Characteristics of fluid inclusions in the Alqal Copper-Lead-Zinc deposit, Xinjiang

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Abstract. The Alqal Copper-lead-zinc deposit is located in the Tarim plate of the Xinjiang. It has undergone multiple stages of tectonic mineralization and is an important deposit in the Kusilafu metallogenic belt of the West Kunlun area. Based on the analysis of the metallogenic geological conditions of the deposit, the composition of fluid inclusions in mining area was studied. The characteristics of metallogenic fluid are discussed. The results show that the uniform temperature of gas-liquid two-phase fluid inclusions in the Alqal deposit is between 145-267 °C, the average uniform temperature is 191 °C; the salinity is 0.71% to 14.87%, and the average salinity is 6.33%. The estimated metallogenic pressure is about 135MPa, and the capture temperature is concentrated around 320°C. The ore-forming fluid has undergone multi-stage superimposed transformation, which is inconsistent with the characteristics of the typical MVT deposit, and it is a sedimentary transformation type deposit.

1. Introduction
West Kunlun Orogen in Xinjiang Uygur Autonomous Region is a key area in China’s strategic deployment of ore exploration, having several Cu-Pb-Zn-Au-Ag metallogenic belts with rich reserves due to the superior ore-forming geological conditions. The Kusilapu metallogenic belt is located at the junction of the northeastern margin of the West Kunlun-Pamir area and the southwestern margin of the Tarim Basin. As an important deposit discovered in this metallogenic belt, the Alqal copper-lead-zinc polymetallic deposit has received extensive attention. The genesis of its deposits is controversial, and different opinions reflect the complexity of mineralization and the versatility of deposits. Preliminary studies have controversy over the ore genesis of carbonate-type Pb-Zn deposit, which greatly restricts
the practice of ore exploration in West Kunlun Orogen[1-5]. Based on previous research and the existential geological data, this paper focuses on the Alqal copper-lead-zinc deposit in Kusilafu metallogenic belt in southern Xinjiang, and studies its ore-forming fluids characteristics in terms of traditional geology, petrography, fluid inclusion, etc., so as to explore the ore-forming process and compare it with standard MVT-type deposit. This paper is expected to offer some guidance to the ore exploration in Kusilafu metallogenic belt.

2. Geological Background

Alqal copper-lead-zinc deposit is located in Kusilafu metallogenic belt of southwestern margin of the Tarim Basin in Xinjiang. The breakup of the Rodina supercontinent in the Neoproterozoic contributed to the formation of the ancient Asian Ocean. From the Neoproterozoic to the Silurian period, the Kusilav copper-lead-zinc ore belt in the West Kunlun was in a relatively stable period of passive continental margin evolution. The area has accepted carbonate facies-clastic facies marine deposits. The Pb and Zn contents in these strata are generally high, making them a good source of minerals. In addition, the unconformity between the ancient crystalline basement and the caprock and the stratum provides a good space for later fluid migration and mineral precipitation. At the beginning of the Carboniferous, the Kusilafu copper-lead-zinc ore belt in West Kunlun entered the stage of continental-continent collision orogeny.

Alqal copper-lead-zinc deposits is located in Kusilafu metallogenic belt of southwestern margin of the Tarim Basin in Xinjiang. The exposure strata of the mining area are the Kezile formation of Middle Devonian, undivided stratum of Upper Devonian-Lower Carboniferous, and the Hosilahu formation of Lower Carboniferous. The geological structure of this area is mainly the North-Northwest-trending fracture and compound folds, and the fold formation of the research area is a complicated syncline, which fractures into a large NNW-fault that cuts deeply into the Hosilahu formation of Lower Carboniferous, the Kezile formation of Middle Devonian and the undivided stratum of Upper Devonian-Lower Carboniferous. Besides, the magmatic activity is relatively weak in this area because large-scale magmatic activities mainly happen in the west of Keziletag-Kusilafu fracture. The surrounding rock consists mainly of limestone, metamorphic siltstone, bioclastic crystalline limestone, micrite limestone, dolomitized bioclastic crystalline limestone, bioclastic micrite limestone, etc (Fig.1). The ore body is located in the hinge zone of syncline fold in the southwestern margins of Tarim Basin ore area, 6000 meters away from Tarim Basin deposit. Specifically, this ore body seemingly lies in the calcium-rich intercalation of fine clastic rock and carbonate rock in the Kezile formation of Middle Devonian[6-7].

Middle Devonian Keziltao Formation: Thicker than 1667m, it is an open continental shallow marine sedimentary environment. The lithology is mainly composed of some calcareous fine clastic rocks intercalated with carbonate rocks. It clearly reflects the changing process of seawater from bottom to top. The lower part is an oxidizing environment, and the upper part is a weak reducing environment. The combination of rocks is gravel sandstone, siltstone, mudstone, etc., mainly lead, zinc and other polymets. The ore-bearing horizons are all produced in a layered or lenticular shape, and are obviously controlled by the strata. Upper Devonian-Lower Carboniferous unseparated strata: The thickness is greater than 500m, it is a shelf shallow marine sedimentary environment, weakly oxidized, and is a set of sand, silt, and muddy deposits, partially sandwiched by a thin layer of carbonate. Lower Carboniferous Hosilahu Formation: 578.35m thick, formed by continental neritic sediments, most of which are in carbonate rocks, rich in carbonaceous carbonate, copper, lead, etc. rich in marine fossils. The metal-rich ore layers of many metals appear to be layered or similar.
Figure 1. The Geological Sketch map of the study area (according to Ref. 6)

1- Carbonate; 2- Clastic; 3- Fault; 4- Axis of syncline; 5- Copper-lead-zinc ore body; 6- Iron ore body

Metamorphic siltstone: The main minerals are quartz (80%), feldspar (15%) and muscovite (2–5%). Quartz particles are semi-automorphic-heteromorphic granules, with low roundness, and overall a slightly directional distribution, with a particle size of about 0.04mm. Feldspar is mostly distributed in the interstices of quartz grains and has strong alteration. The altered minerals are mainly sericite and chlorite. Containing a small amount of muscovite, it is a long strip, scattered among the quartz particles.

Limestone: The main mineral components are calcite (90%), quartz (10%), etc. The calcite is semi-automatic-heteromorphic-semi-rhomboic-irregular, with obvious double crystal grains, and the grain size is mostly between 1 and 2 mm. Quartz particles are filled between calcite particles in irregular shapes with distinct particle sizes.

Crystalline limestone with biological clastics: the main mineral components are calcite (85%), quartz (10%) and biological clastics (5%). Calcite is mostly produced in the form of fine crystals, with a particle size between 0.1 and 0.2 mm, and the recrystallization effect is obvious. There are bands of flint nodules with a width of about 2mm. From the perspective of crystal shape, the biological debris is dominated by crinoid stems.

Dolomite bioclastic crystalline limestone: the main minerals are calcite (60%), dolomite (30%) and bioclastic (10%). The calcite can be seen in the form of bands, the degree of self-shape is general, the phenomenon of agglomeration is obvious, and the particle size is 0.4–0.8mm. Dolomite is a metasomatic origin, distributed on the surface of calcite, with a more euhedral quadrilateral shape, with a particle size of about 0.1mm. The types of bio detritus may be diverse. Judging from the shape, the stems of crinoids are the main ones with a small amount of fossils.

The ore minerals comprise Ccp, Gp, P, Sp, and their oxide; gangue minerals include Dol, Cc, Qrz, Ms, etc.; ore textures are crushed porphyritic crystal texture, strawberry-like texture, replacement remnant texture, and idiomorphic granular texture; ore structure are mainly block structure, disseminated structure and vein structure, most of which are generated through replacement and fissure filling; and the surrounding rock alteration of the ore deposit includes silicification, sulfidation, carbonatization and argillization, in which carbonatization is found in a wide area, and silicification, argillization and sulfidation, which are closely related to mineralization, belong to close-to-ore alternation types. (Fig.2).
The interspersed metasomatism between the minerals was observed under a microscope, and it was found that sphalerite and galena replaced pyrite along the periphery and fissures of the pyrite, so that the residual structure of the transaction was distributed in the galena. Some galena and sphalerite are directly interspersed with pyrite in the form of veins, and the phenomenon of mutual substitution between galena and sphalerite is obvious. The common pyrite calcite veins are filled and developed. The above characteristics indicate that the mining area has the characteristics of multi-stage mineralization, and the generation sequence is roughly as early as dolomite--pyrite+calcite vein--galena+sphalerite.

3. Characteristics of Ore-Forming Fluids

3.1. Inclusion petrography

As the only ancient ore-forming fluid contained in the mineral crystal lattice, fluid inclusion research is the most direct means to understand the physical and chemical properties of ore-forming fluids[8–10]. By selecting samples from different sections in the mine district, this inclusion research divided the fluid inclusions of Alqaldeposit into two main types: inclusions of gas-liquid aqueous solution (Type-I), and liquid inclusions (Type-II, which were mostly formed in later stages and rarely related to mineralization). Inclusions of gas-liquid aqueous solution have a V/T ration ranging mostly between 10% and 25% at room temperature (20°C), are small in size and irregular in shape with diameters mainly between 2μm~4μm, and are distributed in isolationin quartz(Fig.3).
3.2. Inclusion temperature measurement results

The samples of this research were selected from different sections of ore-bearing quartz vein. Rock samples were made doubly-polished thick sections whose thickness is approximately 0.06mm ~ 0.08mm (Guangzhou Tuoyan Detection Technology Co. Ltd and No.3 Institute of Geological & Mineral Resources Survey of Henan Geological Bureau). The temperature measurement was conducted at Petrography Laboratory of Xinyang Normal University, using Linkam THMSG600 Heating/Cooling Stage and Leica Polarized Light Microscopic System. The temperature measured ranges between -196°C and 600°C, and when calibrated by those artificially standardized inclusions like pure liquid inclusion and 0.9% NaCl saline water inclusion, its accuracy reaches 1°C in the range between 30°C and 600°C, and 0.1°C between -196°C and 30°C. The research also measured the homogenization temperatures, frozen temperatures, first ice melting temperatures, and freezing point temperatures of the inclusions, as well as calculated the inclusion salinity using FLINCOR software, Brown-Lamb equation and H2O_NaCl_CaCl2 calculation system. (Table. 1)[11-13].

Table1. Inclusion temperature measurement results

| Sample number | Type | number | Particle size /μm | V/T (20°C) /% | Tm (ice) /°C | Th (to L) /°C | salinity /% |
|---------------|------|--------|-------------------|---------------|---------------|--------------|-------------|
| AQ-2          | I    | 19     | 2.5~5             | 5~25          | -2.5~10.9     | 144.9~178.9  | 4.18~14.87  |
| AQ-7          | I    | 20     | 2.5~4             | 10~35         | -2.0~9.6      | 154.2~254.7  | 3.39~13.51  |
| AQ-12         | I    | 20     | 2.5~6             | 10~25         | -3.0~6.0      | 157.9~189.3  | 4.96~9.21   |
| AQ-20         | I    | 18     | 2.5~4.5           | 20~35         | -0.4~5.3      | 197.6~267.3  | 0.71~8.28   |

Note: V/TI type inclusions represent the percentage of the gas phase to the total volume of the inclusions; Tm (ice)-the melting temperature of ice; Th (to L)-complete homogenization temperature. For type I inclusions, L represents the homogeneous liquid phase; The main mineral of the sample inclusions is quartz.

The test results show that Type-I inclusions of Alqal ore deposit have the homogenization temperature ranging from 145°C to 267°C (191°C on average); salinity varying between 0.71% and 14.87%, ( 6.33% on average) (Fig. 4-a,b,c).
Figure 4. Histogram and scatter plot of uniform temperature and salinity of fluid inclusions

a- Uniform temperature histogram, b- Salinity histogram, c-Uniform temperature-salinity scatter plot

4. Discuss

Based on the average thickness of the covered strata in the research area—about 5km[14], the average density of overlying strata is assumed as 2.7g/cm³, and the metallogenic pressure is estimated to be 135 MPa based on lithostatic pressure (P=ρgh). The homogenization temperatures of the tested inclusions were calibrated by the relation figure of homogenization temperature and pressure of NaCl solution of varying concentration, and the calibration value is approximately +125°C[15]. As a result, the trapping temperature is calculated and estimated to be in the range of 270°C ~ 412°C, mainly around 320°C.

It can be known from Fig. 4 that there are two relatively temperature-salinity concentrated sections in the gas-liquid fluid inclusions of Alqal copper-lead-zinc deposit, one with the homogenization temperature ranging from 140°C to 190°C, and the salinity varying between 7% and 16%; the other with the homogenization temperature ranging from 200°C to 260°C, and the salinity between 0% and 6%. These two concentrated sections of different temperature-salinity indicate that there potentially exist two stages of ore-forming fluids in Alqal copper-lead-zinc deposit. The inclusion with trapping temperature (320°C on average) probably comes from the deep-seated magmatic hydrothermal fluids, while the inclusion with low temperature may derive from meteoric water or basinal hot brine.

The ore-forming fluids of standard MVT-type lead-zinc deposit mostly originate from basinal hot brine, with relatively high salinity (>15%) but relatively low trapping temperature (usually no more than 150°C ~ 200°C)[16]. The original ore-forming fluids in Alqal copper-lead-zinc deposit is probably similar to MVT-type lead-zinc deposit. However, along with the later invasion of deep-seated magma, the deep fluids moved into the spots with weak geological structure, mixed with early fluids and finally formed superimposed mineralization at appropriate structural positions.

The physical and chemical characteristics of the two stages of ore-forming fluids demonstrate that Alqal copper-lead-zinc deposit is a superimposed and modified deposit, and differs to some degree from the standard MVT-type (Mississippi valley type) lead-zinc deposit.

A kind of mineralized breccia is widely distributed in the study area, which mainly appears in or near the junction of the lower clastic rock and the upper carbonate rock (paleo aquifer). Most breccias are closely related to mineralization. Through microscopic observation of the mineralized dolomitic breccia, it is found that the composition of the breccia is dominated by more euhedral rhombohedral dolomite particles, closely inlaid with each other. Sandy quartz and silicified quartz veins can also be seen in the breccia. The cement is also mainly dolomite, and some particles have obvious arc-shaped cleavage and double crystal lines. Pyrite mineralization can be seen at the edge of the breccia. Although mineralized breccia is distributed around the fault, it does not have the characteristics of structural breccia from the perspective of the composition of cement and breccia. The cement is mainly composed of calcareous cement, which is consistent with the surrounding strata. Fracture
marks such as friction surfaces may be caused by hydrothermal metasomatism of carbonate rocks, and the surrounding fractures may play the role of hydrothermal transport channels.

5. Conclusion
After researching and analysing the characteristics of ore-forming fluids in Alqal copper-lead-zinc deposit, it can be concluded that:

1. The homogenization temperature of the gas-liquid fluid inclusions in Alqal deposit ranges between 145°C and 267°C (191°C on average); the salinity varies from 0.71% to 14.87% (NaCl quality percentage, 6.33% on average). The metallogenic pressure is estimated to be 135 MPa, and the trapping temperature (after calibration) of the fluid inclusions centres around 320°C.

2. The fluids of Alqal copper-lead-zinc deposit take on a feature of multi-phase superimposition. The ore-forming fluids of the two phases are respectively related to meteoric water- basinal hot brine and the deep-seated magma.

3. In its early stage, the characteristics of ore-forming fluids in Alqal copper-lead-zinc deposit resemble the lead-zinc deposit of standard Mississippi valley type; in its later stage, the fluid characteristics do not conform to those of Mississippi type, but taking on the fluid characteristics of superimposed and modified deposit.

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References
[1] Zhang CG, Lai JQ, Cao YH, etal, 2016. Polygenetic compound mineralization of Tiekelike copper-lead-zinc deposit, Xinjiang. The Chinese Journal of Nonferrous Metals,26(6):1293-1302.
[2] Wang SL, Wang DB, Zhu XY, etal, 2002. Ore—fluid geochemistry of the Tamu-Kalangu Pb-Zn ore belt in Xinjiang. Geology—Geochemistry, 30(4):34—39.
[3] Zhu XY, Wang DB, Wang SL,1998, Geology and sulphur isotope geochemistry of the Tamu-Kalangu lead—zinc deposits, Akto county, Xinjiang. Mineral Deposits, 17(3):204—214.
[4] Cai AL,2009.Multi-level structural ore-controlling model and metallogenic prediction in the Tamu-Kalangu ancient lead-zinc-copper ore belt. Changsha, Central South University.
[5] Sun HT, Li CJ, Wu H, etal, 2003. Introduction to the west Kunlun metallogenic province. Geological Publishing House, Beijing.
[6] Zhang CG, Lai JQ, 2015. Study on optimum evaluation of prospecting target area in Kuslap copper-Pb-Zn metallogenic belt. Central South University, Changsha.
[7] Kuang WL, Gao ZQ, Yin JP, etal, 2002. Metallogenesis of Tamu MVT type Lead-Zinc deposit and sources of minerogenetic materials in western Kunlun. Bulletin of Mineralogy, Petrology and Geochemistry, 21(4):253-258.
[8] Zhang WH, Chen ZY, 1993. Fluid inclusion geology. China University of Geosciences Press, Wuhan, 1-354.
[9] Lu HZ, Fan HR, Ni P, etal, 2004. Fluid inclusions. Science Press, Beijing, 1-486.
[10] Lai JQ, CHI GX, PENG SL,etal, 2007. Fluid evolution in the formation of the Fenghuangshan Cu-Fe-Au deposit, Tongling, Anhui, China. Economic Geology, 102(5): 949—970.
[11] Brown PE, 1989. FLINCOR: A microcomputer program for the reduction and investigation of fluid inclusion data. American Mineralogist, 74:1390−1393.

[12] Brown PE and Lamb WM. 1989. P-V-T properties of fluids in the system H₂O±CO₂±NaCl: New graphic presentations and implications for fluid inclusion studies. Geochimica et Cosmochim Acta,53:1209-1221.

[13] CHI GX, NI P, 2007. Equations for calculation of NaCl/(NaCl+CaCl₂)ratios and salinities from hydrohalite-melting and ice-melting temperatures in the H₂O-NaCl-CaCl₂ system. Act Petrologica Sinica, 23(1):33−37.

[14] Cai TC, 1999. Litho stratigraphy of Xinjiang Uygur Autonomous Region. China University of Geosciences Press, Wuhan, 219-290

[15] Potter RWII, 1977. Pressure correction for fluid inclusion homogenization temperature based on the volumetre properties of the system NaCl-H₂O. J Res V S GeolSurv, 5:603-607.

[16] Liu YC, Hou ZQ, Yang ZS, etal, 2008. Some insights and advances in study of Mississippi Valley—type(MVT) lead—zinc deposits. Mineral deposits, 27(2):253—264.