europe some date back to Roman times. They occur in many different landscapes in almost all climatic regimes and represent many different rock types. Thus, there is potential for them to be used in comparisons of current weathering processes in different climates. The research itself may have direct benefit to society, industry and the environment. Is this an opportunity for regolith science? What is certain is that the waste-rock stockpile is in disequilibrium with respect to weathering and hence is by no means a weathered 'fossil'. If regolith science is to move towards process and hence more 'active' environments, could waste-rock stockpiles play a role?

REFERENCES

AYERS G.P., GILLETT R.W., SELLECK P., WARNE J.O., HUYSING P. & FORGAN B.W. 1993. A pilot study on rain-water composition at Darwin airport. *Australian Meteorological Magazine* **42**, 143-150.

DAMMER D., CHIVAS A.R. & MCDOUGALL I. 1996. Isotopic dating of supergene manganese oxides from the Groote Eylandt deposit, Northern Territory, Australia. *Economic Geology* **91(2)**, 386-401.

GILLETT R.W., AYERS G.P. & NOLLER B.N. 1994. The concentration and distribution of acidic gases at Jabiru, Northern Australia. *Clean Air* **28(3)**, 35-43.

GILLETT R.W., AYERS G.P. & NOLLER B.N. 1990. Rainwater acidity at Jabiru, in the wet season of 1983/84. *The Science of the Total Environment* **92**, 129-144.

KEENE W.C., GALLOWAY J.N. & HOLDEN J.D. JR. 1983. Measurements of weak organic acidity in precipitation from remote areas of the world. *Journal of Geophysical Research* **88**, 5122-5130.

LIKENS G.E., KEENE W.C., MILLER J.M. & GALLOWAY J.N. 1987. Chemistry of precipitation from a remote terrestrial site in Australia. *Journal of Geophysical Research* **92(D11)**, 13299-13314.

NEEDHAM R.S. 1988. Geology of the Alligator Rivers Uranium Field, Northern Territory. *BMR Bulletin* **224**, Australian Government Publishing Service, Canberra.

NOLLER B.N., CURREY N.A., AYERS G.P. & GILLETT R.W. 1990. Chemical composition and acidity of rainfall in the Alligator Rivers region, Northern Territory, Australia. *The Science of the Total Environment* **91**, 23-48.

NOTT J. 1994. Long-term landscape evolution in the Darwin region and its implications for the origin of landsurfaces in the north of the Northern Territory. *Australian Journal of Earth Sciences* **41**, 407-415.

SEINFELD J.H. & PANDIS S.N. 1998. *Atmospheric Chemistry and Physics: From Air Pollution to Climate Change*. John Wiley and Sons, New York.

TWIDALE C.R. 1994. Gondwanan (Late Jurassic and Cretaceous) palaeosurfaces of the Australian continent. *Palaeogeography Palaeoclimatology Palaeoecology* **112**, 157-186.

Acknowledgments: Research into the waste-rock stockpiles at RUM is also supported by EWL Sciences Pty. Ltd. and ERA-Rio Tinto. Supervisors for the project are Prof. Tony Eggleton (ANU), Dr. David Jones (EWLS), Dr. Patrice de Caritat (CRC LEME/Geoscience Australia) and Dr. Dirk Kirste (GA). This abstract has benefited from comments by all the supervisors, as well as Dr Colin Pain (CRC LEME/GA) and fellow CRCLEME PhD students at the ANU.