Geology and alteration mineralogy of the Karangahake adularia-sericite epithermal deposit, Hauraki Goldfield, New Zealand

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Abstract

The Karangahake deposit was the second largest producer of gold-silver bullion in the Hauraki Goldfield, New Zealand. New mapping of a 2 by 3 km (6 km^2) area demonstrates that hydrothermal alteration surrounds productive veins. Wallrocks proximal to veins are intensely altered and alteration decreases toward the margin of the system.

At Karangahake, distinct zonation of adularia, calcite, epidote, illite, and illite-smectite surrounds gold-bearing lodes with unaltered rocks containing magnetite and plagioclase occurring on the margins. Adularia, illite, illite-smectite, and calcite zonation defines hydrothermal alteration extending 2 km to the east of productive lodes. Epidote and adularia zonation occurs proximal to veins. The adularia zone compares well to potassium/thorium studies conducted in the area. Illite zonation is well developed to the east of the veins grading into interstratified illite-smectite containing 5 to 40% smectite 1.5 km from the Maria Lode. Calcite is restricted to the east of the study area occurring in 18% off surface samples. Less altered rocks containing plagioclase and magnetite occur distal to veins. The magnetite occurrence compares well to aeromagnetic studies conducted in the area.

Adularia and coexisting adularia and albite indicate the host rocks were highly permeable. Epidote, illite, illite-smectite and previous fluid inclusion evidence implies temperatures graded from >240ºC in the core of the system to approximately 150ºC on the periphery. The alteration association of quartz, adularia, calcite, pyrite, chlorite, illite, and illite-smectite reflects a near-neutral to weakly alkaline water. Calcite occurrence and the absence of zeolite imply the fluid contained significant dissolved CO_2.

Keywords: *Karangahake, adularia-sericite, epithermal, alteration, Hauraki Goldfield, mineralisation, Au-Ag.*

Introduction

The Karangahake adularia-sericite deposit is located 120 km southwest of Auckland in the southern part of the Hauraki Goldfield. Past production of 127 tonnes of gold-silver bullion at a grade of 27.0 g/tonne gold equivalents make the Karangahake deposit the second largest bullion producer in the Hauraki Goldfield (Brathwaite, 1989). Mining began with the discovery of gold bearing veins in 1882 and the implementation of the world's first wet cyanidation technique in 1889 (Brathwaite, 1989). Heritage Gold New Zealand was granted an exploration permit in 1995 and continues to explore gold-silver targets within the Karangahake deposit.

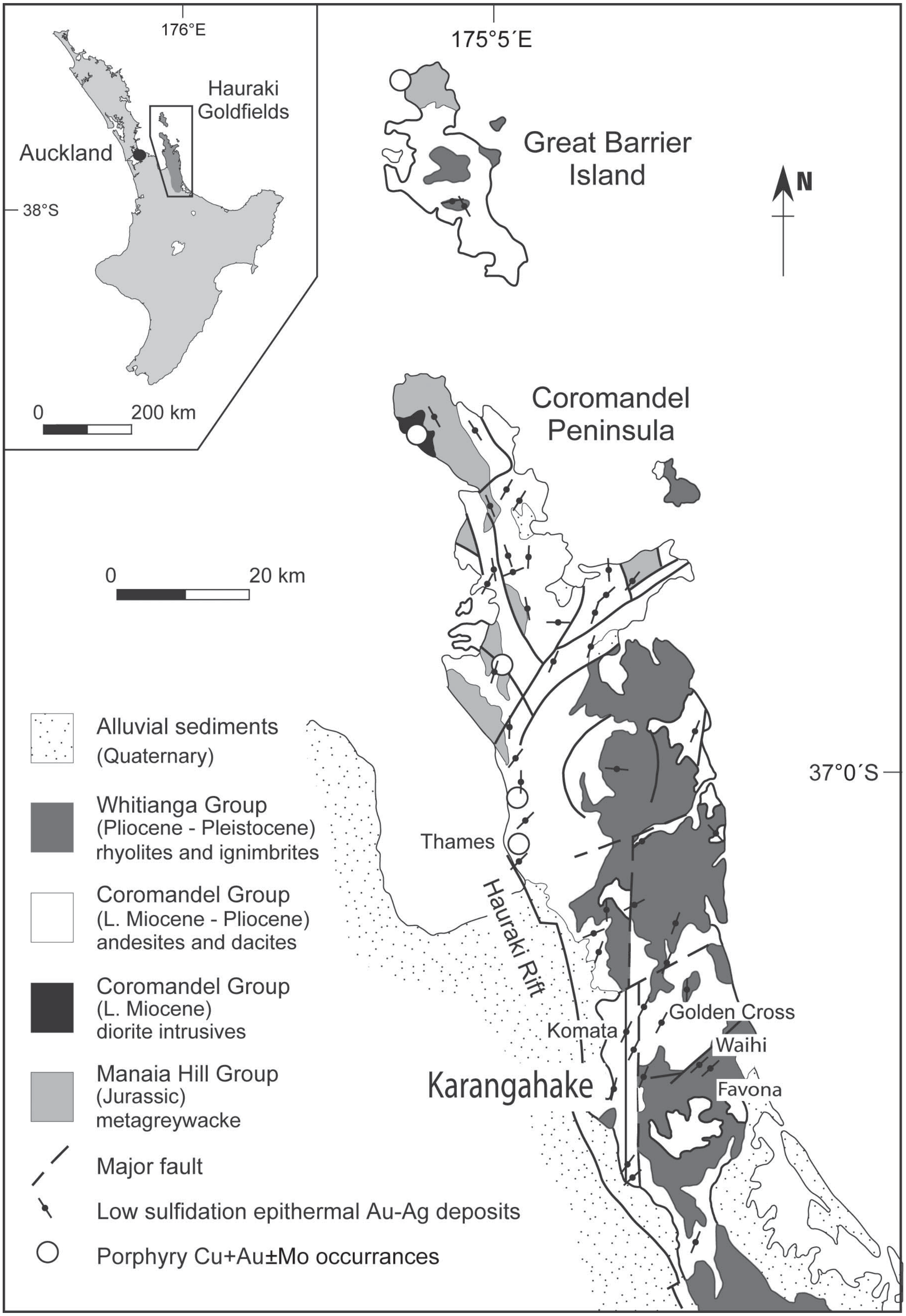

Figure 1. Simplified geology map of the Coromandel Peninsula showing the location of Karangahake.

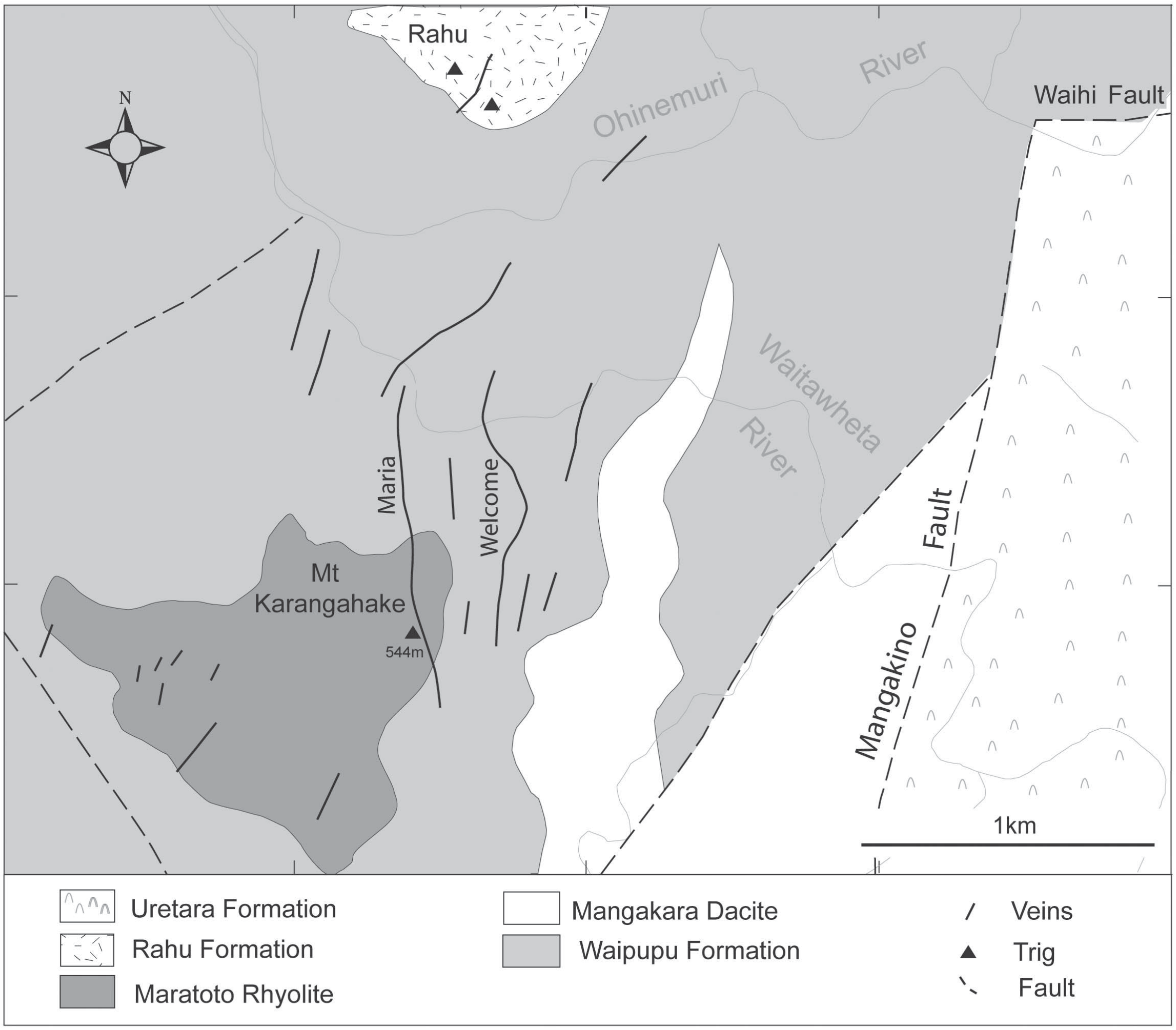

Figure 2. Simplified geology map of the Karangahake area (after Brathwaite and Christie, 1996).

This paper builds on the excellent work of Brathwaite (1989) describing hydrothermal alteration surrounding veins at the Karangahake epithermal deposit based on geological mapping, petrographic studies, and X-ray diffraction analyses of volcanic host rocks in surface outcrops and underground workings. Alteration minerals are used to define the extent of the hydrothermal system and used to infer permeability, temperature and fluid compositions that prevailed during hydrothermal activity.

Regional and local geology

The Karangahake deposit is located at the southern end of the Hauraki Goldfield in the Coromandel Volcanic Zone (Fig. 1); a NNW trending zone of Miocene to early Quaternary subaerial calc-alkaline volcanic rocks (Brathwaite et al. 1989). The Hauraki Goldfield contains approximately 50 epithermal gold-silver deposits that are structurally controlled by extensional, NE trending faults.

The lowermost stratigraphic unit at Karangahake consists of autobrecciated andesite and dacite lava flows of the Waipupu Formation (Brathwaite and Christie, 1996). This unit is up to 620 m thick and is hydrothermally altered throughout most of the study area. These are unconformably overlain by up to 190 m of silicified, spherulitic and flow banded rhyolite of the Maratoto Formation (Brathwaite and Christie, 1996) (Fig. 2). Basement rocks in the area are not seen but presumably consist of Mesozoic greywacke (Brathwaite, 1989). The structural trends are NW, N-S, NNE, and EW striking normal faults (Brathwaite, 1989). The two main mapped faults in the area are the Waihi Fault and the Mangakino Fault.

The Karangahake deposit is an epithermal quartz vein system with gold and silver mineralisation predominantly hosted in andesite with a stockwork of small veins developed in the rhyolite cap (Fig. 2). Most mining was confined to the west-dipping Maria and Welcome/Crown Lodes. The Maria Lode was mined on 16 levels producing 113.5 tonnes of the total 126.7 tonnes gold-silver bullion produced from Karangahake. It has a strike length of 1300 m, an average width of 2 to 3 m, and a vertical extent exceeding 700m (Brathwaite, 1989). The Welcome Lode and its footwall branch the Crown Lode, lie 240 to 340 m east of the Maria Lode. The Welcome/Crown Lode has a strike length of 1100 m with the oxidized ore mined to a vertical extent of 300 m. A central zone of strong silicification surrounds the major quartz lodes and extends 2.5 km from Mt. Karangahake north to Rahu Ridge (Brathwaite, 1989). Rocks in the central part of the system are extensively hydrothermally altered to quartz, adularia, albite, minor epidote, chlorite, calcite, illite, interstratified illite-smectite and pyrite. Andesite on the margin of the deposit and in local 'hard bars' is moderately to weakly altered (Brathwaite, 1989).

Hydrothermal alteration

Hydrothermal alteration was studied from both surface and underground samples collected in an area covering 2 by 3 km (6 km^2) (Fig. 3A). Surface sampling to the west and east was limited by a lack of unweathered outcrops (Fig. 3A). Underground samples were taken from the 265 m long, level 8, Keillors Crosscut that runs west to east from the Maria Lode, through the Mystery Lode and ends at the Welcome/Crown Lode (Fig. 4). The Keillors Crosscut allows sampling of unweathered material in a direct line between the Maria and Welcome/Crown Lodes at a constant elevation.

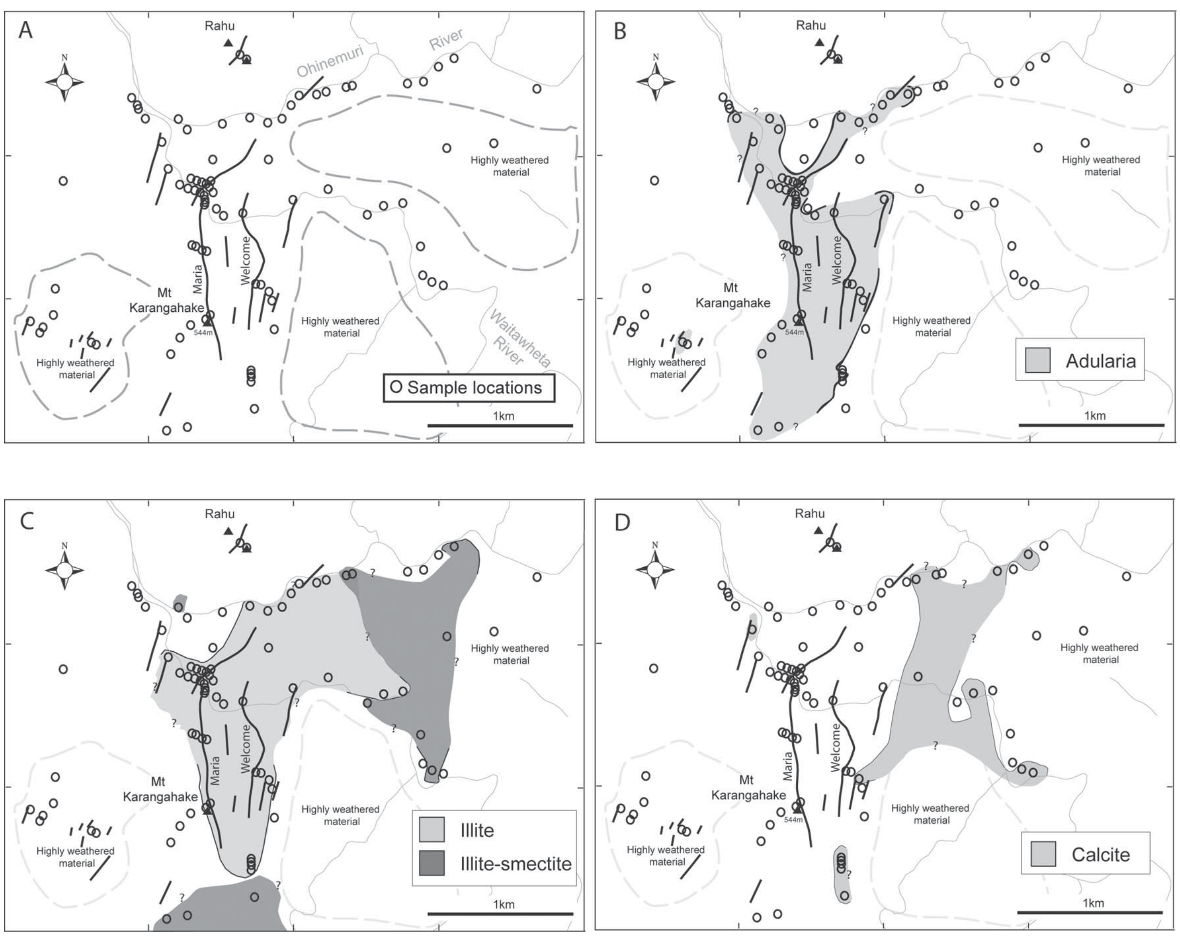

Figure 3. Simplified map of Karangahake area showing A) the distribution of surface samples, B) adularia, C) illite and illite-smectite, D) calcite.

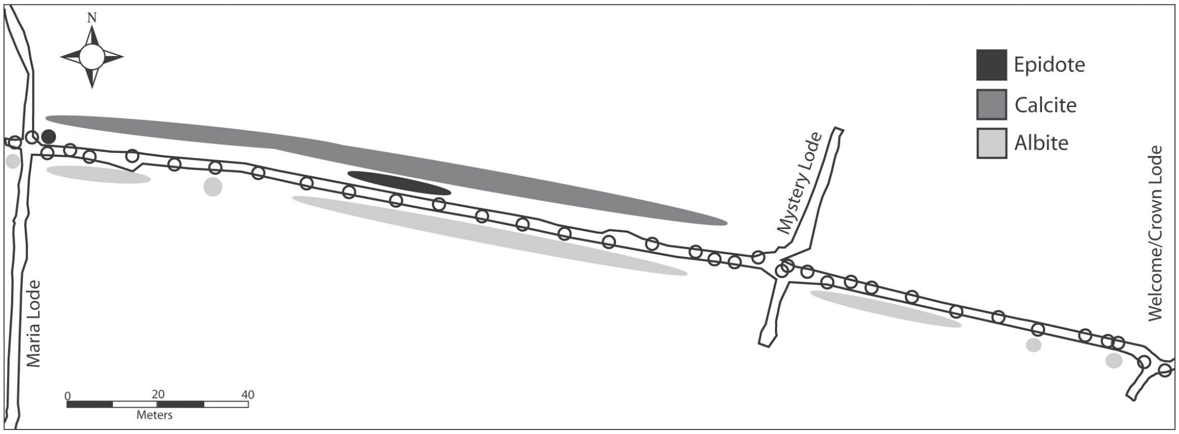

Figure 4. Map of the Keillors Crosscut showing distribution of adularia, albite, calcite and epidote on the 8 level of the Karangahake deposit.

The degree of wall rock alteration varies at Karangahake; rocks surrounding the veins are intensely (90 to 100%) altered although igneous textures are commonly preserved. Less altered rocks occur on the margin of the study area and in rare isolated 'hard bars' of less permeable rocks that contain igneous magnetite and plagioclase. Hydrothermal alteration in surface and underground samples was analysed for 138 samples by X-ray diffraction (XRD) and a sub-suite of these by petrographic techniques with care taken to avoid weathered material. The wall rocks are replaced by many alteration minerals with the most significant discussed below.

Quartz

Quartz is a ubiquitous alteration mineral both in surface and Keillors Crosscut samples. Quartz mainly replaces the groundmass and further replaces mafic and plagioclase phenocrysts. Quartz that replaces the groundmass is typically fine-grained and intergrown with adularia, chlorite, illite and pyrite.

Adularia and albite

Adularia is a common and widespread alteration mineral that envelops veins at the surface (Fig. 3B) and is ubiquitous in the Keillors Crosscut. Albite rarely occurs in surface samples and is closely associated with adularia zonation surrounding lodes. Further petrographic analysis of the surface samples will be required to document the zonation fully. By contrast, in the Keillors Crosscut, albite is a common alteration mineral occurring along most of the 265m length (Fig. 4).

Hydrothermal adularia replaces plagioclase phenocrysts and is variably (20 to 100%) altered, to illite with or without chlorite. Small (<1mm) inclusions of pyrite and leucoxene are common with epidote inclusions occurring proximal to the Maria Lode. Hydrothermal albite is rare in surface samples and where present, coexists with adularia. In the Keillors Crosscut, albite coexists with adularia and is variably altered to illite.

Chlorite, chlorite-smectite, and corrensite

Chlorite is a common alteration mineral surrounding veins at the surface and is a ubiquitous alteration mineral in the Keillors Crosscut. Chlorite replaces pyroxene and variably replaces adularia. The amount of chlorite replacement increases in underground samples closer to veins. Breccia clasts in wall rock samples display alternating haloes of intense and less intense chlorite alteration.

X-ray diffraction profiles of clay mineral separates show that chlorite is characterised by peaks at approximately 14.0, 7.0, 4.75, and 3.55 Å. Samples were then heated to 550ºC for two hours to distinguish chlorite from kaolinite. Following heating all subsequent profiles lacked the 7.0,

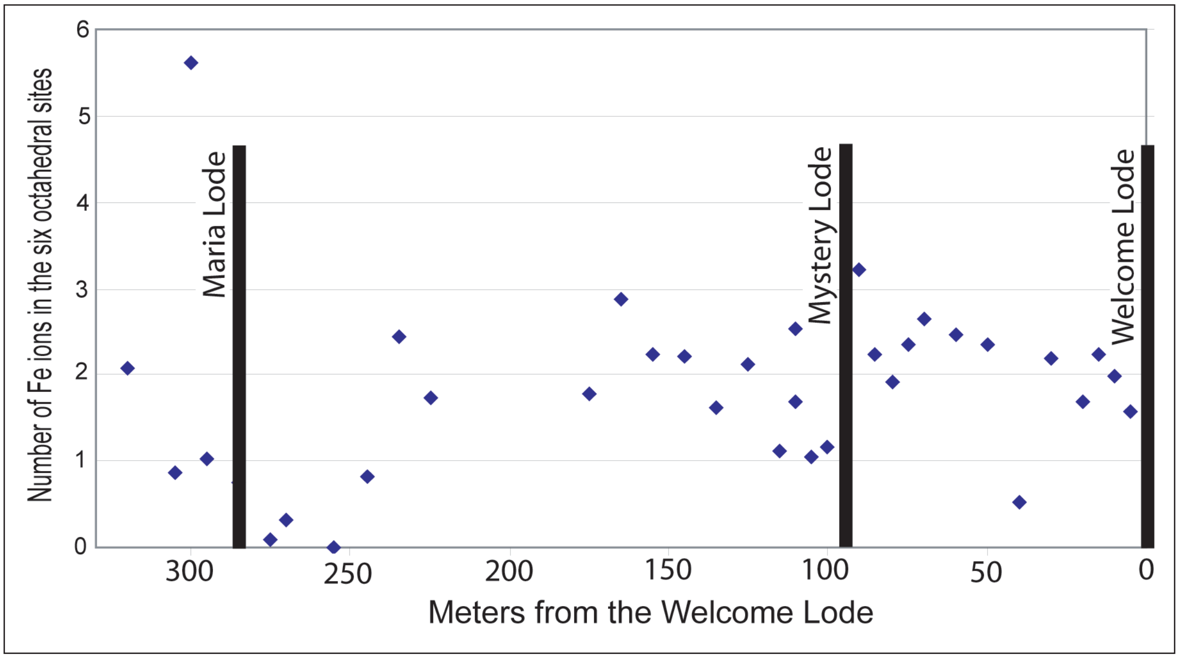

Figure 5. Plot showing of the number of Fe ions in the six octahedral site of chlorite verses distance along the Keillors Crosscut.

4.74, and 3.55 Å peak. This same phenomena was seen at Golden Cross where two types of chlorite were distinguished based on whether chlorite collapsed on heating with the collapse possibly due to chlorite chemistry or grain size (Simpson et al., 2001). The Fe/Mg content of chlorite at Karangahake was also broadly determined from XRD. Calculation of the number of Fe ions using the Brown and Brindley (1980) method documented in Moore and Reynolds (1997) reveals variation of the Fe/Mg ratio in the six octahedral sites of chlorite that ranged from 0 to 4 in the Fe ion levels through the Keillors Crosscut (Fig. 5). There is a general trend of increasing Fe ions in the footwall towards veins marked by a sharp decrease in the hanging wall (Fig. 5). However, the data is moderately scattered, which may in part be a function of the calculations which have an error of up to 25%.

Epidote

Epidote is rarely seen in surface samples and occurs mostly near veins. In the underground workings, epidote is restricted to the footwall of the Maria Lode and the area between the Mystery and Maria Lodes (Fig. 4). Epidote occurs as anhedral intergrowths preferentially replacing the cores of altered plagioclase.

Illite and interstratified illite-smectite

Illite is a common clay mineral, comprising up to 25% of the rock by volume and in surface samples is closely associated with mapped veins (Fig. 3C). Illite is ubiquitous in the Keillors Crosscut replacing 20 to 95% of the phenocrystic and groundmass plagioclase in addition to hydrothermal adularia. Interstratified illite-smectite contains 5 to 40 percent smectite and is comparatively rare, occurring in samples located distal to mapped veins. No interstratified illite-smectite was detected in the Keillors Crosscut.

Calcite

Calcite in surface samples is present to the east, distal to veins (Fig. 3D) and restricted to between the Mystery and Maria Lodes in the Keillors Crosscut. Only 18% of surface samples contain calcite compared to 43% in underground samples. Calcite overprints plagioclase and pyroxene that have been replaced by adularia and illite and is also disseminated in the groundmass.

Pyrite

Pyrite is the most abundant sulfide at Karangahake. At the surface, pyrite is associated with veins and extends at river level out to the east. In the crosscut, pyrite is common and widespread increasing in abundance towards veins. It typically occurs as disseminated, euhedral, <1mm, cubic grains in the groundmass and locally as clots. Pyrite also forms common inclusions in altered plagioclase and pyroxene phenocrysts.

Discussion

Alteration mineral zonation at the Karangahake deposit closely correlates to those seen in other adularia-sericite deposits (Cooke and Simmons, 2000). In these deposits, adularia is common proximal to the veins. The adjacent country rock shows illite alteration of the adularia increasing, pyrite becoming common and quartz abundance diminishing. Hydrothermal alteration may provide information on the temperature and fluid composition during hydrothermal activity based on these mineral occurrences in geothermal systems (Hedenquist and Browne, 1989).

Extent of hydrothermal alteration

At Karangahake, the veins are surrounded by a well defined core zone of adularia that is approximately 2 by 1.5 km (~3.5km^2). The adularia zone grades out to the east into less altered rocks containing plagioclase and magnetite. This area of adularia alteration is slightly larger than the 2.5 km^2 potassium/thorium anomaly mapped from radiometric data by Harris et al. (2005). Intense alteration extends 1.5 km to the east and grades into less altered rocks that contain igneous magnetite and plagioclase. This boundary matches that defined from the aeromagnetic study of Harris et al. (2005) that defines a 6 km^2 north-south elongated magnetically quiet zone that envelops veins.

Permeability of the rocks

Intense alteration suggests significant diffusive fluid flow occurred through the rocks. Adularia and coexisting adularia and albite that surround veins implies host rocks were highly permeable (Browne and Ellis, 1978). In less altered rocks on the eastern margin and in localised hard bars that contain igneous plagioclase and magnetite the permeability of the rocks is inferred to be low.

Temperature of alteration.

Several of the minerals present at Karangahake including epidote, illite, and illite-smectite, may be temperature dependant based on their occurrence in geothermal systems. In geothermal fields, epidote forms at temperatures exceeding approximately 240ºC, illite at greater than 220ºC and illite-smectite between 150º to 220ºC (Steiner 1977; Reyes, 1990). In the Keillors Crosscut, epidote occurs in the footwall of the Maria Lode inferring temperatures exceeded 240ºC. Illite zonation occurs proximal to mapped veins on the surface grading outward to marginal illite-smectite to the east. This overall clay zonation could reflect that much of the area was heated to above 220ºC and that cooler temperatures of less than 220º to 150ºC occurred on the margin of the system. Clay mineral variations can also be attributed to differences in chemistry, degree of alteration and water-rock interaction (Essene and Peacor, 1995, 1997). However, epidote and illite temperatures correlate well with previous fluid inclusion data by Brathwaite (1989) that have a homogenization temperature range of 230-280ºC.

Composition of hydrothermal waters

The alteration association of quartz, adularia, calcite, pyrite, chlorite, illite, and illite-smectite presumably reflects formation from upwelling near-neutral to weakly alkaline chloride waters. The presence of calcite and the absence of zeolite in surface and Keillors Crosscut samples further imply that the fluids contained significant concentrations of dissolved CO_2 (>0.1 molal) (Simmons and Christenson, 1994). Late stage calcite overprinting and calcite veins likely formed from peripheral stream heated CO_2-rich waters that descended back into the core of the hydrothermal system.

Conclusions

Our work confirms and builds on the important and pioneering summary of Brathwaite (1989). At Karangahake, hydrothermal alteration has been mapped covering an area of 2 by 3 km at the surface and in the Keillors Crosscut. Intense alteration is widespread and grades into less altered rock up to 1.5 km to the east that contain plagioclase and magnetite. This boundary correlates well with an aeromagnetic study conducted in the area. Some alteration minerals display well defined zones of occurrence. The presence of an adularia zone enveloping veins implies an area of approximately 3.5 km^2 was altered by the mineralizing fluids that passed through the rocks at Karangahake. This adularia zone is supported by a potassium/thorium anomaly and aeromagnetic data collected by Harris et al., (2005). Illite occurs in the central part of the Karangahake deposit grading into illite-smectite 1.5 km to the east. Calcite is mainly located to the east in surface samples, distal to veins.

The alteration association of quartz, adularia, calcite, pyrite, chlorite, illite, and illite-smectite reflects a near-neutral to weakly alkaline chloride water. The occurrence of calcite and the absence of zeolite imply the fluid contained dissolved carbon dioxide. The presence of epidote, illite and illite-smectite in well defined zones at Karangahake, coupled with previous fluid inclusion data, implies temperature gradients of >240ºC proximal to veins decreasing to 150ºC approximately 2 km from the veins existed.

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