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Ore-Forming Fluid Characteristics of the Naoyangping-Damogou zinc-fluorite ore deposit, Pingli County, Shaanxi Province, China

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Abstract: The Naoyangping-Damogou zinc-fluorite ore deposit is located in the North Dabashan Caledonian fold belt, in the east wing Pingli Anticlinorium, which is one of the most important zinc-fluorite-hosting faults in Shaanxi Province of China. Metallogenesis is controlled by F7 fault structure and other relevant fault structure systems and closely related to the trachyte side. Fluid inclusion (FI) petrography and microthermometry, and analysis of oxygen and hydrogen isotopes for fluid inclusions were conducted to determine the characteristics of the ore-forming fluids and the processes of zinc and fluorite mineralizations. Microthermometry data of FI indicated that ore-forming fluids are characterized by low salinity and low density. The data obtained from geothermometric studies of Sphalerite and fluorite associated with zinc-lead mineralization at the Naoyangping-Damogou mine are compatible with a structurally controlled, Sedimentary-hydrothermal origin. Homogenization and last ice melting temperature of primary fluid inclusion indicate that mineralization taken place over a temperature range 295-335°C and salinities of inclusion fluids range 0.53 to 1.33 wt.% TDS. Ore-forming fluids were dominated by magmatic components in the early mineralization period. In the present paper we report our preliminary research results of the data obtained from geothermometric studies of Sphalerite and fluorite at the Naoyangping-Damogou ore deposit. The present study builds on the existing geological, petrographic and geochemical information of Naoyangping-Damogou.

Keywords: *Naoyangping-Damogou zinc-fluorite ore deposit*, *fluid inclusions*, *Pingli County, Shaanxi Province*, *China*.

I. INTRODUCTION

The Naoyangping-Damogou zinc-fluorite ore deposit was discovered in the2002s. It forms a well-known metallogenic belt in the North China craton. Previous studies focused on the geological characteristic and prospecting prospects of the Naoyangping-Damogou zinc-fluorite ore deposit (Wei D., et al. 2009 and Sun Jian et al., 2012), with the ore-forming fluids of zinc-fluorite ore deposit less studied. The Naoyangping-Damogou zinc-fluorite ore deposit is characterized by its broad veins, dense distribution of ore bodies, and continuous extension along strike. Geological surveys at shallow levels (< 190 m in depth) alone suggest that the resource is of an average size (2 millions tons of contained CaF_2). In the present paper we report our preliminary research results on the ore-forming fluids at the Naoyangping-Damogou zinc-fluorite ore deposit. The present study builds on the existing geological, petrographic and geochemical information of Naoyangping-Damogou.

II. GEOLOGICAL SETTINGS AND SAMPLES

The Naoyangping-Damogou zinc-fluorite deposit, located in the North Dabashan Caledonian fold belt at the east wing Pingli Anticlinorium (Geological Survey of Shaanxi Province, 1989, 2008). Geotectonically, the Naoyangping-Damogou Zn-CaF_2 ore deposit is located in the South Qinling orogen belt and North Dabashan belt contact zone. However, the metallogenesis of zinc-fluorite ore deposit is closely related to the northern Dabashan Mountain side. Ore bodies are hosted to the North Dabashan Caledonian fold belt in the East wing of Pingli Anticlinorium (Zhang Guowei et al., 1997; TU Huaikui, 1997; 1999 and Wei D., et al. 2009).

The Naoyangping-Damogou Zn-(CaF_2) ore deposit is occurs in small scale and has varying mineral species. Its ore-forming and ore-controlling structures are also relatively complicated. The ore-forming and ore-controlling structures of the Naoyangping -Damogou mining area are located in the North Dabashan Caledonian tectonic belt (Fig.1).

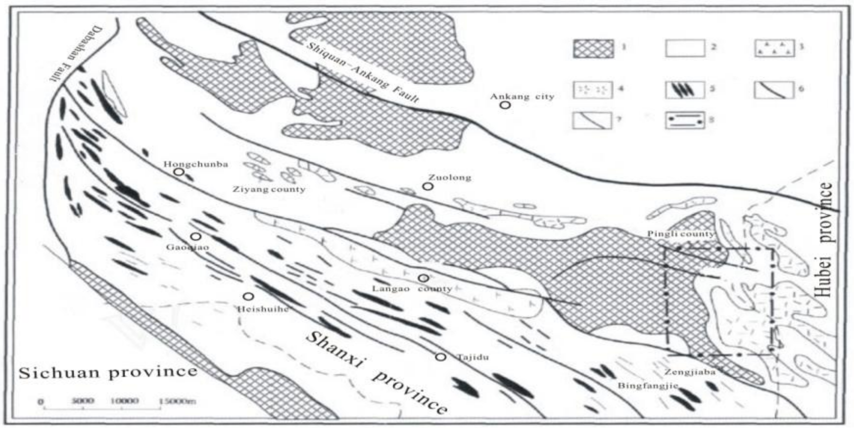

Fig.1 Regional geological tectonic sketch map of North Dabashan Mountain and study area location (Modified after Wei Dong et al., 2009)

1: Precambrian; 2: Early Paleozoic; 3: Basic overflow rocks; 4: intermediate-basic rocks; 5: Basic-ultrabasic rocks vein; 6: Main fault; 7: Secondary fault; 8: the range (scope) study area.

The region is situated within the eastern wing of Pingli Anticlinorium. This system is composed of numerous folds and faults, which generally have a north-west orientation. Two dominant faults sets are found in this region and are grouped according to their orientations, which include the nearly EW-, NW-SE, NWW-SEE and NE-SW-striking fault structures group, with the NWW-SEE fault structures being dominant. Most of the fault structures are characterized by multi-episodes activities. These fault sets appear closely associated with mineralization within the region, with several deposits commonly occurring along these faults (Fig.2). The strata in the region are dominated by the Middle Silurian Zhuxi Group (S_2zh) and Middle-Lower Silurian Meiziya Formation (S_1m), with the Lower Silurian Meiziya Formation strata is clay slate, sandy slate, carbonate-containing banded clay slate, sandy limestone and tuff sandstone. The Middle Silurian Zhuxi Group and Lower Silurian Meiziya Formation rocks are mostly distributed in the form of fault blocks because they were cut by faults and eroded and reworked by magmatic rocks. Regionally, a large area of alkali trachyte rocks is exposed in the east wing of Pingli Anticlinorium which always serves as the main ore-hosting country rocks for minerals and having an important significance in prospecting. There is generally no metallogenic control, but rocks in the Naoyangping-Damogou orefield. Magmatic activity in the Naoyangping-Damogou zinc-fluorite mining area is strong and is a part of multi-time activity of the Caledonian period into the strata. The main rock types in the orefield formed as a result of regional magmatic activities and can be divided into two main types: The first main type is basic-ultrabasic rock with low SiO_2 and the second consist of the neutral—intermediate-acidic—acidic rock with high SiO_2 (trachyte). Metallogenesis is closely related to the trachyte rock side and developed in the Naoyangping-Damogou-Jinshahe fault, and other small fault systems, which is regarded as the main ore-forming parent rock of the Naoyangping-Damogou orefield. The magmatic rocks are developed in the orefield; in space, microstructure (glass). There are two main types of magmatic rocks found in this orefield: that is: pyroxenite which is mainly located in the western part of the orefield, above the Dong-he Group, while the trachyte is to the east of microstructure (glass) pyroxenite; but to the west of Zhuxi Group. This type of distribution indicates that both microstructure (glass) pyroxenite and trachyte is stratiform feature in space. Chronologically speaking, microstructure (glass) pyroxenite is much older, while the trachyte is comparatively younger and both of them originated in early Silurian. Samples for fluid inclusion study were collected at different part of the study area and at both the top and bottom of the orebodies. Systematic fluid inclusion and isotopic geochemistry sampling was carried out based on ore and rock type, alteration, and location. A total of 11 fluid inclusions measured temperature and 14 isotopic geochemistry samples were collected (Table 1).

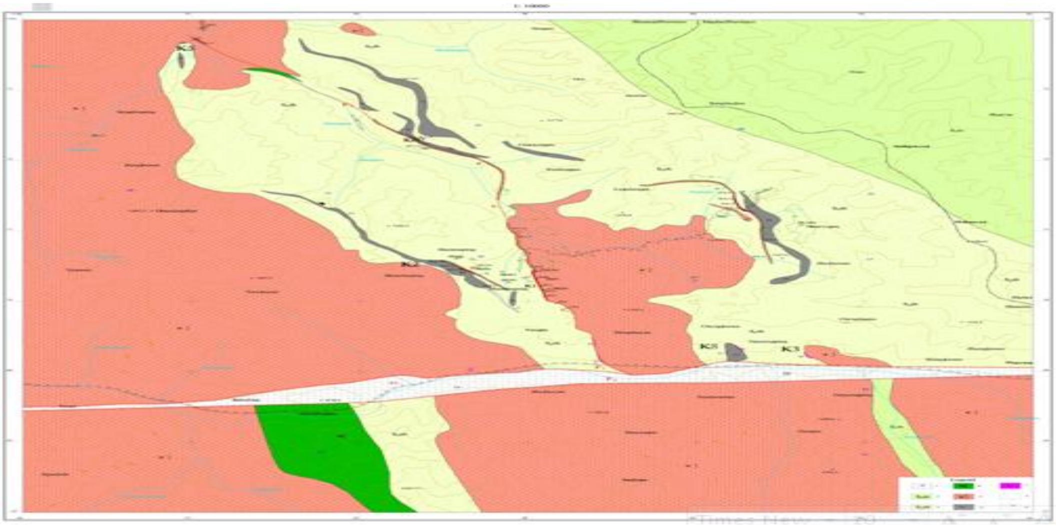

Fig.2 Geological sketch map of distribution schemes of the Naoyangping-Damogou zinc-fluorite ore deposit 1: Quaternary system (Q_4), 2: Meiziya Group (S_1m), 3: Middle Silurian Zhuxi Group (S_2zh), 4: Basic sub-volcanic rock (M^3_3 = Diabase and Gabbro), 5: Intermediate sub-volcanic rock ($\chi\tau^3_3$), 6: Limestone (Ls), 7: Fluorite orebody (F*l*), 8: Geological boundary, 9: F1: F1 fault

III. FLUID INCLUSION

3.1 Fluid inclusion petrography

Primary inclusion and secondary inclusion are easily found in the fluorite ore, and the primary inclusions are the dominant (fig.3), of which liquid-rich inclusions are the major and takes up 80 percent. Fluid inclusions with daughter mineral and fluid inclusions are rarely found, and gas inclusions are few. The shapes of inclusions are numerous, such as elliptical, nearly round, negative form, nearly triangle, and irregular form and so on, of which, the elliptical and the irregular are the dominant. The size of the inclusions fall between 5 and 25 µm, most of which between 10 and 15 µm. And most of the inclusions are distributed separately and randomly, and clustering inclusions are rarely found. Three types of fluid inclusions were identified based on their optical characteristics at room temperature, using the criteria of Roedder (1984) and phase transitions during microthermometry measurements (Fig. 3; Table 1).

Fluorite occurs as fine- to medium grained, euhedral crystals that postdate the trachyte. The fluorite crystals contain numerous two phase aqueous inclusions; rarely, gas-rich and single phase liquid-rich inclusions are present. The presence of coexisting gas- and liquid-rich inclusions is significant because this suggests that the homogenization temperatures closely approximate the true trapping temperatures (Goldstein and Reynolds, 1994). The fluorite-hosted inclusions provide the best direct measure of the temperatures reached.

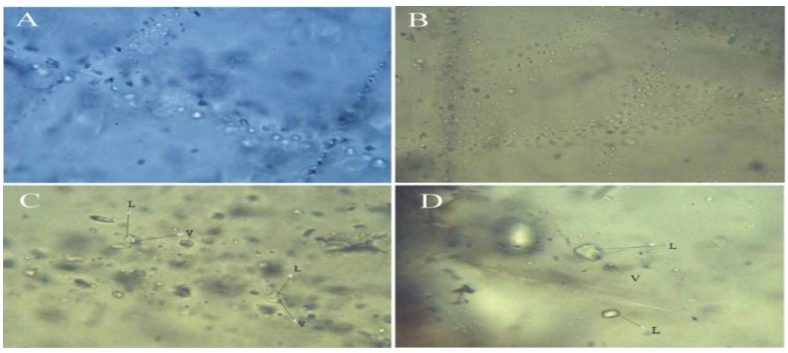

Fig.3. Different types of the Naoyangping-Damogou fluid inclusions: A & B are secondary inclusions; C & D are primary inclusions. A: Damogou K1 orebody 1085 middle section fluorite system of secondary inclusions; B: Naoyangping K3-PD10 fluorite system of secondary inclusions, C: Damogou K1 orebody 1136 middle section system of vapour- rich inclusions, and D: Damogou K1 orebody 1136 middle section system of pure liquid inclusions.

Table 1 Petrography and microthermometry for fluid inclusions in the Naoyangping-Damogou zinc-fluorite ore deposit

Sample No	Sampling location (Lithology)	Host minerals	Type of fluid inclusions	Range of Th (°C)		Phase type	Size (μm)	Gas-liquid ratios	Freezing point (°C)	Range of salinity	Density of fluid
LT01	K1-1085 middle-stage	Purple fluorite	Gas-liquid two-phase	295~335	300~320 (Damogou)	Rich-liquid phase	10~15	1:4	-0.3~ -0.8	0.53~1.33	0.658~0.663
						Pure gas phase	10				
LT03	K1-1136 middle-stage	White fluorite	Gas-liquid two-phase			Rich-liquid phase	5~15	1:8			
						Containing a daughter L+V+S	10~15	1:5			
						Pure liquid phase	10				
LT04	K1-1136 middle-stage	White fluorite	Gas-liquid two-phase			Rich-liquid phase	10~15	1:6			
LT05	K1-open pit	White fluorite	Gas-liquid two-phase	310~340		Rich-liquid phase	5~15	1:8			
LT06	K1-open pit	White fluorite	Gas-liquid two-phase			Rich-liquid phase	5~10	1:8			
LT09	K3-PD10	Purple fluorite	Gas-liquid two-phase		289~329 (Naoyangping)	Rich-liquid phase	5~10	1:8			
						Containing a daughter L+V+S	10				
LT10	K3-PD10	Purple fluorite	Gas-liquid two-phase			Rich-liquid phase	5~10	1:6			
						Containing a daughter L+V+S	15				
						Containing a daughter L+ S	10~25				
LT11	K3-PD10	Purple fluorite	Gas-liquid two-phase	289~329		Rich-liquid phase	5~15	1:6			
						Containing a daughter L+S	10				

L= liquid monophase, V= gas (vapour) monophase, L+V = rich liquid phase, L+V+S = liquid (L) + vapour (V) + solid (S) multiphase inclusions containing solids- contain solid crystalline phases known as daughter minerals, and L+S= rich liquid.

3.2 Microthermometry

Fluid-inclusion studies were performed on doubly polished fluorite samples taken from the mineralization area. Micro thermometric determinations were carried out using a Linkham TH600 heating and cooling stages of the State Key Laboratory of Continental Dynamics of Northwest University, Department of Geology, Xi'an (China). The heating rate during the phase transitions was controlled manually in the range of 5 to 15°C min^{-1}. Repeated measurements indicated that the reproducibility of the temperature determinations was better than ± 0.5 °C.

The majority of the fluid inclusions range in size from 5 to 15 μm. All of the investigated fluorite samples contain primary and secondary fluid inclusions using the definition of Roedder (1984). Primary fluid inclusions are observed as oval to triangle in regular, irregularly isolated or in groups along the fracture planes. Both primary and secondary fluid inclusion populations are dominated by four-phases comprising rich-liquid, pure liquid, pure gas and Containing a daughter liquid (L+V+S). Secondary fluid inclusions are characterized by spherical to square shapes that generally developed along two distinct fracture systems and have different morphological and micro thermometric properties. The homogenization temperatures (*T*h) of fluid inclusions were measured in 8 fluorite samples. The micro thermometric measurements on fluid inclusions in primary and secondary fluid inclusions showing that the Damogou fluorites were formed at temperatures range from 295°C to 335°C and 289°C to 329°C in Naoyangping area (Fig.4; table1). Fluid inclusions in fluorite contain major amounts of multi-phase inclusions containing solids-contain solid crystalline phases and sulfate-bearing daughter minerals. The Damogou inclusions, in general, are dominated by fluids that have low salinities and low densities. These inclusions, therefore, homogenize at moderate temperatures and their freezing point values indicate salinities ranging from -0.3°C to -3.3° C (Fig.5; table1). Homogenization temperatures of all these fluid inclusions in Naoyangping-Damogou are mostly in the range of 289°C to 340°C. The salinities of three types of inclusions varies remarkable and with low salinity from 0.53wt% -1.33wt% NaCl equivalent in NaCl daughter mineral bearing ones. This temperature range approximately corresponds to the main stage of hydrothermal mineralization.

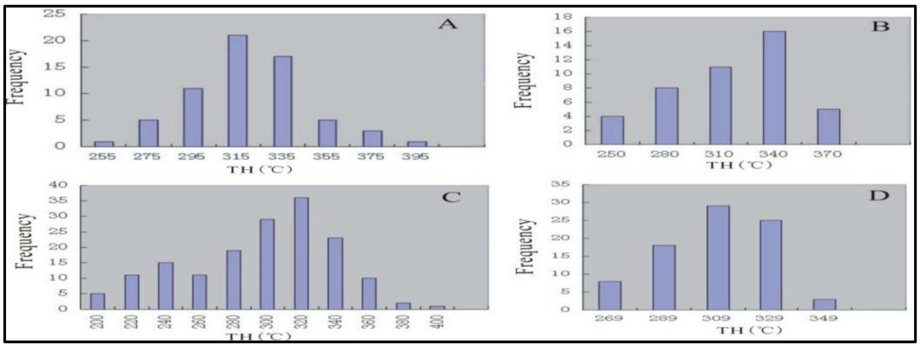

Fig.4 Histogram of fluid inclusion microthermometry of primary and secondary inclusions in the Naoyangping-Damogou ore deposit. A: TH of fluid inclusions in Damogou K1 orebody 1085; B: TH of fluid inclusions in Naoyangping K3 orebody, C: TH of fluid inclusions in Naoyangping K3 orebody, and D: TH of fluid inclusions in Naoyangping K3 orebody PD10. The data for the figures are from this study.

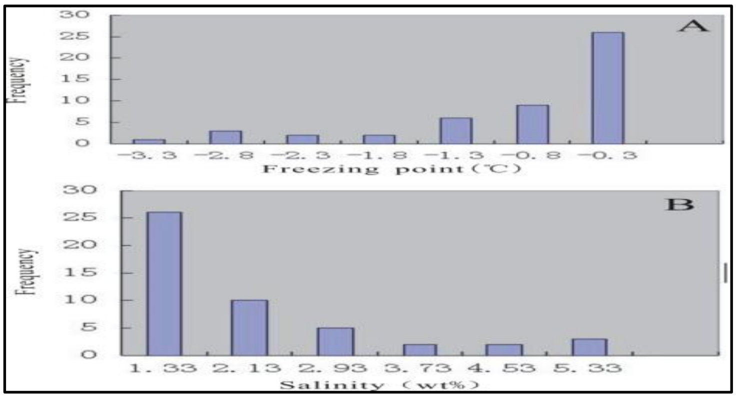

Fig. 5 Freezing point temperature and salinity of the Naoyangping-Damogou fluorite ore deposit. A. Freezing point temperature Damogou fluorite deposit and B: salinity of the Damogou fluorite deposit.

IV. OXYGEN AND HYDROGEN ISOTOPES

Oxygen and hydrogen isotopes analysis data were carried out by Geological survey of Shaanxi Province in the mining area, using MAT-252 mass spectrometer with standard mean ocean water (SMOW) is showed in the Fig.6. This figure illustrates the relative positions in Craig's diagram of H/O-isotopic of various fluid inclusions in fluorite from the Naoyangping-Damogou mining area. For comparison, there are also shown the analytical results for pyrite and sphalerite occurring in magmatic rocks from the same locality. From this figure we can see:

The fluids phase of inclusions in all fluorites and zinc occurring in magmatic rocks shows relatively large negative δD of the fluid inclusions hosted by pyrite in fluorite range between -115‰ and -95‰ and small positives $\delta^{18}O$ values (fluid inclusions hosted by fluorites range between 5‰ to 11‰). The relevant data points fall around the magmatic water line in Craig's diagram, suggesting that these fluorites, in spite of their occurrence in magmatic rocks, resulted from the magmatic water at the late stage.

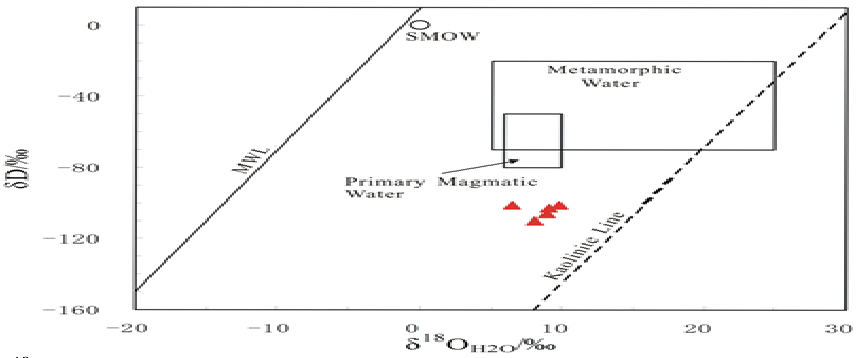

Fig.6 δD and $\delta^{18}O$ characteristics of the fluid inclusion water at Naoyangping-Damogou ore deposit (After: Geological Survey of Shaanxi Province, 2009).

From the Taylor (1974) δD-δ^{18}O isotopic diagram (Fig.5), fluids of the early period plot in and below the box for magmatic fluids. This suggests that early period fluids were derived only from primary magmatic water. The relevant points of ore-forming materials were derived mainly from deep-source magmas which had been brought about the alkali trachyte and Middle Silurian Zhuxi group from the deep interior. This indicates that for the hot-water sedimentary fluorite deposits of the ore-forming fluids were predominantly formation water or mixed water. It appears that while volcanism furnished abundant F for the formation of hot–water sedimentary fluorite deposits, volcanic hydrothermal solutions were also involved in the fluorite formation. As for the genetic type, the Naoyangping-Damogou is a strata-bound sedimentary-hydrothermal fluorite deposits associated with zinc-lead deposit.

V. ACKNOWLEDGMENTS

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