

# 冀西石湖地区多金属矿床成矿流体氦氩碳氢氧同位素特征及地质意义

王自力<sup>1</sup> 牛树银<sup>2,3</sup> 郭鹏志<sup>1</sup> 段焕春<sup>1</sup> 陈志国<sup>1</sup> 郭忠<sup>1</sup> 沈利霞<sup>1</sup>  
胡建勇<sup>1</sup> 王军<sup>1</sup> 王宝德<sup>2</sup> 陈超<sup>2</sup> 李英杰<sup>2,3</sup>

(1.天津华北地质勘查局,天津 300170;2.石家庄经济学院,河北石家庄 050031;  
3.中国地质大学(北京),北京 100083)

**摘要:**石湖地区金、银多金属矿床位于太行山中北段,产出太古界阜平群变质岩系,燕山期麻棚岩体的周边。本文以石湖地区代表性矿床为例,根据多金属矿床黄铁矿流体包裹体中He、Ar同位素及与黄铁矿共生的石英流体包裹体中C、H、O同位素组成,探讨了石湖地区金、银多金属矿床成矿流体来源。分析结果表明石湖地区金、银多金属矿床黄铁矿流体包裹体中<sup>3</sup>He/<sup>4</sup>He介于0.43~2.40 Ra, <sup>40</sup>Ar/<sup>36</sup>Ar介于477~879,显示出本区金、银多金属矿床的成矿流体为地幔流体与地壳流体混合的产物。石英包裹体中 $\delta D_{V-SMOW}$ 介于-62‰~-105‰,  $\delta^{18}O_{V-SMOW}$ 介于9.6‰~13.8‰,表明成矿流体为岩浆水与大气降水的混合; $\delta^{13}C_{PDB}$ 介于-3.5‰~-5.0‰,表明矿区成矿热液来自地幔。氢、氧、碳同位素体系与氦、氩同位素体系的示踪具有一致性,均显示出石湖地区金、银多金属矿床成矿流体为地幔流体与地壳流体混合的产物。

**关键词:**He-Ar; H-O; 同位素; 成矿流体; 石湖; 河北省

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河北省是中国东部地区的产金大省,黄金产量在全国占有举足轻重的地位。相对于冀东、张宣等产金地区,太行山中段虽然是研究新区,但是近年来的地质研究成果显示出其有很好的找矿前景(潜力)。目前本区已发现多处金、银多金属矿床(点),其中以石湖金矿为典型代表,现已成为河北省西部的大型金矿,众多专家学者曾在此区开展过工作<sup>[1-17]</sup>,为本区的地质找矿工作积累了宝贵的经验。

石湖金矿作为区域上金属矿床的代表,矿床成因多年来一直存在较大的争议。刘伟等<sup>[3-5]</sup>、息朝庄等<sup>[8]</sup>、游先军等<sup>[9]</sup>、黄颖洲等<sup>[10]</sup>认为其成矿物质主要来源于矿源层;牛树银<sup>[6-7]</sup>、陈超<sup>[11,13]</sup>、王自力等<sup>[18-20]</sup>提出幔枝构造成矿控矿的观点,认为成矿物质主要来源于地球深部。

近些年来,He和Ar同位素体系被广泛应用于成矿物质和成矿过程的示踪研究,取得了许多其他方法无法获得的重要信息<sup>[21-39]</sup>,其主要原因在于氦、氩同位素体系化学性质稳定,在地质作用过程中不参与化学反应,以及在地壳和地幔中具有独特的同位素组成,因此可以反映成矿流体来源和演化过程的原始信息。本文以石湖地区石湖、西石门、银洞、秋卜洞、丑泥口等金、银多金属矿床为例,通过对黄铁矿流体包裹体氦、氩同位素以及石英流体包裹体的碳、氢、氧同位素的研究,探讨石湖地区多金属矿床的成因机制及成矿流体来源。

## 1 区域地质概况

区域上出露地层主要为太古宇阜平群的中-高

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作者简介:王自力,男,1982年生,硕士,工程师,主要从事矿产勘查与矿床研究工作;E-mail:wangzili1982@163.com。

级变质岩系,由老至新可划分为:索家庄组、团泊口组、南营组、漫山组、木厂组和四道沟组6个岩组,主要岩石类型为黑云斜长片麻岩、角闪黑云斜长片麻岩、浅粒岩、斜长角闪岩和大理岩。原岩主要为陆源碎屑岩夹镁质碳酸盐,变质程度主要为高角闪岩相。其中索家庄组、漫山组、木厂组、四道河组出露较少,团泊口组和南营组出露广泛,局部可见有少量第四系。

石湖地区的金、银多金属矿床(点)处于阜平变质核杂岩核部岩浆-变质杂岩区<sup>[40-44]</sup>,并总体受着区域上北北东向断裂构造和北西向断裂构造的控制。由于两组构造的深切,使深部减压释荷形成岩浆源,并控制岩浆呈脉动式多期次上侵,形成了麻

棚、赤瓦屋、司各庄、王安镇等燕山期岩体。阜平变质核杂岩成矿区先后已经发现和勘查金(铜)矿床(点)100多处,其中太行山中段已发金、银多金属矿床(点)60余处。石湖金矿、西石门金矿、银洞钼矿、丑泥口金矿、秋卜洞银矿、北营银铅锌矿等众多矿床(点)均分布于燕山期麻棚岩体的周边(图1)。

麻棚岩体周边的金、银多金属矿床在时空上与岩体关系密切,岩体在区域成矿过程中起着重要的作用<sup>[45-47]</sup>。岩体受区域性NNE向断裂和NW向断裂控制,与围岩阜平群中深变质岩系呈侵入接触,平面形态呈近椭圆(鞋底)状,系由多个单元组成的复式岩体。岩体内部部分带明显,划分出5个脉动单元,分别命名为大东沟、北庄、前斗岭、观音堂、后斗

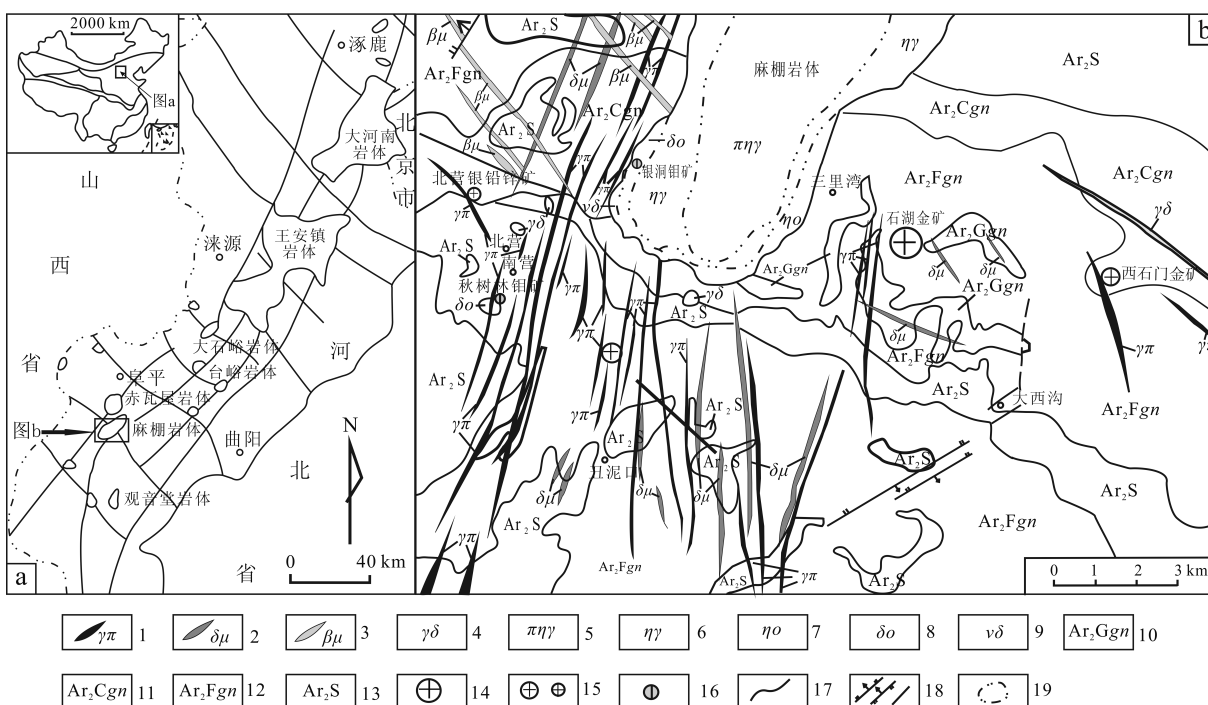


图1 石湖地区地质简图

1—花岗斑岩;2—闪长玢岩;3—辉绿岩;4—花岗闪长岩;5—斑状二长花岗岩;6—二长花岗岩;7—中细粒石英二长岩;8—中细粒石英(二长)闪长岩;9—辉石闪长岩;10—岗南片麻岩:含磁铁矿斜长钾长浅粒岩;11—蔡树庄片麻岩:条带状黑云二长片麻岩;12—坊里片麻岩:条带状、肠状(角闪)黑云斜长片麻岩;13—宋家口岩组:白云石大理岩、钾长(二长)浅粒岩、黑云钾长(二)片麻岩、含砂线石石英球浅粒岩;14—大型金矿;15—中、小型金矿床、矿点;16—钼矿;17—地质界线;18—正、逆断层,性质不明断层;19—脉动侵入界线

Fig. 1 Sketch geological map of Shihu area

1—Granite porphyry; 2—Diorite porphyrite; 3—Diabase; 4—Granite diorite; 5—Porphyritic monzogranite; 6—Monzogranite; 7—Medium-fine-grained quartz monzonite; 8—Medium-fine-grained quartz (monzonite) diorite; 9—Augite diorite; 10—Gangnan gneiss: magnetite-bearing plagioclase-K-feldspar leucocleptite; 11—Caishuzhuang gneiss: banded biotite-monzonitic gneiss; 12—Fangli gneiss: banded, enterolithic (amphibolite) biotite-plagioclase gneiss; 13—Songjiakou rock formation: dolomite marble, K-feldspar (monzonitic) leucocleptite, biotite-K-feldspar (monzonitic) gneiss, sillimanite-bearing quartz spherical leucocleptite; 14—Large-sized gold deposit; 15—Medium-, small-sized gold deposits and ore spots; 16—Mo deposit; 17—Geological boundary; 18—Normal and reverse faults, faults with unknown characteristics; 19—Pulse intrusion boundary

岭。不同脉动单元之间为侵入接触关系,总体演化趋势上表现为,从外到内侵位时代由早到晚,岩性由中基性到中酸性,岩石的颜色由深到浅,辉石、角闪石等暗色矿物含量减少,石英、钾长石等浅色矿物逐渐增多,反映出岩体从中基性向酸性的同源岩浆演化序列。

在构造演化特征上,岩体与围岩,岩体各脉动单元之间均有显著的构造关系。前者表现为主动侵位的强力拓宽占位特征,岩体与围岩之间往往表现为明显的挤压关系,岩体外接触带多表现为明显的构造挤压带,围岩多已形成构造片岩,且从岩体边界向外片理化逐渐减弱,局部地段有明显的绿泥石绿帘石化,这种特征尤其在岩体的东侧表现明显。在岩体内各脉动单元间,多具有明显的侵入关系,后期脉动单元侵入岩中多可见到早期脉动单元侵入岩的捕虏体,有些区段还可见早期脉动单元的捕虏体在后期改造中被拉长定向排列,从构造变形到物质成分均表明了其脉动期次关系。

岩体的岩石化学、微量元素及稀土元素特征均表明岩体来源较深,为壳幔相互作用的产物<sup>[18,45-47]</sup>。据岩体花岗闪长岩 SHRIMP U-Pb 测年<sup>[48]</sup>测得麻棚岩体形成年龄为(125.0±3.4)Ma。

## 2 矿床地质特征

以麻棚岩体为中心,在其周边分布着大量的金、银多金属矿床(点)。在岩浆活动的后期沿断裂构造、破碎带侵入了大量的近南北向、北西向中酸性脉岩,在脉岩的边部破碎带普遍有低温热液矿化活动,形成了麻棚岩体外围金、银、铜、铅、锌多金属成矿带。在众多的矿床(点)中,以石湖金矿最为典型,现已成为河北省西部地区的大型金矿。

石湖金矿床成矿围岩为太古界阜平群团泊口组、南营组片麻岩类,由基性-中基性火山岩-碎屑岩-镁质碳酸盐岩等变质表壳岩和基性-酸性变质深成岩类组成,前者是主要赋矿围岩(图2)。

断裂是矿区最主要的构造,控制了岩脉、矿脉的产状、规模及形态,依其特征可分为近南北向和东西向两组。近南北向断裂是矿区最主要的一组断裂构造,贯穿全区南北,成群成带密集出现。长数百米至数千米,宽数十厘米至数十米不等,矿区北部多向西陡倾,一般倾角70°左右,个别东倾;在

矿区南部则以101号为中点,西倾各脉西倾,倾角65~85°;东侧各脉东倾,倾角65~70°。走向变化由西向东,从近南北向(102号)~NW20°(101号)~NW45°(116号)变化。就力学性质分析,该组构造以压扭性为特征,后经多次构造改造,在走向及倾向上均呈舒缓波状,延长、延深均较大。

近东西向断裂包括北西西和北东东两个方向的断裂构造,但以前者为主,一般都无充填物。延长数十米至数百米,宽数十厘米至数十米,总体来看,该组构造向南西倾斜为主,具平移性质。其形成时间晚于近南北向组,对岩脉、含金矿脉起破坏作用。

石湖—土岭矿区已查明金矿脉46条(石湖矿段16,土岭矿段30条),受近南北向复合性断裂带控制,矿体呈脉状、薄板状、透镜状,具分支复合、尖灭再现之特点,走向近南北者为主,北西向者次之,向西或东倾斜,倾角50~80°,平行、倾斜或交叉状产出。矿体长度一般100~200m,最长3200m,目前最大延深420m(101脉)。矿体平均厚度0.45~2.04m,平均品位 $3.52 \times 10^{-6}$ ~ $27.9 \times 10^{-6}$ 。

依矿物共生组合、结构构造和硅化强度,可将矿石划分为3种自然型:

(1) 含金金属硫化物石英脉型:矿石一般呈致密块状,多具碎裂岩化特征。主要由脉状产出的灰白、烟灰色石英组成,金属硫化物主要为黄铁矿、方铅矿、闪锌矿及少量黄铜矿,多呈不规则状、团块状,黄铁矿多呈条带状、细脉状穿插在石英脉内。

(2) 含金多金属硫化物硅化岩型:矿石中金属硫化物主要有黄铁矿、方铅矿、闪锌矿,其次为黄铜矿、磁黄铁矿等,非金属矿物以石英为主。

(3) 含金黄铁矿化硅化蚀变岩型:矿石具碎裂结构,压碎块状构造。蚀变矿物主要为石英、绿泥石、绢云母等。矿化主要为黄铁矿化,黄铁矿呈细粒浸染状分布于石英颗粒边缘。

矿石自然类型以前2种类型为主,第3种类型较少。

金的赋存状态:矿石主要有用组分为金,伴生少量银、铅、锌等。金:以自然金为主,银金矿微量,呈粒间金、裂隙金,包体金赋于黄铁矿、闪锌矿、方铅矿等硫化物石英脉或蚀变岩中。自然金多呈树枝状、粒状或不规则状,粒径一般0.01~0.3mm,大者3~5mm。



近矿围岩蚀变主要有硅化、绢云母化、黄铁绢英岩化、碳酸盐化、绿泥石化等。从矿脉向围岩,可分为硅化带(矿脉)-绢英岩化带-钾化带-碳酸盐化带-绿泥石化带,但分带并不对称,有的分带也不完全。金矿化强度与黄铁绢英岩化强度及蚀变带宽度成正比。

### 3 样品与分析方法

#### 3.1 稀有气体分析方法

所有研究样品均采自石湖金矿、西石门金矿、银洞钨矿、丑泥口金矿、秋卜洞银矿等矿床(点)的代表性矿石,测试对象为黄铁矿中流体包裹体。黄铁矿样品通过在双目镜下挑选,保证所选样品新鲜、晶形完好,纯度达100%。黄铁矿流体包裹体氦、氩同位素组成测试由中国地质科学院矿产资源研究所完成。使用仪器为乌克兰产MI-1201-IG惰性气体同位素质谱仪,分析方法采用压碎法,使用标准大气Ra: $^3\text{He}/^4\text{He}=1.4\times 10^{-6}$ ,分析过程如下:(1)样品用丙酮在超声波中清洗20 min,烘干;(2)真空中120℃去气24 h;(3)压碎样品,释放出气体;(4)释放出的气体经海绵钛泵、锆铝泵、活性炭液氮冷阱4级纯化,活性气体均被去除,氦、氩被冷冻,纯净的He、Ne进入分析系统;(5)进入分析系统的He、Ne经加液氮的钛升华泵再次纯化去掉微量H<sub>2</sub>、Ar;(6)于-78℃释放Ar,进行Ar同位素分析;(7)根据压碎后通过160目(0.100 mm)的样品重量,计算样品的氦氩含量。

#### 3.2 碳、氢、氧同位素分析方法

研究样品均采自与黄铁矿共生的石英,测试对象为石英中的流体包裹体。石英样品通过在双目镜

下挑选,保证所选样品新鲜,纯度达100%。所有同位素分析均在中国地质科学院矿产资源研究所利用MAT-253EM型质谱计完成。硅酸盐样品的氧同位素分析采用传统的BrF<sub>5</sub>分析方法<sup>[49]</sup>,用BrF<sub>5</sub>与含氧矿物在真空和高温条件下反应提取矿物氧,在700℃与石墨棒反应转化成CO<sub>2</sub>气体,分析精度为±0.2‰,相对标准为V-SMOW。选取40~60目的纯净石英样品,在150℃低温下真空去气4 h以上,以彻底除去表面吸附水和次生包裹体水,然后在400℃高温下爆裂取水,并与金属锌反应生成H<sub>2</sub>,分析精度为±0.2‰,相对标准为V-SMOW。石英流体包裹体中的CO<sub>2</sub>,在热爆法取水分析H同位素的同时分离,提取,分析精度为±0.2‰,相对标准为V-PDB。

### 4 分析结果

从黄铁矿流体包裹体的He、Ar同位素分析结果(表1)可以看出,石湖地区金、银多金属矿床的 $^3\text{He}/^4\text{He}$ 介于 $0.6\times 10^{-6}\sim 3.36\times 10^{-6}$ , $^{40}\text{Ar}/^{36}\text{Ar}$ 介于477~87, $^4\text{He}$ 的含量介于9.16~343.03 cm<sup>3</sup>STP/g。与黄铁矿共生的石英包裹体碳、氢、氧同位素分析结果列于表2。由表2可以看出,石英包裹体中的氧同位素介于9.6‰~13.8‰,氢同位素介于-62‰~-105‰,碳同位素介于-3.5‰~-5.0‰。

### 5 讨论

#### 5.1 氦、氩同位素地球化学特征

黄铁矿中氦、氩同位素的测定值能否代表成矿流体形成时的初始值,一些学者进行了深入研究<sup>[27,50]</sup>。黄铁矿是测定氦、氩同位素理想的分析对象,因为黄铁矿流体包裹体中的氦在流体包裹体被

表1 石湖地区金、银多金属矿床氦、氩同位素组成

Table 1 Helium and argon isotopic composition of gold, silver and polymetallic deposits in Shihu area

样品编号	样品名称	矿床	矿化类型	$^3\text{He}/^4\text{He}$ / $10^{-6}$	$^4\text{He}/10^{-7}$ /(cm <sup>3</sup> STP/g)	$^3\text{He}/10^{-13}$ /(cm <sup>3</sup> STP/g)	$^{40}\text{Ar}/^{36}\text{Ar}$	R/Ra
FXS-1	黄铁矿	西石门	石英脉型	1.98±0.16	213.76	423.24	577±4	1.41
FXS-11	黄铁矿	西石门	石英脉型	2.75±0.18	17.53	48.21	477±1	1.96
FSH-1	黄铁矿	石湖	石英脉型	0.6±0.05	32.21	19.33	879±10	0.43
FCN-1	黄铁矿	丑泥口	石英脉型	3.36±0.34	9.16	30.78	511±4	2.40
FYT-6	黄铁矿	银洞	石英脉型	1.02±0.06	235.85	240.57	805±17	0.73
FQP-14	黄铁矿	秋卜洞	石英脉型	1.61±0.05	343.03	552.28	789±10	1.15

注:数据由中国地质科学院矿产资源研究所(2009)分析。

表2 石湖地区金、银多金属矿床氧、氢、碳同位素组成  
Table 2 The composition of oxygen, hydrogen and carbon isotopes of gold, silver and polymetallic deposits in Shihu area

矿床区	$\delta^{18}\text{O}_{\text{V-SMOW}}/\text{‰}$	平均温度/ $^{\circ}\text{C}$	$\delta^{18}\text{O}_{\text{h}}/\text{‰}$	$\delta\text{D}_{\text{V-SMOW}}/\text{‰}$	$\delta^{13}\text{C}_{\text{PDB}}/\text{‰}$
石湖金矿	13.8		1.83	-87	-4.9
石湖金矿	13.3	196	1.33	-89	-5.0
石湖金矿	11.5		-0.47	-105	-
西石门金矿	13.1	251	4.2	-83	-3.5
秋卜洞银矿	9.8	271	1.78	-66	-4.2
秋卜洞银矿	9.6	253	0.78	-62	-
银洞钨矿	10.2	281	2.59	-87	-3.5
丑泥口金矿	12.2	204	0.74	-77	-4.9

注:由中国地质科学院矿产资源研究所(2007)分析。

圈闭后无明显的丢失<sup>[24,27]</sup>。后生放射成因的氦、氩对分析结果的影响可忽略不计。对于非含钾矿物,其流体包裹体内原地放射成因<sup>40</sup>Ar的量则可忽略不计<sup>[27]</sup>。由于本次所研究的样品均采自采坑道或岩心样品,因此可以排除流体包裹体内存在宇宙成因<sup>3</sup>He的可能性<sup>[21,23,51]</sup>,同时,由于研究区缺乏含锂的矿物,由含锂矿物诱发而产生<sup>3</sup>He对流体中氦浓度的影响,亦可以忽略不计。所分析的样品保存完好,不存在影响流体包裹体<sup>3</sup>He/<sup>4</sup>He的条件(如流体包裹体中异常高的U和Th)。因此,可以认为样品中氦、氩同位素的测定值可代表当初成矿流体的初始值。

已有的研究表明,地壳流体中的稀有气体有3个明显不同的源区,即饱和空气雨水(ASW)、地壳和地幔,其中饱和空气水中<sup>3</sup>He/<sup>4</sup>He=1 Ra,<sup>40</sup>Ar/<sup>36</sup>Ar=295.5;地壳中<sup>3</sup>He/<sup>4</sup>He=0.01~0.05 Ra,<sup>40</sup>Ar/<sup>36</sup>Ar>295.5;地幔中<sup>3</sup>He/<sup>4</sup>He=6~9 Ra,<sup>40</sup>Ar/<sup>36</sup>Ar>40000<sup>[29]</sup>。由于氦在大气中的含量极低,不足以对地壳流体中氦的丰度和同位素组成产生明显影响<sup>[23,52]</sup>。因此,石湖地区金银多金属矿床成矿流体中的氦只可能有两个主要的源区,即地壳和地幔。

表1表明,石湖地区金银多金属矿床成矿流体中的<sup>3</sup>He/<sup>4</sup>He比值介于0.43~2.40 Ra,高于中国云南哀牢山金矿带(0.02~1.42 Ra)<sup>[27]</sup>、大渡河金矿田(0.16~0.86 Ra)<sup>[53]</sup>、小秦岭地区金矿(0.29~0.86 Ra)<sup>[54]</sup>、新疆萨瓦亚尔顿金矿(0.04~1.11 Ra)<sup>[55]</sup>的氦同位素变化范围,明显高于地壳He,但显著低于万古金矿(3.5~9.8 Ra)<sup>[60]</sup>和东坪金矿(0.3~5.2 Ra)<sup>[37]</sup>,更低于地幔特征值。

将石湖地区金、银多金属矿床黄铁矿流体包裹体的氦同位素投点于<sup>4</sup>He-<sup>3</sup>He和<sup>40</sup>Ar/<sup>36</sup>Ar-R/Ra演化图上。从图3~4可以看出,石湖地区的金银多金属矿均落于地幔He与地壳He之间,但更接近于地幔氦,而相对远离大气饱和水(ASW),显示石湖地区金银多金属矿床成矿流体不是单一的地壳或地幔流体,而是二者混合的产物。这与韩国Dae Hwa W-Mo矿床<sup>[23]</sup>、马厂箐铜矿<sup>[25]</sup>、云南哀牢山金矿带<sup>[29]</sup>相似,矿床成矿流体是典型的地幔流体与地壳流体的二元混合模式。

成矿流体是壳幔二元混合模式,可根据<sup>3</sup>He/<sup>4</sup>He计算出地幔流体(Rm)和地壳流体(Rc)所占的比例。其中幔源<sup>4</sup>He的比例由下列公式计算:地幔氦=[(R-Rc)/(Rm-Rc)]。其中,Rm、Rc、R分别代表地幔流体、地壳流体以及样品的氦同位素组成。

## 5.2 碳、氢、氧同位素地球化学特征

根据矿床石英流体包裹体的均一温度,利用 $1000\ln\alpha_{\text{石英-水}} = 3.38 \times 10^6 \times T^{-2} - 3.4$ 及 $1000\ln\alpha_{\text{石英-水}} = \delta^{18}\text{O}_{\text{石英}} - \delta^{18}\text{O}_{\text{水}} (200\sim 500^{\circ}\text{C})$ <sup>[58]</sup>分馏公式计算石英流体包裹体的氧同位素,结果列于表2。将石英样品的 $\delta^{18}\text{O}_{\text{V-SMOW}}$ 换算成 $\delta^{18}\text{O}_{\text{H}_2\text{O}}$ ,其范围为-0.47‰~4.2‰,

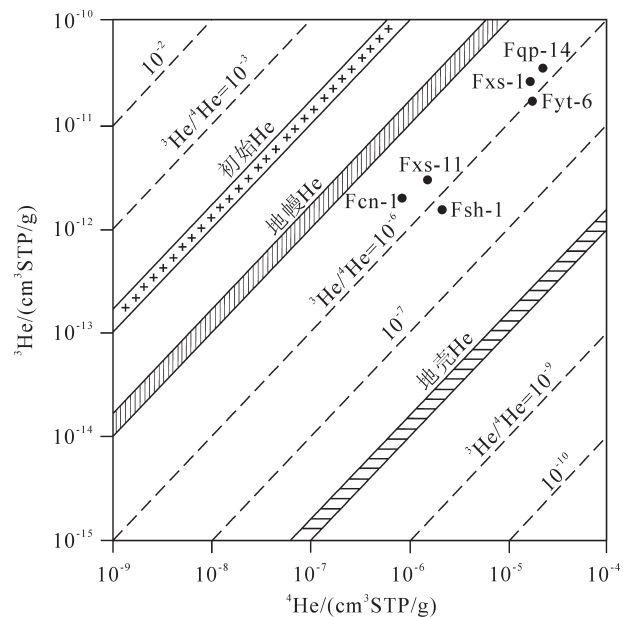


图3 石湖地区金、银多金属矿床流体包裹体<sup>3</sup>He-<sup>4</sup>He图 (据文献[56])

Fig.3 <sup>4</sup>He-<sup>3</sup>He diagram of fluid inclusions in pyrite of gold, silver and polymetallic deposits in Shihu area (after reference [56])

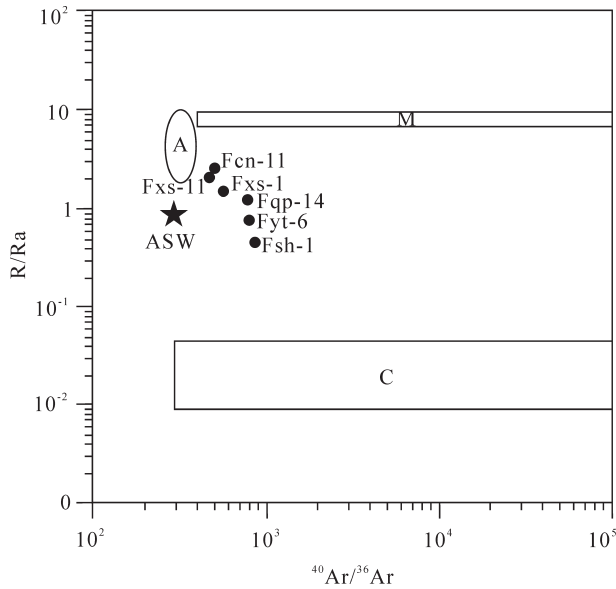


图4 石湖地区金、银、多金属矿床<sup>40</sup>Ar/<sup>36</sup>Ar-R/Ra图  
 ASW—大气饱和水; A—红海和大西洋中脊TAG地区海底热水范围(据文献[31, 57]); M—地幔流体范围; C—地壳流体范围  
 Fig.4 <sup>40</sup>Ar/<sup>36</sup>Ar versus R/Ra diagram of fluid inclusions in pyrite of gold, silver and polymetallic deposits in Shihu area (after reference [31, 57])

低于 Ohmoto<sup>[59]</sup>和 Sheppard<sup>[60]</sup>界定的典型岩浆水+5.5‰~+9.5‰。石英样品中包裹体的 $\delta D_{V-SMOW}$ 范围为-62‰~-105‰,与标准岩浆水 $\delta D_{V-SMOW}$ -40‰~-80‰较为接近。将石英包裹体的 $\delta^{18}O_{H_2O}$ 与 $\delta D_{V-SMOW}$ 数据投影于 $\delta^{18}O$ - $\delta D$ 组成图<sup>[61]</sup>上(图5),可以看出投影点位于岩浆水附近,远离大气降水与变质水,表明矿区成矿流体为岩浆水与大气降水相混合的产物。包裹体中 $\delta^{13}C_{PDB}$ 为-3.5‰~-5.0‰,完全落在了地幔碳 $\delta^{13}C$ 范围( $\delta^{13}C$ =-3‰~-8‰)<sup>[62]</sup>中,结合 $\delta^{18}O_{H_2O}$ ,表明矿区成矿热液中的碳来自地幔<sup>[60]</sup>。

### 5.3 成矿地质意义

中生代以来,太行山地区在深部垂向运动和浅部伸展构造体制控制下快速隆升,使得阜平群变质基底岩系隆升至地表,上覆盖层向周围拆离滑脱,形成典型的阜平变质核杂岩。规模巨大的太行山深大断裂带在其活动过程中导致了太行山岩浆带地强烈活动,自北向南形成大河南、王安镇、司各庄、赤瓦屋、麻棚等花岗质杂岩体。大量幔源岩浆搭载着成矿物质向上运移。在岩浆活动后期,含金、银多金属以流体形式沿深大断裂向地壳浅部运移的过程中,由于成矿系统中的构造环

境、温度、压力等因素的骤然改变,以及含矿热液与地壳内浅部流体地混合作用,并不断与围岩相互交代,从中萃取了部分成矿金属元素,致使含矿热液的成分不断变化,导致流体内的成矿物质在适宜的物理化学条件下沉淀析出,进而在有利的构造部位聚集成矿。石湖地区的金、银多金属矿床即为燕山期麻棚岩浆活动的产物,石湖金矿为其中的典型代表。在地幔与地壳的相互作用过程中,特别是在通过地幔进入地壳至地壳浅部时,不可避免地会混入大量的壳源物质,这就使得所测数据往往位于典型幔源区与壳源区之间,而不是位于其中,大多数呈现过渡型特征<sup>[19-20]</sup>。

## 6 结论

(1)黄铁矿流体包裹体氦、氩同位素组成研究表明,石湖地区金、银多金属矿床黄铁矿流体包裹体的<sup>3</sup>He/<sup>4</sup>He介于0.43~2.40 Ra,<sup>40</sup>Ar/<sup>36</sup>Ar介于477~879。氦、氩同位素系统显示出石湖地区金、银多金属矿床成矿流体为地幔流体与地壳流体的混合来源。

(2)石英包裹体的碳、氢、氧同位素表明石湖地区金、银多金属矿床的成矿流体为地幔流体与大气降水共同作用的结果。

(3)成矿流体的氦、氩与碳、氢、氧同位素体系所反映的流体来源具有一致性,多种同位素体系的相互制约有助于更准确地识别成矿流体的性质及来源。

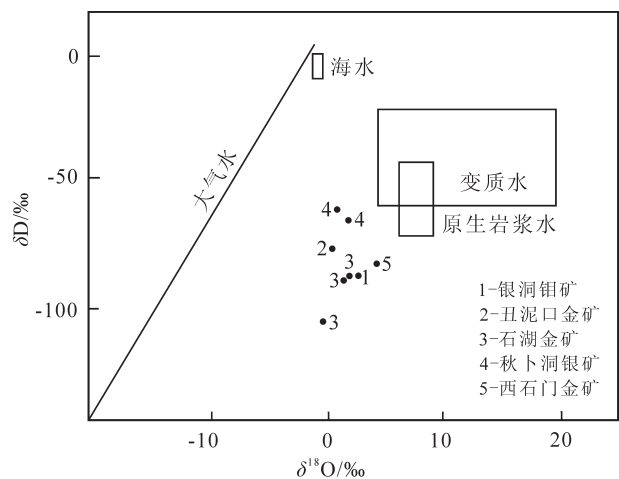


图5 石湖地区金、银多金属矿床 $\delta^{18}O$ - $\delta D$ 相关图  
 (据文献[61])

Fig.5 Correlation of  $\delta^{18}O$ - $\delta D$  for gold, silver and polymetallic deposits in Shihu area (after reference [61])

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## Characteristics and geological significance of helium, argon, carbon, hydrogen, oxygen isotopes in ore-forming fluids of polymetallic deposits in Shihu area of western Hebei Province

WANG Zi-li<sup>1</sup>, NIU Shu-yin<sup>2,3</sup>, GUO Peng-zhi<sup>1</sup>, DUAN Huan-chun<sup>1</sup>,  
CHEN Zhi-guo<sup>1</sup>, GUO Zhong<sup>1</sup>, SHEN Li-xia<sup>1</sup>, HU Jian-yong<sup>1</sup>,  
WANG Jun<sup>1</sup>, WANG Bao-de<sup>2</sup>, CHEN Chao<sup>2</sup>, LI Ying-jie<sup>2,3</sup>

(1. *Tianjin North China Geological Exploration Bureau, Tianjin 300170, China;*

2. *Shijiazhuang University of Economics, Shijiazhuang 050031, Hebei, China;*

3. *China University of Geosciences, Beijing 100083, China)*

**Abstract:** The gold, silver and polymetallic deposits in Shihu area are located in the mid-northern Taihang Mountains and occur in Archean Fuping Group metamorphic rock series around Yanshanian Mapeng granitic intrusion. The gold, silver and polymetallic deposits in Shihu area have attracted the attention of many geologists, and their metallogenesis has long been in dispute. The authors chose pyrite and quartz samples from these deposits in Shihu area to analyze their helium, argon, carbon, hydrogen and oxygen isotopic composition of fluid inclusions and the hydrogen, oxygen and carbon isotopic composition of the quartz in the same ore sample. The analytical results show that  $^3\text{He}/^4\text{He}$  ratios in pyrite range from 0.43 to 2.40 Ra, and  $^{40}\text{Ar}/^{36}\text{Ar}$  ratios range from 477 to 879. The composition of helium and argon isotopic system suggests that the source of ore-forming hydrothermal fluids was the mixture of mantle-derived fluids and crust-derived fluids. It is estimated that the  $\delta\text{D}_{\text{V-SMOW}}$  values of the ore-forming fluid responsible for the formation of the quartz are  $-62\text{‰} \sim -105\text{‰}$ , and the  $\delta^{18}\text{O}_{\text{V-SMOW}}$  values of the fluid inclusions of the quartz are  $9.6\text{‰} \sim 13.8\text{‰}$ , showing that the ore-forming hydrothermal fluids were formed by the mixture of magmatic water and meteoric water. The  $\delta^{13}\text{C}_{\text{PDB}}$  values of quartz vary in a relative narrow range of  $-3.5\text{‰} \sim -5.0\text{‰}$ , showing that the ore-forming hydrothermal fluids were derived from the mantle. The relationship between hydrogen, oxygen, carbon and helium and the argon isotopic systems of ore-forming hydrothermal fluids show tracing consistency in gold, silver and polymetallic deposits of Shihu area. All the noble gas isotopic data, combined with stable isotopic data from five deposits, demonstrate that the ore-forming fluids were a mixture between mantle-derived fluids and crustal-derived fluids.

**Key words:** He-Ar; H-O; isotope; ore-forming fluids; Shihu; Hebei Province

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**About the first author:** WANG Zi-li, male, born in 1982, master, engages in the exploration and study of mineral deposits; E-mail: wangzili1982@163.com.