

# New $^{40}\text{Ar}/^{39}\text{Ar}$ dates of adularia from epithermal deposits in the Hauraki Goldfield, New Zealand

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## Abstract

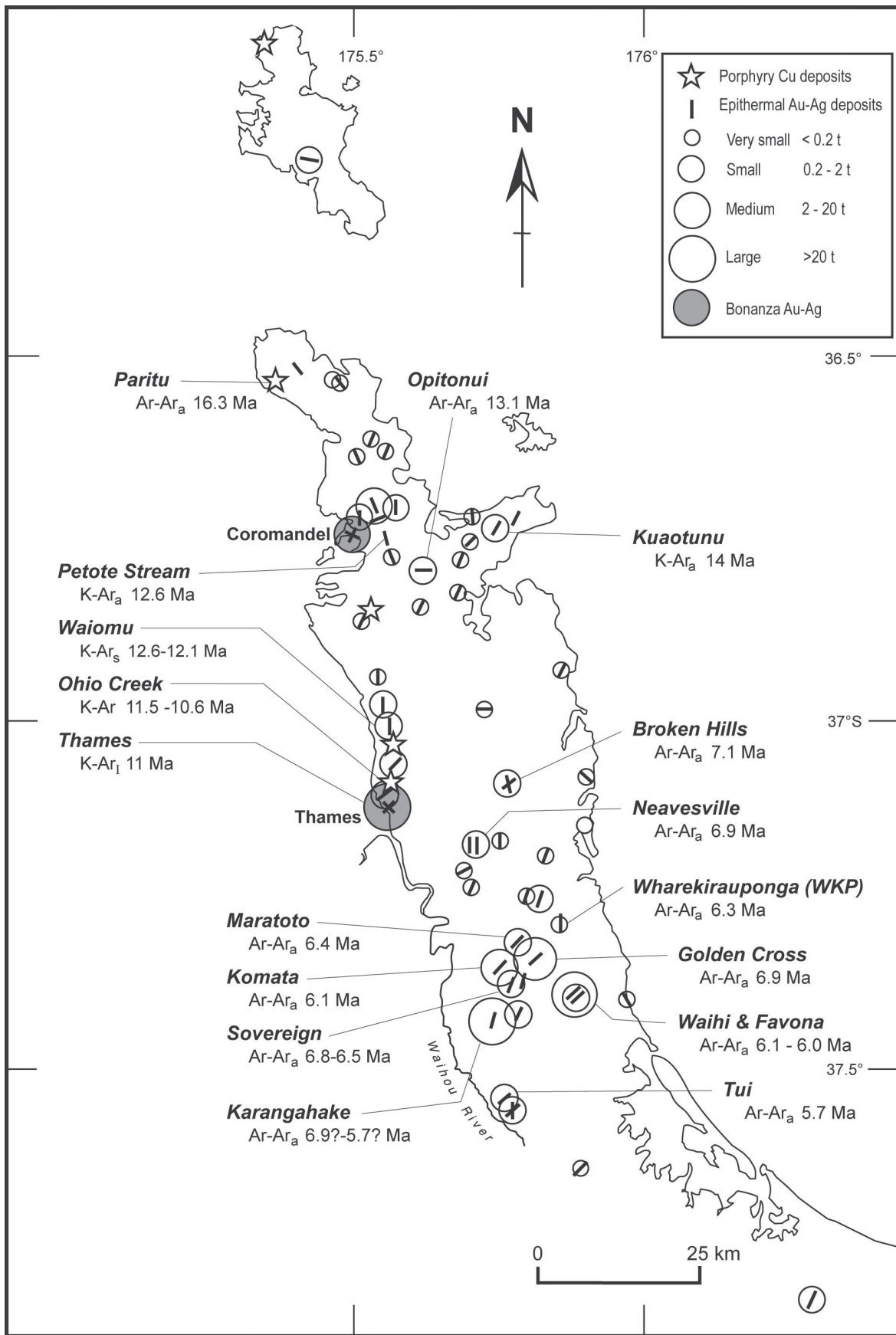
New  $^{40}\text{Ar}/^{39}\text{Ar}$  dates of vein and wall rock adularia from seven epithermal deposits and one porphyry copper prospect help constrain the ages of mineralisation in the Hauraki Goldfield. Vein adularia from the Paritu region yielded a single  $^{40}\text{Ar}/^{39}\text{Ar}$  plateau date of  $16.315 \pm 0.066$  Ma. Five  $^{40}\text{Ar}/^{39}\text{Ar}$  plateau dates of three samples of vein adularia from the Opitonui deposit overlap within error to yield a preferred age of  $13.149 \pm 0.016$  Ma. Two samples of vein adularia from the Night Reef at the Broken Hills deposit yield exceptionally flat  $^{40}\text{Ar}/^{39}\text{Ar}$  plateaus, and all dates overlap within error to provide an age of  $7.121 \pm 0.010$  Ma. Two  $^{40}\text{Ar}/^{39}\text{Ar}$  plateau dates of one sample of vein adularia from the Wharekirauponga deposit overlap within error to provide an age of  $6.318 \pm 0.061$  Ma. Four  $^{40}\text{Ar}/^{39}\text{Ar}$  plateau dates of three samples of vein adularia from the Maratoto deposit overlap within error to provide an age of  $6.411 \pm 0.022$  Ma. Two samples of adularia from altered wall rock at the Sovereign deposit yield three  $^{40}\text{Ar}/^{39}\text{Ar}$  plateau dates that range from  $6.547 \pm 0.021$  to  $6.806 \pm 0.028$  Ma. This suggests that mineralisation formed around 6.6 Ma, but the results are complicated because the adularia contains minor illite that post-dates adularia formation. Results from the Karangahake deposit are complex. Two samples of vein adularia yield three  $^{40}\text{Ar}/^{39}\text{Ar}$  plateau dates that range from  $6.116 \pm 0.116$  to  $6.901 \pm 0.101$  Ma, whereas one sample of wall rock adularia that contains minor late illite yields two  $^{40}\text{Ar}/^{39}\text{Ar}$  plateau dates that overlap within error to provide a date of  $5.734 \pm 0.041$ . The range of dates indicates that more work is necessary to understand the history of mineralisation at this deposit. Two samples of vein adularia from the Tui deposit yield four  $^{40}\text{Ar}/^{39}\text{Ar}$  plateau dates that overlap within error to provide an age of  $5.714 \pm 0.017$  Ma.

These results confirm previous work that indicates that the ages of epithermal deposits young southward in the Hauraki Goldfield. These results are also consistent with previously postulated different ages for deposits hosted in Kuaotunu Subgroup rocks in the northern goldfield (>10 Ma), and deposits hosted in Waiwawa Subgroup rocks in the southern goldfield (7.1 to 5.7 Ma).

**Keywords:**  $^{40}\text{Ar}/^{39}\text{Ar}$ ; Plateau dates; Paritu; Opitonui; Broken Hills; Wharekirauponga; Maratoto; Sovereign; Karangahake; Tui

## Introduction

The Hauraki Goldfield in the Coromandel Peninsula contains adularia-sericite epithermal deposits and porphyry copper prospects within the Coromandel Volcanic Zone (Fig. 1) (Christie and Brathwaite, 1986). Volcanism in the peninsula becomes younger to the south as volcanic activity shifted from the Coromandel Volcanic Zone to the Taupo Volcanic Zone in the late Pliocene (Skinner, 1986; Adams et al., 1994; Carter et al., 2003). This is mirrored by the ages of mineralisation, which also young southward (e.g. Adams et al., 1974; Skinner, 1986; Adams et al., 1994; Mauk and Hall, 2003, 2004).



**Figure 1.** Relative size of past Au-Ag production, main vein orientation and radiometric ages of epithermal Au-Ag deposits of the Hauraki goldfield (modified from Christie et al., 2005). The direction of bar symbol shows the predominant vein strike. Ar-Ar and K-Ar dates for a=adularia, b=biotite, h=hornblende, or s=sericite are from Adams et al. (1974, 1994), Skinner (1986), Hunt and Roddick (1992, 1993), Sinsuat (1992), Brathwaite and Christie (1996), Mauk and Hall (2003, 2004), and this study.

We present new  $^{40}\text{Ar}/^{39}\text{Ar}$  dates of adularia from the Paritu, Opitonui, Broken Hills, Wharekirauponga, Maratoto, Sovereign, Karangahake and Tui deposits in the Hauraki Goldfield. These dates reveal a nine million year span of mineralisation which is older to the north and younger to the south. New  $^{40}\text{Ar}/^{39}\text{Ar}$  ages help constrain the temporal relationships between epithermal mineralisation events in the Hauraki Goldfield. The results of this study suggest that hydrothermal activity in the southern Hauraki Goldfield occurred as overlapping events.

## Geological setting

The Hauraki Goldfield is situated in the Coromandel Peninsula in the Coromandel Volcanic Region (Skinner, 1986). Volcanism was active on the peninsula from 18 to 4 Ma with a maximum regional volcanic hiatus of two million years (Adams et al., 1994). Jurassic greywacke and argillite of the Manaia Hill Group forms the basement of the region and is locally intruded by Late Miocene Coromandel Group diorite intrusives. The Manaia Hill Group is overlain by Miocene-Pliocene Coromandel Group andesites and dacites, and Late Miocene-Pliocene Whitianga Group rhyolites (Skinner, 1986). The epithermal deposits are hosted primarily by andesitic and dacitic rocks with associated rhyolites. The structure of the region is characterised by NNW and NNE striking faults and fractures with a predominantly steep to moderate dips (Christie and Brathwaite, 1986).

We analysed samples from eight deposits in the Hauraki Goldfield. This section describes the local geology of the Paritu, Opitonui, Broken Hills, Wharekirauponga, Maratoto, Sovereign, Karangahake and Tui deposits.

The Paritu porphyry copper deposit in the northern Coromandel Peninsula is hosted by a small diorite to granodiorite pluton which intrudes the basement Manaia Hill Group and Early to mid Miocene andesites. Uplift of the Paritu Volcanics has exposed mineralisation at Paritu as dominantly disseminated pyrite and chalcopyrite with associated molybdenite (Christie and Brathwaite, 1986).

The Opitonui gold-silver epithermal deposit is hosted in Kuaotunu Group andesites and dacites. Mineralisation occurs in N- and E-trending quartz veins (Brathwaite et al., 1989).

The Broken Hills epithermal deposit is hosted in Whitianga Group rhyolite tuff with breccia pipes locally intruding the country rock. Mineralisation occurs in highly silicified breccia pipes and quartz veins that follow N to ENE trends (Moore, 1979; Nortje et al., 2003).

The Wharekirauponga epithermal gold-silver deposit is hosted in Whitianga Group flow-banded rhyolites and rhyolitic tuffs. The rhyolites are bounded in a NNE-trending graben and are intruded by an andesite dyke. Mineralisation occurs in stockwork quartz veins and as disseminated gold within the rhyolites, with considerable mineralisation occurring within the dyke (Rabone et al., 1989; Christie et al., 2003).

The Maratoto epithermal deposit is hosted by highly altered andesites of the Waipupu Formation of the Coromandel Group. Gold-silver mineralisation occurs in NE trending quartz veins with localised fan shaped bonanza mineralisation (Main, 1979).

The Sovereign (formerly know as Maorilands) gold-silver deposit in the southern Waitekauri valley is hosted in andesite, dacite breccias and pyroclastic flows of the Waipupu Formation. Quartz veins follow a NE trend in a highly silicified dacitic tuff breccia (Simpson and Mauk, 2005).

The Karangahake epithermal gold-silver deposit is hosted in Coromandel Group andesite flow breccias with minor dacitic tuff of the Waipupu Formation overlain by Whitianga Group rhyolites. Mineralisation at Karangahake occurs primarily in the Maria and Welcome/Crown Lodes which are quartz veins that contain electrum and associated base metal sulphides. The veins follow the NNW orientation that characterises faults in the region (Brathwaite, 1989).

**Table 1.**  $^{40}\text{Ar}/^{39}\text{Ar}$  age determinations of adularia from the Paritu, Opitonui, Broken Hills, Wharekirauponga, Maratoto, Sovereign, Karangahake and Tui deposits. All errors are  $\pm 1\sigma$ .

AU No	CM Hall No	Location	Plateau age	Comments
56763	MC07-S25a	Paritu	16.315 $\pm$ 0.066	Adularia from quartz vein
56763	MC07-S25b	Paritu	-	Duplicate of above
56760	MC07-S22a	Opitonui	13.165 $\pm$ 0.033	Adularia from quartz vein
56760	MC07-S22b	Opitonui	13.143 $\pm$ 0.038	Duplicate of above
56761	MC07-S23a	Opitonui	13.122 $\pm$ 0.037	Adularia from quartz vein
56761	MC07-S23b	Opitonui	13.162 $\pm$ 0.031	Duplicate of above
56762	MC07-S24b	Opitonui	13.141 $\pm$ 0.042	Adularia from quartz vein
56762	MC07-S24a	Opitonui	12.817 $\pm$ 0.046	Duplicate of above
56756	MC07-S16a	Broken Hills	7.150 $\pm$ 0.027	Rhombohedral adularia crystals
56756	MC07-S16b	Broken Hills	7.119 $\pm$ 0.030	Duplicate of above
56757	MC07-S17a	Broken Hills	7.116 $\pm$ 0.015	Rhombohedral adularia crystals
56757	MC07-S17b	Broken Hills	7.116 $\pm$ 0.017	Duplicate of above
56755	MC07-S29a	Wharekirauponga	6.244 $\pm$ 0.041	Adularia from colloform quartz vein
56755	MC07-S29b	Wharekirauponga	6.369 $\pm$ 0.034	Duplicate of above
18172	MC07-S13b	Maratoto	6.600 $\pm$ 0.034	Coarse adularia in comb quartz vein
18172	MC07-S13a	Maratoto	6.442 $\pm$ 0.027	Duplicate of above
18176	MC07-S15a	Maratoto	6.368 $\pm$ 0.037	Coarse adularia intergrown with comb quartz in vein
18176	MC07-S15b	Maratoto	6.432 $\pm$ 0.041	Duplicate of above
18165	MC07-S14b	Maratoto	6.351 $\pm$ 0.051	Adularia in quartz vein
18165	MC07-S14a	Maratoto	6.289 $\pm$ 0.039	Duplicate of above
56758	MC07-S20b	Sovereign	-	Wallrock adularia
56758	MC07-S20a	Sovereign	6.806 $\pm$ 0.028	Duplicate of above
56759	MC07-S21b	Sovereign	6.547 $\pm$ 0.021	Wallrock adularia
56759	MC07-S21a	Sovereign	6.564 $\pm$ 0.039	Duplicate of above
56764	MC07-S26a	Karangahake	5.746 $\pm$ 0.052	Wallrock adularia
56764	MC07-S26b	Karangahake	5.714 $\pm$ 0.065	Duplicate of above
43582	MC07-S27a	Karangahake	6.901 $\pm$ 0.101	White blueish, brecciated quartz vein
43582	MC07-S27b	Karangahake	6.116 $\pm$ 0.116	Duplicate of above
43566	MC07-S28a	Karangahake	-	Adularia from comb quartz vein
43566	MC07-S28b	Karangahake	6.399 $\pm$ 0.038	Duplicate of above
33870	MC07-S18b	Tui	5.682 $\pm$ 0.018	Coarse Adularia in quartz vein
33870	MC07-S18a	Tui	5.742 $\pm$ 0.020	Duplicate of above
33973	MC07-S19b	Tui	5.743 $\pm$ 0.035	Adularia bands in quartz basemetal sulfide vein
33973	MC07-S19a	Tui	5.723 $\pm$ 0.046	Duplicate of above

The Tui epithermal deposit is unusual in the Hauraki Goldfield as it was mined primarily for sphalerite and galena that occur in quartz veins and vein breccias. The quartz veins occur in andesites with minor andesite breccia and tuff, following the NE trend of regional faults (Wodzicki and Weissberg, 1970; Bates, 1989).

## Sample descriptions and analytical methods

We analysed adularia from veins and wall rock from the Paritu, Opitonui, Broken Hills, Wharekirauponga, Maratoto, Sovereign, Karangahake and Tui deposits. Slabbed samples from each deposit were etched with hydrofluoric acid and stained with sodium cobaltinitrite to highlight potassium bearing minerals in the rock. The stained samples were analysed by X-ray diffraction (XRD) to determine the mineralogy of the potassium-bearing phases. Where adularia was the only detectable potassium-bearing mineral, the stained areas of the slabs were cut out with a rock saw and then crushed to sand-size grains. Adularia separates were then hand picked under a binocular microscope. The adularia separates were checked for purity by XRD and where quartz occurred in the samples, it was considered to be a dilutant as no potassium occurs in the quartz lattice. All samples have Auckland University (AU) numbers, and are lodged in the collection of the Geology Department at the University of Auckland.

The samples were irradiated in location 5C at the McMaster Nuclear Reactor, and analysed at the University of Michigan using techniques described elsewhere (Mauk and Hall, 2003; 2004).

## Results

Table 1 shows  $^{40}\text{Ar}/^{39}\text{Ar}$  dates of adularia from the Paritu, Opitonui, Broken Hills, Wharekirauponga, Maratoto, Sovereign, Karangahake and Tui deposits. Errors within the samples are to one sigma and all samples fall beneath the mean squared weighted deviate (MSWD) of  $<2$ . The samples were run twice and the duplicate analyses are also recorded in Table 1.

## Discussion

New  $^{40}\text{Ar}/^{39}\text{Ar}$  dates of adularia combined with previous geochronology of veins and host rocks of Hauraki Goldfield deposits help constrain the mineralisation history of this important metallogenic province. This section discusses our results beginning with deposits in the north, and working south. We also compare these new dates with previous results.

Adularia from a tourmaline-bearing quartz vein in the Paritu deposit yields a single  $^{40}\text{Ar}/^{39}\text{Ar}$  plateau date of  $16.315 \pm 0.066$  Ma. Because there is only one plateau result, we have not interpreted a preferred age. Early K-Ar dates for the Paritu diorite pluton give the intrusive age as 16.0 to 17.1 Ma (Richards et al., 1966). When readjusted using Steiger and Jager (1977) decay constants, the age of the Paritu plutonics are given as 16.4 to 17.6 Ma (Adams et al., 1994). This age, combined with the single date from our work, is consistent with mineralisation occurring soon after the emplacement of the diorite pluton, but additional work is required.

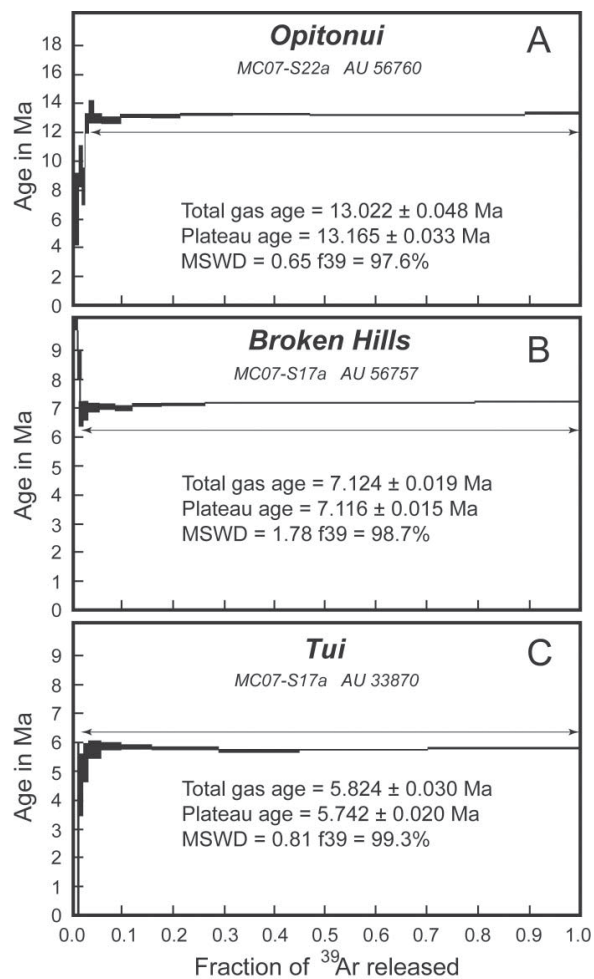
Three samples of adularia from quartz veins in the Opitonui deposit yield six  $^{40}\text{Ar}/^{39}\text{Ar}$  plateau dates that range from  $12.817 \pm 0.046$  to  $13.246 \pm 0.037$  Ma. The plateaus give exceptionally flat spectra, and five dates overlap within error to yield a preferred age of  $13.149 \pm 0.016$  Ma. The Kuaotunu Subgroup host rocks have K-Ar dates of 11.4 Ma for whole rock analyses and  $13.8 \pm 0.3$  Ma for unaltered plagioclase from the Mahinapua Andesite (Adams in Skinner, 1986). Our data suggest that the whole rock age is too young, and that the plagioclase separate may provide a better age of the host rocks.

Two pure rhombohedral adularia crystals from the Night Reef at the Broken Hills deposit yield four exceptionally flat  $^{40}\text{Ar}/^{39}\text{Ar}$  plateaus that range from  $7.116 \pm 0.015$  to  $7.150 \pm 0.027$  Ma (Fig. 2). These results overlap within error giving a preferred age of the deposit of  $7.121 \pm 0.010$  Ma. Obsidian dates of the Whitianga Group host rocks compiled by Skinner (1986) indicate that rhyolite volcanism occurred between 7.2 and 7.8 Ma in the Hikuai region. These results suggest that mineralisation occurred shortly after rhyolite volcanism.

Adularia from one sample of a colloform quartz vein in the Wharekirauponga deposit yields  $^{40}\text{Ar}/^{39}\text{Ar}$  plateaus of  $6.244 \pm 0.041$  and  $6.369 \pm 0.034$  Ma. The dates overlap within error giving our preferred age for the Wharekirauponga deposit as  $6.318 \pm 0.061$  Ma. The deposit is hosted by the Maratoto Rhyolite, constraining the age of mineralisation on the basis of geological relations, to K-Ar dates reported by Brathwaite and Christie (1996) of 7 to 6 Ma. This suggests that mineralisation at Wharekirauponga was broadly contemporaneous with the formation of the Whitianga Group rhyolites.

The Maratoto deposit is hosted by the 7.9 to 6.3 Ma Waipupu Formation (Brathwaite and Christie, 1996), and contains adularia in quartz veins. Six  $^{40}\text{Ar}/^{39}\text{Ar}$  plateau dates of three samples range from  $6.289 \pm 0.039$  to  $6.600 \pm 0.034$  Ma. Four of these values overlap within error and we therefore interpret a preferred age for the deposit of  $6.411 \pm 0.022$  Ma, which suggests that the deposit formed at the waning stages of deposition of the Waipupu Formation. Our  $^{40}\text{Ar}/^{39}\text{Ar}$  plateau dates are broadly similar to previous K-Ar ages of adularia from veins that were reported as 6.2 to 5.2 Ma (Adams in Skinner, 1986).

Two samples of wall rock adularia from the Sovereign deposit yield  $^{40}\text{Ar}/^{39}\text{Ar}$  plateau dates of  $6.547 \pm 0.021$ ,  $6.564 \pm 0.039$  and  $6.806 \pm 0.028$  Ma (Table 1). The dates do not overlap within



**Figure 2.** Representative age spectra for samples from adularia samples from this study. All error estimates and error boxes are  $1\sigma$ . A. Age spectra from Opitonui sample AU 56760. B. Age spectra from Broken Hills sample AU 56757. C. Age spectra from Tui sample AU 33870.

error and therefore we have not interpreted a preferred age. Petrographic analyses indicate that adularia in these samples contains small but variable amounts of illite that post-dates the adularia. Because illite is also a K-bearing phase, we infer that this later illite may perturb the adularia dates. If so, the older date (6.8 Ma) may most closely reflect the time of mineralisation. The Sovereign deposit is also hosted by the 7.9 to 6.3 Ma Waipupu Formation (Brathwaite and Christie, 1996).

Wall rock adularia from the Karangahake deposit yields  $^{40}\text{Ar}/^{39}\text{Ar}$  plateau dates of  $5.714 \pm 0.065$  and  $5.746 \pm 0.052$  Ma. Petrographic analysis of this sample (AU 56764) shows that minor late illite replaces the wall rock adularia, and therefore the plateau dates may be perturbed by this younger event. Two samples of adularia from quartz veins in the deposit yield three  $^{40}\text{Ar}/$

$^{39}\text{Ar}$  plateau dates ranging from  $6.116 \pm 0.116$  to  $6.901 \pm 0.101$  Ma (Table 1). The wall rock adularia dates overlap within error but the quartz vein adularia dates do not, with the wall rock adularia dates up to 1.2 Myr younger than the dates of adularia from the veins. Due to the complexity of these results, we have not interpreted a preferred age for mineralisation at Karangahake. Previous K-Ar results for the Karangahake deposit reported in the literature reflect this complexity. Adularia from altered andesites and associated mineralisation at Karangahake yields dates of  $4.8 \pm 0.1$  and  $6.0 \pm 0.1$  Ma. Unaltered andesites in the southern sector of Karangahake yield ages of 5.4 and 5.1 Ma (Adams, unpublished in Skinner, 1986). The 6 to 7 Ma Maratoto Rhyolite of the Whitianga Group forms a cap over 7.9 to 6.3 Ma Waipupu Formation andesite at Mt Karangahake (Brathwaite, 1989; Brathwaite and Christie, 1996). As stockwork quartz veins cut the rhyolite cap, at least some of the mineralisation must be younger than the Maratoto Rhyolite. The complexity in the results may reflect more than one phase of mineralisation or a separate alteration event for the veins and wall rock. The Karangahake deposit formed at relatively deep levels at higher temperatures than most deposits in the Southern Coromandel (Brathwaite, 1989), and so the complexity of our results might also reflect the deep nature of the deposit, as the dates may be cooling ages rather than crystallisation ages.

Plateaus from the Tui deposit are derived from coarse adularia in a quartz vein and adularia bands in a quartz basemetal sulphide vein. Adularia yields  $^{40}\text{Ar}/^{39}\text{Ar}$  plateaus ranging from  $5.682 \pm 0.018$  to  $5.743 \pm 0.035$  Ma and the results overlap within error (Table 1). The preferred absolute age of mineralisation at the Tui deposit is  $5.714 \pm 0.017$  Ma. K-Ar absolute ages of andesite volcanism at Te Aroha are 16.2–13.6 Ma (Adams et al., 1974). Two K-Ar ages are given for hydrothermal alteration at the Tui deposit, the older age of 6.0–6.9 Ma (Adams et al., 1974) is more consistent with the preferred age presented in this paper. Younger K-Ar ages of 2.6–4.0 Ma (Adams et al., 1974) may represent a later hydrothermal alteration event (Brathwaite and Christie, 1996).

Taken together, the above dates and preferred ages indicate that mineral deposits in the Hauraki Goldfield generally young from north

to south. Previous  $^{40}\text{Ar}/^{39}\text{Ar}$  dates of adularia from Golden Cross (6.9 Ma), Neavesville (6.9 Ma), Komata (6.1 Ma), Waihi and Favona (6.0-6.1 Ma) (Mauk and Hall, 2003; 2004) are broadly consistent with this trend, although expected complexities exist in local areas such as the Waitekauri corridor where a number of closely spaced deposits have different ages that show no apparent correlations between location and age.

## Conclusions

New absolute ages and dates of adularia from deposits in the Hauraki Goldfield range from  $16.315 \pm 0.066$  Ma for mineralisation at the Paritu deposit to  $5.714 \pm 0.017$  Ma for mineralisation in the Tui deposit. The results presented in this paper, combined with other geochronology, suggest that mineralisation was episodic over the period of active volcanism within the Coromandel Volcanic Zone and that there may have been a hiatus in mineralisation between 11 and 7 Ma. Epithermal deposits in the Hauraki Goldfield young southward, which is consistent with mineralisation occurring broadly contemporaneously with southward younging volcanism in the Coromandel Volcanic Zone (Adams et al., 1994). However, full understanding of the detailed relations between volcanic activity and mineralisation awaits future precise and accurate geochronology of unaltered volcanic rocks throughout the Coromandel Volcanic Zone.

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