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Fluid inclusion characteristics and genesis of the Galonggema Cu-polymetallic deposit, Qing hai, China

The Galongema Cu-polymetallic deposit located at the joint area between the Jinwulan-Jinshajiang suture zone and Ganzi-Litang suture zone in the Tibetan Plateau have experienced the ancient Tethyan tectonic evolution and the Himalayan orogeny and is characterized by excellent metallogenic conditions. Fluid inclusion study on the basis of identifying different ore-forming stages provides insight into the genesis of this deposit. According to fluid inclusion petrography, there are two types of fluid inclusions, namely aqueous liquid-vapor inclusions and CO_2-bearing inclusions. There are two identified primary ore-forming events, namely an early-stage volcanic-sedimentary hydrothermal event(A) and a late-stagemoderate-temperature hydrothermal event (B) that caused extensive precipitation of sulfides. Primary fluid inclusion assemblages formed at stages A3, B1 and B2 have been identified in the Galonggema deposit. According to microthermometric analysis, fluid evolution of the Galonggema deposit was not continuous and the fluids at different stages had different physicochemical properties. Fluid inclusion study shows that the fluids responsible for the early-stage mineralization were derived from volcanic exhalative activities with involvement of significant sea water. In contrast, the fluids responsible for the late-stage mineralization were derived from a more recent magma and were mixed with low-salinity ground water. In terms of deposit characteristics and ore-forming process, the Galonggema deposit is distinguishable from typical volcanogenic massive sulfide (VMS) deposits and the enrichment of ore-forming material was related to overprint of late hydrothermal alteration over a pre-existing sedimentary exhalative deposit. The tectonic evolution of the Galonggema deposit can be divided into three stages. The earliest stagewas represented by marine volcanic eruption that caused the early-stage volcanic-sedimentary (hydrothermal) mineralization. During the second stage, the Galonggema area experienced compression in NE-SW direction so that the strata were strongly folded to form an anticline with the volcanic vent as the centre. The latest stage represented moderate-temperature magmatic-hydrothermal mineralization related to emplacement of a late intermediate to felsic magma. The magmatic fluids that migrated up along the faulted belt superimposed the early-formed orebodies to form new mineralization and resulted in alteration of the country rock around the structural belt.

Keywords: *Fluid inclusions, ore-forming fluid, Galonggema, deposit genesis.*

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1. Introduction

Preliminary studies on the Galonggema polymetallic deposit located in the northern part of the Sanjiang metallogenic belt concluded that the Galonggema polymetallic deposit represents a VMS deposit (Li et al., 2010; Zheng et al., 2012). Nevertheless, such conclusion lacks crucial supporting evidence from geochemical characteristics of ore-forming fluids and fluid source. Fluid inclusion study can provide important information on temperatures, salinities and pressures of ore-forming fluids (Lai et al., 2007; Lu et al., 2004). In this contribution, on the basis of identification of ore-forming stages, we investigated fluid sources, physicochemical conditions for mineralization and the genesis of the Galonggema polymetallic deposit, combining fluid inclusion study with geological evidence and stable isotopicanalysis.

2. Geologic setting

The study area situated at the joint area between the Jinwulan-Jinshajiang River suture zone and Ganzi-Litang

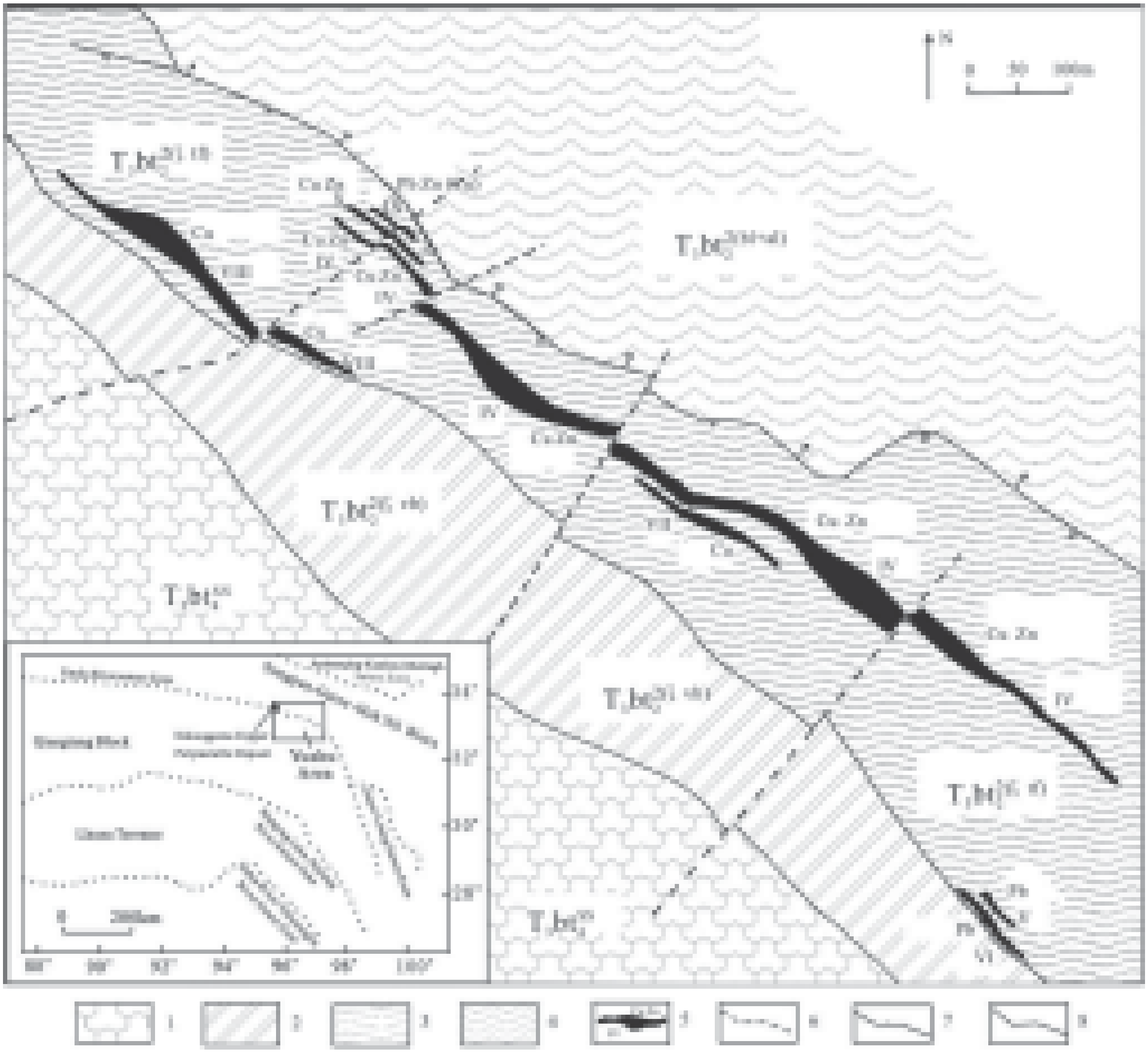

Fig.1 Schematic geologic map of the Galonggema deposit (modified after Liu, 2010)

1- The fourth lithologic formation (feldspar-bearing quartz sandstone); 2- The second lithologic member of the second lithologic formation (dacitic breccia lava interbeded with agglomerate lava); 3- The third lithologic member of the second lithologic formation (dacitic tuff); 4- The second lithologic member of the second lithologic formation (dacitic volcanic breccia); 5- Orebodies (numbered); 6- Inferred faults; 7- Reverse faults; 8- Geological boundaries.

suturezone lies to the northeast of the Qiangtang block and to the south of Songpan-Garze-Hoh Xil block (Fig. 1)

The strata exposed in the study area belong to the Lower Triassic Batang intermediate to felsic volcanic association. The major structures in the area can be broadly divided into two groups: Northwest-southeast-trending structures and North-Northeast-trending structures. The former group controls the distribution of the volcanic rock belt whereas the latter group crosscuts the volcanic rock belt. The study area is located in the Batang volcanic-magmatic arc zone that has experienced multiple stages and multiple circles of magmatic activities (Xu et al., 2013). The distribution of the volcanic rocks is controlled by the regional structures and Paleogene volcanic rocks are well exposed in this area.

3. Section headings geology of orebodies and ore-forming stages

Roughly 24 orebodies which are mainly hosted by dacitic tuff and tuffaceous siltstone have been delineated. The orebodies that are generally 50 to 2000 m in length and 2 to 43 m in true thickness steeply dip northeast and exhibit strike consistent with the direction of the schistocity or the strike of the ductile shear zone. The ore minerals mainly include chalcopyrite, pyrite, galena, sphalerite with lesser chalcocite and malachite. The gangue minerals mainly include sericite and quartz with minor calcite, albite and barite. Common textures of the ore-bearing rocks include granular, metasomaticrelict, stockwork, clastic and skeletal textures. Disseminated, breccia, banded, massive, vein-like, spotted and mottled structures are common. In general, the country rock has experienced pyritization-sericitization-silicification. The main alteration types in the country rock include pyritization, silicification, sericitization and chloritization, of which, the first three alteration types are intimately related to the mineralization.

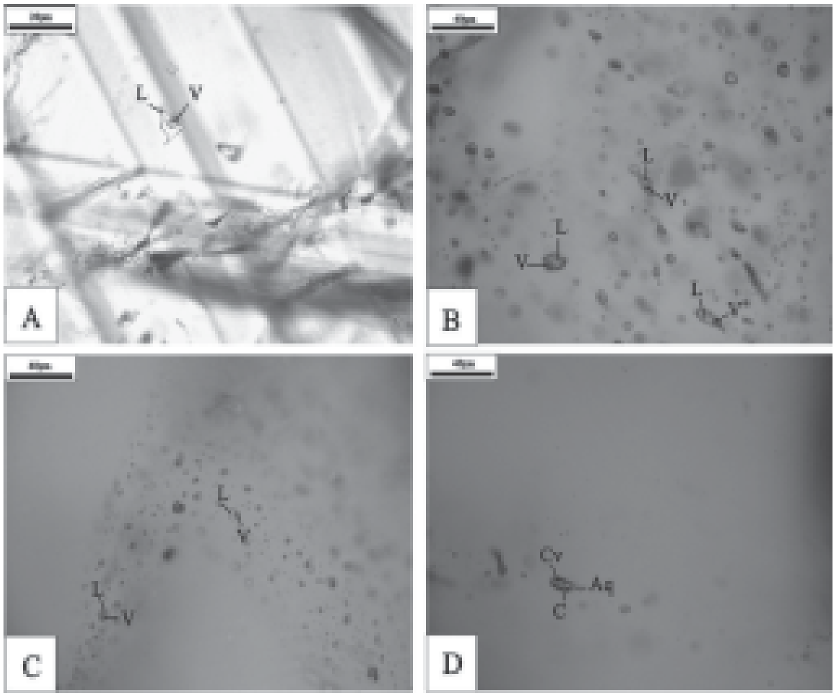

Fig.2 Photomicrographs of fluid inclusions in quartz and calcite from the Galonggema deposit

A- isolated aqueous LV inclusions with negative crystal shape in calcite; B - clustering aqueous LV inclusions with oval or irregular shapes in quartz; C- aqueous LV inclusions of secondary origin in trails D- aqueous-CO_2 LLV inclusions. Abbreviations: L = liquid water, V = vapor, C_l = liquid CO_2, Cv = CO_2 vapor and Aq = aqueous.

Field observation in the tunnels on the east and west sides of the Galonggema deposit and core logging, in combination with petrographic observation, have revealed that there were two primary ore-forming events. The earlier one (A) is related to volcanic-sedimentary hydrothermal fluids while the later one (B) moderate-temperature hydrothermal fluids that caused extensive sulfide precipitation.

The volcanic-sedimentary hydrothermal event (A). Precipitation of ore minerals during this stage mainly happened at shallow level and the mineralization temperature were low to moderate. The mineralization was not strong and pyrite was the predominant ore mineral with sphalerite in minor amounts. The mineralization was likely linked to volcanic activities, representing mineralization caused by volcanic hydrothermal sedimentation and volcanic-subvolcanic hydrothermal fluids. This Event includes three mineral-precipitating stages, namely hydrothermal-sedimentary banded- massive pyrite stage (A1), quartz-pyrite stage (A2) and carbonate stage (A3), in order from earliest to latest. In addition, the moderate-temperature hydrothermal event (B) can be subdivided into to two mineral-precipitating stages, namely Cu-Pb-Zn sulfide stage (B1) and sphalerite-carbonate stage (B2). This ore-forming event can be distinguished from the first ore-forming stage by significant Cu-Pb-Zn sulfide mineralization that was likely caused by magmatic ore-forming fluids. This stage was unlikely to be related to volcanic activities but reflects a more recent magma activity.

4. Fluid inclusion study

4.1 Sampling and analytical methods

Samples containing sulfide ores for fluid inclusion study were collected from the surface and tunnels in Galonggema mine district and drill holes. Rock samples were made doubly-polished thick sections which thickness is 0.06-0.1mm. 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 (Tixs(ice)), final ice melting temperatures (Tm(ice)). Salinity calculations and pressure estimation were conducted using software FLINCOR (Brown, 1989).

4.2 Fluid inclusion petrography and classification

Petrographic observations show that most fluid inclusions are liquid-vapor (LV) inclusions (Fig. 2-A). These fluid inclusions exhibit variability in morphology: oval, negative crystal shape or irregular shape (Fig. 2-B). The inclusion sizes vary from 1?m to 40?m. The individual inclusions are dominated by liquid with vapor/liquid (V/L) volume ratios ranging from 5% to 40%. Rare vapor-rich inclusions are also present, exhibiting V/L volume ratios of 65% - 95%. Based on distribution characteristic, fluid inclusion assemblages (FIAs) can be divided into three types: (1) FIAs consisting of isolated inclusions (in calcite); (2) FIAs consisting of clustering inclusions (Fig. 2-B); and (3) FIAs composed of inclusions in trails (Fig. 2-C). Regardless of the origin for the isolated inclusions, the FIAs consisting of clustering inclusions have been interpreted to be primary while the FIAs distributed in trails secondary. In rare cases, CO2-bearing aqueous, LLV inclusions (Fig. 2-D) are observed and are secondary in origin. Fluid inclusion assemblages can be correlated to different ore-forming stages based on field and petrographic evidence. Fluid inclusion assemblages formed at stages A3, B1 and B2 have been identified.

4.3 Results of microthermometric analysis

Fluid inclusions from 14 ore samples were analyzed, including 128 aqueous liquid-vapor inclusions. The fluid inclusions are hosted in quartz, calcite and dolomite. The microthermometric results are given in Table 1. Homogenization temperatures and salinities for fluid inclusions formed at different stages are also summarized in Fig. 3. Fig.4 is the homogenization temperature-salinity binary plot.

4.3.1 Characteristics of fluid inclusions formed at the carbonate stage (A3)

During heating, the fluid inclusions were homogenized to liquid phase. The homogenization temperatures range from 178 to 235°C (213.8°C on average).

4.3.2 Characteristics of fluid inclusions formed at the Cu-Pb-Zn sulfide stage (B1)

The fluid inclusions determined first ice melting temperatures vary between -50.4 and -20 °C and the final ice melting temperatures range from -7.6 to -0.8°C. The calculated salinities based on the final ice melting temperatures vary in a range of 1.32%-11.22% (5.46% on average). During heating, the homogenization temperatures(vapor to liquid)range from 205 to 373°C (299°C on average). Based on the obtained homogenization temperatures and salinities, the homogenization pressure and fluid density have be estimated to be 0.5 - 20.5MPa and 0.61-1.02g/cm^3, respectively.

4.3.3 Characteristics of fluid inclusions formed at the sphalerite-carbonate stage (B2)

Fluid inclusion freezing temperature, first ice melting temperature, final ice melting temperature -49 to -32.2°C, -39 to -33.9°C and -2.3 to -0.4°C, respectively. The calculated salinity ranges from 0.66% to 3.76%. (1.76% on average). The homogenization temperature (vapor to liquid) varies between 188 and 289 °C (238.6 °C on average). Calculations based homogenization temperature and salinity show that the homogenization pressure and fluid density are 1.0-6.9MPa and 0.76-0.92g/cm^3, respectively.

5. Discussion

5.1 Character of ore-forming fluids

The fluid inclusion assemblages in quartz and calcite from the ore samples are dominated by aqueous liquid-vapor inclusions and no daughter minerals have been observed in the inclusions. In rare cases, CO_2 is present in the inclusions. These observations suggest that the ore-forming fluids are mainly low-salinity aqueous fluids. The freezing temperatures

Table 1: Results of microthermometric analysis of fulid inclusions

Sample no.	Ore-forming stages	Measured inclusions	Size/ μm	V/T(20°C) /%	T_f /°C	T_i(ice) /°C	T_m(ice) /°C	T_h(to L) /°C equiv)	Salinity (wt% NaCl	Density/ (g.cm^{-3})
GD-08	A3	5	2~4	10~25				178~235		
GL-41	B1	10	5~14	30~50	-33~-58	-52	-2.3~-5.3	302~337	3.76~8.51	0.67~0.74
GL-68	B1	6	4~12	20~45	-36~-49		-1.4~-3.7	313~327	2.31~5.93	0.66~0.73
GL-79	B1	13	4~20	15~55	-43~-70		-2.4~-7.6	245~356	3.92~11.22	0.70~1.02
GL-82	B1	11	4~20	15~95	-32~-43		-2.5~-4.8	246~338	4.07~5.93	0.69~0.84
GL-86	B1	10	4~10	22~65	-35~-47		-1.0~-3.9	291~360	1.65~6.23	0.61~0.73
GL-91	B1	7	5~9	35~40	-34~-43	<-26	-0.8~-5.3	277~330	1.32~8.24	0.64~0.82
GL-94	B1	6	3~10	35~50	-48~-52	-35.2	-3.2~-6.1	317~355	5.17~9.32	0.72~0.75
GD-04	B1	11	4~24	15~45	-37~-50	-20~-35	-3.4~-5.2	235~373	5.47~8.10	0.61~0.88
GD-11	B1	9	7~18	10~55	-45~-49	-26~-39	-2.4~-4.8	224~355	3.92~7.11	0.67~0.91
GD-17	B1	11	5~12	20~65	-42~-60	-24.6~-50.4	-1.5~-4.6	205~335	2.47~7.25	0.75~0.98
GD-18	B1	10	8~12	20~45	-40~-45	-28~-33	-1.9~-3.7	254~318	3.12~5.93	0.71~0.85
GL-29	B2	9	7~40	15~35	-32.3~-42	-33.9~-39	-0.4~-2.3	228~244	0.66~3.76	0.82~0.85
GL-30	B2	9	6~12	10~35	-39~-49		-0.6~-1.8	188~289	1.16~2.96	0.76~0.92

V/T(20°C) - fraction of vapor phase of Type 1 inclusions at 20°C; T_f - freezing temperature;T_i(ice) - first ice melting temperature; T_m(ice) - final ice melting temperature;T_h (to L) - homogenization temperature (homogenized to liquid);Salinity is expressed in wt % NaCl eq.

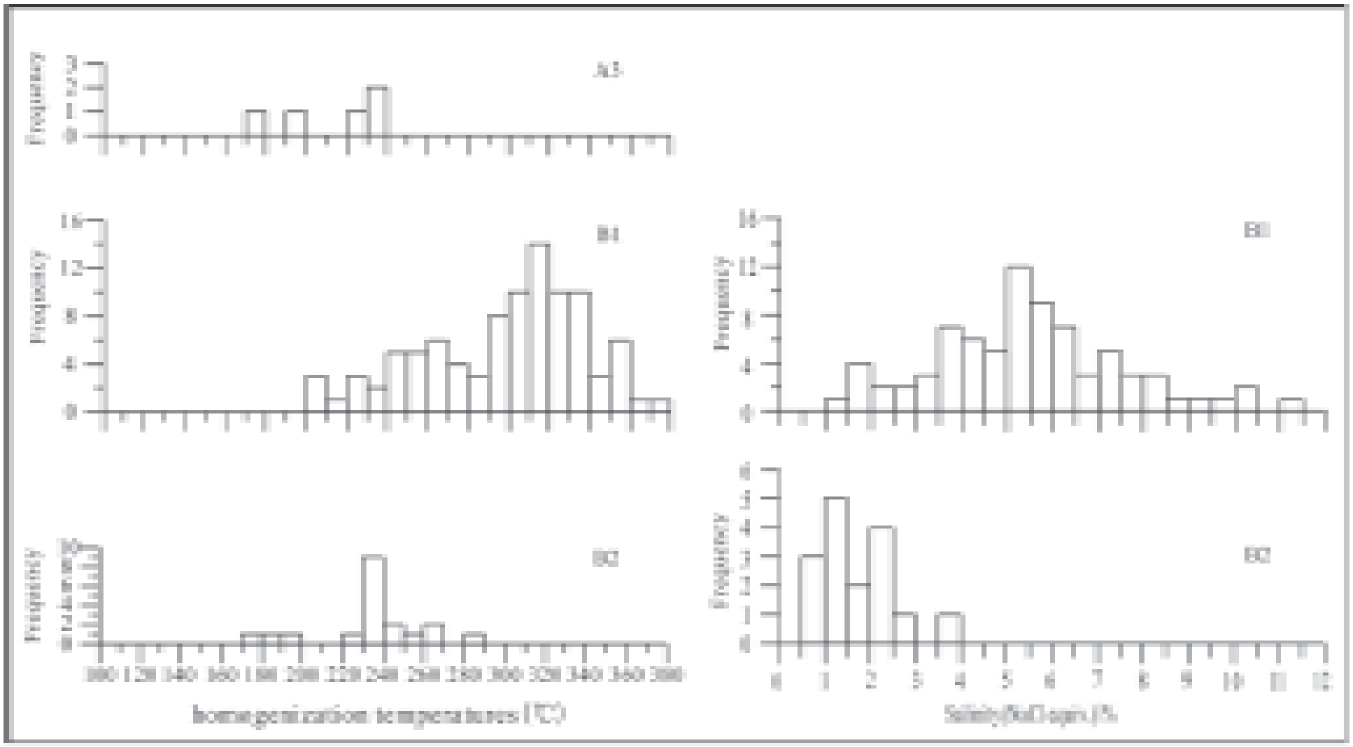

Fig.3 Histograms of total homogenization temperatures and salinities of fluid Inclusion in different mineralization stage

range from -70 to -30°C, mostly lying between -50 and -30 °C whereas the first ice melting temperatures range from -52 to -22°C, mostly lying between -38 and -22°C. The freezing temperatures and first ice melting temperatures likely indicate that the fluids are dominated by NaCl with minor K^+, Mg^{2+} and rare Ca^{2+}.

The fluids at ore-forming stages B1 and B2 in Galonggema area are characterized by low salinities (0.66%-11.22%), of which, the fluid for B1 has salinities ranging from 1.32% up to 11.22%. (5.46% on average) and the fluid for B2 exhibits obviously lower salinities (0.66%-3.76% and 1.76% on average). In light of the variability in salinities, the ore-forming fluids at B1 and B2 stages were unlikely to be homogenous, especially for the fluid at B2 stage that has highly variable salinities. Although the salinity for the fluid at B2 stage are mostly higher than the salinity of sea water (3.5%), the minimum salinity for the fluid at B2 stage is lower than the salinity of sea water. Therefore, the ore-forming fluids at these two stages were unlikely to be originated from sea water or marine brines. Although the study area has experienced low-grade metamorphism, no CO_2 inclusions which are related to the main ore-forming stages have been observed in this study. Field observation suggests that the metamorphism was not high-pressure metamorphism. The folding happened after the formation of the banded structures containing mineralization, which implies that the regional metamorphism was after the main ore-forming stages. Therefore, the ore-forming fluids were unlikely to be metamorphic fluids. Another possibility is that there was mixing between two different fluids. One fluid was characterized by relatively high salinity and may be post-magmatic while the other was a low-salinity fluid and may be derived from underground fresh water. At B2 stage, the salinity of the ore-forming fluids was even lower, which reflects an increased proportion of fresh water at B2 stage.

5.2 Mineralization temperature and pressure

The primary liquid-vapor inclusions in dolomite from one sample formed at A3 stage in Galonggema show homogenization temperatures varying between 178 and 235°C (213.8°C on average). Moreover, the primary liquid-vapor inclusions in quartz and calcite from 11 samples formed at B2 stage exhibit homogenization temperatures ranging from 188 to 265°C (238.6°C on average). Given that the mineralization was intimately related to volcanic activities and is located at shallow level, the pressure for mineralization should be relatively low. The estimated homogenization pressure of fluid inclusions (maximum pressure = 20.5MPa) likely represents the pressure for mineralization. The entrapment temperatures of fluid inclusions obtained after pressure correction were merely ~ 20 °C higher than their homogenization temperatures. Therefore, the ore-forming fluids were moderate-temperature (200-300°C) fluids.

The fluids at A3 stage were relatively low-temperature fluids. The minerals precipitated are predominantly dolomite and almost no sulfides were precipitated at this stage, which indicates that this stage was not an ore-forming stage. Because no microthermometric analysis has been conducted on fluid inclusions formed at stages A1 and A2 and no salinity data is available for fluids at Stage A3, the characteristics of fluids at these three stages cannot be fully explored in this contribution. Nevertheless, the relatively low homogenization temperatures for fluid inclusions formed at Stage A3 indicates that the fluids were low to moderate temperature fluids and that the temperatures of the fluids are lower than the precipitation temperatures for Cu, Pb and Zn sulfides. Considering that fluid event A was closely related to volcanic activities, the hydrothermal veins formed at stages A2 and A3 may imply of metasomatism caused by volcanic hydrothermal fluids.

Stage B1 was characterized by moderate to high temperature and massive precipitation of Cu-Zn sulfides and represents the most important ore-forming stage in the Galonggema deposit. The fluids at this stage had relatively high salinities, which may imply that abundant magmatic fluids were involved. Nevertheless, the presence of low-salinity fluid inclusions indicates that fresh water was involved as well and that the ore-forming environment was likely terrestrial rather than marine. Therefore, Stage B1 has no direct relation to volcanic activities. Instead, mineralization at Stage B1 was likely caused by emplacement of a more recent magma. Stage B2 shows similar features to Stage B1 but was characterized by lower mineralization temperature and fluid salinity, which implies a low to moderate-temperature environment. Also, the temperature of the ore-forming fluids decreased and more fresh water was involved at Stage B2. The formation of abundant carbonate minerals may have defined the end of the ore-forming process.

5.3 Evolution of ore-forming fluids

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 from Stage B1 to Stage B2 in the Galonggema deposit. This trend likely suggests that there was addition of low-salinity fluids during cooling of the fluids

In summary, the Gelonggema deposit had two ore-forming events in which the ore-forming fluids exhibited different character. By use of thermodynamics and fulid inclusions the chenical conditions of mineralization have been studied (Dhahri etal., 2003; Nizar etal., 2007; Zeghbid etal., 2015). Between the two ore-forming events, there was a period in which no mineralization was formed. The early-stage volcanic-sedimentary hydrothermal event (A) was characterized by low to moderate-temperature fluids and the end of this event was defined by the carbonate stage without mineralization. This event represented an ore-forming process caused by sedimentation and hydrothermal metasomatism related to volcanic activities at shallow level in the crust or submarine environment. The fluid, derived from a more recent

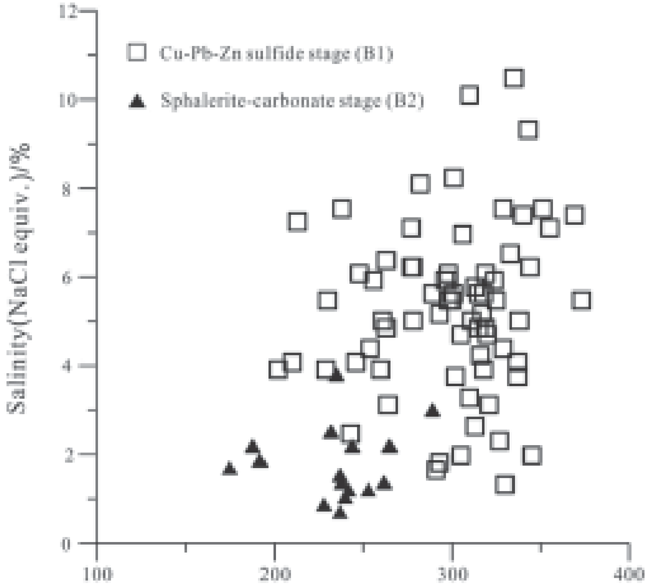

Fig.4 Homogenization temperature-salinity binary plot of moderate-temperature hydrothermal event

magma, was initially characterized by relatively high temperature and moderate salinity during the moderate-temperature hydrothermal event with sulfide precipitation (B). During this event, the involvement of low-salinity ground water also played an important role in mineralization. The evolution trend of the ore-forming fluids during the two events was from fluids with high temperature and moderate salinity to fluids with low-moderate temperature and low salinity. With precipitation of Cu-Pb-Zn sulfides the magmatic fluids were diluted and cooled because of addition of ground water. The inferred mineralization was at shallow level hence the mineralization pressure was low.

5.4 Mineral deposit genesis

The Galongema deposit and Xiacun deposit in the western Sichuan are located in the same structural belt and share similarity in metallogenic conditions (Yu et al., 2000). The tectonic setting for these two deposits is an extensional island arc environment, similar to those Kuroko-type deposits in Japan. Such tectonic environment is favorable for volcanic rock-related mineral deposits (Hou etal., 2004). The Galongema deposit is distinguishable from those typical kuroko-type deposits in terms of deposit characteristics and ore-forming process.

The deposit mineralization was formed through two different events, namely the early-stage volcanic exhalative-sedimentary mineralization hosted in marine felsic volcanic rocks and the late-stage moderate-temperature hydrothermal mineralization related to emplacement of an intermediate to felsic magma. Similar mineralization with involvement of late magmatic-hydrothermal fluids has also been observed in other deposits. For example, the Cu mineralization in the VHMS type Cu -Au deposit at Mt Morgan, Australia was caused by hydrothermal fluids (derived from late magmas) that superimposed early-formed VMS-type pyrite deposit(Ulrich etal., 2003). Therefore, the overprint of late hydrothermal fluids over strati form SEDEX type mineralization is likely an important ore-forming process.

Although only silicification has been observed to be connected to the early-stage volcanic-sedimentary mineralization, the Galonggema deposit may have mineralization zonation similar to SEDEX-type deposits. The observed quartz-pyrite ore-body is comparable to the distal strati form pyrite belt in SEDEX-type deposits. Stratiform Cu-Pb-Zn belt, vein-type mineralization and altered rocks may occur near the vents. The overprint of late magmatic hydrothermal fluids resulted in veinlike and stockwork orebodies and was related to emplacement of late magmas. The fluid was a mixture between magmatic fluids and low-salinity ground water, which is from the early-stage marine volcanic activities.

The Galonggema deposit shows that there are three stages of the mineralization and tectonic evolution. Stage A represents the marine volcanic eruption that caused the early-stage volcanic-sedimentary (hydrothermal) mineralization. At Stage, the Galonggema area experienced compression in NE-SW direction so that the strata were strongly folded to form an anticline centered on the volcanic vents. The two volcanos were compressed to form two volcanic rock belts whose strike is perpendicular to the compression direction. At Stage C, magmatic fluids released during the emplacement of late intermediate to felsic magma resulted in mesothermal mineralization. The magmatic fluids migrated up along the faulted belts and superimposed the early-formed orebodies to cause new mineralization and secritization-chloritization-silicification of the country rock around the faulted belt.

6. Conclusions

(1) Two primary ore-forming events have been recognized in the Galonggema deposit. The earlier one is related to volcanic-sedimentary hydrothermal fluids while the later one moderate-temperature hydrothermal fluids that caused extensive sulfide precipitation. The fluids during the two events had different characters. The volcanic-sedimentary hydrothermal event includes three mineral-precipitating stages, namely hydrothermal sedimentary banded to massive pyrite stage, quartz-pyrite stage and carbonates stage, in order from earliest to latest. In addition, the moderate-temperature hydrothermal event can be subdivided into to two mineral-precipitating stages, namely Cu-Pb-Zn sulfides stage and sphalerite-carbonates stage.

(2) The volcanic-sedimentary hydrothermal event (A) was characterized by low to moderate temperature fluids and the end of this event was defined by the carbonate stage in which no mineralization was formed. This event represented mineralization related to shallow-level or submarine volcanic-sedimentary activities and hydrothermal metasomatism. The ore-forming fluids at the mesothermal sulfides stage (B) were derived from a late magma and moderate to high temperature fluids at beginning. With addition of low-salinity fluids the ore-forming fluids became low-temperature and low-salinity fluids, which resulted in precipitation of Cu, Pb and Zn sulfides. This implies that the magmatic fluids were diluted due to the addition of ground water.

Because the mineralization has intimate connection to volcanic activities and mineralization occurred at shallow level, the mineralization pressure was close to the estimated pressure based on the homogenization temperatures of fluid inclusions. After pressure correction the entrapment temperatures were only 20 °C higher than the measured homogenization temperatures. Therefore, the temperature of the ore-forming fluids was mostly moderate (200-300°C).

(3) The mineralization was intimately related to volcanic activities and controlled by volcanic-sedimentary basin. Therefore, the Gelonggema deposit is a volcanic rock-hosted deposit. In terms of ore-forming process, the Gelonggema deposit is distinctly distinguishable from VMS-type deposits. During the volcanic-sedimentary hydrothermal event the mineralization was relatively weak and mainly represented by banded pyrite that provided sulfur for later mineralization. The Cu-Pb-Zn mineralization was mainly caused by hydrothermal activities related to a more recent magma and represented by veinlike, stockwork and breccia-like ores. The ore-forming fluids were derived from mixing between magmatic fluids and ground water.

(4) The tectonic evolution of the Galonggema deposit can be divided into three stages. Stage A was represented by marine volcanic eruption that caused the early-stage volcanic-sedimentary (hydrothermal) mineralization. During Stage B the Galonggema area experienced compression in NE-SW direction so that the strata were strongly folded to form an anticline centered on the volcanic vents. Stage C represented moderate-temperature magmatic hydrothermal mineralization caused by emplacement of a late intermediate to felsic magma. The magmatic fluids migrated up along the faulted belts and superimposed the early-formed orebodies to cause new mineralization and alteration of the country rock around the structural belt.

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