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Contrasting coeval paragenesis of gold and scheelite in an orogenic hydrothermal system, Macraes mine, New Zealand

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ABSTRACT

The Macraes deposit (>10 Moz resource) is a Cretaceous orogenic system hosted in the Hyde-Macraes Shear Zone (HMSZ) which was mineralised under lower greenschist facies during later stages of lower greenschist facies metamorphism of host metasedimentary schists. Gold is encapsulated primarily in sulphides that have replaced silicates in ductile shears that are focussed in micaceous rocks. The shears anastomose around structurally competent lenses, and were enhanced by hydrothermal graphite deposition and alteration of albite to muscovite. In contrast, scheelite with minor auriferous sulphides occurs in multigenerational quartz veins that filled fractures in competent lithologies. Hence, scheelite was deposited coevally with gold, from the same hydrothermal fluid, but in different structural settings from most gold at all scales from millimetres to hundreds of metres. Consequentially, there is weak correlation between Au and W at all scales in the deposit. Multigenerational gold and scheelite mineralisation occurred during progressive deformation in the shear zone in two contrasting structural and mineralogical styles in *syn*-deformationally weakening gold-bearing micaceous shears, and in *syn*-deformationally hardened competent rocks that became silicified and veined with quartz and scheelite. Hydrothermal fluid flow in the gold-bearing shears occurred at the grain boundary, microshear, and microfracture scales, and was slow (<1 m/year), continuous, and pervasive. In contrast, vein formation in more competent lithologies was episodic, locally rapid (>hundreds of m/year), and was controlled by fracture permeability. The Au and W enrichment in the Macraes deposit resulted from regional scale metal mobility, driven by coeval recrystallisation in higher-grade (upper greenschist to amphibolite facies) metamorphism that persisted structurally below the Macraes deposit for at least 10 Ma after mineralisation ceased.

1. Introduction

Many orogenic gold deposits around the world have some degree of tungsten enrichment, typically as scheelite ($CaWO_4$) which occurs in association with the gold (Antona et al., 1994; Darbyshire et al., 1996; Heinrich et al., 1996; Anglin et al., 1996; Voicu et al., 2000; Kempe et al., 2001; Brugger et al., 2008). These deposits are distinctly different from those that are directly associated with igneous intrusions (Thompson et al., 1999; Goldfarb et al., 2005). The orogenic gold deposits are dominated by vein systems that overprint the metamorphic fabric of their host rocks, and are clearly post-metamorphic with respect to those host rocks (Cox et al., 1991; Bierlein and Crowe, 2000; Hagemann and Cassidy, 2000; Groves et al., 2003; Goldfarb et al., 2005). However, some deposits show evidence for a textural and mineralogical transition between metamorphism and mineralisation (Cox et al., 1991; Goldfarb et al., 2005; Large et al., 2007, 2009, 2011). The Macraes mine of New Zealand is an example of this latter deposit type (Craw et al., 1999; Craw, 2002; Petrie et al., 2005).

The Macraes mine is in an orogenic deposit with no associated igneous body, and the mine area has historically produced scheelite with, or instead of, gold when tungsten prices were high (Williams, 1974). Despite the potentially economic importance of this tungsten enrichment, there has been little work done to examine the emplacement of the scheelite in relation to the gold mineralisation or the mineralising system as a whole. In this study, we address this gap in knowledge by linking and contrasting gold and scheelite mineralisation textures and processes. These observations have significance for interpretation of relationships between gold and tungsten enrichment processes in other orogenic deposits worldwide.

This study focusses primarily on the paragenetic mineralogy and textures of gold and scheelite bearing rocks that have developed in the complex multistage mineralisation process at Macraes. We link those textures to the gold and tungsten contents of the rocks at a range of scales, from microns to hundreds of metres, to evaluate the similarities and differences of the Au and W enrichment processes. Our observations suggest that coeval but spatially separate deposition

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of gold and tungsten occurred as a result of structural and lithological contrasts within the evolving deposit. We then place these disparate processes into the context of the overall metamorphic evolution and metamorphogenic mobilisation of fluids and metals in the host schist belt and the coeval associated late metamorphic structures.

2. General geology

The Macraes mine is a world-class orogenic gold deposit (>10 Moz Au resource; Moore and Doyle, 2015) in the Otago Schist metamorphic belt of Southern New Zealand (Fig. 1a). The schist belt consists predominantly of Mesozoic metasedimentary rocks that were metamorphosed and exhumed in the late Mesozoic (Mortimer, 2000; Gray and Foster, 2004). The rocks of the belt range in metamorphic grade from weakly foliated pumpellyite-actinolite facies metagreywackes and meta-argillites on the flanks to a core of pervasively recrystallised upper greenschist facies schists (Fig. 1a; Mortimer, 1993, 2000; Gray and Foster, 2004; MacKenzie and Craw, 2005). Greenschist facies schists have a flat-lying or shallow dipping foliation that forms a broad antiform whose hinge coincides with the core of the schist belt (Mortimer, 1993, 2000; Gray and Foster, 2004).

The Macraes mine is hosted in lower greenschist facies schists on the northeastern flanks of the Otago Schist belt (Fig. 1a). These rocks were metamorphosed in the late Jurassic and Early Cretaceous, during which time they were partially exhumed during on-going compressional deformation (Craw, 2002; Gray and Foster, 2004; Mortensen et al., 2010). Mineralisation at Macraes occurred in the Early Cretaceous (135–140 Ma) in the latter stages of greenschist facies metamorphism and early stages of exhumation. At the same time, higher grade rocks that now form the exposed core of the belt were still undergoing greenschist facies metamorphism beneath the structural level of gold deposit formation (Gray and Foster, 2004; Mortensen et al., 2010).

The Macraes mineralised rocks occur in a regional-scale structure, the Hyde-Macraes Shear Zone (HMSZ), which is traceable for 30 km along strike (Fig. 1a, b; Teagle et al., 1990). This structure dips gently (10–20°) northeast, sub-parallel to the host schist foliation (Fig. 1c; Teagle et al., 1990; Petrie et al., 2005). The HMSZ formed as a ductile-brittle thrust zone that was >300 m thick, which was subsequently truncated at its base by an unmineralised middle Cretaceous normal fault, called the Footwall Fault in the mine (Fig. 1a,c; Teagle et al., 1990; Craw et al., 1999; Petrie et al., 2005). The Macraes mine consists of a series of open pits along the strike of the HMSZ, and an underground extension of one of those pits (Frasers; Fig. 1b,c).

3. Deposit paragenesis

Previous work has shown that mineralisation in the HMSZ occurred as metamorphogenic fluids from underlying higher grade rocks migrated along the shear zone (Craw, 2002; Pitcairn et al., 2005, 2006;

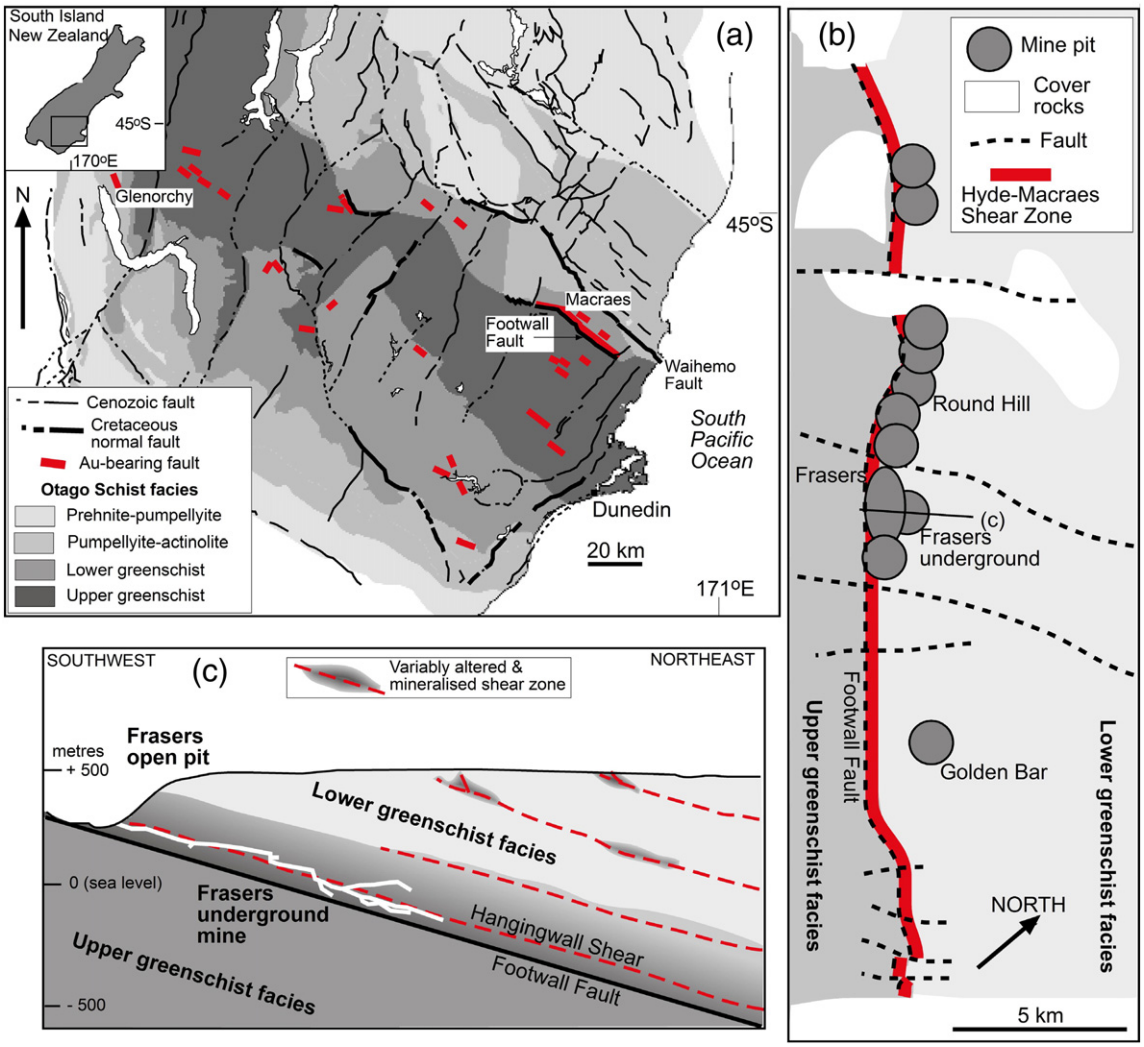

Fig. 1. Location of the Macraes mine and the HMSZ in the Otago Schist (a), with the principal mine pits (b), and the structural setting above the younger Footwall Fault (c).