DURATION OF MINERALIZATION AND TIMING OF VEIN FORMATION AT THE HISHIKARI EPITHERMAL GOLD DEPOSIT, SOUTHERN KYUSHU, JAPAN, DETERMINED BY $^{40}Ar/^{39}Ar$ DATING

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SUMMARY – To elucidate duration of mineralization and timing of vein formation at the Hishikari epithermal gold deposit, Japan, mineralization ages of individual bands within the Hosen-1 vein were determined using $^{40}Ar/^{39}Ar$ dating. Veins at the Hishikari deposit consist mainly of adularia and quartz, showing a precipitation sequence. Since adularia and quartz in the same sequence must have precipitated simultaneously, ages of adularia show timing of vein formation. The result of $^{40}Ar/^{39}Ar$ ages of adularia indicates that intervals among each vein formation varied from approximately 40,000 to 130,000 years and the total duration of mineralization at the vein was about 250,000 years. The veins were formed intermittently.

1. INTRODUCTION

The Hishikari high-grade gold epithermal deposit is located in southern Kyushu, Japan (Figure 1). The total gold content is estimated to be 260 metric tons.

The typical precipitation sequence of adularia-quartz at the Hishikari deposit shows that the abundance of adularia decreases from early to late stages of vein filling (Nagayama, 1993). Adularia, especially columnar adularia, is often observed along the vein selvage, showing adularia deposited immediately after fracturing. In many cases, electrum occurs along side an adularia band. In addition, Uchida et al. (2000) implies a good correlation between an amount of Au and Al. Therefore, the age of adularia should provide a good indicator of the timing of vein opening and electrum deposition.

Fracturing and vein formation at the Hishikari deposit have been discussed by several researchers (e.g., Naito, 1993; Uto et al., 2001; Sekine et al., 2002). However, there are no age data regarding the history of opening within a single vein and the duration of vein formation. In this study, we obtained twelve $^{40}Ar/^{39}Ar$ ages of adularia from several bands in the Hosen-1 vein.

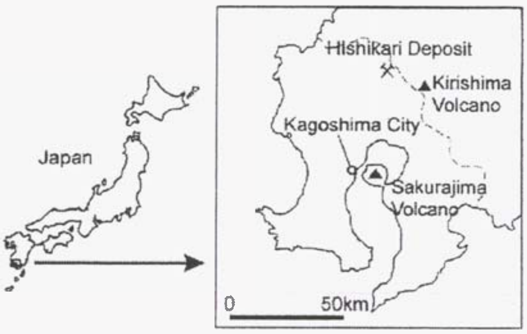

Figure 1 Location of the Hishikari deposit.

2. GEOLOGY

The Hishikari deposit occurs within Pleistocene volcanic rocks of the Hishikari Lower Andesites and basement rocks of the Cretaceous Shimanto Supergroup which consist manly of shale, sandstone and their alternations. The Hishikari Lower Andesites uncomformably overlie the Shimanto Supergroup (Izawa et al., 1990). K-Ar ages indicate that volcanic activity occurred from 1.78 to 0.51 Ma (Izawa et al., 1990) and that mineralization occurred between 1.25 and 0.66 Ma (e.g., Izawa et al., 1993; Sekine et al., 2002).

The Hishikari deposit consists of the Honko-Sanjin zone and the Yamada zone (Figure 2). Veins of the Honko-Sanjin zone are hosted by the Shimanto Supergroup and Hishikari Lower Andesites, whereas veins of the Yamada zone are hosted by the Hishikari Lower Andesites. The Hosen-1 vein is in the Honko-Sanjin zone, hosted by shale of the Shimanto Supergroup.

3. DESCRIPTION OF SAMPLES

In this study, twelve adularia samples for $^{40}Ar/^{39}Ar$ dating were obtained from the Hosen-1 vein at –20 m level and +62.5 m level. Sampling points are shown in Figure 3. The Hosen-1 vein exhibits a banding structure and most parts of the vein are symmetric. The Hosen-1 vein at –20 m level can be divided into four bands, L-I, L-II, L-III, and L-IV. The Hosen-1 vein at +62.5 m level is located, approximately 80 m and 30 m away vertically and horizontally, respectively from the surveyed location at –20 m level, and can be divided into four bands, U-I, U-II, U-III, and U-IV.

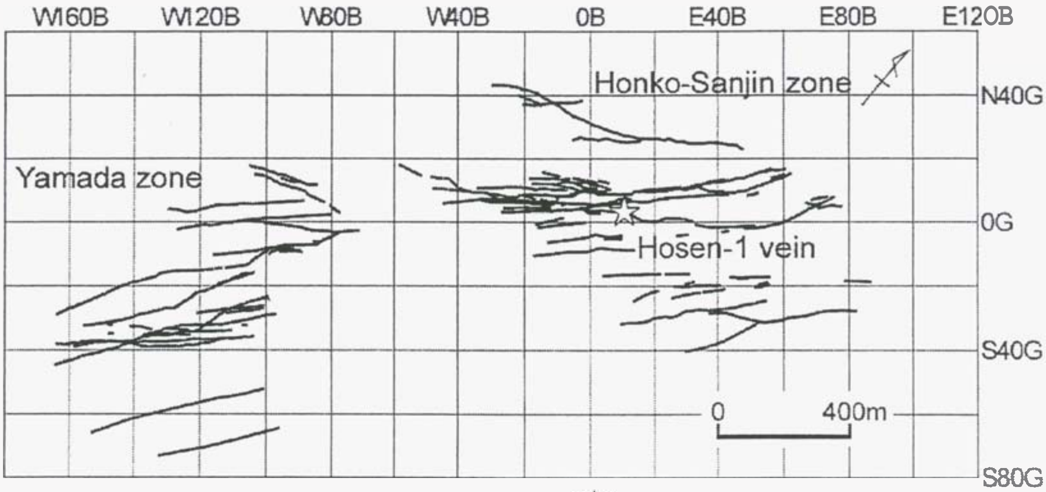

Figure 2. Vein map of the Hishikari deposit. The mark "☆" shows the sampling point of the Hosen-1

In the Hosen-1 vein, a typical precipitation sequence from adularia to quartz was observed. Rhombic adularia and columnar adularia in the samples of the Hosen-1 vein suggest violent boiling and rapid change of thermal fluid (Dong and Morrison, 1995). In many cases, adularia **is** observed as columnar adularia. *Quartz* is fine-grained, and sometimes comb quartz is observed in the last stage of the precipitation.

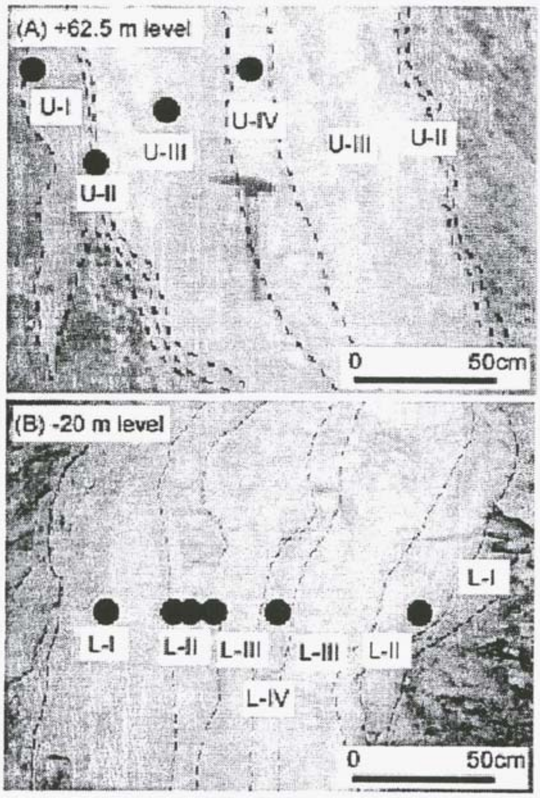

Figure 3 Photographs show sampling points (solid circles) for $^{40}Ar/^{39}Ar$ dating in the Hosen-1 vein at (A) +62.5 m level and (B) –20 m level, respectively. Broken lines show boundaries of each band. The host rock consists of shale of the Shimanto Supergroup.

Description of the samples is summarized in Table 1. At –20 m level, the band L-I consists mainly of bladed quartz and fine-grained euhedral adularia. The band L-II is divided into three sub-bands and characterized by a large amount of columnar adularia. The band L-III contains many small euhedral quark grains in druse and does not contain enough adularia for age dating. The band L-IV consists mainly of fine-grained adularia-quartz and comb quartz in the last stage. The band U-I, the earliest part of the Hosen-1 vein at +62.5 m level, contains coarse grained **quartz** rimmed by columnar adularia. The band U-II, a narrow band (about **4** cm in width), also contains columnar adularia, and is characterized by a crustiform structure including a ginguro (electrum-rich) band in it. The band U-III is the widest band in the Hosen-1 vein at +62.5 m level, however it cannot be divided into sub-bands because there is no apparent banding structure. Smectite and euhedral adularia are observed in this band. The band **U-IV** is similar to the band L-IV, consisting mainly of fine-grained adularia-quartz and comb quartz.

4. ANALYTICAL METHOD

Samples were wrapped in copper foil and loaded in evacuated quartz vials for irradiation at Oregon State University (OSU). FCT-3 biotite was used to monitor the neutron **flux** at the OSU TRIGA reactor. Irradiation was conducted for ***6*** hours at 1 MW. Monitor minerals were placed at multiple vertical positions along the 80 mm center vial in the irradiation tube, which provided neutron **flux** measurements (J values) that varied smoothly in a range of –10 %. Horizontal gradients in J values are known from previous data to be <1 %. J values for sample positions were interpolated from a second-order polynomial fit to the monitors. Errors are accumulated from the individual monitor measurements and gradient fitting, and are about 0.5 %.

Table 1 Description of samples for $^{40}Ar/^{39}Ar$ dating.

Level	Band	Sample name	Texture of adularia	Texture of quartz
+62.5 m	u-I	u-I	columnar	
	U-II	U-II	columnar	crustiform
		u-11*	columnar	crustifom
	U-III	U-III	euhedral	colloform, fine-grained, coarse-grained
	U-N	u-N	subhedral-euhedral	crustiform, fine-grained
-20 m	L-I	L-I	euhedral	bladed
	L-II	L-II-1	columnar	fine-grained
		L-II-2	columnar	fine-grained
		L-II-2**		
		L-11-3	fine-grained	fine-grained
	L-IV	L-Iv	subhedral-euhedral	crustiform, fine-grained

* The sampling point is horizontally **apart** from U-II in several meters.
** The sample was obtained from the band symmetrical to each other.

The ***Ar*** isotope ratios of samples were measured using a MAP-215/50 mass spectrometer. Samples were heated in 25-150 "C increments, from 400 "C to 1400 "C (at which samples fused completely). Each incremental heating experiment was followed by heating at 1550 "C to degas in the furnace. ^{40}Ar, ^{39}Ar, ^{38}Ar, ^{37}Ar, and ^{36}Ar were measured on an electronic multiplier, over 9 or 12 cycles. Line blanks were run routinely for a range of temperatures to correct for the ***Ar*** contribution from the extraction system. The ages for each temperature step were calculated by assuming an initial atmospheric $^{40}Ar/^{36}Ar$ ratio (295.5).

5. RESULTS AND DISCUSSION

5.1 Reliability of radiometric ages

The ages are computed in three ways, plateau ages, total fusion ages, and isochron ages. Plateau ages are the weighted mean of sequential, concordant step ages that comprise over 50 % of the total gas. Total fusion ages are the results of adding all step compositions to derive a single, total gas age. This is essentially equivalent to a conventional **K-Ar** age. Isochron ages are calculated from the slope of the best-fitting line to step compositions.

The errors reported as 2σ, are on the order of 1-3 % for the plateau ages, and are almost concordant with the isochron ages. In general, plateau and isochron ages are concordant, indicating that the effect of non-atmospheric initial ^{40}Ar (excess ^{40}Ar) is scarce. This is confirmed by the average $^{40}Ar/^{39}Ar$ ratio consistent with present-day atmospheric $^{40}Ar/^{39}Ar$ ratio (295.5). In all cases, clear plateaus comprising over 50 % of the total extracted gas were obtained. Accordingly, these $^{40}Ar/^{39}Ar$ ages of adularia at the Hishikari deposit

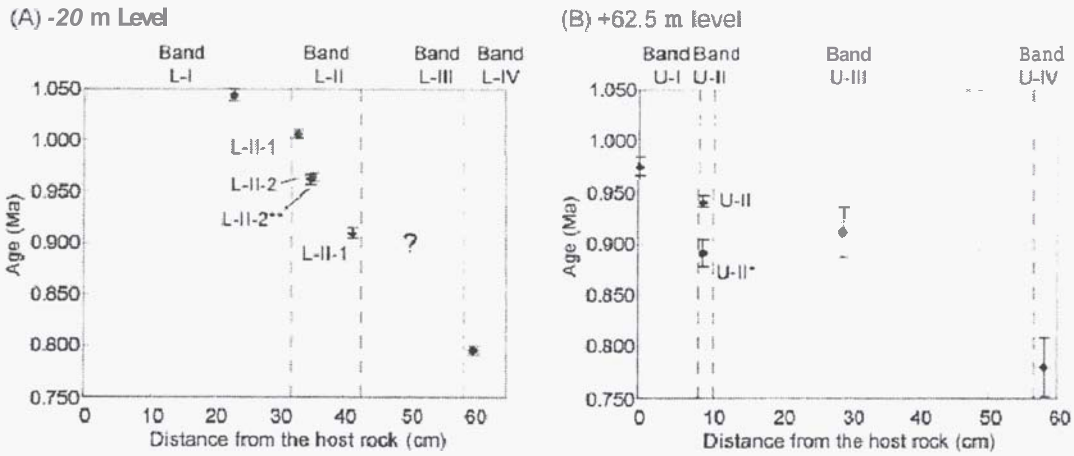

Figure **4** The diagrams show spatiotemporal distribution in the Hosen-1 vein. (A) Vein formation occurred at least ***6*** times at –20 m level though the age of the band L-III could not be measured. (B) Vein formation occurred at least **4** times at 62.5 m level. The band U-III was formed in a very short period, and there was a long interval, about 130,000 years between the band U-III and the band U-IV.

are reliable enough to discuss the history of vein formation.

5.2 Mineralization ages of the Hosen-1 vein

The spatial-temporal distribution of mineralization ages within the Hosen-1 vein is shown in Figure 4. In most cases, each band within the Hosen-1 vein shows different ages. From these results, it is confirmed that two bands symmetrical to each other were formed simultaneously. In other words, in a vein having a symmetrical structure, mineralization occurred from the first band adjacent to the host rock toward the last band at the center of the vein. The different ages within one vein confirm that adularia-quartz precipitation sequence is a good indicator of timing of the relative timing of vein formation.

The time difference between the earlier adularia-quartz sequence and the later one shows an interval of vein formation in which minerals scarcely deposited. Taking the shortest time between the band U-II and band U-III and the longest time between the band U-III and U-IV into consideration, the intervals of vein formation range from approximately 40,000 to 130,000 years at the Hosen-1 vein. The band U-III, about 80 cm in width, was formed in a very short period by only one vein formation because apparent banding structure was not observed. These results suggest that vein formation occurred intermittently in pulses rather than continuously at a constant rate.

Mineralization ages were not always concordant with each other at –20 m level and +62.5 m level. For example, the age of the band L-I is apparently different from that of band U-I despite the earliest bands at the Hosen-1 vein. However, the band L-IV and band U-IV, the last bands of the Hosen-1 vein, have similar texture of adularia and quartz and show the same age. The age difference between band L-I and band L-IV, about 250,000 years, indicate duration of mineralization at the Hosen-1 vein. In this duration, vein formation occurred at least six times at –20 m level in Hosen-1 vein.

6. CONCLUSIONS

The mineralization ages of the Hosen-1 vein indicates the period of its formation. Since the intervals of vein formation range from approximately 40,000 to 130,000 years, vein formation occurred intermittently. The duration of mineralization is about 250,000 years for the Hosen-1 vein, and vein opening occurred at least six times in this period.

7. ACKNOWLEDGEMENTS

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