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Journals, Poland, Directory of Research Journals

International Journal of Earth Sciences and Engineering

www.cafetinnova.org

ISSN 0974-5904, Volume 09, No. 02

April 2016, P.P.691-696

Fluid Inclusion Characteristics and Genesis of the Kengdenongse Polymetallic Deposit, Qing Hai, China

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Abstract: The Kengdenongshe Au-Pb-Zn polymetallic deposit was located in eastern area of Eastern Kunlun orogenic belt with Paleozoic subduction complex. The geological characteristics of the deposit showed that ore bodies were mainly formed within and adjacent the contact zone of volcanic and carbonate rocks. Two types of mineralization porphyry type and epithermal type have been found. 2 epochs and 5 stages have been divided according to characteristics of the deposit, in which the main mineralization stages werw Pb-Zn (Cu) sulfide stage and barite sulfide stage. One type of fluid inclusions has been identified based on Petrographic and microthermometric criteria, which was a type of two-phased aqueous inclusions. The compositions of cation and anion in liquid and gas of the inclusions were mainly respectively Na^+, Ca^{2+}, K^+, Cl_-, SO_4^{2-}; H_2O, CO_2, H_2 and CH_4. The ore-forming fluid was characterized by low salinity (0.17%～11.34%), and low density (0.50～1.06g/cm^3), with low-medium temperature of porphyry mineralization ranging from 139 to 320℃, while the temperature of epithermal mineralization concentrated in two interval, ranging from 150 to 250℃. metallogenic pressure were estimated to be 0.4～21.9Mpa respectively, suggesting that this deposit was formed in a depth of 0.2-0.9km. Late indosinian orogenic process in the area forming a series of cutting wore metamorphic strata NW-NWW to fracture. companied with the magmatic activity, Ore forming fluid intrude into the intersection of the faults. At the same time, hydrothermal solution rich in H_2O and CO_2 rise to shallow crust along the crack controlling system. Then the composition and physicochemical poperties of ore-forming fluids were changed, leading to the Lead-Zinc (Copper) Sulfide deposited in the favorable structures. Abstract was to be in fully-justified italicized text as it was here, below the author information.

Keywords: *Fluid Inclusions, Ore-Forming Fluid, Deposit Genesis, Kengdenongshe, Qinghai*

1. Introduction

Kengdenongshe Au-Pb-Zn polymetallic deposit is located in eastern area of Eastern Kunlun orogenic belt. Limited by the geographical environment, the research work in this area was weak. Fluid inclusion study can provide important information on temperatures, salinities and pressures of ore-forming fluids [1-2]. In this contribution, on the basis of fluid inclusion study, we investigated fluid sources, physicochemical conditions for mineralization and the genesis of the Kengdenongshe deposit, combining geological investigation.

2. Geologic setting:

Kengdenongshe Au-Pb-Zn polymetallic deposit is located in eastern area of Eastern Kunlun orogenic belt with Paleozoic subduction complex where was a joint of two third-grade tectonic units [3]. The strata exposed in the study area belong to the ancient Proterozoic Jinshuikou group, the Carboniferous Haoteluowa Group,the Lower Triassic Hongshuichuan Group and Quaternary. The Triassic volcanic rock was important for area of ore-bearing bed which the Kengdenongshe deposit is hosted in. The major structures in the area are Northwest and North-Northwest-trending structures. Fault structures were spread in ore area and characterized by molystage activities. The Indosinian intrusive rocks are broadly distributed in this area and controlled by the regional structures (Fig. 1).

Roughly 14 ore-bodies which were mainly hosted by subvolcanic rock of The Lower Triassic Hongshuichuan Group have been delineated. The ore-bodies that were generally 80 to 920m in length and 1.4 to 19m in true thickness. The ore-bodies was strictly controlled by NW-NWW trending faults and take stratoid and para-bedded, with their dip northeast and exhibit strike consistent with the attitude of the stratum.

The ore minerals mainly included gold, silver, galena, sphalerite and barite, barite with lesser chalcopyrite, tennantite and bornite. Gangue minerals comprise mainly quartz, calcite and lesser iron dolomite, gypsum, alum, clay minerals. Common textures of the ore-bearing rocks include xenomorphic-hypidiomorphic granular, cataclastic, sphalerite-chalcopyrite exsolution, metasomatic, veinlet interpenetration, poikilitic textures and laminar, massive, veinlet- disseminated structures. The main alteration types in the country rock included Baritization, silication, pyritization, chloritization, sericitization and dolomitization, of which, the first two alteration types were intimately related to the mineralization.

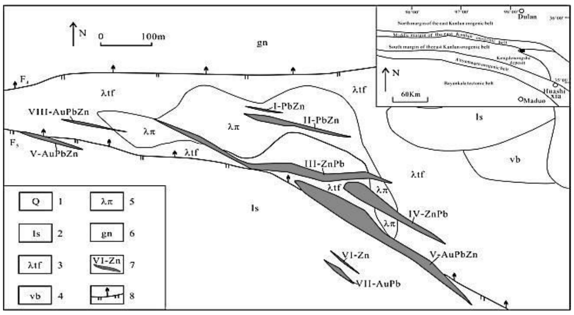

***Fig.1:** Geologic sketch map of the Kengdenongshe deposit (Modified from Ref. [4])*
1-Quaternary; 2-Limestone of The Carboniferous Haoteluowa Group; 3-Tuff of The Lower Triassic Hongshuichuan Group; 4-volcanic breccia; 5-Quartz porphyry; 6-Gneiss; 7-The number and type of ore bodies; 8-Fault and its properties

Field geological surveys and petrographic observation have revealed that there were two primary ore-forming events: porphyry mineralization event and shallow epithermal mineralization event. The porphyry mineralization event (A) includes two mineral-precipitating stages, namely quartz-pyrite stage (A1), Pb-Zn-Cu sulfide stage (A2) and quartz-carbonate-sulfide stage (A3), in order from earliest to latest. In addition, the shallow epithermal mineralization event (B) can be subdivided into to two mineral-precipitating stages, namely barite-sulfide (B1) and quartz barite-sulfide stage (B2).

3. Fluid inclusion study:

3.1. Sampling and analytical methods:

As in this heading, they should be Times New Roman 10-point boldface, initially capitalized, flush left, with 5-point blank line before, and one after. Samples containing sulfide ore-bodies and rock mass for fluid inclusion study were collected from the drill holes in Kengdenongshe deposit. Rock samples were made doubly-polished thick sections which thickness is 0.06-0.09mm. Microthermometric analysis was performed using Linkam THMSG600 Heating/Cooling Stage at the Fluid Inclusion Lab, Central South University. Measured parameters for aqueous inclusions include freezing temperatures (Tf), first ice melting temperatures (Ti(ice)), final ice melting temperatures (Tm(ice)). Salinity（mass fraction, NaClequiv）calculations and density estimation were conducted using software FLINCOR [5].

Quartz and barite were selected as samples of gas and liquid compositions for fluid inclusion analysis, and the purity was over 98%. Gas and liquid compositions for fluid inclusion analysis were performed using DX-120 Ion Chromatograph and Varian-3400 gas chromatography at the key laboratory of metallogenic prediction of nonferrous metal, Central South University.

3.2. Fluid inclusion petrography and classification:

The study of the fluid inclusions from the deposit revealed that most of them are liquid-vapor inclusions which were hosted in quartz, barite and sphalerite. (Fig.2). These fluid inclusions exhibit variability in morphology: oval or irregular shape. The inclusion sizes varied from 3 micron to 6 microns. The inclusions are dominated by liquid with vapor/liquid (V/L) volume ratios ranging from 5% to 40%. Fluid inclusion assemblages (FIAs) could be divided into two types: isolated primary inclusions hosted in quartz, barite and chained secondary inclusions along fractures in sphalerite.

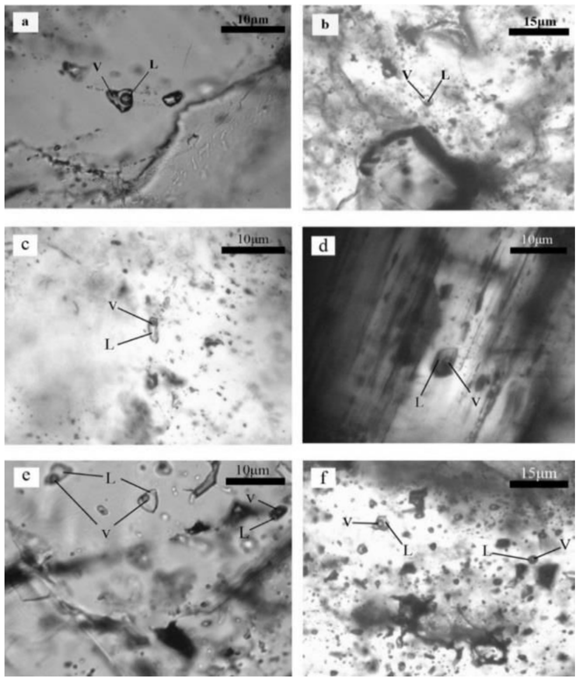

***Fig. 2:** Micrographs of fluid inclusions in the Kengdenongshe deposita-isolated LV inclusions; b-Primary LV inclusions in quartz vein of porphyry mineralization event; c- Primary aqueous LV inclusions of shallow epithermal mineralization event; d-Secondary LV inclusions in barite and sphalerite; e-Swarms of inclusions hosted in barite; f -Swarms of inclusions hosted in quartz; L=liquid water, V=vapor*

3.3. Results of microthermometric analysis:

Fluid inclusions from different mineralization stages were analyzed, including 208 aqueous inclusions. The characteristics of samples and microthermometric data results were given in Table 1. Homogenization temperatures and salinities for fluid inclusions formed at different stages are also summarized in Fig. 3.

***Table 1:** Characteristics of samples and microthermometric datas of fluid inclusions in Kengdenongshe deposit*

Sample No.	Host crystal	Mineralizing stages	Number	Size/μm	φv/%[1]	$T_{m(ice)}$/℃	$T_{m(to\ L)}$/℃	Density/g.cm^{-3}
ZK0007-07	Barite	B1	16	2.2~6.9	10~55	-2.7~-0.1	142~331	0.63～0.95
ZK0007-18	Barite	B1	15	2.0~4.8	10~40	-7.4~-0.1	126~330	0.72～1.00
ZK0007-19	Barite	B1	15	2.8~7.7	15~30	-7.7~-0.1	105~254	0.79～1.04
ZK0009-19	Quartz	B2	15	2.6~6.7	15~55	-2.2~-0.4	165~340	0.63～0.93
ZK0009-21	Sphalerite and Barite	B1	11	2.8~6.4	15~20	-3.7~-0.3	123~189	0.88～0.97
ZK0009-26	Barite	B1	20	3.2~10.3	15~60	-5.6~-0.1	185~379	0.54～0.91
ZK0009-33	Barite	A2	16	2.2~5.2	10~30	-4.8~-0.5	139~255	0.79～0.96
ZK0304-13	Barite	A2	20	3.4~9.7	10~60	-3.9~-0.2	135~387	0.50～0.96
ZK0304-15	Barite	A2	16	2.6~7.7	15~60	-5.8~-0.1	150~348	0.61～0.93
ZK0409-11	Quartz	A3	16	2.6~5.6	10~30	-6.7~-1.2	142~286	0.84～0.97
ZK0409-14	Quartz	A3	20	2.7~7.9	15~55	-3.2~-0.1	163~373	0.54～0.94
ZK3306-13	Barite	B1	18	2.7~8.2	10~45	-14.8~-0.2	113~297	0.71～1.06
ZK3306-16	Barite	B1	14	2.5~11.7	10~35	-0.1~-3.4	134~302	0.69～0.97

1）-φv/%-fraction of vapor phase of inclusions in 20℃; Tm(ice)-final ice melting temperature; Th (to L)-homogenization temperature (homogenized by vapor vanished)

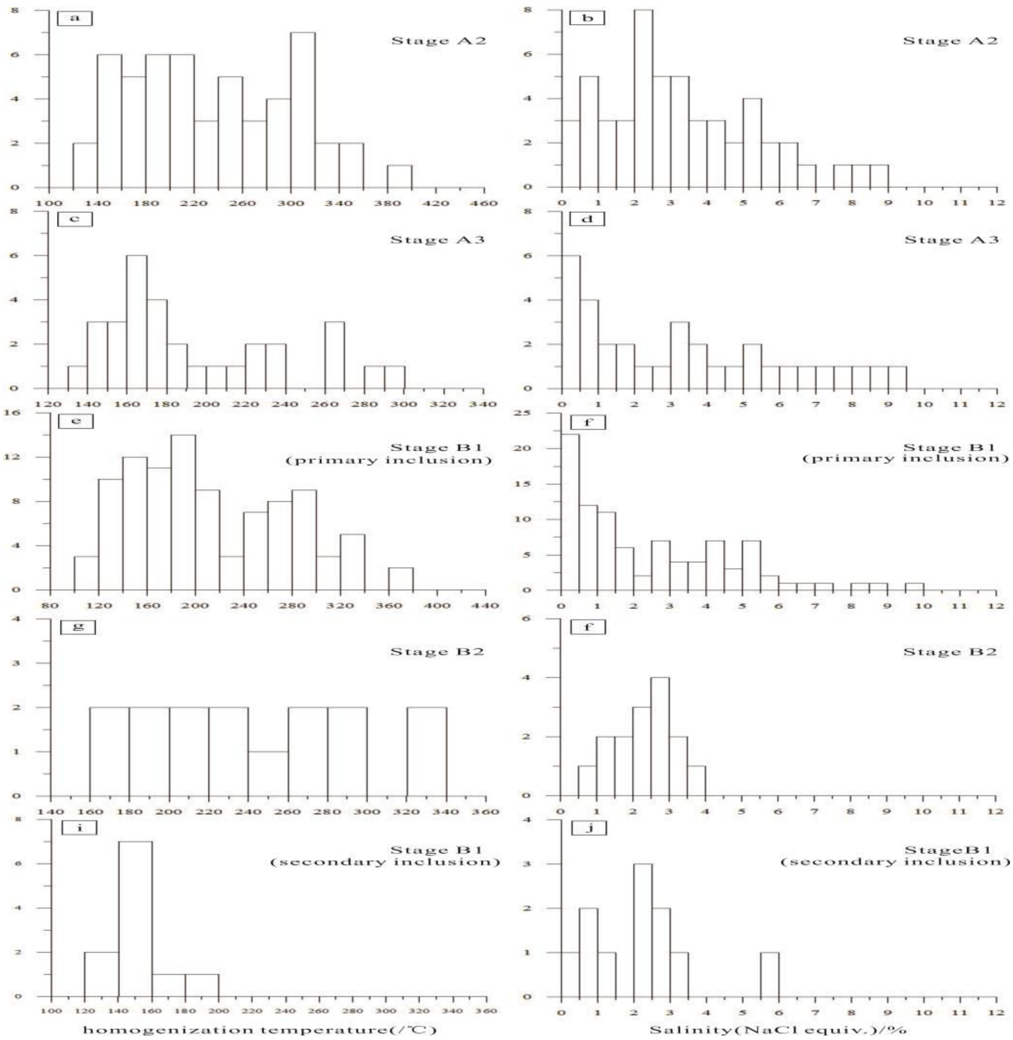

***Fig. 3:** Histograms of total homogenization temperatures and salinities of fluid Inclusion in different mineralization stages*

The calculated salinity of the fluid inclusions formed at the A2 stage ranges from 0.17% to 8.92% (focus on 0.50%～5.50%). During heating, the homogenization temperatures (vapor to liquid) range from 135 to

387°C (focus on 139～320℃). Based on the obtained homogenization temperatures and salinities, the homogenization pressure and fluid density have be estimated to be 0.4～23.8MPa and 0.50～0.96g/cm^3, respectively (Fig. 3-a, b).

The calculated salinity of the fluid inclusions formed at the A3 stage ranges from 0.17 to 10.10% (focus on 0.17%～4.00%). During heating, the homogenization temperatures m (vapor to liquid) range from 142 to 373°C (focus on 40～190℃ and 260～300℃). The homogenization pressure and fluid density have been estimated to be 0.5～20.5MPa and 0.54～0.97g/cm^3, respectively (Fig.3-c,d).

The calculated salinity of the primary inclusions hosted in barite formed at the B1 stage ranges from 0.17% to 11.34% (focus on 0.17%～5.50%). The homogenization temperature (vapor to liquid) varies between 105 and 379°C (focus on 150～220℃ and 240～300℃). Calculations based homogenization temperature and salinity show that the homogenization pressure and fluid density are 0.4-21.9MPa and 0.54-1.06g/cm^3, respectively (Fig. 4-e,f).

The calculated salinity of the secondary inclusions hosted in sphalerite formed at the B1 stage ranges from 0.50% to 5.90% (focus on 0.50%～3.00%). The homogenization temperature (vapor to liquid) varied between 123 and 189°C (focus on 140～160℃). Calculations based homogenization temperature and salinity show that the homogenization pressure and fluid density were 0.5-1.0MPa and 0.88-0.97g/cm^3, respectively (Fig. 3-i, j).

The calculated salinity of the fluid inclusions formed at the B2 stage ranges from 0.66% to 3.60% (focus on 1.00%～3.50%). During heating, the homogenization temperatures (vapor to liquid) range from 105 to 340°C (focus on 160～280℃). The homogenization pressure and fluid density have be estimated to be 0.6～14.0MPa and 0.63～0.93g/cm^3, respectively (Fig. 3-g, h).

3.4. Compositions of fluid inclusion analysis:

The compositions of cation and anion ions in liquid and gas of the inclusions are mainly respectively Na+, Ca^{2+}, K^+, Mg^{2+}; SO_4^{2-}, Cl^-, F^-; H_2O, CO_2, H_2 and CH_4. Some samples include minor C_2H_2 and C_2H_6. The fluid inclusion hosted in quartz contained more gas compositions than in barite (Table 2 and Table 3).

***Table 2:** Gas compositions of fluid inclusion in Kengdenongshe deposit (Unit: □g/g)*

Sample No.	Mineralizing stages	Mineral	Gas phase composition							
			H_2	O_2	N_2	CH_4	CO_2	C_2H_2	C_2H_6	H_2O
ZK0009-31	B2	Quartz	4.305	—	trace	13.726	736.846	5.409	5.458	1032
ZK0304-11	B1	Barite	0.212	—	trace	5.524	15.371	trace	0.376	528
ZK3306-01	B2	Quartz	8.052	—	trace	25.503	121.191	1.877	7.818	2061
ZK3306-13	B1	Barite	0.446	—	trace	17.946	42.242	trace	trace	741

***Table 3:** Liquid compositions of fluid inclusion in Kengdenongshe deposit (Unit:g/g)*

Sample No.	Mineral	Liquid phase composition										
		F^-	Cl^-	NO_3^-	PO_4^{2-}	SO_4^{2-}	Li^+	Na^+	NH_4^+	K^+	Mg^{2+}	Ca^{2+}
ZK0009-31	Quartz	0.792	6.592	—	—	39.802	—	2.158	—	1.723	trace	12.592
ZK0304-11	Barite	trace	1.104	—	—	8.259	—	0.729	—	0.043	—	6.826
ZK3306-01	Quartz	1.145	4.262	—	—	44.208	—	2.728	—	1.898	trace	15.293
ZK3306-13	Barite	0.058	2.359	—	—	9.492	—	0.857	—	0.179	trace	8.419

Trace means <0.01%; "—" means not detected

4. Discussion:

By use of thermodynamics and fulid inclusions the chenical conditions of mineralization have been studied [6-7]. The homogenization temperature vs. salinity binary plot (Fig. 4) shows that there is obvious scatter in the fluid temperature and salinity. Although homogenization temperatures and salinities are quite variable, it is clear that the ore-forming fluids generally exhibited decrease in both temperature and salinity not only from Stage A2 to A3 but also from Stage B1 to B2 in the Kengdenongshe deposit. The homogenization temperatures, salinity and density for fluid inclusions formed at event A indicates that the fluids were low to moderate temperature, low salinity and low density fluids. On the contrast, the fluid inclusions formed at event B indicates that the fluids were low temperature, low salinity and low density fluids.

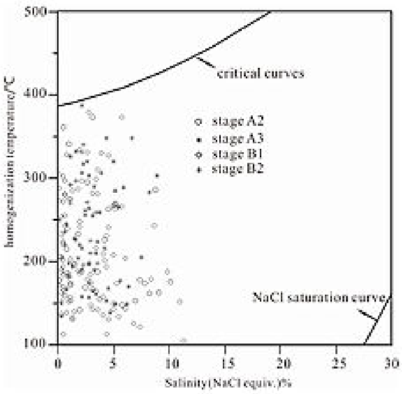

***Fig.4**: Scatter diagrams of homogenization temperature vs. salinity of fluid inclusions*

The maximum homogenization pressures for stage A2, A3, B1 and B2 estimated using FLINCOR program are 23.8 Mpa, 20.5 Mpa, 21.9Mpa and 14.0MPa. Given that, the depth of mineralization for stage A2, A3, B1 and B2 estimated by lithostatic pressure are located at 880m, 760m, 810m, 510m. These depths are less than typical depth of mineralization of epithermal deposit [8]. So we suppose that Kengdenongse deposit was formed in a depth of 0.2-0.9km. Mining of deep ore bearing possibility exists.

The ore-forming hydrothermal fluids in Kengdenongse deposit are characterized by low density, low salinity, rich in H_2O and a certain amount of CO_2, CH_4. Wallrock alteration is characterized by silicification, sericitization, and iron-dolomitization.

This means that ore forming fluids are rich in Si, alkali and CO_2. As a kind of weak acid, CO_2 plays an important part in PH buffer of ore-forming fluid. The existence of the CO_2 benefits phase separation of fluids [9]. Source of the CO_2 probably came from mantle-derived, senior metamorphic fluid of the lower crust or magmatic hydrothermal. Source of the CH4 probably came from juvenile fluid or metamorphism of the sediment rich in organic matter. Orogeny caused by the strong subduction and collisio n during the Early Paleozoic to Late Paleozoic-Early Mesozoic in the east Kunlun area not only produced abundant tectonic phenomena and metamorphism but also brought the extremely rich geological fluid, which has become the important carrier of metal elements in this area[10]. At the mine, whether fault zone containing Ag, Pb, Zn or porphyry vein are posterior to the metamorphic rock of the Jinshuikou Group. But all of they are later than Variscan granite. The mafic magmatism occurred before the mineralization suggests that initial ore forming fluid came from Variscan and Indosinian ectonic-magmatic activity. The ore forming fluids were mainly from deep and high degree evolution magma and suffered extensive metamorphism in the post-collision orogeny process.
The magmatic activity in this mining area shows up as the intrusion of monzonitic granite, granite, granite porphyry, quartz porphyry dyke, and brought some ore-forming material. Late indosinian orogenic process in the area forming a series of cutting wore metamorphic strata NW- NWW to fracture. Companied with the magmatic activity, ore forming fluid intrude into the intersection of the faults. At the same time, hydrothermal solution rich in H2O and CO2 rise to shallow crust along the crack controlling system. Then the composition and physicochemical poperties of ore-forming fluids were changed, leading to the Lead-Zinc (Copper) Sulfide deposited in the favorable structures.

5. Conclusions:

The Kengdenongshe deposit was hosted by subvolcanic rock of The Lower Triassic. The metallogenic stage can be divided into porphyry mineralization event and shallow epithermal mineralization. And then it can subdivide into five stages: quartz-pyrite stage, Pb-Zn-Cu sulfide stage and quartz-carbonate-sulfide stage, barite-sulfide and quartz barite-sulfide stage. The main mineralization stages are Pb-Zn (Cu) sulfide stage and barite sulfide stage.

The compositions of cation and anion ions in liquid and gas of the inclusions are mainly respectively Na^+, Ca^{2+}, K^+, Mg^{2+}; SO_4^{2-}, Cl^-, F^-; H_2O, CO_2, H_2 and CH_4.The ore-forming fluid is characterized by low salinity, low density and low temperature. This deposit was formed in a depth of 0.2-0.9km.

The formation of Kengdenongshe deposit had close relation with magmatic fluid and hydrothermal solution. Genetic types of this deposit include porphyry and epithermal type related to intermediated-acidic intrusion.

Acknowledgements:

This research project was funded by integrated exploration project of Qinghai province. Acknowledgements should also be given to the Yin Tian geophysical and chemical exploration limited liability company for their contribution to understanding the geology of the Tibetan Plateau.

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