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# Tetrahedrite-Group Minerals in the Jinjitai Gold Deposit, Western Sichuan

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**Abstract** There are quite a few tetrahedrite-group minerals in the Jinjitai gold deposit, western Sichuan, which occur in an interstratified fractured zone of Middle Devonian carbonate rock series. The gold ore consists of pyrite, chalcopyrite, tetrahedrite-group minerals, galena, sphalerite and gold-silver series minerals, with an element association of Au-Cu-Ag-Pb-As-Sb-Bi. Electron microprobe analyses of the tetrahedrite-group minerals gave the following results: copper 40.04 to 42.27% (average 40.04%), iron 1.24 to 7.78% (average 4.13%), zinc 0.39 to 7.06% (average 3.58%), arsenic 5.41 to 17.40% (average 8.84%), antimony 2.70 to 20.46% (average 15.87%), and silver 0.02 to 0.73% (average 0.28%). The mineral varieties include zinc-antimony-tetrahedrite, iron-antimony-tetrahedrite, iron-tennatite and zincotennatite. These data show that there is a complete isomorphous series between Sb and As. From above downwards tetrahedrite varies from zinc- and antimony-rich to iron- and arsenic-rich compositions. Their occurrence and zonal features are very important for exploration of the same type of gold deposits in western Sichuan.

**Key words**: gold deposit, tetrahedrite-group minerals, Jinjitai, China

## 1 Introduction

Tetrahedrite is one of common sulphosalt minerals in hydrothermal sulphide deposits. It occurs widely in lead-zinc deposits and copper-bearing polymetallic deposits, as well as in gold deposits. Its general formula is $M^{+}_{10}M^{2+}_{2}(M^{3+}, M^{4+})_4(S, Se)_{13}$, in which $M^{+}$ is mainly represented by $Cu^{+}$ and $Ag^{+}$ with subordinate $Au^{+}$; $M^{2+}$ mainly by $Fe^{2+}$, $Zn^{2+}$ and $Cu^{2+}$ with subordinate $Pb^{2+}$, $Hg^{2+}$, $Cd^{2+}$, $Co^{2+}$, and $Ni^{2+}$; $M^{3+}$ and $M^{4+}$ mainly by $Sb^{3+}$ and $As^{3+}$ with subordinate $Bi^{3+}$, $Sn^{4+}$ and $Te^{4+}$(Wang Pu et al., 1982; Wu, 1987; Mao and Li, 1987; Wang Lingzi, 1989; Li and Wang, 1990; Xu, 1990; Shuai, 1990; Cao, 1991; Mao, 1992; Hu et al., 1993; Yan et al., 1994). The chemical composition of tetrahedrite-group minerals may reflect the geochemical features and ore-forming conditions of ore deposits to a certain degree. In this paper an attempt is made to discuss the typomorphic significance of the chemical composition of tetrahedrite through a study of the chemical compostion of tetrahedrite in the Jinjitai gold deposit, western Sichuan, China.

## 2 Deposit Geology

The Jinjitai gold deposit in western Sichuan is tectonically located east of the Jinhe-Qinghe fault, on the boundary between the western margin of the northern sector of the Kangdian axis and the Songpan-Ganzê geosynclinal fold belt. High-grade metamorphic rocks of the Archaeozoic Kangding Group and Middle Devonian and Triassic carbonate and clastic rocks outcrop in the region. Magmatic rocks are chiefly intermediate-acid volcanic rocks and Hercynian basic intrusive rocks. Gold orebodies occur in carbonate rocks of the Middle Devonian Huomushan Formation and are controlled by interstratified faults. Host rocks are dolostone and dolomitic marble, in which hydrothermal alteration is well-developed, including silicification, carbonation, sericitization and chloritization. The near-ore location may be indicated by the simultaneous development of silicification and sericitization, but gold mineralization is most closely related to silicification. Gold ores have stockwork, lumpy, massive and disseminated structures, and crystal granular and metasomatic textures. The ore minerals are mainly pyrite, tetrahedrite and galena with subordinate chalcopyrite, sphalerite and bornite and occasional skinnerite, arsenopyrite, native gold, electrum and hessite. The gangue minerals are quartz, dolomite, calcite, sericite and chlorite. The element association of gold ores is gold-copper-silver-lead-arsenic-antimony-bismuth. According to the mineral associations and their relationship, three stages of hydrothermal mineralization can be recognized as follows: the early sericite-quartz stage, the main pyrite-tetrahedrite-quartz stage and the late calcite-quartz stage. The polymetallic sulphide mineral association bearing gold-silver series minerals formed in the main mineralization stage. The supergene mineralization is characterized by the formation of limonite and malachite. From isotope, trace element and fluid inclusion studies, it can be known that the Jinjitai gold deposit was formed by high-salinity, low-density underground hot brines under epithermal, alkaline and reducing environment (Wang Xiaochun, 1993, 1994a, 1994b; Wang and He, 1994).

## 3 Occurrence of Tetrahedrite-Group Minerals

The tetrahedrite-group minerals in the gold deposit are only next to pyrite in amount, which are products of the main stage of hydrothermal mineralization. They are anhedral finely granular and occur together with native gold, pyrite, chalcopyrite, galena, sphalerite and arsenopyrite. They often replace pyrite in gold ores and occur as pseudomorphs after pyrite or as irregular veinlets cutting pyrite. The more the tetrahedrite-group minerals in ores, the higher the gold grade.

## 4 Chemical Compositions of Tetrahedrite-Group Minerals

The results of electron microprobe analyses and chemical formulas of the tetrahedrite-group minerals in the Jinjitai gold deposit are shown in Tables 1 and 2. It can be seen from the tables that the compositions of tetrahedrite in the ores have the following features.

(1) The contents of the major components such as Cu, Ag, Fe, Zn, Sb and As in tetrahedrite have a wide variation range. The tetrahedrite-group minerals contain 0.04 to 42.27% copper (average 40.04%), 1.24 to 7.78% iron (average 4.13%), 0.39 to 7.06% zinc (average 3.58%), 5.41 to 17.40% arsenic (average 8.84%), 2.70 to 20.46% antimony (average 15.87%), and 0.02 to 0.73% silver (average 0.28%). The contents of iron and zinc are actually in the range between the pure iron variety and pure zinc variety. Antimony and arsenic show a complete isomorphous series. Their copper and sulphur contents show a narrow variation range and the silver content is low. In addition, there are trace amounts of lead, tin and gold.

(2) The tetrahedrite-group minerals have different characteristic parameters such as [Ag/(Ag+Cu)×100%], [Sb/(Sb+As)×100%] and [Fe/(Fe+Zn)×100%] (Table 2). The ratio of Ag/(Ag+Cu) (%) is most highly

**Table 1 Electron microprobe analyses of tetrahedrite-group minerals (wt%)**

| Serial No. | Sample No. | Cu | Fe | Zn | As | Sb | Ag | S | Sn | Pb | Au | Σ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | JT008-4 | 39.63 | 2.47 | 5.09 | 6.84 | 20.15 | 0.62 | 26.12 | 0.06 | 0 | 0 | 100.96 |
| 2 | JT008-6 | 39.71 | 2.48 | 4.90 | 6.31 | 19.69 | 0.73 | 24.94 | 0.07 | 0.04 | 0 | 98.86 |
| 3 | $Cd_1h99b1$-11 | 38.88 | 2.34 | 3.73 | 6.33 | 19.03 | 0.31 | 25.19 | 0 | 0 | 0 | 95.81 |
| 4 | $Cd_1h99b1$-12 | 38.97 | 2.22 | 5.11 | 6.43 | 20.07 | 0.19 | 26.50 | 0.05 | 0 | 0 | 99.54 |
| 5 | $LL_4b9$-14 | 39.62 | 2.89 | 4.51 | 6.54 | 18.57 | 0.35 | 26.17 | 0.11 | 0 | 0 | 98.77 |
| 6 | $CD_1C9$-20 | 39.07 | 2.87 | 4.35 | 7.10 | 19.60 | 0.44 | 27.35 | 0 | 0 | 0 | 100.78 |
| 7 | $CD_1C9$-20-1 | 40.00 | 3.08 | 4.69 | 6.63 | 20.46 | 0.28 | 26.20 | 0 | 0 | 0 | 101.34 |
| 8 | $CD_1CH_3DF5$ | 39.56 | 3.20 | 4.27 | 6.22 | 19.38 | 0.38 | 27.07 | 0 | 0.21 | 0 | 100.29 |
| 9 | $CD_{11}YMSH3$ | 40.48 | 1.24 | 7.06 | 9.35 | 14.03 | 0.19 | 25.87 | 0.08 | 0.19 | 0 | 98.47 |
| 10 | JT072-63 | 41.67 | 7.78 | 0.90 | 15.20 | 6.44 | 0 | 25.89 | 0 | 0 | 0 | 97.89 |
| 11 | JT072-64 | 41.59 | 7.72 | 0.71 | 15.12 | 6.34 | 0.06 | 27.09 | 0 | 0 | 0 | 98.63 |
| 12 | JT072-67 | 42.27 | 7.66 | 0.77 | 17.40 | 2.70 | 0.02 | 27.29 | 0.06 | 0.11 | 0.02 | 98.30 |
| 13 | $CD_{14}H28$ | 39.10 | 7.76 | 0.39 | 5.41 | 19.80 | 0.02 | 25.42 | 0 | 0 | 0 | 97.89 |

Note: Analysed at the Chengdu Institute of Geology and Mineral Resources.

varied, ranging from 0.02 to 1.29, with an average of 0.53. The ratio of Fe/(Fe+Zn) (%) ranges from 14.91 to 95.17, with an average of 57.24 and the ratio of Sb/(Sb+As) changes from 24.51% to 78.79%, with an average of 60.57%. These suggest that the tetrahedrite-group minerals are depleted in silver, zinc and arsenic, and rich in iron and antimony.

According to the mineral chemical formulas calculated from the analytical results (Table 2), the varieties of the tetrahedrite-group minerals include zinc-antimony-tetrahedrite, iron-antimony-tetrahedrite, iron-tennatite and zincotennatite.

## 5 Vertical Zoning of Tetrahedrite-Group Minerals

Tetrahedrite-group minerals in the deposit show a certain vertical compositional zoning. In level I (elevation 2252 m), including sample Nos.1 to 8 in Tables 1 and 2, zinc-antimony-tetrahedrite is dominant, with ratios of Fe/(Fe+Zn), Ag/(Ag+Cu) and Sb/(Sb+As) bearing 37.01%, 1.04% and 74.97% respectively. In level III (elevation 2170 m), including sample Nos. 9 to 12 in Tables 1 and 2, iron-tennatite and zincotennatite predominate, with ratios of Fe/(Fe+Zn), Ag/(Ag+Cu) and Sb/(Sb+As) being 71.78%, 0.17% and 33.38% respectively. In level IV (elevation 2090 m) (No. 13 in Tables 1 and 2) , iron-antimony-tetrahedrite is dominant, with ratios of Fe/(Fe+Zn), Ag/(Ag+Cu) and Sb/(Sb+As) being 95.17%,0.05% and 78.55% respectively. From above downwards the chemical composition of the tetrahedrite-group minerals shows a trend of variation from zinc- and antimony-rich to iron- and arsenic-rich. In addition, there is also a trend of decrease in silver content.

The variation in chemical composition of the tetrahedrite-group minerals may be chiefly due to the compositional evolution of ore-forming fluids. The ore-forming fluids migrated upwards. The early-stage ore-forming fluids were rich in iron and arsenic; therefore iron and arsenic were easy to enter the crystal lattices of the tetrahedrite-group minerals. With ongoing ore-forming processes, the underground hot brines became more and more depleted in iron and arsenic but relatively enriched in zinc, antimony and silver. As a result, the late-formed tetrahedrite-group minerals, which are distributed in the upper part of the deposit, were relatively rich in zinc, antimony and silver. This can be evidenced by the fact that pyrite is rich in silver, antimony and zinc in the upper part of the deposit and rich in arsenic in the lower part, and that the gold-silver series minerals are rich in silver etc. in the upper part (Wang Xiaochun, 1993).

**Table 2 Chemical formulas of tetrahedrite-group minerals**

| Ser. No. | Crystal formula | Name | Fe/(Fe+Zn) ×100% | Sb/(Sb+As) ×100% | Ag/(Ag+Cu) ×100% |
|---|---|---|---|---|---|
| 1 | $(Cu_{10.199}Ag_{0.076})_{10.275}(Fe_{0.616}Zn_{1.494})_{2.110}(Sb_{1.670}As_{2.211})_{3.881}S_{13}$ | zincotennatite | 26.05 | 55.11 | 1.25 |
| 2 | $(Cu_{8.831}Ag_{0.057})_{8.896}(Fe_{1.363}Zn_{0.702})_{2.075}(Sb_{3.007}As_{1.316}Bi_{0.017})_{4.340}S_{13}$ | Fe-Sb-tetrahedrite | 62.39 | 78.79 | 1.09 |
| 3 | $(Cu_{10.316}Ag_{0.079})_{10.395}(Fe_{0.975}Zn_{1.155})_{2.130}(Sb_{2.438}As_{1.831}Bi_{0.116})_{4.385}S_{13}$ | Zn-Sb-tetrahedrite | 41.90 | 68.40 | 1.29 |
| 4 | $(Cu_{9.874}Ag_{0.061})_{9.935}(Fe_{0.767}Zn_{1.115}Pb_{0.002})_{1.884}(Sb_{2.564}As_{1.391}Sn_{0.005})_{3.960}S_{13}$ | Zn-Sb-tetrahedrite | 37.01 | 74.97 | 1.04 |
| 5 | $(Cu_{10.261}Ag_{0.028})_{10.289}(Fe_{0.357}Zn_{1.738}Pb_{0.014})_{2.109}(Sb_{1.855}As_{2.011}Sn_{0.011})_{3.877}S_{13}$ | zincotennatite | 14.91 | 60.00 | 0.46 |
| 6 | $(Cu_{10.257}Ag_{0.004}Au_{0.001})_{10.262}(Fe_{2.154}Zn_{0.188}Pb_{0.003})_{2.345}(Sb_{0.660}As_{3.307}Sn_{0.003})_{3.970}S_{13}$ | iron-tennatite | 90.73 | 24.51 | 0.07 |
| 7 | $(Cu_{10.091}Ag_{0.003})_{10.094}(Fe_{2.278}Zn_{0.099})_{2.377}(Sb_{2.665}As_{1.183})_{3.848}S_{13}$ | Fe-Sb-tetrahedrite | 95.17 | 78.55 | 0.05 |
| 8 | $(Cu_{9.999}Ag_{0.001})_{10.000}(Fe_{1.242}Cu_{0.731}Zn_{0.471}Pb_{0.058})_{2.502}(Sb_{1.253}As_{2.924}Sn_{0.002})_{4.179}S_{13}$ | iron-tennatite | 69.27 | 41.06 | 0.02 |
| 9 | $(Cu_{10.502}Ag_{0.036}Au_{0.001})_{10.539}(Fe_{0.581}Zn_{1.651})_{2.232}(Sb_{2.512}As_{1.688})_{4.2}S_{13}$ | Zn-Sb-tetrahedrite | 23.11 | 70.75 | 0.58 |
| 10 | $(Cu_{9.997}Ag_{0.003})_{10.000}(Fe_{1.33}Cu_{0.955}Zn_{0.205})_{2.496}(Sb_{2.146}As_{2.151}Sn_{0.003})_{4.300}S_{13}$ | iron-tennatite | 84.70 | 61.86 | 0.05 |
| 11 | $(Cu_{9.962}Ag_{0.038})_{10.000}(Fe_{1.329}Cu_{0.413}Zn_{0.379}Pb_{0.021})_{2.146}(Sb_{2.078}As_{1.777}Sn_{0.002})_{3.857}S_{13}$ | Fe-Sb-tetrahedrite | 74.98 | 65.54 | 0.62 |
| 12 | $(Cu_{10.671}Ag_{0.008})_{10.679}(Fe_{1.398}Zn_{0.742}Pb_{0.001})_{2.141}(Sb_{1.832}As_{2.532}Sn_{0.021})_{4.385}S_{13}$ | iron-tennatite | 61.66 | 54.05 | 0.13 |
| 13 | $(Cu_{11.095}Ag_{0.018})_{11.113}(Fe_{1.427}Zn_{0.740})_{2.167}(Sb_{1.881}As_{2.626}Sn_{0.009})_{4.516}S_{13}$ | iron-tennatite | 62.24 | 53.80 | 0.28 |

Note: Serial numbers same as in Table 1.

## 6 Typomorphic Significance of the Chemical Composition of the Tetrahedrite-Group Minerals

In summary, tetrahedrite-group minerals are major ore minerals in the Jinjitai gold deposit. They are products of the main hydrothermal mineralization stage. The compositional zoning of tetrahedrite-group minerals is very important for exploration of the same type of gold deposits in the study area and other areas. It can be used in determining the erosional depth of gold deposits and forecasting gold orebodies at depths. From the compositional zoning features of tetrahedrite-group minerals we may draw the following conclusion: zinc-tetrahedrite predominates in the upper part of the deposit, tennatite and zincotennatite are dominant in the middle part, and tetrahedrite occurs in the lower part. From this knowledge, we may forecast the following: the denudation degree is moderate in the Jinhuadong and Dayanfang gold occurrences in the surrounding areas of the deposit and gold orebodies might exist at depths, and the denudation degree is great in the Huangshuigou deposit and the prospect of the deposit is poor. This prediction relatively coincides with the results of the field exploration.

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