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冀东峪耳崖金矿床辉钼矿 Re-Os 年龄及其地质意义

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摘要: 峪耳崖金矿床是冀东地区重要的金矿之一, 位于华北板块燕山造山带东段, 马兰峪复背斜北翼。金矿体赋存于峪耳崖花岗岩及其与灰质白云岩接触带中, 矿化类型包括石英脉型和细脉浸染型, 属中温热液型矿床。本次工作采用 Re-Os 同位素测年技术, 对该矿床主成矿阶段的 7 件辉钼矿样品进行了精确定年, 获得模式年龄为 (168.4±2.5) Ma~(171.7±3.0) Ma, 加权平均年龄为 (169.84±0.95) Ma, 等时线年龄为 (171.9±2.7) Ma, 表明矿床形成于中侏罗世, 与成矿花岗岩侵位时间基本一致。辉钼矿的铼含量为 50.63×10^{-6} ~ 116.1×10^{-6} , 平均 84.61×10^{-6} , 指示成矿物质可能为壳幔混合来源。结合前人研究成果资料分析, 峪耳崖金矿是冀东地区燕山早期区域性强烈构造-岩浆-成矿作用的产物。

关键词: Re-Os 同位素测年; 辉钼矿; 成矿物质来源; 峪耳崖金矿; 冀东

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冀东地区位于华北板块北东部, 地质演化历史长, 构造、岩浆活动强烈, 矿产种类多样, 是中国金矿的主要产地之一, 已先后发现金矿床(点) 197 处^[1] (图 1), 如金厂峪金矿、峪耳崖金矿、华尖金矿、东梁金矿、唐杖子金矿、牛心山金矿等。其中, 峪耳崖金矿位于河北承德宽城满族自治县峪耳崖镇, 已查明资源量达大型规模。

峪耳崖金矿床的地质工作始于 20 世纪 50 年代, 研究程度较高。于润林(1995)^[2]认为峪耳崖金矿矿石多为细脉浸染型, 属斑岩型金矿; 戚龙水等(1999)^[3]研究了矿床地质特征, 认为其成因类型为中温热液型; 邱检生等(1994)^[4]指出峪耳崖金矿是冀东地区与中生代花岗岩有关的金矿床的典型代

表, 邱检生等(1994)^[4]及王自力等(2008)^[5]认为成矿花岗岩体具陆壳改造型(S型)花岗岩的特点, 成矿物质来自岩浆体系^[6]。廖香俊等(1995)^[7]、雷书浩(1989, 1991)^[8-9]及吴丹等(1998)^[10]分别对矿床中自然金、黄铁矿及石英等矿物进行了成因矿物学研究, 认为黄铁矿及暗灰色石英对金的吸收、富集作用十分有利, 自然金主要赋存在黄铁矿及其裂隙中; 孔德鑫等(2013)^[9]对金属矿物特征及其组合进行了分析, 认为该矿床为中-深成中温岩浆热液矿床; 赵纯福(1991)^[11]及金天尚(2003)^[12]观察并分析了矿田构造, 指出矿化受 NE 向联合构造体系控制。对峪耳崖花岗岩岩体年代学的研究也很多, 获得的数据包括 K-Ar 年龄 149~169 Ma^[13]、K-Ar 稀

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法年龄 223.8 Ma^[14]、全岩 Rb-Sr 等时线年龄 145 Ma^[15]、锆石 U-Pb SHRIMP 年龄 174 Ma、175 Ma^[16]。

尽管如此,对于金矿成矿时代及其与花岗岩的关系一直没有厘定清楚,虽然李颖等(1993)^[17]测定峪耳崖金矿石英包裹体 Rb-Sr 等时线年龄为 163.8 Ma,余昌涛等(1989)^[18]测得含金石英脉中绢云母 K-Ar 年龄 187.8 Ma,但均为间接测定的成矿时代数据。汤云晖等(2003)^[19]利用裂变径迹法对花岗岩内的磷灰石和锆石进行了成矿时代的测定(3个成矿高峰期 180~200 Ma、140 Ma 和 120 Ma),但不够精确。随着测年技术的不断发展,辉钼矿 Re-Os 法^[20-24]逐渐成熟,即使辉钼矿经历了后期热变质作用或热液活动,也难以破坏其 Re-Os 同位素体系的封闭性,Re-Os 年龄也与岩浆锆石年龄相互吻合^[25-26],因此成为研究金属内生矿床成矿时代最直接的重要手段^[27-28]。本文在详细野外调研的基础上,首次利用辉钼矿 Re-Os 同位素体系准确厘定了成矿时代,并结合前人研

究成果资料,探讨了成矿与成岩的关系,为进一步探讨该区金成矿作用提供新的依据。

1 区域地质

冀东地区位于华北板块北缘燕山造山带的东段(图 1), 马兰峪复背斜为区内规模最大的褶皱构造,其核部出露太古宙结晶基底,主要有辉石麻粒岩、黑云斜长片麻岩夹辉石变粒岩、斜长角闪岩、黑云斜长变粒岩等,原岩以基性、中基性及中酸性火山岩为主,其次为碎屑岩和含铁硅质岩。其两翼主要为中新元古界的沉积岩系,岩性以碎屑岩、粘土岩和碳酸盐岩为主,夹少量火山碎屑岩。区域基本断裂构造格架以印支期近 EW 向喜峰口—青龙大断裂与燕山期 NE 向凌源—喜峰口大断裂为主导^[29-30], NW 向冷口深大断裂属先存断裂,在印支运动和燕山运动阶段活化,与燕山板内造山带整体特征不一致^[30]。断裂带控制了区域中酸性岩浆岩的侵入和展

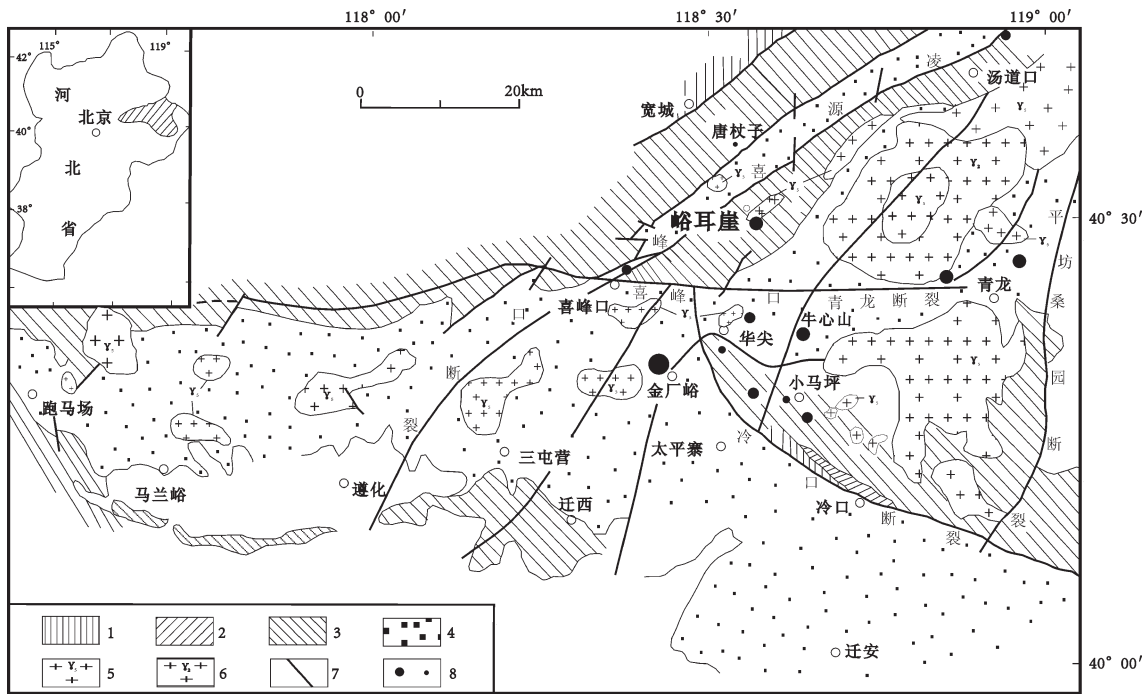


图1 冀东地区区域地质及金矿床分布简图(修改自文献[1])

1—中侏罗世地层;2—古生代地层;3—中、新元古代地层;4—遵化—青龙太古宙变质杂岩;5—印支期花岗岩;6—燕山期花岗岩;7—断裂;8—金矿床(点)

Fig.1 Regional geological sketch map of eastern Hebei (modified after reference [1])

1—Middle Jurassic strata; 2—Paleozoic strata; 3—Mesoproterozoic—Neoproterozoic strata; 4—Zunhua—Qinglong Archean metamorphic rock; 5—Indo—Chinese granite; 6—Yanshanian granite; 7—Fault; 8—Gold deposit (ore spot)

布^[31],对该区金矿成矿具有重要意义。

区内岩浆活动强烈,太古宙、元古宙、古生代和中生代岩浆岩都有发育,其中以太古宙、中生代岩浆活动最为强烈。侵入岩主要为花岗岩类,如印支期都山花岗岩基^[32]、燕山期峪耳崖花岗岩体、唐杖子花岗斑岩等,其次为闪长岩,另有少量正长岩类和镁铁质-超镁铁质岩,如南部的燕山期孤山子超基性-基性杂岩体;火山岩以中生代玄武岩-安山岩系列和安山岩-流纹岩系列为主。

2 矿床地质

峪耳崖金矿床位于马兰峪复背斜的北缘,矿区褶皱构造不甚发育(图2),以断裂构造为主,按走向可分为NE、NNE、NEE、NW和近EW向5组,为同一构造系多期活动所形成^[12]。矿床主要受NE、NNE向断裂控制。NE向压性逆断层倾向北西,倾角一

般较缓为30°~45°,北部较陡为60°~75°,断裂北部多出露地表,南部多隐伏,往深部产状由陡变缓。该NE向断裂多被矿脉充填,直接控制着矿脉的形态及产状。NNE向断裂倾向北西,倾角37°~66°,发育碎裂岩、片理化、斜擦痕,显示压扭性特征。

矿区出露的岩浆岩为峪耳崖花岗岩,侵位于长城系高于庄组灰质白云岩内,其形成与燕山早期岩浆活动有关^[16,19],可分为灰白色中细粒黑云母花岗岩和肉红色中粗粒黑云母花岗岩,前者多分布于岩体的顶部、边部或白云岩捕虏体、顶垂体的周围;后者多分布于岩体中、深部。两种花岗岩均呈花岗结构、块状构造,主要矿物碱性长石含量50%~55%,呈似斑晶或斑晶,半自形-他形;斜长石15%,自形一半自形或他形粒状;石英25%~30%,他形粒状;其他少量矿物包括黑云母、黄铁矿、磁铁矿、磷灰石、锆石等。李颖等(1990)^[17]认为2种不同颜色的花岗岩

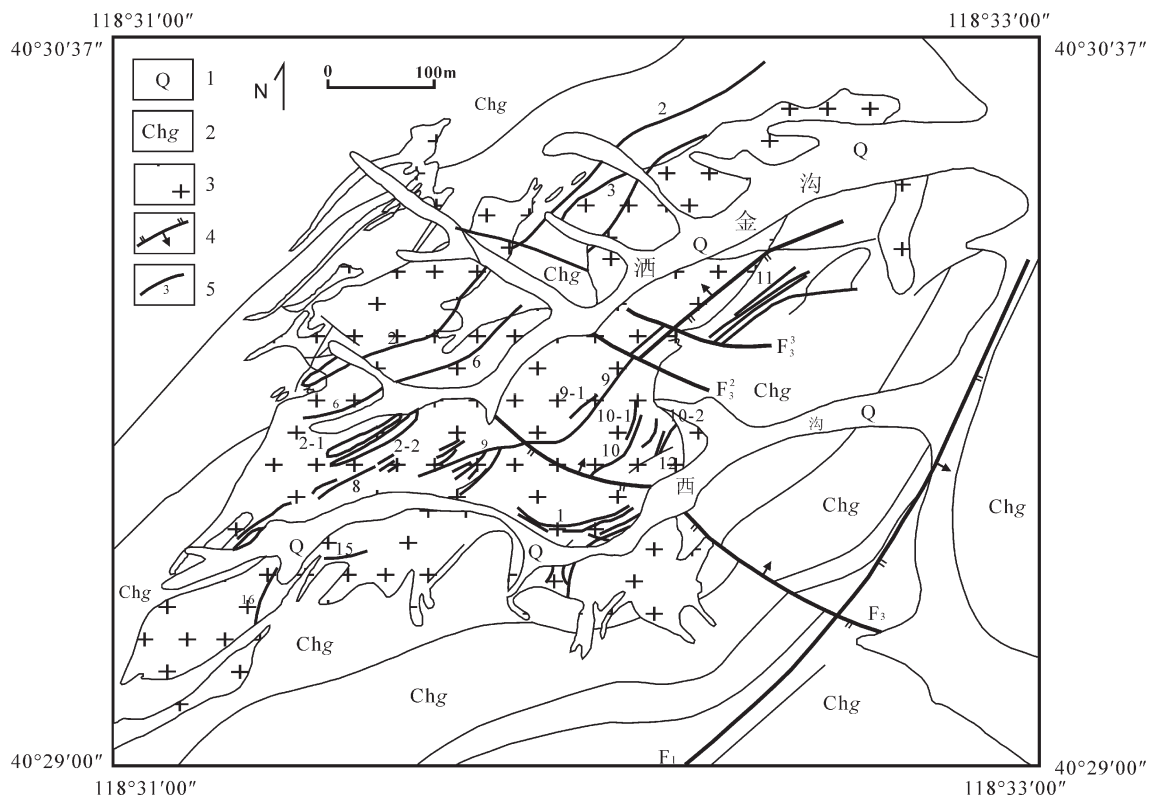


图2 冀东峪耳崖金矿地质图(改自文献[33])

1—第四系;2—高于庄组灰质白云岩;3—燕山期峪耳崖花岗岩;4—断裂;5—矿脉及编号

Fig.2 Geological map of the Yuerya gold deposit (modified after reference [33])

1-Quaternary; 2-Gaoyuzhuang Formation limy dolomite; 3-Granite; 4-Fault; 5-Orebody and its serial number

是不同期次侵入的,但二者之间无明显的界线,肉红色花岗岩比灰白色花岗岩钾长石含量略高,钾长石化、绢云母化及碳酸盐化更强。峪耳崖花岗岩富 SiO_2 、 K_2O 、 Na_2O , 贫 Al_2O_3 、 CaO 、 Fe_2O_3 及 FeO ^[34], $\text{ANCK}<1$, 而 $A>1$, 为准铝型岩石,属于I-S型的过渡类型^[35]。岩体属轻稀土富集型, La/Yb 为9.03, Eu亏损明显,岩体与区域太古界迁西群岩石Pb同位素特征相似,推测岩体系迁西群在少量幔源成分参与下发生深熔形成的再生重熔岩浆侵位的产物^[34]。峪耳崖花岗岩体的铷锶初始比 $^{87}\text{Sr}/^{86}\text{Sr}$ 为0.7069,显示幔源成因特征,为壳幔混熔成因花岗岩^[16,36]。

矿体主要赋存于花岗岩体及其接触带中(图3),矿体展布严格受断裂控制,多集中分布在岩体南部、中部和北东部,多为盲矿体,多数以NE、NNE向产出。矿化类型可以分为含金石英脉型和细脉浸染型,前者主要产于花岗岩和灰质白云岩的裂隙或断裂破碎带及其接触带,后者分布于含矿断裂带两侧次级裂隙发育部位。

围岩蚀变强烈,以黄铁矿化、绢云母化、硅化、钾化、钠长石化为主,其次为绿泥石化、黄铁绢英岩化、高岭土化等,其中黄铁绢英岩化、硅化与矿化关系密切。在矿体与围岩灰质白云岩接触带中还发育矽卡岩化、大理岩化及黄铁矿化。

矿石矿物主要为黄铁矿、黄铜矿,其次为磁黄铁矿、闪锌矿、辉铜矿、辉钼矿等;脉石矿物以石英为主,还可见长石、方解石、绿泥石、绢云母及铁白云石等。矿石结构主要为自形一半自形及他形粒状结构、压碎结构、交代结构和充填结构;构造以细脉状、浸染状、块状等为主。按矿物共生组合及相互关系,可将成矿作用划分为5个阶段:Ⅰ、黄铁矿-石英阶段,早期热液成矿阶段,粗粒自形一半自形黄铁矿多呈浸染状分布于石英脉内,基本不含金,无工业价值;Ⅱ、石英-磁黄铁矿-黄铁矿阶段,黄铁矿多呈半自形-他形,共生磁黄铁矿、黄铜矿及少量辉钼矿,发育金矿化,偶见自然金;Ⅲ、石英-黄铁矿阶段,半自形-他形黄铁矿呈细脉或网脉状充填裂隙,

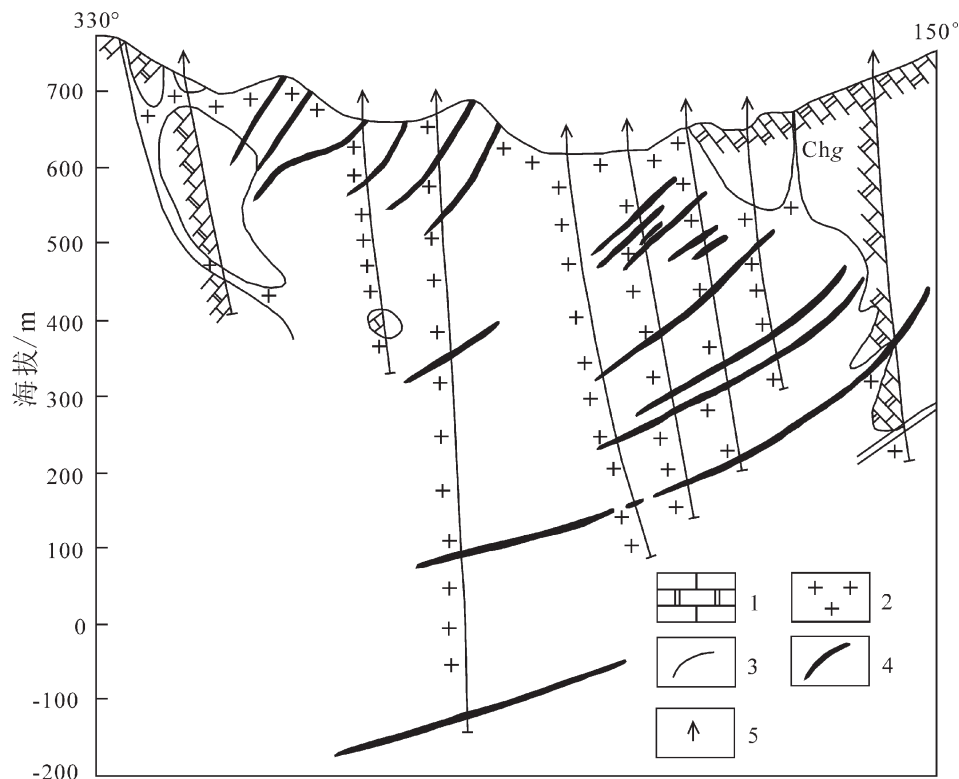


图3 峪耳崖金矿2号勘探线剖面图(引自文献[31])

1—灰质白云岩;2—花岗岩;3—地质界线;4—矿脉;5—钻孔

Fig.3 Geological section along No. 2 exploration line of the Yuerya gold deposit (after reference [31])

1—Limy dolomite; 2—Granite; 3—Geological boundary; 4—Orebody; 5—Drill hole

金品位高;IV、石英-多金属硫化物-自然金阶段,黄铜矿、方铅矿和闪锌矿等硫化物呈微细脉状分布于石英裂缝及碎裂黄铁矿中,矿石含银较高;V、黄铁矿-碳酸盐岩阶段,晚期热液活动的产物,无金矿化。其中,第II、III、IV成矿阶段的黄铁矿与金矿化关系密切,第III阶段金矿化最好。

3 样品及测试方法

本次工作用于Re-Os同位素测年的7件辉钼矿样品(表1)采于峪耳崖露天矿区的不同位置,样品均为刚揭露出开采面花岗岩岩体内第II阶段的辉钼矿化石英脉,石英脉围岩为黄铁绢英岩化花岗岩。其中,辉钼矿有2种分布形式:一种呈薄层状(图4-a),分布于烟灰色石英脉边部,与黄铁矿、黄铜矿共生(图4-c、e),辉钼矿呈弯曲叶片状,粒度较小,黄铁矿呈半自形-他形,构成辉钼矿-黄铁矿-石英脉;另一种呈薄膜状(图4-b),分布于石英脉脉壁,与黄铁矿、黄铜矿等共生(图4-d、f),呈叶片状,粒度更细,黄铁矿呈半自形粒状。伴生的蚀变有黄铁绢英岩化、绿帘石化、铁白云石化等。

辉钼矿单矿物的分离是在河北省廊坊市诚信地质服务有限公司完成。矿石样品经粉碎、分离、粗选和精选,获得纯度>99%的辉钼矿单样品,无污染,符合测试要求。

辉钼矿样品Re、Os同位素测试工作在国家地质实验测试中心Re-Os同位素实验室完成。分析

方法及程序详见有关文献^[38-39]。现简述如下:

准确称取待分析样品,加入到Carius管中进行分解,用¹⁸⁵Re和¹⁹⁰Os混合稀释剂稀释样品,再依次加入其他试剂,待Carius管底溶液冻实后,用液化石油气和氧气火焰加热封好carius管的细颈部分,逐渐升温到230℃,保温24h。将Carius管中溶液转入蒸馏瓶中,连接蒸馏装置,加热微沸30min。所得OsO₄水吸收液可直接用于ICPMS测定Os同位素比值。将蒸馏残液转入Teflon烧杯中,经过加热降低酸度,加NaOH溶液促进样品转为碱性介质;再经离心处理得到Re。

采用美国TJA公司生产的电感耦合等离子体质谱仪TJA X-series ICP-MS测定Re、Os同位素比值。对于Re-Os含量很低的样品采用美国热电公司(Thermo Fisher Scientific)生产的高分辨电感耦合等离子体质谱仪HR-ICP-MS Element 2进行测量。对于Re:选择质量数185、187,用190监测Os。对于Os:选择质量数为186、187、188、189、190、192。用185监测Re。

4 测试结果

Re-Os模式年龄 t 按如下公式计算:

$$t = \frac{1}{\gamma} \left[\ln \left(1 + \frac{{}^{187}\text{Os}}{{}^{187}\text{Re}} \right) \right]$$

其中, γ (¹⁸⁷Re衰变常数)= $1.666 \times 10^{-11} \text{a}^{-1}$ 。

表1 冀东峪耳崖金矿床露天矿区辉钼矿 Re-Os 同位素年龄测试样品特征
Table 1 Characteristics of samples from the Yuerya gold deposit for Re-Os age dating

| 样品编号 | 采样位置 | 产出形态描述* | 共生矿物组合 | 成矿阶段 |
|-----------|---------------------------------|-------------|--------------------|------|
| YEY-B10-1 | E118°32'20", N40°29'19", H452 m | 薄层状分布于石英脉边部 | 石英+辉钼矿+黄铁矿 | II阶段 |
| | 及该点附近 | | | |
| YEY-B10-2 | 同上 | 薄层状分布于石英脉边部 | 石英+辉钼矿+黄铁矿+绢云母 | II阶段 |
| YEY-B10-3 | 同上 | 薄层状分布于石英脉边部 | 石英+黄铁矿+黄铜矿+辉钼矿+绢云母 | II阶段 |
| YEY-B10-4 | 同上 | 薄膜状分布于石英脉脉壁 | 石英+黄铁矿+黄铜矿+辉钼矿+绢云母 | II阶段 |
| YEY-B10-5 | 同上 | 薄膜状分布于石英脉脉壁 | 石英+黄铁矿+辉钼矿+绢云母 | II阶段 |
| YEY-B10-6 | E118°32'10", N40°29'09", H508 m | 薄膜状分布于石英脉脉壁 | 石英+黄铁矿+黄铜矿+辉钼矿+绢云母 | II阶段 |
| YEY-B10-7 | 同上 | 薄膜状分布于石英脉脉壁 | 石英+黄铁矿+黄铜矿+辉钼矿+绢云母 | II阶段 |

注:*由于薄膜状的辉钼矿颗粒细小,厚度极小,像薄膜一样附着在石英脉两侧的脉壁上,描述为“薄膜状分布于石英脉脉壁”;而薄层状的辉钼矿也分布在石英脉两侧,但其较厚,附着感很弱,描述为“薄层状分布于石英脉边部”。

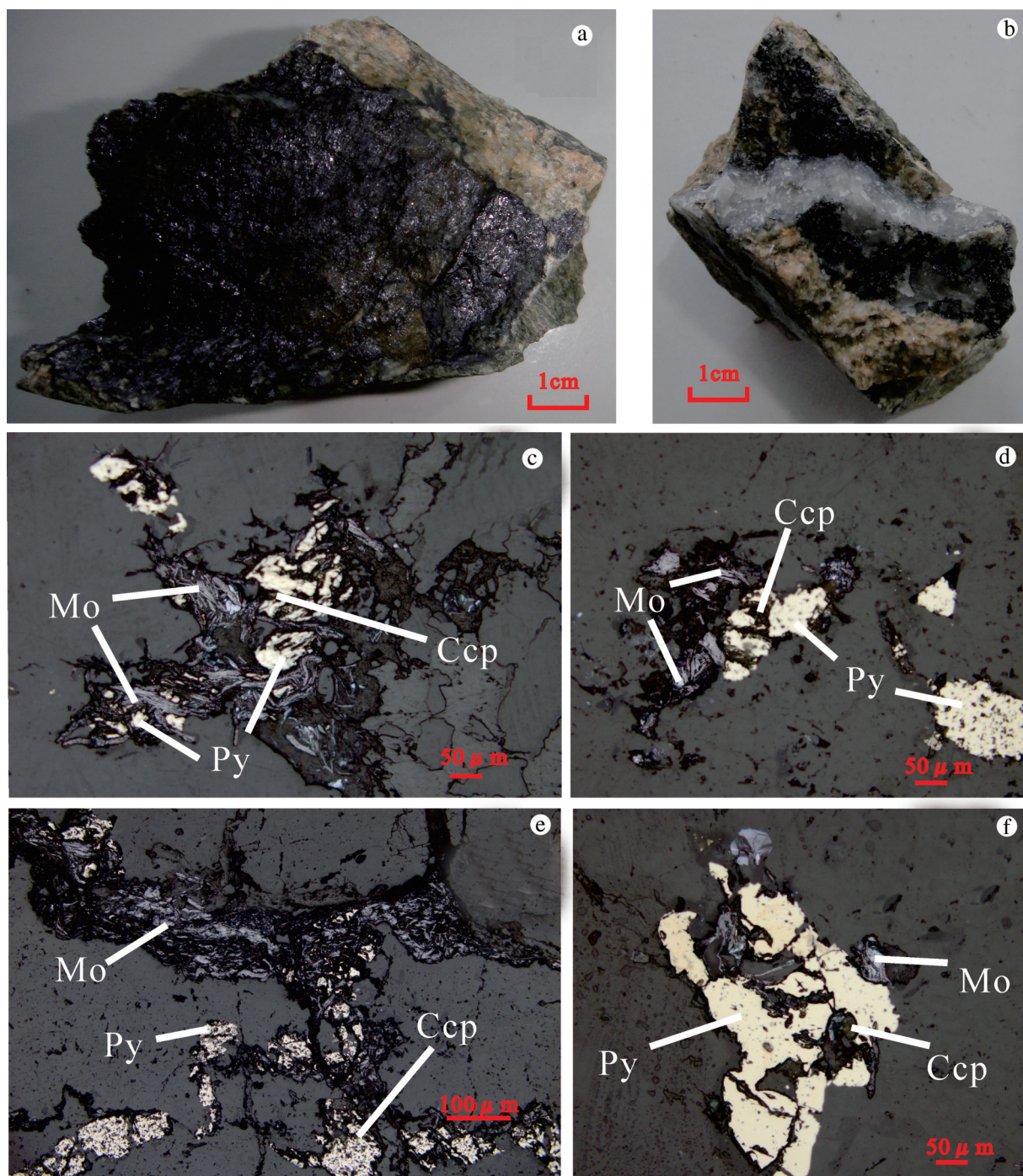


图4 峪耳崖金矿辉钼矿样品及其镜下照片

a—薄层状辉钼矿,分布于石英脉边部(YEY-B10-1样品);b—薄膜状辉钼矿,分布于石英脉边部(YEY-B10-7样品);c、e—薄层状辉钼矿镜下照片,辉钼矿呈叶片状,与黄铁矿、黄铜矿共生(YEY-B10-3样品);d、f—薄膜状辉钼矿镜下照片,辉钼矿颗粒较薄层状辉钼矿更细小,呈叶片状,与黄铁矿、黄铜矿共生(d, YEY-B10-6样品; f, YEY-B10-7样品);Mo—辉钼矿;Py—黄铁矿;Ccp—黄铜矿

Fig.4 Photographs of molybdenite samples from the Yuerya gold deposit

a—Lamellar molybdenite, distributed along the edge of the quartz vein (sample YEY-B10-1); b—Pellicular molybdenite, distributed along the edge of the quartz vein (sample YEY-B10-7); c, e—Micrographs of lamellar molybdenite, which has micro-leaf-shaped structure and is associated with pyrite and chalcopyrite (sample YEY-B10-3); d, f—Micrographs of pellicular molybdenite, which has micro-leaf-shaped structure and finer grains than the lamellar molybdenite, and is also associated with pyrite and chalcopyrite (d, sample YEY-B10-6; f, sample YEY-B10-7);

Mo—Molybdenite; Py—Pyrite; Ccp—Chalcopyrite

峪耳崖金矿床辉钼矿样品 Re-Os 同位素测试结果见表2。7件辉钼矿样品获得相近的 Re-Os 模式年龄值,最大(171.7±3.0) Ma, 最小(168.4±2.5) Ma, 加权平均年龄为(169.84±0.95) Ma(图5)。采用 ISOPLOT 软件计算获得等时线年龄为(171.9±2.7) Ma, MSWD=0.95, 初始¹⁸⁷Os 为(-1.7±2.1)(图6)。显而易见, 等时线年龄与模式年龄的加权平均值在误差范围内基本一致。

5 讨论

5.1 成矿时代

峪耳崖花岗岩体灰白色花岗岩和肉红色花岗

岩的 SHRIMP 锆石 U-Pb 年龄分别为(175±1) Ma 和 (174±3) Ma, 是同一岩浆活动的产物^[16]。本次工作所测得峪耳崖金矿辉钼矿 Re-Os 年龄为(171.9±2.7) Ma, 表明成岩成矿时代接近, 均形成于中侏罗世。峪耳崖花岗岩的金平均丰度为 15.029×10⁻⁹, 较同类花岗岩的 4×10⁻⁹ ^[34,39]高出近4倍之多, 可见, 峪耳崖金矿床的成矿物质可能主要来源于岩体^[34]。王自力等(2008)^[5]对矿石 Pb 同位素进行测定, 平均 Pb 同位素比值分别为 ²⁰⁶Pb/²⁰⁴Pb=15.863、²⁰⁷Pb/²⁰⁴Pb=15.151、²⁰⁸Pb/²⁰⁴Pb=35.773, 与成矿花岗岩 Pb 同位素比值相接近, 表明二者都来自燕山期的岩浆活动。因此矿化与峪耳崖花岗岩关系密切, 矿体和岩体应

表2 冀东峪耳崖金矿床中辉钼矿 Re-Os 同位素测试数据
Table 2 Re-Os isotope data for molybdenite from the Yuerya gold deposit

| 样号 | 样重/g | Re/ (μg.g ⁻¹) | | 普 Os/ (ng.g ⁻¹) | | ¹⁸⁷ Re/ (μg.g ⁻¹) | | ¹⁸⁷ Os/ (ng.g ⁻¹) | | 模式年龄/Ma | |
|-----------|---------|---------------------------|------|-----------------------------|-------|--|------|--|------|---------|-----|
| | | 测定值 | 2σ | 测定值 | 2σ | 测定值 | 2σ | 测定值 | 2σ | 测定值 | 2σ |
| YEY-B10-1 | 0.00507 | 84.79 | 1.06 | 0.023 | 0.012 | 53.29 | 0.66 | 152.7 | 1.4 | 171.7 | 3.0 |
| YEY-B10-2 | 0.00534 | 96.21 | 0.80 | 0.063 | 0.132 | 60.47 | 0.50 | 171.1 | 1.4 | 169.6 | 2.4 |
| YEY-B10-3 | 0.00541 | 97.60 | 0.98 | 0.061 | 0.096 | 61.34 | 0.62 | 174.8 | 1.6 | 170.8 | 2.7 |
| YEY-B10-4 | 0.00556 | 56.40 | 0.47 | 0.128 | 0.132 | 35.45 | 0.30 | 100.2 | 0.9 | 169.5 | 2.5 |
| YEY-B10-5 | 0.00542 | 90.57 | 0.68 | 0.063 | 0.134 | 56.92 | 0.43 | 160.3 | 1.4 | 168.7 | 2.4 |
| YEY-B10-6 | 0.00534 | 50.63 | 0.42 | 0.030 | 0.136 | 31.82 | 0.27 | 89.39 | 0.82 | 168.4 | 2.5 |
| YEY-B10-7 | 0.00522 | 116.1 | 1.1 | 0.132 | 0.204 | 73.00 | 0.72 | 208.4 | 1.8 | 171.1 | 2.6 |

注:① Re, Os 含量的不确定度包括样品和稀释剂的称量误差、稀释剂的标定误差、质谱测量的分馏校正误差、待分析样品同位素比值测量误差, 置信水平 95%;② 模式年龄的不确定度还包括衰变常数的不确定度(1.02%), 置信水平 95%。

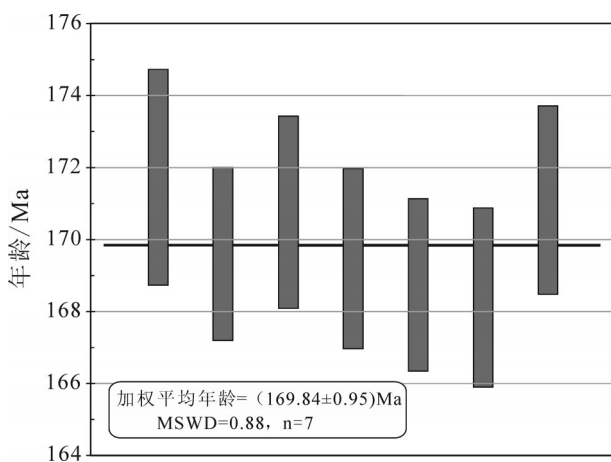


图5 承德峪耳崖金矿辉钼矿 Re-Os 模式年龄加权平均值
Fig.5 Weighted mean of Re-Os model for molybdenite from the Yuerya gold deposit

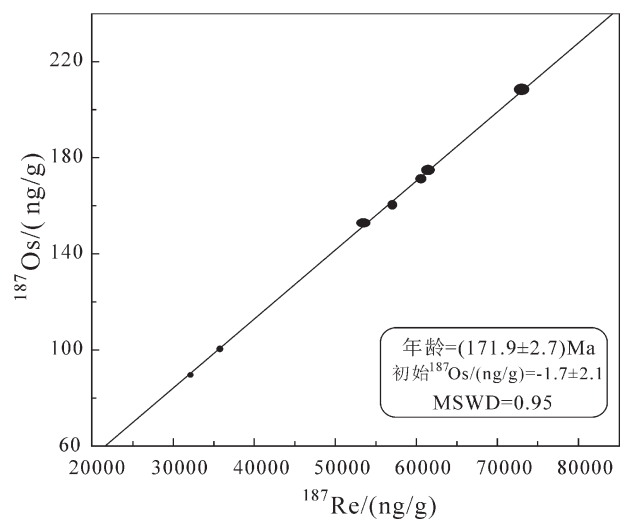


图6 峪耳崖金矿辉钼矿 Re-Os 同位素等时线图
Fig.6 Re-Os isochron age for molybdenite from the Yuerya gold deposit

该为同一成岩成矿系统的产物。

冀东地区岩浆多期次活动,岩石类型多样,从古生代到中生代的岩浆岩均有出露,但燕山期中酸性岩体内金含量最高(中性岩 Au 含量为 1.35×10^{-9} ,酸性岩 Au 含量为 1.32×10^{-9}),呈高背景值分布,对金矿的形成十分有利,区内的大部分金矿床产于燕山期中酸性岩体内或其接触带附近^[40]。区域内,位于峪耳崖金矿南东方向的牛心山金矿成矿花岗岩的侵位年龄为 $(172 \pm 2) \text{ Ma}$ ^[6]、 $(173 \pm 2) \text{ Ma}$ ^[41],金矿脉石英⁴⁰Ar-³⁹Ar 年龄为 175.8 Ma ^[17,42];峪耳崖金矿以北的唐杖子金钼矿花岗斑岩锆石 SHRIMP 年龄为 $(173 \pm 2) \text{ Ma}$ ^[41],金钼矿成矿辉钼矿 Re-Os 成矿年龄为 $(170.1 \pm 1.6) \text{ Ma}$ (李正远等,待刊^①);金厂峪金矿位于峪耳崖金矿西南地区,矿区内青山口花岗岩体 U-Pb 年龄为 $(199.1 \pm 2) \text{ Ma}$ ^[43]、全岩 Rb-Sr 等时线年龄 186.8 Ma ^[36],虽然宋扬等(2011)^[44]利用辉钼矿所测得的金成矿年龄为 $(242.6 \pm 6.8) \text{ Ma}$,属印支期,早于花岗岩体侵位时间,但金矿蚀变岩绢云母 K-Ar 法年龄 169.8 Ma ^[45]表明燕山期青山口花岗岩对金矿床也有叠加改造的作用。黄典豪等(1996)^[46]采用 Re-Os 法测得华北克拉通北缘与花岗斑岩有关的钼矿床辉钼矿的 Re-Os 模式年龄范围为 177~192 Ma,冀东地区大部分金矿成矿的绝对年龄均在 181.1~110 Ma^[40]。可见,区域岩浆活动对金、钼矿床的形成起着重要作用,成岩成矿均发生于燕山运动早期。毛景文等(2005)^[47]提出中国北方大规模成矿作用出现在 200~160 Ma,140 Ma 左右和 120 Ma 左右 3 个峰期,明显冀东地区金的成矿作用属第一成矿期。

在区域构造方面,自印支晚期到侏罗纪中期,中国北方仍处于内陆碰撞造山阶段^[47]。内陆造山的主要动力来自 160 Ma 最终闭合的蒙古-鄂霍次克大洋向南北两侧的俯冲^[47-48]。印支运动和燕山运动阶段,燕山地区曾受到主体为 SN 向和 NW-SE 向的构造应力挤压而发生造山作用^[30],翟明国等(2004)^[49]也指出华北北缘似乎表现出 230~210 Ma 和 180(170)~160(150) Ma 两期挤压构造从而形成了以 EW 向和 NE 向构造占主体的燕山板内造山带^[30],控制了区域岩浆岩的侵位。区域构造演化、岩浆活动和成矿作用时空的一致性表明,冀东地区在燕山

期经历了强烈的构造-岩浆作用过程,对于该区燕山期大规模成矿作用具有重要意义。

5.2 成矿物质来源

通过对峪耳崖金矿床成矿期石英 O、H、C 同位素的测定分析,柴社力(1989)^[15]、邱检生等(1994)^[4]、王宝德等(2002)^[50]和孔德鑫等(2013)^[6]都认为成矿流体主要来自岩浆水;邱检生等(1994)^[4]、王自力等(2008)^[5]和孔德鑫等(2013)^[6]对矿石 S 同位素进行了测定,发现 $\delta^{34}\text{S}$ 变化范围较窄,接近陨硫,具幔源特征,即主要来自岩浆体系。

Mao et al. (1999, 2003)^[22, 51]在综合分析对比了中国各种类型钼矿床中辉钼矿的铼含量后总结认为,从地幔到壳幔混源再到地壳,矿石中的铼含量呈 10 倍地下降,从幔源→I 型→S 型花岗岩有关的矿床,Re 含量从 $n \times 10^{-4} \rightarrow n \times 10^{-5} \rightarrow n \times 10^{-6}$ 。因此,辉钼矿的 Re 含量可以指示成矿物质的来源^[51-52]。本次研究获得峪耳崖金矿中辉钼矿的铼含量为 $50.63 \times 10^{-6} \sim 116.1 \times 10^{-6}$,平均 84.61×10^{-6} ,表明成矿物质主要为壳幔混合来源,与成矿花岗岩同为壳幔混源,与前人得出的结论一致。

5.3 地质意义

峪耳崖金矿是冀东地区典型的大型金矿,矿床类型为中温热液型,与区内金矿、钼矿等都有密切关系,在构造背景、地质特征及成矿流体-物质来源方面都有一定的相似性。因此,本次获得的峪耳崖金矿的准确成矿时代对区内其他金(钼)矿床有一定的约束意义。该矿床以及区内部分金(钼)矿床与燕山早期花岗岩有密切关系,都为同一岩浆-热液体系活动的产物。

6 结 论

冀东峪耳崖金矿床辉钼矿 Re-Os 同位素模式年龄为 $(168.4 \pm 2.5) \sim (171.7 \pm 3.0) \text{ Ma}$,等时线年龄为 $(171.9 \pm 2.7) \text{ Ma}$,指示其成矿时代为中侏罗世,成岩与成矿大致同时形成。辉钼矿的 Re 含量为 $50.63 \times 10^{-6} \sim 116.1 \times 10^{-6}$,平均 84.61×10^{-6} ,指示成矿物质可能为壳幔混合来源。该金矿与成矿花岗岩为同一成岩成矿系统的产物,是燕山早期造山运动下地壳局部熔融成岩成矿的产物。

①李正远,叶会寿,曹晶,等. 冀东唐杖子金(钼)矿辉钼矿 Re-Os 同位素年龄及其地质意义. 待刊.

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Re-Os age of molybdenite from the Yuerya Au deposit in eastern Hebei Province and its geological significance

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Abstract: The Yuerya Au deposit, one of the important Au deposits in eastern Hebei Province, is located in the northern limb of the Malanyu anticlinorium on the eastern side of the Yanshan orogenic belt. The gold orebodies, which belong to mesothermal hydrothermal type, are mainly hosted in the granite and its contact zone with the limy dolomite, and the ores include quartz vein type and veinlet-disseminated type. The Re-Os isotopic dating of 7 molybdenum samples of the main ore-forming stage yielded model ages ranging from (168.4±2.5) to (171.7±3.0) Ma, with the average model age being (169.84±0.95) Ma and the isochron age being (171.9±2.7) Ma, indicating that the mineralization of the Yuerya Au deposit took place in the Middle Jurassic, corresponding to the intruding epoch of the Yuerya granite. The content of Re, 50.63×10^{-6} – 116.1×10^{-6} with an average of 84.61×10^{-6} , shows that its material was mainly derived from crust-mantle mixture. In combination with the previous research results, the authors hold that the Yuerya Au deposit resulted from the strong tectono-magmatic-mineralization activities during early Yanshanian period of Mesozoic in eastern Hebei Province.

Key words: Re-Os isotopic age; molybdenite; source of ore material; Yuerya gold deposit; eastern Hebei Province

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