Map of chalcophile elements: Chalcophile and key element distribution in the Eastern Goldfields

Introduction

The regional geochemistry of the Eastern Goldfields was studied as part of the Predictive Mineral Discovery Cooperative Research Centre's (*pmd**CRC*) Y2 project, the primary purpose of which was to create a 3D geological model of the Eastern Goldfields, Yilgarn Craton. This component of Y2 focused on producing a map of chalcophile elements within the basement rocks across selected portions of the Eastern Goldfields region.

Objectives and Aims of Project

The aim of the geochemical analysis was to potentially identify regional chalcophile corridors within the bedrock (partly as a complement to CRCLEME's regolith studies) which could be used as an aid in locating gold prospects. Two aspects of the regional geochemistry were considered:

1) the distribution of chalcophile elements from bottom-hole whole rock geochemistry along the seismic line EGF01, and
2) the regional distribution of chalcophile and trace elements by creating geochemical contour maps from available data.

The geochemical analysis data (mainly bottom hole geochemistry) was obtained from Geoscience Australia, the Geological Survey of Western Australia and a little from companies. BHP had already compiled most of this data; however it became too difficult to gain access to this dataset.

The relevant elements were compiled into a database and then plotted. These plots are shown in the attached PDF's. A few selected images are included herein.

Milestones:
1. **Compilation of available chalcophile elements and maps of various chalcophile elements available June 2003.**

Work progress:

Geochemical data was obtained from Geoscience Australia and the Geological Survey of Western Australia, analysed for duplication and plotted. These data images were presented at the 2003 Y2 Project Development Team meeting (held 10/2/03 - 12/2/03).

This objective was discussed at this Y2 PDT meeting. The feeling of the Industry members present at the meeting was that there was a large amount of restricted data within companies and that they were doing this type of research already. The PDT meeting decided to stop further work on this objective. The results from the work done to date were to be written up and displayed on the project page within the pmd*CRC web site for comment. They suggested that the report include information on what had been achieved in analysis of regional bedrock geochemistry data and on correlation between various chalcophile elements distributions and bedrock and faults locations.

The report was completed before the end of that quarter and delivered to sponsors, and put on TWIKI by March 2003.

Outputs prepared as part of this objective included the following:

A PowerPoint presentation showing chalcophile and other trace element distributions along the 1991 deep seismic reflection traverse 99-EGF01;
(See - egf01_geochemistry.pdf)

and a PowerPoint showing chalcophile and other trace element distributions throughout the eastern Goldfields province.
(See - yilgarn01_geochemistry.pdf)

Methodology

Once the data was collated, two aspects of the regional geochemistry were worked up. These were the distribution of chalcophile elements from bottom-hole whole rock geochemistry along the seismic line EGF01, and the regional distribution of chalcophile and trace elements by creating geochemical contour maps from available data.

Distribution of chalcophile elements along the seismic line EGF01

Bottom-hole geochemistry values were plotted as profiles, along with the location of known faults and lithology in an attempt to identify possible geochemical leakage along crustal scale faults.

The location of the seismic traverse EGF01 is shown in Figure 4-1. An example of the output produced for this component of work is shown in Figure 4-2. The complete results are shown in **egf01_geochemistry.pdf.**

Regional distribution of chalcophile and trace elements

Data was read into both Arcview and Petrosys for griding and plotting. To assist in the identification geochemical leakage along crustal scale faults, the major fault system were imported into Petrosys and these were used as a constraint in the griding process.
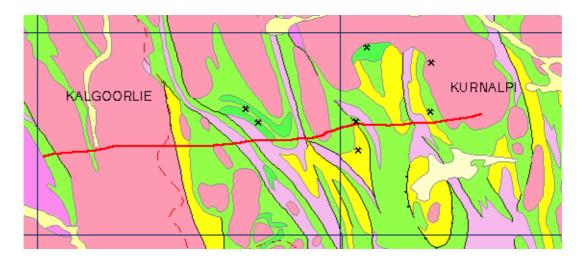
Figure 4-1: The Kalgoorlie Seismic Transect EGF01 (thick red line) on the Kalgoorlie and Kurnalpi 1:250 000 sheets. Dotted line is a magnetic boundary. Derived from the GA database.

In summary, the key points of this aspect of the work were:

- Petrosys, a program usually applied to petroleum geology, was used to produce geochemical grids and contour maps.
- Data from Geoscience Australia's geochemical database (Ozchem) was used to produce geochemical grids and contour maps for the Eastern Goldfields.
- Grids were generated using the Distance Weighted Averages (DWA) interpolation method and unless stated otherwise, a 200m x 200m cell size was used.
- The area covered by the grids is the entire Eastern Goldfields region from 119º45'E to 123ºE and 33ºS to 25ºS.
- Minimum values were generally set at an estimated background level to eliminate background 'noise'. Input values were adjusted to produce the best grids. These values are stated next to the images.
- Major faults were included in the final stages of the griding process. These faults were current in January 2003.
- A combination of the best grids and contours were produced, together with a small reference geological map.

The location of the sample points used in the regional work and an example of the output produced for this component of work is shown in Figure 4-3. The complete results are shown in **yilgarn_geochemistry.pdf.**
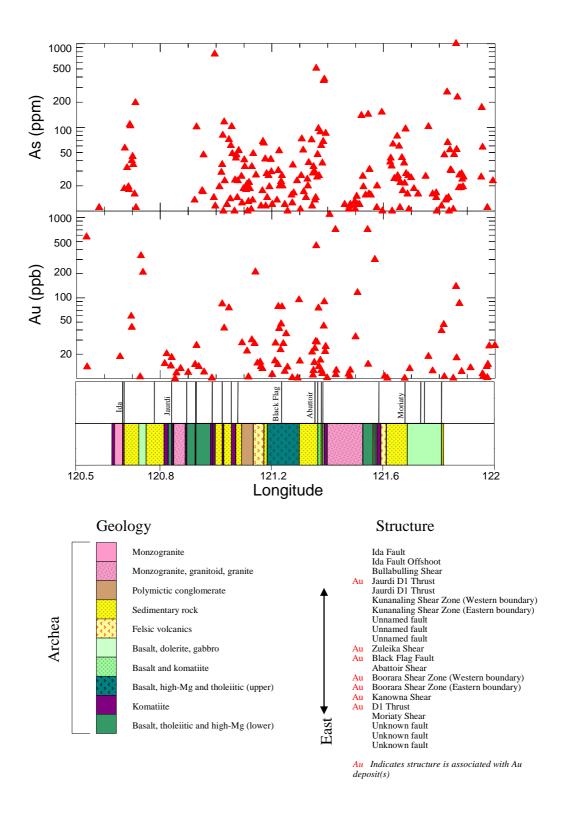
Figure 4-2: *Au and As variations along part of the Kalgoorlie Seismic Transect EGF01. Main faults plotted over general lithology. Data derived from the GA database.*
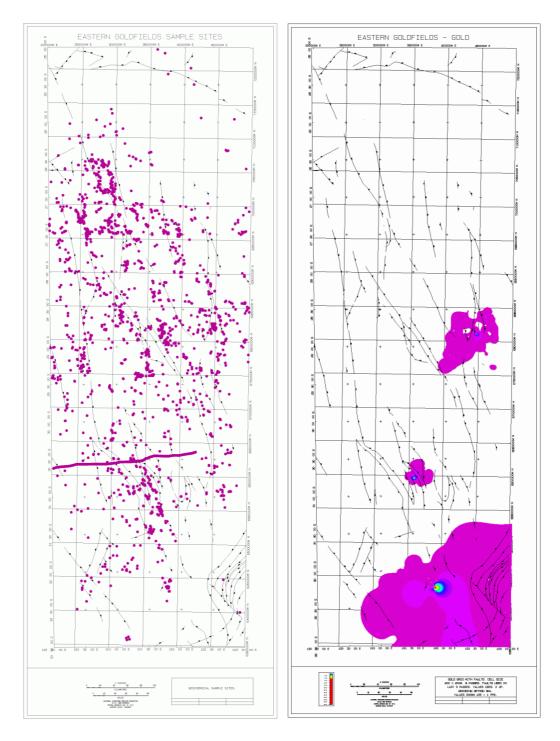
Figure 4-3: *Sample locations used for analysis of regional distribution of chalcophile and trace elements within the Eastern Goldfields region, WA and example of output for one element. Main province scale faults plotted over general lithology. Data derived from the GA database.*

Some questions addressed during the work:
- What is the distribution of elements in the Kalgoorlie area?
- Are any elements associated with gold?
- Do any elements increase / decrease systematically with gold?
- Are there any broad halos?
- Which elements correspond to the underlying lithology and which are lithology independant?
- Which elements correspond directly to faults / fluid conduits?
- Which elements correspond to faults linked with mineralisation?
- What do S, O and C isotopes in the veins and around the deposits show?
- Is the fluid source magmatic? Connate? Metamorphic?
- Is there an association between gold and granites?

Implications to pmd*CRC

This work supported the following:
- The geochemical approach to exploration for gold has been used successfully in the past in the Eastern Goldfields.
- Gold and arsenic have been identified as the best indicators of mineralisation.
- Most exploration has therefore been constrained both spatially (to company leases), and chemically (to gold and arsenic).
- It is therefore important to assess the geochemistry, chalcophile, and key element distribution in the bedrock on a regional scale through contouring and geochemical profiling.
- Although the geochemical data used here is not as dense (spatially) as company data, it has the advantage of being well distributed on a regional scale, as well as encompassing a suite of elements.

This work indicated that:
- As expected from studies on a local scale, generally areas of high gold and arsenic coincide on a regional scale, and these areas also tend to coincide with faults or fault junctions.
- Arsenic appeared to be a good indicator of mineralisation from a regional perspective.
- Arsenic 'halos', however, are spatially almost as restricted as gold anomalies (from a regional perspective).
- The distribution of Au and As seems to be more closely related to faults and fault junctions than lithology.
- The distribution of Ag is similar to that of Au, and so could be an indicator of mineralisation but not a vector to it.
- The distribution of Ni, Cr, Zn, Cu are controlled much more by lithology than structure.
- Several of the elements investigated are particularly useful as vectors to gold mineralisation.
- These elements are much more useful as local indicators of mineralisation.

Points of interest:

- Gold seems to be the best tracer of gold deposit associated fluid pathways.

- Arsenic seems to be associated with gold to some extent. In some cases, anomalously high As values are recorded in conjunction with anomalously high Au values, however, in other cases, high Au values are accompanied by very low As values. Although this does limit the usefulness of As in estimating fluid pathways or pinpointing Au deposits, it does support the theory that these chemical signatures are primary and not due to leaching of deposits. The variability of arsenic abundance could well be due to the extraction of As from the fluid as it moves through sulphur-rich rocks.

- There is both a temporal and spatial association between gold and granites / granitoids, however, there is no genetic link between the two. Metamorphism to granulite grade of the lower crust would have dehydrated the lower and middle crust of a great deal of water. The fluid travelling through crustal-scale structures carrying gold, would have caused mineralisation in structures in the middle crust. The same metamorphic event and consequent de-watering would have caused crustal melting and therefore granite emplacement pre and post mineralisation. Both the fluid and the magma would have used the same crustal-scale structures to travel through. Thus, they are both spatially and temporally associated, with some gold deposits in granitoids, although the granites are not the source of either gold or fluid.

- Elements thought to have some association with gold include:
  - Silver, although it doesn't seem to be very abundant.
  - Bismuth, which has very low abundances is sometimes associated with gold and at other times completely separated.
  - Molybdenum, although again abundances are very low.
  - Tungsten, which unfortunately either wasn't analysed or was present below detection levels.

- Lithology is likely to have a strong influence on the following elements:
  - Nickel, which has an almost exclusive association with komatiite flows.
  - Copper and zinc are likely to be associated with mafic rocks – basalts and komatiites.
  - Lead and rubidium are likely to be associated with granites or sediments.

Gold and trace elements:

There are a number of elements which could potentially be associated with gold deposits through being carried in the same fluid. Some elements are associated with the ore, some are associated with wall rock alteration and others are depleted in the ore zone or wall rock.

- Ore metal (local) associated elements include Au, Ag, W, As, Te, Sb, Cu, Pb, Bi, Sn
- Wall rock alteration includes CO_2 (carbonate), K, S (pyrite) $\pm$B, V, Ba, Rb, Li, Sr enrichment.

- Depletion or remobilisation of the following elements / minerals from the ore zone can occur: Na, Ca, Fe_2O_3.
- In addition there are element ratios which could be useful in tracing fluid pathways and gold occurrences. Some examples include K/Rb, K/Na, K/Ba, Te/Au, Ag/Au, Au/Ag, Sb/Au, Te/Se, Cu/Pb
- Geochemical dispersion halos of the following elements are useful on a regional scale: Au, As, enriched pisolites, enriched / anomalous soils, BIF's

Other element trends and associations

Rubidium and lead are both incompatible elements and as such will be found in primary melts such as granites and granitoids. Figure 4-4 is a graph showing the essentially 1:1 relationship between these two elements, excluding a few outlying values.
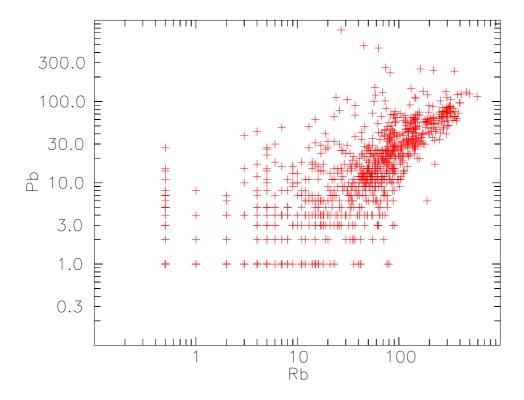

Figure 4-4: Plot of Pb vs RB along the seismic line. Data derived from the GA database.

Geochemistry along seismic line EGF-01

The seismic transect EGF01 was completed in 1991. It is 213 km in length, originated approximately east-west, and is some 30 km north of Kalgoorlie (Figure 4-1). Major features of the Eastern Goldfields granite-greenstone terrane (including rock types and structures) were encountered along its length including its boundary with the Southern Cross terrane. Sample material was collected from the bottom (nominally 40m depth) of each shot hole (giving a total of 883 samples) and analysed for 30 trace elements (Goleby *et al.*, 1993). An effort was made to collect and analyse only bedrock samples. Inevitably, however, regolith samples were incorporated into the collection

due the depth of regolith cover in the Yilgarn craton, and so the results should be regarded with caution.

Samples were analysed by X-ray fluorescence using the method of Norrish and Chappell (1977). Concentrations were obtained for the following elements: Ag, As, Ba, Be, Bi, Ce, Cr, Cu, Ga, Ge, Hf, Li, Mn, Mo, Nb, Nd, Ni, Pb, Rb, Sc, Se, Sn, Ta, Th, U, V, Y, Zn and Zr. In addition, the same samples were analysed at the Geological Survey of Western Australia (GSWA) for Au, Pt and Pd.

Chemistry compared to structures and geology

The abundance of each element was plotted against the geology and structure (according to maps current in November 2002) encountered by the seismic line. One of the outcomes of the analysis of the seismic line was to reinforce the idea that the best geochemical indicator of gold mineralisation is gold itself.

Anomalies in the distribution of gold along the seismic line reflect the positions of faults rather than changes in lithology (Figure 4-5). The limited mobility of gold ensures tight, discrete peaks which, where they exist, correspond directly to individual structures. From this evidence and the current consensus on the orogenic, structure-hosted nature of the gold deposits in the Yilgarn Craton it can be concluded that where positive gold anomalies exist in conjunction with faults, the faults are most likely associated with mineralisation which may exist within the fault or, more often, within splays.
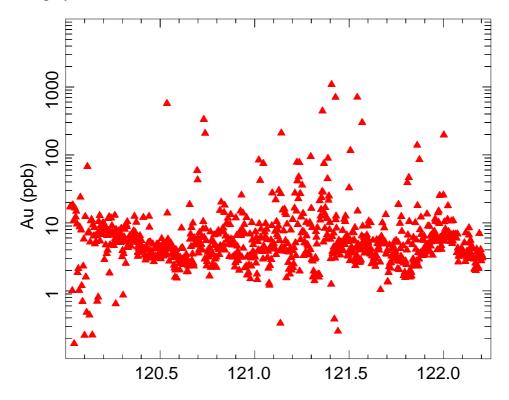

Figure 4-5: *Log Graph of abundance of Au along the seismic traverse (longitude on x-axis).*

This consistent relationship between gold and faults or shear zones leads to two further hypotheses:

Firstly, a structure not associated with a positive gold anomaly was either not a mineralising fluid conduit (not connected to the mineralising network of faults) by being a later or inactive structure at the time of mineralisation; or the fault / shear was the 'backbone' of the plumbing system and so was completely flushed out of its gold residue by syn- and post-mineralisation fluids. It is probable that very little gold would have precipitated in this type of fluid conduit. A possible example is the Ida fault.

Secondly, positive gold anomalies not obviously associated with recognised structures are either inconsistent (not fault related) anomalies and could be associated with, for example, porous basin sequences, ore, more likely, are indicative of faults which have not been identified. In support of the latter, at least two positive anomalies were recognised that were used to identify two previously unknown faults between the Ida Fault to the west and the Bullabulling Shear to the east (Figure 4-2).

After assessing the abundance of gold along the seismic traverse, a background value of 10ppb for gold was selected. Of all the analyses, the element that was found to be most closely associated with gold mineralisation is arsenic (background value 10ppm). The distribution of gold and arsenic is shown compared to structures and geology (current in November 2002) for the Eastern Goldfields section of the seismic line, from 120º30'E to 122º00'E. (Figure 4-2).

Summary

Questions raised but not resolved include:
- what elements show a correlation with Au
- for elements that don't, is there a dependence on rock type (i.e. felsic > 50% SiO_2, mafic, <50% SiO_2)
- Correlation of seismic line samples with faults and lithology
- As expected from studies on a local scale, in general areas of high gold, gold and arsenic coincide. Is this applicable on a regional scale?
    - so arsenic should be a good indicator of mineralisation from a regional perspective
    - but, arsenic 'halos' are spatially almost as restricted as gold anomalies (from a regional perspective)
- Are there much more useful as local indicators of mineralisation
- The distribution of Au and As seems to be more closely related to faults and fault junctions than lithology. Is this actually indicating fluid movement up crustal penetrating faults as suggested

In summary, this study of the chalcophophile distribution and geochemistry in the Eastern Goldfields indicates that:

- The geochemical approach to exploration for gold has been used successfully in the past in the Eastern Goldfields.

- Gold in particular, and arsenic, have been identified as the best indicators of mineralisation.

- Most exploration has therefore been constrained both spatially (to company leases) and chemically (to gold and arsenic).

- There has been a change in emphasis from geochemistry to attempting to understand the evolution of the Eastern Goldfields and the tectonic setting of gold deposits.

References

Goleby, B.R., Rattenbury, M.S., Swager, C.P., Drummond, B.J., Williams, P.R., Sheraton, J.E., Heinrich, C.A., 1993. Archaean crustal structure from seismic reflection profiling, Eastern Goldfields, Western Australia. *AGSO Record*, **1993/15**, 54 p.

Mikucki, E.J., 1998. Hydrothermal transport and depositional processes in Archaean lode-gold systems: a review. *Ore Geology Reviews,* **13**, 307–321.

Norrish, K. and Chappell, B.W., 1977. X-ray fluorescence spectrometry. *In*: Zussman, J. (Ed.), *Physical Methods in Determinative Mineralogy* (2nd ed.). Academic Press, New York, 201–272.

Attachments

4.1.   A PowerPoint presentation showing chalcophile and other trace element distributions along the 1991 deep seismic reflection traverse 99-EGF01.
    (See - egf01_geochemistry.pdf)
4.2.   A PowerPoint showing chalcophile and other trace element distributions throughout the eastern Goldfields province.
    (See - yilgarn01_geochemistry.pdf)
4.3.   Original Figures for chalcophile variations along seismic traverse EGF01 and for regional variation.
    (See various images)
4.4.   A PDF of a summary of CRCLEME report P241A describing geochemical variation in the regolith.
    (See Summary_P241A.pdf)