SELECTIVE EXTRACTION TECHNIQUES FOR THE RECOGNITION OF BURIED MINERALIZATION, CURARA WELL, WESTERN AUSTRALIA

D.J. Gray

CRC LEME OPEN FILE REPORT 96

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(CSIRO Division of Exploration and Mining Report 210R, 1996. 2nd Impression 2001.)
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RESEARCH ARISING FROM CSIRO/AMIRA YILGARN REGOLITH GEOCHEMISTRY PROJECTS 1987-1996

In 1987, CSIRO commenced a series of multi-client research projects in regolith geology and geochemistry which were sponsored by companies in the Australian mining industry, through the Australian Mineral Industries Research Association Limited (AMIRA). The initial research program, “Exploration for concealed gold deposits, Yilgarn Block, Western Australia” had the aim of developing improved geological, geochemical and geophysical methods for mineral exploration that would facilitate the location of blind, buried or deeply weathered gold deposits. The program commenced with the following projects:

Its scope was development of methods for sampling and interpretation of multi-element laterite geochemistry data and application of multi-element techniques to gold and polymetallic mineral exploration in weathered terrain. The project emphasised viewing laterite geochemical dispersion patterns in their regolith-landform context at local and district scales. It was supported by 30 companies.

The project investigated the distribution of ore and indicator elements in the regolith. It included studies of the mineralogical and geochemical characteristics of weathered ore deposits and wall rocks, and the chemical controls on element dispersion and concentration during regolith evolution. This was to increase the effectiveness of geochemical exploration in weathered terrain through improved understanding of weathering processes. It was supported by 26 companies.

These projects represented an opportunity for the mineral industry to participate in a multi-disciplinary program of geoscience research aimed at developing new geological, geochemical and geophysical methods for exploration in deeply weathered Archaean terrains. This initiative recognised the unique opportunities, created by exploration and open-cut mining, to conduct detailed studies of the weathered zone, with particular emphasis on the near-surface expression of gold mineralisation. The skills of existing and specially recruited research staff from the Floreat Park and North Ryde laboratories (of the then Divisions of Minerals and Geochemistry, and Mineral Physics and Mineralogy, subsequently Exploration Geoscience and later Exploration and Mining) were integrated to form a task force with expertise in geology, mineralogy, geochemistry and geophysics. Several staff participated in more than one project. Following completion of the original projects, two continuation projects were developed.

The approach of viewing geochemical dispersion within a well-controlled and well-understood regolith-landform and bedrock framework at detailed and district scales continued. In this extension, focus was particularly on areas of transported cover and on more complex lateritic environments typified by the Kalgoorlie regional study. This was supported by 17 companies.

The significance of gold mobilisation under present-day conditions, particularly the important relationship with pedogenic carbonate, was investigated further. In addition, attention was focussed on the recognition of primary lithologies from their weathered equivalents. This project was supported by 14 companies.

Most reports related to the above research projects were published as CRC LEME Open File Reports Series (Nos 1-74), with an index (Report 75), by June 1999. Publication now continues with release of reports from further projects.

P252: Geochemical exploration for platinum group elements in weathered terrain. Leader: Dr C.R.M. Butt.
This project was designed to gather information on the geochemical behaviour of the platinum group elements under weathering conditions using both laboratory and field studies, to determine their dispersion in the regolith and to apply this to concepts for use in exploration. The research was commenced in 1988 by CSIRO Exploration Geoscience and the University of Wales (Cardiff). The Final Report was completed in December 1992. It was supported by 9 companies.

P409: Geochemical exploration in areas of transported overburden, Yilgarn Craton and environs, WA.
Leaders: Drs C.R.M. Butt and R.E. Smith.
About 50% or more of prospective terrain in the Yilgarn is obscured by substantial thicknesses of transported overburden that varies in age from Permian to Recent. Some of this cover has undergone substantial weathering. Exploration problems in these covered areas were the focus of Project 409. The research was commenced in June 1993 by CSIRO Exploration and Mining but was subsequently incorporated into the activities of CRC LEME in July 1995 and was concluded in July 1996. It was supported by 22 companies.

Although the confidentiality periods of Projects P252 and P409 expired in 1994 and 1998, respectively, the reports have not been released previously. CRC LEME acknowledges the Australian Mineral Industries Research Association and CSIRO Division of Exploration and Mining for authority to publish these reports. It is intended that publication of the reports will be a substantial additional factor in transferring technology to aid the Australian mineral industry.
PREFACE

The CRCLEME-AMIRA Project "Exploration in Areas of Transported Overburden, Yilgarn Craton and Environ" (Project 409) has, as its principal objective, development of geochemical methods for mineral exploration in areas with substantial transported overburden, through investigations of the processes of geochemical dispersion from concealed mineralization. The Project has two main themes. One of these, 'Surface and subsurface expression of concealed mineral deposits' is addressed by this report, which focuses on the use of selective extraction at Curara, which has Au-rich laterite covered by up to 20 m of transported overburden in a relatively undisturbed site. Over the past few years selective extractions have regained popularity as a technique for the location of buried mineralization. If effective, they would offer an inexpensive and easy method for exploration in areas of transported overburden. Assessment of the utility and range of these methods is considered to be an important component of Project 409.

The investigations carried out as part of this report have been conducted in order to determine: whether soil extraction anomalies exist over buried mineralization; can these anomalies be observed using different techniques; and what is the primary cause of the anomalies? It is intended that these results would form part of a database for the Yilgarn Craton to determine the utility of such techniques for Au exploration in this region.

C.R.M. Butt,
Project Leader.
February, 1996
ABSTRACT

The Curara site was selected for initial investigations of the utility of partial/selective extraction for mineral exploration in the Yilgarn. There are up to 20 m of barren transported overburden over laterite, which is enriched in Au above primary mineralization. It was considered that MMI (mobile metal ion) extractions were successful in locating the buried mineralization. This was tested, using one soil profile in the middle of the mineralized zone, two traverses across the region of Au-rich laterite and one traverse in a background area, which were treated using standard selective extraction techniques. The first extraction, acetate, which measures pH 5 soluble metals, shows no direct correlations with underlying Au-rich laterite, except for Mn, which appears to be moderately enriched directly above mineralization. The second extraction, hydroxylamine, which extracts Mn oxides and amorphous Fe oxides, gives higher levels of Fe, Mn, Cu, Zn and Pb overlying mineralization. The best signal to noise contrast was obtained for Mn, and is clearly caused by significant concentrations of separate phase Mn oxides above the Au-rich laterite. Analysis of the data suggests that the higher concentrations of extractable base metals are primarily due to association of these metals with Mn oxides. Furthermore, examination of the MMI results suggested that those MMI extractable metals showing high contents over mineralization (e.g., Cu and Cd) were also associated with Mn oxides.

The enrichment in Mn over mineralization is greater than 800 ppm, which cannot be characterized as a subtle extraction anomaly. Despite some evidence for moderate Mn enrichment in groundwaters contacting mineralized areas, it is considered that there is unlikely to be a direct link between the surface Mn anomaly and the Au-rich laterite ten or more metres below. Instead, it is likely that surface phenomena, such as an observed drainage system through the anomalous area, is the cause of this effect. This suggests that the MMI and CSIRO extraction results showing a correlation of greater extractable metals with buried Au-rich laterite at Curara is coincidental.

It is considered that partial extractions (such as MMI or enzyme leach) can only be understood and interpreted correctly if conducted in conjunction with determinations of the levels of critical soil phases such as Mn oxides, amorphous Fe oxides and/or any other materials expected to adsorb or otherwise accumulate dissolved ions at the site under investigation.
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1 INTRODUCTION

Selective extraction is a technique whereby particular soil phases are dissolved in a controlled manner, and the resulting solutions analysed for trace elements of interest. These techniques can be used to investigate how trace elements are distributed between the phases. In addition, these extractions have been used in the past for geochemical exploration because it has been perceived that elements associated with mineralization (especially those hosted by sulphides) are more likely to be released during weathering than those in barren rocks (hosted by silicates), more widely dispersed, and more probably held by secondary minerals and hence likely to be preferentially released by extraction solutions. In contrast, many of the new extraction techniques currently been introduced for geochemical exploration are partial rather than selective digests: i.e., they extract part of a phase or phases, rather than a selected mineral. These new methods are being claimed to have a high efficacy in the location of buried or otherwise hidden orebodies, and there has been a high degree of interest in their application. This study has been designed to examine the chemistry of partial/selective extraction and the mineralogical implications more fully.

Various phases that could be of significance in the distribution of trace elements include phyllosilicates (e.g., kaolinite), Fe oxides\(^1\) (e.g., goethite and hematite), Mn oxides, carbonates or resistate minerals such as chromite, zircon or monazite. Extraction schemes were chosen for this site so as to test easily extractable ions and ions associated with Mn oxides and/or amorphous Fe oxides. These phases are commonly thought to influence the mobilities of a wide range of metals and pathfinder elements and may be important controls for the metals and elements commonly tested in commercial partial leach techniques.

The aims of the project are:

(i) to investigate the potential for selective extraction as an exploration method at Curara;
(ii) to yield data on geochemical dispersion processes;
(iii) to contribute to a database on selective extraction techniques at various sites, and to enhance our understanding of dispersion processes in mineralized zones.

The scope of this study includes the correlation of selective extraction results with the underlying mineralization, effect of Mn oxides and amorphous Fe oxides on extractability of various base metals and investigation of other partial leach techniques used at Curara.

2 SITE STUDY AND METHODS

2.1 Site characteristics

The Curara Well Au prospect is located some 420 km NNE of Perth and some 310 km from the west coast (Figure 1). It is situated within the Wydgee Fold Belt immediately south of the Mount Magnet Greenstone Belt. Outcrop is extremely poor (< 1%). Exploration to date has identified a possible 100,000 oz laterite resource overlying mineralized bedrock. The prospect is located over a tonalitic porphyry stock that is bounded on its eastern side by a package of mafic amphibole schists. Detailed aeromagnetics have shown that the porphyry stock is cut by a number of NW-NNW trending fault splays off a regional shear that occurs to the east of the prospect. The laterite mineralization straddles one splay in particular, and the greatest tenor of mineralization is developed where a wedge

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\(^1\) In this report Fe oxides and Mn oxides are taken to include all classes of separate phase oxides, oxyhydroxides and hydroxides.
of porphyry has been faulted out from the main body of the porphyry stock by this splay. The present day drainage system over the mineralized zone also follows this fault splay. Bedrock mineralization is present within both the porphyry fault wedge and the hanging wall mafic schists immediately to the east. The Au mineralization shows some association with thin (<1 cm) quartz-actinolite veins. The overall percentage of sulphide (pyrite-pyrrhotite and trace chalcopyrite) associated with the mineralization is low (<3%).

(David Hamdorf, CRA, Personal communication)

Figure 1: Location of the Curara Well Au prospect.

The majority of the prospect is covered by 0 - 10 m of alluvium and hardpan (Figure 2), and some 30 - 60 m of partially preserved lateritic weathering profile. The buried laterite profile is generally stripped back to lower laterite, mottled zone or upper saprolite. Much of the laterite mineralization is hosted by nodular mottled zone, with deeper supergene Au enrichment. There is laterite outcrop in the south west corner of the anomaly, over much of the deposit the laterite is covered by about 10 m of sediments. Laterite Au enrichment well defines the primary mineralization.
Figure 2: Sampling traverses and depth of transported overburden at Curara (using data provided by CRA Exploration Ltd.).

The area has a semi-arid to arid climate, with an average annual rainfall of approximately 230 mm. Rainfall variability is high and results mostly from frontal systems from the west and south-west in winter and from patchy, convectional storms and cyclone-related rain-bearing depressions in summer. Summers generally are dry and hot to very hot; winters are cool to mild, with a few frosts. The vegetation is dominated by mulga (Acacia spp.) and by various types of poverty bush and turpentine (Eremophila spp.).

2.2 Sample collection, treatment and elemental analysis

The first series of regolith samples were collected by CSIRO personnel in late-1993. This involved two traverses at 27300N (24000 - 25700E) and at 27500N (24200 - 25600E) (Figure 2). Sampling at 27500N was done so as to repeat previous samples used for MMI (Mobile Metal Ions; ® Wamtech Pty Ltd.) analysis conducted on samples collected by CRA staff. The soils were collected by spade, after scraping away the top 1 to 2 cm, including any debris and or humus, to approximately 20 cm depth, and commonly duplicated previous samples taken by CRA personnel for MMI investigations. A soil profile was sampled down to 0.4 m (to hardpan) at 24750E / 27500N.
Additional traverse samples were sampled in late-1994, extending the 27500N line to the west and east and adding a traverse at 25200N.

Selected samples (specifically the first series of traverse samples and the soil profile at 24750E/27500N) were pulverized to nominal < 75 μm and analysed for Ag, As, Au, Ba, Br, Ce, Co, Cr, Cs, Eu, Fe, Hf, Ir, K, La, Lu, Mo, Na, Rb, Sb, Sc, Se, Sm, Ta, Th, U, W, Yb and Zn by neutron activation (NAA) and for Zn, Cu, Ni, Ti, V, Mn and Pb, using X-ray fluorescence (XRF) of pressed disks.

2.3 Selective extractions

Samples were sieved to < 2 mm for extractions, and then sequentially extracted by the methods described below:

pH 5 acetate (carbonates and surface adsorbed metals).

Five g of sample was shaken with 95 mL 1 mole/litre (M) ammonium acetate at pH 5 for 6 hours. The mixture was then centrifuged (4000 rpm, 15 minutes) and the extraction repeated. The two aliquots were combined and digested with aqua-regia, and then made up to 100 mL in 0.2 M hydrochloric acid (HCl) for analysis for Fe, Mn, Cu, Zn and Pb.

Hydroxylamine (Mn oxides and amorphous Fe oxides).

The solid residue from the extraction was then mixed with 95 mL 0.25 M hydroxylamine hydrochloride in 0.25 M HCl at 60°C for 2 hours. The mixture was centrifuged and the extraction repeated for 30 minutes. The two aliquots were combined and treated as for the previous extraction.

3 RESULTS

3.1 Compiled results

Analytical results are compiled and plotted in the Appendices. Data for the soil profile are shown as Figures A1.1 - A1.29, and data for the first set of samples taken at traverses 27500N and 27300N shown in Figures A2.1 - A2.36 and A3.1 - A3.32, respectively. Elemental analyses undertaken by CRA and MMI results are also shown in Figures A2.1 - A2.36. Extraction data for all traverses, including the later sampling (Section 2.2) are summarized in Figures A4.1 - A4.10. Error bars in the Figures in Appendixes 1 - 3 represent the error as measured by duplicate extractions of the same sample, whereas in Appendix 4, all repeat extractions are shown in the plots, with averaged extraction results given as crosses. Critical plots are reproduced in the text.

Batch effects and/or poor sample reproducibility were observed for pH 5 acetate Fe, Cu, Zn and Pb (Figures A4.1, A4.5, A4.7 and A4.9). The Zn results also included occasional spikes (up to 10 or 20 times normal) which were not repeatable - these have been ignored. The most precise and reproducible results were for Mn by both methods (Figures A4.3 and A4.4).

The various anomalies discussed below are for the element concentrations only. Various ratios [e.g., (extractable metal concentration / total metal concentration), (extractable metal / extractable Mn) etc.] were tested, but all gave poorer signals than the concentrations alone. Reasons for this are discussed in the text.

3.2 Soil profile

Elemental abundances and selective extractions are highly uniform to a depth of 40 cm (Figures A1 - A29; results for total Fe and Mn given in Figures 3 and 4). The uppermost sample (0 - 0.02 m) is
slightly less concentrated in total Fe, Sc, Cr, Co, Ba, K, As, REE and Th, possibly because of dilution by recently transported material (e.g., sheet-wash). It also has slightly more Cu and Zn, and more pH 5 acetate-extractable Mn, possibly due to enrichment of Cu and Zn in organic matter, and degradation of Mn oxides by organic matter causing higher levels of amorphous Mn oxides close to the surface. This uppermost material is generally removed during normal soil sampling (Section 2.2), and mass balance calculations (Appendix 5, Figures A5.1 - A5.34) indicate that, even if included, this part of the sample would have negligible effect on the final totals or extraction results, with the single exception of Mn extracted using pH 5 acetate (Figure 6). This suggests that sampling depth, within the top 40 cm, will not be a critical parameter for selective extraction determinations at this site.

Figure 3: Total Fe vs. depth for soil profile.  
Figure 4: Total Mn vs. depth for soil profile.

Figure 5: Calculated mass balance for total Mn (with error bars shown) for soil profile.  
Figure 6: Calculated mass balance for pH 5 acetate Mn (with error bars shown) for soil profile.
3.3 Traverse 27500N

This traverse was originally sampled by CRAE personnel for elemental and MMI analysis, and the sampling line was repeated, and extended, as part of this project. The MMI results showed greater Cu, and possibly Cd, concentrations directly above the laterite mineralization here at approximately 10 m depth (Figures 7 and 8), whereas the distributions of Zn, Pb, Ni and Ag were not correlated with mineralization (Figures A2.4 - A2.7). The CSIRO pH 5 acetate extractions show greater Mn, but not Fe, Cu, Zn or Pb, overlying mineralization, whereas the concentrations of all 5 elements analysed are greater over mineralization for the hydroxylamine extractions (Figures A2.1 - A2.5, shown for hydroxylamine Mn and Cu in Figures 9 and 10). However, this effect is expected for this traverse as even total Fe, Mn, Cu, Zn, Ni, Sc, V, Co, Sb and REE concentrations are enriched over mineralization.

Figure 7: MMI Cu from traverse line 27500N. Shaded area represents Au content of buried laterite.

Figure 8: MMI Cd from traverse line 27500N. Shaded area represents Au content of buried laterite.
Figure 9: Hydroxylamine extractable Mn for all traverses. First sample set is shown as thick traverse line and second sample set as thin line. Where multiple samples were extracted, average results are shown as crosses. Region of buried Au-rich laterite shown in grey.

Figure 10: Hydroxylamine extractable Cu for all traverses. First sample set is shown as thick traverse line and second sample set as thin line. Where multiple samples were extracted, average results are shown as crosses. Region of buried Au-rich laterite shown in grey.
3.4 Traverse 27300N

This traverse differs from 27500N in that there is no anomaly observed for the total concentration of any of the elements, except Mn (Figure A3.2). However, pH 5 acetate Mn (Figure A3.2) and hydroxylamine Fe, Mn, Cu, Zn and Pb (Figures A3.1 - A3.5, also shown for Mn and Cu in Figures 9 and 10) were all enriched above Au-rich laterite. Thus, these extraction results, as for traverse 27500N (Section 3.3) are correlated with the Au-rich laterite, and are doing so where total results are showing poor correlations. Such results would appear to suggest that extraction methods can work effectively even where total concentrations are not giving useful exploration results.

3.5 Traverse 25200N

This traverse overlies Au-poor laterite and differs from the other two traverses in a number of ways:

(i) extractable Fe (both methods; Figures A4.1 and A4.2) is higher;
(ii) extractable Mn (both methods; Figures A4.3 and A4.4, shown for hydroxylamine Mn in Figure 9) is low and approximately matches the background for the other traverses. In particular, hydroxylamine extractable Mn (Figure 9) does not show the very clear enrichment observed over mineralization at 27300 and 27500N;
(iii) extractable Cu, Zn and Pb (Figures A4.5 - A4.10, shown for hydroxylamine Cu in Figure 10) also lack the enrichments observed from the other traverses.

Thus, results from this traverse appear to support the suggestion that the higher extraction levels above Au-rich laterite in traverses 27500N and 27300N are related to mineralization.

4 Discussion

4.1 What is the controlling factor for the extraction results?

Curara was chosen as a site where MMI and other selective extraction methods gave soil anomalies that correlated with underlying mineralization. A number of elements, including MMI Cu and Cd, pH 5 acetate Mn and hydroxylamine Fe, Mn, Cu, Zn and Pb, appear to be enriched directly above Au-rich laterite, suggesting that selective extraction may well be a potential exploration method at this site. However, these data need closer examination. The greatest amount of metal dissolved was for Fe (10 - 20 ppm by pH 5 acetate and 500 - 2500 ppm by hydroxylamine), though this represents only a minor proportion of the total Fe (about 2.5% in background areas and up to 5% of the total Fe above Au-rich laterite). This Fe could be from various amorphous forms (ferrihydrite, Fe in Mn oxides, Fe in other amorphous phases such as allophane) or from surfaces or edges of crystalline Fe oxides (i.e., goethite and hematite). The “best” results, in terms of the magnitude and the signal to noise ratio is Hydroxylamine Mn (Figure A4.4). Comparison of the extractable Mn, relative to the total Mn (Figures A1.2, A2.2 and A3.3) shows a clear linear relationship between extractable (in this case pH 5 acetate + hydroxylamine) and total Mn (Figure 11). For samples with total Mn less than 100 ppm all of the Mn is incorporated in non-extractable phases. Where samples have higher total Mn roughly half of the Mn over 100 ppm is soluble in the extractants used. Presumably, the extracted Mn is from separate phase Mn oxides, whereas the insoluble Mn remaining is associated with other minerals, most probably Fe oxides such as goethite and hematite, that are not dissolved with these reagents.

Other elements, such as Cu, Zn and Pb, that are enriched above the Au-rich laterite appear to do so because they are correlated with extractable Mn (e.g. Figure 12). However, the metal/Mn ratio actually DECREASES above mineralization, with the greatest reduction for Cu (Figure 13) and the least for Pb (Figure 14). Therefore, the primary effect is NOT enhanced extractable trace elements,
but an increase in separate phase Mn oxides and, possibly, amorphous Fe above the Au-rich laterite. Indeed, if trace element extraction data is “normalized” by dividing by extractable Mn, the mineralized area will show a negative anomaly.

Figure 11: Extractable (pH 5 acetate + hydroxylamine) Mn vs. total Mn at Curara.

Figure 12: Cu vs. Mn for hydroxylamine extractions
4.2 How do CSIRO and MMI extractions compare?

The Curara site was originally selected on the basis of MMI results: MMI Cu and, to a lesser extent, Cd showed enrichments above Au-rich laterite (Figures 7 and 8). Could this effect be due to similar factor as the anomalies observed by the CSIRO extractions? The CRA and CSIRO samples, though they show similar distributions across the 27500N traverse, are different (Appendix 2), so MMI results can not be directly compared to the CSIRO extractions. However, extractable Mn is directly correlated with total Mn (Section 4.1; Figure 11) in the CSIRO samples, and Mn was determined for
the CRA samples. Both MMI Cu and Cd are correlated with total Mn (Figures 15 and 16), with correlation coefficients \( r^2 \) of 0.84 and 0.85 (significant to the 99.9% level), respectively.

![Graph showing Total Cu vs. total Mn for CRA samples](image)

Figure 15: Total and MMI Cu vs. total Mn for CRA samples

![Graph showing MMI Cd vs. total Mn for CRA samples](image)

Figure 16: MMI Cd vs. total Mn for CRA samples

Note that MMI Cu and Cd are zero at total Mn approximately equal to 100 ppm, indicating that they behave similarly to hydroxylamine Cu, Zn and Pb: *i.e.*, they appear to be associated with separate phase Mn oxides. In contrast, MMI Zn is poorly correlated \( (r^2 = 0.0) \) and MMI Pb is negatively correlated \( (r^2 = -0.75) \) with total Mn. It is not known why Zn and Pb behave differently using MMI compared with the CSIRO extractions, though the MMI values for these elements are low and possibly close to detection.
4.3 Are the extraction anomalies due to the buried Au mineralization?

The results from this site can be directly related to other investigations demonstrating "false anomalies" due to adsorptive phases such as Fe or Mn oxides. For example, Butt and Nichol (1979) showed a relationship between Zn and Mn in stream sediments in Northern Ireland (Figure 17) that is similar to that observed for extraction trace elements at Curara: *i.e.*, for low Mn samples up to a threshold value (in this area 1000 - 2000 ppm) Zn was low (about 50 ppm). For high Mn samples there is an approximately linear relationship between Zn and Mn. In this region, anomalous samples have a higher Zn/Mn ratio than background (Figure 17). An analogous significant anomaly is NOT observed at Curara (compare Figure 17 with Figures 11, 12, 15 and 16). That is, none of the samples at Curara are anomalous for trace metals, the high concentration merely being due to the presence of Mn oxides and/or, possibly, amorphous Fe oxides.

![Figure 17: Zinc and Mn contents of active stream sediments from the Low Sperrins, Co. Tyrone, Northern Ireland. Sediments from streams draining mineralized areas show marked deviations from this correlation. (Modified from Butt and Nichol, 1979)](image)

Thus, the correlations of pH 5 acetate Mn, hydroxylamine Mn, Cu, Zn and Pb and MMI Cu and Cd with the Au-rich laterite are due to a correlation of free Mn oxide with underlying buried Au-rich laterite. In terms of developing exploration strategies in such areas it is important to determine the source of this correlation. Previous results (Gray, 1991, 1992, 1994) have indicated that groundwater contacting mineralized lithologies can be moderately enriched in Fe and Mn. However, the magnitude of the soil anomaly (2000 ppm above background for Fe and up to 800 ppm above background for Mn) would appear to make it unlikely to be due to this factor. In addition, other elements commonly enriched in mineralized groundwaters (*e.g.*, Au, Mo, W; *ibid.*) do not show any enrichment in the soils overlying mineralized laterite. A more likely alternative is a surface phenomenon: a present-day drainage system runs across the area of Au-rich laterite at 27300 N and 27500 N (David Hamdorf, CRA, personal communication), which is clearly seen in aerial photographs. Such a system might well be a source for deposition of amorphous Mn and Fe.
4.4 Further work

The results obtained at Curara and comparison with the previously obtained MMI results has lead to a number of hypotheses on the origin and significance of selective extraction anomalies. However, a number of these speculations require significant further testing. A number of sites should be investigated by various techniques, combined with standard techniques to test the occurrence and concentration of critical phases, *i.e.*, "amorphous" Fe oxides, Mn oxides, and any other weak acid soluble phases.

Particular questions that should be addressed include:

(i) is there a correlation of Mn with buried mineralization at other sites;
(ii) how do the CSIRO extractions relate to other techniques - *e.g.*, MMI, enzyme leach, weak acid digests;
(iii) do enzyme leach and/or CSIRO pH 5 acetate tend to dissolve an approximately constant amount of Mn;
(iv) does enzyme leach give similar results to other methods.

The object of such an investigation would be to advance the knowledge on when selective extractions are useful, and what criteria should be used by explorationists to determine their utility at a certain site.

5 Summary

At Curara up to 20 m of transported material overlies a lateritic Au resource developed above deep primary mineralization. One shallow profile in the middle of the mineralized zone and three traverses were tested using standard extraction techniques. Results for pH 5 acetate show no direct correlations with underlying Au-rich laterite, except for Mn. Hydroxylamine, which extracts Mn oxides and amorphous Fe oxides, gives higher levels of Fe, Mn, Cu, Zn and Pb overlying mineralization. Analysis of the data suggests that the higher concentrations of extractable base metals are primarily due to association of these metals with Mn oxides. Close analysis of the MMI results suggested that those extractable metals showing high contents over mineralization (*e.g.*, Cu and Cd) did so because they were higher in samples with higher Mn oxide contents.

The magnitude of the Mn oxide anomaly over mineralization (> 800 ppm) would suggest that there is unlikely to be a direct link between this anomaly and the Au-rich laterite ten or more metres below. Instead, it is likely that surface phenomena, such as an observed drainage system through the anomalous area, is the cause of the geochemical anomaly.

The new extraction techniques currently being introduced for geochemical exploration are partial rather than selective digests: *i.e.*, they extract part of a phase or phases, rather than a selected mineral. They therefore have the potential problem that mineralogical effects (*e.g.*, presence of Mn oxides) may have important effects in the generation of "false anomalies", without information on these effects being available via the extraction results. Therefore, partial extractions such as MMI or enzyme leach can only be understood and interpreted correctly if conducted in conjunction with determinations of the levels of critical soil phases such as Mn oxides or other materials expected to adsorb or otherwise accumulate trace elements.
ACKNOWLEDGMENTS

I would like to thank the staff of CRA Exploration, who have given extensive assistance both in the field, and in discussions and access to data for this site. Much of the extraction work was done by G.D. Longman at CSIRO laboratories, while total analyses were done by M. Hart at CSIRO and Becquerel Laboratories at Lucas Heights. Finally, C.R.M. Butt and A.P.J. Bristow gave extensive advice in the preparation of this report.

REFERENCES

APPENDIX 1:

Elemental and Extraction Data for

Soil Profile at 24750E / 27500N
Figure A1.1: Total Fe in soil profile at 24750E/27500N.

Figure A1.2: pH 5 acetate Fe in soil profile at 24750E/27500N. Error bar shows sample variation.

Figure A1.3: Hydroxylamine Fe in soil profile at 24750E/27500N. Error bar shows sample variation.

Figure A1.4: Total Mn in soil profile at 24750E/27500N.

Figure A1.5: pH 5 acetate Mn in soil profile at 24750E/27500N. Error bar shows sample variation.

Figure A1.6: Hydroxylamine Mn in soil profile at 24750E/27500N. Error bar shows sample variation.
Figure A1.7: Total Cu in soil profile at 24750E/27500N.

Figure A1.8: pH 5 acetate Cu in soil profile at 24750E/27500N. Error bar shows sample variation.

Figure A1.9: Hydroxylamine Cu in soil profile at 24750E/27500N. Error bar shows sample variation.

Figure A1.10: Total Zn in soil profile at 24750E/27500N.

Figure A1.11: pH 5 acetate Zn in soil profile at 24750E/27500N. Error bar shows sample variation.

Figure A1.12: Hydroxylamine Zn in soil profile at 24750E/27500N. Error bar shows sample variation.
Figure A1.13: Total Pb in soil profile at 24750E/27500N.

Figure A1.14: pH 5 acetate Pb in soil profile at 24750E/27500N. Error bar shows sample variation.

Figure A1.15: Hydroxylamine Pb in soil profile at 24750E/27500N. Error bar shows sample variation.

Figure A1.16: Total Sc in soil profile at 24750E/27500N.

Figure A1.17: Total V in soil profile at 24750E/27500N.

Figure A1.18: Total Cr in soil profile at 24750E/27500N.
Figure A1.19: Total Co in soil profile at 24750E/27500N.

Figure A1.20: Total Ni in soil profile at 24750E/27500N.

Figure A1.21: Total Ba in soil profile at 24750E/27500N.

Figure A1.22: Total Na in soil profile at 24750E/27500N.

Figure A1.23: Total K in soil profile at 24750E/27500N.

Figure A1.24: Total TiO$_2$ in soil profile at 24750E/27500N.
Figure A.1.25: Total Sb in soil profile at 24750E/27500N.
Figure A.1.26: Total As in soil profile at 24750E/27500N.

Figure A.1.27: Total Br in soil profile at 24750E/27500N.
Figure A.1.28: Total La in soil profile at 24750E/27500N.

Figure A.1.29: Total Ce in soil profile at 24750E/27500N.
Figure A.1.30: Total Sm in soil profile at 24750E/27500N.
Figure A1.31: Total Eu in soil profile at 24750E/27500N.

Figure A1.32: Total Yb in soil profile at 24750E/27500N.

Figure A1.33: Total Lu in soil profile at 24750E/27500N.

Figure A1.34: Total Hf in soil profile at 24750E/27500N.

Figure A1.35: Total Mo in soil profile at 24750E/27500N.

Figure A1.36: Total Rb in soil profile at 24750E/27500N.
Figure A1.37: Total Eu in soil profile at 24750E/27500N.

Figure A1.38: Total W in soil profile at 24750E/27500N.

Figure A1.39: Total U in soil profile at 24750E/27500N.
APPENDIX 2:

Elemental and Extraction Data for

Traverse 27500N (Initial Sampling)
Figure A2.1: Total and extractable Fe from line 27500N. (Calculated uncertainty given as error bars. Shaded area represents Au content of buried laterite).
Figure A2.2: Total and extractable Mn from line 27500N. (Calculated uncertainty given as error bars. Shaded area represents Au content of buried laterite).
Figure A2.3: Total and extractable Cu from line 27500N. (Calculated uncertainty given as error bars. Shaded area represents Au content of buried laterite).
Figure A2.4: Total and extractable Zn from line 27500N. (Calculated uncertainty given as error bars. Shaded area represents Au content of buried laterite).
Figure A2.5: Total and extractable Pb from line 27500N. (Calculated uncertainty given as error bars. Shaded area represents Au content of buried laterite).
Figure A2.6: Total and extractable Ni from line 27500N
(shaded area represents Au content of buried laterite).

Figure A2.7: Extractable Ag from line 27500N (shaded area represents Au content of buried laterite).
Figure A2.8: Extractable Cd from line 27500N (shaded area represents Au content of buried laterite).

Figure A2.9: Total Sc from line 27500N (shaded area represents Au content of buried laterite).

Figure A2.10: Total V from line 27500N (shaded area represents Au content of buried laterite).
Figure A2.11: Total Cr from line 27500N (shaded area represents Au content of buried laterite).

Figure A2.12: Total Co from line 27500N (shaded area represents Au content of buried laterite).

Figure A2.13: Total Ba from line 27500N (shaded area represents Au content of buried laterite).
Figure A2.14: Total Na from line 27500N (shaded area represents Au content of buried laterite).

Figure A2.15: Total K from line 27500N (shaded area represents Au content of buried laterite).

Figure A2.16: Total TiO\(_2\) from line 27500N (shaded area represents Au content of buried laterite).
Figure A2.17: Total Sb from line 27500N (shaded area represents Au content of buried laterite).

Figure A2.18: Total As from line 27500N (shaded area represents Au content of buried laterite).

Figure A2.19: Total Br from line 27500N (shaded area represents Au content of buried laterite).
Figure A2.20: Total La from line 27500N (shaded area represents Au content of buried laterite).

Figure A2.21: Total Ce from line 27500N (shaded area represents Au content of buried laterite).

Figure A2.22: Total Sm from line 27500N (shaded area represents Au content of buried laterite).
Figure A2.23: Total Eu from line 27500N (shaded area represents Au content of buried laterite).

Figure A2.24: Total Yb from line 27500N (shaded area represents Au content of buried laterite).

Figure A2.25: Total Lu from line 27500N (shaded area represents Au content of buried laterite).
Figure A2.26: Total Hf from line 27500N (shaded area represents Au content of buried laterite).

Figure A2.27: Total Mo from line 27500N (shaded area represents Au content of buried laterite).

Figure A2.28: Total Rb from line 27500N (shaded area represents Au content of buried laterite).
Figure A2.29: Total Th from line 27500N (shaded area represents Au content of buried laterite).

Figure A2.30: Total W from line 27500N (shaded area represents Au content of buried laterite).

Figure A2.31: Total U from line 27500N (shaded area represents Au content of buried laterite).
Figure A2.32: Total Bi from line 27500N (shaded area represents Au content of buried laterite).

Figure A2.33: Total P from line 27500N (shaded area represents Au content of buried laterite).

Figure A2.34: Total Sn from line 27500N (shaded area represents Au content of buried laterite).
Figure A2.35: Total Pd from line 27500N (shaded area represents Au content of buried laterite).

Figure A2.36: Total Pt from line 27500N (shaded area represents Au content of buried laterite).
APPENDIX 3:

Elemental and Extraction Data

for Traverse 27300N
Figure A3.1: Total and extractable Fe from line 27300N. (Calculated uncertainty shown as error bars. Shaded area represents Au content of buried laterite).
Figure A3.2: Total and extractable Mn from line 27300N. (Calculated uncertainty shown as error bars. Shaded area represents Au content of buried laterite).
Figure A3.3: Total and extractable Cu from line 27300N. (Calculated uncertainty shown as error bars. Shaded area represents Au content of buried laterite).
Figure A3.4: Total and extractable Zn from line 27300N. (Calculated uncertainty shown as error bars. Shaded area represents Au content of buried laterite).
Figure A3.5: Total and extractable Pb from line 27300N. (Calculated uncertainty shown as error bars. Shaded area represents Au content of buried laterite).
Figure A3.6: Total Sc from line 27300N (shaded area represents Au content of buried laterite).

Figure A3.7: Total V from line 27300N (shaded area represents Au content of buried laterite).

Figure A3.8: Total Cr from line 27300N (shaded area represents Au content of buried laterite).
Figure A3.9: Total Co from line 27300N (shaded area represents Au content of buried laterite).

Figure A3.10: Total Ni from line 27300N (shaded area represents Au content of buried laterite).

Figure A3.11: Total Ba from line 27300N (shaded area represents Au content of buried laterite).
Figure A3.12: Total Na from line 27300N (shaded area represents Au content of buried laterite).

Figure A3.13: Total K from line 27300N (shaded area represents Au content of buried laterite).

Figure A3.14: Total TiO₂ from line 27300N (shaded area represents Au content of buried laterite).
Figure A3.15: Total Sb from line 27300N (shaded area represents Au content of buried laterite).

Figure A3.16: Total As from line 27300N (shaded area represents Au content of buried laterite).

Figure A3.17: Total Br from line 27300N (shaded area represents Au content of buried laterite).
Figure A3.18: Total La from line 27300N (shaded area represents Au content of buried laterite).

Figure A3.19: Total Ce from line 27300N (shaded area represents Au content of buried laterite).

Figure A3.20: Total Sm from line 27300N (shaded area represents Au content of buried laterite).
Figure A3.21: Total Eu from line 27300N (shaded area represents Au content of buried laterite).

Figure A3.22: Total Yb from line 27300N (shaded area represents Au content of buried laterite).

Figure A3.23: Total Lu from line 27300N (shaded area represents Au content of buried laterite).
Figure A3.24: Total Hf from line 27300N (shaded area represents Au content of buried laterite).

Figure A3.25: Total Mo from line 27300N (shaded area represents Au content of buried laterite).

Figure A3.26: Total Rb from line 27300N (shaded area represents Au content of buried laterite).
Figure A3.27: Total Th from line 27300N (shaded area represents Au content of buried laterite).

Figure A3.28: Total W from line 27300N (shaded area represents Au content of buried laterite).

Figure A3.29: Total U from line 27300N (shaded area represents Au content of buried laterite).
APPENDIX 4:

Elemental and Extraction Data

for all Traverses
Figure A4.1: pH 5 acetate extractable Fe for all traverses. First sample set is shown as thick traverse line and second sample set as thin traverse line. Where multiple samples were extracted, average results are shown as crosses. Region of buried Au-rich laterite shown in grey.
Figure A4.2: Hydroxylamine extractable Fe for all traverses. First sample set is shown as thick traverse line and second sample set as thin traverse line. Where multiple samples were extracted, average results are shown as crosses. Region of buried Au-rich laterite shown in grey.
Figure A4.3: pH 5 acetate extractable Mn for all traverses. First sample set is shown as thick traverse line and second sample set as thin traverse line. Where multiple samples were extracted, average results are shown as crosses. Region of buried Au-rich laterite shown in grey.
Figure A4.4: Hydroxylamine extractable Mn for all traverses. First sample set is shown as thick traverse line and second sample set as thin traverse line. Where multiple samples were extracted, average results are shown as crosses. Region of buried Au-rich laterite shown in grey.
Figure A4.5: pH 5 acetate extractable Cu for all traverses. First sample set is shown as thick traverse line and second sample set as thin traverse line. Where multiple samples were extracted, average results are shown as crosses. Region of buried Au-rich laterite shown in grey.
Figure A4.6: Hydroxylamine extractable Cu for all traverses. First sample set is shown as thick traverse line and second sample set as thin traverse line. Where multiple samples were extracted, average results are shown as crosses. Region of buried Au-rich laterite shown in grey.
Figure A4.7: pH 5 acetate extractable Zn for all traverses. First sample set is shown as thick traverse line and second sample set as thin traverse line. Where multiple samples were extracted, average results are shown as crosses. Region of buried Au-rich laterite shown in grey.
Figure A4.8: Hydroxylamine extractable Zn for all traverses. First sample set is shown as thick traverse line and second sample set as thin traverse line. Where multiple samples were extracted, average results are shown as crosses. Region of buried Au-rich laterite shown in grey.
Figure A4.9: pH 5 acetate extractable Pb for all traverses. First sample set is shown as thick traverse line and second sample set as thin traverse line. Where multiple samples were extracted, average results are shown as crosses. Region of buried Au-rich laterite shown in grey.
Figure A4.10: Hydroxylamine extractable Pb for all traverses. First sample set is shown as thick traverse line and second sample set as thin traverse line. Where multiple samples were extracted, average results are shown as crosses. Region of buried Au-rich laterite shown in grey.
APPENDIX 5:

Mass Balance Calculations for

Soil Profile at 24750E / 27500N
Data for the soil profile at 24750E/27500N (Appendix 1) were used to calculate the predicted value for particular sample intervals, namely:

(i) 0 - 0.2 m  
(ii) 0.02 - 0.2 m  
(iii) 0.05 - 0.2 m  
(iv) 0 - 0.4 m  
(v) 0.02 - 0.4 m  
(vi) 0.05 - 0.4 m  
(vii) 0.05 - 0.3 m

This was done by addition of the concentrations at each relevant soil depth, weighted appropriately. Thus, for example, calculations for total Fe for the 0 - 0.2 and 0.05 - 0.4 m fractions are described below.

Table A5.1: Total Fe for soil profile

<table>
<thead>
<tr>
<th>Upper depth (m)</th>
<th>Lower depth (m)</th>
<th>Fe (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.02</td>
<td>3.06</td>
</tr>
<tr>
<td>0.02</td>
<td>0.05</td>
<td>3.86</td>
</tr>
<tr>
<td>0.05</td>
<td>0.1</td>
<td>3.96</td>
</tr>
<tr>
<td>0.1</td>
<td>0.15</td>
<td>3.95</td>
</tr>
<tr>
<td>0.15</td>
<td>0.2</td>
<td>4.01</td>
</tr>
<tr>
<td>0.2</td>
<td>0.3</td>
<td>4.07</td>
</tr>
<tr>
<td>0.3</td>
<td>0.4</td>
<td>4.36</td>
</tr>
</tbody>
</table>

Calculated Fe (0 - 0.2 m) = \( (3.06 \times 0.02) + (3.86 \times 0.03) + (3.96 \times 0.05) + (3.95 \times 0.05) + (4.01 \times 0.05) \)

\[\frac{0.2}{= \ 3.87 \%}\]

Calculated Fe (0.05 - 0.4 m) = \( (3.96 \times 0.05) + (3.95 \times 0.05) + (4.01 \times 0.05) + (4.07 \times 0.1) + (4.36 \times 0.1) \)

\[\frac{0.35}{= \ 4.11 \%}\]

Calculated data, with estimated uncertainties as error bars, is plotted in Figures A5.1 - A5.34. The variations of virtually all of the elements across the various calculated depths was insignificant and/or less than the analytical error. One exception to this was method A Mn, which was significantly higher at the top of the soil profile, possibly due to degradation of Mn oxides by organic matter.
Figure A5.1: Mass balances for total Fe.

Figure A5.2: Mass balances for pH 5 acetate Fe.

Figure A5.3: Mass balances for hydroxylamine Fe.

Figure A5.4: Mass balances for total Mn.

Figure A5.5: Mass balances for pH 5 acetate Mn.

Figure A5.6: Mass balances for hydroxylamine Mn.
Figure A5.7: Mass balances for total Cu.

Figure A5.8: Mass balances for pH 5 acetate Cu.

Figure A5.9: Mass balances for hydroxylamine Cu.

Figure A5.10: Mass balances for total Zn.

Figure A5.11: Mass balances for pH 5 acetate Zn.

Figure A5.12: Mass balances for hydroxylamine Zn.
Figure A5.13: Mass balances for total Pb.

Figure A5.14: Mass balances for pH 5 acetate Pb.

Figure A5.15: Mass balances for hydroxylamine Pb.

Figure A5.16: Mass balances for Sc.

Figure A5.17: Mass balances for V.

Figure A5.18: Mass balances for Cr.
Figure A5.19: Mass balances for Co.

Figure A5.20: Mass balances for Ni.

Figure A5.21: Mass balances for Ba.

Figure A5.22: Mass balances for Na.

Figure A5.23: Mass balances for K.

Figure A5.24: Mass balances for TiO₂.
Figure A5.31: Mass balances for Hf.

Figure A5.32: Mass balances for Rb.

Figure A5.33: Mass balances for Th.

Figure A5.34: Mass balances for U.