Preliminary studies of fluid inclusions in Damoqujia gold deposit along Zhaoping fault zone, Shandong province, China

YANG LiQiang[1,2*], DENG Jun[1,2], ZHANG Jing[1,2], WANG QingFei[1,2], GAO BangFei[1,2], ZHOU YingHua[1,2], GUO ChunYing[1,2] and JIANG ShaoQing[1,2]

1. *State Key Laboratory of Geological Processes and Mineral Resources*, *China University of Geosciences*, *Beijing* 100083, *China*
2. *Key Laboratory of Lithosphere Tectonics and Lithoprobing Technology of Ministry of Education*, *China University of Geosciences*, *Beijing* 100083, *China*
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Abstract The Damoqujia gold deposit, discovered recently and located in the north of Zhaoping fault zone, is a large altered rock type deposit. In this paper, we report the preliminary research results of the fluid inclusions and discuss its metallogenic implications. The homogenization temperatures of fluid inclusions fall into four ranges: 310 ~ 350℃, 230 ~ 270℃, 160 ~ 200℃ and 110 ~ 150℃; corresponding to the four stages of hydrothermal ore-forming processes: coarse grain pyrite-milk white quartz stage (Ⅰ), smoky gray Au-bearing quartz-fine grain pyrite stage (Ⅱ), Au-bearing polymetallic sulfide-quartz stage (Ⅲ), and quartz-carbonate stage (Ⅳ). Ore-forming fluid is with low salinity and low density, ranging from 1.4 Wt_{NaCl}% to 13.6 Wt_{NaCl}% and from 0.48g/cm^3 to 1.03g/cm^3 respectively. The inclusions are dominated by H_2O and CO_2 in gaseous compositions, and Na^+ and K^+ in positive ions, SO_4^{2-} and Cl^- in negative ions of liquid compositions. Au-S complex is the major form for transportation of gold. The pressure varied from 260MPa to 340MPa during the formation of CO_2-bearing inclusions at the early mineralization; the fluids are rich in SO_4^{2-} and Na^+. The pressure is $26 - 49 \times 10^5$ Pa during the formation of the aqueous salt inclusions in late mineralization, the inclusions are rich in Cl^- (F^-), Na^+. $\delta^{18}O_{qurrtz}$ is 10.64 ~ 12.68‰, and the corresponding $\delta^{18}O_{H_2O}$ and δD is −5.44 ~ 6.47‰ and −95.52 ~ −106.48‰ respectively. Based on the studies about compositions and hydrogen and oxygen isotopes of inclusions, it is evidenced that ore-forming fluid is magmatic hydrothermal fluid in early period, but affected by meteoric water in late.

Key words Damoqujia gold ore deposit, Fluid inclusion, Zhaoping Fault Zone, Jiaodong gold province, China

1 Introduction

The Jiaodong gold province is located on the eastern Shangdong (Jiaodong) Peninsula of eastern China. Jiaodong Peninsula accounts for 0.3% of China in area, but possesses 25% of the total national gold reserves (about 1500t) and the total national gold production (about 40 ~ 50t per year). It is the most important gold concentration area in China. Supracrustal rocks in Jiaodong Peninsula comprise both metamorphosed Precambrian sequences and Mesozoic intrusions. Precambrian sequences are composed of late Archaean Jiaodong group and early Proterozoic Jingshan group and Fenzishan group. Mesozoic intrusions are composed of Mesozoic granitoid, Cretaceous potassium-basaltic medium-acidic vocanics and scattered Cenozoic basalt. Mesozoic Linglong type biotite granite and Guojialing type granodiorite and Precambrian sequences are the ore-related host rock. Regional NE-NNE trending Sanshandao fault, Jiaojia fault and Zhaoping fault, totally taking near 80% of proved gold resources in whole Jiaodong Peninsula, and is principal ore-controlling structures (Lü *et al.*, 1993; Deng *et al.*, 1996; Wang *et al.*, 1998; Zhou and Lü, 2000; Zhai *et al.*, 2001; Qiu *et al.*, 2002; Wang *et al.*, 2002; Mao *et al.*, 2003; Fang *et al.*, 2003; Deng *et al.*, 2003, 2006; Yang *et al.*, 2004, 2006; Chen *et al.*, 2004; Yang *et al.*, 2006). Zhaoping fault zone, with a length of less than 100 km, occupies 14 medium and large-superlarge gold deposits, and

* E-mail: lqyang@cugb.edu.cn

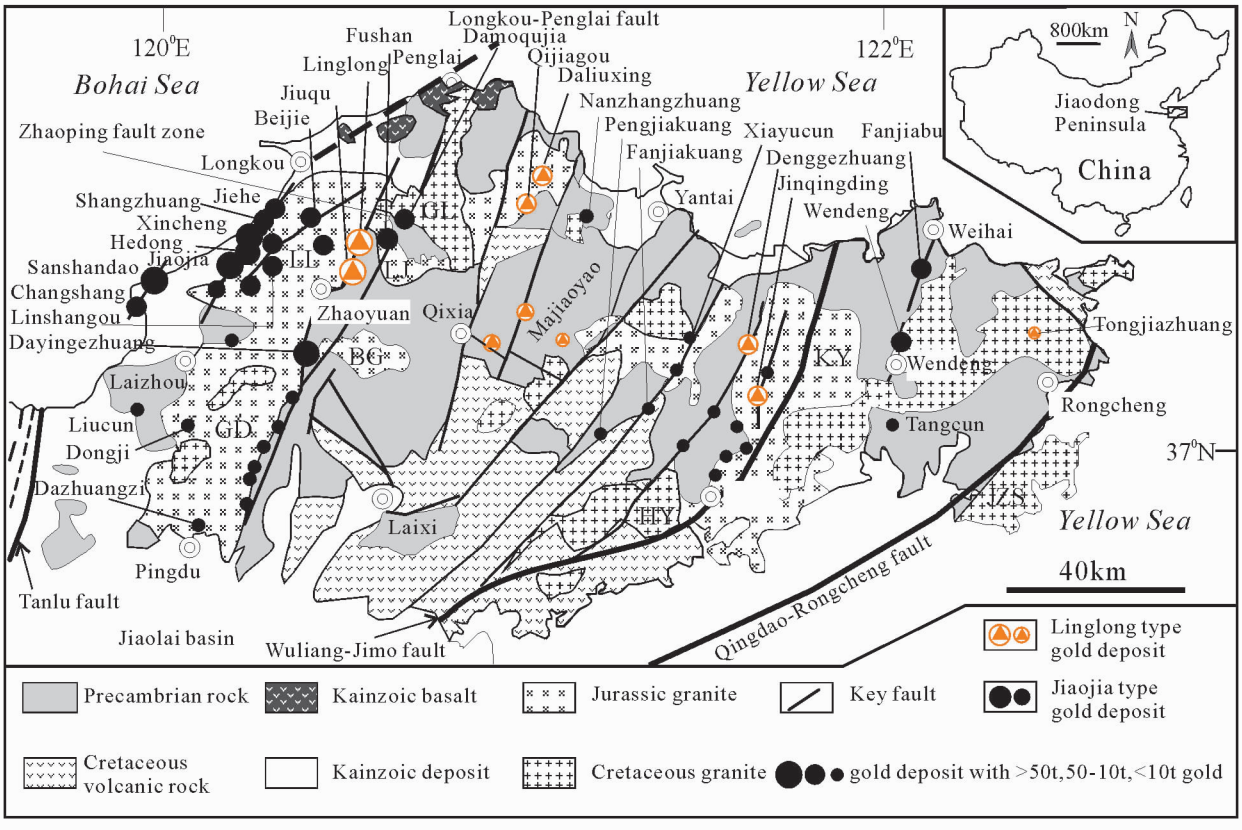


Fig. 1 Simplified geological map of the Jiaodong Peninsula showing location of the major gold deposits.
Data from Cun and Chen, 1992; Hu *et al.*, 1997; Ma, 2002; Fan *et al.*, 2003; Deng *et al.*, 2003; Mao *et al.*, 2003. Abrreviations for granitoid intrusions: BG, Biguo; GD, Guojiadian; GL, Guojialing; HY, Haiyang; KY, Kunyushan; KY, Luanjiahc; LL, Linglong

possesses proved reserves more than 700 t. Moreover, recent studiesshow that the Zhaoping fault zone has a great prospecting foreground in both the deep and the direction of strike (e. g. Damoqujia gold deposit) (Deng *et al.*, 2006; Yang *et al.*, 2006) (Fig. 1).

Damoqujia gold deposit is a typical disseminated- and stockwork-style Jiaojia-type, located in the north part of Zhaoping fault zone. It is sited in the conjoint area of Longkou and Zhaoyuan region and 15 km north to the Zhaoyuan city (Fig. 1). In 1990, gold community of Longkou city entrusted the fourth geological survey of Ministry of Metallurgy to construct 3 drill holes at the No. 302 gold vein. And industrial orebodies were discovered at the level from +20 to −350m. Since 2000, geological work of the No. 7 gold geology party of CAPF suggested that gold orebodies are stretching in the deep part. Up to the present, inferred intrinsic economic and prognostic (333 +334) gold metallic reserves of Damoqujia gold ore deposit amount to 60 t. However, basic geological works of Damoqujia gold ore deposit are lack and far from sufficient degree for the exploration engineering networks, the research work on special issues of the gold deposits are needed. As the Jiaojia-type deposits are now recognized as the most important type of gold resources in the province, research on the geology and geochemistry of the Damoqujia deposit have broad metallogenic and exploration implications. Moreover, the studies are significant to clarify the genesis and ore-forming processes of gold deposits located along the Zhaoping fault zone. Therefore, we carried out systematic geology-geochemistry studies since 2002. In this paper, we report the primary research results of the ore-forming fluids at the Damoqujia deposit and discuss its metallogenic implications. Our study is based on existing geological, petrographic and geochemical information in the Damoqujia gold ore deposit.

2 Ore geology and sampling

Damoqujia gold deposit is located in the north-eastern of Lionglong orefield and adjacent to Fushan gold deposit in southwest (Fig. 1). Exposed strata in the region comprise late Archaean Jiaodong group with the lithology of amphibolite, biotite granulitite and biotite plagiogneiss. The Guojialing-type granodiorites largely are cropped to the east part of the deposit. The Linglong-type biotite granites, with lots of different styles of dike rocks inside, were distributed at the bottom wall of the Zhaoping fault zone. The ore deposit has experienced polygenic tectonism and the gold mineralizaion is spatially controlled by faults. Zhaoping fault zone controls the spatial distribution, occurrence, mineralizing styles, mineral assemblage of orelodes. Cataclasis altered zone controls the occurrence and scale of gold

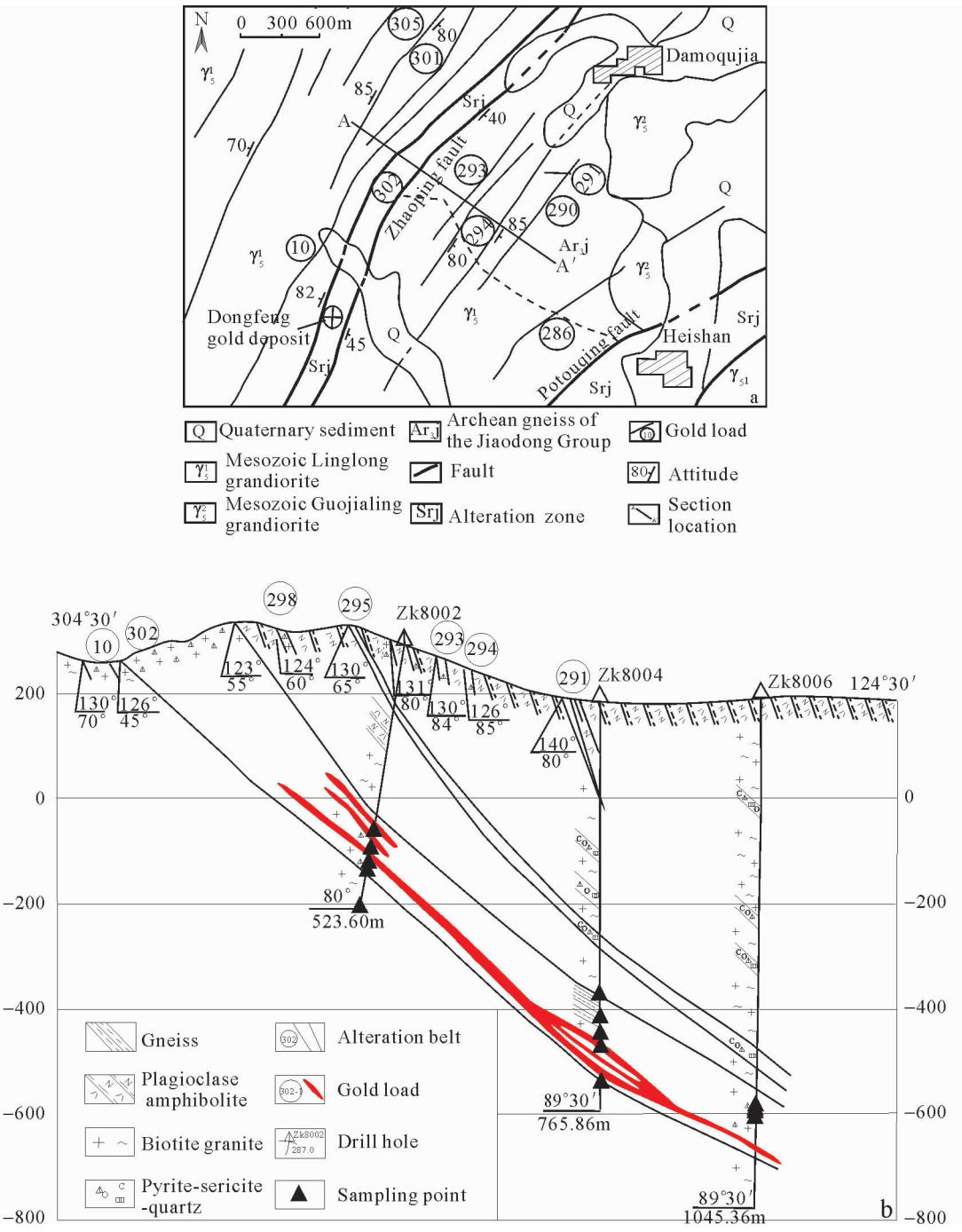


Fig. 2 General geological map (a) and cross section (b) of the Damoqujia gold deposit.
Gold-bearing zones at the Damoqujia deposit are mainly controlled by the NE-SW-trending Zhaoping fault. The sampling locations are showed with solid triangle.

orebodies. Rocks in fault zone are intensively broken and underwent abroad alteration. The bulk of the ore is characterized by strong silicification, sericitization, sulphidation and K-feldspar alteration. K-feldspar alteration and mylonitization are near-ore symbols (Fig. 2).

More than 30 gold veins have been found in Damoqujia ore region. In these veins, No. 302 gold vein is the biggest and others are secondary. Gold ores are composed of gold hosted beresitization rock, beresitization cataclasite, and beresitization granite and quartz vein. Wallrock alteration related to gold orebodies are beresitization, sericite-quartz alteration, silicification, sericitization, pyritization, potassic alteration, carbonatation and some chloritization and kaolinization.

Based on ore textures, structures and mineral assemblage, hydrothermal ore-forming process can be divided into four stages: coarse grain pyrite-milk white quartz stage (Ⅰ), smoky gray Au-bearing quartz-fine grain pyrite stage (Ⅱ), Au-bearing polymetallic sulfide-quartz stage (Ⅲ), and quartz-carbonate

stage (Ⅳ). The Ⅱ and Ⅲ stages are the main ore-forming stages; moreover, the superposition of the two stages mineralization causes the formation of rich ore columns. Fluid inclusion sampling takes the intensity of mineralization and the zoning characteristics of wallrock into account. Samples are collected at both top and bottom of the orebodies. A critical section cutting across the No. 302 gold vein is selected. On the profile, orebodies, alteration zone and non-mineralization area are confirmed. Systematic fluid inclusion and isotopic geochemistry sampling are carried out based on the orebodies and adjacent altered wallrocks. Totally, 15 fluid inclusions and 5 isotopic geochemistry samples are collected (Fig. 2b).

3 Features of fluid inclusion

3.1 Fluid inclusion petrography

Micro-petrography of inclusion was examined at state key laboratory of geological processes and mineral resources (GPMR), China University of Geosciences, Beijing (CUGB). Fluid inclusions were found in quartz of different style of altered rocks. Shapes of these inclusions are mainly regular negative crystal, similar circular, oval, irregular triangle and scoop. Most of them are about 5 ~ 10 μm and few bigger than 10μm in diameter (Fig. 3).

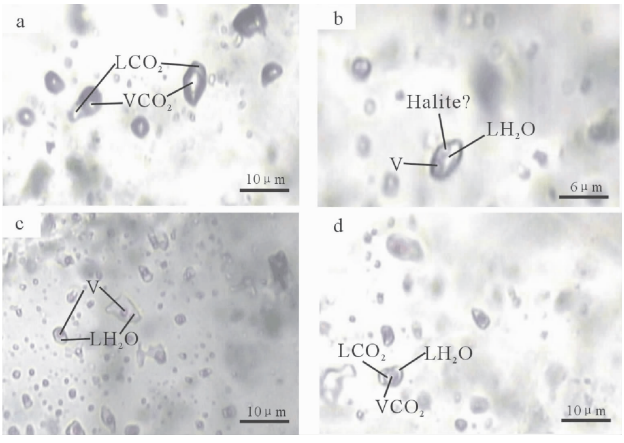


Fig. 3 Photomicrographs showing different types of fluid inclusions in the Damoqujia gold deposit.

a-pure CO_2 inclusions with big bubbles; b-bubble, liquid and a halite crystal (?) inclusion; c-bubbles and liquid two phase inclusions; d-three phase vapor CO_2, liquid CO_2 and liquid inclusion. All inclusions are in quartz.

Inclusions consist of single phase, two phases and three phases. Pure vapour phase inclusions (Ⅰ-g type) are filled by gas. Inclusions of this type show dark to black colour, and light only appear at the centre of the bubble. Pure liquid inclusions (Ⅰ-l type) are mostly blank, with liquid compositions containing H_2O, liquid CO_2 or brine lixiviant. Inclusions of two phases (Ⅱ type) with coexisting liquid and spheroidal vapour are the most important type of inclusions in Damoqujia deposit. This kind of inclusions can be sub-divided into two types: the vapour inclusions (Ⅱ-g type) with $V/(V+L) > 50\%$ and the liquid inclusions (Ⅱ-l type) with $< 50\%$. Damoqujia gold deposit is dominated by the Ⅱ-l type inclusions, with the $L/(V+L)$ value of 8 ~ 30%. Ⅱ type inclusions consist of H_2O, CO_2 or brine lixiviant, mostly lixiviants dominated. In addition, CO_2-riched Ⅱ-g type inclusions, Th < 31.1℃, also possesses a certain portion. CO_2-bearing three phases inclusions (Ⅲ$_{CO_2}$ type, i. e. $V_{CO_2} + L_{CO_2} + L_{H_2O}$ type), with their $V_{CO_2} + L_{CO_2}$ amount to 20% ~ 40% of the bulk volume of inclusions, in some samples coexisting with II-l type inclusions reflecting the information of fluid evolution. Three phases inclusions containing daughter minerals (Ⅲ$_{NaCl}$ type) can be rarely seen in some samples and the daughter minerals are of small volumes (Fig. 3).

3.2 Microthermometric results

Microthermometric study of inclusions is carried out by a Leitz microscope and a Linkam THMS 600 programmable heating-freezing stage at state key laboratory of GPMR, CUGB. Based on the mircoexamination of inclusions, we choose some typical samples to test the primordial-melting temperatures (Teu), ice-melting temperatures (TmIce) and homogeneous temperatures (Th) of Ⅱ type of fluid inclusions. While, carbonic phase melting temperatures ($TmCO_2$), clathrate melting temperatures (Tmclath), CO_2 homogeneous temperatures ($ThCO_2$) and CO_2-H_2O total homogeneous temperatures (Th) of the ⅢCO_2 type of fluid inclusions are also examined (Fig. 4).

(1) CO_2 melting temperatures $TmCO_2$.

CO_2-riched Ⅱ type inclusions are rare in Damoqujia gold ore deposit. Carbonic phase melting temperatures of ⅢCO_2 can be determined by the temperatures of phase change using heating-freezing stage. Carbonic phase melting temperatures of samples range from −58.2℃ to −57.3℃ and are concentrated in −57.4 ~ −56.6℃, which is equal to or a little lower than the three phase point of pure CO_2 (−56.6℃). This suggests that there exist volatile components in inclusions except CO_2, such as N_2, CH_4 and H_2S that have lower three phase point temperature than CO_2.

(2) Ice-melting temperatures TmIce.

Most of the samples contain Ⅱ type inclusions, and their ice-melting temperatures change from -5.3℃ to −0.3℃ and focus on −4 ~ −2℃. Based on these data, it can be calculated that salinities of inclusions are of 0.53 ~ 8.28wt%, which shows the features of low salinity of aqueous solution in inclusions (Lu *et al.*, 2004).

(3) Clathrate ($CO_2 \cdot 5.75H_2O$) melting temperatures TmClath.

Clathrate melting temperatures vary from 3.4℃ to 8.8℃ and their homogeneous temperatures are a little higher than the Ⅱ type inclusions. According to this, the salinities of inclusions are of 2.42 ~ 11.43wt% (Bozzo *et al.*, 1973). The salinities of H_2O-bearing inclusions show the characteristics of low salinity, although they are slightly higher than the Ⅱ type inclusions. It can be inferred that the early ore-forming fluids are dominated by medium-low salinity deep-rooted fluids, while the fluids without metals are characterized by both low salinities and low homogeneous temperatures.

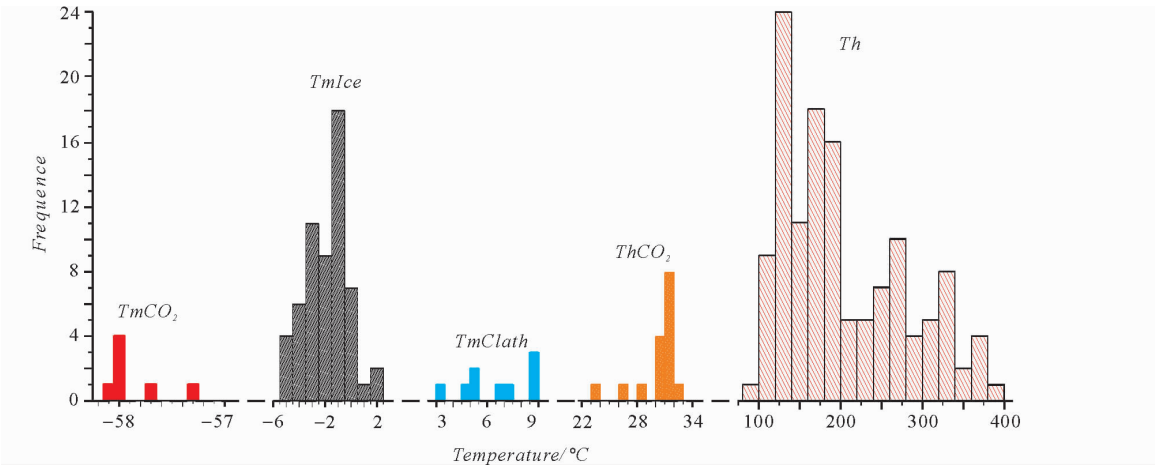


Fig. 4 Histograms of microthermometric measurements from fluid inclusions in the Dayingezhuang deposit.
a-Microthermometric data for $TmCO_2$, TmIce, Tmclath and $ThCO_2$; b-Homogenization temperatures

Table 1 Results of fluid inclusion compositions analyses from the Damuqujia gold deposit (Gas components in mol%; liquid components in μg/g)

Sample No.	H_2O	N_2	CO_2	He	Ar	CH_4	C_2H_6	H_2S	F^-	Cl^-	SO_{4-}	Na^+	K^+	Mg^{2+}	Ca^{2+}
QJ802-2	91.87	0.1396	7.466	0.0008	0.0067	0.2600	0.0708	0.187	0.525	1.11	7.65	4.12	1.90	0.155	1.07
QJ802-3	95.41	0.1674	1.074	—	0.0064	0.1185	0.0178	3.206	3.32	0.675	29.9	5.15	11.1	0.465	3.32
QJ802-4	94.19	1.395	3.980	0.0003	0.0387	0.2285	0.0693	0.098	1.91	2.83	28.0	6.20	5.50	0.370	>10
QJ802-5	91.61	1.496	5.586	0.0004	0.0165	0.1355	0.0291	0.056	2.65	1.25	27.4	5.40	2.93	0.175	>10
QJ802-10									2.45	0.83	1.80	1.68	1.21	6.95	25.75*
QJ804-13*	96.84	—	0.103	—	0.0023	0.0247	0.0039	3.023	4.84	—	16.4	13.1	96.8	0.615	>10
QJ804-14	92.65	0.788	4.647	0.0005	0.1309	1.4754	0.3083	—	2.77	0.77	7.10	2.32	8.10	0.100	0.320
QJ804-15	92.63	0.3680	4.299	—	0.0106	0.3662	0.0477	2.278	0.66	2.02	4.57	3.68	1.82	0.086	0.795
QJ804-17	87.96	1.7836	9.471	0.0004	0.0402	0.6366	0.1080	—	3.32	3.88	7.75	2.80	2.96	0.150	9.70
QJ804-19	92.39	0.2313	5.171	—	0.0039	0.2352	0.0486	1.920	0.695	2.27	6.60	5.85	2.14	0.130	0.750
QJ806-14	93.42	—	1.066	—	0.0061	0.0228	—	5.393	2.17	0.370	21.2	4.11	6.35	0.175	1.26
QJ806-15	91.2	1.263	1.150	—	0.0396	0.1473	0.0359	6.164	0.945	0.22	34.3	7.84	2.46	0.090	0.705
QJ806-16	85.94	2.322	10.22	0.0001	0.0881	0.5071	0.1046	0.815	2.73	0.46	24.6	2.68	8.10	0.200	3.78
QJ806-17	92.58	1.7350	5.518	0.0005	0.0205	0.0893	0.0350	0.0211	0.500	1.16	2.65	2.42	1.14	0.110	0.700

Instrument and working condition of gas components are as follows: Instrument is HIC-6A Ion chromatograph Japan SHIMADZU. Column is Shim-pack IC-A3, Shim-pack IC-C3. Mobile phase. Flow is Anio 1.2 ml/min and Ion 1.0 ml/min. Temperature is 40℃. Detector is CCD-6A 3.2μs/cmFS. Inj. Vol is 50μl. Reproducibility for gas components is about ±5‰ (1σ). Instrument and working condition of liquid components are as follows: Instrument is RG202 Quadrupole mass spectrometer made by Japan ULVAC. SME voltage is -1.22V. Ionization way is EI. Ionizing energy is 50eV. Measure speed is 50msec/amu. Reproducibility for liquid components is about ±5‰(1σ). Analyzing procedure is as following: The dried washed sample, weighing 50mg, was put in a clean quartz tube, and was heated to 100 degree centigrade. Then, valve was turned on and the gas pipe was. When the pressure in the quartz tube was less than this value (6×10^{-6}Pa), the burst stove was heated to 550 degree centigrade. The vacuum valve was turned on for determination of gaseous composition. "—" shows under the detection limit. "*" shows the results can be referenced

(4) CO_2 homogeneous temperatures $ThCO_2$.

Homogeneous temperatures of CO_2-riched Ⅱ type inclusions and Ⅲ CO_2 type inclusions range in 23 ~ 31.4℃, most of which are lower than the homogeneous temperature of pure CO_2 (31.1℃). Inclusions are homogeneous to liquid.

(5) Homogeneous temperatures of Ⅱ-l type of aqueous inclusions and total homogeneous temperatures Ⅲ CO_2.

Total homogeneous temperatures of inclusions have a wide range. From the histogram, homogeneous temperatures are concentrated in following several intervals, 110 ~ 150℃, 160 ~ 200℃, 230 ~ 270℃ and 310 ~ 350℃. CO_2-H_2O total homogeneous temperatures of Ⅲ CO_2 type inclusions are consistent with the homogeneous temperatures of Ⅱ-l type aqueous inclusions on the early-medium stage of mineralization. Thus shows the characteristics of CO_2-riched fluids in the early stage, which may be relative to magmatic fluids or deep-rooted solutions.

3.3 Compositions of fluid inclusion

Gas and liquid components analysis of group of inclusions are carried out at the Institute of Geology and Geophysics, Chinese Academy of Sciences (IGGCAS). The results show that (Table 1), gas composition of inclusions are dominated by H_2O, with the mole percent as 90.915% ~ 99.346%. CO_2 is in the second place, and then comes the small amount of CH_4, C_2H_6, N_2 and H_2S. These small amounts of gas indicate the

reducing conditions during mineralization. As showed in figure 1, liquid compositions of inclusions are dominated by Na^+ and K^+, with their content of 1.68 ~ 7.84% and 1.14 ~ 11.1% respectively, then the Ca^{2+} of 0.32 ~ >10%, and then Mg^{2+} of 0.086 ~ 6.95%. Negative ions in fluid inclusions are dominated by Cl^-, SO_4^{2-} and F^-, with the content of 0.22 ~ 3.88%, 1.8 ~ 34.3% and 0.5 ~ 3.32% respectively.

4 Oxygen and hydrogen stable isotopes

Oxygen and hydrogen isotopes testing are also carried out at IGGCAS. Oxygen isotope of equilibrium fluids are calculated by oxygen isotopic equilibrium fractional equation: $1000\ln\alpha_{quartz\text{-}water} = 3.38 \times 10^6 T^{-2} - 3.40$ (Clayton *et al.*, 1972) based on the oxygen isotope data of fluid inclusion captured in quartz. The $\delta^{18}O$ values of quartz are relative high ranging from 10.64 to 12.68. $\delta^{18}O$ values calculated according to equilibrium fractional equation range from −5.44 to 6.47 (Table 2), corresponding to that δD values vary form −95.52 to −106.48.

Table 2 Results from oxygen and hydrogen isotope analyses in the Damoqujia gold deposit

Sample No.	$\delta^{18}O_{qz}$ (‰)	$\delta^{18}O_{fluid}$ (‰)	δD_{fluid} (‰)	Th (℃)
QJ804-13	10.64	1.69	−95.52	250
QJ804-14	11.03	−2.78	−97.71	170
QJ804-14	11.03	−5.37	−97.71	140
QJ804-15	10.96	4.75	−96.53	320
QJ804-15	10.96	2.01	−96.53	250
QJ804-15	10.96	−5.44	−96.53	140
QJ804-17	11.72	2.77	−102.26	250
QJ804-19	12.68	6.47	−106.48	320
QJ804-19	12.68	3.73	−106.48	250

Oxygen was liberated from quartz by reaction with BrF_5. The $\delta^{18}O$ and δD determinations were made on a MAT-252 mass spectrometer. Reproducibility for isotopically homogeneous pure quartz is about ± 0.1‰ (1σ), and analyses of standard water samples suggest a precision for δD of ±3‰ (1σ). Oxygen isotopic compositions of hydrothermal waters in equilibrium with quartz were calculated using an extrapolation of the fractionation formula from Clayton *et al.* (1972)

In the $\delta^{18}O$-δD diagram (Fig. 5), points plotted lie below the domains of magmatic fluids and metamorphic fluids. The $\delta^{18}O$ points show the close relation to the magmatic fluids, while δD points deviate to the meteoric waters.

5 Discussion and conclusions

5.1 Pressure-temperature-density estimation of ore-forming fluids

The homogeneous temperature data are got by a heating-freezing stage on the atmospheric pressure condition; however, fluid inclusions are trapped on a certain pressure condition. Therefore, the measured homogeneous temperatures should be

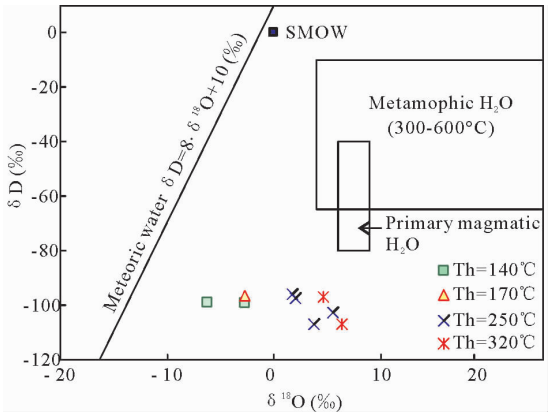


Fig. 5 Fluid δD and $\delta^{18}O$ characteristics of the gold-depositing fluids at Damoqujia. Also shown are the isotopic fields for common geological waters

revised by pressure correction based on the correction curve. A diagram supplied by Potter (1977) is the most practical and prevalent one (Lu *et al.*, 2004). According to the primary data about homogeneous temperature, salinity and pressure of the fluid inclusions of the Damoqujia gold ore deposit, a correction value of 10 ~ 50℃ is got using the *P-T* diagram of NaCl solution of various densities.

Densities of the Ⅱ type of fluid inclusions are calculated based on the density equation of brine lixiviant inclusions (Lu *et al.*, 2004). Densities of ore-forming fluids range between 0.79 and 0.99g/cm^3, which are consistent with the density data that got by the *T-ρ* phase diagram (Bischoff *et al.*, 1991) or the *T-W-ρ* phase diagram (Bodnar, 1983) of NaCl-H_2O system. Densities of CO_2-riched Ⅱ type of fluid inclusions, calculated according to the equation supplied by Touret1 (1979), range between 0.367 and 0.589g/cm^3. Densities of the aqueous solution and the whole fluids of the Ⅲ CO_2 type of fluid inclusions are calculated based on density equation of CO_2 three phase supplied by Sterner *et al.* (1991), with the data ranging from 0.995 to 1.085g/cm^3 and from 0.869 to1.018g/cm^3, respectively. In general, densities of ore-forming fluids of Damoqujia gold ore deposit ranging between 0.48 and 1.03g/cm^3 show the characteristics of low density fluids.

Pressure calculation of Ⅱ type of fluid inclusions are based on homogeneous pressure p_h (bar) equation of NaCl aqueous solution supplied by Bain (1964) and Haas (1976) (cited from Lu *et al.*, 2004). It is suggested that fluid inclusions are trapped at the pressures concentrated in $26 - 49 \times 10^5$Pa and $3 - 9 \times 10^5$Pa. These fluid inclusions, with the homogeneous temperatures no more than 160℃, are inferred to be secondary inclusions. Pressures calculated by both equation method and graphic method (Roedder, 1984, 1993, cited from Lu *et al.*, 2004) are approximate. Pressure calculation of CO_2-riched Ⅱ type of fluid inclusions are carried out based on the equation supplied by Walas (1985) and the results range between 73×10^5Pa and 75×10^5Pa.

The pressure calculation of Ⅲ CO_2 type of CO_2 three phase fluid inclusions are different with the changing of solution salinities. When the salinities are less than 6wt%, the graphic diagram by Schwartz (1989) is taken and the pressures of fluid

inclusions' formation can be evaluated by the partial homogeneous temperatures, total homogeneous temperatures and salinities of these type of fluid inclusions. On the contrary, when the salinities may range between 6wt% wt% and 10wt%, the graphic diagram by Brown (1989) is taken and the pressures of fluid inclusions formation range between 260MPa and 340MPa. If these pressures are thought to be lithostatic pressures, the depth of mineralization may range between 10km and 13km according to the lithostatic gradient of 25MPa per kilometer. In northwestern Jiaodong region, ore-forming pressures range between 20MPa and 50MPa based on the H_2O-CO_2 system and the corresponding depth of mineralization is restricted in 800m ~ 2000m (lithostatic pressure gradient is 25MPa/km). Whereas, mineralization depth calculated based on NaCl-H_2O type of fluid inclusions range between 572m ~ 1418m (Wang *et al.*, 1994), which are consistent with this calculating results in Damoqujia gold deposit.

However, the calculated depth of mineralization seems to be on the low side with the consideration of realistic geological environment (Yang *et al.*, 2006). The cause of the unreasonable phenomenon is the effect of ore-controlling faults. Faults not only supply the pathways for fluid transport, but also connect the fluid system to the atmosphere. This makes the fluid system to be an opening system. In this case, ore-forming depth calculation by pressures may be reasonable according to the hydrostatic pressure.

5.2 Possible sources of ore-forming fluids and gold transport

Homogeneous temperatures of fluid inclusions in both altered rocks with bare mineralization and in altered rocks with little mineralization are concentrated in 110 ~ 150℃. While, homogeneous temperatures of fluid inclusions in altered rocks with much mineralization are much higher, concentrating in 350 ~ 160℃. These high temperatures are approximately corresponded to the main stage of hydrothermal mineralization. Compositions of fluid inclusions are dominated by H_2O and CO_2, and the positive ions and negative ions are dominated by Na^+, K^+ and SO_4^{2-}, Cl^- respectively. Fluids of the early ore-forming stage are deep-rooted solutions characterized by high CO_2 component and middle-low salinities, whereas, brine lixibiants of the late mineralizing stage are low salinities solutions with various fluid inclusion types.

The $\delta^{18}O$ values of quartz in all samples are close to the $\delta^{18}O$ values of quartz in Jiaodong group gneissic amphibolites (Zhang *et al.*, 1994; Li and Yang, 1993; Wang *et al.*, 1994; Chen *et al.*, 1997). This is suggested that $\delta^{18}O$ composition of ores had inherited the characteristics of country rocks or that the ore-forming fluids were magmatic hydrothermals derived from the magmatic bodies formed by the remelting and reconstructing of Jiaodong group metamorphic rocks. Moreover, converted $\delta^{18}O$ values of ore-forming fluids show obviously the intensive reconstruction of meteoric waters.

Comprehensive analysis on microthermometric, compositions, oxygen and hydrogen isotopes and trace elements of fluid inclusions indicate that ore-forming fluids were dominated by magmatic hydrothermals in the early stage of mineralization and then affected by meteoric waters in the late stage. Based on the mineralizing temperatures and ore fluids properties, it can be inferred that Au was transported as Au-S complex: $Au^\circ + H_2S(aq) + HS^- = Au(HS)^{2-} + 0.5H_2(g)$.

5.3 Constraints on gold metallogeny

Damoqujia gold ore deposit is located in Linglong orefield. Great deals of previous studies are focused on the metallogenic chronology (Fig. 6) (Yang *et al.*, 2000, 2003; Lu *et al.*, 1999; Lü *et al.*, 1993, 1999; Zhang *et al.*, 1994). The dating of Linglong gold field indicates that there were three stages of gold mineralization. The main gold mineralization occurred in 100 ~ 130Ma, while the early and the late stage of gold mineralization occurred in 150 ~ 140Ma and 70 ~ 90Ma, respectively. Geological and geochemical characteristics of fluid inclusions of Damoqujia gold ore deposit mentioned above show the information of the evolution of ore-forming fluids. In the early ore-forming stage, deep-rooted magmatic hydrothermals with high CO_2, SO_4^{2-} and Na^+ components transported along the fault and reacted with wallrocks by means of exchange of elements and isotopes. Ore-forming materials were extracted from the wallrocks and transported by metallogenic fluids. In the middle stage, low salinity and Cl^- and Na^+ riched meteoric water infiltrated through the extensional fissures and extracted ore-forming materials from the wallrock via water-rock reaction. In the middle to late stage, metallogenic fluids are dominated by meteoric water. When fluids transporting at the feasible structural conditions, coupling with the change of physical-chemical conditions and the variation of fluids properties, ore-forming materials contained by hydrothemals precipitated and the ore deposit formed.

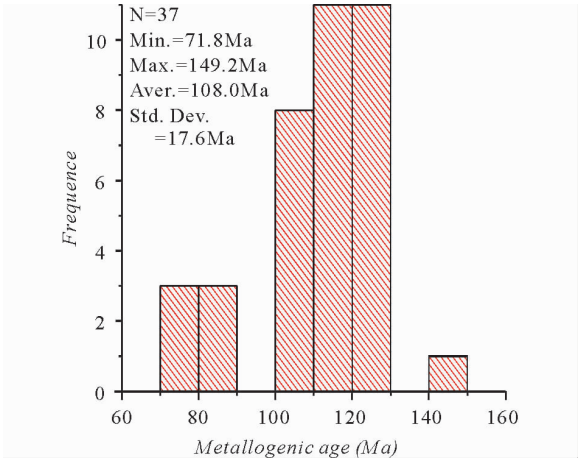


Fig. 6 Histograms of metallogenic age in the Linglong gold field, Shangdong province, China

Data from Yang *et al.*, 2000, 2003; Lü *et al.*, 1999; L, 1993, 1999; Zhang *et al.*, 1994

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