Mineralisation and structural setting of the Rise and Shine Shear Zone, Otago Schist: comparisons to the Macraes deposit

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Abstract

The Rise and Shine Shear Zone is a mineralised low-angle deformation zone traceable for at least 7 km through biotite zone schist of the Dunstan Range, central Otago. The zone is commonly believed to be similar to the actively mined Macraes deposit. The Rise and Shine Shear Zone occurs in the immediate footwall of the Thomsons Gorge Fault, a regional scale Cretaceous normal fault that juxtaposes chlorite zone schist against biotite zone schist. Most mineralised rocks are deformed and record a progression from early stages of semiductile deformation to more brittle cataclasis. Folds in mineralised rocks trend northwards. The mineralised schist is hydrothermally altered with variable silicification, sericitisation, chloritisation, replacement of titanite by rutile, and carbonate alteration. Gold is associated with pyrite and arsenopyrite and occurs in both ductile and brittle microstructures. Sheared and mineralised schist is cut by north-striking fault zones which host mineralised quartz veins. Veins in the shear zone contain hydrothermal albite. Trace element analyses show enrichment in As, U, Th and rare earth elements. Many of the above features are similar to Macraes deposit, but there are important differences. In particular, the Macraes deposit is hosted in lower grade rocks and truncated beneath by a normal fault, Macraes has no U or Th enrichment, Macraes veins have no albite, and folds at Macraes trend NW-W. Rise and Shine mineralised rocks have no Cr enrichment and no hydrothermal graphite.

Keywords: *Otago Schist; Rise and Shine; Macraes; shear zone; gold; faults; mineralisation, veins*

Introduction

Extensive mine exposures at the active Macraes mine in the Hyde-Macraes Shear Zone (HMSZ; Fig. 1) have shown that some parts of the deposit are dominated by mineralised schist with only minor quartz veins. Gold occurs in sulfides disseminated through sheared schist that has been pervasively hydrothermally altered. This type of deposit has not been identified historically in Otago, where previous mining and exploration has focussed on well-defined auriferous quartz vein systems. This disseminated style of deposit is therefore an interesting new target for exploration in Otago. Another zone of mineralised schist that has some similarities to the Macraes deposit is the Rise and Shine Shear Zone (RSSZ; Fig. 1; Park, 1908; Corner, 1986; Grieve, 1991; MacKenzie et al., 2005). This shear zone apparently has a similar strike, and occurs along regional strike from, the HMSZ (Fig. 1). Recent exploration history and results in the RSSZ have been summarised by MacKenzie et al. (2005). This paper describes general geological and geochemical studies carried out by the University of Otago Geology Department to provide background information for future exploration. We report these preliminary results as direct comparisons to observations at the Macraes deposit.

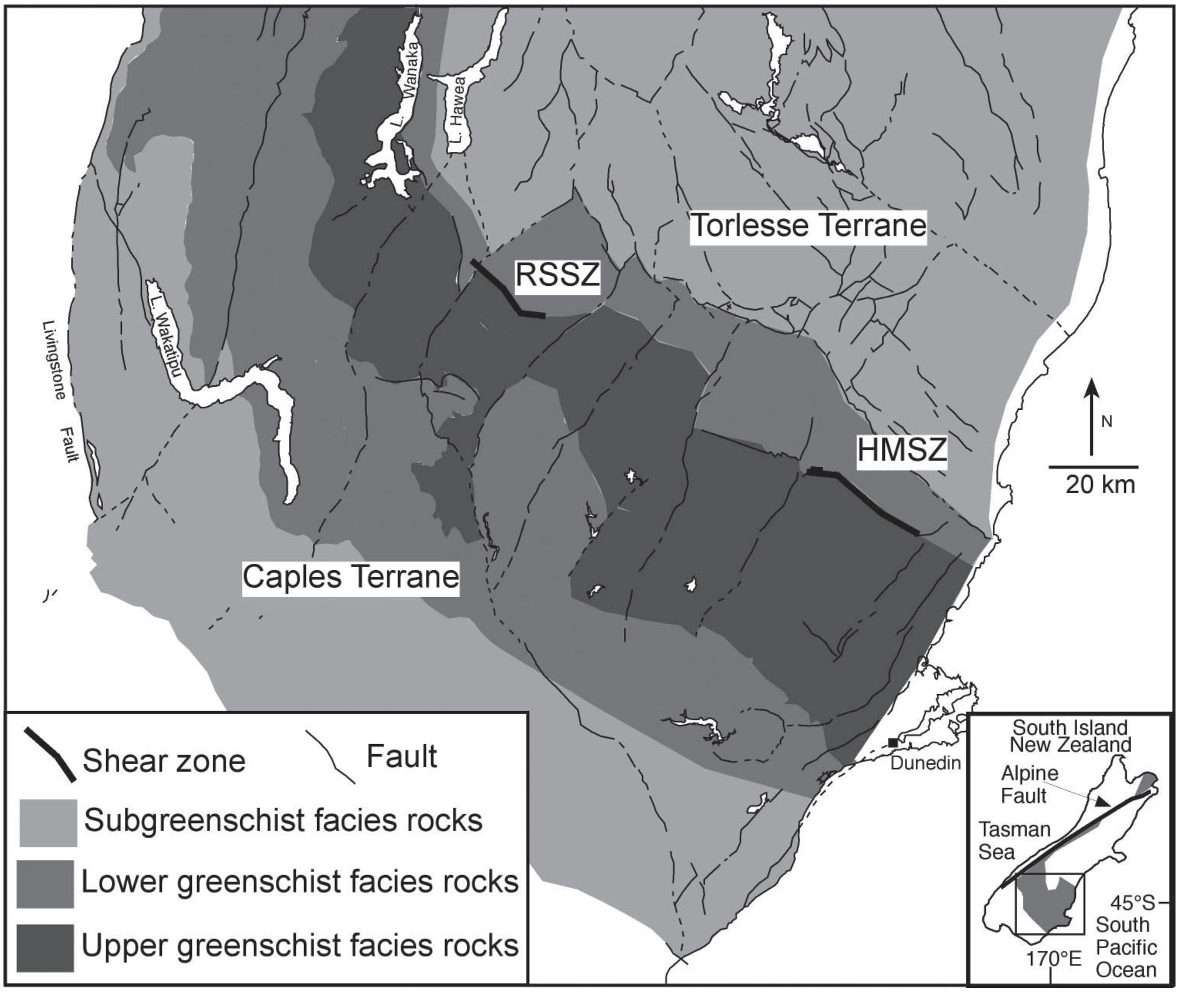

Figure 1. Metamorphic facies map of Otago, New Zealand, showing the location and structural setting of the Rise and Shine Shear Zone (RSSZ) and Hyde-Macraes Shear Zone (HMSZ). *Inset* shows the Otago Schist belt in the lower South Island of New Zealand.

Shear zone structure

The present outcrop patterns of both shear zones imply that they are shallow-dipping features (Fig. 2). The HMSZ generally has a well-defined upper shear (Hangingwall Shear; Fig. 2A) that dips at 15-20° to the NE. The RSSZ crops out on a gently dipping hillside that slopes ca. 10-15° to the NE (Fig. 2C). Both shear zones appear to be parallel to the pervasive foliation in the host schist (Fig. 2). Within both shear zones, rocks have abundant microshears (micron to mm scale) that are parallel or subparallel to the host schist foliation (see Fig. 5 in Craw et al., this volume). These microshears were closely associated with the early stages of mineralisation (see below). Fracturing, quartz veining and cataclasis also occurred during later stages of mineralisation. Hence, mineralisation occurred under ductile and brittle conditions, as both shear zones were uplifted through the brittle-ductile transition.

Despite the apparent lithological uniformity of Otago Schist, there are some minor differences reflecting compositional variations. At Macraes, this shows up as interlayering on the 1-20 m scale of massive schist dominated by relatively feldspar-rich rocks, and fissile schist contains abundant interlayered micaceous rocks (Fig. 2A). Interlayering of these rocks results in localised perturbations to the shear zone structure (Fig. 2A). In contrast, the Rise and Shine Shear is located almost entirely in micaceous schist (Fig. 2C). However, mineralised shears locally wrap around more siliceous layers (m scale) in the host schist.

Both HMSZ and RSSZ occur at the boundary between lower greenschist facies rocks (chlorite zone) and upper greenschist facies rocks (biotite-garnet zone) (Fig. 1). This boundary is a low-angle normal fault in both cases (Figs. 2B and C). At Macraes, the HMSZ is in the lower grade rocks in the hangingwall of the normal fault (=Footwall Fault; Fig. 2B), and the mineralised shear zone is truncated below by the Footwall Fault. In contrast, the RSSZ is hosted by biotite zone schists, structurally beneath the lower grade rocks. The RSSZ is truncated above by the Thomsons Gorge Fault (Fig. 2C) that juxtaposed the schists of different metamorphic grade after mineralisation occurred in the higher grade rocks. The HMSZ is mainly confined to the zone between the Hangingwall Shear and the Footwall Fault (Figs. 2A and B), although some disseminated mineralised rocks occur above the Hangingwall Shear locally (Fig. 2A). In contrast, the RSSZ becomes progressively less mineralised structurally down-section (Fig. 2C).

Mineralised rocks in both shear zones have undergone some synmineralisation mesoscopic folding. In both cases, the folds are accompanied by reverse shears indicating overall contractional deformation. Folds have sharp to rounded hinges and weak fold axial surface fracturing, and they deform foliation-parallel microshears. Fold axes trend west or northwest in the Macraes

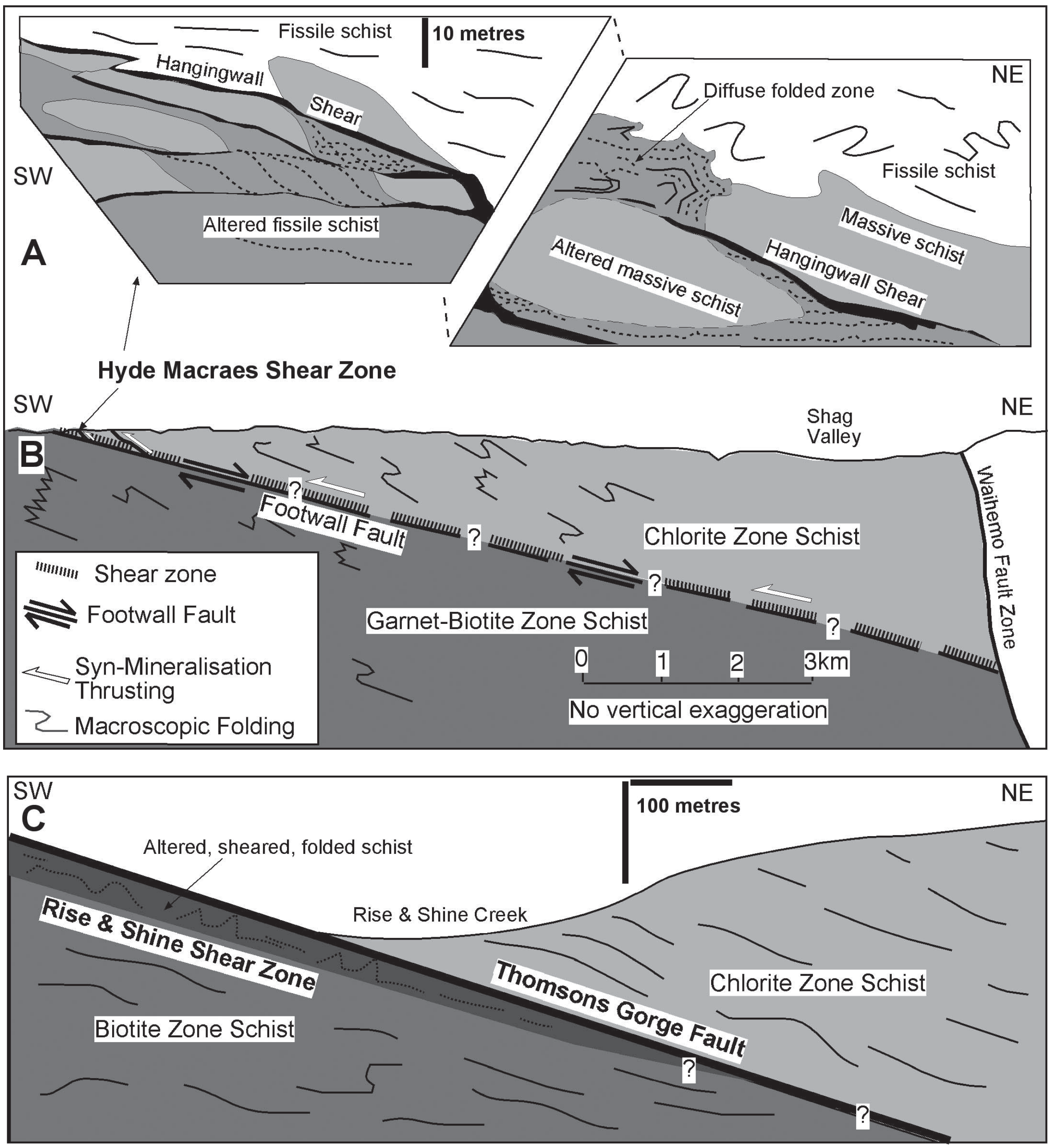

Figure 2. Schematic sections showing the distributions of lithologies and intervening structures at A, Frasers pit within B, the Hyde Macraes Shear Zone and at C, the Rise and Shine Shear Zone (Fig. 2A modified after Petrie et al., 2005).

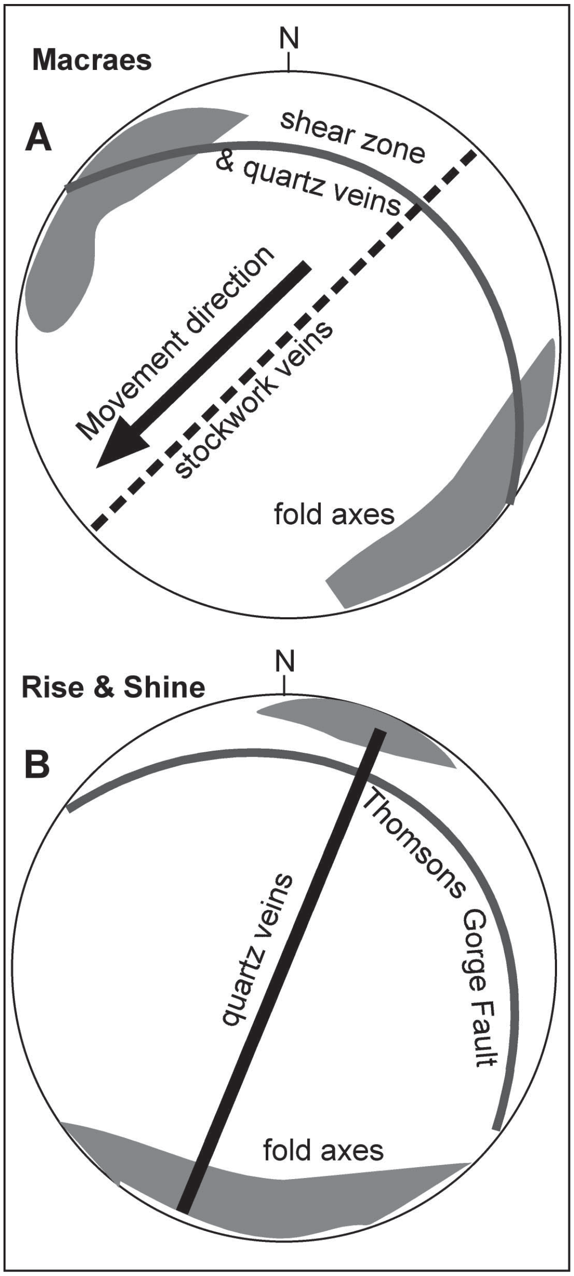

Figure 3. Stereonet projections of structural elements. A, Macraes fold axes outlined by shaded areas, mean orientation of shear zone and shear parallel quartz veins as solid great circle, steeply dipping extensional quartz veins represented by dashed line, and movement along the fault in direction of arrow. B, Rise and Shine fold axes outlined by shaded areas, mean orientation of Thomsons Gorge Fault as solid great circle, and steeply-dipping mineralised veins represented by solid line.

deposit (Teagle et al., 1990; Petrie and Craw, 2005), and north to NNE in the RSSZ (Fig. 3). Shear-parallel quartz veins (cm to m scale) occur throughout the HMSZ (Fig. 3A), and have commonly been deformed and disrupted with the shear zone. In addition, small (mm to cm scale) steeply dipping extensional quartz veins occur as swarms (stockworks) through parts of the Macraes deposit, particularly in massive schist pods. These stockwork veins strike northeast, approximately parallel to the movement direction of the shear zone (Teagle et al., 1990; Begbie and Craw, 2004). Mineralised veins in the RSSZ occur principally with N-NE strike, and are closely associated with fold and fracture zones with similar N-NE trend (Fig. 3B).

Mineralogy

Both HMSZ and RSSZ mineralised rocks have pyrite and arsenopyrite replacement of schist minerals along microshears, and gold is closely associated with these sulfide minerals. Sulfide addition has been accompanied by recrystallisation of quartz, muscovite and chlorite to fine grain size in microshears and fold hinges. This mineral recrystallisation was also accompanied by transformation of titanite to rutile, and epidote to Fe-bearing carbonate and kaolinite. Additional carbonate mineralisation has occurred in both mineralised zones: calcite in the HMSZ, and calcite + ankerite in the RSSZ. Fe-bearing carbonate (ankerite) is most prominent in the RSSZ as the carbonate weathers to a distinctive red-brown colour that permeates all mineralised rocks. Abundant hydrothermal graphite has been added to the HMSZ during mineralisation, but no synmineralisation graphite has been added to the RSSZ. However, some postmineralisation graphitisation has occurred along the Thomsons Gorge Fault.

Veins at Macraes are dominated by quartz, with minor auriferous sulfides, muscovite, chlorite, and scheelite. In contrast, the most prominent RSSZ veins contain abundant coarse-grained (mm scale) albite intergrown with quartz. Minor coarse-grained auriferous sulfides and chlorite accompany the quartz and albite in these RSSZ veins.

Geochemistry

Deformation, recrystallisation, and mineralisation in both shear zones have had little geochemical effect on the host rocks other than elevated As, S and C (see mineralogy, above). Silicification has been minor, so silica contents of rocks remain essentially unchanged. Some Macraes mineralised rocks have had albite replaced by muscovite (sericite) with associated increase in potassium content (Craw et al., 1999). This alteration is not detectable in the RSSZ, and albite is a stable mineral in veins (above). RSSZ rocks are distinctly elevated in U and Th and rare earth elements compared to immediate host rocks and to Macraes rocks (Fig. 4A). Macraes rocks are elevated in Cr and Ni, and Cr has been locally enhanced by mineralisation processes (Fig. 4B; Craw et al., 1999). In contrast, the Cr and Ni levels in RSSZ mineralised rocks are indistinguishable from the immediate host rocks (Fig. 4B).

The abundant calcite that accompanied mineralisation at Macraes commonly has distinctively low $d^{13}C$, as part of a trend towards equilibrium with graphite that also accompanied mineralisation (Fig. 5; Craw, 1992). RSSZ carbonates do not show the same trend, and $d^{13}C$ is approximately uniform near -6 per mil (Fig. 5). Some RSSZ carbonates have lower $d^{18}O$ than at Macraes or other Otago Au-bearing vein systems (Fig. 5). This may be due to some meteoric overprint during weathering, as unweathered material is rare.

Discussion and conclusions

There are some strong similarities between the RSSZ and HMSZ, particularly regarding mineralisation of both structures spanning the transition from ductile to brittle deformation. Microshears containing pyrite, arsenopyrite, rutile and recrystallised muscovite and chlorite dominate large volumes of mineralised schist in both shear zones. Both shear zones have relatively sparse quartz veins compared to the mineralised schist component. However, the shear zones are different in structural detail, as they formed under different structural regimes. The HMSZ originated as a SW-directed thrust fault zone (Teagle et al., 1990), and mesoscopic structures at Macraes reflect this origin (Petrie

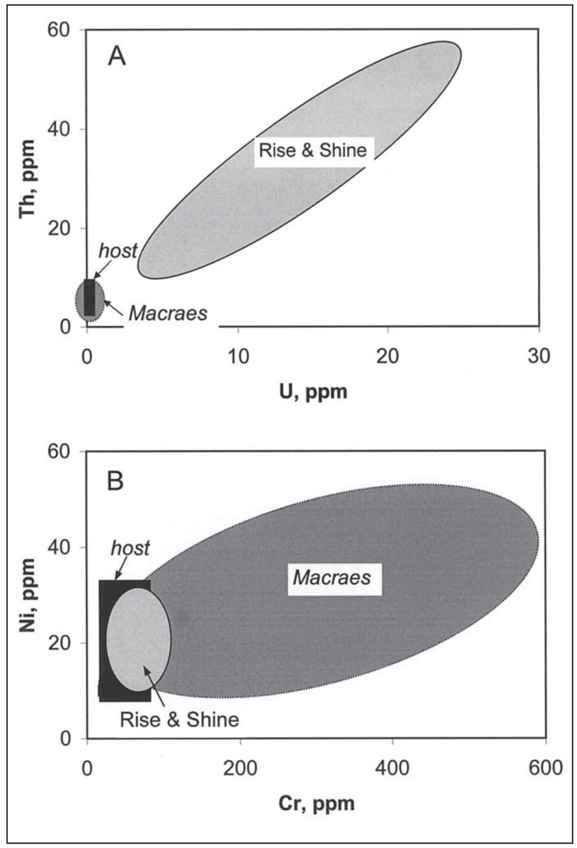

Figure 4. Geochemical plots comparing altered rocks from the Rise and Shine (light grey) and Hyde-Macraes (dark grey) shear zones to immediate host rocks (solid black). A, Thorium versus uranium. B, Nickel versus chromium.

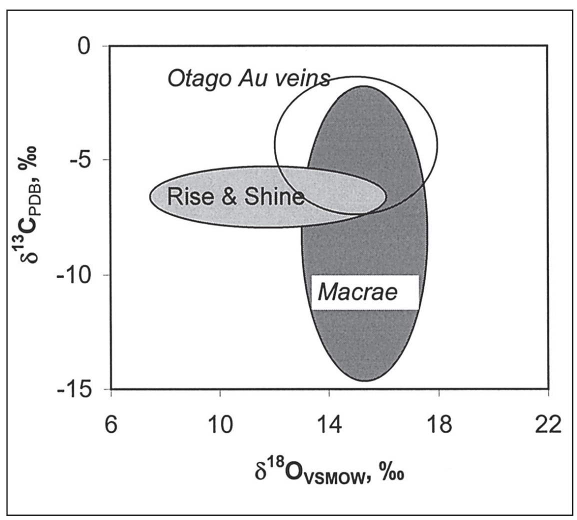

Figure 5. Isotopic carbon and oxygen compositions of vein carbonate at the Rise and Shine and Hyde-Macraes shear zones compared to other Otago gold-bearing veins.

and Craw, 2005). The RSSZ also initiated as a contractional feature, but has mesoscopic folds with distinctly different orientations (N to NE trend) from those of the HMSZ, and internal fractures and shears are more steeply dipping than in the HMSZ. Further, the RSSZ is hosted in higher grade schist than the HMSZ, and is truncated above by a low-angle normal fault, whereas the HMSZ is truncated below by a normal fault. Hence, the two shear zones were not formed as part of a single homogeneous structure during uplift of the Otago Schist, and the occurrence of the RSSZ apparently along regional geological strike from the HMSZ (Fig. 1) is at least partly coincidental.

The two shear zones have generally similar mineralogy and geochemistry, but there are some significant differences. The abundant synmineralisation graphite that characterises the mineralised zone at Macraes is absent from the RSSZ. Instead, the RSSZ has more abundant ankerite. RSSZ also has elevated U, Th, and rare earth elements compared to Macraes, and these may be related to the ankerite alteration. Veins in the RSSZ contain abundant albite, which has not so far been reported from Macraes veins. Mineralisation in both shear zones involved crystallisation and/or recrystallisation of greenschist facies minerals under greenschist facies conditions, and was probably related to late metamorphic processes in the Otago Schist (see Craw et al., this volume). However, the mineralisation processes were slightly geochemically different in the two shear zones, and this may reflect different local fluid pathways or differences in timing of mineralisation.

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