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DISTRIBUTION OF GOLD, ARSENIC, CHROMIUM AND COPPER IN THE REGOLITH AT THE HARMONY DEPOSIT, PEAK HILL, WESTERN AUSTRALIA.

A.F. Britt and D.J. Gray

CRC LEME OPEN FILE REPORT 225

November 2008

(CRC LEME Restricted Report 143R / E&M Report 739R, 2001
2nd Impression 2008)

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CRC LEME is an unincorporated joint venture between CSIRO-Exploration & Mining, and Land & Water, The Australian National University, Curtin University of Technology, University of Adelaide, Geoscience Australia, Primary Industries and Resources SA, NSW Department of Primary Industries and Minerals Council of Australia.

Headquarters: CRC LEME c/o CSIRO Exploration and Mining, PO Box 1130, Bentley WA 6102, Australia

The CRC LEME–AMIRA Project 504 "**SUPERGENE MOBILIZATION OF GOLD IN THE YILGARN CRATON"** was carried out over the period 1998 to 2001. Twelve reports resulted from this collaborative project.

CRC LEME acknowledges the support of companies associated with and represented by the Australian Mineral Industries Research Association (AMIRA), and the major contribution of researchers from CSIRO Exploration and Mining.

Although the confidentiality periods of the research reports have expired, the last in July 2002, they have not been made public until now. In line with CRC LEME technology transfer goals, re-releasing the reports through the **CRC LEME Open File Report (OFR) Series** is seen as an appropriate means of making available to the mineral exploration industry, the results of the research and the authors' interpretations. It is hoped that the reports will provide a source for reference and be useful for teaching.

OFR 217 – Characteristics of gold distribution and hydrogeochemistry at the Carosue Dam prospect, Western Australia – DJ Gray, NB Sergeev and CG Porto.

OFR 218 – Gold distribution, regolith and groundwater characteristics at the Mt Joel prospect, Western Australia – CG Porto, NB Sergeev and DJ Gray.

OFR 219 – Supergene gold dispersion at the Argo and Apollo deposits, Western Australia – AF Britt and DJ Gray

OFR 220 – Geochemistry, hydrogeochemistry and mineralogy of regolith, Twin peaks and Monty Dam gold prospects, Western Australia – NB Sergeev and DJ Gray.

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OFR 226 – Supergene gold dispersion in the regolith at the Kanowna Belle and Ballarat Last Chance deposits, Western Australia – DJ Gray

OFR 227 – Supergene gold dispersion, regolith and groundwater of the Mt Holland region, Southern Cross province, Western Australia – AF Britt and DJ Gray.

OFR 228 – Supergene mobilization of gold and other elements in the Yilgarn Craton, *Western Australia* – ***FINAL REPORT*** – DJ Gray, NB Sergeev, CG Porto and AF Britt

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PREFACE

The principal objective of CRC LEME-AMIRA Project 504, *Supergene mobilization of gold and other elements in the Yilgarn Craton*, is to determine the mechanisms of supergene/secondary depletion, enrichment and dispersion of Au and other elements, so as to improve selection of drilling targets and further optimize interpretation of geochemical data.

Harmony gold mine is situated just north of the Yilgarn Craton in the Capricorn Orogen and extensive regolith analyses for Au, As, Cr and Cu were available. Groundwaters are fresh and neutral, contrasting with acidic and saline to hypersaline groundwaters of the southeastern Yilgarn, particularly those in the Kalgoorlie region. As neutral, fresh groundwaters are poor at dissolving Au, Au redistribution within the regolith at Harmony is significantly different to the patterns observed at southern sites, with minimal Au depletion/remobilization. Arsenic and Cr are elevated over mineralization and appear to be associated with Fe oxides in the upper saprolite, lateritic residuum and alluvium. In comparison, Cu concentrations are only slightly elevated over the ore body and do not appear to have an Fe oxide affinity.

D.J. Gray
Project Leader
May 2001

ABSTRACT

The Harmony deposit is located in the Peak Hill mining district, approximately 9 km west of Peak Hill and some 120 km north of Meekatharra. It lies on the sheared contact between the Narracoota metavolcanics and the Ravelstone metasediments (turbidites), within the southern part of the Capricorn Orogen. Mineralization occurs at this contact and is predominantly associated with quartz veins and various structural features. The ore body also includes a sub-horizontal, near surface zone of supergene enrichment.

The deposit is located on a depositional plain that covers a palaeo-landscape with some 40 m relief. Prior to infill, the ore body was located on a palaeohigh with a major palaeochannel on its southern side and a smaller palaeochannel to the north. Four regolith layers could be distinguished from previous CRC LEME logging: alluvium, palaeochannel sediments, lateritic residuum and saprolite/bedrock. Alluvium (mean thickness 3.4 m), palaeochannel sediments (0.5 m) and lateritic residuum (1.2 m) are thinnest over the ore body and much of the palaeohigh is actually devoid of lateritic residuum and palaeochannel sediments. Lateritic residuum only occurs on the flanks of the palaeohigh and within the palaeochannels. In an adjacent background area the alluvium, lateritic residuum and palaeochannel sediments average 6.3, 1.7 and 2.1 m thickness, respectively.

Within the ore body, saprolite has a mean Au concentration of 265 ppb, which decreases to 170 ppb in the lateritic residuum. The palaeochannel sediments have relatively little Au (65 ppb), with more in the alluvium (115 ppb). In the background area, the saprolite has a mean Au concentration of 35 ppb, increasing to 70 ppb in the lateritic residuum. Gold content in the background palaeochannel sediments is similar to those over the ore body (50 ppb) with a slight increase in mean Au concentration in the alluvium (65 ppb).

Three-dimensional models show that Au mineralization occurs in the regolith profile as a mass with slight north-south elongation. There is dispersion of Au in the upper profile downslope towards the palaeochannel. Cross sections of Au distribution at the Harmony deposit show that, whilst the maximum mean Au concentration (390 ppb) occurs at approximately 50 m depth, high concentrations of Au occur at all elevations. This contrasts to the southeast Yilgarn (e.g., Kalgoorlie) where many sites are strongly depleted in Au in the upper regolith and acid/saline groundwaters are conducive to Au mobilization. Harmony has neutral and fresh groundwaters, which do not actively mobilize Au.

Mean Cr concentrations show little variability with depth, within the ore body and background, until approximately 25 m below surface, above which Cr increases towards the surface, particularly in the background area. Chromium is significantly concentrated in the lateritic residuum (615 ppm) over the ore body and is also elevated in the palaeochannel sediments (535 ppm) and alluvium (515 ppm), as compared with saprolite (335 ppm). The background area also shows increased Cr in the lateritic residuum (265 ppm) compared to saprolite (135 ppm), with the palaeochannel sediments averaging 180 ppm and the alluvium 395 ppm. The increased levels of Cr in the upper regolith most likely reflect increased amounts of Fe oxides, with which it is often associated.

At the ore body, As concentration averages 25 ppm in the saprolite/bedrock, increasing to 45 ppm in the lateritic residuum and 60 ppm in the palaeochannel sediments, but decreasing to 30 ppm in the alluvium. Background concentrations of As (10 to 15 ppm in the saprock/saprolite and 20 ppm in the alluvium) are lower and less variable. The increased concentration of As in the lateritic residuum, palaeochannel sediments and alluvium, like Cr, probably reflects as association with Fe oxides.

Copper concentrations are similar in both the ore body and background areas. The maximum mean Cu concentration over the ore body occurs at approximately 50 m depth where Cu content is 85 ppm. Over background, maximum Cu concentration (75 ppm) occurs at 70 m depth. From these points Cu concentrations decrease up profile and mean Cu concentration at the surface over both background and the ore body is approximately 45 ppm. Unlike Cr and As, Cu does not appear to be concentrating with Fe oxides.

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1 INTRODUCTION

1.1 Objective

The principal objective of CRC LEME-AMIRA Project 504, *Supergene mobilization of gold and other elements in the Yilgarn Craton*, is to determine the mechanisms of supergene/secondary depletion, enrichment and dispersion of Au and other elements, so as to improve selection of drilling targets and further optimize interpretation of geochemical data.

Within this framework, this study has investigated the geochemical dispersion of Au, Cu, As and Cr at the Harmony deposit using the Mining Visualization System (MVS) program. This program is a useful tool for visualizing the three-dimensional distributions of these elements in the regolith and calculating degrees of depletion and enrichment. This project was of value as it offered data on the redistribution of Au and other elements in an environment significantly different from that in the southern areas of the Yilgarn Craton.

1.2 Location and history

The Harmony deposit is located in the Peak Hill mining district, approximately 9 km west of Peak Hill and some 120 km north of Meekatharra, Western Australia, at 25°39'S, 118°37E (Figure 1). It is within the Baxter Mining Centre and was previously known as the Contact deposit.

Harmony was discovered in 1991 by AFMECO Pty Ltd in an area with neither bedrock exposure nor previously known mineralization (Harper *et al.*, 1998). The deposit was found through a shallow RAB drilling program sampling buried ferruginous lateritic residuum and a follow-up drill program located mineralization in what is now the southern part of the Harmony Pit (Robertson *et al.*, 1996). In 1994 Plutonic (Baxter) Pty Ltd took over AFMECO's interests in the area and mining commenced in July 1995 and was completed in November 1997. The Peak Hill and Harmony mines produced 661,000 oz of Au from May 1988 until stockpiles were exhausted in November 1999 (RIU, 2000). Peak Hill and Harmony are currently owned by Homestake Mining Company, through Plutonic Resources Ltd (66.67%) and North Ltd (33.33%).

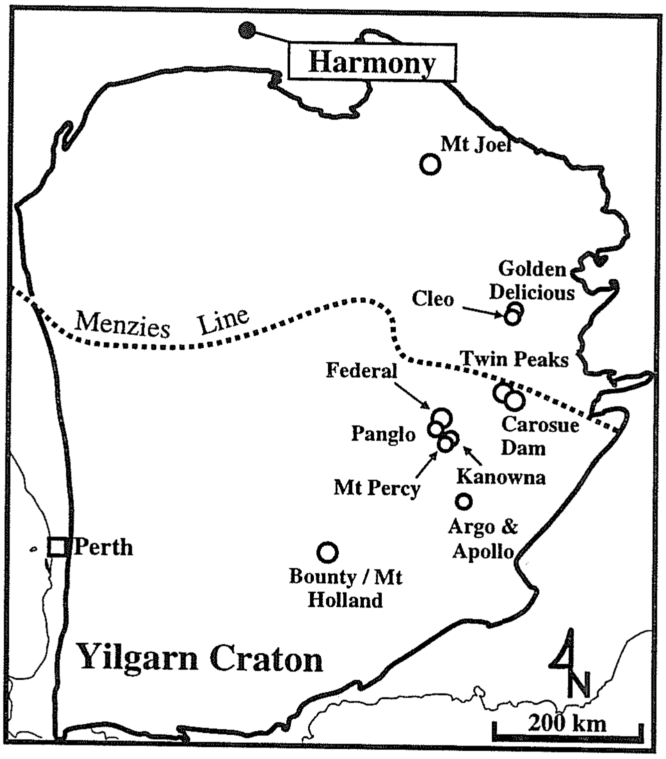


Figure 1: Location of the Harmony Au deposit (black dot) and other P504 study sites.

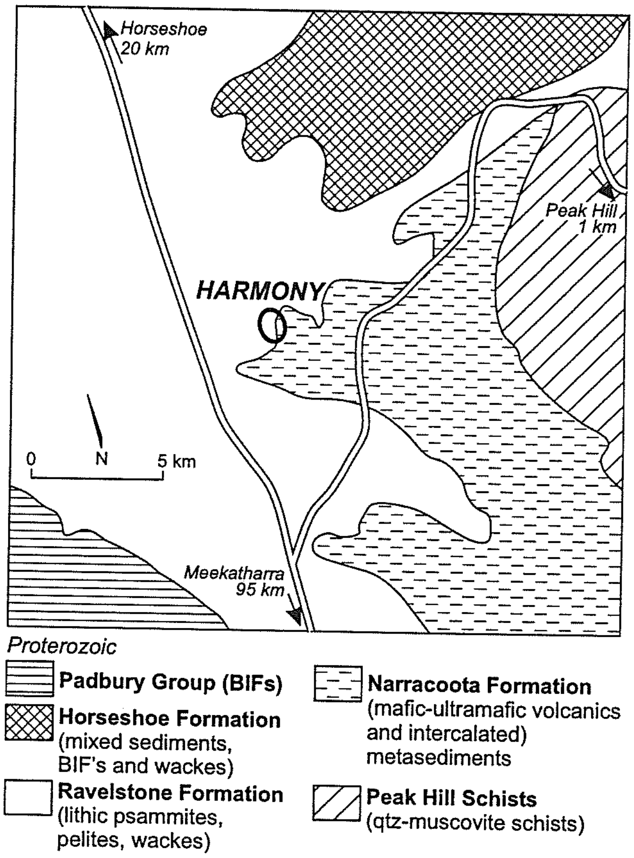


Figure 2: *Local geology of the area around the Harmony deposit (from Robertson et al., 1999).*

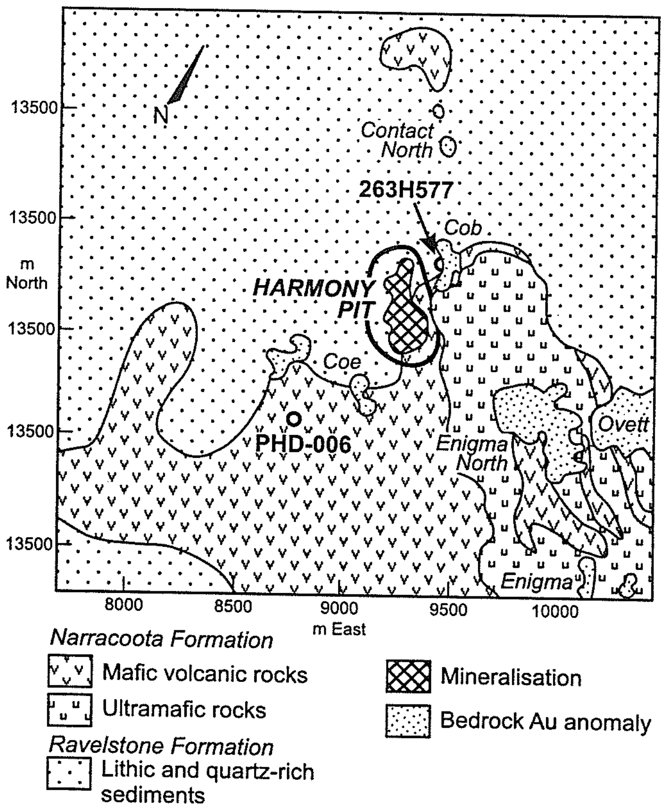


Figure 3: *Local geology of the area surrounding the Harmony pit (from Robertson et al., 1999).*

2 METHODS

2.1 Data treatment and modelling

The data for the geochemical modelling were supplied by AFMECO Pty Ltd, with regolith logging derived from a previous CRC LEME-AMIRA project, Project 409 *"Geochemical exploration in areas of transported overburden, Yilgarn Craton and environs"*, for which over 700 RAB drill holes were logged (Robertson *et al.*, 1996) as bedrock/saprolite (combined), lateritic residuum, palaeochannel sediments and alluvium. The logging did not distinguish between saprolite, saprock and bedrock, so these units are combined.

The regolith layers were modelled using Mining Visualization System (MVS, © C Tech Corporation). The program grids three-dimensional data by kriging, which is able to take into account variables such as trends and bias. Output was manually filtered with "point" anomalies individually assessed. In general, small errors were deemed acceptable, but data resulting in large errors were disregarded, though with a bias for including data, rather than removing them and thus losing information. Kriging and filtering took several cycles, and as the logging was regarded as highly consistent, very few (< 1%) of the data points were excluded from the modelling in this project. Regolith stratigraphy, Au, As, Cr and Cu values were kriged.

Two areas were gridded (Figure 4): the ore body only and the larger Harmony region. The results of each area are presented in the report as the mineralized area (ore body only), total area (Harmony region) and background (Harmony region minus the ore body). The gridding parameters used for each area are presented in Appendix 1. The Harmony region covers an area of 1000 x 1000 m and, as well as the ore body, includes the large Waste Dump Palaeochannel to the southwest, and a small tributary, the Harmony Palaeochannel, feeding into another palaeochannel to the north-east just outside the modelled area. The ore body is situated on a palaeohigh and the area kriged covers 400 x 700 m.

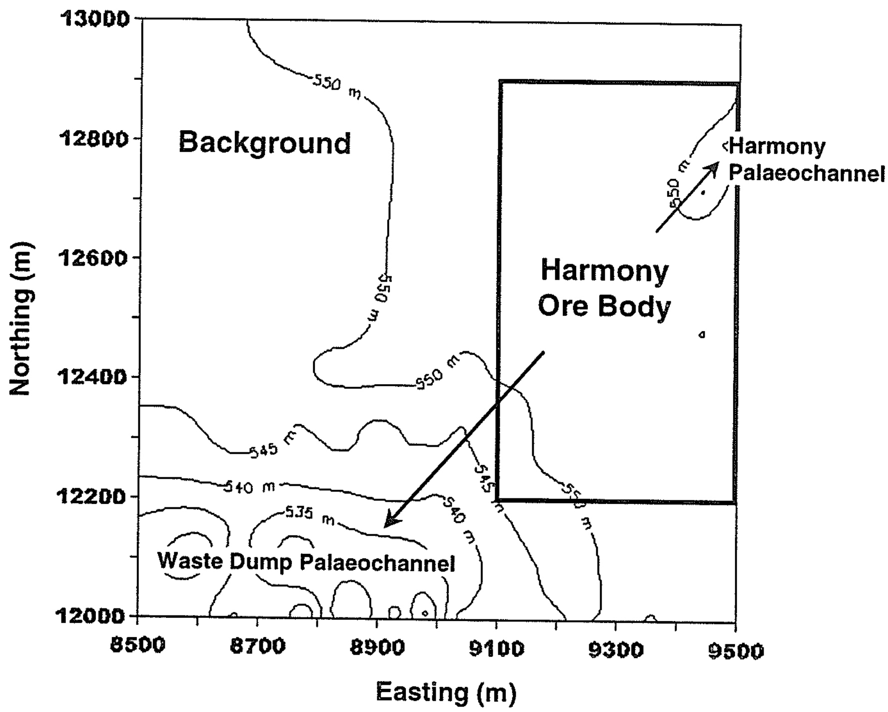


Figure 4: Plan view of the palaeotopography over the Harmony region (elevation = mRL). The Harmony ore body is located on a palaeohigh between two palaeochannels. The ore body and the larger Harmony region were modelled with MVS and background values were obtained by subtracting the ore body values from those of the total region. The arrows depict the main directions of shedding from the palaeohigh into the Waste Dump and Harmony Palaeochannels (see Robertson et al., 1999).

2.2 Regolith stratigraphy

The regolith stratigraphy of the Harmony ore body and the Harmony region were modelled in three dimensions, in cross sections are along nominated northings and eastings, and in horizontal sections at nominated elevations. The cross sections of regolith stratigraphy match those of Au distribution, all of which are on the enclosed CD (see Appendix 2), with the regolith boundaries shown.

2.3 Geochemical distribution

Gold distribution at the Harmony ore body was modelled in three dimensions and in cross section, the diagrams of which are on the CD (see Appendix 2). The three-dimensional models show those parts of the regolith (coloured by stratigraphy) that contain a greater concentration of Au than a nominated value. These diagrams are referred to in this report as "cut-off" diagrams.

As described above, cross sections of Au distribution are along nominated eastings, northings and elevations and match the regolith stratigraphy cross sections. The colour scale for the Au concentration is logarithmically set from 10 ppb or lower (blue) to 1 ppm or greater (red) to enhance contrast.

2.4 Gold, As, Cu and Cr concentration calculations

The MVS program was used to calculate Au, As, Cu and Cr concentrations in the regolith over the Harmony region, and separated into the Harmony ore body and the background area (Figure 4). Density data were not provided so uniform density was assumed. As the element concentration data are mass/mass rather than mass/volume, uniform density has only a minor influence on most calculations. The calculated concentrations do not compensate for leaching of mobile constituents: if half of the minerals have dissolved and been leached, then the concentration of a given element will double because of residual concentration.

Mean concentrations were calculated for each regolith layer and for 3 m thick slices defined by distance from the surface and distance from the unconformity (e.g., 3 to 6 m below the unconformity; Figure 5). Gold concentrations were also calculated against elevation (e.g., 549 to 552 mRL). The results of these calculations are presented in Section 4.

Although this method for calculating concentration is (arithmetically) correct, it can lead to over- or under-estimations as the slices get further from the boundary in question. This is because, ultimately, the slice being analyzed is incomplete. This can be expressed as a reliability factor, which is the mass of the slice divided by the mass of an untruncated slice (Figure 5). A reliability index of 85% indicates that the slice is 15% truncated.

As the reliability index decreases, significant errors can occur. Figure 6 shows the results of Au content measurement for each slice from the unconformity. Though the deeper slices are truncated (Figure 6a), they can still contain mineralized material, as in this example (Figure 5). Thus, similar masses of Au are being divided by smaller and smaller masses of regolith, which leads to anomalous calculations of Au concentration (Figure 6b). In this example, the results indicate that the deepest slice has up to 440 ppb Au even though the "real" Au content is invariant at 80 ppb, except for the depletion zone at the top of the *in situ* regolith.

When all the slices with reliability indices less than 60% are removed, the remaining results can be coded for reliability (Figure 6c). A much clearer picture of Au trends emerges, illustrating depletion towards the unconformity. Note that this example is for the maximum possible overestimation of Au concentration (the maximum overestimation = 100 ÷ reliability: e.g., if reliability is 60%, maximum overestimation is 1.67; if reliability is 90%, maximum overestimation is 1.11). In other cases, underestimation can occur for low reliability samples due to a truncated intersection with mineralization. In summary, samples with reliabilities less than 80% are suspect (but can still be valuable if treated with caution), whereas those with reliability less than 60% should generally not be used.

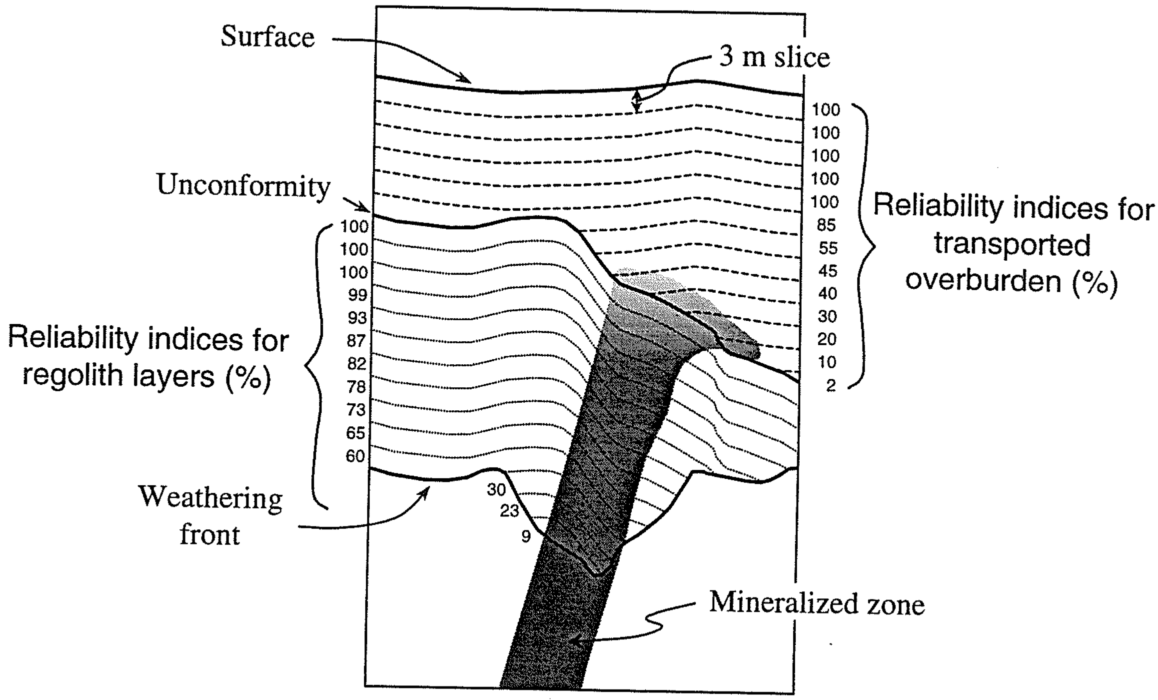


Figure 5: *Diagrammatic representation of method for calculating Au concentration from slices defined for the upper surface and for the unconformity. The shaded area represents mineralization, with depletion near the top of the in situ regolith.*

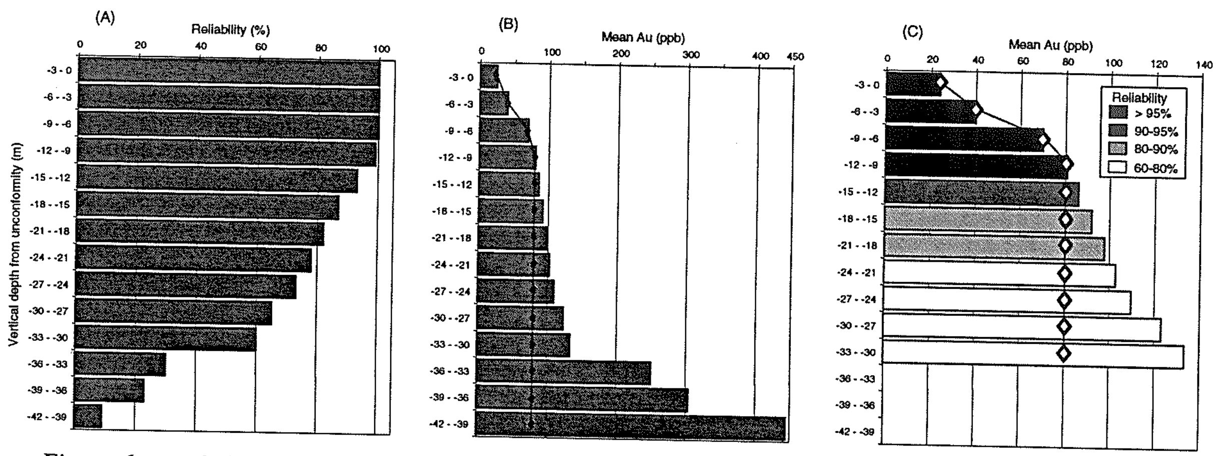


Figure 6: *Calculated (a) reliability (b) unfiltered Au concentration and (c) filtered (> 60% reliability) Au concentration, colour coded to reliability, for in situ regolith. Diamonds represent expected Au concentration. Data based on situation represented in Figure 5.*

3 REGOLITH STRATIGRAPHY, PALAEOTOPOGRAPHY AND GEOMETRY OF THE AU DEPOSIT

3.1 Regolith stratigraphy

Using the CRC LEME logging from the previous work at Harmony (Robertson *et al.*, 1996), four regolith layers could be distinguished for modelling. These are referred to as alluvium, palaeochannel sediments, lateritic residuum and saprolite/bedrock (Figure 7), with saprolite, saprock and bedrock not distinguished. Robertson *et al.* (1996) describe these regolith layers (Table 1).

Table 1: Regolith Layers and descriptions for the Harmony region.

Regolith Layer (this report)	Description (Robertson *et al.*, 1996)	Comment
Alluvium	Broad colluvial-alluvial plain mainly consisting of dark brown gravels, sands and silts. The upper parts are silicified to red-brown hardpan.	This layer covers the total Harmony region modelled in this report.
Palaeochannel Sediments	Dominated by smectitic-kaolinitic clays probably derived from the local saprolite. They are soft, puggy and mainly grey, green and light brown. Mottled, indicating post-depositional weathering, and appear to have been somewhat eroded prior to placement of the alluvium.	Confined to the palaeochannels.
Lateritic Residuum	Lateritic duricrust and lateritic gravels, up to 19 m thick but typically much less. Nodules are generally dark red with distinctive yellow-brown cutans.	In this report, the lateritic residuum is regarded as part of the residual profile, although it is may have been transported locally.
Saprolite/Bedrock	The saprolite forming the palaeohigh and hosting the ore is weakly indurated and ferruginous, mostly grey and light yellow-brown. Weathering beneath the palaeochannels is more extensive and the saprolite is clay-rich and mottled (white powdery kaolinite with dark red or yellow-brown nodules). The depth of oxidation over the ore body is approximately 80 m.	Saprolite, saprock and bedrock were not distinguished in the drill logging and are discussed together in this report. Bedrock is described in Section 1.3.

3.2 Palaeotopography

Prior to infill, the Harmony region had relief estimated at some 40 m (Robertson *et al.*, 1996). The ore body is located on a palaeohigh and, to the south, the east-northwest trending Waste Dump Palaeochannel is the dominant feature, with northwesterly flow implied by the topography. The smaller Harmony Palaeochannel intersects the palaeohigh to the northeast and Robertson *et al.* (1996) concluded that this connects to a smaller shallower palaeovalley to the north of the deposit that parallels the Waste Dump Palaeochannel. These authors consider that the alignment of the palaeovalleys is most likely to be related to underlying bedrock structures and lithological differences. They also note that it is likely that the palaeochannel sediments were once more extensive but the area has been eroded before being blanketed in alluvium. Thus, the palaeotopography is regarded as a minimum surface and relief might have been greater.

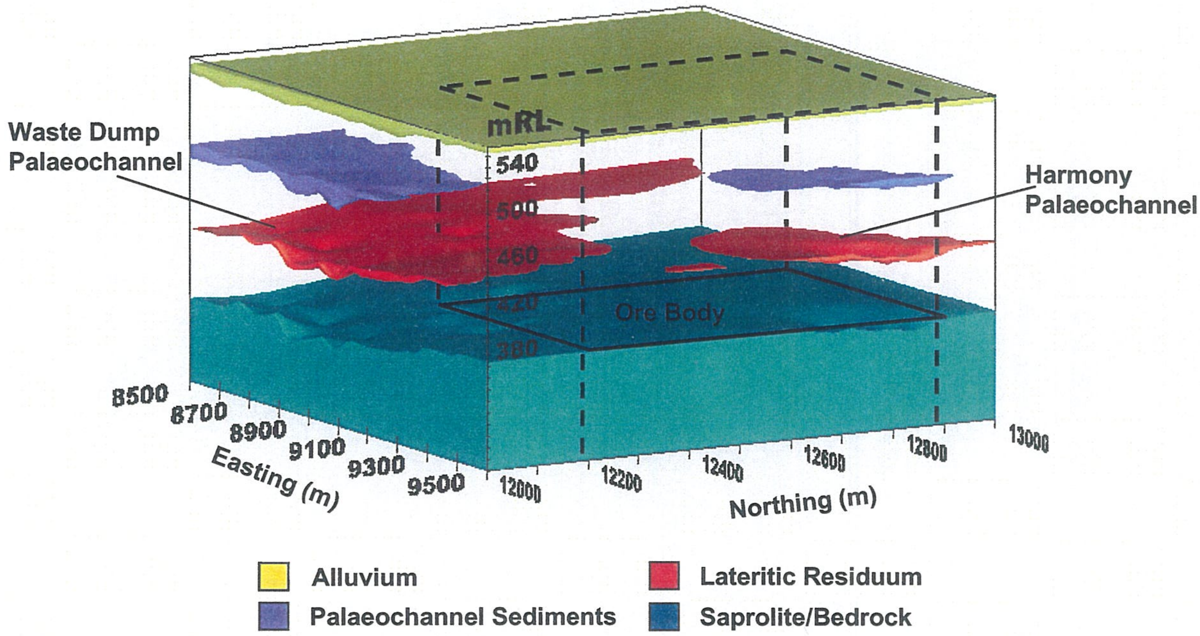


Figure 7: *MVS model of regolith stratigraphy over the Harmony region. Exploded view to the north-west. The ore body is located on a palaeohigh with lateritic residuum on the flanks. Sediments (purple) fill the main palaeochannel to the south-west and the smaller palaeo-tributary to the north-east. The entire region is covered by alluvium, though it is very thin over the ore body.*

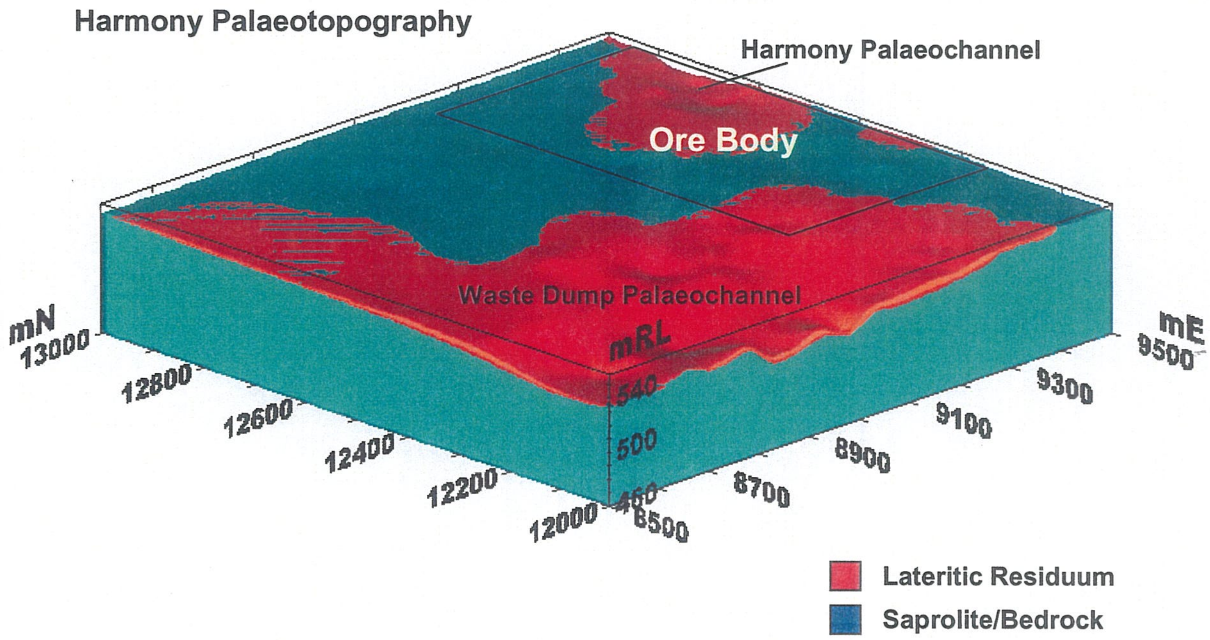


Figure 8: *Palaeotopography of the Harmony region. Lateritic residuum has developed on saprolite but is absent from the palaeohigh. Greater thicknesses on the hill flanks suggest some degree of erosion from the hilltop. View is to the north-east.*

Over the ore body, alluvium (3.4 m), palaeochannel sediments (0.5 m) and lateritic residuum (1.2 m) are thinner than in the background area, where they average 6.3, 1.7 and 2.1 m, respectively. The ore body is located on a palaeohigh (Figure 8) and is mostly devoid of lateritic residuum and palaeochannel sediments. Lateritic residuum only occurs on the flanks of the palaeohigh and within the palaeochannels (Figure 8) and has, perhaps, been eroded prior to further sedimentation. Similarly, the palaeochannel sediments are confined to the palaeovalleys. The base of oxidation averages approximately 80 m depth over the ore body (Robertson *et al.*, 1996), thus saprolith dominates the weathering profile.

3.3 Gold distribution in the regolith

Gold distribution in the Harmony regolith was investigated with three-dimensional models and with cross sections, which are included on the report CD (see Appendix 2).

Three-dimensional models show that Au mineralization occurs in the regolith with a slight north-south elongation. The 150 ppb Au cut-off diagram (Figure 9) indicates downslope dispersion of Au in the upper profile towards the palaeochannel. Gold dispersion towards the palaeochannel can also be seen in cross section (Figure 10). This cross section also shows that, within the mineralized zone, patches of strong Au concentration occur throughout the regolith profile, in contrast to more southerly regions in the Yilgarn (e.g., Kalgoorlie) in which Au tends to be depleted from the upper profile.

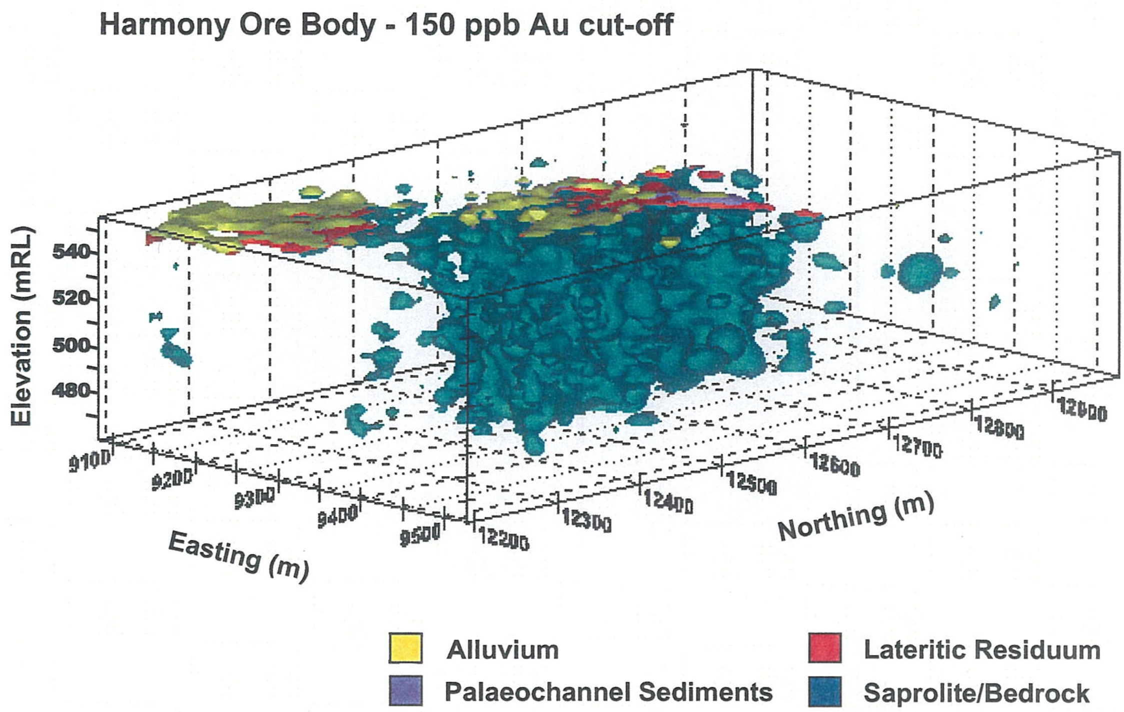


Figure 9: *Model of the Harmony ore body showing all those parts of the profile that contain Au concentrations of > 150 ppb. Lateritic residuum, palaeochannel sediments and alluvium contain Au where they overly the ore body. Also, Au has dispersed in the lateritic residuum and alluvium downslope, towards the Waste Dump Palaeochannel.*

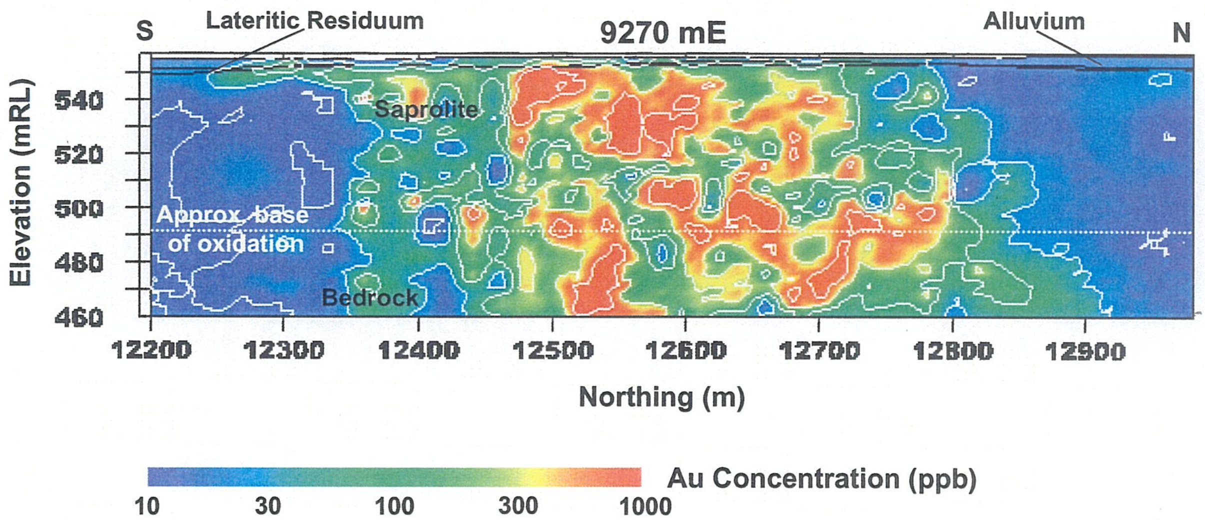


Figure 10: *Gold distribution along a north-south section of the Harmony deposit at 9270 mE. This cross-section shows the typical distribution of Au in the profile. Gold does not appear to be depleted from the upper profile but has patches of high concentration at all elevations. Gold is also dispersed downslope within the upper saprolite, lateritic residuum and the alluvium (see Figure 9). The approximate base of oxidation is taken from Robertson et al. (1996).*

4 CALCULATIONS OF AU, AS, CU AND CR CONCENTRATIONS IN THE REGOLITH

4.1 Mean Au, As, Cr and Cu concentrations in each regolith layer

The mean Au, As, Cr and Cu concentrations of each regolith layer were calculated for the region, the ore body and background (Figure 11). The ore body saprolite has a mean Au concentration of 265 ppb, which decreases to 170 ppb in the lateritic residuum. The palaeochannel sediments have relatively little Au (65 ppb) but the alluvium has somewhat more (115 ppb). The background pattern is somewhat different. Gold has a mean value of 35 ppb in the saprolite but increases in the lateritic residuum to 70 ppb. Gold content in the background palaeochannel sediments is similar to those over the ore body (50 ppb) with a slight increase in mean Au concentration in the alluvium (65 ppb).

The lateritic residuum above the ore body has significantly more As (45 ppm) than the underlying saprolite (25 ppm). The palaeochannel sediments have a still greater concentration (60 ppm) but As content is lower in the alluvium (30 ppm). Background concentrations of As are significantly lower and less variable (Figure 11).

Like As, Cr is significantly concentrated in the lateritic residuum over the ore body (615 ppm) compared to the underlying saprolite (335 ppm). Concentrations are also elevated in the palaeochannel sediments (535 ppm) and alluvium (515 ppm). Background measurements also show an increase in Cr concentration in the lateritic residuum compared to saprolite, 265 and 135 ppm, respectively. The palaeochannel sediments contain less Cr (180 ppm) but the mean concentration is greater in the alluvium (395 ppm).

Copper concentrations are similar in both the ore body and background areas (Figure 11). They are highest in the saprolite (75 ppm within the ore body, 70 ppm within background) and decrease up profile. The lowest values (45 ppm) are found in the palaeochannel sediments over the ore body.

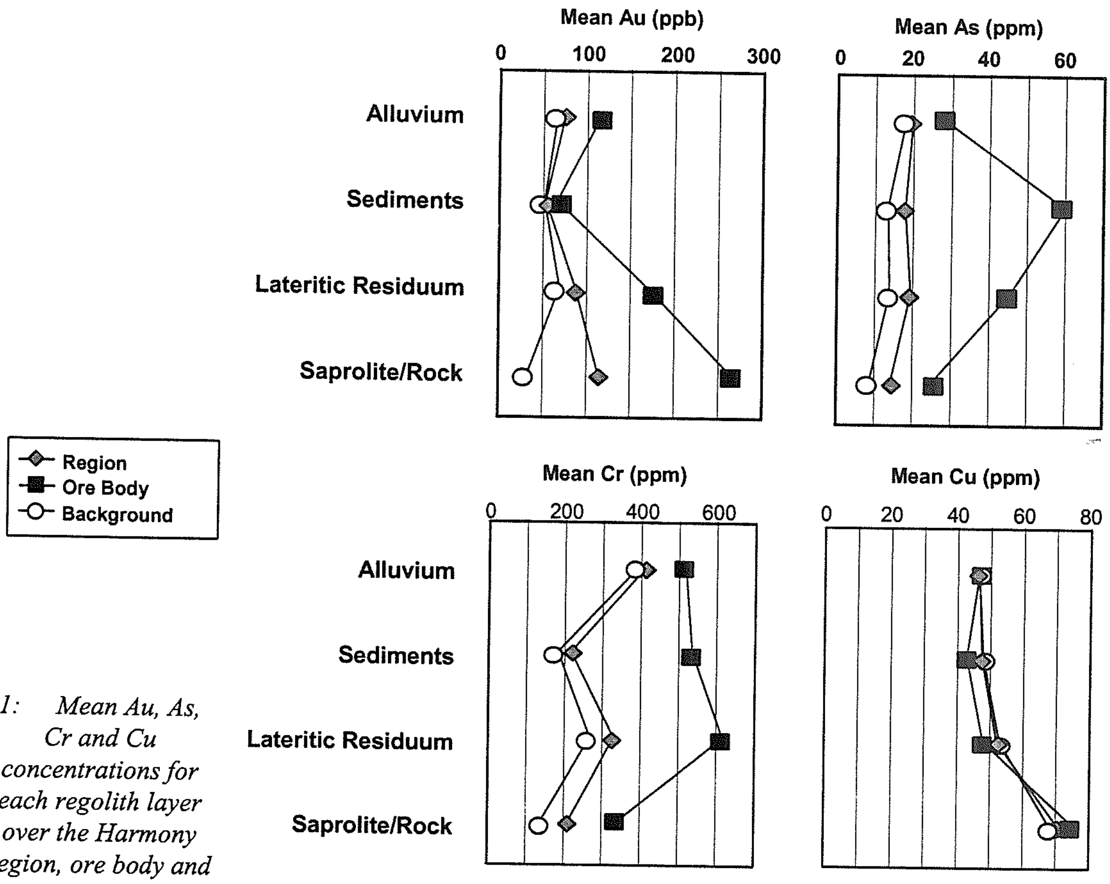


Figure 11: Mean Au, As, Cr and Cu concentrations for each regolith layer over the Harmony region, ore body and background.

4.2 Variation of Au, As, Cr and Cu contents with depth

The mean concentrations of Au, As, Cr and Cu were plotted as a function of depth from the ground surface (Figure 12). Mean Au concentrations within the ore body saprolite are extremely variable, ranging from a maximum of approximately 390 ppb at 53 m depth to a minimum value of 180 ppb at 95 m depth (though this is most likely a bedrock value). The upper three metres of alluvium over the ore body contain less Au, averaging 115 ppb. Mean background Au concentrations vary little within the residual regolith, ranging from 45 ppb to 30 ppb. Gold content increases slightly in the alluvium which has a mean Au content of 50 ppb in the upper three metres.

In contrast to Au, As displays relatively little variability in the residual profile over the ore body, averaging approximately 25 ppm. Within the residual profile over background, As values are lower, generally less than 10 ppb but they gradually increase towards the surface from about 30 m depth. Over both the ore body (30 ppm) and background (20 ppm), As values in the uppermost three metres of alluvium are higher than within the residual profile. It is likely that As is associated with Fe oxides in the upper saprolite, lateritic residuum and alluvium.

Mean Cr concentrations show little variability, over the ore body and background, until approximately 25 m from the surface, from which point Cr content increases towards the surface. Over the ore body, Cr increases from 335 ppm at 25 m depth to 530 ppm at the surface, however the Cr increase is relatively greater in the background area, tripling from 135 ppm at 25 m depth to 430 ppm at the surface. Like As, Cr is likely to be associated with increasing amounts of Fe oxides in the upper regolith.

Conversely, Cu concentration decreases towards the surface. The maximum mean Cu concentration (85 ppm) within the ore body saprolite occurs at approximately 50 m depth, above which Cu decreases, with 45 ppm Cu concentration at the surface. Over background, Cu content is quite homogenous below 60 m depth, with maximum Cu concentration (75 ppm) at 70 m depth. Mean Cu concentration at the surface over background is also 45 ppm.

Gold variations in the regolith were further investigated by plotting mean Au concentration against elevation (Figure 14). As the Harmony area is generally flat, plotting Au concentrations against elevation is similar to plotting Au concentrations against depth; the main difference is that there is no distinction between residual and transported regolith in each slice (see Section 2.4). The results show that within the ore body the highest mean Au concentrations occur between 500 and 520 m elevation, with a peak of 420 ppb at approximately 505 m elevation. This peak is similar to the maximum mean Au value (390 ppb at 53 m depth) obtained from plotting Au against depth (Figure 12). Mean Au concentrations within the ore body are approximately 8 times greater than those over background.

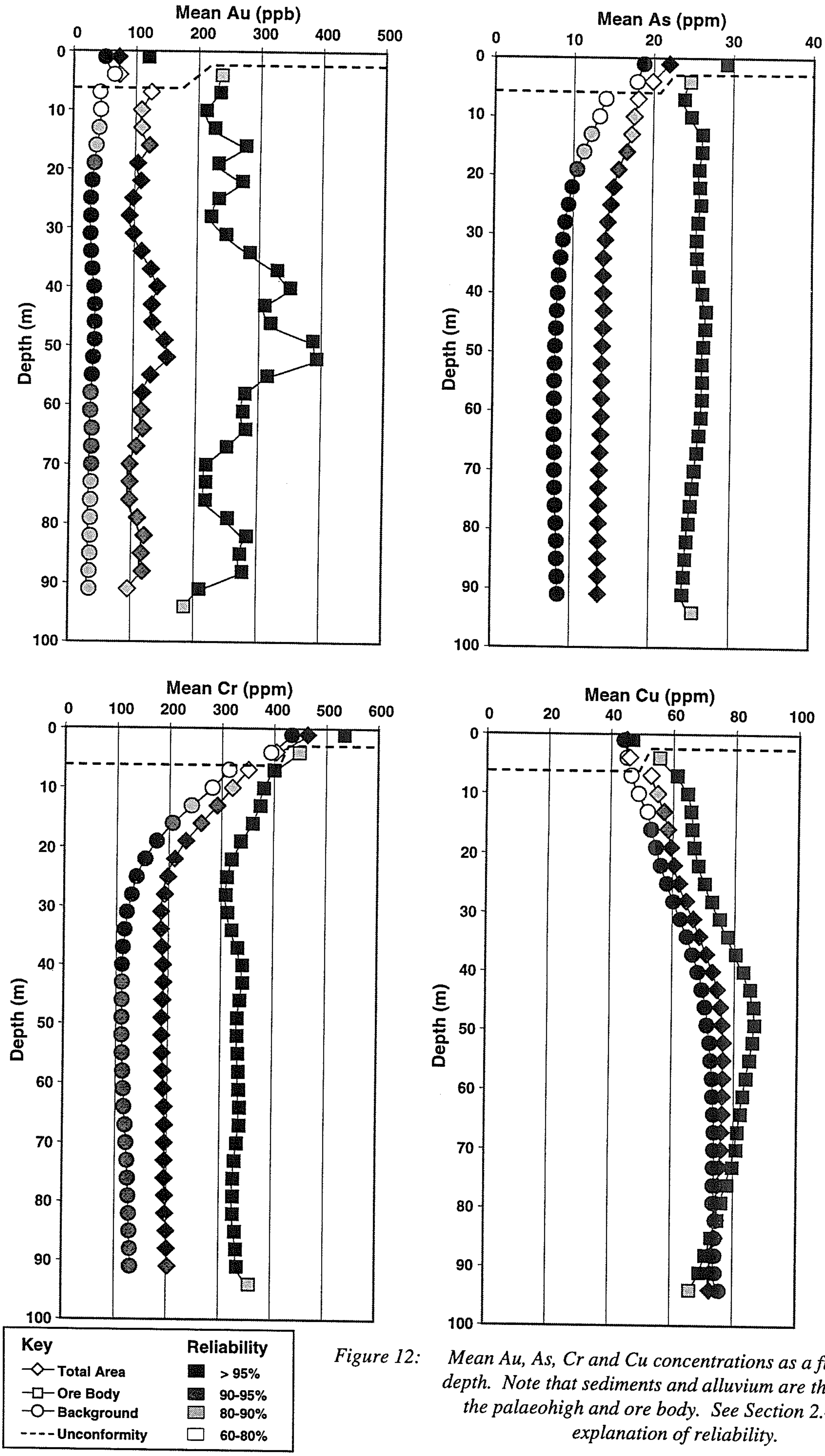
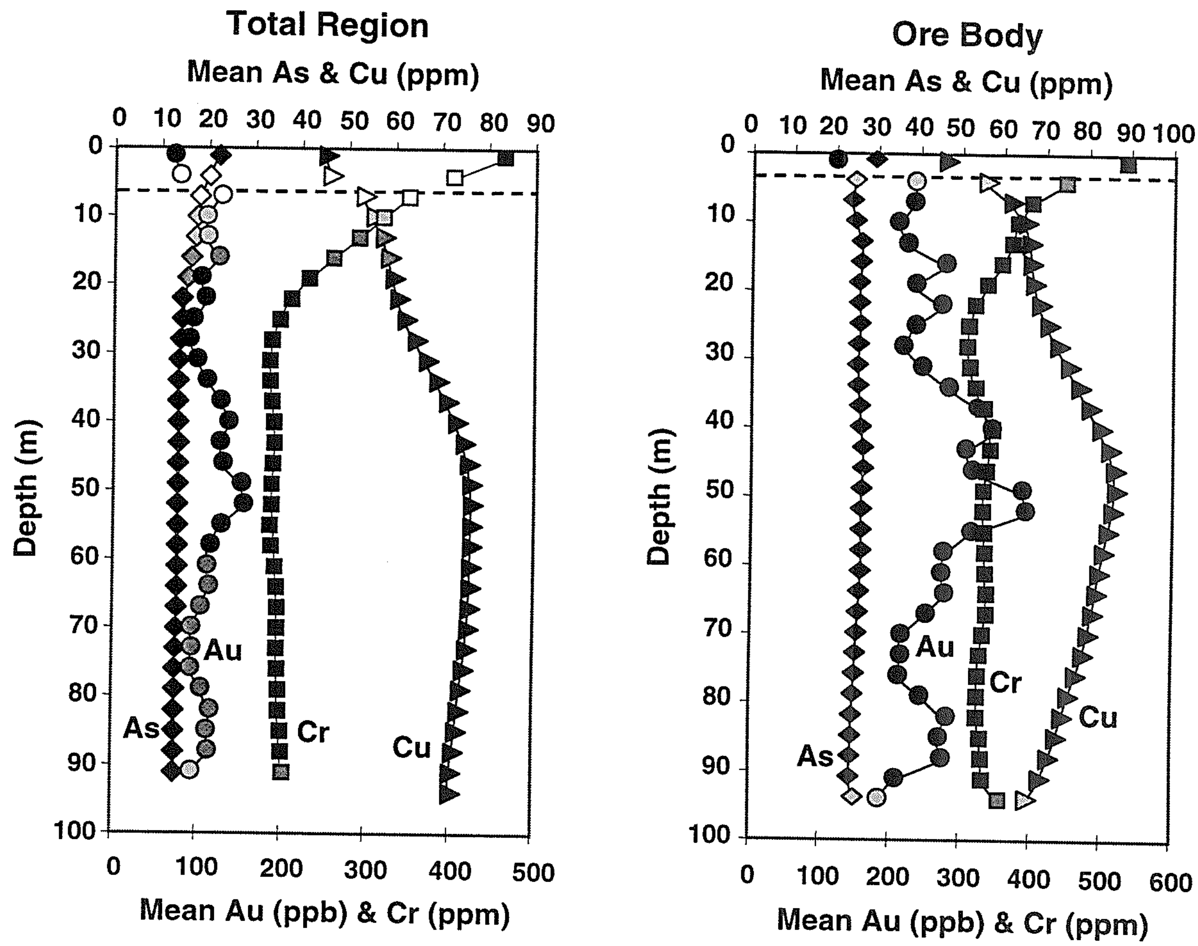
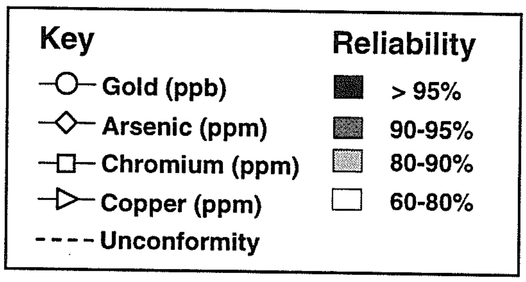


Figure 12: Mean Au, As, Cr and Cu concentrations as a function of depth. Note that sediments and alluvium are thinner over the palaeohigh and ore body. See Section 2.4 for an explanation of reliability.





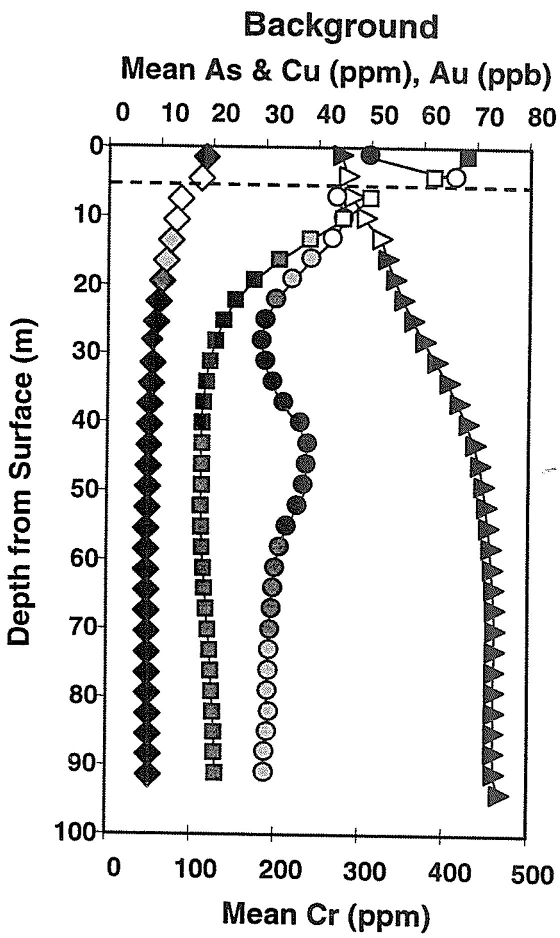


Figure 13: *Comparisons of mean Au, As, Cr and Cu trends with depth over the total area, the ore body and background. See Section 2.4 for an explanation of reliability.*

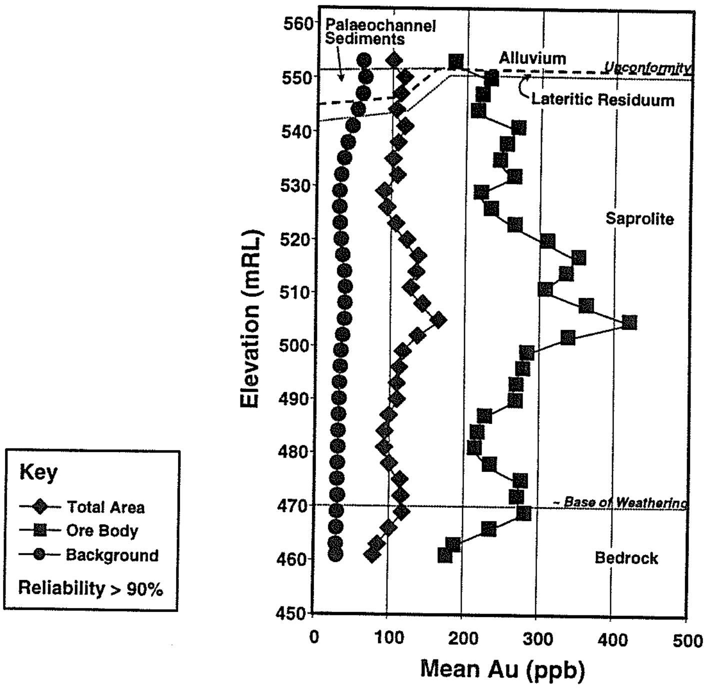


Figure 14: Mean Au concentrations plotted against elevation at Harmony. The unconformity is marked, as are the approximate positions for the lateritic residuum-saprolite boundary and the base of weathering.

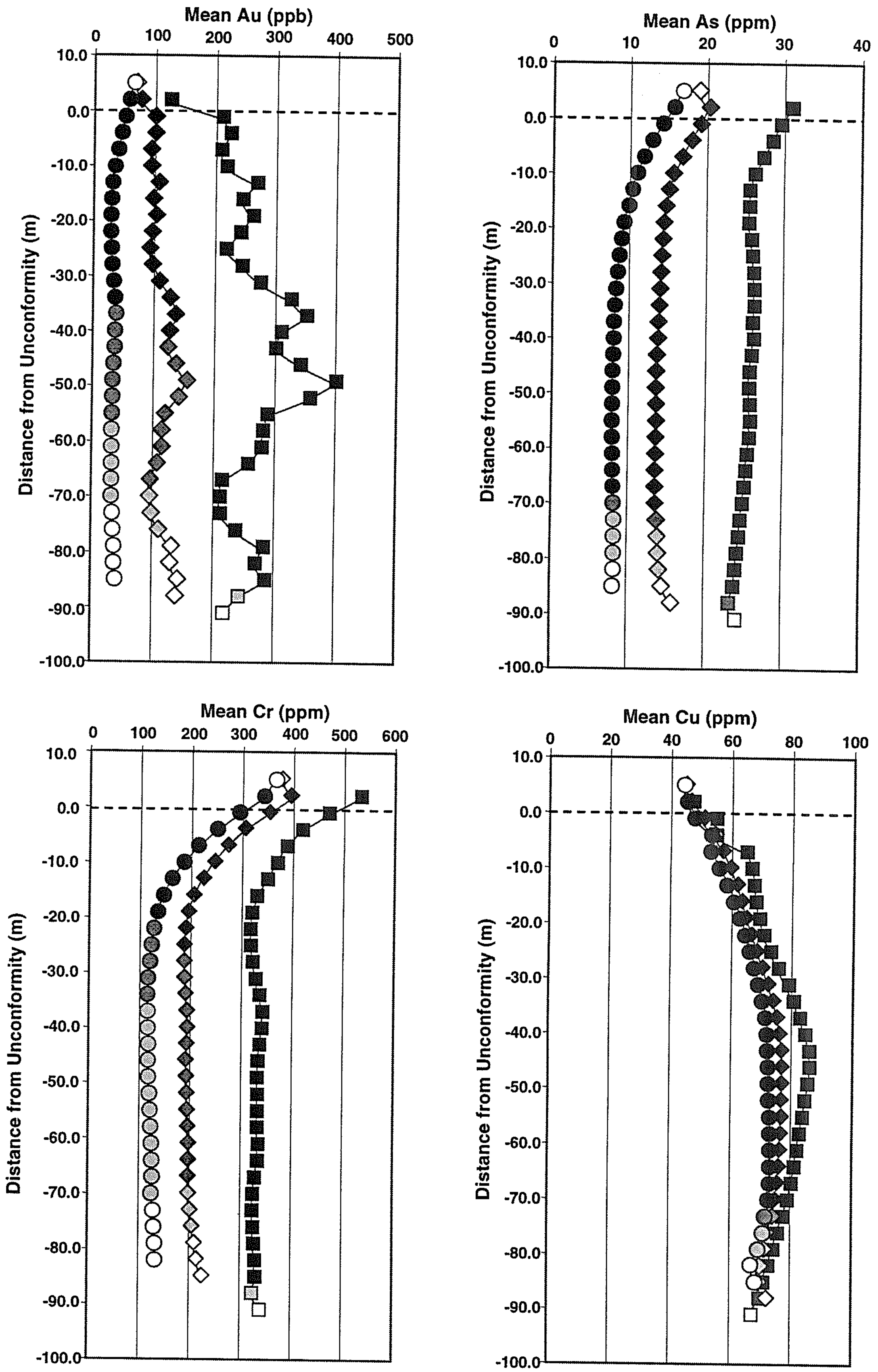
4.3 Gold, As, Cr and Cu trends at the unconformity

Gold concentrations over the ore body decrease significantly above the unconformity (Figure 15). Mean Au concentration is 210 ppb at the top of the residual profile but only 120 ppb in the overlying alluvium. Over background, however, there is little change in Au content between the residual profile and the alluvium, with Au at 50 ppb below the unconformity and 55 ppb just above it. These values, however, are higher than those deeper in the regolith, suggesting the possibility of dispersion from the mineralization outcropping on the palaeohigh. From approximately 10 m below the unconformity, Au content typically ranges between 30 and 35 ppb.

Arsenic, which is commonly associated with Au mineralization, has elevated concentrations over the ore body compared to background (Figure 15). In the ore body, the mean As concentration is 30 ppm the top of the residual profile, and slightly greater in the alluvium. Arsenic concentrations over background, whilst lower (14 ppm at the top of the residual profile), display the same trend of gradual increase towards the unconformity and past it into the alluvium.

From approximately 20 m below the unconformity, mean Cr concentrations, similarly to As, progressively increase within the residual profile towards the unconformity and into the alluvium (Figures 15 and 16). As discussed in Section 4.2, this probably reflects association of As and Cr with Fe oxides, which also increase in the upper saprolite, lateritic residuum and alluvium. Chromium is also elevated over the ore body compared to background, probably due to higher primary abundances of Cr in the mafic and ultramafic rocks of the Narracoota Formation compared to the sedimentary units of the Ravelstone Formation, which comprise most of the background area.

Copper concentrations, conversely, decrease within the residual profile towards the unconformity and into the alluvium (Figures 15 and 16), suggesting that, unlike Cr and As, it is not strongly associated with Fe oxides. Copper content is similar over the ore body and background, with the ore body having only slightly greater Cu concentrations (e.g., 85 ppm Cu compared to 70 ppm Cu, respectively, at 40 m below the unconformity). There is little difference in mean Cu concentrations in the alluvium over background and the ore body, both being approximately 45 ppm.



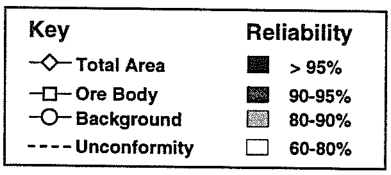
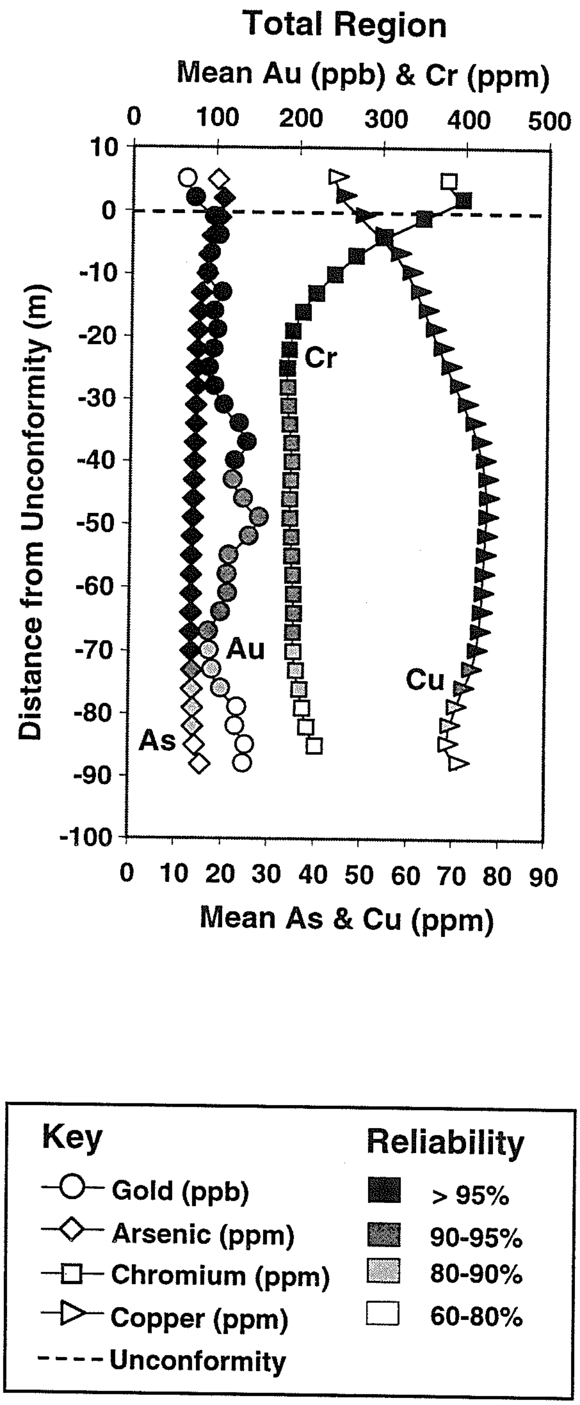


Figure 15: Mean Au, As, Cr and Cu concentrations as a function of distance from the unconformity. See Section 2.4 for an explanation of reliability.



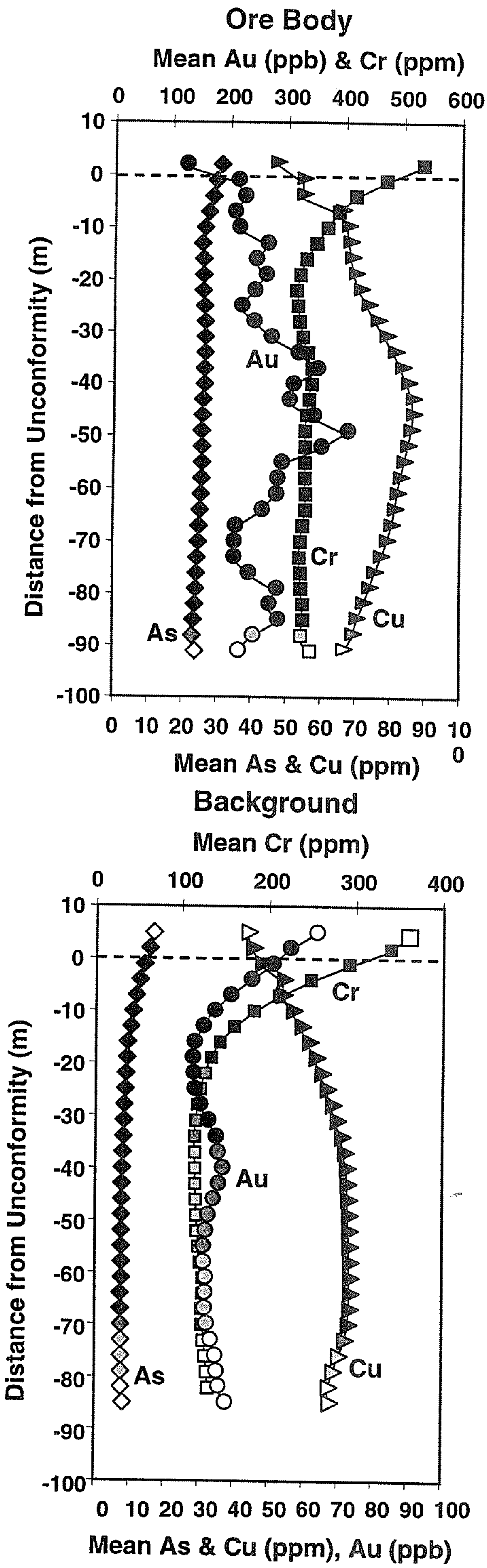


Figure 16: *Comparisons of mean Au, As, Cr and Cu trends from the unconformity over the total area, the ore body and background. See Section 2.4 for an explanation of reliability.*

5 DISCUSSION AND CONCLUSION

Groundwaters at the Harmony deposit are neutral and fresh (Gray, 1995), contrasting with groundwaters to the south, such as the neutral/saline groundwaters around the Menzies Line and the acidic, oxidising and saline to hypersaline groundwaters of the Kalgoorlie region. These later groundwaters are highly effective at dissolving Au (0.05 ± 0.46 ppb; Gray *et al.*, 2001), whereas neutral and fresh Northern groundwaters are poor at dissolving Au (Gray, 2000). Gold concentrations in Harmony groundwaters are very low (close to detection) suggesting that dissolved Au is unlikely to be of use in deposit delineation or in regional exploration in similar areas (Gray, 1995).

Cross sections of Au distribution at the Harmony deposit show that, whereas the maximum mean Au concentration (420 ppb) occurs at approximately 50 m depth (Figure 14), strong concentrations of Au occur at all depths (Figure 10). In contrast, many Kalgoorlie sites are strongly depleted in Au in the upper regolith. Argo and Apollo, two adjacent deposits 28 km SE of Kambalda (Figure 1), have > 90% and > 80% depletion of Au in the top 25 m of regolith, respectively (Britt and Gray, 1999). Panglo, located 30 km north of Kalgoorlie, has approximately 85% depletion of Au above 35 m depth (Gray, 1999). Cleo, in the Central region, like Harmony, is located adjacent to a palaeochannel. Within the Cleo palaeochannel there is evidence that Au has preferentially reprecipitated along a particular elevation within the channel sediments (Gray and Britt, 2000). These sites all have saline and acid groundwaters, conducive to Au remobilization. It is concluded that the minimal Au depletion/remobilization in the Harmony residuum is due to the neutral/fresh groundwaters.

Previous investigations at Harmony (Robertson *et al.*, 1996) indicated preferential enrichment of Au in the upper pisolitic valley sediments (maximum 224 ppb) and lower colluvium (maximum 125 ppb). The Au contents of the remainder of the sediments (mean 25, maximum 74 ppb) and underlying channel saprolite (maximum 33 ppb) are relatively low. These authors concluded that there has been mechanical dispersion of Au downslope from the ore body and that later hydromorphic dispersion might have also introduced Au.

The results from this study also indicate increased Au in the background lateritic residuum and alluvium, compared to the underlying saprolite (Figure 11). It is likely that Au has concentrated during the early stages of weathering in the lateritic materials over mineralization and has since been eroded. There is very little lateritic and palaeochannel material over the ore body (Figure 7 and Figure 8) and this probably accounts for the higher concentrations of Au in the alluvium compared to channel sediments. Alluvium directly overlies mineralized saprolite across much of the palaeohigh (Figure 7), and the alluvium is generally between 0.5 to 3 m thick. In those areas where it is very thin (< 1 m), the soil is weakly enriched in Au (15 ppb) and W (4 ppm) (Robertson *et al.*, 1996). It is likely that bioturbation has probably assisted in the dispersion of Au into the overlying alluvium and soil from the saprolite.

Robertson *et al.* (1996) consider it improbable that present conditions at Harmony have been maintained since the inception of weathering. Past conditions appear to have been wet enough to form lateritic residuum, weather the upper parts of the valley-fill sediments and produce fluctuating water tables with still-stands that resulted in the complex mottled zones within the sedimentary profile. Further, there is considerable Au content in the duricrust (in places, up to several tens of ppm over the Harmony pit) implying substantial residual accumulation occurring with the formation of the duricrust during an earlier, seasonally humid period. Gold mobility could have been achieved by mechanical processes, residual accumulation and some chemical mobility assisted by organic ligands possibly related to the primitive vegetation suggested by the palaeontology (Robertson *et al.*, 1996).

The ultramafic rocks of the Narracoota Formation are clearly defined by Cr and Ni in the upper regolith. The remaining lithologies of the Narracoota Formation and those of the Ravelstone Formation are poor in Cr and Ni, though Cr is concentrated in the lateritic duricrust compared to ferruginous saprolite (Robertson *et al.*, 1996). This study did not model the lithologies so no comment can be made about the affinity of Cr for any particular rock type although the observation that Cr is enriched in the lateritic material is confirmed. Calculations (Section 4) indicate that, from about 20 m below the unconformity, Cr concentration increases towards surface (Figure 12) and, relative to saprolite, is enriched in the lateritic residuum and alluvium (Figure 11). It is probable that Cr is associated with the high Fe content of these materials.

The ultramafic rocks of the Narracoota Formation are also enriched in Cu (> 80 ppm) relative to their basaltic equivalents (Robertson *et al.*, 1996). The results from this study show that although the ore body has slightly elevated Cu concentrations in the saprolite (mean 75 ppm compared to 70 ppm over background), the surface regolith is generally low in Cu with the lowest values (45 ppm) found in the palaeochannel sediments deposited over the ore body area. In contrast, both the Ravelstone and Narracoota Formations are poor in As (< 30 ppm) and Sb (< 3 ppm) (Robertson *et al.*, 1996). These authors report that both elements have reduced concentration in the ferruginous saprolite on the palaeohigh, whereas the lateritic duricrust is enriched. The only exception is regolith developed on ultramafic rocks, which is enriched in As. Similarly, the As concentration statistics (Section 4) show that, over the ore body, As is enriched in the lateritic residuum (45 ppm) compared to saprolite (25 ppm).

In conclusion, although past conditions at Harmony were wetter and Au may have been more mobile, this modelling indicates that Au was not significantly remobilized or depleted from the upper *in situ* regolith.

Acknowledgements

The authors thank AFMECO Pty Ltd for the provision of the database. Dr Ian Robertson and Mr Cajetan Phang are thanked for reviewing this report prior to release. CRC LEME is established and supported under the Australian Government's Cooperative Research Centres Program.

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APPENDIX 1: GRIDDING PARAMETERS

Gridding parameters for the Harmony region and ore body. Background values were obtained by subtracting the ore body values from the Harmony region values.

		Harmony Region	Harmony Ore Body
Krig_3D_Geology Parameters			
Kriging	Minimum X	8500	9100
	Maximum X	9500	9500
	Minimum Y	12000	12200
	Maximum Y	13000	12900
	Points	80	80
	X resolution	101	28
	Y resolution	101	48
	Boundary Offset	0	0
	Smoothing	0	0
	Gridding Option	Rectilinear	Rectilinear
Krig_3D Parameters			
Kriging	Minimum X	8500	9100
	Maximum X	9500	9500
	Minimum Y	12000	12200
	Maximum Y	13000	12900
	Minimum Z	460	459.996
	Maximum Z	557.1	557.095
	Points	20	75
	X resolution	28	101
	Y resolution	48	101
	Z resolution	40	42
	Rectilinear Offset	0	0
	Horiz./Vert. Anisotropy	2.5	2.5
Post Processing	Clip Minimum	0.001	0.001
	Clip Maximum	1000000	300

APPENDIX 2: LIST OF CD CONTENTS

🗁Orebody

🗁Au Cut-offs

This folder contains three-dimensional images of Au distribution at particular cut-offs and orientations. For example, 30ppbNE.bmp shows all those parts of the profile that contain greater than 30 ppb Au concentration as seen from a viewpoint looking towards the NE. The profile is coloured according to regolith stratigraphy.

100ppbNE.bmp
100ppbNW.bmp
150ppbNE.bmp
150ppbNW.bmp
1ppmNE.bmp
1ppmNW.bmp
200ppbNE.bmp
200ppbNW.bmp
2ppmNE.bmp
2ppmNW.bmp
300ppbNE.bmp
300ppbNW.bmp
30ppbNE.bmp
30ppbNW.bmp
500ppbNE.bmp
500ppbNW.bmp
50ppbNE.bmp
50ppbNW.bmp
700ppbNE.bmp
700ppbNW.bmp
70ppbNE.bmp
70ppbNW.bmp

🗁Au Slices

This folder contains three subfolders - Eastings, Elevations and Northings. Each contains images of Au distribution along slices through the deposit along particular eastings, elevations (plan view) and northings. The slices of Au distribution can be matched with the corresponding slices of regolith distribution in the "Regolith Slices" folder. Also, narrow gaps in the Au distribution slices represent the regolith boundaries.

🗁Eastings

9100mE.bmp
9150mE.bmp
9200mE.bmp
9210mE.bmp
9220mE.bmp
9230mE.bmp
9240mE.bmp
9250mE.bmp
9260mE.bmp
9270mE.bmp
9280mE.bmp
9290mE.bmp
9300mE.bmp
9310mE.bmp
9320mE.bmp
9330mE.bmp
9340mE.bmp
9350mE.bmp
9360mE.bmp
9370mE.bmp
9400mE.bmp
9450mE.bmp
9500mE.bmp

🗁Elevations

460mRL.bmp
470mRL.bmp
480mRL.bmp
490mRL.bmp
500mRL.bmp
510mRL.bmp
520mRL.bmp
530mRL.bmp
540mRL.bmp
545mRL.bmp
550mRL.bmp
554mRL.bmp
555mRL.bmp

🗁Northings

12200mN.bmp
12250mN.bmp
12300mN.bmp
12350mN.bmp
12400mN.bmp
12450mN.bmp
12460mN.bmp
12470mN.bmp
12480mN.bmp
12490mN.bmp
12500mN.bmp
12510mN.bmp
12520mN.bmp
12530mN.bmp
12540mN.bmp
12550mN.bmp
12560mN.bmp
12570mN.bmp
12580mN.bmp
12590mN.bmp
12600mN.bmp
12610mN.bmp
12620mN.bmp
12630mN.bmp
12640mN.bmp
12650mN.bmp
12660mN.bmp
12670mN.bmp
12680mN.bmp
12690mN.bmp
12700mN.bmp
12710mN.bmp
12720mN.bmp
12730mN.bmp
12740mN.bmp
12750mN.bmp
12800mN.bmp
12850mN.bmp
12900mN.bmp
12950mN.bmp

🗁Au Surfaces
lat-NE.bmp
lat-plan.bmp
sap-iso-plan.bmp
sap-NE.bmp
sap-plan.bmp
seds-NE.bmp
seds-plan.bmp
surface-NE.bmp
surface-plan.bmp

This folder contains images of Au distribution along regolith boundaries at the Harmony ore body, both in plan and three-dimensionally.

Key: lat - laterite/palaeochannel sediments interface
sap - saprolite/laterite interface
seds - palaeochannel sediments/alluvium interface
surface - surface
iso - Au concentration isolines

🗁Regolith
allNE.bmp
allNW.bmp
lateriteNE.bmp
lateriteNW.bmp
saproliteNE.bmp
saproliteNW.bmp
sedsNE.bmp
sedsNW.bmp

This folder contains three-dimensional images of the regolith layers at the Harmony ore body at orientations looking NW and NE.

Key: all - all regolith layers
laterite - saprolite and lateritic residuum only
saprolite - saprolite only
seds - saprolite, laterite and palaeochannel sediments only

🗁Regolith Slices
🗁Eastings
9100mE.bmp
9150mE.bmp
9200mE.bmp
9210mE.bmp
9220mE.bmp
9230mE.bmp
9240mE.bmp
9250mE.bmp
9260mE.bmp
9270mE.bmp
9280mE.bmp
9290mE.bmp
9300mE.bmp
9310mE.bmp
9320mE.bmp
9330mE.bmp
9340mE.bmp
9350mE.bmp
9360mE.bmp
9370mE.bmp
9400mE.bmp
9450mE.bmp
9500mE.bmp

🗁Elevations
530mRL.bmp
540mRL.bmp
545mRL.bmp
550mRL.bmp
554mRL.bmp
555mRL.bmp

This folder contains three subfolders: Eastings, Elevations and Northings. Each contains images of regolith distribution along slices through the deposit along particular eastings, elevations (plan view) and northings. The slices of regolith distribution can be matched with the corresponding slices of Au distribution in the "Au Slices" folder.

🗁Northings

12200mN.bmp
12250mN.bmp
12300mN.bmp
12350mN.bmp
12400mN.bmp
12450mN.bmp
12460mN.bmp
12470mN.bmp
12480mN.bmp
12490mN.bmp
12500mN.bmp
12510mN.bmp
12520mN.bmp
12530mN.bmp
12540mN.bmp
12550mN.bmp
12560mN.bmp
12570mN.bmp
12580mN.bmp
12590mN.bmp
12600mN.bmp
12610mN.bmp
12620mN.bmp
12630mN.bmp
12640mN.bmp
12650mN.bmp
12660mN.bmp
12670mN.bmp
12680mN.bmp
12690mN.bmp
12700mN.bmp
12710mN.bmp
12720mN.bmp
12730mN.bmp
12740mN.bmp
12750mN.bmp
12800mN.bmp
12850mN.bmp
12900mN.bmp
12950mN.bmp

🗁Region

🗁Regolith

allNE.bmp
allNW-ex.bmp
allSE-ex.bmp
lateriteNE.bmp
saproliteNE.bmp
sedsNE.bmp

This folder contains three-dimensional images of the regolith layers over the Harmony region at orientations looking NW, NE and SE.

Key: all - all regolith layers
ex - exploded
laterite - saprolite and lateritic residuum only
saprolite - saprolite only
seds - saprolite, lateritic residuum and palaeochannel sediments only

🗁Report

Harmony.doc
Harmony.pdf

This folder contains the P504 Harmony report as Microsoft Word 97 document and a PDF.