Stable Isotope and Geochemical Observations in the Kago Low-Sulfidation Au/Ag Deposit, Southern Kyushu, Japan

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Abstract

The Kago low-sulfidation Au/Ag deposit was an extensively excavated mine, primarily in the Edo-period (1684), reaching as far as 1943. Au grades ranged from 4.1-13.3g/t, while Ag ranges from 2.6-6.6g/t. The higher grades of gold made this deposit more favourable to mine, in comparison to other operating mines such as Serigano towards the north. The deposit is located approximately 5km from both the Kasuga and Iwato high-sulfidation deposits located towards the south. In this study, surficial quartz veins were measured for $^{18}$O in quartz and $^{34}$S in pyrite hosted in the veins. Where available, fluid inclusion microthermometry was carried out to establish the likely temperature of the mineralising fluids. Fluid $^{18}$O compositions were estimated using microthermometry results. Host rocks surrounding the veins were analysed for their alteration mineralogy. Within the Central Vein Group (CVT), veins typically exhibit low temperature argillic alteration grading out into a regional propylitic zone.

1. INTRODUCTION

The Kago deposit is located in the southwestern area of the Nansatsu District, Southern Kyushu, Japan. The Nansatsu district is recognised as hosting a number of classic high-sulfidation Au/Cu deposits which carry the name "Nansatsu-type", namely Kasuga, Iwato and Akeshi deposits, present as disseminated silicific ore bodies. High-sulfidation deposits exhibit temperatures of around 250-300°C, with an ore mineral assemblage of higher sulfidation state minerals such as enargite and luzonite. Additionally the pH tends to be somewhat acidic. This is in contrast to low-sulfidation deposits, such as Kago, which typically have a lower temperature of around 150-250°C and adularia precipitation, the pH tends to be near neutral to alkaline. The Kago Deposit sits relatively proximal to the Nansatsu-type deposits, but is present as a series of quartz veins. In this study we seek to establish the relationship of the Kago deposit to the Nansatsu deposits in terms of the geochemical variations exhibited between the juxtaposed ore zones.

2. GEOLOGICAL SETTING

The Nansatsu District is uniformly underlain by the Kawanabe Formation, corresponding to the Lower Shimanto-Supergroup. The Shimanto-Supergroup is largely made up of two units, the Lower and Upper Units, with the Lower Shimanto-Supergroup located from southwestern Shikoku Island to the base of the Satsuma Peninsula on southern Kyushu. Typical lithology of the Kawanabe Formation comprises of sandstone and interstratified sandstone/mudstones. Radiolarian biostratigraphy has suggested an age of between 89.3 to 83.5 Ma (Teraoka et al., 1986). The Upper Formation of the Nansatsu Group Volcanics are distributed to the south and west of the Kago deposit, which host Kasuga and Iwato deposits, these are typically composed of course grained two-pyroxene andesite flows, mudstone/pyroclastics and tuffaceousbreccias. These are dated at around 7.6 to 5.9 Ma (Izawa, 1992, Ministry of International Trade and Industry (MITI), 1985). To the northeast the Nansatsu Middle Volcanics are widely distributed, comprising hornblende andesites, which also host Akeshi deposit. This Formation is dated to approximately 4.6-3.4 Ma. Quaternary pyroclastic rocks are spread widely over much of the surface exposure, particularly Ata Pyroclastics, erupted from Ata caldera 30km to the east in the mouth of Kagoshima Bay. K-Ar age dating suggests gross mean age of 108 ± 3ka (Matsumoto et al., 1997). Later eruptions from Aira caldera, in the northern region of the Kagoshima graben, lie to the north of the Nansatsu District and are dated at approximately 24.5 ka (Ikeda, 1995).

3. Structural and Vein Morphology

The veins of the Kago deposit can be classified into three dominant groups; the Northern, Central and Southern Vein Groups (NVG, CVG and SVT, respectively). The NVT was not examined in this study due to poor surface exposure, however mine tunnel illustrations show a number of operated excavations following strike of the NVG.
(Kagoshima Deposit Development Report, 1968), these are typically in an east-west orientation. The CVG has the largest concentration of exposed veins and also appears to have been where much of the mining operation in the past was focused. Veins strike in a NE-SW direction and dip at 60-70°N. Veins range from 4-20 cm in width and extend for as much as 1 km. Similar to the CVG, the SVG has veins oriented NE-SW direction and exhibit a steep dip of 70°S.

4. SAMPLING AND METHODOLOGY
Samples were collected from the CVT and SVG along veins that were exposed on the surface. Quartz veins were collected for petrographic, ore mineral, stable isotope and microthermometric analysis. Host rock surrounding the veins was used to perform alteration mineral determinations by liquid separation and measurement by x-ray diffraction (XRD).
5. MICROTHERMOMETRY
Quartz from the CVG was used to do preliminary inclusion analysis. Inclusions are relatively sparse in the samples, however a representative amount was found in sample 090710-5a. Inclusions are typically liquid rich, however where primary inclusions can be identified, they tend to be liquid + vapour.

Results
Temperature measurements range from 160-270°C (Fig. 2), with a strong modal composition in the range 220°C. Much of the lower values are interpreted to be secondary inclusions, largely the result of necking down.
Salinity was estimated from the ice melting temperature of bi-phase inclusions. Results range from 0.53 to 1.1 NaCl eq. wt%, with an average composition of 0.76 NaCl eq. wt%.

6. STABLE ISOTOPE GEOCHEMISTRY
6.1. \( \delta^{18} \text{O} \)
Quartz samples were lightly crushed to 0.5mm grains and purified in an aqua regia bath to remove any sulphide contaminants. Following this they were thoroughly rinsed in deionised water and dried at room temperature. A representative portion of the recovered sample was crushed and checked by XRD to ensure the purity. Oxygen was liberated from the samples by conventional fluorination using CIF$_3$ and fixated as CO$_2$ following the methods of Clayton and Mayeda (1963). The gas was then ran in a mass spectrometer. All results are represented relative to Standard Mean Ocean Water (SMOW).

6.2. \( \delta^{34} \text{S} \)
Sulphur gas, obtained from pyrite, was derived from mineral separate by heating in a furnace and passed through a conventional sulphur line, using an n-pentane trap to remove CO$_2$ impurities. The gas separate was sent to a mass spectrometer for analysis.
All samples analysed at the Stable Isotope Facility, Scottish Universities Environmental Research Centre, Glasgow, U.K. $^{18}$O/$^{16}$O ratios were measured using an Edwards Mass Spectrometer, whilst $\delta^{34}$S/$^{32}$S was measured using a Thermo Fisher MAT 253 mass spectrometer. $\delta^{34}$S is represented relative to Canon Diablo Troilite (CDT).

**Results**

Quartz results range from +5.8% to 13.1% (Table 1). The majority of samples range from 5.8% to 8.2%, with only one sample (10-2) showing a higher $\delta^{18}$O value (13.1%). Sulphur values range from -1.8% to 2.7% (Table 2).

### 7. DISCUSSION

#### 7.1. Fluid Calculated $\delta^{18}$O Composition

Composition of the mineralising fluid is estimated using the fluid inclusion microthermometry temperature data and the measured $\delta^{18}$O values. The fractionation equation for quartz-H2O systems is provided by Matsuhisa et al., (1979).

![Histogram of homogenisation temperature range of sample 090710-5a.](image)

**Table 1: $\delta^{18}$O results from quartz**

<table>
<thead>
<tr>
<th>Sample No:</th>
<th>Mineral</th>
<th>Yield</th>
<th>$\delta^{18}$O (SMOW)</th>
</tr>
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<tbody>
<tr>
<td>10-2</td>
<td>Qtz</td>
<td>16.7</td>
<td>13.1</td>
</tr>
<tr>
<td>090710-5a</td>
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<tr>
<td>100710-1a</td>
<td>Qtz</td>
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<tr>
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<td>Qtz</td>
<td>16.3</td>
<td>5.8</td>
</tr>
<tr>
<td>100710-1b</td>
<td>Qtz</td>
<td>16.6</td>
<td>8.2</td>
</tr>
<tr>
<td>300310-3</td>
<td>Qtz</td>
<td>16.6</td>
<td>7.3</td>
</tr>
<tr>
<td>090710-3</td>
<td>Qtz</td>
<td>16.9</td>
<td>6.6</td>
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</tbody>
</table>

**Table 2: $\delta^{34}$S from pyrite**

<table>
<thead>
<tr>
<th>Sample No:</th>
<th>Mineral</th>
<th>% Yield</th>
<th>$\delta^{34}$S (CDT)</th>
</tr>
</thead>
<tbody>
<tr>
<td>300310-3</td>
<td>Py</td>
<td>41</td>
<td>2.7</td>
</tr>
<tr>
<td>090710-2</td>
<td>Py</td>
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<tr>
<td>300310-2</td>
<td>Py</td>
<td>62</td>
<td>-1.8</td>
</tr>
</tbody>
</table>

From the fluid inclusion data, three possible temperature ranges can be utilised: 190°C, 220°C and 260°C. These give calculated values of: -4.6% (190°C), -2.8% (220°C) and -0.8% (260°C). The most likely composition is from the modal value derived from fluid inclusion measurement, favouring -2.8% at 220°C. This would suggest that the fluids that were responsible for silicate mineralisation were derived from surficial fluids.

#### 7.2. Sulphur Isotopes

Sulphur isotope values are dominantly negative, with only one positive value (+2.7%). Sample 300310-3 is from an area of extreme silicification of the Shimanto-Supergroup and as such much of the pyrite is disseminated throughout, rather than following a unique bounded vein. As such, it may be interpreted as a bulk value for the silicified rock, rather than a unique value.
ACKNOWLEDGEMENTS
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References