Source of fluids in the Longquanzhan gold deposits in the Yishui area, Shandong, China

Huabin Hu, Shuyin Niu, Baode Wang, Aiqun Sun, Chuanshi Xu
The Shijiazhuang University of Economics, 302 Huainan Road, Shijiazhuang, China

Yongfeng Li, Mengwen Li
China University of Geosciences, 29 Xueyuan Road, Beijing, China

Abstract. The Longquanzhan gold deposit, hosted in Archean gneiss is located along the Tanlu fault zone, on the southeastern margin of the North China craton. The orebodies occur as veins striking 15°- 18° and dipping SE at 35°–62°. Wall rock alteration types include silicification, pyritization, and sericitization, and chloritization, calcitization. Metallic minerals in ores are dominated by pyrite. Gold occurs mainly in the form of electrum. All inclusions are two-phase (L+V) NaCl- H_2O type. The inclusions generally range in diameter from 2 to 8 μm with a vapour/liquid ratio of 5–90% and mainly 5–10%. The homogenization temperatures of fluid inclusions in the Longquanzhan gold deposit are between 108 and 300°C. The ice-melting temperatures vary from –2.0 to –8.6°C, at a peak of –2.5 to –7.0°C. The salinities determined from the ice-melting point of the fluid inclusions range from 3.39 to 12.39 wt.% NaCl equiv. According to isotope fractionation equation and mean homogenization temperatures, the $\delta^{18}O$ values of the mineralizing fluids are calculated, ranging from –0.28‰ to +4.07‰, showing mixing of ore-forming fluids and meteoric waters. The $^3He/^4He$ ratios of fluid inclusions in pyrite are 0.14–0.24 Ra, suggesting the crustal source of ore-forming fluid. The assemblage of alteration minerals, the characteristics of fluid inclusions and stable isotopes indicate that the Longquanzhan gold deposit belongs to epithermal type deposit.

Keywords. Longquanzhan gold deposit, inclusion, stable isotope, source of fluid, China

1 Introduction

The Longquanzhan gold deposit is situated approximately 20 km south of Yishui County, Shandong, located tectonically in the Tanlu fault zone in the southeastern margin of the North China craton. The gold deposit, discovered by the Institute of Shandong Geology and Mineral Resources in 2002, is now being prospected. The previous work of the gold deposit was scarce.

This paper describes the metallogenic setting and geological characteristics of the gold deposit. Fluid inclusion investigations, S, O and H stable isotope data and He and Ar isotope data from fluid inclusions are presented. These data form the basis for an assessment of possible sources of the ore-forming fluids.

2 Regional geological setting

The strata of the region consist of the basement and cover strata. The basement rocks are composed of the Meso-Archean Yishui Group with a residual zircon SHRIMP U-Pb age ranging from 2.82 to 3.07Ga (Shen et al 2004), the Neoarchean Taishan Group-complex with an age range from 2767 to 2490Ma (Jahn et al. 1988) and trondhjemite-tonalite-granodiorite suite (TTG) and Paleopro- terozoic orogenic granites (Fletcher et al. 1995). The Taishan Group-complex is composed dominantly of amphibolite and biotite granulite (leptite) with minor TTG gneisses, which suffered from medium- to low-grade metamorphism. The cover rocks comprise the Neoproterozoic Tumen Group and its overlying Paleozoic strata, lithologically including carbonate rocks and clastic rocks (Shen et al. 2000; Hu et al. 2004).

Tan-Lu fault zone, which extends NNE for more than 3000 km, constitutes a conspicuous tectonic belt along the northeastern margin of the Asia continent. In Shandong province, the Tan-Lu fault zone strikes at 10°to 25° for about 330 km, can subdivided from west to east into Tangwu-Gegou fault, Yishui- Tangtou fault, Anqiu-Juxian fault and Changyi-Dadian fault. The Tan-Lu fault zone is a sinistral shear zone with a slip about 540 km and repeated extension (Okay and Sengor 1992; Yin and Nie 1993). The age of the Tan-Lu fault is open to debate, assigning to Precambrian (Fletcher et al. 1995), Paleozoic (Yin and Nie 1993), and Mesozoic (Xu et al. 1987; Okay and Sengor 1992).

Mesozoic potassium-rich volcanic rocks are distributed mostly in terrestrial down-faulted volcanic-sedimentary basins. They consist predominantly of subalkaline-intermediate-basic pyroclastic rocks and lava, as well as trachybasalt, shoshonitic rocks, determined to be $^{40}Ar/^{39}Ar$ plateau ages varying from 114.8 ± 0.6 to 124.3 ± 0.6 Ma (Qiu et al. 2001).

3 Geology of gold deposit

The strata exposed in the Longquanzhan ore district include Cretaceous volcanic- clastic rocks, Neoarchean gneiss and granite with zircon SHRIMP U-Pb ages ranging from 2.51 to 2.62Ga(Shen et al 2004). The gold deposit hosts in the Neoarchean gneiss in the bottom wall of the Yishui- Tangtou fault (Fig. 1). Up to now, two orebodies referred to as the No. I and No. II have been discovered. Orebody No. I strikes 15° and dips at 35-50°, with ~1600m long and 0.5-3m thick. Its grades range from

2.05 to 15.3g/t, with a mean of 4.52g/t. Orebody No. II strikes 18° and dips at 48°–62°, with ~1200m long and 0.84-4.62m thick. Its grades range from 1.08 to 5.48g/t, with a mean of 1.75g/t (Li et al. 2004).

Wall rock alteration types include silicification, pyritization, sericitization, chloritization, and calcitization, of which silicification, pyritization, sideritization are closely associated with the gold mineralization.

Metallic minerals in ores are dominated by pyrite, accounting for 5-15%, with minor chalcopyrite and galena. Gangue minerals comprise chlorite, quartz, sericite and plagioclase.

Gold occurs mainly in the form of electrum, and minor native gold. Gold mineral is gold-yellow in colour, with a strong metallic lustre, and mainly occurs as grains, ranging from 0.003 to 0.18mm in size. Microprobe analysis gave the following composition (%) of electrum: Au 67.97, Ag 30.92, Cu 0.59, Fe 0.52.

4 Fluid Inclusion studies

4.1 Samples and analytical methods

Microthermometric measurements were carried out on a Linkam THMSG 600 programmable heating- freezing stage (-196 to +600°C) at the Laboratory of the Faculty of Geosciences and Mineral Resources, China University of Geosciences, Beijing. The heating rate was 0.1 to 1 °C/min below 10 °C, whereas the heating rates were about 3 to 5°C/min at 10 to 31°C, with a reproducibility of ± 0.1°C. The heating rate was 5 and 10°C/min at higher temperatures (>100°C), with a reproducibility of ± 2°C.

4.2 Inclusion types and characteristics

Fluid inclusions were examined in 10 samples from the gold deposit. There were abundant fluid inclusions in quartz and calcite of alteration minerals. Measurements in transparent minerals were typically restricted to primary or pseudosecondary inclusions. All inclusions are two-phase (L+V)NaCl- H2O type, consisting of aqueous liquid and vapor bubbles, with a vapor/liquid ratio of 5–90% and mainly 5–10%. The inclusions generally range in diameter from 2 to 8 μm, and in a few individual cases may reach a maximum of 18μm. Most inclusions have elliptical, rounded, elongated and irregular shapes.

4.3 Microthermometric results

The homogenization temperatures of fluid inclusions in the Longquanzhan gold deposit are between 108 and 300°C. The ice-melting temperatures vary from -2.0 to -8.6°C, at a peak of -2.5 to -7.0°C. The salinities determined from the ice-melting point of the fluid inclusions range from 3.39 to 12.39 wt.% NaCl equiv (Bodnar 1992). We obtained corresponding fluid densities between 0.708 and 0.981 g/cm^3 by consulting the table of Liu and Shen (1999) according to the homogenization temperatures and salinities of the aqueous fluid inclusions.

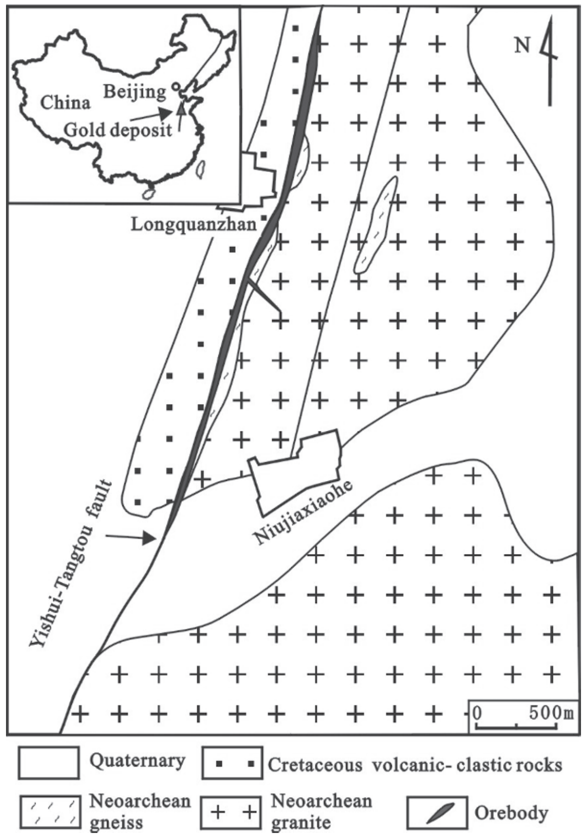

Figure 1: Geological sketch map of the Longquanzhan gold deposit in Yishui, Shandong

5 Stable isotope studies

5.1 Samples and analytic methods

Four fresh pyrite samples were collected for sulphur isotope measurements, which were selected under the binocular microscope to ensure their purities were over 99%. Cu_2O was used as the oxidizer for the preparation of sulphide samples. Sulphate minerals were purified to pure $BaSO_4$ by the carbonate-zinc oxide semi-melt method, and then SO_2 was prepared by the V_2O_5 oxide method. The SO_2 released was measured for sulphur isotopes.

Four samples were selected for helium and argon isotope measurements. Each pyrite sample was picked using a binocular microscope and its purity was over 99%. Helium and argon isotopes were analyzed at the Stable Isotope Laboratory, Institute of Mineral Resources, Chinese Academy of Geological Sciences. The analytical procedure is as follows (Mao et al. 2002a).

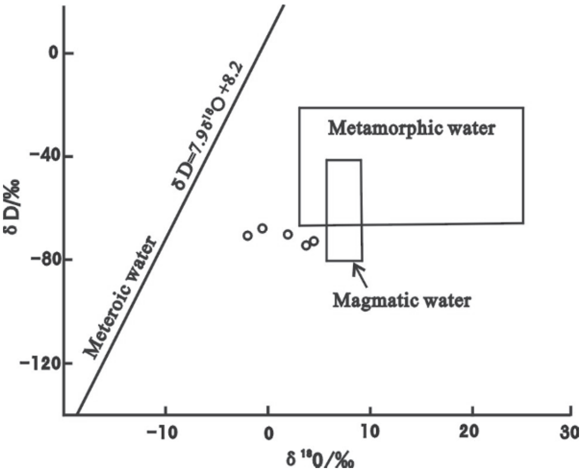

Figure 2: Hydrogen and oxygen isotopic compositions of ore-forming fluids from the Longquanzhan gold deposit

For analysis of hydrogen isotope, the water in fluid inclusion was released by decrepitation method. Then the water was reacted with Zn at 400°C to produce H_2 (Coleman et al. 1982), which was collected in sample tube with activated charcoal at liquid N_2 temperature (Mao et al. 2002b). All SO_2, CO_2, and H_2 were analyzed in a Finningan MAT 251 mass spectrometer, at the Stable Isotope Laboratory of the Institute of Mineral Resources, Chinese Academy of Geological Sciences. Analytical reproducibility in this study is ± 0.2‰ for S, O and C isotopes, and ± 2‰ for H isotopes.

5.2 Results and discussion

The $\delta^{34}S$ values of pyrite range from -4.2 to 4.4‰ with a mean of 1.55‰, suggesting a mantle or lower crust source of sulphur in the ores.

In the Longquanzhan gold deposit, $\delta^{18}O$ values of alteration minerals range from 8.3 to 12.0‰ . The mean homogenization temperature of 290? was obtained by averaging homogenization temperatures of 58 inclusions in quartz from the Longquanzhan gold deposit. According to the quartz-water isotope fractionation equation $1000\ln\alpha = 3.42\times10^6\,T^{-2} - 2.86$‰ (Zhang et al. 1989, the $\delta^{18}O$ values of the mineralizing fluids were calculated ranging from 1.77 to 4.07). The mean homogenization temperatures of 190? were obtained by averaging homogenization temperatures of 90 inclusions in calcite. Using the calcite-water isotope fractionation equation $1000\ln\alpha = 2.78\times10^6\,T^{-2} - 2.89$ (O'Neil et al. 1969), the $\delta^{18}O$ values of the mineralizing fluids are calculated, ranging from -0.28 to 1.78‰. The $\delta^{18}O_{fluid}$ values of ore fluids of the Longquanzhan gold deposit are relatively low, from -0.28‰ to +4.07‰, being notably deviated from the $\delta^{18}O$ fluid range (5.5 to 9.5‰) of magmatic water defined by Sheppard (1986). In the δD vs. $\delta^{18}O_{fluid}$ diagram (Fig. 2), five data points are plotted between magmatic water and meteoric water and have a tendency to "drift" to the meteoric water line, showing mixing of ore-forming fluids and meteoric waters.

The $^3He/^4He$ ratios of fluid inclusions in pyrite are 0.14-0.24 Ra, which are 5-10 times higher than that of the crust (0.01-0.05 Ra) (Stuart et al. 1995) but 20-40 times lower than that of the mantle (6-9 R/Ra), suggesting the ore-forming fluid from crust source. The lower $^3He/^4He$ ratios of the ore are obviously different from those (3.5-9.8Ra) from the Wangu gold deposit adjacent to the Tan-Lu fault (Mao et al 2002c), and from those (0.5-5.2Ra) from the Dongping gold deposit (Mao et al 2003), which are reported to have involved some mantle-derived fluids during mineralization. $^{40}Ar/^{36}Ar$ ratios are 289-482, slightly higher than those of the atmosphere ($^{40}Ar/^{36}Ar$=295.5), indicating the existence of a small amount of excess argon produced probably by higher radiogenic ^{40}Ar.

Therefore, The assemblage of alteration minerals, the characteristics of fluid inclusions and stable isotopes suggest that the Longquanzhan deposit belongs to epithermal gold deposit (Lindgren, 1922).

The sulfur, hydrogen and oxygen, and helium and argon isotopic compositions indicate that ore-forming fluid originated from lower crust and mixed with deeply circulating meteoric water.

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