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Geochemical Characteristics of Fluid Inclusions and Isotopes in Zhazixi Sb-W Deposit

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ABSTRACT

Zhazixi Sb–W deposit, where Sb and W coexist in different orebodies, features a unique metal association between the two minerals. This study aims to analyze the respective sources of Sb and W, through temperature measurement of fluid inclusions, laser-based Raman spectroscopy, as well as isotope test. The ore-forming fluid of Zhazixi Sb-W deposit was found to be a CO_2-N_2-H_2O-NaCl system, which is rich in CO_2 and N_2. N_2-rich inclusions and C, H, O isotopes were observed, indicating that the ore-forming fluid mainly comes from deep magmatic rocks, and secondarily from the metamorphic hydrothermal fluids. The detected S and Pb isotopes suggest that the ore-forming material stems from multiple sources. After comprehensive analysis of the geological features of the deposit and the local region, we believed that the Sb in Zhazixi Sb-W deposit stems from Banxi group, but W comes from the concealed rock body. The results provide a theoretical basis for the metallogenic research and prospecting direction of Xuefengshan metallogenic belt.

1. INTRODUCTION

Zhazixi Sb-W deposit, a part of southern China's Xuefengshan metallogenic belt, is a typical Sb deposit in Precambrian strata. In the deposit, Sb and W coexist in different orebodies, and display a unique metal association. In fact, the deposit is located in the intersection between Xuefengshan metallogenic belt and the NW-trending Xinhua-Lianshao regional fault. To the east of the regional fault lies a world-class Sb deposit called Xikuangshan Sb deposit (about 2 million tons). Since it was discovered in 1906, Zhazixi Sb-W deposit has been utilized as a producing area of Sb orebodies. In 1990, the total Sb reserve in the deposit was proved to be 112,700 tons. In 2007, new Sb resources were discovered in the deep and edge parts. Apart from Sb, Zhazixi deposit boasts an abundance of W, the reserve of which is predicted to be 165,000 tons.

The research of Zhazixi Sb–W deposit is important to the development of Sb deposits, Sb-W deposits, and Sb-Au deposits in Xuefengshan metallogenic belt and Central Hunan Province. The previous studies on Zhazixi Sb–W deposit [1-6] mainly focus on the geological features, ore control factors, and metallogenic epoch, but rarely discuss about the sources of ore-forming material. Besides, the research about the respective source of Sb and W is virtually blank.

Drawing on the previous research, field observations, and regional mineral / geologic features, this study explores the lithology and Sb content of the strata in Zhazixi Sb-W deposit, as well as wall rock alteration, mineralization features, orebody features, fluid inclusions, and C, H, O, S, Pb isotopic compositions, with the aim to reveal the ore-forming process, identify the control factors of mineralization, and clarify the sources of Sb and W. The research results provide a new reference for ore search in Xuefengshan metallogenic belt.

2. OVERVIEW OF STUDY AREA

Zhazixi Sb–W deposit is situation in the northeastern part of Xuefengshan metallogenic belt, where the Xuefeng uplift trends to the northeast from the east (Figure 1). Most of the outcrops in the deposit belong to Banxi group strata, Cambrian strata, and Devonian strata. The principal ore-hosting strata is Banxi group, a suit of clastic rocks containing volcanic material.

The study area has gone through Xuefeng movement, Jinning movement, Caledonian movement, Hercynian movement, Indo-China movement, and Yanshannian movement. The geological structure of the area trends to the northeast. The imbricating NE folds and faults together form the fault-block modes. The deposit (pit) distribution in the region is jointly controlled by regional faults and Banxi group.

In Xuefengshan metallogenic belt, the magmatic rocks distribute unevenly. Granite bodies and dikes appear in the north and east, while few mafic-ultramafic dikes exist elsewhere. Many Au deposits (pits), Sb deposits (pits) and W deposits (pits), including some super large deposits, and even world-class deposits, have been found in this belt. The Sb deposits fall into three categories: single Sb deposits (e.g., the world-class Xikuangshan Sb deposit), Sb-W deposits (e.g., Zhazixi Sb–W deposit), and Sb-Au-W deposit (e.g., the super large Woxi Sb-Au-W deposit).

The large faults in the region control the distribution of ore zones or ore fields. The secondary brittle faults control the range of ore deposits. In addition, the local interlayer fractures and fault fractures control the sites of the orebodies. Overall, the deposits spread in the NE direction. There are two types of deposits: fissure filling deposits, and interlayer facture zone deposits.

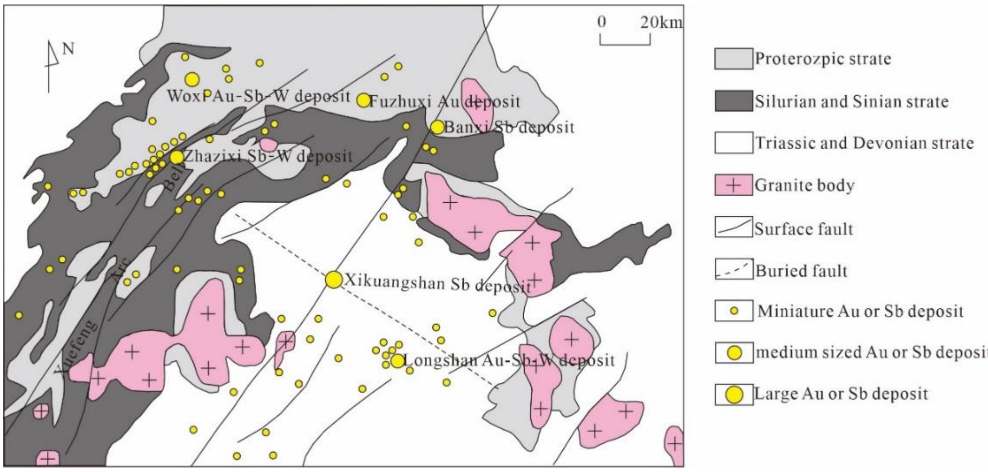

Figure 1. Geological map of the study area

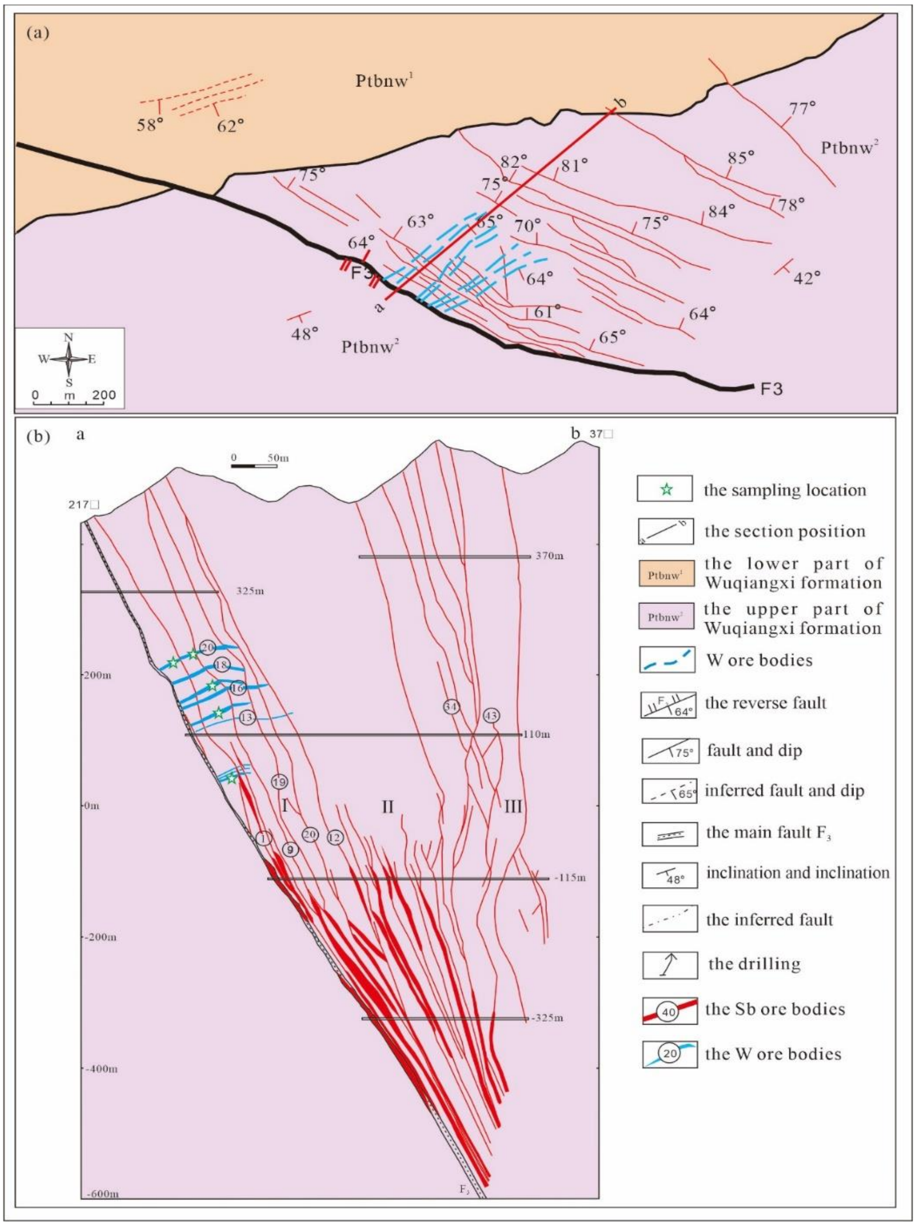

Figure 2. Geological map and sectional drawing of Zhazixi Sb-W deposit

3. GEOLOGICAL FEATURES

3.1 Strata features

The ore-hosting strata is Wuqiangxi Formation of Banxi group. This 1,085.26-1,533.5m-thick formation is a suit of low-metamorphic sandstones, containing volcanic materials. According to age, particle size, color, and composition, Wuqiangxi formation can be further divided into a lower part ($Ptbnw^1$), and an upper part ($Ptbnw^2$). The lower part is composed of silty slate, greywacke, quartz sandstone, tuffaceous sandstone, and tuffaceous siltstone. The top of this part is tuffaceous siltstone or tuffaceous slate; The total thickness is greater than 500m.

The 1,220m-thick upper part is the main ore-bearing horizon of Sb and W (Figure 2). It can be split into four lithologic layers: The first layer contains quartzite sandstone, greywacke, or tuffaceous sandstone, which are intercalated with tuffaceous slate, slate, and a small amount of unstable tuff. The second layer mainly encompasses tuffaceous slate, locally silty slate, with a mixed layer of stable tuff, unstable tuffaceous siltstone, and tuffaceous sandstone in the middle and upper portions. The third layer mostly consists of tuffaceous sandstone and greywacke, intercalated with tuffaceous slate, tuffaceous siltstone, and sandy slate. The fourth layer involves tuff, laminated tuffaceous slate and tuffaceous siltstone, plus a layer of stable tuff.

In the mining area, Sb orebodies mainly occur in the first, second and third lithologic layers.

3.2 Structural features

Wuqiangxi formation takes the form of a monoclinic fold with a steady attitude. Zhazixi Sb–W deposit is dominated by interlayer fractures and NW-trending faults (Figure 2). The interlayer fractures are composed of slip interfaces along the boundary between the thick-bedded sandstone and tuff, and the secondary joint fissures in the thick-bedded sandstone. The NW-trending faults consist of the F_3 fault and its secondary faults on the hanging wall.

The F_3 fault extends for about 2.6 km along 295° and dips toward the northeast with a dip angle ranging between 52° and 80°. This fault is featured by horizontal and vertical sinistrally reverse-movements with 80m displacements, as well as the development of stibnite. Secondary faults are generally NW trending and converge in the depth of the F_3 fault. In the facture zone of the F_3 fault, Sb mineralization occurs in varying degrees. In some sections, the Sb grade reaches more than 4% [5]. Right-hand reverse translation is a general property of the F_3 fault. The distance of the right-hand horizontal fault can reach 80m, while that of the vertical fault falls between 62m and 88m.

3.3 Orebody features and wall rock alteration

In Zhazixi deposit, W and Sb mineralization is controlled by different structures, each of which carries different mineralization features. The Sb orebodies, which are hosted by the secondary faults on the hanging wall of the fault F_3, mainly encompass quartz and stibnite veins. Sb mineralization strikes 290°–330° NWW, dips 55°-88° NE to NNE, and exhibits reversed horse-tail structures in a representative cross section and occurs in groups (Figure 2). In the shallow part, the Sb orebodies are sparse, thin, and widely spaced. In the deep part, these orebodies are dense, thick, and narrowly spaced. All Sb orebodies converge towards the deep site of the F_3 fault. Lateral Sb orebodies are also arranged regularly. The density of these orebodies increases with the proximity to the fault (Figure 2). The F_3 fault is also mineralized with stibnite, suggesting its role as a conduit for Sb-bearing fluids.

In contrast, the W orebodies are jointly controlled by lithology and structure, especially by lithology. These orebodies, which are nearly perpendicular to the Sb vein, are restricted to the interlayer fractures, and dominated by scheelite and quartz veins. The W-bearing fractures are often developed in tuffaceous sandstone and quartz sandstone in the third lithologic layer of the upper Wuqiangxi formation. To date, 11 economic W orebodies have been discovered above the -160 m level within a 10–250 m wide zone on the hanging wall of the F_3 fault. The W orebodies mainly occur as lenses and usually run parallel to the wall rocks, with striking 20°–58° NE and dipping 57°–69° SE. In general, the W orebodies are 30–200m long along the strike, spreading obliquely to a depth of 320 m along the plunge. Some angular wall rock breccias have also been discovered in the W orebodies (Figure 3). In addition, the W orebodies in Zhazixi Sb–W deposit are offset by the NW-trending Sb mineralization (Figure 2).

On both sides of Sb orebodies, the surrounding rock alteration is mainly developed in the range of several millimeters to tens of centimeters. The dominant type of alteration is silicification, followed by pyritization, discoloration, and chloritization. Silicification is closely related to Sb mineralization. The surrounding rock alteration of W orebodies is silicification, with occasional carbonation. The alteration is not obvious or in the range of several centimeters.

3.4 Natural types and textures of ores

Quartz vein is the natural type of sb ores and W ores. Macroscopically, the W ores are formed earlier than Sb ores. According to the mineral assemblage, the W ores can be divided into two natural types, namely, quartz scheelite ore (the main type), and quartz stibnite scheelite ore. In comparison, the Sb ores belong to one type only: quartz stibnite ore.

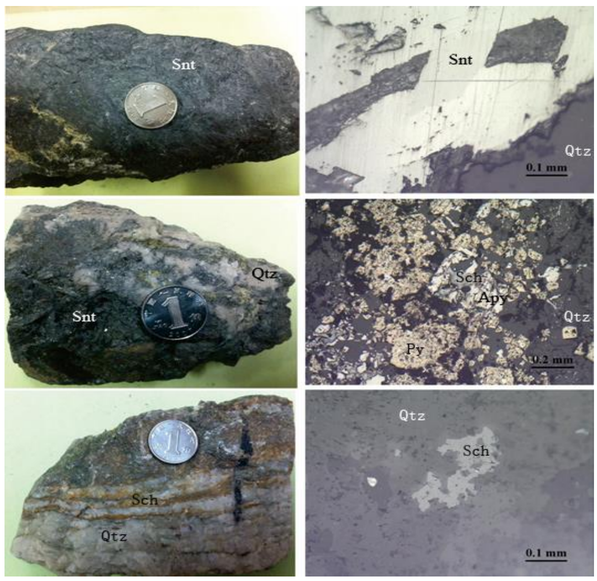

Figure 3. Manual specimens and microscopic images of Sb and W ores in Zhazixi Sb-W deposit (Qtz- Quartz; Snt- Stibnite; Sch- Scheelite; Apy- Arsenopyrite; Py-Pyrite)

Judging by mineral assemblage, ore structure, and mineral interspersion, the mineralization of Zhazixi Sb-W deposit goes through four stages: the quartz scheelite stage, quartz stibnite scheelite stage, quartz stibnite stage, and quartz carbonate stage. The possible ore structures of stibnite and scheelite are disseminated, veinlet, veinlet disseminated, breccia, lump, mottled, etc. The two minerals are respectively stored in the ore-hosting quartz vein. For stibnite, the main metal minerals are stibnite, and pyrite, plus a small amount of natural gold (Figure 3). For W ores, the metal minerals are mainly scheelite (Figure 3), a small amount of stibnite, pyrite, trace wolframite, sphalerite, etc. Gangue minerals include lots of quartz, and a small amount of carbonate minerals.

4. FEATURES OF FLUID INCLUSIONS

4.1 Sample collection and testing method

A total of 40 samples were collected manually from the underground exposures of Zhazixi Sb–W deposit. Based on the output features and observation results of the manual samples, 23 samples were selected and ground into thin sections. Then, the fluid inclusions were observed petrographically. Based on the observation results, samples were selected for temperature measurement, and soaked and cleaned with acetone. Finally, homogenization freezing was implemented to measure temperature, and analyze compositions.

We examined the fluid inclusions in scheelite and quartz, which that coexists with scheelite and stibnite. Micro-thermometric measurements were performed in the Analysis and Test Center of Beijing Research Institute of Uranium Geology, using a Linkam THMSG 600 programmable heating/freezing stage mounted on aLeica DM2500 P microscope. The uncertainty of the temperature measurements was approximately ±0.2℃ below 50℃ and ±2℃ above 100℃. The heating was carried out at the rate of 0.1℃/min, aiming to approach the ice-melting and homogenization temperatures. The compositions of the selected fluid inclusions were determined in the Analysis and Test Center of Beijing Research Institute of Uranium Geology, using a LabRam HR800 laser-based Raman spectrometer.

4.2 Fluid inclusion petrography

Three different fluid inclusions were distinguished in the quartz from Zhazixi Sb–W deposit (Figure 4), according to the phase behavior at room temperature and the change of fluid inclusions during the temperature measurement: the liquid-rich two-phase saline water inclusions (NaCl-H_2O inclusions), the CO_2-bearing three-phase inclusions (CO_2-H_2O-NaCl inclusions), and the N_2-rich inclusions (N_2-H_2O-NaCl inclusions).

NaCl-H_2O inclusions are composed of liquid water (L_{H2O}) and gaseous water (V_{H2O}) at room temperature. The gas-liquid ratio is 5-30%, mostly 8-10%. The diameter falls in 6-46μm, mostly 6-20μm. The shape is mostly elliptical, polyhedral, rice-shaped, or irregular. These inclusions are often distributed in large or small groups, or associated with other single-phase inclusions. They form the largest type of inclusions in Zhazixi Sb deposit, accounting for about 85%.

CO_2-H_2O-NaCl inclusions are composed of liquid water (L_{H2O}), liquid CO_2 (L_{CO2}), and gaseous CO_2 (V_{CO2}). At room temperature, only liquid water and gaseous CO_2 exist. When the temperature is cooled to about 10℃, both gaseous and liquid CO_2 would appear. The diameter of these inclusions falls in the range of 3-20μm in diameter, mostly 5-16μm. The shape is mostly oval and rectangular. Often associated with other types of inclusions, CO_2-H_2O-NaCl inclusions are secondary inclusions in Zhazixi Sb deposit, accounting for about 10%.

N_2-H_2O-NaCl inclusions are composed of liquid water (L_{H2O}), and gaseous N_2 (V_{N2}). The composition remains basically unchanged, when the temperature is cooled down to -196℃. For CO_2 and CH_4, the ice point is -56.6℃ and -182.5℃, and the supercritical temperature is 31.2℃ and -82.6℃, respectively. When these inclusions are cooled to -196℃, both CO_2 and CH_4 will change into the solid phase. According to the laser-based Raman spectroscopy, N_2 is the only gaseous component of N_2-H_2O-NaCl inclusions. In addition, the gas-liquid ratio of these inclusions is at least 65%. With a diameter between 10 and 30μm, N_2-H_2O-NaCl inclusions are independent of each other.

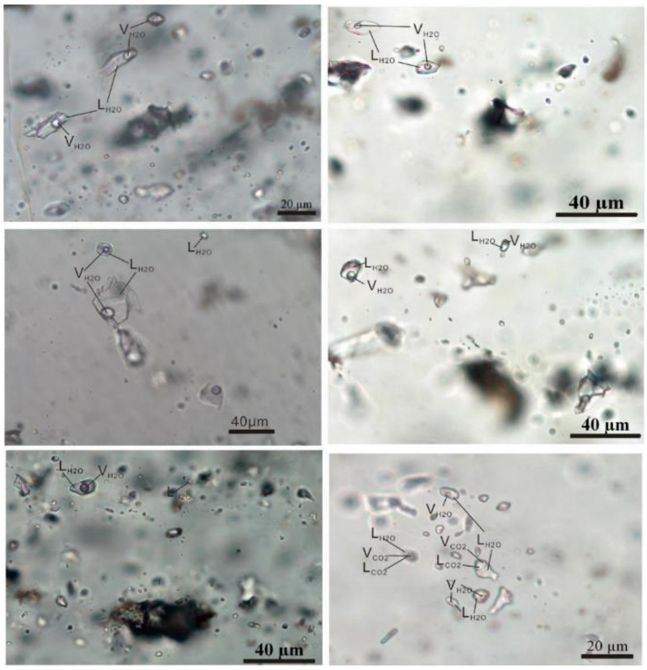

Figure 4. Microphotograph of quartz fluid inclusions of Zhazixi Sb-W deposit (L_{H2O}-liquid water; V_{H2O}-gaseous water; L_{CO2}-liquid CO_2; V_{CO2}-gaseous CO_2)

4.3 Laser-based Raman spectroscopy

The three kinds of fluid inclusions were subjected to laser-based Raman spectroscopy. In this way, the gas composition was identified (Figure 5). For the fluid inclusions in quartz I, the vapor bubbles exhibited a strong signal of H_2O in 3,431 cm^{-1}, 3,423 cm^{-1} and 3,452 cm^{-1}, a weak signal of CO_2 in 1,287 cm^{-1} and 1,389 cm^{-1}, and a weak signal of N_2 in 2,331 cm^{-1}. Thus, the gas components of NaCl-H_2O inclusions are mostly H_2O, with a few CO_2 and N_2. For the fluid inclusions in quartz II, the vapor bubbles showed a strong signal of CO_2 in 1,286 cm^{-1}, 1,287cm^{-1} and 1,389cm^{-1}, indicating that the gas components of CO_2-H_2O-NaCl inclusions are all CO_2. For the fluid inclusions in quartz III, the vapor bubbles displayed a strong signal of N_2 in 2,329 cm^{-1}, suggesting that the gas components of N_2-H_2O-NaCl inclusions are all N_2.

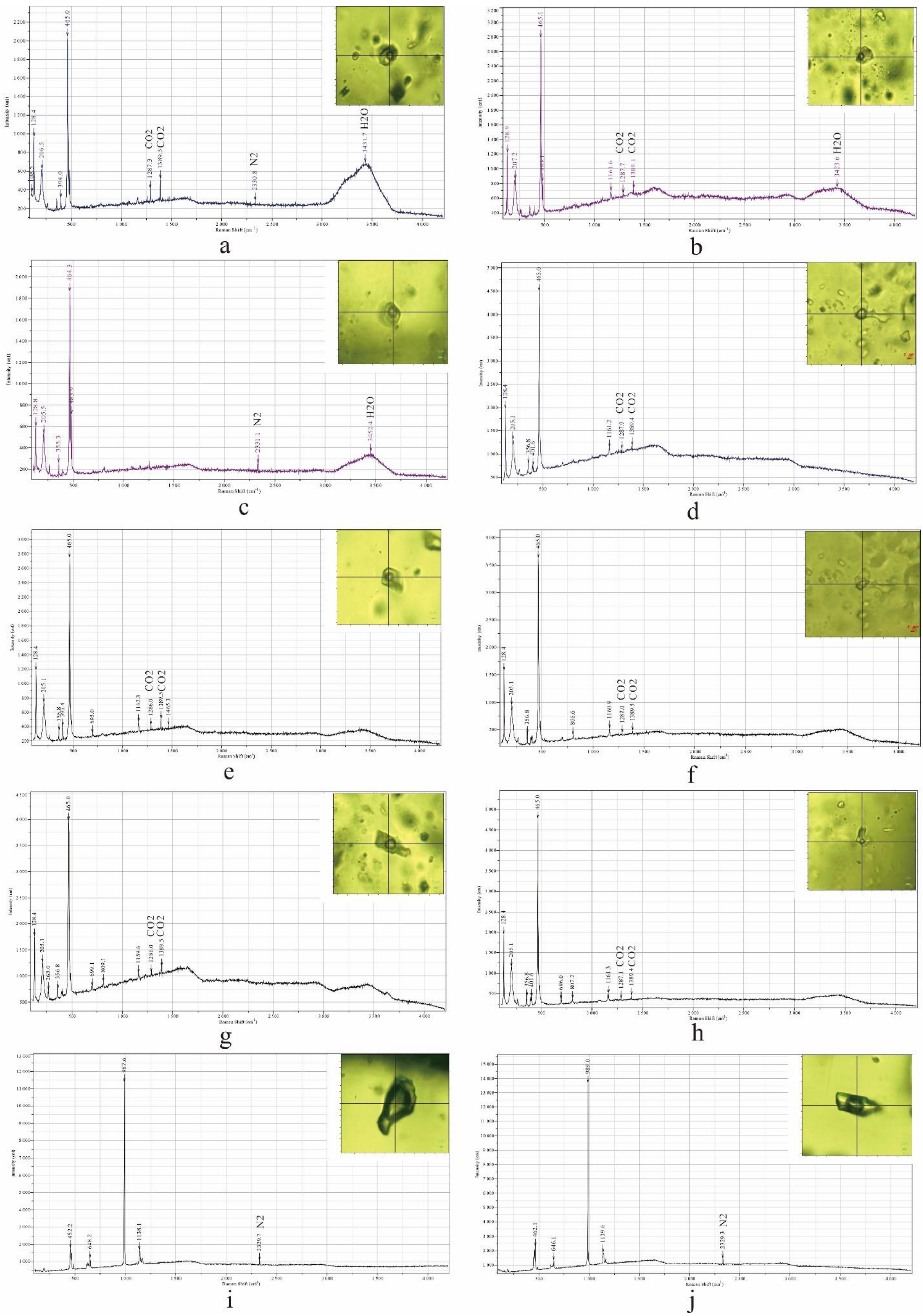

Figure 5. Laster-based Raman spectrogram of fluid inclusions of Zhazixi Sb-W deposit

4.4 Microscopic temperature measurement

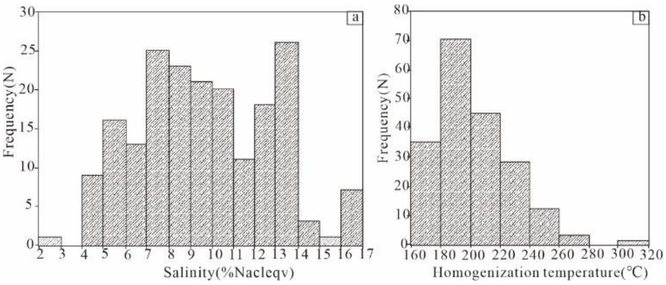

Figure 6. Histogram of salinity and homogenization temperature of fluid inclusions of Zhazixi Sb-W deposit

As shown in Figure 6, the salinity of fluid inclusions was 2.57%-6.34%NaCleqv with two peaks: 7%-8%NaCleqv and 13%-14%NaCleqv. The homogenization temperature stood at 161-300°C, peaking in 180-200°C.

4.5 Metallogenic pressure and depth

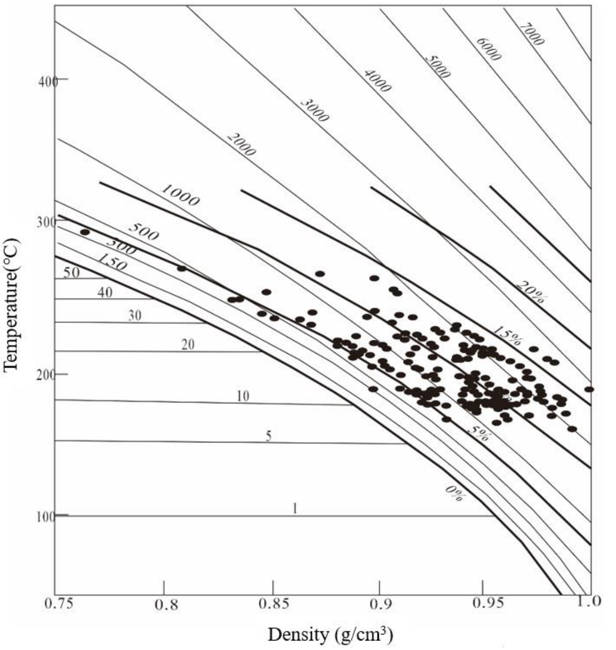

Figure 7. D-T-P diagram of fluid inclusions of Zhazixi Sb-W deposit

Figure 7 shows the relationship between homogenization temperature, density, and pressure (D-T-P) of NaCl-H_2O system. It can be observed that the pressure in metallogenic stage is approximately 500×10^5-$2{,}000\times10^5$Pa. Since the ground pressure gradient is 270×10^5Pa/km, and the standard atmospheric pressure is 1.013×10^5Pa, the metallogenic depth can be estimated to as 1.9km-7.4km, belonging to the middle-shallow level.

5. ISOTOPE FEATURES

5.1 Sample collection and analysis method

All samples were manually collected from underground exposures of the Zhazixi Sb–W deposit. The polished blocks and thin sections were examined through reflected and transmitted light microscopy in the Test Center of Beijing Research Institute of Uranium Geology, aiming to characterize the mineralogy, textures, and mineral paragenesis of these samples.

(1) C, H, O isotopic analyses

To test H isotopes, the water of fluid inclusions was taken by the decrepitation method. Each sample was put into a high-temperature resistant vessel. The vessel was pumped into a vacuum for heating. Once the temperature rose to the burst temperature, the inclusions would burst. After the explosion, the released H_2O was collected, and reacted with metal zinc as reducing agent to produce hydrogen. To test O isotopes, strong oxidant BrF_5 was used to oxidize the inclusions, and pure O_2 was collected from quartz to make CO_2. To test C isotopes, the 100% phosphoric acid method was employed.

The C, H and O isotopic compositions were measured by MAT-253 mass spectrometer in the Test Center of Beijing Research Institute of Uranium Geology. The H and O isotopes were measured against the standard mean ocean water (SMOW) scale, while C isotopes were measured against the Pee Dee Belemnite (PDB) standard. The accuracy of C, H, O isotope analyses is ±2‰.

(2) S isotopic analyses

With Cu_2O as oxidant, each sample reacted with sulfide single mineral to produce SO_2. The gas was collected by freezing, and determined by MAT-251 mass spectrometer. The S isotopes were measured by the Vienna Cañon-Diablo Troilite (VCDT) scale, with an analysis accuracy of ±0.2‰.

(3) Pb isotopic analyses

Each sample was dissolved and separated, under the relative humidity of 36% and room temperature of 20°C. According to the *Determinations for isotopes of lead, strontium and neodymium in rock samples* (GB/T17672-1999), the lead isotope ratio was measured by an IsotopX IsoProbe-T thermal ionization mass spectrometer (GV Instruments, Britian). The results were corrected by The NBS981 standard. The measuring error was smaller than 2σ.

5.2 S and Pb isotopes

As shown in Table 1, the $^{34}S_{V\text{-}CDT}$ values of stibnite ranged from -2.6‰ to 3.5‰, and averaged at 1.1‰.

Table 1. S and Pb isotopes in the Zhazixi Sb-W deposit

Sample number.	Simple mineral	$\delta^{34}S_{VCDT}$‰	$^{206}Pb/^{204}Pb$	$^{207}Pb/^{204}Pb$	$^{208}Pb/^{204}Pb$
ZZX01	Stibnite	2.1	18.575	15.619	38.753
ZZX02	Stibnite	3.5	18.079	15.624	38.591
ZZX03	Stibnite	2.2	18.157	15.625	38.167
ZZX04	Stibnite	0.3	18.815	15.674	38.928
ZZX05	Stibnite	-2.6	18.186	15.616	38.324

Table 2. C, H and O isotopes in the Zhazixi Sb-W deposit

Sample number.	Simple mineral	$\delta^{13}C_{PDB}$‰	$\delta D_{V\text{-}SMOW}$‰	$\delta^{18}O_{V\text{-}SMOW}$‰	$\delta^{18}O_{H2O}$‰
ZZX01	Quartz	-5.1	-68	17.9	6.2
ZZX02	Quartz	-4.7	-57	19.1	7.4
ZZX03	Quartz	-2.3	-49	15.2	3.5
ZZX04	Quartz	2.1	-56	17.3	5.6
ZZX05	Quartz	0.8	-78	18.2	6.5

5.3 C, H and O isotopes

As shown in Table 2, the $\delta^{13}C_{PDB}$ values of quartz-stibnite veins ranged from -5.1‰ to 2.1‰, with an average of -1.84‰. The δD_{H2O} values of quartz-stibnite veins ranged from -49‰ to -78‰, with an average of -61.6‰. The $\delta^{18}O_{quartz}$ values of quartz-stibnite veins ranged from 15.2‰ to 18.2‰, with an average of 17.54‰. The $\delta^{18}O_{H2O}$ values of quartz-stibnite veins ranged from 3.5‰ to 7.4‰, with an average of 5.84‰.

6. DISCUSSION

6.1 Sources of mineralization fluids

Many researchers have studied the ore forming fluid extensively, focusing on Sm-Nd isotope and Sr isotope in scheelite, and He and Ar isotopes in stibnite. Different results were drawn by these predecessors. For example, Peng et al. [1] discovered the high radio genic Sr, classified the Nd isotopes in scheelite samples to two groups based on initial composition, and proposed two possible sources of the ore forming fluid: the clastic rocks of Proterozoic sequence or underlying terrigenous basement; the basic/ultrabasic rocks of Lengjiaxi group. Wang et al. [3] found that the initial composition of Nd isotope in scheelite samples is consistent with that in Banxi group, and traced the ore forming fluid to Proterozoic strata or older strata. Zeng et al. [4] explored He and Ar isotopes in stibnite, and held that the ore forming fluid comes from the crust. In this study, the ore-forming fluid is a CO_2-N_2-H_2O-NaCl system fluid with a medium to low temperature and a low salinity. The N_2-rich inclusions are discovered earlier than other types of inclusions in the deposit. To understand the properties of ore-forming fluid, it is significant to clarify the source of the N_2-rich inclusions.

The previous studies have shown that N_2 is an important component of low-metamorphic sedimentary rocks, granulite, and eclogite [7-14]. Covering a large area, the low-metamorphic sedimentary rocks have an abundance of organic carbon, and provide a large amount of N_2. However, the organic matter of these rocks will decompose in a low-grade metamorphic environment, producing a low-grade metamorphic fluid dominated by N_2 and CH_4. To date, CH_4 has not been found in the fluid inclusions of the deposit. Thus, N_2 cannot be derived from the shallow metamorphism of the surrounding rocks.

So far, N_2-rich inclusions have only been found in ultra-high pressure metamorphic fluid. For instance, inclusions with 0-100mol% N_2 and pure N_2 were discovered in spinel pure peridotite xenoliths in Lanzarote, Canary Islands [15]. Therefore, N_2 in fluid inclusions of the deposit may come came from deep materials.

The C isotope is a tracer of ore-forming fluids, because it remains almost the same during the diagenetic process. Previous studies have attributed the C isotope in ore-forming fluid to three sources: (1) the upper mantle or magmatic rocks, ranging from -5‰~-2‰ to -9‰~-3‰ [16]; (2) the degassing of carbonate rocks or the interactions of brine with perlite, ranging from -2‰ to +3‰ [17]; (3) the organic carbon in rocks, ranging from -30‰ to -15‰ [18]. Our analysis shows that the C isotopes of Zhazixi Sb–W deposit (-5.1‰~2.1‰) have a similar composition as the upper mantle and magmatic rocks. As shown in Figure 8, the C isotopic fluid inclusions in quartz bear resemblance to the C isotopic composition of diamond and carbonatite rocks, and differ significantly from organic carbon. Thus, the carbon in the Zhazixi Sb–W deposit should come from deep magmatic rocks.

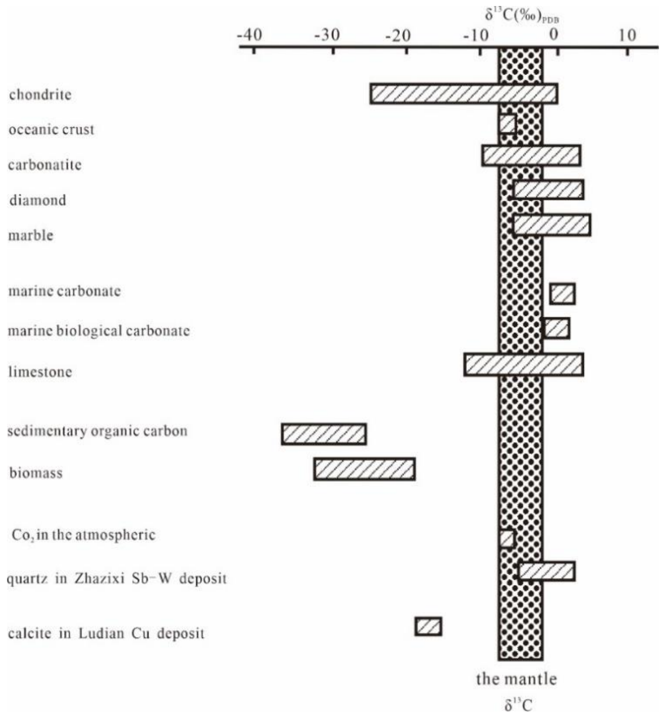

Figure 8. Composition of C isotopes in Zhazixi Sb-W deposit

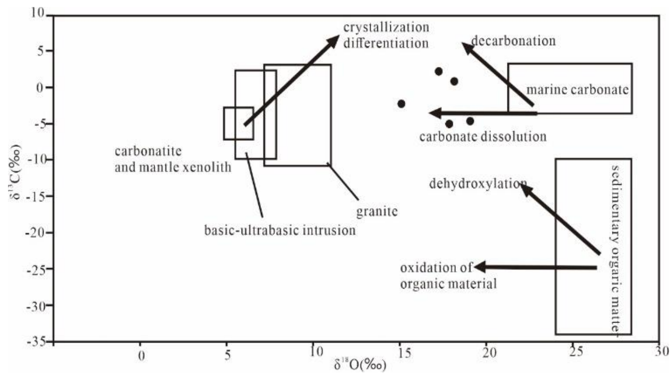

Figure 9. $\delta^{18}O_{H2O}$-$\delta^{13}C_{PDB}$ isotopes compositions in granite vein fluid of Zhazixi Sb-W deposit

Figure 9 shows the compositions of $\delta^{18}O_{H2O}$-$\delta^{13}C_{PDB}$ isotopes in granite vein fluid of Zhazixi Sb-W deposit. The range of C and O isotopes from the upper mantle or magmatic rocks, marine carbonates and organic carbon are presented, and the change trend of each source is indicated by an arrow. It can be seen that the C isotopes in the ore-forming fluid of Zhazixi Sb-W deposit mostly come from the mantle, while a few is formed by the dolomitization of marine carbonate. According to the δD_{SMOW}-$\delta^{18}O_{SMOW}$ (H_2O) isotopes compositions (Figure 10), the samples of the Zhazixi deposit are mostly plotted as magmatic water. Based on these results, the thermal fluids associated with mineralization must stem from magmatic water and metamorphic water.

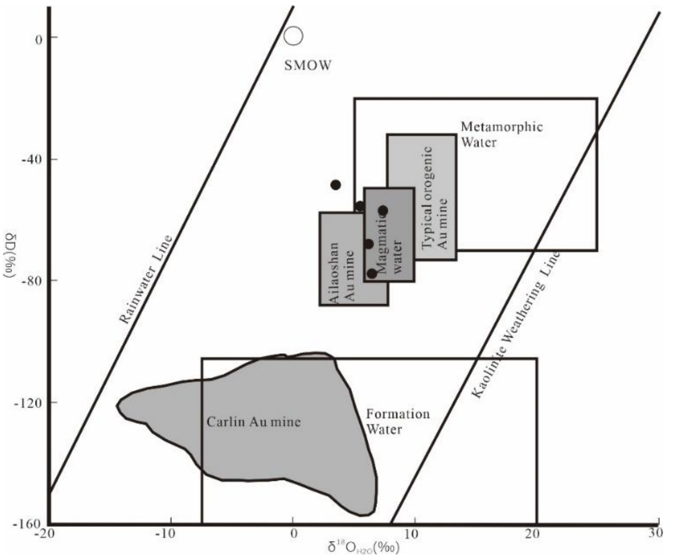

Figure 10. δD_{SMOW}-$\delta^{18}O_{SMOW(H2O)}$ isotopes compositions in granite vein fluid of Zhazixi Sb-W deposit

6.2 Sources of mineralization materials

On the source of ore-forming materials, the predecessors have done much research by tracing the rare earth elements in ores and S and Pb isotopes in stibnite, yielding very different results. For example, Zeng et al. [4] discovered that S comes from Wuqiangxi formation of the Banxi group, and Pb from upper- lower crust, after examining the mixed S and Pb isotopes in stibnite. Based on geochemical data, previous studies deduce the source of ore-forming materials from that of the ore-forming fluid. Zhazixi Sb-W deposit is a special deposit, where Sb orebodies and W orebodies coexist. But the deposit is not that unique. Xuefengshan metallogenic belt is a huge polymetallic belt of Au, Sb, and W. In the belt, Au deposits, Sb deposits and W deposits follow a definite rule of distribution. It is scientific to investigate the source of ore-forming materials based on the geochemical and geological features of the deposit, and the geological features of the region.

According to the source of ore-forming fluid, the metallogenic materials of Zhazixi Sb-W deposit could come from three sources: buried igneous rocks, the strata containing the ore-forming fluid, and the mixture of the first two sources. The test results show that S isotopes cover a wide range, and come from various sources. As shown in Figure 11, Zhazixi Sb-W deposit fell on the lower crust and the orogenic belt. The results of S and Pb isotopic testing suggest that the ore-forming materials come from mixed sources like buried igneous rocks, and the strata containing the ore-forming fluid. This is similar to the results of C, H, and O isotopes. This study infers that the ore-forming materials originate from basement strata and deep magmatic rocks.

In Zhazixi Sb-W deposit, there are significant differences between Sb and W orebodies in ore-controlling structure, ore type and fabric. The Sb orebodies contain almost no W minerals. Hence, the ore-forming materials of Sb and W orebodies must come from different sources. In the surroundings of the study area, W deposits occur in or near granite rock masses within a magmatic rock region in the south of Xuefengshan metallogenic belt, such as Xingfengshan Au-W deposit, Shaxi W deposit, Lishanpo W deposit, Shangchasha W deposit, Zhongcun W deposit, Zhaixishan W deposit, Darongxi W deposit, and Situpu W deposit. Even intermediate-acid magmatic veins were found in Woxi Au-Sb-W deposit [19]. Wang et al. [3] determined the metallogenic age as 227.3± 6.2Ma, similar to the age of some magmatic rocks in region. Moreover, Sb deposits have been discovered throughout Xuefengshan metallogenic belt, often near Banxi group: 44 of 71 Sb deposits occur in Banxi group (62%). After investigating 4 long geochemical sections of unaltered rocks in Madiyi formation, and Banxi group, predecessors put the Sb background value at 1.0ppm and the average Sb content of two lithologic members at 7.4ppm and 25ppm, respectively. The results far exceeded the concentrations in the upper crust (0.2ppm) [20]. Therefore, Banxi group is a potential source of mineralization materials for Sb deposits.

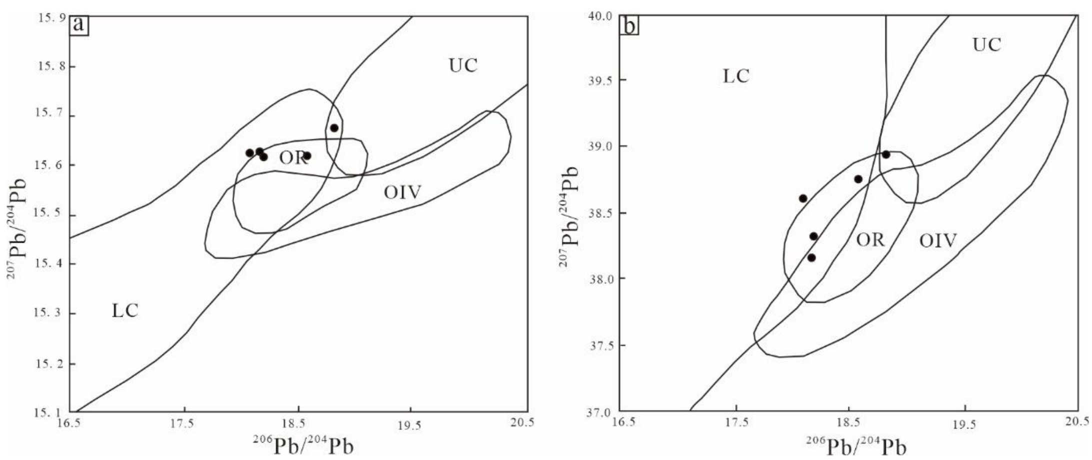

Figure 11. $^{206}Pb/^{204}Pb$-$^{207}Pb/^{204}Pb$ and $^{206}Pb/^{204}Pb$-$^{208}Pb/^{204}Pb$ of Zhazixi Sb-W deposit (UC-upper crust; LC-lower curst; OR- orogenesis belt; OIV-mantle)

All in all, we concluded that the Sb in Zhazixi Sb-W deposit stems from Banxi group, but W comes from the concealed rock body.

7. CONCLUSIONS

(1) According to the analysis on inclusions, the ore-forming fluid of Zhazixi Sb-W deposit is CO_2-N_2-H_2O-NaCl system, which is rich in CO_2 and N_2, and medium-to-low in temperature. The deposit is a medium epithermal type deposit.

(2) According to the analysis on N_2-rich inclusions and C, H, and O isotopes, N_2 comes from deep source; ore-forming fluid mainly originates in deep magmatic rocks, and secondarily from metamorphic hydrothermal fluids.

(3) According to the analysis on S and Pb isotopes, the ore-forming materials have multiple sources. After a comprehensive analysis on the geological features of the deposit and the region, we believed that the Sb in Zhazixi Sb-W deposit stems from Banxi group, but W comes from the concealed rock body.

(4) The deposit is a polygenetic compound deposit formed in early Yanshanian period. The formation of the deposit is closely related to the magmatic thermal events in that period.

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