Geochemistry, Geochronology and Genesis of Gold Mineralization in Nurt of Northern Altay, Xinjiang: A Case Study on the Aketishikan Gold Deposit

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Abstract Gold deposits such as the Aketishikan, Togetobie, Tasbig-Kokeydlas, Kums and Hongshanzui gold deposits in the Nurt area in Altay of Xinjiang were found in Member 3 rhyolite tuffava, fragmental lava and ignimbrite of the Carboniferous Hongshanzui Group. Trace and rare earth elements, sulfur, lead, oxygen and hydrogen isotopes, and geochronological studies indicate that the ore-forming material was mostly supplied by the Carboniferous volcanic rocks through water-rock interaction under a low-to-moderate temperature, and the hydrothermal ore-forming fluid came from meteoric water with some magmatic water input evolved from the granitic magmas. Gold deposits in the Nurt area as well as in the northern Altay might form in multiple stages, and the Yanshanian mineralization period should be paid more attention besides the Variscan mineralization period.

Key words: gold deposit, geochemistry, geochronology, Aketishikan, Altay, Xinjiang, China

1 Introduction

The Northern Altay of Xinjiang, China, is rich in gold mineral resources. Gold deposits are distributed regionally along linear structural zones and mostly concentrated in the Devonian and Carboniferous volcanic and pyroclastic strata overlying the Precambrian Kuwei Formation. The Nurt area of the Altay is located in the east of the northern Altay region, adjacent to the People’s Republic of Mongolia. Gold mineralization in this region is obvious, and the scale and intensity of gold anomaly are also great. It has become an important prospecting area of gold resource in northern Xinjiang. There are some important gold deposits such as the Aketishikan, Togetobie, Tasbig-Kokeydlas, Kums and Hongshanzui gold deposits (occurrences) discovered in these region in the past. But due to the high altitude, bad climate and difficult traffic, further study on gold mineralization in Nurt is to be carried out.

It has been commonly accepted that gold deposits in the northern Altay including Nurt were formed in the Paleozoic, especially in the Late Paleozoic (Xiao et al., 1992; He et al., 1994). Attitudes about the genesis of gold mineralization are also controversial (Zhu and Dong, 1995; Rui, 1994; Zhou et al., 2000a, 2000b). In this paper, through a case study on the Aketishikan gold deposit, the most important gold deposit in this region, the geochemical characteristics of gold mineralization in Nurt are investigated and reported, and its genesis is also discussed.

2 Geology of Ore Deposits

The Nurt region of the Altay is located in the northern part of the boundary between the Siberian and the Kazakhstan-Junggar plates.

Gold deposits in Nurt such as the Aketishikan, Togetobie, Tasbig, Kokeydlas, Kums and Hongshanzui gold deposits (occurrences) posses similar geological characteristics (Zhou et al., 2000a). So, the Aketishikan gold deposit here is taken as an example. The Aketishikan gold deposit is located in the south of the Nurt intraplate volcanic fault depression and the intersection of the subsidiary interlayer reverse fault of the Hongshanzui faulted zone and the NNW- and E-W-trending faults (Fig. 1). The major outcropping strata are Member 2 and Member 3 of the Carboniferous Hongshanzui Group. The lower part of Member 2 of the Hongshanzui Group includes limestone rich in fossil organism and marlrite. The middle part of Member 2 consists of alternate layers of siltstone having flat bedding and pelitic siltstone. The upper part of this Member 2 is sandstone containing volcanic debris, tuffaceous sandstone and siltstone. Member 3 of the Hongshanzui Group has four beds and the gold orebody mainly occur in the first (lowest) bed. This bed includes and gray rhyolitic tuffava, tuff, clastic phanerocryalline lava and flood tuff, in which the beds of rhyolitic tuffava, fragmental lava and ignimbrite are the major ore-bearing strata. Granitic intrusions distribute widely and the Aketishikan biotite monzonitic (adamellite) granite intruded the Hongshanzui Group (Fig. 1). Granites in this area were formed in the Late Paleozoic.
and in the Mesozoic. Their isotopic ages concentrated at 250 Ma to 220 Ma and 186–123 Ma (Zhou et al., 2000b). The Atish biotite monzonic intrusion contact the Hongshanzi Formation, which has sericitization and kaolinization. This intrusion was dated as 133±1 Ma (Table 1, Zhou et al., 2000b).

Ore bodies of the Aketishikan deposit are composed of three strip-shaped mineralization layers, which are controlled by secondary fault and rupture zone between layers. The mineralization includes the altered rock type and the quartz vein type. The ore minerals are mainly arsenopyrite, pyrrhotite, pyrite, natural gold and galena. The vein minerals are quartz, sercite, adularia, montmorillonite, illite and so on. The mineralization period can be divided into a hydrothermal stage and a hypogene stage. The hydrothermal stage includes a quartz-oxide phase, quartz-sulfide phase and carbonate phase. And the quartz-sulfide phase is the principal mineralization stage of this deposit. The alteration of wall rocks is strong and well developed, which mainly includes beresitization, silicification, adularization, carbonatation and propylitization. The alteration has level zoning.

3 Geochemical Characteristics

3.1 Trace elements

Trace elements of the Aketishikan gold deposit were analyzed (Zhou et al., 2000a). The unaltered wall rocks have a rather high content of mineralizing elements such as Cu, Zn, Pb, and a low content of As, Ag, Sb, Bi, Hg, W, Sn and Mo, and the Au content is also higher than the background Au content of the regional rocks. Altered rocks of weak (propylitization) or strong (beresitization) all possess a higher content of Cu, Zn, Pb, As, Ag, Sb, Bi, Hg, W, Sn and Mo, and the beresitized rocks have obviously a higher content of As and Ag than the propylitized rocks, for example, the As content of beresitized rock and the propylitized rock is $1.11 \times 10^{-3}$ and $5.25 \times 10^{-5}$, respectively. It indicates that the gold mineralization is closely related to the As and Ag element geochemical behavior. On the other hand, the gold ore also has higher content of Cu, Zn, Pb, As, Ag, Sb, Bi, Hg, W, Sn and Mo, among which the As
content is extremely higher. The highest As content can reach $1.25 \times 10^{-2}$, which also imply that the gold mineralization has close relation with As activity.

With the application of the isochron method (Grant, 1986), it is revealed that trace elements, especially Au and As, were very mobile during hydrothermal alteration and strong input and output of ore-forming material had taken place during the formation of the Aketishkian gold deposit. From the weakly altered rocks to the strongly altered rocks, the output amount of Cu, Zn, Pb from the source rocks of 100 m$^3$ is 33 kg, 1931 kg, and 146 kg, respectively, while from the strongly altered rocks to the mineralized rocks, the input and output of Cu, Zn, Pb is not obvious. At the same time, through hydrothermal activity, 100 m$^3$ of source volcanic rocks can provide 0.924 kg of Au, 1369 kg of As and 14.6 kg of Ag for the deposit. So, most of the ore-forming material in the Aketishkian gold deposit came from the surrounding volcanic rocks by water-rock interaction processes.

3.2 Rare earth elements

The REE abundances of granite, volcanic rocks and gold ores in the Aketishkian gold deposit have been analyzed (Zhou et al., 2000a). It shows that the chondrite-normalized REE pattern of the granite is of the LREE-rich type, with negative $\delta$Eu and a less negative $\delta$Ce anomalies. The REE patterns of the wall rocks including clastic phanerocryst lava and tuff are also LREE-rich, with negative $\delta$Eu and less negative $\delta$Ce anomalies. The REE patterns of gold ore are also LREE-rich, with negative $\delta$Eu and less negative $\delta$Ce anomalies. The chondrite-normalized REE patterns show that the patterns of gold ores are similar to those of the adamellite and the wall rocks, and the REE in the ores may come from the volcanic rocks or the granite or both.

The concentration of REE in the hydrothermal fluid in balance with the granitic melts can be calculated by using the data of distribution coefficient of REE between the fluid and crystallizing magma (Klinic and Burnham, 1972; Flynn and Burnham, 1978; Ling et al., 2003), by using the chemical compositions of the granites (Zhou et al., 2000a). The result shows that the chondrite-normalized REE pattern of the hydrothermal fluid in balance with the granitic magma is LREE-rich, but gently curved, with a less negative $\delta$Eu anomaly, but the $\delta$Ce anomaly is almost indistinguishable. This characteristics are different to those of the gold ores. Thus, the ore-forming hydrothermal fluids have little relation with the hydrothermal fluid from the magma.

Isocon diagrams of rocks from the wall rocks to near-orebody wall rock and from near-orebody wall rock to gold orebody suggest that the REE are inert and the fractionation is indistinguishable during the metasomatic alteration. The REE characteristics of the gold ores of altered rocks type are similar to those of the wall rocks, and the REE of the gold ores inherited the characteristics of REE from their source rocks. So, the ore-forming material may mostly be originated from the volcanic wall rocks.

3.3 Physicochemical conditions and fluid inclusions

Through microthermometer measurement of fluid inclusions and thermodynamic calculation (Sun et al., 2003), the quartz-sulfide stage of the Aketishkian gold deposit was determined to have a temperature between 200°C and 300°C and a depth of about 700 m. The ore-forming fluid is moderate to weak alkaline with an average pH value of 6.63. The reduction parameters are between 0.12 and 17.02. The oxygen fugacity ($\log f_O^2$) is between $-38.38$ and $-59.83$, and the sulfur fugacity ($\log f_S^2$) is between $-11.0$ and $-12.0$, which indicates a reduction ore-forming environment.

The gas components of fluid inclusions are predominantly CO, H$_2$O, and CH$_4$, with CO/ H$_2$O ratios larger than 1.0. In the liquid composition of the fluid inclusion, the F/Cl and SO$_4^{2-}$/(F+Cl$^-$) ratios are all larger than 1.0, and K$^+$ and Na$^+$ are predominant components; and Ca$^{2+}$, HCO$_3^-$ and SO$_4^{2-}$ are also important. It suggests the existence of interactions between the fluids and the wall rocks, which led to the leaching out of material such as Ca$^{2+}$ from their host rocks.

3.4 Isotopes

Sulfur isotope compositions ($\delta^{34}S$, per mil) of ores, granites and volcanic(-sedimentary) rocks are 5.6‰ to 7.8‰, 10.24‰ to 10.26‰ and 10.20‰ to 10.64‰, respectively. With water/rock ratios between 0.01 and 0.1 at the mineralizing temperatures, a ore-forming hydrothermal fluid with a sulfur isotope composition ($\delta^{34}S$) between 5.6‰ and 7.8 ‰ can form through interactions between fluids with the granites or the volcanic (-sedimentary) rocks.

The Pb isotope characteristics shows that the lead Pb in ores of the Aketishkian gold deposit is originated from multiple sources. All data are plotted on the right side of the Zero isochron in the $^{206}Pb$/$^{204}Pb$-$^{207}Pb$/$^{204}Pb$ diagram (Zartman and Doe, 1981), which suggests the Pb belongs to abnormal Pb, and it may come from an orogenic belt and is contributed by the Carboniferous volcanic strata. Through hydrothermal activities, Pb from different sources migrated into the ore-forming fluids and deposited as a component of the ores.

The oxygen and hydrogen isotopes of quartz and the fluid inclusions of the quartz-sulfide stage of the Aketishkian gold deposit had also been measured (Zhou et al., 2000a and b). Taking into consideration of the
mineralizing temperature, the oxygen and hydrogen isotope composition of the fluid was calculated using the Quartz-H₂O oxygen partition equation (Taylor, 1977). The δD_{H₂O} of the ore-forming fluid of the Aketishkan gold deposit is between -84‰ and -99.7‰. The δ¹⁸O_{H₂O} are between 0.38‰ and 7.75‰. In the δ¹⁸O-δD diagram (Taylor, 1977), they are plotted in the area between the magmatic water domain and the Mesozoic meteoric water line. This indicates that the ore-forming fluid of the deposit is supplied by both meteoric water and magmatic water. The circulated hydrothermal solution may be driven by the cooling of Mesozoic granitic magmas (or rocks) of the Atish biotite monzonitic intrusion.

4 Geochronology

The ages of the Aktishkan gold deposit and some other deposits in the Nurt area were determined by geochronology methods at the Isotope Laboratory of the Institute of Geology and Geophysics, Chinese Academy of Sciences, and the Isotope Laboratory of the Nanjing Institute of Geology and Mineral Resources, Chinese Academy of Geological Sciences (Zhou et al., 2000b). The ⁴⁰Ar/³⁹Ar dating shows that the forming age of the Aktishkan gold deposit is 138±2 Ma, corresponding to a Yanshanian metallogenetic epoch. The Kums and Togetobie gold deposits in Nurt are similar to the Aktishikan gold deposit in geology (Fig. 1), and they are also dated by K-Ar dilute age determination. Chlorite from the Kums gold deposit to the east of the Aktishikan gold deposit (Fig. 1) gives an age of 166±4 Ma (Table 1), whereby chlorite and sericite from the Togetobie gold deposit to the west of the Aktishikan gold deposit (Fig. 1) yield an age of 158±10 Ma and 144±3 Ma (Table 1), respectively. They all belong to a Yanshanian mineralization. Besides, there is also a report of 178 Ma of K-Ar age for adularia, one of the alteration minerals in the Aktishikan gold deposit (Rui, 1993) (Table 1).

5 Discussion and Conclusions

Trace elements studies have shown that during the hydrothermal alteration process, metallic elements, especially Au, were very active. Obvious amount of ore-forming material had been activated and migrated into the ore-forming fluids from the Carboniferous volcanic (-sedimentary) rocks of the Hongshanzi Group, which became the most important source of the gold mineralization in the Nurt area. The characteristics of REE in the Aktishikan gold deposit also show that the ore-forming fluid had interacted with the wall rocks (the volcanic rocks). Magmatic water was not the only origin of the ore-forming fluid. Oxygen and hydrogen isotope characteristics suggested that the hydrothermal fluid forming the ores mostly came from meteoric (atmospheric) water with some magmatic water evolved from the granitic magmas input. Sulfur and lead isotope all provided strong support that the volcanic (-sedimentary) strata were the major source to provide the ore-forming material. The mineralization process is outlined in Fig 2.

In the northern Altay of Xinjiang, the mineralization time of metallic ore deposits has long been regarded as in Variscan period. In the area south of Nurt in the northern Altay, for example, the quartz fluid inclusion Rb-Sr isochron age of the Saidu gold deposit is 305.6±7 Ma (Li et al., 1998), the Pb-Pb isochron age of Salbuluk gold deposit is 304.1±7 Ma, the quartz fluid inclusion Rb-Sr isochron age of the Ouulanasiy gold deposit is 269±13 Ma, and the quartz fluid inclusion Rb-Sr isochron age and the altered gold-bearing rock K-Ar age are 272–305 Ma and 294–316 Ma, respectively (Li et al., 1998; Chen et al., 2002). Hu et al. (1997) even divided the isotopic age of gold deposits in northern Xinjiang into three time domains: 360–350 Ma, 300–280 Ma and 250–240 Ma. Li et al. (1998) divided the mineralization epochs in northern Xinjiang into six periods, in which the Hercynian period is the most important. But Yanshanian mineralization is also occasionally reported in the Mountain Altay, the Mining Altay and the Mongolian Altay in adjacent countries. So far, there are more than one hundred isotopic age data on the Yanshanian magmatism and metasomatic events reported in the northern Altay (Zhou et al., 2000a; Wang et al., 2002). As a matter of fact, it is well known that the Mesozoic is a very important mineralization period for gold mineralization in China. Gold deposits in the Nurt area as well as in the northern Altay might form in multiple stages, especially in the

<table>
<thead>
<tr>
<th>Mineral Occurrence</th>
<th>Sample Geology</th>
<th>Samples</th>
<th>Dating Methods</th>
<th>Age (Ma)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aketishkan</td>
<td>Gold-bearing quartz vein</td>
<td>Quartz</td>
<td>⁴⁰Ar/³⁹Ar</td>
<td>138±2.1</td>
</tr>
<tr>
<td></td>
<td>Altered gold ore</td>
<td>Adular</td>
<td>K-Ar</td>
<td>178</td>
</tr>
<tr>
<td></td>
<td>Biotite granite</td>
<td>K-feldspar</td>
<td>K-Ar</td>
<td>133±3</td>
</tr>
<tr>
<td>Togetobie</td>
<td>Altered gold ore</td>
<td>Chlorite</td>
<td>K-Ar</td>
<td>158±10</td>
</tr>
<tr>
<td></td>
<td>Altered gold ore</td>
<td>Sericite</td>
<td>K-Ar</td>
<td>144±3</td>
</tr>
<tr>
<td></td>
<td>Adamellite</td>
<td>K-feldspar</td>
<td>K-Ar</td>
<td>103±10</td>
</tr>
<tr>
<td></td>
<td>Adamellite</td>
<td>Biotite</td>
<td>K-Ar</td>
<td>138</td>
</tr>
<tr>
<td></td>
<td>Adamellite</td>
<td>Biotite</td>
<td>K-Ar</td>
<td>180</td>
</tr>
<tr>
<td></td>
<td>Porphyritic granite</td>
<td>Whole rock</td>
<td>K-Ar</td>
<td>117±1</td>
</tr>
<tr>
<td>Kums</td>
<td>Altered gold ore</td>
<td>Chlorite</td>
<td>K-Ar</td>
<td>166±4</td>
</tr>
</tbody>
</table>
Variscan period and in the Yanshanian period. The Yanshanian mineralization also should be noted and investigated (Zhou et al., 2000a).

Based on the above studies, the genesis and processes of the gold mineralization can be concluded. On the basis of volcanic activities, sedimentation and magmatic intrusion of the Variscan period, the first and also the most important gold mineralization took place. When the northern Altay evolved into the Yanshanian era, due to the compression between the Siberian and the Kazakhstan-Junggar plates and the mantle uplifting (Wang et al., 1998; Zhou et al., 2000a), local activation, tectonic movement (Rui, 1993), magmatic intrusion took place which released some magmatic water and heated the downward meteoric water to form a circulation fluid system. Interaction between the hydrothermal solution and the Carboniferous volcanic (sedimentary) rocks of the Hongshanzui Group lead to the release of most ore-forming material entering the ore-forming fluid and to form the gold (and poly-metallic) mineralization. The gold deposits in Nurt belong to low-to-moderate hydrothermal ore deposits.

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between a silicate melt and co-existing aqueous phase from 2 to 8 kilobars. *Econ. Geol.*, 67: 231–235.


