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GEOCHEMISTRY OF WEATHERED ROCKS AT THE TELFER GOLD DEPOSIT, PATERSON PROVINCE, WESTERN AUSTRALIA

Volume I

J.R. Wilmhurst

CRC LEME OPEN FILE REPORT 70

February 1999

(CSIRO Division of Exploration Geoscience Report 187R, 1991.
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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 70) is a Second impression (second printing) of CSIRO, Division of Exploration Geoscience Restricted Report 187R, first issued in 1991, 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 in association with Module 2 of this project (AMIRA Project 241) - "Gold and Associated Elements in the Regolith - Dispersion Processes and Implications for Exploration".

The objects of this Module are, *inter alia*, to obtain a better understanding of the nature and genesis of supergene gold deposits and to determine characteristics useful in exploration for supergene and primary deposits, including those of commodities other than gold.

The subject of this report, the Telfer gold Deposit, differs somewhat from others in this Project in that it is not situated in the Yilgarn Block. However, although Telfer is one of Australia's most important gold deposits, there have been few descriptions of its surface expression. Because, fortunately, a suite of samples of outcropping and near-surface gossans was collected by John Wilmshurst in 1978, it was decided to take the opportunity to document their geochemistry for this Project, since the resultant information would be relevant to investigations at other locations.

C.R.M Butt.

Project Leader.

December 1990.

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[Available as data disk, on request]



PLATE 1. EAST LIMB MVR CREEK OUTCROP



PLATE 2. WEST LIMB MVR OUTCROP

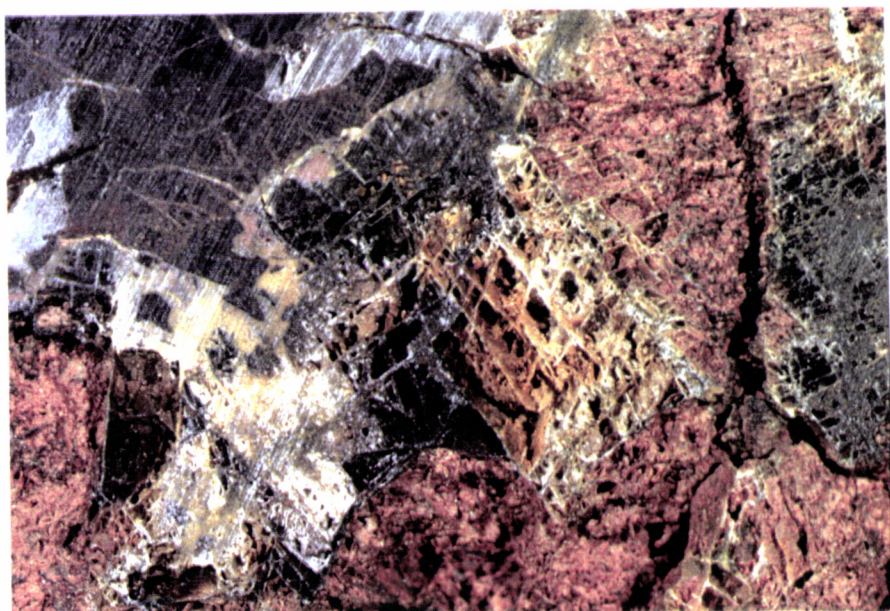


PLATE 3. 67061 CARBONATE BOXWORK

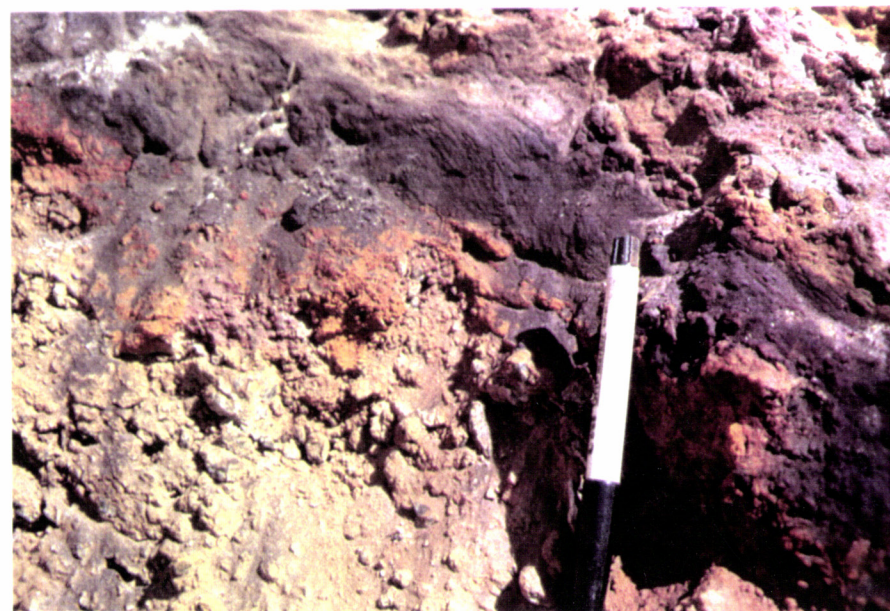


PLATE 4. MVR EXPOSURE 11940N RL 450

SUMMARY

A study has been made of a suite of surface rocks and sub-surface profile samples from the Telfer Gold Deposit, Paterson Province, W.A.

The surface rocks are weathered material, generally gossanous, from the East and West limbs of the Middle Vale Reef (MVR) and from the West Dome, together with three from the Fallows Field prospect; color illustrations are available for definition and reference. Profile samples are from the East and West limbs of the MVR, and from the overlying E-1 Reef.

Chemical analysis was performed by *icp-oes*, *icp-ms*, *inaa* and *XRF* methods, with data being obtained for the following elements:

Ag, Al, As, Au, Ba, Bi, Br, Ca, Cd, Ce, Co, Cr, Cs, Cu, Eu, Fe, Hf, Ir, K, La, Lu, Mg, Mn, Mo, Na, Ni, P, Pb, Rb, S, Sb, Sc, Se, Si, Sm, Sr, Ta, Ti, Th, Tl, U, V, W, Y, Yb, Zn, Zr.

In general, the subordinate elements can be divided into those with an affinity for the iron-oxides, residual phases (primary and secondary), secondary oxidate minerals and secondary silicates.

While the affinity of the several elements for the iron-oxides is a function of pH during the formation of the oxides, and hence the absolute concentrations may vary in a carbonate bearing system, *cobalt*, *copper*, *nickel*, *zinc*, *arsenic* and *molybdenum* vary with iron as expected. *Tungsten*, *phosphorus* and *sulfur* also associate with iron-oxides but each is bimodal in its associations as are *bismuth* and *lead*. *Uranium*, also, has an apparent affinity for the iron-rich rocks. It is notable that zinc is present in only very low concentration.

Residual phosphate minerals, monazite and xenotime, probably account for a high proportion of the *lanthanide* and *phosphorus* content; the *titanium* - *thorium* association, as found in this study, might be accounted for by 'residual' anatase, and *zirconium* by zircon. The high degree of correlation between thorium and titanium was unexpected, but is not unique. In the surface rocks, and in the upper part of the profile *gold* is resistate.

Secondary oxidate minerals are rare in the surface rocks and hence are of minor importance except in that *silver*, *antimony*, *bismuth* and *lead* are, in varying degree, hosted by such minerals which are subject to leaching, thus accounting for variation in concentration of these elements. In spite of the moderately high content of copper, and of arsenic, secondary minerals are little in evidence in hand specimen or at the macro-scale.

Although thorium is not so evident in the high-iron gossans, the concentrations of both thorium and uranium are exceptionally high in the surface and profile rocks and

while this may be a function of the weathering history of the total sedimentary sequence, it warrants further consideration.

The clay mineral, illite, might be expected to host boron but there is no evidence for associations with other clays, although there is evident distinction between potassic and magnesian zones. The latter implies a higher local pH and buffer capacity.

The gossans are very largely directly derived from the sulfidic precursor with general indication of a sulfide content in the form of boxworks or pseudomorphs; some, however, are evidently deposited from solution more or less remotely from the site of oxidation, and the Fallows Field material shows indication of ferruginisation well in excess of the initial sulfide content. Pyrite of larger scale was common in the Telfer rocks, as evidenced by pseudomorphs of both cubic and pyritohedral forms, and a number of the West Limb gossans are derived from rock carrying well crystallised carbonate, probably at the centimetre scale. Many of the West Limb gossans carry visible gold, but it is not so visually evident in the East Limb material despite a high analytical content.

The profile samples, in their intersections of the MVR, show many of the associations noted for the surface rocks, but since there is a lower proportion of iron, and a higher clay content, the absolute concentrations of the several iron-associated elements is usually much lower; however, the association between titanium and thorium is more clearly evident.

The peak concentration of the lanthanides is found at the upper contact of the MVR, in association with phosphorus; this is therefore possibly a primary feature. The data also suggest that there has been mobilisation of the lanthanides since there is some separation of the light and heavy members, although this could well be explained by the presence of a second lanthanide phase with a much higher proportion of the heavy elements.

If the epithermal model of Goellnicht et al. (1989) is correct, the data as given here might be used with little modification; however, it is likely that there would be lateral and vertical haloes of the more mobile elements around the mineralisation channelways, and hence variation in relative abundances. The present study suggests that the elements can be prioritised for likely effectiveness in further exploration in the Province, thus:

High - Au, As, Cu, Co, W, Bi, Sb, ?Mo, ?Ag, Zn

Probable - Lanthanides

Possible - Th, Ti, U, Zr

Informative - Fe, Si, Al, Ca, Mg, S, Mn, P

[both Sn and B have a high potential priority, but further data is needed.]

However, if gold itself was not introduced largely by epithermal activity in association with the above elements, and the mineralisation has a more complex and perhaps multi-episodic origin, the relationship of this suite of elements to gold, as seen in the Main Dome data, might not hold on a more regional scale. (The relative intensity of the several phases of mineralisation might vary from one locality to another.) It is important to note, however, that the above suite of elements would not necessarily be 'absent' in the case of a non-epithermal genesis since their occurrence is not restricted to epithermal style mineralisation. Nonetheless, it would seem prudent to regard each member of the above suite as very significant in reinforcement or confirmation, but not as an essential factor in a multielement strategy.

1. INTRODUCTION.

The Telfer Gold Deposit is located in the Paterson Province of Western Australia, at latitude 21°44' S, longitude 122°12' E on the margin of the Great Sandy Desert, (Chin and Hickman, 1977). The mineralisation is within the Telfer Formation of the Yeneena Group, the latter a succession of Proterozoic argillaceous siltstones, sandstones and dolomitic rocks.

The climate is arid with average annual rainfall some 250mm, but unreliable; most precipitation occurs between November and March and is associated with cyclonic activity. The potential evaporation, however, is approximately 2700mm per annum. The average daily maximum temperature approximates 40° C in summer and 25° C in winter (Chin and Hickman, 1977).

Vegetation is sparse and consists mostly of spinifex and grasses with widely scattered shrubs and mulga. The elevation is some 300m above sea-level and relief is low, with Main Dome at 330m and West Dome some 20m higher. Although there is no significant sand cover over the study area (of the Domes), sand cover is general over the surrounding lower-lying countryside, dunes are extensive. The effects of weathering extend as deeply as 290m over the East Limb of the Deposit and deeper still down faults.

The mineralisation is essentially stratabound, although more recent work appears to show that a limited but significant proportion of the gold is carried within vein systems in the footwall to the Middle Vale Reef (MVR). Goellnicht et al. (1989) suggest that the mineralisation is of an epigenetic (replacement) origin, although earlier work by Turner (1982) had emphasised the sedimentary aspects and the extensive nature of the system, showing that the initial environment was one of a complex intracratonic basin.

Goellnicht et al. (1989) recognise some three styles of mineralisation.

- i. the very extensive and most economically significant stratabound / stratiform reefs - the MVR and the higher E-reefs ;
- ii. stockwork veining within the Telfer Formation, locally ore-grade, and
- iii. fault-bounded stockwork veining in the Outer Siltstone Member, the host to the E - reefs.

It is also noted that high grade mineralisation is (was) invariably due to supergene enrichment consequent to oxidation of the sulfide component of the initial rock. However, at least on the local scale, it seems that this observation may not be strictly correct and quite high gold grades were probably present prior to weathering.

Nevertheless, it appears that secondary enrichment has been important in the redistribution of gold, copper and cobalt. Mann and Nickel (1985) examined gold from several parts of the Deposit and discussed the possible processes involved in its mobilisation, based on their interpretation of the pre-existing mineralogy. The present-

day groundwater however, is of only low-to-moderate salinity and is near neutral in pH (carbonate buffered), in contrast with that seemingly required by their model, namely a low pH together with moderate to high salinity.

The weathering and oxidation of the MVR was destructive of the sulfide and other labile components, with very extensive leaching, such that little if any larger scale textures indicative of the non-silicates remains (but see discussion of the West Limb, below). Thus there is little direct indication of the mineral relationships or of areal variation in the mineralised system in what appears to have been the most extensively developed part of the pre-weathering, ore-body, namely the East Limb of the MVR. Extrapolation from mineralisation-at-depth presents some difficulty in that it is of much lower grade and the Reef itself is less well developed. The mineralisation of the more westerly Limb of the MVR appears to have been less extensively developed, although it has been suggested that the variation in gold-grade between the two limbs results from the lesser angle of dip of the latter and hence a lesser degree of secondary enrichment.

The (chemical) composition of the mineralisation is complex and possibly distinctive. The more significant elements are (iron), gold, arsenic, copper, cobalt and the lanthanides, with much lower concentrations of bismuth, lead and molybdenum. Earlier work in this laboratory had also shown the presence of tellurium, tin and tungsten in both fresh rock and gossan; mercury, while present at ppm levels in pyrite, was found at only sub-ppm levels in the whole rock.

There appears to be little public information on the spatial distribution of the trace and minor elements, but our data suggests that tin and tungsten may be fault related, and it is likely that there has been some contribution to the association from detrital and other minerals of the sedimentary sequence.

In an internal Telfer report, McMichan (1983, quoted by Mann and Nickel) proposed a prototype weathering profile for the East limb of Main Dome based on extensive mine data, thus:

Zone A: Surface zone	5m thick	gold enriched
Zone B: Pallid zone	10-15m thick	gold variable
Oxidised zone	40-45m thick	gold depleted
Zone C: Secondary enriched zone	10m thick	gold enriched
Zone D: Oxidised zone	20-25m thick	gold depleted
Zone E: Supergene zone	40m thick	gold enriched
Zone F: Primary zone	sulfide zone	

The Telfer Gold Deposit was sampled during 1978 (by the author) as part of a study of techniques for the recognition of mineralisation-related weathered rock. Material was taken from outcrop, from exposures in the Pit and from grade control samples. However, even at that time, much of the oxide zone of the East Limb of the MVR had been removed and this precluded a fully adequate sampling of this important part of the Deposit.

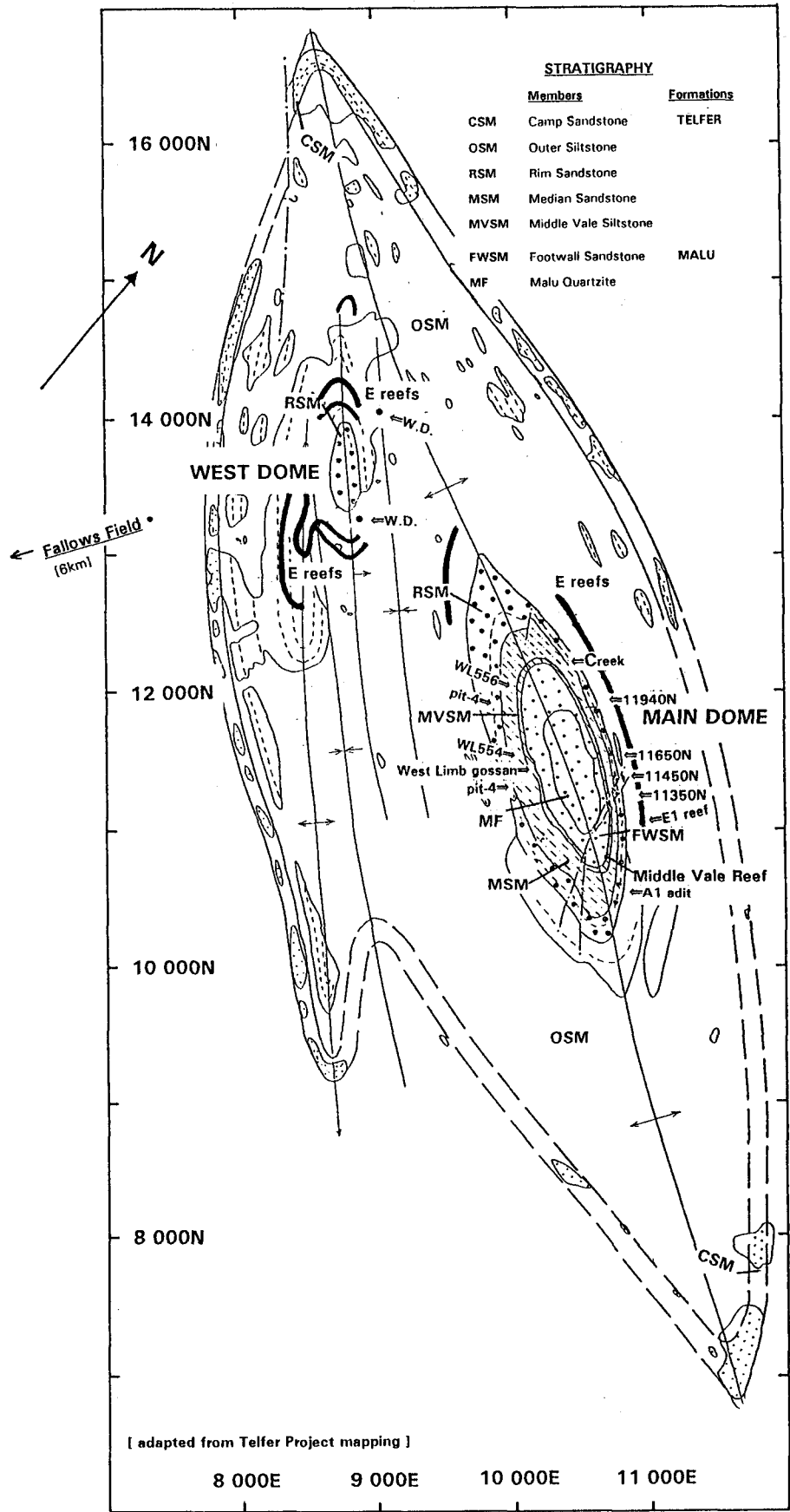
The initial intent of this study was :

- i. to determine the geochemical and textural or structural characteristics of the weathered rocks in their relationship to gold mineralisation;
- ii. to consider the nature and processes of the weathering to facilitate the recognition of such or related rocks elsewhere, and
- iii. to suggest which elements serve as residual indicators in such an environment and conversely those that might present a broader target.

It was also accepted that it might be possible to discern aspects of primary dispersion and thus to suggest hidden mineralisation.

These aims and objectives remain relevant in the relationship to the AMIRA Project P241, although the age and style of mineralisation, and in part the weathering regime, differs from that which pertains to deposits within the Archaean Yilgarn Block.

SIMPLIFIED GEOLOGY OF THE TELFER DOME



Map 1. Geology of the Telfer Dome and Sample Locations

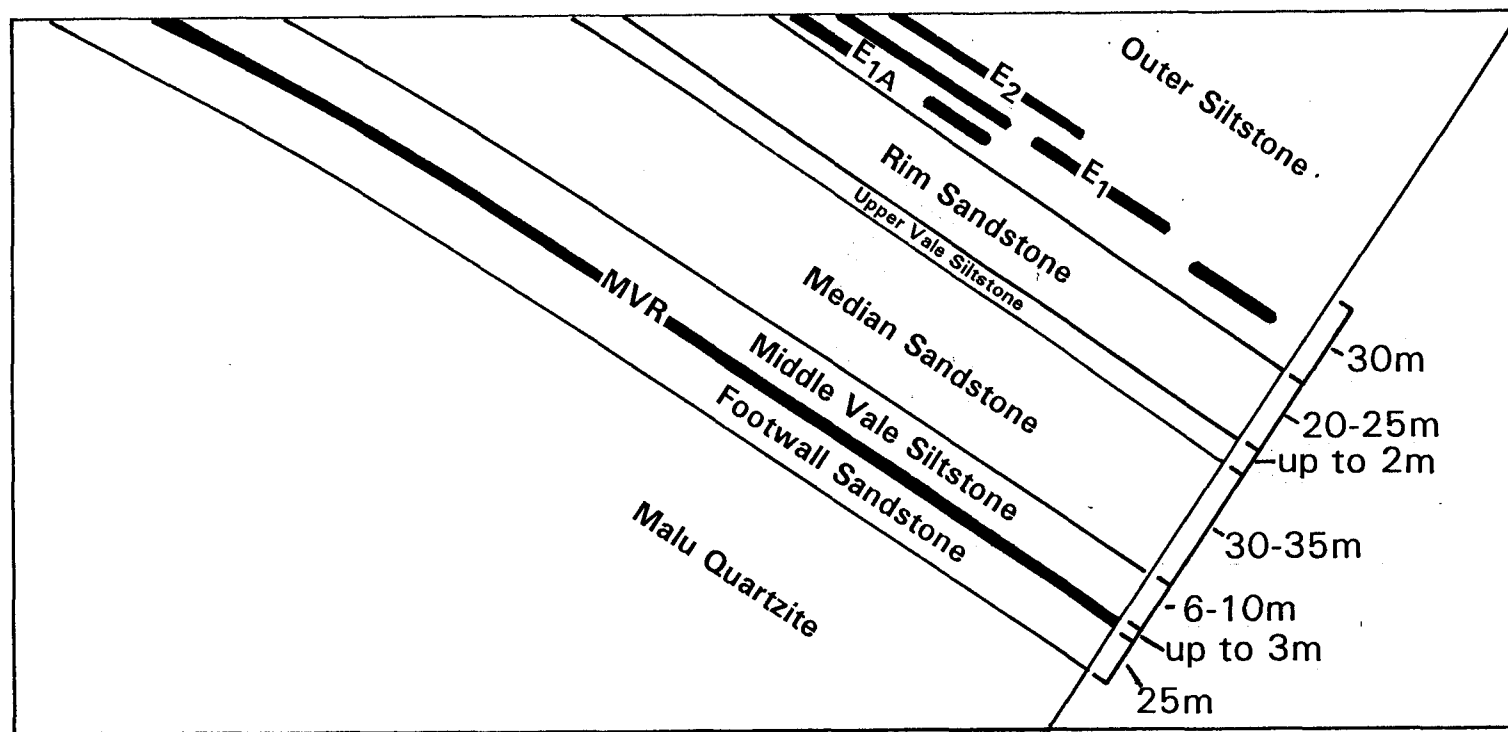


Figure 1. Schematic Section of East Limb of Main Dome
 [modified from Goellnicht et al.]

2. SAMPLING and ANALYSIS

2.1 Sampling

The gossans and weathered rocks were collected so as to include the typical types and their sub-types, and in the case of the West Limb, samples were taken over the extent of the gossan exposure to allow for spatial variation.

East Limb material came from the 'Discovery Outcrop' where the reef was exposed in a 'creek' bed. Although rock at the site had originally contained clearly visible gold, this was no longer the case; the rocks are, however, highly auriferous as shown by analysis. Other surface sampling along East Limb of the MVR was opportunistic and involved the collection of residual outcrop since most of the reef had been removed in the initial stages of mining.

The sample descriptions for the hand specimens are given as part of the data set, in the Appendix, and color photographs are available.

The channel samples were taken from the MVR exposure in the main pit (as at that time), although it appeared that the reef, and mineralisation, was less well developed at the only accessible location, at 11940N. The present analytical data, however, shows the presence of quite significant gold, and on examination the reef quartz was found to contain visible gold. The samples were taken vertically across the reef (which dips at an angle somewhat less than 30°) with the upper contact given at 0m, and negative downwards.

Sub-samples (the profile samples) were taken from grade control material from the East Limb to examine dispersion and variation-with-depth. Much of the earlier mining sample material had been discarded so that it was not possible to obtain a complete or fully competent collection. What was taken was the best approximation possible (although not all samples taken have been examined in the course of this study). The samples are from vertical grade control drilling, hence 0m is the RL as given for each profile and with depth-down-hole. The sample interval was 0.25m. The estimated upper and lower reef contacts are given in the prolog to the data for each profile.

The West Limb profile samples WL 554 and WL 556 were chosen to provide comparison with the outcrop. These are vertical grade control holes, from surface, with depth-down-hole, sample interval 0.25m. The estimated MVR contacts are given in the prolog to the data for each profile.

The nature of the East limb 'Discovery Outcrop', the nature of the West limb outcrop over the gossan sampling area and the pit exposure of the MVR at 11940N, RL 450 are each illustrated with Plates 1, 2 and 4.

The sample set is summarised as follows:

Surface gossans and weathered rocks:

West Limb

gossan , [Appendix B, Table 1; n = 37] ,

Pit-4, weathered rock [Appendix B, Table 3; n = 12] ;

East Limb,

creek exposure, weathered rock, [Appendix B, Table 2; n = 9] ,

residual MVR surface gossan, [Appendix B, Table 2; n = 8],

adit-1 and sub-surface samples, [Appendix B, Table 2; n = 11] ;

E-1 Reef,

weathered rock, [Appendix B, Table 3; n = 7] ;

West Dome

gossan, [Appendix B, Table 3; n = 7];

Fallows Field

weathered rock, [Appendix B, Table 3; n = 3].

Weathered profile including grade control samples:

East Limb

11350N RL 525 [Appendix B, Table 4; n = 16],

* [Profile zone A, surface zone - gold enriched]

11350N RL 455 [Appendix B, Table 4; n = 20],

[Profile zone D, oxidised zone - gold depleted]

11450N RL 505 [Appendix B, Table 5; n = 22],

[Profile zone B, oxidised zone - gold depleted]

11650N RL 510 [Appendix B, Table 6; n = 20];

[Profile zone A, surface zone - gold enriched]

West limb

WL 554, 11450N 10065E [Appendix B, Table 8; n = 11],

WL 556, 12000N 10065E [Appendix B, Table 8; n = 8] ;

and channel samples:

East Limb

[Profile zone B, oxidised zone - gold depleted]

11940N RL 475 [Appendix B, Table 7; n = 10],

11940N RL 450 [Appendix B, Table 7; n = 15].

* Tentative zone assignment to McMichan's profile, see Introduction, page 5

2.2 Sample Preparation

Solid samples were first crushed in a manganese-steel jaw crusher and then ground in a manganese-steel ring mill; the grade control samples were reground in the ring mill. Accordingly, the analytical figure for manganese should be taken to be an upper limit in all cases with the same proviso for the chromium data for the grade control samples (since a chrome-steel mill had been used for the initial grinding).

2.3 Chemical Analysis

The analytical data were obtained by the use of icp-oes, icp-ms, XRF and inaa methods. Each is a multi-element technique and there is some duplication of data for a number of the elements; where this is so, only the most reliable data has been incorporated into the Geochemical Data Tables (Appendix B) which are used as the basis for the present discussion. The complete compilation, however, is given in Appendix E. In these tables the detection level is denoted by a negative prefix; note that in the case of the inaa method, the detection level is matrix dependent and hence variable. (In plotting the data for the Chart sequences, a value of half the detection level has generally been assigned to below-detection-level data.) The *preferred methods* of analysis and the full *element-by-method* listing are given in Tables 1 and 2 respectively.

A borate fusion method was used in the XRF analyses while for the icp methods, the sample was subjected to an initial HF/HNO₃ attack followed by fuming with HClO₄.

TABLE 1. PREFERRED METHODS of ANALYSIS

Ag	icp	Co	naa	Lu	naa	S	icp	U	icpms
Al	XRF	Cr	icp	Mg	XRF	Sb	naa	V	icp
Au	naa	Cu	icp	Mn	icp	Sc	naa	W	naa
Ba	naa	Eu	naa	Mo	icp	Si	XRF	Y	icp
Bi	icpms	Fe	icp	Na	icp	Sm	naa	Yb	naa
Ca	icp	Hf	naa	Ni	icp	Sr	icp	Zn	icp
Cd	icp	K	XRF	P	XRF	Ti	XRF	Zr	icp
Ce	naa	La	naa	Pb	icp, icpms	Th	icpms		

TABLE 2. METHODS of ANALYSIS - FULL LISTING

	icp	icpms	XRF	naa		icp	icpms	XRF	naa
Ag	X			X	Na	X			
Al	X		X		Ni	X			
As				X	P	X		X	
Au				X	Pb	X	X		
Ba	X			X	Rb				X
Bi		X			S	X		X	
Br				X	Sb				X
Ca	X		X		Sc	X			X
Cd	X				Se				X
Ce				X	Si			X	
Co	X			X	Sm				X
Cr	X *			X	Sr	X			
Cs				X	Ta				X
Cu	X				Ti	X *		X	
Eu				X	Th		X		X
Fe	X		X	X	Tl		X		
Hf				X	U		X		X
Ir				X	V	X			
K	X		X		W				X
La	X			X	Y	X			
Lu				X	Yb	X			X
Mg	X		X		Zn	X			X
Mn	X		X		Zr	X *			
Mo	X			X					

NOTE. * the dissolution of minerals containing this element may not be complete.

3. RESULTS.

3.1 General

The results and data for this study are presented in the form of the *analytical tabulations* (Appendix B, Tables 1 - 8), *graphic representations of the elemental variations* for each sample set (Appendix C, Chart sequences 1 - 6) together with a composite sequence for the full set of the gossans and weathered rocks (Appendix E) and the *sample descriptions*. The *color illustrations* (Appendix D) are available but have not generally been included.

The gossan and weathered rock samples are grouped and discussed (the gossans and non-profile samples in brief abstract form) according to their source location. Statistical treatment of the data is generally inappropriate because of the diversity of sample types.

3.2 Surface gossan and weathered rock.

This suite of gossan and weathered rock comprises eight sub-sets, namely

- West-limb surface gossan
- West-limb Pit-4 weathered rock
- East-limb 'creek exposure' gossan and weathered rock
- East-limb surface gossan
- East-limb adit and other oxidised zone weathered rock
- E-1 Reef oxidised zone weathered rock
- West Dome gossan, and
- Fallows Field weathered rock.

The composite data for this group is given in *CHART SEQUENCE 1* (Appendix C) and shows the variation and similarities between the several groups of rocks. This sequence is referred to again in the General Discussion. In the following section, the comment on each of the above groups of samples refers implicitly to the above graphic compilation.

3.2.1 West Limb gossan

Surface rocks. [n = 37]

The samples were taken from an area of outcrop on the western flank of the Main Dome, at sample locations given in Table 1, Appendix B. The nature of the outcrop is shown in Plate 2 and the ferruginous style of some of the rocks is clearly evident. The set is notable for the moderately large particle size and the very high concentration levels of gold. For these reasons, it is difficult to discern correlations between the several elements and gold itself.

As a set, the samples are strongly anomalous although there is minimal evidence of secondary oxidate minerals of the chalcophile elements; however more than half of the specimens carry visible gold. Arsenic, bismuth, cobalt, copper, gold, phosphorus, silver and tungsten are present in significant concentration, while nickel, lead and zinc are of little direct relevance. Antimony is present in only low concentration (median 3ppm) in contrast with bismuth (median 20ppm). The rocks are relatively low in thorium (median 2ppm); the uranium concentration is generally higher with a median of some 5ppm.

The tungsten content appears to be significantly higher in samples toward the south of the area of outcrop with the two nominal groups having median concentrations of 1200 and 200ppm.

3.2.2 Pit 4 samples.

Weathered rocks. [n = 12]

These are grab samples of the MVR horizon in Pit 4, West Limb, and hence tend to be more clay-rich. They are near-surface samples, in comparison with the surface gossans as described in section 3.2.1. The samples were taken from two locations, 11300N and 11880N, some 600m apart, from a depth of approximately 22m. The more southerly of the two sets approximates the gossan locality. The samples show some marked geochemical differences between the two (Pit-4) localities, particularly in gold, cobalt, copper, tungsten and iron. The more southerly set, which appears to be within a gypsiferous zone in the profile, is very distinctly more iron-rich and has the higher concentrations of cobalt, copper and tungsten, whereas the northerly set, which is in a carbonate dominant zone, has significantly higher gold values. The set includes only one ironstone.

The elements arsenic, bismuth, cobalt, copper, gold, molybdenum, phosphorus and tungsten are particularly significant, with the proviso that the chalcophile elements are strongly correlated with iron. Nickel also is so correlated and is found at some

500ppm in the most iron-rich sample. Thorium occurs in the series with a median of 28ppm and is closely correlated with titanium, but uranium has a median concentration of only 4ppm. The lanthanides are present in moderate to high concentration, with cerium having a range from 130 to 2200ppm; there is a trend following phosphorus and very probably an association with the gold mineralisation.

3.2.3 East Limb - Creek exposure gossan.

Gossan and weathered rock. [n = 9]

This set of samples comes from the 'Discovery Outcrop' area at an exposure in a small water-course (Plate 1) on the eastern flank of the Main Dome and to the north of the main pit. The set is, with one exception, low in iron, and is somewhat disparate, with three sub-groups, reef with a substantial 'clay' content, iron-oxide coated reef quartz and ferruginised (?) siltstone. The samples lack visible gold.

Gold is at a high concentration in six of the nine samples and significant in the remaining three, which are two clay-rich rocks and a ferruginised siltstone. Arsenic is significant in all samples, as is copper, although at a lower concentration than in many of the surface rocks; cobalt also is relatively low but is less consistent. Tungsten, thorium and lead are each notable, but variable. Bismuth is significant in only one sample, which also contains an anomalously high lead concentration.

3.2.4 East Limb - gossan and weathered rock.

Gossan and weathered rock. [n = 12]

The gossan samples were taken from areas along the edge of the main pit, and mostly represent residual MVR, while the sub-surface samples represent MVR exposures within the pit. Locations and levels are given in Appendix B, Table 2. All samples contain high gold concentrations with a median of some 30ppm; of the samples, three have low proportionate silver contents and hence it is likely that the gold in these samples, in particular, is mostly secondary.

Arsenic, bismuth and copper are generally significant in this series as is tungsten, although that element is bimodal in concentration with means of 240 and 2800ppm. Cobalt also shows a bimodal behaviour in contrast with the more consistent behaviour of copper. The samples contain, for Telfer, moderately high concentrations of lead, mean 200ppm; an extreme concentration of 5200ppm is found in a high phosphorus content sample.

Uranium has a median of 8ppm, a little higher than that of thorium (6ppm), with the concentration appearing to follow that of vanadium, but there is a somewhat ambiguous relationship with phosphorus.

3.2.5 East Limb - weathered rock, Adit-1.

Gossan and weathered rock. [n = 7]

This is a set of seven nominally ferruginous rocks through the MVR at Adit-1, RL 400, approx 120m below surface at the southern end of the main pit. The iron content varies from less than 1% to a high of 52%, with an inverse clay content. One iron-stone (65942) is clearly solution-deposited. Gold ranges in concentration from 230ppb to 130ppm with a median of some 12ppm, the three lower values are found in samples of high clay content.

The samples mostly have high concentrations of arsenic, copper and tungsten with somewhat elevated levels of lead. Cobalt is high in concentration in two of the specimens, but moderate to low in the remainder. Thorium is present generally at a moderate level with a median concentration much in excess of that of uranium, although the latter occurs at the unusually high concentration of 17ppm in one sample. In the latter there is an association with vanadium and with phosphorus.

3.2.6 E-1 Reef Weathered rock.

Weathered rock. [n = 7]

These samples were taken vertically downward across the E - 1 reef (sample 68313 at top) from a depth of approximately 25m. They are generally clay-rich with a low to moderate iron content. These rocks have a gold content lower than those from the MVR, the maximum concentration is 6730ppb with a median of some 1300ppb.

The high gold concentrations are associated with elevated contents of iron, arsenic, cobalt, copper and tungsten. Arsenic and tungsten appear to be lower in concentration than in the MVR, but cobalt and copper are each affected to a lesser extent; all four elements show an association with iron. Bismuth also has an association with iron and is found at a concentration of 7ppm in the two samples of higher iron content. Thorium is present with a mean of 20ppm, but uranium is found with a maximum concentration of only 4.9ppm.

3.2.7 West Dome gossan.

Gossan. [n = 7]

These are a suite of iron-rich surface gossan samples from over West Dome. All but one are from a single location and are broadly similar. The remaining sample, 67090, comes from well to the north and gives indication of a higher sulfide content. Gold is found at significant concentrations in all samples, the maximum value is 10.2ppm with a median of 6.5ppm.

The samples are particularly high in arsenic, with a median of 3000ppm and maximum of 6760ppm. However, while bismuth, cobalt, copper and tungsten are highly significant, the concentrations appear to be proportionately lower than are found in the West Limb gossans. Phosphorus, also, appears to be diminished, but with a mean of 1214ppm excluding the northerly sample, 2400ppm, which has a lanthanide association. Lead is present in only low concentration, mean 14ppm.

3.2.8 Fallows Field weathered rock.

Ferruginous weathered rock. [n = 3]

These three samples were taken to represent the most visibly ferruginous area of the outcrop which was at an elevation of approximately 2m. On the basis of the structural detail, the three samples would normally be assigned a low priority since one is a ferruginised rock while the others come from rock with a low sulfide content. The unusual elongate nature of some casts in sample 67136 is of interest, although very probably after pyrite, (such has been observed elsewhere by the author). Gold is present in the ferruginised rock at only 39ppb but is at 1160 and 13000ppb in the other two.

In it's higher contents of manganese, cobalt and copper and low gold and bismuth contents, the ferruginised sample is rather different from those which had clearly contained sulfide. Normalised to iron, the arsenic concentration is also perhaps low in relation to other Telfer material (2710ppm), but this would not seem to be diagnostic.

The remaining two samples contain significant concentrations of arsenic, bismuth and copper; lead is somewhat elevated and one sample has an unusually high antimony content of 25ppm. The concentrations of cobalt and of tungsten are low.

3.3 The weathered profiles.

This suite of profile and channel samples comprises eight sets, namely:

		[depth]*
East Limb profile	- 11940N RL 475,	35m.
East Limb profile	- 11940N RL 450,	60m.
East Limb profile	- 11350N RL 525,	from surface
East Limb profile	- 11350N RL 455,	50m.
East Limb profile	- 11450N RL 505,	12m.
East Limb profile	- 11650N RL 510,	2m.
West Limb profile	- WL 554,	from surface
West Limb profile	- WL 556,	from surface

The first two of the above sets are vertical channel samples across the MVR while the remainder are from grade control drilling. The individual samples from grade control represent 0.25m intervals; the intervals for the channel samples are given in Table 7 (Appendix B). In the grade control sampling, the MVR is generally near the top of the section and extends well into the footwall. (Note that the graphic data is shown as a line graph, which may mislead if attention is not paid to the sample density.)

In the following section, the comment on each of the sets should be read in association with the appropriate graphic compilation, CHART SEQUENCE 2 through 6 (Appendix C) and the analytical Tables which are in Appendix B. Illustrations are not available for these sample sets other than by way of Plate 4 which shows the MVR at 11940N, RL 450 (RL 475 is very similar). The discussion of the data is more extensive for the profile samples since the individual samples are spatially related and trends can be observed.

* depth below surface of datum, 0m. on chart.

3.3.1a East Limb profile 11940N RL 475

Weathered rocks. [n = 10]

This set of ten channel samples represents a vertical profile on the MVR exposure at this location, 35m. below surface, where the reef has an apparent vertical width of 1m. The upper contact of the reef is given at 0m. while the lower contact is at approximately 1.0m. This profile is tentatively assigned to McMichan's Profile Zone B - (oxidised zone, gold depleted). The data are plotted in Chart Sequence 2 of Appendix C, with analytical data in Appendices B and E.

Silver.

Silver increases from 6 to 11ppm downward across the reef. It is without evident control and with the exception of the uppermost sample is much in excess of that required to give a nominal primary silver to gold ratio 1 : 9.

Arsenic.

The arsenic contents follow those of iron reasonably well within the profile, although there is some variation in those zones where iron is particularly low.

Gold.

The interval above the upper contact reports an exceptionally high level of gold, 466ppm, within a ferruginous zone which is generally anomalous. Particulate gold was not observed in that sample, but was seen in samples from within the reef, attached to quartz, and with a silver content of some 10%*. The data suggest that the gold is rather uniformly distributed within the reef, but perhaps with a maximum somewhat below the upper contact.

Bismuth.

Bismuth reports unusually high concentrations in this profile. Within the reef bismuth ranges from 6 to 73ppm and is broadly sympathetic with iron. The sample on the upper margin of the reef, however, carries some 228ppm, with tungsten and antimony showing a similar high contrast.

Lanthanides.

The lanthanides, cerium and lanthanum, show strong maxima below the upper contact of the reef immediately above, or coincident with the maximal gold values within the reef. The variation through the profile closely follows that set by phosphorus. Europium and samarium follow this trend, but the heavy lanthanides, lutetium and ytterbium, do not conform and exhibit maximum concentrations nearer the lower contact of the reef.

* a preliminary analysis only

Cobalt.

Cobalt is at a low level in this section with a mean of only 4.3ppm; it follows iron generally and does not seem to respond to variation in manganese.

Copper.

Copper is at a moderate concentration, with a mean of some 270 and maximum of 680ppm. It is generally sympathetic with iron, but shows a peak at the bottom of the section, below the nominal lower reef contact. Copper is also concentrated in the anomalous ferruginous zone at the upper contact of the reef.

Iron.

Iron has a mean concentration of around 8%, and a high variability due to the presence of quartz within the reef and clay without.

Manganese.

Manganese reports a maximum of only 250ppm, it is sympathetic with iron but does not show the higher contrast of that element.

Molybdenum.

Molybdenum occurs in the section sympathetically with iron, the maximum concentration being 17ppm; that concentration, however, occurs in the uppermost interval.

Nickel.

Nickel is found at only a low concentration in this profile, and while the variation follows iron within the reef proper, it is below detection in the two bounding samples. The maximum value is 37ppm, in excess of the concentration shown by cobalt!

Phosphorus.

Phosphorus appears to show two peaks, at the top and bottom of the reef, but with concentrations of only 600 and 300ppm respectively. This distribution is also reflected in the lanthanide concentrations.

Lead.

Lead also shows dual peaks, symmetrical within the reef, and following phosphorus very closely. The maximum value is 490ppm, near the lower contact.

Sulfur.

Sulfur has a maximum value of 560ppm and follows the iron distribution closely.

Antimony.

Antimony values are quite low within the reef, with a maximum of 2.2ppm near the upper contact. However it shows a higher concentration of 7.4ppm in the anomalous zone above the upper contact.

Titanium.

Titanium reports substantial concentrations within the reef, with a high value of 1.28% in the lower section. The pattern is similar to that of phosphorus, but is a little lower in the profile. There is a significant overlap with potassium.

Thorium.

The thorium concentration follows titanium very closely with high absolute values. Within the reef the maximum is 52ppm whilst some 65ppm is found immediately above the upper contact.

Uranium.

Uranium has a maximum value of 12.9ppm in this profile, and can be seen to follow iron quite closely. There is little evidence of association with vanadium or with phosphorous.

Tungsten.

Tungsten is distributed within the reef with a maximum value of 231ppm in the upper half. The concentration immediately above the upper contact, however, is very much higher at 948ppm.

Zinc.

Zinc is at a notably low level throughout this profile, showing an upper value of only 6ppm.

3.3.1b East Limb profile 11940N RL 450

Weathered rocks. [n = 12 + 3]

This vertical profile through the MVR was taken from the exposure at RL 450, 60m below surface. Three additional sub-samples were taken to represent a ferruginous zone at the base of the reef (67004), and the upper (67012) and the main part (67013) of the ex-sulfide ferruginous zone within the reef. The upper contact of the MVR is given at 0m. and the lower at approximately 1.3m. This profile is tentatively assigned to McMichan's Profile Zone B - (oxidised zone, gold depleted). The data are plotted in Chart Sequence 2 of Appendix C, with analytical data in Appendices B and E.

Silver.

Silver is found in significant concentration in the upper part of the reef with a mean of some 7.5ppm, and in the interval immediately above the reef. The concentration seems again to be rather in excess of that needed by primary gold, see above.

Arsenic.

Arsenic follows the iron variation closely. The concentration in the hangingwall at this RL is much lower, but this likely follows the low iron content of the uppermost interval (2.07%), in contrast with some 22% in the corresponding zone at RL 475. The maximum value is rather high at 5130ppm, a concentration close to that in the specific sulfide derived samples (Appendix B) .

Gold.

There is a significant concentration of gold in the sample above the reef, 5.7ppm, but not the anomalously high values seen in the higher section. The major concentration (mean 15.6ppm) is found just below the upper contact with lesser values toward the base of the reef. The gold variation follows that of iron in a general sense.

Bismuth.

Bismuth is extensive through the profile with a range of 3 to 25ppm. The variation pattern shows a positive relationship with iron, but there is far from a one-to-one relationship.

Lanthanides.

There is a major concentration of cerium and lanthanum at the top of the section with a minor concentration at the base. These seem to be on the outer contacts of the reef. At this RL the remaining lanthanides, europium, samarium, lutetium and ytterbium behave rather similarly, without the apparent separation seen at RL 475. The distribution of phosphorus is very similar to that of the lanthanides.

Cobalt.

Cobalt is at a maximum in the upper part of the (ferruginous) reef, but shows significant concentrations lower in the section. The 'high' value in the footwall ferruginous sample is notable. There is no indication that manganese has a significant association with cobalt.

Copper.

Copper shows a high concentration in the ferruginous zone in the upper part of the reef, reaching 1600ppm. While there is an association with iron, the relative concentration is rather lower in the bottom part of the profile.

Iron.

Iron shows a major zone in the upper half of the reef with lesser zones somewhat lower. A narrow ferruginous zone also occurs at the lower contact of the reef.

Manganese.

Manganese reaches a much higher concentration at this RL, 980ppm, but does not appear to have a significant role as a control.

Molybdenum.

Molybdenum has a concentration similar to that at the higher RL with a maximum of 13ppm, but it is apparently restricted to the upper part of the reef in association with iron.

Nickel.

Nickel is not significant, with a maximum of only 42ppm, and reports in only three of the more ferruginous samples at the top of the profile.

Phosphorus.

Phosphorus again shows the maximum concentration, 600ppm, at the top of the reef with a lesser enrichment toward the footwall. The lanthanides reflect this distribution.

Lead.

Lead is present in lower concentration only, maximum 88ppm, and again is maximal at or immediately below the lower contact of the reef.

Sulfur.

Sulfur very largely reflects the iron variation, but is present at a somewhat higher concentration, 740ppm, than at the higher RL. Unfortunately the relationship with barium is obscured by the variable and high detection level of that element.

Antimony.

Antimony also is present at a slightly higher concentration at this RL. It shows a maximum level of 6.7ppm in the upper ferruginous zone, but, surprisingly, is present at a much lower level (0.2ppm) in the specific ex-sulfide samples (Appendix B).

Titanium.

Titanium is at a maximum at the contacts, 1.12 and 1.18% upper and lower, respectively. The overall level within the reef, however, is substantial with a mean of some 5900ppm.

Thorium.

Thorium has a distinct bilateral symmetry with maxima, 62 and 45ppm at top and bottom of the reef. The pattern is quite similar to that of titanium, but with the absolute maxima reversed. The minimum concentration within the reef is 10ppm.

Uranium.

Uranium reports with a mean of some 6.6ppm. The variation pattern is closely similar to that of iron, although the level in the lower part of the profile is proportionately greater. An association with vanadium is rather more plausible in this profile, but may merely be an reflection of a 'rabbit ear' distribution of that element.

Tungsten.

Tungsten has a mean concentration of some 60ppm through the reef, but with a distinct maximum of 190ppm at the upper contact. There is indication that the higher values are found toward top and bottom of the reef.

Zinc.

There appears to be little positive significance in the zinc data, maximum 10ppm.

3.3.2a East Limb profile 11350N RL 525

Profile samples [n = 16]

The sequence is a near-surface intersection of the MVR with the upper contact of the reef at approximately 4.5m below surface (4.63m) and the lower contact some 1.25m lower (5.88). Footwall mineralisation occurs some 6m. below the reef (11.9m). These samples comprise a vertical profile from grade control drilling, taken at a high elevation on the Dome. This profile is tentatively assigned to McMichan's Profile Zone A - (surface zone, gold enriched). The data are plotted in Chart Sequence 3 of Appendix C, with analytical data in Appendices B and E.

Silver.

Silver can be seen near the top of the reef at 8 and 11ppm, these concentrations represents a high ratio to gold (17 and 30ppm respectively).

Arsenic.

Arsenic shows a rabbit ear distribution within the reef, corresponding to higher iron concentrations, with levels of 1790 and 1930ppm. A second arsenic response, 1310ppm, can be seen 6.5m lower in a footwall zone.

Gold.

Gold occurs at a concentration of 6ppm immediately above the upper contact of the reef and with a mean of 23.7ppm over the width of the reef. A footwall zone reports values in the range of 4.7 to 9.5ppm. The intervening interval between the reef and footwall zone carries levels of 400 to 600ppb.

Bismuth.

Bismuth has a mean content of 29.6, maximum 89ppm, over the extent of the reef with the element detectable some distance into the footwall. It can be seen also, at 10ppm, a short distance above the footwall mineralisation.

Lanthanides.

The lanthanides, cerium and lanthanum, show a high maximum near the upper contact of the MVR, 1415 and 1130ppm respectively, with elevated levels near the base. Europium and samarium show a similar pattern, but lutetium and ytterbium are significantly higher in relative concentration at the base of the reef.

There is a slight increase in lanthanide concentration at the footwall mineralised zone.

Cobalt.

Cobalt is only moderately elevated in concentration through the MVR with a mean of 8.6ppm. It is detectable throughout the profile and rises to some 5.6ppm (at 8.38m.), it is also somewhat elevated in the lower auriferous zone. The concentration is overall conformable to variation in the iron concentration.

Copper.

Copper is not especially high in the section, having a mean of only 362ppm in the reef. Significantly, it reaches similar levels in an intermediate ferruginous zone and in the footwall mineralisation. The variation follows that of iron, but the copper to iron ratio is much higher in the footwall zone at 11.88m.

Iron.

Iron shows bilateral symmetry within the reef, with maxima of some 5%. Weakly ferruginous zones occurs some 2.5m below the base of the reef and in the zone of footwall mineralisation.

Molybdenum.

Molybdenum is detected at the upper and lower contacts of the reef, 13 and 10ppm respectively, and also in the footwall mineralisation at 14ppm.

Nickel.

Nickel is detected only in the reef, at a concentration of some 30ppm.

Phosphorus.

Phosphorous has peak concentrations within the reef at the upper, 900ppm, and lower contacts, 500ppm. The concentration rises slightly with the footwall mineralisation.

Lead.

Lead displays maximum values within the reef, some 900ppm, but also increases in concentration immediately above and below the MVR and again in the lower mineralised zone.

Sulfur.

Sulfur has a mean value of 390ppm, peak 580ppm, within the MVR, with bilateral symmetry following iron, and is at a level of 390ppm in the lower mineralised zone.

Antimony.

Antimony is at a very low level, 1.3 and 2.7ppm within the reef and 0.7ppm in the lower ferruginous zone at 7.38m.

Titanium.

Titanium is at a maximum immediately above and below the MVR, 7600 and 6500ppm respectively. The level within the reef averages 2200ppm. The concentration is again high, 5100ppm, in the footwall auriferous zone.

Thorium.

Thorium is high in concentration throughout the profile with complex variation. The concentration is at a high to each side of the reef contacts and again toward the base of the profile above the mineralised zone at 9.38m.

There is a close relationship between thorium and titanium. The thorium maximum is 45ppm, bracketing the upper reef contact.

Uranium.

Uranium has a distribution pattern somewhat similar to that of thorium, but with a pronounced maximum above the upper contact and with reduced values within the reef. The maximum content is 10.8ppm with an average within the reef of 3.3ppm. The value in the lower mineralised zone at 13.4m. is 4.8ppm.

There is a high degree of correspondance with the iron variation.

Tungsten.

The tungsten concentration is enhanced in the vicinity of the reef. The highest levels however, 1080 and 1310ppm, are found within the MVR in the zones of highest iron content. The concentration in the footwall mineralised zone is also somewhat elevated, 120ppm, again with an iron association.

Zinc.

Zinc is at its highest concentration above the MVR, 250ppm, with a mean of some 50ppm within the reef. It is a little elevated in the ferruginous footwall zones, reaching 105ppm in auriferous zone at 13.4m.

3.3.2b East Limb profile 11350N RL 455

Profile samples [n = 20]

This profile has been taken on the same section of the reef as the previous example but some 70m below surface and approximately 130m downdip. The reef is rather wider and the internal structure more complex at this location. The estimated reef contacts are at 4.63 and 6.63m. This profile is tentatively assigned to McMichan's Profile Zone D (oxidised zone, gold depleted). The data are plotted in Chart Sequence 3 of Appendix C, with analytical data in Appendices B and E.

Silver.

Silver shows a mean content of 6.5ppm in the upper (higher gold) section of the MVR. The silver to gold ratio is some 1 : 1.3 over this interval.

Arsenic.

Arsenic shows what seems to be quite a complex distribution pattern within the reef with higher concentrations at both upper and lower contacts and with a central zone, which carries 1950ppm. This pattern very likely results from the dilutional effect arising from distribution of quartz within the reef. There is a further zone of enrichment lower in the profile (8.38m) which is associated with sub-ppm values of gold and elevated levels of bismuth, copper and molybdenum. It is some distance above the lower gold zone.

Arsenic follows the iron distribution quite closely.

Gold.

The gold distribution is dominated by high values at and toward the top of the reef, mean 15.4ppm; however ppm levels are found over much of the profile. The lower part of the reef is fairly uniform with a mean of 2.5ppm and extending through the lower contact. Two significant auriferous zones occur toward the base of the profile, 3 and 5ppm, without appreciable iron or arsenic enhancement.

Bismuth.

Bismuth occurs at the ppm level throughout the profile, generally following the pattern set by arsenic, and iron. It is perhaps significant that the distributional peaks are displaced from those of gold.

Lanthanides.

The lanthanides are at a somewhat lower concentrations in this profile with cerium and lanthanum peaking at 690 and 570ppm respectively. Enrichment occurs within the reef near the upper contact but with a second major concentration some 2.25m below the

(estimated) lower contact. This lower zone appears to be enriched, relatively, in the heavier lanthanides, lutetium and ytterbium.

Cobalt.

Cobalt follows iron closely throughout the profile, but is present at only a low concentration. The maximum level, at the top of the reef, is 14ppm.

Copper.

Copper, however, while varying with iron, is present in high concentration, maximum 1050ppm, and peaks near the centre of the MVR. It also reports at the significant level of 197ppm in the ferruginous zone above the foot-wall mineralisation.

Iron.

Iron has quite a complex distribution pattern, but which is influenced by the distribution of quartz. It shows three distinct zones within the MVR itself, reaching 13%. There is a further zone at 2.5% some 2.5m lower and a weakly ferruginous zone, 0.8%, at the base of the profile.

Manganese.

Manganese is significantly higher in concentration at this RL. There is a strong peak at the upper contact of the reef, 640ppm, together with weaker responses, following iron, within the reef and below. The manganese peaks occur slightly above those of iron and generally coincide with those of cobalt.

Molybdenum.

Molybdenum is not detected within the MVR itself, but is found at the upper and lower contacts, 14 and 12ppm respectively, and in and around the lower ferruginous zone at 8.38m with a maximum of 16ppm.

Nickel.

Nickel is very low and can be seen only at and immediately below the upper contact of the MVR, the mean is 28ppm.

Phosphorus.

Phosphorus has a maximum of 700ppm in the MVR at the upper contact. Minor enrichments occur in the two lower ferruginous zones of the reef and across the lower contact. A significant enrichment of 500ppm can be seen at 8.88m immediately below the footwall ferruginous zone.

Lead.

Lead reports a maximum of 172ppm, within the reef. There are two zones of lead enrichment, one in the upper part of the MVR, with a second, just below the footwall and extending more deeply into the profile. The zones do not coincide directly with iron, but are somewhat deeper.

Sulfur.

Sulfur, maximum 580ppm, follows the iron variation pattern very closely.

Antimony.

The levels of antimony are low with a maximum of 2ppm in the upper part of the reef. The element persists through the reef and into the immediate footwall.

Titanium.

Titanium shows strong contrast through the profile with peaks at the hanging and footwall contacts of the reef, and high concentrations through the footwall, peaking at 8300ppm at 9.38m. The mean concentration within the reef amounts to some 4000ppm.

Thorium.

Thorium has a distribution pattern which closely resembles that of titanium. Levels at the upper and lower contacts of the MVR are 31 and 26ppm respectively with a mean of some 15ppm within the reef. The concentration beneath the reef is generally high with a peak of 50 ppm at 9.38m coincident with the maximum in titanium.

Uranium.

Uranium has quite a complex distribution pattern, but with a maximum of only 7.3ppm. There is a very distinct relationship with iron within the MVR, but in the footwall, where the iron levels are very much lower, the picture is not so clear. It is probable, however, that there is an association with phosphorus, particularly in the intervals around 9.38m .

Tungsten.

Tungsten has a distribution closely similar to that of uranium, including the variation within the reef, and the concentrations in the footwall. The absolute content of the element is not high, the maximum, at the base of the reef being only 92ppm and with lesser concentrations in the footwall.

Zinc.

Zinc is present at a mean concentration of less than 50ppm through the profile. The maximum value is found at the base of the section and is perhaps related to an increase in magnesian clays at that point.

3.3.3 East Limb profile 11450N RL 505

Profile samples [n = 22]

This profile intersects the MVR at a depth approximately 23m. beneath surface. However, the reef is some 6m. below the expected depth and the residual iron content is especially low although the gold content is high. The reef is quite thin at this locality. The estimated reef contacts are at 10.88 and 11.63m. This profile is tentatively assigned to McMichan's Profile Zone B - (oxidised zone, gold depleted). The data are plotted in Chart Sequence 4 of Appendix C, with analytical data in Appendices B and E.

Silver.

Silver is detected in only one sample, at 6ppm in the high gold zone. This is a lower ratio to gold than is seen in many of the other profiles described here.

Arsenic.

Arsenic is notably low in this profile with a profile-maximum of 291 and MVR-maximum of 190ppm. Even so there is a reasonably close association with iron. There is a response to the gold zones but arsenic is rather more extensive. There are three principal zones of arsenic enrichment, namely around the MVR, in a slightly ferruginous interval some 2m. lower at 13.88m., and the wider interval beneath this, which is low in iron.

Gold.

There are two principal auriferous horizons, the MVR with a mean of 54ppm, and a footwall zone of mean 10ppm. There is significant gold above the reef, and immediately below the lower contact .

Bismuth.

Bismuth is above detection level throughout the profile, but is more significant in the MVR and in the footwall auriferous zone (15.88m.) with 6ppm in each. It is also slightly elevated with 2ppm in the intermediate ferruginous horizon at 13.88m.

Lanthanides.

The lanthanides have a major peak at the top of the reef with a second lesser one with the footwall gold (13.88m.). In the reef, the peak is above the interval with maximum gold, with cerium and lanthanum at 783 and 550ppm respectively; the peaks for the heavier lanthanides, lutetium and ytterbium occur lower in the profile. In the footwall, cerium and lanthanum are at the lower levels of 218 and 143ppm and all lanthanides show coincident peaks. The maxima are coincident with those of phosphorus.

Cobalt.

Cobalt varies sympathetically with iron, thus there are peak concentrations above the MVR, in the mineralised horizon of the MVR and with the footwall mineralisation. The highest levels are 34ppm within the MVR and 7.7ppm in the footwall.

Copper.

Copper also is closely related to iron. The reef itself and the immediately enclosing rocks carry moderate levels of copper with a maximum value of 570ppm near the base of the MVR. Concentration levels in the intermediate (13.88m.) and footwall horizons (15.38m.) are 194 and 143ppm. The intermediate zone is minimally enriched in gold.

Iron.

Iron concentrations in and below the MVR are exceptionally low, with maxima of 1.26% in the reef and 1.28% in the intermediate zone in the footwall. A higher concentration, 3.56% is found immediately above the reef.

Manganese.

This profile is very low in manganese, showing a maximum value of only 27ppm.

Molybdenum.

Molybdenum is detected in the immediate envelope to the reef at a level of 10ppm.

Nickel.

Nickel follows iron closely, the maximum concentration however is some 48ppm above the reef while within the MVR itself, the peak value is only 28ppm.

Phosphorus.

Phosphorus is seen at 400ppm in the MVR, accompanied by the lanthanides, and again in a wide zone around the footwall mineralisation, mean 300, peak 400ppm. The lanthanide concentrations however are very much less in the deeper zone.

Lead.

Lead occurs principally in the sulfate zone extending across the upper contact of the MVR, mean 200ppm, and in a lower zone at 12.88m. (150ppm). It is present at only some 50ppm in the footwall mineralisation.

While lead appears to follow iron in the footwall, there is some ambiguity in the sulfate zone.

Sulfur.

Sulfur is present at the high concentration of 0.99% at the top of the profile, in association with enhanced calcium levels. Concentrations through the profile however are relatively low.

Antimony.

Antimony reaches its maximum value of 8.4ppm at the hanging-wall contact to the MVR, and is detected through the profile. Minor peaks, each some 1.4ppm, can be seen near the base of the reef and in the intermediate (13.38m.) and footwall mineralisation.

Titanium.

Titanium is present at moderately high concentration through the profile, with maxima of some 6000ppm in the envelope surrounding the reef. The mean level within the MVR is some 3200ppm. There is also indication of a spatial association with the intermediate and footwall mineralisation.

Thorium.

There is near 1:1 relationship between titanium and thorium concentrations. Thus the maximum level for thorium, 33ppm, is at the footwall contact of the MVR with a mean level of some 23ppm in the sub-reef portion of the profile.

Uranium.

Uranium has a maximum of only 5.4ppm in the profile. The distribution appears bimodal with a concentration within the reef of around 2ppm and with a mean perhaps some 2 times higher lower in the profile. The higher values near the base of the profile coincide with a phosphorus and lanthanide concentration peak.

Tungsten.

Tungsten occurs through the profile with a range from 22 to 263ppm. Higher values are seen above the upper contact of the reef, 100ppm, while the mean is 163ppm across the lower contact. Other enrichment zones coincide with the gold and iron zones immediately beneath the reef. There is only a minimal response in the footwall zone at 15.88m.

Zinc.

Zinc shows a maximum of 38ppm in the envelope to the MVR and responds to the increase in the iron content in the lower part of the profile with a maximum of 72ppm.

3.3.4 East Limb profile 11650N RL 510

Profile samples [n = 20]

This profile is effectively from surface and is topographically lower than at 11350N by some 15m. It is within a calcareous horizon, the lower part of which carries significant concentrations of gypsum, the upper part carbonate. The position of the reef is not well defined, especially the upper contact, but the foot-wall contact might be placed tentatively at 2.63m This profile is tentatively assigned to McMichan's Profile Zone A (surface zone, gold enriched). The data are plotted in Chart Sequence 5 of Appendix C, with analytical data in Appendices B and E.

Silver.

With reservations previously expressed regarding the unfortunately high detection figure for silver, the element is detected in only one sample, that showing the peak gold value. The concentration is arguably close to that which could be expected in gold with around 10% silver.

Arsenic.

The arsenic levels are unexpectedly low having regard to the iron and gold concentrations, the maximum being only 381ppm.

Two zones carry significant arsenic. The uppermost is high in the profile with 352ppm, whilst the second, 381ppm, is above the probable footwall contact.

Gold.

Gold is present at the ppm-level over much of the profile with especially high values near-surface and above the nominal footwall. These translate to 25ppm over 0.75m. and 38ppm over 1 metre, respectively.

Bismuth.

Bismuth is present at the low-ppm level through the profile with peaks of 6ppm in the ferruginous zone near-surface, and 13ppm within the reef. The latter corresponds to a ferruginous zone carrying the maximum gold content.

Lanthanides.

The lanthanides are present at a moderately high concentration within the reef with cerium and lanthanum peaking at 922 and 659ppm respectively; a lower zone carries 564 and 377ppm. The latter of the two zones is anomalous in the non-coincidence of the heavy and light lanthanides, the highest concentrations of lutetium and ytterbium are displaced downwards. Both zones coincide with peaks in the phosphorus concentration.

Cobalt.

Cobalt is present in moderate concentration near-surface with a peak maximum of 114ppm in the ferruginous zone. A second peak of 54ppm occurs lower in the reef in a zone of higher iron concentration.

Copper.

Copper is found at a significantly high concentration through much of the profile. In the uppermost ferruginous horizon it shows a maximum of 630ppm and peaks again lower in the MVR, at 500ppm. The element appears to follow iron and possibly gold.

Iron.

There are two distinct ferruginous zones in the profile, the one, mean 7.2%, at the top of the profile, and the second, mean 4.4%, within the MVR.

Manganese.

Manganese reports with a mean of 205ppm, peak 330ppm, in the upper-most three samples of the profile. There is a subordinate peak of 75ppm within the MVR followed by a gradual decrease down the section.

Molybdenum.

The element is not detected in this profile.

Nickel.

Similarly to manganese, nickel has peak concentrations at the top of the profile, 71ppm, and within the MVR, 55ppm.

Phosphorus.

Phosphorus peaks in two zones in the profile. The first (500ppm), which is in the upper ferruginous zone, has only a minimal lanthanide association and is apparently related to the high iron content. The other which occurs within the MVR, with a peak of 700ppm, is broad and apparently extends across the footwall contact. It is associated with high lanthanide concentrations.

Lead.

Lead is found in moderate concentration through the extent of the profile. While some 117ppm is found in the upper iron-rich zone, the concentration reaches 212ppm near the top of the reef with a subordinate enrichment of 109ppm, nearer the footwall. These latter two zones give the impression of association both with iron and with phosphorus. A minor enrichment at the base of the profile is associated with a high sulfur zone.

Sulfur.

Sulfur occurs in three principal zones, near the top of the reef, 0.52%, below the reef, 2.0%, and at the base of the profile, 1.2%. The latter two zones are associated with

high calcium contents which approximate a 1:1 ratio with sulfur. Barium is present at appreciable levels in the upper half of the profile and again, below the reef.

Antimony.

Antimony is present in the upper ferruginous zone with a peak concentration of 3ppm and also within the reef, coincident with the highest gold values (2.3ppm).

Titanium.

Titanium occurs in the reef with a peak concentration of 3700ppm, but with the higher content in the footwall rocks. The maximum concentration of 6400ppm is found immediately beneath the MVR while a second zone near the base of the profile reaches 4400ppm.

Thorium.

The data for thorium shows a close replication of the variation seen in titanium. The highest concentrations in the profile, 28ppm, occur in the high titanium zone beneath the reef.

Uranium.

Uranium is low in concentration, peaking at 3.2ppm toward the base of the section. Within the MVR, it appears to follow iron with maxima top and bottom of the reef, the subsequent minima appear to be due to a higher quartz content. Uranium, however, has not been proportionately enriched in the high-iron interval at the top of the profile.

Tungsten.

Tungsten has concentration peaks in the iron-rich zone at the top of the profile (110ppm,) and at, or immediately below the lower contact (140ppm).

Zinc.

With iron, zinc reaches a concentration of 180ppm above the reef, but within it, the mean amounts to only 50ppm. In the footwall the peak value is 41ppm.

3.3.5a West Limb profile WL 554 11450N 10066E

Profile samples [n = 11]

This profile set is taken from the initial grade control hole WL 554 which is at the northern end of the sampling area for the West limb gossan but some 200m. to the west, down-dip. The hole is vertical and intersects the reef some 32m below surface, however the contacts to the reef are not well defined and the iron content is low with aluminium high. The data from the East Limb suggests that the lanthanides might be used as a reef-marker; if so the top of the MVR is at approximately 31.6m. Some caution is necessary however since the near-surface data apparently also shows that gold and other of the elements may be concentrated immediately above the reef. The position of the footwall is not defined. Insofar as these samples have been taken high in the weathering profile, and, moreover, are over the West Limb, it is difficult to assign them a position in McMichan's Profile. The data are plotted in Chart Sequence 6 of Appendix C and analytical data in Appendices B and E.

Silver.

Silver is detected in only one sample, 5ppm, in the zone of maximum gold. The ratio of silver to gold is approximately 1 : 9.

Arsenic.

Arsenic is exceptionally low in concentration with a maximum in the auriferous zone of only 160ppm, and does not respond to the iron content overall.

Gold.

The peak gold concentration is 43.4ppm with an average in the auriferous zone of 8.5ppm over 2m. There is indication of association with arsenic, bismuth and copper.

Bismuth.

Bismuth peaks near the top of the auriferous zone with a concentration of 9ppm, but with low values through the remainder of the profile.

Lanthanides.

Only one zone of lanthanide enrichment is observed in this profile, but the total content is relatively high and coincides with phosphorus. The zone is at the top of the auriferous interval, with cerium and lanthanum respectively 983 and 664ppm; europium and samarium, 10 and 82.8ppm; lutetium and ytterbium, 1.5 and 8.5ppm are coincident. There is perhaps suggestion of a minor increase in concentration at the base of the gold-rich zone.

Cobalt.

Cobalt peaks with gold at the top of the interval with a mean of 38ppm, both iron and manganese are low. A second peak, at the base of the mineralisation, 11ppm, accords with the iron enrichment in that zone.

Copper.

Copper also has the maximum content at 32m. with a mean of 350ppm, but it is somewhat more evenly distributed through the interval than is cobalt. The ratio between the upper and lower 'zones' however is similar to that of cobalt.

Iron.

Iron increases from a low of 0.4% near the top of the interval to 1.6% near the base. It is notable that arsenic, cobalt and copper do not respond to this trend in a simple and expected manner. This suggests that iron is not unimodal.

Manganese.

Manganese essentially follows iron with a peak concentration of 95ppm at the base of the interval.

Molybdenum.

Molybdenum is detected only lower in the interval, but with the relatively high value of 30ppm.

Nickel.

Nickel is barely detectable at the top of the interval, however, like molybdenum, the concentration at the base of the reef is unexpectedly high, 380ppm. This is the more surprising because of the low iron content of the profile.

Phosphorus.

Phosphorus has a single peak of 300ppm near the top of the interval together with the lanthanides. The concentration elsewhere is particularly low.

Lead.

The response and contrast in lead is low, with a maximum value of only 53ppm.

Sulfur.

Sulfur is above the detection level of 430ppm in only the one sample, that carrying the highest iron content at the base of the interval.

Antimony.

Antimony is present with a mean of 1.6ppm in the upper part of the interval, falling to some 0.75ppm in the more ferruginous zone.

Titanium.

Titanium is present at 5700ppm at the top of the interval, and falls continuously to a low of 2400ppm.

Thorium.

The thorium concentration pattern follows that of titanium closely, but with a rather broader peak symmetrical about that of titanium. The peak value is 31ppm, falling to a low of 11ppm.

Uranium.

Uranium shows a mean through the interval of 3.2ppm. The peak values, 4.5ppm, occur above the more ferruginous zone; uranium varies with iron in this zone, but it does not do so overall. This behaviour is similar to that of several of the chalcophilic elements.

Tungsten.

Tungsten shows a single and strong peak (819ppm) lower in the interval at 33.38m. This is also the zone of maximum iron, but it is remarkable that tungsten should show such a strong contrast while that of iron is quite low.

Zinc.

The mean value for zinc through the profile amounts to 63ppm, with a maximum of 104ppm. There is some variation with iron but the picture is not convincing.

3.3.5b West Limb profile WL 556 12000N 10065E

Profile samples [n = 8]

This profile is taken from the initial grade control hole WL 556 which is located 520m. to the north of the West Limb gossan sample area and approximately 140m. north and 85m. west of the northern Pit-4 sample location. The vertical hole intersects the MVR some 18m. below-surface. However as with the intersection in WL 554, the interval is low in iron and high in aluminium such that the reef contacts are not self-evident. Using the same criteria as above (3.1.13a) would place the upper contact at approximately 18m. Insofar as these samples have been taken high in the weathering profile, and, moreover, are over the West Limb, it is difficult to assign them a position in McMichan's Profile. The data are plotted in Chart Sequence 6 of Appendix C and analytical data in Appendices B and E.

Silver.

Silver was not detected in the profile.

Arsenic.

Arsenic peaks with iron in two zones, at the upper contact of the reef and some 1.2m. lower near the (?)footwall contact. The concentrations are significantly higher than found in WL 554, namely 629 and 484ppm.

Gold.

Gold has a maximum concentration of 13.7ppm with a mean of 7.5ppm over 1.25m. It appears to be restricted to the putative MVR.

Bismuth.

The maximum concentration of 12ppm occurs at the upper contact of the reef, with a gradual fall to 0.4ppm at the base of the interval.

Lanthanides.

The peak concentrations for the lanthanides are found at the upper contact of the reef with cerium 560ppm, lanthanum 456ppm, europium 2.8ppm, samarium 27.7ppm, lutetium 2.1ppm and ytterbium 12.0ppm. The data suggest however that the ratios vary significantly across the width of the reef. The association is with phosphorus.

Cobalt.

Cobalt is very low in concentration in this interval, with a maximum of 7.2ppm near the upper contact of the reef, and a mean of 3.1ppm across it. While there is some degree of variation with iron, the association is not clear-cut.

Copper.

The peak concentration for copper occurs nearer the lower contact (320ppm, with a mean of 116ppm). There appears to be a close relationship with iron in that the variation patterns are quite similar.

Iron.

Iron is present at 1.9% above the upper contact of the reef. Within the MVR, the concentration rises from 1.07% near the upper contact to 2.2% toward the footwall.

Manganese.

Manganese is very low in concentration with a maximum of only 50ppm. With the exception of the sample above the upper contact, it follows the iron variation trend.

Molybdenum.

Molybdenum appears to follow iron with a peak concentration of 14ppm lower in the reef.

Nickel.

The element is not detected at 20ppm.

Phosphorus.

The maximum concentration of 400ppm is found near the upper contact of the reef in association with peaks in the lanthanides.

Lead.

The maximum concentration of 175ppm is found immediately above the upper contact. The concentration then falls uniformly to some 5ppm at the base of the interval.

Sulfur.

Sulfur is found in higher concentration in the ferruginous zones within the interval, although it peaks (280ppm) in a calcareous zone at the upper contact.

Antimony.

Antimony is at a maximum above the contact at 1.8ppm, and although very low in concentration appears to vary with iron within the reef.

Titanium.

The maximum concentration of titanium occurs immediately above the reef, 7100ppm. The level is somewhat lower in the upper part of the MVR, but rises quickly again to 7000ppm down-profile.

Thorium.

The concentration pattern for thorium again closely resembles that of titanium, however while the upper trend is identical, the lower thorium trend is displaced downward.

Uranium.

The mean concentration for uranium is some 5.8ppm, with a maximum of 7.9ppm near the base of the reef. Minimum levels are found in the upper part of the reef, likely due to a dilutional effect.

Tungsten.

Tungsten is moderately low in concentration and contrast, with a mean of 36 ppm over the interval. There is only a subtle response to variation in the iron concentrations

Zinc.

The zinc concentrations vary generally with iron, but with one very marked anomaly, 260ppm against a mean of some 31ppm. The maximum value occurs at the top of the reef, but without clear reason.

4. GENERAL DISCUSSION

The material collected for this study probably represents the only generalised sample set of the surface expression of the Telfer gold deposit still available, but like most studies of operating mines, the sample coverage is incomplete, and particularly that of the East limb. Thus it is difficult to determine what compositional variations might have existed along strike, and especially what effects faulting may have induced (both in the primary mineralisation and in the course of alteration and weathering). Because the Telfer Deposit* is extensive both along strike and down dip, it seems probable that there were initial significant qualitative and quantitative variations over the extent of the mineralisation.

4.1 Weathering.

As observed in sub-surface exposures, the weathered MVR is a physically fragile system which would be broken down and dispersed by surface weathering agents. In particular, there are not the more massive ironstones and secondary-silicification products capable of resisting even moderately aggressive weathering, and the reef-quartz generally is not physically massive. This perhaps suggests that the more obvious mineralisation-related surface rocks may be atypical in one way or another. In the present instance, factors which have a bearing on this and which appear to have resulted in rocks of greater resistance are faulting and the presence of larger amounts of carbonate gangue. Massive idiomorphic pyrite, also, seems more likely to undergo 'pseudomorphic oxidation' and to be preserved due either to intrinsic properties or to the associated mineralogical assemblage.

A less obvious result of the open nature of the weathered (East limb) reef is the accessibility of both the free and liberated gold to percolating solutions with an enhanced likelihood of dissolution or equilibration. (Allowing that this is relevant only if the ground-water composition is such as to allow the transport of significant concentrations of gold. This does not seem to be the case at present.)

Whilst it is of somewhat lesser relevance to the nature and geochemical composition of the gossans and weathered rocks which formed *directly* from the sulfidic parent, the past weathering history and climate and cyclicity has had a great deal of influence on the nature and variation within the over-all profile. The profile is a quantitative entity in which variation and continuity can be observed directly and is made-up variably of components derived from the initial sulfide/gangue assemblage

* referring only to Main and West Domes.

together with oxidation products of the supergene materials. This system has been overwritten to a greater or lesser extent by equilibration with the ground-water regime.

A plausible interpretation of McMichan's generalised Main Dome profile (p 5) suggests three major periods or episodes of weathering before the present cycle.

a). The first episode led to the establishment of a supergene zone with a redox barrier at a depth corresponding to Zone C, some 60m below the present surface. The penetration of the weathering front was likely continuous and rapid.

b). An episode of slower oxidation then allowed the supergene zone to further concentrate the particular elements gold, silver, copper, cobalt, arsenic, and mercury, as leached from the overlying oxide zone. As the oxidation slowed, the nature of the groundwater changed and the pH increased as equilibration took place with the carbonate bearing host-rocks. The oxidation proceeded but the resultant oxide zone now retained a greater proportion of the above elements as less iron was lost. Gold was retained both because of an increased grain size and perhaps particularly because of the possibility for armouring by dense iron-oxides. It is not known whether any appreciable lateral dispersion took place during this period, in analogy with some areas in the Yilgarn Block. This is, however, less likely at Telfer because of the defined plumbing and the trap presented by the well defined supergene horizon.

c). The rate of oxidation subsequently increased and weathering progressed as far as the presently observed supergene zone. The present cycle, however, is very likely again one with a slow rate of oxidative penetration.

The surface enrichment, as observed, might be assigned principally to the residual concentration of gold as the surface zone of the reef is gradually eroded and winnowed. The possibility of concentration by evapo-transpiration is improbable since this would require a low pH/higher salinity system in order to maintain significant gold in solution, and similarly, there seems little evidence to suggest that vegetative up-take has been appreciable. The presence of the 'pallid' zone however is a little problematic but invokes an analogy with weathering in the Yilgarn, and indeed Chin and Hickman (1977) make reference to laterite capping in areas within the Province; certainly the disperse nature of the iron oxides within the oxidised reef would render them more readily reducible and mobile. The variability in the gold content within this pallid zone might merely be a reflection of the presence of larger primary particles and reference in this context to the present primary zone is likely to be inappropriate and misleading. In contrast, the high surface gold content of the West Limb gossan collection area, as discussed in the present report, is a direct result of the high gold content of the primary mineralisation, but this is perhaps an exceptional situation with regard to the general nature of the Telfer mineralisation.

Alteration and oxidation of the sulfides (with some resultant silicification) also took place down fault zones as seen in material from a depth of 374m. The faults formed part of the ground-water system and might have permitted water flow and thus an increased rate of alteration and the development of an uneven oxidation front. Residual, or perched, sulfide blocks might also originate in this way. Conjecturally, such uneven oxidation would contribute to conditions more favourable to the dissolution of gold, see below.

In so far as much of the gold appears to have become 'armoured' by the more massive ironstones during their formation, post-oxidation effects have apparently been limited in the case of most of the surface samples studied here, but McMichan's profile model might be applied to the several profile sample sets and to a lesser degree to the subsurface low-iron samples. Thus the East Limb profile samples - 11350N-RL525, 11450N-RL505 and 11650N-RL510 fall within the nominal zone of surface enrichment whereas 11350N-RL455 and those at 11940N are within the nominal depletion zone. However, direct quantitative or even semi-quantitative comparison is of dubious value without consideration of compositional or other variation in the initial mineralisation and perturbation due to local effects in the development of the profile.

4.1.1 The non-sulfides.

The rate and extent of alteration and leaching of the non-sulfide components of the ore can be linked, generally, to the development of a lower pH consequent to sulfide oxidation, (although the carbonate content may be locally sufficient to buffer the system, see p46). The carbonates are subject to rapid and complete dissolution at a lower pH, but the behaviour of the phosphates, the titanium bearing minerals, the tungstates (assuming that tungsten does not occur within complex phosphates) and tourmaline is less obvious; the stability of each, however, would be expected to decrease with a lowering of the pH.

The moderate to high concentrations of the lanthanides and phosphorus, suggest that the rare earth phosphates are fairly resistant to the effects of weathering in this system. Tungsten, however, is closely associated with the iron-oxides indicating that the tungsten-bearing mineral is significantly labile as might be expected. The association of thorium with titanium is less expected, but suggests that the respective host minerals undergo significant weathering; the evident affinity of the two elements is explicable on the basis of the chemical properties of the two cations, but requires that an active titanium (alteration or hydrolysis) product be present to trap or adsorb thorium from solution. This could result from the effect of a lower pH on ilmenite or other titanium phase.

There is also a generally high level of phosphorus associated with the iron-oxides of the gossans and iron-stones (without corresponding lanthanides or calcium). This applies also to the West limb material where there was less opportunity for 'down-dip' percolation. Thus there was clearly a significant phosphorus concentration in the ground-water during oxidation, and this would likely have come from leached apatite or rare-earth phosphates in the profile, or perhaps from apatite associated with an exhalative phase of the total mineralisation sequence. Accordingly, at least a proportion of the lanthanides may be present in a secondary (phosphate) phase, although it has not been possible to investigate this; uranium and thorium, however, would show a preference for iron and titanium oxides respectively.

4.2 Geochemistry of the weathered rocks.

The matrix* of the weathered rocks falls generally within a ternary 'system' of *iron-oxide* (goethite - hematite), *silica* and *aluminous clays* (illite - kaolinite), hence the minor and trace element composition of the rock is largely controlled by its position within this system (but certainly not completely). In making comparisons it can be argued that silica is *essentially* an inert diluent (but see below) and should be factored out, to leave a binary iron-oxide + clay system. Considering the data in this sense it can be seen that the weathered rocks fall into three groups with respect to clay content.

The West and East limb surface gossans are generally lowest in clays, the East limb creek exposure, West Dome and Fallows Field rocks are intermediate in content whilst the remainder are relatively clay-rich. The clay content may be significant in that:

- i. certain elements associate chemically with the clays,
- ii. certain elements, or minerals, may be residual in weathered clay-rich rocks,
- iii. the clay may act as a simple diluent.

The free-silica content is due to the inclusion of both reefal and detrital quartz. However, the more massive quartz is associated with the MVR itself, that is, the Reef and cross-cutting veins whereas the detrital material is sand size. Although the reef quartz may well carry geochemical information in terms of (ultra-) trace components and solid or fluid inclusions, an examination of these has not been part of the present study. Indeed the nature of the quartz is such that its study presents considerable difficulty. There is little clear crystalline material but ample evidence of reworking and multiple generations of inclusions. There appears to be exceptionally little clear quartz of whatever generation in the collected material.

The following non-matrix* elements are found generally at a significant geochemical concentration in the Telfer weathered rocks and gossan:

(Silver), arsenic, gold, bismuth, cobalt, copper, lead, phosphorus, sulfur, thorium, tungsten, and uranium. The lanthanides and titanium are also present at a considerable concentration, but rarely in solution deposited ironstones or direct gossan.

Nickel is present in some of the ironstones, but seldom at a high concentration, while antimony is present at notable levels of concentration in only a few samples. Zinc is noteworthy in that it rarely exceeds background levels. Both nickel and zinc are iron-associative in gossans but their concentrations are markedly dependent on the conditions of formation, with retention being favoured by a higher pH. Antimony however is essentially fugitive.

The range in content for selected elements is given in Table 3.

4.2.1 The chalcophile elements.

Silver.

The MVR gossans, generally, carry significant levels of silver (6 to 45ppm for the West Limb and up to 29ppm for the East Limb). Where the content is low, the specimen is often quartzose, or weathered rock of low initial sulfide content. In some instances, the ratio of silver to gold (around 1:10) suggests that the latter is the host phase, but in others the silver content is considerably in excess of this figure. It is unusual for silver levels such as these to be found in rocks with so small an amount of secondary oxidate minerals. Silver more often behaves ultimately as a fugitive element which is leached from the weathered rock together with the oxidate minerals. In contrast, the silver content in material from the E1 reef, from the West Dome and from Fallows Field is at or below the detection level.

In the profile samples (MVR), silver is closely associated with the mineralised horizon with no evidence of wider dispersion, but the poor detection limit would mitigate against recognition of any mobilisation.

There is no direct information on the primary concentration of silver or of its host-phases in the upper zones of the pre-weathering ore-body, but it is probable that a significant proportion would have been present in sulfides or sulfosalts, consequently there is no reason to expect to see a direct relationship between gold and silver except perhaps in the most mature gossan which have been leached of secondary silver-bearing minerals. Primary sulfide from the East Limb contains only 25 and 6ppm silver, but if

* matrix = iron-oxide, silica, clays

	11360N RL 525	11360N RL 455	11450N RL 505	11650N RL 510	11940N RL 475	11940N RL 450	WL 556	WL 554	WL gossan	EL gossan	E-1 w. rock	WD gossan
Ag	11 nd	9 nd	6 nd	7 nd	11 nd	10 nd	nd nd	5 nd	45 6	29 nd	nd nd	nd nd
As	1930 32	1950 34	291 11	352 8	5700 55	5130 377	629 35	160 14	6110 81	7780 227	743 49	6760 2010
Au	45.7 0.31	25.8 0.33	54.8 0.02	84.2 0.02	466 0.6	21.1 0.9	13.7 0.06	43.6 0.2	692 2.3	224 0.5	6.7 0.1	10.2 2
Bi	89 0.4	29 0.5	6 0.2	13 0.3	228 6	26 3	12 0.4	9 0.5	157 2	100 1	7 0.3	38 4
Ca	330 108	360 89	12800 117	52200 560	600 96	480 138	3460 176	750 95	3030 103	3510 110	8700 108	480 142
Ce	1540 60	690 68	783 45	922 60	1090 58	1220 120	560 100	983 41	1940 1	1120 6.5	289 150	495 0.5
Co	12 2.4	14 0.5	34 0.5	114 nd	8.7 1	23 3.2	7.2 0.5	44 0.5	4810 6	2670 0.5	1110 17	1180 12
Cu	580 42	1050 16	460 16	630 25	680 12	1600 38	320 20	390 34	5500 194	9500 42	1240 280	800 249
Fe %	4.9 0.19	13 0.27	3.6 0.23	11.2 0.41	22 0.28	24.8 1.1	2.2 0.32	1.7 0.11	54 3.6	55.6 4.8	13.4 1.4	51 25.2
K	29100 300	28300 800	18200 400	4200 230	2300 200	23000 1600	20800 2700	24900 2100	1400 nd	7700 nd	3800 300	14100 nd
La	1220 41	570 47	550 28	659 38	879 53	708 79	456 66	664 24	1950 2	1310 5	198 99	393 8
Mg	900 50	3500 100	2400 50	3100 50	1200 50	1400 200	3000 50	3100 100	2000 nd	3200 nd	3800 200	6500 600
Mn	83 2	640 8	27 5	330 7	246 4	980 60	50 6	95 8	860 29	1220 18	1190 53	1060 51
Mo	14 nd	18 nd	11 nd	nd nd	14 nd	12 nd	14 nd	30 nd	20 nd	16 nd	nd nd	nd nd
Na	590 230	840 50	460 123	2130 330	710 195	580 197	710 290	400 50	350 nd	1860 nd	1890 340	950 138
Ni	30 nd	34 nd	48 nd	71 nd	37 nd	42 nd	nd nd	380 nd	970 10	450 10	165 10	165 10
P	900 50	700 50	400 50	700 50	600 50	600 50	400 50	300 50	3900 100	3500 50	700 100	2400 700
Pb	990 40	172 8	229 17	212 22	490 22	88 6	175 5	53 22	1060 28	5200 28	143 42	37 6
S	580 50	580 50	9900 50	20000 229	560 108	740 50	280 50	430 50	2800 143	1060 106	280 50	800 290
Sb	2.7 nd	2 nd	8.4 0.1	3 0.4	7.4 0.2	6.7 0.2	1.8 0.1	2.2 0.2	74.7 0.5	5.6 0.5	1.9 0.1	2.6 0.5
Si %	43.5 26.6	42.5 30.2	43.6 27.2	41.4 28.3	46.4 19.2	44.6 25.4	37.8 27.4	43.3 33.3	44.5 1	40.8 1.3	39.5 27.3	21.9 4.5
Ti	7600 400	8000 1300	6400 1800	6400 700	12800 1400	11800 2500	7100 3400	5700 1700	200 50	3800 50	5400 2200	1400 400
Th	45 6.3	50 11.4	33 8.4	28 4.5	65 2.3	62 10	47 18	31 11	17 0.3	30 0.6	24 13.9	17 1
U	10.8 1.3	7.3 2.6	5.4 1.4	2.7 1.2	12.9 2.5	12.7 2.1	7.9 2.3	4.5 2	22 0.7	19.4 1.3	4.9 1.6	5.5 2.2
W	1310 56	92 45	263 22	140 21	948 64	190 42	52 27	819 17	4340 24	5350 10	130 11	1550 34
Zn	250 34	152 13	72 10	180 16	16 2.7	10 2	280 18	104 32	480 6	180 2	23 2	82 23

Table 3 Range for Selected Elements

Note. i. except Fe and Si, all concentrations in $\mu\text{g/g}$.
 ii 'n.d' - below detection limit.

the West Limb gossan represents remobilised sulfide, as seems probable from the grain size of carbonate and pyrite, it is possible that the silver content of that locality was rather higher due to the presence of increased concentrations of sulfosalts.

Mann and Nickel, and Gray comment on the dissolution of silver from gold alloys and on the significance of pH in the oxidation regime. A higher pH permits the formation of (short life-time) solubilising sulfur species which on oxidation are likely to deposit a silver-gold alloy, whereas a low pH will lead to separation from gold, and usually incorporation into a host mineral (e.g. a jarosite) or deposition as a halide salt; it is deposited less frequently as the native element. Thus, the silver content of gold present in the oxidised rocks is controlled largely by the chemical regime during oxidation.

It can be anticipated that silver which is not alloyed with gold will be present in the oxidised rocks mostly as the bromo-chloride or perhaps bromide. These are very much less soluble than silver chloride (cerargyrite) and it is perhaps significant that bromine was reported in the naa data for a number of the samples.

It is possible that more subtle distributional effects would be seen if an analytical procedure with a lower detection level were to be employed. Other studies have shown that a detection level of 0.1ppm is more appropriate and particularly when the rocks are mature and pervasively leached.

Arsenic.

Arsenic concentrations are high, in absolute terms, in the gossans, except for those which are low in iron; the latter, however, are also quite significant if the arsenic content is normalised to iron. Considering the high concentrations, distinct oxidate minerals are surprisingly rare. In the profiles, the concentrations are rather lower but so too is the iron content.

There is general correlation with gold mineralisation, but the data sets also suggest a zonation in arsenic along the East Limb. Whilst it would not be unexpected to observe variation in the arsenic content of the primary mineralisation, or as a result of remobilisation, the weathering regime itself can control the behaviour of arsenic subsequent to oxidation. There are two aspects to this:

Firstly, arsenic concentrates at the oxidation interface both in oxidate species (in the anionic form) and on reduction as the element or as one or more of the arsenides. The presence of cobalt, in particular would favour the latter. Subsequent change in the water table makes the secondary minerals again accessible to oxidation with a changed ratio of elements.

Secondly, the adsorption of arsenic by the ferro-oxides is favoured by lower pH. Thus if oxidation, or deposition of the iron oxides takes place at a higher pH, partitioning into the solid phase will be less favoured, and there is some evidence to suggest that samples

with a higher initial carbonate content do carry less arsenic. It is possible that this is a reflection of the primary compositions but if such samples do represent a remobilised assemblage, see above, the probability is for a higher, not lower, primary arsenic content.

Gold

Many of the surface samples carry visible gold and only five of those collected contain less than 200 ppb. The profile samples also show high concentrations in the reef intersections and in some cases in the footwall; the latter can be related to the primary mineralisation. The data cannot be taken to be fully quantitative because of the obvious sampling problem, most particularly with the West limb gossans. There is clearly a wide range in the particle size of the gold which ranges from mm. to a few μm .

Gold from a selection of the more visibly auriferous West limb gossans carries significant silver (mean 10 wt%), although the sampling was biased to larger particle size. This is, however, in line with the data reported by Mann and Nickel for the Pit-4 area.

Mann and Nickel concluded that a high proportion of the gold from the East Limb of the MVR is secondary on the basis on its low silver content, whereas that collected from the West Limb, which contains approximately 10% silver, was assumed to be primary. Two principal factors might contribute to this apparent difference. Firstly, the East Limb and is well developed with a thickness generally in excess of 1m. and dips steeply whereas the West limb dips at a shallower angle and is much thinner. Secondly, the particle size of the gold in the West Limb gossans is quite large and this might apply also in the adjacent Pit-4 area. Thus the East Limb gold has been exposed to the effects of aggressive weathering for a longer period and very probably of greater intensity.

The mineralogy of the West Limb could also be quite important, allowing that the gossan does in fact represent typical mineralisation. Thus the oxidation of the larger grained pyrite might have taken place more slowly such that the carbonate gangue and the ground water, presumedly in equilibrium with the carbonate bearing host-rocks, would have together restricted the development of acidity. The presence of oxide pyrite-pseudomorphs indicates an environment of higher pH.

Although the timing of the weathering of the Telfer deposit is unclear, the present day groundwater from the MVR and from the E reef (see table above) is not especially saline (0.05M), and is evidently buffered by carbonate to a pH of 7. Thus it would be most unlikely that gold is presently, or recently, mobile as a halide complex within the upper oxidation profile. On the other hand, mobilisation as a thio-species complex would be favoured by a high pH buffered groundwater and by the carbonate content of the mineralisation and of the host rocks. The very high gold content and the

distinct 'plumbing' of the Telfer system seem to indicate effects other than those due to (near-surface) lateritic weathering as have applied in the Yilgarn block.

Telfer Water Analysis¹

	E-Reef	MVR
	mg/l	mg/l
Ca	149	124
Mg	95	100
Na	340	395
K	42	29
Cl	739	752
SO ₄	371	429
HCO ₃	145	88
pH	6.4	7.3

The manner in which gold might be transported in a system such as at Telfer is clearer in abstract than in practice. If one considers the halide transport model, the oxidation of pyrite at the weathering-front is required to generate an excess acidity sufficient to allow the oxidation of gold (alloy) in the presence of the halide complexing agent. But if the system is in equilibrium, the presence of any sulfide will ensure that the Eh remains low and thus outside the oxidation field.* A more plausible situation exists during the oxidation of *perched* sulfide blocks or fragments (but only if the rate of ground-water flow and its buffering capacity cannot neutralise the slowly oxidising sulfide). The low-pH oxidation products will percolate downward through the underlying oxidised zone and the chemical regime could therefore be within the oxidation field for gold and its alloys. The rate and extent of dissolution might be expected to depend on particle size and alloy composition. Precipitation of low-silver gold will occur when the auriferous solution encounters the low Eh supergene zone, most probably at the nucleation sites presented by pre-existing gold particles. A variation of this second mechanism would invoke the intermediate formation of a jarosite, or salt of a trivalent cation, which on subsequent dissolution might generate a local low-pH (due to cation hydrolysis) within the oxide zone.

Alternatively, or in addition, a thio-species most likely thiosulfate, acts as the complexing and solubilising agent having formed at the oxidation front in a higher-pH regime as buffered by carbonate and other minerals with a high rest-pH,. While it

¹ Telfer Project data.

* The behaviour of 'invisible' gold within a sulfide host is almost certainly more complex, and is outside the scope of this present discussion.

would be possible for precipitation to occur due to formal oxidation, see for example Gray, the behaviour of thiosulfate is complex in the presence of heavy metals and it is by no means certain that other mechanisms do not exist; in particular, microbiological influences cannot be ignored. But again it is almost certain that the gold will precipitate or aggregate at pre-existing nucleation sites. The composition of the secondary gold is effectively indeterminate in these cases since non-sulfide silver would also have been taken into solution along with the gold. (Whether the thiosulfate mechanism is in reality effective in a complex natural system with substantial concentrations of heavy metals such as at Telfer, however, remains to be demonstrated.)

In either of the above cases the gold most readily attacked will be that which is most finely divided and that with the higher silver content.

The information presented by Mann and Nickel indicates a predominance of low-silver gold, perhaps suggesting that the low-pH/halide model has been effective. However, as stated above, this appears to be incompatible with present day groundwater conditions and would imply that the past condition was more saline. There is little mineralogical or chemical evidence (apart from the low-silver gold) that this occurred. However, some gold, considered to be secondary on textural evidence, was found to contain up to 10% silver; this may perhaps suggest that the moderate-pH / thio-species model has also been active.

From a practical point of view, it seems that the redistribution of gold serves to cause zonation in grade and most likely a coarsening of grain size. While these effects may be critical in a low-grade deposit, they would be of lesser importance at Telfer.

Bismuth.

Bismuth is at a significant concentration in many of the surface samples, but without extreme values and it is notable that it is weakly anomalous in W.Dome and Fallows Field samples, with some indication in the E1 reef. The element is also evident in the profile samples, but there is an indication of lateral zonation, as with arsenic, and of increased concentration with depth. Bismuth is dominant over antimony in the Telfer rocks. It is not closely associated with the iron-oxides in the oxidised zone and trends to lower concentration in mature gossan. The observation of an increased concentration with depth is in accord with this.

Cobalt.

Cobalt is highly variable, with some samples containing surprisingly high concentrations; the variability is rather greater than that of copper. It is anomalous in most surface samples including those from W. Dome and there is a correlation with iron. In contrast, the profile samples, including the 'channel' samples at 11940N, are barely anomalous with perhaps the one exception at 11650N. This last near-surface

profile carries moderate concentrations of cobalt in the upper part of the interval, where carbonate is dominant.

There are three factors to be considered regarding the distribution of cobalt; the primary dispersion, the enrichment in the secondary zone and its mobility during the early stages of weathering. There is little or no information on the primary dispersion, but it is quite likely that the secondary enrichment was less than uniform and, importantly, the retention or sorption of cobalt by the iron-oxides is pH controlled. Thus a lower pH is unfavourable for retention of cobalt, and the leached nature of much of the profile MVR shows that this was the case. This is in contrast with much of the gossan where the oxides remain in-situ. Conversely cobalt may be trapped by solution-transported iron oxides especially where the manganese content is higher. The fault ironstones from the East Limb however are low in cobalt.

Copper.

Copper is present in moderate to high concentration in the majority of the gossans and there is the expected correlation with iron. Despite the arsenic and carbonate associations, there is little visual, or other, evidence of copper oxidate minerals. This might be taken to indicate a relative maturity for the surface rocks.

In contrast with cobalt, the profile material is strongly anomalous in copper, and over wider zones. This is probably due to a greater degree of incorporation by the iron oxides on initial oxidation, but also suggests that oxidate phases might occur sub-surface, as would be favoured by the ground-water composition. Visual recognition, however, is difficult in the presence of the clays..

Although the concentration of copper in primary sulfide is low, and would afford only a low concentration in directly derived gossan, very much higher concentrations have resulted from supergene enrichment. This is reflected in the oxidation profiles and in other of the iron stones. The copper distribution for the East limb of the MVR is reported by Goellnicht et al., thus:

MVR	oxide/supergene sulfide	50 000 - 100 000 ppm
	supergene sulfide	20 000 - 60 000
	hypogene sulfide	0 - 1 000
stockwork	oxide/supergene sulfide	2 800
	supergene sulfide	4 200 - 28 000
	hypogene sulfide	1 400 - 2 000

Iron.

Whilst the majority of the surface samples are iron stones, the profile samples are, with few exceptions, of a lower iron content. The channel samples however contain

narrow zones of higher iron content, but these are very friable in nature and would undergo considerable mixing and dilution during drilling (as in grade control drilling).

There is a further discrimination between the profile and surface samples, much of the present surface material is compact and carries pseudomorphic oxides after sulfide, indication that oxidation took place at a higher pH and that the oxides were immediately precipitated. But, as already noted, the channel samples, which might be regarded as representative of the MVR in-profile, are texturally open, and friable, as is to be expected when oxidation takes place at a lower pH.

Mercury.

Mercury was not found in the surface rocks at levels significantly above a general background of 10ppb, but is present at higher concentrations in subsurface samples taken from drill core. For the MVR intervals:

ddh 449	6m	350ppb
	96.65m	100ppb, sulfide
	97m	105ppb
ddh 397	189.4m	75ppb, sulfide
	259.5m	120ppb

In contrast, the mercury content of partly oxidised, chalcocite bearing zones in these holes is much greater.

ddh 449	94.5m	32ppm (fine pyrite)
		3ppm (coarse pyrite)
ddh 397	374m	157ppm (sulfide - fault zone)

These high concentrations are almost certainly due to secondary enrichment. It appears that the mercury content of the mineralisation at Telfer is generally low.

Manganese.

Manganese levels, in the profiles studied, show a depth effect with a maximum content of 330ppm in those near-surface and 980ppm in the deeper zone. The range in maxima for the surface samples is 860 to 1220ppm, but with one West limb Pit-4 outlier of 4070ppm. The dioxide can be a significant oxidant, and is often quoted in this context in reference to gold; it also has an affinity with cobalt in soils and in weathered rock. However manganese seems not to play a significant role in the rocks examined to date.

Molybdenum.

The molybdenum content of surface rock and of profile samples range to 20 and 30ppm respectively. In the oxidised state, molybdenum is anionic and its association with iron is favoured by a lower pH during precipitation, as evidenced in the data.

The profile information is ambiguous, with high concentrations indicating either an effective retention during reef-sulfide oxidation (which is likely), and/or that there has been accumulation from solution if the groundwater pH is or has been sufficiently high. It is possible that the molybdenum concentrations are higher at the upper contact of the MVR in the profile intersections.

The relatively high levels of molybdenum which must have been present in the primary rock is not genetically definitive since VMS mineralisation may contain appreciable quantities of the element.

Nickel.

Nickel occurs at only low concentration in the profile samples (max. 71ppm); this cannot be accounted for solely by the lack of iron-rich zones in the material sampled. The iron stones, however, carry some 800ppm nickel, and with a strong correlation with cobalt. This association is also present in the profile set, but is less pronounced because of the low concentration of both elements. Nickel, too, is less effectively trapped at low pH and is relatively mobile during oxidation. Thus the iron oxides that contain higher concentrations of nickel are likely to be those which formed pseudomorphically, or remotely, at a higher pH.

Lead.

Lead is variable in concentration in the surface weathered rocks; some samples from the MVR show high levels, up to 5200ppm, but the mean concentration is not high. Both the E1 reef and Fallows Field have lower but significant concentrations of lead. The W. Dome samples are the lowest of the suite.

Lead is also present in the profile samples. Over the East limb the higher concentrations are found near-surface (max. 990ppm) while the West limb profiles show a maximum of 175ppm.

Sulfur.

The sulfur contents of the surface samples are generally within the bounds of 1000 to 2000ppm as commonly encountered in mature gossan in association with iron-oxides. The profile samples have an association with calcium in the upper horizons of the profile, reflecting the presence of gypsum.

Antimony.

The antimony content of the surface samples rarely exceeds 10ppm but there is good discrimination due to the high sensitivity of the analytical method. It is relevant

that the Fallows Field samples are significant within this suite since there is no immediate indication of other than a low sulfide content. The antimony concentration in the profile samples is also low, (max. 8, mean 2ppm) but there is a general correlation with the extent of development of the mineralisation.

Antimony was probably only a minor trace element in the primary mineralisation and because of its high mobility only low concentrations have been retained. In general, it is a useful pathfinder for gold, but in these rocks it is clearly subordinate to bismuth.

Tellurium.

Whilst tellurium was not determined in the weathered rocks, it is probable that the data would be useful since it has been shown in some circumstances tellurium behaves as a residual indicator in its association with iron-oxide. Tellurium is anionic and hence its adsorption is favoured by low pH. The concentration of tellurium in fresh MVR is about 1.5ppm.

Selenium, Tellurium and Tin in Fresh MVR.

		<u>Selenium ppm</u>	<u>Tellurium ppm</u>	<u>Tin ppm</u>
ddh 449	94.4m	4.3	1.6	1
ddh 397	374m (fault)	2.5	1.5	100

Tin.

Tin was not determined in the weathered rocks but it too can provide useful information. It is a resistate oxidate-mineral in gossan, whether as primary oxide tin or as cassiterite resulting from the oxidation of stanniferous sulfide. The samples, above, gave concentrations of 1ppm and 100ppm respectively (note that the latter is a fault intersection). It is relevant that Volcanogenic Massive Sulfide deposits can carry appreciable tin and there is some suggestion that its distribution is bimodal, occurring both high in the sequence and in the basal copper system.

Zinc and Cadmium.

The zinc content of surface gossan and weathered rock is low with a median of rather less than 50ppm. In the profile sections zinc varies with the mineralisation, but at low absolute concentrations (2 to 260ppm). Cadmium is generally proportionate to zinc and is below detection limits in many of the samples.

These low concentrations result both from low primary concentrations and from the tendency of these elements to be leached from the system during, and subsequent to oxidation.

4.2.2 The non-chalcophile elements.

Aluminium.

Aluminium is an indication of the initial phylosilicate content of the sample. In the weathered rocks it may persist in clays, some neo-formed, or be present in aluminous iron oxides; the latter is more probable when the weathering rock has been subjected to a low pH either because of a high sulfide content or consequent to replacement ferruginisation.

Aluminium contents are generally low in the gossans of the E. and W. Limbs of the MVR but are somewhat higher in the W. Dome and Fallows Field material (in aluminous iron oxides) probably as a result of ferruginisation. The higher aluminium concentration in the remainder of the surface set, and the the profile samples, is indicative of a higher primary clay content.

Barium.

Barium occurs at concentrations up to some 2000ppm in the surface rocks, although there is apparently no indication of barite in the mineralisation. In the profiles the data suggest a possible association with mineralisation.

Barium is somewhat mobile in the weathering profile and evidently precipitates in response to an increased sulfate concentration. Thus although the observed concentrations suggest that the barium levels may have been high initially, the concentrations now observed in the oxidised rocks may be due to precipitation of barium derived from the host rocks at a sulfate concentration boundary resulting from the sulfide oxidation. If barium anomalies are related to primary mineralisation the element might provide a further exploration parameter .

Boron.

Boron was not included in this study. Preliminary analyses found 8ppm boron in two West limb iron-rich gossans, and 50ppm in iron-poor Fallows Field samples which contained casts, possibly from tourmaline.

Calcium.

Calcium is generally low in concentration in the weathered rocks (see data tabulations), except where gypsum or carbonate occurs in the higher levels of the profile. The profile (11650N) shows a gradation from largely carbonate control near surface to a largely sulfate control some 2m lower.

Lanthanides.

The lanthanides are present at significant concentration in the profile and appear to be associated with the mineralisation. Concentrations in the iron-rich rocks, however, are generally quite low, but reach >4000ppm (cerium plus lanthanum). Similarly high

maximum concentrations are found in the profiles with the highest concentrations at the upper contact of the reef; variation within the reef is cryptic.

The data suggest that there has been some separation of the light and heavy lanthanides across the reef, perhaps due to separation during weathering; this would imply some dissolution of the host mineral. It seems perhaps unlikely that there would have been two lanthanide bearing phases with very distinctly different end-member ratios but more precise information is necessary if this point is to be pursued.

The presence of these concentrations of a rare earth phosphate is interesting in itself, but the association with titanium minerals suggests a (primary) detrital origin, but information from more widely sourced samples is necessary if this is to be elucidated. Goellnicht et al. (1989) suggest that the phosphates are epigenetic in origin, which would require that they be restricted (essentially) to the mineralisation, but this model does not seem to explain the apparent distribution of the minerals within the reef. The question is relevant to understanding the depositional and regional environment.

Potassium.

Potassium contents are generally low in the surface materials, but are in the percent range within the profiles. It is principally a component of the clays, but could contribute locally to jarosite. A number of the surface rocks contain weathered mica but, the spatial extent is not defined and it is unclear whether this is an alteration effect related to mineralisation or is attributable to local or regional metamorphism.

Magnesium.

Magnesium is not found at concentrations above some 4000ppm, but would seem to indicate the presence of a zone of smectitic clays, and a locally higher equilibrium pH within the weathered zone.

Phosphorus.

Phosphorus is present in moderately high concentration in many of the surface samples, up to 3900ppm, but in very few instances is it associated with elevated levels of the lanthanides. There is also indication of association with lead in some situations. In contrast, in the profile samples there is clear evidence of zonation of phosphorus and of association with the lanthanides (see below).

It seems that phosphorus is present both as a primary resistant mineral, such as monazite or xenotime, and also in an association with the ferro-oxides. The association with lead probably reflects the stability of some oxidate phosphate minerals.

Scandium.

Scandium is enriched in a number of the surface rocks, with concentrations to some 500ppm, though generally an order less. There is an association with iron-oxides which is reasonable on the basis of its chemical properties, but there is also an

association with phosphorus and with tungsten possibly due to the presence of residual minerals.

Titanium.

Titanium reaches concentrations in excess of 1% in the clay-rich surface and profile samples but the values are much lower in the ironstones (200ppm max. in the West limb gossans). With the proviso that information is not available for host sediments remote from mineralisation, high concentrations appear to be associated with the reef. A particular interest in titanium is in the association with thorium, below, which would suggest that the element is now, or has been in a chemically active form which has been adsorbed by or co-precipitated with an oxidised form of that element (perhaps anatase).

Thorium.

The concentration of thorium is relatively low in the ironstones (typ. < 5ppm in the West limb gossans), but the low-iron surface rocks and the profiles both have maximum values in the tens-of-ppm range (max. 65ppm). A weak association with phosphorus and tungsten probably reflects the presence of residual phosphate minerals. There is also a strong correlation with titanium, see above, which has also been observed elsewhere by K. M. Scott (pers. comm. 1990) during electron micro-probe analysis.

Uranium.

Uranium and thorium show contrasting behaviour in the oxidised zone, a reflection of their divergent chemical properties. Uranium has a principal association with the iron oxides, whereas thorium associates with titanium; consequently the relative concentrations of uranium and thorium are largely dependent on the initial titanium and final iron contents of the weathered rock. Many of the iron-rich surface rocks contain more than 5ppm uranium. There appears to be a weak association with scandium-phosphorus-(tungsten), and since this association exists generally in primary phosphates, it is possible that the oxidised zone association is due both to this but, more importantly, to sorption by iron oxide. A weak correlation between uranium and vanadium may, in this instance, reflect a common association with iron oxides.

The median level for uranium for the profile set is rather lower and the concentrations have a lesser spread than the surface samples but the elemental association appear similar.

Tungsten.

The tungsten contents of the surface rocks are highly variable (range 10 to 5350ppm), but with a high mean value. Tungsten-rich samples tend also to be enriched in all the chalcophile elements. This does not imply that tungsten was initially present as

the sulfide, but rather that in the oxide form, tungsten has acidic properties and like phosphorus, has both an association with iron oxides and salts which are mostly sparingly soluble.

Significant tungsten concentrations (range 17 to 1310ppm) occur in the profiles with a distribution that suggests an association both with the lanthanide and chalcophile groups. The association with the lanthanides may be due to either or both the spatial distribution of the primary lanthanide- and tungsten-bearing minerals and to the presence of tungsten in some phosphate minerals.

The association of tungsten with primary gold mineralisation is very widespread, commonly as scheelite, but no information was available regarding the nature of the tungsten distribution in the uppermost levels of the Telfer mineralisation.

Zirconium.

The surface ironstones have relatively low zirconium contents typically <25ppm, but the more clay-rich weathered rocks generally contain 100 to 300 ppm. In the profiles, zirconium is generally in the range 50 to 400 ppm. The relationships are not clear, but the zirconium contents vary inversely with iron when the latter is at higher concentrations.

Zirconium was probably present as zircon of detrital origin.

5. RECOMMENDATIONS FOR FUTURE WORK

The present study has in effect been a preliminary investigation which has opened-up a number of questions.

The first area of uncertainty relates to the nature of the Telfer Deposit itself: its physical nature, the nature and mode of occurrence of the minor and trace elements and, hence, the manner of formation (and comparison with unmineralised equivalent sequences) - questions which are relevant to regional exploration.

The second concerns the more detailed weathered zone geochemistry of the various elements which have been described as significant in this study. This is needed to confirm concepts which have been put forward and to suggest how the geochemical controls so defined might be employed in an exploration context. It seems that there is a need to understand better those elements which can act as halo or remote indicators, as well as those which are residual.

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