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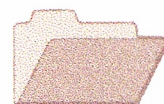Cooperative Research Centre for
Landscape Evolution & Mineral Exploration

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MORPHOLOGY AND GEOCHEMISTRY OF PARTICULATE GOLD IN THE LATERITIC REGOLITH, MYSTERY ZONE, MT. PERCY, KALGOORLIE, WESTERN AUSTRALIA

A.Z. Gedeon and C.R.M. Butt

CRC LEME OPEN FILE REPORT 23

October 1998

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RESEARCH ARISING FROM CSIRO/AMIRA REGOLITH GEOCHEMISTRY PROJECTS 1987-1993

In 1987, CSIRO commenced a series of multi-client research projects in regolith geology and geochemistry which were sponsored by companies in the Australian mining industry, through the Australian Mineral Industries Research Association Limited (AMIRA). The initial research program, "Exploration for concealed gold deposits, Yilgarn Block, Western Australia" (1987-1993) had the aim of developing improved geological, geochemical and geophysical methods for mineral exploration that would facilitate the location of blind, buried or deeply weathered gold deposits. The program included the following projects:

P240: Laterite geochemistry for detecting concealed mineral deposits (1987-1991). Leader: Dr R.E. Smith.
Its scope was development of methods for sampling and interpretation of multi-element laterite geochemistry data and application of multi-element techniques to gold and polymetallic mineral exploration in weathered terrain. The project emphasised viewing laterite geochemical dispersion patterns in their regolith-landform context at local and district scales. It was supported by 30 companies.

P241: Gold and associated elements in the regolith - dispersion processes and implications for exploration (1987-1991). Leader: Dr C.R.M. Butt.
The project investigated the distribution of ore and indicator elements in the regolith. It included studies of the mineralogical and geochemical characteristics of weathered ore deposits and wall rocks, and the chemical controls on element dispersion and concentration during regolith evolution. This was to increase the effectiveness of geochemical exploration in weathered terrain through improved understanding of weathering processes. It was supported by 26 companies.

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

P240A: Geochemical exploration in complex lateritic environments of the Yilgarn Craton, Western Australia (1991-1993). Leaders: Drs R.E. Smith and R.R. Anand.
The approach of viewing geochemical dispersion within a well-controlled and well-understood regolith-landform and bedrock framework at detailed and district scales continued. In this extension, focus was particularly on areas of transported cover and on more complex lateritic environments typified by the Kalgoorlie regional study. This was supported by 17 companies.

P241A: Gold and associated elements in the regolith - dispersion processes and implications for exploration. Leader: Dr. C.R.M. Butt.
The significance of gold mobilisation under present-day conditions, particularly the important relationship with pedogenic carbonate, was investigated further. In addition, attention was focussed on the recognition of primary lithologies from their weathered equivalents. This project was supported by 14 companies.

Although the confidentiality periods of the research reports have expired, the last in December 1994, they have not been made public until now. Publishing the reports through the CRC LEME Report Series is seen as an appropriate means of doing this. By making available the results of the research and the authors' interpretations, it is hoped that the reports will provide source data for future research and be useful for teaching. CRC LEME acknowledges the Australian Mineral Industries Research Association and CSIRO Division of Exploration and Mining for authorisation to publish these reports. It is intended that publication of the reports will be a substantial additional factor in transferring technology to aid the Australian Mineral Industry.

PREFACE

The CSIRO-AMIRA project "Exploration for Concealed Gold Deposits, Yilgarn Block, Western Australia" has as its overall aim the development of improved geological, geochemical and geophysical methods for mineral exploration that will facilitate the location of blind, concealed or deeply weathered gold deposits.

This Report presents results of research conducted as part of Module 2 of this project (Weathering Processes, Project P241) and is part of a comprehensive investigation of geochemical dispersion in the lateritic regolith at Mt. Percy. The aim of the study reported herein has been to obtain information concerning the nature and origin of gold in the regolith by examining the morphological and geochemical characteristics of gold particles. The location, shape, degree of corrosion and composition of the particles can indicate the aspects of the genetic history not only of the gold itself but also of the regolith in which it occurs. The study is complementary to similar investigations of gold-grain morphology carried out earlier in the Project at Bardoc, Reedy and Beasley Creek and differences in the findings can be related to the Ag-rich nature of the primary mineralization.

C.R.M. Butt.
Project Leader.

October, 1990.

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MORPHOLOGY AND GEOCHEMISTRY OF PARTICULATE GOLD IN THE LATERITIC REGOLITH, MYSTERY ZONE, MT. PERCY, KALGOORLIE, WESTERN AUSTRALIA

A.Z. GEDEON AND C.R.M. BUTT

Division of Exploration Geoscience, CSIRO,
Private Bag, PO, Wembley, Western Australia, 6014

ABSTRACT

The characteristics of grains of free gold in different horizons of the lateritic regolith have been studied at the Mystery Zone of the Mt. Percy mine, Kalgoorlie. Primary mineralization consists of Ag-rich (to 50% Ag) free gold and Au and Ag tellurides in pyritic carbonate alteration zones and quartz veins. The gold distribution in the regolith is typical for the region, with minor enrichment and wide lateral dispersion in surficial lateritic gravels and duricrust, leaching and depletion in the underlying clay-rich horizons (5-15m depth) and some secondary concentration and possible minor dispersion within the saprolite.

Gold grains have been mechanically panned and examined by scanning electron microscopy, observing particularly their size, shape, morphology, condition and composition. Primary gold grains persist only into the lower saprolite, where they are associated with Ag-poor secondary gold and Ag halide crystals. Secondary gold was recovered from all horizons of the regolith except from the depleted zone. Several different morphologies have been observed, namely subhedral to euhedral crystals, anhedral (including xenomorphic) forms and irregular, hackly aggregates having the form of three-dimensional dendritic growths. The majority of grains are less than $50\mu m$ in diameter and most are nearly equant in shape. Most grains are corroded, some severely so, whereas others are pristine, and it is assumed that these represent several generations of gold mobilization and precipitation. Only very few gold grains were recovered from the lateritic duricrusts and gravels or soils and it is assumed that most of the gold in these horizons is present as very fine particles in secondary iron oxides or pedogenic carbonates.

The observed gold distribution is probably the result of two or three mechanisms of chemical dispersion. Firstly, mobilization occurred during lateritization, when most, if not all, primary gold in the duricrust was dissolved and presumably reprecipitated as very fine particles with iron oxides. The second phase has been during later arid periods, when primary gold remaining in the saprolite has been dissolved by saline groundwaters and, in particular, leached from the upper clay-rich horizons, and reprecipitated as Ag-poor grains, again in the saprolite. Finally, remobilization via vegetation has led to the accumulation of gold in the pedogenic carbonates.

1. INTRODUCTION

The Mystery Zone of the Mt. Percy Mine was selected for a substantial study because it offered the opportunity to investigate geochemical dispersion from gold mineralization at a site with an almost complete lateritic regolith. It was also expected to exemplify many of the characteristics of dispersion in similar sites in the Kalgoorlie area. The specific aspect of the study described in this report has been to examine the morphology and chemical composition of gold grains in a lateritic weathering profile. The techniques used were similar to those used at Bardoc, Beasley Creek and Reedy (Freyssinet and Butt, 1988a, b, c). The major change was the use of mechanized panners, rather than hand panning, to standardize the method and hence increase comparability between samples. The results augment knowledge about the behaviour of gold in areas which have lateritic regoliths and provide data for comparison with equivalent studies in other regions which have had different weathering histories. The Mt. Percy Mine was selected because it gave access to the profile while the open pit was excavated.

2. GEOLOGICAL AND GEOMORPHOLOGICAL SETTING

Mt. Percy is about 2km NE of the centre of Kalgoorlie. It lies at the northern end of the Kalgoorlie-Kambalda greenstone sequence, about 8km N of the Golden Mile and 1.5km N of Mt. Charlotte. At Mt. Percy, the Hannan's Lake Serpentinite, Devon Consols Basalt, Kapai Slate and Williamstown Dolerite form part of the hinge zone and steeply east-dipping limb of the Kalgoorlie Anticline (Travis et al., 1971). The sequence is cross-cut by a series of north-trending, west-dipping dextral faults, including the Maritana, Reward, Charlotte and Mystery Faults. In contrast to the Golden Mile and Mt. Charlotte, therefore, where primary Au mineralization occurs mainly in the Golden Mile Dolerite, mineralization at Mt. Percy is lower in the sequence, being located in the Hannan's Lake Serpentinite in the Mystery Zone and the Devon Consols Basalt in the Union Club and Sir John Zones (Sauter et al., 1988). In the Mystery Zone, the Hannan's Lake Serpentinite is intruded by porphyries, with strong fuchsite-carbonate alteration occurring at the contact. Primary gold mineralization is largely confined to a series of irregular lenses, mostly steeply-dipping within the porphyries and adjacent alteration zones.

Mt. Percy is situated in a relatively high part of the landscape, in a region that has a total relief of only a few tens of metres. The elevation is probably due to the shielding effect of lateritic duricrust (cuirasse), here developed most strongly over the Hannan's Lake Serpentinite. As a consequence, a more or less complete lateritic regolith, 50-70m thick, is present over most of the area. This regolith is the host to secondary gold mineralization within the lateritic duricrust and the saprolite.

Mining at Mt. Percy originally took place in the period 1893-1910, extracting about 70,000 tonnes of primary and secondary ore from underground workings (Sauter *et al.*, 1988). Most of the surface was dry-blown. Recent exploration commenced in 1977 by Occidental Minerals and was continued by Windsor Resources. Open cut mining at the Union Club - Sir John pit commenced in 1985. Mining of the southern end of the Mystery Zone commenced in 1987 and sampling for this study was undertaken from that time.

3. SAMPLING

The objective of the sampling program was to illustrate the vertical and lateral distribution of a range of elements in the regolith developed over gold mineralization and its wallrocks. Of the two sections across the mineralized zone, for this report, that at 15850N has been chosen for study. A sub-set of samples was selected on the basis of the gold distribution determined for the comprehensive geochemical study (Butt 1990). The distribution of gold in the section and locations of the samples selected for this study are shown in Figure 1; coordinates and geological data pertaining to these samples are listed in Table 1.

Three sampling procedures were used for the general study and some of each type were selected for panning.

1. Channel rip samples.

Samples for mine grade control were taken by ripping shallow trenches across strike by bulldozer and hand-collecting and compositing the spoil over 1m intervals. Duplicates of the few kilogram samples taken for grade control were collected for this study. Samples were taken from the original ground surface and at 2.5m intervals thereafter, as mining progressed. From RL 392.5, sample composites were collected every second metre. Between RL 390.0 and 365.0 inclusive, sampling was on traverse lines 5m to the north, i.e. 15855N; this was necessary because of a change in the procedure used for grade control sampling on the original lines.
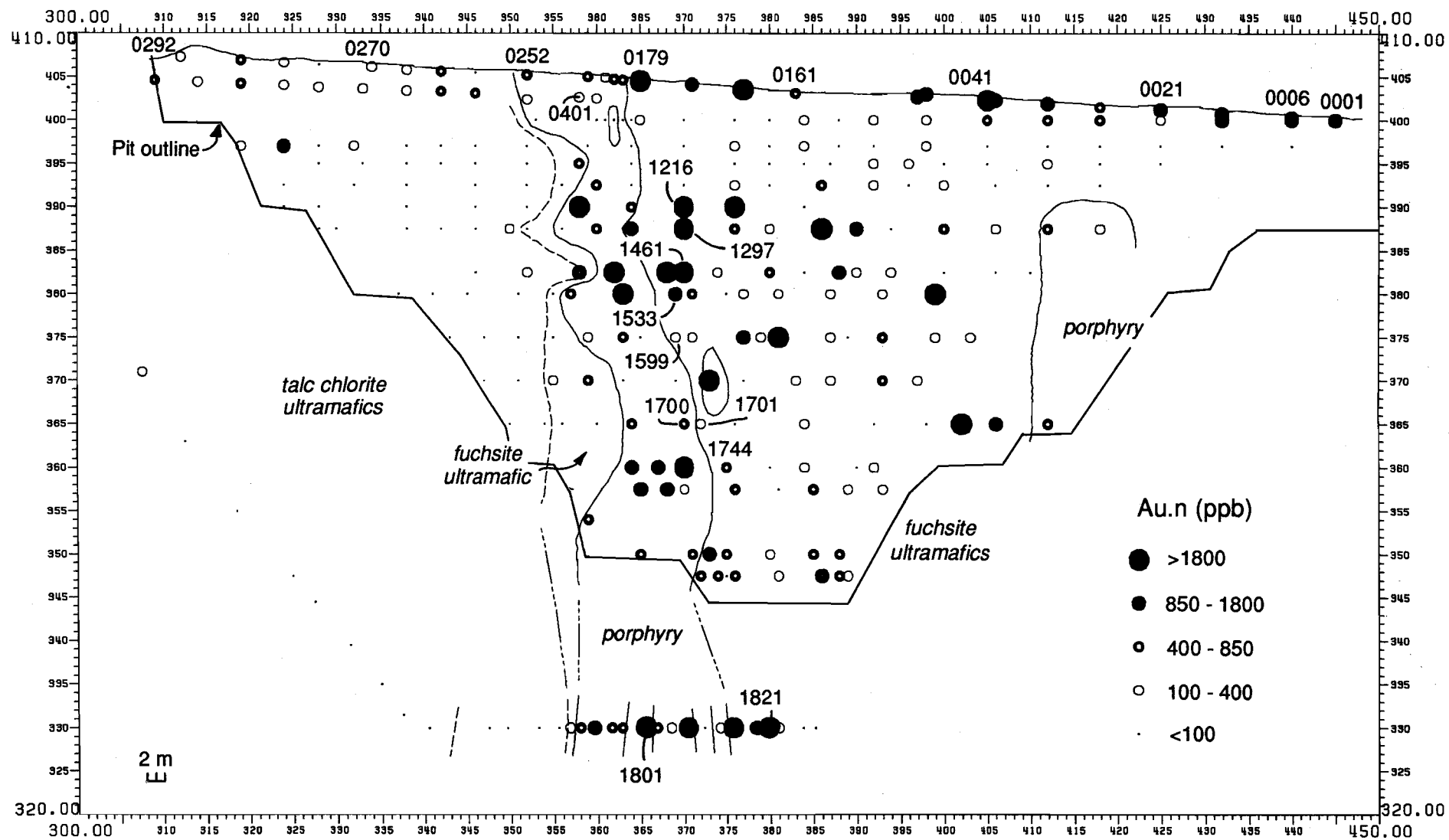
Fig. 1. Plot of sample locations, gold distribution and geology of Mt. Percy Section 15850N.

Table 1.   Locations, source rocks and regolith units of selected samples from Mt. Percy Section 15850N.

ID	Easting	Relative level (RL)	Fresh rock		Regolith unit	
0001	445.000	400.000	Asf?	ultramafic	Ak	lateritic soil with calcrete
0006	440.000	400.300	Asf?	ultramafic	Ak	lateritic soil with calcrete
0021	425.000	401.200	Asf?	ultramafic	Ak	lateritic soil with calcrete
0041	405.000	402.300	Asf?	ultramafic	Ak	lateritic soil with calcrete
0161	383.000	403.100	Asf?	ultramafic	Lk	pisolitic laterite with calcrete
0173	371.000	404.100	Asf?	ultramafic	Lk	pisolitic laterite with calcrete
0179	365.000	404.500	As	talc (chlorite) ultramafics	Lk	pisolitic laterite with calcrete
0252	352.000	405.200	As	talc (chlorite) ultramafics	Lk	pisolitic laterite with calcrete
0270	334.000	406.100	As	talc (chlorite) ultramafics	Lk	pisolitic laterite with calcrete
0292	312.000	407.300	As	talc (chlorite) ultramafics	L	pisolitic laterite
0401	358.000	402.600	Asf?	ultramafic	Lk	pisolitic laterite with calcrete
0545	384.000	400.000	As	talc (chlorite) ultramafics	Mc	mottled clay
1216	370.000	390.000	Asf	fuchsite carbonate ultramafic	Sc	saprolite clay
1297	370.000	387.500	Asf	fuchsite carbonate ultramafic	S	saprolite
1461	370.000	382.500	Asf	fuchsite carbonate ultramafic	S	saprolite
1533	369.000	380.000	Asf	fuchsite carbonate ultramafic	S	saprolite
1599	369.000	375.000	Asf	fuchsite carbonate ultramafic	S	saprolite
1700	370.000	365.000	Af	porphyry	S	saprolite
1701	372.000	365.000	Asf	fuchsite carbonate ultramafic	S	saprolite
1744	375.000	360.000	Asf	fuchsite carbonate ultramafic	S	saprolite
1801	376.800	286.700	Asf	fuchsite carbonate ultramafic	R	
1804	378.700	284.300	Af	porphyry	R	
1809	381.800	280.500	Af	porphyry	R	
1818	387.400	274.000	Asf	fuchsite carbonate ultramafic	R	
1821	391.200	269.200	Asf	fuchsite carbonate ultramafic	R	
1838	392.600 *	290.000	Asf	fuchsite carbonate ultramafic	R	

remarks   * from Hole KND 22, 15900N
             ? identification uncertain

ഗ

2.   Rock drill samples

From RL 360 to the base of the pit at RL 345, the hardness of the weathered and fresh rock necessitated a change to drill and blast mining. Grade control samples were obtained from the drill spoil and duplicates were collected for this study. The holes were drilled at one or two m intervals across strike, at an angle of 60°, for a vertical depth of 5m. An upper and a lower sample were collected per hole, each representing a composite sample of a 2.5m vertical interval.

3.   Diamond drill samples

A diamond drill hole, KND 181, was drilled at an angle of 51° to pass vertically below section 15850N. The hole was precollared by percussion drilling to 90m down-hole and diamond-drilled to 181.4m.   Sections of approximately 1m of quarter core were collected; representative samples were taken in the unmineralized wallrocks and a continuous section was sampled close to and through the mineralization.   Each core sample included heterogeneities due to veining, but was otherwise lithologically homogenous. Only a limited quantity of this sample material was available for panning.

4.   SAMPLE PREPARATION AND ANALYSIS

Geochemical analysis

All samples selected for analysis were dried, a sub-sample taken for reference and the remainder jaw-crushed to 4mm or smaller. The material was then riffle split and a minimum of 100g extracted for grinding to less than 75μm. Initially, samples were ground in an agate ring mill, but this proved very slow and the majority of samples were ground in a Mn steel mill.

Samples were analysed as follows:

1.   Neutron activation analysis (NAA), 30g sample (Becquerel Laboratories Pty. Ltd.):
       As, Au, Cr, Fe, Sb, W.

2.   X-Ray fluorescence (XRF) on pressed powders using a Philips PW1220C instrument by the methods of Norrish and Chappell (1977) and Hart (1989), with Fe determined for matrix correction (CSIRO):
       Ba, Fe, Na_2O, S, TiO_2, Zr.

3.   Inductively coupled plasma emission spectrometry (ICP) on a Hilger E-1000 following fusion of 0.25g samples with Li metaborate and solution in dilute HNO_3 (CSIRO):

        SiO_2, Al_2O_3, Fe_2O_3, CaO, MgO.

4.   Inductively-coupled plasma mass spectrometry (IMS), following digestion in $HClO_4$-HNO_3-HF acid mixture and solution in dilute HCl (Analabs Pty. Ltd):

        Ag.

5.   Atomic absorption spectrometry, following aqua regia digestion and hydride generation (HYD),(Analabs Pty. Ltd.):

        Te.

Sample preparation for gold grain morphology

The samples were crushed to a maximum grain size of about 500μm by jaw crusher and disc grinder; these conditions were expected to liberate the gold particles and cause only minor damage. The gold particles, and other heavy minerals, were then concentrated using a superpanner and micro-panner and collected on filter papers. These were mounted on solid epoxy resin polished section blanks, with the particles fixed using a low viscosity epoxy resin. These mounts were then examined by scanning electron microscopy. The sample preparation details are given in the Appendix 1.

Scanning electron microscopy (SEM) was used for all morphological studies. Backscattered electron mode was employed, using an ISI-100B instrument. All gold grains were analysed qualitatively by energy dispersive X-ray spectrometry (EDAX) and many (about one in five) were photographed. Details of the SEM search procedure are given in Appendix 2.

The mineralogy of the heavy mineral concentrates was determined by XRD using CuKα radiation on a Philips PW1050 Diffractometer fitted with a graphite monochromator and a Sietronics 112 automation package.

5. CHARACTERISTICS OF GOLD GRAINS

The external characteristics of the gold grains are here described in terms of their *size, shape, morphology, condition* and *composition* as observed by SEM.

Size. The size of the gold grain is expressed as the square root of the product of the lengths of the long and short axes. After sorting into categories the occurrence *found* and % frequency of this product are shown for each sample in Table 2.

Shape. The shape is expressed by grouping the lengths of the axes into different classes (Table 3). Equant grains appear on the diagonal, whereas increasingly elongated grains plot more distant from it. The numbers in the plot represent the count observed for each size and shape.

Morphology. Five different morphologies of gold grains were recognized:

1. subhedral - euhedral: these grains have shapes conforming to cubic crystals, with variations from perfect cubes through octahedra to irregular combination of cubes and octahedra, commonly having unevenly formed faces (Figures 10, 11, 13 and 14).

2. anhedral: irregularly shaped grains, some having xenomorphic imprints of neighbouring minerals (Figures 8, 9, 12 and 15).

3. hackly: irregular aggregates having a 3 dimensional dendritic or 'cauliflower' appearance. (Figures 3, 4, 5 and 17).

4. miscellaneous: sheets, plates and scales (Figure 21).

5. damaged: grains mechanically damaged by the disc grinder during sample preparation. Some are recognisably rolled hackly grains (Figure 6), whereas others are anhedral or subhedral grains that have become rounded, with micro indentations due to impact with other minerals and the grinder disc (Figure 22).

Table 2. Size distribution of gold grains collected from selected samples from Mt. Percy Section 15850N.

Size, (square root of length by width product), in µm:

ID	Fresh rock	Reg	RL (m)	Au NAA	to 10 found	to 10 %	to 22 found	to 22 %	to 32 found	to 32 %	to 71 found	to 71 %	to 100 found	to 100 %	to 316 found	to 316 %	>316 found	>316 %
0001	Asf?	Ak	400.0	1060			1	100										
0006	Asf?	Ak	400.3	1240														
0021	Asf?	Ak	401.2	1580							3	100						
0041	Asf?	Ak	402.3	2210									1	100				
0161	Asf?	Lk	403.1	696											1	100		
0173 *	Asf?	Lk	404.1	1540	1	2	4	9	7	16	24	56	4	9	3	7		
0179	As	Lk	404.5	2060							1	100						
0252	As	Lk	405.2	554									1	50	1	50		
0270	As	Lk	406.1	360					1	33			1	33	1	33		
0292	As	L	407.3	150					1	100								
0401	Asf?	Lk	402.6	260														
0545	As	Mc	400.0	340														
1216	Asf	Sc	390.0	2420	11	4	52	19	55	20	136	49	12	4	8	3		
1297	Asf	S	387.5	7100	6	10	14	23	20	32	22	35						
1461	Asf	S	382.5	3230	4	10	3	7	6	14	3	7	10	24	16	38		
1533	Asf	S	380.0	1450			2	40			1	20	1	20	1	20		
1599	Asf	S	375.0	290			3	18	3	18	8	44	2	11	2	11		
1700	Af	S	365.0	821			2	6	3	10	18	58	3	10	3	10	2	6
1701	Asf	S	365.0	350			2	13	2	13	7	44	3	19	2	13		
1744	Asf	S	360.0	480							2	50	2	50				
1801	Asf	R	286.7	4240			1	33					1	33	1	33		
1821	Asf	R	269.2	13400											1	50	1	50

| ID | Fresh rock | Reg | RL (m) | Au NAA | to 10 found | % | to 22 found | % | to 32 found | % | to 71 found | % | to 100 found | % | to 316 found | % | >316 found | % |

Comments on samples:
0001   - 340g sample
0173 * - bulk sample of 3.5kg, made up of samples 0173 to 0179
1216   - additional 41 gold grains possible
1297   - several grains were lost on transfer, method was modified

Table 3.   Shape distribution of gold grains found in selected samples from
Mt.Percy Section 15850N. Shape is illustrated by length versus
width.

length   (long axis of gold grain)

width \ length	0	5	10	15	20	30	40	50	60	70	80	90	100	120	140	160	180	200	240	280	320	360
0	4	4	1	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
5		10	9	10	2	3	.	1	.	.	.	.	.	.	.	.	.	.	.	.	.	.
10			6	17	16	4	1	3	.	.	.	.	.	.	.	.	.	.	.	.	.	.
15				7	21	19	7	1	2	.	.	.	1	1	.	1	.	.	.	.	.	.
20					27	42	12	7	11	6	3	1	.	1	.	.	1	.	.	.	.	.
30						30	24	13	15	9	3	2	.	1	.	.	.	.	.	.	.	.
40							12	9	6	3	4	3	1	1	.	1	.	.	.	.	.	.
50								7	6	4	3	.	3	1	1	1	.	.	.	.	.	.
60									2	3	2	2	.	1	.	.	.	.	.	.	.	.
70										3	3	5	4	2	.	.	.	.	.	.	.	.
80											.	2	4	.	.	.	.	.	.	.	.	.
90												3	2	1	.	2	.	.	.	.	1	
100													6	2	1	1	.	.	.	.	.	.
120														.	3	1	.	.	.	.	.	.
140															.	1	.	1	.	.	.	.
160																.	.	.	.	1	.	
180																	2	.	.	.	.	
200																		2	1	.	.	
240																			.	.	.	
280																				.	2	
320																						1

length   (long axis of gold grain)

Condition. The condition of the grain refers to its external appearance, which may be affected by changes to its environment after deposition:

pristine: grain surfaces having negligible imperfections, e.g. due to corrosion (Figures 8, 9, 10 and 15);

corroded: having small to large, (relative to the grain size), irregularly shaped etched pits and cavities. These are most evident on euhedral and anhedral grains (Figures 4 and 13);

partly dissolved: having smooth rounded surfaces, commonly with large intra-granular voids (Figures 2, 14 and 20).

The morphology and condition of the different grain types are summarized on Table 4. Hackly grains are the most common, with euhedral crystals being next most abundant. This classification is inevitably subjective, since the surfaces of individual grains may exhibit more than one type of morphology or condition (e.g. see Figures 9 and 12).

Composition. The composition of grains was established by EDAX but due to surface effects of the unpolished grain surfaces, the information obtained is at best semi-quantitative. The majority of gold grains contained no Ag or other alloyed metals at the detection limit of the EDAX (estimated between 0.1 and 1%). Some samples from deep in the profile (particularly below 17m) do, however, contain Ag and semi-quantitative analyses were obtained for these. Separation and preparation of grains for quantitative analysis by electron microprobe was difficult due to the small grain sizes and only one Ag-rich grain was so analysed (Table 5).

A number of other unusual minerals were found and analysed during SEM examinations. The results of these observations are summarized in Table 6 by probable mineral name or by element abundance, where assigning a mineral name was difficult.

Table 4. Morphology of gold grains from selected samples from Mt. Percy Section 15850N.

ID	Fresh rock	Reg	RL (m)	Au NAA	total	hackly pr	hackly co	hackly di	anhedral pr	anhedral co	anhedral di	euhedral pr	euhedral co	euhedral di	misc	damaged pr	damaged co
0001	Asf?	Ak	400.0	1060	1								1				
0006	Asf?	Ak	400.3	1240	0												
0021	Asf?	Ak	401.2	1580	3			1					2				
0041	Asf?	Ak	402.3	2210	1		1										
0161	Asf?	Lk	403.1	696	1						1						
0173 *	Asf?	Lk	404.1	1540	43	5	9	2	3	3		4	11		3	3	
0179	As	Lk	404.5	2060	1											1	
0252	As	Lk	405.2	554	2	1										1	
0270	As	Lk	406.1	360	3											3	
0292	As	L	407.3	150	1											1	
0401	Asf?	Lk	402.6	260	0												
0545	As	Mc	400.0	340	0												
1216	Asf	Sc	390.0	2420	271	37	67	21	9	4	4	65	31	16	10	4	3
1297	Asf	S	387.5	7100	62	8	23	12				2	8		2	7	
1461	Asf	S	382.5	3230	43	9	4	7			4	1	1		2	2	13
1533	Asf	S	380.0	1450	5										1	4	
1599	Asf	S	375.0	290	18	2	1	5			1	7	1	1			
1700	Af	S	365.0	821	31	8	10	6				4	3				
1701	Asf	S	365.0	350	15	3	2	7				2	1				
1744	Asf	S	360.0	480	4	1	1	1					1				
1801	Asf	R	286.7	4200	3								3				
1821	Asf	R	269.2	13400	2					1			1				

pr - pristine, co - corroded, di - partly dissolved

Comments on samples:
- 0001 — 340g sample
- 0173 * — bulk sample of 3.5kg, made up of samples 0173 to 0179
- 1216 — additional 41 gold grains possible
- 1297 — several grains were lost on transfer, method was modified
- 1801 — 125g sample
- 1821 — 125g sample

Table 5.   Semiquantitative composition of mixed gold/silver grains
            collected from selected samples from Mt. Percy Section
            15850N.

ID	grain #	Au count	Au %	Ag count	Ag %	ID	grain #	Au count	Au %	Ag count	Ag %
1297	17		76		24	1700	12	300	75	35	25
1599	5		76		24		13	17	5	130	95
	12		71		29		14	300	72	38	28
1700	1	900	82	80	18		19	360	67	60	33
	2	248	47	115	53		23	81	54	22	46
	3	30	4	460	96		26	220	73	27	27
		50	15	118	85		28	280	69	40	31
		86	16	223	84		29	400	79	36	21
	4	170	54	50	46		30	680	72	100	28
	5	330	71	47	29		31	90	49	30	51
	7	323	69	52	31						
STD1		510	22	1905	78	STD3		1297	60	575	40
STD2		889	40	1096	60	STD4		1676	80	190	20

Quantitative electron beam microprobe results on polished grain section
from 1801 grain 3 (Figure 29)

spot #	Au %	Ag %	Te %	Sb %	Hg %	Cu %	Fe %
1	77.63	19.38	0.09		0.80	–	–
2	–	–	–	–	–	32.73	28.80
3	–	66.41	37.12	0.31	–	–	–
4	23.12	41.03	31.68	0.23	–	–	–

Table 6.   Additional SEM observations on panned heavy concentrates from selected samples collected from Mt. Percy Section 15850N.

Other heavy minerals accompanying the gold-silver fraction analyzed during SEM examinations.   Probable mineral names were assigned or element symbols are listed in decreasing peak height order when naming was difficult.

ID   interpreted minerals or element associations observed

0001:   Zircon

0173 * :   Barite,   galena   350*220μm   size,   pyrite,   arsenopyrite,   REE-phosphate, Zn oxide/carbonate, zircon

0292:   Ni and Pb grains (?oxide/carbonate)

1216:   Barite, chalcopyrite, chromite

1297:   Cerianite (20μm sphere), Se (?oxide) 30*30μm

1461:   Arsenopyrite, chromite

1700:   Mixed Au ± Ag ± Te chlorides and bromides, Hg sulphide

1701:   Yttrium phosphate, Co(Ni)sulpharsenide

1801:   Arsenopyrite, galena, pyrite, AgCdTe 5*20μm, pyrite with anhedral Au (Fig.30), pyrite with AgTe grain (Fig.31), pyrite and chalcopyrite with AgTe and NiTe, complex sulpharsenides of SbTeCuZn

1804:   AsPb, Pb (?oxide/carbonate), REE grains, TIS

1809:   Barite, ?chalcopyrite, dolomite, pyrite, REE phosphates, Ni-Fe sulphides

1818:   Chalcopyrite, chromite, Ni sulphides

1821:   Ilmenite, pyrite, Ni sulphides

1838:   Barite, zoned Ni-Fe sulphides

0173 *   bulk sample of 3.5kg, made up of samples 0173 to 0179

6. REGOLITH GEOCHEMISTRY AND MINERALOGY

Gold distribution

The distribution of gold in the regolith as shown by total analysis of the samples from section at 15850N (Figure 1) is characteristic of many deposits in the Kalgoorlie region. The distribution is typically patchy, even at the close (relative to exploration) sampling interval used in the study. This presumably reflects inhomogeneities in the occurrence of both primary gold and secondarily dispersed gold, as well the variable presence of coarse particulate gold. The principal features of the distribution pattern are as follows:

1.   There is a widespread zone of gold enrichment close to the surface, within the lateritic duricrust. Not all the gold is associated with the ferruginous material; a significant proportion is present in the pedogenic calcrete, which constitutes over 20% of some samples, and the samples with the highest gold contents are the most calcareous. Pedogenic calcrete is known to be an important host for gold in the Kalgoorlie region and elsewhere in the southern Yilgarn Block (Lintern, 1989).

2.   A leached and depleted zone (mostly <100 ppb Au), 5 - 10m thick, underlies the lateritic duricrust. This corresponds approximately to the clay-rich mottled zone and upper saprolite of the lateritic profile.

3.   A zone of possible supergene enrichment, 10-15m thick, occurs from a depth of about 17m. The distribution suggests some homogenization and dispersion into the weathered porphyry and fuchsitic ultramafic rocks from the primary source.

4.   Only minor dispersion of gold has taken place deep in the regolith (below about 30m depth). Although much of the gold is secondary, it appears to have remained close to the original host unit.

Samples were selected to investigate whether the numbers, morphologies and composition of gold grains varied according to position in the profile and relationship to primary and secondary concentrations of gold. The locations of the samples are indicated in Figure 1 and relevant geological data given in Table 1. Analytical data are listed in Tables 7 and 8 and the mineralogy of the heavy mineral concentrates is given in Table 9.

Table 7. Major elements analyses of bulk samples selected from Mt. Percy Section 15850N.

ID **	Fresh rock	Reg	RL (m)	SiO$_2$ ICP	Al$_2$O$_3$ ICP	Fe$_2$O$_3$ NAA	MgO ICP	CaO ICP	Na$_2$O XRF	TiO$_2$ XRF	S XRF
0001	Asf?	Ak	400.0	50.40	10.00	4.86	1.980	15.00	.30	.44	.143
0006	Asf?	Ak	400.3	42.90	10.00	10.00	1.600	14.40	.18	.49	.172
0021	Asf?	Ak	401.2	37.50	8.80	16.87	1.640	15.40	.09	.68	.117
0041	Asf?	Ak	402.3	42.50	9.20	11.39	1.890	15.10	.20	.88	.117
0161	Asf?	Lk	403.1	28.20	12.00	38.32	.823	4.79	.14	2.42	.063
0173	Asf?	Lk	404.1	30.40	13.00	26.16	1.230	8.44	.25	2.30	.914
0179	As	Lk	404.5	27.10	10.00	22.30	1.150	15.90	.19	1.91	.558
0252	As	Lk	405.2	13.30	9.70	47.61	.775	9.95	.15	4.94	.077
0270	As	Lk	406.1	2.88	7.80	74.20	.204	1.24	.01	12.67	.055
0292	As	L	407.3	6.47	15.00	64.05	.146	.24	.01	7.65	.152
0401	Asf?	Lk	402.6	15.60	16.00	47.04	.306	.56	.31	6.21	1.580
0545	As	Mc	400.0	58.10	18.00	11.41	.700	.02	.32	1.02	.117
1216	Asf	Sc	390.0	69.70	8.80	6.72	.559	.02		.31	2.347
1297	Asf	S	387.5	51.90	14.00	26.16	.501	.03		.68	.893
1461	Asf	S	382.5	57.30	16.00	3.00	.711	.05		.46	5.035
1533	Asf	S	380.0	62.30	13.00	13.41	.626	.03	.22	.52	.608
1599	Asf	S	375.0	64.80	17.00	2.43	.570	.02	.23	.40	.223
1700	Af	S	365.0	83.70	6.60	2.14	.230	.01	.19	.24	.010
1701	Asf	S	365.0	63.48	11.41	14.27	1.00	.00	.47	.49	.079
1744	Asf	S	360.0	65.30	14.00	12.22	.88	.05	.27	.57	.043
1801	Asf	R	286.7	30.63	6.20	9.42 2	1.66	2.66	.03	.30	.161
1804	Af	R	284.3	59.98	13.40	3.29	3.96	4.33	5.97	.46	1.068
1809	Af	R	280.5	66.80	11.30	3.43	3.26	2.91	1.82	.41	1.016
1818	Asf	R	274.0	34.57	5.00	7.58 1	4.18	10.37	.50	.24	.708
1821	Asf	R	269.2	49.94	6.90	8.78	7.25	7.59	.11	.31	2.799
1838 *	Asf	R	290.0	46.18	5.30	8.30 1	3.18	3.00	.38	.24	1.661
ID **	Fresh rock	Reg	RL (m)	SiO$_2$ ICP	Al$_2$O$_3$ ICP	Fe$_2$O$_3$ NAA	MgO ICP	CaO ICP	Na$_2$O XRF	TiO$_2$ XRF	S XRF

Remarks: values are in wt.%, * from Hole KND 22, 15900N; ** Reg - regolith
Analytical methods used: ICP - inductively coupled plasma emission spectrometry
NAA - neutron activation analysis
XRF - X-ray fluorescence analysis

Table 8.   Selected trace elements analyses of bulk samples from Mt. Percy Section 15850N.

ID **	Fresh rock	Reg	RL (m)	Ag IMS	As NAA	Au NAA	Ba XRF	Cr NAA	Sb NAA	Te HYD	W NAA	Zr XRF
0001	Asf?	Ak	400.0	190	12	1060	496	270	2	0.1	3	104
0006	Asf?	Ak	400.3	280	35	1240	1072	370	3	<0.1	4	92
0021	Asf?	Ak	401.2	280	97	1580	663	1080	5	<0.1	4	77
0041	Asf?	Ak	402.3	190	18	2210	521	838	3	<0.1	4	111
0161	Asf?	Lk	403.1	200	201	696	401	2670	8	0.1	15	157
0173	Asf?	Lk	404.1	200	110	1540	401	1300	5	<0.1	13	149
0179	As	Lk	404.5	240	100	2060	435	1110	6	0.1	14	116
0252	As	Lk	405.2	190	29	554	162	500	6	<0.1	22	166
0270	As	Lk	406.1	360	34	360	230	390	11	<0.1	42	242
0292	As	L	407.3	280	73	150	293	927	9	<0.1	32	203
0401	Asf?	Lk	402.6	230	160	260	168	1320	9	<0.1	33	198
0545	As	Mc	400.0	100	58	340	154	3660	11	0.2	13	94
1216	Asf	Sc	390.0	<100	88	2420	309	2750	8	0.8	11	26
1297	Asf	S	387.5	140	258	7100	454	2130	10	0.1	11	82
1461	Asf	S	382.5	110	67	3230	567	3940	6	0.1	8	34
1533	Asf	S	380.0	160	160	1450	483	3260	22	22	110	90
1599	Asf	S	375.0	160	61	290	429	3040	4	0.7	9	31
1700	Af	S	365.0	620	18	821	514	160	5	1	13	67
1701	Asf	S	365.0	110	457	350	1324	3750	10	1.1	22	30
1744	Asf	S	360.0	1960	19	480	490	2320	7	1.4	9	68
1801	Asf	R	286.7	12400	508	4240	181	2310	8	11	12	15
1804	Af	R	284.3	2980	28	4990	566	170	7	0.2	27	129
1809	Af	R	280.5	17900	59	5450	1202	160	34	7	23	114
1818	Asf	R	274.0	4830	17	2090	93	2040	5	4	7	11
1821	Asf	R	269.2	15400	212	13400	290	2090	17	18	16	14
1838	Asf	R	290.0	18800	28	3670	95	1900	9	18	5	9
ID **	Fresh rock	Reg	RL (m)	Ag IMS	As NAA	Au NAA	Ba XRF	Cr NAA	Sb NAA	Te HYD	W NAA	Zr XRF

Values are in ppm, ppb for Ag and Au;   *   from Hole KND 22, 15900N;   ** Reg - regolith
     Analytical methods used: IMS - inductively coupled plasma - mass spectrometry
                                 NAA - neutron activation analysis
                                 XRF - X-ray fluorescence analysis
                                 HYD - hydride generation - atomic absorption spectrometry

Table 9. Magnetic behaviour and mineral composition of heavy concentrates, after gold was removed
Selected samples from Mt. Percy Section 15850N.

ID	Fresh rock	Reg	RL (m)	Type	Minerals observed									
					alu	ca	ga	go	he	ka	magh	mu	qtz	ru
0001	Asf?	Ak	400.0	magnetic		ca		go	he		magh		qtz	ru
0006	Asf?	Ak	400.3	magnetic		ca		go	he	ka	magh	mu	qtz	ru
0021	Asf?	Ak	401.2	magnetic		ca		go	he	ka			qtz	ru
0041	Asf?	Ak	402.3	magnetic					he		magh		qtz	ru
0161	Asf?	Lk	403.1	magnetic				go	he				qtz	ru
0173 *	Asf?	Lk	404.1	magnetic				go	he		magh		qtz	ru
0179	As	Lk	404.5	magnetic				go	he		magh		qtz	ru
0252	As	Lk	405.2	magnetic					he		magh ?		qtz	ru
0270	As	Lk	406.1	magnetic				go	he		magh ?			ru
0292	As	L	407.3	magnetic				go	he		magh		qtz ?	ru
0401	Asf?	Lk	402.6	magnetic				go	he		magh ?			ru
0545	As	Mc	400.0	magnetic				go	he		magh		qtz	ru
1216	Asf	Sc	390.0	mineralogy not determined										
1297	Asf	S	387.5	mineralogy not determined										
1461	Asf	S	382.5		alu			go		ka		mu	qtz	ru
1533	Asf	S	380.0					go	he	ka		mu	qtz	
1599	Asf	S	375.0		alu ?					ka		mu	qtz	ru
1700	Af	S	365.0					go	he				qtz	ru
1701	Asf	S	365.0					go	he				qtz	
1744	Asf	S	360.0					go	he				qtz	
1801	Asf	R	286.7				ga						py	
1821	Asf	R	269.2										py	

Type - magnetic behaviour of heavy concentrate
alu - alunite, ca - calcite, ga - galena, go - goethite, he - hematite, ka - kaolinite,
magh - maghemite, mu - muscovite, py - pyrite, qtz - quartz, ru - rutile.
0173 * - bulk sample of 3.5kg, made up of samples: 0173, 0174, 0175, 0176, 0177, 0178, 0179.

Geochemistry and mineralogy of panned samples

The geochemistry and mineralogy of the samples selected for this study (Tables 5 - 9) reflect the principal effects of weathering.

1. Iron, Ti and Zr are concentrated in the lateritic duricrust and associated soils. The Fe has been released from mafic minerals and has reprecipitated as goethite, hematite and maghemite. Titanium and Zr are retained principally as resistant rutile and zircon.

2. In the unweathered rocks Ca and Mg occur mainly as dolomite, with some Mg still in ferromagnesian minerals such as chlorite and talc. Both are strongly leached from the saprolite but Ca in particular is concentrated in the soil and upper duricrust as calcite and minor dolomite.

3. Aluminium shows some concentration as a result of weathering in saprolite and lateritic duricrust derived from ultramafics.

4. Chromium is present principally in chlorite and chromian muscovite (fuchsite) in unweathered rocks; chromite is uncommon. In the regolith, Cr is concentrated in clay-rich horizons of the upper saprolite and mottled zone but has been leached from the lateritic duricrust. Chromium is commonly strongly enriched as resistant chromite in duricrusts derived from ultramafics; the absence of such an enrichment at Mt. Percy reflects its occurrence in weatherable primary host minerals such as chlorite.

5. Sulphur, Ag, Te, As, Sb and W are associated with the primary Au mineralization but each behave differently during weathering. Sulphur is present as primary sulphides, principally pyrite, and is strongly leached from the lower saprolite. However, S is concentrated in the middle to upper saprolite as alunite. Silver and Te are markedly enriched in the primary mineralization; Ag halides, Ag and Au tellurides and Ag rich electrums have been recovered during this study. Both Ag and Te, however, are strongly leached during weathering. Moderate As, Sb and W enrichments are spatially associated with the primary mineralization and remain anomalous in the regolith. Tungsten has potential as a pathfinder element for gold, since it appears to occur as a resistant mineral, probably scheelite.

7.   MORPHOLOGY OF GOLD GRAINS

Lateritic soil (Samples MW 0001, 0006, 0021, 0041)

The lateritic soil yielded few gold grains relative to its bulk gold content. This is possibly due to the gold grains being present in size extremes, either very small or very large. This would lead to less efficient recovery, either by loss of small grains (especially <5μm) with the technique used or low probability of occurrence of large grains. The few grains recovered were either euhedral or hackly, and all were strongly corroded (Figures 2 and 3). All had low Ag contents.

Pisolitic lateritic duricrust   (Samples MW 0161, 0173, (0174, 0175, 0176, 0177, 0178)
0179, 0252, 0270, 0292, 0401)

The recovery of gold grains from the pisolitic duricrust was approximately proportional to bulk Au content but again generally poor, except for the composite sample from which a proportionally very high recovery was obtained. Over one third of the grains are irregular, hackly aggregates of secondary gold, many of which are moderately to strongly corroded (Figures 4, 5 and 6). The hackly grain shown in Figure 6 illustrates the damage caused by disc grinding during sample preparation. There are a similar number of subhedral to euhedral crystals (Figures 10 and 11) and the remainder are either anhedral or display a mixture of morphological types. For example, a hackly grain with some octahedral faces is shown in Figure 4, and predominantly anhedral grains with a few crystal faces are shown in Figures 7, 8 and 9. Although most of the grains are corroded, several are nearly pristine (Figures 7-10) or have only localized corrosion (Figure 11). The crystal in Figure 11 appears to have a re-entrant (possibly xenomorphic) face with later granules deposited on it, which themselves are now partly corroded. Many of the very irregular, pristine, anhedral grains may have been liberated from enclosing material (e.g. quartz or Fe oxides) during sample preparation. The cavities may contain quartz (Figure 7) or be xenomorphic imprints. The low Ag contents of these grains suggest that they are secondary, or at least secondarily refined, rather than primary.

Mottled clay zone (Sample MW 0545)

This horizon corresponds to the leached, depleted zone illustrated by the Au distribution (Figure 1). No Au grains were recovered.

Saprolitic clay zone (Sample MW 1216)

This sample is from the top of the saprolite and yielded a far greater number of grains than expected from its analysed Au content. The grains occur almost equally in two morphological classes, namely hackly (47% of the total) and subhedral to euhedral (41%) (Figures 12-14). Of the hackly grains, approximately a third are pristine and the remainder are moderately to strongly corroded. On subhedral or euhedral grains the corrosion may be selective, apparently only affecting some faces and not others. For example, the grain shown in Figure 13 is corroded on two apparently re-entrant faces; similarly, although much of the grain shown in Figure 14 is severely pitted by cavernous dissolution voids, some faces are almost uncorroded. However, over half of the subhedral to euhedral grains are pristine (Figure 12) or have only minor corrosion. A small proportion of the grains are anhedral, including partly xenomorphic types. The xenomorphic "faces" of the grain in Figure 15 are pristine, possibly having been exposed during sample preparation, whereas other, possibly exposed, surfaces are moderately corroded. Similarly, the hackly/anhedral grain in Figure 16 has moderately corroded exposed surfaces; this grain still incorporates enclosed quartz grains.

Mid-saprolite (Samples MW 1297, 1461, 1533, 1599)

Most of the gold grains in this zone have a hackly appearance (Figures 17, 18, 19), with only a few subhedral to euhedral crystals (Figure 20); a few were damaged during sample preparation. Most of the grains are moderately corroded, and the euhedral grain of Figure 20 has been partly dissolved by severe cavernous pitting.

Alunite occurs in a zone approximately 15m thick in the upper saprolite, particularly over the fuchsitic ultramafic rocks. It is patchily distributed and represented by sulphur contents of 0.5-5.0%. Some of the hackly grains that were recovered were embedded in alunite (Figures 18, 19), suggesting that the precipitation of at least some alunite postdates that of gold. Two samples (MW 1297, 1599) from this part of the saprolite also contain one and two grains, respectively, that semi-quantitative EDAX analysis indicates may contain about 20-30% Ag. The grain in MW 1297 (Figure 21) has an unusual subhedral form that appears to be an aggregate of pseudo-hexagonal plates, partly obliterated by corrosion. The grains from MW 1599 are also subhedral and slightly corroded; the grain illustrated in Figure 22 had been rounded by the disc grinder.

Lower saprolite (Samples MW 1700, 1701, 1744).

The most important characteristic of the 31 gold grains recovered from this horizon is that half (16) are Ag-bearing ("electrum"). In addition, and not included in the tabulated statistics, a further 20 grains consist dominantly of Ag with little Au. A few of the "pure" Au grains are subhedral-euhedral (Figure 23) but the majority are predominantly hackly (Figure 24); most are corroded to varying degrees. The majority of the Ag-bearing Au grains are strongly corroded and difficult to classify morphologically. The only uncorroded grains are either euhedral crystals or are very irregular and xenomorphic. The latter is illustrated in Figure 25 which, although slightly damaged, is probably an Au boxwork, with the striations on one face possibly imprinted from adjacent pyrite. The composition of this grain is approximately half Au, half Ag (MW 1700, grain 31; Table 5). Many of the other grains have a hackly appearance which has possibly developed from the corrosion of anhedral or xenomorphic forms similar to that in Figure 28.

A further 16 Ag-bearing grains in MW 1700 were analysed semi-quantitatively by EDAX. The results (Table 5) indicate concentrations of 20 to 95% Ag and, despite the uncertainties involved, show that the gold at Mt. Percy is very silver rich. The Ag grains are complex chlorides and bromides, some with Te and Au, as well as Ag tellurides. An irregular, possibly hackly, Ag chloride-bromide grain, with a thin coating of pure gold, is shown in Figure 26 and an anhedral, possibly subhedral, grain of Ag chloride-bromide with minor Au, with a coating of apparently Ag-rich (10%) gold is shown in Figure 27. The halides, and therefore the coatings, are secondary; the presence of Ag in such coatings may have implications for the mechanism of Au mobilization in this part of the profile. Silver telluride grains are present as corroded anhedral to subhedral forms; that illustrated in Figure 28 also has some Hg sulphide adhering to it.

Unweathered rock (Samples MW 1801, 1821).

Although only a small mass of each sample (125g) was available for panning, these samples contain over 4 and 13 ppm Au, so that the very low recovery of Au grains (5) was unexpected. These few grains were all Ag-bearing, either anhedral or subhedral. Only one grain (Figure 29) was successfully extracted and polished for electron microprobe analysis. This grain is a complex intergrowth of Ag-rich gold, Ag telluride and chalcopyrite. The microprobe analyses (Table 5) confirm the semi-quantitative data from EDAX analysis, which have suggested that the gold from Mt. Percy is very Ag-rich. The data also indicate an intimate association of Sb and Hg with some gold and Ag tellurides.

Five samples of unweathered rocks, including those panned, were also examined in polished section. Only two Au-bearing grains were found, in samples MW 1801 and MW 1838. The grain in sample MW 1801 (Figure 30) is an irregular, anhedral mass apparently containing over 10% each of Te and Ag; that in MW 1838 is very small (5*5μm) and only Au was detected. Other minerals with high net atomic numbers found in these sections include Ag tellurides (Figure 31), pyrite, chalcopyrite, Ni sulphides and arsenopyrite (Table 6). Of these, only pyrite is present as other than a minor accessory mineral.

Size and shape of gold grains

More than 500 grains were recovered by mechanical panning of the 28 samples. Over half of these (280) have a maximum dimension of less than 50μm, with the smallest grains recovered being about 5μm. Still smaller grains were no doubt abundant in the original samples, but could not be recovered. The majority of the grains were equant in shape (i.e. long and short axes of approximately the same length, hence plotting on the diagonal of Table 3), with axes of 30 - 50μm and square root of length x width products of 30 to 70. The numbers of grains recovered are too small to establish more than very general relationships between grain size and shape and location in the regolith. Equant and near-equant grains with axes of 10-40μm are the most common shape and size in all horizons. Larger grains (>100μm) are uncommon, but are most frequent in the lateritic duricrust and particularly in the mid-saprolite (MW 1461), whereas smaller grains (<30μm) are most frequent in the clay rich upper saprolite (MW 1216, 1297).

8. DISCUSSION

Occurrence and distribution of gold grains in the profile

The geochemical data (Butt, 1990) for the mineralized zone show that porphyries and fuchsitic ultramafics both have mean Au contents of approximately 1000 ppb Au, with some high grade zones (2000-13400 ppb Au) associated with quartz veining. Silver and Te have broadly similar distributions to that of Au, and peak values of Au, Ag and Te occur together. The Ag and Te concentrations are both in the range 0.24-19.0 ppm in the mineralized zone (i.e. higher than Au) with Ag/Au (and Te/Au) ratios mostly between 1 and 5 and Ag/Te ratios of approximately 1. The data obtained in this study confirm the Ag-rich nature of the free gold (25-50% Ag) and demonstrate the presence of Ag tellurides in the primary mineralization, but only relatively few such grains were found. Insufficient information has been obtained to determine whether the poor physical recovery of gold is due to poor sampling statistics (small

sample weights and coarse grains) or to its mode of occurrence, for example as very fine grains, perhaps contained within other minerals, including pyrite.

The primary geochemical association of Au, Ag and Te is retained in the lower saprolite, but the assemblage includes both primary and secondary minerals. The top of the lower saprolite is marked by an increase in competence and hardness, demonstrated, for example, by the necessity to change the sampling procedure from ripping to drilling at RL 360. These increases appear to be accompanied by a decrease in porosity and there are a number of compositional features at this level (e.g. disappearance of albite, concentration of rare earth elements) that suggest it to be the site of weathering and chemical activity, either at present or in the recent past, perhaps associated with the water-table or a perched water-table (Butt, 1990). The nature and diversity of the Au and Ag minerals are further evidence for chemical activity at this depth. The majority of the Ag-bearing grains are strongly corroded - the few pristine grains probably being freshly released from protecting minerals during sample preparation. The Ag-free gold grains are interpreted as being secondary, products of the reprecipitation of gold released by corrosion of the Ag-rich grains. The halides are an equivalent secondary mineralogy for the Ag that is released, but whereas Ag-poor secondary gold remains more or less throughout the regolith, the Ag halides are present only at this level and are leached from higher in the profile. The Au coating on some Ag halides and the corrosion of the secondary gold indicate there to be multiple solution and deposition events. The presence of Ag in one such coating has not been verified; the Ag recorded by EDAX may be due to X-rays derived from the halide grain, either through the coating or scattered from adjacent exposed areas. However, if the coating is indeed Ag-bearing, it implies that one phase of Au mobilization may differ from the others, perhaps involving thiosulphate ligands, from which Ag and Au may deposit together.

Above RL 355 in the profile, Au grains of high fineness predominate, with Ag-bearing primary grains being very rare. There is no evidence for the preservation of primary grains in upper horizons of the profile, similar to those found at Bardoc (Freyssinet and Butt, 1988a) or in lateritic profiles in the humid tropics (Freyssinet et al., 1989). A feature of the results from Bardoc was the presence of at least a few primary grains in all horizons of the profile, with an especially high proportion (40%) in the ferruginous lateritic gravels and soil. This was attributed to the grains being protected and preserved, probably within Fe oxide segregations precipitated during lateritization. At Mt. Percy, no primary gold grains (or, indeed, many secondary grains) were found in the lateritic duricrusts or gravelly soils. The absence of primary grains are probably due to:

1.   from limited evidence, the low abundance of large (>20μm) grains in the primary mineralization;

2.   the higher Ag contents of primary gold at Mt. Percy (20->50%) compared to Bardoc (4-10%), and hence their lower stability in the weathering environment (Mann, 1984).

Neither the geochemical data nor the results of panning provide any evidence of the enrichments of gold sought by the early prospectors at the base of the lateritic duricrusts and gravels. It is not certain whether the gold - these enrichments, or that recovered by dry blowing, was primary or secondary.

Secondary gold

The secondary Au grains are of two main types - subhedral to euhedral crystals and irregular, hackly aggregates. Many of the latter have a three-dimensional dendritic form, giving them a "coralline" or "cauliflower" appearance. In addition, there are a number of irregular, anhedral grains whose growth has been constrained by surrounding minerals; these grains are commonly partly xenomorphic. The hackly and euhedral crystal forms have probably developed under different conditions. By analogy with crystal growth from aqueous solution, the hackly form is assumed to represent relatively rapid deposition in irregular voids or within a soft matrix, whereas euhedral and anhedral forms have grown more slowly, the former without restriction.

The occurrence of secondary gold is a result of the mobilization and deposition of gold during weathering. In common with other sites in Western Australia, much of the mobilization has probably been as halide complexes, particularly chlorides, under acid oxidizing conditions developed under arid climates. This is confirmed in the regolith by the presence of Ag halides and of alunite, for which Al is derived by dissolution of aluminosilicates in acid environments (pH <4.5). The coexistence of pristine and corroded secondary gold grains is evidence that the mobilization has been an intermittent process, although in part may be due to variable protection by enclosing minerals. Pseudo-hexagonal secondary grains are, however, rare at Mt. Percy. Such crystals are abundant at Hannan South (Lawrance, 1988) and Panglo (Scott and Davis 1990) and occasional at Bardoc, and their occurrence appears to be related to deposition in very saline environments. Their virtual absence from Mt. Percy is consistent with this interpretation, for Mt. Percy is situated relatively high in the landscape whereas Hannan South and Panglo are both in drainages, with regoliths saturated by hypersaline groundwaters.

The external appearance, or condition, of a grain is a function of the weathering conditions that have prevailed since its deposition or exposure. Thus, pristine surfaces indicate that the grain may have only recently been deposited, has not been exposed to corrosive solutions or has been protected by other mineral grains. By analogy with the etching and solution of other metals, the corroded grains are possibly the product of slow, localized dissolution, whereas the rounded or cavernously-pitted grains have formed by more rapid dissolution.

Behaviour of gold during profile evolution

There is no direct evidence at Mt. Percy for the behaviour of gold during lateritization. It is possible that primary grains were preserved through to the ferruginous zone, as is generally observed in lateritic environments, but if so, they were either destroyed during the formation of that horizon, or at least were not protected from subsequent leaching events. Gold is thought to be mobilized by humic complexes during lateritization, being dissolved from the surface horizons and reprecipitating with iron oxy-hydroxides deeper in the ferruginous and mottled zones (Butt, 1989). Such secondary gold is Ag-poor and generally very fine grained, hence difficult to recover by panning. Some of the gold within the present duricrust at Mt. Percy may have this origin. Most mobilization of gold, however, probably occurred during the post-lateritic arid phases, by multiple solution and deposition events involving halide complexing, caused by the intermittent development of acid, oxidizing conditions. This process has caused extreme leaching of gold from the clay-rich upper horizons of the profile, a common characteristic of Au distributions in the regolith in Western Australia. However, it is not clear whether this can be attributed to the cumulative effect of multiple leaching events or to a single event early in the post-lateritic evolution of the regolith at a time when the water-table was still relatively high. Gold mobilization is possibly still continuing slowly at local sites throughout the profile, but is most probable in the lower saprolite, where primary grains are present, and in the duricrust and soil. The pedogenic carbonates in these upper horizons are enriched in gold which is probably actively accumulating by cycling through the vegetation. By analogy with other sites (e.g. Mt. Hope, Lintern, 1989), this gold is probably very fine grained or even present as a colloid and cannot be recovered by panning.

9. ACKNOWLEDGEMENTS

10. REFERENCES

Butt, C.R.M., 1989. Genesis of supergene gold deposits in the lateritic regolith of the Yilgarn Block, Western Australia. In: Economic Geology Monograph 6, The geology of gold deposits: The perspective in 1988, Reid R. Keays, W.R.H. Ramsay, David I. Groves, Editors. pp. 460-470.

Butt, C.R.M., 1990. (in prep.) Dispersion of gold and associated elements in the lateritic regolith, Mystery Zone, Mt. Percy, Kalgoorlie, Western Australia. CSIRO Division of Exploration Geoscience, Restricted Report.

Freyssinet, Ph and Butt, C.R.M., 1988a. Morphology and geochemistry of gold in a lateritic profile, Bardoc Mine, Western Australia. CSIRO Division of Exploration Geoscience, Restricted Report No. 59, 24pp.

Freyssinet, Ph and Butt, C.R.M., 1988b. Morphology and geochemistry of gold in a lateritic profile, Beasley Creek, Laverton, Western Australia. CSIRO Division of Exploration Geoscience, Restricted Report No 60, 11pp.

Freyssinet, Ph and Butt, C.R.M., 1988c. Morphology and geochemistry of gold in a lateritic profile, Reedy Mine, Western Australia. CSIRO Division of Exploration Geoscience, Restricted Report No 58, 15pp.

Freyssinet, Ph., Zeegers, H. and Tardy,Y., 1989. Morphology and geochemistry of gold grains in lateritic profiles of southern Mali. J. Geochem. Explor., 32: 17-31.

Hart, M.K.W., 1989. Analysis for total iron, chromium, vanadium and titanium in varying matrix geological samples by XRF, using pressed powder samples. Standards in X-ray analysis. Australian X-ray Analytical Association (WA Branch) Fifth State Conference. 117-129.

Lawrance, L.M., 1988. The morphology and geochemistry of supergene gold at Hannan South gold mine, Western Australia. In: Bicentennial Gold 88, Extended Abstracts, Poster Programme, Volume 1, Compiled by Goode, A.D.T., Smyth, E.L., Birch, W.D., Bosma, L.I., 360-364.

Lintern, M.J.,1989. Study of the distribution of gold in soils at Mt. Hope, Western Australia. CSIRO Division of Exploration Geoscience, Restricted Report No.24, 17pp.

Mann, A.W., 1984. Mobility of Gold and Silver in Lateritic Weathering Profiles: Some Observations from Western Australia. Econ. Geol., 79:38-49.

Norrish, K. and Chappell, B.W., 1977. X-ray fluorescence spectrometry. In Zussman, J. (Ed): Physical methods in determinative mineralogy. Academic Press, London. 201-272.

Sauter, P.C.C., Hyland, S.J. and Bradley, T., 1988. The Mount Percy Gold Mine. In: Bicentennial Gold 88, Excursion Guidebook, Compiled and Edited by Groves, D.I., Barley, M.E., Ho, S.E. and Hopkins, G.M.F., 84-86.

Scott, K.M. and Davis, J.J., 1990. Gold morphology and composition at Panglo, Eastern Goldfields, Western Australia. CSIRO Division of Exploration Geoscienece Report.

Travis, G.A., Woodall, R. and Bartram, G.D., 1971. The geology of the Kalgoorlie goldfield. In: Glover, J.E. (ed.), Symposium on Archaean Rocks. Spec. Publs Geol. Soc. Aust 3, 175-190.

Gold grains from the lateritic soil.

Fig. 2.   Euhedral gold grain with corrosion pits and large dissolution voids, no detectable silver. (MW 0021, grain 3).

Fig. 3.   Hackly gold grain with severe corrosion pitting, no detectable silver. (MW 0041).

Gold grains from the lateritic duricrust.

Fig. 4.   Hackly gold grain with subhedral crystal at the top, strongly corroded, no detectable silver. (MW 0173, grain 7).

Fig. 5.   Hackly gold grain, moderately corroded, no detectable silver. (MW 0173, grain 34).

Fig. 6.   Hackly gold grain, moderately corroded and rolled during sample preparation, no detectable silver. (MW 0173, grain 4).

Fig. 7.   Cluster of subhedral crystals intergrown with quartz, no detectable silver. (MW 0173, grain 5).

2

3

4

5

6

7

10 µm
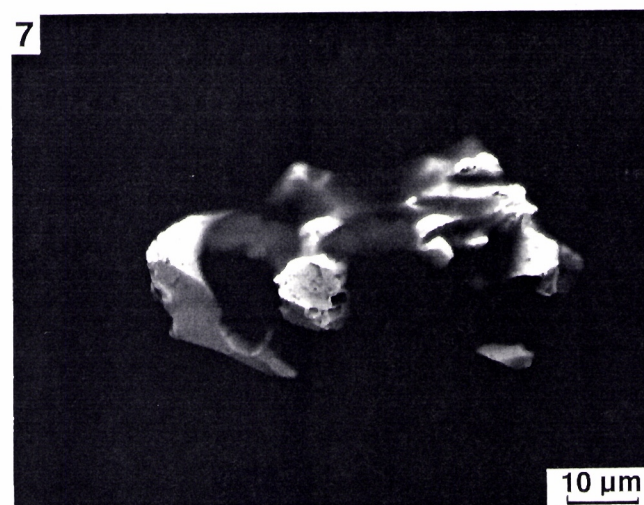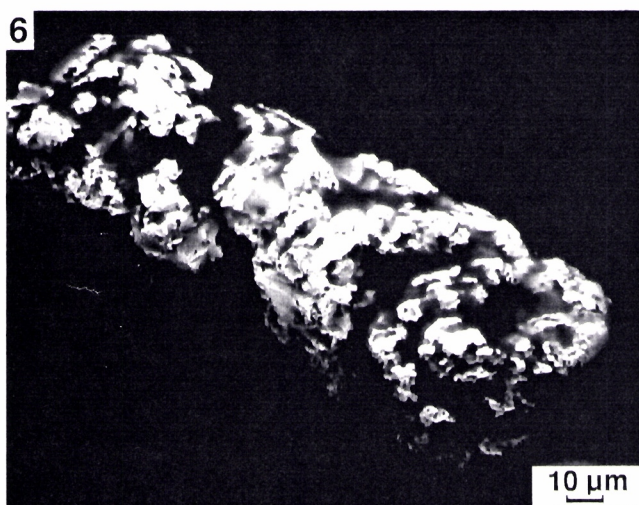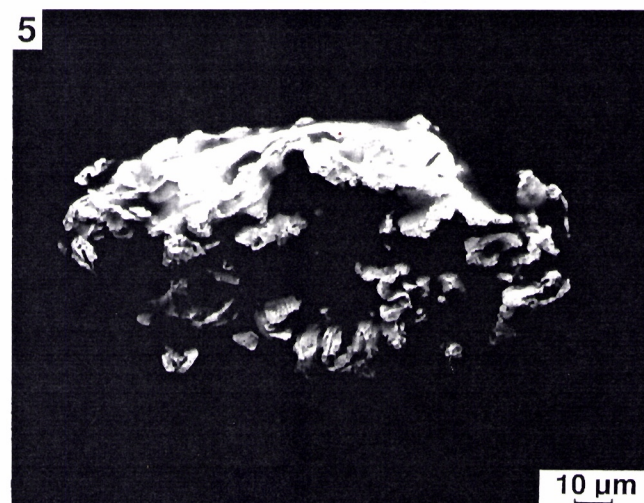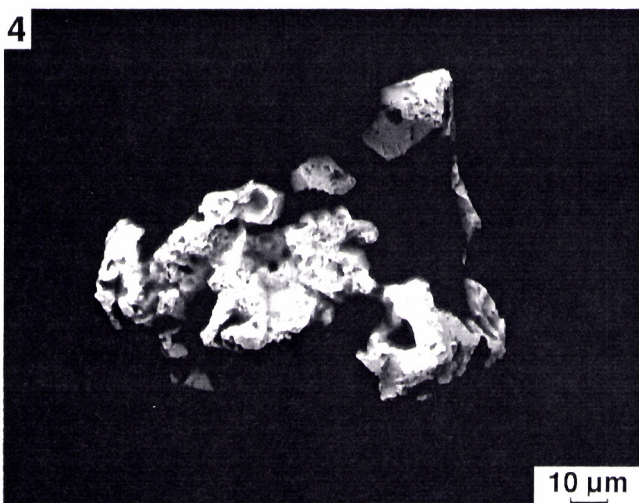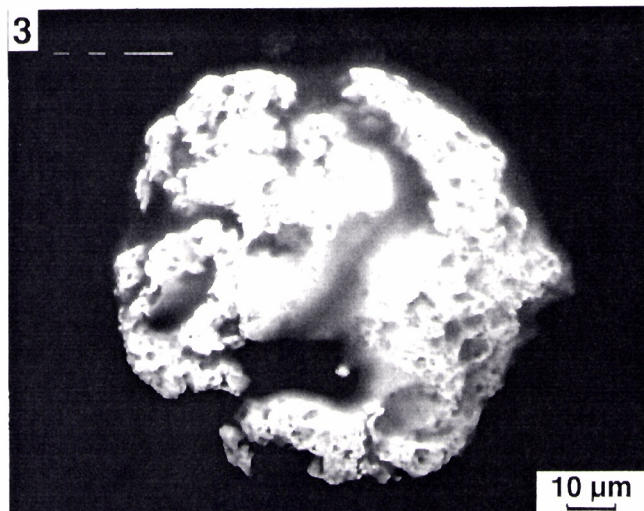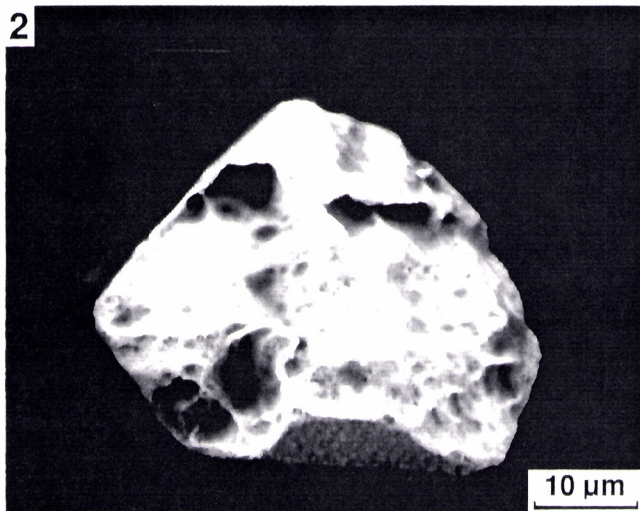
Gold grains from the lateritic duricrust (cont'd).

Fig. 8.   Gold grain showing euhedral and anhedral morphology, lightly corroded, no detectable silver. (MW 0173, grain 6).

Fig. 9.   Gold grain with dominantly anhedral xenomorphic morphology but with some crystal faces; lightly corroded, no detectable silver. (MW 0173, grain 17).

Fig. 10.   Pristine euhedral gold grain with insignificant corrosion, no detectable silver. (MW 0173, grain 9).

Fig. 11.   Euhedral gold grain, with secondary deposition, subsequently corroded on re-entrant or xenomorphic faces, no detectable silver. (MW 0173, grain 18).

Gold grains from the saprolitic clay zone.

Fig. 12.   Euhedral to subhedral gold grain, partly corroded, no detectable silver. (MW 1216, grain 3).

Fig. 13.   Euhedral gold grain with dissolution void; strong corrosion on re-entrant or xenomorphic faces; no detectable silver. (MW 1216, grain 53).

8

10 µm

9

10 µm

10

10 µm

11

10 µm

12

10 µm

13

1 µm
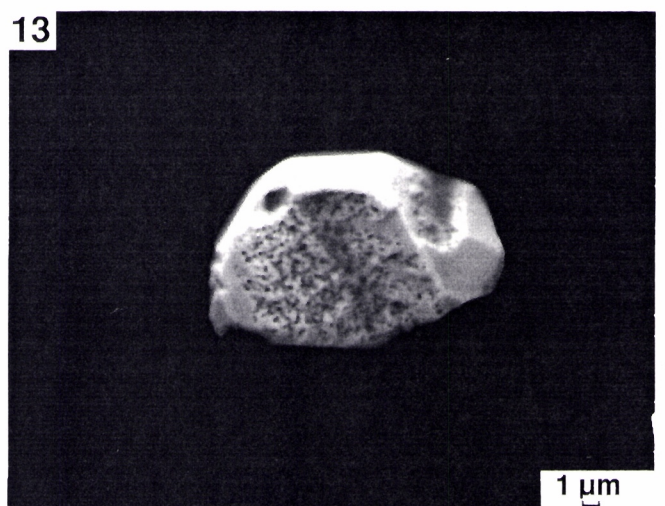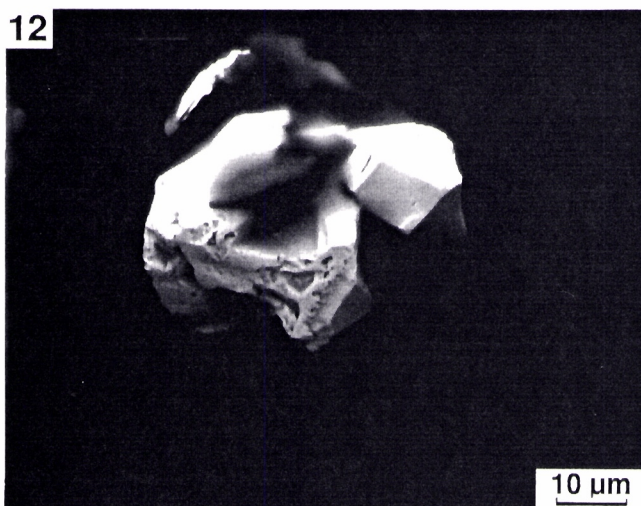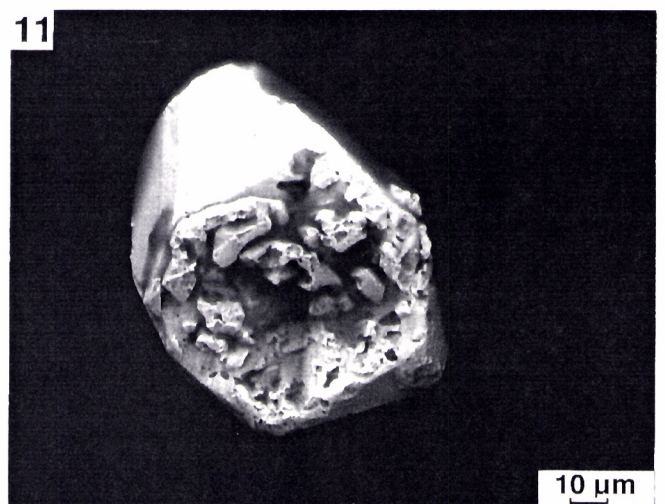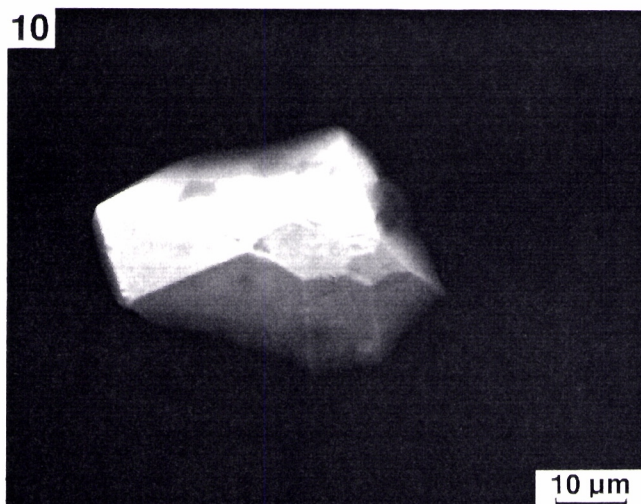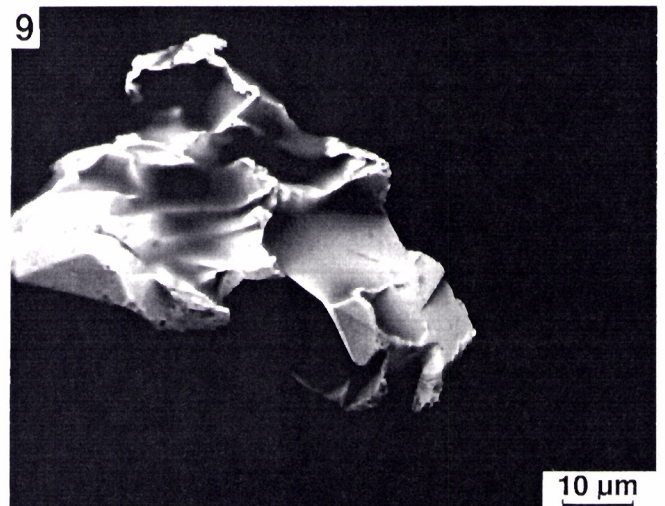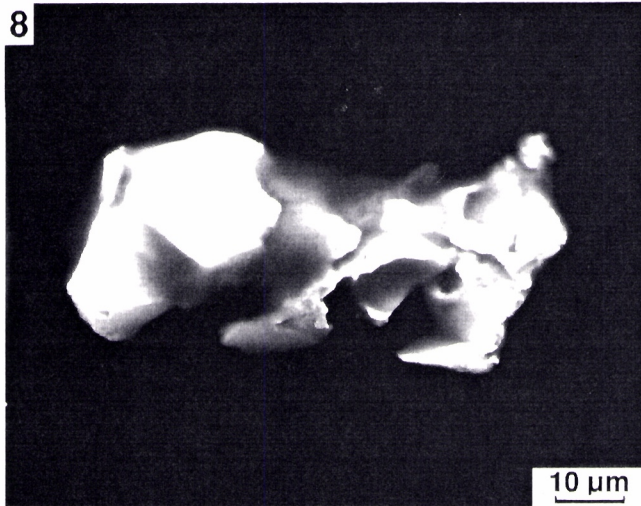
Gold grains from the saprolitic clay zone (cont'd).

Fig. 14.   Euhedral gold grain with large dissolution voids and some corrosion, no detectable silver. (MW 1216, grain 153).

Fig. 15.   Anhedral, xenomorphic mostly pristine gold grain with moderate corrosion, no detectable silver. (MW 1216, grain 74).

Fig. 16.   Hackly/anhedral gold grain with corrosion pits, no detectable silver. (MW 1216, grain 69).

Gold grains from the mid saprolite.

Fig. 17.   Hackly gold grain with corrosion pits, no detectable silver. (MW 1461, grain 4).

Fig. 18.   Hackly gold grain embedded in alunites, no detectable silver. (MW 1461, grain 2).

Fig. 19.   Hackly gold grains embedded in alunite, no detectable silver. (MW 1461, grains 8,9).

14

10 μm

15

10 μm

16

10 μm

17

10 μm

18

10 μm

19

10 μm
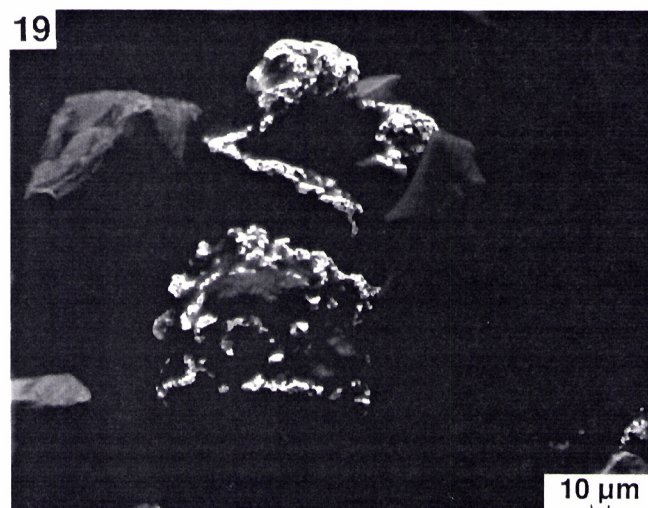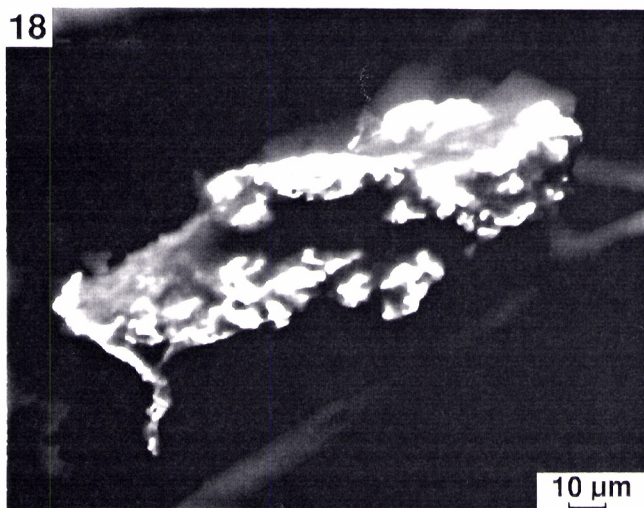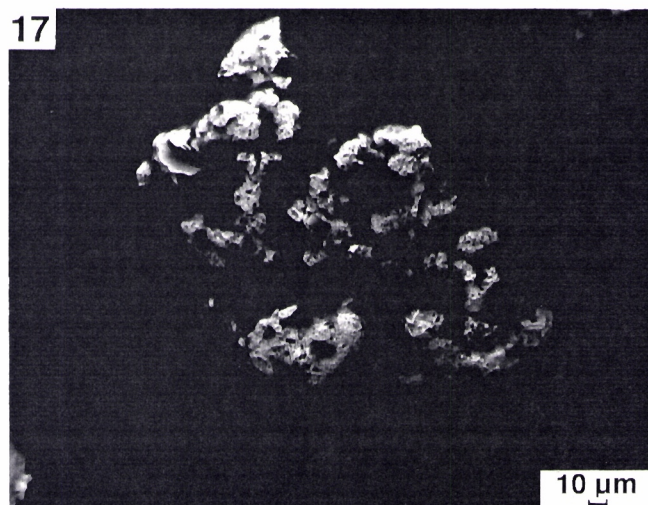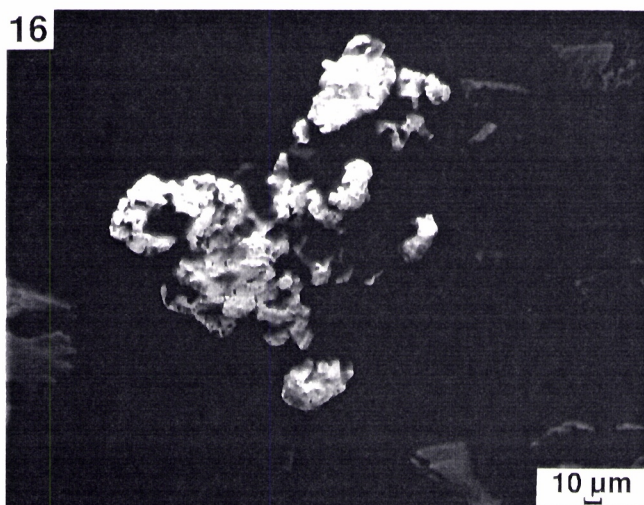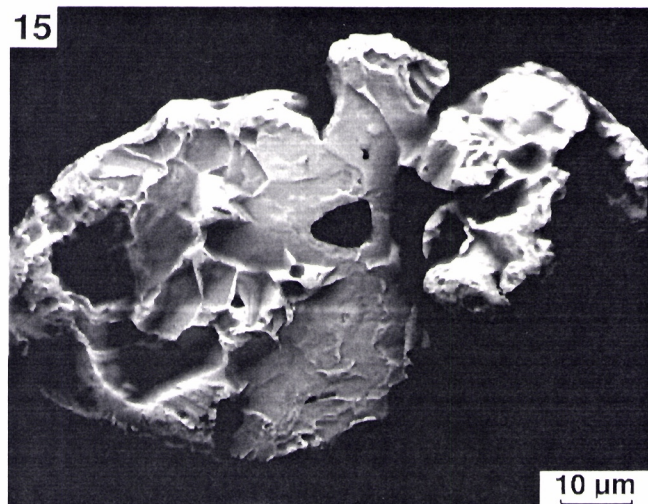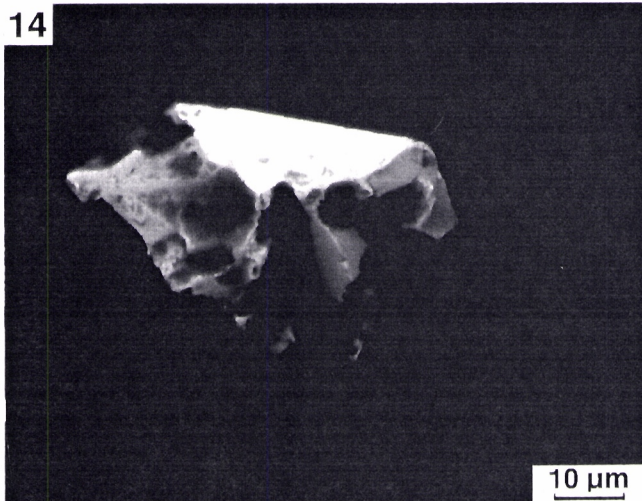
Gold grains from the mid saprolite (cont'd).

Fig. 20.   Severely corroded, possibly euhedral gold grain with secondary euhedral growth, no detectable silver. (MW 1461, grain 18).

Fig. 21.   Aggregate of apparently pseudo-hexagonal platelets of Ag-rich gold. Moderately - strongly corroded. (MW 1297, grain 17).

Fig. 22.   Primary Ag-rich gold grain, rounded and abraded during sample preparation. (MW 1599, grain 12).

Gold and silver grains from the lower saprolite.

Fig. 23.   Corroded face of a probably euhedral gold grain, no detectable silver. (MW 1700, grain 27).

Fig. 24.   Strongly corroded, probably hackly gold grain, no detectable silver. (MW 1700, grain 24).

Fig. 25.   Gold - silver grain, anhedral with xenomorphic imprint, possibly after pyrite, little corrosion. (MW 1700, grain 31).
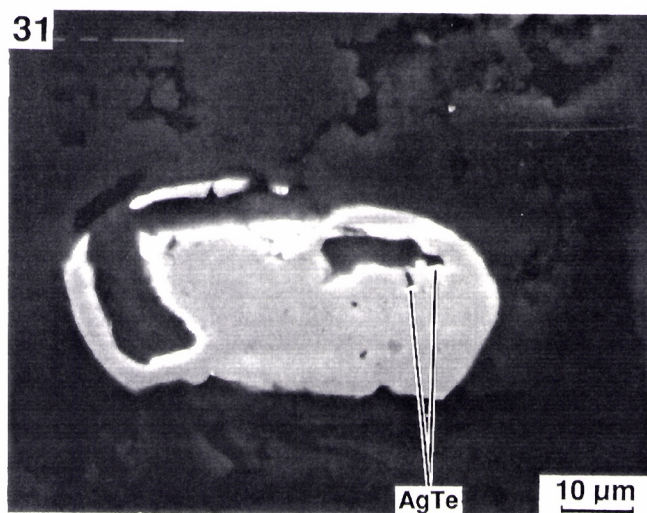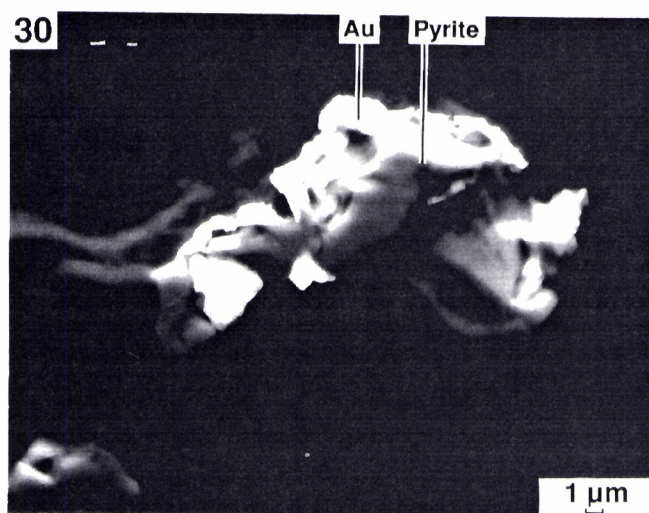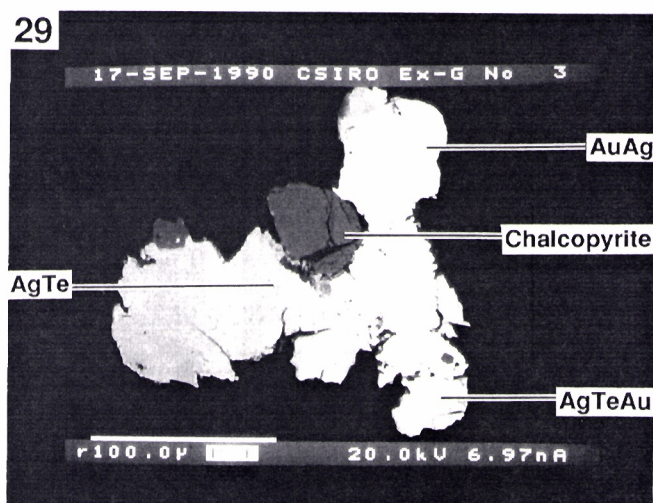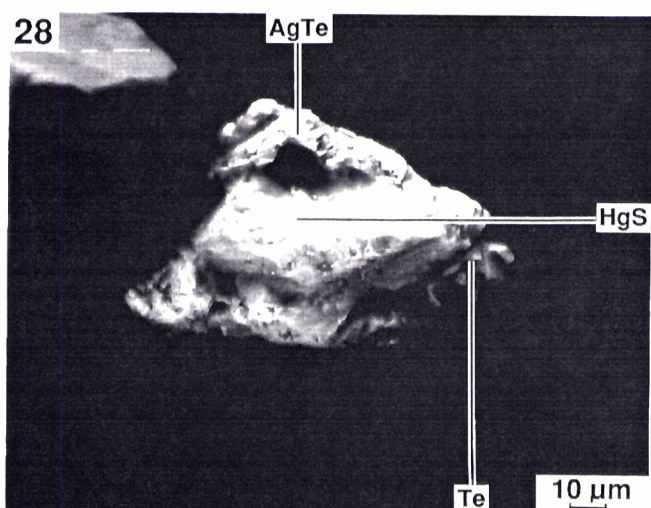
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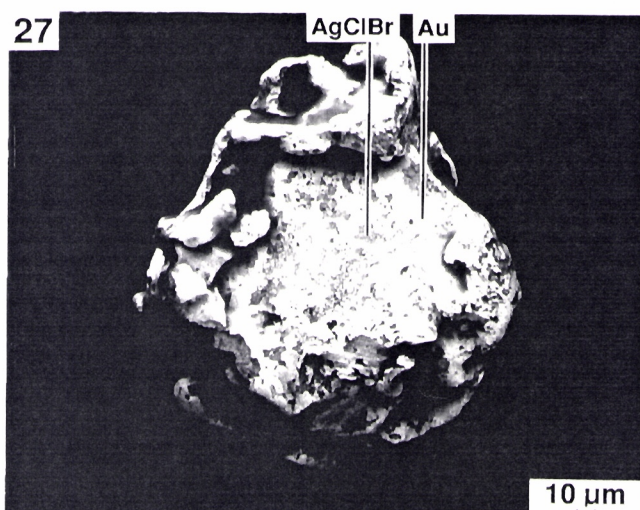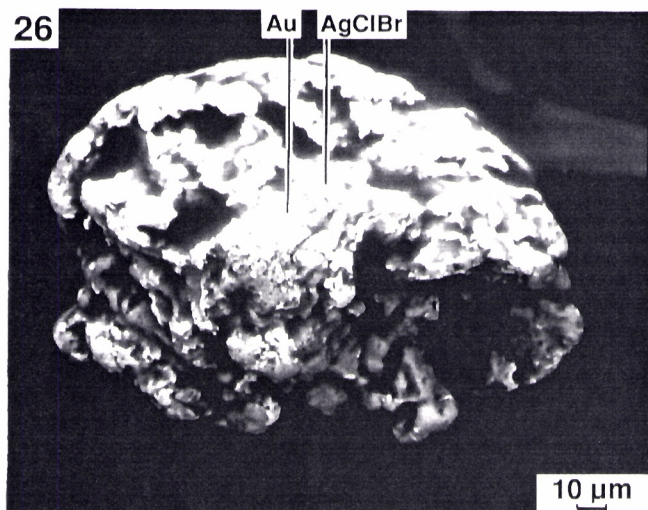21 10 μm

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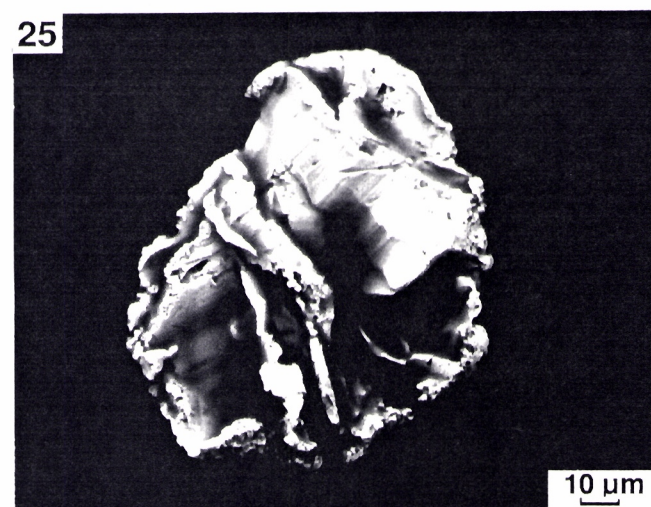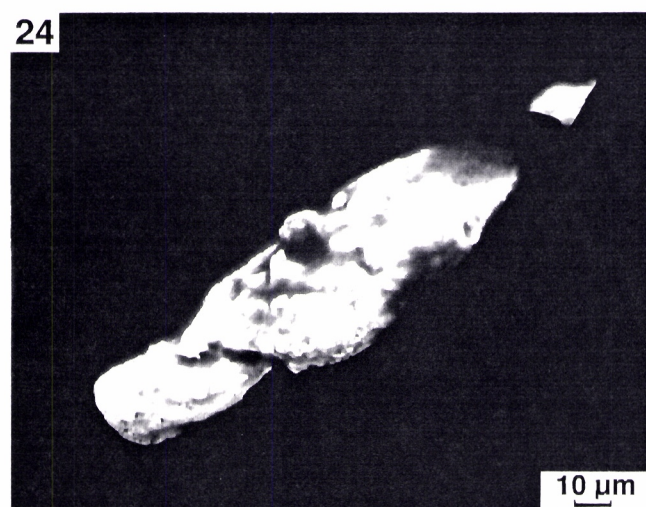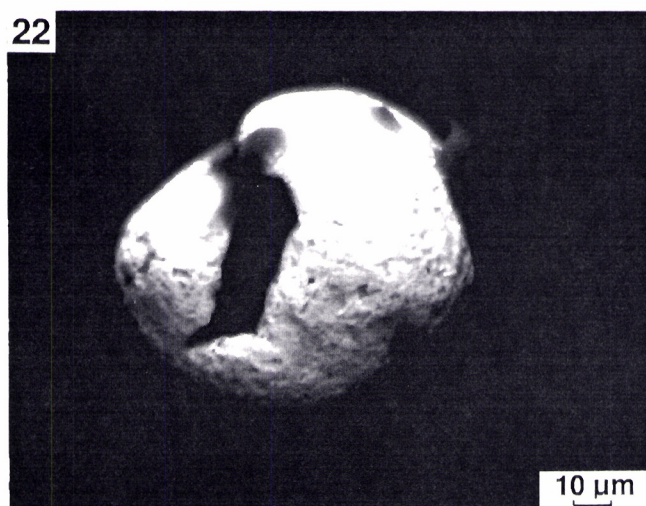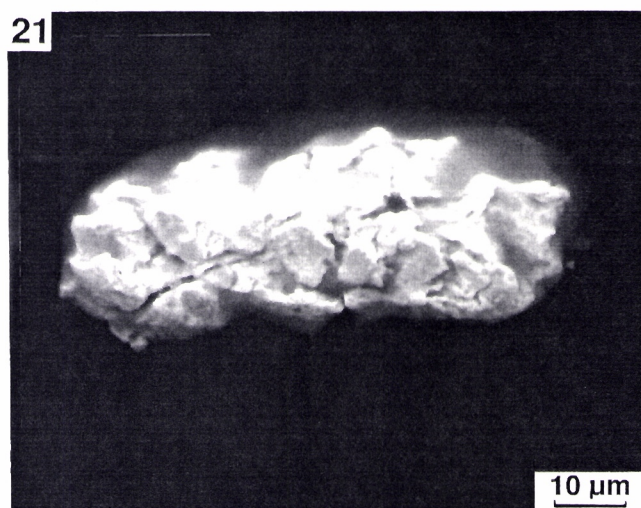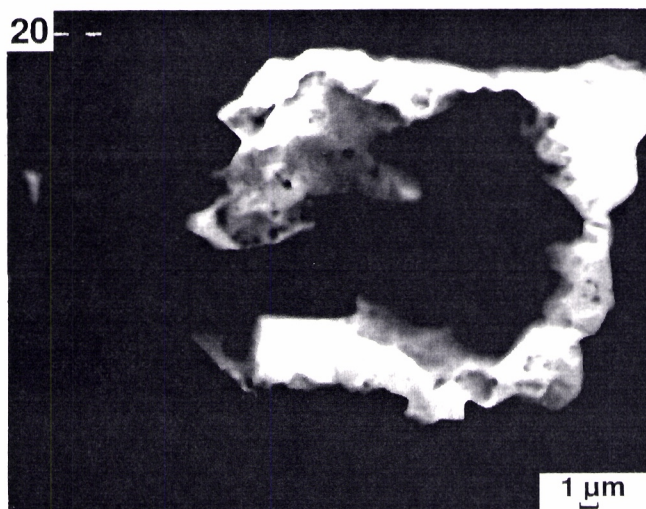
Gold and silver grains from the lower saprolite (cont'd).

Fig. 26.   Silver halide grain, probably hackly, with pure gold deposited on the surface. (MW 1700, Ag grain 6).

Fig. 27.   Silver halide grain, with gold coating (possibly Ag rich). (MW 1700, Ag grain 12).

Fig. 28.   Silver telluride grain, possibly euhedral, with Hg sulphide deposit in the middle. (MW 1700, Ag grain 1).

Gold in the primary, unweathered mineralization.

Fig. 29.   Polished section of complex grain containing gold - silver, chalcopyrite, silver telluride and silver - gold telluride. (MW 1801, grain 3).

Fig. 30.   Polished section of gold on pyrite. (MW 1801).

Fig. 31.   Silver telluride in void in pyrite. (MW 1801).

26 — Au, AgClBr — 10 µm

27 — AgClBr, Au — 10 µm

28 — AgTe, HgS, Te — 10 µm

29 — 17-SEP-1990 CSIRO Ex-G No 3 — AuAg, Chalcopyrite, AgTe, AgTeAu — r100.0µ — 20.0kV 6.97nA

30 — Au, Pyrite — 1 µm

31 — AgTe — 10 µm

APPENDIX 1

Sample preparation

After drying, the samples were jaw crushed to nominal 3mm size and then further comminuted by disc grinder to a maximum grain size of 500μm. These conditions were expected to liberate the gold grains but cause only minimal damage to them.

The heavier minerals, including gold grains were separated on a Haultain Superpanner, where possible using a 500g sample. One quarter of each sample was treated at a time. The superpanner is essentially a mechanized version of the prospectors pan to obtain gravity separation. It consists of a 72cm long shallow v-shaped trough, varying from 12 to 24cm 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 7mm axial bump amplitude. A 10mm side shake amplitude was applied at each end in opposing sense, to cause rotational oscillation around a vertical axis. The trough angle was varied during the treatment. Initially a shallow pool of deionized water, containing a non-ionic surfactant (0.01% Triton X-100), was loaded and the dry sample was slowly introduced at one third from the low end during agitation. After the dispersion was complete (determined by touch), the agitation was continued for two minutes. During this period the denser and larger minerals congregated at the top end of the trough. Wash water was introduced by hand at the top end, taking care to avoid forming air-bubbles, while the agitation continued. With increasing slope of the trough, continued agitation and washing, a thin tail of heavy minerals was obtained in the top quarter of the trough. The agitation was then stopped and the tail of heavy minerals was collected into a small suction flask by vacuum. This cycle, i.e. dispersion, agitation at shallow slope, wash at steeper slope and collection, was repeated once on each subsample already in the trough. The remaining light mineral fraction was also removed by suction into a collector. The separation process was repeated on the other three subsamples. The trough was then thoroughly washed and wiped clean with damp tissue until there was no discolouration. The possibility of cross-contamination by very small particles still remained, so after drying, the trough was covered with strips of masking tape. When this was ripped-off, a check under the scanning electron microscope revealed the presence of various mineral grains, gold included.

The small, gram size concentrate collected from the Haultain Superpanner was transferred into the trough of a micropanner. This trough is 10cm wide and 25cm long and is provided with changeable slope, cross-wise rocking and trough length direction tapping. A combination of varying slope angle and wash rate was used to separate gold from the other minerals. The progress of the separation was observed with a binocular microscope, when the motion was temporarily halted. Occasionally, larger size tramp minerals had to be removed by a thin wooden skewer. The heavy concentrate was retained and its mineralogy was determined by XRD.

The gold and nearby other heavy grains were recovered by suction through a 3mm i.d. pvc tube attached to a syringe shell with 1mm needle. Additional wash water flowed through the needle to assist in picking up the grains. The tube was connected to a 25mm Millipore filter holder containing a disc of filterpaper. A water-jet suction pump provided the necessary vacuum.

The wet filter paper was transferred with tweezers onto an epoxy polished section blank 3cm diameter 1cm thick. A teflon ring was placed on the perimeter of the filter paper to avoid curling of the paper and the blank was placed in a petri dish and dried at about 50 °C. The dry disc required careful handling, avoiding draughts and static electricity. This heavy mineral sample on the paper was examined under a binocular microscope to ensure that there were no mineral clusters or multiple layers of grains. The grains were then fixed in place by adding a few drops of low viscosity epoxy resin in an acetone atmosphere, to fill the voids of the filterpaper and wet the mineral grains from below. After curing, the bond was found sufficient to hold the grains in the SEM against electrostatic forces.

Polished mounts for quantitative analysis by microprobe were prepared by totally imbedding the grains in epoxy and carefully polishing down to expose the grains. For the drill core samples, routine polished sections were prepared for SEM study.

APPENDIX 2

Scanning electron microscopy

All morphological studies were done by scanning electron microscopy in backscattered electron mode, using an ISI-100B instrument fitted with an environmental sample chamber. This permitted the examination of samples without a conductive coating. The instrument used was modified in the CSIRO so that in addition to the usual slow scan screen it was provided with a screen driven at TV scan rate. This provided 25 images per second, thus allowed faster visual scans when the TV screen was used.

After marking a reference point and direction on the grain support disc, each was positioned on the SEM sample loader stage to permit observation of half area of the disc. The limitation was imposed by the maximum travel of the stage. Strips of the surface of the specimen were scanned with a slight overlap. Using 75 fold magnification the scans were reproduced on the TV screen and grains of even a few μm size with a high atomic number were readily visible. The strip scans were repeated until the first half has been covered, then the specimen was removed and repositioned by 10mm on the stage using the reference direction. The process was repeated for the remainder of the specimen. Once a potential high atomic number target was found, it was positioned in mid-field on the slow scan scope screen and examined under increased magnification. EDAX analysis points were analyzed for several hundred counts on the gold peak to improve the detection limit for silver. Some of the grains were photographed. All grains described in this report were qualitatively analyzed by EDAX.

Grain 3, MW 1801, was quantitatively analysed on the CAMECA microprobe.