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GEOCHEMISTRY, HYDROGEOCHEMISTRY AND MINERALOGY OF REGOLITH, TWIN PEAKS AND MONTY DAM GOLD PROSPECTS, WESTERN AUSTRALIA

N.B. Sergeev and D.J. Gray

CRC LEME OPEN FILE REPORT 220

June 2007

(CRC LEME Restricted Report 116R / E&M Report 643R, 1999,
2nd Impression 2007)

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, established and supported under the Australian Government's Cooperative Research Centres Program.

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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.

OFR 221 - Supergene gold dispersion in the Panglo Gold deposit, Western Australia - DJ Gray.

OFR 222 - Gold concentration in the regolith at the Mt Joel prospect, Western Australia - DJ Gray.

OFR 223 - Gold dispersion I nthe regolith at the Federal Deposit, Western Australia - NB Sergeev and DJ Gray.

OFR 224 - Supergene gold dispersion in the regolith at Cleo deposit, Western Australia - AF Britt and DJ Gray.

OFR 225 - Distribution of gold arsenic chromium and copper in the regolith at the Harmony Deposit, northern Yilgarn, Western Australia - AF Britt and DJ Gray

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 Grey, NB Sergeev, CG Porto and AF Britt

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PREFACE

The CRCLEME-AMIRA Project 504 *Supergene mobilization of gold and other elements in the Yilgarn Craton* has, as its principal objective, determination of the mechanisms of supergene depletion, enrichment and dispersion of Au and other elements, so as to improve selection of drilling targets and further optimize interpretation of geochemical data. This report details the investigations undertaken at the Twin Peaks and Monty Dam deposits as part of this project.

The Twin Peaks and Monty Dam deposits, S of Lake Rebecca, are located within tenements held by Goldfields Exploration Pty Ltd and are two of three sites being investigated in the Old Plough Dam area; the other site, Carosue Dam, is within a tenement originally held by Aberfoyle Resources Ltd. Although all three sites are within felsic rocks, regolith, geomorphological environments and mineralization styles vary. In particular, the thickness of alluvial cover varies from less than 1 m to greater than 80 m. This area is valuable for enhancing our knowledge of the behaviour of Au and pathfinder elements during weathering of felsic rocks and understanding the importance of geomorphological environment on the mobility of Au. It is of major importance to develop methods for recognition and understanding of mechanisms of geochemical mobilization. The Twin Peaks deposit has been intensively examined, with mainly hydrogeochemical and 3D modelling conducted at Monty Dam. This report gives the results on the regolith stratigraphy, geochemistry, hydrogeochemistry and 3D distribution of Au and other elements at the two sites.

D.J. Gray,
Project Leader.
August, 1999

ABSTRACT

The dispersion of Au and other elements in the regolith and groundwater has been studied at the Twin Peaks and Monty Dam Au deposits, within the Old Plough Dam district, Western Australia. Gold mineralization occurs primarily within felsic volcanogenic sediments of andesitic to dacitic composition. Mineralization consists of a quartz stockwork in brecciated metasediments, with arsenopyrite at Twin Peaks and pyrite at Monty Dam as principal ore minerals. The mineralized sequences have been deeply weathered and probably truncated to the mottled zone and upper saprolite. At Twin Peaks, the residual regolith is partly concealed beneath a 0.5 - 4.0 m of thick soil, commonly including a calcrete horizon.

A long complex regolith history has caused supergene redistribution of many elements. Thus, at Twin Peaks, Cu, Pb, Zn, Co, Ni, Mn and REE are leached from the upper horizons and precipitated in the saprolite below. Ore-related As is also depleted in the mottled zone and enriched in the upper saprolite, at 10 - 20 m depth, with some lateral dispersion. At Monty Dam, Cu, Pb and Zn are slightly depleted from the upper regolith horizons without convincing evidences of their enrichment below. Arsenic, which abundances are low at the site, shows slight enrichment upward through the regolith profile in contrast to the Twin Peaks.

The gold geochemistry and mineralogy demonstrate its apparent redistribution in the regolith. At Twin Peaks, there is supergene enrichment at the mid to lower saprolite boundary below the depleted zone, extending as a continuous blanket up to 230 m length (20 ppb cut off). This supergene enrichment is coincident with a Fe^{2+}/ Fe^{3+} redox front and a porosity barrier in the lower saprolite. In contast, at Monty Dam, Au is depleted upward progressively through the regolith profile, with strongly depleted zone above the mid to lower saprolite transition. There is a slight (91 ppb) Au concentration near the base of weathering, which may be mostly residual. Gold dispersion has presumably occurred by dissolution in laterally moving, highly saline, oxidized groundwaters, with deposition at the redox front. Within the saprolite enrichment at the both sites, Au principally occurs as supergene, high-fineness crystals with minor anhedral grains. At Twin Peaks, Au is closely associated with REE within the supergene depletion and enrichment zones. Gold is correlated with Ce, Y and Yb and occurs as complex intergrowths of the supergene Au crystals with Ca-REE-phosphates.

At Twin Peaks, Au is also concentrated close to the surface, forming a dispersion halo within pedogenic calcrete and soil. Partial extraction analyses, Au mass balance calculations and Au grain studies suggest that 36 to 96 wt % (mean 58 wt %) of the Au present is residual.

The high salinity of groundwaters in the district implies that Au will be soluble as chloride ($AuCl_2^-$) or iodide (AuI_2^-) complexes where acid and oxidizing conditions are present. The low concentrations of dissolved Au for the Twin Peaks groundwaters, despite optimum conditions for dissolution, is probably because the sampling depths for the groundwaters are all within the Au-leached zone. Where groundwater conditions are suitable, groundwaters at and near Monty Dam have high dissolved Au concentrations.

In the acidic Twin Peaks groundwaters, concentrations of anionic chalcophile elements (*e.g.*, As, Sb) are low, whereas concentrations of base metals (Sc, Y, Pb, U, Cr and, to a lesser extent, Mn, Co and Ni) and REE are relatively high. However these enrichments are significantly less than in equivalent acid and saline groundwaters in contact with weathered mafic and ultramafic rocks (*e.g.*, in the Kalgoorlie region). This suggests that acid groundwaters contacting weathered felsic rocks are likely to show reduced hydrogeochemical signatures, once pH effects are taken into account. In contrast, the Monty Dam groundwaters are generally neutral, and therefore have very low base metal and REE concentrations and high dissolved concentrations of Ti, Ga, Ge, Cd, Sn, Sb and W.

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1. INTRODUCTION

1.1 Location

The Twin Peaks and Monty Dam deposits are located in the Old Plough Dam tenements, Mulgabbie area, about 100 km NE of Kalgoorlie at 30°04’ S and 122°18’ E (Figure 1). The Twin Peaks deposit was discovered by the Keith Kilkenny Joint Venture in 1991 with resources (estimated as of 1996) at 780,000 t at 4.5 g/t Au. The discovery of Twin Peaks is attributed to auger drill sampling of pedogenic calcrete in transported cover. First pass sampling on 1 km spaced lines with 50 m spaced samples generated an anomaly of 100 ppb Au and 65 ppm As on line 21000 mN. The deposit is located 100 m to the south of this anomaly. Sampling on the 21000 mN line was fortuitous given the short strike of the mineralization (Matthew Longworth, personal communication). Monty Dam was brought to resource status in November 1993, with an estimated 1,280,000 t at 2.85 g/t Au.

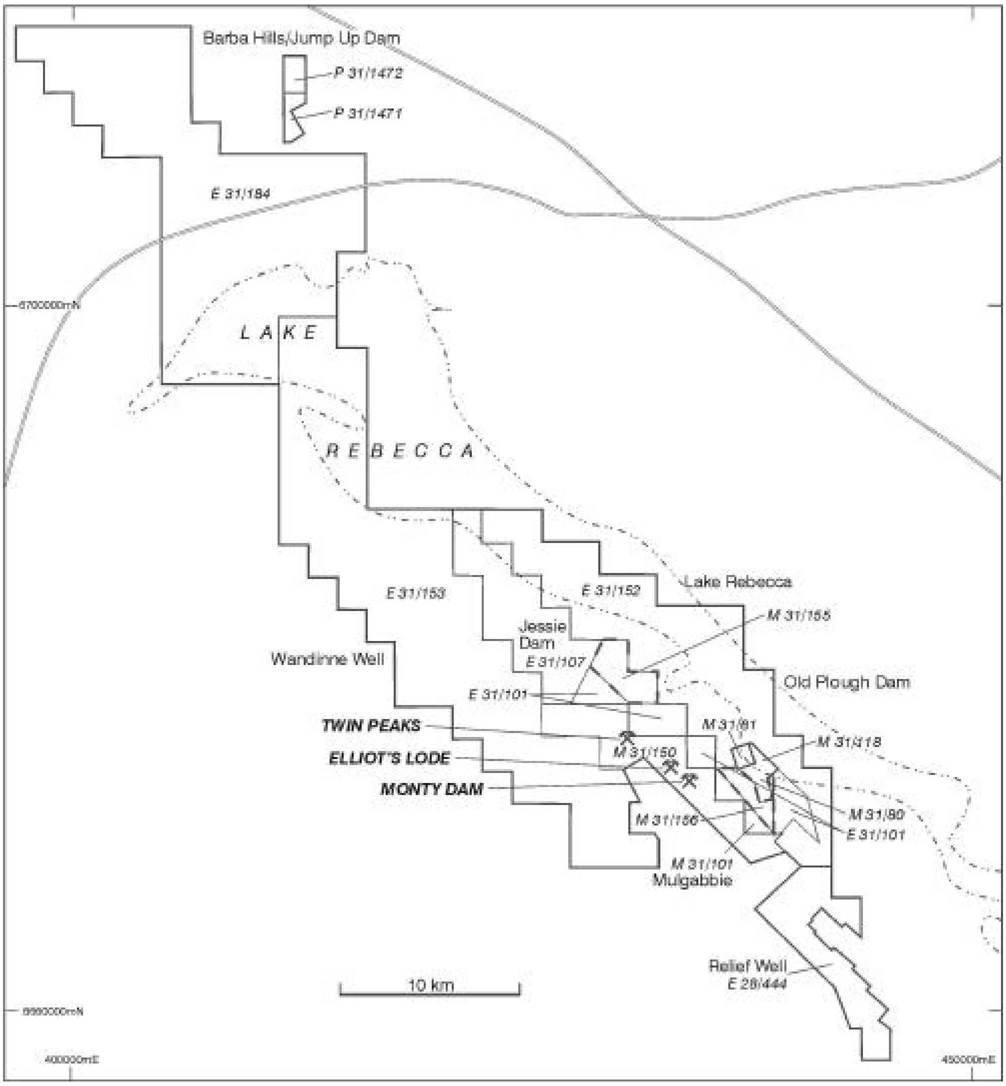

Figure 1: Location of Twin Peaks and Monty Dam (from Longworth, 1996).

1.2 Geology and mineralization

The Mulgabbie area lies in the eastern part of the Norseman-Wiluna greenstone belt in the Eastern Goldfields Province of the Yilgarn Craton. The area belongs to the Pinnacles greenstone belt, which may be a southern extension of the Malcolm belt (Morris, 1994). The Mulgabbie area straddles the

Kurnalpi and Jubilee terranes - tectonostratigraphic subdivisions within the Archaean Craton (Swager and Ahmat, 1992). The region comprises variously folded, faulted and metamorphosed greenstone sequences surrounded by granitoids, mainly monzogranite.

Matthew Longworth, Goldfields Exploration Pty Ltd, supplied the following information on the Twin Peaks and Monty Dam prospects. Twin Peaks is located on the western limb of the regional Yilgangi Syncline on the southwest side of the Keith Kilkenny Lineament. Mineralization is hosted by a folded sequence of arenitic and argillitic felsic volcanogenic sedimentary rocks, andesitic to dacitic in composition. The overturned sequence, dipping 50 to 70° to the northeast, strikes northwest. To the west, the host sequence is bounded by a cherty iron formation within sericite schist, reflecting a shear, known locally as the Monty to Twin Peaks Shear. To the east, the host sequence passes into intermediate volcaniclastic sediments and lavas of trachyandesitic composition; the nature of the contact is unknown. The sequence is cross-cut by a narrow east trending dolerite dyke (Figure 2). The mineralized zone has a strike length of less than 100 m and a thickness of between 1 and 50 m. It plunges at approximately 25° to the southeast, dipping 50 - 60° to the east. Mineralization consists of a quartz stockwork with arsenopyrite and minor pyrite in brecciated metasediments. The alteration sequence includes (from distal to proximal): calcite - dolomite - sericite - silica. Weak carbonate alteration rarely extends more than 10 - 40 m into the unmineralized sediments.

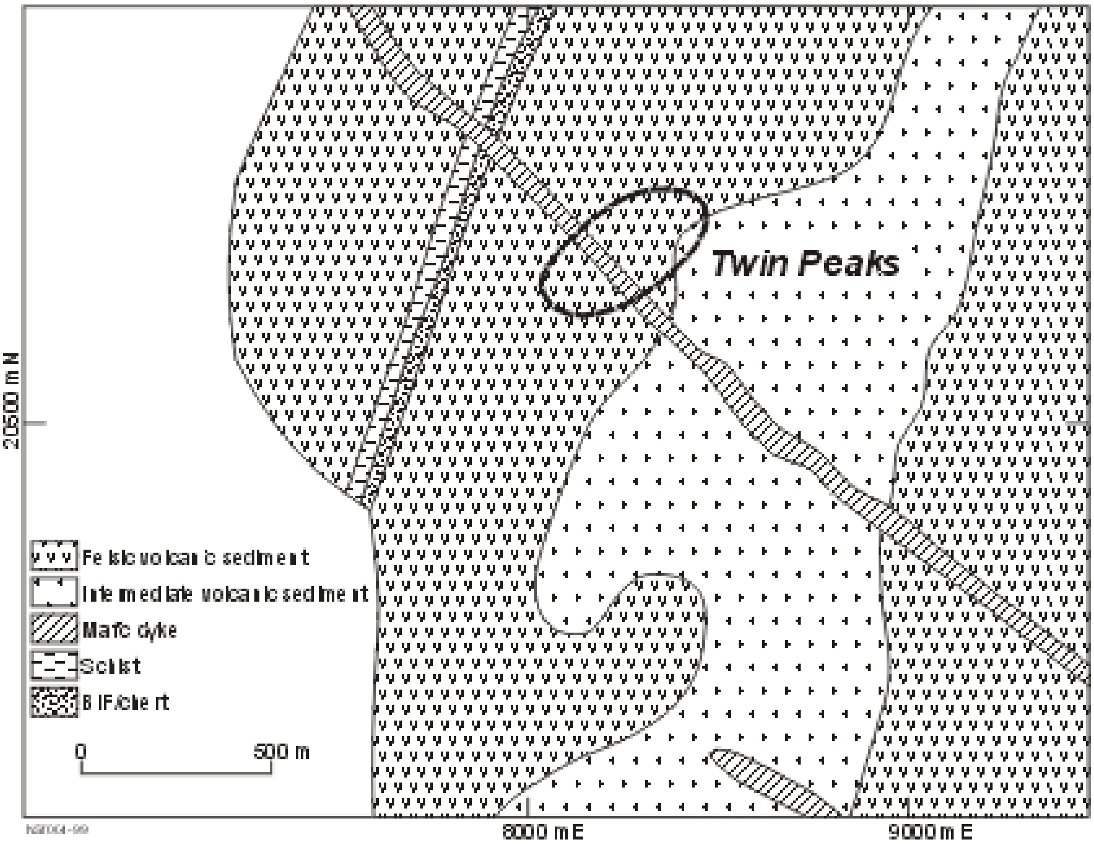

Figure 2: Simplified geology and position of mineralization at Twin Peaks.

The Monty Dam Au deposit (Longworth, 1996) is hosted in a volcaniclastic sequence of andesitic to trachyandesitic (latite) composition, with minor possible lavas and a fractionated intrusive (Figure 3). These units dip east at approximately 65°. Mineralization is generally hosted within, or proximal to, strong hematite - silica - pyrite - sericite - chlorite ± biotite and magnetite alteration zones (Figure 4). Alteration can be traced between and within sections with a high degree of certainty. The geological interpretation at Monty Dam is supported by the chert marker horizon to the east of the resource.

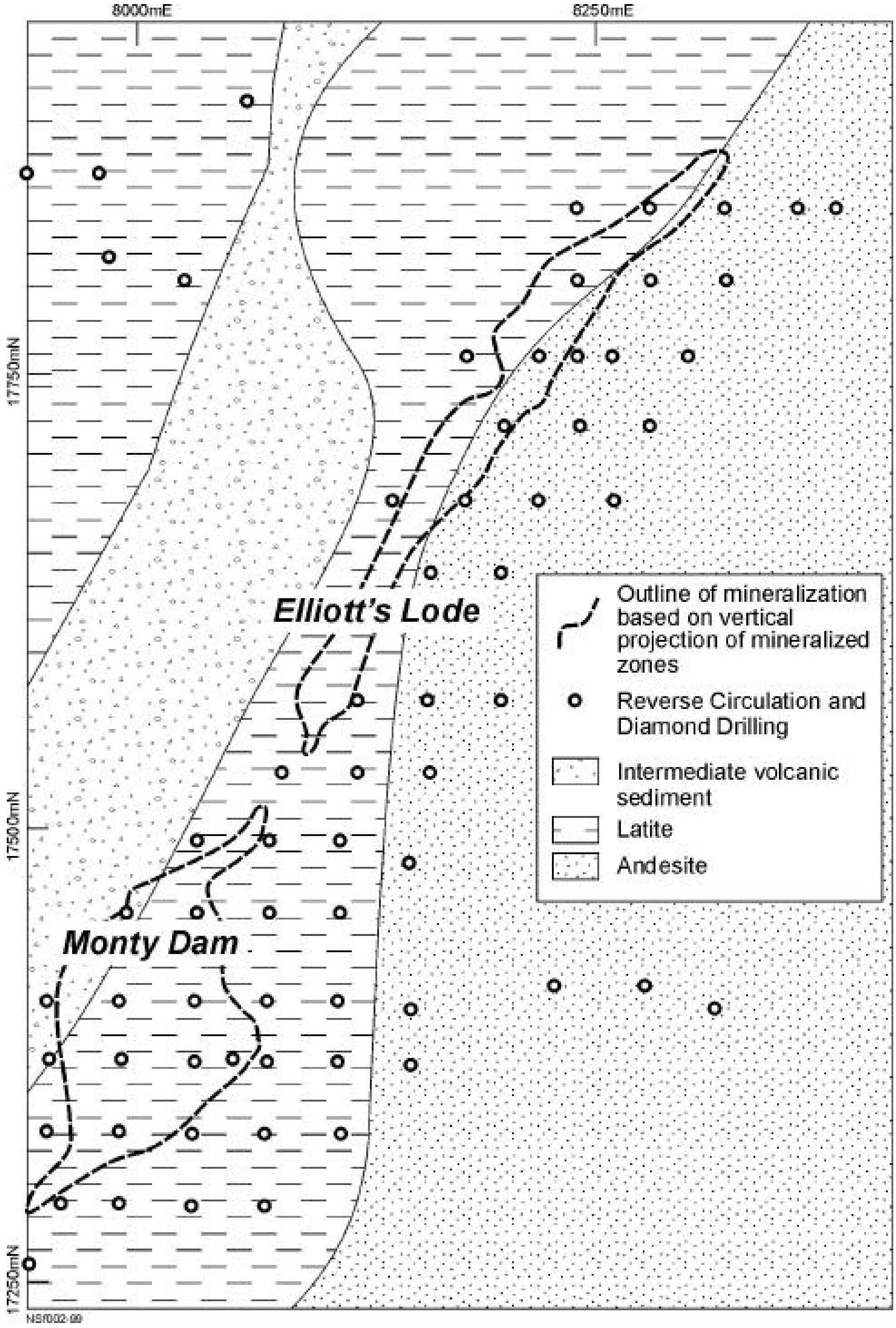

Figure 3: Simplified geology of the Monty Dam area.

Subsequent to deposition of the volcaniclastic sequence, an early alteration event took place introducing hematite - magnetite - silica - pyrite and some Au. This is supported by petrography and logging where visible Au is reported from early pyrite magnetite veinlets. From vein relationships, at least two further alteration events have introduced quartz veining, one of these is likely to be concurrent with D_4 which is not recognized as a mineralizing event. There is a component of northerly plunge, which has implications for further exploration. This is indicated by plunging of some of the resource blocks at both sites, *e.g.*, 17410 mN/17450 mN sections. The interpretation is supported by a similar plunge in the veins.

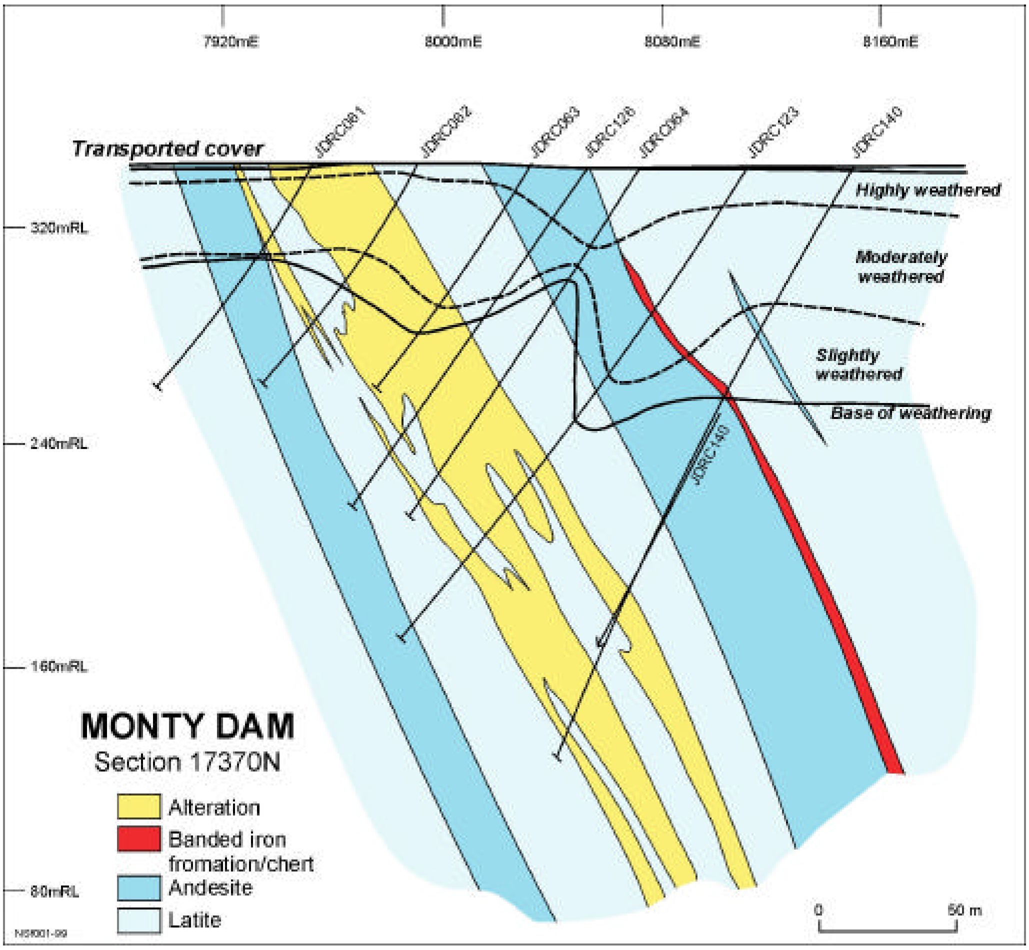

Figure 4: Geological section 17370 mN, Monty Dam.

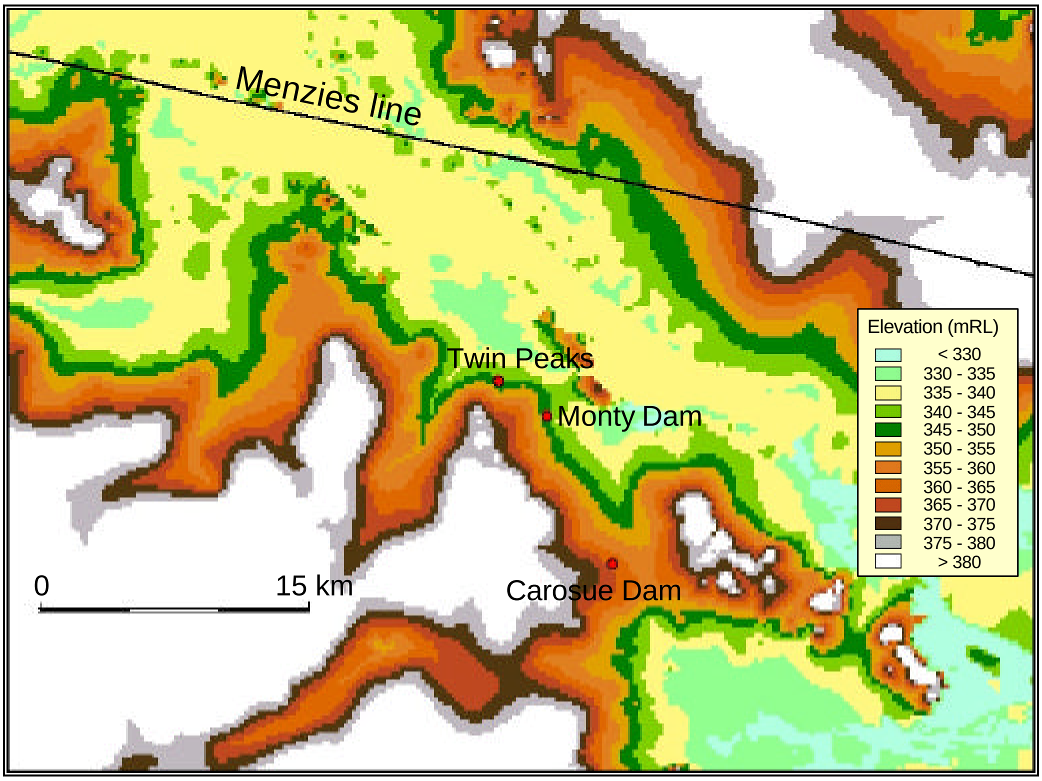

Figure 5: Regional topography around the Twin Peaks, Monty Dam and Carosue Dam prospects.

1.3 Geomorphology, climate and vegetation

The Twin Peaks deposit is situated on a very gently sloping erosional plain (RL 350 - 355 m), dividing well-dissected hill areas (RL 365 - 390 m) to the west and south and the playa, lake Rebecca, to the northeast (RL 325 - 335 m) (Figure 5). Monty Dam is on the southern margin of Lake Rebecca.

The present climate is semi-arid, with a highly variable rainfall throughout the year (average <250 mm). These deposits, and the Carosue Dam deposit (separately investigated by Gray, 1998), are near the Menzies Line (Figure 5), where the surface is dominated by scattered eucalypts, acacia scrub, and bluebush.

2. STUDY METHODS

2.1 Sampling and analysis

2.1.1 Drill hole sampling

An EW section across the mineralized zone at 20920 mN was selected for detailed work on the basis of geological information and condition of RC drill spoils. The mineralized area was RC drilled mainly in 1991 - 1992. During the sampling trip in late 1997 some drill spoils were unavailable for sampling, so two drill holes, JDRC 8 and JDRC 42, from the adjacent 20900 mN section were sampled instead. Approximately 1 - 2 kg were taken from drill spoils at each metre or composited according to geology, weathering features and Au grades. Selected bulk samples (10 - 20 kg) were collected for Au grain studies.

2.1.2 Multi-element geochemical analysis

All regolith and rock samples were dried at <40°C, jaw crushed, and a subsample taken for reference. The 200 g splits were pulverized to <75 µm in a hard carbon steel ring mill (Robertson et al., 1996). A 10 g aliquot of each pulverized sample was analyzed by instrumental neutron activation analysis (INAA). Detection limits were as follows (ppm): Ca (10000); K (2000); Fe, Zr (500); Na, Ba, Zn (100); Rb (20); Ag, Se, Te, Cr, Mo (5); Br, Ce, U, W (2); As, Co, Cs, Ta (1); La, Eu, Yb, Hf, Th (0.5); Sb, Sm, Lu (0.2); Sc (0.1); Ir (0.02); Au (0.005) (Becquerel Laboratories Pty. Ltd.). X-Ray fluorescence spectroscopy (XRF) was conducted on fused discs (1.6 g sample and 6.4 g lithium borate flux) using a Philips PW1480 instrument. Detection limits were as follows (ppm): Na, Mg, Al, Si (100); Fe (50); Ti, Mn (30); P, Cl, Ba (20); Ce (15); S, K, Ca, Cr, Co, Cu, La, Ni (10); Pb, Rb, Sr, V, Y, Zn, Zr (5); Nb (4); Ga (3) (CSIRO).

2.1.3 Mineralogical analysis

Selected pulverized samples were examined by XRD using a Philips PW1050 diffractometer, fitted with a graphite crystal diffracted beam monochromator using CuKα radiation. Each sample was scanned over the range 2-65° 2θ at a speed of 2° 2θ/min. Mineral compositions were determined by comparison with JCPDS files and laboratory standards. Halite was observed in many samples, but was considered an artefact of drying moist or wet samples from areas of saline groundwater and ignored in later studies. Mineralogical compositions of heavy concentrates were studied using a binocular microscope, optical microscope and scanning electron microscope (SEM).

2.1.4 Pedogenic carbonate: sampling and analysis

Pedogenic carbonates were sampled along a 935 m long surface traverse on section 20900 mN. Samples (1-2 kg) were collected 5 cm below the upper boundary of a pedogenic calcrete horizon, usually 5 to 30 cm below the ground surface. The samples were analyzed for Au and trace elements by INAA and for Ca and Mg by ICP OES. The mineralogy of the calcretes was studied by XRD and PIMA, and the residue from carbonate dissolution investigated using an optical microscope and SEM.

The following partial extractions were performed to test the solubility of Au:

(i) Deionized water: dissolves the most soluble Au.
(ii) Iodide: a 0.1M KI solution is adjusted to pH 7.4 with HCl whilst CO_2 is bubbled through. This extraction dissolves more Au than water alone.
(iii) Cyanide: 0.03M KCN solution saturated with CaO dissolves all but the most refractory Au (including large Au particles and Au encapsulated within resistant material such as quartz).

Extraction was performed on pulverized materials with additional unpulverized sub-samples of some of the sample also selected. A 25 g portion of sample material was mixed with 50 mL of the extracting solution in a screw-cap polyethylene plastic bottle with a plastic mesh sachet containing 1 g of activated carbon, and then gently agitated for one week. The carbon sachet was removed, washed in deionized water, and analyzed for Au by INAA with a detection limit of 1 ppb, equivalent to a detection limit of 0.04 ppb for a 25 g subsample. The deionized water and iodide extractions were performed on separate subsamples, whereas the cyanide extraction was performed on the residue of the iodide extraction.

Four samples with high Au concentrations were investigated in detail to obtain data on distribution and speciation of Au within the calcrete. The samples were crushed by hand and treated by pH 5 acetic acid for several weeks until the carbonate was completely dissolved. The residue and solution were separately analyzed by INAA for Au. The residue was separated into several fractions using panning. Heavy concentrates and mineral fractions were weighed and analyzed for Au. Gold grains recovered from heavy concentrates were studied using an optical microscope and SEM.

2.1.5 Gold grain separation and analysis

Eleven bulk samples were collected for separation of heavy minerals, including Au particles. Samples were dried, split and 4.0 - 4.5 kg subsamples washed with a non-ionic surfactant (0.01 % Triton X-100). Separation was performed on a Haultain Superpanner, which is essentially a mechanized version of the prospectors pan, to obtain gravity separation. It consists of a 72 cm long shallow v-shaped trough, varying from 12 to 24 cm wide, mounted on a 3 point suspension. The trough slope is variable. The trough is shaken by a cam which gives a bump on each rotation; in addition a variable frequency side shake with independently variable amplitude at each end can be applied. The Superpanner was set to a 284 cam rpm and 7 mm axial bump amplitude. A 10 mm side shake amplitude was applied at each end in opposing sense, to cause rotational oscillation around vertical axis. The trough angle was varied during the treatment. After the dispersion was complete, the pulp was slowly introduced at the middle part of the trough during agitation. With increasing slope of the trough, a thin tail of heavy minerals was obtained in the top quarter of the trough. As fractionation progressed, the light mineral fraction was removed by suction into the collector and a new portion of the pulp was added. This cycle was repeated and the final tail of heavy minerals was collected into a small suction flask by vacuum. The trough was then thoroughly washed and wiped clean with damp tissue (until there was no discolouration) before the next sample was introduced.

The small, gram-size concentrate was transferred into the trough of a micropanner. This trough is 10 cm wide and 25 cm long and is provided with a changeable slope, cross-wise rocking and trough length direction tapping. A combination of varying slope angle and wash rate was used to separate Au from the other minerals. Gold particles were recovered under a binocular microscope by sticky needle and deposited on the slide on two-sided adhesive tape. More than 100 Au particles were separated from the majority of the samples.

The morphology of the Au grains and their size distribution were examined and measured using an optical microscope. Following this, the morphologies of the selected particles were examined by SEM. Their Ag content and the composition of neighbouring minerals were determined semi-quantitatively (limited by surface effects of the unpolished grains) using an energy dispersive detector. The SEM study was done in backscattered electron mode, using Jeol JSM-2 and Philips XL40 instruments fitted with an environmental sample chamber. This permitted examination of samples without a conductive coating.

Selected Au grains were analysed quantitatively by electron microprobe using a Cameca SX-50 instrument operated at 30 kV and 450 nA. Polished mounts were prepared by totally embedding and carefully polishing down to expose the grains. Long count times (100 sec) were used to reduce detection limits. Native Au was analysed for Au, Ag, Cu, Fe, Si and Pd.

2.1.6 Groundwater sampling and analysis

Thirteen groundwater samples were collected from Twin Peaks, along with eight from Monty Dam, on the edge of Lake Rebecca (Figure 5), and one sample from a bore (Main Bore) between the two sites (Figure 6), by pump-sampler in late 1997. Waters were analysed for pH, temperature, conductivity and oxidation potential (Eh), at the time of sampling. A 125 mL aliquot was collected in a polyethylene bottle (with overfilling to remove all air) for HCO_3^- analysis by alkalinity titration in the laboratory. About 1.5 L of water was immediately filtered through a 0.2 µm membrane filter. About 100 mL of the filtered solution was acidified [0.1 mL 15 moles/litre (M) nitric acid (HNO_3)], and analysed for:

(i) Al, B, Ba, Be, Ca, Cd, Co, Cr, Cu, Fe, K, Li, Mg, Mn, Mo, Na, Ni, P/I (distinction between P and I is difficult due to spectral overlap), SO_4 (measured as S), Si, Sr, Ti, V, and Zn by Inductively Coupled Plasma - Atomic Emission Spectroscopy;
(ii) Ag, Bi, Cd, Ce, Dy, Er, Eu, Ga, Gd, Ge, Ho, La, Mo, Nd, Pb, Pr, Rb, Sb, Sc, Sm, Sn, Tb, Th Tl, Tm, U, W, Y, Yb and Zr by Inductively Coupled Plasma - Mass Spectroscopy;
(iii) total phosphate by the molybdenum blue colormetric method (Murphy and Riley, 1962);
(iv) I by subtraction of P from P/I concentration.

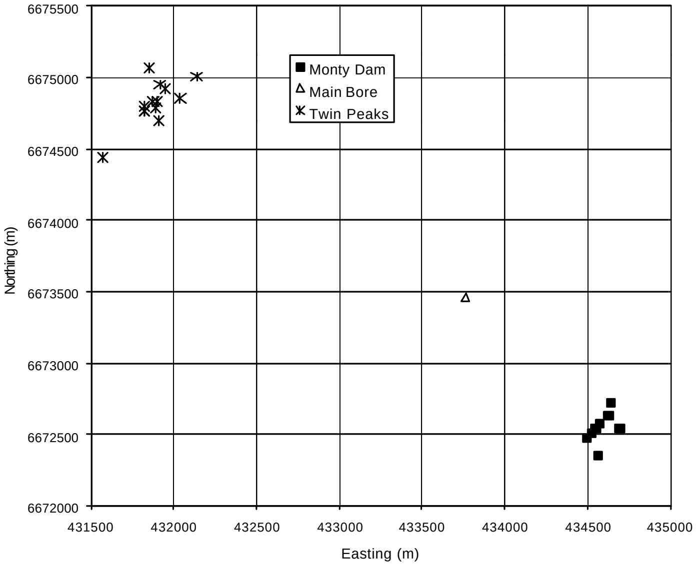

Figure 6: Groundwater sample positions for Old Plough Dam.

About 50 mL of the filtered water was collected separately, without acidification, and analysed for Cl by the Technicon Industrial method (Zall *et al.*, 1956).

A one litre sub-sample of the filtered water was acidified with 1 mL 15 M HNO_3 and a one gram sachet of activated carbon plus 30 g sodium chloride added. The bottle was rolled for eight days in the laboratory and the water discarded. The carbon was then analysed for Au by Instrumental Neutron Activation Analysis (INAA) at Becquerel Laboratories, Lucas Heights. The method was tested by shaking Au standards of varying concentrations, and in varying salinities, with activated carbon (Gray, unpublished data).

The solution species and degree of mineral saturation were computed from the solution compositions using the program PHREEQE (Parkhurst *et al.*, 1980; described in detail in Gray, 1990 and Gray, 1991), which determines the chemical speciation of many of the major and trace elements. To obtain highly accurate speciation data on a limited suite of the major elements (Na, K, Mg, Ca, Cl, HCO_3, SO_4, Sr and Ba), the specific ion interaction model known as the Pitzer equations was applied, using the program PHRQPITZ (Plummer and Parkhurst, 1990). These programs calculate the solubility indices (SI) for each water sample for various minerals. If the SI for a mineral equals zero (empirically from -0.2 to 0.2 for the major element minerals, and -1 to 1 for the minor element minerals), the water is considered to be in equilibrium with that mineral, under the conditions specified. Where the SI is less than zero, the solution is under-saturated with respect to that mineral, so that, if present, the phase may dissolve. If the SI is greater than zero, the solution is over-saturated with respect to this mineral, which can potentially precipitate from solution. Note that this analysis only specifies possible reactions, as kinetic constraints may rule out reactions that are thermodynamically allowed. Thus, for example, waters are commonly in equilibrium with calcite, but may become over-saturated with respect to dolomite, due to the slow rate of solution equilibration and precipitation of this mineral (Drever, 1982).

The determinations are important in understanding solution processes at a site. They have particular value in determining whether the spatial distribution of an element is correlated with geological phenomena such as lithology or mineralization, or whether they are related to weathering or environmental effects. Thus, if Ca distribution is controlled by equilibrium with gypsum in all samples, then the spatial distribution of dissolved Ca will reflect SO_4 concentration alone and have no direct exploration significance.

2.2 3D gridding and visualization

2.2.1 Form of the data-base for modelling

Geochemical (Au, As and, to a lesser extent, Cu, Pb and Zn) and logging information were made available by Goldfields Exploration Pty Ltd for processing and viewing within MVS (Mining Visualization System; © C Tech Development Corporation). Logging showed major spatial and temporal variations, presumably due to changes in staff logging and emphasis on regolith units over time. After careful checking and filtering, the four separate horizons were distinguished:

(i) highly weathered rocks (comprising soil, extremely and highly weathered rocks);
(ii) moderately weathered rocks;
(iii) slightly weathered rocks;
(iv) unweathered rock.

At Monty Dam, logging information also allowed discrimination of the alluvial soil horizon. Regolith horizons were gridded, "point" anomalies removed by filtering of the input data, and the data re-gridded. Although filtering has the potential to bias the data, it was considered necessary to give coherent weathering horizons. Pre-processing of the data included logarithmic transform (base 10) of Au concentrations before gridding. Although this can affect the gridded magnitude of the main mineralization pattern, this is used to enhance detail of the subtle supergene redistributions. Surface geochemical data were commonly collected as 4 m composites, which can lead to deeper and weaker surface anomalies (*e.g.*, a horizon that is 1 m at 0.5 ppm, then 3 m at 0.1 ppm, will effectively be 4 m at 0.2 ppm). However, this effect should be minor, as 4 m compositing was most commonly done in Au-poor areas.

2.2.2 Gridding parameters

The grid size used was X:Y:Z 10 m:10 m:3 m, and a 95% confidence filter was done on the final result to remove all node points with poor calculated accuracy. The stratigraphy was gridded using the KRIG_3D_GEOLOGY module (within MVS), using Convex hull (which confines the kriging domain to a region defined by the sample locations), the maximum number of samples points set to 80, convex hull boundary offset to 0.05, and other settings at default. The geochemical data were then gridded in relation to the surfaces, using the KRIG_3D module, with maximum number of data points (within the specified reach) that will be considered for the parameter estimation at a model node set to 180, horizontal/vertical anisotropy set at 2.5, rectilinear offset parameter at 0.05, post-processing at 0.005 - 10 ppm Au, and all other settings at default. All survey data used for 3D modelling are local, and can be transformed to real RL by reducing by approximately 642 m.

2.2.3 Graphical output

Various plots are included as JPG files in the accompanying CD, in separate directories, divided first into the two sites (Twin Peaks and Monty Dam), then into the 5 elements (Au, As, Cu, Pb and Zn), and then into the directories described briefly below, and listed in Appendix 4:

(i) the SLICES directory includes vertical slices mainly at constant northing (with a few plots at constant easting), with plots named according to the particular northing (or easting);
(ii) the LAYERS directory includes the various layers coloured as in Figure 14, either merged together to show the true stratigraphy (TOGETHER.JPG), exploded as in Figure 14 so as to show the characteristics of the various layers (EXPLODED.JPG), or with a particular Au grade cut off;
(iii) the PLANS directory includes plans of calculated Au grade at a particular elevation (*e.g.*, the plot of the calculated Au concentrations at elevation 960 m is named 960.JPG) at a particular surface (*e.g.*, the plot of the calculated Au grade at the base of weathering is named B_WEATH.JPG) or at a set vertical distance from a weathering surface (*e.g.*, the plot of the calculated Au grade 2 m below the unconformity is named UNCON-2.JPG).
(iv) the THICKNESS directory includes plots of layer thicknesses and elevations of transitions.

2.2.4 Gold concentration calculations

The volume and Au concentration for individual regolith layers was calculated within MVS using the VOLUME_AND_MASS module. No attempt was made to model different densities for different units, with density assumed to be uniform. This assumption has only a minor influence on most calculations as the Au concentration data are as mass/mass rather than mass/volume. The calculated concentrations do not compensate for leaching of mobile constituents: if half of the minerals have been leached then the Au concentration will double because of residual concentration.

In addition, by using the ISOVOLUME module, Au content can be calculated for slices defined either by elevation (e.g., 390-393 m elevation) or distance from a regolith transition (e.g., 3-6 m above the unconformity) (Figure 7). Although this method is arithmetically correct, it can lead to problems as the slices get further from the surface in question. This is because, ultimately, the slice being analyzed is incomplete. This can be expressed as a reliability factor, which is the volume of the slice divided by the volume of an untruncated slice (Figure 7). A reliability index of 85% indicates that the slice is 15% truncated.

As the reliability index decreases, significant errors can occur. Figure 8 shows the results of Au concentration measurement for each 3 m slice from the unconformity. Though the deeper slices are truncated (Figure 8a), they can still contain mineralized material, as in this example (Figure 7). Thus, a similar mass of Au is being divided by lesser and lesser masses of regolith, which leads to anomalous estimates of the Au concentrations in each slice (Figure 8b). In this example, the results indicate that 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.

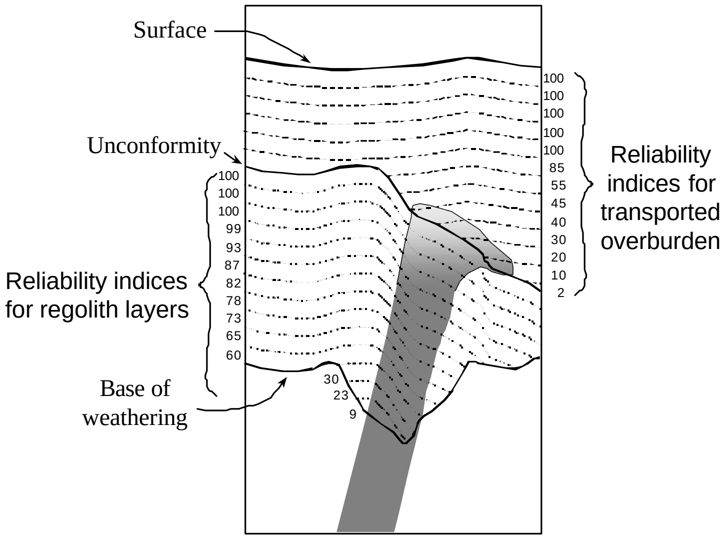

Figure 7: Diagrammatic representation of method of calculating Au grade from slices defined for the upper surface and for the unconformity.

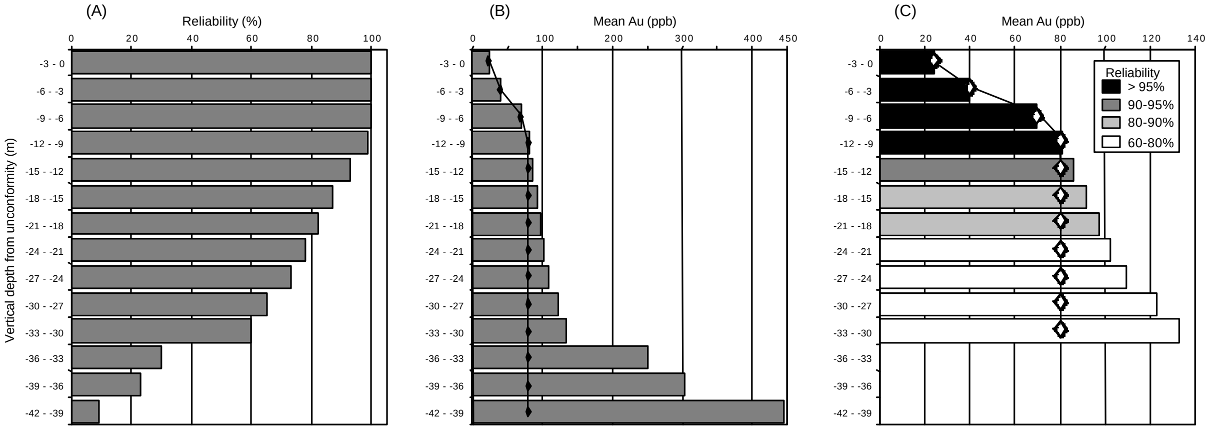

Figure 8: Calculated (a) regolith reliability, (b) unfiltered Au grade and (c) filtered (>60% reliability) Au grade colour coded to reliability. Diamonds represent expected Au grade. Data based on situation represented in Figure 7.

When all slices with reliability indices of less than 60% are removed, the remaining results can be coded for reliability (Figure 8c). A much clearer picture of the Au concentration trends is observed, with the major feature being the depletion towards the unconformity. Note that this example is for the maximum possible overestimation of Au grade (the maximum overestimation = 100 ÷ reliability: e.g., when reliability is 60%, maximum overestimation is 1.67; when reliability is 90%, maximum overestimation is 1.11). In other cases, underestimation can occur for low reliability samples (due to truncated intersection with mineralization). In summary, those samples with reliabilities less than 80% are suspect (but can still be valuable if treated with caution), whereas those with a reliability of less than 60% should generally not be used.

3. REGOLITH STRATIGRAPHY

3.1 Twin Peaks

3.1.1 Introduction

In the Twin Peaks area, soil and thin alluvium overlie mottled zone. There is no lateritic residuum. The regolith thickness varies widely, reaching 65 – 70 m to the northwest of the mineralized structure in the 21100 mN area. In the vicinity of the deposit, its thickness is generally reduced down to 50 - 55 m (Figure 9).

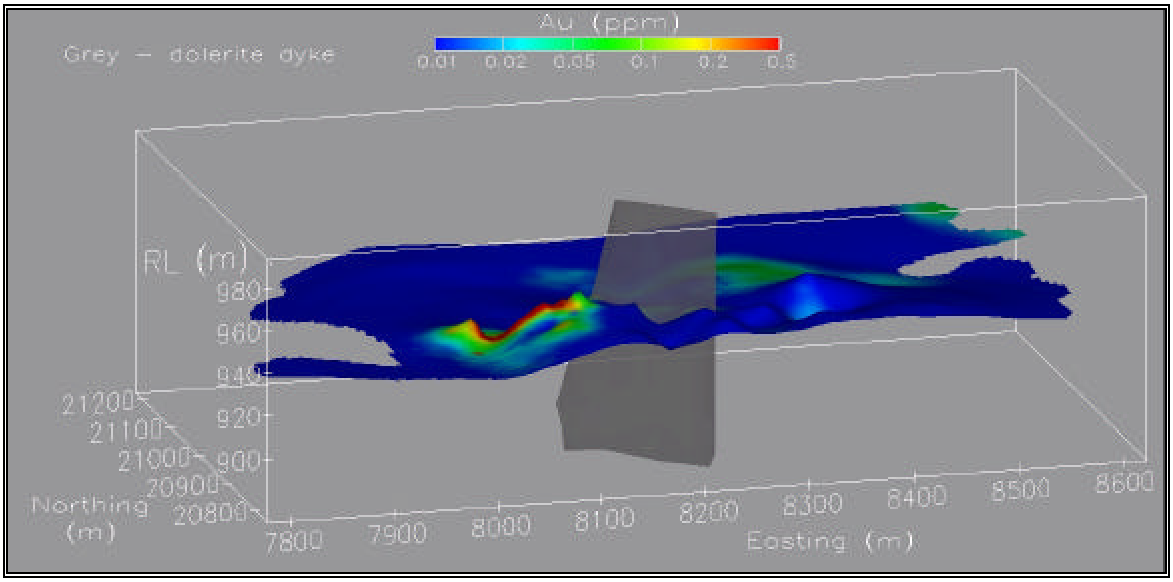

Figure 9: Topography and Au grade of the base of weathering in the Twin Peaks area.

3.1.2 Regolith stratigraphy

The regolith stratigraphy was studied in detail on 4 drill holes in the combined 20900 - 20920 mN line, using field logging, sieving and an analysis of the coarse fraction, XRD and multi-element geochemistry. The mineralogical changes within the profiles are shown in Tables 1 to 4, and stratigraphic columns for the regolith are presented in Figures 10 to 13, with discussion below.

Table 1. XRD data for drill hole JDRC 53.

Depth (m)	Zone	Quartz	Kaolinite	Chlorite	Muscovite	Goethite	Feldspar	Dolomite	Smectite
2-3	US	xx	xx		xx				
10-12	US	xx	xx		xx	x			
18-21	US	xx	xx		xx	xx			
23-25	US	xx	xx		xx	x			
27-30	US	xx	x		xx	x	x		
32-34	MS	xx	x		xx	x	xx		x
37-40	MS	xx	x	x	xx	x	xxx		x
46-47	MS	xx	x	x	xx	tr	xxx		
49-50	LS	xx	x	x	xx		xxx		
51-52	LS	xx		x	x		xxx		
54-55	LS	xx		x	x		xxx		
58-60	LS	xx		x	xx		xxx	x	
70-71	SR	xx		xx	xx		xxx		
78-79	F	xx		xx	xx		xxx	x	

xxx - abundant; xx - moderate; x - minor; tr - trace

US - upper saprolite; MS -mid saprolite; LS -lower saprolite; SR - saprock; F - fresh rock

Table 2. XRD data for drill hole JDRC 8.

Depth (m)	Zone	Quartz	Kaolinite	Chlorite	Muscovite	Goethite	Feldspar	Calcite	Dolomite	Smectite
1-2	C	x	xx		x	x		x		
11-13	US	xx	xxx		xx	xx				
15-17	US	xx	xxx		xx	xx				
23-25	US	xx	xx		xx	xx				tr
29-31	MS	xx	xx		x	x	x			x
35-37	MS	xx	x		xx		xx			x
39-40	MS	xx	x		xx	x	xx			x
41-42	MS	xx	x	x	xx	x	xx			tr
44-45	LS	xx	x	x	xx	x	xx			tr
45-46	LS	xx		x	xxx	x	x			tr
47-48	LS	xx		x	xxx	x	xx			tr
49-50	LS	xx		x	xxx		xx			tr
52-53	LS	xx		x	xx		xx		x	
53-54	SR	xx		xx	xx		xxx		xx	
57-58	SR	xx		xx	xx		xxx		xx	
58-59	SR	xx		xx	xx		xxx		xx	

xxx - abundant; xx - moderate; x - minor; tr - trace
C - soil; US - upper saprolite; MS -mid saprolite; LS -lower saprolite; SR - saprock

Table 3. XRD data for drill hole JDRC 44.

Depth (m)	Zone	Quartz	Kaolinite	Chlorite	Muscovite	Goethite	Feldspar	Calcite	Smectite
5-7	M	xx	xxx		xx	x	x		
14-16	US	xx	xxx		xx	x	x		
23-25	US	xx	xx		xx	x	x		
31-33	MS	xx	x		x		xx		x
37-38	MS	xx		x	xx		xxx		
40-41	MS	xx		x	xx		xxx		
43-44	MS	xx		x	xx		xxx		
47-48	MS	xx		x	xx		xxx		
49-50	LS	xx		x	x		xxx		x
50-51	LS	xx		xx	xx		xxx		x
52-53	LS	xx		x	x		xxx		x
53-54	LS	xx		xx	xx		xxx		x
54-55	LS	xx		xx	xx		xxx		
58-59	LS	xx		x	x		xxx		x
60-61	LS	xx		x	x		xxx		x
62-63	SR	xx		xx	x		xxx		
68-69	F	xx		xx	x		xxx	x	

xxx - abundant; xx - moderate; x - minor; tr - trace
M - mottled zone; US - upper saprolite; MS -mid saprolite; LS -lower saprolite; SR - saprock; F - fresh rock

Table 4. XRD data for drill hole JDRC 118.

Depth (m)	Zone	Quartz	Kaolinite	Chlorite	Muscovite	Hematite	Goethite	Feldspar	Calcite	Dolomite	Smectite
1-2	C	xx	x		x	x		tr	xx	x	
6-8	M	xx	xx		x		xx	x			
16-18	US	xx	x		x		x	xx			
32-33	MS	xx	x		x		x	xx			x
38-39	MS	xx	x	x	xx		x	xx			x
39-40	MS	xx	x	x	xx		x	xx			x
41-42	MS	xx		x	x		x	xx			x
42-43	LS	xx		xx	xx		x	xxx			x
46-47	LS	xx		xx	xx		tr	xxx			
48-49	LS	xx		xx	xx			xxx			

xxx - abundant; xx - moderate; x - minor; tr - trace
C - soil; M - mottled zone; US - upper saprolite; MS -mid saprolite; LS -lower saprolite

The regolith over felsic volcanogenic sedimentary rocks at Twin Peaks consists of saprock, lower, mid and upper saprolite, mottled zone and red-brown soil, commonly including a calcrete horizon.

Fresh rock is grey in arenitic metasediments, grey-greenish for argillic facies and grey-pinkish for K-feldspar enriched units. The mineral composition of unmineralized rocks is characterized by the assemblage of quartz, albite, chlorite, K-feldspar and muscovite with minor amounts of calcite and dolomite. Chlorite and K-feldspar are mostly replaced by muscovite, quartz and albite in the alteration zone proximal to mineralization (Eilu and Mikucki, 1996).

Saprock is grey to grey-greenish with slight ferruginization along fractures, with commonly more than 50% coarse (>1 mm) rock fragments. Reduction in Ca content reflects leaching of calcite and dolomite at the onset of weathering. The thickness of saprock varies from 2 to 8 m.

Lower saprolite. The transition from saprock to lower saprolite is marked by reduction in the proportion of the unweathered coarse fragments and in the Mg content, presumably due to oxidation of ferromagnesian minerals (amphiboles, pyroxenes). The rocks become greenish and softer, and contain some secondary smectite. The lower saprolite is 9 – 27 m thick.

Mid saprolite. Above the quite sharp interface with the lower saprolite, the regolith becomes softer and more clay-rich. Colouration of the rocks changes to yellow and orange-yellow. Chlorite diminishes and is replaced by kaolinite and iron hydroxides, generally goethite. Smectite occurs as an intermediate product of weathering of plagioclase and biotite. The concentrations of Mg, P and Sr are reduced in this zone. The mid saprolite is generally 13 – 22 m thick.

Upper saprolite. This is commonly bright yellow to yellow-orange kaolinitic clay. The abundances of albite and smectite decrease sharply at the bottom of the zone, with kaolinite and goethite becoming the principal minerals. The upper saprolite is richer in Al and Fe, and slightly poorer in Si than the mid saprolite. The zone is 13 – 30 m thick.

Mottled zone. This is mostly composed of purple, red and white clays. The principal regolith minerals are kaolinite and goethite, with muscovite partly retained in this zone. The concentrations of Fe and Al are increased in the upper parts of the zone. The mottled zone is up to 11 m thick.

Soil and *calcrete.* The soil is red-brown to brown polymictic clay-rich rock commonly 0.5 - 4.0 m thick, containing ferruginous nodules, quartz and saprolite fragments. The soil is calcareous, with fine-grained calcite dispersed in the matrix and also occurring as calcrete nodules and fracture fillings. Near the surface, calcrete occurs as a massive horizon up to 0.5 m thick. Complex laminar, massive and nodular structures indicate a mature stage of calcrete formation.

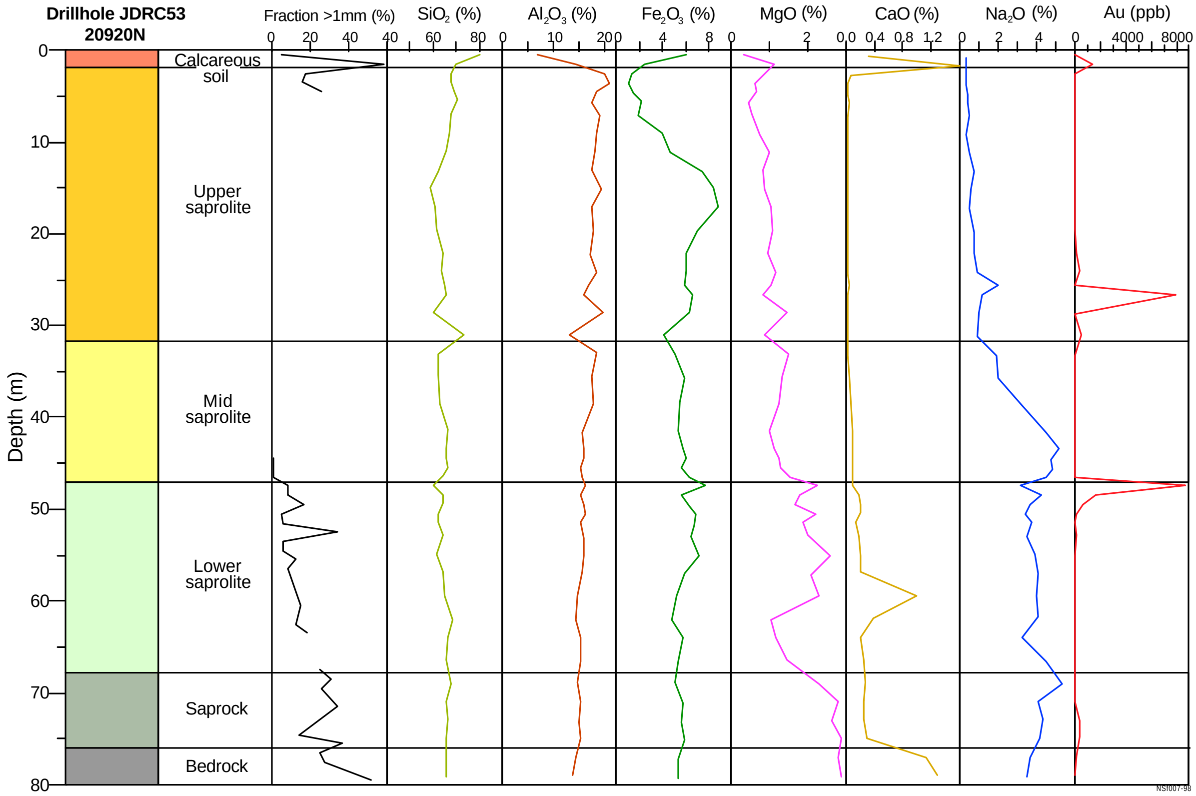

Figure 10: The principal regolith stratigraphic units in drill hole JDRC 53.

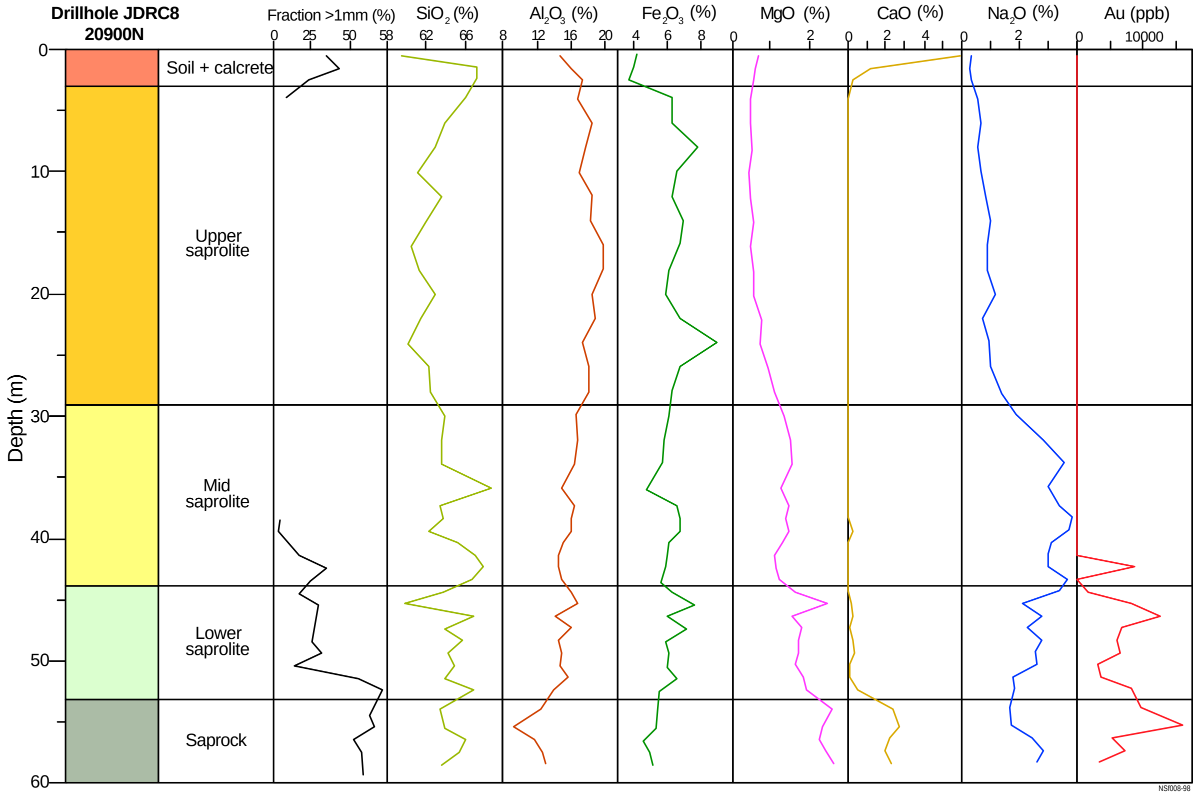

Figure 11: The principal regolith stratigraphic units in drill hole JDRC 8.

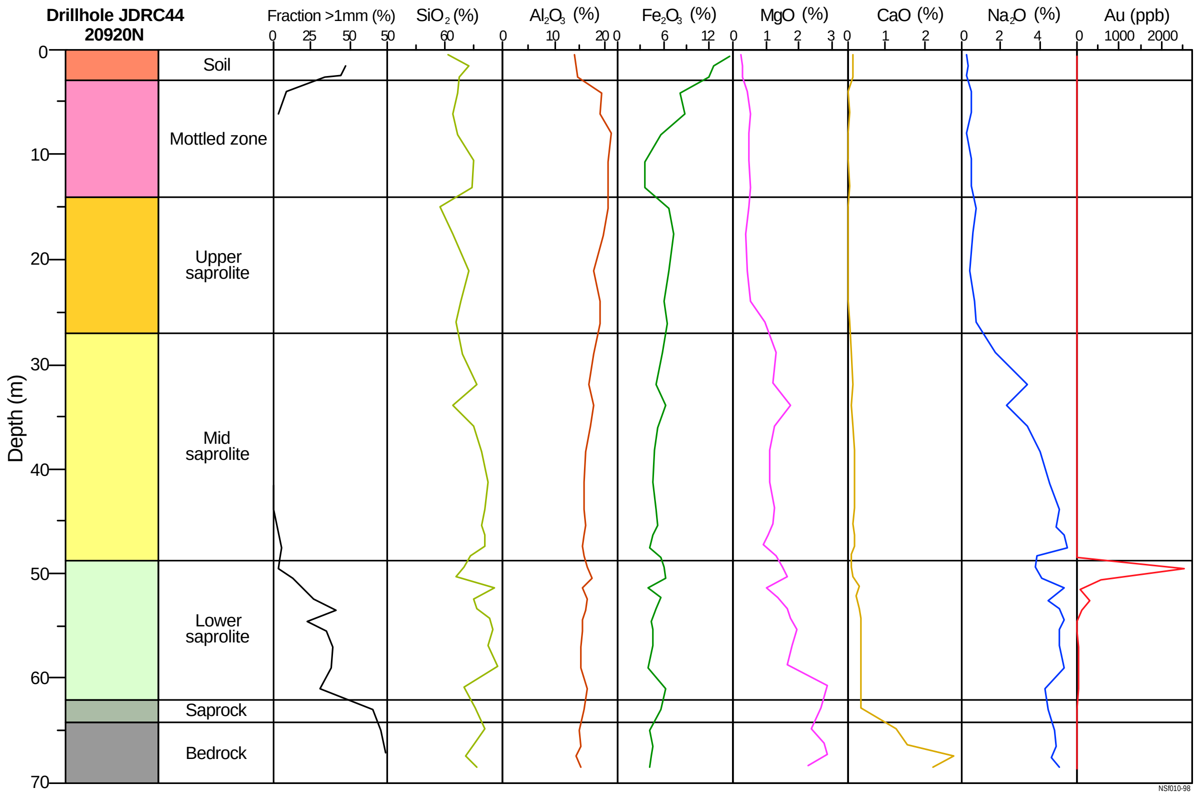

Figure 12: The principal regolith stratigraphic units in drill hole JDRC 44.

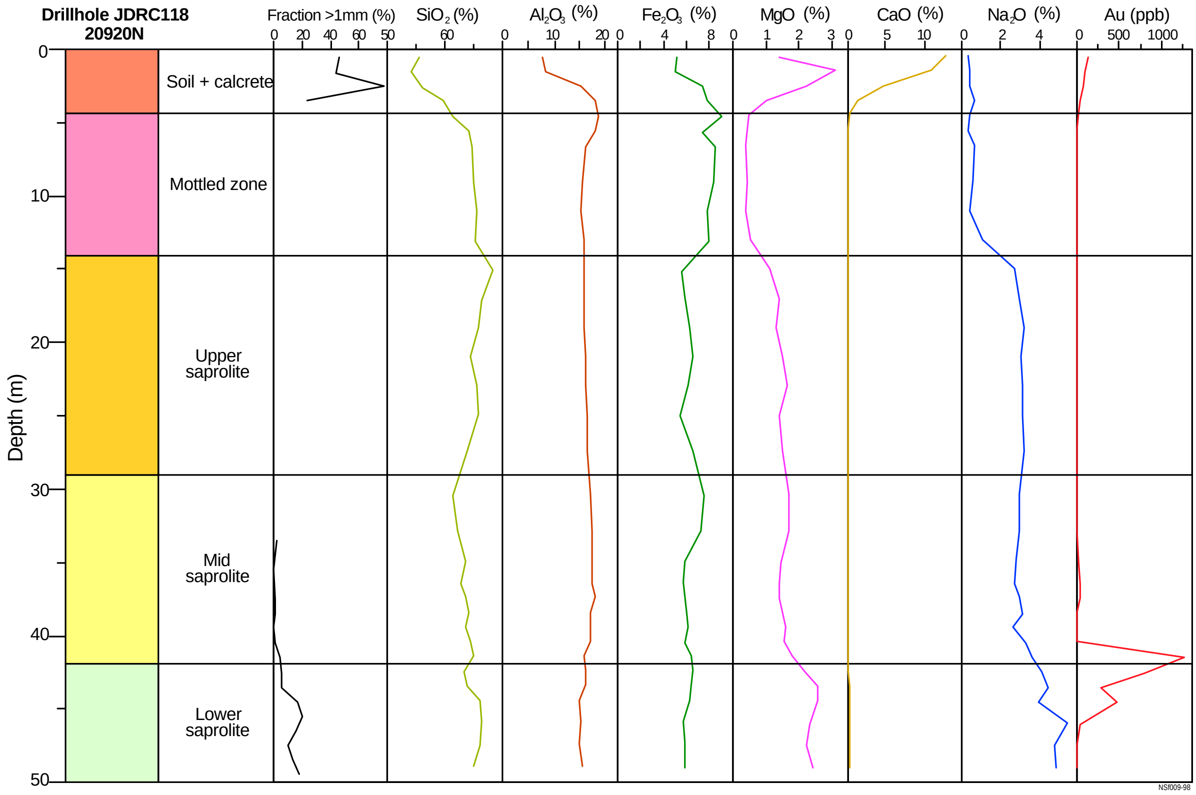

Figure 13: The principal regolith stratigraphic units in drill hole JDRC 118.

Logging by Goldfields Exploration Pty Ltd (Figure 14) has been used for the 3D geochemical modelling (Section 2.1.6). There is imperfect correlation between logging by CRC LEME and Goldfields Exploration Pty Ltd. In general, materials logged by Goldfields Exploration Pty Ltd as highly and extremely weathered rocks correspond to the mid saprolite and above, moderately weathered rocks to the lower saprolite, and slightly weathered rocks to part of the lower saprolite and saprock.

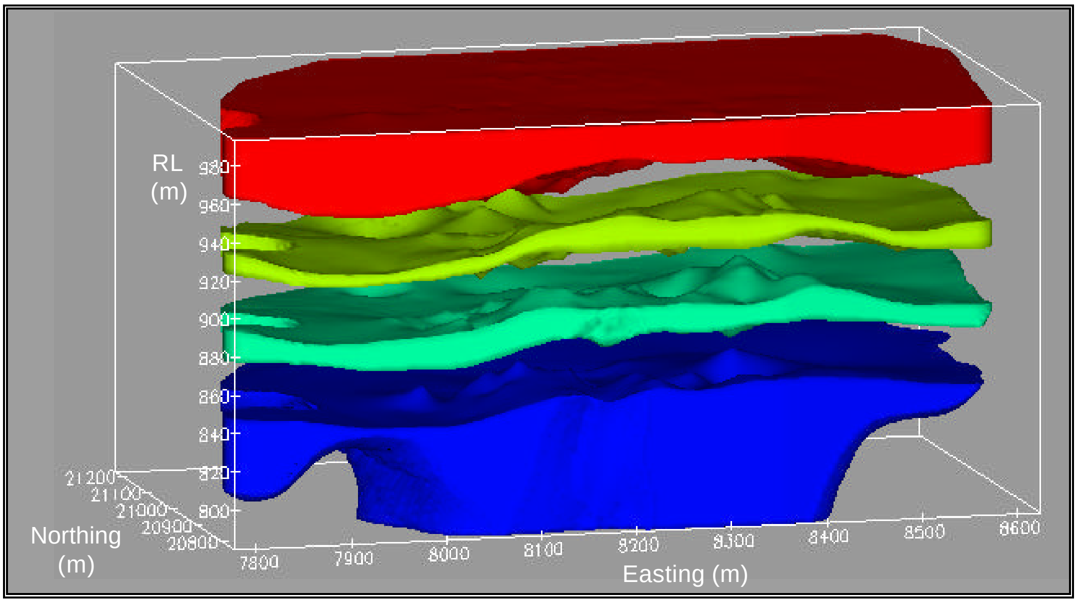

Figure 14: Regolith stratigraphy of the Twin Peaks area, using Goldfields Exploration Pty Ltd logging. Key: blue - fresh rock, aqua - slightly weathered, yellow - moderately weathered, red - highly weathered.

3.2 Monty Dam

3.2.1 Introduction

As the Twin Peaks, the Monty Dam area is within an erosional landform regime and covered by patchy, thin transported overburden, averaging 1 m thick over the main mineralized structure. In places, there is no alluvium and the mottled zone outcrops. The thickness of alluvium increases slightly to the north, reaching 1.5 - 2.5 m over the Elliot's Lode mineralized zone (Figure 15).

The regolith cover varies widely in thickness, being thickest (*i.e.*, the weathering front is deepest) along the northeast striking mineralized zone, reaching 60 - 70 m depth (Figure 16). To the northwest, the base of weathering rises up to 20 - 25 m below surface, probably due to a lithological change from latite to intermediate volcanic sediment, more resistant to weathering.

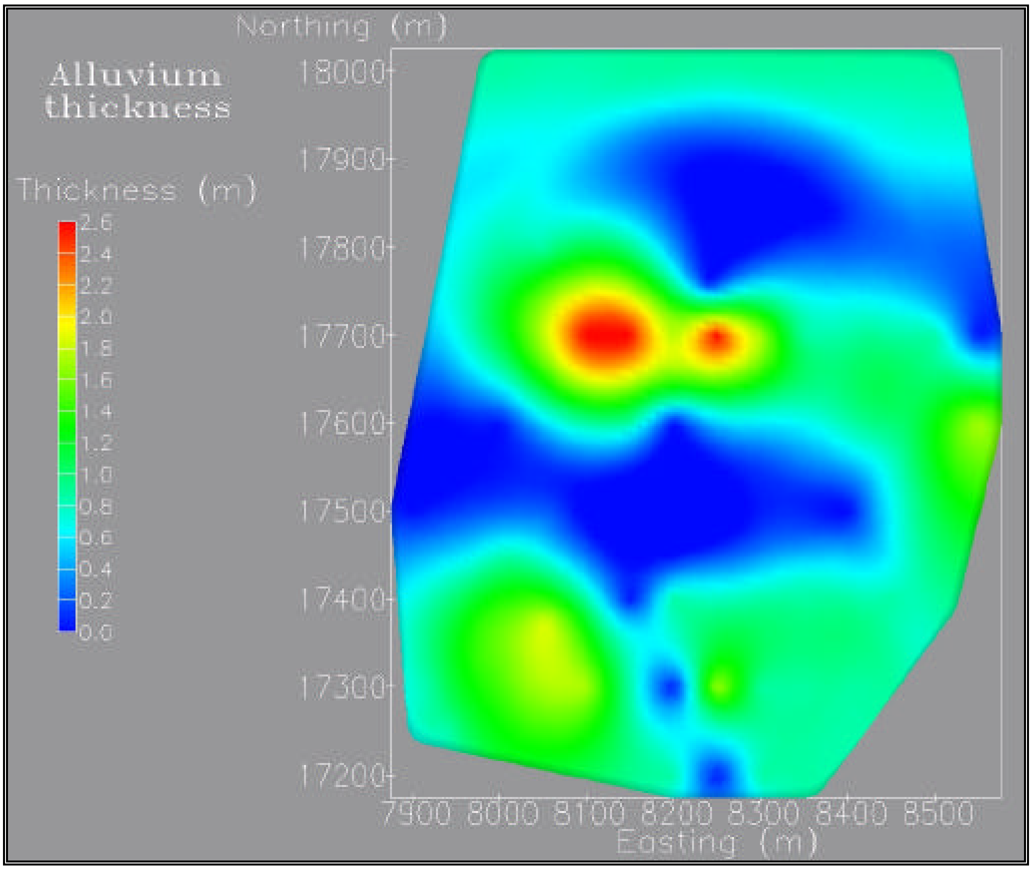

Figure 15: Alluvium thickness in the Monty Dam area.

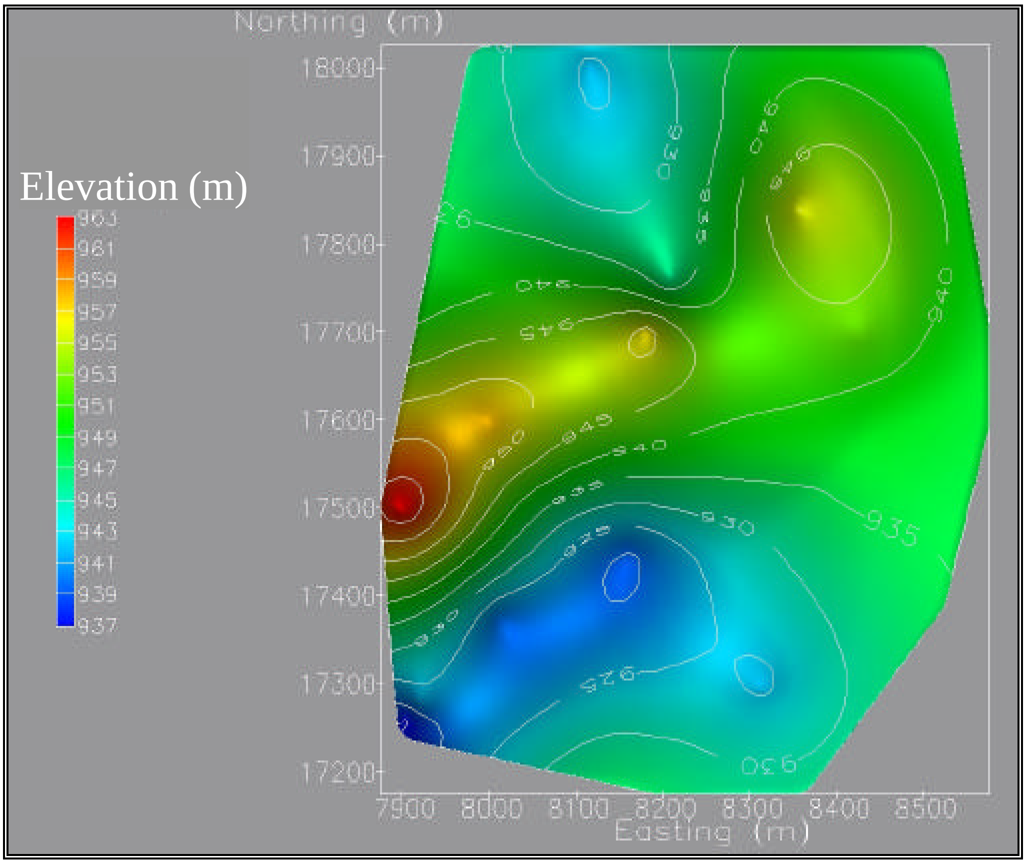

Figure 16: Depth of the weathering front at Monty Dam.

3.2.2 Regolith stratigraphy

Three major regolith units were defined in logging by Goldfields Exploration, these being slightly, moderately and highly weathered rocks, as well as alluvium (Figure 17). The slightly weathered rock (corresponding approximately to saprock and lower saprolite) is thicker at this site than in the Twin Peaks area (Section 3.1.2), ranging from 20 to 30 m and increasing to 40 - 45 m over the mineralized structure.

The moderately weathered rock varies widely from 20 - 32 m thick over the Monty Dam orebody to several metres thick, north of 17600 mN. The topography of the transition from slightly to moderately weathered rock is similar to that of the base of weathering with a depression over the mineralized structure (940 - 945 m RL) and an rise (965 - 970 m RL) north of 17500 mN (Figure 18).

The highly weathered unit is quite thin close to the mineralization, ranging from 4 to 16 m thick. The strongly to moderately weathered rocks transition is more smooth, ranging in elevation from 970 to 980 m in the major part of the area (Figure 19).

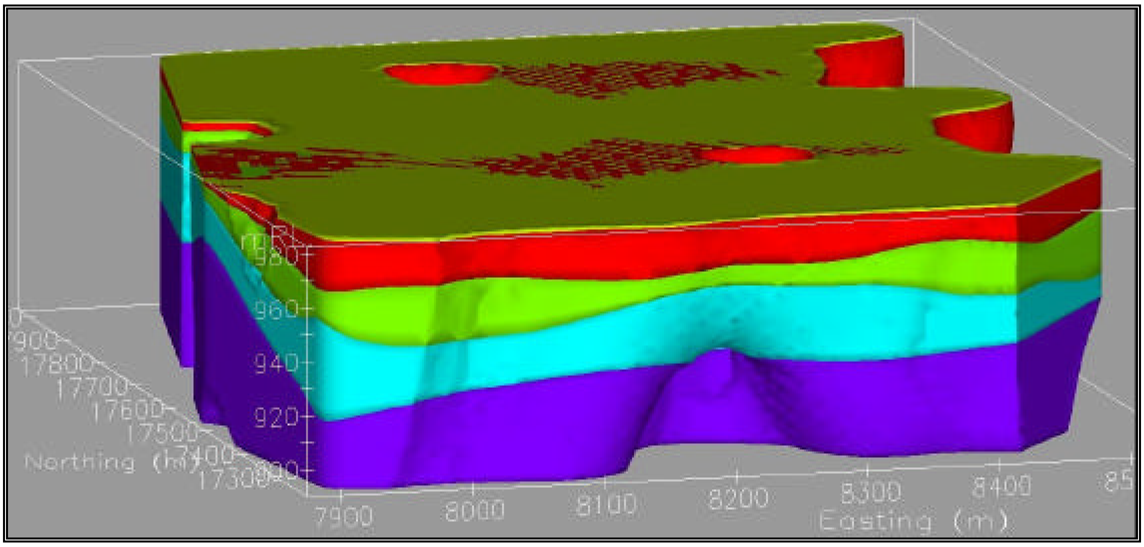

Figure 17: *Regolith stratigraphy of the Monty Dam area, using Goldfields Exploration Pty. Ltd logging. Key: mauve - fresh rock, aqua - slightly weathered, green - moderately weathered, red - highly weathered, yellow-green – alluvium.*

The Monty Dam area is characterized by deepening of the regolith over the mineralized structure, in contrast to the Twin Peaks area, where the opposite trend occurs. The regolith is 5- 25 m thicker at Monty Dam, being greater than at Twin Peaks. The regolith structure is also different, with a thicker slightly weathered rock unit and a thinner highly weathered rock unit at Monty Dam. The rock types at these sites are quite similar, so differences in the regolith depth and structure seem to be due to differences in the ore mineral composition and permeability of the mineralized structures. The deeper weathering at Monday Dam may be due to the presence of abundant pyrite, whereas at Twin Peaks, mineralization contains arsenopyrite, which is more resistant to weathering.

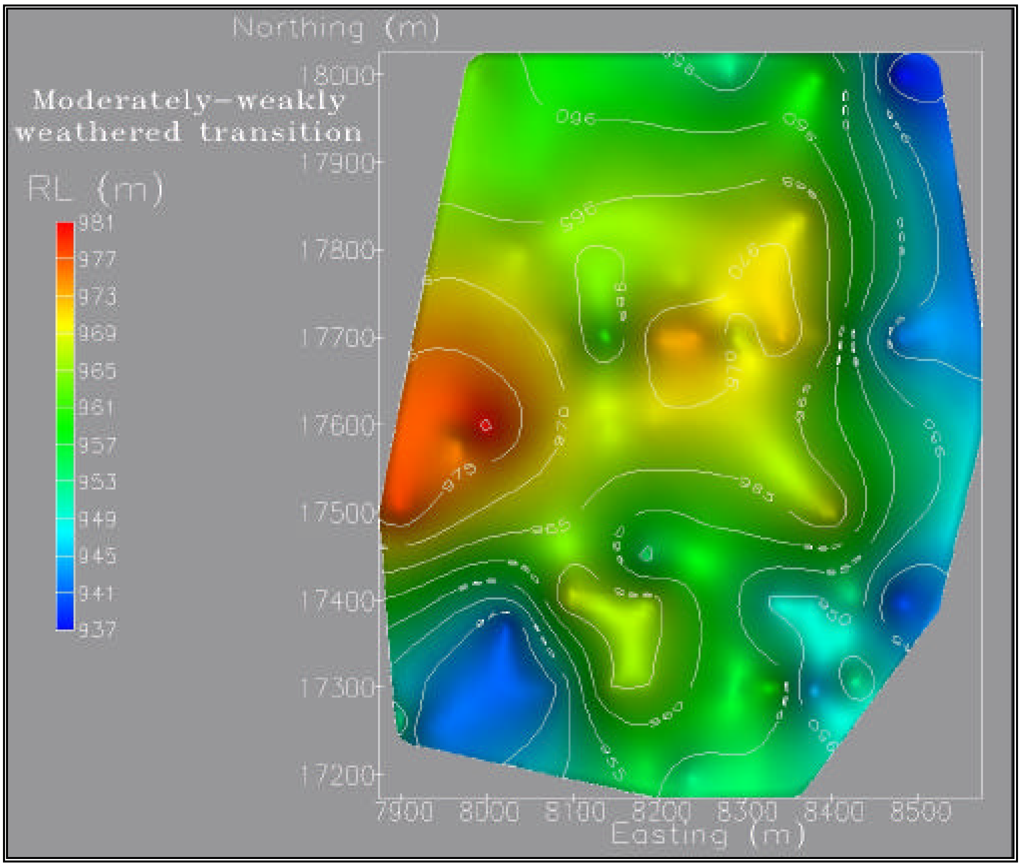

Figure 18: Elevation of the slightly to moderately weathered rock transition at Monty Dam.

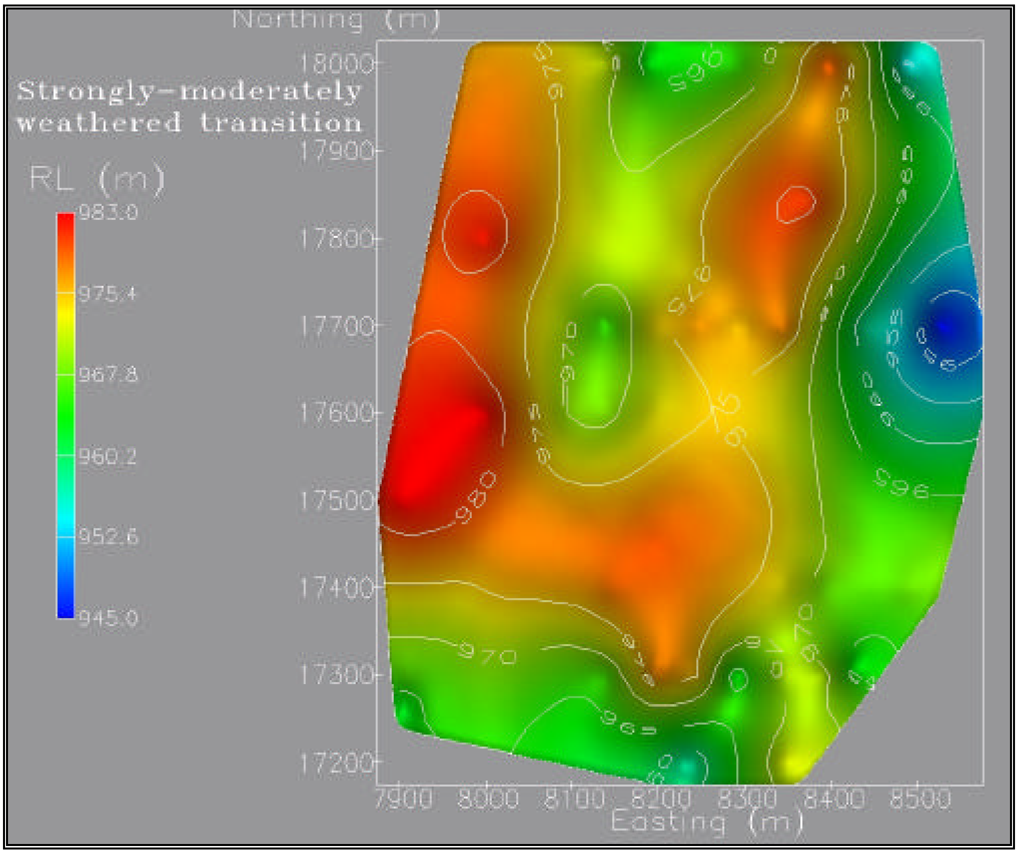

Figure 19: Elevation of the moderately to highly weathered rock transition at Monty Dam.

4. REGOLITH GEOCHEMISTRY AT TWIN PEAKS

4.1 Gold

4.1.1 Gold distribution within the regolith

Primary Au mineralization consists of a quartz-arsenopyrite stockwork, associated with quartz-sericite-carbonate alteration in brecciated metasediments. Gold is associated with W, As, Sb and Ag within the mineralized rocks (Eilu and Mikucki, 1996). According to the 3D visualization, the ore zone (100 ppb cut off) is columnar and dips 50 - 60° to the east. Also, several parallel, although less Au-rich (up to 100 ppb), zones occur NE along the strike of mineralization (Figure 20).

Visualization and modelling of the Au distribution study in the regolith at Twin Peaks is based on a Goldfields Exploration Pty. Ltd data set of 12281 assays. The data for Twin Peaks and Monty Dam were gridded and viewed in 3D, as detailed in Section 2.1.6. The 3D and 2D visualization images of the Au distribution are supplied in the accompanying CD, with some critical plots given below.

Gold at the Twin Peaks deposit is mostly retained residually in the saprock, and remnants of the main orebody may be traced to the surface. There are two prominent supergene Au enrichments in the regolith: at the mid to lower saprolite boundary (described in Goldfields Exploration Pty. Ltd logging as moderately weathered rocks) and close to the surface (Figure 20). The depleted zone lies between the enrichments. The principal enrichments and depletion features are as follows:

1. There is an elongate Au dispersion halo close to the surface, within the pedogenic calcrete and soil. It extends up to 350 m east of the axis of the mineralization, with a width of up to 230 m (using a 20 ppb cut off). The sharp northwestern boundary of the anomaly presumably reflects a location of the mineralized strike. In places, Au concentrations are >1 ppm in the surface anomaly. The average thickness of the surface Au anomaly is 2 m.

2. The Au-poor zone is located beneath the soil, extending to the lower saprolite with the strongest depletion (mostly <30 ppb Au) from 15 – 25 m depth, in the lower parts of the mid saprolite just above the supergene blanket. There are local Au concentrations of up to 7.9 ppm in the depleted zone, coincident with quartz veins, presumably being quartz-protected remnants of the primary mineralization.

3. The Au-rich supergene blanket (up to 12.2 ppm Au) occurs just below the depleted zone at the top of the lower saprolite from a depth of about 40 m. The shape of the halo resembles that of the surface anomaly: it extends as a continuous, narrow zone to the northeast along the mineralized strike and as patchy cover to the east, up to approximately 230 m, with a maximum width of 200 m (20 ppb cut off) and approximately 6 - 9 m vertical thickness. There is a sharp transition from the depleted zone (Au concentrations are commonly <5 ppb) to the high grades at the top of the enriched horizon, with gradual decrease in Au concentrations (to <40 ppb) at the base of this zone (Table 5).

Table 5. Mean Au grades at every 2 m interval through the regolith above the Au enrichment, based on data shown in Figure 22.

Elevation (m)	Mean Au (ppm)	RL (m)	Mean Au (ppm)
968-970	0.03	958-960	0.09
966-968	0.04	956-958	0.27
964-966	0.07	954-956	0.10
962-964	0.02	952-954	0.23
960-962	0.04	950-952	0.70

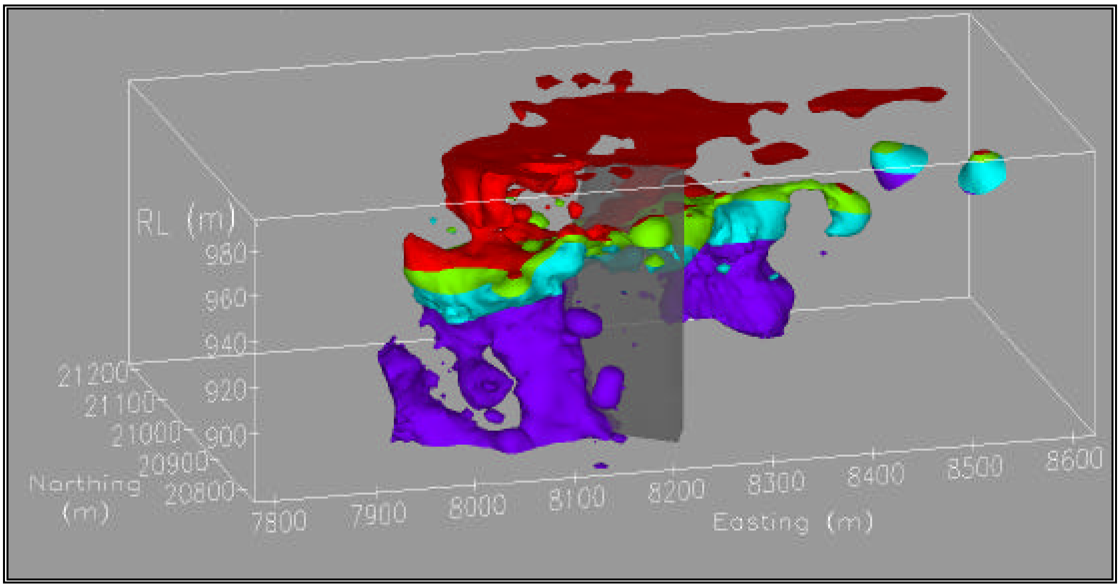

Figure 20: Gold distribution using a 0.03 ppm cut off, Twin Peaks. Where Au is greater than 0.03 ppm, the area is coloured according to the regolith horizon. Key: mauve - fresh rock, blue - slightly weathered, green - moderately weathered, red - highly weathered, grey - dolerite dyke.

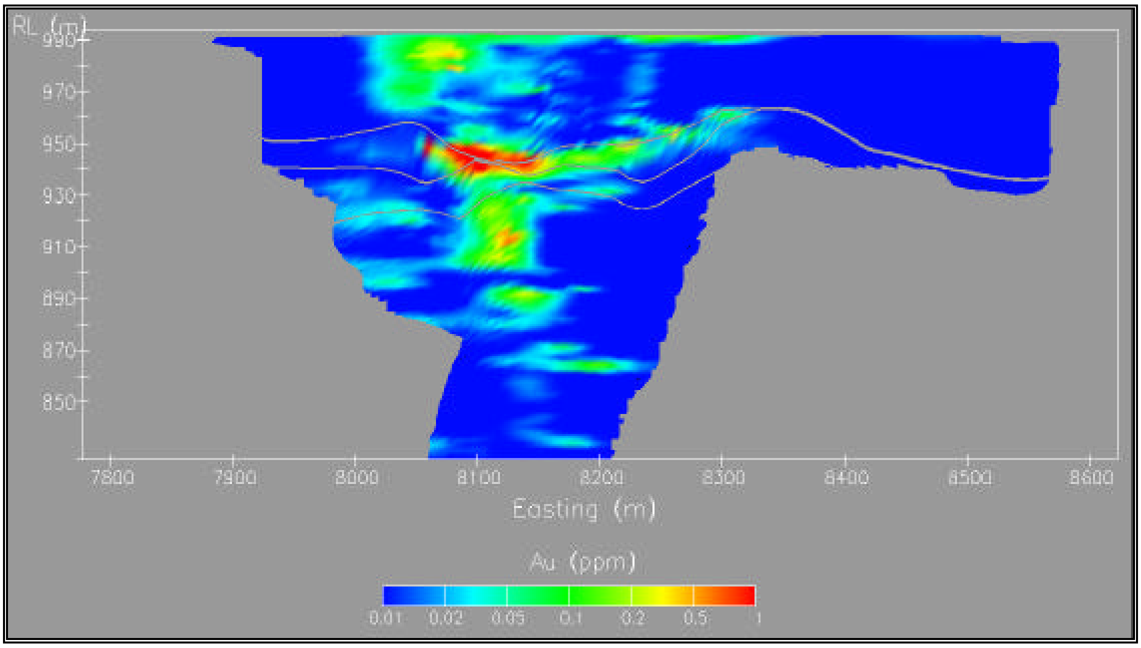

Figure 21: Calculated Au grade for 20940 m N section, Twin Peaks.

4.1.2 Gold concentration calculations

Initial investigations on the raw geochemical data clearly are biased by a greater sampling density in the central mineralized zone, but will not have been smoothed by gridding (see below). Gold concentrations were combined into each metre RL and the mean (Figure 22) and geometric mean (Figure 23) Au grade plotted against elevation. Above 960 m RL (approximately 35 m below surface) the regolith contains much less Au than at depth, indicating both depletion and transported cover in the top of this zone. Intermediate Au grades occur between 960 and 953 m RL. There is an enrichment at surface (note that the apparent peak in Au, 2 m below surface, is due to the data being graphed against elevation rather than depth from surface, and that some of the surface data is from 4 m composites), with values >1 ppm Au recorded. Comparing Figures 20 and 21 indicates that the geometric mean overestimates the surface anomaly, relative to the underlying mineralization: thus, for the surface, the geometric mean is more than ½ the arithmetic mean, whereas for the deeper mineralized zone the geometric mean is less than $^1/_{10}$ the arithmetic mean. This is due to the surface material having a more normal Au distribution than that at depth.

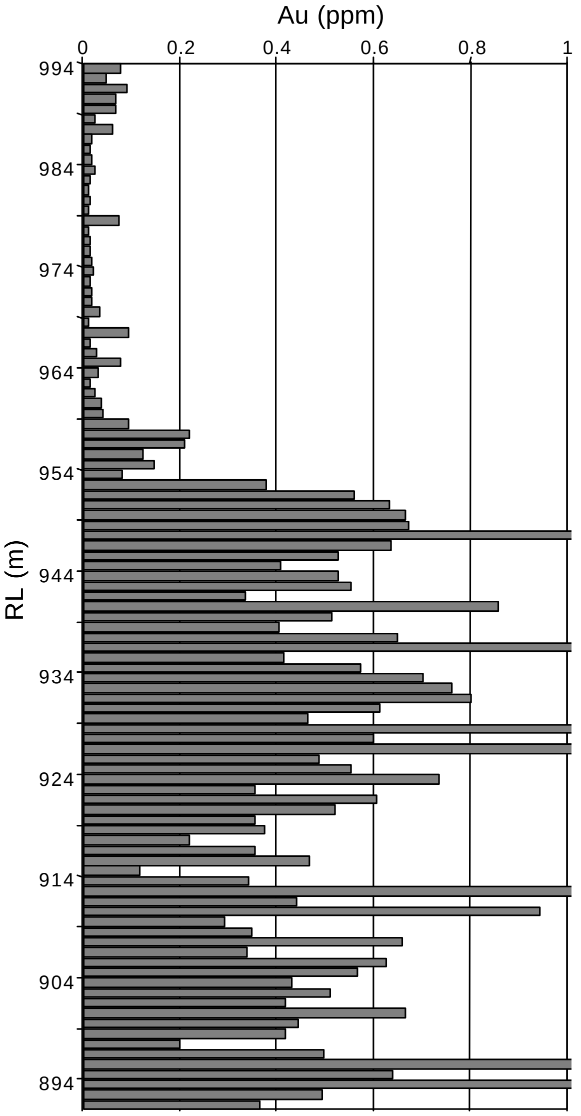

Figure 22: Mean Au concentration vs. RL for raw data, Twin Peaks.

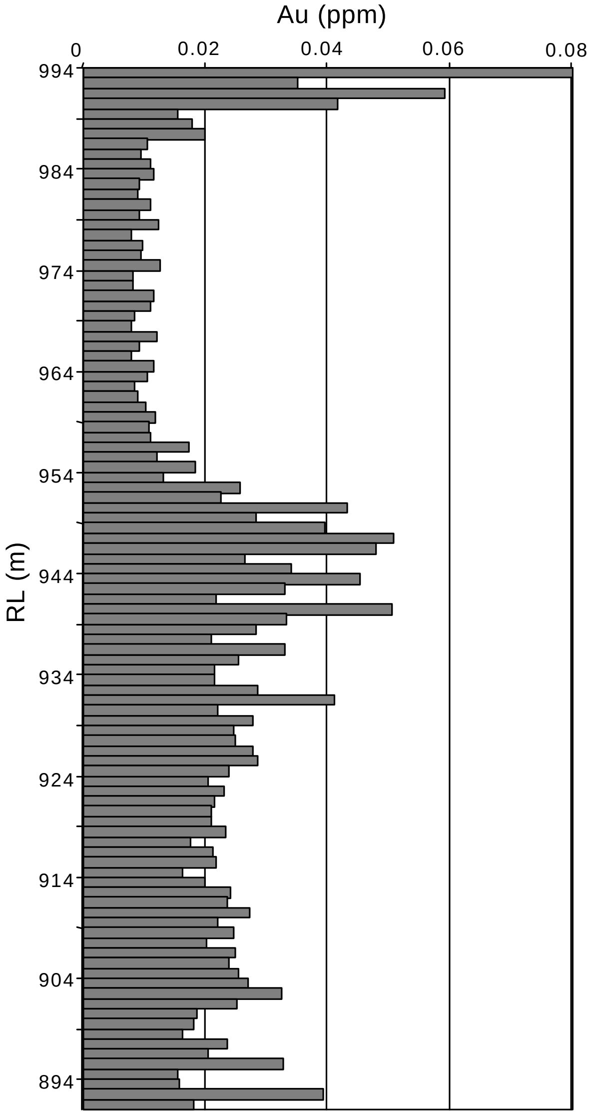

Figure 23: Geometric mean Au concentration vs. RL for raw data, Twin Peaks.

Statistical calculations were performed for two cases: the Twin Peaks area, as defined in the various Figures (*e.g.,* Figure 20), and the orebody only. The spreadsheet data files for both cases are included in the accompanying CD (in 'Au concentration calculations' Folder; Appendix 4). Generally, the results for both cases were similar, with the Twin Peaks orebody having higher Au concentrations than for the Twin Peaks area case – the orebody case is discussed in detail below.

Calculations of the volume of each regolith layer within the Twin Peaks orebody (Figure 24) indicate small proportions of moderately (14%) and slightly (19%) weathered, relative to the thicker highly weathered layer (67%). There is a major increase in mean Au concentration (Figure 25) from bedrock (119 ppb) through slightly (145 ppb) to moderately weathered (289 ppb) rocks. The high Au concentration in the moderately weathered rocks could be due to residual concentration, though it is possible that it includes a component of absolute enrichment from Au leached from above.

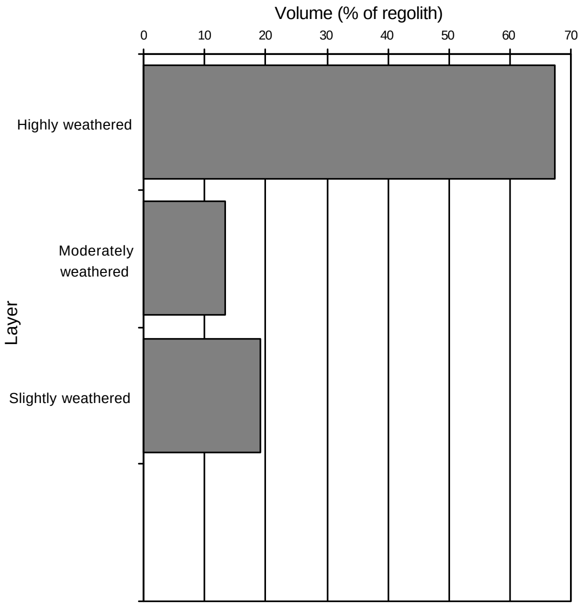

Figure 24: Comparative volume of each regolith layer, Twin Peaks orebody, as a percentage of the total regolith.

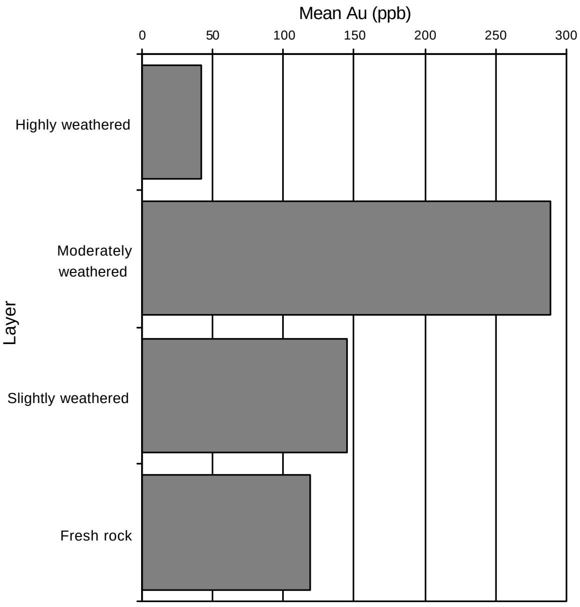

Figure 25: Mean Au for each regolith layer, Twin Peaks orebody.

The highly weathered layer has a mean grade of 42 ppb, which is considerably less than the deeper layers discussed above. This depletion is even more evident if the highly weathered unit is split into 3 zones: the lowest 6 m (which is within the transition to the deeper and Au-rich moderately weathered zone); the top 6 m (which has relatively higher Au associated with carbonate); and an intervening zone that comprises 46% of the total weathered material (Figure 26). This has a mean concentration of only 23 ppb Au (Figure 27) which is 8% of the mean Au grade of the moderately weathered rock unit and 20% of the mean bedrock grade, and referred to as the “depleted zone”.

Further calculations of mean Au for the Twin Peaks orebody are based on 3 m thick slices taken above and below the weathering front and the highly to moderately weathered transition and from the surface. The reliability of the results of each slice has been calculated using the method described in Section 2.2.4. Only those slices considered 60% reliable or greater were used. (Clarification of these concepts is given in Section 2.2.4).

Calculations of mean Au content as a function of distance from the weathering front (Figure 28) show that Au grade in the bedrock varies with a low of 93 ppb 21-24 m below the weathering front to a high just below the weathering front of >150 ppb. Mean Au concentrations increase above the weathering front to a maximum value of 242 ppb 9-12 m above the weathering front and remain high for at least another 6 m. The reliability of the data becomes too low for useful measurement above this.

Figure 29 shows mean Au grade as a function of distance from the highly to moderately weathered rock transition. Gold concentrations peak immediately below this transition (311 ppb 3-6 m below). As discussed above, this could represent the upper limit for residual concentration of Au, above which depletion is observed or there could be a component of absolute enrichment from Au leached from the highly weathered zone. Gold concentration is strongly decreased above the highly to moderately weathered rock transition, reaching a minimum of 17 ppb 18 - 21 m above the transition. The first two slices above the highly to moderately weathered rock transition were combined to give the “bottom 6 m of highly weathered” unit used for Figure 26 and Figure 27.

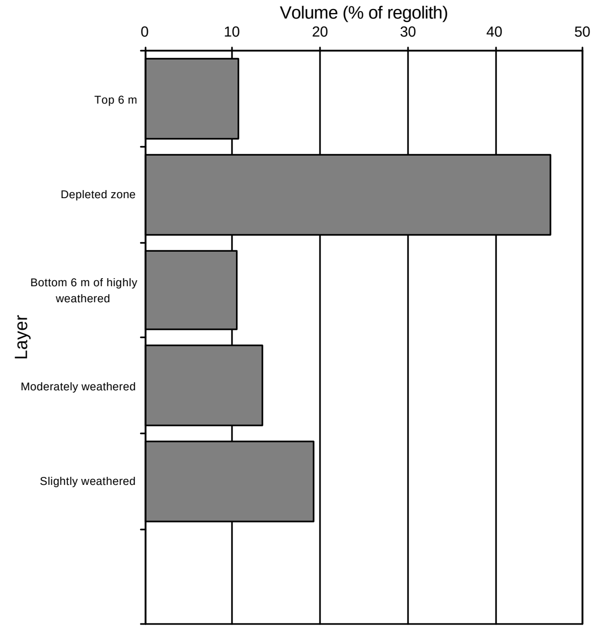

Figure 26: Comparative volume of regolith layers optimized for Au concentration discrimination, Twin Peaks orebody, as a percentage of the total regolith.

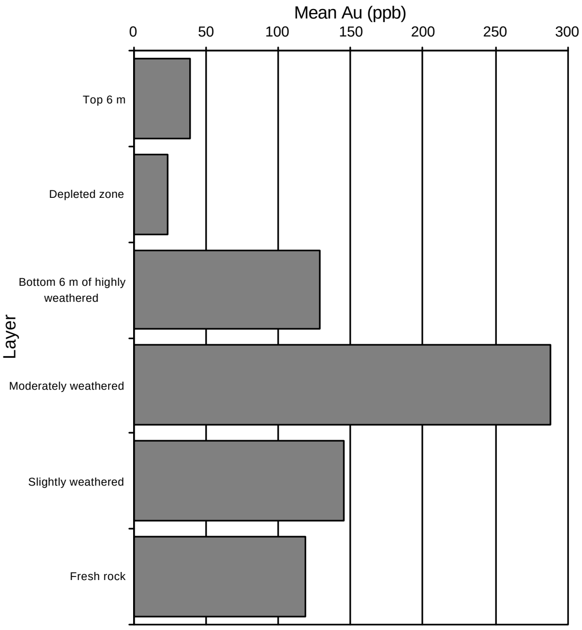

Figure 27: Mean Au of regolith layers optimized for Au concentration discrimination, Twin Peaks orebody.

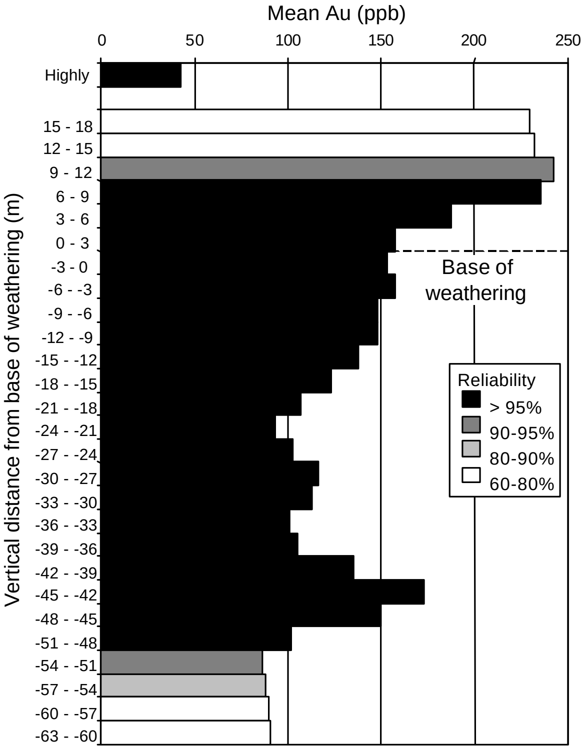

Figure 28: Mean Au vs. distance from the weathering front, Twin Peaks orebody.

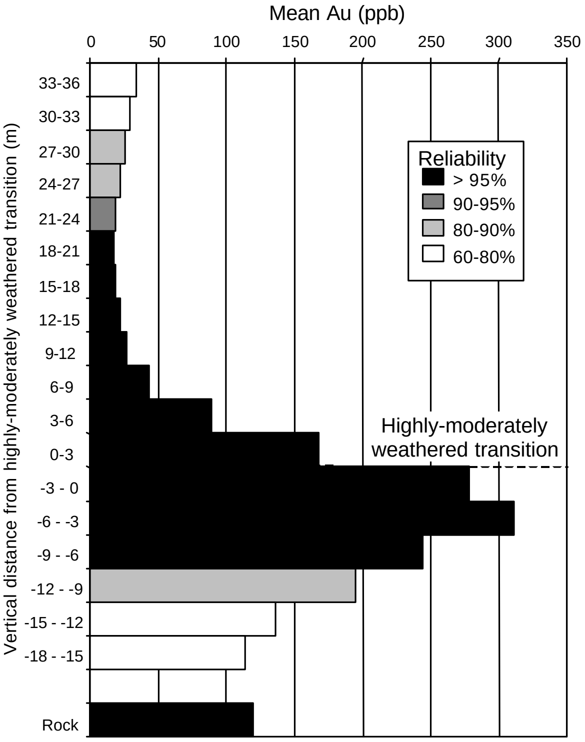

Figure 29: Mean Au vs. distance from the highly to moderately weathered transition, Twin Peaks orebody.

The mean Au concentrations show a significant peak at the surface (Figure 30) of 46 ppb in the top 3 m, decreasing to 20 ppb at approximately 15 m depth before increasing at depth as the slices progressively approach the highly to moderately weathered transition.

Calculations of Au grade in the residual regolith, as a function of elevation (Figure 31), shows variation in Au grade of 57 - 181 ppb between 870, and 930 m elevation, which are the depths dominated by unweathered rock. Above this elevation, Au grade steadily increases to 189 ppb Au at 939 - 942 m, above which it increases abruptly to 308 - 310 ppb Au at 945 - 951 m, marking the top of the moderately weathered rock. This sharp increase suggests absolute Au enrichment. Above this, Au concentration decreases, reaching a minimum of 20 - 21 ppb from 972 to 984 m elevation. Thus, the features observed by studying successive slices away from the regolith transitions (Figures 28 - 30) are also clearly seen by taking elevation cuts (Figure 31). As the regolith transitions are sub- horizontal, this is not surprising, but results in some ambiguity as to whether the Au depletion is controlled by the regolith surfaces or by processes that are more a function of elevation (*e.g.*, groundwater processes). This issue is discussed further in Section 4.1.3.

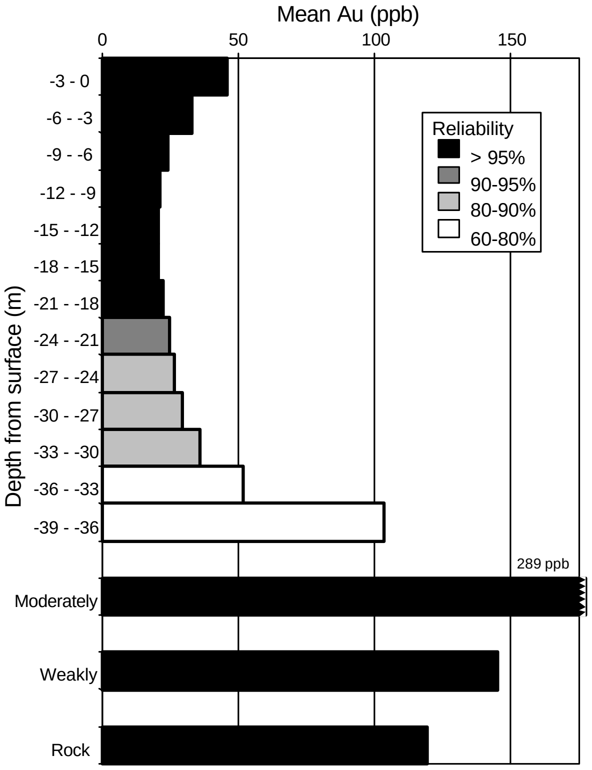

Figure 30: Mean Au vs. depth from surface for the Twin Peaks orebody.

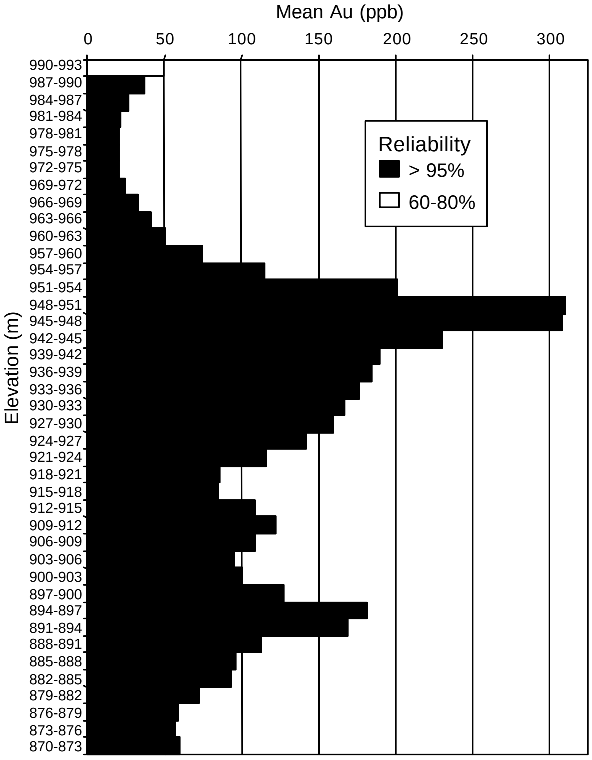

Figure 31: Mean Au vs. RL for the Twin Peaks orebody.

Comparisons of Figure 22 and Figure 31 show general similarity, though the results for Figure 31 are much smoother, as expected for gridded data with 3 m, rather than 1 m, slices. The gridded data (Figure 31) give mean concentrations below the depleted zone less than half that for the raw data (Figure 22). This could well be due to the sampling bias in the raw data: the drill hole density and sampling interval are greater for the Au-rich zones leading to erroneously high mean Au grades.

4.1.3 Enrichment and dispersion in the saprolite

The data on Au distribution in vertical profile, discussed in previous section, show that the upper, sharp boundary of the enrichment is generally coincident with the moderately to slightly weathered rock at 951 - 954 m RL. These data were compared with information on the position of the dispersion halo in the regolith profile. According to the results of the detailed regolith logging on section 20920 mN, the sharp upper boundary of the dispersion blanket, as well as the enrichment, is coincident with the mid/lower saprolite interface where physical characteristics and compositions of the host rocks change dramatically. Below this interface, the proportions of coarse fragments in drill cuttings sharply increase (Figures 32 to 35), indicating the porosity barrier position. At the interface, ferromagnesian silicates, mainly chlorite, are oxidized and destroyed with formation of kaolinite and iron oxides. The latter are very important, because Fe^{3+} mainly controls the oxidation potential of the medium. Across the boundary, pH changes surprisingly gradually, although the interface is coincident with slight increase in pH from about 6.6 to 6.9, except for drill hole JDRC 53, where the pH is slightly less (Figures 32 to 35). However, the upper boundary of the enrichment zone and dispersion halo varies from 42 to 49 m depth, indicating better control by the regolith boundary than by depth or elevation.

The Au associations in the depletion and enrichment zones differ from those in the regolith below the enrichment (Table A1.10, Figures A1.45 - A1.46, Appendix 1). According to the results of cluster analysis, in the saprock and lower saprolite, Au is associated with W, As, Sb, S and Ca, *i.e.*, reflecting the primary mineralization and alteration. Within the depleted and enrichment zones, Au is associated with Cs, Y, Yb and Lu. In sections 20880 – 20940 mN, results for some drill holes suggest a coincidence of the supergene Au enrichment with a thicker zone of As accumulation, though the data are inconsistent, probably due to lower As abundance.

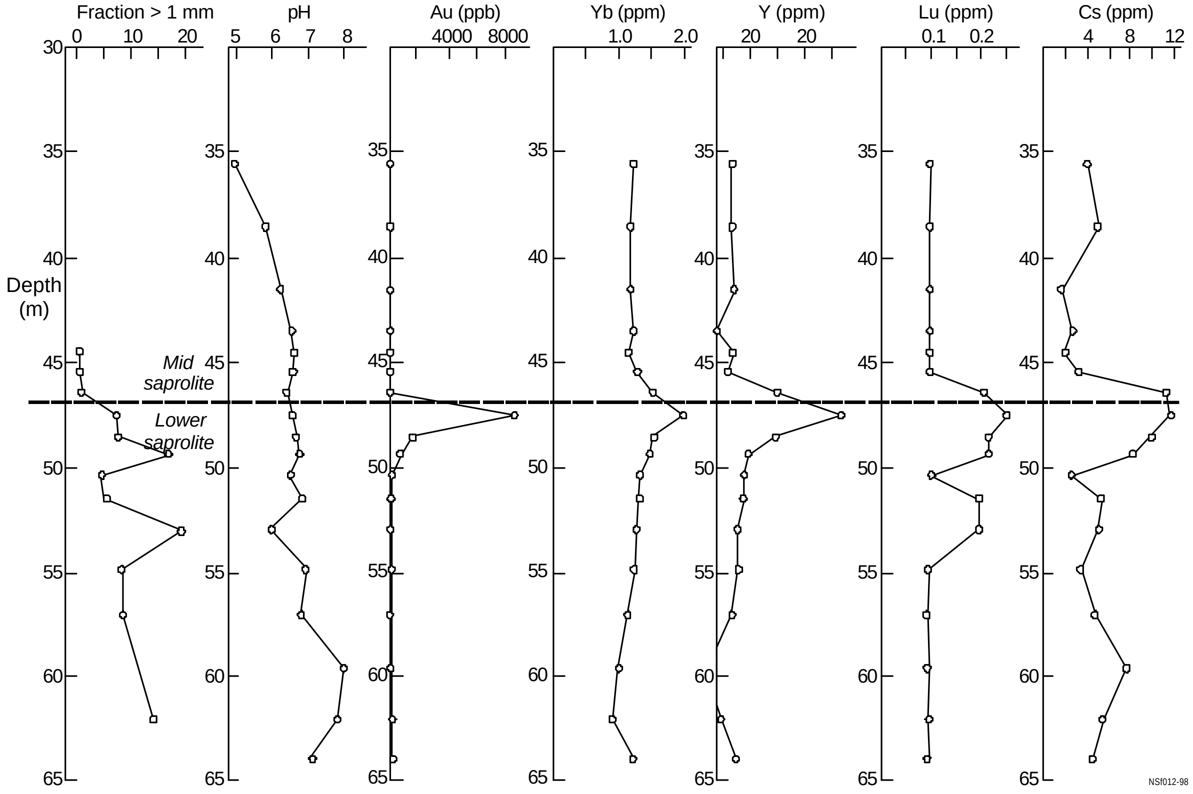

Figure 32: Selected physical characteristics and element distributions, drill hole JDRC 53.

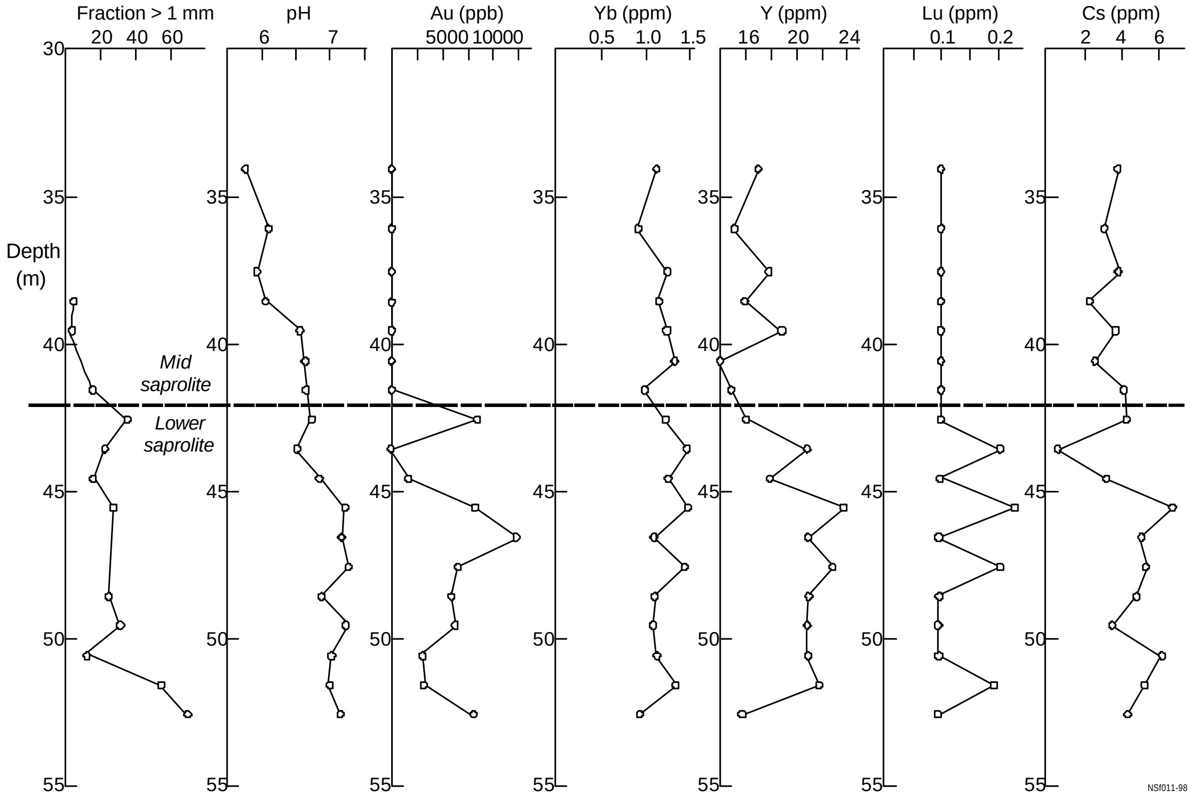

Figure 33: Selected physical characteristics and element distributions, drill hole JDRC 8.

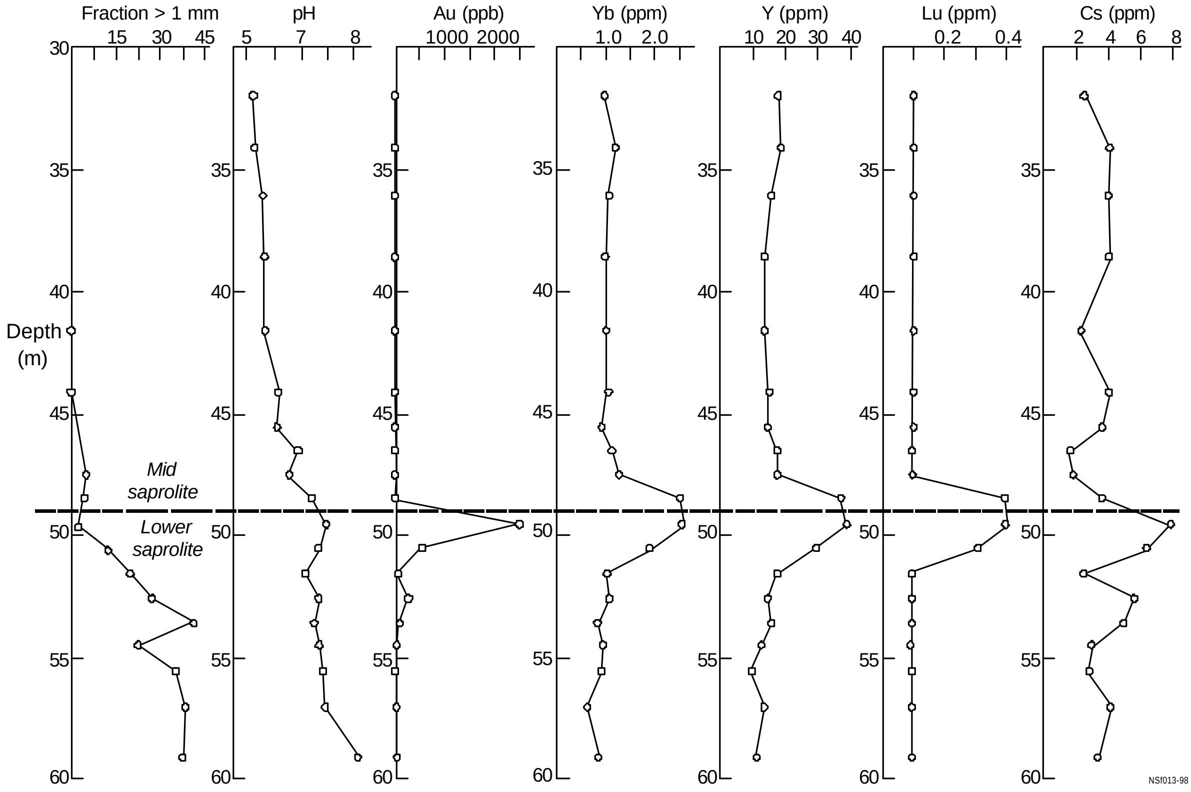

Figure 34: Selected physical characteristics and element distributions, drill hole JDRC 44.

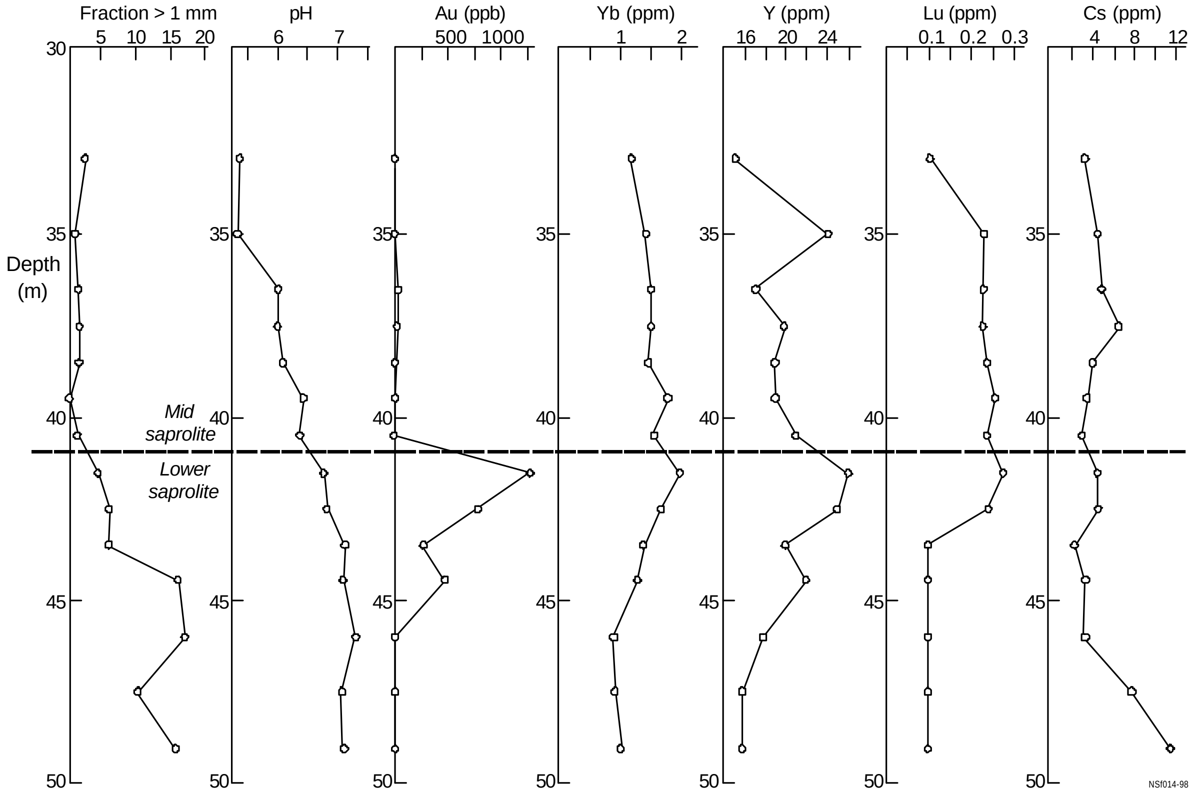

Figure 35: Selected physical characteristics and element distributions, drill hole JDRC118.

4.1.4 Gold mineralogy and chemistry within the calcrete anomaly

A 2 m thick Au anomaly occurs within the pedogenic calcrete and soil. The calcrete anomaly was sampled across the mineralized trend along 935 m long west-east traverse on section 20900 mN. Mineral and chemical compositions of calcrete, the Au distribution and speciation within the calcrete materials were studied in detail, using techniques described in Section 2.1.4.

Mineral and chemical compositions of calcrete

The carbonates are dispersed in the soil matrix and as calcrete nodules and fracture fillings. Near the surface, massive calcrete occurs as a horizon up to 0.5 m thick. The calcrete has nodular, laminar and massive structures indicating a mature stage of calcrete formation (Figure 36). Commonly, coarse lithic fragments, quartz cobbles and ferruginous nodules are irregularly dispersed within a fine-grained carbonate matrix. Coarse fragments are commonly the nuclei of carbonate nodules, which in turn are cemented by thin laminar deposits of carbonate. The carbonate cement varies from white to dark-brown, depending on impregnation by fine-grained iron oxides.

The calcrete consists principally of calcite and quartz, with minor kaolinite, dolomite, goethite, muscovite, Na-feldspar and rutile (Table 6). PIMA also detected some halloysite and ankerite. When Ca and Mg concentrations are calculated as mineral compositions (assuming that all Mg occurs as dolomite), the calcrete is shown to consist of 2-35% dolomite and up to 54% calcite (Table A1.2, Appendix 1). In the TP-C15, calculated negative calcite values are presumably due to occurrence of other Mg minerals in the calcrete, possibly magnesite.

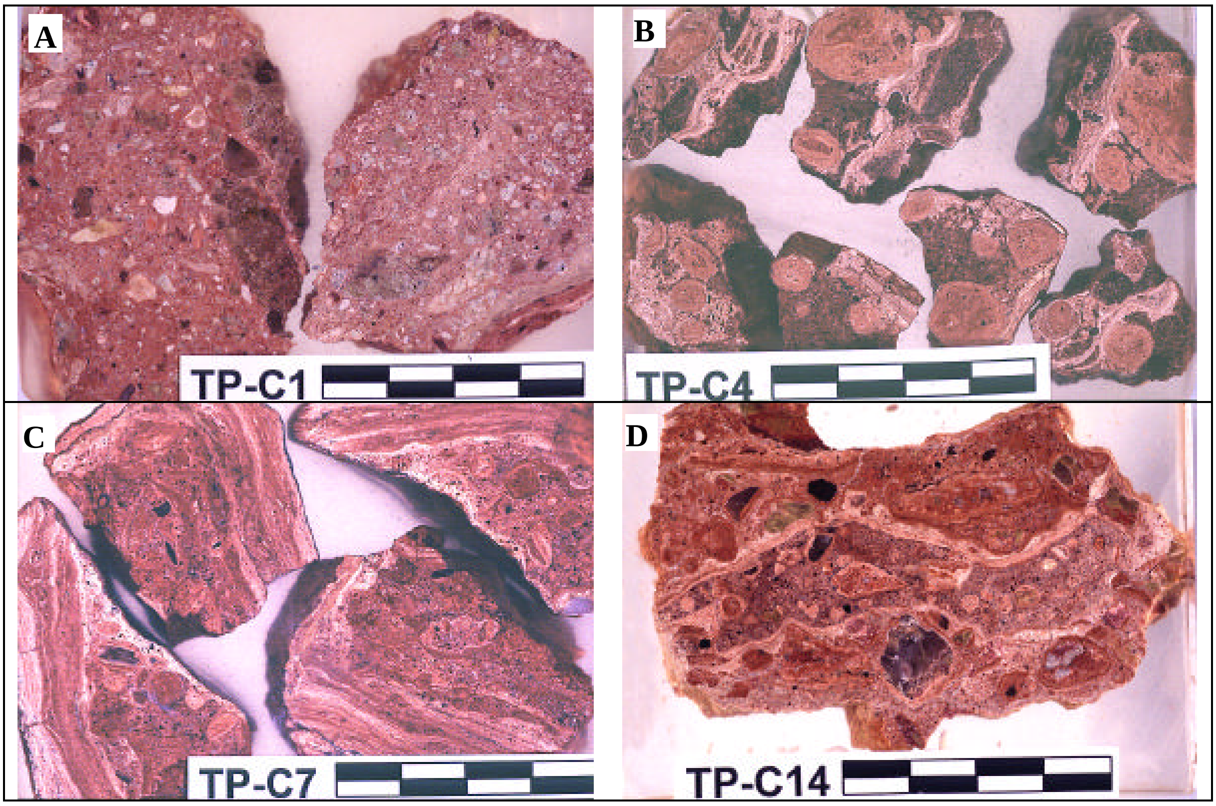

Figure 36: Calcrete structures, Twin Peaks: a – massive; b – nodular; c, d – laminated.

Table 6: XRD data for the subsurface calcrete traverse, Twin Peaks

Sample	Quartz	Kaolinite	Rutile	Muscovite	Goethite	Na-Feldspar	Calcite	Dolomite
TP-C10	x	x		x		x	xxxx	x
TP-C9	xxxx	xx					xxx	xx
TP-C8	xxx	x	x				xxxx	
TP-C7	xx	x					xxxx	
TP-C6	xxx	xx	x	?			xxxx	
TP-C5	xx	x		x		x	xxx	
TP-C4	xx	?					xxxx	
TP-C3	xx	x		x		x	xxx	x
TP-C2	xx	x	x		x	?	xxx	
TP-C1	xx	xx		x	x		xxx	
TP-C11	x	xx					xxx	
TP-C12	xx	x		x		x	xxx	
TP-C13	xx	x				x	xxxx	x
TP-C14	xx	x		xx			xxx	x
TP-C15	xx	x				x	xxx	xxx
TP-C16	xx	x	x			?	xxx	xx
TP-C17	xx	x	x		x	x	xxx	
TP-C18	xxx	x		x			xxxx	x

xxxx - abundant; xxx - moderate; xx - minor; x - trace

Gold distribution along the traverse

Gold concentrations in calcrete, sampled 5 cm below the upper boundary of a pedogenic calcrete horizon, show contrast up to 230 ppb anomaly, extending up to 500 m (75 ppb cut off) to the east from projection of the hanging wall of the mineralized zone at the surface (Figure 37).

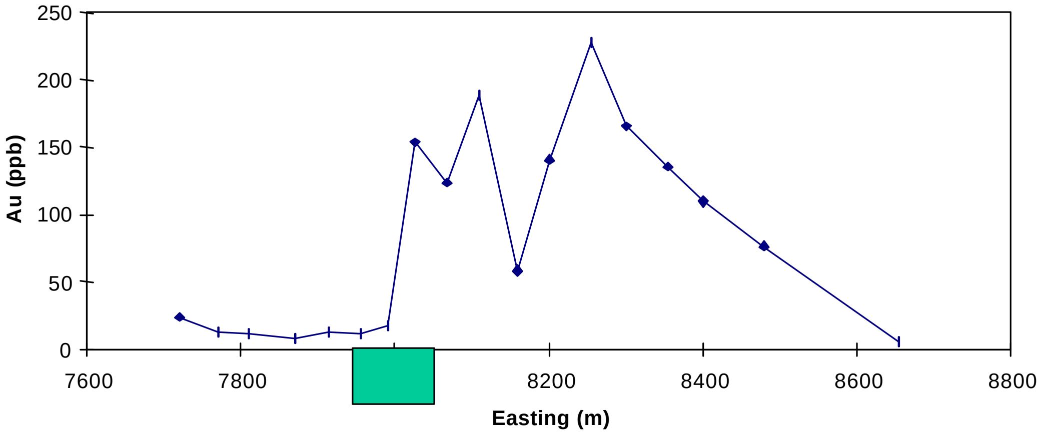

Figure 37: Gold concentrations in the calcrete materials, Section 20900 mN. Shaded area is the orebody projected to surface.

Partial extraction analyses

Results of the partial extractions by deionized water, iodide and cyanide solutions performed on pulverized and selected unpulverized samples are presented in Table 7, Table 8 and Figure 38.

Table 7: Partial Au extractions for pulverized calcrete samples, Twin Peaks.

Easting (mN)	Water Au (ppb)	Iodide Au (ppb)	Cyanide Au (ppb)	Total Au, INAA (ppb)
7720	1.66	14.28	3.49	24.1
7770	0.95	5.88	1.70	13
7810	0.45	4.60	1.77	12
7870	0.22	1.36	0.67	8.9
7915	0.50	4.08	2.75	12.9
7955	0.65	4.00	2.32	11.8
7990	0.93	6.92	3.31	17.5
8027	5.36	67.20	31.72	154
8068	4.96	69.60	30.60	124
8110	3.10	56.80	9.80	188
8160	3.87	38.36	5.84	58.7
8200	5.44	82.80	26.60	140
8255	9.92	138.00	36.12	227
8300	8.60	90.00	28.08	166
8355	4.40	73.60	22.20	136
8400	4.16	62.40	22.32	109
8480	4.00	41.60	21.04	75.9
8655	0.83	4.16	1.13	6.4

Table 8: Partial Au extractions for selected crushed calcrete samples, Twin Peaks.

Easting (mN)	Water Au (ppb)	Iodide (ppb)	Cyanide (ppb)	Total Au, INAA (ppb)
7770	0.96	5.48	1.85	13
7810	0.89	3.60	0.89	12
7870	0.22	1.00	0.77	8.9
7915	0.60	2.48	2.95	12.9
7955	0.96	5.52	-0.20	11.8
8110	8.00	29.44	9.20	188
8160	3.14	18.76	5.32	58.7
8200	10.12	3.10	54.80	140
8255	17.04	73.20	52.80	227

Data on extractions on pulverized materials show a lower percentage of iodide-soluble Au than for other carbonate soils in the Yilgarn Craton (Gray and Lintern, 1993), indicating a lower proportion of mobile Au at Twin Peaks. Data on unpulverized subsamples demonstrate less cyanide-soluble Au than total Au concentrations (INAA analysis), reflecting a substantial amount of Au occluded by resistant minerals, possibly Fe oxides.

Gold mass balance

Four calcrete samples with higher (136-227 ppb) Au concentrations were treated with pH 5 acetate acid for several weeks until the carbonate minerals were completely dissolved. The solution and residue were analyzed for Au by INAA. Solutions show low (5-7 ppb) Au concentrations, indicating that most of the Au is retained in the residue (Table 9). Substantial errors (+/- 29%) in the Au mass balance are possibly due to inhomogenity of the unpulverized samples analyzed by INAA.

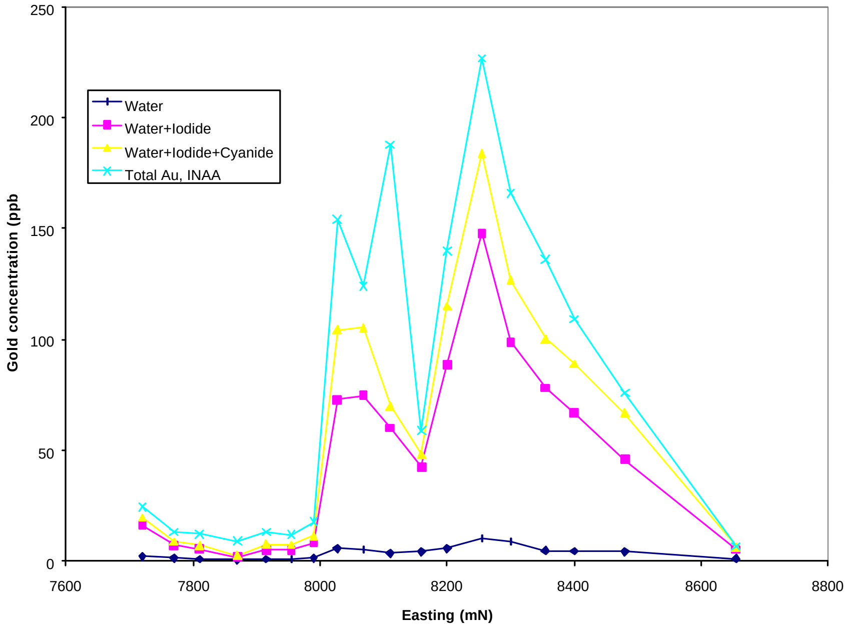

Figure 38: Partial Au extractions for pulverized calcrete samples, Twin Peaks.

Table 9: Gold concentrations and mass balance for calcrete, Twin Peaks.

Sample	Original sample			Solution	
	Weight, g	Au content, ppb	Au mass, 10^{-5}g	Au content, ppb	Au mass, 10^{-5}g
TP-C1	469.43	188	88253	5.20	2440
TP-C13	395.52	227	89783	7.36	2910
TP-C14	429.44	166	71287	7.08	3040
TP-C15	458.67	136	62379	6.89	3160
Sample	Residue			Total Au	
	Weight, g	Au content, ppb	Au mass, 10^{-5}g	Solution+residue, 10^{-5} g	Error, %
TP-C1	245.52	245	60152	62592	-29
TP-C13	229	492	112668	115578	29
TP-C14	255.48	348	88907	91947	29
TP-C15	248.25	166	41210	44370	-29

The residues were separated using two-step panning into eight fractions, and analyzed for Au. The results show very low Au concentrations within quartz, and slightly increased values for Superpanner preconcentrates and magnetic and non-magnetic ferruginous materials (Table 10). Gold is mostly concentrated within saprolite fragments, fine-grained materials and heavy concentrate. The micropanner concentrates show the highest (up to 39 ppm) Au concentrations, but absolute Au mass is not big because of small proportion of heavy concentrate in total sample. From 56 to 90% of the total Au is enclosed within rock fragments in samples TP - C13 and TP - C14, indicating significant contribution of residual Au. The majority of Au occurs within the fine-grained (<0.1 mm) fraction of the residues.

Gold grains were separated from heavy concentrates of four bulk samples and from the fine-grained residue of sample TP - C13 to understand the origin of Au and find Au grains specific to remobilization in the calcrete environment.

Heavy concentrates.

Each heavy concentrate yielded 6-7 Au particles, ranging from 15 to 80 μm in length and varying in shape from irregular grains to pristine crystals. Approximately half of the grains contain Ag, indicating a residual origin (Table 11). Some of the grains containing Ag have high-fineness rims, depleted in Ag and Cu (Table 12). One, presumably residual, Au grain has inclusions of arsenopyrite. Crystals and angular fragments of arsenopyrite, cinnabar and greenockite (CdS) were identified within the heavy concentrate, indicating residual primary ore materials in the calcrete anomaly.

Table 10: Gold concentrations and mass balance for calcrete, Twin Peaks.

Sample	Fraction	Magnetic susceptibility	Weight (g)	Au content (ppb)	Au mass (10^{-5} g)	Percentage (%)
TP-C1	Fine-grained material		111.89	588	65792	71.6
	Saprolite fragments		113.20	20.2	2287	2.49
	Quartz		4.95	1.1	5.44	0.01
	Ferruginous fragments	Non-magnetic	3.46	10.4	36	0.04
		Magnetic	0.17	45.7	7.95	0.01
	Superpanner concentrate	Non-magnetic	0.86	159	136.26	0.15
		Magnetic	0.08	10.0	0.81	0.00
	Micropanner concentrate		0.61	38900	23651	25.7
	Total		235.22		91916	
TP-C13	Fine-grained material		46.28	973	45028	55.9
	Saprolite fragments		167.82	209	35074	43.6
	Quartz		0.85	5.7	4.85	0.01
	Ferruginous fragments	Non-magnetic	1.88	74.8	140.70	0.17
		Magnetic	1.25	162	202.50	0.25
	Superpanner concentrate	Non-magnetic	0.55	58.6	32.05	0.04
		Magnetic	0.23	31.5	7.31	0.01
	Micropanner concentrate		0.14	10.0	1.40	0.00
	Total		219.00		80491	
TP-C14	Fine-grained material		73.20	62.50	45755	4.60
	Saprolite fragments		170.61	524	89400	89.9
	Ferruginous fragments	Non-magnetic	0.35	103	35.8	0.04
		Magnetic	0.35	145	50.5	0.05
	Superpanner concentrate	Non-magnetic	0.49	211	104.2	0.10
		Magnetic	0.12	30.6	3.79	0.00
	Micropanner concentrate		0.35	10.0	3.48	0.00
	Total		245.48		99413	
TP-C15	Fine-grained material		203.90	371	75648	82.7
	Quartz		0.86	8.2	7.0	0.01
	Ferruginous fragments	Non-magnetic	17.91	193	3457	3.78
		Magnetic	13.36	186	2486	2.72
	Superpanner concentrate	Non-magnetic	1.75	53.8	94.1	0.10
		Magnetic	0.28	25.4	7.0	0.01
	Micropanner concentrate		0.20	32300	6363	6.95
	Total		238.25		91518	

Fine-grained fraction

A total of 185 Au particles were recovered, most were < 40 µm in length with 60% of particles < 20 µm. Calculations indicate the Au grains represent approximately 35% of the total Au mass within the fine-grained fraction. Assuming poor recovery of < 10-15 µm Au grains, a contribution of free fine Au grains appears to be very significant in the total mass balance.

Table 11: Electron microprobe analyses of residual Au from calcrete, Twin Peaks (ppm).

Element	Mean	Det. limit	Min	Max
Ag	140263	494	116083	155319
Cu	57	29	<29	105
Si	37	37	<37	54
Fe	<26	26	<26	<26

Table 12: Electron microprobe analyses of core and rims of residual Au grains from the calcrete, Twin Peaks (ppm).

Sample	Area	Ag	Cu	Si
1	Core	141905	38	<39
	Rim	17423	<29	<39
2	Core	144409	38	51
	Rim	4342	<29	<39

Crystals prevail (55%) with significant proportion of flakes (20%) and elongated grains (11%). Morphologies of crystals are similar to those observed in the saprolite (Photos 19 - 24). Most crystals are tabular and prismatic with minor platy and elongated crystals. No specific Au morphologies that could be related to Au redeposition in the calcrete environment were identified. The crystals are commonly subhedral and uncorroded or slightly corroded and contain no Ag at the detection limit of the EDXS.

4.1.5 Discussion.

The data obtained indicate a complex origin of the Au calcrete anomaly at Twin Peaks. According to the results of partial extractions, Au mass balance and Au grain study, the contribution of residual Au is substantial at Twin Peaks.

The residual Au is occluded within saprolite and ferruginous fragments, and occurs as Ag-containing grains in the heavy concentrate and fine-grained residue. It is difficult to estimate the amount of residual Au grains in the fine-grained residue because of their small size but, assuming that all the irregular grains analysed by SEM (sample TP - C13) contain Ag, at least 30% of Au mass within the fine-grained material appear to be residual. Also taking in an account the amount of Ag-containing grains in heavy concentrates, the calculated proportion of residual Au varies from 36 wt% for TP - C15 to 96 wt% for TP - C14 with 58 wt% average.

These calculations are based on the hypothesis that all the supergene, high-fineness Au grains in the calcrete are the result of Au mobilization within the calcrete themselves. However, the characteristics of the supergene Au crystals in calcrete are very similar to those in saprolite (Section 7.1.5).

Three possible explanations are suggested:

(i) Au migrates in similar forms within both calcrete and saprolite, presumably as halide complexes, resulting in newly formed Au crystals with similar characteristics.
(ii) The morphology of newly formed Au crystals is unrelated to the complex and solution composition, and Au migrates within calcrete differently.
(iii) All high-fineness crystals were formed in the saprolite and accumulated residually by erosion at surface. In this case, the calcrete anomaly is completely residual, due to physical separation and accumulation of the regolith materials at surface.

4.2 Elements associated with Au mineralization: As, Sb, W

Primary Au mineralization is enriched in As (mean 1850 ppm) and S (mean 1060 ppm). The abundances of Sb (0.4 - 9.1 ppm) and W (1.0 - 17.7 ppm) are low, although they show strong correlations with Au and the other ore-related elements.

Arsenic is present mainly in arsenopyrite in unweathered rocks. High As concentrations (up to 1.4%) occur in the primary mineralized zone, with minor, parallel, As-enriched zones to the east. The mean concentrations of As decrease from 380 ppm in the saprock to 7 ppm in the mottled zone. Arsenic is widely dispersed in the regolith at the <30 ppm concentration level, with a 10 - 20 ppm halo extending 100 m to the east. 3D distribution patterns, using a 50 ppm cut off, indicate that As is mainly confined within the strike of the mineralized zone, with some cross-strike dispersion into wall rocks (Figure 39). 2D vertical distribution patterns across the mineralized structure are T-shaped, with strong (up to 1000 ppm As) accumulations in the upper saprolite (approximately 10 - 20 m depth) and an apparent depleted zone above (Figure 40). The distribution of As at Twin Peaks is presumably due to both residual accumulation and chemical redistribution during weathering.

4.3 Other elements

Data for other elements are mostly based on vertical distributions of elements analysed in drill holes JDRC 53, 8, 44 and 118, on sections 20900 mN and 20920 mN, as shown in Figures A1.1 - A1.44, Appendix 1. The raw data are given in Table A1.1, and summary statistics of the main regolith units are given in Tables A1.3 - A1.10, Appendix 1. Results of cluster analysis of elements are represented as dendrograms in Figures A1.45 - A1.46, Appendix 1.

4.3.1 Major elements: Fe, Si, Al

Iron is present dominantly in chlorite in the unweathered rocks with minor amounts of magnetite, ilmenite and sulphides associated with Au mineralization. In the regolith, Fe is commonly retained, with higher abundances (>7.5%) in the mottled zone and soil. Iron occurs as goethite in the residual products, and mainly as hematite in the surficial samples: the strong correlations with Cr, V and Cu being due to their occurrence in Fe oxides. Local concentrations of Fe in the upper saprolite (8 - 20 m, JDRC 53) correspond to an As-Sb-Pb-Cu-W peak, indicating the location of weathered primary mineralization. The bleached interval above (2 - 8 m) is probably due to locality of a weathered alteration halo.

Silicon concentrations are low in the mottled zone and commonly in the soil and pedogenic calcretes, except for JDRC 53, where high Si values in the soil correspond to an occurrence of abundant quartz fragments. The SiO_2 variability throughout the saprolite (61 - 68%) can be attributed to quartz veining.

Aluminium abundances increase progressively throughout the profile with mainly residual accumulation in the mottled zone due to Si leaching. In the soil and calcrete, Al abundances are relatively low (6 - 15%).

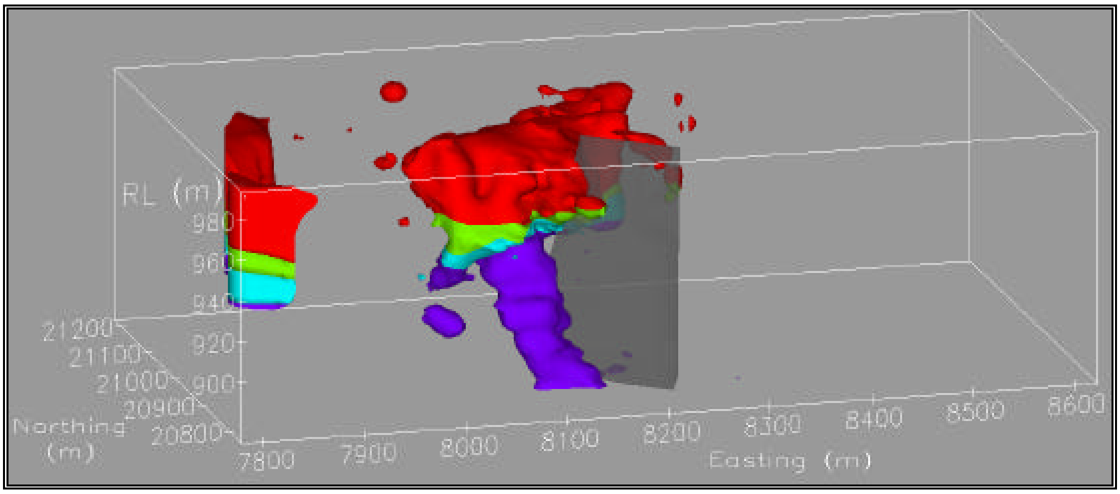

Figure 39: Arsenic distribution using a 50 ppm cut off, Twin Peaks. Key: mauve - fresh rock, blue - slightly weathered, green - moderately weathered, red - highly weathered, grey - dolerite dyke.

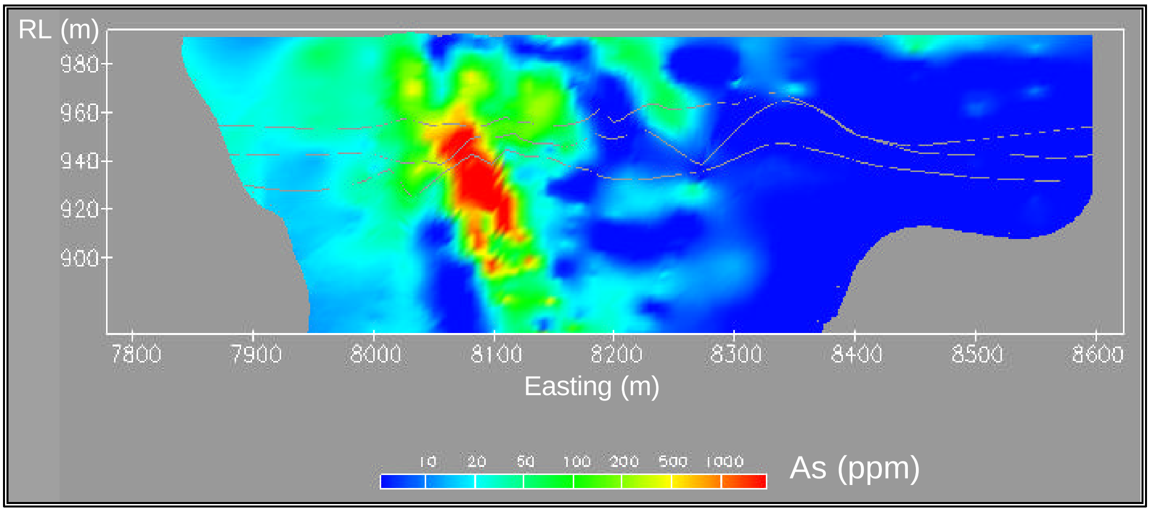

Figure 40: Calculated As distribution for 20900 mN traverse.

4.3.2 Alkaline earth elements: Ca, Mg, Sr, Ba

Calcium, Mg and Sr have some similarities in their behaviour during weathering, being strongly leached at the base of the regolith. Barium commonly occurs as barite in mineralized areas and is relatively immobile, being partly leached only close to the surface.

Calcium is present as ankerite and dolomite in the fresh rock. It is strongly depleted throughout the regolith, with the greatest reduction within the saprock. However, at the surface, Ca is precipitated in pedogenic carbonates, as calcite and, less commonly, dolomite, with concentrations of up to 31% Ca.

Magnesium is hosted predominantly by ferromagnesian silicates (chlorite, amphibole) in the fresh rocks. It is leached less strongly than Ca, gradually decreasing in content upwards through the regolith. Strongly depletion of Mg occurs in the mottled zone, with concentrations generally 0.4 - 0.6% Mg. However, Mg abundances increase in calcrete up to 3%, where it occurs mainly as dolomite.

Strontium has a distribution pattern similar to that of Ca in the regolith, with two definite decreases in concentration at the lower to mid saprolite and mid to upper saprolite boundaries. The latter reduction corresponds to destruction of Na-feldspar as shown by XRD patterns (Table 1 to Table 4).

Barium probably occurs as barite and feldspars in the unweathered rocks. The concentrations of Ba throughout the residual regolith are highly variable (200 - 900 ppm), with slight increases of the mean Ba concentrations in the lower saprolite, upper saprolite and the mottled zone. However, Ba content is reduced at the top of the mottled zone, possibly indicating some barite dissolution. In the soil and calcrete, Ba concentrations are variable randomly, indicating Ba occurring predominantly as accessory barite.

4.3.3 Alkali metals: Na, K, Rb, Cs

The *Sodium* distribution generally resembles that of Mg and Sr, being retained in the lower and mid saprolite, and mostly depleted higher in the profile, presumably due to albite leaching. Sodium occurs in feldspar in the fresh rocks, and mainly in smectite and halite in the regolith.

Potassium, Rb and *Cs* are strongly correlated and show similar distribution patterns in the regolith. The concentrations of K, Rb and Cs decrease upwards through the regolith, particularly in the upper saprolite and mottled zone, presumably due to weathering of micas and feldspars. There appears to be a minor accumulation in the lower saprolite in the zone of supergene Au enrichment, for reasons not presently understood.

4.3.4 Halogens: Cl, Br

Chlorine is accumulated in the regolith. Concentrations of up to 8300 ppm in the upper saprolite presumably reflect the high Cl content of the groundwaters. Chlorine distribution appears random throughout the regolith, with local accumulations in the saprolite and mottled zone and common lower concentrations near the surface. Chlorine principally occurs as halite in weathered materials, either naturally precipitated in rock cracks as a result of water evaporation, or precipitated during drying of wet materials after sampling.

Bromine concentrations are comparatively low (1 - 19 ppm) at the site with strong correlation with Cl (Figures A1.6, A1.17, A1.28, A1.39, Appendix 1). The tendency for Br accumulation in the clay-rich zones, and particularly in the mottled zone, is more definite than for Cl.

4.3.5 Base and transition metals: Cu, Pb, Zn, Co, Ni, Mn

The Goldfields Exploration Pty. Ltd database for Pb, Cu and Zn were used in addition to data from CRC LEME analyses. Using MVS (Section 2.1.6), 3D computer visualisation was performed and series of 3D and 2D distribution patterns were generated, as shown in Figure 41 - 44.

Copper. Unweathered felsic volcaniclastic rocks contain 40 - 50 ppm Cu, with the highest concentrations, up to 100 ppm, along the mineralized strike (Figure 41). In regolith, Cu shows a (presumably) residual distribution in the saprock to upper saprolite, and is apparently depleted in the mottled zone and upper bleached saprolite (20 - 30 ppm). Copper is slightly concentrated (30 - 40 ppm) near the surface in the eastern part of the area (Figure 42).

Lead abundances are generally low (<20 ppm) in fresh rocks. In the regolith, Pb is slightly concentrated up to 35 ppm in the lower saprolite, and, at the top of the profile, with some dispersion to the east of the primary zones (Figure 43). Between the enrichments (*i.e*., in the upper saprolite) Pb is slightly depleted.

Zinc shows a generally homogeneous distribution in fresh rocks with concentrations of 60 - 80 ppm. It is enriched in the lower to mid saprolite with apparent absolute accumulations (>100 ppm) near the top of the mid saprolite (Figure 44). Above this level, Zn is leached (20 - 40 ppm) (Figure 45).

Cobalt and *Ni* are commonly enriched in the saprock and lower saprolite and leached higher in the profile. They have similar distribution patterns, but Ni shows less mobility in the mid to upper saprolite.

Manganese is concentrated in the saprock and lower saprolite with strong depletion in the upper parts of the regolith. There is also minor concentration of Mn in the soil and calcrete.

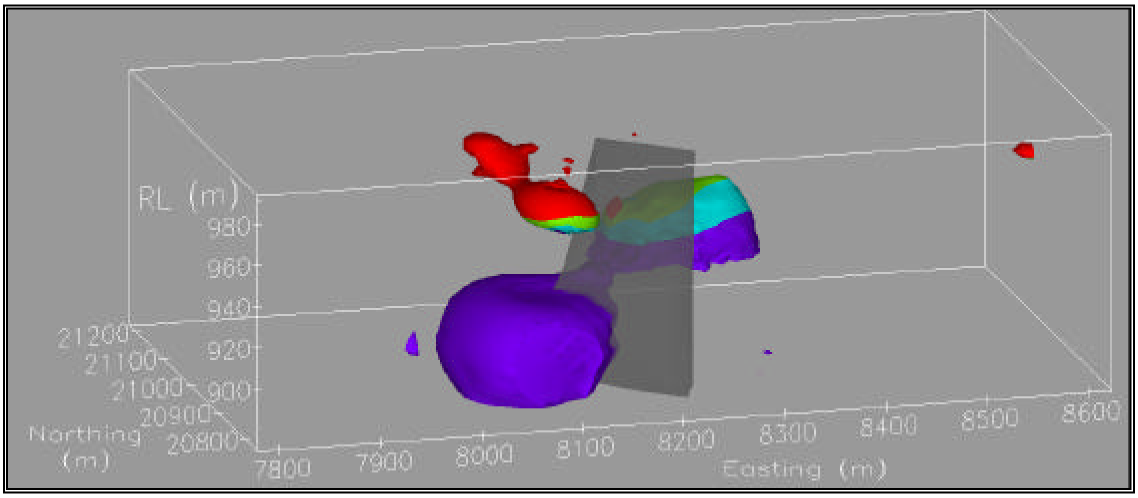

Figure 41: Copper distribution using a 50 ppm cut off, Twin Peaks. Key: mauve - fresh rock, blue - slightly weathered, green - moderately weathered, red - highly weathered, grey - dolerite dyke.

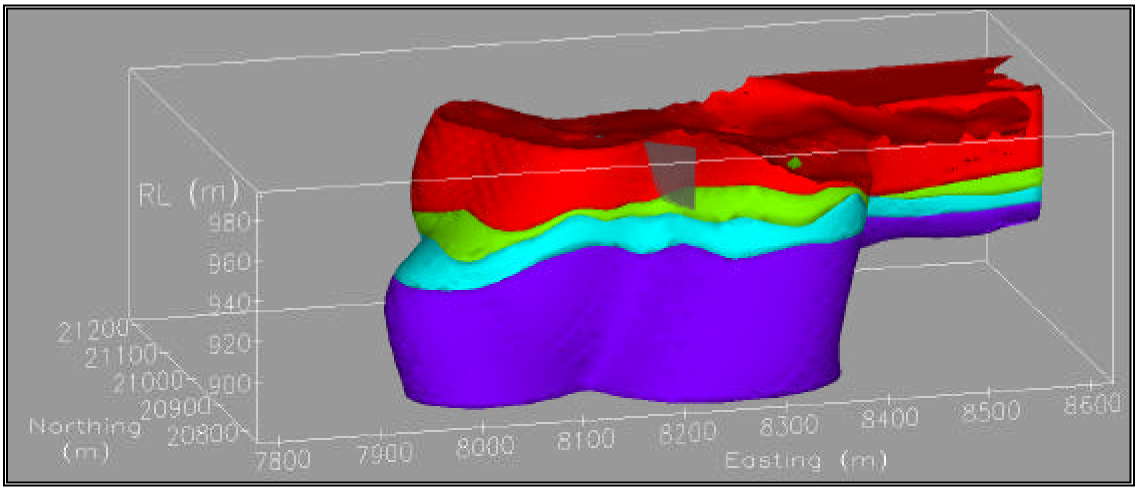

Figure 42: Copper distribution using a 30 ppm cut off, Twin Peaks. Key: mauve - fresh rock, blue - slightly weathered, green - moderately weathered, red - highly weathered, grey - dolerite dyke.

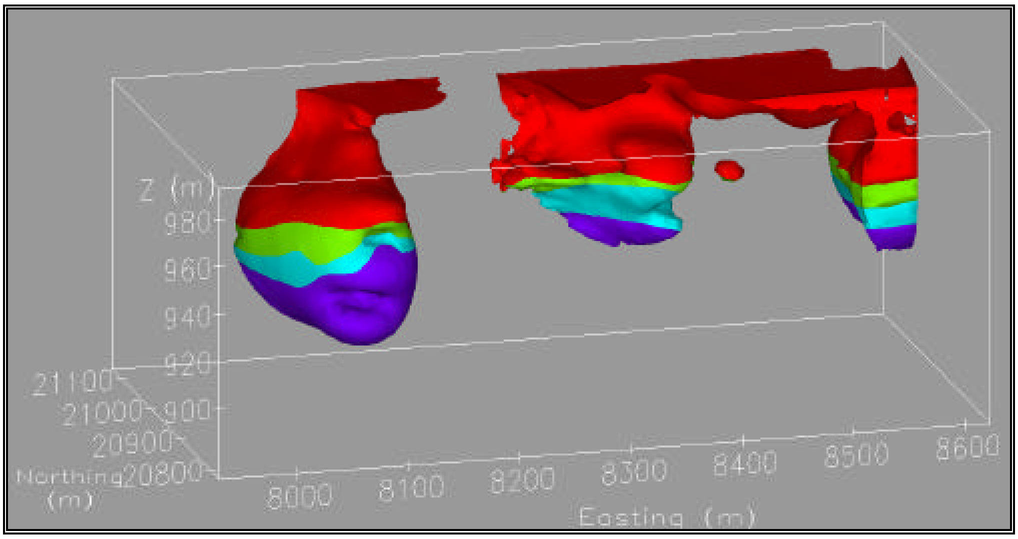

Figure 43: Lead distribution using a 20 ppm cut off, Twin Peaks. Key as below..

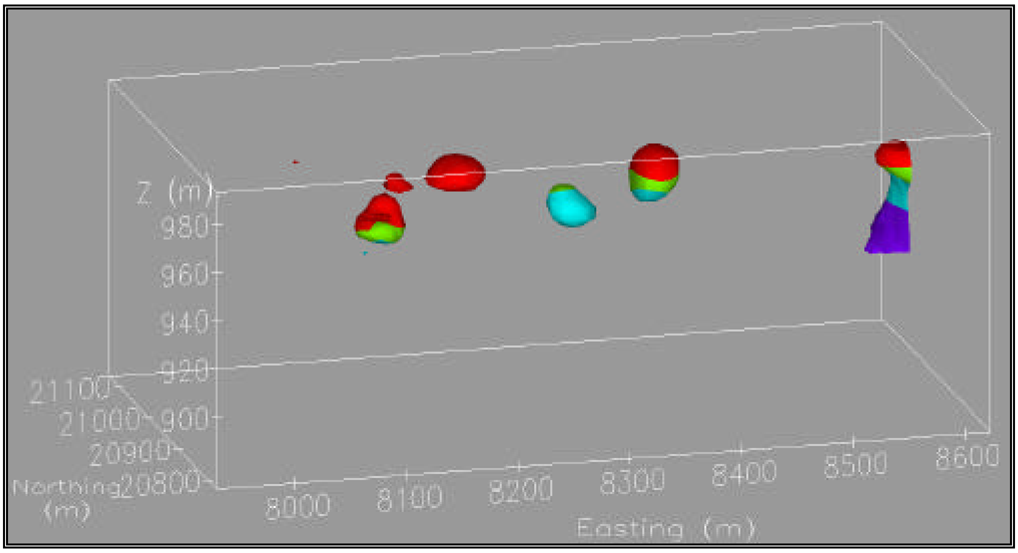

Figure 44: Zinc distribution using a 100 ppm cut off, Twin Peaks. Key as below.

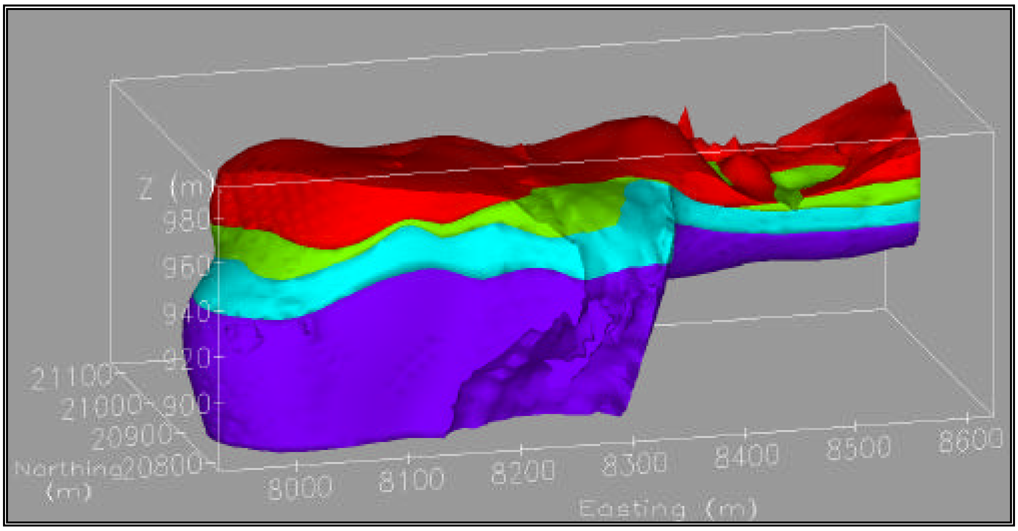

Figure 45: Zinc distribution using a 60 ppm cut off, Twin Peaks. Key: mauve - fresh rock, blue - slightly weathered, green - moderately weathered, red - highly weathered.

4.3.6 Lithophile transition elements: Ti, Cr, V, Sc

The distribution patterns of Ti, Cr, V and Sc are broadly similar, with progressive enrichment throughout the regolith. These elements are hosted by chlorite and accessory ilmenite, magnetite and chromite in the unweathered rocks, and are mostly residually accumulated in Fe oxides in the regolith. Concentrations of the elements appear random near the surface, possibly related to the distribution of ferruginous materials.

4.3.7 Immobile elements: Zr, Hf, Th, Nb

The concentrations of these elements slightly increase upwards through the regolith. Strong correlations between Zr and Hf reflect their principal occurrence in zircon. Correlations of Zr and Hf with Th are weaker, and some Th may be present in monazite or apatite. The increased concentrations of Zr and Hf in the mottled zone of JDRC 118, coincident with enrichments of Ti and Ba, are probably due to relative accumulations, as the result of Si leaching from this zone.

4.3.8 Rare earth elements: Y, La, Ce, Sm, Eu, Yb, Lu

The distributions of these elements are generally similar, with some differences between light (La, Ce, Sm, Eu) and heavy (Yb, Lu) REE and Y, particularly in the upper regolith.

Lanthanum, Ce, Sm and *Eu* are enriched in the lower to mid saprolite with two peaks at the base of the upper saprolite and the mid to lower saprolite boundary. In the upper saprolite, light REE are strongly depleted, with concentrations near detection limits.

In contrast, *Yb, Lu* and *Y* show less evidence of strong leaching in the upper saprolite and enrichment in the mid saprolite (Figures 16 to 19). Leaching of HREE is weaker and more progressive than that of LREE. Ytterbium and Lu show strong correlations in the regolith despite the low Lu abundances. The concentrations of both light and heavy REE in the soil and pedogenic calcrete are relatively low.

The depletion of light REE in the upper saprolite reflects their mobilization in an acid environment and leaching during the development of the kaolinitic zone. Similar REE leaching from the clay and mottled zones have been previously observed at Mt Percy and Golden Delicious (Butt, 1991; Bristow *et al.*, 1996). At these sites, close relationships between La and Ba were also observed, suggesting their joint occurrence in albite. The absence of correlations between La and Ba at Twin Peaks is probably due a more widespread distribution of barite within the mineralized zone.

The enrichments of REE at the mid/lower saprolite boundary are coincident with the supergene Au accumulations. Possible explanations are discussed below (Section 8).

5. REGOLITH GEOCHEMISTRY AT MONTY DAM

5.1 Gold

5.1.1 Gold distribution within the regolith cover

The Au distribution study at Monty Dam is based on a Goldfields Exploration Pty. Ltd data set of 13750 assays within the study area. Primary Au mineralization is hosted by hematite-silica-pyrite-sericite-chlorite alteration zones within volcaniclastic rocks of andesitic to trachy-andesitic composition. 3D visualization (500 ppb cut off) shows two column-shaped ore zones steeply dipping east, namely Monty Dam and Elliot's Lode (Figure 46). Small patches of high grade Au between these orebodies mark the northeast striking mineralized trend. This structure can be seen more clearly at the low cut off level of 30 ppb.

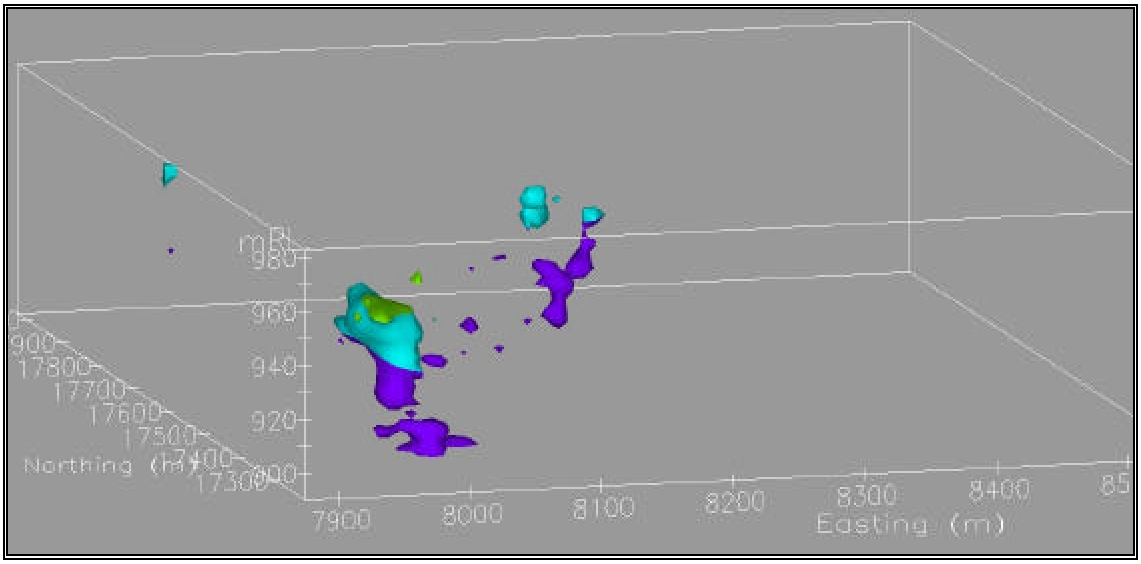

Figure 46: Calculated 500 ppb Au plume, Monty Dam.
Key: mauve - fresh rock, aqua - slightly weathered, green - moderately weathered.

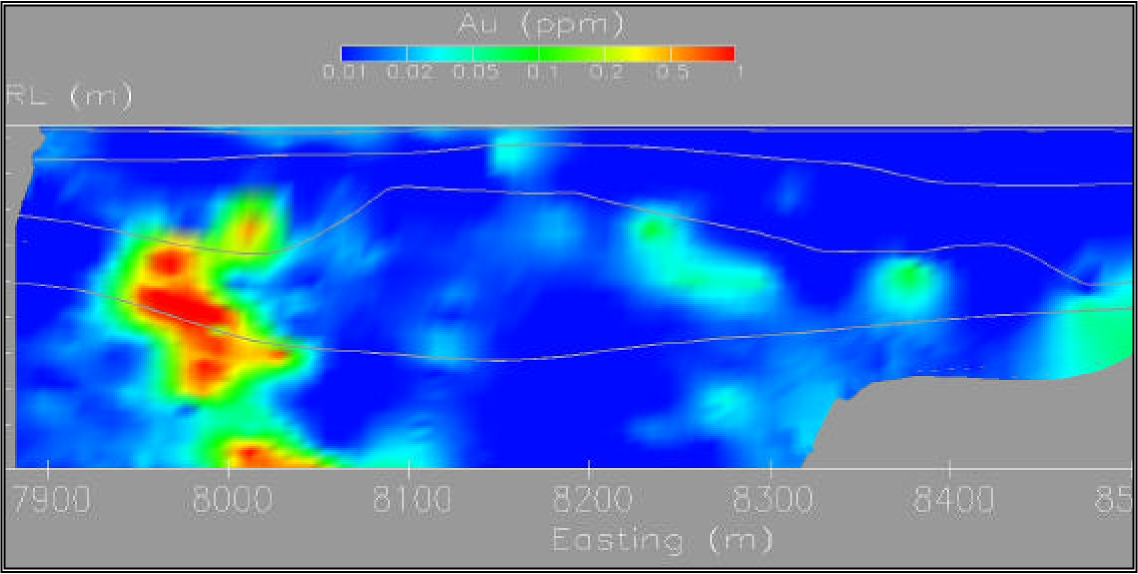

Figure 47: Calculated Au grade for 17400 mN section, Monty Dam.

In the regolith, Au is retained residually in the slightly weathered to lower moderately weathered rocks, and is strongly depleted above, in the highly weathered rocks. In contrast to Twin Peaks, lateral Au dispersion is very weak and may be seen only in cross-sections (Figure 47). Visual analysis of raw geochemical data in sections shows a thin (1 to 2 m), lateral dispersion halo at the 10 ppb cut off, extending up to 80 m to the east from the mineralization.

Monty Dam is in an erosional regime and surface anomalies are very small,. using a 30 ppb cut off. Anomalies are broader, up to 100 m, at a 20 ppb cut off and are located as projections of primary mineralized zones at the surface (Figure 48 and Figure 49).

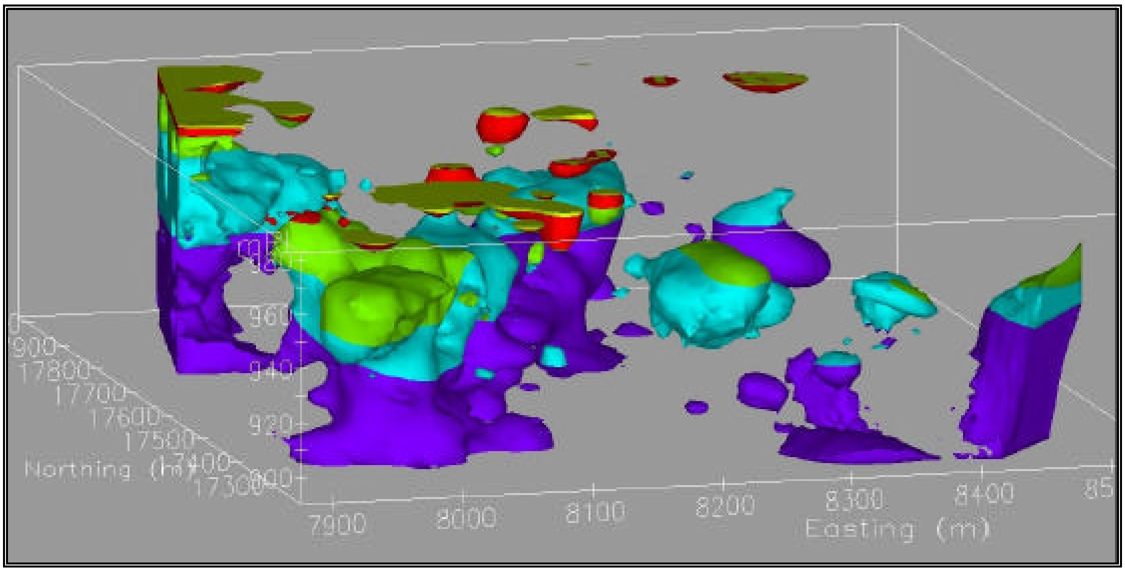

Figure 48: Calculated 20 ppb Au plume, Monty Dam. Key: mauve - fresh rock, aqua - slightly weathered, green - moderately weathered, red - highly weathered, yellow-green – alluvium.

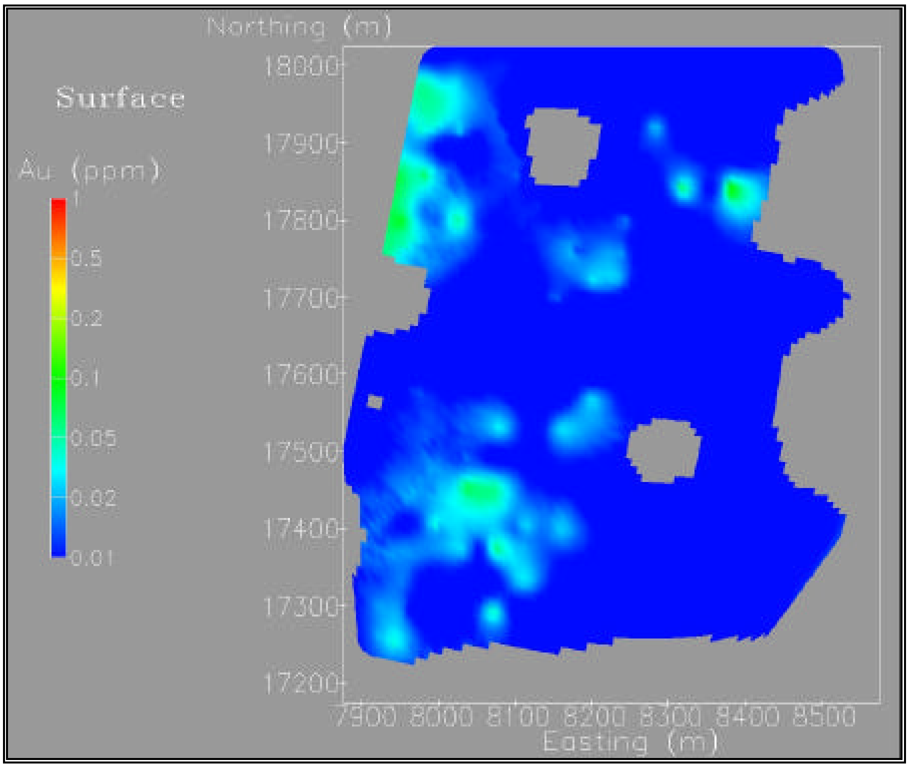

Figure 49: Calculated Au distribution at the surface, Monty Dam.

Cross-sections show four major levels of Au enrichment in the vertical profile, as follows:

(i) Within transported overburden and soil;
(ii) In the moderately weathered rock zone at about 40 m depth;
(iii) At the base of weathering;
(iv) Within fresh rocks approximately 30-35 m below base of weathering.

5.1.2 Gold concentration calculations

As at Twin Peaks, the raw geochemical data at Monty Dam was investigated by combining Au values into each metre elevation, and the mean (Figure 50) and geometric mean (Figure 51) Au plotted vs. RL. Results for Monty Dam are similar to those for Twin Peaks, though with a slightly shallower depth of depletion and a weaker Au anomaly at surface.

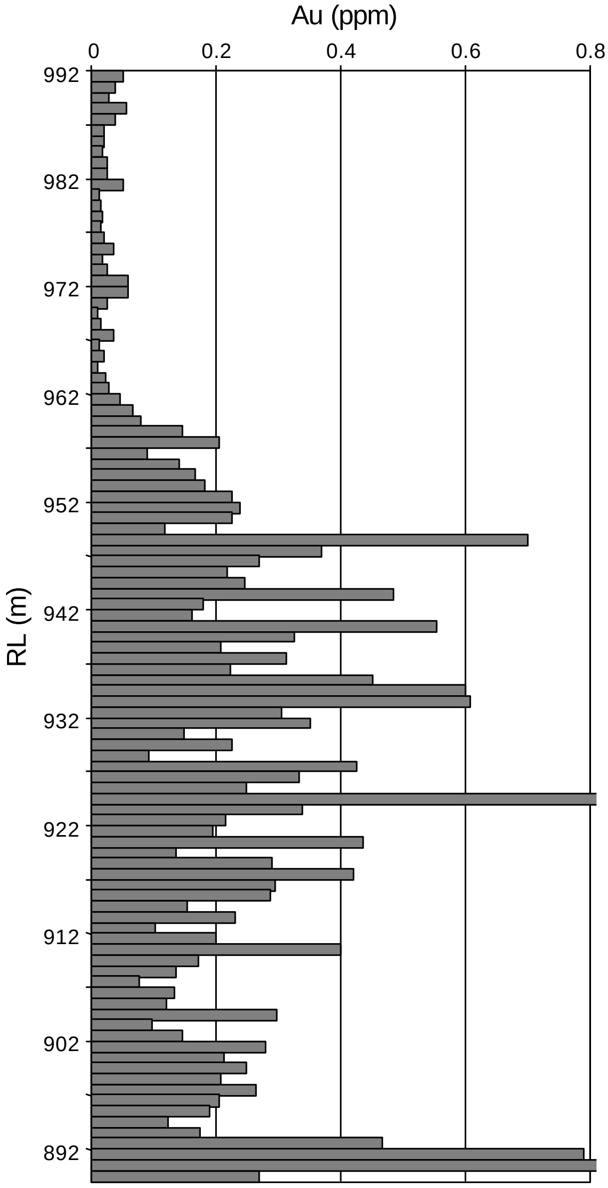

Figure 50: Mean Au grade vs. RL, using raw data, Monty Dam.

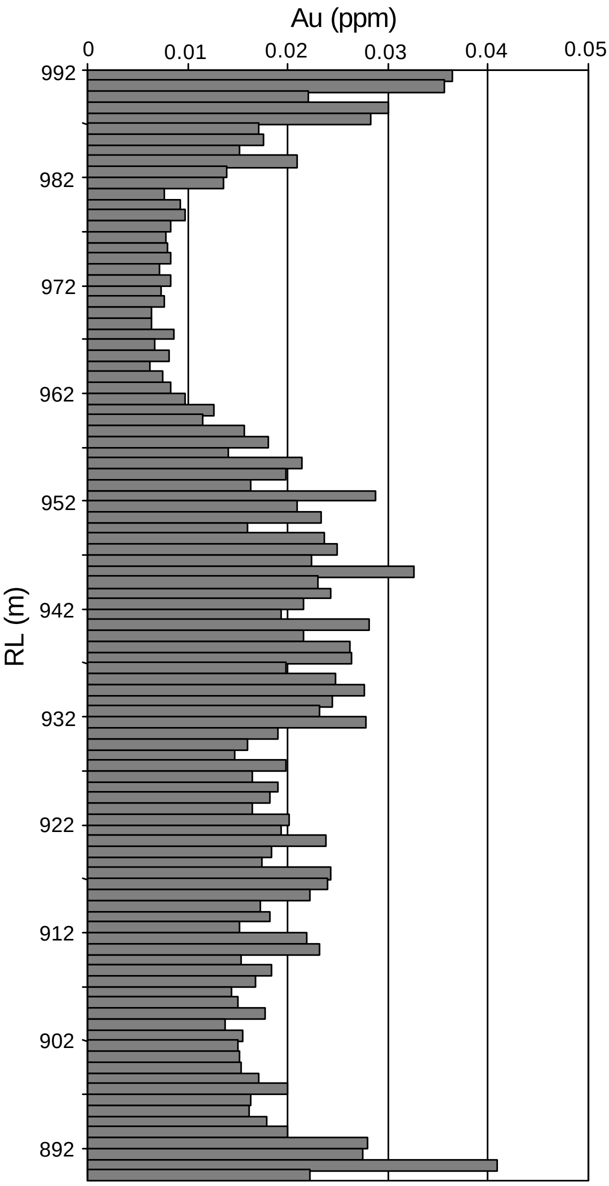

Figure 51: Geometric mean Au grade vs. RL, using raw data, Monty Dam.

Gold concentration calculations were performed on the 3D grid of Monty Dam. The spreadsheet data files for both cases are included in the accompanying CD (in 'Au concentration calculations' Folder; Appendix 4) and the results discussed in detail below.

Calculations of the volumes of each regolith layer within the Monty Dam deposit (Figure 52) indicate considerably higher proportions of moderately (25%) and slightly (51%) weathered rocks, relative to Twin Peaks (14% and 19% respectively; Section 4.1.2). The upper highly weathered layer is much thinner than at Twin Peaks (23% compared with 67%). Additionally, there is a thin layer of alluvium (1.6%). Unlike Twin Peaks, (Section 4.1.2; Figure 25), where there is a considerable increase in mean Au concentration from bedrock through slightly to moderately weathered rock, at Monty Dam (Figure 53), the increase in mean Au content going from bedrock (66 ppb) to slightly weathered rocks (68 ppb) is modest. The Au content decreases in the moderately weathered rocks (37 ppb) and further still in the highly weathered rocks (12 ppb). There is a slight enrichment in the thin alluvium (14 ppb), presumably reflecting a minor surface enrichment.

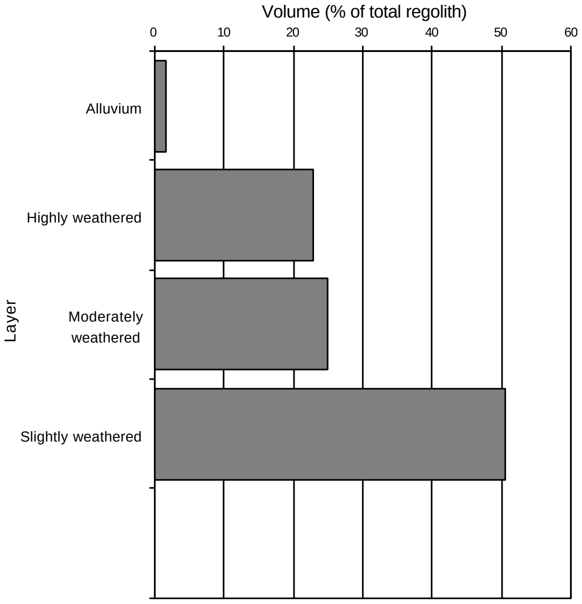

Figure 52: Comparative volume of each regolith layer from Monty Dam, as a percentage of the total regolith.

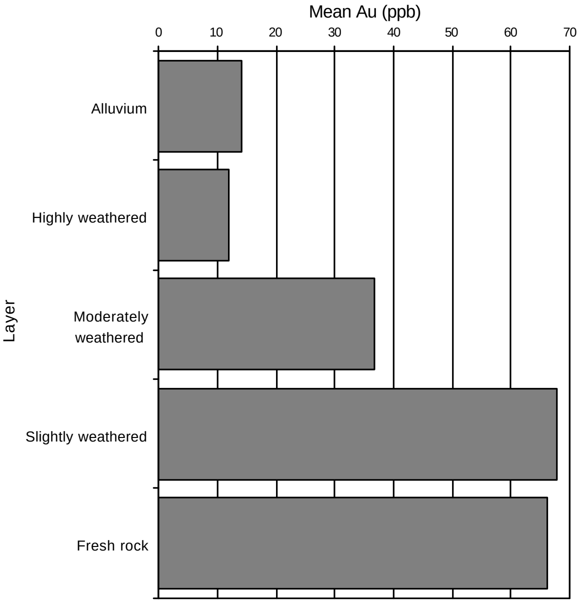

Figure 53: Mean Au for each regolith layer from Monty Dam.

The greatest contrast in mean Au concentrations is obtained by combining the slightly and moderately weathered units and splitting the combined material by RL (Figure 54). As shown in Figure 55, the lowest weathered zone (below 948 m) had a significant Au enrichment (91 ppb) relative to bedrock. Between 948 and 966 m is a intermediate zone (50 ppb Au), with the material above 966 m (15 ppb) having a little more Au than the highly weathered zone. Unlike Twin Peaks, this intermediate zone is thick, being 35% of the total weathered material. The slight surface enrichment is better observed by combining the thin alluvium with any highly weathered material within 3 m of the surface, which demonstrates the top 3 m of the regolith contains 15 ppb Au.

Further calculations of mean Au contents for Monty Dam are based on 3 m thick slices taken above and below the weathering front (Figure 56) and the highly to moderately weathered transition (Figure 57) and below the surface (Figure 58). The reliability of the results of each slice have been calculated using the method described in Section 2.2.4. Only those slices considered at least 60% reliable were used.

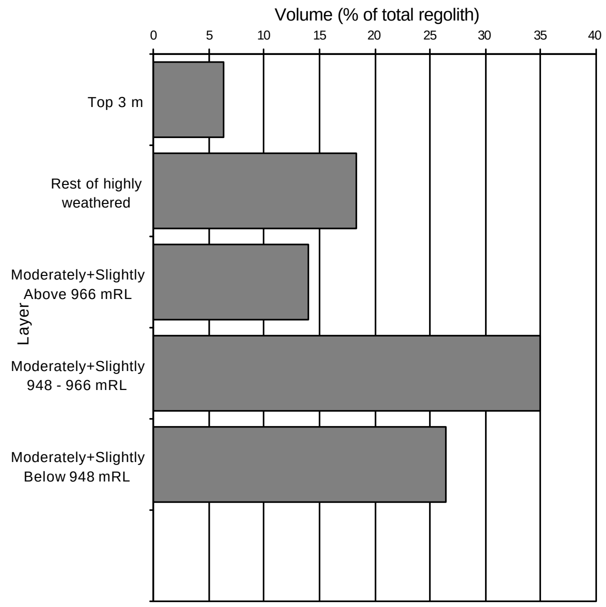

Figure 54: Comparative volume of regolith layers optimized for Au concentration discrimination, Monty Dam, as a percentage of the total regolith.

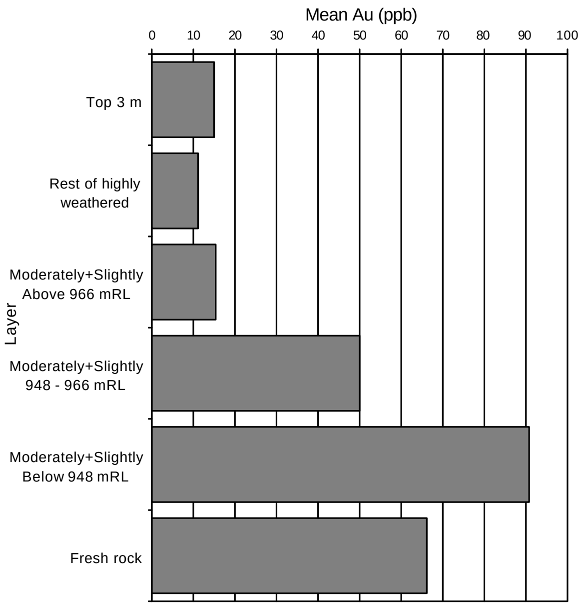

Figure 55: Mean Au of regolith layers optimized for Au concentration discrimination, Monty Dam.

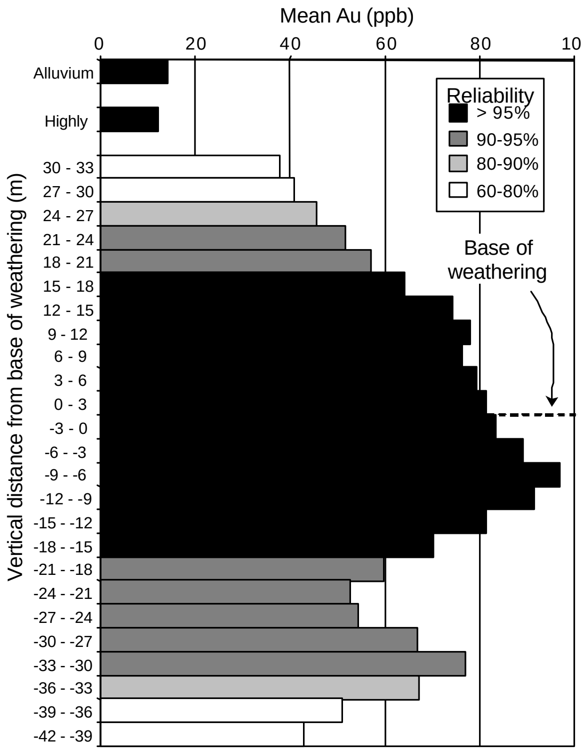

Figure 56: Mean Au vs. distance from the weathering front for Monty Dam.

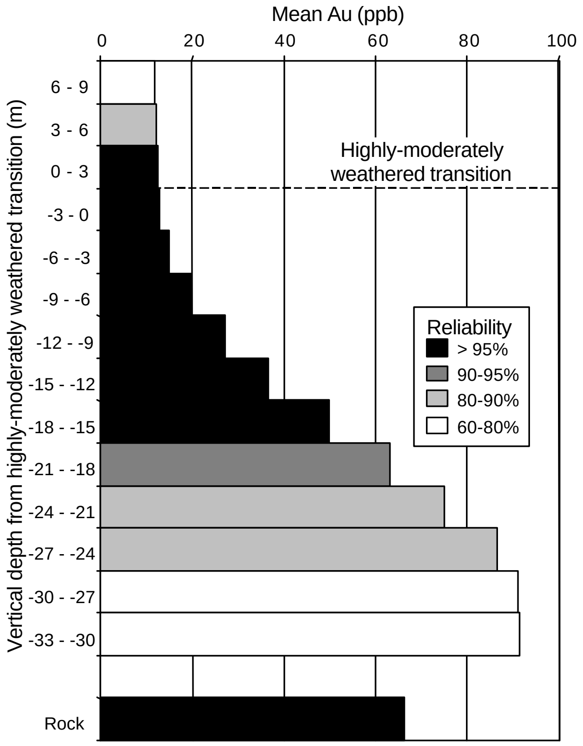

Figure 57: Mean Au vs. distance from the highly to moderately weathered transition for Monty Dam.

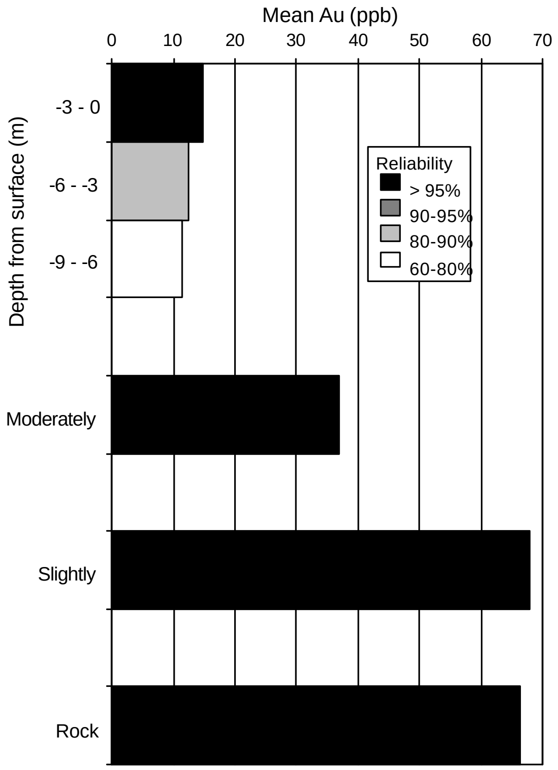

Figure 58: Mean Au vs. depth from surface for Monty Dam.

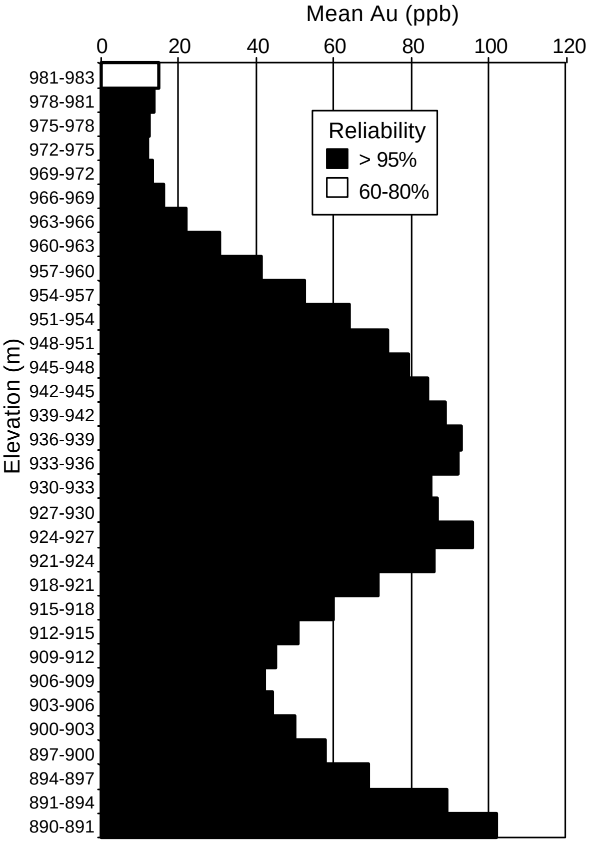

Figure 59: Mean Au vs. elevation for Monty Dam.

Calculations of mean Au as a function of distance from the base of weathering (Figure 56) show that Au concentration in the bedrock varies with a low of 53 ppb 21-24 m below the weathering front to a high of 97 ppb 6 – 9 m below the weathering front. There is a decrease in Au concentration above the weathering front. This Au depletion continues from the weathering front to the highly to moderately weathered transition (Figure 57) (about 30 m depth). In comparison, at Twin Peaks, depletion occurs above this boundary (Figure 29).

Mean Au concentrations in the top 3 m are 15 ppb (Figure 58), declining to 11 ppb below 6 m, before increasing with depth at the approach to the highly to moderately weathered transition.

Calculations of Au concentrations in the residual regolith, as a function of elevation (Figure 59), shows variation in Au concentrations of 42 - 96 ppb between 870 and 930 m elevation, which are the depths dominated by unweathered rock. Immediately above this elevation there is little change in Au grade followed by a gradual depletion starting at 942 m elevation, in contrast to the sharper depletion front at Twin Peaks (Figure 31).

5.1.3 Dispersion in the saprolite.

In contrast to Twin Peaks, there is no prominent Au accumulation below the depletion at Monty Dam. Lateral dispersion is also very slight, occurring as very thin and low - grade halo (see Section 5.1.1) just at the boundary between mid- and lower-saprolite. PIMA data and results of wet sieving for four drill holes on section 17370 mN indicate that the upper boundary of the supergene halo is coincident with the front of chlorite to kaolinite transformation and an interval of gradual downward increase in the proportion of coarse fragments in drill cuttings. In contrast to Twin Peaks, Au within the depleted zone and saprolite dispersion halo does not show correlations with REE.

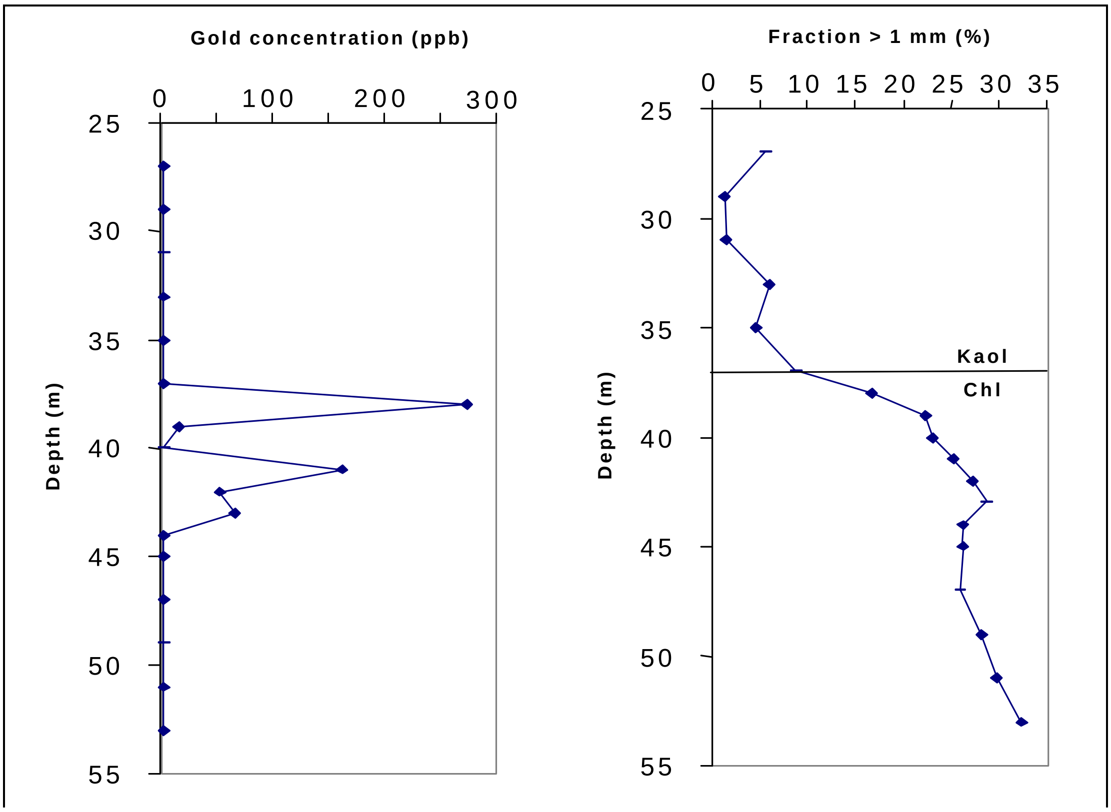

Figure 60: Gold distribution, the proportion of coarse fragments in drill cuttings and position of the kaolinite/chlorite transition (Kaol/Chl) in vertical profile, drill hole JDRC 64.

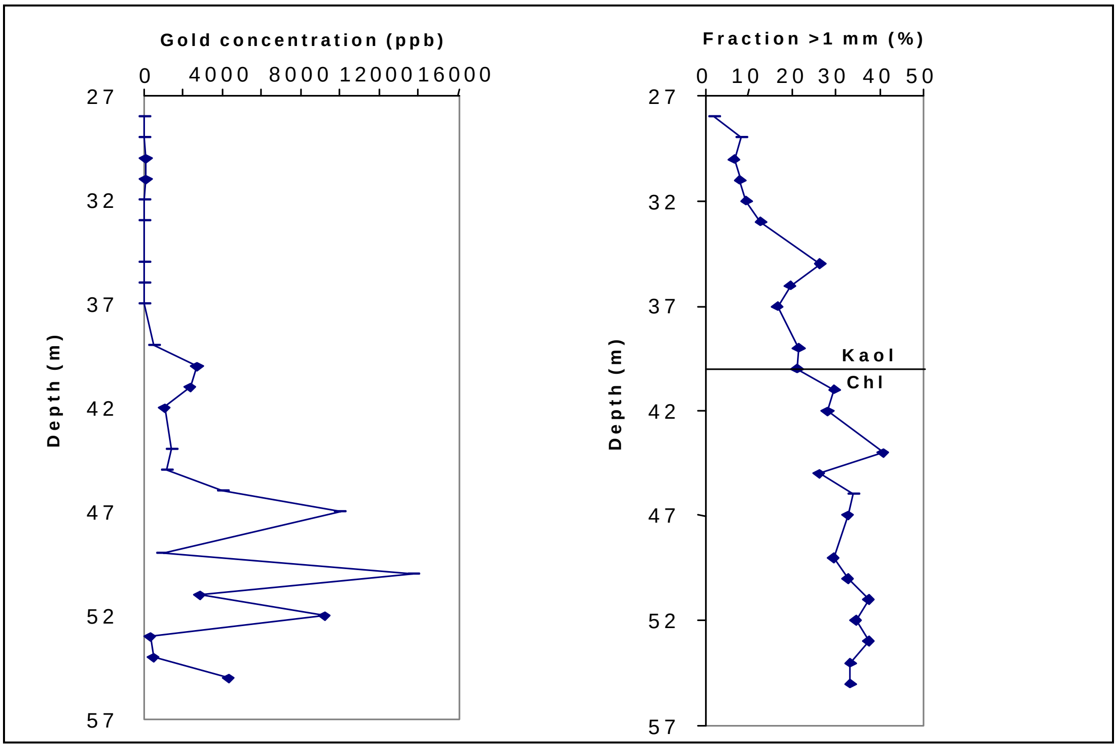

Figure 61: Gold distribution, the proportion of coarse fragments in drill cuttings and position of the kaolinite/chlorite transition (Kaol/Chl) in vertical profile, drill hole JDRC 62.

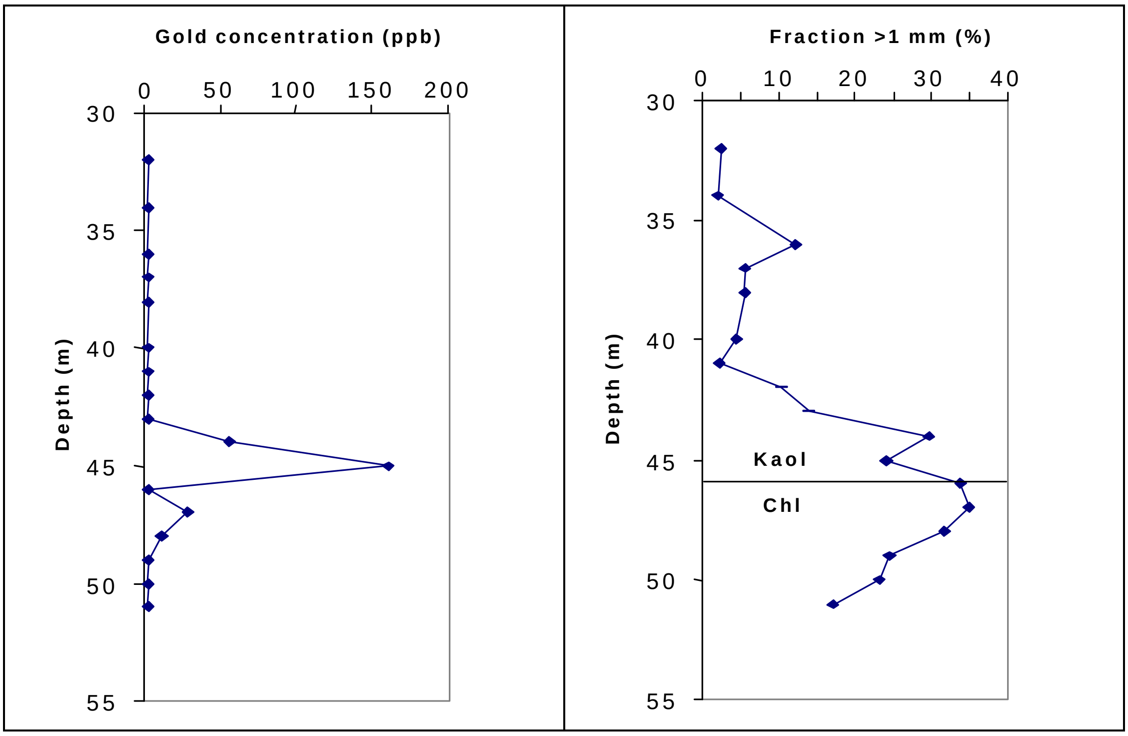

Figure 62: Gold distribution, the proportion of coarse fragments in drill cuttings and position of the kaolinite/chlorite transition (Kaol/Chl) in vertical profile, drill hole JDRC 114.

5.2 Other elements

Arsenic. Arsenic is much less abundant than at Twin Peaks and seems not to be associated with Au at Monty Dam. Local, up to 15 ppm, As concentrations occur in fresh rocks to the west and east of the mineralized structure, with slight enrichment upward through the regolith profile (Figure 63).

Copper. The wall rocks east of the mineralized structure are enriched in Cu, using a 100 ppm cut off, with the local high of 300 ppm Cu in the regolith in the 17300 - 17400 mN area (Figure 64).

Lead. Two local spots enriched in Pb occur in the Monty Dam area. One of the anomalies at a 150 ppm cut off is located in the 17700 - 17800 mN area, and the other, a Pb - Zn anomaly, occurs in the southeastern part of the area. Lead is slightly depleted above the middle of the weakly weathered regolith (Figure 65).

Zinc is generally concentrated (>50 ppm) in the eastern flank, with the greatest (up to 300 ppm) concentrations associated with Pb in the southeastern part of the area (Figure 66).

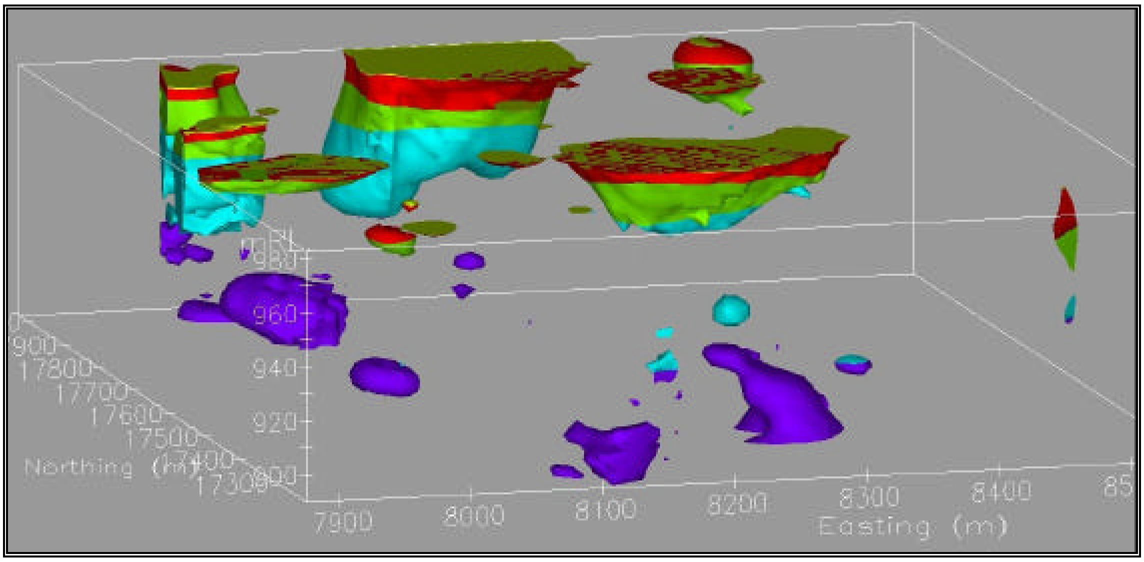

Figure 63: Calculated 10 ppm As plume, Monty Dam. Key: mauve - fresh rock, aqua - slightly weathered, green - moderately weathered, red - highly weathered, yellow-green – alluvium.

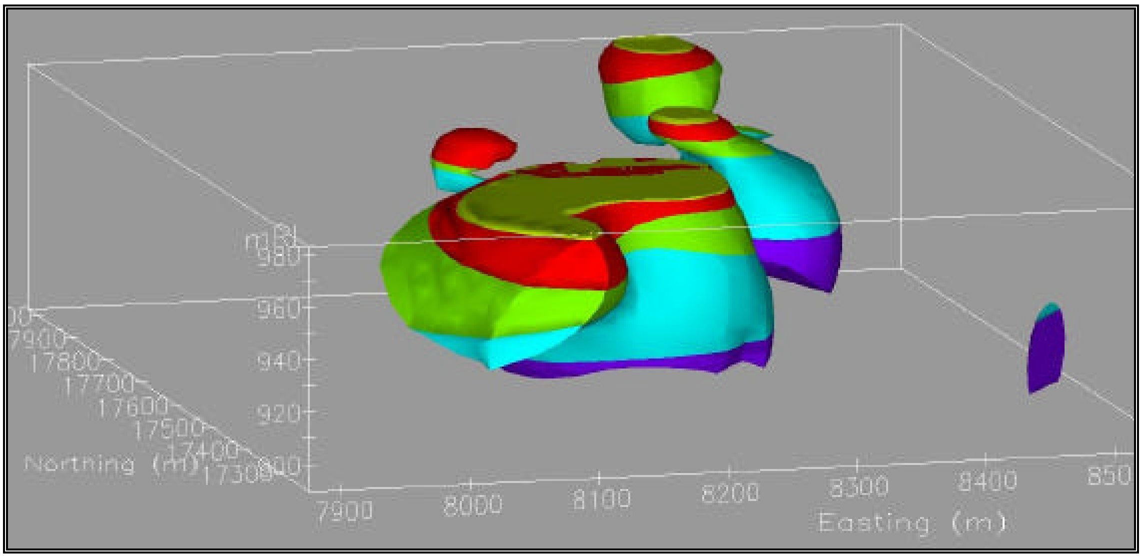

Figure 64: Calculated 100 ppm Cu plume, Monty Dam. Key: mauve - fresh rock, aqua - slightly weathered, green - moderately weathered, red - highly weathered, yellow-green – alluvium.

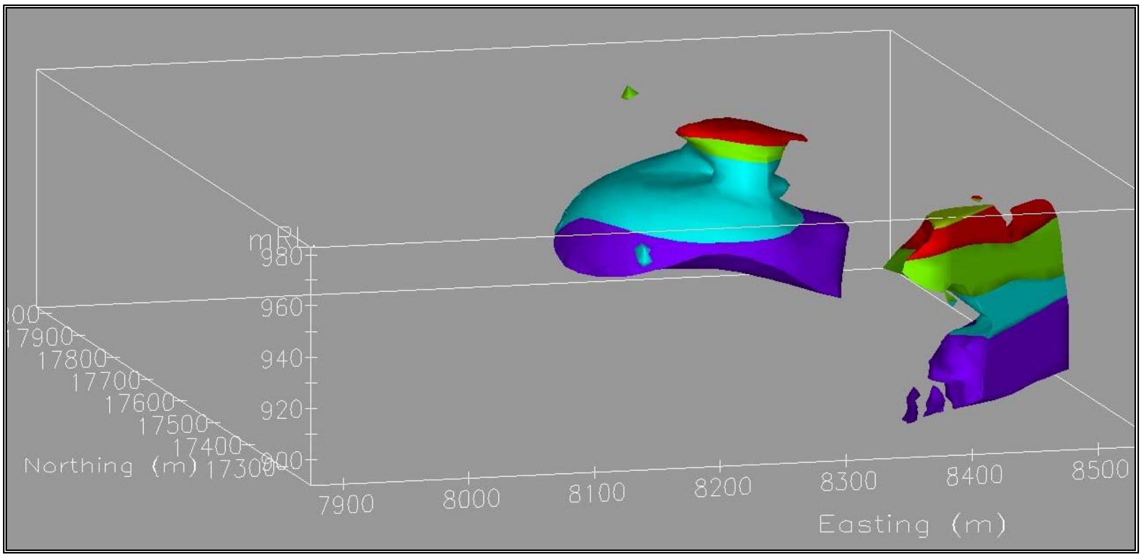

Figure 65: Calculated 100 ppm Pb plume, Monty Dam. Key: mauve - fresh rock, aqua - slightly weathered, green - moderately weathered, red - highly weathered, yellow-green – alluvium.

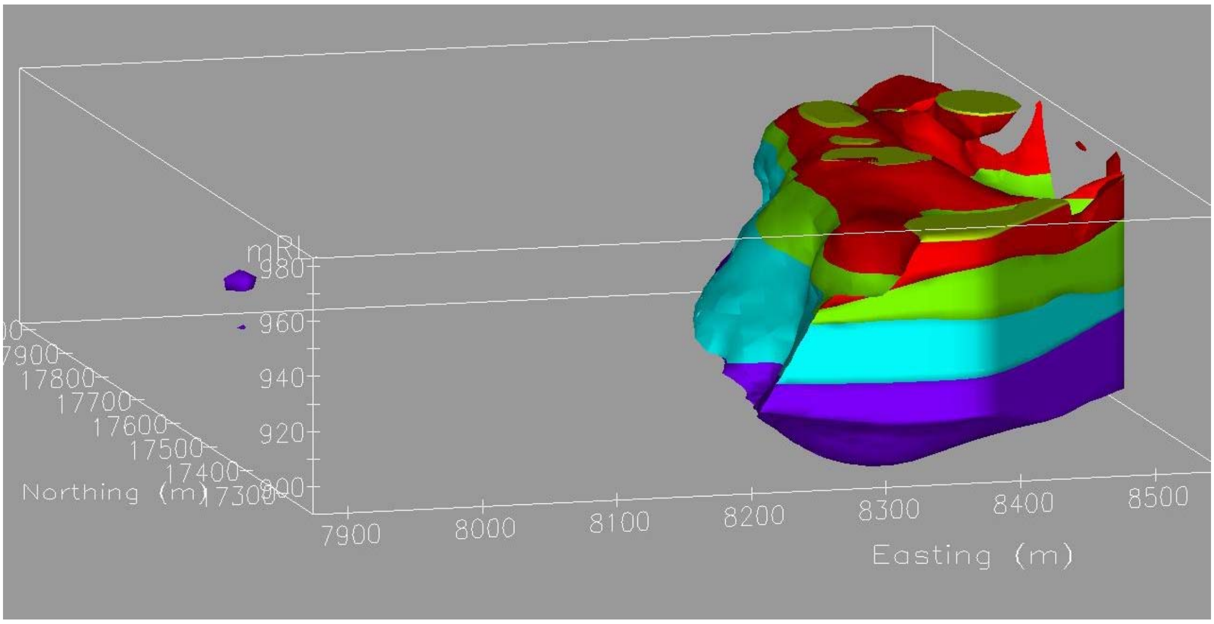

Figure 66: Calculated 100 ppm Zn plume, Monty Dam. Key: mauve - fresh rock, aqua - slightly weathered, green - moderately weathered, red - highly weathered, yellow-green – alluvium.

6. HYDROGEOCHEMISTRY

6.1 Introduction

A primary justification given for the use of hydrogeochemistry in mineral exploration is that groundwater anomalies may be broader and more regular than the mineralization and secondary dispersion halo in the regolith, thus enhancing the geochemical signature. In addition, areas of high chemical reactivity (*e.g.*, faults and shear zones) may have distinct hydrogeochemical signatures even where they are unremarkable in terms of elemental abundances, and where petrographic study is difficult. However, such effects may also be counter-productive, as interpretation may become complicated by the various factors.

Hydrogeochemical studies also provide information on how various materials are weathering. This enhances understanding of active dispersion processes and assists in the development of weathering and geochemical models, which are essential for effective exploration in regolith-dominated terrain.

The aims of this hydrogeochemical study were, therefore:

(i) to yield data on geochemical dispersion processes, and to assist in interpretation of geochemical data;
(ii) to provide information on whether groundwater can be used successfully as an exploration medium in this area in particular and in the central Yilgarn in general;
(iii) to check for differences in groundwaters contacting felsic rocks in comparison with other Archaean lithologies;
(iv) to contribute to a groundwater database on the characteristics of groundwaters at various sites, and to enhance our understanding of groundwater processes in mineralized zones.

The scope of this investigation includes the effect of underlying lithology on the observed water chemistry, thermodynamic modelling, mapping of the data and comparison with results from other Western Australian sites.

6.2 Compilation of results and comparison with other sites

The concentrations of various ions at the Old Plough Dam sites (*i.e.*, Twin Peaks, Monty Dam and the intermediate Main Bore; Figure 6) and at other sites are plotted versus TDS, pH or Eh in Appendix 2, Figures A2.1 - A2.46. The sea water data (Weast, 1983) are used to derive the line of possible values (denoted as the sea water line) if sea water were diluted with freshwater or concentrated by evaporation; the line is shown on each figure except when the concentration in sea water is too low, relative to the concentration of the element in groundwaters. The results from the Old Plough Dam sites can be compared with those from other areas in south WA, which are grouped as follows:

(i) *Northern groundwaters* (N Yilgarn and margins) -
Lawlers (Gray, 1994) and Baxter (Gray, 1995).
Groundwaters in these areas are fresh and neutral, trending more saline in the valley floors.
(ii) *Central groundwaters* (close to and north of the Menzies line) -
Granny Smith (Gray 1993a), Golden Delicious (Bristow *et al.*, 1996), Mt. Gibson (Gray, 1991) and Boags (Gray, 1992a)
Groundwaters are neutral and brackish (commonly <1% TDS) to saline (about 3% TDS), trending to hypersaline (> 10 - 30% TDS) in the playas, commonly with increased salinity at depth.
(iii) Kalgoorlie groundwaters -
Golden Hope mine, (Gray, 1993b), Wollubar palaeochannel (Gray, 1993b), Panglo deposit (Gray, 1990), Baseline mine, Mulgarrie palaeochannel (Gray, 1992b), Steinway palaeochannel (Lintern and Gray, 1995a) and Argo palaeochannel (Lintern and Gray, 1995b).

These groundwaters are commonly acid (pH 3 - 5), except where buffered by extremely alkaline materials (e.g., ultramafic rocks), and saline within the top part of the groundwater mass, trending to more neutral (pH 5 - 7) and hypersaline at depth and when within a few kilometres of various playas in the region.

(iv) Officer Basin -
Mulga Rock palaeodrainage system (Douglas et al., 1993).
Groundwaters are saline to hypersaline and neutral to acid. The major ion chemistry is similar to that of the Kalgoorlie region, but the dissolved concentration of many other ions is low, due to the presence of lignites in the channel sediments

Wollubar, Baseline and Panglo are acid groundwater systems, whereas the other sites have dominantly neutral groundwater. Comparisons with other sites may be useful in indicating the significance of any particular element anomaly, and whether the groundwater composition is affected by particular lithological interactions. Specific descriptions of the varying sites are found in the referenced reports, with generalized descriptions of the hydrogeochemistry of the Yilgarn Craton given in Gray (1996) and Butt *et al.* (1997).

Saturation index (SI; Section 2.1.6) values for varying minerals are plotted in Appendix 3, Figures A3.1 - A3.30. The equilibrium point is shown as the dashed line. The shaded area denotes the zone in which waters may be in equilibrium with that mineral. Note that where a mineral has a very broad zone, this indicates significant uncertainty in the thermodynamic data for this mineral or calculation problems - *i.e.*, samples within that zone are not necessarily at equilibrium, though samples above or below the zone are out of equilibrium.

6.3 Acidity and oxidation potential

An Eh-pH plot of waters from Old Plough Dam and other sites is shown in Figure 67. Groundwaters are combined into the various groundwater groups, as described in Section 6.2. The Twin Peaks groundwaters are acid (pH 3.0 - 5.4) and range from moderately to highly oxidising (270 - 690 mV), similar to the pH and Eh range of Kalgoorlie groundwaters, such as Panglo (Gray, 1990). The exception is a single near-neutral and reduced (pH 6.7, Eh 220 mV) groundwater SW of Twin Peaks deposit (Figure 6). Three of the Twin Peaks groundwaters have Eh values high enough to allow dissolution of >2 µg/L Au, with another 3 groundwaters able to dissolve >0.2 µg/L Au. The Main Bore groundwater is also acid and oxidizing enough to allow dissolution of >2 µg/L Au (pH 3.5, Eh 630 mV). In contrast, the Monty Dam groundwaters are weakly acid to neutral (pH 5.8 - 6.8), presumably due to pH control by the adjacent Lake Rebecca. These groundwaters are commonly reducing (Eh 230 - 400 mV) except for a single, anomalously oxidizing (720 mV), sample (Figure 67).

6.4 Salinity effects and major element hydrogeochemistry

Data are plotted in Appendix 2, Figures A2.1 - A2.14. The Old Plough Dam groundwaters range from saline (4.2%, compared with sea water salinity of 3.5%) to hypersaline (19.7%), with particular characteristics demonstrated by a plot of pH vs. TDS (Figure 68). The Old Plough Dam groundwaters are unlike the Central groundwaters, which have a wide range of salinities and remain neutral, and instead closely match the pH and salinity variations found for the Kalgoorlie groundwaters. For many of the major groundwater elements (*e.g.*, Na, Mg, Cl), the element/TDS plot lie on a straight line defined by that for dilution or precipitation of sea water (Figures A2.1, A2.3 and A2.5): this implies that these groundwaters are in some manner (*e.g.*, by previous sea water incursion or aerosol) sourced from sea water and then subsequently concentrated by evaporation. Some of the Twin Peaks groundwaters are moderately depleted in Ca, relative to the concentrations expected if the groundwater were diluted sea water (Figure A2.4), presumably due to gypsum and/or calcite precipitation. These groundwaters also show significant K depletion (though not as great as that for Kalgoorlie groundwaters; Figure A2.2) and moderate SO_4 depletion (Figure A2.6), presumably due to alunite [$KAl_3(SO_4)_2(OH)_6$] in acid groundwater systems, as a by-product of the dissolution of kaolinite and other alumino-silicates (Gray, 1996). Alunite has been noted at several sites in the southern Yilgarn, *e.g.*, Panglo and Mt. Percy.

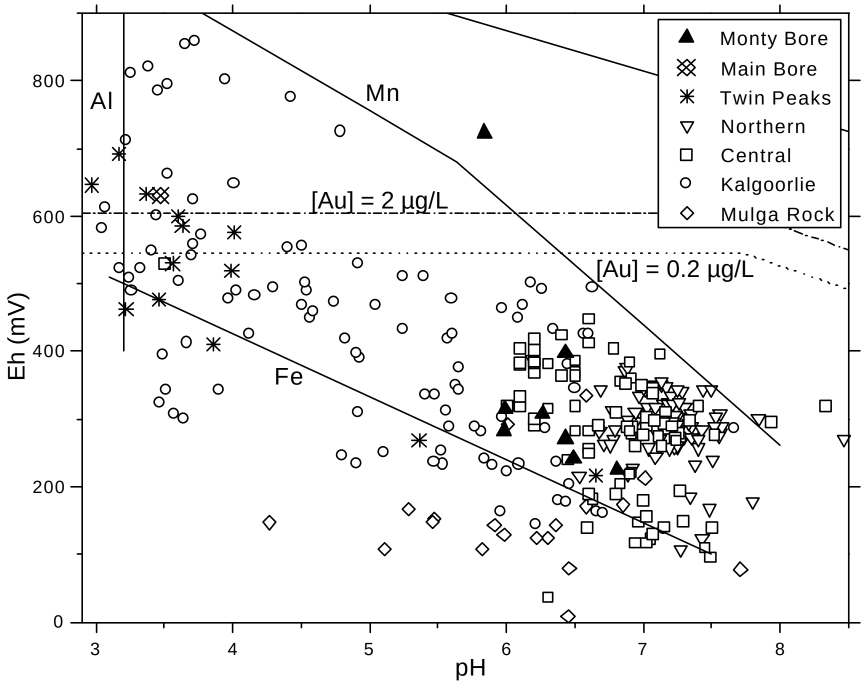

Figure 67: Eh vs. pH for groundwaters from Old Plough Dam and other sites.

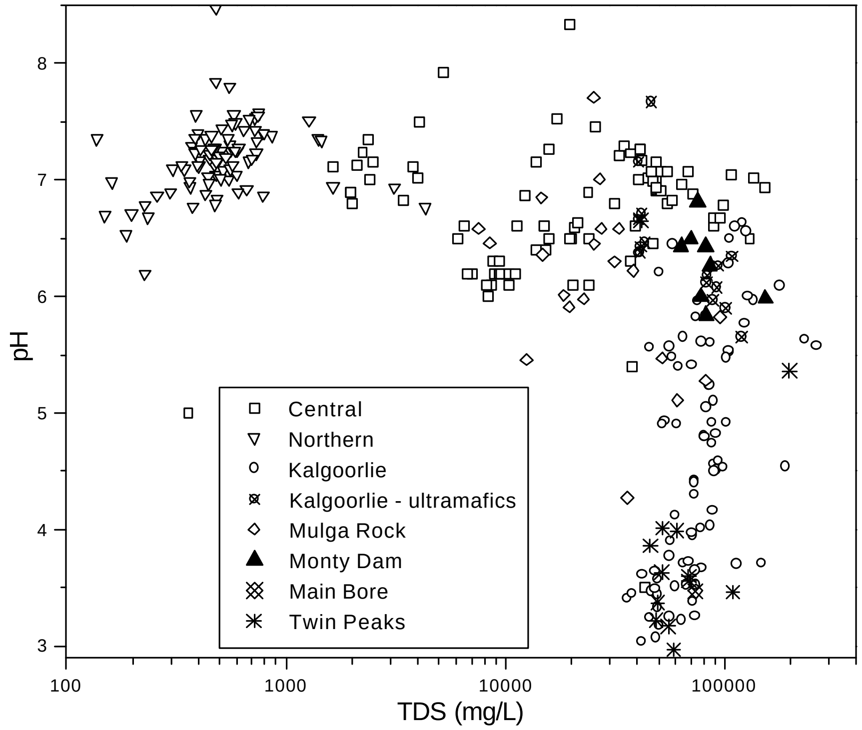

Figure 68: pH vs. TDS for groundwaters from Old Plough Dam and other sites

The potential for dissolution or precipitation of minerals from the Old Plough Dam groundwaters has been tested by speciation analysis (Section 2.1.6). The SI values of the water samples for a number of relevant solid phases are plotted in Appendix 3, Figures A3.1 - A3.30. As discussed in detail in Section 2.1.6, in general a SI of zero indicates the solution is saturated with respect to that mineral, a SI less than zero indicates under-saturation and a SI greater than zero indicates the solution is over-saturated with respect to the mineral phase.

The groundwaters at Old Plough Dam have salinities well below that required for halite saturation (Figure A3.1), although the Monty Dam and more saline Twin Peaks groundwaters are in equilibrium with gypsum (Figure A3.2). The groundwaters are in almost all cases undersaturated with respect to the Ca and Mg carbonates (Figures A3.5 - A3.7). Other major elements that appear to be controlled by mineral equilibration in some or all of the groundwaters are Ba (barite; Figure A3.4), Si (amorphous silica; Figure A3.8) and Al (kaolinite, alunite, jurbanite and possibly amorphous alumina; Figures A3.10 - A3.13). Aluminium solubility is much greater for the acid Twin Peaks groundwaters than for Monty Dam (Figure A2.17) and Si also shows an increase in solubility with lower pH (Figure A2.18). This is presumably due to dissolution of alumino-silicates at the lower pH. Below pH 3.8, groundwaters are in equilibrium, or undersaturated, with respect to kaolinite (Figure A3.10), indicating that even this normally resistant mineral can be dissolved under these conditions. At least some of the released Al is probably incorporated into alunite, giving rise to the K depletion discussed above. However, the gross over-saturation of the groundwaters with respect to alunite (Figure A3.11), and the close equilibration with jurbanite across 3 pH units (Figure A3.12) suggests that Al is not DIRECTLY precipitating as alunite, but instead as an intermediate, possibly amorphous, Al-sulphate which then absorbs K and transforms to alunite. This is discussed in detail in Gray (1990).

6.5 Minor element hydrogeochemistry

Concentrations of the minor elements (Table 13; Figures A2.19 - A2.46) show some similarities to Kalgoorlie groundwaters, as expected for an acid/saline environment (discussed in Gray, 1996). In particular, base metals and REE (*e.g.*, Figures A2.25 - A2.28, A2.39 and A2.40) have higher dissolved concentrations than the neutral central and northern groundwaters, whereas anionic chalcophile elements (*e.g.*, As, Sb; Figures A2.31 and A2.38) have low concentrations. However, close examination of the data show some significant variations, which may be due to the different rock type to the other sites previously examined (*i.e.*, felsic rather than mafic/ultramafic or granitic). At Twin Peaks, Sc, Y, REE, Pb, U, Cr and, to a lesser extent, Mn, Co and Ni (Figures A2.19, A2.32, A2.39, A2.40, A2.43, A2.46, A2.22, A2.23, A2.25 and A2.26) tend to have significantly lower concentrations at any particular pH than those for the Kalgoorlie groundwaters (which mainly represent mafic/ultramafic lithologies). (This lithological discrimination has been observed previously: in particular, at Panglo, shales, mafic and ultramafic rocks all have distinct dissolved base metal signatures; Gray, 1990.) Additionally, the Twin Peaks groundwaters generally show stronger pH control on the solubility of all these elements than previous sites. This suggests that groundwaters contacting weathered felsic rocks are likely to show lower dissolved metal signatures, once pH effects are taken into account. This observation requires confirmation for other areas of felsic rocks elsewhere in the Yilgarn.

The acid Main Bore sample has a generally similar composition to the Twin Peaks groundwaters. However, the more neutral Monty Dam groundwaters are distinctive chemistry, having very low base metal and REE contents, as expected. In addition, they have high dissolved concentrations of Ti, Ga, Ge, Cd, Sn, Sb, W (Figure A2.20, A2.29, A2.30, A2.36 - A2.38, A2.41), for reasons not understood at this stage.

Table 13: Median minor element compositions of groundwaters.

	Twin Peaks	Monty Dam	Main Bore	Northern	Central	Kalgoorlie	Mulga Rock	Sea water	Controls
I	1.9	2.3	1.8	0.2	5	5.8	0.32	0.06	S/Sal ?
Li	0.21	0.05	0.17	<0.005	<0.005	0.9	nd	0.18	Ac ?
Rb	0.048	0.017	0.044	0.013	0.051	0.032	nd	0.12	Min ?
Ba	0.029	<0.005	<0.005	0.04	0.02	0.04	0.03	0.013	Eq/Min
Sc	<0.005	<0.005	<0.005	0.009	0.017	0.019	nd	0.000001	Ac/Min
V	<0.005	<0.005	<0.005	0.007	<0.005	<0.005	nd	0.002	?
Cr	<0.005	<0.005	0.005	0.01	<0.005	0.003	0.002	0.0003	Um
Mn	5.1	0.9	2.6	0.01	0.1	2	0.3	0.0002	Mf/Um/Ac
Fe	0.4	0.9	0.04	0.003	0.05	0.1	1	0.002	S
Co	0.10	0.006	0.099	<0.0005	0.002	0.16	<0.002	0.00002	Um/Mf/Ac
Ni	0.17	<0.01	0.19	0.002	0.001	0.26	0.020	0.00056	Ac/Mf/Um
Cu	0.038	0.006	0.054	0.003	0.003	0.05	0.00	0.00025	Ac/Mf
Zn	0.18	0.02	0.176	0.006	0.01	0.05	0.04	0.0049	Ac/Mf
Ga	<0.001	0.009	0.009	0.002	<0.005	0.006	nd	0.00003	S
As	<0.02	<0.02	<0.02	<0.0002	0.09	<0.02	<0.02	0.0037	S
Mo	<0.01	<0.01	<0.01	0.001	0.009	<0.01	nd	0.01	S
Ag	<0.005	<0.005	<0.005	<0.001	0.0005	0.001	nd	0.00004	?
Cd	0.003	0.012	0.009	<0.002	0.001	<0.002	<0.001	0.00011	?
Sb	<0.001	0.003	0.002	<0.0003	0.001	<0.001	<0.0004	0.00024	S
REE	0.20	0.019	0.45	<0.002	<0.008	0.8	0.013	0.000013	Ac
W	<0.001	0.005	0.004	<0.0002	0.001	0.001	nd	0.0001	S
Au	0.044	0.006	0.499	0.004	0.03	0.05	0.001	0.004	Min
Tl	0.002	0.002	0.003	<0.0002	0.001	<0.002	0.0005	0.000019	S
Pb	0.05	0.02	0.09	<0.001	0.001	0.06	0.012	0.00003	Ac/Min
Bi	<0.001	<0.001	<0.001	<0.0002	0.001	<0.001	<0.002	0.00002	S ?
Th	<0.001	<0.001	<0.001	<0.0002	<0.001	<0.002	<0.001	0.000001	?
U	0.007	0.002	0.014	0.0003	0.002	0.004	<0.002	0.0032	Ac

All concentrations in mg/L (ppm), except Au in µg/L (ppb)   nd: not determined

Eq	mineral equilibrium	Min	enriched in waters contacting Au mineralization
Ac	enriched in acid groundwaters	S	enriched in waters contacting weathering sulphides
Um	enriched in waters contacting ultramafic rocks	Sal	enriched in saline groundwaters
Mf	enriched in waters contacting mafic rocks	?	not clearly defined

6.6 Gold chemistry

The high salinity of the groundwaters at Old Plough Dam implies that the dominant mechanism for the mobilization of Au in the southern Yilgarn, namely as the chloride complex ($AuCl_2^-$):

$$2Au_{(S)} + 4Cl^- + \frac{1}{2}O_2 + 2H^+ \Leftrightarrow 2AuCl_2^- + H_2O \qquad ...(1)$$

is expected to be significant for the acid/oxidizing groundwaters at Twin Peaks and Main Bore, but less important for the more neutral/reduced groundwaters at Monty Dam. Speciation analysis also indicates that the iodide complex AuI_2^- may also be important, which is why the Eh levels shown in Figure 67 for dissolution of Au are lower than shown elsewhere. Dissolved Au concentrations for the most acid groundwaters are at, or possibly below, equilibrium for Au metal (Figure A3.25). The Au concentrations for Main Bore and the oxidized Monty Dam sample are, as expected, high (Figure 69), but the Twin Peaks groundwaters have surprisingly low Au concentrations. This may be a consequence of the depth of sampling. Most of the Twin Peaks bores had collapsed at or above 30 m angled (approximately 26 m vertical) depth. Thus, in terms of bottom of hole or sampling depth the Twin Peaks samples were all within the Au-poor part of the regolith (see Figure 22). The lack of available Au in the regolith may mean poor dissolved Au response, even when the groundwaters have the physio-chemical characteristics to enable Au dissolution.

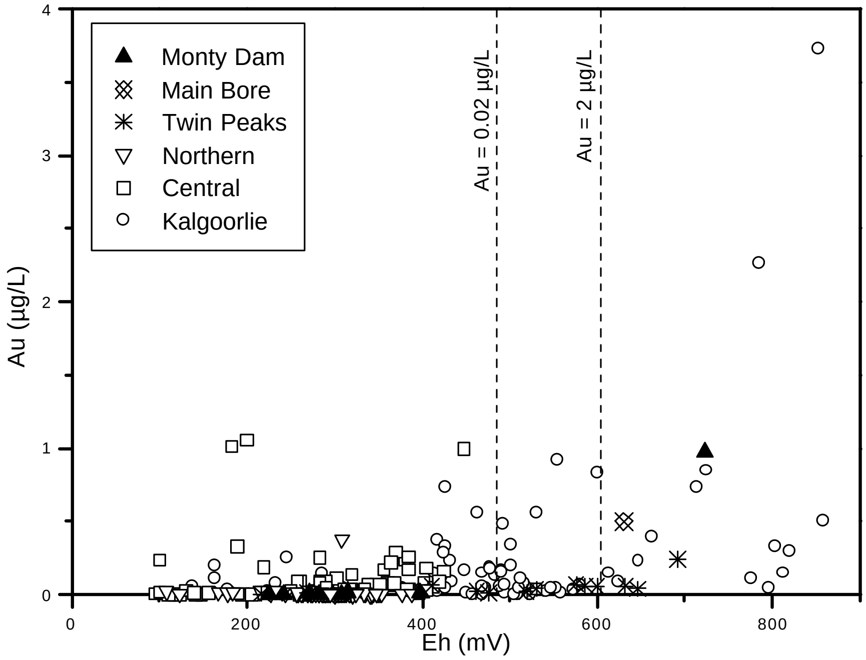

Figure 69: Dissolved Au concentration vs. Eh for Old Plough Dam and other Western Australian groundwaters, with the Eh values for dissolution of 0.02 and 0.2 µg/L Au shown and the dashed lines.

7. CHARACTERISTICS OF PARTICULATE GOLD

7.1 Twin Peaks

7.1.1 Introduction

Gold grains were extracted from 11 bulk samples from the regolith and primary mineralization for detailed study. After panning, fine fractions of the tailings were analysed by INAA for Au to estimate the proportion of fine-grained (<10 µm) Au in the samples, with results given in Table 14. The characteristics of the Au grains are described in terms of their size, morphology, associations and composition as observed by SEM. The objectives of this study were to:

(i) improve understanding of the nature of Au enrichments within regolith;
(ii) determine the contributions of residual and supergene components to Au accumulations;
(iii) obtain more information on the forms of supergene Au mobilization.

Table 14. The proportion of fine-grained Au in the bulk samples (%)

Sample	Zone CRCLEME	Zone Goldfields	Au total (ppm)	Au <10 µm (ppm)	Au <10 µm (%)
TP-53/2-3	US	HW	4.88	0.15	3
TP-53/26-27	US	MW	2.71	0.69	25
TP-118/39-40	MS	HW	1.07	0.05	5
TP-8/44-45	MS	MW	2.18	1.18	54
TP-53/47-48	LS	MW	7.85	4.19	53
TP-39/48-49	LS	MW	10.35	5.62	54
TP-44/49-50	LS	MW	2.69	1.35	50
TP-8/52-53	LS	SW	10.15	2.04	20
TP-39/57-58	LS	SW	2.75	2.58	94
TP-8/65-66	F	F	10.40	0.65	6
TP-44/115-116	F	F	6.15	0.21	4

Zones: US - upper saprolite; MS -mid saprolite; LS -lower saprolite; F - fresh rock;
HW – highly weathered rock, MW – moderately weathered, SW – slightly weathered.

7.1.2 Characteristics of Au grains

Size. The length of Au grains is used as their size characteristic. The grains were sorted into 12 categories and the results are shown for each sample in Table 15 and Table 16.

Morphology. Five different morphologies of Au grains were recognized:

1. Crystals: shapes conforming to euhedral-subhedral combinations of cubes and octahedra, pseudohexagonal and trigonal platy, prismatic and elongated crystals (Photos 7 - 9, 13 - 15).
2. Equant grains: anhedral-subhedral equidimensional and sub-spherical particles (Photo 2).
3. Irregular grains: hackly, anhedral, xenomorphic, generally very complex grains, many having imprints of neighbouring minerals (Photos 3 - 4, 28 - 30).
4. Flat grains: anhedral sheets, plates and flakes.
5. Elongated grains: anhedral grains, generally with very rough surfaces.

The morphologies of the different grain types are summarized in Table 17.

Table 15: Size distribution of gold grains collected from bulk samples from Twin Peaks

Sample	Zone CRC LEME	Zone Gold fields	Au (ppm)	No. grains	Size (µm)											
					<10	10 - 20	20 - 30	30 - 40	40 - 50	<50	50-100	100-150	150-200	200-250	250-300	>300
TP-53/2-3	US	HW	4.88	50	1	7	7	7	3	25	4	6	4	4	0	7
TP-53/26-27	US	MW	2.71	122	10	31	31	24	8	104	17	0	1	0	0	0
TP-118/39-40	MS	HW	1.07	55	0	8	10	18	12	48	7	0	0	0	0	0
TP-8/44-45	MS	MW	2.18	142	1	1	13	28	34	77	56	4	2	3	0	0
TP-53/47-48	LS	MW	7.85	111	1	1	6	16	23	47	57	7	0	0	0	0
TP-39/48-49	LS	MW	10.35	139	1	3	20	26	28	78	44	14	2	0	0	1
TP-44/49-50	LS	MW	2.69	104	0	6	11	31	22	70	33	1	0	0	0	0
TP-8/52-53	LS	SW	10.15	133	1	2	25	16	19	63	36	4	5	4	7	14
TP-39/57-58	LS	SW	2.75	126	0	2	18	29	21	70	38	9	4	0	3	2
TP-8/65-66	F	F	10.40	115	1	12	20	22	25	80	27	4	3	1	0	0
TP-44/115-116	F	F	6.15	126	0	2	7	1	7	17	21	31	15	10	9	23

Zones: US - upper saprolite; MS -mid saprolite; LS -lower saprolite; F - fresh rock;
HW – highly weathered rock, MW – moderately weathered, SW – slightly weathered

Table 16: Size distribution (in % of total) of gold grains collected from bulk samples from Twin Peaks.

Sample	Zone CRC LEME	Zone Gold fields	Au (ppm)	Size (µm)											
				<10	10 - 20	20 - 30	30 - 40	40 - 50	<50	50-100	100-150	150-200	200-250	250-300	> 300
TP-53/2-3	US	HW	4.88	2.0	14.0	14.0	14.0	6.0	50.0	8.0	12.0	8.0	8.0	0	14.0
TP-53/26-27	US	MW	2.71	8.2	25.4	25.4	19.7	6.6	85.2	13.9	0	0.9	0	0	0
TP-118/39-40	MS	HW	1.07	0	14.6	18.2	32.7	21.8	87.3	12.7	0	0	0	0	0
TP-8/44-45	MS	MW	2.18	0.7	0.7	9.2	19.7	23.9	54.2	39.4	2.8	1.4	2.1	0	0
TP-53/47-48	LS	MW	7.85	0.9	0.9	5.4	14.4	20.7	42.3	51.4	6.3	0	0	0	0
TP-39/48-49	LS	MW	10.35	0.7	2.2	14.4	18.7	20.1	56.1	31.7	10.1	1.4	0	0	0.7
TP-44/49-50	LS	MW	2.69	0	5.8	10.6	29.8	21.1	67.3	31.7	1.0	0	0	0	0
TP-8/52-53	LS	SW	10.15	0.8	1.5	18.8	12.0	14.3	47.4	27.1	3.0	3.8	3.0	5.3	10.5
TP-39/57-58	LS	SW	2.75	0	1.6	14.3	23.0	16.7	55.5	30.2	7.1	3.2	0	2.4	1.6
TP-8/65-66	F	F	10.40	0.9	10.4	17.4	19.1	21.7	69.5	23.5	3.5	2.6	0.7	0	0
TP-44/115-116	F	F	6.15	0	1.6	5.6	0.8	5.5	13.5	16.7	24.6	11.9	7.9	7.1	18.3

Zones: US - upper saprolite; MS -mid saprolite; LS -lower saprolite; F - fresh rock
HW – highly weathered rock, MW – moderately weathered, SW – slightly weathered

7.1.3 Gold grains in the primary mineralization

Gold grains vary in size in the primary mineralization: the two samples show variation in the proportion of small-grained (<50 µm) Au from 14 to 70% (Table 16). The proportion of fine-grained (<10 µm) Au is markedly less than in the regolith (Table 14).

The shape distribution patterns of Au in the primary mineralization are similar: most grains (47 - 81%) are irregular and xenomorphic (Figure 70), with few (12 - 33%) equant grains; crystals, elongated and flat particles are rarely observed. Unlike supergene Au, all primary Au grains, including crystals, contain 12 - 16 % Ag.

Table 17: Shape distribution (% of total) of Au grains collected from bulk samples from Twin Peaks.

Sample	Zone CRC LEME	Zone Gold fields	Octahedra/ cube	Platy crystal	Prismatic crystal	Crystal aggregate	Total crystals	Equant	Irregular	Flat	Elongated
TP-53/2-3	US	HW	16.0	8.0	14.0	8.0	46.0	14.0	28.0	0	10.0
TP-53/26-27	US	MW	0	7.4	30.3	25.4	63.1	10.7	17.2	4.1	4.9
TP-118/39-40	MS	HW	0	9.1	41.8	21.8	72.7	12.7	5.5	1.8	3.6
TP-8/44-45	MS	MW	7.0	7.0	10.6	33.8	58.5	16.9	18.3	5.6	0.7
TP-53/47-48	LS	MW	18.0	3.6	28.8	27.9	78.4	9.0	10.8	0.9	0.9
TP-39/48-49	LS	MW	15.1	3.6	22.3	23.7	65.5	17.3	16.6	1.4	0
TP-44/49-50	LS	MW	7.7	6.7	22.1	32.7	69.2	13.5	8.6	4.8	3.8
TP-8/52-53	LS	SW	2.3	6.0	14.3	12.0	34.6	26.3	33.8	0.8	4.5
TP-39/57-58	LS	SW	1.6	4.8	17.5	11.9	35.7	19.0	37.3	0.8	4.0
TP-8/65-66	F	F	0	1.7	5.2	2.6	9.5	33.0	47.0	3.5	7.0
TP-44/115-116	F	F	0	0	2.4	0	2.4	11.9	81.7	1.6	2.4

Zones: US - upper saprolite; MS -mid saprolite; LS -lower saprolite; F - fresh rock
HW – highly weathered rock, MW – moderately weathered, SW – slightly weathered

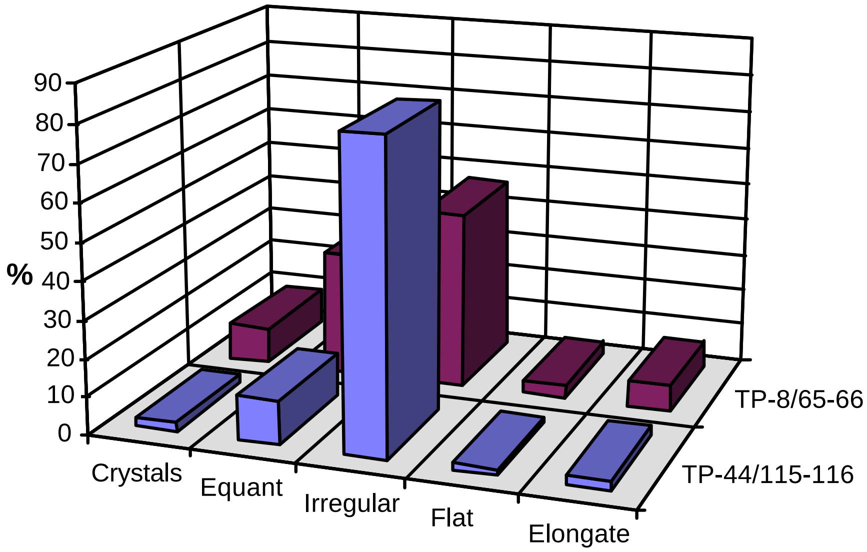

Figure 70: Shape distribution of gold grains in the primary mineralization, in %

The surfaces of the primary grains are very rough, with numerous pits, cavities, fractures, scratches and imprints from adjacent minerals. Some of the scratches are probably the result of mechanical damage to the grains during drilling and sample preparation.

Gold is mainly associated with arsenopyrite as complex intergrowths, indicating simultaneous deposition of the both minerals (Photos 1-2). Less commonly, Au is associated with quartz and calcite, occurring as small inclusions (Photos 3-4).

Electron microprobe analyses of 13 grains show that primary Au has high Ag contents, ranging from 12.7 to 16.3% (mean 14%). Also, Au contains detectable amounts of Cu (50 - 105 ppm) and sporadically Si concentrations ((up to 82 ppm - Table 18).

Table 18: Electron microprobe analyses of Au from the primary mineralization, 13 samples (ppm).

Element	Mean	Det. limit	Min	Max
Ag	139532	506	127267	163181
Cu	87	29	50	105
Si	38	37	<37	82

7.1.4 Gold grains below the supergene enrichment zone

Gold grains in the lower saprolite below the supergene blanket are mainly small, with 47 - 56% of the grains less than 100 µm. However, there are also some large (>200 µm) Au particles (Table 16). The shape distribution patterns of the Au grains in the lower saprolite (Figure 71) show large increases in the proportion of crystals, relative to primary rocks (Figure 70).

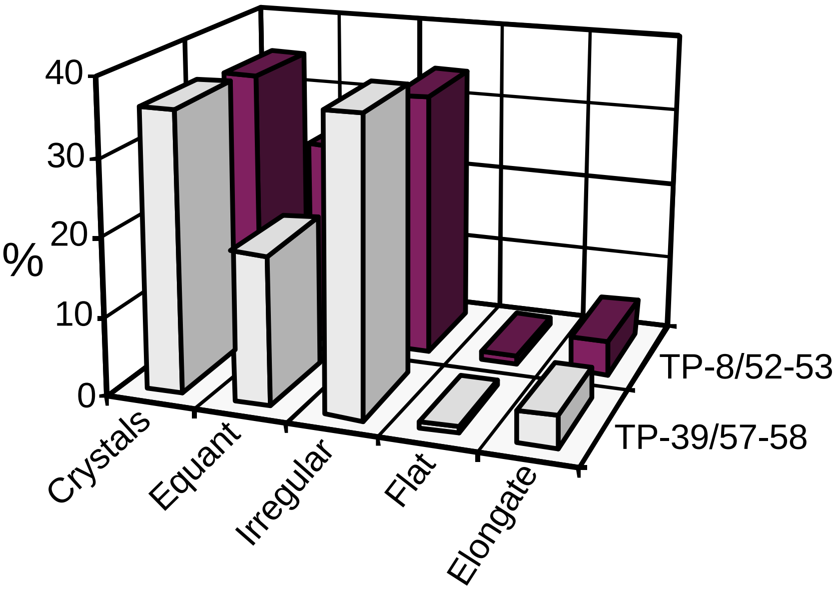

Figure 71: Shape distribution of gold grains in the lower saprolite below the enrichment, in %

Coarse Au grains are mostly residual, with up to 15% Ag and traces of Cu, Si and Fe (Table 19). Some of the residual grains have high-fineness rims, depleted in Ag and Cu (Table 20).

Table 19: Electron microprobe analyses of the residual Au from the saprolite, 31 samples (ppm).

Element	Mean	Det. limit	Min	Max
Ag	147796	536	127444	185155
Cu	61	29	<29	110
Si	96	38	<37	205
Fe	<26	26	<26	101

Table 20: Electron microprobe analyses of cores and rims of the residual Au from the saprolite (TP – 8/52) (ppm).

Sample	Area	Ag	Cu	Si	Fe
1	Core	127757	84	<37	<27
	Rim	632	<29	68	27
2	Core	133757	69	56	<27
	Rim	232	<29	42	<27
3	Core	136979	59	37	<27
	Rim	167	45	37	<27

7.1.5 Gold grains within the enrichment blanket

The Au grains are also small in size in this zone, with the majority (88 - 100%) less than 100 µm (Table 16). The shape distribution patterns are very similar for different parts of the supergene blanket: crystals prevail (42 - 87%), with a substantial proportion of equant grains (9 - 17%) (Figure 72).

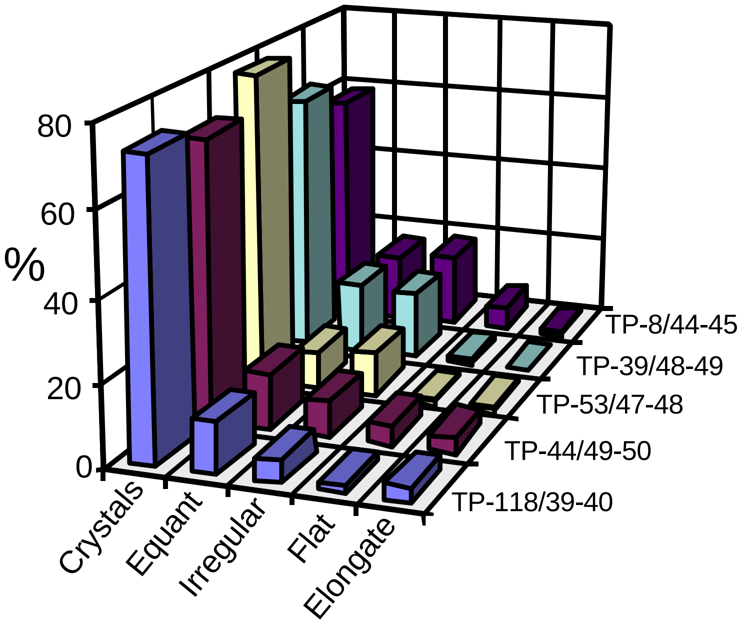

Figure 72: Shape distribution of gold grains within the supergene blanket, in %

The majority of the Au crystals are subhedral, with euhedral crystals less common. The main habits are prismatic and tabular, with a few pseudohexagonal and trigonal platy crystals and combinations of cubic and octahedral forms. Commonly, complex aggregates occur, composed of subhedral crystals or irregular crystalline grains. Pristine crystals are rare, whereas crystals with rough surfaces, pits, cavities and imprints from adjacent minerals are common (Photos 6, 8). Some crystals are corroded (Photo 10). Some morphologies could be interpreted as being multi-stage (Photo 11).

All crystals and the majority of equant and irregular grains in the zone are of high fineness and contain no Ag and only traces of Cu, Si and Fe (Table 21). The marked differences in morphology and composition of these Au crystals from grains in bedrock suggest a supergene origin. Most of the pure, equant grains and some of the irregular grains are presumably also secondary.

Table 21: Electron microprobe analyses of the supergene Au from the saprolite, 11 samples (ppm).

Element	Mean	Det. limit	Min	Max
Ag	<146	146	146	171
Cu	<29	29	<29	30
Si	172	40	126	222
Fe	<27	27	<27	54

Supergene gold is mainly associated with Fe oxides, forming complex intergrowths or being covered by films of Fe oxides (Photo 12). The oxides commonly contain some Si, with minor Al, Ti and Ca. Inclusions of quartz, chlorite and micas are less common. Surprisingly, all five samples studied by SEM show the supergene Au crystals to have complex intergrowths with phases of Ca-P and Ca-P-Ce-Fe-Yb-Sr compositions (Photos 13 - 16). These minerals presumably belong to a group of Ca-phosphates, with the Ca-P phase probably apatite. These data are in a good agreement with the correlations of Au with Ce, Y and Yb in the depletion and enrichment zones, discussed in Section 4.1.

7.1.6 Gold grains in the upper saprolite

Two samples from the bottom (26 - 27 m depth) and the top (2 - 3 m depth) of the upper saprolite demonstrate differences in the grain size and shape distributions. The characteristics of Au grains from the base of the zone are similar to those within the enrichment zone: small in size, with 85% of the particles being less than 50 µm, 94 wt % less than 100 µm and occurring mainly as crystals (63%). At the top of the upper saprolite, the Au is coarser (50% grains >50 µm) with a higher percentage of irregular grains.

In the upper saprolite, Au occurs mainly as supergene crystals, with minor irregular and equant grains (Figure 73). The crystals are commonly uncorroded, in contrast to irregular grains which show moderate to strong corrosion, especially at the grain edges (Photo 18). Corroded Au grains contain some Ag and presumably are relict primary Au.

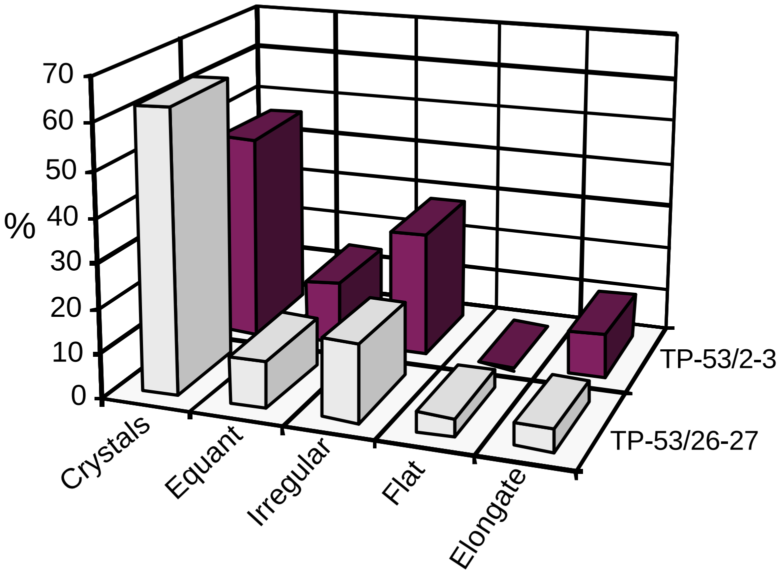

Figure 73: Shape distribution of gold grains in the upper saprolite, in %

7.2 Monty Dam

Gold grains were separated from 3 bulk samples from the orebody and the dispersion halo in the saprolite to compare Au grain characteristics with the adjacent Twin Peaks deposit. The results are shown in Table 22.

Table 22: Gold grains characteristics, Monty Dam

Drill hole	**Location**	**Depth, m**	**No. grains**	**<50 µm, %**	**50-100 µm,%**	**>100 µm, %**	**Crystals, %**	**Irregular grains, %**
63	Orebody	42-43	163	44.2	26.4	29.4	20.2	33.1
63	Dispersion	37-38	90	78.9	21.1	0	63.4	6.7
64	Dispersion	37-38	132	74.2	24.2	1.6	53.8	6.8

The Au grains are smaller than at Twin Peaks, with >98% less than 100 µm in the dispersion halo. Within the dispersion blanket, the majority of Au occurs as crystals (54-63% of total) similar to Twin Peaks with 42-78 % of crystals. Within the enriched orebody, Au occurs as a mixture of residual, generally irregular grains and supergene Au crystals.

The majority of the Au crystals are subhedral, with few euhedral crystals. The crystal morphology is similar to that at Twin Peaks: prismatic and tabular crystal forms are predominant with minor combinations of octahedra, cubes and elongated prisms (Photos 25-26). Many crystals form complex aggregates. The Au at Monty Dam is characteristically substantially corroded, even the supergene high-fineness crystals (Photos 28-29).

The supergene crystals are mainly associated with Fe oxides, forming complex intergrowths or are covered by films of Fe oxides. Inclusions of quartz and silicates are less common. Associations of the supergene Au crystals with phosphates (as at Twin Peaks) have not been detected, possibly because of the limited number of SEM analyses. An interesting finding was a close intergrowth of halite with a supergene Au crystal, indicating possible participation of Cl in supergene Au migration (Photo 30). Halite may be a more common, but the two-step gravity separation in water would tend to remove water-soluble minerals.

All of the 17 crystals studied by microprobe are of high fineness and contain no Ag above detection (146 ppm) and only sporadic concentrations of Si (up to 190 ppm), Fe (up to 128 ppm) and Cu (up to 39 ppm).

8. DISCUSSION AND CONCLUSIONS

The Old Plough Dam area is a typical environment for supergene Au dispersion in the Yilgarn Craton. This particular area was selected for substantial study because it offered an opportunity to investigate three adjacent deposits, namely Twin Peaks, Monty Dam and Carosue Dam, hosted by felsic volcanogenic rocks and located close to the Menzies Line. This allowed comparison of Au dispersion from several styles of mineralization. This report includes data from two sites, Twin Peaks and Monty Dam. The results from Carosue Dam have been reported upon separately (Gray, 1998).

8.1 Regolith stratigraphy and landform evolution.

The geochemical and mineralogical data, presented in this study, are consistent with the general features established for the regolith evolution in the Yilgarn Craton (Butt, 1991). The deeply weathered regolith in the Old Plough Dam area was probably developed under warm, humid conditions of the Cretaceous to mid-Miocene, with the complete regolith profile, where it occurred, presumably including lateritic residuum, mottled zone and saprolite. The saprolite at Twin Peaks, studied in detail, can be informally divided into three zones, namely upper, mid and lower saprolite, which reflect mineral transformations during weathering. The lower saprolite has a quartz-chlorite-albite-muscovite composition with minor smectite. In the mid saprolite, chlorite is replaced by kaolinite and goethite, and albite is partly weathered to smectite. The lower to mid saprolite interface seems to be an important geochemical boundary as a Fe^{2+}/Fe^{3+} redox front and a porosity barrier. In the upper saprolite, the abundances of albite and smectite sharply decrease, with kaolinite and goethite becoming the principal minerals.

The regolith has been modified by erosion and weathering under arid to semi-arid climates since the Miocene. The laterite profile has been stripped, mainly to the mottled zone, with deeper truncation (to the upper saprolite) in the western parts of the area. Lateritic debris is retained as a significant component of transported overburden and soils. Increasing aridity caused lowering of the water table and precipitation of carbonates as pedogenic calcretes in soil.

8.2 Geochemistry

The geochemistry and mineralogy of Au demonstrate its redistribution in the regolith at both sites. Thus, at Twin Peaks, there are two prominent supergene Au enrichments in the regolith: close to the surface, within calcrete and soil, and at the top of the lower saprolite. The depleted zone lies between these enrichments.

The Au dispersion halo within the pedogenic calcrete and calcareous soil is about 2 m thick up to 350 m east of the axis of the mineralization (using a 20 ppb cut off). The sharp northwestern boundary of the anomaly presumably reflects the location of the mineralized strike. Gold concentrations are up to >1 ppm in places and the mean concentration in the top 3 m thick is 46 ppb. The results of partial extraction analyses, Au mass balance calculations and Au grain studies suggest that there is a substantial residual component in the Au anomaly at Twin Peaks. The majority of the Au within the calcrete anomaly is residual, with Ag-rich grains occluded within lithic and ferruginous fragments and disseminated within the carbonate matrix. Calculated proportions of the residual Au vary from 36 to 96 wt %. Morphologies of Au grains recovered from the calcrete are similar to those observed in the saprolite. No specific Au morphologies that could be related to Au redeposition in the calcrete environment were identified.

The lower Au-rich supergene enrichment (up to 12.2 ppm Au) with lateral dispersion halo occurs below the depleted zone at the top of the lower saprolite from the depth of about 40 m. The shape of the supergene halo resembles that of the surface anomaly: it extends as a continuous, narrow zone to the northeast along the mineralized strike and occurs as a patchy blanket to the east, for up to 230 m, with maximum width of 200 m (20 ppb cut off) and approximately 6 - 9 m vertical thickness.

In contrast to Twin Peaks, there is no prominent supergene enrichment at Monty Dam. Gold is depleted upward progressively through the regolith, with a strongly depleted zone (mean 11 ppb) above the mid-lower saprolite transition. There is a slight (91 ppb) Au concentration near the base of weathering, which may be mostly residual. At the surface, Au concentrations are low due to the erosional regime in the area. Weak anomalies, 20 – 30 ppb, up to 100 m length occur as projections of primary mineralized zones at the surface. Lateral Au dispersion is also very weak at a 10 ppb cut-off; the dispersion halo occurs as a thin (1 - 2 m), patchy blanket spreading up to 80 m to the east from the mineralized trend.

The position of the Au dispersion in the profile is coincident with a Fe^{2+}/ Fe^{3+} redox front and a porosity barrier in the lower saprolite. Gold dispersion presumably occurs by dissolution in laterally moving, highly saline, oxidized groundwaters with deposition at the redox front. Close associations of Au with Fe oxides suggest the importance of Fe in the Au migration cycle. Within the saprolite enrichment at both sites, Au principally occurs as supergene, high-fineness crystals with minor anhedral grains. At Twin Peaks, Au shows close association with REE within the supergene depletion and enrichment zone. Gold is correlated with Ce, Y and Yb and occurs as complex intergrowths of the supergene Au crystals with Ca-REE-phosphates. Coincidence of Au and REE lateral dispersions has previously been observed at Mt Percy (Butt, 1991). In contrast to Twin Peaks, geochemical and mineralogical data indicate no relationships of Au and REE within the dispersion halo at Monty Dam.

The long and complex regolith history caused supergene redistribution of many elements in the Old Plough Dam area. Thus, at Twin Peaks, base and transition metals (Cu, Pb, Zn, Co, Ni, Mn) are leached from upper horizons and precipitated in the upper (Cu), mid (Zn), and lower (Co, Ni, Mn) saprolite. Rare earth elements also show depletion from the upper regolith, with apparent enrichments within the saprolite. Although heavy REE show less leaching than light REE, they are accumulated at the mid to lower saprolite boundary. Arsenic, which is strongly enriched with mineralization at Twin Peaks, is depleted from the upper horizons and enriched in the upper saprolite, at 10-20 m depth. There is some lateral dispersion of the As in this enrichment zone, to the northeast along the mineralized strike and to the east into the wall rocks. To some extent, the As dispersion halo is coincident with that of Au, but is much thicker and has less lateral extent. At Monty Dam, Cu, Pb and Zn are slightly depleted in the upper regolith with little evidence of enrichment below. Arsenic, in low abundances at the site, shows slight enrichment upward through the regolith profile in contrast to Twin Peaks.

8.3 Hydrogeochemistry

All the Old Plough Dam groundwaters are saline to hypersaline (4.2 - 19.7%), and show significant K depletion, probably due to alunite precipitation in acid conditions. The Twin Peaks and Main Bore groundwaters are acid (pH 3.0 - 5.4) and oxidizing (270 - 690 mV), whereas the Monty Dam groundwaters are weakly acid to neutral (pH 5.8 - 6.8), presumably due to pH control by the adjacent Lake Rebecca. These groundwaters are reducing (Eh 230 - 400 mV) except for a single, anomalously oxidizing (720 mV), sample.

Concentrations of minor elements show some similarities to the acid/saline Kalgoorlie groundwaters. In particular, base metals and REE have higher dissolved concentrations than the neutral central and northern groundwaters, whereas anionic chalcophile elements (*e.g.*, As, Sb) have low concentrations. However, at Twin Peaks, Sc, Y, REE, Pb, U, Cr and, to a lesser extent, Mn, Co and Ni tend to have significantly lower concentrations at any particular pH than those for the Kalgoorlie groundwaters (representing primarily mafic/ultramafic lithologies) and show very strong pH control on the solubility. This suggests that acid groundwaters in contact with weathered felsic rocks are likely to show lower dissolved metal concentrations than similar groundwaters contacting mafic and/or ultramafic lithologies, once pH effects are taken into account. In contrast, the neutral Monty Dam groundwaters have very low base metal and REE contents, as expected, and high dissolved concentrations of Ti, Ga, Ge, Cd, Sn, Sb and W.

The high salinity of the groundwaters at Old Plough Dam implies that the dominant mechanisms for the mobilization of Au in the southern Yilgarn, namely as the chloride ($AuCl_2^-$) or iodide (AuI_2^-) complexes, are expected to be significant for the acid/oxidizing groundwaters at Twin Peaks and Main Bore, though less important for the neutral/reduced groundwaters at Monty Dam. The Twin Peaks groundwaters generally have relatively low Au concentrations, probably because the sampling depths for the groundwaters are all within the Au-leached zone. At Main Bore and for the oxidized Monty Dam groundwater, dissolved Au concentration is high.

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REFERENCES

Bristow, A.P.J., Gray, D.J. and Butt, C.R.M., 1996. Geochemical and spatial characteristics of regolith and groundwater around the Golden Delicious Prospect, Western Australia. CSIRO Division of Exploration and Mining Restricted Report 280R, Perth, Australia. 175pp.

Butt, C.R.M., 1991. Geochemical dispersion in the regolith, Mystery Zone, Mt. Percy mine, Kalgoorlie, Western Australia. CSIRO Division of Exploration Geoscience Restricted Report 156R, Perth, Australia. Vols I and II. 226pp.

Butt, C.R.M., Gray, D.J., Robertson, I.D.M., Lintern, M.J., Anand, R.R., Britt, A., Bristow, A.P.J., Munday, T.J., Phang, C., Smith, R.E. and Wildman, J.E., 1997. AMIRA P409 - Yilgarn Transported Overburden Final Report. CSIRO Division of Exploration and Mining Restricted Report 333R, Perth, Australia. 164 pp.

Douglas, G.B., Robertson, I.D.M. and Butt, C.R.M., 1993. Mineralogy and geochemistry of the Lights of Israel Gold Mine, Davyhurst, Western Australia. CSIRO Division of Exploration Geoscience Restricted Report 393R, Perth, Australia. 89pp.

Drever, J.I., 1982. The Geochemistry of Natural Waters. Prentice-Hall, Inc., Englewood Cliffs, N.J. U.S.A. 388 p.

Eilu P. and Mikucki E.J., 1996. Primary geochemical haloes associated with the Twin Peaks deposit, Keith – Kilkenny: assessment of alteration indices for use in exploration. MERIWA Report 176 Perth, Australia. Vol VI. 78 pp.

Gray, D.J., 1990. Hydrogeochemistry of the Panglo Gold Deposit. CSIRO Division of Exploration Geoscience Restricted Report 125R, Perth, Australia. 74pp.

Gray, D.J., 1991. Hydrogeochemistry in the Mount Gibson Gold District. CSIRO Division of Exploration Geoscience Restricted Report 120R, Perth, Australia. 80pp.

Gray, D.J., 1992a. Hydrogeochemistry of sulphide weathering at Boags Pit, Bottle Creek, Western Australia. CSIRO Division of Exploration Geoscience Restricted Report 237R, Perth, Australia. 13pp.

Gray, D.J., 1992b. Geochemical and hydrogeochemical investigations of alluvium at Mulgarrie, Western Australia. CSIRO Division of Exploration Geoscience Restricted Report 339R, Perth, Australia. 66pp.

Gray, D.J., 1993a. Investigation of the hydrogeochemical dispersion of gold and other elements from mineralized zones at the Granny Smith Gold Deposit, Western Australia. CSIRO Division of Exploration Geoscience Restricted Report 383R, Perth, Australia. Vols I and II. 93pp.

Gray, D.J., 1993b. Investigation of the hydrogeochemical dispersion of gold and other elements in the Wollubar Palaeodrainage, Western Australia. CSIRO Division of Exploration Geoscience Restricted Report 387R, Perth, Australia. Vols I and II. 133pp.

Gray, D.J., 1994. Investigation of the hydrogeochemical dispersion of gold and other elements at Lawlers, Western Australia. CSIRO Division of Exploration and Mining Restricted Report 26R, Perth, Australia. Vols. I and II. 151 pp.

Gray, D.J., 1995. Hydrogeochemical dispersion of gold and other elements at Baxter, Western Australia. CSIRO Division of Exploration and Mining Restricted Report 169R, Perth, Australia. 85 pp.

Gray, D.J., 1996. Hydrogeochemistry in the Yilgarn Craton. CSIRO Division of Exploration and Mining Restricted Report 312R, Perth, Australia. 75pp.

Gray, D.J., 1998. Characteristics of gold distribution and hydrogeochemistry at the Carosue Dam Prospect, Western Australia: Preliminary Report. CSIRO Division of Exploration and Mining Restricted Report 550R, Perth, Australia. 90pp.

Gray, D.J. and Lintern, M.J., 1993. Further aspects of the chemistry of gold in some Western Australian soils. (CSIRO/AMIRA P241: Weathering Processes). CSIRO Division of Exploration Geoscience Restricted Report 391R. 50pp.

Lintern, M.J., and Gray, D.J., 1995a. Progress Statement for the Kalgoorlie Study Area - Steinway Prospect, Western Australia. CSIRO Division of Exploration and Mining Restricted Report 95R, Perth, Australia. 121 pp.

Lintern, M.J., and Gray, D.J., 1995b. Progress Statement for the Kalgoorlie Study Area - Argo Deposit, Western Australia. CSIRO Division of Exploration and Mining Restricted Report 96R, Perth, Australia. 153 pp.

Longworth, M., 1996. Resource – Monty Dam (GRE2) and Elliots Lode (GRE1). Goldfields Exploration Pty Ltd Report. 47 pp.

Morris, P.A., 1994. Geology of the Mulgabbie 1:100 000 sheet. Geological Survey of Western Australia, Department of Minerals and Energy.

Murphy, J. and Riley, J.P., 1962. A modified single solution method for the determination of phosphate in natural waters. Analytica Chimica Acta, 27: 31-36.

Parkhurst, D.L., Thorstenson, D.C. and Plummer, L.N., 1980. PHREEQE, a computer program for geochemical calculations. U.S. Geological Survey Water Resources Investigations 80-96, 210p.

Plummer, L.N., and Parkhurst, D.L., 1990, Application of the Pitzer Equations to the PHREEQE geochemical model, in Melchior, D.C., and Bassett, R.L., eds., Chemical modeling of aqueous systems II: American Chemical Society Symposium Series 416, Washington, D.C., American Chemical Society, p. 128-137.

Robertson, I.D.M., Dyson, M., Hudson, E.G., Grabb, J.F., Willing, M.J. and Hart, M.K.W., 1996. A case-hardened, low contamination ring mill for multi-element geochemistry. Journal of Geochemical Exploration, 57: 153-158.

Swager, C.P. and Ahmat A.L., 1992. Greenstone terraines in the southern part of the Eastern Goldfields Province, in Mineral exploration and mining geology in the Eastern Goldfields: Proceedings, Geology Symposium, Department of Mineral Exploration and Mining Geology, Western Australian School of Mines, Kalgoorlie, pp.71-72.

Weast, R.C., Astle, M.J. and Beyer, W.H. (1984). "CRC Handbook of Chemistry and Physics." F-154 Elements in Sea Water. (64th Edition; CRC Press Inc., Florida, USA).

Zall, D.M., Fisher, D. and Garner, M.D., 1956. Photometric determination of chlorides in water. Analytical Chemistry, 28:1665.