Paper 72

Biogeochemistry of the Northern Yilgarn Craton, Australia

Lintern, M. [1], Ibrahimi, T. [1], Cornelius, A. [1], Anand, R. [1], Reid, N. [1]

1. CSIRO Mineral Resources, ARRC, 26 Dick Perry Avenue, Kensington, Australia

ABSTRACT

The last decade has witnessed an increasingly strong increase in the use of biogeochemistry as an important tool in mineral exploration, particularly in Australia. Ten years ago, biogeochemical maps of thousands of square kilometres and comprising thousands of samples would not have been considered practical or useful. Orientation studies using trees and shrubs at individual mineral exploration targets have now become routine, but a lack of coordination between individual companies have made interpretation difficult. In this study which was conducted over several years, a large biogeochemical survey is combined with several other regional and site data sets to produce a data base. Geochemical maps and statistical treatment have shown surprising patterns in the data that highlight the potential of biogeochemistry as another tool in the geochemist's toolbox. The data set will provide a lasting legacy for which future biogeochemical surveys and data will be compared.

INTRODUCTION

Biogeochemistry is attracting increasing interest in Australia as it is perceived as a novel method of exploring for mineral deposits, and in particular those hidden beneath transported regolith such as sand dunes, colluvium and/or alluvial sediments (Anand et al., 2014a). In remote areas, bores or drill holes are often absent and so in the initial phases of exploration the geochemist may have to rely solely on less proven exploration techniques. Alternatively, pattern drilling of geophysical targets has to be employed which is a relatively more expensive option. Deep-rooted plants represent a type of geochemical sample media capable of integrating the geochemical signal of a large volume of the regolith (Figure 1). Extensive areas of buried bedrock can leave traces of critical elements to reveal their sub-surface presence at the surface as a result of biogeochemical processes. Biogeochemical anomalies may help target drilling by better defining areas of interest with greater confidence and supplement other techniques such as soil or stream sediment sampling which may be less effective in these areas. Biogeochemistry has been effective at detecting mineralisation targets and has been used extensively in Canada (Dunn, 1986; Dunn, 2007), and Russia (Malyuga, 1963; Kovalevsky, 1987), and trialed in Australia (Cole , 1965; Brooks et al., 1995; Lintern et al., 1997; Lintern, 2007; Anand et al., 2007; Reid et al., 2008; Reid et al., 2009) but remains largely untested in a regional sense except for a few cases in Canada (Dunn, 1981). The principal scientific objective was to undertake a biogeochemical survey in the NW Yilgarn Craton and then combine these generated data with other regional surveys (e.g. NE Yilgarn Craton) to determine if biogeochemical techniques can be successfully applied to the whole of the northern Yilgarn Craton. The regional data were compared with data from 19 site studies.

STUDY AREA

Geology

Sampled sites were located in the SW of Western Australia and are shown in Figure 2. The geology of the north Yilgarn Craton is comprised of variably distributed Archaean granites and greenstones. The greenstones occur in a series of longitudinal belts, including the Norseman-Wiluna, Yandal, Duketon, Meekatharra, and Windimurra (Myers and Hocking, 1998; Morris and Sanders, 2001).

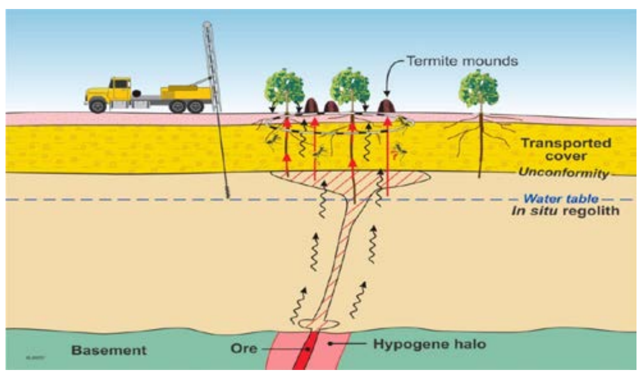

Figure 1: Use of biota, and in particular trees, to bring metals to the surface from deeply buried ore deposits to facilitate exploration. (Modified from Anand et al., 2009; 2014b.)

Cassidy et al. (2006) summarized the tectonic evolution of the Yilgarn Craton. The NE Yilgarn is split by a continental divide; to the east is the Southern Cross Domain and to the west is the Murchison Domain, which are both part of the Youanmi Terrane. Both domains in this area have granitic rocks and granitic gneiss associated with extensive northeast oriented greenstone belts (Williams, 1975; Myers, 1997). The granitic rocks comprise granodiorite-monzogranite, with deformed and

In "Proceedings of Exploration 17: Sixth Decennial International Conference on Mineral Exploration" edited by V. Tschirhart and M.D. Thomas, 2017, p. 835–839

metamorphosed monzogranites. The greenstones comprise mafic and ultramafic volcanic rocks underlain by quartzite, BIF and minor felsic volcanics. The Narryer Terrane in the NW part of the study area contains some of the oldest rocks in the Yilgarn Craton (>3.3 billion years old; Myers, 1990).

Mineral Deposits

There are many mineral deposits in the north Yilgarn Craton, covering various commodities, particularly in the NE. The numerous Ni deposits are hosted by greenstones associated with ultramafic volcanic rocks, particularly concentrated along the Agnew-Wiluna greenstone belt (Hagemann and Cassidy, 2001). There are Archaean orogenic Au deposits throughout the region particularly associated with greenstone structures, including the Sunrise Dam and Agnew mining areas as well as Meekatharra-Mount Magnet and Yandal belt districts. There are several volcanogenic massive sulphide (VMS) deposits including Jaguar, Bentley, Teutonic Bore and several smaller ore bodies which make up the Quinns Prospect. Secondary carnotite-style deposits (calcrete uranium) are prevalent along the drainage systems throughout the region, and include the world class Yeelirrie deposit; other U occurrences are found in the NW Yilgarn Craton bordering and within the Murchison River catchment.

Vegetation

In general the vegetation profile of the north Yilgarn Craton is open woodland dominated by *Acacia aneura* (a mulga) across most landscape settings (Figure 3). *Triodia* spp. (spinifex) is common across sand plains and sand dunes. *Callitris glaucophylla* (white cypress pine) is present along breakaways throughout the region. River gums (*Eucalyptus camaldulensis*) are prominent trees that occur along watercourses throughout the north Yilgarn Craton.

Mulga has an irregular distribution across central and southern Australia. It is a shrub or tree, up to 10 m high with many different forms and phyllode (modified stalk that resembles a leaf) types (Miller et al., 2002). The tree has bright yellow, oblong flowers and terete to elliptic phyllodes, 2–11 cm long and up to 1 cm wide. *Acacia aneura* is a dominant mulga species of many shrublands or woodlands of inland Australia (Moore, 2005).

Physiography

The dominant landforms of the north Yilgarn Craton are sandplains, plateaus, breakaways, colluvial and alluvial plains, bedrock, salt lakes, and sand dunes (Jutson, 1950). The landforms are generally gently undulating with low relief; the elevation across the sampling area ranges from 350 to 600 m ASL, gradually decreasing north to south. The relatively flat surface belies the complex underlying regolith that has been exposed to significant events of weathering, erosion, deposition and a variety of climatic conditions pre and post burial of sediments.

Climate

The north Yilgarn Craton is semi-arid to arid and has a generally Mediterranean style climate with hot, dry summers and cool, wet winters. Mean annual rainfall is between 200–300 mm and the annual evaporation is between 2500 and 4000 mm (Meekatharra; Bureau of Meteorology, 2016). Rainfall is episodic and bimodal occurring with peaks in summer and winter. Mean average maximum temperature is ~38°C in January, 19°C in July and average minimum temperatures range from ~24°C in January to ~7°C in July.

METHODS

Sample collection

A calico bag was filled with terminal branches of mulga (*Acacia* sp.) from around individual trees at a consistent height (generally chest height), ensuring the sample was as free of dust as possible. Trees were selected that had no seedpods or flowers, and had been minimally grazed. Several factors are important when sampling vegetation, including the following:

1) The plant species must be widely distributed and have an extensive root structure (Dunn, 2007; Hulme and Hill, 2003); mulga has a wide-ranging distribution and has a significantly large rooting volume.
2) The age of the sampled plant must be relatively consistent (tree height and width was recorded), and the organ sampled must be healthy, as insects, bacteria or fungi can alter the chemical structure of the medium
3) Samples should be collected at the same time because of potential seasonal variation in element concentrations. This was not practicable for large surveys of this type due to logistics. Samples were taken over several months.

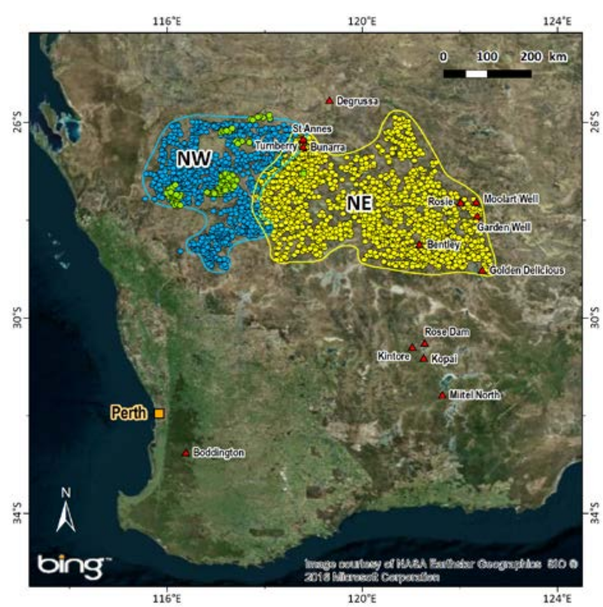

Figure 2: Location of samples in southwestern Australia. The NE (yellow dots), NW (blue dots) and green dots represent regional surveys while the red triangles are some of the site studies compared.

Sample Preparation

Samples were dried in an oven (45°C for 48 hours) while still in their original calico collection bags. The samples were of terminal branchlets which contained phyllodes and twigs in varying proportions. In previous studies at Jaguar (Anand et al., 2007) mulga samples had a consistent proportion of phyllode to twig in each sample. In the NE survey, the phyllodes were separated from other parts of the foliage. The dried, separated samples were ground to a fine powder using a cross beater mill (Retsch GmbH, Haan, Germany), and then the milled samples were split for duplicate analyses. The mill was cleaned with ethanol and compressed air before each sample to remove all traces of the previous sample.

Sample Analysis

The NW samples were re-labelled with new sample numbers, and duplicate samples were prepared for every nth sample (where n is between 15 and 25). The full batch was sent to Bureau Veritas Laboratories, Perth. Here, 4 g of milled sample was dissolved in 10 mL of nitric acid for >12 hours. Following on, another 10 mL of nitric and 10 mL of hydrochloric acid was added which was then digested for 2 hours at 90°C. The solution was then analysed by Inductively Coupled Plasma Mass Spectrometry (ICP-MS) and Optical Emission Spectrometry (ICP-OES) for over 60 elements.

RESULTS

Major outcomes of the project were:

1) Summary statistics and percentiles were produced for each element to provide immediate information that can be compared with data collected by other future (site) surveys. For example, the 90th percentile for Au is 1.0 ppb and 1% of the data is over 3.1 ppb Au based on 2130 samples.
2) There is little correlation between hydrogeochemistry, laterite, soil and rock data, and the biogeochemistry data suggesting that one data set cannot act as a surrogate for the others, however, each may be individually useful in identifying areas of interest.
3) The data were classified according to categories and classes. The significance of the t-test statistic was used as a tool to compare classes for different elements; numerous significant differences were recorded between classes for different elements suggesting, for example, that some elements (or combination of them) could be used to discriminate between different regolith and geological units, e.g. Narryer Gneiss mulga phyllodes have much higher mean U concentrations than other geological classes.
4) An Atlas provided a preliminary interpretation of the geochemical data, how the different classes in the categories relate, and how data between sites and regional data sets compare (Figure 3). Element distribution plots showed the spatial distribution of elements across the north Yilgarn Craton (Figure 4).
5) Three indices (or multiple element combinations) were used in an attempt to identify regions within the element distribution maps that may be worthy of follow-up. The indices were Au- , Ni- and dust-based. Some areas were identified by the Au index and Ni index but generally there does not seem to be any great advantage in the use of the indices over individual elements themselves.
6) A correlation matrix table showed which elements in the phyllodes were associated with one another. The results were not unexpected, e.g. the REE, Ca-Sr and Fe-Ga-Th-Ti were correlated.

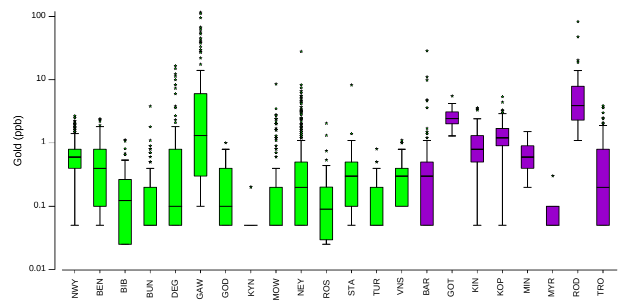

Figure 3: The histograms of the site data for Au (ppb) compared with the regional data. This histogram forms part of the Atlas pages for each element. The green and purple shading denotes mulga and Eucalyptus foliage sampled, respectively. The site codes are as follows: NWY (NW Yilgarn); BEN (Bentley, VMS); BIB (Bibra, Au); BUN (Bunarra, Au); DEG (Degrussa, Cu-Au); GAW (Garden Well, Au); GOD (Golden Delicious, Au); KYN (Kyntyre, U), MOW (Moolart Well, Au); NEY (North East Yilgarn); ROS (Rosie, Ni); STA (St Annes, Au); TUR (Turnberry, Au); VNS(VS) (Regional study); BAR (Barns, South Australia, Au); GOT (Golden Triangle, Au); KIN (Kintore, Au); KOP (Kopai, Au); MIN (Miitel North, Ni); MYR (Myrtle, Northern Territory, VMS); ROD (Rose Dam, Au); TRO (Tropicana, Au).

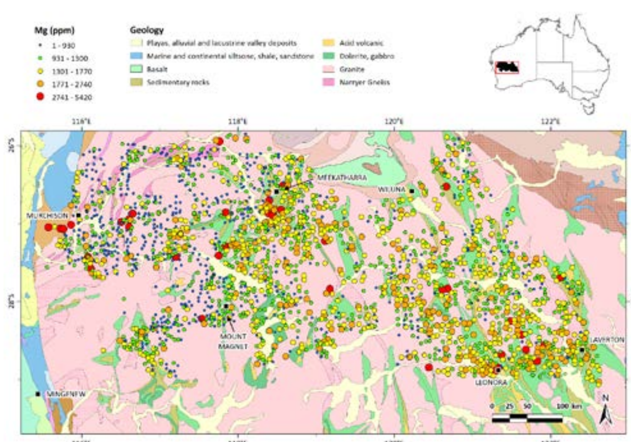

Figure 4: Magnesium data for mulga phyllodes in the northern Yilgarn Craton.

7) The robust principal component analysis does not add significantly to the interpretation of the element distributions. Principal component (PC) 1 was influenced by REE, PC2 by dust, PC3 by Mo, P and

Rb and PC4 by alkaline earth elements as evidenced by positive loadings.

8) Individual site studies demonstrated the importance of the larger regional data set as geochemical data is put into deposit-related context.

CONCLUSION

The data set generated for the North Yilgarn Craton and compilation of the site studies from other data sets will be a powerful tool for explorers that use biogeochemistry when searching for mineral deposits. Exploration companies will be able to compare data generated within their own projects to these data and investigate whether their leases are worthy of further investigation. A regional survey has not been done before with one plant genus in Australia on this scale. Correct interpretation of biogeochemical data from prospects has been previously difficult since these data have not been available. This project is part of a long-term CSIRO strategy to investigate the use of biogeochemistry for mineral exploration at different scales including prospect, district, regional and national scales.

REFERENCES

Anand, R.R., M. Cornelius, and C. Phang, 2007, Use of vegetation and soil in mineral exploration in areas of transported overburden, Yilgarn Craton, Western Australia: a contribution towards understanding metal transportation processes: Geochemistry: Exploration, Environment, Analysis, 7, 267-288.

Anand, R.R., M.J. Lintern, B. Townley, R.R.P. Noble, S. Wakelin, C. Macfarlane, R. Hough, P. Smith, M. Aspandiar, G. Carr, M. Korsch, F. Reith, C. Phang, N. Reid, D.J. Gray, S. Soongpankhao, C. Soto, F. López, R. Luca, S. Hill, T. Pinchand, A. Gregg, and M. Reich, 2009, AMIRA P778 Final Report: Predictive geochemistry in areas of transported overburden: Final Report. CSIRO Report P2009/1788, 138 p.

Anand, R., M. Lintern, R. Noble, M. Aspandiar, C. Macfarlane, R. Hough, A. Stewart, S. Wakelin, B. Townley, and N. Reid, 2014a, Geochemical dispersion through transported cover in regolith-dominated terrains – towards an understanding of process, in K.D. Kelley and H.C. Golden, eds., Building Exploration Capability for the 21st Century: Society of Economic Geologists Special Publication, 18, 97-126.

Anand, R. R., M.J. Lintern, R.R.P. Noble, N. Reid, A. Stewart, M. Aspandiar, X. Wang, and T. Pinchand, 2014b, Predictive geochemistry in areas of transported overburden – AMIRA P778A Final Report: CSIRO, Minerals Down Under, Australia, 141 p.

Brooks, R.R., C.E. Dunn, and G.E.M. Hall, 1995, Biological Systems in Mineral Exploration and Processing: Ellis Horwood Limited.

Bureau of Meteorology, 2016, http://www.bom.gov.au/climate/averages/tables/cw_007045.shtml, accessed 01 November 2016.

Cassidy, K.F., D.C. Champion, B. Krapez, M.E. Barley, S.J.A. Brown, R.S. Blewett, P.B. Groenewald, and I.M. Tyler, 2006, A revised geological framework of the Yilgarn Craton, Western Australia: Western Australia Geological Survey Record 2006/8, 8 p.

Cole, M.M., 1965, The use of vegetation in mineral exploration in Australia, in J.T. Woodcock, R.T. Madigan and R.G. Thomas, eds., Eighth Commonwealth Mining and Metallurgy Congress. Aus IMM, 1429-1458.

Dunn, C., 1981, The biogeochemical expression of deeply buried uranium mineralization in Saskatchewan, Canada: Journal of Geochemical Exploration, 15, 437-452.

Dunn, C.E., 1986, Biogeochemistry as an aid to exploration for gold, platinum and palladium in the northern forests of Saskatchewan, Canada: Journal of Geochemical Exploration, 25, 21-40.

Dunn, C.E., 2007, Biogeochemistry in mineral exploration. Handbook of Exploration and Environmental Chemistry, 9, Elsevier.

Hagemann, S.G. and K.F. Cassidy, 2001, World-class gold camps and deposits in the Eastern Goldfields Province, Yilgarn Craton: diversity in host rocks, structural styles and mineralization styles, in S.G. Hagemann, P. Neumayr and W.K. Witt, eds., World-class Gold Camps and Deposits in the Eastern Yilgarn Craton, Western Australia, with Special Emphasis on the Eastern Goldfields Province: Western Australia Geological Survey, Record 2001/17, 7-44.

Hulme, K.A. and S.M. Hill, 2003, River red gums as a biogeochemical sampling medium in mineral exploration and environmental chemistry programs in the Curnamona Craton and adjacent regions of NSW and SA, in I.C. Roach, ed., Advances in Regolith: Proceedings of the CRC LEME Regional Regolith Symposia 2003, 205-210.

Jutson, J.T., 1950, The physiography of Western Australia: Bulletin of the Geological Survey of Western Australia (Third Edition), Geological Survey of Western Australia, Perth, 366 p.

Kovalevsky, A.L., 1987, Biogeochemical exploration for mineral deposits: VNU Science Press.

Lintern, M.J., 2007, Vegetation controls on the formation of gold anomalies in calcrete and other materials at the Barns Gold Prospect, Eyre Peninsula, South Australia: Geochemistry: Exploration, Environment, Analysis, 7, 249-266.

Lintern, M.J., C.R.M. Butt, and K.M. Scott, 1997, Gold in vegetation and soil - Three case studies from the goldfields of southern Western Australia: Journal of Geochemical Exploration, 58, 1-14.

Malyuga, D.P., 1963, Biogeochemical methods of prospecting: V.I. Vernadskii Institute of Geochemistry and Analytical Chemistry, Moscow, 205 p.

Miller, J.T., R.A. Andrew, and B.R. Maslin, 2002, Towards an understanding of variation in the Mulga complex (*Acacia aneura* and relatives): Conservation Science Western Australia, 4 (3), 19–35.

Moore, P., 2005, A Guide to Plants of Inland Australia: New Holland Publishers (Australia) Pty Ltd.

Morris, P.A. and A.J. Sanders, 2001, The effect of sample medium on regolith chemistry over greenstone belts in the northern Eastern Goldfields of Western Australia: Geochemistry: Exploration, Environment, Analysis, 1, 201-210.

Myers, J.S., 1990, Western Gneiss Terrane, in Geology and Mineral Resources of Western Australia: Western Australia Geological Survey, Memoir 3, 13-31.

Myers, J.S., 1997, Preface: Archaean geology of the Eastern Goldfields of Western Australia – regional overview: Precambrian Research, 83, 1-10.

Myers, J.S. and R.M. Hocking, 1998, Simplified geological map of Western Australia 1:2 500 000 (13th edition): Western Australia Geological Survey.

Reid, N., S.M. Hill, and D.M. Lewis, 2008, Spinifex biogeochemical expressions of buried gold mineralisation: the great mineral exploration penetrator of transported regolith: Applied Geochemistry, 123, 76-84.

Reid, N., S.M. Hill, and D.M. Lewis, 2009, Biogeochemical expression of buried Au-mineralisation in semi-arid northern Australia: Penetration of transported cover at the Titania Gold Prospect, Tanami Desert Australia: Geochemistry: Exploration, Environment, Analysis, 9 (3), 267-273.

Williams, I.R., 1975, Eastern Goldfields province, in Geology of Western Australia: Western Australia Geological Survey Memoir, 2, 33-55.