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Geochemical Characteristics and Genesis of Majiayao Gold Deposit in Jiaodong

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Abstract: *Majiayao Gold Mine, located in Qixia City, Shandong Province, is a quartz vein-type gold deposit. In order to explore the source of the metallogenic materials of the Majiayao gold deposit, the previous experimental results of the pyrite and galena in the Majiayao gold deposit were collected in this paper. The S isotopic results show that the $\delta^{34}S$ values of gold-related sulfide in Majiayao gold deposit are 4.4‰~8.8‰, indicating that the ore-forming materials come from the mantle and crust. The metallogenic mechanism of the Majiayao gold deposit is the upwelling of mantle-derived magma, and then exchanges material with the metamorphic rocks of the Jiaodong Group to form ore-forming fluids rich in metamorphic components. The ore-forming fluid migrated upward, the temperature and pressure decreased and the atmospheric water was mixed, and the ore-forming fluid was immiscible, resulting in the precipitation of gold.*

Keywords: *Isotopic geochemistry; Ore-forming material; Majiayao gold deposit*

1. Introduction

As the largest gold producer in the world, gold resources in China are widely distributed [1-2]. Jiaodong region is the largest gold producing area in China, with more than 150 proven gold deposits and over 5000t gold reserves [2-3]. Such enrichment of gold resources in Jiaodong Peninsula has attracted many scholars to conduct research, and a large number of research achievements have been made in the nature of gold mineralization in Jiaodong Peninsula, metallogenic age, metallogenic geodynamic environment and other research fields [4-7]. The origin of ore-forming materials in Majiayao gold deposit is still controversial.

2. Regional geology

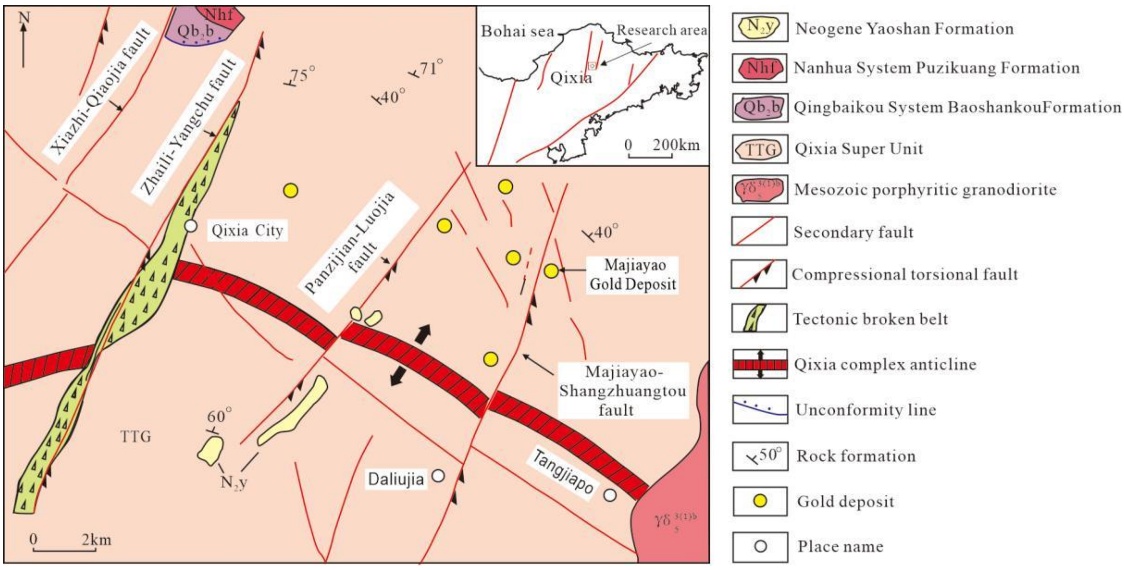

Figure 1: The position of Majiayao gold deposit (Modified after reference [8-9])

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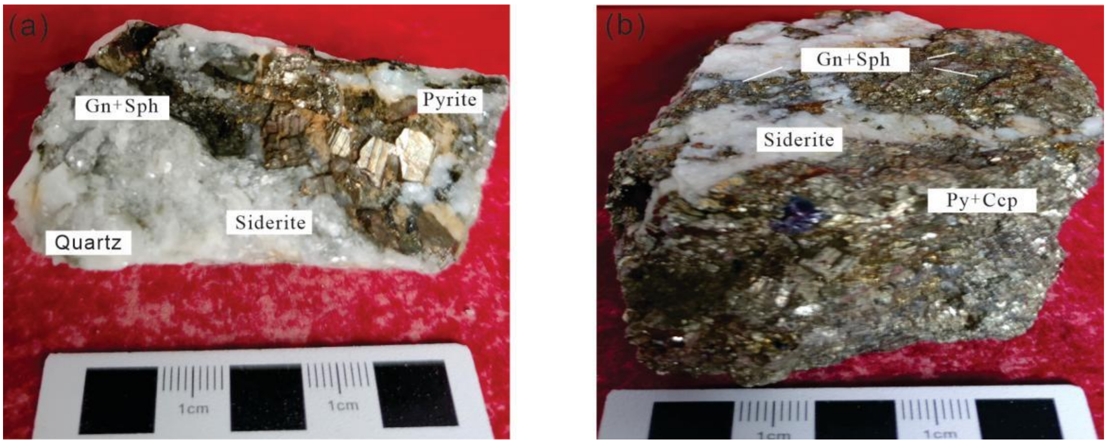
Majiayao gold deposit is located in xia-Penglai metallogenic belt in western Jiaodong. It belongs to jiaodong uplift of North China Plate jiabei uplift origin area. In the mining area, the Strata of Jiaodong Group of Neoarchean are distributed sporadically in small-scale inclusion, and the Quaternary of Cenozoic is distributed along lowlands such as valleys and floodplains. NW, NE and NNE trending faults are developed in the area. The magmatic rocks are mainly TTG series of Qixia Super Unit (Fig. 1).

The tectonic movement is active in Qixia area, mainly including Qixia complex anticline (near EW direction) and compressional fault (NE direction). The faults in the area are majiayo-Shangzhuangtou fault, Panjian-Luojia fault, Zhaili-Yangchu fault and Xiadio-Qiaojia fault from east to west, and a series of secondary fault structures are derived. The EW-trending Qixia complex anticline is divided into multiple sections by the fault system composed of four main faults and their secondary faults (Fig. 1).

The ore in the Majiayao gold deposit is composed of metallic minerals such as pyrite, siderite, chalcopyrite and natural gold and non-metallic minerals such as quartz, sericite, chlorite and calcite.

Common metal sulfides such as pyrite, galena and sphalerite are distributed in veins along quartz fractures (Fig. 2).



Abbreviation: Py, pyrite; Ccp, chalcopyrite; Sph, sphalerite; Gn, galena.

Figure 2: Ore photos of Majiayao gold deposit

3. S Isotopic geochemistry

The $\delta^{34}S$ value of pyrite helps to trace the source of sulfur [10]. Gold is mainly transported in the form of $Au(HS)^{2-}$ in Jiaodong area, and understanding the source of sulfur is crucial to determine the source of gold [11].

In this paper, the previous results of sulfur isotope analysis of the Majiayao gold mine were collected, and the specific data are shown in Table 1. The variation range of gold-related sulfide $\delta^{34}S$ in Majiayao gold deposit is small, ranging from 4.4‰ to 8.8‰ (Table. 1), with a range of 4.4‰ and an average value of 6.5‰. The $\delta^{34}S$ value of the Jiaodong Group is 7.0‰~7.8‰, with an average value of 7.4‰; the $\delta^{34}S$ value of the Jingshan Group is 8.2‰~12.0‰, and the average value is 10.1‰; The average value is 6.9‰; the $\delta^{34}S$ value of Linglong granite is 7.9‰~10.2‰; the $\delta^{34}S$ value of Guojialing granite is 2.7‰~11.8‰.

The $\delta^{34}S$ values of majiayao gold deposit are 4.4‰~8.8‰, and the peak values are 4.8~5.8‰ and 6.5~8.8‰ (Fig. 3a). The $\delta^{34}S$ value of sulfide in the deposit deviates from the meteorite sulfur in a small range and has the characteristics of slight enrichment. The $\delta^{34}S$ values of gold-related sulfide in Jiaodong gold deposit generally range from 2‰ to 14‰, and the peak value ranges from 7 to 12‰[6,12]. The peak value of $\delta^{34}S$ of gold-related sulfide in Majiayao gold deposit is slightly lower, which may be caused by oxidation, resulting in the oxidation of $\delta^{34}S$ to form SO_4^{2-} or other oxidation states, resulting in a relatively low value of $\delta^{34}S$ of pyrite formation. Although gold can be transported in the form of disulfide or chloride complexes, experiments have shown that gold ions are mainly transported in the form of $Au(HS)_2^-$ and $Au(HS)^0$ in intermediate-temperature hydrothermal fluids [13-14]. In the Majiayao gold deposit, gold is commonly found in pyrite, indicating that gold is most likely transported as gold disulfide. The reaction principle is shown in formula (1)[15]:

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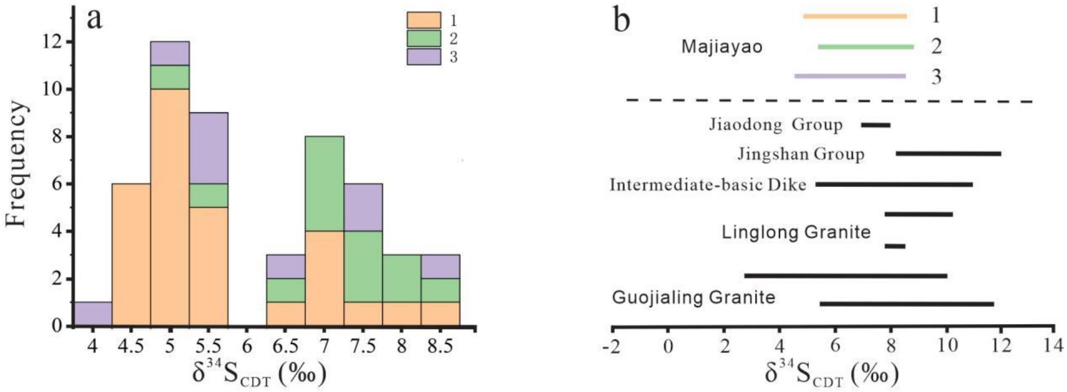
Table 1: S isotopic composition of Majiayao gold deposit and related rock masses

Deposit	Sample No.	Sample type	$\delta^{34}S_{CDT}$ (‰)	$\delta^{34}S$ Average Value	Reference
Majiayao gold deposit	15MJY17-1@5	Pyrite	7.2	5.8	Feng et al., 2021
	15MJY17-1@6		8.6		
	15MJY17-1@7		7.2		
	15MJY17-1@8		7.0		
	14MJY32@1		5.4		
	14MJY32@2		5.3		
	14MJY32@3		5.4		
	14MJY32@4		5.3		
	14MJY32@5		8.2		
	14MJY32@6		5.3		
	14MJY32@7		5.3		
	15MJY24@1		7.1		
	15MJY24@2		7.9		
	15MJY24@3		5.7		
	15MJY24@4		5.1		
	15MJY24@5		4.8		
	15MJY24@6		4.9		
	15MJY24@7		6.5		
	15MJY24@8		5.6		
	15MJY24@9		5.4		
	15MJY24@10		5.6		
	15MJY24@11		5.2		
	15MJY24@12		5.8		
	15MJY24@13		5.6		
	15MJY24@14		4.8		
	15MJY24@15		4.8		
	15MJY24@16		4.8		
	15MJY24@17		4.8		
	15MJY24@18		5.0		
	SD17-68B1-2	Pyrite	8.8	7.4	Tian J.P., 2020
	SD17-68B1-3		8.4		
	SD17-68B1-4		8.4		
	SD17-68B1-5		7.8		
	SD17-68B1-6		7.7		
	SD17-68B1-7		7.3		
	SD17-71B1-1		7.4		
	SD17-71B1-2		6.5		
	SD17-71B1-3		7.0		
	SD17-71B1-4		5.4		
	SD17-71B1-5		7.9		
	SD17-71B1-6		5.8		
	SD17-71B1-7		7.4		
	MJY-ZD-185-YM-B11	Pyrite	6.9	6.4	Wang J.L., 2013
	MJY-ZD-80-B4		7.6		
	MJY-ZD-80-B3		7.9		
	MJY-ZD-80-B6		8.6		
	MJY-1#-ZD-150-YM-B18		5.6		
	MJY-JK		5.5		
	MJY-1#-ZD-150-YM-B18	Galena	5.3		
	MJY-ZD-185-YM-B28		4.4		
	MJY-JK		5.5		
Jiaodong Group		Pyrite	7.00 ~7.80	7.40	Wang, Y.W., 2002
Jingshan Group		Pyrite	8.20 ~12.00	10.10	Zhang, Z.R., 1999
Intermediate-basic dyke		Whole rock	5.30 ~10.80	6.90	Hang, D.Y., 1994
Linglong Granite		Pyrite	7.90 ~10.20	9.50	Wang, Y.W., 2002
		Pyrite	7.90 ~8.40	8.20	Mao, et.al., 2005
Guojialing granite		Pyrite	2.70 ~10.00	6.70	Li, Z.L.,1993
		Pyrite	5.50 ~11.80		Chen, et.al., 1993

$$2Au\ (HS)_2^- + Fe^{2+} = FeS_2 + 2Au + 2H^+ \quad (1)$$

The $\delta^{34}S$ values of Majiayao gold deposit and gold-related sulfide (4.4‰~8.8‰), Jiaodong Group (7.0‰~7.8‰), Jingshan Group (8.2‰~12.0‰), Intermediate-basic dyke (5.3‰~10.8‰), Linglong granite (7.9‰~10.2‰), The $\delta^{34}S$ values (2.7‰~11.8‰) of the Guojialing granite coincide in some interval (Fig. 3b), indicating that the sulfur source of Majiayao gold deposit is not a single source, and the above terrae may be the sulfur source of ore-forming materials of Majiayao gold deposit.



1 Sulfur isotope data from Feng, et.al., 2021[16]; 2 Sulfur isotope data from Tian Jiepeng, 2020[17]; 3 Sulfur isotope data from Wang Jialiang, 2013[18].

Figure 3: S isotope histogram of Majiayao gold deposit (a) and sulfur isotope composition of sulfide minerals in Majiayao gold deposit and regional rocks (b) diagram

There are three main sources of sulfur isotopes on earth[19]: (1) mantle, where the $\delta^{34}S$ mean is close to 0 (0±3‰); (2) Seawater, average $\delta^{34}S$ of 20‰ (3) crust; The $\delta^{34}S$ value may be greater or less than that of mantle or seawater.

The $\delta^{34}S$ value of Majiayao gold deposit is 4.4‰~8.8‰, and the $\delta^{34}S$ value of Majiayao gold deposit is higher than that of the mantle, indicating that sulfur is not only from the mantle. The variation range of $\delta^{34}S$ values is small (Fig. 3a), indicating a high degree of homogenization of sulfur, indicating the characteristics of sulfur in deep magma [20]. The $\delta^{34}S$ values of Majiayao gold deposit coincide with those of Jiaodong Group, Jingshan Group, meso-mafic dikes, Linglong granite and Guojialing granite (Fig. 3b), indicating that the sulfur in Majiayao gold deposit may be inherited from the above terrims. Combined with data characteristics (Table 1), it is analyzed that gold-related sulfide sources in Majiayao gold mine may be mixed by mantle source and crust source.

4. Conclusion

The S isotope results of the Majiayao gold deposit and gold-related minerals show that the ore-forming materials are affected by crust-mantle mixing. It is speculated that mantle-derived magma migrated upward, and the lower crust was heated and partially melted, activating the ore-forming materials in the lower crust. The mantle-derived magma exchanged components with metamorphic rocks in the lower crust, and the components of the lower crust were mixed into them. Therefore, the ore-forming materials of Majiayao gold deposit show the characteristics of crust-mantle mixing.

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