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MORPHOLOGY AND GEOCHEMISTRY OF GOLD IN A LATERITIC PROFILE, BARDOC MINE, WESTERN AUSTRALIA

Ph. Freyssinet and C.R.M. Butt

CRC LEME OPEN FILE REPORT 5

November 1998

(CSIRO Division of Minerals and Geochemistry Report MG59R, 1988. Second impression 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.

This report (CRC LEME Open File Report 5) is a Second impression (second printing) of CSIRO, Division of Minerals and Geochemistry Restricted Report MG59R, first issued in 1988, which formed part of the CSIRO/AMIRA Project P241.

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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 (AMIRA Project 241):

"Gold and Associated Elements in the Regolith - Dispersion Processes and Implications for Exploration".

The Objectives of this Module are:

I. To obtain a better understanding of the nature and genesis of lateritic and supergene gold deposits.
II. To determine characteristics useful for exploration, especially in areas of transported overburden, for:
    (a) further lateritic and supergene deposits, and
    (b) primary mineralization - including that with no expression as appreciable secondary mineralizaton.
III. To increase knowledge of the properties and genesis of the regolith.
IV. To provide data applicable for exploration for other commodities in and beneath the regolith.

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 may indicate the aspects of the genetic history not only of the gold itself but also of the regolith in which it occurs. The results will be compared with those of similar studies conducted in West and Central Africa, where lateritic weathering profiles have not been modified by a change to arid conditions.

C.R.M. Butt
Project Leader
November 1988

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MORPHOLOGY AND GEOCHEMISTRY OF GOLD IN A LATERITIC PROFILE, ZOROASTRIAN MINE, BARDOC, WESTERN AUSTRALIA

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ABSTRACT

The morphology and geochemistry of gold grains have been studied at different levels of the lateritic profile in the Zoroastrian Pit at Bardoc. At the bottom of the pit, 40% of the grains associated with the mineralized quartz veins were primary whereas in the saprolite halo only 17% were primary. The percentage decreases higher in the profile to only 4% in the mottled clay zone. However, in the ferruginous horizon, the proportion of residual primary grains increases to 42%.

Several different secondary gold morphologies have been observed, falling into four main categories: xenomorphic forms, euhedral crystals, flat pseudo-hexagonal crystals and irregular aggregates. Some grains are strongly corroded whereas others are quite well preserved and it can be assumed that there are several generations of secondary gold grains.

Electron microprobe analysis of polished sections indicates that primary gold contains 4 to 11% silver and that secondary gold is extremely pure. Secondary gold does, however, contain traces of iron, probably as micro-inclusions of iron oxide.

The observed gold distribution is probably the result of two mechanisms of chemical dispersion. Gold remobilization first occurred during lateritization, principally in the ferruginous horizon, but dissolution was not complete. The second phase was during a later arid period when gold was strongly dissolved by saline groundwaters and dispersed in the saprolite and mottled clay zone.

INTRODUCTION

The objective of this study has been to examine the morphology and chemical composition of gold grains in a lateritic weathering profile as part of the broader research programme of the Weathering Processes module of the CSIRO/AMIRA Gold Project. The techniques employed are essentially the same as those used for similar studies in West Africa by one author (Freyssinet). The results from the two study areas, therefore, will permit comparison of the behaviour of gold in areas which have a common history of lateritic weathering followed by different post-lateritic regimes, namely arid and humid savanna. The Zoroastrian Pit at Bardoc was selected because it provided access to mineralization throughout an almost complete laterite profile.

GEOLOGICAL SETTING

The Bardoc gold mine area has two main deposits, Zoroastrian and Excelsior, but only the former has been studied in detail. The Bardoc deposits are located on the Eastern limb of a synform which comprises part of the Kalgoorlie-Menzies Greenstone belt. A brief geological description is given by Bottomer and Brabham (1987).

The Zoroastrian mineralization is situated in a metadolerite host rock. A number of quartz-filled faults within the dolerite parallel the north-south regional strike. Northwest-striking faults are also prominent. A cross-cutting mafic dyke intrudes one of the northwest structures; exposures in underground workings indicate this dyke postdates the lode structures and mineralization. Three mineralized lode structures are known. The main lode dips West at 45 to 55 degrees.

The main lode consists of a persistent hangingwall quartz vein up to 1 m thick, with variable parallel and crosscutting quartz veins in the footwall. Primary mineralization consists of 2 to 5 mm pyrite blebs and disseminated euhedral arsenopyrite within quartz and in adjacent altered wallrock. Optically, gold is visible as particles 5 to 15 μm in size in cracks in arsenopyrite and on grain boundaries. Lead and As serve as clear geochemical pathfinders at Zoroastrian.

The weathering profile is about 50-60 m deep and consists mainly of dark red or brown saprolite in which all the primary fabrics and structures are preserved. The saprolite is overlain by a mottled clay zone, 3-5 m thick, pale in colour but with numerous iron stains. The primary rock fabric is progressively destroyed, but the numerous quartz veins retain their original orientation. The mottled horizon outcrops in places around the Zoroastrian Pit, but is mostly covered by 1-3 m of ferruginous soil having a dark red clayey matrix containing numerous iron oxide nodules and cemented pisolitic blocks. Calcrete concretions are also present in the soil.

METHODS

The following sampling and processing procedures were used:

Sampling: bulk samples of 10-15kg were collected at several depths in the profile, both from the mineralized lode system and from the adjacent saprolitic wall rocks.

Crushing: the total sample was jaw crushed to about 5 mm, then disc ground to 1.5 mm.

Panning: samples were washed to remove clays, and panned to 5-10g or less. The residue was panned further on a micropanner. It should be noted, of course, that the data discussed in this report refer only to the grains that can be recovered by this procedure. A high proportion of grains smaller than 10 μm will have been lost, with moderate losses of those between 10 and 20 μm.

Optical examination: the gold grains were removed, and examined and measured using a binocular microscope.

Scanning electron microscopy: the morphology of the grains was examined by SEM and their Ag content determined semi-quantitatively using an energy dispersive detector.

Polished sections: selected gold grains were examined in polished section.

Cameca SX50 electron microprobe: selected grains were analysed for Au, Ag, Cu, Ni, Fe, S and As.

MORPHOLOGY OF GOLD GRAINS

Base of the saprolite

Gold in quartz veins

The main quartz lode, at the bottom of the pit (40 m approx), contains two main groups of gold grains. Half of the grains have high Ag contents and the remainder very low Ag contents.

The Ag-bearing grains are primary. A few are xenomorphic, having large smooth and bright faces showing the imprint of the surrounding crystals (Photos. 1 and 2). Most, however, are already strongly etched even at this depth in the profile. They are rounded, with small etching pits on the surface, giving them a characteristically dull lustre. Many grains seem to be depleted in silver on the exposed faces, suggesting that they have been partially leached. Some grains have secondary gold spherules adhering to their etched surfaces (photo 3).

The characteristic shapes and high fineness of the other grains indicate that they are probably secondary. The following forms have been recognized:

1. Euhedral, commonly prismatic and well formed crystals (photo 4), 15 to 40 μm in size. Most have large etching pits or strongly rounded faces. Depressions and etching pits may be filled with silica or iron oxides. Many grains consist of several intergrown euhedral crystals (photo 5).

2. Very complex, irregular aggregates, comprising several gold spherules and dendrites fused together (photo 6) in an irregular mass. A few micron-size euhedral prismatic crystals can be observed on some surfaces but the grains are mostly anhedral. Most cavities are filled with silica and iron oxides.

3. Occasional flat, pseudo-hexagonal crystals and other forms.

The same gold grain morphologies are present in the lateral quartz veins (which are generally weathered to "sugar quartz") as in the main mineralized zone; however, only 10% of the grains contain silver and hence may be considered as primary.

Gold in the saprolite halo

Samples were collected a few metres from the main lode, avoiding quartz vein material, to examine gold dispersed in the (weathered) wall rocks. Gold grains in the saprolite are characterized by their small size (10-20 μm) compared to those in the adjacent quartz veins. About 10% of the grains contain significant amounts of Ag and show etched primary shapes, indicating that there was a primary gold halo in the metadolerite close to the mineralization. All such grains have euhedral prismatic forms and show very little corrosion. Most of the remaining grains are Ag-poor, euhedral, prismatic single crystals. There are also some xenomorphic grains, generally flattened, probably because they have crystallized along the foliation, and a few irregular aggregates.

Secondary gold in the saprolite shows several stages of etching. Most xenomorphic grains are corroded and rounded; there are, nevertheless, two categories of euhedral crystals, namely crystals without corrosion features and having smooth faces, and strongly corroded crystals having large etching pits or rounded forms.

Gold in the upper saprolite

Samples were collected at about 25 m depth among quartz veins and saprolitic wall rocks known to have high gold grades.

Gold in weathered quartz veins

In the quartz veins, only 5% of the grains still contain silver and have features characteristic of primary gold. All such grains are strongly etched and very rounded (photo 7), with many small spherules of high fineness gold adhering to their surfaces (photo 8).

Most of the secondary gold grains are irregular aggregates, as previously described in samples from the base of the saprolite. However, at this level, many grains have some small euhedral crystals developed on their surfaces (photo 9-10), a phenomenon not observed at the bottom of the mine. A few grains have a pseudo-hexagonal form.

At this level in the profile, there is little corrosion of secondary gold grains and, indeed, most are not corroded at all. Several grains show evidence of a number of successive generations of supergene gold. For example, some etched grains have a more recent coating of platy gold crystals without any corrosion features (photo 11); this late coating may be equivalent to that expressed as small spherules on some grain surfaces (photo 12).

Gold in the saprolite halo

Samples were collected from two situations in the saprolitic wall rocks: (i) close to the quartz veins and (ii) at the contact between the metadolerite and the dolerite dyke where gold grades were known to be high.

Gold grains have similar morphologies to those described in the quartz veins. The presence of a few rounded, strongly etched and Ag-bearing grains, presumably primary in origin, is significant. They demonstrate that there was probably mineralization or a primary halo at the contact between the dolerite dyke and the metadolerite and that the enrichment is not entirely due to supergene precipitation of gold from water flowing along the contact. Most of the secondary grains are irregular aggregates. There are few individual, euhedral prismatic crystals, but small crystals have developed on the surfaces of many aggregates. Several intermediate stages between the irregular aggregates and aggregates of euhedral crystals (photo 10) have been observed. In general, there is little corrosion of the secondary gold and the aggregates of euhedral crystals in particular are quite well preserved.

Gold in the mottled clay zone

Despite the destruction of most traces of the primary rock fabrics in the mottled clay zone, some quartz veins remain undissolved and in approximately their original orientation. Gold grains associated with these veins have the same morphology as in the upper saprolite at 25 m depth. Only 5% of the grains appear to be primary. The supergene grains are similar to those located in the saprolite haloes, generally being as irregular aggregates (photo 13) with many euhedral crystals developed on their surfaces. Nevertheless, corrosion of the supergene gold seems to be greater than in the saprolite and many grains are strongly etched and rounded (photo 14). As in the saprolite, some grains exhibit more than one generation of supergene gold, with a more recent layer coating an etched secondary surface (photos 16, 17).

Gold in the surface ferruginous horizon

In the ferruginous horizon, the percentage of residual primary grains in the recovered gold reaches 50%, far greater than in the underlying horizons of the weathered profile. These grains are mostly more or less flattened, strongly rounded and have many etching pits infilled by iron oxides (photo 18). This morphology is very characteristic of residual gold in lateritic duricrusts. A few grains have been fully protected and have preserved their primary shapes (photo 19). Secondary gold in this horizon consists principally of euhedral crystal aggregates (photos 20 and 21) with only a very few irregular aggregates.

Gold in calcretes

In calcrete developed in the ferruginous soil, some particularly well preserved, residual, primary gold grains occur; these were probably enclosed within ferruginous fragments. Silver-bearing grains in the carbonate matrix itself, however, have a thin outer layer or coating of Ag-poor supergene gold (photo 24). In "purer", Fe-poor calcretes developed in soils derived from the mottled clay zone, only secondary gold is present; there is no characteristic morphology and grains are always strongly etched (photo 23). There is no clear evidence that these gold grains have precipitated in the carbonate matrix; they could equally well be derived from the underlying mottled zone.

GRAIN SIZE DISTRIBUTION

All gold particles have been measured and classified into the following groupings: the main mineralization at the base of the saprolite; the gold halo in the saprolite; the gold halo in the mottled clay zone; the ferruginous and pisolitic layer associated with calcrete development (Table I, Figure 1).

Table I. Average size of gold grains in different horizons.

	Number of grains	Mean size μm	Standard deviation
Ferruginous horizon	106	79	58
Mottled zone halo	96	61	23
Saprolite halo	113	67	54
Oxidised Mineralization	169	103	93

In the weathered mineralization, the mean size is about 100 μm; most grains are between 50 and 125 μm but there are a few coarser than 400 μm. In the haloes in the saprolite and mottled clay zone, the mean grain size is about 60-65 μm, with most particles smaller than 75 μm. Only a few grains exceed 250 μm. In the pisolitic ferruginous horizon, the mean size is similar to that in the mottled clay zone, but there is a more significant coarse fraction (>250 μm). This coarse fraction consists mainly of residual primary grains.

It appears that primary gold in the main mineralization is coarser than secondary gold in the saprolite or the mottled clay zone. The largest particles are always primary and residual.

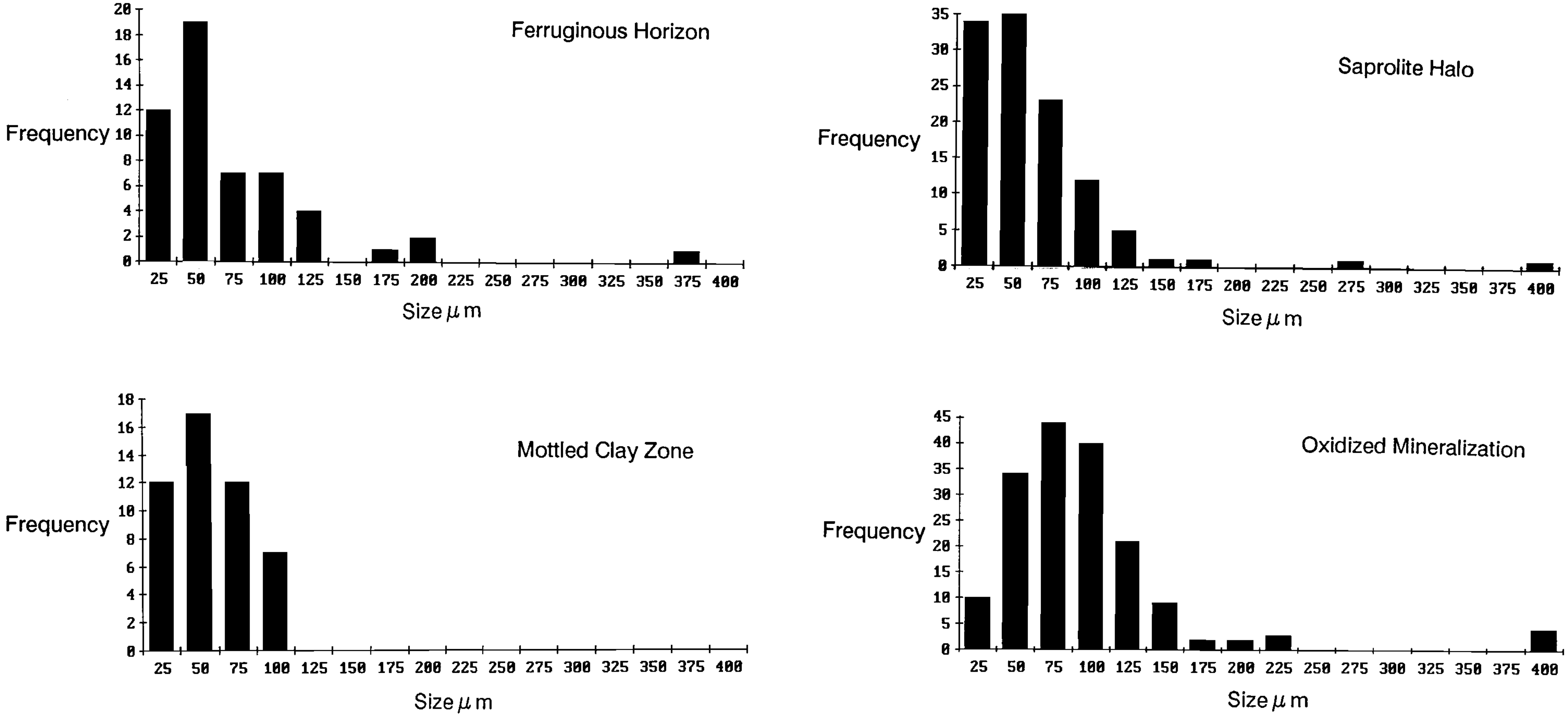


Figure 1: Size distribution of gold grains in different horizons of the lateritic weathering profile.

CHEMICAL COMPOSITION OF GOLD GRAINS

Analytical conditions

The chemical composition of gold has been determined by electron microprobe analysis of polished sections of grain mounts, using the CAMECA SX50. The following seven elements have been determined: Au, Ag, Cu, Fe, Ni, As and S. The detection limits and counting times are shown in Table II.

Table II: Detection limits and counting times for electron microprobe analysis. Counting time for Au: 20 seconds. The results for S are not reliable at this level.

	Ag	Cu	Ni	Fe	S	As
Detection limit (ppm)	720	180	160	160	200	160
Counting time (seconds)	40	40	40	40	100	140

Gold and silver distributions

Silver is the only element, other than gold, present as a major component. There are two separate classes of gold grains:

1. those containing 2-11% Ag, and
2. those containing <700 ppm Ag (ie the detection limit).

There are no grains with compositions between these two classes (Figure 2).

Most of the Ag-bearing grains contain 8 to 10% Ag; such grains appear primary and unweathered (see photos. 1 and 2). All grains containing 2 to 6% Ag are etched and rounded (e.g. photo 3) and either located at the base of the profile or preserved in the pisolitic ferruginous horizon. This phenomenon is also illustrated on a local scale in Figure 3, where a progressive depletion of Ag is evident around cracks or boundaries of grains. In some places, Ag is completely absent. Such preferential leaching seems to be related to weathering rather than being a primary feature; it is systematically observed on chemically etched particles and occurs only on exposed surfaces or along cracks.

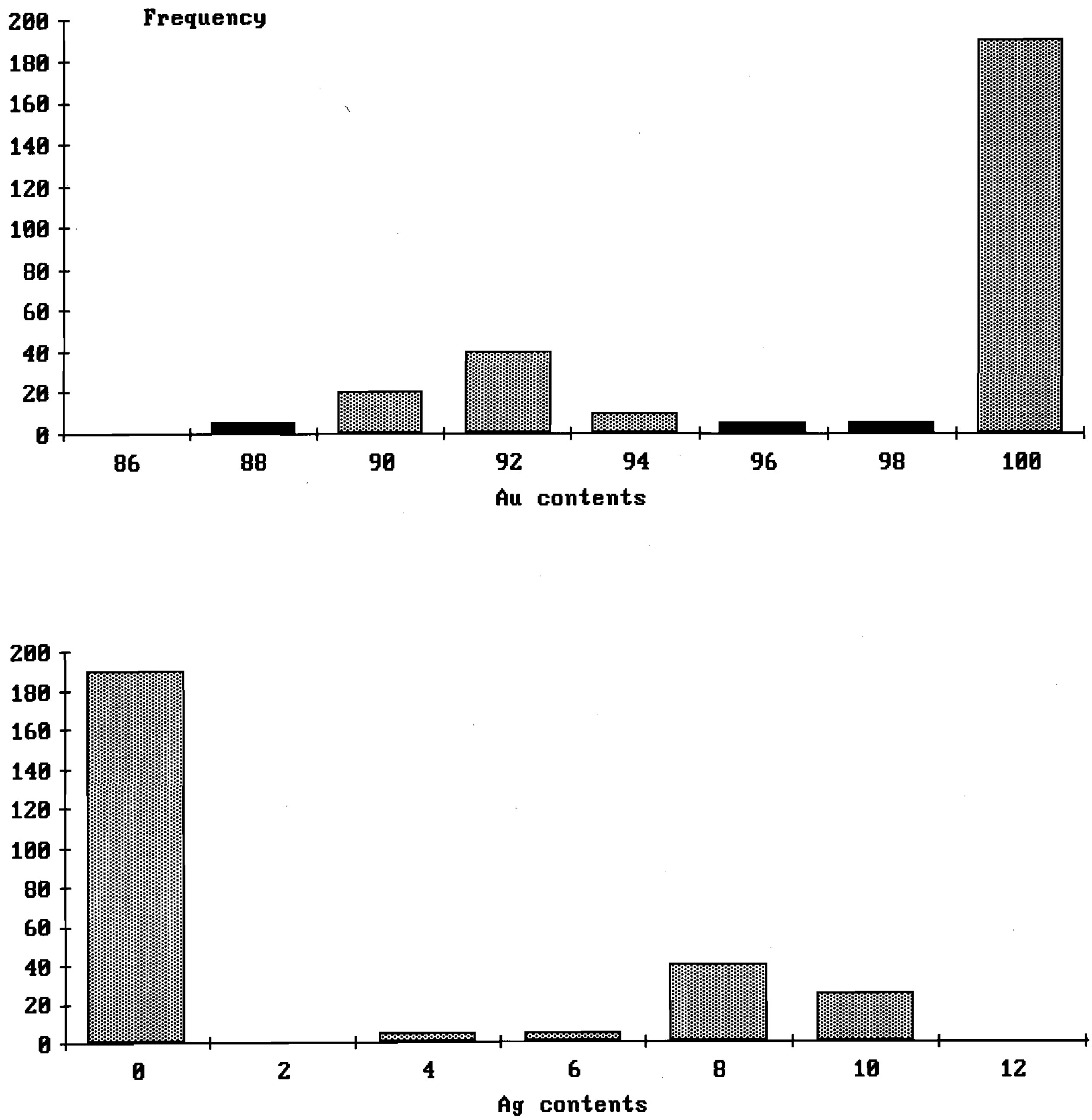


Figure 2: Bar charts indicating gold and silver contents of gold grains.

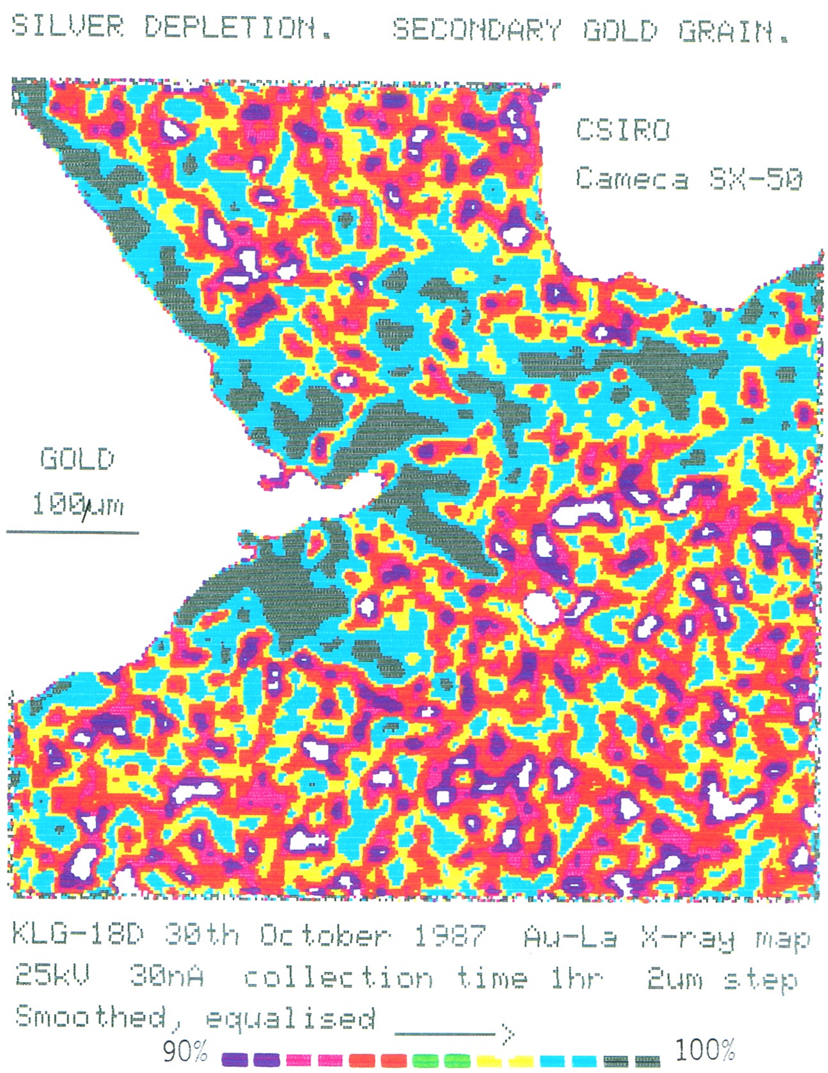


Figure 3: Depletion of silver on from the rim and along a crack in a gold grain.(False colour images, Cameca SX50 electron microprobe).

Trace element distributions

The results of the trace element analyses are given in Table III, subdivided into the two classes of particles indicated by the Ag content. Whereas the distribution of Ag is generally uniform within the grains, that of trace elements such as Fe, Cu or Ni is erratic and may represent discrete inclusions. The marginally higher Cu content of the Ag-rich gold grains could be a primary feature, whereas the higher Fe and, perhaps, As contents of high fineness gold may be secondary (Figures 4 and 5). There is no significant difference in Ni or S contents between the two classes.

Table III: Average chemical composition of gold particles classified according to silver content.

Class (Ag%)	No. Samples	Au %	Ag %	Cu ppm	Fe ppm	Ni ppm	As ppm	S ppm
>0.5%	76	92.0	8.0	115	43	17	20	93
<0.5%	192	100.0	0.0	71	148	22	30	116

Statistical treatment of the data to determine element associations does not give very significant results because few grains contain detectable concentrations of more than two trace elements. However, plots of such data that are available suggest possible correlations of Fe-As, Fe-Cu and perhaps Cu-As (Figures 6, 7 and 8). Such associations could indicate the presence of microscopic inclusions of sulphides, eg arsenopyrite or chalcopyrite, in primary grains, or of iron oxides in secondary grains.

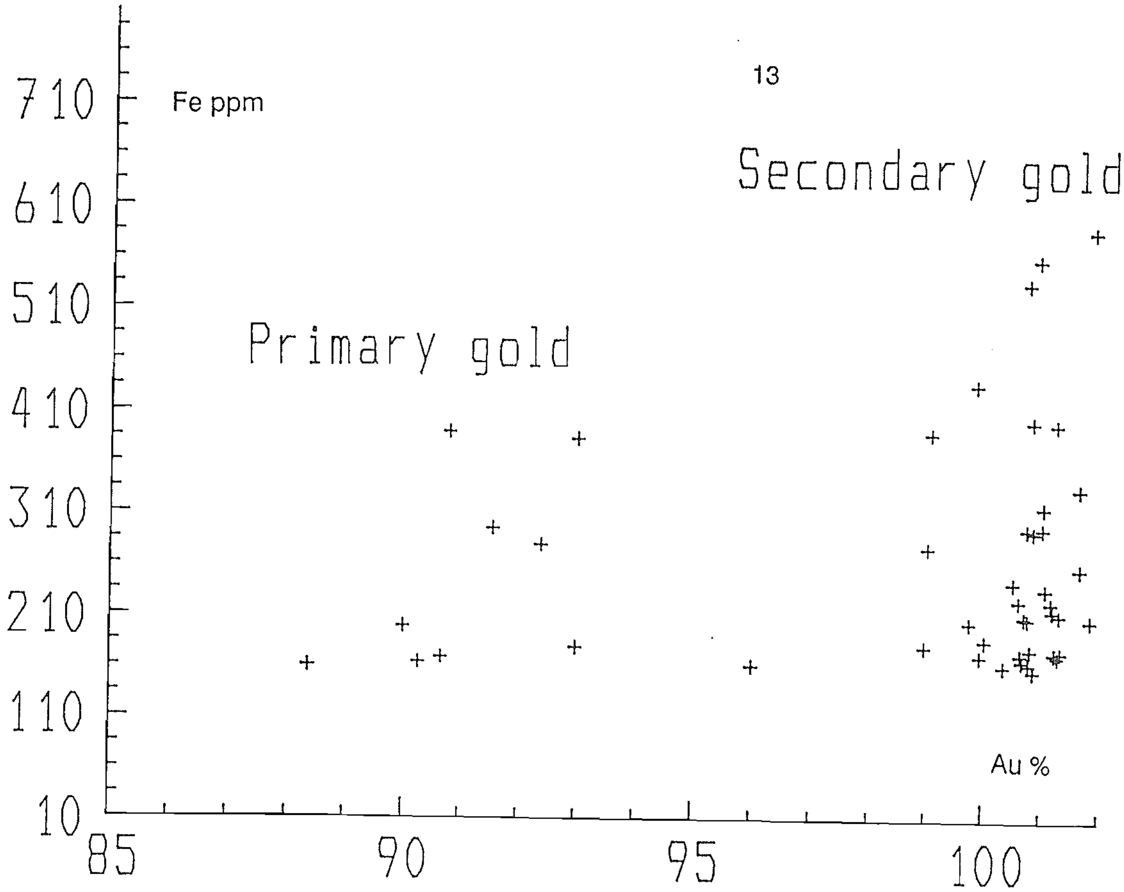


Figure 4: Scattergram of iron and gold in grains of primary and secondary gold.

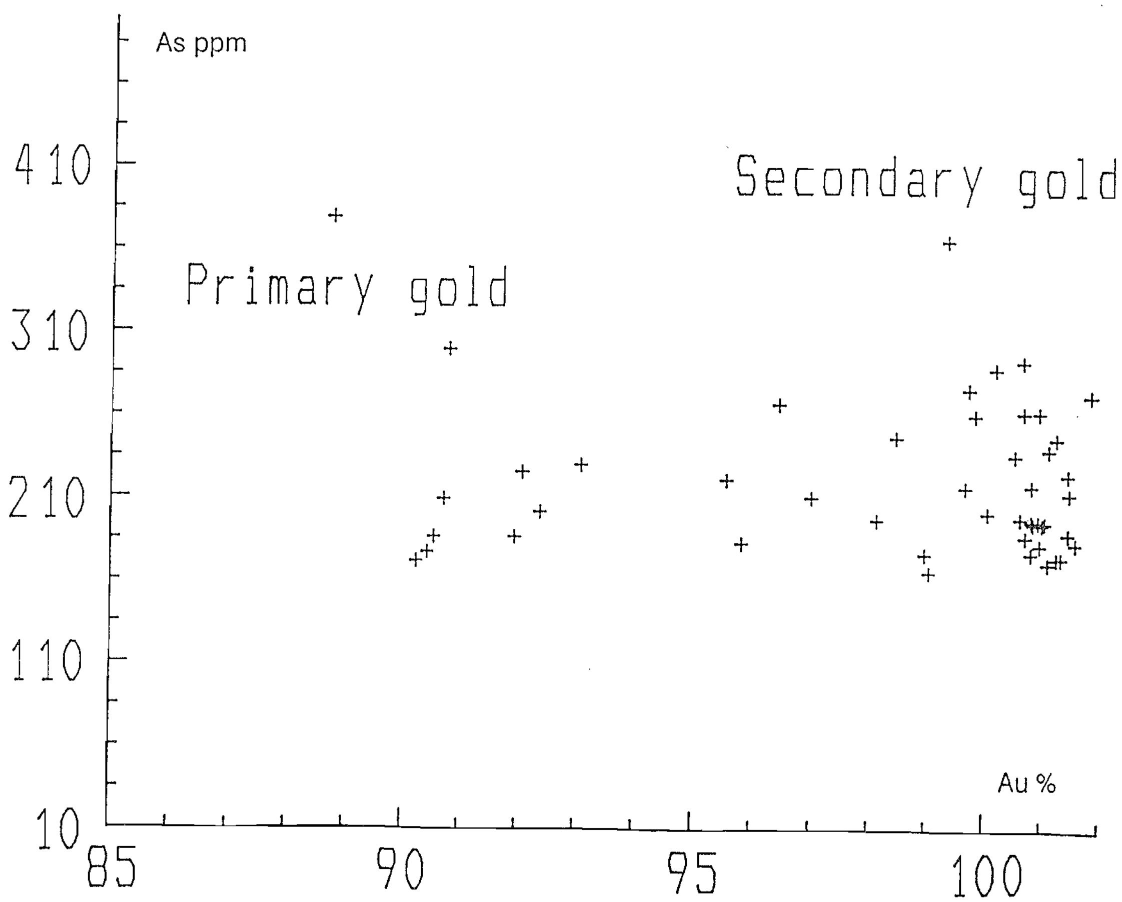


Figure 5: Scattergram of arsenic and gold in grains of primary and secondary gold.

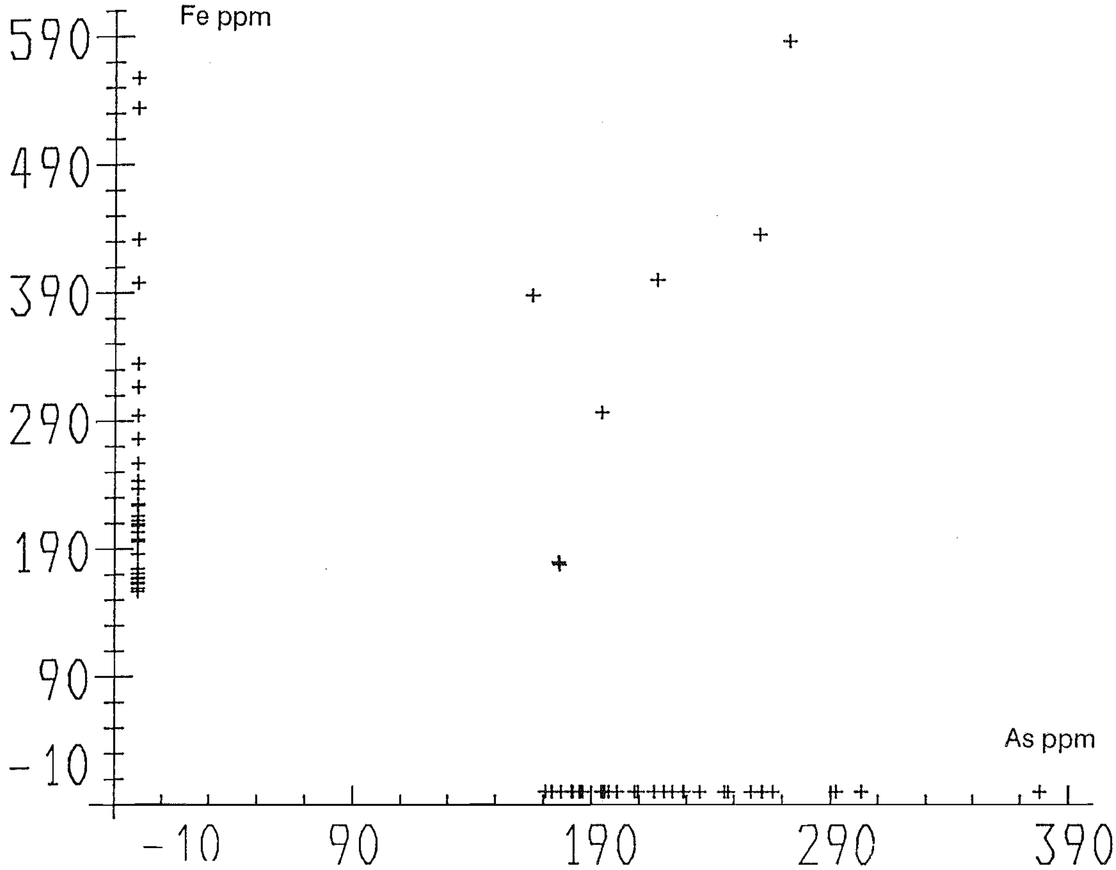


Figure 6: Scattergram of Iron and Arsenic in gold.

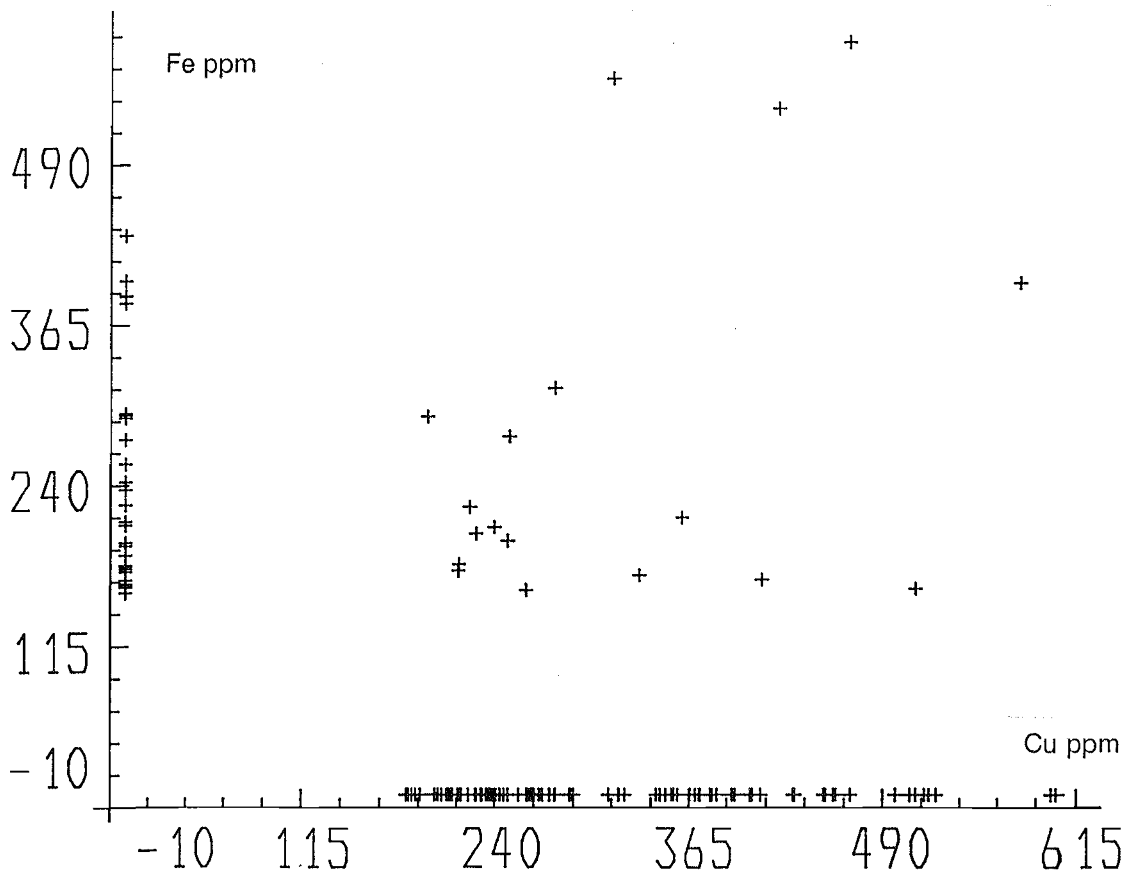


Figure 7: Scattergram of iron and copper in gold.

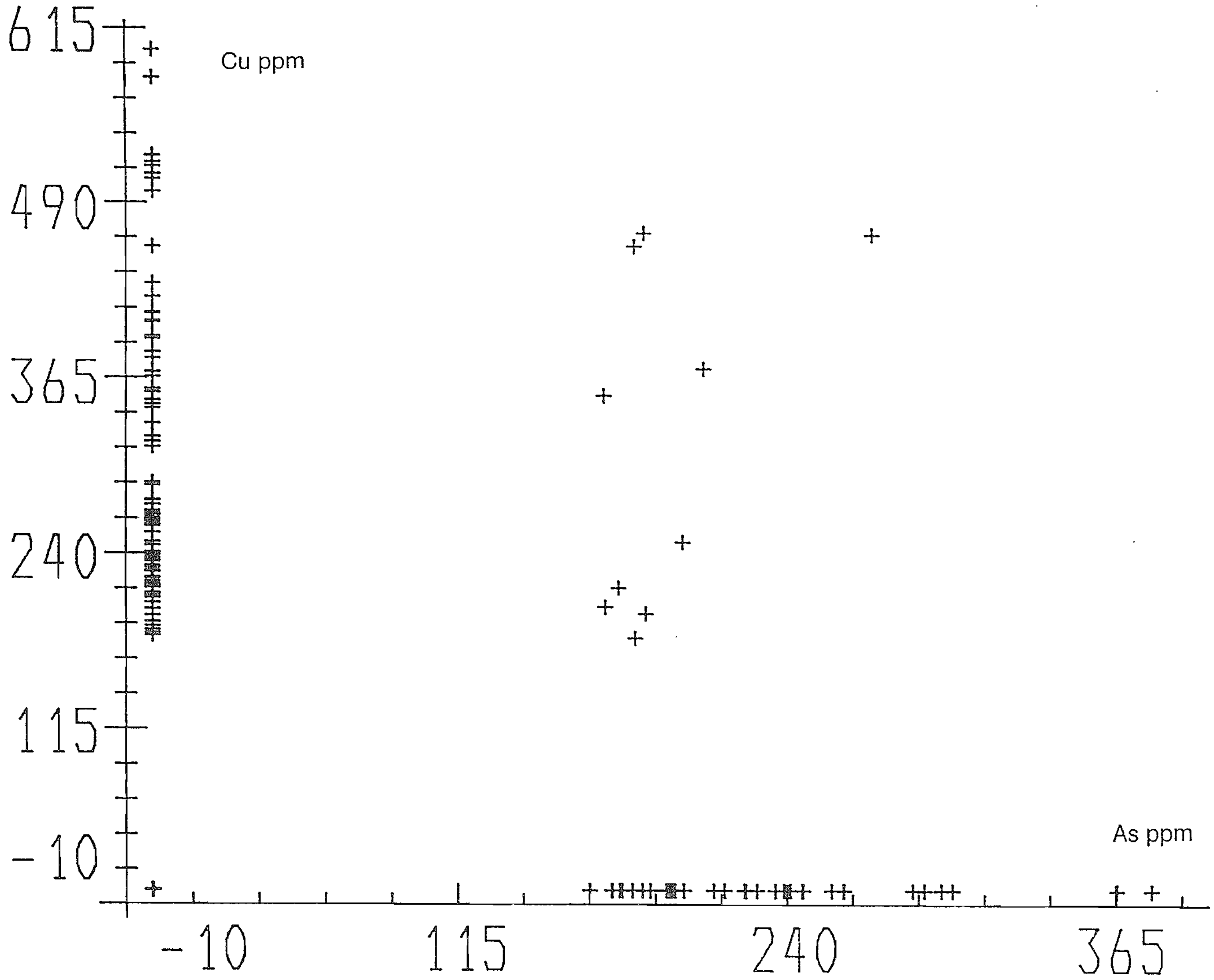


Figure 8: Scattergram of copper and arsenic in gold.

DISCUSSION

At the bottom of the pit, close to the base of weathering, the principal morphology of primary gold is of xenomorphic grains, the majority of which are already etched and rounded. Secondary gold is also present as euhedral crystals and irregular aggregates. The presence of a few primary grains in the saprolite close to the mineralization indicates that there was an original primary halo, although it may have been enhanced and enlarged by the subsequent precipitation of secondary gold. Quite different stages of etching are present and both very etched and completely uncorroded crystals can be present in the same sample.

In the upper saprolite, gold occurs mainly as irregular aggregates that are only weakly corroded. There are no etched euhedral crystals. A similar grain morphology is present in the mottled clay zone except that numerous euhedral crystals are developed on the surfaces of the irregular aggregates. Such crystals are not at all corroded.

These features indicate that there are probably several generations of secondary gold that have developed at different periods and different levels in the profile.

The percentage of Ag-bearing gold particles in each horizon is illustrated in Figure 9. (The presence or absence of Ag was determined using the energy dispersive spectrometer on the SEM). That the Ag content is a primary feature is indicated by the increasing proportion of Ag-rich grains towards the weathering front; this proportion is probably still greater in the unweathered mineralization. Higher in the profile, such grains become increasingly rare (5% in the mottled zone) and, as discussed above, the great majority of grains are of undoubted supergene origin, as characterized by a particular morphology and the complete absence of Ag. In the pisolitic horizon, however, the trend is reversed; many gold particles contain Ag and appear primary, although they are etched and chemically rounded.

These observations can be explained by gold having been remobilized by different processes at different times. During lateritization, chemical mobilization of gold was probably relatively minor and largely restricted to the top of the profile, in the ferruginous horizon. The dissolved gold became dispersed in this layer and may have created a secondary halo around the mineralized structure. Later remobilization probably occurred under arid conditions, when groundwaters were saline. Gold solubilization was greater than during lateritization and took place mainly in the saprolite and mottled zone. Most of the primary gold was dissolved, even in the quartz veins, and reprecipitated as secondary gold of high fineness within the original mineralized zone and/or as enriched zones in the weathered wall-rocks.

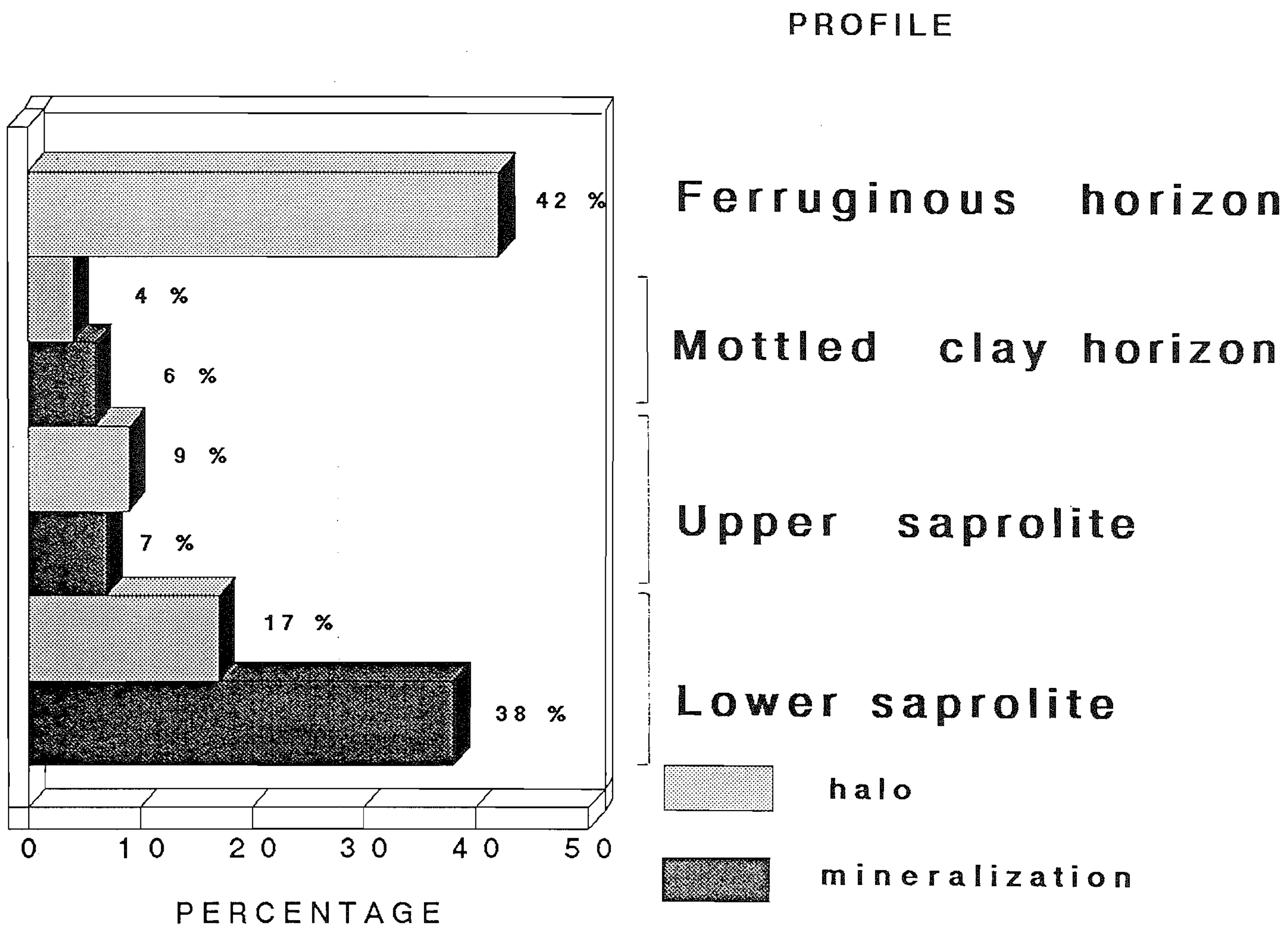


Figure 9: Percentages of silver-bearing gold grains in different horizons of the weathering profile.

Possible mechanism of gold remobilization

The common presence of traces of Fe in secondary gold could indicate that Fe plays an important role in the process of remobilization. It does not seem to be due simply to ferruginous inclusions reflecting the composition of the lateritic environment because gold precipitated in the saprolite and the mottled clay horizon is also Fe-bearing. Furthermore, these horizons are richer in quartz and kaolinite than iron oxides but there are no traces of Si or Al in the gold.

An Fe-Au association is suggested by the mobilization mechanism proposed by the redox reaction:

$3Fe^{3+} + 3e^{-} ==> 3Fe^{2+}$ iron dissolution

$Au^{0} ==> Au^{3+} + 3e^{-}$ gold dissolution

The dissolving iron is regarded as an oxidant for gold, which is mobile only when oxidized. Thus, in zones where iron is being strongly dissolved, gold may dissolve also, subject to the presence of ligands such as chlorides or bromides able to form stable gold complexes (eg. $AuCl^{4-}$, $AuCl^{2-}$, $AuBr^{4-}$ or $AuBr^{2-}$). These ligands are, of course, abundant where groundwaters are saline, as in many arid regions.

PLATE 1

GOLD GRAINS FROM THE MAIN QUARTZ VEIN SYSTEM AT THE BASE OF THE SAPROLITE

Photo 1: KGL 6. Primary xenomorphic grain characterized by smooth faces and the impressions of surrounding crystals (probably quartz). The grain has a high Ag content and is etched and slightly rounded on the exposed faces. Iron oxides are present on the surface.

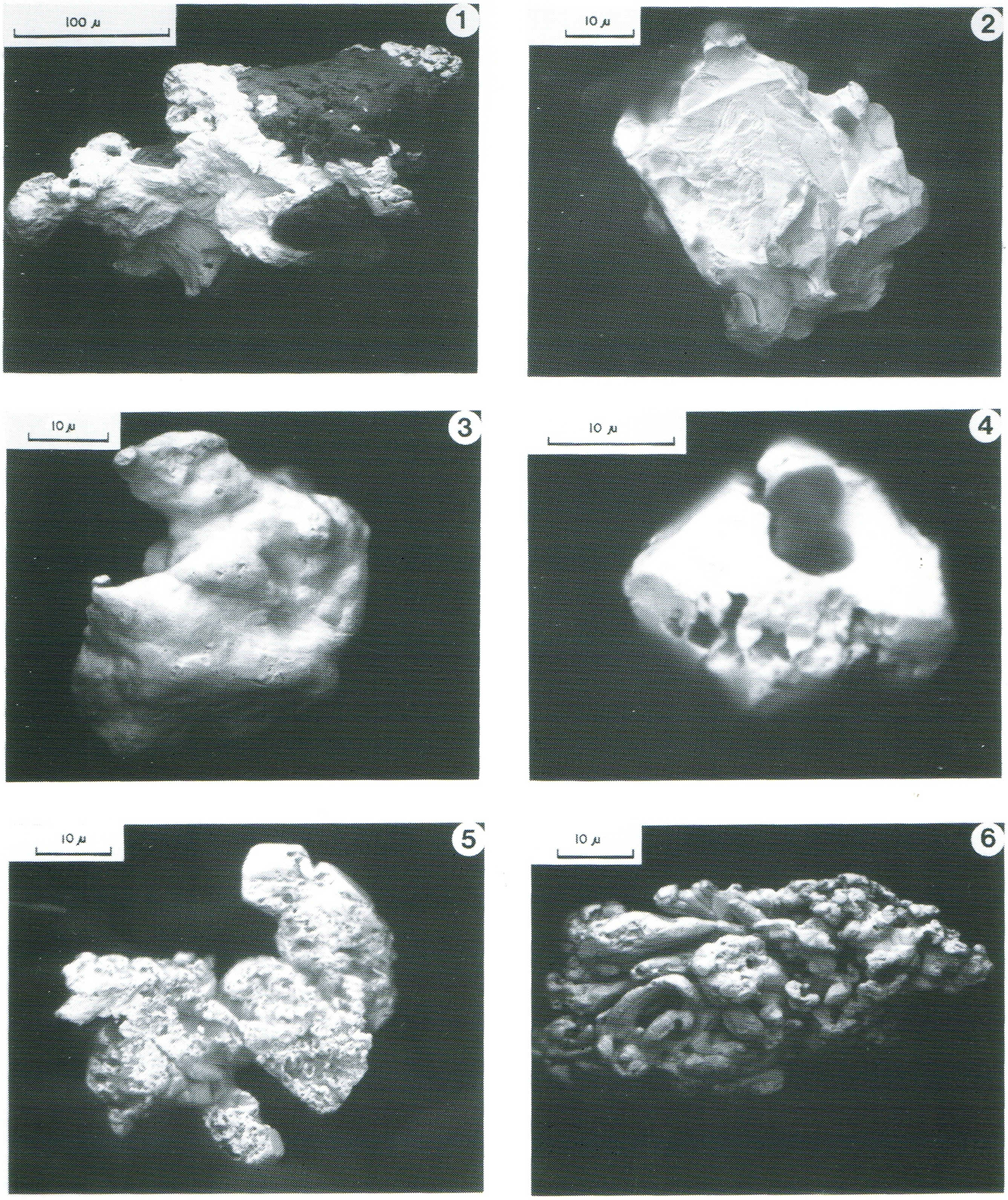
Photo 2: KGL 1. Primary xenomorphic grain with the impressions of the surrounding quartz crystals. High Ag content, with traces of Ni on the surface. No corrosion features are observable.

Photo 3: KGL 6. Residual primary gold grain having a very rounded shape characteristic of chemical etching. The grain surface is roughened by numerous small etching pits and has small gold aggregates adhering to it. The Ag content of the grain itself seems lower than in the fresh mineralization; the aggregates contain no silver and are probably supergene.

Photo 4: KGL 1. Secondary octahedral crystal with large etching pits on the surface; no detectable silver.

Photo 5: KGL 1. Flattened grain composed of several crystals of secondary gold. The large faces are strongly corroded. No detectable silver.

Photo 6: KGL 1. Irregular aggregate of secondary gold. No detectable silver.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2
10 µ
3
10 µ
4
10 µ
5
10 µ
6

PLATE 2

GOLD GRAINS IN THE UPPER SAPROLITE

Photo 7: KGL 10. Residual primary grain from a weathered quartz vein at 25 m depth. The very rounded shape is characteristic of chemical etching; the grain surface is roughened by numerous small etching pits and has small gold aggegates adhering to it. The Ag content of the grain seems lower than in the fresh mineralization and none is detectable in the aggregates, which are probably supergene.

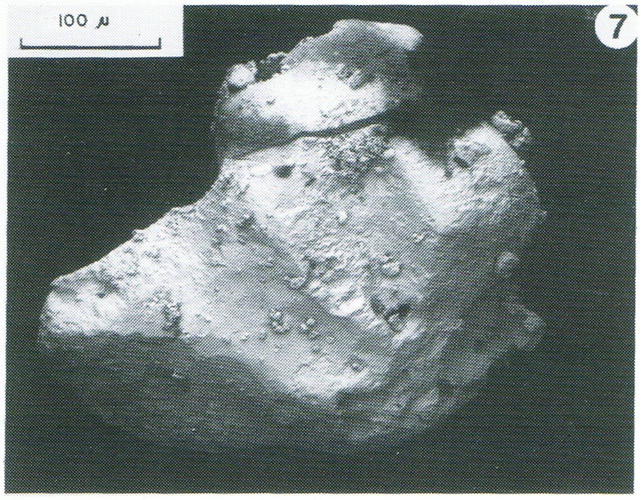
Photo 8: KGL 10. Detail of photo 7. Secondary gold aggregate on the etched surface of the primary grain.

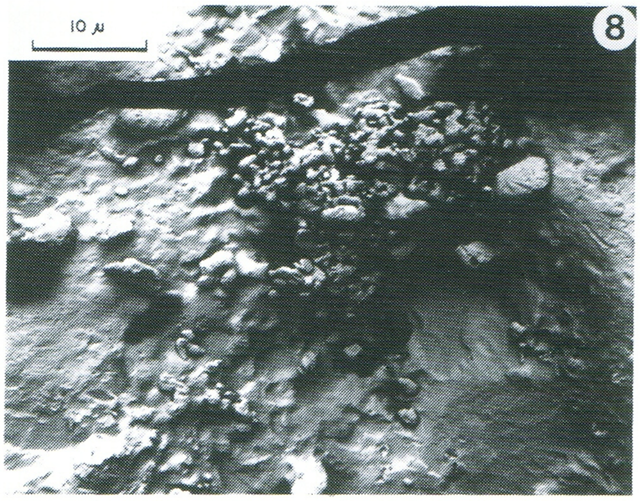
Photo 9: KGL 10. Secondary gold grain from a weathered quartz vein at 25 m depth. Irregular aggregates with several euhedral faces on the surface. No corrosion. No detectable silver.

Photo 10: KGL 10. Secondary gold from the anomalous halo in the saprolite at the contact between the dolerite dyke and the metadolerite. Aggregate of several euhedral crystals. No corrosion. No detectable silver.

Photo 11: KGL 11. Secondary gold grain from a weathered quartz vein at 25 m depth. A recent generation of flat triangular or pseudo-hexagonal crystals without corrosion features covering an etched and rounded secondary gold grain. No detectable silver.

Photo 12: KGL 11. Secondary gold grain from a weathered quartz vein at 25 m depth. Recently formed aggregates of spherules of supergene gold (cf photographs 6-9) are adhering to an etched grain which was probably constituted of 3 or 4 flat pseudo-hexagonal crystals fused together. No detectable silver.


100 μ
7


10 μ
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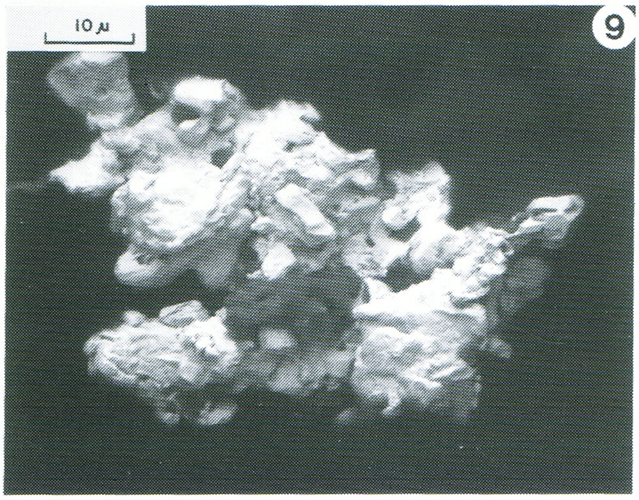
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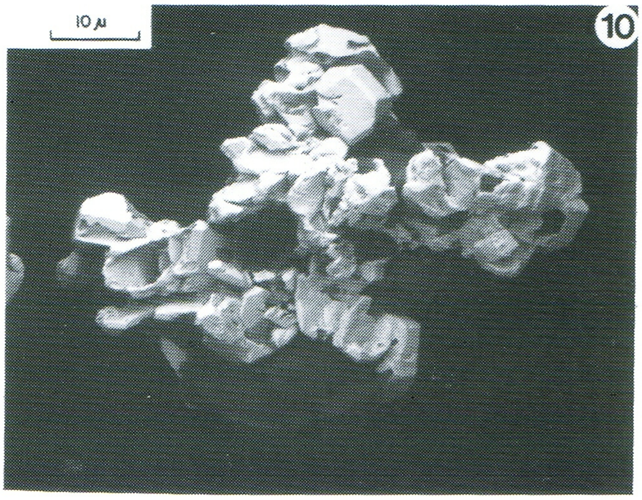
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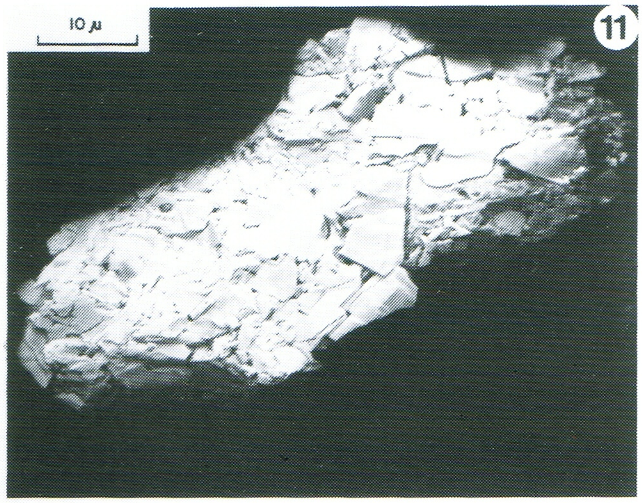
10


10 μ
11

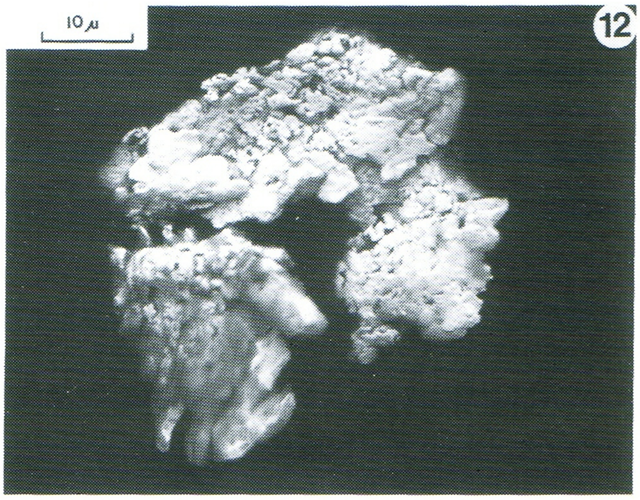

10 μ
12

PLATE 3

GOLD GRAINS IN THE MOTTLED CLAY ZONE

Photo 13: KGL 17. Irregular aggregate of secondary gold with numerous euhedral faces on the surface. No detectable silver.

Photo 14: KGL 16. Chemically rounded secondary gold grain; surface covered by numerous etching pits. No detectable silver.

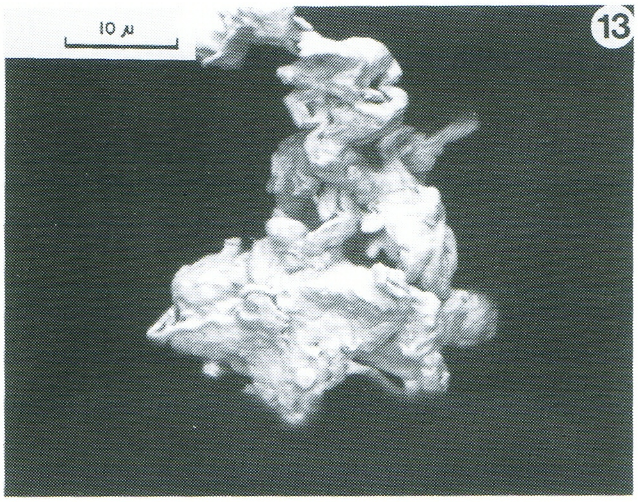
Photo 15: KGL 19. Aggregate grain of secondary gold consisting of several flat pseudo-hexagonal crystals. No corrosion observed. No detectable silver.

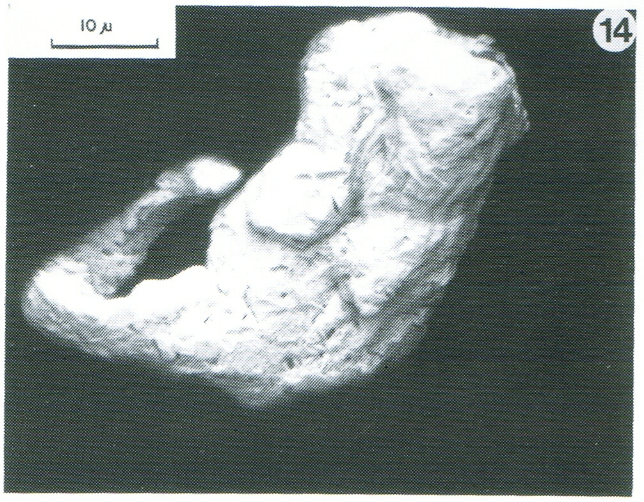
Photo 16: KGL 22. Etched grain of secondary gold grain with a recent generation of supergene gold composed of aggregates of many "spherules" adhering to it. No detectable silver.

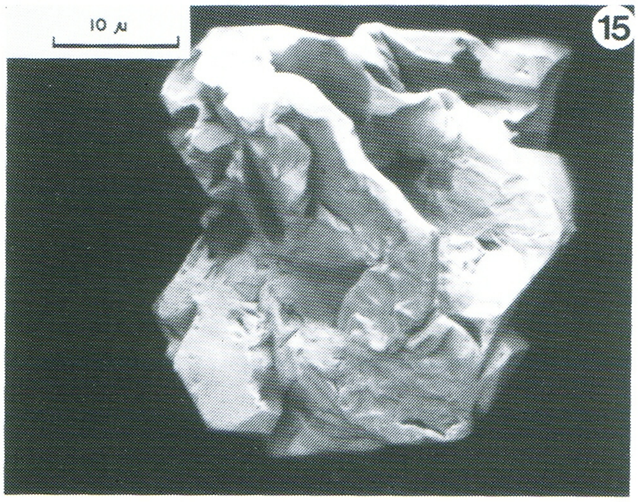
Photo 17: Detail of the last generation of supergene gold from photo 16. Two morphologies are present: small spherules $<1\ \mu m$ and flat pseudo-hexagonal crystals.

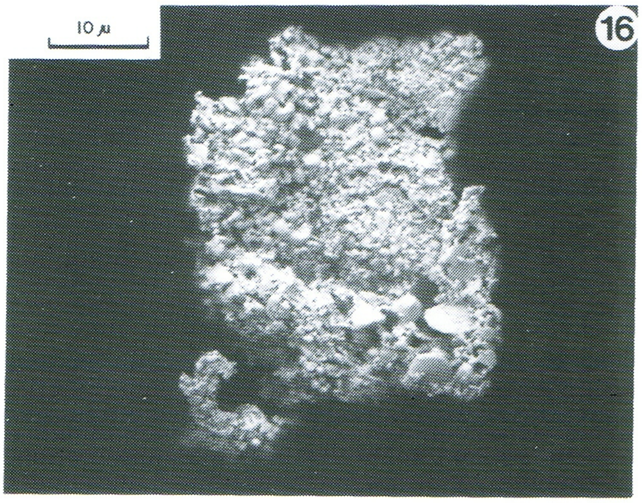
GOLD GRAINS FROM THE FERRUGINOUS HORIZON

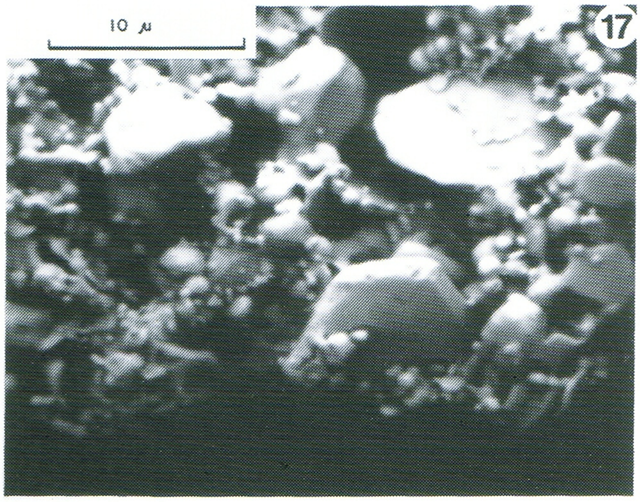
Photo 18: KGL 29. Residual primary grain; strongly etched surface covered with numerous etching pits filled with iron oxide. High silver content.


10 µ
13


10 µ
14


10 µ
15


10 µ
16


10 µ
17

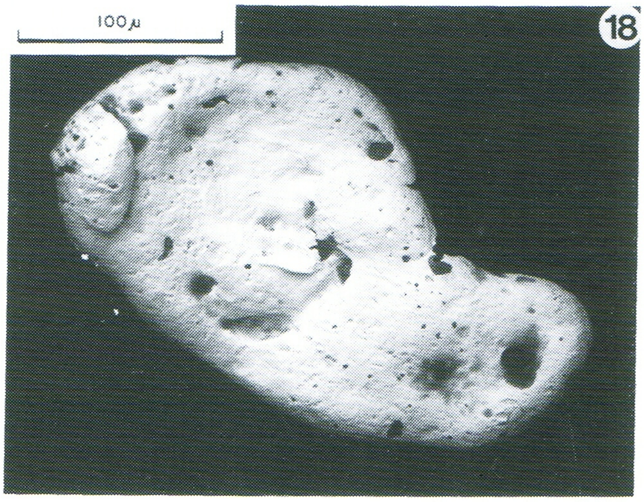

100 µ
18

PLATE 4

GOLD GRAINS FROM THE FERRUGINOUS HORIZON

Photo 19: KGL 32. Residual, xenomorphic primary grain, apparently protected from the corrosive effects of weathering. High silver content.

Photo 20: KGL 29. Secondary gold. Aggregate of several euhedral prismatic crystals fused together. No corrosion observable. No detectable silver.

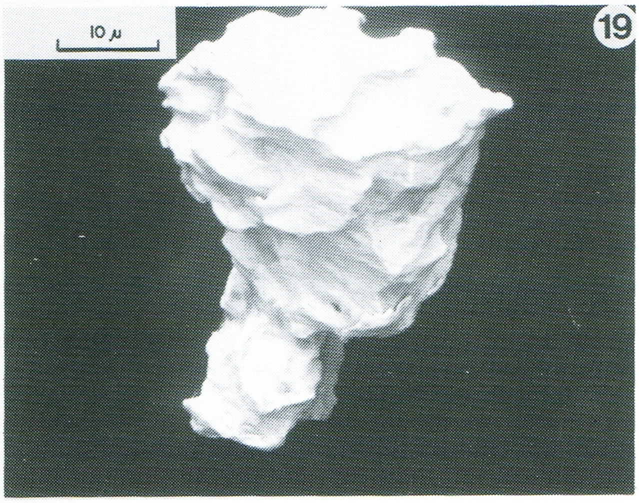
Photo 21: KGL 31B. Secondary gold. Aggregate of several euhedral, flat pseudo-hexagonal crystals fused together. The grain is slightly etched on the exposed faces (right hand side) and the large faces have numerous etching pits. No detectable silver.

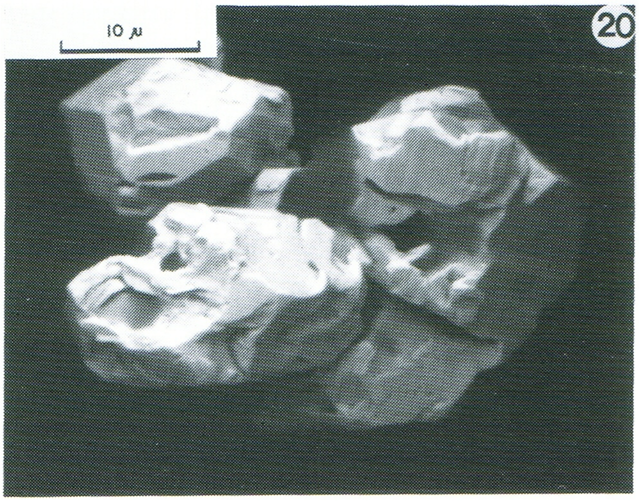
Photo 22: KGL 31B. Aggregate of several spherules of secondary gold. Some spherules have more or less euhedral shapes. No corrosion observable. No detectable silver.

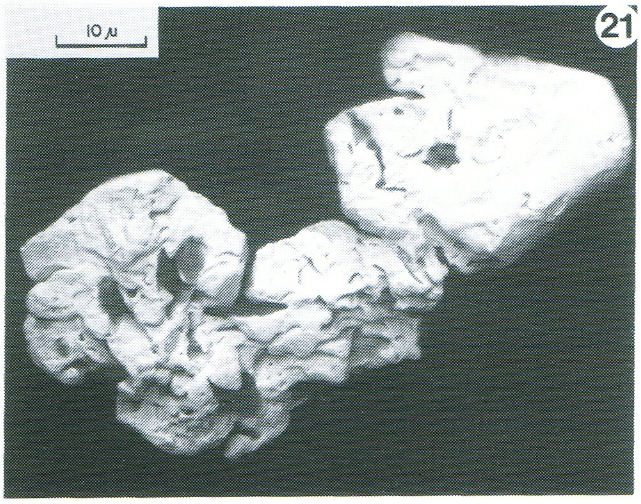
GOLD GRAINS IN THE CALCRETES

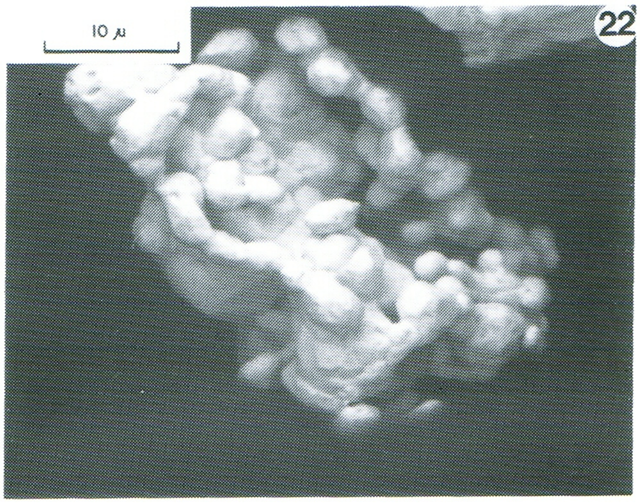
Photo 23: KGL 18. Strongly etched grain of secondary gold; depressions filled with iron oxides and calcite. No detectable silver.

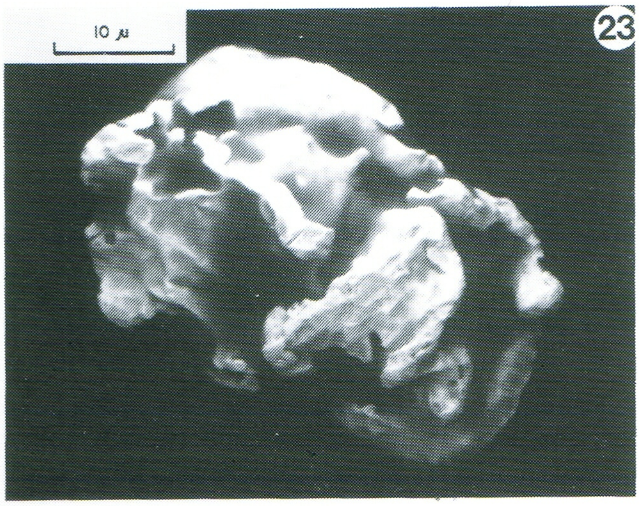
Photo 24: KGL 18. Detail of nugget of secondary gold embedded in the calcite matrix. The nugget is coated with numerous flat polygonal crystals. Depressions are filled with calcite. No detectable silver.

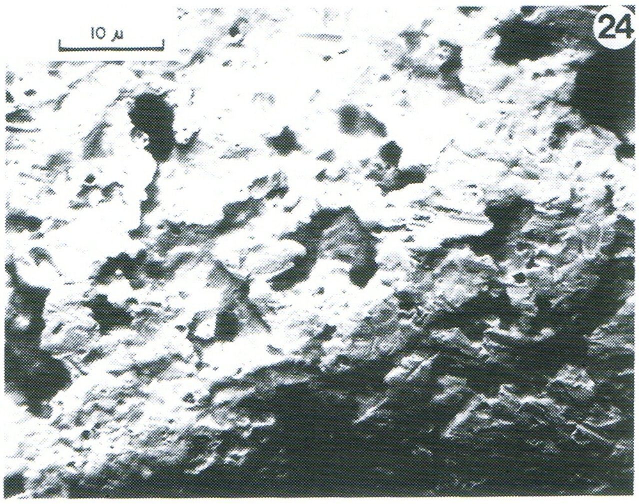

10 μ
19


10 μ
20


10 μ
21


10 μ
22


10 μ
23


10 μ
24

APPENDIX

SAMPLE DESCRIPTIONS

ZOROASTRIAN PIT

KGL 1:	Quartz vein at the base of pit, main mineralized structure; 0.5 m thick. High grade gold. Milky quartz.
KGL 2:	Brown saprolite (metadolerite) in the 10 m wide dispersion halo. Base of pit, 6-7 m from mineralization.
KGL 3:	Sub-vertical vein of weathered "sugar quartz"; 0.5 m thick. Base of pit.
KGL 4:	Purple saprolite (metadolerite), at 3 m from the sugar quartz vein.
KGL 5:	Sub-horizontal milky-quartz vein and surrounding saprolite. Bottom of pit wall.
KGL 6:	Sub-vertical weathered quartz vein, 1 m thick. North part of the main mineralized zone.
KGL 7:	Yellow saprolite, southern wall of the pit. First berm, about 25 m depth.
KGL 8:	Purple saprolite near KGL 7.
KGL 9:	Ferruginous "gossan vein". First berm, 25 m depth.
KGL 10:	Sub-horizontal weathered quartz vein, 5 cm thick. First berm, 25 m depth.
KGL 11:	Milky quartz vein perpendicular to the principal axis of mineralization. First berm, 25 m depth.
KGL 12:	Yellow saprolite. First berm, 25 m depth.
KGL 13:	Surficial brown humic soil, 15 cm thick, containing calcrete nodules. Sampled at the South end of the pit.
KGL 14:	Calcrete nodules from the surface, near KGL 13. Little ferruginous material.
KGL 15:	Weathered quartz vein outcropping at the surface, south end of pit.
KGL 16:	Mottled clay zone from old surface workings, south of pit.
KGL 17:	Mottled clay zone outcropping at surface and indurated by calcrete. No calcrete nodules. South end of pit.
KGL 18:	Surface calcrete nodules, 3 cm diameter. Little ferruginous material. South end of pit.
KGL 19:	Mottled clay zone outcropping at surface beside old workings, south of pit. White matrix with ochre-red mottling.
KGL 20:	Mottled clay zone with many ferruginous veins at the surface. Southern margin of pit.
KGL 21:	Mottled clay zone at the surface. Southern margin of pit.
KGL 22:	Mottled clay zone at the surface. Southern margin of pit.
KGL 23:	Green-brown saprolite of Proterozoic dolerite dyke, first berm, 25 m depth. Near contact between the dyke and the Archaean meta-dolerite.

KGL 24: Purple saprolite of Archaean metadolerite, first berm, 15 m from KGL 23, near contact with the Proterozoic dyke.

EXCELSIOR PIT

KGL 25: Saprolite of green chloritic talc schist in pit wall, 15-20 m depth. Sub-ore zone. (Not processed).

KGL 26: Weathered sub-vertical quartz vein, 2 m thick, near KGL 25. Ore zone. (Not processed).

KGL 27: Saprolite of white talc schist. Sub ore zone. Pit wall at 15-20 m depth. (Not processed).

KGL 28: Purple saprolite. Ore zone. Pit wall at 15-20 m depth. (Not processed).

KGL 29: Ferruginous horizon with iron oxide nodules. No calcrete. Surface sample close to pit.

KGL 30: Similar to KGL 29.

KGL 31A: Pisolitic horizon with calcrete nodules.

KGL 31B: Similar to KGL 29.

KGL 32: Similar to KGL 31A.