AGSO

AUSTRALIAN GEOLOGICAL SURVEY ORGANISATION

NOTES ON A VISIT TO TELFER: JULY 11-12, 1995

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Professional Opinion 1995/3

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GEOSCIENCE FOR AUSTRALIA'S FUTURE

A Research Bureau of the Department of Primary Industries & Energy

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1.1 Introduction

At the invitation of Newcrest Mines Limited I visited the Telfer Gold Mine from Tuesday July 12, returning on Thursday morning July 13th. Whilst at the site, I visited the open pit accompanied by Don Thompson, and with Don, Nick Langsford and Campbell Mackey visited sites of the Mount Crofton Granite at Mount Crofton, Minyari Granite at Minyari Hills, and the Wilkie Granite some 15 kms east of the Telfer mine. I also examined granite core in holes ORC 1-6. These notes describe my thoughts on the sites that I visited, and also give some recommendations for some potential future work. I have prepared these notes at the request of Nick Langsford and they contain information that is essentially off the top of my head. Please note that they are not meant to be comprehensive and that I have not had time to validate anything that is within them. I prepared these at the Newcrest Office in Perth on Thursday afternoon of July 13th and that I did some minor refinements to them back at AGSO on July 17th.

1.2 Previous AGSO work

1.2.1 Data Held within AGSO

Within AGSO's ROCKCHEM data base there are 75 whole-rock geochemical analyses of granites from the Telfer District. These were done in collaboration with Nicky Netherway (nee Goellnicht) when she was doing her Ph.D, when AGSO agreed to do additional trace elements on her samples. AGSO in fact redid all her trace elements for her, but I note that none of this data is in her Ph.D, and the trace element values between the two data sets are in some instances discrepant, particularly for Sn and Ba. (I have since checked with UWA and they acknowledge that they do have a problem with their Ba). A copy of the AGSO data on these granites was sent to Newcrest in 1992, and when we have fixed the location problem we will send you another copy.

1.2.2 Interpretation

The most notable features in the granite geochemical data were the high abundances of Rb, U and Y at high level of SiO_2. These trends were shown in two main granite types: the granites of the Mount Crofton area and the 'Desert's Revenge Granite'. Mineralogical descriptions of the granites also highlighted the presence of magnetite and that there was traces of hornblende present. These observations implied two things, firstly that the primary magma is oxidised, and secondly that the granite has also undergone significant fractionation. Both features are required for granite-related Au ± base metal mineralisation. The high oxidation state of the granite is important as late stage magmatic fluids derived from these granite types are typically enriched in Au, Cu, Bi, W, Mo, REE, U and Se.

In AGSO we had previously noted that the geochemical data from the Telfer district has characteristics more common to granites of the Pine Creek District, Tennant Creek and the Tanami Region than to those of the Olympic Dam and eastern Mount Isa Region (Appendix 1).

1.2.3 The Granite Related Au ± base metal Mineral Systems concept

Work to date in AGSO on compiling empirical evidence on Proterozoic granite-related Au ± base metal mineralisation has noted that with the exception of Olympic Dam, none are hosted within granite, and that for Olympic Dam the host is not pristine granite but a highly altered assemblage. Most Au deposits are well outside of the granite contact and can be up to 5 kms away. We have also noted that there is an important host rock control on precipitation, with ironstones being important hosts in the Tennant Creek and Pine Creek areas, and graphitic hosts or methane rich ground waters being important in Pine Creek. These are also now considered important in Tennant Creek.

For exploration we have thus emphasised that in the Proterozoic, the granite-related Au ± base metal mineralisation is part of a regional mineral system and that there are 3 important regional scale components in any granite related-mineralisation. These are:

1) the granite system
2) the host rock
3) suitable structures to move the fluid from the granite to the host.

1.3 Some Thoughts on the visit to Telfer

1.3.1 The Mine Visit

The Telfer pit reminded me very much of a visit to a series of deposits in Pine Creek. The structure was similar to the Goodall and Enterprise Pits, whilst the rock types and the mineralisation in veins and fractures resembled exposures that I had seen in the Batman deposit. Although the general opinion was that the main cause on precipitation at Telfer was a drop in pressure and temperature, it seemed to me that there was some host rock control as well. This was particularly evident in the pod of mineralisation in the anticlinal closure at Pit 9 south of West Dome. Here the mineralisation was hosted by the Upper Vale Siltstone, and only passed into the overlying Rim Sandstone where there were fractures. Some alteration had extended into the Rim Sandstone, but the main mineralisation was hosted by the unit below. This suggest that the unit below had reacted in some way with the mineralising fluids, but that the Rim Sandstone was either impermeable and/or unreactive to the mineralising fluids.

The idea of there being some host rock control at Telfer seems to go down like a lead balloon. However, most of the rocks exposed in the pit are highly weathered, and the presence (and also subtle changes in the abundance) of reactive minerals such as carbonate, graphite and sulphide, each of which could have an important effect not only on what metal was precipitated, but also the grade and tonnage may be being missed.

1.3.2 The dominance of carbonate

Compared to other Proterozoic mineralised areas (e.g., Tanami, Pine Creek, Tennant Creek) the one striking feature of the regional geology surrounding the Telfer deposit is the amount of carbonate. This contrasts say Tennant Creek, which is an iron-rich, siliciclastic basin and Pine Creek which is dominated by siliciclastics which contain some graphite and iron-rich rocks. In most of the Proterozoic areas, carbonates do not make good hosts and very little of the Au mineralisation is actually hosted by carbonate rocks.

1.3.3 The Composition of the Ore Fluids

The abundance of sericite and some reported kaolinite (provided it is not weathering) points to an acid to neutral fluid. Red K-feldspar veins at O'Callaghans overprinted the sericitic alteration. These reddish veins suggest an oxidised ore fluid of similar composition to the Pine Creek and Tennant Creek areas, particularly when the high salinities are also taken into account. The change from sericitic to K-feldspar alteration was also suggesting that the pH of the fluid was becoming more neutral as it evolved, possibly as a result of interaction with the abundant carbonates.

1.3.4 The Crofton Granite

In the site that I visited, there was considerable petrographic variation. This granite was exactly as Nicky had described it to me: a pink to red, magnetic granite with a reasonable amount of heterogeneity. Provided that the pink colour is genuine, and not a function of weathering, this is also a common characteristic of oxidised granites. In these, the pink colouration of the K-feldspars is due to the presence of hematite dusting, and is common in oxidised, K-feldspar bearing granites. The heterogeneity is also indicative of a fractionating granite system as non-fractionating granites tend to be more uniform in composition.

1.3.5 The Minyari Granite

This was reported by Goellnicht in her Ph.D. and subsequent papers as S-type and ilmenite bearing, even though it does contain hornblende (which is a more 'I-type' characteristic). I worry about the S-type classification, as she stated they were S-type because of the ratio of molecular $Al_2O_3/(CaO + Na_2O + K_2O)$ alias the ASI ratio, as being high. Checking her results, the ratios are all <1.1. The cut off for S-types is that the whole suite is > 1.1. This common misconception is because Chappell and White have said that all S-types are very peraluminous and have ASI >1.1. In Shand's 1933 traditional definition of peraluminous, the ASI is >1.0, but Chappell and White were actually qualifying it to emphasise the highly peraluminous nature of the Palaeozoic Lachlan Fold Belt S-type granites.

The presence of ilmenite in the Minyari Granite interesting as it usually indicates a reduced granite (and was also one of the reasons why Nicky called the Minyari Granite 'S-type'). On geophysics, the Minyari Granite is also a magnetic low. Although on the magnetics it plots within the main ENE trending belts of granite, extending from the magnetic granites at Mount Crofton, it is possible that it does not belong with the main Mount Crofton Group. The magnetics also shows a NNW trending belt of small non-magnetic granites including those termed Zero and Zero East. These could be a second cross cutting suite of granites that the Minyari actually belongs to. It is also possible that the Minyari Granite is part of the Mount Crofton suite, but has been locally reduced as a result of intruding reduced sediments. This is a possibility, as both are hornblende bearing. However, I cannot find out sufficient information on the mineralogical composition of the country rock sediments to see if this theory is a viable option.

Further sampling of the NNW trending suite could resolve which suite the Minyari Granite belongs to.

1.3.6 The Wilkie Granite

This granite outcropped so poorly it was impossible to say which suite it belonged to. On reasonable site was visited: this should be sampled for analysis.

1.3.7 The Deserts Revenge Granite

Samples from this granite were chemically very interesting as they showed enrichment in Rb and U and were high in SiO_2. The locations of these samples were in doubt, but the samples were found to be located within the western part of a circular magnetic high. In some maps, this anomaly is shown as consisting of two plutons, Deserts Revenge (on the west) and O'Callaghans (on the east), in other maps this anomaly is shown as consisting entirely of O'Callaghans Granite. Not only had Goellnicht used the two fold subdivision in her Ph.D., she had also placed the two sets of closely spaced data into two separate granite suites. Looking at the plots on Figure 1, I feel that the two are part of the one suite, and that the Deserts Revenge samples are more fractionated. The samples labelled O'Callaghans Granite came from the eastern edge of this anomaly, and probably represent an earlier, more mafic phase of the intrusion. The Deserts Revenge samples are from further into the anomaly and could represent a more fractionated core. I did not see the Desert's Revenge samples in core. The samples I saw of O'Callaghans were from the ORC drill holes. The granite was biotite bearing, but was also highly altered, with an early extensive sericitic alteration overprinted by a late, red-K-feldspar alteration in drill hole ORC 1. This red alteration was significant as not only did it carry visible molybdenite, it indicated an oxidised alteration fluid. This red colouration of the K-feldspars is due to the presence of hematite in the alteration fluid and is very indicative of oxidised fluids which are typical of these Proterozoic Au ± base metal systems.

The core that I was shown was related to a W prospect, which I gather was Au free. This metal distribution around the O'Callaghans Granite is also characteristic of the Pine Creek Inlier, with W and M occurring in the alteration at the edge of the granite or else hosted by skarns adjacent to the granite (Figure 2). Au is always located some distance away, and the low Au tenor of the O'Callaghans prospect is not surprising at all. The presence of this oxidised fluid is at variance with the Ph.D work of Rowins who suggested a reduced fluid was responsible for ore deposition at Telfer. In most of the other Proterozoic granite related Au ± base metal deposits the fluids are characteristically oxidised as is also supported by the metal assemblage of Au, Cu, Co, W, Sn, Mo, REE, U and Se.

1.4 Recommendations for further work:

1.4.1 Sampling of the granites

Further granite sampling is warranted to solve a few outstanding problems. As AGSO have already done the bulk of the granites analyses in the district, I will offer to do the following so that we do not have to cope with inter-laboratory problems:

1) More samples of O'Callaghans and Deserts Revenge to see if the two are part of the one system

2) Sampling of the more mafic varieties as all of Goellnicht's samples are very felsic and she did not sample many mafic types.

3) Sampling of the northwest trending non-magnetic granites to see if the Minyari Granite is part of that suite or the Mount Crofton Suite.

4) Deliberate sampling of altered granites including at least the red K-feldspar phases and the sericite altered material. This is needed to confirm what the extreme alteration patterns are, so that any subtle alteration that may be present in the fresh samples can be detected.

1.4.2 Fluid Inclusions:

A useful study would be to do a pilot study of 4 samples for Laser Raman work. This technique will pick up the composition of any gas phases present including methane, which when present in the connate fluids in the Pine Creek and Tennant Creek regions forms an effective precipitation mechanism. The technique can also identify the composition of the solid phases present including hematite. The four samples would be

1) quartz veins associated with the red K-feldspar in the ORC 1 drill hole.

2) the sericitic alteration within the O'Callaghans granite to confirm the composition of the alteration associated with the granite.

3) Two additional samples should be done from the pit including one associated with the sericite alteration (to look for hematite) and one which focuses on the fluid that is supposedly dominated by the connate waters.

AGSO would offer to do these as part of a pilot study to determine if a more extensive study would be warranted.

1.4.3 Fluid modelling

In view of the interesting fluid modelling that has been done in Pine Creek and Tennant Creek, it would be worthwhile for someone to model the effect of this carbonate in the system and answer the following:

1) Does carbonate influence the transporting mechanisms ? (Some preliminary work has suggested that high carbonate can promote transport of Au, although this needs to be confirmed).

2) Does carbonate influence the site of ore precipitation ?

3) If the ore fluids are acid, does the high carbonate assist in creating secondary permeability by dissolution ?

This would be similar to the modelling that AGSO did in the Coronation Hill area (where Newcrest geologists also argued that there was no host rock control on precipitation !).

1.4.4 Mineralogical Characterisation of the Host Sediments away from the Mineralised Zone

This is essential. On previous experience I remain totally unconvinced that there is not some influence of host rock composition on the tonnage and grade and also the various metals that are precipitated within the Main and West Dome. I also base this assertion on the pod of mineralisation that I saw trapped in an anticlinal closure in Pit 9, south of West Dome. I could well be wrong, but I think it would be a worthwhile exercise to look at the distribution and abundance of reactive minerals (feldspar, carbonate, graphite, sulphide, magnetite, hematite, etc.) that existed within these units prior to the emplacement of the ore fluids. (For example, in some provinces the abundance of sulphide in the host rocks influences the distribution of Cu). Sufficient information for this exercise may be in Turner's 1982 Ph.D.

Better characterisation of the sediments could also useful for exploration. For example, the sandstones of the Rim Sandstone of the Telfer Formation contain albite, and hence away from the mineralised area on regional radiometrics have no response on the K channel. As albite is susceptible to alteration, near the mineralised areas, it shows as a K high due to sericitisation. By understanding the mineralogical changes that happen with alteration, some useful regional exploration guides may appear.

1.5 Summary

The Telfer region obviously has a fractionating oxidised granite system present. These granites have exsolved an oxidised, high temperature, low to neutral pH, high salinity fluid as is supported by the metal association of Au, Cu, W, Mo, REE and Sn. The next components of the mineralising system are the structure and the trap environment. To date exploration has focussed on the appropriate structure as precipitation is felt to be mainly controlled by pressure and temperature drop.

Even if precipitation in the Telfer Dome area is related to a drop in pressure and temperature, based on experience in other Proterozoic granite-related mineralised terrains, I feel that is important to understand the regional distribution of the reactive minerals, and look for regions where chemical reactions may have caused precipitation.

It is also critical to pin down the composition of the ore-forming fluids and also that of the connate brines that existed in the area. Once these are better understood, then it is possible to start to predict where appropriate host lithologies are likely to be present and look for sites where ***chemical*** reactions may have played a role in precipitating ore. That is there may be potential for other deposit styles that exist in other areas surrounding these fractionated oxidised granites than has been considered in the Telfer region. I feel that by comparison with the Pine Creek district there is potential for many other styles and types of commodities including shear hosted Au and various types of W and Mo deposits as shown in Figure 2.

Figure (1)

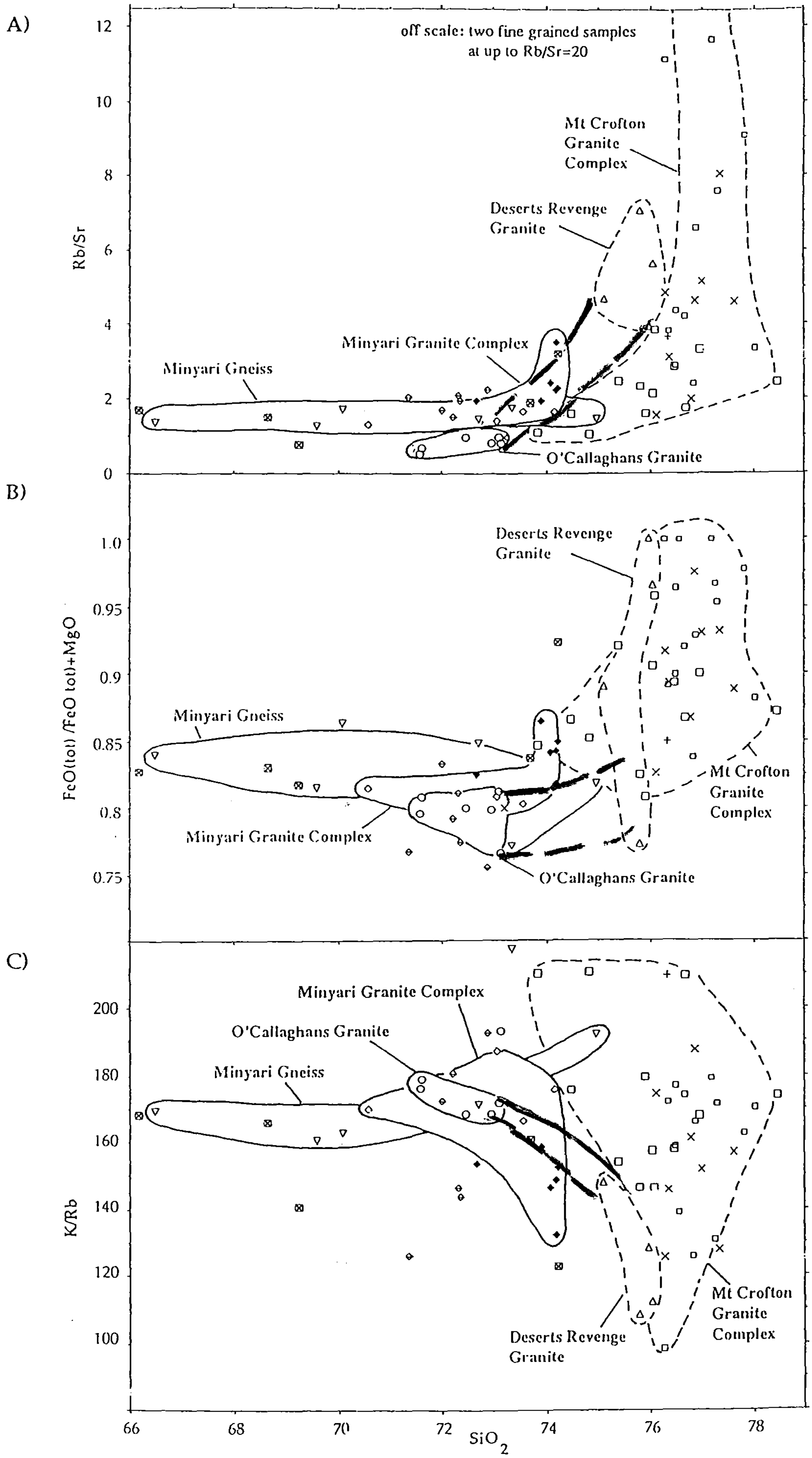

Figure 6.2. Harker variation diagrams (symbols are as for Figure 6.1). Dashed lines enclose data from the Mt Crofton Suite; solid lines enclose data from the O'Callaghans and Minyari Suites.

From Goellnicht Ph.D. 1992

Figure 2 From AGSO Bulletin 229.

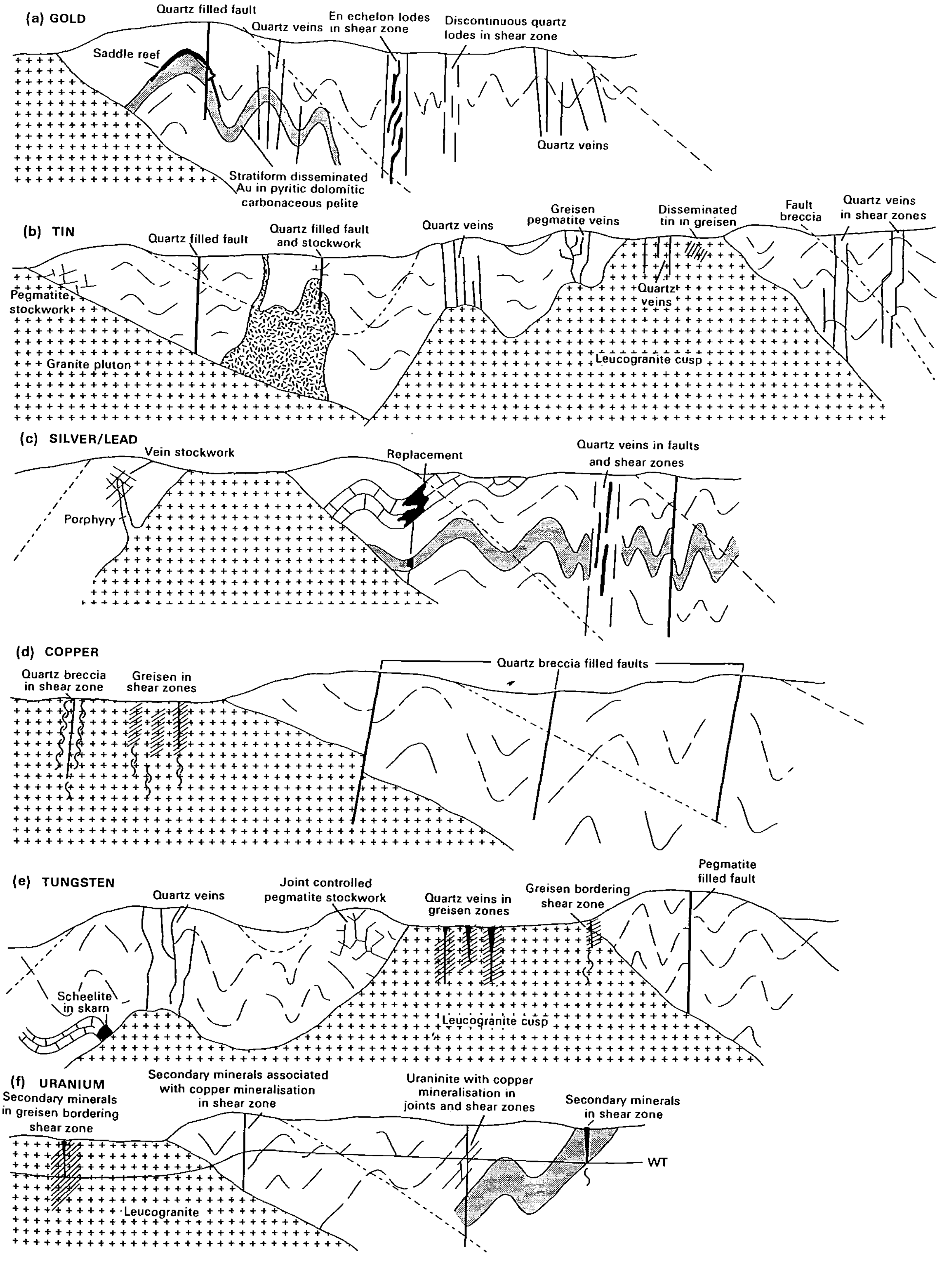

Fig. 38. Schematic sketch showing setting and major characteristics of hydrothermal deposits.

Appendix 1

GEOLOGICAL SOCIETY OF AUSTRALIA, ABSTRACTS NO.37
12th Australian Geological Convention, Perth, September 1994

EXPLORATION CRITERIA TO DETERMINE WHICH AUSTRALIAN PROTEROZOIC GRANITES MAY BE ASSOCIATED WITH GOLD ± BASE METAL MINERALISATION

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Summary - Proterozoic granites associated with Au ± base metal mineralisation in Australia have distinct geochemical characteristics from those which are not associated with mineralisation and also from magmas associated with porphyry Cu deposits. As most mineralisation is hosted in country rock up to 3 km from the granite body, the composition of these rocks has an important influence on whether there is economically significant precipitation of metals.

INTRODUCTION

As more exploration in the Proterozoic is focussing on hydrothermal Au± base metal mineralisation, granites are now being considered as an essential component of the mineralising system, even though mineralisation can occur up to 3 km from the granite body. An Australia-wide compilation shows that Proterozoic granites which have hydrothermal Au± base metal mineralisation within 2 to 3 km of the contact have many field, petrographic and broad chemical characteristics in common. For this paper, the term 'granite' is used to apply to all felsic intrusive rocks including diorites, tonalites, granodiorites, adamellites, and granites (*sensu stricto).*

SPECIFIC CHARACTERISTICS OF GRANITES ASSOCIATED WITH MINERALISATION

In the field, granites related to mineralisation are heterogenous, and individual plutons are often circular in shape. Some plutons consist entirely of leucogranite and have >74 wt% SiO_2. Pegmatites, aplites and greisens, indicating late-magmatic fluid saturation, are common in some of these more felsic end members. Some plutons are strongly zoned, whilst others are uniform and dominated by granodiorite to adamellite compositions. In any suite, the more mafic varieties contain magnetite, hornblende, and sometimes clinopyroxene. Where comagmatic felsic volcanics occur, they are usually compositionally distinct from their coeval intrusives. The granite intrusions have distinct and mappable contact aureoles up to 3 km wide, and upper amphibolite grade contact metamorphism is often recorded adjacent to the intrusions. Specific geochemical characteristics include a wide range in SiO_2 contents from at least as low as 56 up to 78 wt%. The more felsic end members have high values of Rb (>250 ppm) and U (>15 ppm), which increase exponentially with increasing SiO_2 whilst the K/Rb ratio decreases. In some areas Y (> 40 ppm) and Li may also increase with fractionation. The more mafic end members all have the alumina saturation index (ASI) below 1.1, increasing above 1.1 in some of the more fractionated members.

A review of ROCKCHEM, the whole-rock geochemical data base of AGSO, shows that granites from the following areas have the above signatures:

- Tennant Creek Block: several unnamed porphyries
- Davenport Block: Elkedra Granite, Devils Marbles Granite
- Granites Tanami Inlier: Lewis Granite and the Winnecke Granophyre
- Murphy Inlier: Nicholson Granite Complex
- Paterson Province: Mount Crofton Granite (Telfer area)
- Pine Creek Inlier: Cullen Batholith
- Mount Isa: Ewen Granite (limited data) and Williams and Naraku Batholiths
- Gascoyne: Minnie Creek Batholith (limited data)
- Stuart Shelf: various granites of the Olympic Dam Region

Within this listing, the granites are of two distinctive geochemical types. Most belong to Type 1, which is dominated by hornblende-bearing T-type. Type 2 is represented by the granites of the Olympic Dam region and the Williams and Naraku Batholiths of Mount Isa, which are high temperature granites and are dominated by red-coloured granites. Each geochemical type is associated with a specific mineral district. The mineral deposits associated with Type 1 granites have Au dominant with minor Cu± base metals (eg. Cullen Mineral Field, Telfer and Granites-Tanami areas), whilst Type 2 granites are associated with Cu + Au ± U (Olympic Dam, Ernest Henry).

THE IMPORTANCE OF THE COMPOSITION OF THE COUNTRY ROCK

In contrast to Phanerozoic porphyry-style mineralisation, Au ± base metal deposits associated with Proterozoic granites commonly occur in the adjacent country rock, and are not always hosted by, or near, the granite itself. The mineralogy of the host rock exerts an important control on the type of commodity precipitated. Carbonate-rich, but carbon-poor rocks, commonly host Pb and Zn mineralisation; rarely, if ever, do they host Au or Cu mineralisation. Au mineralisation is predominantly hosted by reduced (C- or Fe^{2+}-rich) rocks, including banded iron formations, mafic volcanics, magnetite-bearing felsic volcanics, earlier more mafic magnetite-bearing phases of the granite itself (rare), carbon-bearing rocks, sulphide-bearing shales and magnetite-bearing skarns which replace silicate, but not carbonate rocks. Possible causes of this preference for a particular host rock could be related to vapour/brine separation, where Au and Cu are preferentially carried in a S-enriched vapour phase, and will precipitate in reductant-bearing units: Pb and Zn are carried in a Cl-enriched brine, which will preferentially interact with carbonate hosts (Heinrich *et al.*, 1992).

STRUCTURAL CONTROLS

As deposits can occur up to 3 km from the granite boundary migration pathways are always along major fracture zones and faults. Therefore structural analysis of the areas surrounding the granite intrusions to identify dilatant, high permeability zones which focussed fluid flow, is essential to target potentially prospective areas.

EXPLORATION CRITERIA

Key exploration criteria emphasise granites of a specific type, and country rocks that are dominated by reducing hosts, such as rocks rich in magnetite, graphite and/or sulphide (although interaction with a reducing fluid could also cause precipitation). Exploration criteria should focus on the combination of appropriate host rock types with suitable dilatant structures, which show some potential linkage to the granite system. Larger grades and tonnages occur in the deposits hosted by Fe-rich lithologies, as opposed to those hosted by or near graphitic units. This is probably because firstly, the host ironstones are present in greater volumes than carbonaceous hosts, and secondly, the Fe-rich hosts are also more likely to fracture and brecciate, enhancing wall-rock interaction.

CAN WE PREDICT WHICH PROTEROZOIC GRANITES ARE NOT PROSPECTIVE?

Proterozoic granite types, which to date have no known associated significant mineralisation, are characterised by at least one of the following: abundance of restite; high fluorine content throughout all phases of the granite present; a limited silica range (in particular those suites which are only have more than 70 wt% SiO_2); and small volume. Some areas which do contain granites of the appropriate composition are unprospective because of unsuitable host rocks.

RELATIONSHIP TO TECTONIC SETTING AND AGE

Much granite work in the Proterozoic of Australia focuses on trying to define the tectonic setting of the granite. Empirically definitions of the supposed tectonic setting are not particularly useful in selecting which granites have the potential for mineralisation. Proterozoic granites associated with Au± base metal mineralisation also have a considerable range in age, suggesting that base geochemical and mineralogical features of source granites and depositional host rocks, rather than age criteria or tectonic hypotheses, should be used for exploration area selection.

REFERENCE

Heinrich, C.A., Mernagh, T.P., Ryan, C.G., 1992a. Metal segregation by magmatic gases - first results from new fluid inclusion technique. *BMR Research Newsletter*, 16, 12-13.

Acknowledgments. This paper is published with the permission of the Executive Director of the Australian Geological Survey Organisation.