

Fluid inclusions, H-O-S isotopic characteristics and genesis of the Chambishi copper deposit, Zambia

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Abstract. In this paper, fluid inclusions and H-O-S isotope geochemistry of the Chambishi copper deposit in Zambia are studied. According to the fluid inclusion in quartz and H-O-S isotope characteristics, it is concluded that ore-forming hydrothermal fluid is derived from mantle source and crust source magma mingling, the cause of copper precipitation, sedimentary type sulfur layered mineralization are mainly from diagenetic sulfides and seawater sulfate. Sulfate is mainly reduced by thermochemical method. The hydrothermal vein mineralization of Chambishi copper deposit is closely related to the magmatic activity in the middle Neoproterozoic, and the sedimentary stratified mineralization is mainly related to the large-scale orogeny and regional metamorphism in the late Neoproterozoic.

1 Introduction

Sedimentary copper deposits are an important source of copper, and the Central African copper belt is the highest grade and largest copper deposit in the world. As an important part of the Central African copper belt, Chambishi copper deposit in Zambia is a typical large-scale sand shale copper deposit. Previous studies have been carried out on the basic geological characteristics, ore-bearing structures, mineralization types, ore-controlling structures, prospecting prospects and prospecting marks of Chambishi copper deposit, and abundant results have been obtained.

Some researchers by geochemical anomalies delineated the ore-prospecting prospective area ([1]), puts forward the regional structure, strata, sedimentary equal in mineral zonation and the ore-prospecting criteria ([2]), at the same time also to the southeast of the copper deposit ore body, the main orebody and west ore body have found some molybdenite ([3]), Re-Os isotopic dating shows that molybdenite was formed in Late Cambrian (491 ~ 509 Ma, [4]).

In addition, some researchers have carried out comparative studies on the Chambishi deposit with large sedimentary and metamorphic deposits, such as Dongshengmiao deposit, Tanyaokou deposit and Huogeqi deposit in Inner Mongolia, China ([5]).

However, the study on fluid inclusions and H-O-S isotope geochemistry of Chambishi copper deposit is still weak, and the study on the relationship between fluid evolution and mineralization is seldom involved, which is not beneficial to the correct understanding of the ore-forming fluid properties and the source of ore-forming materials of Chambishi copper deposit. Therefore, in this paper, the analysis of the ore-bearing

vein fluid inclusions and chalcopyrite/bornite sulfur isotopes in Chambishi copper deposit is helpful to reveal the properties of ore-forming fluids and trace the source of ore-forming materials, thus providing a new basis for the correct understanding of the origin of Chambishi copper deposit.

2 Methods

2.1 Temperature measurement of fluid inclusion

Eleven fluid inclusion samples were collected for the observation of the petrographic characteristics and temperature measurement of the inclusions. The samples were all from the ore-bearing vein in the mineralization stage of the hydrothermal period in the southeast mining area of Chambishi copper deposit.

The microthermometry of fluid inclusions was completed in Guilin Mineral Geology Analysis and Testing Center. The instrument is Linkam-THMS600 hot and cold platform (temperature range is below zero 196 °C ~ 600 °C) made in UK.

2.2 H-O isotope

The hydrogen and oxygen isotopic compositions of 11 quartz fluid inclusions were analyzed in Beijing Institute of Geology of Nuclear Industry. The instrument MAT-253 mass spectrometer was used to obtain $\delta^{18}\text{O}$ and δD with SMOW as standard.

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2.3 S isotope

The sulfur isotope test was carried out on 25 chalcopyrite/bornite samples collected from the main west orebody and southeast orebody of the deposit. Single mineral separation was completed in Langfang Tuoxuan Rock-Mine Inspection Service Co., Ltd., and sulfur isotope test was completed in the State Key Laboratory of Mineral Deposit Geochemistry, Institute of Geochemistry, Chinese Academy of Sciences. After ultrasonic cleaning, the selected single mineral chalcopyrite/bornite was ground to 200 mesh or below. The sulfur isotope composition was tested by MAT253 stable isotope mass spectrometer. The test results were presented according to V-CDT standard.

3 Results

3.1 Petrographic characteristics and inclusion temperature measurement

Through the observation of the petrographic characteristics of fluid inclusions, it is found that the fluid inclusions of ore-bearing vein with hydrothermal filling vein mineralization are of different shapes and sizes, with the largest being up to 20 μm and the smallest being about 1 μm. They are mainly elliptic, oblate and irregular (Fig. 1), and are primary fluid inclusions. The temperature measurement results show that the homogenization temperature of the hydrothermal ore-bearing vein fluid inclusions varies widely from 97 to 445 °C, mainly from 100 to 350 °C, with a peak value of 200 to 250 °C (Fig. 2a), belonging to the medium and low temperature fluid. The range of salinity also varies greatly, ranging from 7.3 to 46 wt.% NaCl, mainly from 11 to 19 wt.% NaCl (Fig. 2b), with an average value of 14.9 wt.% NaCl, belonging to the medium and low salinity fluid.

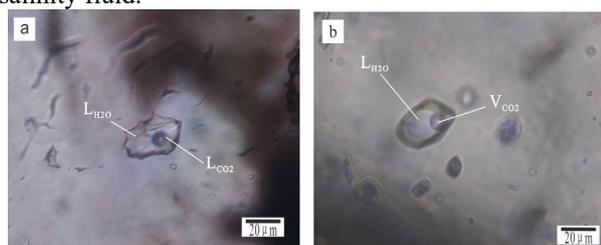


Fig.1. Microscopic photos of fluid inclusions from the Chambishi Cu deposit.

a: Type I-rich liquid and gas-liquid two-phase primary fluid inclusions;
 b: Type II - three-phase inclusion containing CO₂: L-H₂O- liquid phase water

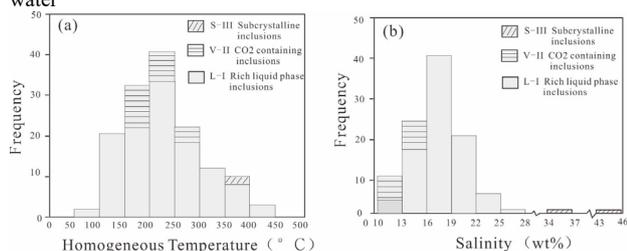


Fig.2. Histograms of homogenization temperature and salinity of hydrothermal fluid inclusions

3.2 H-O isotope

According to the test results (Table 1), the variation ranges of δ¹⁸O_{V-SMOW} and δD_{V-SMOW} are 11.5‰ to 13.4‰ and -64.0‰ to -52.6‰, and the average values are 12.5‰ and -58.7‰, respectively.

3.3 S isotope

The sulfur isotope test results are shown in Table 2. The results show that the (³⁴S_{CDT}) values of 18 sulfur isotope samples ranged from 6.0‰ to 21.0‰, with an average of 10.65‰ and a standard deviation of 4.33; The (³⁴S_{CDT}) values of seven sulfur isotope samples in the late vein copper-molybdenum orebody ranged from 5.5‰ to 12.1‰, with a mean value of 7.07‰ and a standard deviation of 2.43.

Table 1. H-O isotopic compositions of samples

Sample No.	Mineral	δD _{V-SMOW} (‰)	δ ¹⁸ O _{V-SMOW} (‰)	δ ¹⁸ O _{H₂O} (‰)
QES560-01	Quartz	-52.6	12.0	2.07
QES560-02	Quartz	-57.7	12.3	2.37
QES680-01	Quartz	-58.6	12.9	2.97
QES680-02	Quartz	-53.0	12.4	2.47
ES680C8-1	Quartz	-63.5	12.6	2.67
ES680C8-2	Quartz	-60.5	12.5	2.57
QES560-03	Quartz	-60.0	12.7	2.77
QES560-04	Quartz	-58.5	12.8	2.87
QES680-03	Quartz	-58.4	12.6	2.67
QES680-04	Quartz	-58.6	13.4	3.47
ES680C8-3	Quartz	-64.0	11.5	1.57

Table 2. S isotopic compositions of samples

Sample No.	Describe	Mineral	δ ³⁴ S _{CDT} (‰)
w232m6-1	Layered copper bodies	Chalcopyrite	10.4
w232m6-2-H	Layered copper bodies	Chalcopyrite	8.9
w232m6-2-B	Layered copper bodies	Bornite	8.2
w184m4-1-H	Layered copper bodies	Chalcopyrite	7
w184m4-1-B	Layered copper bodies	Bornite	6.8
w184m3-2-H	Layered copper bodies	Chalcopyrite	7.3
w184m3-2-B	Layered copper bodies	Bornite	7.4
w184m4-2	Layered copper bodies	Chalcopyrite	7.2
w184m3-2-1	Layered copper bodies	Chalcopyrite	6.6
w184m4-h7-B	Layered copper bodies	Bornite	6
se980-9-H	Layered copper bodies	Chalcopyrite	19.2
se980-9-B	Layered copper bodies	Bornite	21
se980-16	Layered copper bodies	Chalcopyrite	11.5
se980-10-H	Layered copper bodies	Chalcopyrite	13.8

Sample No.	Describe	Mineral	$\delta^{34}\text{S}_{\text{CDT}}(\text{‰})$
se980-10-B	Layered copper bodies	Bornite	14.1
es98004-4	Layered copper bodies	Chalcopyrite	12.3
es98004-5	Layered copper bodies	Chalcopyrite	12.1
es98004-3	Layered copper bodies	Chalcopyrite	11.9
w184m4-h7-H	Vein-like copper - molybdenum ore body	Chalcopyrite	6.1
mob-1-H	Vein-like copper - molybdenum ore body	Chalcopyrite	8.4
mob-1-B	Vein-like copper - molybdenum ore body	Bornite	12.1
mob-2	Vein-like copper - molybdenum ore body	Chalcopyrite	6.1
mob-3-H	Vein-like copper - molybdenum ore body	Chalcopyrite	5.6
mob-3-B	Vein-like copper - molybdenum ore body	Bornite	5.5
mob-4	Vein-like copper - molybdenum ore body	Chalcopyrite	5.7

4 Discussion

4.1 Ore-forming fluid

The average $\delta^{18}\text{O}_{\text{H}_2\text{O}}$ value of hydrothermal filling vein mineralized fluid inclusions is 2.59‰ (Table 1), different from the $\delta^{18}\text{O}_{\text{H}_2\text{O}}$ value of magmatic water (5.5‰ ~ 9.5‰) and the $\delta^{18}\text{O}_{\text{H}_2\text{O}}$ value of meteoric water (-80‰ ~ -40‰) ([6]).

In the $\delta^{18}\text{O}_{\text{H}_2\text{O}}-\delta\text{D}_{\text{V-SMOW}}$ diagram (Fig. 3), the sample points mainly fall into the region near magmatic water/metamorphic water, suggesting that the type is mainly magmatic water/metamorphic water.

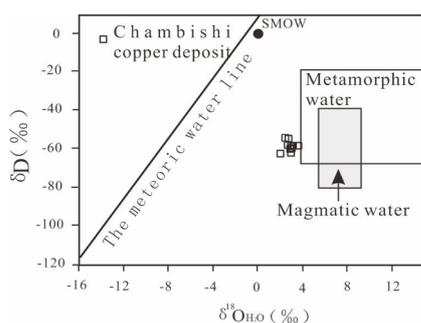


Fig.3. Plot of $\delta^{18}\text{O}_{\text{H}_2\text{O}}$ versus $\delta\text{D}_{\text{V-SMOW}}$ of fluid inclusions from the Chambishi Cu deposit (modified from Taylor, 1974)

Hydrothermal stage of microscopic characteristics of fluid inclusions shows that type I, II, III inclusions have no close coexist in the same horizon (Fig. 1), the micro measurement results show that the main metallogenic stage I type inclusions homogenization temperature are mainly distributed in the low temperature range, in the uniform temperature and salinity diagram, the salinity of the fluid inclusions and uniform temperature range is larger, these features also indicate fluid mixing. Therefore, the ore-forming fluids in the late hydrothermal period of Chambishi copper deposit are

formed by the mixing of various fluids with different properties, and their sources are characterized by multi-source characteristics. The mixing of fluids is the main cause of copper precipitation.

4.2 Source of ore-forming material

4.2.1 Sedimentary stratified mineralization

The $\delta^{34}\text{S}_{\text{CDT}}$ values of chalcopyrite and bornite in sedimentary stratified deposits are positive, ranging from 6.0‰ to 21.0‰, with the highest $\delta^{34}\text{S}_{\text{CDT}} = 21.0\text{‰}$. The S isotope composition is similar to that of Marine sulfate ($\delta^{34}\text{S}_{\text{CDT}} = 20\text{‰}$), and it is presumed that part of S is derived from palaeo-seawater sulfate. It is suggested that the sulfur source of Chambishi copper deposit is mainly the mixed sulfur of diagenetic sulfide and seawater sulfate. Previous studies have suggested that the variation of sulfur isotopes in seawater is related to transgression and regression. In general, transgression leads to lighter $\delta^{34}\text{S}_{\text{CDT}}$ values, while regression leads to heavier $\delta^{34}\text{S}_{\text{CDT}}$ values ([7]). The high $\delta^{34}\text{S}_{\text{CDT}}$ value of sulfide in the lower orebody of sedimentary stratified ore (Table 2) may be caused by the decay of $\delta^{34}\text{S}_{\text{CDT}}$ in a large water body during the regressive stage, which reflects that the sedimentary environment has undergone a transition from regressive to transgressive.

4.2.2 Hydrothermal filling vein mineralization

The $\delta^{34}\text{S}_{\text{CDT}}$ values of seven sulfur isotope samples of the late hydrothermal filling vein copper body range from 5.5‰ to 12.1‰, with an average of 7.07‰, which is significantly lower than the $\delta^{34}\text{S}_{\text{CDT}}$ values of the sedimentary bedded copper body (6.0‰ to 21.0‰, with an average of 10.65‰), and close to the $\delta^{34}\text{S}_{\text{CDT}}$ values of mantle flow (0 ~ 3‰). It is suggested that part of S in the late ore-forming hydrothermal fluids originated from the late mantle-derived magmatism. Considering the chambishi region has experienced strong Lufrian orogeny in the late neoproterozoic (600 ~ 500 Ma) ([8]), It is speculated that the sulfur isotopes of the late hydrothermal filling vein mineralization show the characteristics of mantle flow, which may be related to the mantle-derived magmatism caused by the strong orogeny in the late Neoproterozoic.

The $\delta^{34}\text{S}_{\text{CDT}}$ values of the sedimentary and hydrothermal type ores from Chambishi copper deposit are positive (6.0‰ ~ 21.0‰ and 5.5‰ ~ 12.1‰, respectively, Table 2), suggesting that their sulfate reduction mechanism is mainly a thermochemical reduction mechanism, which causes SO_4^{2-} to H_2S more thoroughly.

In conclusion, the sulfur sources of Chambishi copper deposit may have multiple sources or multi-stage mineralization. The sulfur sources in the early sedimentary period were mainly derived from diagenetic sulfide and palaeo-seawater sulfate, and the S isotopic composition was also affected by transgression and regression. Late-stage hydrothermal sulfur source

affected by late Neoproterozoic orogeny ([9]) and shows the characteristics of mantle flow.

It is worth noting that there is still a lack of detailed chronological data for the formation age of Chambishi copper deposit. According to the previous studies, the main mineralization age of Chambishi copper deposit is the middle Neoproterozoic (883 ~ 760 Ma, [10]), based on the fact that the ore bodies of Chambishi copper deposit mainly occurred in the Lower Ronan formation. It is mainly characterized by sedimentary stratified mineralization. Since then, the Chambishi region in the late Neoproterozoic (600 ~ 500 Ma) has experienced strong Lufrian orogeny and regional metamorphism, leading to mineralization in the area activated again, prompting copper, cobalt, molybdenum, such as enrichment of ore-forming elements occur again. It is mainly characterized by hydrothermal filling vein mineralization.

5 Conclusion

The sulfur of the Chambishi sedimentary stratified mineralization mainly comes from the diagenetic sulfide and the palaeo-seawater sulfate, and the S isotopic composition is also affected by transgression and regression. The sulfur isotopes of hydrothermal vein mineralization mainly exhibit the characteristics of mantle sulfur. The sedimentary stratified mineralization is closely related to the magmatic events in the middle Neoproterozoic (883 ~ 760 Ma), and the hydrothermal filling vein mineralization is mainly related to the large-scale orogeny and regional metamorphism in the late Neoproterozoic (600 ~ 500 Ma).

Acknowledgments

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