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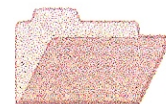
Cooperative Research Centre for  
Landscape Evolution & Mineral Exploration



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# **MINERALOGY AND GEOCHEMISTRY OF THE GLASSON GOLD DEPOSIT, CALLION, YILGARN BLOCK, WESTERN AUSTRALIA**

*S.M. Llorca*

**CRC LEME OPEN FILE REPORT 16**

September 1998

(CSIRO Division of Exploration Geoscience Report 58R, 1989.  
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 16) is a Second impression (second printing) of CSIRO, Division of Exploration Geoscience Restricted Report 058R, first issued in 1989, 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 Au 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, inter alia:

- I. To obtain a better understanding of the nature and genesis of lateritic and supergene Au deposits.
- II. To determine characteristics useful for exploration for:
  - a. Further lateritic and supergene deposits, and
  - b. Primary mineralisation - including that with no expression as appreciable secondary mineralisation.
- III. To increase knowledge of the properties and genesis of the regolith.

This study addresses these objectives through a mineralogical and geochemical study of the Glasson gold deposit. The report documents the progressive weathering of the gold mineralization and the basaltic host rocks and describes the dispersion of gold and associated elements in the context of the weathering history of the region. It is important to note the role of pedogenic carbonates (calcrete) as hosts of secondarily dispersed gold, a phenomenon being investigated by the Project at other sites.

C.R.M. Butt  
Project Leader  
August 1989.

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## ABSTRACT

This report describes a mineralogical and geochemical study of the weathered Glasson Au deposit and its country-rocks, in the Callion area, Yilgarn Block, Western Australia. The fresh country-rocks are amphibole- and plagioclase-rich metabasalts. On weathering, the amphibole and plagioclase are initially replaced by smectites, opaline silica and kaolinite, and then, higher in the profile, by kaolinite, opaline silica and goethite. As the amphibole and plagioclase are weathered, Ca, Mg, Mn and some Si are leached; as, in turn, the smectites are consumed, the remaining Mg, Co and some more Si are leached away. This results in an increased relative concentration of elements such as Fe, Al, Ti, Cr, Cu, Zr, Ga and Sc. Nickel and Zn seem to accumulate in this part of the profile where smectites disappear.

The fresh mineralization consists of quartz veins within a shear zone containing additional amphibole, chlorite and mica, plus small amounts of sulphides. Gold is present both as free Au in the quartz and in the sulphides. In the overlying weathered zone, the sulphides are replaced by mixtures of goethite and rutile. Amphibole and chlorite are gradually replaced by smectites and kaolinite, passing upwards to kaolinite and goethite. Mica is residual, though it is altered to hydromica. Some halite has precipitated from groundwaters permeating the shear zone.

Lateritization occurred under humid conditions during the Cretaceous-mid Miocene. As the sulphides weathered, Cu, Zn, As, Au, Pb and W were mobilized. These elements precipitated with the goethite, both within the weathered sulphide zone and in the country-rock (as far as 10-20 m away for As, Pb, Au). Although the Au included in the sulphides was redistributed, Au in the quartz vein remained in situ. Some of this Au was still protected by the quartz and the Au located along the fractures which was attacked (its Ag leached), and the Au was re-cemented virtually in situ by the goethite precipitated in these fractures. Previously deposited secondary Au was also partially re-cemented in the fractures within goethite. Chloride-rich solutions that circulated along the quartz vein under the post-lateritisation arid conditions mobilized some of the Au that had been so far protected by the quartz. This Au was redeposited within the quartz vein and within 20 cm of it.

During the Cretaceous-mid Miocene humid period, Au close to the surface was remobilized and dispersed for up to 100 m from the quartz vein, probably by complexing with humic acids derived from soil organic matter. In the drier climates that followed, calcrete formed close to the surface and Au was fixed within it. Finally, mechanical dispersion at the surface caused As, Au, Pb and Cr enrichments in the pisolitic cover as far as 100 m away.

In a context such as the one of the Glasson deposit, the best indicators for Au mineralization are Au, As and, to a lesser extent, Pb and W. Chromium seems a good indicator of the shear zones.



## 1.0 INTRODUCTION

This study is part of the AMIRA Project 241 which has the objective of improving exploration for supergene or primary concealed Au deposits, through a better understanding of the formation of the weathered profile and behaviour of Au and other elements during weathering. For this purpose, deposits and prospects representing a variety of rock-types, primary ore types, geomorphology and climate have been selected for study, the Callion deposit being one of them. The objectives of the work at Callion were to study:

- the distribution of Au in the weathered profile
- the nature and characteristics of host rocks in the weathered profile, and
- the dispersion of pathfinder elements

## 2.0 GEOLOGY

Callion is located 100 km NNW of Kalgoorlie. The area is almost flat with very low hills (with slopes of less than 5°) and covered with sclerophyll bush. The climate is presently semi-arid with a winter rainfall of approximately 200 mm. Evaporation far exceeds precipitation.

Callion lies within the Davyhurst - Mt. Ida branch of the Archaean Norseman-Wiluna greenstone belt and, more particularly, within a sequence of metabasalts, interflow metasediments and local felsic metatuffs (Fig. 1). The sequence generally dips steeply to the east and has undergone amphibolite facies metamorphism. It is the host to various quartz-filled shear zones, some of which contain economic Au mineralization. In general, the shear zones strike and dip subparallel to the stratigraphic units (Glasson *et al.*, 1988). The area is intensely weathered to a depth of approximately 50 m and outcrops are rare.

Gold was first discovered at Callion in 1895 in an outcropping quartz vein. From 1899 until 1956, several companies mined the Callion deposit, and recovered a total of 2302 kg of Au from 146000 tonnes of ore from underground workings. In 1984, exploration by soil geochemistry led to the discovery of lateritic Au mineralization and subsequently underlying quartz vein mineralization, 6 km SW of the old Callion mine which is the location of the BC laterite and vein mineralization previously reported (Llorca, 1988). The newly-discovered mineralisation is now known as the Glasson Deposit.

The opening of costeans and subsequent drilling that followed the discovery of the Glasson deposit outlined a lenticular, auriferous laterite about 300 m in length, 70 m wide and 3 m thick. Ore reserves were estimated at 103,000 t at 1.9 g/t Au (Glasson *et al.*, 1988). This laterite deposit covers an extensively mineralized quartz vein system which is over 1000 m in length, has an average width of 3 m, is oriented north, dips 45-60° E and is oxidized to a depth of 60-70 m. Economic mineralization (1 ppm Au cut off) occurs over a length of 300 m and down to a maximum depth of 100 m, even though the shear structure continues further along strike and down dip (Fig. 2) (Glasson *et al.*, 1988). The fresh mineralization consists of free Au and disseminated sulphides. The shear zone and enclosed quartz veins are hosted by a grey, medium-grained metabasalt and occur close to the lower contact of this unit with a dark, fine-grained metabasalt (Fig. 2). Ore reserves for the quartz vein system alone were estimated to be about 104,000 t at 7.9 g/t (Glasson *et al.*, 1988).

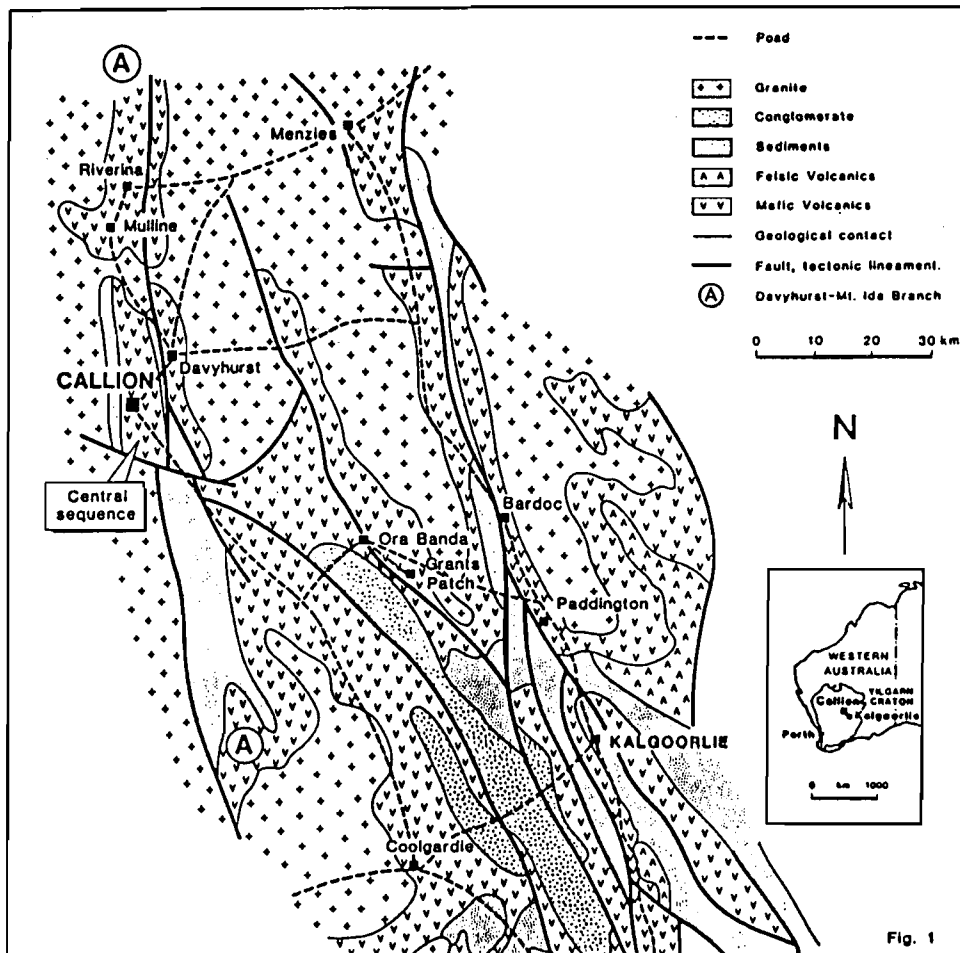


Figure 1. Generalized geologic map of the Callion area, after Glasson *et al.*, 1988.

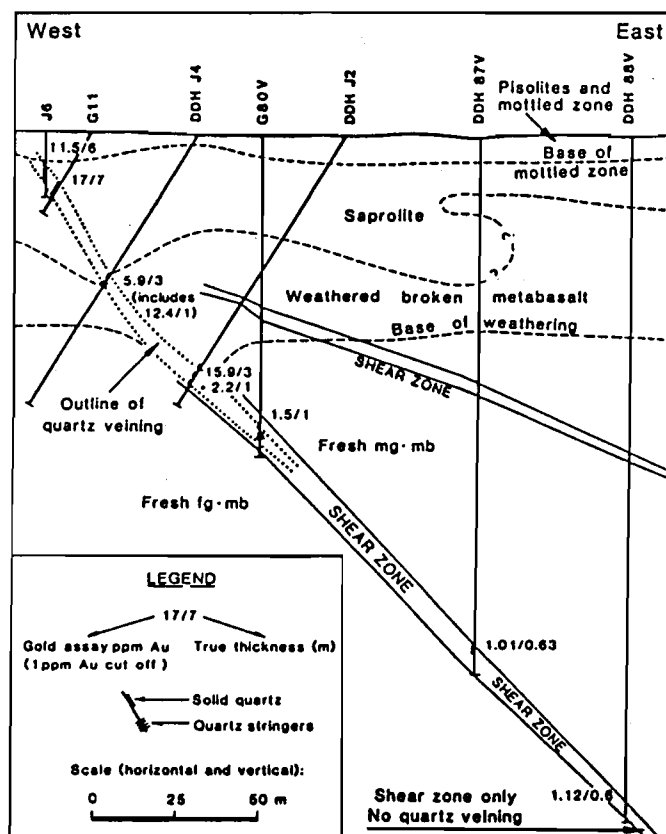


Figure 2. Cross-section through the Glasson vein on line 7505, after Glasson *et al.*, 1988.

### 3.0 SAMPLING

At the time of sampling by CSIRO (November 1987), the pisolitic cover (laterite) had been mined and a pit 20 m deep had been excavated below it, exposing the upper part of the mineralized quartz vein system and the host metabasalts within 20 m of the vein system (Fig. 3). The upper part of the weathered profile, exposed in the pit, consists of a calcrete horizon, just beneath the pisolitic cover, which overlies a yellow grey to yellow red-brown kaolinite horizon, grading to yellow-green with depth. The colours of the kaolinite horizon depend on the proportions of Fe oxides and oxyhydroxides. The base of the saprolite is known only in drill cores. Weathering is first seen along joints and progressively suffuse the whole rock, which becomes soft and turns to beige-green higher in the profile.

In all, 120 samples were collected from both the mineralized quartz vein system and host metabasalts (up to 100 m away), at various depths within the weathered profile, from surface down to fresh rock. These samples are from the open pit, drill cores, RC chips and powders from a cross section on line 750 S, and from a shallow costean to the W of the open pit, close to the same cross section (Fig. 3).

### 4.0 ANALYTICAL TECHNIQUES

A small representative part of each sample was kept as reference material and for polished blocks. The remaining sample of about one kg was crushed and riffle-split and 50 g were ground, using a Mn-steel jaw-crusher and ring mill. This pulp was then split for XRD, chemical analysis and Au determinations (10 g aliquot), after a series of tests on selected samples had established the reliability of such subsampling for Au analysis.

All 120 samples were analysed by X-ray diffraction. One hundred of these samples were chemically analysed and 15 samples were selected for optical microscope and electron microprobe studies.

X-ray powder diffraction patterns were obtained using a Philips PW 1050 powder diffractometer, with Cu K $\alpha$  radiation, graphite crystal monochromator and a scanning speed of 1° 2 $\theta$ /min from 4 to 68° 2 $\theta$ .

X-ray fluorescence spectrometry (XRF) was used to determine the major and minor elements, Si, Fe, Al, Ti, Mg, K, Na, Ca, Mn, S and P as well as the trace elements As, Bi, Pb, W and Rb. Additional trace element analysis for Ba, Be, Co, Cr, Cu, Ni, Sr, Y, Zn, Zr, Sc, La, Cd and Yb was by inductively coupled plasma emission spectrometry (ICP). Semi-quantitative optical emission spectrometry (OES) was used for Ag, B, Ga, Mo, Sb, Sn and Tl. Carbon was determined by Leco CR 12 analyser and Cl by pyrohydrolysis followed by ion-chromatography. Gold was measured by ICP-MS, following preconcentration by fire assay. Lanthanum, Cd, Yb, Sb and Tl, all determined but present below the detection limits of 20, 5, 1, 30 and 3 ppm respectively, have been omitted from the tables of analyses given in this report.

Polished blocks were examined in reflected light, using a Zeiss microscope. Microprobe analyses were made with a Camebax Microbeam.

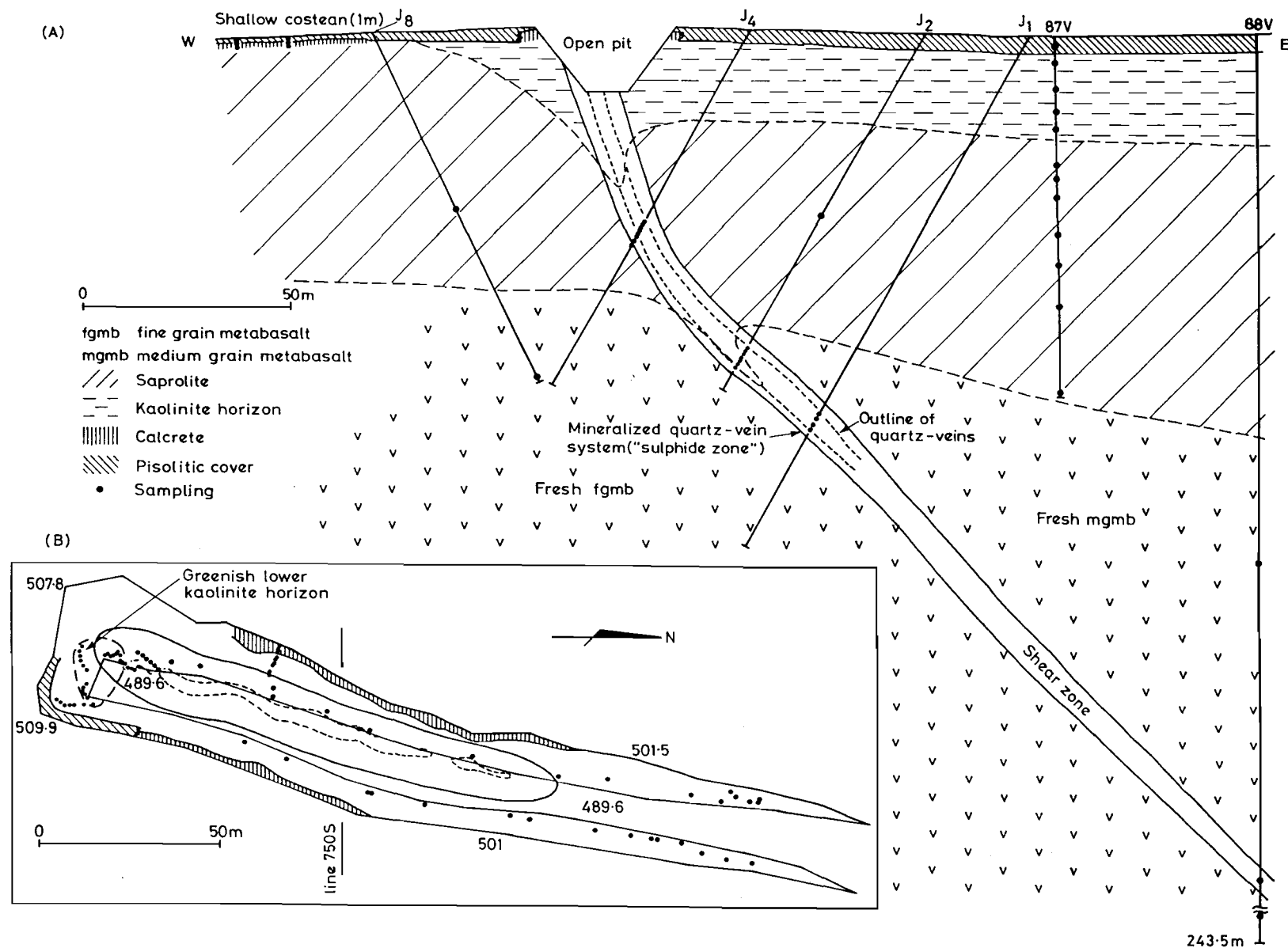


Figure 3. Weathered profiles and sampling location. (A) Cross section on line 750 S. (B) Map of the pit.

## 5.0 RESULTS AND DISCUSSION

The terms smectite horizon and kaolinite horizon, used in this report, are subdivisions of the saprolite made on the basis of the bulk mineralogy shown by the X-ray diffraction analysis; the smectite horizon starts with the appearance of secondary minerals and ends with the disappearance of weatherable primary silicates.

### 5.1 X-Ray diffraction data

The XRD study was carried out to establish the bulk mineralogical composition of the weathered profiles over both the sulphide-zone and the country rock. The results are shown schematically in Fig. 4.

#### 5.1.1 *Country-rock*

The fresh metabasalts contain amphibole and plagioclase, with small amounts of chlorite and minor quartz. Amphibole predominates over plagioclase. Diffractograms from the medium-grained metabasalt show diffraction peaks at 3.04 and 4.12 Å which do not appear on the diffractograms from the fine-grained metabasalt. They appear to reflect a difference in the composition of the amphibole (see Section 5.3).

In the smectite horizon, the amphibole, plagioclase and chlorite are progressively replaced, up the profile, by smectites and kaolinite; smectites usually predominate over kaolinite.

In the kaolinite horizon, the primary silicates, apart from quartz, have been completely weathered. Smectites are present only in the lower part of this horizon, kaolinite alone remaining further up. Variable amounts of goethite are also present.

Carbonates overlying the kaolinite horizon, associated with the weathered sulphide zone were found to be dolomite and those above the saprolite, to the west, were calcite.

The pisolitic cover consists of hematite, quartz, kaolinite (with small amounts of goethite) and, locally, small amounts of mica.

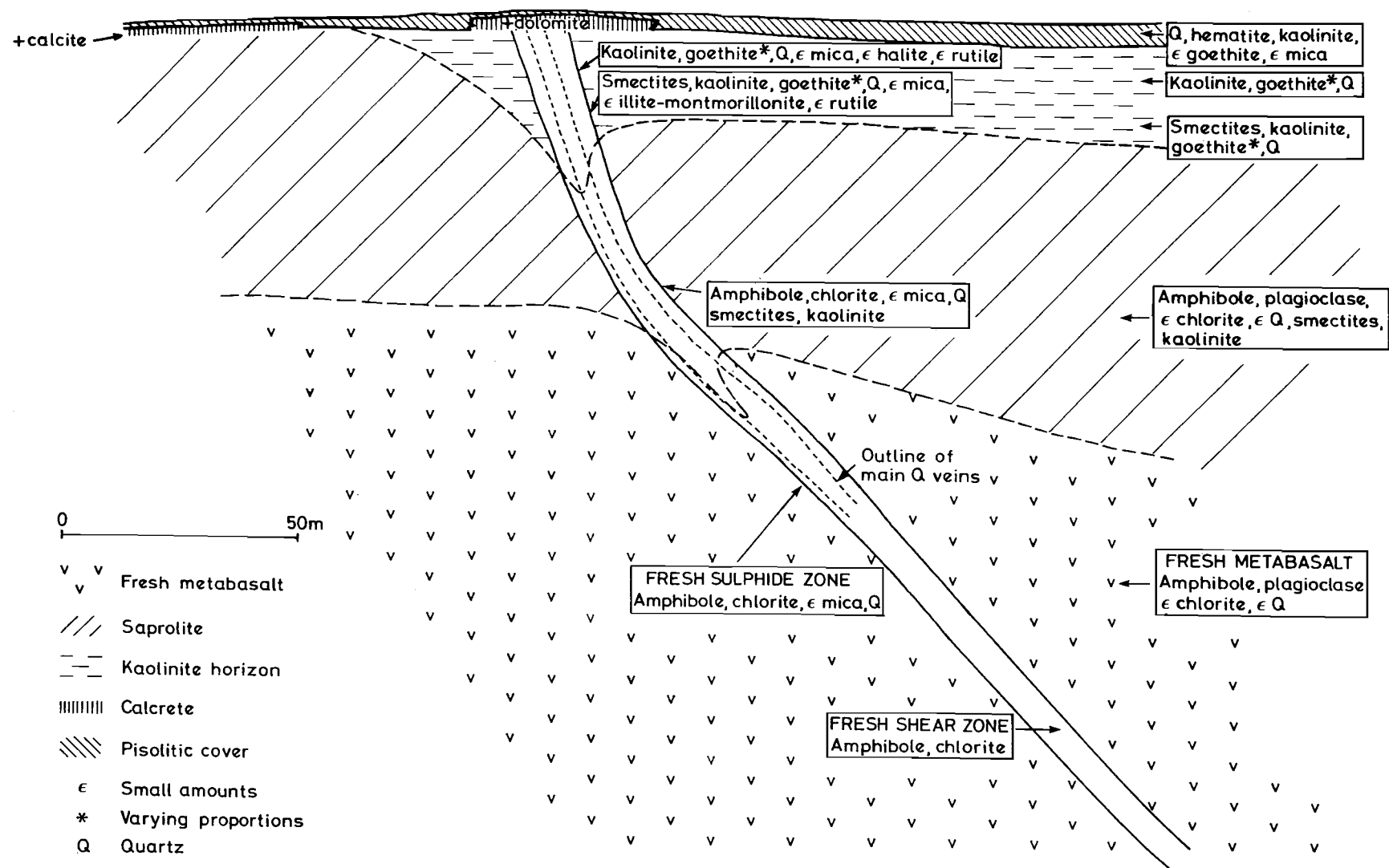
#### 5.1.2 *Sulphide zone*

Unweathered material from a non-sulphidic part of the shear zone, contains amphibole and chlorite in equal proportions. In the fresh sulphide zone, in addition to the amphibole and chlorite, some mica, usually in small amounts, is also present with quartz restricted to the quartz veins.

In the smectite horizon, amphibole and chlorite are progressively replaced by smectites and kaolinite, the smectites usually predominating over the kaolinite. The amphibole weathers more readily than the chlorite and has almost disappeared before the chlorite is attacked. Mica and quartz are resistant.

In the kaolinite horizon, amphibole and chlorite have completely disappeared but mica and quartz are still present. The smectites are present only in the lower part of the horizon, kaolinite alone further up. Variable amounts of goethite are present in this horizon. Small amounts of rutile were found in places, particularly in the goethite-poor samples





**Figure 4.** Mineralogical composition of the weathered profiles from both sulphide zone and country rock according to the X-ray Diffraction analysis and reported on a cross section on line 750 S.

and, as shown below, are associated with the weathered sulphides. Halite in places occurs in the upper part of the horizon; its association with the weathered sulphide zone is due to groundwaters permeating the shear zone. A mineral giving a diffraction peak at 12.2-12.5 Å, probably an interstratified illite-montmorillonite, is present locally, particularly where the smectites disappear. This suggests the illite-montmorillonite formed after or in place of smectites, as conditions became drier and the concentration of K-ions in solution increased, perhaps recently and contemporaneously with deposition of halite.

## 5.2 Chemical data

The geochemical evolution of the weathered profiles, from both sulphide zone and country-rock, are described below and summarized in Fig. 5. The geochemical analyses which form the basis of this section are given in Tables 1 to 9.

### 5.2.1 *Country-rock*

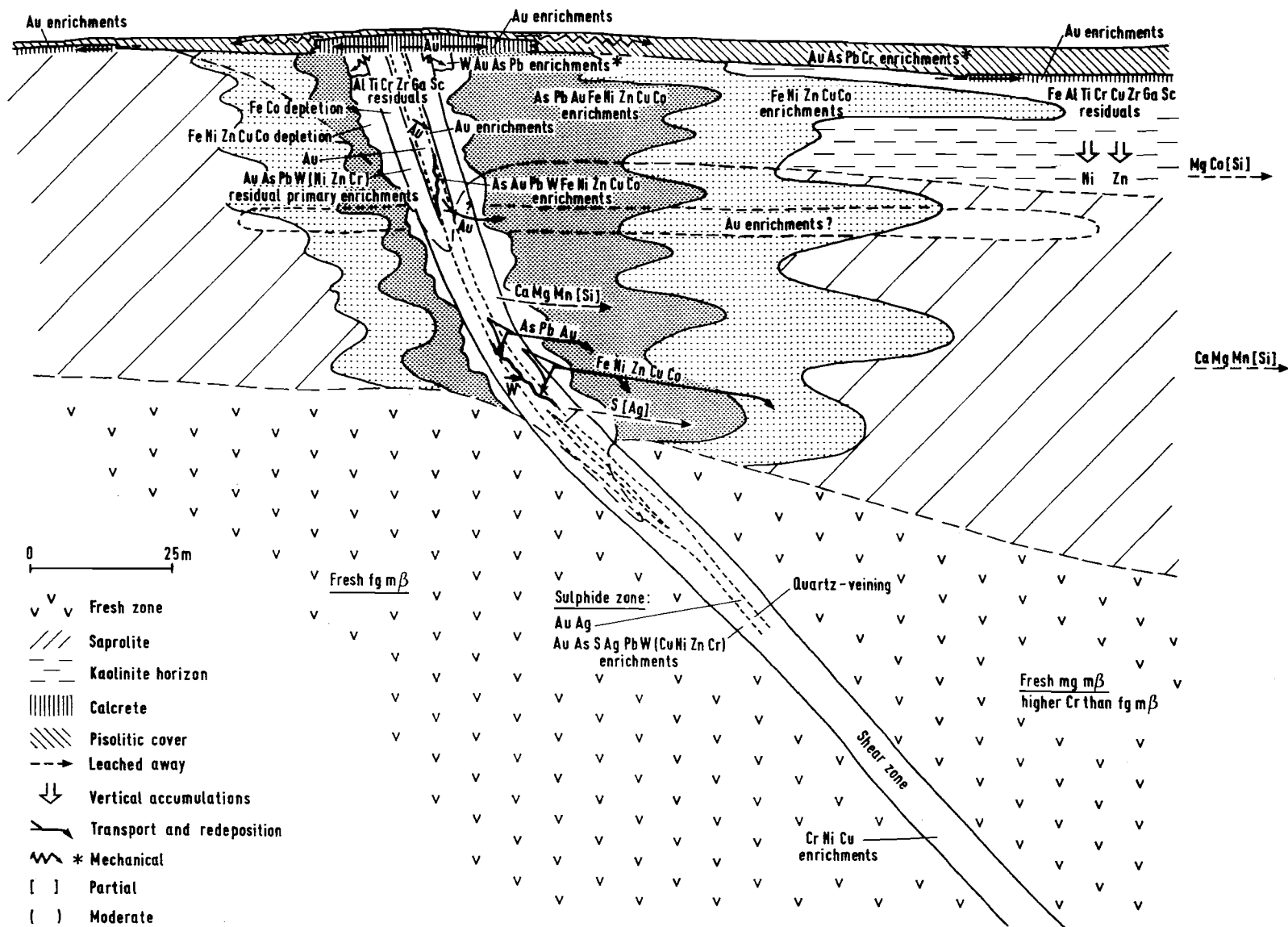
Data from the fresh metabasalts show that the fine-grained metabasalt is richer in Al, Ti, Zn and poorer in Mg, Cr, Ni than the medium-grained metabasalt (Table 1).

In the smectite horizon, away from the sulphide zone (Table 2), Ca, Mg, Mn and some Si are leached as the amphibole, plagioclase and chlorite gradually disappear. This results in a slight relative concentration of most other elements, such as Fe, Al, Ti, Co, Cr, Cu, Ni, Zn, Zr, Ga and Sc. These elements could be incorporated in the newly formed smectites and kaolinite or contained in resistant accessory minerals. Yttrium, Ba and Rb show abnormal concentrations; Ba and Rb are probably derived from the sulphide zone, which is located up-slope and is enriched in these elements, whereas Y may have accumulated in this horizon, being leached from higher in the profile. Gold is abnormally concentrated at the top of the smectite horizon, where small amounts of Cl are also present. This may suggest mobilization of some Au from the sulphide zone by chloride-rich solutions that circulated during the post-lateritisation period with horizontal dispersion at a water table located at this level, according to a mechanism described by Butt (1989).

There is very little Ca in the lower, smectitic part of the kaolinite horizon (Tables 3 and 4) but there is some Mg. Here, all primary silicates, apart from quartz, have been consumed. This suggests that Mg rather than Ca must be the exchange-cation in these smectites. As the smectites are consumed in their turn, higher in the profile, so Mg, Co and more Si are leached. As a result residual Fe, Al, Ti, Cr, Cu, Zr, Ga and Sc are further concentrated. Nickel and Zn seem to accumulate in this lower part of the kaolinite horizon but are depleted higher up in the profile.

The concentrations of several elements in the kaolinite horizon cannot be explained through a process of vertical accumulation and must involve lateral migration from the adjacent sulphide zone (Tables 3, 4 and 5). These include:

- i) Elevated Fe, Ni, Zn, Cu and Co contents extending at least 100 m from the weathered sulphide zone.
- ii) Enrichments of As within 10 m and Au and Pb within at least 20 m of the sulphide zone. The Au, Pb and As enrichments occur with Fe, Ni, Zn, Cu and



**Figure 5.** Geochemical evolution and resulting characteristics of the weathered profiles from sulphide zone and country-rock, reported on a cross section on line 750 S.

**TABLE 1**  
Chemical analyses of samples from fresh zone  
(from drill holes 88V, J<sub>1</sub>, J<sub>2</sub>, J<sub>8</sub>).

	1*	1	2	2*	3	3	4	4	4	4	5	5
SiO <sub>2</sub>	49.37	48.72	51.10	51.45	49.04	49.78	48.73	45.46	45.84	45.72	91.94	98.85
Fe <sub>2</sub> O <sub>3</sub>	12.66	13.55	12.56	11.33	13.05	11.55	12.86	12.90	16.66	12.48	2.53	0.60
Al <sub>2</sub> O <sub>3</sub>	15.06	15.57	12.58	12.61	11.55	10.84	11.45	10.74	9.69	9.63	1.37	0.01
TiO <sub>2</sub>	1.08	1.08	0.70	0.71	0.69	0.64	0.66	0.57	0.58	0.64	0.07	0.01
MgO	6.21	6.67	10.41	9.23	12.86	12.38	13.03	15.03	12.59	14.39	1.47	0.01
K <sub>2</sub> O	0.09	0.11	0.10	0.05	0.17	0.06	<u>1.29</u>	33.00	<u>1.39</u>	0.22	0.09	0.01
Na	2.20	1.57	1.30	1.58	0.88	1.02	0.57	0.22	0.45	0.24	0.05	0.01
CaO	10.06	11.12	10.10	9.63	8.63	10.18	7.09	8.57	6.31	11.20	1.62	0.10
MnO <sub>2</sub>	0.24	0.27	0.28	0.23	0.27	0.27	0.28	0.21	0.29	0.25	0.01	0.01
SO <sub>3</sub>	0.01	0.24	0.18	0.01	0.12	0.30	0.38	<u>2.24</u>	0.75	<u>3.40</u>	0.58	0.01
C	0.04	0.02	0.07	0.01	0.10	0.02	0.01	0.05	0.01	0.13	0.06	0.04
Cl	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.06	0.01	0.01	0.01
P <sub>2</sub> O <sub>5</sub>	0.14	0.12	0.11	0.01	0.11	0.01	0.10	0.01	0.01	0.01	0.01	0.01
Loss	1.00	0.70	1.79	1.90	2.86	1.60	3.50	3.00	4.80	1.70	0.60	1.00
Total	98.17	99.75	101.29	98.76	100.34	98.66	99.96	99.35	99.43	100.02	100.41	100.67
Au	4	4	2	8	4	10	600	230	54	2000	10800	6
Ag	0.01	0.60	0.10	2.00	0.10	0.30	0.60	0.70	0.40	1.00	6.80	0.10
As	1	1	1	1	1	1	<u>218</u>	82	<u>299</u>	25	1	1
B	5	5	5	2	8	4	<u>15</u>	6	<u>7</u>	5	4.4	8
Ba	35	20	20	11	43	11	<u>163</u>	45	<u>147</u>	44	24	1
Be	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Bi	0.5	0.5	5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	9	0.5
Co	51	50	56	51	67	66	72	72	66	71	11	0.5
Cr	140	164	610	560	880	1210	1030	1530	1040	1390	152	15
Cu	49	159	80	32	158	260	67	<u>192</u>	136	<u>460</u>	106	7
Ga	20	20	20	15	10	10	20	15	15	25	2.2	0.1
Mo	1	15	1	2	1	0.8	1	1	2	2.2	3	
Ni	152	154	235	195	440	420	480	550	440	450	68	2
Pb	1	1	1	1	1	1	16	1	1	1	259	1
Rb	0.5	0.5	5	0.5	10	0.5	63	19	69	13	7	0.5
Sc	37	38	37	37	35	36	37	35	34	33	6	15
Sn	1	2	2	2	2	3	3	2	3	2	0.1	0.1
Sr	115	112	72	100	44	73	52	76	0.5	39	8	0.5
W	0.5	0.5	0.5	0.5	0.5	0.5	0.5	228	10	0.5	21	9
Y	18	19	13	14	13	14	13	13	12	10	2	8
Zn	108	92	72	76	81	74	101	<u>167</u>	159	<u>189</u>	64	5
Zr	23	20	29	34	37	51	55	49	51	48	0.5	28

1 Fine grained metabasalt

2 Medium grained metabasalt

3 Shear zone

4 Sulphide zone

5 Quartz-vein

\* Very slightly oxidized

Majors in wt%; traces in ppm; Au in ppb

— Abnormal concentrations

**TABLE 2**

Chemical analyses of saprolite samples from drill hole 87V,  
100 m distant from sulphide zone.

SiO <sub>2</sub>	50.60	50.60	54.17	50.52	50.22	49.79	51.80	51.81
Fe <sub>2</sub> O <sub>3</sub>	12.66	12.37	12.83	12.57	13.07	13.20	13.30	13.72
Al <sub>2</sub> O <sub>3</sub>	12.54	13.22	12.97	12.79	13.34	13.44	13.54	14.61
TiO <sub>2</sub>	0.70	0.73	0.73	0.72	0.74	0.76	0.79	0.79
MgO	10.47	9.28	9.15	9.04	7.77	8.68	4.63	4.19
K <sub>2</sub> O	0.14	0.08	0.10	0.10	0.10	0.24	0.20	0.20
Na	1.21	1.30	1.29	1.29	1.28	1.10	1.21	0.80
CaO	9.05	8.80	8.42	8.42	7.24	6.76	4.16	3.09
MnO <sub>2</sub>	0.27	0.22	0.24	0.29	0.18	0.27	0.01	0.12
SO <sub>3</sub>	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
C	0.005	0.21	0.07	0.08	0.18	0.09	0.18	0.16
Cl	0.02	0.03	0.005	0.03	0.06	0.03	0.09	<u>0.13</u>
P <sub>2</sub> O <sub>5</sub>	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Loss	3.42	3.33	4.05	3.95	5.43	6.43	9.71	10.43
Total	101.11	100.19	100.05	99.82	99.63	100.81	99.64	100.07
Au	2	4	6	4	2	6	4	<u>22</u>
Ag	0.2	0.6	0.1	0.01	0.01	0.1	0.01	0.1
As	1	1	1	1	1	1	1	1
B	4	10	6	8	10	10	25	40
Ba	30	18	37	<u>76</u>	<u>110</u>	<u>70</u>	<u>196</u>	44
Be	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Bi	5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Co	57	57	61	108	67	64	78	59
Cr	610	640	640	610	540	620	670	650
Cu	56	92	70	70	64	83	69	6
Ga	20	20	20	20	20	20	15	20
Mo	2	2	2	3	5	2	5	5
Ni	260	249	260	270	270	270	300	280
Pb	1	11	1	1	1	1	1	1
Rb	9	6	10	8	<u>10</u>	<u>15</u>	<u>16</u>	<u>18</u>
Sc	38	40	3	40	40	42	39	34
Sn	2	2	1	2	2	1	2	2
Sr	76	95	85	84	70	64	70	39
W	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Y	14	13	15	<b>26</b>	<b>73</b>	<b>14</b>	7	5
Zn	80	81	75	75	80	86	64	71
Zr	50	36	35	35	45	60	41	32

First column: saprolite base; last column: saprolite top.

Abnormal concentrations, probably due to lateral migration from the sulphide zone.

**Bold** Abnormal concentration probably due to vertical accumulation.

Majors in wt%; traces in ppm; Au in ppb.



**TABLE 3**

Chemical analyses of samples from kaolinite horizon and pisolitic cover  
from drill hole 87V, 110 m away from sulphide zone.

	1	2	3	4	4
SiO <sub>2</sub>	21.72	39.68	25.47	41.44	50.86
Fe <sub>2</sub> O <sub>3</sub>	52.66	21.52	42.6	23.89	14.14
Al <sub>2</sub> O <sub>3</sub>	16.02	23.56	16.37	17.42	16.77
TiO <sub>2</sub>	1.32	1.17	.74	1.05	.76
MgO	.20	.28	.34	1.27	1.24
K <sub>2</sub> O	.04	.09	.08	.10	.35
Na	.02	.14	.10	.34	.45
CaO	.005	.06	.005	.23	.06
MnO <sub>2</sub>	.01	.01	.01	.01	.01
SO <sub>3</sub>	.01	.01	.01	.01	.01
C	.11	.42+	.13	.34	.28
Cl	.005	.005	.02	.12	.13
P <sub>2</sub> O <sub>5</sub>	.01	.01	.01	.01	.01
Loss	8.88	14.37	14.52	14.64	15.86
Total	101.01	101.325	100.405	100.87	100.93
Au	20	32+	8	14	4
Ag	.8	.1	.1	.01	.01
As	1	1	1	18	31
B	50	70	100	150	100
Ba	30	20	14	13	38
Be	4	.2	2	.2	.2
Bi	5	.5	5	5	5
Co	27	19	55	49	75
Cr	2490	1240	810	1280	910
Cu	65	116	234	109	113
Ga	70	30	25	40	20
Mo	5	2	2	3	15
Ni	110	105	152	196	<b>400</b>
Pb	42	1	1	1	1
Rb	12	10	10	9	8
Sc	70	54	66	44	43
Sn	4	3	2	2	2
Sr	7	22	10	19	24
W	.5	.5	.5	.5	.5
Y	6	3	3	5	4
Zn	30	40	75	35	<b>100</b>
Zr	120	54	30	53	27

- 1 Pisolitic cover  
2 Top kaolinite horizon (+ calcrete)  
3 Upper kaolinite horizon, abnormally enriched in Fe, Ni, Zn, Cu and Co  
4 Lower kaolinite horizon  
Depth increasing from left to right  
**Bold** High concentration due to vertical accumulation  
Majors in wt%; traces in ppm; Au in ppb.

**TABLE 4**  
Chemical analyses of samples from kaolinite horizon  
between 5 and 10 m from sulphide zone (from open pit)

	1	1	1	1	2	2	2	2	3	3	4	4	4
SiO <sub>2</sub>	55.22	46.81	31.78	44.12	42.41	33.46	27.02	41.21	45.82	35.57	38.06	42.47	42.67
Fe <sub>2</sub> O <sub>3</sub>	16.74	20.12	37.49	19.63	26.25	19.60	40.56	24.08	17.90	28.40	21.25	21.44	15.05
Al <sub>2</sub> O <sub>3</sub>	15.52	19.46	16.26	21.09	16.44	23.09	17.41	19.04	19.10	21.21	18.57	17.60	20.14
TiO <sub>2</sub>	0.80	1.08	1.10	1.13	0.84	1.43	0.98	1.47	1.13	1.28	0.89	1.06	0.93
MgO	0.12	0.13	0.18	0.12	0.38	0.41	0.47	0.27	0.33	0.25	1.42	1.08	1.60
K <sub>2</sub> O	0.04	0.01	0.06	0.01	0.09	0.07	0.36	0.05	0.09	0.01	0.09	0.28	0.10
Na	0.09	0.06	0.04	0.06	0.25	0.25	0.20	0.15	0.54	0.18	0.43	0.34	0.46
CaO	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.090	0.050	0.140
MnO <sub>2</sub>	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
SO <sub>3</sub>	0.01	0.01	0.01	0.01	0.01	0.23	0.01	0.14	0.42	0.01	0.01	0.01	0.01
C	0.01	0.01	0.04	0.02	0.02	0.05	0.04	0.02	0.10	0.03	0.03	0.02	0.02
Cl	0.005	0.005	0.005	0.010	0.010	1.520	0.220	0.010	1.020	0.030	0.300	0.150	0.230
P <sub>2</sub> O <sub>5</sub>	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Loss	11.67	12.81	12.93	13.57	14.05	19.72	14.12	14.29	13.76	13.76	19.33	15.62	19.33
Total	100.25	100.53	99.92	99.79	100.87	99.86	101.42	101.01	100.24	100.75	100.49	100.16	100.74
Au	62*	150*	250*	14	16*	30*	48*	18*	4	8	10	18*	12
Ag	0.01	0.1	0.2	0.4	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
As	96	54	72	82	69	133	392	53	84	202	54	138	37
B	50	50	50	25	100	150	100	80	100	100	100	80	100
Ba	320	22	214	20	67	66	79	18	15	17	1	29	1
Be	0.2	0.2	3	2	3	3	3	3	2	2	0.2	0.2	0.2
Bi	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Co	17	22	26	51	66	66	30	21	20	36	47	56	68
Cr	1770	2030	3080	2280	1520	1520	2260	300	2210	2310	2260	2220	1320
Cu	121	163	237	216	240	241	390	280	225	198	166	160	148
Ga	30	40	60	25	20	50	20	40	50	50	25	20	20
Mo	2	0.6	1	0.8	0.03	0.5	1	0.03	2	0.8	8	0.4	0.4
Ni	99	119	141	128	840	840	460	207	140	160	<b>440</b>	<b>830</b>	<b>820</b>
Pb	15	14	24	28	13	13	33	55	11	32	48	26	18
Rb	6	7	7	8	7	0.5	25	6	6	0.5	7	19	6
Sc	35	57	56	56	59	61	64	66	86	74	41	38	36
Sn	5	8	8	5	5	5	2	1	5	5	5	5	2
Sr	11	8	9	6	12	12	29	0.5	0.5	8	21	26	29
W	0.5	0.5	0.5	0.5	0.5	0.5	8	0.5	0.5	0.5	0.5	22	0.5
Y	2	3	2	3	14	14	9	4	3	4	3	16	9
Zn	86	63	49	46	230	232	163	204	27	86	<b>189</b>	<b>270</b>	<b>228</b>
Zr	63	86	110	98	55	55	7	52	93	116	75	90	70

1 Pedoturbated top kaolinite horizon

2 Upper kaolinite horizon, abnormally enriched in Fe, Ni, Zn, Cu and Co

3 Upper kaolinite horizon

4 Lower kaolinite horizon (smectites decreasing from right to left)

**Bold** High concentration due to vertical accumulation

· Pedoturbation (mechanical)

\*

Majors in wt%; traces in ppm; Au in ppb.

**TABLE 5**  
Chemical analyses of samples from kaolinite horizon  
between 10 and 20 m from sulphide zone (open pit)

	1	1	1	2	2	2	2	3	3	3	3	3
SiO <sub>2</sub>	37.79	39.23	42.05	23.7	32.51	31.76	26.27	34.58	32.74	37.61	54.61	61.54
Fe <sub>2</sub> O <sub>3</sub>	26.55	21.95	17.8	52.06	38.62	51.33	41.69	30.56	28.15	18.06	12.51	2.28
Al <sub>2</sub> O <sub>3</sub>	19.66	24.98	25.73	9.85	12.16	6.05	17.1	20.23	23.74	27.64	20.15	21.5
TiO <sub>2</sub>	0.95	1.19	1.25	0.37	0.49	0.32	0.73	1.07	1.25	1.52	0.85	1.3
MgO	0.54	0.25	0.13	0.26	0.15	0.26	0.23	0.24	0.2	0.18	0.15	0.13
K <sub>2</sub> O	0.16	0.07	0.005	0.005	0.07	0.04	0.15	0.38	0.11	0.05	0.06	0.06
Na	0.15	0.15	0.07	0.05	0.04	0.05	0.1	0.07	0.07	0.09	0.1	0.16
CaO	0.27	0.005	0.005	0.005	0.05	0.08	0.04	0.005	0.005	0.005	0.005	0.005
MnO <sub>2</sub>	0.01	0.01	0.01	0.15	0.2	0.01	0.01	0.01	0.01	0.01	0.01	0.01
SO <sub>3</sub>	0.01	0.01	0.15	0.26	0.17	0.23	0.14	0.23	0.01	0.01	0.01	0.14
C	0.08	0.04	0.05	0.03	0.06	0.03	0.05	0.08	0.03	0.02	0.01	0.02
Cl	0.03	0.03	0.03	0.07	0.05	0.02	0.02	0.03	0.02	0.02	0.005	0.02
P <sub>2</sub> O <sub>5</sub>	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Loss	14.26	13.59	13.76	13.88	12.95	10.59	15.2	13.2	14.14	14.38	12.71	13.17
Total	100.47	101.515	101.05	100.7	97.53	100.78	101.74	100.695	100.485	99.605	101.19	100.345
Au	110•	36•	18•	40*	24*	6	6	6	6	4	14	12
Ag	0.1	0.01	0.01	0.2	0.1	0.01	0.01	0.1	0.01	0.01	0.01	0.01
As	1	1	1	1	1	1	1	1	1	1	14	1
B	100	150	70	60	70	50	100	100	80	100	50	80
Ba	157	1	1	40	58	19	103	111	22	1	90	420
Be	0.2	0.2	0.2	2	0.2	0.2	0.2	0.2	0.2	2	0.2	0.2
Bi	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	6	0.5
Co	20	19	19	119	179	37	32	24	31	31	19	15
Cr	1830	2260	1860	1730	1010	1170	2140	1345	1880	2120	870	620
Cu	136	129	109	195	231	158	213	148	181	168	106	55
Ga	60	50	40	10	20	7	25	60	60	50	25	25
Mo	0.8	0	0.03	0.3	0.5	0.5	0.3	0.4	0.2	0.2	0.03	0.03
Ni	192	320	260	1090	580	250	137	130	135	148	160	157
Pb	12	1	1	1	20	22	28	28	23	18	1	12
Rb	15	8	7	8	7	7	12	22	8	6	7	6
Sc	38	33	41	87	56	45	60	44	59	64	57	39
Sn	5	4	5	5	2	2	3	3	3	5	2	4
Sr	46	21	0.5	0.5	19	11	17	19	10	7	11	42
W	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Y	3	3	1	32	23	6	4	4	4	5	2	2
Zn	46	30	30	460	560	290	119	54	60	45	79	90
Zr	82	75	82	33	47	35	76	115	117	129	75	103

1 Pedoturbated upper kaolinite horizon

2 Upper kaolinite horizon, abnormally enriched in Fe, Ni, Zn, Cu and Co

3 Upper kaolinite horizon

Mechanism suggested for mobilization of gold: \* thiosulphate ions, • pedoturbation (mechanical).  
Majors in wt%; traces in ppm; Au in ppb.

Co, suggesting that these elements were precipitated together with goethite. However, the contents of As, Pb and especially Au (20-50 ppb) are low compared to the equivalent horizon in the weathered sulphide zone. Therefore, the mobilization of Au as thiosulphate complexes, during the weathering of sulphides, which appears to be the process involved here, only led to a very slight dispersion of Au into the country rock.

Tungsten enrichments were found in the pedoturbated upper part of the kaolinite horizon within 5 m of the sulphide zone, together with more substantial enrichments of Au, As and Pb (Table 6). These enrichments could thus be due to limited mechanical dispersion within 8 m of the surface, due to reworking by plant roots.

The highest Au contents in the regolith overlying the country rocks were found in calcrete. Gold enrichments occur for at least 100 m from the weathered sulphide zone (Tables 6, 7 and 3) in calcrete immediately beneath the pisolitic cover. Samples collected from calcrete in the costean to the west (Table 7) showed a correlation between Au, C and Ca, confirming that Au is associated with carbonate. The Au was probably remobilized from the sulphide zone and transported at the surface by complexing with humic acids derived from soil organic matter (Butt, 1989). This may have occurred during the humid Cretaceous to Mid Miocene period, when vegetation was abundant. Fixation of Au with carbonate would have occurred during a subsequent period dry enough to allow the Ca to precipitate as calcite. However wide the dispersion of Au is at the surface, Au values are greater in the calcrete overlying the sulphide zone (to 16 ppm, Glasson *et al.*, 1988).

Chemical analysis of 3 samples from the pisolitic cover, located between 65 m and 110 m from the sulphide zone, showed higher contents in Au, As, Pb, and Cr than those expected through normal residual concentration. Gold and As contents decline sharply away from the sulphide zone (Tables 7 and 3). Thus, limited mechanical dispersion occurred at the surface above the sulphide zone that constitutes the hill top. It is interesting to note that Au is less enriched in the pisolitic cover than in the immediately underlying calcrete; the same phenomenon was observed by Glasson *et al.*, (1988) over the sulphide zone itself.

### 5.2.2 Sulphide zone

The fresh shear zone, whether sulphide-bearing or not, is enriched in Cr, Ni, Mg, Cu, Zr and Co and is poorer in Na and Ca than the country rock metabasalts by factors of 1.2-10.0 (Table 1). The higher Mg and lower Na and Ca are accounted for by the presence of chlorite and absence of plagioclase. The fresh sulphide zone is also enriched in Au (by a factor of about 1000), As, S, Ag, Pb, W (by factors of 10-50), Cu, K, Rb, Ba (by factors of 3-5), Zn and B (by a factor of 2) (Table 1). Arsenic, Ba and Rb values follow the K values, suggesting an association with mica. Copper and Zn values follow the S values and are higher in the chlorite-rich samples, suggesting a sulphide association with chlorite. Gold is correlated with Ag only; it occurs as free Au in the quartz but is also present throughout the sulphide zone, possibly in both pyrite and arsenopyrite. Both W and Pb enrichments are sporadic.

Analyses of the smectite horizon (Table 8) show that as the sulphides break down, the S is readily leached. As the amphibole and chlorite are progressively consumed, Ca and Mg are leached, as in the country rock but also a more significant proportion of Si and some Fe, Co and Ni. This is due to the increased mobility of these elements caused by the acid

**TABLE 6**  
Chemical analyses of samples from an oblique profile  
on western face of open pit

	1	1	1	2	2	2	2	2
SiO <sub>2</sub>	40.56	35.62	19.95	48.32	45.27	42.92	43.89	45.7
Fe <sub>2</sub> O <sub>3</sub>	6.22	1.92	1.2	6.03	4.48	3.58	9.84	7.18
Al <sub>2</sub> O <sub>3</sub>	16.98	15.95	12.16	28.67	33.65	30.65	29.52	32.11
TiO <sub>2</sub>	1.04	0.83	0.72	1.81	1.96	1.98	1.78	1.5
MgO	4.92	7.25	12.49	0.36	0.27	0.57	0.33	0.22
K <sub>2</sub> O	0.17	0.18	0.08	0.11	0.09	0.12	0.1	0.35
Na	0.34	0.35	0.19	0.43	0.27	0.84	0.38	0.15
CaO	7.59	11.49	18.97	0.01	0.01	0.01	0.01	0.01
MnO <sub>2</sub>	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
SO <sub>3</sub>	0.01	0.01	0.01	0.14	0.11	0.47	0.2	0.01
C	3.01	4.6	7.73	0.05	0.1	0.02	0.03	0.03
Cl	0.03	0.06	0.04	0.52	0.32	1.57	0.48	0.13
P <sub>2</sub> O <sub>5</sub>	0.01	0.01	0.01	1	0.01	0.01	0.01	0.01
Loss	22.05	26.69	35.02	14.28	14.71	17.45	15	13.74
Total	102.94	104.97	108.58	100.75	101.26	100.20	101.58	101.15
Au	560+	790+	290+	220*	480*	36*	200*	110*
Ag	0.1	0.01	0.2	0.2	0.3	0.1	0.2	0.01
As	48	27	16	350	285	226	335	343
B	150	100	50	100	80	150	80	60
Ba	157	25	39	39	12	13	56	28
Be	0.2	0.2	0.2	2	2	2	2	2
Bi	0.5	0.5	0.5	0.5	0.5	5	7	0.5
Co	20	11	11	12	10	9	13	10
Cr	420	209	146	670	860	880	1300	2830
Cu	49	47	24	82	64	43	86	67
Ga	40	25	15	50	50	60	50	30
Mo	0.5	0.1	0.01	1	0.6	1	2	0.01
Ni	81	61	45	44	29	27	59	44
Pb	22	10	15	27	28	29	33	53
Rb	7	8	0.5	0.5	6	6	7	21
Sc	24	23	16	51	53	54	55	59
Sn	2	1	1	3	3	4	4	0.1
Sr	260	234	230	0.5	0.5	0.5	0.5	6
W	0.5	0.5	0.5	65	111	79	100	493
Y	3	10	2	2	2	2	2	3
Zn	27	23	20	10	15	17	22	17
Zr	44	30	22	90	104	95	102	134

1 Calcrete between 5 and 10 m away from the sulphide zone.

2 Pedoturbated upper kaolinite horizon between 0 and 5 m from the sulphide zone, abnormally depleted in Fe, Ni, Zn, Cu and Co.

Depth increasing from left to right.

Mechanism suggested for remobilization of gold: + humic acids, \* pedoturbation (mechanical).

Majors in wt%; traces in ppm; Au in ppb.



**TABLE 7**  
Chemical analyses of samples from shallow costean.

	1A	2A	3A	1B	2B	3B
SiO <sub>2</sub>	43.50	36.29	52.18	49.78	49.42	52.27
Fe <sub>2</sub> O <sub>3</sub>	27.92	5.25	10.04	25.58	11.96	7.43
Al <sub>2</sub> O <sub>3</sub>	17.01	7.12	14.95	15.56	12.21	14.73
TiO <sub>2</sub>	0.93	0.39	0.70	0.91	0.66	0.78
MgO	0.29	1.78	1.80	0.30	1.35	1.19
K <sub>2</sub> O	0.35	0.14	0.15	0.40	0.48	0.12
Na	0.06	0.33	0.72	0.06	0.14	0.44
CaO	0.38	22.63	4.13	0.18	10.32	6.51
MnO <sub>2</sub>	0.01	0.01	0.01	0.01	0.01	0.01
SO <sub>3</sub>	1.00	0.11	0.01	0.01	0.01	0.01
C	0.96	5.15	0.93	0.26	2.20	1.42
Cl	0.01	0.01	0.04	0.01	0.01	0.03
P <sub>2</sub> O <sub>5</sub>	0.01	0.11	0.01	0.01	0.01	0.01
Loss	10.45	26.67	15.90	8.09	14.70	16.33
Total	101.89	105.99	101.57	101.16	103.48	101.28
Au	130	280	58	58	160	44
Ag	0.3	0.01	0.01	0.01	0.1	0.01
As	63	1	14	58	15	1
B	40	50	70	50	70	100
Ba	82	244	144	110	240	270
Be	3	0.2	0.2	3	0.2	0.2
Bi	0.5	0.5	0.5	0.5	0.5	0.5
Co	20	12	19	20	20	18
Cr	840	93	149	850	300	127
Cu	122	117	115	93	110	105
Ga	40	8	20	60	25	20
Mo	2	0.01	0.1	2	1	0.6
Ni	97	74	106	101	90	94
Pb	27	1	1	24	14	1
Rb	19	9	15	25	26	7
Sc	47	11	19	43	21	17
Sn	3	1	1	2	2	2
Sr	23	330	200	20	165	183
W	0.5	0.5	0.5	0.5	8	0.5
Y	6	7	3	6	9	3
Zn	36	18	30	34	32	22
Zr	78	24	35	74	60	21

- A From a profile 65 m from sulphide zone.  
B From a profile 77 m from sulphide zone.  
1 0-0.2 m, pisolitic cover.  
2 0.2-0.4 m, calcrete.  
3 0.4-0.6 m, calcrete and saprolite.  
Majors in wt%; traces in ppm; Au in ppb.

**TABLE 8**  
Chemical analyses of saprolite samples from sulphide zone  
(from drill holes J<sub>2</sub> and J<sub>4</sub>)

				Q	Q
SiO <sub>2</sub>	42.01	42.87	43.93	98.84	0
Fe <sub>2</sub> O <sub>3</sub>	15.07	14.41	15.35	1.05	0
Al <sub>2</sub> O <sub>3</sub>	16.57	15.06	14.45	0.21	0
TiO <sub>2</sub>	0.99	0.86	0.83	0.01	0
MgO	4.28	5.85	10.52	0.01	0
K <sub>2</sub> O	0.34	1.08	1.07	0.01	0
Na	0.82	0.80	0.45	0.01	0
CaO	0.74	2.43	1.90	0.01	0
MnO <sub>2</sub>	0.01	0.01	0.01	0.01	0
SO <sub>3</sub>	0.01	0.01	0.01	0.01	0
C	0.02	0.01	0.01	0.02	0
Cl	0.31	0.39	0.18	0.01	0
P <sub>2</sub> O <sub>5</sub>	0.01	0.01	0.10	0.01	0
Loss	18.00	16.00	11.00	1.00	0
Total	99.18	99.79	99.81	101.20	0
Au	3000	2000	0	0	4000
Ag	2	0.7	1	0.1	0
As	212	99	1	16	0
B	50	40	15	5	0
Ba	42	176	46	15	0
Be	0.2	0.2	0.2	0.2	0
Bi	0.5	0.5	0.5	0.5	0
Co	52	48	85	7	0
Cr	1900	1610	1510	22	0
Cu	520	570	75	18	0
Ga	30	25	25	0.01	0
Mo	0.3	0.03	0.03	2	0
Ni	550	410	690	28	0
Pb	64	1	47	56	0
Rb	14	46	24	0.5	0
Sc	55	42	44	0.5	0
Sn	5	4	5	0.1	0
Sr	17	37	8	0.5	0
W	91	96	132	15	0
Y	26	18	15	0.1	0
Zn	980	610	270	17	0
Zr	85	71	68	0.5	0

Q Quartz-vein

0 Not-determined

Majors in wt%; traces in ppm; Au in ppb.

conditions created by the weathering of sulphides (Blain and Andrews, 1977; Nickel and Daniels, 1985; Taylor, 1987). Insufficient samples from the smectite horizon were analysed to define the behaviour of the sulphide-related elements (e.g. Zn and Cu).

The kaolinite horizon derived from the sulphide zone (Table 9), and from the country-rock within 5 m of it (Table 6), is depleted in Fe, Ni, Zn, Cu and Co, although Ni and Zn have not been completely leached from the sulphide zone. These elements are hosted by goethite in the weathered country-rock, in the fractures associated with the quartz veins within the weathered sulphide zone and within 20 cm of these fractures (Table 9). Arsenic and, to a lesser extent, Pb and W have been partially mobilized and reprecipitated with the Fe, Ni, Zn, Cu and Co. Tungsten, the least mobile of these elements, has been redeposited within the limits of the sulphide zone. Lead and W have also been dispersed and minor enrichments are present throughout the weathered sulphide zone.

The leaching of Fe from the sulphide zone and adjacent country rock caused further concentration of the less mobile elements such as Al, Ti, Cr, Zr, Ga and Sc. Only Ti and Zr can actually be considered as purely residual, because small amounts of Al, Cr, Ga, Sc are present with the Fe, Zn, Cu, Ni, Co, As, Pb and W precipitated in fractures.

In the kaolinite horizon derived from the sulphide zone, most of the Au is in the quartz vein or immediately beside it. Less Au is present within 20 cm of the quartz vein and less again in the rest of the shear zone (Table 9). In the quartz vein, Au abundances vary independently of the intensity of fracturing and the enrichment in Fe, Ni, Zn, Cu, Co, As, Pb and W, suggesting this Au is mostly residual. Gold is correlated with As and Pb (Fig. 6) in the sulphide zone more than 20 cm from the quartz vein and in the country-rock (below the zone of pedoturbation). The Au-Pb correlation is closer where Fe is depleted, whereas the Au-As correlation is closer where Fe is enriched. This is probably because Au is associated with As and, especially Pb, in the fresh sulphides and, as the sulphides weathered, the three elements were mobilized and then redeposited together. Within 20 cm of the quartz vein, where Au is more abundant, it is not correlated with either As or Pb. The high Cl content, present as halite, suggests that this excess Au may be due to a partial remobilization of the residual free Au from the quartz vein by Cl-rich solutions, under the more recent arid conditions. The Au-As, and Au-Pb correlations in the sulphide zone and country-rock over 20 cm from the quartz vein seems to show that the Cl-rich solutions did not affect the Au originating from the sulphides and held in the goethite. It also suggests that Au originating from the quartz vein and remobilized by the Cl-rich solutions did not disperse any further than 20 cm, at least in the kaolinite horizon.

### 5.3 Microscope and microprobe data

#### 5.3.1 *Country rock*

The fresh country-rocks consist of amphibole and plagioclase, plus some scattered chlorite and ilmenite. Microprobe analysis of the amphibole, plagioclase and chlorite identified them as hornblende, andesine (and bytownite) and sheridanite respectively (Table 10 columns 1 to 4). Calculation from the bulk analysis shows that the plagioclase must be dominantly andesine and that the proportion of amphibole and plagioclase are respectively about 80% and 20%.

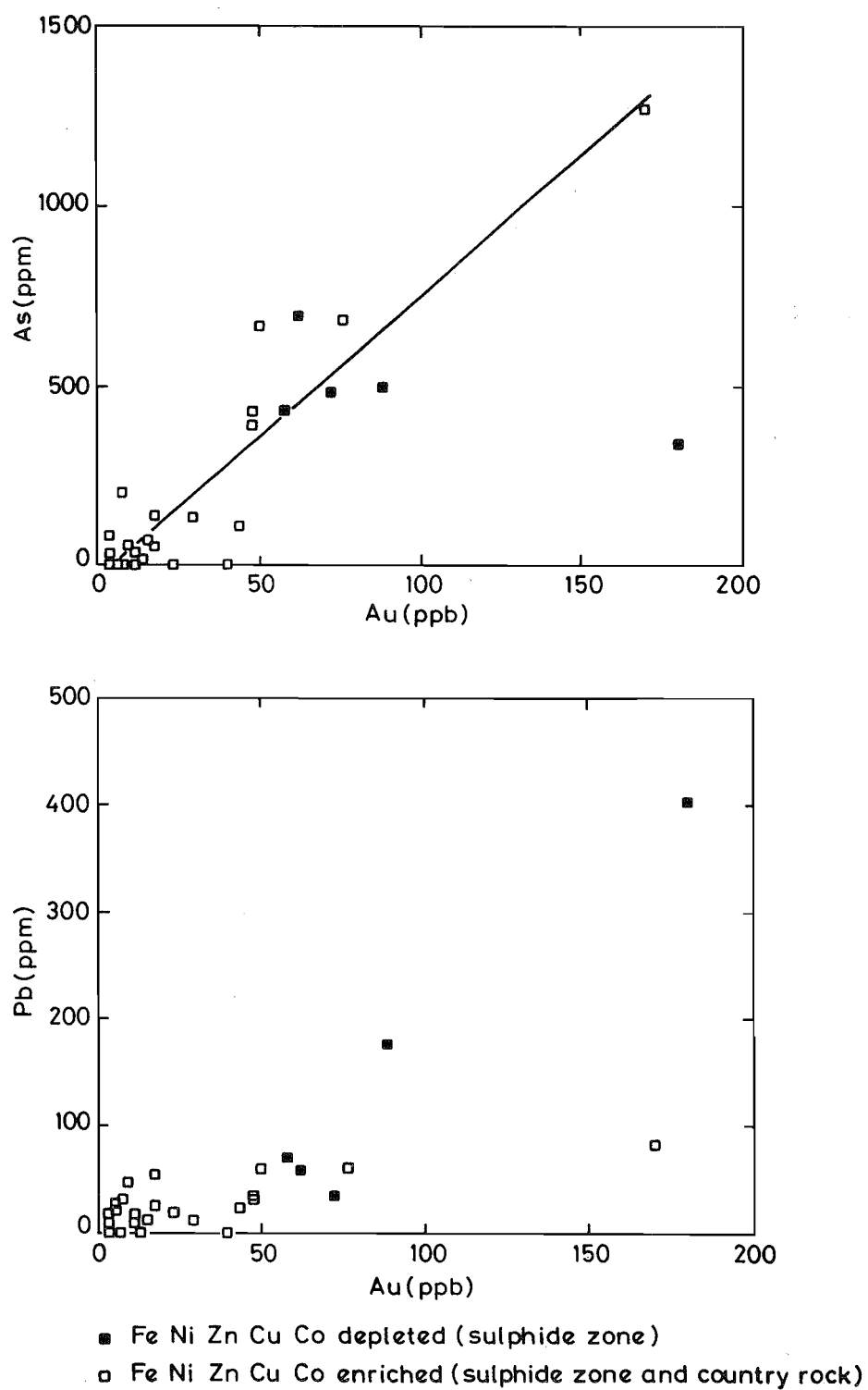
Samples from the smectite horizon, away from the sulphide zone, show the nature of the replacement of the amphibole, plagioclase and chlorite (Fig. 7) due to weathering.

**TABLE 9**  
Chemical analyses of samples from kaolinite horizon from sulphide zone.

	1	1	1	1	1	1	2	3	3	3	3	3	3	3	3	3	4	4	4	4	4	5	6	6	6
SiO <sub>2</sub>	0	0	39.29	67.06	90.40	97.91	17.32	35.27	41.08	36.88	31.05	45.44	37.85	35.47	43.90	31.57	41.55	47.40	46.32	45.23	47.77	17.84	38.21	37.05	42.09
Fe <sub>2</sub> O <sub>3</sub>	0	0	50.19	12.08	6.80	1.71	58.95	21.90	12.39	24.36	25.84	12.20	29.88	24.83	23.40	36.67	7.17	3.17	2.05	3.71	15.04	60.61	26.48	27.20	23.90
Al <sub>2</sub> O <sub>3</sub>	0	0	2.64	11.36	0.97	0.39	8.98	24.50	29.62	22.82	22.51	20.78	16.22	16.60	15.89	15.19	33.15	33.86	34.24	32.28	22.25	5.85	18.62	18.62	17.23
TiO <sub>2</sub>	0	0	0.05	0.01	0.07	0.01	0.82	1.42	1.54	1.36	1.48	2.11	1.47	1.72	1.51	0.94	1.71	1.65	1.97	2.22	1.24	0.35	1.14	0.92	1.12
MgO	0	0	0.15	0.01	0.01	0.01	0.30	0.37	0.25	0.33	0.57	0.87	0.44	0.82	0.59	0.63	0.21	0.11	0.31	0.35	0.46	0.41	0.65	0.73	0.64
K <sub>2</sub> O	0	0	0.01	0.05	0.01	0.01	0.17	0.20	0.26	0.15	0.12	0.13	0.19	0.45	0.50	0.35	0.46	0.35	0.42	0.61	0.82	0.22	0.49	0.47	0.62
Na	0	0	0.05	0.04	0.04	0.01	0.10	0.42	0.30	0.42	0.77	0.50	0.34	1.26	0.79	0.27	0.36	0.12	0.36	0.55	0.27	0.11	0.35	0.30	0.31
CaO	0	0	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.04
MnO <sub>2</sub>	0	0	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.13	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
SO <sub>3</sub>	0	0	0.13	0.01	0.01	0.01	0.13	0.18	0.10	0.14	0.32	0.13	0.11	0.48	0.31	0.01	0.16	0.01	0.18	0.23	0.01	0.01	0.01	0.01	0.01
C	0	0	0.04	0.01	0.01	0.02	0.04	0.05	0.01	0.01	0.04	0.01	0.04	0.10	0.03	0.06	0.01	0.03	0.03	0.02	0.06	0.07	0.07	0.08	0.04
Cl	0	0	0.13	0.01	0.04	0.02	0.09	0.77	0.45	0.58	1.54	0.56	0.33	2.33	1.44	0.22	0.64	0.08	0.67	1.01	0.28	0.02	0.45	0.09	0.26
P <sub>2</sub> O <sub>5</sub>	0	0	0.18	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Loss	0	0	8.62	8.74	2.07	0.86	12.78	14.64	14.55	13.09	15.05	16.50	12.36	16.31	12.09	13.98	15.00	13.00	14.76	14.83	12.74	13.22	13.93	15.60	13.59
Total	0	0	101.49	99.40	100.45	100.98	99.71	99.75	100.57	100.29	99.32	99.25	99.26	100.40	100.48	99.92	100.44	99.81	101.34	101.07	100.97	98.74	100.43	101.10	99.87
Au	3700-	90-	16000-	330-	24000-	8000-	22000-	460/	340/	140/	300/	550/	370/	440/	850/	12	62	58	180	88	72*	170*	76*	48*	50*
Ag	0	0	0.4	0.5	0.01	0.01	0.01	0.01	0.1	0.01	0.01	0.01	0.01	0.1	0.01	0.01	0.01	0.1	0.3	0.1	0.01	0.01	0.01	0.01	0.01
As	0	0	342	280	74	27	462	262	459	589	524	175	342	202	201	259	696	431	335	495	81	1270	684	429	667
B	0	0	40	70	15	10	60	100	100	100	150	250	200	150	100	100	50	50	60	60	20	100	150	150	150
Ba	0	0	1	12	1	1	49	58	216	16	29	21	50	53	72	109	80	33	38	64	6	80	48	30	60
Be	0	0	0.2	0.2	0.2	0.2	3	2	0.2	3	2	0.2	3	3	2	3	0.2	2	2	3	2	4	3	2	2
Bi	0	0	11	0.5	0.5	0.5	0.5	7	0.5	0.5	0.5	0.5	0.5	6	5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Co	0	0	16	17	0.5	0.5	35	70	14	17	36	59	38	20	22	30	15	9	10	17	16	35	25	20	21
Cr	0	0	840	1100	240	54	3570	3250	2360	1950	3630	3920	3330	2470	2700	2350	2720	3520	4040	2830	1870	1680	2150	1600	1530
Cu	0	0	750	232	63	15	420	330	240	242	350	180	360	270	290	260	130	71	84	207	260	520	370	290	300
Ga	0	0	2	2	2	0.1	20	50	30	40	30	50	40	40	40	25	60	50	50	60	38	20	30	25	30
Mo	0	0	0.8	2	2	2	0.6	0.6	0.4	0.6	0.6	0.6	0.5	0.4	1	0.1	0.8	0.5	0.5	1	1	1	0.6	0.2	1
Ni	0	0	149	155	40	2	310	450	355	450	570	510	330	228	209	320	194	71	216	165	225	40	425	280	460
Pb	0	0	439	92	24	1	153	33	33	47	18	46	68	83	54	41	60	71	404	177	37	4	63	36	61
Rb	0	0	7	5	0.5	0.5	14	15	18	10	11	9	15	28	34	27	21	26	32	53	1	31	37	40	40
Sc	0	0	20	34	7	0.5	45	67	55	48	68	52	51	43	42	43	76	69	75	77	55	3	54	28	45
Sn	0	0	2	5	0.1	0.1	5	3	5	5	4	10	8	7	6	4	8	7	8	8	5	5	6	6	6
Sr	0	0	0.5	6	0.5	0.5	27	15	16	15	16	23	23	34	37	23	10	0.5	11	9	34	2	28	24	29
W	0	0	158	93	14	12	20	21	52	46	21	96	77	63	63	18	10	316	61	20	47	5	74	69	83
Y	0	0	4	3	0.1	0.1	12	7	4	4	5	5	5	4	3	5	3	4	4	5	7	1	10	6	10
Zn	0	0	350	56	30	10	430	136	193	110	134	141	100	110	113	214	83	27	88	246	248	51	220	138	300
Zr	0	0	0.5	0.5	0.5	0.5	101	310	134	121	123	167	192	148	129	83	151	162	175	205	113	5	104	121	106

- 1 Fractured quartz-vein
- 2 Immediately next to 1
- 3 Within 20 cm from 1
- 4 > 20 cm from 1 and 5, depleted in Fe, Ni, Zn, Cu and Co
- 5 Fracture in quartz-vein (> 20 cm from it)
- 6 < 20 cm from 5.

Suggested origin for the gold: - residual primary free gold, bold residual gold from weathered sulphides, \* gold mobilized by thiosulphate ion from weathering sulphides during lateritisation, / gold mobilized by Cl  
Major in wt%; traces in ppm; Au in ppb.



**Figure 6.** Au-As and Au-Pb correlations in the kaolinite horizon at more than 20 cm from the quartz vein and below pedoturbation level.



**TABLE 10**  
Microprobe analyses of silicates from  
fresh and weathered country-rock

	1	2	3	4	5	6	7	8	9	10
Na <sub>2</sub> O	0.76	8.11	2.99	0.11	0.46	0.38	0.90	0.26	0.10	0.18
K <sub>2</sub> O	0.09	0.05	0.01	0.01	0.18	0.10	0.07	0.09	0.07	0.25
CaO	11.78	6.50	15.54	0.51	0.32	0.10	0.10	0.16	0.02	0.45
TiO <sub>2</sub>	0.31	0.01	0.01	0.09	0.15	0.32	0.22	0.03	0.20	0.56
FeO	12.46	0.11	0.14	15.88	-	-	-	-	-	-
Fe <sub>2</sub> O <sub>3</sub>	-	-	-	-	8.76	5.48	2.63	2.08	1.62	1.78
MnO	0.20	-	-	0.11	0.04	0.02	-	-	0.01	-
MgO	14.30	0.01	-	19.01	0.94	0.45	0.28	0.34	0.11	0.86
Al <sub>2</sub> O <sub>3</sub>	8.80	25.94	33.61	21.33	21.53	14.97	7.79	4.83	27.00	26.96
SiO <sub>2</sub>	49.49	63.39	51.75	26.33	49.16	60.97	70.37	80.22	56.58	36.48
H <sub>2</sub> O	1.82	-	-	16.13	18.46	17.19	17.63	11.98	14.29	12.41
Total	100.00	104.12	104.14	100.00	100.00	100.00	100.00	100.00	100.00	100.00

- 1            Amphibole (hornblende), fresh country-rock.
- 2            Plagioclase feldspar (andesine), fresh country-rock.
- 3            Plagioclase feldspar (bytownite), fresh country-rock.
- 4            Chlorite (sheridanite), fresh country-rock.
- 5, 6, 7, 8   Smectite (beidellite) mixed with varying amounts of silica, neoformed after primary silicates, saprolite.
- 9            Kaolinite mixed with silica (average of 4 analyses), matrix, upper kaolinite horizon.
- 10           Kaolinite mixed with silica, associated with carbonate, calcrete.
- H<sub>2</sub>O        Obtained by difference.

### **FIGURES 7, 8 AND 9.**

- Figure 7.** Microprobe photograph showing the primary silicates being replaced by smectite and silica in the smectite horizon from the country-rock. 1 amphibole, 2 plagioclase, 3 chlorite, 4 smectite + silica, 5 mixture amphibole + neoformed smectite-silica.
- Figure 8.** Microprobe photograph showing the smectites and included micronic goethite-rutile grains in the smectite horizon from the sulphide zone. 1 smectites, 2 goethite-rutile grains.
- Figure 9.** Photographs of Au grains from the quartz vein in the upper kaolinite horizon (from same sample). Microscopy in reflected light, except for microprobe. 1. primary Au grains, 2. fragments from primary Au grains, 3. ribbons of secondary Au, 4. fragments from these ribbons, 5. cryptocrystalline secondary Au, 6. quartz, 7. goethite, 8. highly porous goethite, 1 unweathered primary Au grain. 1' Ag-free weathered primary Au grain.



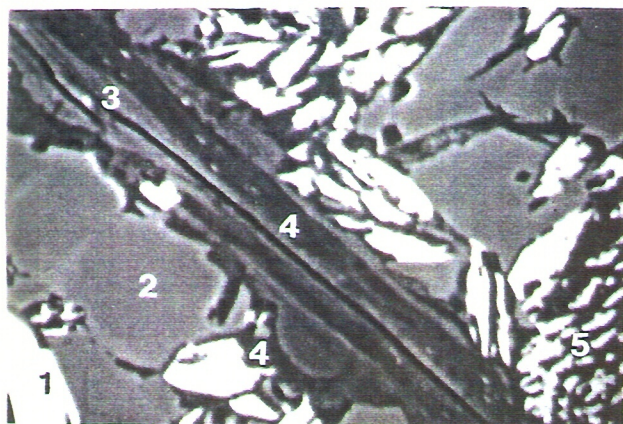


Fig. 7

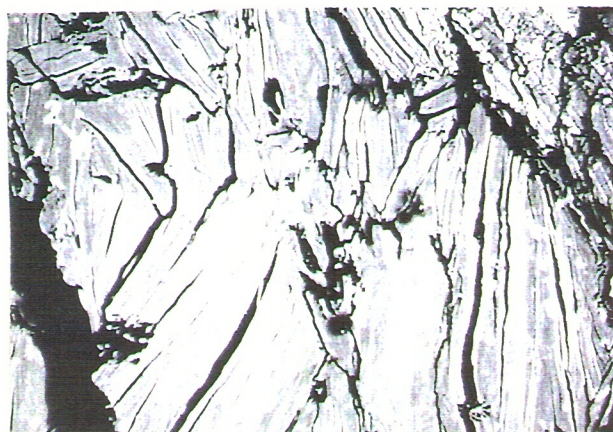


Fig. 8

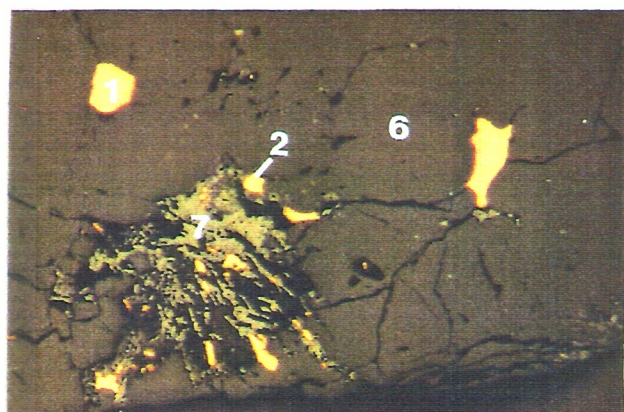


Fig. 9a

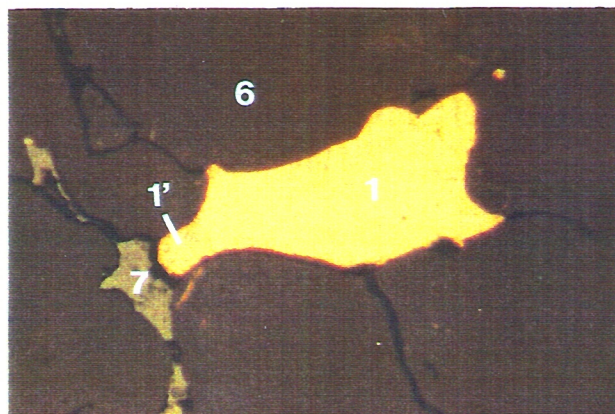


Fig. 9b

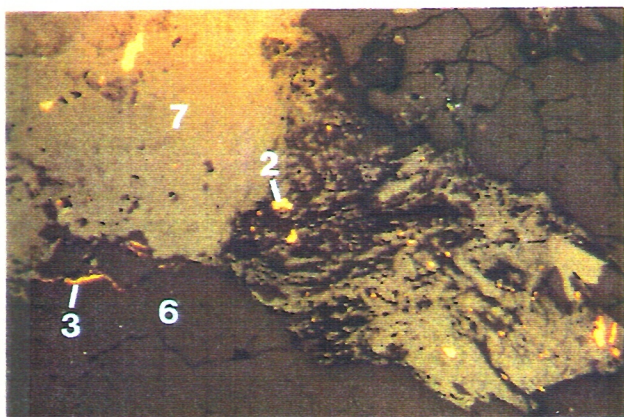


Fig. 9c

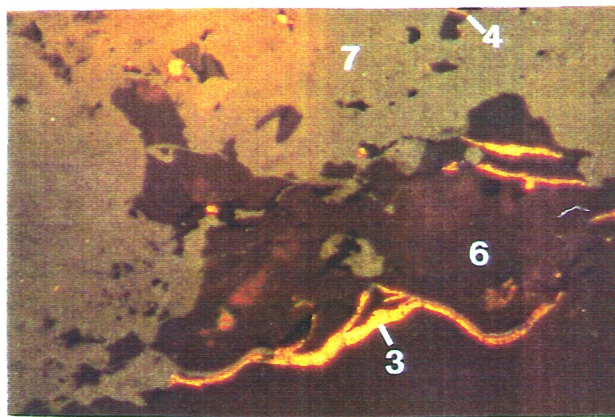


Fig. 9d

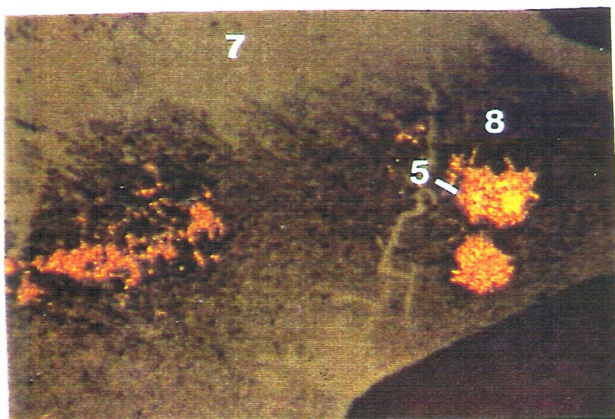


Fig. 9e

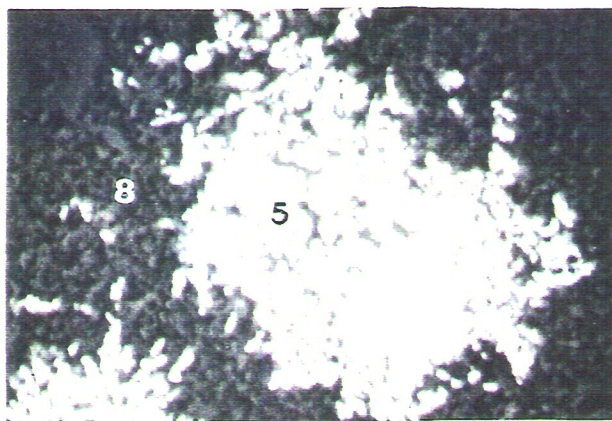


Fig. 9f



Replacement of the amphibole starts along the cleavages, giving a fine-grained, intimate mixture of elongated amphibole, silica and smectite (beidellite, Table 10, columns 6 to 8). The silica comes from the  $\text{SiO}_2$  released by the transformation of amphibole ( $\text{SiO}_2/\text{Al}_2\text{O}_3 = 5$ ) into beidellite ( $\text{SiO}_2/\text{Al}_2\text{O}_3 = 2$ ). As shown previously, a small part of this  $\text{SiO}_2$  is also leached. The ilmenite grains are unchanged.

Samples from the upper kaolinite horizon, from which all primary silicates and smectites have disappeared, have a uniform matrix of kaolinite and opaline silica (Table 10, column 9). Scattered in this matrix are primary oxides such as ilmenite, minute rutile and some Cr-spinel. One Fe-Ni-Zn-Cu-Cr-Co-Y- and Au-enriched sample showed some concretionary goethite occurring along fissures in which remnants of a quartz stringer could be seen, implying that the quartz lodes and stringers provide channelways for the circulation of solutions. Microprobe analysis of the goethite showed minor or trace amounts of Ni, Zn, Cr and Cu (Table 11, column 1); Co, Y and Au are below the detection limits.

Weathered rock from the upper pedoturbated portion of the kaolinite horizon, within 5 m of the weathered sulphide zone, in which enrichments of W, Au, As and Pb occur, is traversed by root channels filled with weathered sulphides and pisoliths containing weathered sulphides. These infillings are detrital, having been washed down from the surface through the root channels. Analyses of the weathered sulphides and pisoliths are given in Table 11 (columns 2 to 4).

The calcrete overlying the kaolinite horizon, near the weathered sulphide zone, consists of fragmented kaolinitic material cemented by dolomite and, in places, a mixture of kaolinite and opaline silica (Table 10 column 10). Gold is very finely dispersed in the carbonate and was not found.

### 5.3.2 *Sulphide zone*

Microscope and microprobe examination of material from the fresh sulphide zone showed it consists mainly of amphibole (hornblende with actinolite) and chlorite (sheridanite to clinocllore), with some mica (Table 12, columns 1 to 3), pyrite, chalcopyrite and sphalerite. The chalcopyrite grains show myrmekitic or lamellar intergrowth of rutile and sphene; the sphalerite was observed as micron-sized grains in the silicates. Quartz from the fresh sulphide zone contains minor pyrite, chalcopyrite and galena; microprobe examination showed the pyrite contains inclusions of Au but no As. Although no As- and W-bearing minerals were found, it must be assumed that arsenopyrite and wolframite or scheelite are present in the fresh sulphide zone.

The smectite horizon contains smectites (montmorillonite-nontronite and beidellite) and kaolinite (Fig. 8, Table 12, columns 4 to 6). In contrast with the country rock, there is no silica mixed with the smectites. More Si is leached from the sulphide zone than from the country-rock and some silica is required for the transformation of chlorite into smectite. The weathered sulphide grains appear corroded and consist of As-Cr-Cu-Zn-W-Ni-bearing goethite, in places finely mixed with rutile (Table 13, columns 1 and 2). Micron-sized grains of similar composition occur along the cleavages of the smectites (Fig. 8, Table 13, column 3), which are derived from the weathering of minute sulphide grains present in the fresh silicates. Chromium, Cu, Zn and Ni occur not only in the weathered sulphides but in the silicates as well, particularly in the smectites (Table 14).

**TABLE 11**

Microprobe analyses of oxides from weathered country-rock

	1	2	3	4
Fe <sub>2</sub> O <sub>3</sub>	71.21	66.15	23.39	86.37
TiO <sub>2</sub>	0.11	0.23	63.55	0.93
Al <sub>2</sub> O <sub>3</sub>	3.77	8.65	0.57	1.83
SiO <sub>2</sub>	5.31	0.56	2.03	0.95
Cr <sub>2</sub> O <sub>3</sub>	0.38	0.16	0.21	0.53
Co <sub>2</sub> O <sub>3</sub>	-	-	-	-
CuO	0.07	0.16	0.02	-
NiO	0.22	-	0.01	-
PbO	0.0000*	-	0.17	-
W <sub>2</sub> O <sub>3</sub>	0.0000*	-	0.04	-
ZnO	0.0756*	0.01	0.09	0.02
As <sub>2</sub> O <sub>3</sub>	0.05	2.61	0.29	0.35
H <sub>2</sub> O	18.59	21.37	9.38	8.96
Total	100.00	100.00	100.00	100.00

- 1 Goethite as colloform concretions filling cracks, upper kaolinite horizon.
- 2 Goethite neoformed after sulphides, detrital in root channel, pedoturbated top part of kaolinite horizon.
- 3 Goethite-rutile mixture neoformed after sulphides (average of 2 analyses), detrital in root channel, pedoturbated top part of kaolinite horizon.
- 4 Goethite or hematite, pisolith containing weathered sulphides, detrital in root channel, pedoturbated top part of kaolinite horizon.
- \* Special procedure for trace-element analysis.
- H<sub>2</sub>O Obtained by difference.

**TABLE 12**

Microprobe analyses of silicates from fresh and weathered sulphide zone.

	1	2	3	4	5	6	7	8
Na <sub>2</sub> O	0.85	0.16	0.04	0.43	0.14	0.06	0.06	0.13
K <sub>2</sub> O	0.19	0.02	-	0.30	0.07	0.24	0.08	4.78
CaO	12.43	12.82	0.01	1.27	0.30	0.06	0.02	0.16
TiO <sub>2</sub>	0.40	0.07	0.03	0.34	0.08	0.01	-	-
FeO	9.42	7.09	13.22	-	-	-	-	0.53
Fe <sub>2</sub> O <sub>3</sub>	-	-	-	11.82	8.73	1.78	0.20	-
MnO	0.14	0.18	0.16	0.05	0.02	0.01	0.02	-
MgO	14.56	19.10	21.03	7.75	4.30	0.12	0.06	0.21
Al <sub>2</sub> O <sub>3</sub>	9.70	2.14	20.55	18.13	24.66	34.37	35.88	37.92
SiO <sub>2</sub>	48.42	56.06	25.96	44.27	42.36	43.66	44.65	47.86
H <sub>2</sub> O	3.87	2.28	18.89	15.64	19.28	19.71	19.03	8.29
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

- 1 Amphibole (hornblende), fresh sulphide zone.  
2 Amphibole (actinolite), fresh sulphide zone.  
3 Chlorite (sheridanite-clinocllore), fresh sulphide zone.  
4 Smectite (montmorillonite-nontronite) (average of 3 grains), saprolite.  
5 Smectite (beidellite), saprolite.  
6 Kaolinite, saprolite.  
7 Kaolinite, matrix, upper kaolinite horizon where Fe, Ni, Zn, Cu and Co depleted.  
8 Hydromuscovite, upper kaolinite horizon where Fe, Ni, Zn, Cu and Co depleted.  
H<sub>2</sub>O Obtained by difference.

**TABLE 13**  
Microprobe analyses of oxides from weathered sulphide zone.

	1	2	3	4	5	6	7	8	9	10
Fe <sub>2</sub> O <sub>3</sub>	67.18	39.42	38.87	79.29	14.64	0.43	31.83#	80.43	71.45	74.62
TiO <sub>2</sub>	— +	37.63	17.12	0.7	72.16	97.93	0.25	0.01	0.02	0.16
Al <sub>2</sub> O <sub>3</sub>	4.59	3.21	7.91-	3.65	1	0.09	19.17	0.96	2.34	2.57
SiO <sub>2</sub>	3.03	2.52	14.82-	0.36	0.65	0.06	0.05	1.94	3.49	4.36
MgO	-	-	-	-	-	-	3.75	-	-	-
Cr <sub>2</sub> O <sub>3</sub>	0.45	0.93	0.96	0.67	0.55	0.31	42.31	0.23	0.32	0.33
Co <sub>2</sub> O <sub>3</sub>	-	-	-	-	0.08	-	-	-	-	-
CuO	0.43	0.24	0.22	0.29	0.05	0.02	-	0.18	0.04	0.04
NiO	0.08	0.03	0.07	0.06	0.01	0.01	-	0.04	0.09	0.06
PbO	-	0.03	0.02	0.27	0.3	-	0.1	0.0827*	0.04	0.01
W <sub>2</sub> O <sub>3</sub>	-	0.18	0.16	-	0.08	-	0.06	0.0485*	-	-
ZnO	0.29	0.22	0.19	0.02	0.99	-	2.47	0.0528*	0.03	0.04
As <sub>2</sub> O <sub>3</sub>	2.44	0.81	0.81	2.3	0.58	0.16	-	0.22	0.2	0.13
H <sub>2</sub> O	20.75	14.19	18.82	12.35	6.37	-	-	16.97	18.59	17.32
Total	100.00	100.00	100.00	100.00	100.00	99.02	100.00	100.00	100.00	100.00

- 1 Goethite, neoformed after sulphides (average of 2 grains), saprolite.
  - 2 Goethite-rutile mixture, neoformed after sulphides (average of 3 analyses from 1 grain), saprolite.
  - 3 Goethite-rutile mixture, neoformed after minute-sulphides, and surrounding smectite (—) (average on 2 grains), saprolite.
  - 4 Goethite, neoformed after sulphides, upper kaolinite horizon.
  - 5 Goethite-rutile mixture neoformed after sulphides (average of 3 analyses from 1 grain), upper kaolinite horizon.
  - 6 Rutile from above mixture 5.
  - 7 Spinel (chromite), residual, upper kaolinite horizon.
  - 8 Goethite as collomorphous concretions, filling cracks in a quartz-vein (average of 6 analyses), upper kaolinite horizon.
  - 9 Goethite filling cracks in a quartz-vein (average of 4 analyses), upper kaolinite horizon.
  - 10 Goethite filling cracks and as pseudomorphs after primary silicates, next to a quartz-vein (average of analyses from both), upper kaolinite horizon.
- \* Special procedure for trace-element analysis.
- H<sub>2</sub>O Obtained by difference.
- MgO Not determined; obtained by difference for analysis 7.
- # All iron is given as Fe<sub>2</sub>O<sub>3</sub>.
- + Determined qualitatively.

**TABLE 14**  
Microprobe analyses of minor components in silicates from saprolite  
in sulphide zone (wt%)

	1	2	3	4
Cr <sub>2</sub> O <sub>3</sub>	0.40	0.49	0.23	0.21
Co <sub>2</sub> O <sub>3</sub>	0.01	-	0.03	
CuO	0.13	0.17	0.10	0.07
NiO	0.04	0.05	0.06	0.04
PbO	-	0.03	-	0.01
W <sub>2</sub> O <sub>3</sub>	-	-	-	-
ZnO	0.20	0.30	0.13	0.05
As <sub>2</sub> O <sub>3</sub>	0.04	0.02	-	-

- 1, 2    Smectite (montmorillonite-nontronite).  
3       Smectite (beidellite).  
4       Kaolinite.  
       Same analytical procedure as for major components.



Calculation shows that the Cr, Cu, Zn and Ni from the bulk analysis are mainly within the smectites, whereas As (and possibly W) are within the weathered sulphides.

The upper kaolinite horizon, which is leached of Fe, Ni, Zn, Cu and Co, consist of a very pure kaolinitic matrix containing weathered sulphides, residual micas (hydromuscovite) and some residual quartz and Cr- spinels (Table 12, columns 7 and 8 and Table 13, columns 4 to 7). Microprobe analyses of the sulphide pseudomorphs demonstrated the presence of As, Zn, Pb, Cr, Cu and W. Calculations indicate that all of the As, Pb and W, most of the Zn and at least part of the remaining Cu are in the sulphide pseudomorphs, whereas most of the Cr, Ni and possibly part of the Cu are carried by the kaolinite. Some Cr and small amounts of Zn are in the spinel.

The quartz veins of the upper kaolinite horizon and material within 20 cm of these veins in which Fe, Ni, Zn, Cu and Co have been deposited, showed some goethite filling the cracks and occurring as colloform concretions and pseudomorphs after primary silicates. The goethite replaces the amphibole and emphasizes the cleavages of the chlorite (now converted to kaolinite) and mica. This implies that deposition of goethite occurred as the amphibole was weathering in the lower smectite horizon. Microprobe analyses confirmed the presence not only of Al, Cr, Zn, Cu and Ni, but also As, Pb and W in the goethite (Table 13, columns 8 to 10).

The small amounts of finely dispersed Au that are present in both weathered sulphides and goethite, deposited along the fractures (Section 5.2.2), are below the detection limits of the electron microprobe. However, as previously discussed, most of the Au in this upper kaolinite horizon is within the quartz vein, or proximal to it, and is independent of the Fe, Ni, Zn, Cu, Co, As, Pb, W enrichments. This Au was observed as occurring in a variety of forms:

- 1) as primary grains in the quartz (Figs. 9a and b);
- 2) as fragments of leached primary grains, 1 to 200  $\mu\text{m}$  in size, included in goethite filling the cavities and fractures in and along the quartz vein (Figs. 9a and c);
- 3) as rare ribbons of pure Au in thin cracks in the quartz and as fragments in the goethite (Figs. 9c and d). This Au is clearly secondary as it is both Ag-free (the primary grains contain 8% Ag), and different in appearance from the primary grains. This secondary Au was deposited prior to the goethite. Two explanations are proposed:
  - a) deposition was contemporaneous with the leaching and fragmentation of nearby Au grains and results from a partial mobilization of Au during this process.
  - b) it is derived by mobilization as chloride complexes in saline groundwaters that circulated prior to lateritisation, or early in this period during a temporarily drier climate.
- 4) as secondary Au filling very thin cracks in the goethite and as secondary, cryptocrystalline Au intimately mixed with a highly porous goethite (Figs. 9e and f). Both these forms were precipitated after lateritisation, under more arid conditions. Microprobe analysis of the highly porous goethite containing cryptocrystalline Au, showed minor amounts of Cl, whereas none was present in

the surrounding non-porous goethite. It is possible that all the pores were occupied by NaCl most of which dissolved during the polishing. This secondary Au would thus be due to Cl-rich solutions that circulated after lateritisation.

The secondary Au represents only a small proportion of the total Au present in the quartz vein. Primary Au grains and fragments of leached primary Au grains are the most common forms.

Under the optical microscope, all the forms of secondary Au, the fragments of leached primary Au grains occurring in the goethite, and those parts of the primary Au grains that are weathered, are brighter yellow than the primary grains or the parts of the primary grains that are still protected by quartz. Within one primary grain, the colour change occurs without any other visible change (Fig. 9b). The unweathered Au contains 8% Ag, whereas both the weathered primary Au and the secondary Au are of high fineness.

## **6.0 CONCLUSIONS**

### **6.1 Distribution of gold**

Several processes have affected the primary Au mineralization of the Glasson deposit. A reconstitution of these events is presented below.

As the disseminated sulphides of the shear zone weathered, during the Cretaceous-mid Miocene humid period, the Au associated with them was partially mobilized (possibly by thiosulphate complexes), its mobility being close to that of As. The Au was redeposited with goethite together with As, Pb, W, Ni, Zn, Cu, and Co. This resulted in a lateral dispersion of Au from the shear zone into the country-rock for 20 m. As a result, the overall Au content of the shear-zone (excluding the quartz veins) was lowered from about 0.5 ppm to less than 0.1 ppm.

Although the Au originating from the sulphides was mobilized and dispersed, the free Au present in the quartz vein remained, partially protected by the quartz. Silver was leached from the Au located along fractures but the Au remained, fragmented, until cemented by the goethite deposited in these fractures. Rare ribbons of secondary Au can be seen along cracks in the quartz, also partially cemented by the goethite deposited in the fractures. They may result from a partial mobilization of the Au during the leaching and fragmentation of primary grains and immediate dedeposition in nearby cracks. They could also result from the mobilization of some of the Au by chloride-rich solutions that would have circulated prior to the Cretaceous-mid Miocene lateritisation period or early in this period, during a temporary drier climate.

Close to the surface, however, Au was mobilized and dispersed at least 100 m from the quartz vein, probably by complexing with humic acids from the soil. This is likely to have happened during the Cretaceous-mid Miocene humid period. Gold contents remain higher above the mineralized quartz vein system. This Au was later fixed within carbonates that were precipitated close to the surface during the post-lateritisation arid climate. As a result, the calcretes present at the top of the profiles are enriched in Au, more so than the overlying pisolitic cover.

The chloride-rich solutions that circulated during the drier, post-lateritic climate, mobilized some of the primary Au still present in the quartz vein. This Au was redeposited as pure Au in small cavities or cracks within the quartz vein or within 20 cm of it. This process resulted in a very slight dispersion of Au around the quartz vein. There may also have been dispersion at the top of

the smectite horizon where some Au may have spread as far as 100 m due to a former water-table located at this level. Secondary Au, precipitated earlier and held locked in the goethite or in the carbonates, appears to have remained unaffected by these chloride-rich solutions that circulated after the cessation of the lateritisation processes. Finally, Au contained in the pisolitic cover was mechanically dispersed for at least 100 m from the quartz vein system.

## **6.2 Distribution of the associated elements**

When the sulphides weathered during the Cretaceous-mid Miocene humid period, Cu, Zn, Pb, W, As and Au were partially leached, together with most of the Fe, Zn, Cu, Ni, Co from the surrounding shear zone and adjacent country-rock. This was due to the acid conditions created by the weathering of sulphides. All of these elements coprecipitated with goethite in the fractures within both the sulphide zone and the country-rock. This process resulted in a dispersion within the limits of the weathered sulphide zone for W, of 10-20 m for As, Pb (and Au), and 100 m for Fe, Zn, Cu, Ni and Co.

Close to the surface, a slight dispersion of Pb, As and W is apparent due to the mechanical action of roots. Finally, As, Pb and Cr in the pisoliths have been dispersed for up to 100 m.

## **6.3 Suitable indicators for Au-mineralization**

In an environment such as at the Glasson deposit, the best surface indicators of Au mineralization are Au and As, which are strongly enriched in the primary mineralization and moderately dispersed in the weathered zone. Arsenic has a more homogeneous distribution within and around the weathered sulphide zone than Au which occurs only erratically. Where calcrete is present however, only Au is recommended as an indicator of mineralization. Lead and W, are also good pathfinder elements, although less strongly enriched than Au and As in the fresh mineralization and dispersed less than As in the weathered zone. Chromium is enriched in the fresh, medium-grained metabasalt compared to the fine-grained metabasalt and even more enriched in the fresh shear zone. It is substantially retained in the weathered profile and seems to be a good indicator of the shear zones and of the contact between the two metabasalts (which appears to control the mineralization).

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