Sr Isotope Constraints on the Age and Source of Ore-Forming Materials of Gold Deposits, Southwestern Hunan

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Abstract: We have measured Rb and Sr concentrations in fluid inclusions of quartz in gold deposits, southwestern Hunan. The Rb-Sr isochron ages of 435 ± 9Ma and 412 ± 33Ma are respectively determined, revealing that gold mineralization in this area took place in the Caledonian period rather than in the Wuling-Xuefeng period as traditionally considered. Sr isotope geochemistry of the hydrothermal fluid indicates that the ore-forming materials are of crust origin, derived largely from the ore-hosting strata rather than from the basic dikes.

Key words: Sr isotope; source of ore-forming materials; gold deposit; Hunan

Introduction

The Xuefeng ancient land, tectonically being a part of the Jiangnan uplift of the Yangtze Platform, is an important gold-producer in South China, 80 percent of the proven gold reserves in Hunan Province is concentrated in this area. The gold mineralizing belt may be divided into 3 metallogenic zones, i.e., eastern Hunan (the Huangjintong is a typical deposit, similarly hereinafter), western Hunan (Woxi) and southwestern Hunan (Mobin).

Despite previous detailed studies of the geology and geochemistry of gold deposits in southwestern Hunan (Zhou Dezhong et al., 1989; Yu Dalong, 1990; Niu Hecai et al., 1991; Yan Ming et al., 1994; Peng Jiantang et al., 1999), uncertainties are still involved in their age and the source of ore-forming materials. The estimated ages range from the Wuling-Xuefeng period (1000 – 800Ma) to the Late Yanshanian period (120 – 90Ma). The inability to constrain the timing of migration of ore fluids, and then discern the tectonic and/or geological events responsible for gold mineralization, limits any genetic model for gold metallogeny.

In recent years, the application of Rb-Sr isotope systematics in fluid inclusions in gangue minerals (Shepherd and Darbyshire, 1981; Changkakoti et al., 1988; Kesler et al., 1988; Li Huaqin et al, 1993) or in sulfides (Nakai et al., 1990, 1993; Brannon et al., 1992; Chrisrensen et al., 1995), together with the Sr-isotope geochemistry data (Kessen et al., 1981; Norman and Landis, 1983; Medford et al., 1983; Kesler et al., 1988; Brannon et al., 1991), provides a powerful technique for determining the age of mineralization and for constraining the source of ore fluid. In the present study, we attempt to date the gold mineralization in southwestern Hunan using the Rb-Sr method and to constrain the source of ore-forming materials.

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The Xuefeng ancient land consists mainly of Middle to Upper Proterozoic metamorphic rocks (the Lenjiaxi and Banxi groups). The area studied is located at the SW margin of the ancient land, where there occur a great number of Au- (Sb) vein deposits. Among them, the most important economic deposits include the Mobin, Tiaojinchong, Xiaojia, Pingcha, Yangwantuan, and so on. The strata exposed there are mainly the Upper Proterozoic Wuqiangxi Formation, which consists of metasedimentary clastic rocks. The other strata are generally Palaeozoic and Mesozoic in age. Owing to extremely weak magmatic activities, no igneous rock has been found within or around the mining district, but basic-, ultra-basic dykes occurring along the deep-giant fault can be seen in Aikou and Dongyusi. This region has experienced multi-stage tectonic movements, of which the Wuling-Xuefeng (1000 − 800Ma), Caledonian and Yanshanian movements are, respectively, responsible for the regional metamorphism, uplift, and tectono-magmatic activities in this area.

Gold deposits in the area studied predominantly occur in the Wuqiangxi Formation of the Banxi Group (Pt_{3w}), with a few in the Lower Sinian Jiangkou Formation (Z_{1j}). The gold deposits are of the typical sulfide-poor quartz vein type; sulfides in ores usually account for less than 5 percent. The ore bodies are strictly restricted within the Wuqiangxi or Jiangkou unit, some are stratiform and stratoid in shape (e.g. the Mobin and Yangwantuan) and the others take the shape of steeper veins (e.g. the Tiaojinchong and Pingcha). Quartz is the most important gangue mineral, with carbonate, chlorite and sericite coming next. Pyrite and arsenopyrite are common minerals in all the deposits, secondary sulfides are galena and sphalerite, and stibnite and bournonite can also be found in a few deposits (e.g. the Pingcha deposit). Wall-rock alteration is usually weak, less than 1m in width, laterally developed along the veins. The most important alterations are silicification and pyritization, with bleaching, chloritization, sericitization and carbonatization being subordinate. Gold is dominated by native gold, and it even can be seen in hand specimens with naked eyes.

Samples and Analytical Techniques

Samples analyzed in this study were auriferous quartz veins from the Xiaojia gold deposit (occurring in the Wuqiangxi Formation) and the Pingcha Au-Sb deposit (occurring in the Jiangkou Formation). First, thin sections were prepared for the observation of fluid inclusions under an optical microscope in order to choose quartz samples suitable for dating and for fluid inclusion microthermometry, then chips were cut from hand specimens and slightly crushed to 0.25 to 0.5 mm in size, and finally quartz was handpicked under a binocular microscope.

Samples (0.1 − 1g) were cleaned in HCl acid to dissolve carbonate and then were washed using high purity water, and were re-cleaned in HNO_3 acid to remove sulfides. Finally, the samples were repeatedly washed with high purity water in an ultrasonic vibrator. The fluid inclusions were opened by way of thermal decrepitation and totally spiked with mixed ^{87}Rb-^{86}Sr spikes. Rb and Sr were separated using cation-exchange technique, and all isotope ratios were measured on a MAT-261 multi-collector mass spectrometer at Yichang Institute of Geology and Mineral Resources.

All isotopic compositions were normalized to $^{87}Sr/^{86}Sr = 0.1194$, using power law fractionation correction. An average value of 0.7102334 ± 54 (2σ, $n = 7$) was determined for NBS 607 Sr standard, and Rb and Sr concentrations in NBS 607 were determined at 524.30×10^{-6} and 65.460×10^{-6}. The uncertainties of Rb and Sr concentrations are less than $\pm 0.08\%$ and $\pm 0.004\%$, respectively, and Rb and Sr procedure blanks were 1.5 and 2.0 pg. Analytical uncertainty is estimated to be $\pm 0.02 - \pm 0.008\%$ for $^{87}Sr/^{86}Sr$. Details are given in Li Huaqin et al. (1993).

Table 1. Rb and Sr isotope analyses of fluid inclusions in the gold deposits, southwestern Hunan

Deposit	Sample	Locality	Rb($\times 10^{-6}$)	Sr($\times 10^{-6}$)	Rb/Sr	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr \pm 2\sigma$
	XJ-4	326 level	0.375	0.763	0.491	1.491	0.72284 ± 3
	X-1	346 level	0.187	0.958	0.195	0.563	0.71737 ± 3
Xiaojia	X-3	346 level	0.306	0.736	0.416	1.198	0.71954 ± 2
	XJ-18	388 level	0.176	1.232	0.143	0.412	0.71720 ± 6
	XJ-28	388 level	0.320	1.170	0.274	0.790	0.71913 ± 2
	P-2	No. 4 well	0.154	1.070	0.144	0.416	0.71532 ± 2
	P-2*		0.146	1.053	0.139	0.401	0.71530 ± 3
Pingcha	PK-1	No. 6 well	0.303	1.429	0.212	0.611	0.71722 ± 4
	P10-3	No. 10 well	1.614	1.579	1.022	2.955	0.73135 ± 2
	P11-2	No. 11 well	0.046	1.485	0.031	0.090	0.71349 ± 3
	PCX-2	New well	0.093	0.558	0.167	0.481	0.71624 ± 4

* represents the sample for duplicate analysis.

Rb-Sr Geochronology

The results of the Rb-Sr isotope analyses are presented in Table 1 and shown in Fig. 1. The fluid inclusions in auriferous quartz display a positive correlation between Rb concentrations and $^{87}Rb/^{86}Sr$, but there is no correlation with Sr concentrations. In the Xiaojia, the Sr concentrations tend to decrease upward in the mining district. Ages were calculated using the regression contained in the ISOLPOT Software (Ludwig, 1994). On the Rb-Sr diagram (Fig. 1a, b), samples from the Xiaojia and Pingcha deposits yield a distinct isochron, respectively. The data for the Xiaojia deposit yield a slope corresponding to an age of 412 ± 33 Ma and an intercept of 0.71446 ± 0.00042, with a correlation coefficient of 0.9936. The Pingcha deposit defines a slope of 435 ± 9 Ma and an intercept of 0.71310 ± 0.00011, with a correlation coefficient of 0.9994. Despite the differences in mineral assemblage and ore-hosting strata, the above deposits are identical in mineralizing age within the limit of errors.

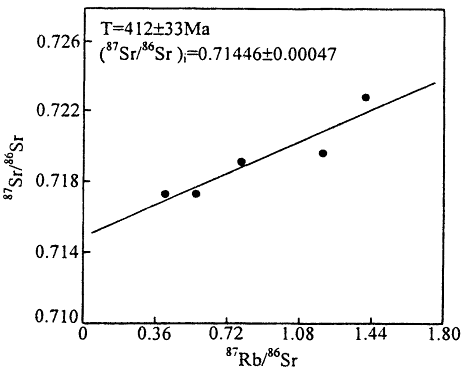

Fig. 1a. Rb-Sr isochron of fluid inclusions from the Xiaojia gold deposit.

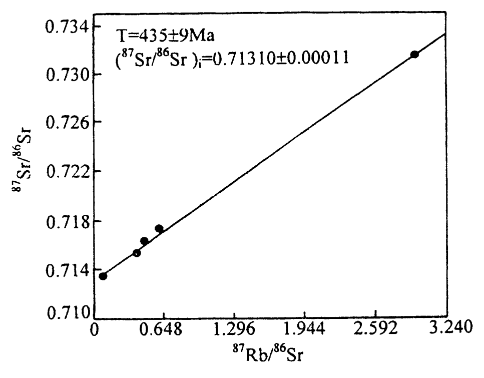

Fig. 1b. Rb-Sr isochron of fluid inclusions from the Pingcha gold deposit.

Due to extremely weak magmatic activities and no obvious connection between gold deposits and magmatic rocks, gold mineralization in this area is generally thought to have resulted from regional metamorphism, that is, the mineralizing age should be 1000 – 800 Ma (Luo Xianlin et al., 1989; Zhang Jingrong et al., 1989; Ma Dongsheng et al., 1991). But a few held that the gold deposits are closely connected with the Yanshanian tectono-magmatic movement (Liu Jishun et al., 1993; Wang Puren et al., 1993). However, as shown above, the Rb-Sr isochron ages are of 412 ± 33 Ma and 435 ± 9 Ma. Considering that many deposits in SW Hunan are strictly controlled by Caledonian fault structures, we think that our data are more reasonable and believable. Recently, the age of 404.20 Ma for the Mobin deposit determined on feldspar by the K-Ar method (Wang Xiuzhang et al., 1999) lends strong support to our conclusion. The data indicated by the isochrons corresponding to the Caledonian period may reflect that gold mineralization is closely connected with the Caledonian uplift event in this area. In fact, gold mineralization during the Caledonian period is of extensive occurrence in the Precambrian low-grade metamorphic rocks in South China. Therefore, the Caledonian period can be regarded as an important epoch of gold mineralization in South China (Peng Jiantang, 1997; Wang Xiuzhang et al, 1999).

Constraints on the Source of Ore-Forming Materials

Most researchers thought that gold deposits in the Xuefeng ancient land belong to the stratabound type, and the ore-hosting strata are responsible for the ore-forming materials (Tu Guangzhi, 1984; Luo Xianlin, 1990; Zhou Dezhong et al., 1989; Ma Dongsheng et al., 1991). But some disagreed with the above opinion. In their opinions, gold abundance in the Proterozoic strata in this area is very low (Wang Puren et al., 1993; Yang and Blum, 1999), thus the host strata are incapable of providing enough ore-forming materials. Instead, they proposed that the basic dyke (Wang Purong et al., 1993) or the fossil hydrothermal system (Yang and Blum, 1999) was responsible for the gold mineralization.

As shown above, the Rb/Sr ratios of fluid inclusions are 0.143 – 0.491 (Xiaojia) and 0.031 – 1.022 (Pingcha), respectively. Although some are less than the value of the continental crust (0.24), all the Rb/Sr ratios in fluid inclusions are higher than the corresponding value in the mantle (0.025), which indicates that the ore-forming materials probably come from the crust rather than from the mantle. The initial $^{87}Sr/^{86}Sr$ isotopic ratios in the ore-forming fluid, by far higher than those of mantle-source materials, also support the opinion of crust origin.

In order to further investigate the source of ore-forming materials, we made a comparison on $^{87}Sr/^{86}Sr$ between ore-forming fluids, host wall-rocks and basic dyke. $^{87}Rb/^{86}Sr$ ratios in the Wuqiangxi metasedimentary rocks (with a Rb-Sr isochron age of 884.7Ma) vary between 0.2757 and 1.1900 and range from 0.713060 to 0.724839, with an initial $^{87}Sr/^{86}Sr$ value of 0.709837. The $^{87}Sr/^{86}Sr$ values of the host rocks are calculated at 0.71455 – 0.71463 at the time of 412 Ma, with an average of 0.71458 (Peng Jiantang, 1997), which are essentially identical to the initial Sr ratios of ore-forming fluid in the Xiaojia deposit. Rb-Sr isotope geochemistry data indicated that the isochron age of 1145 Ma for the Aikou ultra-basic and basic dyke, the $^{87}Rb/^{86}Sr$ of the dyke is 0.073555 – 0.233386, the $^{87}Sr/^{86}Sr$ varies within the range of 0.706971 – 0.710059, and the corresponding initial $^{87}Sr/^{86}Sr$ is 0.706294 (Huo Ansheng, 1995). The calibrated $^{87}Sr/^{86}Sr$ values of the dyke at the time of gold mineralization range from 0.70645 to 0.70766, averaging 0.70716 (Peng Jiantang, 1997), by far less than the initial Sr ratio of the ore-forming fluid. So it is not difficult to conclude that the ore-forming materials are derived from the host strata rather than from the basic dyke. The same conclusion has been drawn from the Pb and S isotope and REE geochemistry of the gold deposits (Peng Jiantang, 1997).

Conclusions

Rb-Sr dating of fluid inclusions in auriferous quartz offers great potential for constraining the time of gold mineralization. The Rb-Sr isochron ages of 412 ± 33 Ma and 435 ± 9 Ma are consistent with the geological constraints and are in good agreement with the feldspar K-Ar ages measured by Wang Xiuzhang et al. (1999). Therefore, gold mineralization in southwestern Hunan took place in the Caledonian period rather than in the Wuling-Xuefeng or Yanshanian period as expected previously. Gold mineralization is probably connected with the Caledonian uplift event. Sr isotope is an effective tracer for the source of ore-forming materials, and $^{87}Sr/^{86}Sr$ ratios in the host rocks at the mineralizing time are 0.71455 – 0.71463, which are identical to the initial Sr ratios of ore-forming fluid, but the calibrated $^{87}Sr/^{86}Sr$ ratios in the dykes in this area are 0.70645 to 0.70766, by far less than the corresponding values of the ore-forming fluid. Thus, the ore-forming materials should be derived from the host strata rather than from the basic dyke.

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