



Sources of Ore-Forming Fluids and Materials of Gold and Antimony Deposits in Southwestern Guizhou

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ABSTRACT

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Southwestern Guizhou is a main distribution area of Carlin-type gold deposits in China, and rich in epithermal deposits like antimony, arsenic and mercury. The elemental paragenesis-separation is common among these deposits, especially between gold and antimony. This paper systematically analyzes the fluid inclusions and isotope geochemistry of two typical deposits in southwestern Guizhou, namely, Shuiyindong gold deposit and Dachang antimony deposit. The analysis shows that the ore-forming fluids from the two deposits have similar properties and the same origins, and the ore-forming materials of the two deposits come from the same sources: the ore-forming fluids from both deposits are of low to medium temperature, low to medium salinity and medium density; both of them might belong to the system of H₂O-NaCl-KCl-CO₂. The tests on gas-liquid phase compositions and H-O isotopes indicate that the ore-forming fluids of both gold and antimony deposits come from multiple sources; the main source is the underground hot fluid formed from meteoric water, and a few amount of magmatic fluid and even mantle fluid might also be involved in the formation of the fluids. The sulfur isotope test reveals that the $\delta^{34}\text{S}$ values of gold and antimony deposits both concentrate in a small range near 0‰, and the S isotope composition is similar to that of mantle sulfur, indicating that the sulfur in the ore-forming materials of the gold and antimony deposits mainly come from deep mantle. The research results lay the theoretical basis for the metallogenic factors in southwestern Guizhou.

1. INTRODUCTION

Epithermal deposits of gold, antimony, arsenic and mercury are widely and densely distributed across southwestern Guizhou, creating an enrichment area of gold-arsenic-mercury-antimony deposits in the Youjiang Basin. The enrichment area is an important part of the giant South China low-temperature metallogenic domain [1]. Shuiyindong gold deposit and Dachang antimony deposit are typical deposits in this enrichment area.

The cluster of gold deposits in this area is associated with numerous deposits of other minerals, namely, antimony, arsenic, mercury and thallium. The elemental paragenesis-separation is common among these deposits, especially between gold and antimony. Studies have attributed the phenomenon to the fact that gold and antimony can migrate together and deposit separately; the ore-forming fluid that can effectively transport gold must be able to transport antimony [2, 3]. The paragenesis-separation between gold and antimony is greatly affected by the physical and chemical changes of the ore-forming fluid [4, 5].

In recent years, significant progress has been achieved in the research of gold and antimony deposits of southwestern Guizhou. In terms of metallogenic age, Sm-Nd dating results show that the calcite, which coexists with realgar, in

Shuiyindong gold deposit, formed at 134±3Ma~146.5±3.3Ma [6, 7]; the fluorite in Dachang antimony deposit mainly formed between 141±20Ma and 148±8.5Ma [4, 8]; gold and antimony in southwestern Guizhou both formed in the Yanshanian period [4, 8].

So far, mineralogists have generally reached consensus on elemental paragenesis-separation and metallogenic age of gold and antimony deposits. However, there is great disagreement about the metallogenic factors. For Shuidong gold deposit, the ore-forming fluid may come from deep mantle [9-11] or basin construction water [12], or from mixed sources [9, 13]; the ore-forming materials of the deposit may originate from Emeishan basalt [14], or mixed sources [9, 13]. For Dachang antimony deposit, the ore-forming fluid may come from basin fluid [15], meteoric precipitation [16] or multiple sources [17]; the ore-forming materials may originate from sedimentary strata [15, 16], tuffs related to eruption of Emeishan basalt [17], or deep mantle [4].

Taking Shuiyindong gold deposit and Dachang antimony deposit as objects, this paper systematically analyzes the ore-forming background, geological features, fluid inclusions, and isotope geochemistry of the two deposits, and compares the sources of ore-forming fluids and materials of gold and antimony deposits in the area. The research results lay the theoretical basis for the metallogenic factors in southwestern

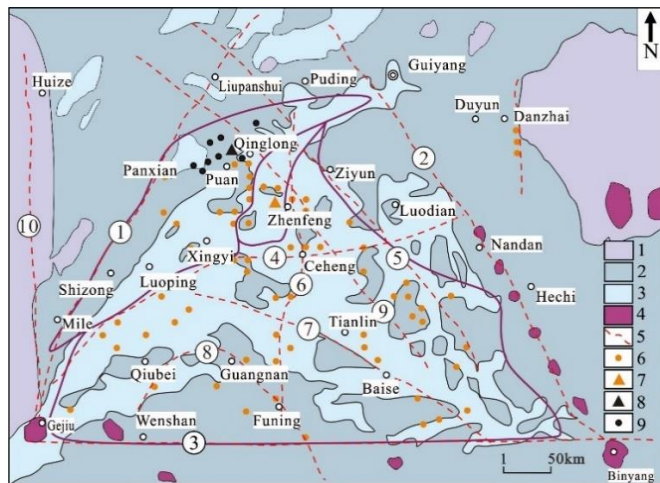
Guizhou.

2. ORE-FORMING BACKGROUND

2.1 Regional geology

Southwestern Guizhou lies at the junction of the southwestern margin of the Yangtze Craton and the west extension of the Youjiang fold belt of the South China fold system. The geological structure of the region took shape in the Indosinian-Yanshan period, featuring complex and diverse combinations of tectonic deformations. The epithermal deposits of gold, antimony, arsenic and mercury are widely distributed in the triangular area enclosed by the NE-trending Miele-Shizong deep fault, the EW-trending Gejiu-Binyang deep fault and the NW-trending Nandan-Kunlun deep fault. This “golden triangle” spans across three provincial administrative regions in Southwest China, namely, Yunan, Guizhou and Guangxi.

Gold and antimony deposits are concentrated in southwestern Guizhou, the northeast tip of the “golden triangle”. The gold deposits often have antimony ore spots, and the antimony deposits often have gold ore spots. The developed faults and folds in the region provide favorable geological settings for the formation of gold and antimony deposits (Figure 1).



1. Proterozoic eon-Sinian system; 2. Paleozoic eratherm; 3. Triassic system; 4. Granites; 5. Deep faults; 6. Gold deposits and spots; 7. Shuiyindong gold deposit; 8. Dachang antimony deposit; 9. Antimony deposits and spots; ① Shizong-Mile deep fault; ② Nandan-Kunlun deep fault; ③ Gejiu-Binyang deep fault; ④ Kaiyuan-Pingtang deep fault; ⑤ Ziyun-Yadu deep fault; ⑥ Puding-Cheheng fault; ⑦ Youjiang fault; ⑧ Qinglong-Cheheng fault; ⑨ Xiaojiang fault

Figure 1. Geological map of gold and antimony deposits in southwestern Guizhou (Adapted from the data from the 105 Regional Survey Team, Bureau of Geology and Mineral Exploration and Development, Guizhou Province)

In this region, the exposed strata in are mainly Devonian to Triassic rocks. Triassic rocks are the most widely distributed, followed by Permian rocks. Devonian and Carboniferous rocks only appear in a few anticline cores. The magmatic rocks, which are related to ore formation, have a wide exposure. These rocks are mainly slightly alkaline basites or ultrabasites, and belong to mantle-derived ultrabasic complex rocks with a relatively stable platform environment. The spatial

distribution of these rocks may depend on the regional large fault zone. The magmatic rocks in the region is part of the Emeishan basalt formation, one of Earth’s large igneous provinces.

2.2 Geological features

2.2.1 Shuiyindong gold deposit

Shuiyindong gold deposit is situated in the eastern section of Huijiabao ore cluster in the “golden triangle”. The EW-trending Huijiabao anticline directly controls the occurrence of the gold deposit (Figure 2). The ore occurrence is mostly stratabound and partly fault-controlled.

The stratabound ores mainly exist in the altered rocks, which were formed under tectonic actions and hydrothermal metasomatism, near the uncomfortable interfaces between the Upper Permian Longtan Formation (P₃l), the Middle Permian Maokou Formation (P₂m), and the Upper Permian Longtan Formation (P₃l). The ore bodies occur in lamellar, quasi-lamellar and lenticular forms. The occurrence is consistent with the occurrence of the rock strata. The vein undulates upwards and sinks eastward. The ore-bearing rocks mainly include bioclastic limestone, strongly silicified breccia limestone and silicified breccia claystone.

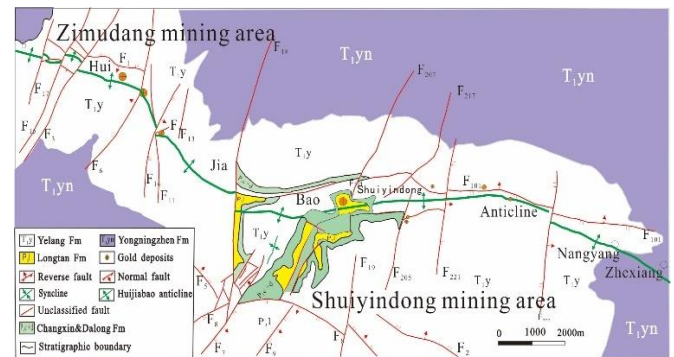
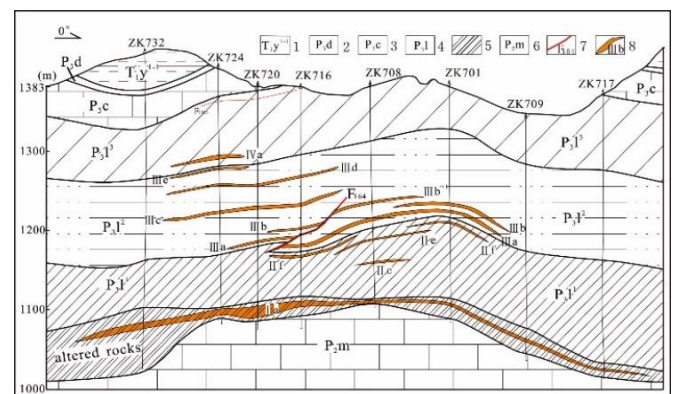


Figure 2. Geological map of Shuiyindong gold deposit (Adapted from the data from the 105 Regional Survey Team, Bureau of Geology and Mineral Exploration and Development, Guizhou Province)



1. The first section of Yelang Formation; 2. Dalong Formation; 3. Changxing Formation; 4. Longtan Formation; 5. altered rocks; 6. Maokou Formation; 7. Faults; 8. Ores

Figure 3. Profile of exploration line 7# in Shuiyindong gold deposit (Adapted from the data from the 105 Regional Survey Team, Bureau of Geology and Mineral Exploration and Development, Guizhou Province)

The fault-controlled ores exist in a gently inclined reverse fault close to the axis of the anticline. Strictly controlled by the fault fracture zone, these ores are formed in the same system as the stratabound ores. The only difference between them lies in the spatial location (Figure 3).

Shuiyindong gold deposit features a complex mineral combination. The ore minerals include pyrite, stibnite, realgar/orpiment, and arsenopyrite. Among them, pyrite is an important gold-bearing mineral. The gangue minerals include quartz, calcite, dolomite, fluorite, clay minerals, etc. The surrounding rocks were mainly altered into pyrite, dolomite, realgar/orpiment, calcite, stibnite, and fluorite. Pyritization, silicification, and dolomitization are closely associated with gold deposition. The three alterations are observable in any gold mine.

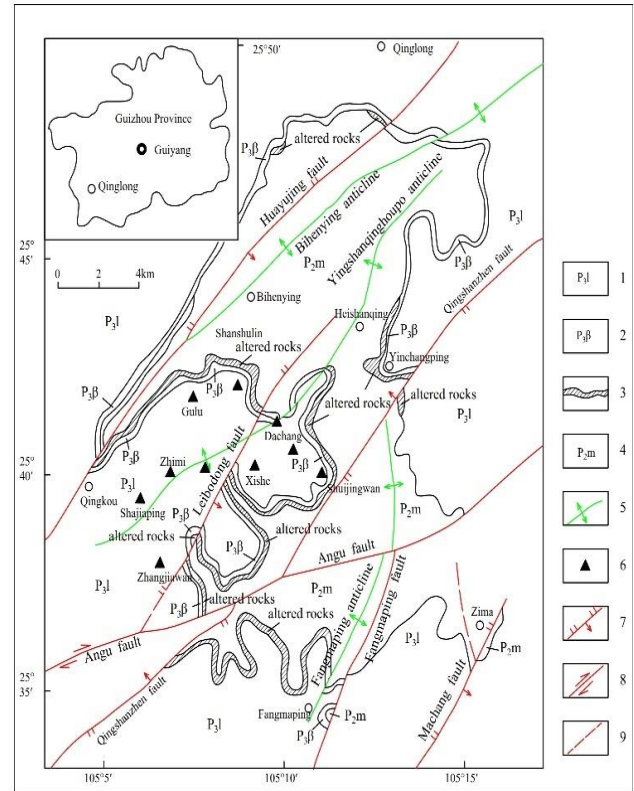
2.2.2 Dachang antimony deposit

Dachang antimony deposit falls on the south east wing of the Bihengying anticline in the “golden triangle”. The antimony occurrence is controlled by the anticline (Figure 4). The ore bodies occur in lamellar, quasi-lamellar and lenticular forms in the altered rocks near the uncomfortable interfaces between the Middle Permian Maokou Formation (P_{2m}), and the Upper Permian Emeishan basalt formation ($P_{3\beta}$). The altered rocks are several meters to over 40m in thickness, showing a large variation in thickness (Figure 5).

The ore-bearing rocks are strongly silicified limestone, breccia claystone, siltstone, basalt and tuff. The deposit has a simple mineral combination: the ore minerals are mainly stibnite, pyrite, and arsenopyrite. The gangue minerals mainly include quartz, fluorite, calcite, kaolinite and barite. The surrounding rock alteration is relatively simple. The surrounding rocks were mostly altered into silicon, pyrite, fluorite, clay and barite.

To sum up, the gold and antimony deposits in southwestern Guizhou were formed in Yanshanian period, and are distributed within the “golden triangle” enclosed by an NE-trending, an EW-trending and an NW-trending deep faults. The ore bodies mainly occur in lamellar, quasi-lamellar and lenticular forms in the altered rocks, and are strictly controlled by anticline structure. In terms of space, elemental

paragenesis-separation takes place between gold and antimony deposits, i.e. the gold deposit has antimony ore spots, and the antimony deposit has gold ore spots. The two deposits are similar in mineral composition and alteration of surrounding walls. Therefore, it is feasible to compare the ore-forming factors of the two deposit.



1. Longtan Formation; 2. Emeishan Basalt Formation; 3. altered rocks; 4. Maokou Formation; 5. Anticline; 6. Antimony deposit; 7. Normal faults; 8. Translational faults; 9. Faults with unknown properties

Figure 4. Geological map of Dachang antimony deposit (Adapted from the data from the 105 Regional Survey Team, Bureau of Geology and Mineral Exploration and Development, Guizhou Province)

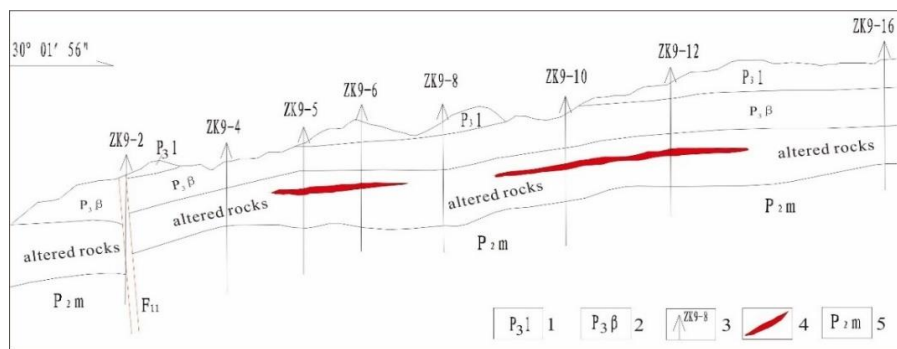


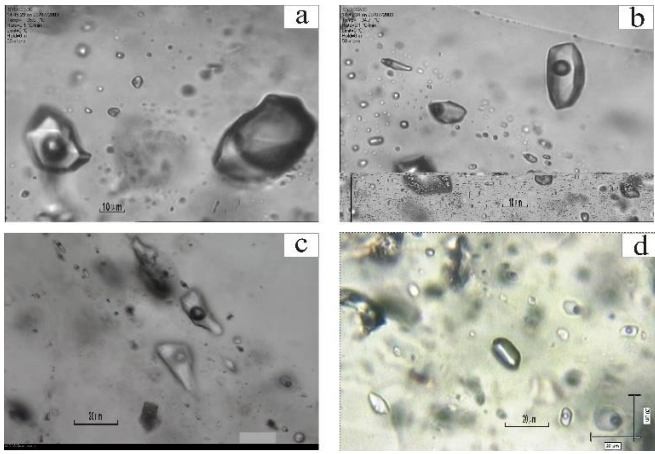
Figure 5. Profile of exploration line 9# in Xishe section, Dachang antimony deposit (Adapted from the data from the 105 Regional Survey Team, Bureau of Geology and Mineral Exploration and Development, Guizhou Province)

3. GEOCHEMISTRY OF FLUID INCLUSIONS

3.1 Main features

The fluid inclusions in gangue minerals like quartz and

fluorite were sampled from the altered rocks in the main ore-bearing horizons of the target gold and antimony deposits. The fluid inclusion specimens were prepared in the Institute of Geochemistry, Chinese Academy of Sciences, and observed under a polarizing microscope.



(a) (b) The fluid inclusions in the quartz from Shuiyindong gold deposit; (c) (d) The fluid inclusions in the fluorite from Dachang antimony deposit

Figure 6. The features of fluid inclusions from the two deposits

The observations (Figure 6) show that the primary fluid inclusions in the quartz from Shuiyindong gold deposit exist as isolated elongated negative crystals, with diameter between 5 and 60 μm . The fluid inclusions are categorized as liquid phase, gas phase, and gas-liquid phase.

Moreover, the primary fluid inclusions in the fluorite from Dachang antimony deposit exist as clustered elliptical, elongated and irregular negative crystals, with diameter between 8 and 50 μm . The fluid inclusions are also categorized as liquid phase, gas phase, and gas-liquid phase.

Therefore, the two deposits have similar types of fluid inclusions. Different primary fluid inclusions often coexist in the same plane or crack, indicating that the ore-forming fluids are immiscible.

3.2 Microscopic temperature measurement

Besides providing the temperature of fluid inclusions, the microscopic temperature measurement of fluid inclusions helps to ascertain other important parameters of fluid inclusions, namely, salinity and density [10]. The fluid inclusions from the two deposits were subjected to microscopic temperature measurement in the Fluid Inclusion Laboratory, Institute of Geochemistry, Chinese Academy of Sciences. The measuring instrument is a THMSG600 geology thermal stage (Linkam, UK). The measured results are recorded in Table 1. The salinity was calculated by:

$$W_{\text{NaCl}} = 0.00 + 1.78T_m - 4.42 \times 10^{-2}T_m^2 + 5.57 \times 10^{-4}T_m^3$$

where, T_m is the absolute value of freezing temperature [18].

Table 1. The measured temperatures and calculated results of the fluid inclusions from the two deposits

Deposit	Sample number	Mineral	Number	Homogenization temperature (Th/°C)	Ice-point temperature (Tm/°C)	Salinity (wt% NaCleqv)
Shuiyindong gold deposit	SYD-1-1	Quartz	171	170~316	-5.1~-0.2	0.35~8.00
	SYD-1-2	Quartz	9	190.4~241	-2.9~-2.6	4.34~4.80
		Quartz*	76	200~220		5.00~6.00
	Dcgl-2-8	Quartz*	23	110~293	-6.5~-0.4	0.64~9.86
Dachang antimony deposit	Dcgl-2-13	Quartz	31	145.9~192.7	-1.2~-0.2	0.35~2.07
	Dcgl-2-14	Quartz	23	129.4~177	-1.8~-0.4	0.70~3.06
	Dcgl-2-13	Fluorite	40	131.3~192.7	-1.9~-0.2	0.35~3.23
		Fluorite/Barite*		104~221	-1.9~-0.1	0.18~3.23
		Fluorite/Quartz/Calcite/Barite*		150~180		6.10~7.00
						10.00~12.00

Note: The data marked with an asterisk are from the research of Chen et al. [13], Chen [19] and Ye [20].

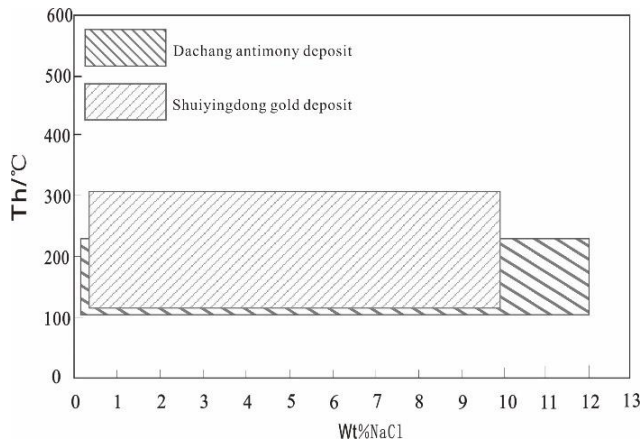


Figure 7. Relationship between salinity and uniform temperature of fluid inclusions from the two deposits

As shown in Table 1, the uniform temperature and salinity of fluid inclusions from Shuiyindong gold deposit fell within 110~316°C and 0.35~9.86%, respectively; the uniform

temperature and salinity of fluid inclusions from Dachang antimony deposit fell within 104~214°C and 0.18~12.00%, respectively. The lower temperature can be regarded as the lowest temperature for the capture of ore-forming fluid, i.e. the lower bound for ore-forming temperature. From the relationship between salinity and uniform temperature (Figure 7), it can be seen that both deposits have low to medium salinity.

Then, the density ρ (g/cm^3) of the saline solution can be empirically derived from the measured temperature and salinity range [21]:

$$\rho = A + Bt + Ct^2$$

where, t is the uniform temperature (°C); A, B and C are salinity functions:

$$\begin{aligned} A &= 0.993531 + 8.72147 \times 10^{-3} \times S - 2.43975 \times 10^{-5} \times S^2 \\ B &= 7.11652 \times 10^{-5} - 5.2208 \times 10^{-5} \times S + 1.26656 \times 10^{-6} \times S^2 \\ C &= -3.4997 \times 10^{-6} + 2.12124 \times 10^{-7} \times S - 4.52318 \times 10^{-9} \times S^2 \end{aligned}$$

where, S is salinity (wt% NaCl_{eqv}) (Table 1). It is calculated that the density of ore-forming fluid fell within 0.71~0.99 g/cm³ in Shuiyindong gold deposit, and within 0.93~1.11 g/cm³ in Dachang antimony deposit. This means the ore-forming fluids from the two deposits are both of medium density.

The above analysis shows that the typical gold and antimony deposits in southwestern Guizhou have similar ore-forming fluids: both are hydrothermal fluids of low to medium temperature, low to medium salinity and medium density.

3.3 Chemical composition

3.3.1 Gas phase composition

The gas phase composition of fluid inclusions in minerals from the two deposits were quantified by a GC2010 gas chromatograph in the Fluid Inclusion Laboratory, Institute of

Geochemistry, Chinese Academy of Sciences. According to the quantification results (Table 2), in the fluid inclusions from Shuiyindong gold deposit, H₂O and CO₂ are the main gas phases, and CH₄, N₂ and C₂H₆ exist in small amounts; in the fluid inclusions from Dachang antimony deposit, H₂O and CO₂ are still the main gas phases, followed by N₂ and O₂, and organic gases like CH₄ and C₂H₆ exist in small amounts.

Hence, the ore-forming fluid of gold deposit has basically the same gas phases as that of antimony deposit. However, no O₂ was detected in the fluid inclusions from the gold deposit, while a large volume of O₂ was found in some fluid inclusions from the antimony deposit. This means the ore-forming fluids of the two deposits may differ in physical and chemical environment: gold tends to deposit and accumulate in a reductive environment, while the antimony deposit tends to form in an oxidizing environment.

Table 2. Gas phase composition of fluid inclusions from the two deposits

Deposit	Sample number	Mineral/Unit	H ₂ O	CO ₂	N ₂	O ₂	CH ₄	C ₂ H ₂ + C ₂ H ₄	C ₂ H ₆	H ₂ S	
Shuiyindong gold deposit	SDY021		89.57	8.789	0.345		1.265		0.0242	0.0002	
	SDY037		96.07	3.282	0.125		0.509		0.0104	0.0001	
	SDY038	*Quartz/%	93.34	4.679	0.196		1.762		0.0199	0.00008	
	SDY039		96.70	2.798	0.102		0.398		0.0096	0.00004	
	SDY041		95.86	3.73	0.159		0.222		0.0213	0.0001	
	SDY053		96.87	2.909	0.112		0.092		0.014	0.00011	
Dachang antimony deposit	DCGL-2-13	Fluorite/ug/g	738.824	195.259	96.246	20.151	0.517	0.028	0.019	0	
	DCGL-10		746.095	131.391	36.647	6.726	0.404	0.138	0.03	0	
	*Quartz/mol%		93.78~	0.803~	0.464~			0.121~0.949		0.074~0.0003~	0.674 0.003
			98.5	2.7	1.715						
	*Fluorite/mol%		88.63~	1.243~	0.114~			0.036~1.337		0.016~0.0001~	
			98.53	4.572	4.426					1.012	0.001

Note: The data marked with an asterisk are from the research of Chen et al. [13] and Wang [22].

3.3.2 Liquid phase composition

The liquid phase composition of fluid inclusions in minerals from the two deposits were tested by an HIC-SP super ion chromatograph (Shimadzu, Japan) in the Fluid Inclusion Laboratory, Institute of Geochemistry, Chinese Academy of Sciences. The test data (Table 3) show that, in the fluid inclusions from Shuiyindong gold deposit, Na⁺ is the main

cation, followed by K⁺ and Ca²⁺, plus a few amount of Mg²⁺; Cl⁻ and SO₄²⁻ are the main anions, plus a few amount of NO₃⁻ and F⁻. In the fluid inclusions from Dachang antimony deposit, K⁺ is the main cation, followed by Na⁺ and Mg²⁺; SO₄²⁻ is the main anion, followed by Cl⁻ and NO₃⁻; the SO₄²⁻ content is very high.

Table 3. Liquid phase composition of fluid inclusions from the two deposits (μg/g)

Sample location	Sample number	Minerals	Na ⁺	K ⁺	Mg ²⁺	Ca ²⁺	F ⁻	Cl ⁻	NO ₃ ⁻	SO ₄ ²⁻
Shuiyindong*	SYD021	Quartz	1.59	0.09	<0.02	0.51	<0.02	1.47	0.11	1.11
	SYD037		2.04	0.30	<0.02	0.39	<0.02	1.47	0.10	2.46
	SYD038		3.03	0.78	<0.02	0.60	0.23	2.58	0.11	4.56
	SYD039		4.02	0.81	1.05	0.60	0.24	3.99	0.14	1.23
	SYD041		1.41	0.30	<0.02	0.39	0.06	1.26	<0.02	1.65
	SYD053		3.00	1.23	<0.02	1.11	<0.02	1.29	0.10	5.43
Dachang	DCGL-2-13	Fluorite	1.50	12.39	0.51	—	—	0.87	0.47	89.46
	DCGL-10	Fluorite	1.28	7.10	1.06	—	—	1.21	0.68	20.88

Note: The data marked with an asterisk are from the research of Chen et al. [13].

Therefore, the fluid inclusions from the two deposits have similar liquid phase composition: the main ions are both Na⁺, K⁺ and Cl⁻. However, the fluid inclusions from Dachang antimony deposit has a high content of SO₄²⁻, which is possibly the result of the heavy presence of barites in that deposit.

Judging by the gas-liquid phase compositions, the ore-

forming fluids of the two deposits might belong to the system of H₂O-NaCl-KCl-CO₂. On the one hand, the ore-forming fluids of both deposits mainly consist of H₂O and CO₂, which are abundant in mantle fluids [23]; on the other hand, the CO₂, CH₄ and SO₄²⁻ in the fluid inclusions are related to sedimentary rocks, which reflect the features of meteoric precipitation.

Therefore, the ore-forming fluids in southwestern Guizhou come from multiple sources. The fluids might be a mixture of meteoric precipitation and mantle fluid. In addition, the ore-forming fluids of the two deposits may differ in physical and chemical environment: gold tends to deposit and accumulate in a reductive environment, while the antimony deposit tends to form in an oxidizing environment.

4. ISOTOPE GEOCHEMISTRY

4.1 Hydrogen and oxygen isotopes

Ore-forming fluid is an important medium for elements to migrate and enrich into ores. Currently, the source of ore-forming fluid is usually determined through H-O isotope projection. The quartz from Shuiyindong gold deposit and fluorite from Dachang antimony deposit were selected under the microscope, and sent to Analytical Laboratory of CNNC Beijing Research Institute of Uranium Geology (BRIUG) for H-O isotope test. The test results (Table 4) show that the $\delta^{18}\text{D}_{\text{H}_2\text{O}}$ and $\delta^{18}\text{O}_{\text{H}_2\text{O}}$ of the fluid inclusions from Shuiyindong gold deposit ranged in $-112.5\sim-75.4\text{‰}$ and $+5.79\sim+9.59\text{‰}$, respectively; the $\delta^{18}\text{D}_{\text{H}_2\text{O}}$ and $\delta^{18}\text{O}_{\text{H}_2\text{O}}$ of the fluid inclusions from Dachang antimony deposit ranged in $-128.1\sim-63\text{‰}$ and $-3.5\sim+6.2\text{‰}$, respectively.

According to the $\delta^{18}\text{D}-\delta^{18}\text{O}$ map in Figure 8, three of the H-O isotope projection points of Shuiyindong gold deposit fell within the range of primary magmatic water, and the rest of the points fell in the hydrothermal area near the magmatic water. Studies have shown that under high temperature and low water-rock ratio, the H-O isotope composition of meteoric precipitation may evolve into that of magma-derived fluids [24]. Considering the low presence of hydrogen-containing minerals in the gold deposit, the measured $\delta^{18}\text{D}_{\text{H}_2\text{O}}$ might represent the H isotope composition of the original ore-forming fluid. Since the gold ores are mostly borne in bioclastic limestone, the O isotope might be exchanged under the water-rock interaction between meteoric precipitation and limestone. The O isotope value of meteoric precipitation is thus increased, such that more projection points move closer to the magmatic water area. Therefore, the ore-forming fluid mainly originates from the underground hot fluid formed by meteoric precipitation. Of course, magmatic hydrothermal fluid cannot be excluded as a source of the ore-forming fluid.

It can also be seen from Figure 8 that the H-O isotope projection points of Dachang antimony deposit fell to the right of the meteoric water line, most of which were close to the lower left of the magmatic water area. The $\delta^{18}\text{O}$ value of the ore-forming fluid obviously drifted to the right. The drift is a prominent feature of the hydrothermal fluid formed from meteoric water, and a possible outcome of the O isotope exchange between rainwater and silicate and carbonate rocks [26]. This is consistent with the fact that strongly silicified limestone was formed through the hydrothermal alteration of the main rocks in the deposit. Therefore, the ore-forming fluid of the deposit mainly comes from meteoric water, and may involve some magmatic heat sources.

The H-O isotope features show that the ore-forming fluids of the gold and antimony deposits originate from multiple sources: the main source is the underground hot fluid formed from meteoric water, and magmatic hydrothermal fluid might also be involved in the formation of the fluids.

Table 4. H-O isotope composition of fluid inclusions from the two deposits

Deposit	Sample number	Mineral	$\delta^{18}\text{D}_{\text{H}_2\text{O}}$ ‰	$\delta^{18}\text{O}_{\text{H}_2\text{O}}$ ‰
Shuiyindong gold deposit	2013SY-7	Quartz	-75.40	6.99
	SY-1		-86.50	6.99
	SY-7		-82.50	6.79
	SY-10		-75.50	8.39
	ZK4076-4-4		-112.50	6.59
	ZK4233-2		-90.90	5.79
	ZK2070-1		-78.30	9.59
	ZK2310-1		-89.80	5.89
	25116-5		-78.90	9.19
	Dachang antimony deposit*		Fluorite/Stibnite	-66.0~-63.0
-128.1		5.9		
-105.9		3.8		
-118.6		6.2		
Quartz		-105.8		5.6
			-113	5.8

Note: The data marked with an asterisk are from the research of Ye [20] and Wang [22].

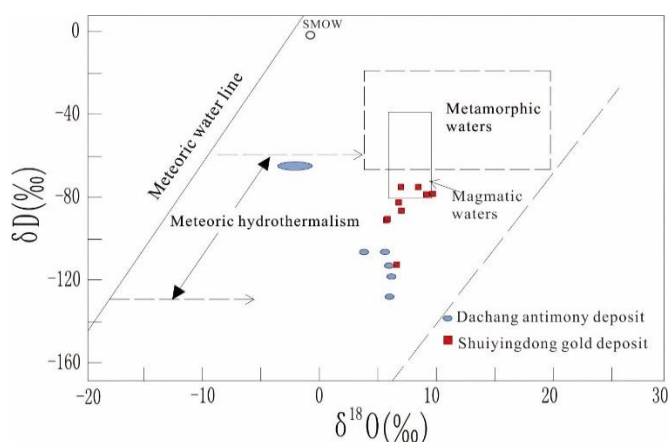


Figure 8. The $\delta^{18}\text{D}-\delta^{18}\text{O}$ map of H-O isotope projection [25]

4.2 Sulfur isotopes

For most deposits, sulfur is one of the most important elements in the ore-forming process. The S isotopes are often taken as the most direct and effective tracers of the source of sulfur in ore-forming fluids [26]. The composition and source analysis of S isotopes helps to reveal the ore-forming factors of a specific deposit.

There are three major sulfur reservoirs on the earth: mantle sulfur (magmatic sulfur), seawater sulfur and reduced sulfur in sediments. The mantle sulfur has an $\delta^{34}\text{S}$ value of $-3\text{‰}\sim+3\text{‰}$, seawater sulfur. The seawater sulfur is characterized by a high $\delta^{34}\text{S}$ value. In modern seawater, the $\delta^{34}\text{S}$ value is close to 20‰ . The reduced sulfur has a large range of $\delta^{34}\text{S}$, which is often greatly negative [27].

In this research, the sulfide minerals deeply involved in ore-forming process, including orpiment, realgar, stibnite and pyrite, are selected from the two deposits, and subjected to S isotope test in the Fluid Inclusion Laboratory, Institute of Geochemistry, Chinese Academy of Sciences.

Table 5. The S isotope composition of the two deposits

Deposit	Sample number	Mineral	$\delta^{34}\text{S}/\text{‰}$
Shuiyindong gold deposit	sy-1	Pyrite	3.97
	ZK23916-31	Pyrite	1.91
	ZK34388-37	Pyrite	3.03
	sy-17	Stibnite	1.47
	sy-18	Stibnite	-3.92
	sy-19	Stibnite	-4.42
	Bj-2	Stibnite	-0.26
	42332	Realgar	3.27
	SYD-XH	Realgar	2.64
	27108-XH	Realgar	2.10
	26724-2	Realgar	2.74
	DCGL-2-7	Stibnite	-2.66
	DCGL-2	Stibnite	-2.53
	DCGL-04	Pyrite	-2.22
Dachang Antimony deposit	DCGL-05	Stibnite	1.97
	DCGL-08	Pyrite	2.80
	DCGL-10	Stibnite	2.65
	DCGL-11	Stibnite	2.70
	DCGL-12	Pyrite	-0.50
	DCGL-13	Pyrite	2.69
	DCGL-14	Pyrite	2.48
	DCGL-14	Stibnite	3.04

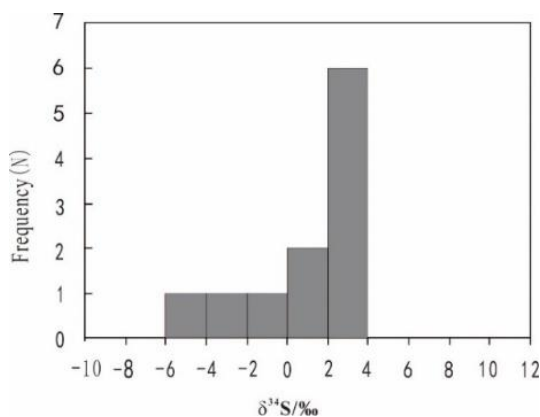


Figure 9. Frequency histogram of S isotope in Shuiyindong gold deposit

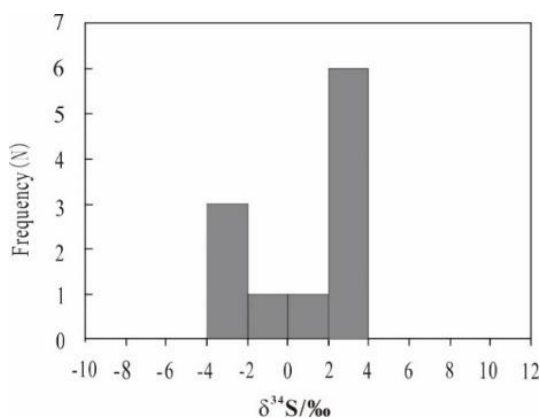


Figure 10. Frequency histogram of S isotope in Dachang antimony deposit

The test results (Table 5) show that the $\delta^{34}\text{S}$ of sulfides from Shuiyindong gold deposit fell within $-4.42\text{‰}\sim+3.97\text{‰}$, averaging at 1.14‰ . The $\delta^{34}\text{S}$ value changed in a small range, a sign of high uniformity.

As shown in Figure 9, the sulfur isotope of Shuiyindong gold deposit concentrated near 0‰ , exhibiting an obvious

“tower effect”. The distribution range of S isotope basically coincides with that of mantle sulfur, indicating that the sulfur in the ore-forming fluid mainly comes from the deep mantle. Meanwhile, the $\delta^{34}\text{S}$ of a number of specimens were large positive values, i.e. some sulfur may come from marine sulfates in the ore-bearing formation. In addition, a very few specimens had large negative $\delta^{34}\text{S}$ values. Thus, a few amount of sulfur may come from the reduced sulfur in sediments.

Similarly, the $\delta^{34}\text{S}$ value of sulfides from Dachang antimony deposit changed in a small range: $-2.66\text{‰}\sim+3.04\text{‰}$ (mean: 0.95‰). As shown in Figure 10, the $\delta^{34}\text{S}$ values concentrated near 0‰ , exhibiting an obvious “tower effect”. The S isotope composition bears a high resemblance with that of mantle sulfur. This agrees with the conclusions of Chen [19] and Ye [20].

In summary, the $\delta^{34}\text{S}$ values of gold and antimony deposits in southwestern Guizhou both concentrate near 0‰ , and the S isotope composition is similar to that of mantle sulfur, indicating that the sulfur in the ore-forming materials of the gold and antimony deposits mainly come from deep mantle, with a few from seawater sulfur and reduced sulfur in sediments.

5. CONCLUSIONS

The gold and antimony deposits in southwestern Guizhou have similar ore-forming backgrounds: both deposits were formed in Yanshanian period, and are strictly controlled by anticline structure; the two deposits are similar in mineral composition and hydrothermal alteration. The gold deposits often have antimony ore spots, and the antimony deposits often have gold ore spots.

The ore-forming fluids of the two deposits might belong to the system of $\text{H}_2\text{O}-\text{NaCl}-\text{KCl}-\text{CO}_2$. No O_2 was detected in the fluid inclusions from the gold deposit, while a large volume of O_2 was found in some fluid inclusions from the antimony deposit, indicating that the ore-forming fluids of the two deposits may differ in physical and chemical environment: gold tends to deposit and accumulate in a reductive environment, while the antimony deposit tends to form in an oxidizing environment. This difference might be a reason for the paragenesis-separation between gold and antimony.

The gold and antimony deposits have similar ore-forming fluids: both are hydrothermal fluids of low to medium temperature, low to medium salinity and medium density. The ore-forming fluids come from multiple sources, i.e. exist as the mixture of fluids from different sources. The main source is the underground hot fluid formed from meteoric water, and a few amount of magmatic fluid and even mantle fluid might also be involved in the formation of the fluids.

The S isotope test shows that the $\delta^{34}\text{S}$ values of gold and antimony deposits both concentrate in a small range near 0‰ , and the S isotope composition is similar to that of mantle sulfur, indicating that the sulfur in the ore-forming materials of the gold and antimony deposits mainly come from deep mantle.

To sum up, the typical gold and antimony deposits in southwestern Guizhou have similar ore-forming fluids and the same sources of ore-forming minerals: ore-forming fluids both belong to the system of $\text{H}_2\text{O}-\text{NaCl}-\text{KCl}-\text{CO}_2$ with low to medium temperature and salinity, and come from multiple sources; the ore-forming materials mostly come from the deep mantle.

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