Carpathian Journal of Earth and Environmental Sciences, August 2014, Vol. 9, No. 3, p. 221 - 230

THE GEOCHEMISTRY RESEARCH ON FLUID OF THE DAXIGOU GOLD MINE, FENGNING, HEBEI PROVINCE

Deng LEI[1,2,3], Cao YE[4] & Zhang JIEJIE[5]

[1]School of Earth Environment and Water Resources, Yangtze University, Wuhan, Hubei Province, 430100, China
[2]Key Laboratory of Exploration Technologies for Oil and Gas Resources, Ministry of Education, Wuhan, Hubei Province, 430100, China
[3]Yangtze University College of Engineering Technology, Jingzhou, Hubei Province, 434000, China
[4]China Chemical Geology and Mine Bureau, Beijing, 100013, China
[5]School of Earth Sciences and Resources, China University of Geosciences, Beijing, 100083, China
Corresponding author: e-mail: cykaiyang@163.com

Abstract: Using temperature in microscope, composition and hydrogen and oxygen isotope testing, this study provides an in-depth analysis on fluid inclusions' parameters of the Daxigou gold mine and the characteristics of the ore-forming fluid. The results show that the inclusions in the quartz which displays close relations with Daxigou gold mineralization contain three types of inclusions: gaseous inclusion, gas-liquid inclusion and liquid inclusion, of which the latter two types are most common. The homogenization temperatures of the inclusions are mainly concentrated in 175°C ~ 275°C, with the salinity of 2% to 7%, the fluid density of 0.804 ~ 0.959g/cm^3, and the mineralization depth of 1.01 ~ 2.24km. The vapor in fluid inclusions is mainly composed of H_2O and CO_2; in fluid inclusions liquid, the main cations are Na+ followed by Ca^{2+}, K^+, and the anions are SO_4^{2-} and Cl^- followed by only traces of F^-. The $\delta^{18}O$ water values in quartz are 2.1 ‰ ~ 5.8 ‰, and the δD values are -87‰ ～ -103.67%, reflecting the ore-forming fluids coming from magmatic water and atmospheric precipitation. By calculating the gas fugacity, gold in the Daxigou gold ore-forming fluids mainly migrates in the form of complex $[Au (HS)_2]^-$. The complex process and hydrothermal alteration are the major factors for gold precipitation and enrichment.

Keywords: Fluid inclusion; ore-folding fluid; geochemistry; Daxigou gold mine; Hebei

1. INTRODUCTION

The Daxigou gold mine, in Fengning County, Hebei province, is located in the northern margin of the North China mineralization belt and has been found as a large mineral deposit in recent years. Previous research rarely focused on this area, especially on the research of ore-forming fluid and its effect. This paper studies in detail the different types of inclusions in quartz in different ore-forming phases, gas and liquid compositions and hydrogen and oxygen isotopic composition of the Daxigou gold mine, determines the physico-chemical conditions of the gold mine, and discusses the source, characteristics, and evolution of the ore-forming fluids.

2. GEOLOGY SETTING

The study area is at the arch fault (III level) in the northern margin of the Inner Mongolia east axis in North China Platform, locating in the Shanghuangqi magmatic rock sub-belt(IV level), at the northern edge of the east-west trending Yinshan fault block in the North China Craton (the third order tectonic unit). The outcropping strata are simple. Paleoproterozoic Hongqiyingzi Group, where metamorphic basement was exclusively but sparsely distributed, mainly constructed by intermediate-acid rocks in the upper Jurassic Baiqi Formation and Zhangjiakou Formation. Host rocks are porphyritic granites, monzonite granites, quartz orthophyres, andesites, etc.

The main ore-controlling structure is the NE striking Huangqi-Wulonggou deep fault which was strongly active during Yanshan period (Fig. 1). The mining area is divided into three sections: Jinshan I, Jinshan III and Jinshan V (Fig. 2), the overall strike of the ore body is northeast 50° ~ 60°, dipping SE with the dip between 40° ~ 50°. The ore body outcrops mostly as veins, bands, lenticular or irregular structures, having no clear boundaries with surrounding rock, and it is crushing altered rock in terms of industrial type. Major metal minerals are pyrite, chalcopyrite, sphalerite, and galena, etc. And the main gangue minerals are feldspar, quartz, chlorite, and calcite, etc. Gold minerals are gold and electrum. The ore is mainly in heterogranular texture, cataclastic texture, metasomatic texture, and network texture. And ore structures are block structure, banded structure, breccias structure, crack-filling structure, and so on. The typical alterations of host rocks are potassium feldspathization, silicification, pyritization, chloritization, and carbonation.

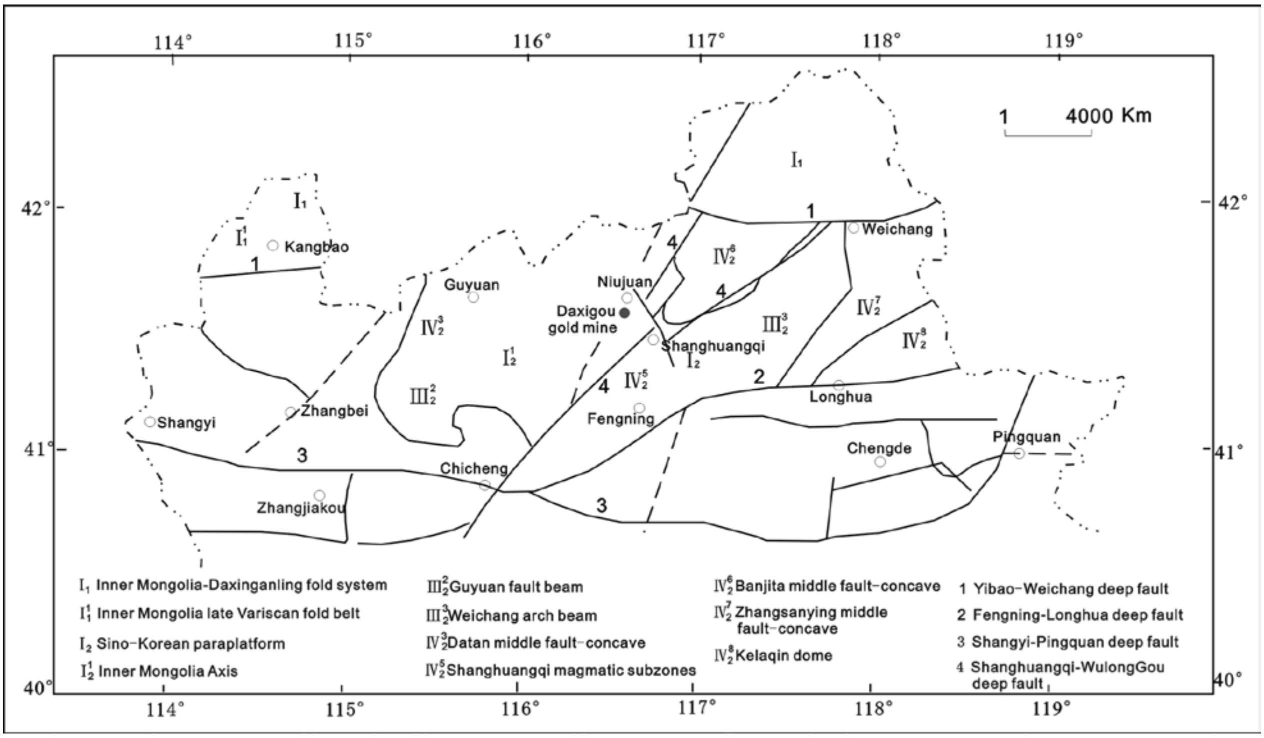

Figure 1. The tectonic unit zone map of northern Hebei

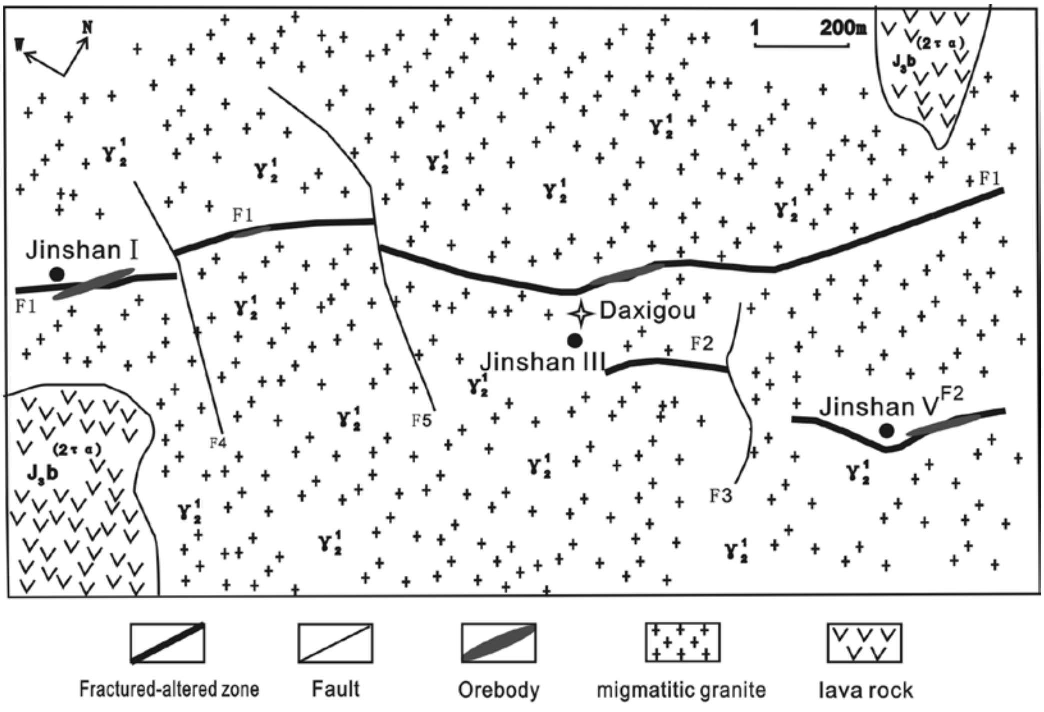

Figure 2. Geological sketch map of the Daxigou gold mining area
1- Fragmented -altered zone; 2-Fault; 3-Orebody; 4-migmatitic granite;5- volcanic rock

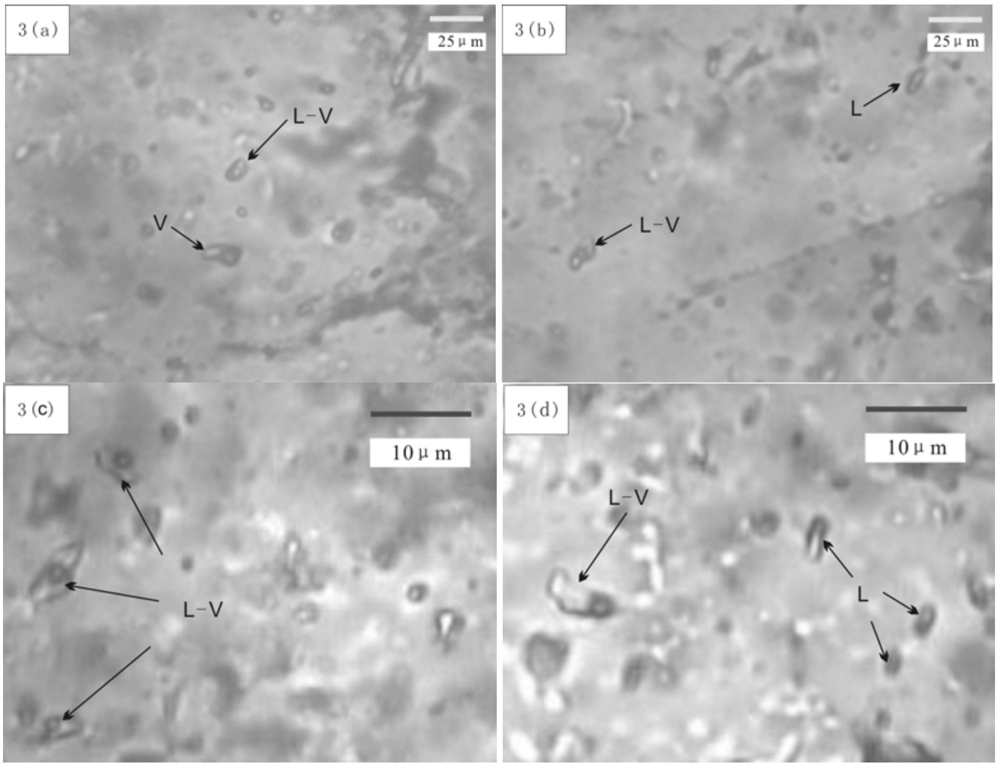

Figure 3. The micrographs of fluid inclusions in the Daxigou gold mine.

According to the crosscuting relations of the veins in the field, the mineral assemblages and the texture and structure characteristics, Daxigou gold mineralization can be divided into four stages, of which the stage (II) is the main mineralization stage.

(I) pyrite - quartz stage: the main mineral is quartz, with minor pyrite. Quartz is milky, allotriomorphic, with a few to be subhedral. Pyrite crystals are coarse, euhedral, or subhedral which develop cataclastic texture and porphyroclastic texture.

(II) quartz - polymetallic sulfides stage: ore minerals are pyrite, chalcopyrite, galena, sphalerite, native gold, etc. The main gangue minerals are quartz, feldspar, and chlorite. Mostly, quartz is smoky gray and pyrite is fine-medium-grained, sometimes fine-powdered. Hypidiomorphic crystal and allotriomorphic crystal develop.

(III) quartz - chlorite stage: the minerals are mainly chlorite and quartz, occasionally with a small amount of fine-grained pyrites which are stellate distributed. The ore grade is low and it belongs to lean ore.

(IV) carbonate stage: carbonate, quartz, chlorite and other minerals dominate, almost without pyrite.

3. THE BASIC CHARACTERISTICS OF FLUID INCLUSIONS

The quartz related closely to mineralization in this area contains abundant inclusions, with primary inclusions predominating and few secondary and false secondary inclusions orienting in linear direction along the quartz cracks. Gas-liquid ratios of the inclusions vary from 5% to 70%, but the most common gas-liquid ratios are in the range from 5% to 25%. Such inclusions have similar gas-liquid ratios, and the internal composition is also consistent. Generally, there is little difference in the size of the inclusions, mostly ranging from 2 to 6μm, individually up to 10μm. Inclusions are discovered in complex and diverse forms, such as relatively regular oval, diamond and triangle, as well as irregular forms of elongated strip and curved tube, etc. (Table 1). The subjects of the study are primary inclusions. Based on the phase characteristics and compositions of inclusions, the Daxigou gold quartz inclusions are divided into the following three types:

1）Gas inclusions (V-type): inclusions visible at room temperature are L- and V phase states with the gas-liquid ratio >50%, rarely seen but mostly develop in the mid mineralization stage (II). Its long axis ranges from 2 to 10μm, mostly between 4 and 8μm, usually distributing in isolated elliptical or irregular shape. These inclusions belong to primary inclusions. Inclusions with high content of gas are dark brown (Fig. 3a).

2）Gas-liquid inclusions (L-V type): inclusions visible at room temperature are liquid phase with the gas-liquid ratio of 10% to 50%. Inclusions can be seen in each mineralization stage, but mainly develop in the early and middle mineralization stages (I, II), accounting for more than 50% of total inclusions with the gas-liquid ratios mainly between 10% and 30%; its long axis ranges from 1to 8μm, mostly 2 ~ 6μm. The inclusions are in irregular, oval or rounded shapes (Fig. 3a, 3b, 3d), and distributed in groups (Fig. 3c); they belong to primary inclusions. But the secondary inclusions are occasionally distributed along the linear healed cracks in grains (Lu et al., 2004) and mainly develop in the early stages of mineralization.

3）Fluid inclusions (L-type): main type of inclusions in the mining area, with the gas-liquid ratio from 5% to 10% observed at room temperature. Due to the relatively smaller gas-liquid ratio, most of the bubbles display in black spot shape. This type of inclusions more develop in the late mineralization stages (III, IV), accounting for more than 45% of the total inclusions. The inclusions are characterized by irregular or round particulate shapes, etc.; long axes range from 1 to 6μm, mostly between 2 and 4μm, distributed in groups (Fig. 3d).

4. THE PHYSIOCHEMICAL PARAMETERS OF FLUID INCLUSIONS

4.1 Homogenization temperature

The author systematically collected more than 50 samples formed in the four block mineralization stages from three Daxigou gold mines, Fengning, Hebei. And 13 samples were selected to study microscopic inclusions thermometry in total. The analysis on inclusions was finished in China University of Geosciences (Beijing). The Geological Laboratory Center Inclusions Laboratory. Instruments used was British produced Linkam THM600 freezing and heating system, with instrument temperature ranging from -196°C ~ 600°C. At 0°C ~ 600°C, the accuracy was ± 1°C, and at -196°C ~ 0°C, the accuracy was ±0.1°C. Reproducible homogenization temperature error was less than 2°C; reproducible freezing temperatures error was less than 0.2°C. The test results are shown in table 2.

As shown in figure 4, pyrite - quartz stage: the homogenization temperature range of this stage was relatively wide, from 123°C ~ 361°C, but relatively concentrated in 125°C ~ 175°C and 250°C ~ 300°C. Because quartz was developed in the early stage of mineralization, many cracks were formed by the influence of tectonic activities; in a later stage, it developed a certain number of primary inclusions and secondary inclusions due to hydrothermal superimposition and re-crystallization. A small quantity of the secondary inclusions outcropped as L type, and the homogenization temperature mainly fell between 100°C and 200°C. Most primary inclusions formed in the early stage of mineralization were L-V type with the temperature ranging from 250°C to 300°C. The average homogenization temperature of this stage was 264.3°C.

Quartz-polymetatallic sulfide stage: homogenization temperatures ranged from 117°C ~ 373°C. There were mainly three temperature ranges in which the data were concentrated: low temperature zone 100°C ~ 150°C, middle temperature zone 200°C ~ 250°C and high temperature zone 300°C ~ 325°C. This is the main mineralization stage. Quartz in this stage experienced more thermal events and presented multi-stage characteristics, which were reflected in the homogenization temperature curve. The average homogenization temperature of this stage was 238.3°C.

Table 1 The characteristics of the inclusions in each mineralization stage in Daxigou gold mine

No. sample	Mineralization stage	Distribution	Form	Size/μm	Type
B11 BC3-6 BJ3-6 BJ2-2	Pyrite - quartz (I)	Distributed rarely, mainly primary, rare secondary along the healed fissures.	Irregular 60% Oval 15% Rounded 10% Regular 15%	1～5	L-type60% L-Vtype37% V-type≤3%
BD2-4 BC2-3 B07 BD2-4	Quartz-polymetatllic sulfides (II)	Randomly distributed, mainly primary inclusions with rare false secondary inclusions.	Irregular 50% Regular 20% Oval 25% Rounded <5%	2～10	L-type40% L-Vtype50% V-type10%
BC2-5 BC1-6 BC2-6	Quartz - chlorite (III)	Distributed extremely uneven, inclusion content scarce, mainly primary inclusions	Irregular 70% Regular 25% Oval 5%	1～7	L-type65% L-Vtype35%
BJ3-5 B08	Carbonate (IV)	Primary inclusions distributed even in quartz. The most primary inclusions distributed in calcite, but a large number of secondary inclusions outcrop in linear distribution.	Irregular 40% Regular 40% Oval 10% Rounded 10%	1～6	L-type80% L-Vtype20%

Table 2 The results of the fluid inclusion homogenization thermometry

Sample No.	Stage	Size/μm	Number/N	Homogenization temperature (Average)/℃	Freezing Temperature (Average)/℃	Average Salinity /wt%	Average density /g·cm^{-3}	Average pressure /Mp	Depth /km
B11	I	2-4	25	147～319 (263)	-0.6～-5.5(-3.1)	5.11	0.819	70.5	2.11
BC3-6	I	1-5	27	123～308 (248)	-1.2～-4.8(-2.9)	4.80	0.838	66.2	1.98
BJ3-6	I	2-4	27	189～361 (277)	-1.4～-6.0(-3.5)	5.71	0.804	74.7	2.24
BJ2-2	I	2-5	23	139～324 (269)	-0.3～-7.7(-4.0)	6.45	0.823	72.9	2.18
BC2-2	II	2-7	25	202～318 (244)	-2.9～-4.3(-3.3)	5.41	0.849	65.6	1.97
BC2-3	II	3-6	26	158～377 (225)	-0.7～-3.4(-2.2)	3.71	0.861	59.0	1.77
B07	II	2-10	26	117～298 (233)	-1.0～-5.7(-3.0)	4.96	0.860	62.3	1.87
BD2-4	II	2-8	25	140～319 (251)	-1.2～-6.3(-2.8)	4.65	0.832	66.9	2.00
BC2-6	III	2-5	26	129～237 (189)	-0.6～-6.0(-2.3)	3.87	0.907	49.7	1.49
BC1-6	III	1-7	29	137～325 (155)	-0.4～-6.8(-1.9)	3.23	0.939	40.2	1.21
BC2-5	III	2-6	25	114～296 (177)	-1.4～-3.1(-2.0)	3.39	0.917	46.1	1.38
B08	IV	2-4	22	107～238 (147)	-0.7～-4.3(-2.2)	3.71	0.950	38.5	1.16
BJ3-5	IV	1-6	20	115～283 (131)	-1.1～-5.8(-1.7)	2.90	0.959	33.7	1.01

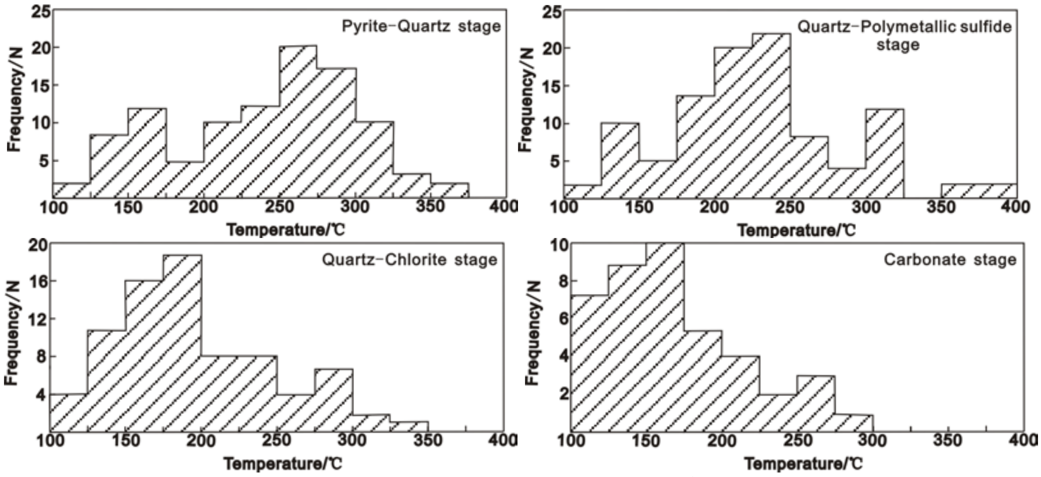

Figure 4. Homogenization temperature histogram of each mineralization stage.

Quartz - chlorite stage: homogenization temperatures ranged from 114°C to 325°C, mainly concentrated in 150°C~200°C, but there was a small quantity of inclusions with homogenization temperatures concentrated in 275°C~300°C. Because this stage closed to the late mineralization stage, the inclusions mainly belonged to L-type inclusion with corresponding temperature ranging from 150°C to 200°C. The ore-forming fluid temperature remarkably decreased, along with weakened mineralization, but there was still a small amount of mineralization. The mineral-rich fluids were mostly wrapped to form L-V-type inclusions during the crystallization process of quartz, with homogenization temperatures concentrating between 275°C and 300°C. The average homogenization temperature of this stage was 173.7°C.

Carbonate stage: relatively narrow temperature range located within 115°C and 283°C. Without mineralization in this stage, hydrothermal activities calmed down to form L-type inclusions. And the homogenization temperature was mainly between 100°C and 200°C; the average homogenization temperature was 139.0°C.

The homogenization temperatures of fluid inclusions are mainly concentrated between 175°C and 275°C, with an average of 234.1°C in Daxigou gold mine, Fengning, Hebei province. It is a low-temperature deposit. The temperatures decrease with weakening mineralization in various stages.

4.2 Salinity and density

In order to gets the salinity of the ore forming fluids, freezing point tests were conducted for the gas-liquid inclusion. According to the freezing point conversion table (Liu et al., 1999), we obtained the salinity of the fluid inclusions.

To sum up, it can be seen (Fig. 5) that, during the pyrite - quartz (I) stage, the salinity range is within 0.53% and11.34%, mainly concentrated from 4% to 7%, with an average of 5.51%; at the quartz - polymetallic sulfide (II) stage, the salinity range is within 1.23% - 9.60%, mainly concentrated from 4% to 6%, with an average of 4.68%; at the quartz - chlorite (III) stage, the salinity ranges from 0.71% to 10.24%, mainly concentrated in 3% to 5%, with an average of 3.49%; at the carbonate (IV) stage, the salinity range is between 1.23% and 8.95%, mainly concentrated from 2% to 4%, with an average of 3.31%.

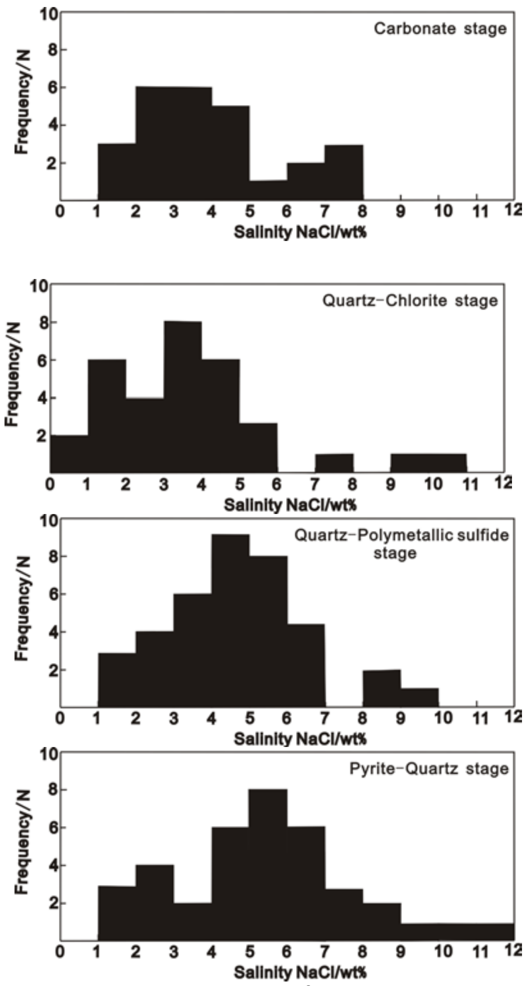

Figure 5. The salinity histogram of each mineralization stage

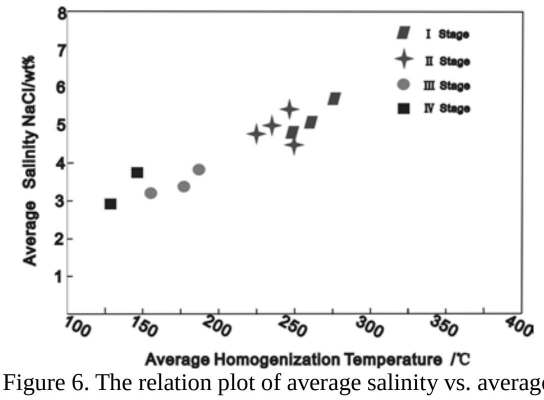

Figure 6. The relation plot of average salinity vs. average homogenization temperature

With the evolution of mineralization from early to late stages, the variability of salinity of ore forming fluids generally weakens with decreasing temperatures (Fig. 6). At the I, II stages, the salinities do not obviously vary but within a moderate range; at either the III or the IV stage, the salinity shows little change, but the fluid salinities in the two stages are not close to each other. , reflecting that low salinity fluids might mix into the ore - forming fluids at the mineralization stage of the Daxigou gold mine (Jia et al., 2004).

According to the fitting density formula by Liu & Duan (1987): ρ = a + bt + ct2 (a, b, c are dimensionless parameters). The results (Table 1) show that the average density of the fluids in the Daxigou gold mine ranges from 0.804 ~ 0.959g/cm^3, belonging to the medium-low-density fluid. With mineralization evolving from early to late stages, the density of ore-forming fluid increases.

4.3 Mineralization pressure and depth

Using the empirical formula of fluid pressure (Shao, 1988): $P=P_0t_h/t_0(P_0=219+2620w, t_0=374+920w)$, corresponding average pressure of the fluid was obtained. The results (Table 1) show that the ore-forming fluid pressure is in the range of 33.7~70.5Mp. Considering the lithostatic pressure of 33.3MPa/km for mineralization depth, the estimated depth for the Daxigou gold mineralization is roughly at 1.01~2.24km, belonging to a shallow mineralization environment.

5. COMPOSITION AND CHARACTERISTICS OF FLUID INCLUSIONS

5.1 Compositions of fluid inclusions

The vein quartz was crushed into 0.4 ~ 0.2mm meshes, cleaned and dried with deionized water by 2 times. Open the fluid inclusions with thermal blast method. Varian 3400 gas chromatograph analysis system was used to identify the gas phase composition of the inclusions; we used liquid chromatography analysis to identify the anions in liquid phase and the atomic absorption spectrometry to analyze the cations. The analysis results of the gas-liquid phase composition of fluid inclusions in Daxigou gold mine are listed in table 3.

Table 3 shows that the cations in the liquid-phase composition of the inclusions are mainly Na^+, followed by Ca^{2+}, K^+ and only a trace of Mg^{2+}. Anions are mainly SO_4^{2-} and Cl^-, traces of F^-; no NO_3^-, PO_4^{3-} and Br^- etc detected. H_2O and CO_2 are dominant in the gas-phase composition, with a small quantity of CH_4, C_2H_6 and traces of H_2S and Ar detected. The dominance of H_2O content and the small variety of low content reductive gases like CH_4 lead to a low reductive parameter R 0.084～0.117, reflecting weak reducibility of the ore-forming fluid.

Table 3 Thecomposition and characteristics of the gas and liquid phase in fluid inclusions of Daxigou gold mine

Sample No.		B11	BC3-6	BJ3-6	BJ2-2	BD2-4
Test Mineral		Quartz	Quartz	Quartz	Quartz	Quartz
Stage		I	I	I	I	II
Liquid Phase Composition (μg/g)	Na^+	4.92	3.33	2.79	2.58	3.33
	K^+	0.810	0.957	1.300	0.324	1.010
	Ca^{2+}	0.813	1.810	1.130	0.489	0.876
	Mg^{2+}	-	-	-	-	-
	F^-	-	-	0.072	0.036	0.048
	Cl^-	5.88	2.01	1.85	3.57	4.62
	SO_4^{2-}	6.27	37.5	9.63	1.46	5.10
Gas Phase composition (Mol %)	H_2O	95.200	88.820	87.180	80.550	86.120
	CO_2	4.380	9.837	11.570	17.779	12.487
	CH_4	0.214	0.583	1.122	1.384	1.213
	C_2H_6	0.045	0.242	0.080	0.107	0.144
	H_2S	0.140	0.324	0.019	0.003	0.015
	N_2	-	-	-	-	-
	Ar	0.022	0.194	0.029	0.068	0.021
Gas-liquid Phase composition	Na^+/ K	6.07	3.48	2.14	7.96	3.29
	$Na^+/(Ca+Mg)^{2+}$	6.05	1.84	2.46	5.28	3.80
	F^-/ Cl^-	-	-	0.039	0.010	0.010
	CO_2/H_2O	0.046	0.111	0.133	0.220	0.145
	R(Reductive parameter)	0.091	0.117	0.106	0.084	0.110

Source: tested by Institute of Geology and Geophysics, Chinese Academy of Sciences Note: R for Reductive parameter=$(CH_4+C_2H_6+H_2S)/CO_2$

Table 4 Physiochemical parameters of fluid inclusions

Sample No.	Mineral	Stage	$lgfO_2$	fCO_2	fCH_4	fH_2S	fH_2O	Eh	Ph
B11	Quartz	I	-34.6	3.16	0.217	0.0635	10.4	-0.329	4.95
BC3-6	Quartz	I	-35.8	6.87	0.581	0.142	8.92	-0.299	4.62
BJ3-6	Quartz	I	-33.7	8.61	1.16	0.00889	10.2	-0.326	4.89
BJ2-2	Quartz	I	-34.3	12.9	1.42	0.00137	8.94	-0.317	4.80
BD2-4	Quartz	II	-35.7	8.79	1.21	0.00663	8.85	-0.297	4.56

Table 5. The hydrogen and oxygen isotope compositions of the fluid inclusions in Daxigou gold mine

Sample No.	Attitude	Test Mineral	$\delta^{18}O_{Q-SMOW}$/‰	$\delta^{18}O_{W-SMOW}$/‰	δD_{W-SMOW}/‰	Source
BJ2-2	Jinshan 1	Quartz	13.83	5.8	-103.67	This paper
BD2-4	Jinshan 3	Quartz	11.73	3.7	-99.36	This paper
D-1-7	Jinshan 1	Quartz	11.83	3.5	-97	①
P2-2	Jinshan 3	Quartz	10.63	2.3	-108	①
P2-8	Jinshan 3	Quartz	10.43	2.1	-87	①
Z-N402	Jinshan 3	Quartz	10.73	3.4	-89	①

5. 2 Characteristics of ore-forming fluids

From the results of the inclusion composition analysis, the ore-forming fluids in Daxigou gold mine belong to the H_2O-NaCl-CO_2 system. The Parameters of Daxigou gold ore-forming fluids are calculated by the H_2O-NaCl-CO_2 system pH value computing method (Crerar et al., 1978), the gas fugacity and Eh values computing formula (Liu & Shen 1999), which are derived from the experimental data. The parameters are shown in table 4.

The parameters of the Daxigou gold mineralization hydrothermal fluid indicate that the pH value of the ore-bearing hydrothermal fluid is 4.56 ~ 4.95, with an average of 4.76, indicating weak acid; Eh value is within the range of -0.297 ~ -0.329, with an average of 0.313, reporting small changes and generally keeping at a low level, reflecting that the mineralization setting is weak reducing environment.

6. HYDROGEN AND OXYGEN ISOTOPE

The samples were crushed into 60 to 80 meshes or finer. Quartz with purity greater than 99% was selected under a binocular microscope, placed in a dilute nitric acid of 60 ~ 80°C for 12 hours, and then rinsed with deionized water. Removed impurities with ultrasonic centrifuge and dried. Oxygen isotopic composition ($\delta^{18}O$ quartz) in quartz was prepared by BrF_5 method for O_2. As for hydrogen isotopic composition (δD water) in quartz, firstly obtained water from the inclusions by using the thermal burst method, then used metal Zn to prepare H_2, and finally analyzed with mass spectrometry. Test results are shown in table 5.

As seen from table 1, $\delta^{18}O$‰ value of quartz is high and concentrated in 10.43‰ ~ 13.83‰. Using quartz - water oxygen isotope equilibrium fractionation equation $1000\ln\alpha_{Q-W} = 3.38 \times 10^{6}T^{-2} - 2.90$ (Clayton et al., 1972) the $\delta^{18}O_w$ value was 2.1‰ ~ 5.8‰ when fluid reaches the fractionation equilibrium with quartz (Table 5). The test found water δD value of the inclusions was -87‰ ~ -103.67‰.

7. RESULTS & DISCUSSIONS

7.1 RESULTS

By studying the inclusions in quartz which is closely related to the mineralization in the area, we found that the Daxigou gold mine is a shallow (1.01~2.24km) epithermal gold deposit with medium-low temperature (175°C~ 275°C), medium-low salinity (2% to 7%), and medium-low density (0.804~0.959g/cm^3).

Daxigou gold ore-forming fluids belong to the K-Na-Ca-Mg-F-CL-SO_4 system, with major cations abundance as $[Na^+]>[Ca^{2+}]>[K^+]$, anions $[SO_4^{2-}]>[Cl^-]>[F^-]$; the main gas-phase components are H_2O and CO_2 and weak reductive.

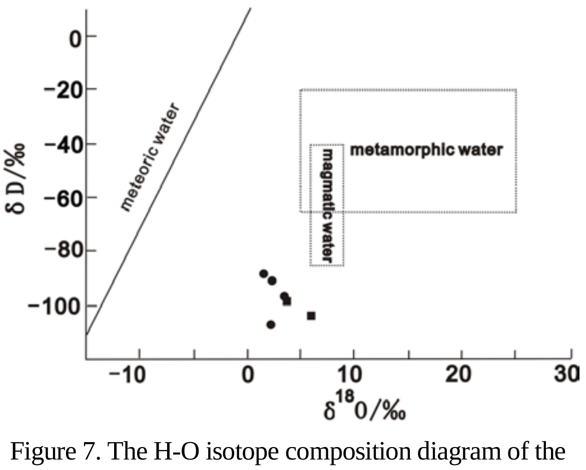

Figure 7. The H-O isotope composition diagram of the inclusions in Daxigou gold mine

7.2 The source of the ore-forming fluids

Plotting the values of the H-O isotope of this area on the δD-$\delta^{18}O$ coordinate diagram (Fig. 7), it can be seen that the values of H-O isotope in the ore-forming fluids are out of the area of primary magmatic water and metamorphic water, and move to the area of the atmospheric precipitation with a big change of $\delta D\delta^{18}O$ values. It indicates that the ore-forming hydrothermal fluid of this area experienced complicated evolution stages.

The salinity of the ore-forming fluid in Daxigou gold mine ranges from 0.53% to 11.34%, mainly concentrated a middle-low level of 2% to 7%. Its salinity fluctuation is greater than that of the Au-Ag-Te Gies mine in Montana, the US and the Au-Te Emperor mine in Fiji (5.7%～8.0% (Zhang & Spry 1994) and 4.0%～7.1% respectively (Ahmad et al., 1987). In the Creple Creek gold mine in the US, halite crystals were discovered with max salinity of 44% (Tompson et al., 1985). Roedder (1984) summarized that the salinities in the shallow, epithermal mines in Nevada, Colorado, Mexico, Peru and Fiji were between 1%~13.8% (Roedder, 1984) similar to the salinity of the inclusions in the Daxigou gold mine. According to the study (Roedder, 1976), the salinity of the fluid inclusions in magmatic hydrothermal deposit is generally less than 10%. The similar situation can be found in the salinity of the Daxigou gold deposit, indicating the ore-forming fluids might originate from magmatic fluid.

Roedder (1976) identified an empiric indicator of hydrothermal ore-forming fluid after years of research, namely: when the $Na^+/K^+ < 2$, $Na^+/(Ca + Mg)^{2+} > 4$, it is typical magmatic hydrothermal; when $Na^+/K^+ > 10$, $Na^+/(Ca + Mg)^{2+} < 1.5$, it is typical hot brine; in between, $2 < Na^+/K^+ < 10$, $1.5 < Na^+/(Ca + Mg)^{2+} < 4$, it is possibly altered hydrothermal. The Na^+/K^+ ratio of ore-forming fluids in Daxigou gold deposit ranges from 2.14 to 7.96, with an average of 4.59, while the $Na^+/(Ca + Mg)^{2+}$ ratio is within 1.84 ~ 6.05, with an average of 3.89. This indicates the ore-forming fluids in the deposit originate as magmatic hydrothermal. The fluid is dominant by Na^+ ions while the relatively fewer K^+ may reflect a large amount of circulating atmospheric water adding in the ore-forming fluids, leading to an increased Na^+ ion proportion.

In summary, the ore-forming hydrothermal source in Daxigou gold deposit features the mixed characteristics of magmatic water and atmospheric precipitation.

7.3 Au migration pattern

Au migrates in the ore-forming hydrothermal fluids mainly as sulphide complexes and chloride complexes (Benning & Seward 1996; Edward, 1998; Hayashi & Ohmoto 1991; Ilchik & Barton 1997).

Fluid inclusion studies indicate that the area is characterized by low salinity fluid and weak reductive environment without chlorine alteration in the host rock; the ingredients of the ore-bearing fluids are H_2O, CO_2, Na^+, K^+, SO_4^{2-}, Cl^- with SO_4^{2-} >Cl^-. Since SO_4^{2-}content reflects the number of HS^- in the media closely linked with the migration of gold, the gold in deposit probably migrate as $[Au(HS)_2]^-$complex compound.

Daxigou gold deposit was formed at medium-low temperature (175 ~ 275°C), with the upper limit close to 300°C. At 300°C, it can be seen on the fO_2-pH plot (Fig. 8 according to Seward, 1984) that when pyrite keeps stable, gold in the solution mainly migrates as a complex of $[Au(HS)_2]^-$, in line with the above inference. The gold content of the ore-bearing solution is within $1 \times 10^{-9} \sim 1 \times 10^{-8}$.

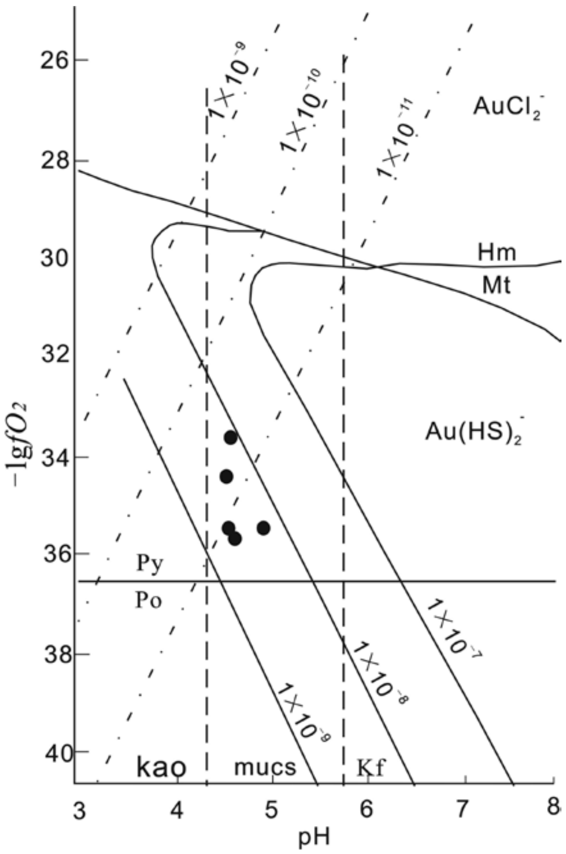

Figure 8. The dissolubility chorisopleth of $AuCl_2^-$ and [Au（HS_2] at 300℃. Mt-magnetite; Hm-hematite; Py-pyrite; Po-pyrrhotite. The black spots in Fig8 are the ore-forming fluids in this area

7.4 Precipitation of gold

Precipitation of gold first requires appropriate space, such as fracture and crack; otherwise, gold is likely to spread, rather than to form deposits. The reasons for Au precipitation vary from boiling, mixing, to hydrothermal alteration, etc (Zhang 1997).

Daxigou gold mineralization inclusions have neither daughter minerals nor signs of boiling. Apparently, gold precipitation mechanism of reduced pressure boiling is not suitable for this deposit. Rocks in this structure-developed area are highly fragmented and well permeable, which can play a role in the diversion of hydrothermal activity, and provide a good channel and storage space for gold migration. Hydrothermal fluids migrate to crushed zones and mix with downward atmospheric precipitation. The original fluid is reductive ore-forming fluid, featuring relatively high temperature and salinity, while the atmospheric precipitation is oxidized, reporting lower temperature, salinity and gas (Lu 1997; Hofstra et al., 1991; Wilkinson, 2001). The mixing of atmospheric precipitation in the open environment results in changes of the fluid’s composition and its physico-chemical properties, such as increased oxygen fugacity, reduced concentration of the ligand complexes and lower temperature, and in these conditions, the solubility of Au would decrease and more Au. According to the causes and characteristics of the deposit, magmatic hydrothermal mixed with meteoric water is considered as a major factor in gold precipitation.

Hydrothermal alteration is another important factor of the chemical composition changes and gold precipitation of Daxigou ore-bearing fluids (Wang & Zhu 2006). Potassic alteration, silicification, and chlorite and calcite alteration are widespread in the deposit. And the gold deposits are always related to hydrothermal alteration, especially for those consisting of disseminated ore formed by the alteration. In the process of hydrothermal migration, fluids rich in mineralized and acidic components reacted with the host rock. The physic-chemical conditions (such as T, pH and fO_2) changes with the migration of the components and gold and sulfide precipitations occur ~~in~~ during the course. The study of Wang et al., (1992) on Au-Si-complex showed that in the silicon-system AuH_3, SiO_4 gradually replaced $[Au(HS)_2]^-$ to become the chief migration form of Au with increasing SiO_2. Hence, strong solidification is conducive to gold migration and precipitation. The positive correlation between silicification and gold mineralization is consistent with the above-mentioned experiments.

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Received at: 11. 03. 2014
Revised at: 18. 06. 2014
Accepted for publication at: 23. 06. 2014
Published online at: 26. 06. 2014