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Gold occurrence of Jiaojia gold mine in Shandong province

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Abstract: The microscopy and scanning electronic microscopy (SEM) were used to study the gold occurrence of Jiaojia gold mine, Shandong province. The results show that the gold-bearing minerals are composed of pyrite, chalcopyrite, gangue, sphalerite and galena. 77.12% of gold minerals are the sulphides and 22.88% are the gangues. The gold occurrence is composed of 60.28% fissure gold, 21.63% inclusion gold and 18.09% crystal fractured gold. The morphology of gold mineral is composed of sphere, triangle, rectangle, strip and erose. The Jiaojia gold mineral owns large grain size range from 3−5 μm to 100 μm. 1.5% of gold grains is more than 0.104 mm, 5.26% is 0.074−0.104 mm, 23.31% is 0.043−0.074 mm, 3.76% is 0.043−0.037 mm and 64.29% is less than 0.037 mm. The occurrence of gold mineral is composed of native gold, electrum, native silver, iron-bearing native silver, goldcuprid and acanthite. Electrum is the most important mineral, accounting for 71.56%. The average quality is 641.26‰ for gold and silver mineral.

Key words: gold mine; gold occurrence; gold-bearing mineral; gold mineral

1 Introduction

As one of the most important gold minerals home, Jiaodong of Shandong province owns 1/3 proved rock gold in China [1]. Jiaojia gold mineral is the research hotspots as the gold mine type of altered granite of hydrothermal fracture zone and one of independent gold mineral in China [2−6]. Four mineral distracts provide crude minerals for concentrators. The mineral composition and gold occurrence change along with mining depth [7−8]. The current grade of gold mineral is 3−5 g/t and mineral tailing is 0.2−0.3 g/t. The occurrence of gold mineral was studied to improve recovery, composite indexes of mineral processing and flow of new processing plant in the second stage.

2 Experimental

LEICA-DMLP dual microscope with polarization and reflection was produced in Germany. LEICA-MZ95 stereomicroscope with phase analysis software was produced in Germany. The scanning electron microscope (SEM) is Japanese Shimadzu SSX−550. MALVERN-HYDRO 2000M-MU laser particle size analyzer was produced in the United Kingdom. The mineral was used to produce polished pills and slice to study under the microscopy and SEM.

3 Gold occurrence

3.1 Gold-bearing minerals

The gold-bearing sulphide minerals are composed of pyrite (Py), chalcopyrite (Cp), sphalerite (Bl) and galena. The gold-bearing gangue is composed of quartz (Q) and feldspar. 77.12% gold grain is in the sulphide mineral and 22.88% is in the gangue as listed in Table 1. Figures 1−4 show that the important gold-bearing minerals are composed of pyrite, chalcopyrite and quartz and change significantly compared with previous

Table 1 Gold bearing minerals of Jiaojia gold mine (mass fraction, %)

Pyrite	Chalcopyrite	Sphalerite	Galena
62.00	13.50	1.12	0.50
Gangue quartz	**Gangue feldspar**		**Total**
20.18	2.70		100

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research. 62.00% gold occurs in the pyrite, 13.50% is in the chalcopyrite and 20.18% is in the quartz [7−9].

There are three crystals for the pyrite in crystallization periods, euhedral crystal in the pre-mineralization, hypautomorphic crystal and allotriomorphic crystal in the metallogenic epoch and euhedral crystal in the post- mineralization, as shown Figs. 5 and 6. The fragmentation of pyrite is caused by stress. The chalcopyrite associates with pyrite nearly and is wrapped by pyrite in metallogenic epoch. The fissure of pyrite is filled by chalcopyrite to prove synchroneity. The gold grains in the forms of fissure gold, inclusion gold and crystal fractured gold embed in the pyrite as the important gold-bearing minerals. The micro fine gold is difficult to liberate and is easy to lose. The minimal grain size of pyrite is 0.002 mm and the maximal grain size is 2.7 mm, and dispersed in the range of 0.037−0.147 mm as list in Table 2.

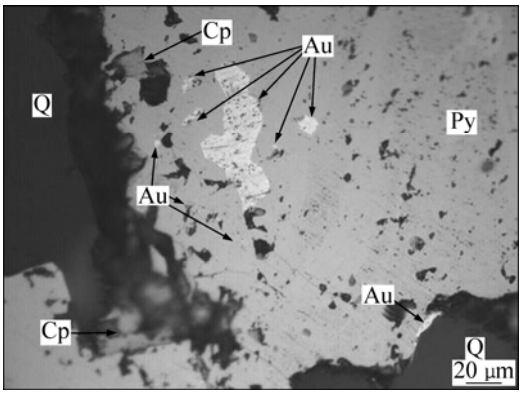

Fig. 1 Microscope image of gold-bearing pyrite composed of chalcopyrite

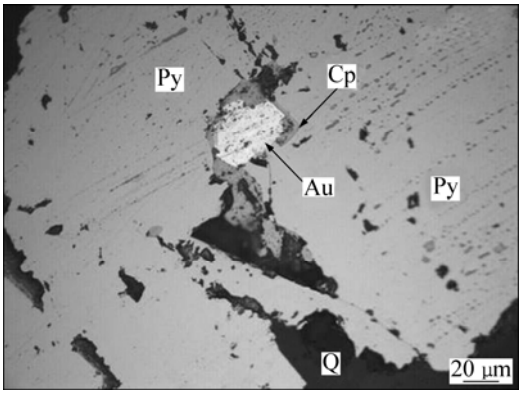

Fig. 2 Microscope image of gold-bearing chalcopyrite

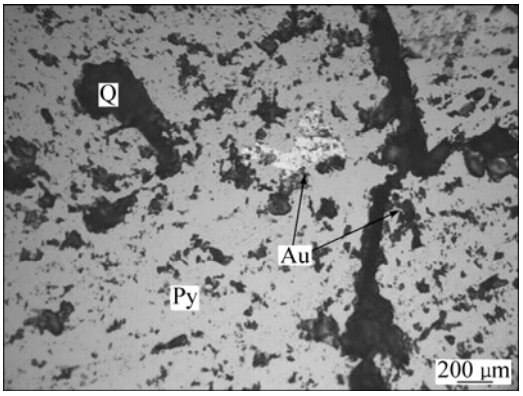

Fig. 3 Microscope image of gold-bearing pyrite

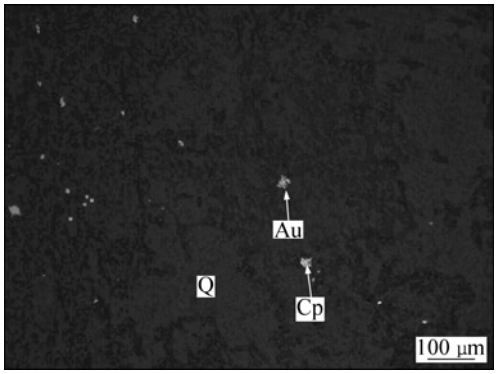

Fig. 4 Microscope image of gold-bearing quartz

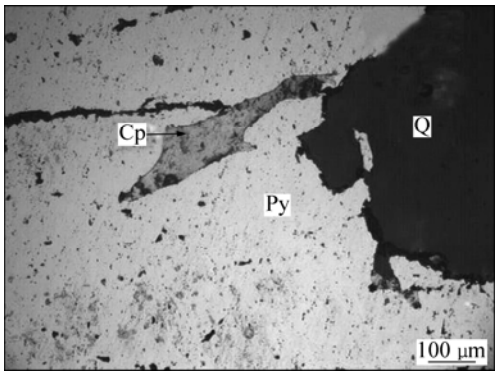

Fig. 5 Microscope image of pyrite in metallogenic epoch

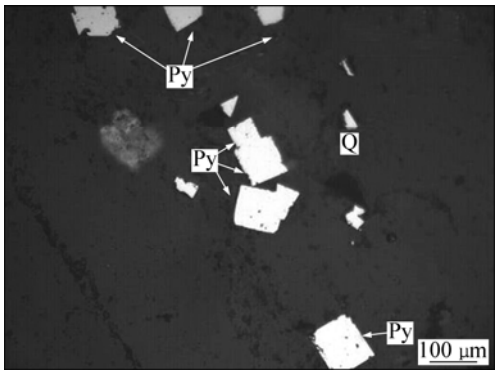

Fig. 6 Microscope image of euhedral pyrite in post-mineralization

The chalcopyrite is the important gold-bearing mineral and main copper mineral, as shown in Fig. 7. The microscopy observation shows that the chalcopyrite is character of brass, dappled tarnish such as blue, purple and brown on the surface with strong metalluster because of oxidization, as shown in Fig. 8. The rigidity is 3−4 and specific gravity is 4.1−4.3. The grains of chalcopyrite are nonuniform and embed in the gangue.

Table 2 Grain size of pyrite

Size/mm	Mass fraction/%
>0.147	6.26
0.104−0.147	20.21
0.074−0.104	31.43
0.043−0.074	25.62
0.037−0.043	11.23
<0.037	5.25
Total	100

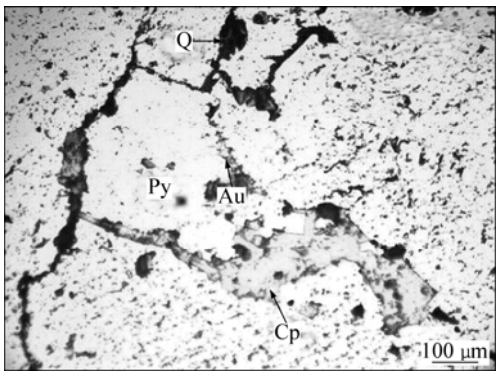

Fig. 7 Microscope image of chalcopyrite as important gold-bearing minerals

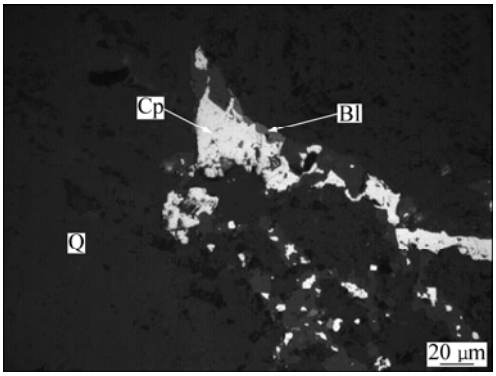

Fig. 8 Microscopy observation of vein chalcopyrite embedded in gangue

The usual chalcopyrites are allotriomorphic. The fine and micro fine chalcopyrites are difficult to liberate as the same as monomer in the process of grinding and very easy to lose in the tailings. It is difficult to separate copper and zinc because of solid solution separation composed of partial chalcopyrite and sphalerite. Sometimes the chalcopyrite embeds in the pyrite as inclosure or wraps of the pyrite to liberate. The chalcopyrite ties up tetrahedrite which embeds along the edge of chalcopyrite. The gold grains in the form of fissure gold, inclusion gold and crystal fractured gold embed in the chalcopyrite as the important gold-bearing minerals. The minimal grain size of pyrite is 0.002 mm and the maximal grain size is 0.8 mm, and dispersed in the range of 0.037−0.147 mm, as listed in Table 3.

Table 3 Grain size of chalcopyrite

Size/mm	Mass fraction/%
>0.147	3.12
0.104−0.147	5.21
0.074−0.104	26.88
0.043−0.074	38.12
0.037−0.043	21.29
<0.037	5.38
Total	100

3.2 Gold occurrence

The gold occurrence is composed of 60.28% fissure gold, 21.63% inclusion gold and 18.09% crystal fractured gold, as shown in Figs. 9−11 according to the mosaics of gold minerals and gold ores as list in Table 4.

3.3 Morphology of gold minerals

The morphology of Jiaojia gold mineral is composed of 50.00% spherical gold, 8.27% triangular gold, 6.77% rectangular gold, 24.81% strip gold and 8.27% erose gold, as shown in Figs. 12−14 and Table 5.

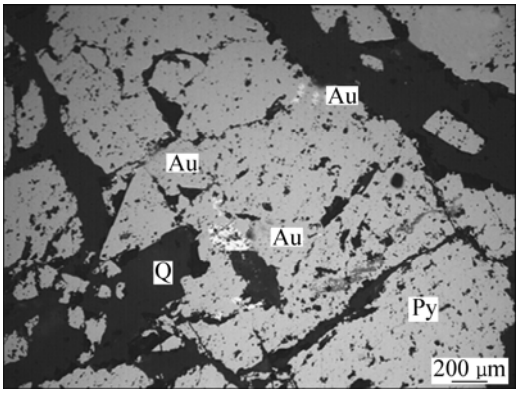

Fig. 9 Microscope image of fissure gold in pyrite

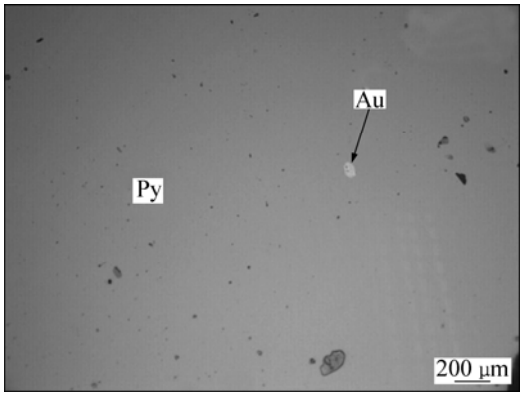

Fig. 10 Microscope image of inclusion gold in pyrite

3.4 Granularity of gold minerals

Jiaojia gold mineral owns large granularity from 3−5 μm to 100 μm, as listed in Table 6. 1.5% of gold

grain is more than 0.104 mm, 5.26% is 0.074−0.104 mm, 23.31% is 0.043−0.074 mm, 3.76 is 0.037−0.043 mm and 64.29% is less than 0.037 mm. The results show that most of gold grains are less than 0.037 mm. The gold grains are distributed in the pyrite and chalcopyrite as large grain, distribution group or isolated grain. The small and isolated grains are distributed in the gangue, as shown Figs. 15 and 16.

Most of gold minerals are fine dissemination. The larger gold grains are the sulphide minerals and smaller

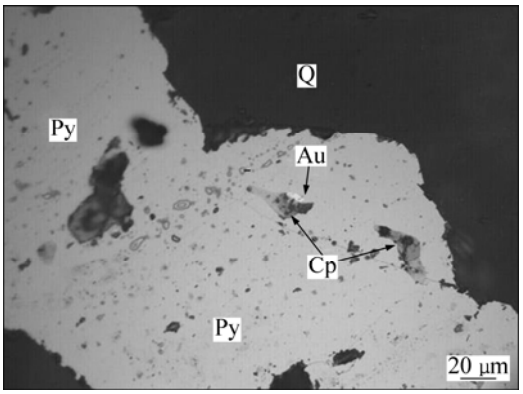

Fig. 11 Microscope image of crystal fissure gold between pyrite and chalcopyrite

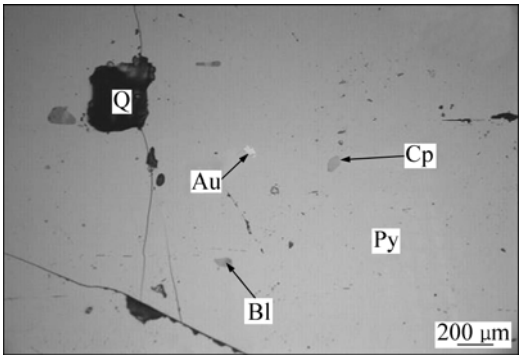

Fig. 12 Microscope image of spherical inclusion gold

Table 4 Gold occurrence of Jiaojia gold mine (mass fraction, %)

Fissure gold	Inclusion gold	Crystal fractured
60.28	21.63	18.09

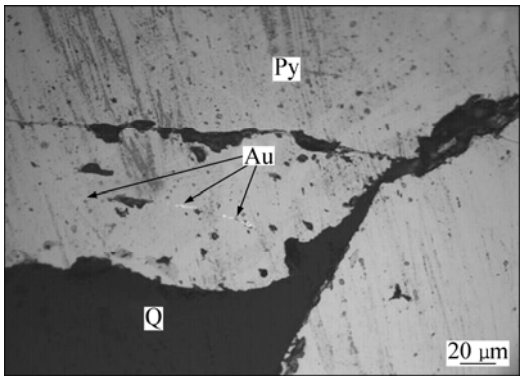

Fig. 13 Microscope image of strip fissure gold

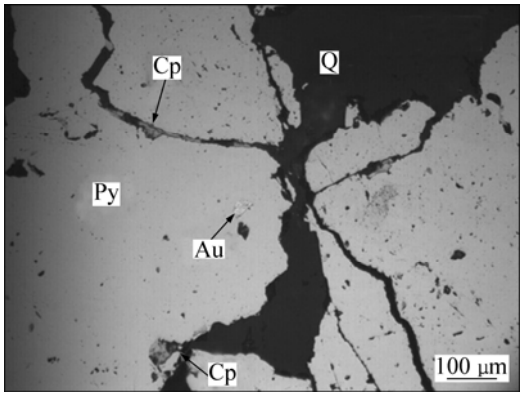

Fig. 14 Microscope image of triangular inclusion gold

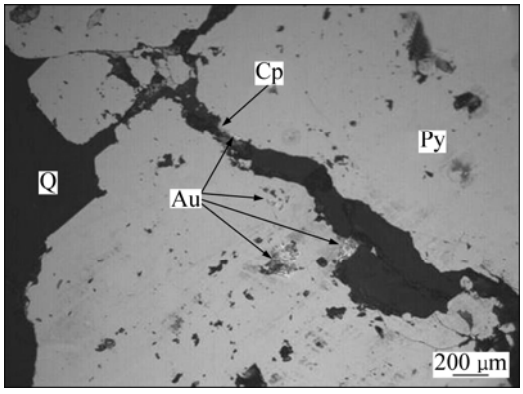

Fig. 15 Microscope image of gold grain in groups

Table 5 Shape of Jiaojia gold mineral (mass fraction, %)

Sphere	Triangle	Rectangle	Strip	Error	Total
50.00	8.27	6.77	24.81	8.27	100.00

Table 6 Shape of Jiaojia gold mineral (mass fraction, %)

Size/mm	Sphere	Triangle	Strip	Rectangle	Error	Total
>0.147	0	0	1.50	0	0	1.50
0.074−0.104	0	0.38	1.88	0.75	2.26	5.26
0.043−0.074	5.64	3.01	8.27	2.63	3.76	23.31
0.037−0.043	1.50	0.38	1.50	0	0.38	3.76
<0.037	42.86	4.51	11.65	3.38	1.88	64.29
Total	50.00	8.27	24.81	6.77	8.27	

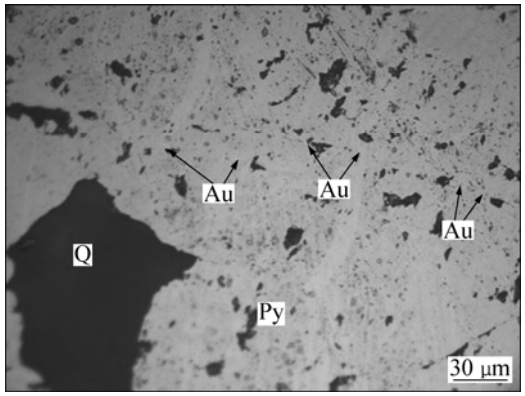

Fig. 16 Microscope image of isolated small gold grains

gold grains are the gangue, as listed in Table 7. It is difficult to liberate and float gold mineral in the mineral processing because of improved gold content in the tailings. It is necessary to fine grinding to recover gold in the gangue.

Table 7 Gold granularities in gold-bearing minerals

Size/mm	Gold content in sulphide ineral/%	Gold content in gangue/%	Total/%
>0.104	1.50	0	1.50
0.074−0.104	5.26	0	5.26
0.043−0.074	17.30	6.01	23.31
0.037−0.043	2.20	1.56	3.76
<0.037	49.06	15.23	64.29

3.5 Kind and grade of gold mineral

There are 98 kinds of gold minerals and gold-bearing minerals, 47 kinds of usual gold minerals and more than 10 kinds of industrial gold minerals in the world. There are 27 kinds of gold minerals in China. But there are no enough mineralogy data about gold. Gold mineral is divided into seven divisions and 13 subdivisions according to the crystal chemistry. There are plenty of gold minerals and silver minerals in the Jiaojia gold mineral, including native gold, electrum, native silver, iron-bearing native silver, goldcuprid and acanthite belonging to the first division (natural element), the second division (intermetallics) and the seventh (gold-silver sulphide) minerals as listed in Table 8 [10−11]. The process mineralogy research is very important for beneficiation process and flowage structure [12−15]. There are 88.14% goldargentid, 6.12% goldcuprid and 5.37% acanthite, and there is 71.56% electrum in the goldargentid. The average quality is 641.26‰ for goldargentid mine.

The results show that gold grains in the sulphide mineral are low grade and belong to the electrum, and many small gold grains are in high content and grade, and denominated native gold mineral. The composition of large gold grains is 62.831% Au and 37.1696% Ag, as shown in Fig. 17. The composition of fissure gold is 79.754%Au, 17.636%Ag and 2.610%Fe, and iron exists in the fissure gold, as shown in Fig. 18.

Table 8 Classification of Jiaojia gold minerals

Gold and silver minerals	Mineral name	Content/%
Natural element	Native gold	13.72
	Electrum	71.56
	Native silver	3.13
	Iron-bearing native silver	0
Intermetallics	Goldcuprid	6.12
Gold-silver	Acanthite	5.37
Total		100.00

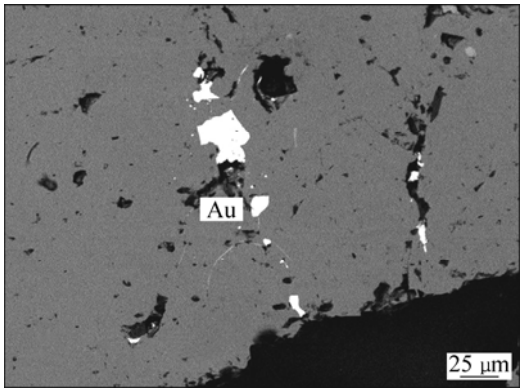

Fig. 17 SEM image of large gold grains

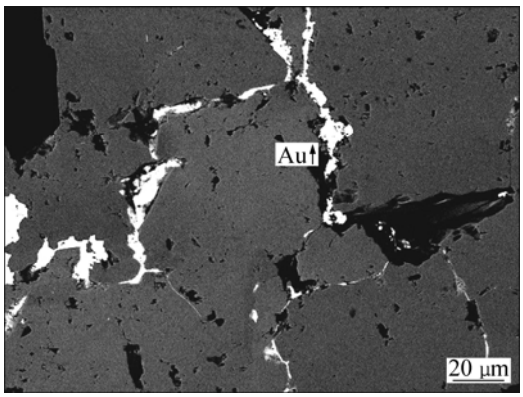

Fig. 18 SEM image of iron in fissure gold

4 Conclusions

1) The gold-bearing minerals are composed of pyrite, chalcopyrite and gangue as gold-bearing mineral, sphalerite and galena. 77.12% of gold grains is the sulphide and 22.88% is the gangue. 62.00% gold occurs in the pyrite, 13.50% in the chalcopyrite and 22.88% in the gangue.

2) The gold occurrence is composed of 60.28% fissure gold, 21.63% inclusion gold and 18.09% crystal fractured gold.

3) The morphology of Jiaojia gold mineral is composed of 50.00% sphere gold, 8.27% triangular, 6.77% rectangular, 24.81% strip and 8.27% erose gold.

4) The Jiaojia gold mineral owns large grain size ranging from 3−5 μm to 100 μm. 1.5% of gold grain is 0.104 mm, 5.26% is 0.074−0.104 mm, 23.31% is 0.043−0.074 mm, 3.76 is 0.037−0.043 mm and 64.29% is less than 0.037 mm. The results show that 64.29% gold grain is less than 0.037 mm. Lots of small gold grains lead to the loss of gold in the mineral tailings.

5) There are plenty of gold minerals and silver minerals in the Jiaojia gold mineral including native gold, electrum, native silver, iron-bearing native silver, goldcuprid and acanthite. Fe, Cr and Cu exist as impurities in the gold and silver minerals. The gold mineral is complex and composed of 88.14% gold and silver mineral, 6.12% goldcuprid and 5.37% acanthite. The acanthite is the most important gold mineral. The average quality is 641.26‰ for gold and silver mineral.

References

[1] ZHAO Peng-yun, GU Xue-xiang, DENG Xiao-hua. Genesis and metallogenic model of Jiaojia gold deposit, Shandong [J]. Geology and Prospecting, 2007, 43(4): 29−35. (in Chinese).

[2] CHEN Yan-jing, IRAJNO F P, LAI Yong. Metallogenic time and tectonic setting of the Jiaodong gold province, eastern China [J]. Acta Petrologica Sinica, 2004, 20 (4): 907−922.

[3] YU Hong-dong. Process mineralogical features of a gold mineral in Guangdong province [J]. Mining & Metallurgy, 2009, 18(1): 89−92. (in Chinese)

[4] MAO J W, WANG Y T, ZHANG Z H, YU J J, NIU B G. Geodynamic settings of Mesozoic large-scale mineralization in North China and adjacent areas (Implication from the highly precise and accurate ages of metal deposits [J]. Science in China Series D: Earth Sciences, 46: 838−851.

[5] SUN Jing-gui. Relations of gold abundance in geologic bodies to genesis of gold deposits, Jiaodong [J]. Contributions to Geology and Mineral Resources Research, 1999, 14 (2): 43−54.

[6] LI De-ting, LU Ai-zhen, SUN Yan-li. The new recognition of genesis and mechanism about Jiaojia gold mine [J]. Gold Science and Technology, 2007, 10(4): 1−6. (in Chinese)

[7] FU Yi-mo. Study on process mineralogy in Jiaojia gold mine [J]. Mining & Metallurgy, 2000, 9(3): 39−45. (in Chinese)

[8] LI De-ting, LU Ai-zhen. Analysis on trace element and gold-bearing mineral in the deep of Jiaojia gold deposit [J]. Nonferrous Mines, 2002, 31(5): 1−5. (in Chinese)

[9] LI De-ting, XU Jiu-hua, SHAN Li-hua, XU Dao-xue. Study on the mineralization feature and technological characteristic of mineral mineral in deep of Jiaojia gold mine [J]. Gold Science and Technology, 2001, 9(5): 9−22. (in Chinese)

[10] ZHNAG Zhen-ru. Research on gold mineral [M]. Changsha: Central South University of Technology Press, 1989. (in Chinese)

[11] YANG Hong-ying, YANG Li, CHEN Gang. Study on technological of cyaniding sample gold Jinchanggouliang gold mine [J]. Gold Journal, 1999, 1(2): 81−84. (in Chinese)

[12] ZENG Lin-xi. Process mineralogy of a gold ore and its relevance to ore concentration [J]. China Mining Magazine, 2008, 17(4):73−74. (in Chinese)

[13] WANG Wen-qian. Four challenges and countermeasures in mineral processing [J]. Mining and Metallurgical Engineering, 1993, 13(3): 21−26. (in Chinese)

[14] QIN Hong-gen, SONG Bin-jie, LIN Chun-ying. The study on process mineralogy of a gold ore from Zhenyuan gold mine [J]. Gold, 2005, 26(12): 36−39. (in Chinese)

[15] MAO Shui-he. EPMA study of occurrence of ultramicro gold in ore [J]. Acta Mineralogica Sinica, 1990, 10 (1): 69−72. (in Chinese)

山东省焦家金矿的金赋存状态

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摘 要：采用显微镜和扫描电子显微镜研究了山东省焦家金矿的金赋存状态。研究发现，该矿石中载金矿物有黄铁矿、黄铜矿、脉石矿物、闪锌矿和方铅矿。在硫化矿中金粒占 77.12%，脉石中金粒占 22.88%。金的赋存状态有裂隙金、包裹金和晶隙金，裂隙金占 60.28%，包裹金占 21.63%，晶隙金占 18.09%。金矿物的形态主要有球状、三角形、矩形、条状和不规则形状。焦家金矿石中金矿物的粒度范围较大，大的颗粒达到 100 μm，小的金颗粒只有 3−5 μm，其中大于 0.104 mm 粒级的金颗粒占 1.50%，0.074~0.104 mm 粒级的金颗粒占 5.26%，0.043~0.074 mm 粒级的金颗粒占 23.31%，0.037~0.043 mm 粒级的金颗粒占 3.76%，小于 0.037 mm 的金颗粒占 64.29%。焦家金矿石中金矿物有自然金、银金矿、自然银、含铁自然银、金铜矿和螺硫银矿。其中，银金矿是最重要的金矿物，占 71.56%。金银矿物平均成色为 641.24‰。

关键词：金矿；金赋存状态；载金矿物；金矿物

(Edited by LI Xiang-qun)