

河南祁雨沟金成矿系统辉钼矿 Re-Os 年龄和锆石 U-Pb 年龄及 Hf 同位素地球化学*

姚军明¹ 赵太平^{1**} 李晶¹ 孙亚莉¹ 原振雷² 陈伟¹ 韩军³

YAO JunMing¹, ZHAO TaiPing^{1**}, LI Jing¹, SUN YaLi¹, YUAN ZhenLei², CHEN Wei¹ and HAN Jun³

1. 中国科学院广州地球化学研究所, 广州 510640

2. 河南省国土资源科学研究院, 郑州 450053

3. 河南金源黄金矿业有限责任公司, 嵩县 471400

1. Guangzhou Institute of Geochemistry, CAS, Guangzhou 510640, China

2. Academy of Land and Resources of Henan Province, Zhengzhou 450053, China

3. Henan Jinyuan Corporation of Gold Mining, Songxian 471400, China

2008-11-24 收稿, 2008-12-13 改回.

Yao JM, Zhao TP, Li J, Sun YL, Yuan ZL, Chen W and Han J. 2009. Molybdenite Re-Os age and zircon U-Pb age and Hf isotope geochemistry of the Qiyugou gold system, Henan Province. *Acta Petrologica Sinica*, 25(2):374–384

Abstract The Qiyugou gold system in Henan Province is hosted in breccia pipes in the Xiong'er terrane of the northernmost Qinling Orogen, and is consequently of typical breccia pipe-type deposits in genetic classification. Zircon grains from the granite porphyry underlying the No. 16 breccia pipe yield $\varepsilon_{\text{Hf}}(t)$ values of $-10.50 \sim -14.43$ and Hf model ages of $2.57 \sim 2.93\text{Ga}$, indicating that they originated from partial melting of an ancient crust. The granite porphyry is dated to be $134.1 \pm 2.3\text{Ma}$ by LA-ICPMS zircon U-Pb method, which is in accordance to the Re-Os isochron age of $135.6 \pm 5.6\text{Ma}$ of the molybdenite flakes from the No. 7 breccia pipe. These ages are also consistent with zircon U-Pb ages of the other granites in the Xiong'er terrane, and holistically suggesting that the Qiyugou breccia-pipes emplaced during Early Cretaceous crustal extension-and-thinning following a crust shortening-and-thickening which was caused by the syn-collisional northward A-type subduction along the Machaoying fault. The A-type subduction led to the formation of the Xiong'er Au-dominated ore-province including the Qiyugou Au system, Yanshanian granites and orogenic-type lode deposits.

Key words Zircon LA-ICPMS U-Pb age; Hf isotope; Molybdenite Re-Os age; Qiyugou gold system; Xiong'er terrane

摘要 河南祁雨沟金矿位于秦岭造山带最北部, 属典型的角砾岩筒型成矿系统。矿区 16 号角砾岩筒下伏斑岩体锆石的 $\varepsilon_{\text{Hf}}(t)$ 值为 $-10.50 \sim -14.43$, Hf 模式年龄为 $2.57 \sim 2.93\text{Ga}$, 表明花岗斑岩主要来源于古老下地壳的部分熔融。锆石 LA-ICPMS U-Pb 年龄为 $134.1 \pm 2.3\text{Ma}$, 与 7 号角砾岩筒中的辉钼矿 Re-Os 等时线年龄 $135.6 \pm 5.6\text{Ma}$ 一致。这些年龄数据与熊耳山地区燕山期花岗岩体的侵位年龄基本相同, 共同指示其形成于地壳缩短增厚之后的伸展减薄过程。熊耳地体的地壳缩短增厚缘于同碰撞时期沿马超营断裂带的 A 型俯冲作用, 而 A 型俯冲导致了包括祁雨沟金矿系统、燕山期花岗岩类和脉状造山型矿床在内的熊耳矿集区的形成。

关键词 锆石 LA ICPMS U-Pb 年龄; Hf 同位素; 辉钼矿 Re-Os 年龄; 祁雨沟金矿; 熊耳地体

中图法分类号 P597.3; P618.65

* 本文得到国家 973 计划项目(2006CB403500)、河南省科技攻关项目(豫财招标采购(2006)26407号)、国家自然科学基金项目(40730421, 40872067, 40425006)资助。

第一作者简介: 姚军明, 1970 年生, 博士后, 矿床学专业, E-mail: junming_yao@yahoo.com.cn

** 通讯作者: 赵太平, 研究员, E-mail: tpzhao@gig.ac.cn

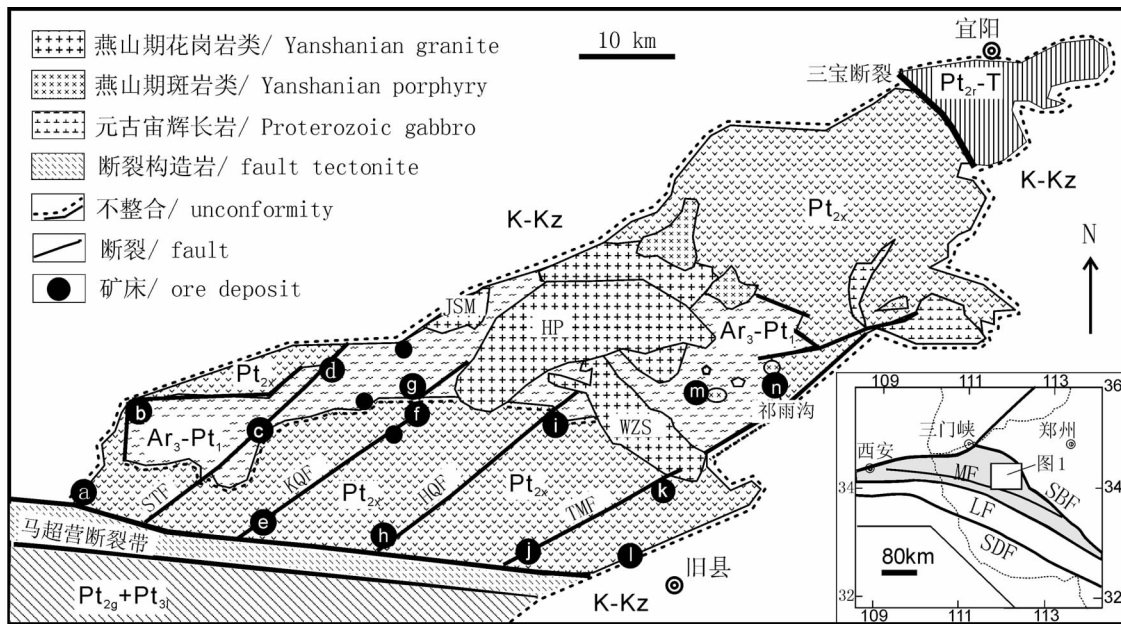


图1 祁雨沟金矿构造位置和区域地质图(据 Chen *et al.*, 2005)

地层代号注释:Ar₃-Pt₁为太华超群变质基底(新太古代-古元古代);Pt_{2x}为中元古代熊耳群安山岩建造,Pt_{2g}+Pt_{3l}为中元古代官道口群和新元古代栾川群,Pt_{2r}-T为中元古代汝阳群-三叠系地层,K-Kz为白垩纪-新生代冲积物。岩体名称:WZS-五丈山岩体,HP-嵩坪岩体,JSM-金山庙岩体。断裂名称:STF-三门-铁炉坪断裂,KQF-康山-七里坪断裂,HQF-红庄-青岗坪断裂,TMF-陶村-马园断裂;SBF-三宝断裂;SDF-商丹断裂;MF-马超营断裂;LF-栾川断裂。矿床名称:a~n依次为沙沟银铅锌矿床、嵩坪沟银铅矿、铁炉坪银铅矿、小池沟金矿、康山金银铅矿、上宫金矿、虎沟金矿、红庄金矿、青岗坪金矿、潭头金矿、瑶沟金矿、前河金矿、雷门沟钼(金)矿和祁雨沟金矿

Fig.1 Sketch map showing the locality and regional geology of the Qiyugou gold deposit (modified after Chen *et al.*, 2005)

Stratigraphic abbreviations: Ar₃-Pt₁-Taihua Supergroup, metamorphic basement of Neoproterozoic; Pt_{2x}-Xionger Group andesites of Mesoproterozoic; Pt_{2g}+Pt_{3l}-Guandaokou Group of Mesoproterozoic and Luanchuan Group of Neoproterozoic; Pt_{2r}-T-sediments of Mesoproterozoic-Triassic. Abbreviations of intrusions: WZS-Wuzhangshan granite; HP-Haoping granite; JSM-Jinshanmiao granite. Fault Name: STF-Sanmen-Tieluping fault; KQF-Kangshan-Qiliping fault; HQF-Hongzhuang-Qinggangping fault; TMF-Taocun-Mayuan fault; SBF-San-Bao fault; SDF-Shang-Dan fault; MF-Machaoying fault; LF-Luanchuan fault. Name of ore deposits: a-Shagou Ag-Pb-Zn; b-Haopinggou Ag-Pb; c-Tieluping Ag-Pb; d-Xiaochigou Au; e-Kangshan Au-Ag-Pb; f-Shangong Au; g-Hugou Au; h-Hongzhuang Au; i-Qinggangping Au; j-Tantou Au; k-Yaogou Au; l-Qianhe Au; m-Leimengou Mo-(Au); n-Qiyugou Au

祁雨沟金矿位于河南嵩县境内,地处华北陆块南缘熊耳地体(即熊耳山地区)东北缘,是熊耳地体最早(1978年之前)发现的金矿^①。祁雨沟金矿的发现带动了熊耳山地区10多个大、中型金矿的陆续发现(图1),使熊耳地体成为我国著名的金矿集中区之一。

熊耳地体燕山期岩浆岩发育,北中部有由五丈山岩体、嵩坪岩体等花岗岩体组成的花山花岗岩基。花山花岗岩基东北侧发育大量燕山期花岗岩斑岩小岩株、岩脉和爆破角砾岩筒(图2;邵克忠等,1992),它们呈北西向展布,蕴涵著名的祁雨沟大型金矿(胡受奚等,1988;陈衍景和富士谷,1992;陈衍景等,2007;李诺等,2008)和雷门沟大型斑岩钼矿床(Chen *et al.*, 2000;李诺等,2007a)。其中,祁雨沟金矿由多个角砾岩筒组成,以16号角砾岩筒距离花山花岗岩最近,7号角砾岩筒规模最大、找矿潜力最大。近年,随着采矿和找矿工作的开展,在7号角砾岩筒中发现了钼及铅锌矿化,在16号角砾岩筒的深部发现了花岗斑岩体(图2)。

祁雨沟金矿的地质地球化学研究一直受国内外学者的重视,积累了大量研究资料和认识(吴新国和杨竹森,1991;邵克忠等,1992;陈衍景和富士谷,1992;范宏瑞等,1993,2000;程广国,1994;任富根等,1996;郭东升等,2007;李诺等,2008;Chen *et al.*, 2009)。目前,对于花山花岗岩基与祁雨沟爆破角砾岩筒成矿系统之间的成因关系,以及角砾岩筒与金矿化之间的成因联系等,仍然存在一些分歧。例如,邵克忠等(1992)认为祁雨沟角砾岩筒及矿床是花山花岗岩结晶分异的产物,即属“母子关系”;而另一些学者则认为二者是A型俯冲至不同深度的彼此独立的产物,即“兄弟关系”(陈衍景和富士谷,1992;郭东升等,2007;李诺等,2008;Pirajno, 2008;Chen *et al.*, 2009)。不难理解,解决这一分歧的关键之一就是确定二者的形成时间。前人运用多种方法测定祁

① 河南地质三队. 1978. 河南嵩县祁雨沟金矿2号角砾岩体及外围普查报告

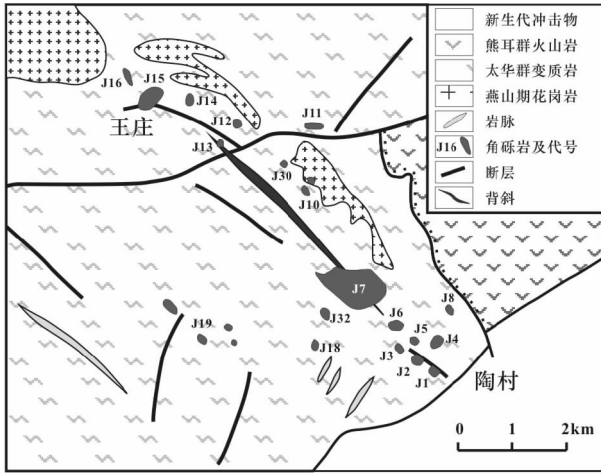


图2 祁雨沟角砾岩带分布图(据邵克忠等,1992 修改)

Fig. 2 The distributing map of breccia pipes in the Qiyugou gold deposit (modified after Shao *et al.*, 1992)

雨沟金矿系统的形成年龄,但因缺乏理想的测年对象和方法本身的限制,获得的年龄变化范围较大(详见 Chen *et al.*, 2009 及其引文),使祁雨沟爆破角砾岩筒及金矿化的年龄至今未能准确厘定。显然,16号角砾岩筒深部花岗斑岩体和7号角砾岩筒辉钼矿化的发现为解决上述疑难问题提供了可能。因此,本文报道作者关于16号角砾岩筒深部的花岗斑岩的地球化学和锆石年代学研究结果以及7号角砾岩筒的辉钼矿 Re-Os 同位素年龄测定结果,并据此探讨祁雨沟金矿的成因。

1 区域地质及矿床地质

熊耳地体的东、西边界为新生代断陷盆地,南、北边界分别是马超营断裂和三门峡—宝丰断裂(图1)。熊耳地体核部出露变质核杂岩(王志光等,1997;张进江等,1998),变质核杂岩由早前寒武纪结晶基底太华超群组成,太华超群主要由角闪岩类、片麻岩类和条带状混合岩类等岩石组成,属于中深变质的O型花岗-绿岩地体(Chen and Zhao, 1997; Chen *et al.*, 1998)。在熊耳地体四周,特别是南部和北部,广泛发育1750Ma左右的熊耳群安山岩系(Zhao *et al.*, 2002, 2004b),熊耳群角度不整合在太华超群之上,其形成构造背景有多种解释(陈衍景等,1992;赵太平等,2007;He *et al.*, 2008; Zhao *et al.*, 2004a)。熊耳地体南侧广泛发育中元古代的官道口群和新元古代的栾川群地层,主要岩性为浅变质的碳酸盐岩、硅质岩、碳质页岩、粉砂岩和少量的砾岩、火山岩夹层(陈衍景等,2003;祁进平等,2005)。熊耳地体北侧出露中-新元古代、早古生代、晚古生代和三叠系地层(Chen *et al.*, 2004, 2005)。

强烈的中生代造山作用使熊耳地体发育大量中生代碰撞型花岗岩类和热液矿床(胡受奚等,1988;陈衍景和富士

谷,1992;范宏瑞等,1993,1994; Li *et al.*, 2001; Chen *et al.*, 2008)。规模较大的蒿坪、五丈山、花山、金山庙等花岗岩体位于熊耳地体的核部,构成WNW向的花山花岗岩基(陈衍景等,2003)。在花山花岗岩基带南侧,大量发育NE向断裂构造,它们属马超营断裂的次级构造,具有等距性排列的特征,控制了铁炉坪等造山型银矿和康山、上宫、青岗坪、前河、瑶沟等造山型金矿(Chen *et al.*, 2004, 2005, 2006, 2008)的产出。在花山花岗岩基东北侧,发育大量规模较小且成群、成带分布的斑岩或爆破角砾岩筒,并蕴涵祁雨沟金矿、雷门沟斑岩钼矿,称为雷门沟—祁雨沟斑岩-爆破角砾岩带。

祁雨沟爆破角砾岩型金矿区及附近发育多个规模较小的燕山期斑岩体和32个爆破角砾岩筒(邵克忠等,1992; Chen *et al.*, 2009),角砾岩筒或斑岩体多受NW和NE向的断裂构造控制,多产于两组构造的交汇处,成群成带分布,由东向西分为四个角砾岩带。最东部的王庄-陶村角砾岩带(图2)围岩为太华超群变质岩,角砾岩带呈NW向展布,宽2km,长19km,包括了本文研究的16号和7号等20个角砾岩筒(图2)。角砾岩筒以陡倾的筒状为主,深部有变小的趋势,平面上呈椭圆状、纺锤状和不规则状,出露面积一般为0.001~0.005km²。其中,7号角砾岩筒出露面积最大,而钻探证明16号角砾岩体深部为花岗斑岩(图3A、B)。前人已经详细介绍了祁雨沟金矿床的爆破角砾岩及其金矿床地质特征和同位素地球化学特征(如郭东升等,2007;李诺等,2008; Chen *et al.*, 2009),本文不再赘述。

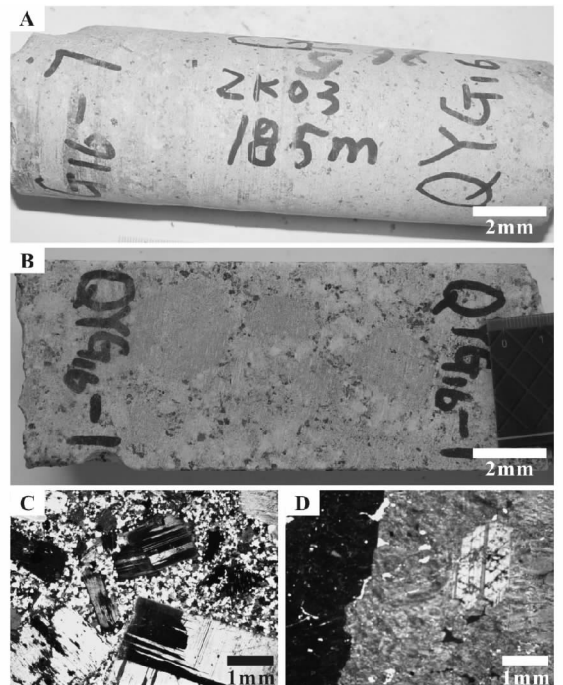


图3 祁雨沟16号角砾岩筒下伏岩体岩石及显微照片

Fig. 3 Petrographic images of the granite porphyry under the No. 16 breccia pipe in Qiyugou

2 样品特征

花岗斑岩样品 QYG16-5 采自祁雨沟金矿 16 号角砾岩筒的钻孔岩芯。岩性主要为灰白-肉红色的黑云母花岗斑岩,矿物组合为石英+斜长石+钾长石+黑云母(角闪石)。岩石为似斑状结构,斑晶主要为钾长石,基质为斜长石、钾长石、石英(图 3A、B)。斜长石自形程度高,普遍具有钠长石律聚片双晶,有时可见钾长石交代现象;钾长石以正长石、条纹长石为主,其中条纹长石的条纹细密,缺乏交代形成的宽大条纹现象,亦很少出现微斜长石。副矿物组合为榍石+磁铁矿+磷灰石+锆石+黄铁矿,含微量的钽石、金红石、锐钛矿、褐帘石(图 3C、D)。通过人工重砂法从样品中分选出锆石,锆石为浅黄色,颗粒晶形良好,大部分呈短柱状,少数长柱状。参考 SHRIMP 定年锆石方法(宋彪等,2002)制备样品靶,即:首先将锆石单矿物粘在双面胶上,然后用无色透明的环氧树脂固定,待环氧树脂充分固化后抛光至锆石露出平面。

本文所测 5 个辉钼矿样品(包括一个重复样)均采自 7 号角砾岩筒的石英-辉钼矿细脉,辉钼矿以鳞片状集合体和薄膜状产于石英细脉中,部分呈浸染状产于矿脉围岩中。样品经粉碎、分离、粗选和精选,在双目镜下挑选出辉钼矿矿物碎片,辉钼矿单矿物纯度 >99%,最后用玛瑙钵碾细。

3 分析方法

锆石 U-Pb 年龄测定在中国科学院地质与地球物理研究所完成,使用仪器为 Neptune 多接收电感耦合等离子体质谱仪(MC-ICPMS)、Agilent7500a 型四级杆电感耦合等离子体质谱仪(Q-ICPMS)和 193nm 激光取样系统,仪器详细情况参见 Xu *et al.* (2004)和 Wu *et al.* (2005)。锆石 U-Pb 年龄测定采用国际标准锆石 91500 作为外标标准物质(Wiedenbeck *et al.*, 1995),外标校正方法为每隔 4~5 个样品分析点测一次标准,保证标准和样品的仪器条件完全一致。样品的同位素比值采用 GLITTER(ver 4.0, Macquarie University)程序,年龄计算及谐和图的绘制采用 Isoplot(Ludwig, 1991)完成。

主量元素测试在中国科学院广州地球化学研究所元素与同位素地球化学重点实验室完成,样品经过 900℃ 烧后进行玻璃片制样,然后用 Rigaku ZSX 100e 型 X-射线荧光光谱法(XRF)测定,分析精度优于 2%。微量元素分析在香港大学地球科学系元素分析实验室运用 ICP-MS 质谱计完成,分析方法见 Qi *et al.* (2000),精度高于 5%。

辉钼矿样品分解以及 Re、Os 纯化分离等前处理工作在中国科学院广州地球化学研究所同位素年代学和地球化学重点实验室完成,仪器分析在长安大学国土资源部成矿作用及其动力学开放研究实验室完成,所用仪器为美国热电公司生产的 X7 型 ICP-MS。分析方法及流程(Sun *et al.*, 2001; 李

诺等,2007b)为:1)称样后依次加入 NaOH 和 Na₂O₂,置于马弗炉中熔融,避免了样品熔融时的喷溅现象;2)丙酮萃取 Re 后,有机相直接置于电热板上加热挥发;3)采用 NaClO₄ 氧化剂从分解样品中分离纯化 Os。因 Os 含量低,辉钼矿 Re/Os 年龄数据的可靠性取决于 Os 分析数据的质量。以 Os 最高价态氧化物 OsO₄ 水溶液进样,Os 的 ICP-MS 测定灵敏度被提高了 40 倍以上(Sun *et al.*, 2001),从而获得了准确的 Os 分析数据。实验采用国家标准物质 GBW04435 和 GBW04436 检测化学流程和分析数据的可靠性。

4 分析结果

4.1 岩石地球化学特征

祁雨沟金矿 16 号角砾岩筒深部斑岩体的主量元素测试结果列于表 1。岩体 SiO₂ 为 66.67%~75.17%, Al₂O₃ 为 12.57%~15.52%。岩体钾、钠含量高, Na₂O > 3.19% (3.19%~4.05%), K₂O + Na₂O 总量大于 7.48%, Na₂O/K₂O 为 0.64~1.01, 铝饱和指数 A/CNK 为 0.97~1.03, 小于 1.1。在 TAS 分类图上,大部分样品都落在石英二长岩的范围内,少数处于石英二长岩、花岗闪长岩及花岗岩的重叠部位(图 4);在 SiO₂-K₂O 图中,大部分样品落入高钾钙碱性系列,个别样品(其一为深部斑岩)落入橄榄粗玄岩系列区域(图 5)。

斑岩体的微量和稀土元素测试结果也列于表 1。岩体富集大离子亲石元素(LILE,如 Ba、Sc、Rb、K),相对亏损高场强元素(HFSE,如 Nb、P、Ti、HREE)(图 6a)。稀土总量为 119.20 × 10⁻⁶~162.20 × 10⁻⁶, LREE/HREE 为 10.44~16.34, (La/Yb)_N 为 8.01~40.83,具轻稀土富集、重稀土亏损的右倾特点(图 6b);δEu 为 0.64~0.96,显示较弱的铕负异常。

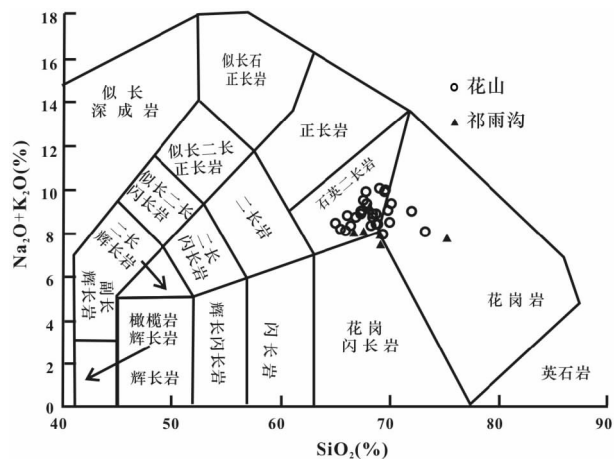
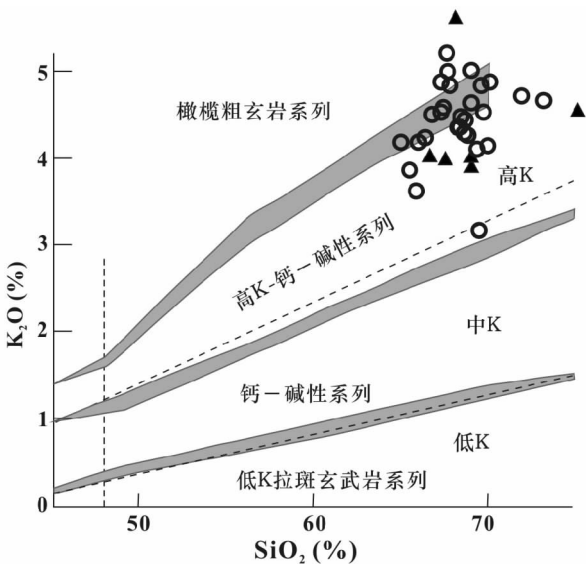


图 4 祁雨沟 16 号角砾岩筒下伏斑岩体 TAS 分类图
Fig. 4 The TAS diagram of the granite porphyry under the No. 16 breccia pipe in Qiyugou

表1 祁雨沟金矿16号角砾岩筒下伏斑岩体主量元素(wt%)和微量元素($\times 10^{-6}$)测试结果Table 1 Major (wt%) and trace ($\times 10^{-6}$) element compositions of the granite porphyry under the No. 16 breccia pipe in Qiyugou

sample	SiO ₂	TiO ₂	Al ₂ O ₃	Fe ₂ O ₃ ^T	MnO	MgO	CaO	Na ₂ O	K ₂ O	P ₂ O ₅	A/ CNK	Na ₂ O + K ₂ O	Na ₂ O/ K ₂ O	
QYG-16-1	69.01	0.40	15.03	3.59	0.05	1.26	2.37	3.90	4.05	0.19	0.99	7.95	0.96	
QYG-16-5	67.51	0.48	15.30	4.02	0.07	1.54	2.62	4.05	4.01	0.24	0.97	8.07	1.01	
QYG-16-5-1	69.08	0.48	14.66	4.03	0.06	1.44	2.39	3.54	3.94	0.25	1.01	7.48	0.90	
QYG-16-6	68.07	0.40	15.52	3.33	0.06	1.24	1.79	3.60	5.64	0.20	1.02	9.23	0.64	
QYG-16-7	75.17	0.26	12.57	2.29	0.03	0.72	1.09	3.19	4.58	0.11	1.03	7.76	0.70	
QYG-16-8	66.67	0.54	15.39	4.53	0.08	1.67	2.62	4.00	4.05	0.27	0.98	8.05	0.99	
	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
QYG16-1	41.82	70.20	7.36	26.02	4.45	1.11	3.47	0.54	2.92	0.54	1.71	0.25	1.57	0.24
QYG16-5	30.99	50.01	6.27	23.25	4.34	1.05	3.31	0.52	2.78	0.60	1.76	0.24	1.63	0.26
QYG16-5-1	31.91	54.47	6.41	22.55	4.28	0.99	3.27	0.52	2.83	0.57	1.71	0.26	1.69	0.27
QYG16-6	33.41	60.46	6.66	23.60	4.30	1.20	3.32	0.50	2.70	0.53	1.62	0.25	1.50	0.22
QYG16-7	35.94	52.83	4.78	15.61	2.66	0.50	2.12	0.31	1.68	0.34	1.05	0.15	1.05	0.17
QYG16-8	36.98	65.27	7.88	28.45	5.36	1.20	3.92	0.64	3.40	0.68	2.05	0.29	1.93	0.31
	Rb	Sr	Y	Zr	Nb	Cs	Ba	Hf	Ta	Th	U	δ Eu	$\left(\frac{La}{Yb}\right)_N$	LREE/ HREE
QYG16-1	151.2	424	15.35	60.36	16.71	2.16	823	2.16	1.21	21.77	5.40	0.86	17.95	13.43
QYG16-5	68.63	305	16.15	57.34	16.60	1.72	1138	2.06	1.16	13.14	2.32	0.84	12.80	10.44
QYG16-5-1	81.32	255	15.92	52.09	18.55	2.61	883	2.06	1.36	17.65	3.01	0.80	12.71	10.84
QYG16-6	167.7	542	14.55	48.73	15.51	3.18	2658	1.65	1.15	15.07	6.16	0.96	15.05	12.17
QYG16-7	179.8	141	9.23	68.07	16.38	3.52	261	2.81	1.09	33.10	8.08	0.64	22.99	16.34
QYG16-8	77.12	374	18.55	56.00	18.98	2.11	1273	2.21	1.39	15.20	2.96	0.80	12.94	10.98

图5 祁雨沟16号角砾岩筒下伏斑岩体SiO₂-K₂O图解Fig. 5 The SiO₂-K₂O diagram of the granite porphyry under the No. 16 breccia pipe in Qiyugou

4.2 U-Pb 年龄及 Hf 同位素特征

由表2可见,单颗粒锆石每个点的²⁰⁶Pb/²³⁸U 年龄值都比较集中,位于124.6Ma到144.4Ma之间。利用Isoplot软件得到这个样品的²⁰⁶Pb/²³⁸U 加权平均年龄为133.9 ± 1.7Ma,

MSWD为2.1(2σ);而且大部分点的²⁰⁶Pb/²³⁸U 年龄与²⁰⁷Pb/²³⁵U 年龄比较谐和,利用同位素比值在Isoplot软件中求得的谐和年龄为134.1 ± 2.3Ma,MSWD为1.9(1σ)(图7)。

祁雨沟16号角砾岩筒下伏斑岩体QYG16-5 锆石的Hf同位素测试数据列于表3。样品¹⁷⁶Hf/¹⁷⁷Hf 初始值介于0.282282~0.282397之间,ε_{Hf}(t)值为-10.5~-14.4(图8)。Hf同位素单阶段模式年龄(t_{DM})集中于1.21~1.37Ga,两阶段模式年龄(t_{DM2})集中于2.57~2.93Ga。

4.3 辉钼矿 Re-Os 年龄

祁雨沟7号角砾岩筒中辉钼矿的Re-Os同位素测试结果见表4,模式年龄值从131.6到139.6Ma,其加权平均年龄为134 ± 4Ma,MSWD为2.3(1σ);利用Isoplot软件获得Re-Os等时线年龄为135.6 ± 5.6Ma,MSWD为2.0(1σ)(图9)。

5 讨论

5.1 角砾岩筒下伏斑岩体岩石成因

祁雨沟16号角砾岩筒下伏斑岩体中黑云母为褐黑色(图3),副矿物主要为榍石、磷灰石及黄铁矿等硫化物。SiO₂含量集中在66.67%~75.17%,岩体钠含量高(Na₂O > 3.19%),铝饱和指数A/CNK < 1.1。

通过对祁雨沟角砾岩筒下伏斑岩体的锆石Hf同位素研

表 2 祁雨沟金矿 16 号角砾岩筒下伏斑岩体锆石 U-Pb 同位素数据

Table 2 U-Pb isotopic compositions of zircons from the granite porphyry under the No. 16 breccia pipe in Qiyugou

分析点号	同位素比值						年龄 (Ma)					
	$\frac{^{207}\text{Pb}}{^{206}\text{Pb}}$	1σ	$\frac{^{206}\text{Pb}}{^{238}\text{U}}$	1σ	$\frac{^{207}\text{Pb}}{^{235}\text{U}}$	1σ	$\frac{^{207}\text{Pb}}{^{206}\text{Pb}}$	1σ	$\frac{^{206}\text{Pb}}{^{238}\text{U}}$	1σ	$\frac{^{207}\text{Pb}}{^{235}\text{U}}$	1σ
QYG16-5 01	0.06675	0.0047	0.02124	0.0005	0.19548	0.0129	829.8	139.8	135.5	3.42	181.3	10.97
QYG16-5 02	0.06411	0.0029	0.02023	0.0004	0.17884	0.0076	745.2	92.46	129.1	2.22	167.1	6.56
QYG16-5 03	0.04905	0.0028	0.021	0.0004	0.14207	0.0079	150.4	129.2	134	2.41	134.9	6.98
QYG16-5 04	0.07664	0.0036	0.02111	0.0004	0.22306	0.0099	1111.8	91.89	134.6	2.49	204.5	8.25
QYG16-5 05	0.05243	0.0028	0.02073	0.0004	0.14985	0.0076	304.4	116.1	132.2	2.36	141.8	6.69
QYG16-5 06	0.06381	0.0021	0.0209	0.0003	0.18391	0.0056	735.4	66.47	133.3	1.83	171.4	4.77
QYG16-5 07	0.06111	0.0026	0.02073	0.0004	0.17467	0.0071	643.1	89.86	132.3	2.19	163.5	6.14
QYG16-5 08	0.04874	0.0048	0.02266	0.0007	0.15228	0.0143	135.2	215.1	144.4	4.35	143.9	12.57
QYG16-5 09	0.04866	0.0054	0.02038	0.0007	0.13672	0.0145	131.4	240.6	130	4.25	130.1	12.93
QYG16-5 10	0.05773	0.0034	0.0217	0.0005	0.17276	0.0097	519.5	125.4	138.4	2.84	161.8	8.44
QYG16-5 11	0.0488	0.0036	0.02222	0.0005	0.1495	0.0105	138.2	163.6	141.7	3.18	141.5	9.29
QYG16-5 12	0.0488	0.0031	0.02103	0.0004	0.14155	0.0087	138.4	143.4	134.2	2.77	134.4	7.69
QYG16-5 13	0.04894	0.0065	0.02184	0.0009	0.1474	0.0188	145.1	285.4	139.3	5.56	139.6	16.62
QYG16-5 14	0.06569	0.0032	0.02079	0.0004	0.18832	0.0086	796.5	98.39	132.6	2.43	175.2	7.36
QYG16-5 15	0.04856	0.0034	0.02065	0.0005	0.13825	0.0093	126.5	156.7	131.7	2.92	131.5	8.25
QYG16-5 16	0.05526	0.0029	0.022	0.0004	0.16765	0.0084	422.6	113.2	140.3	2.56	157.4	7.33
QYG16-5 17	0.04881	0.0032	0.02165	0.0005	0.14571	0.0093	138.9	148.8	138.1	2.9	138.1	8.21
QYG16-5 18	0.04872	0.0038	0.02152	0.0005	0.14454	0.0109	134.2	175.2	137.2	3.42	137.1	9.64
QYG16-5 19	0.05655	0.0061	0.01952	0.0007	0.15222	0.0157	473.1	224.6	124.6	4.39	143.9	13.85
QYG16-5 20	0.05692	0.0028	0.02064	0.0004	0.16198	0.0075	487.7	103.9	131.7	2.26	152.4	6.52

表 3 祁雨沟金矿 16 号角砾岩筒下伏斑岩体锆石 Hf 同位素数据

Table 3 Hf isotopic compositions of zircons from the granite porphyry under the No. 16 breccia pipe in Qiyugou

sample	t_{Ma}	$\frac{^{176}\text{Yb}}{^{177}\text{Hf}}$	$\frac{^{176}\text{Lu}}{^{177}\text{Hf}}$	$\frac{^{176}\text{Hf}}{^{177}\text{Hf}}$	2σ	$\varepsilon_{\text{Hf}}(0)$	$\varepsilon_{\text{Hf}}(t)$	t_{DM1}	t_{DM2}	$f_{\text{Lu/Hf}}$
QYG16-5 01	135.5	0.021069	0.000878	0.282387	0.000015	-13.62	-10.73	1218.24	2597.82	-0.97
QYG16-5 02	129.1	0.028510	0.001139	0.282316	0.000015	-16.13	-13.40	1326.16	2832.51	-0.97
QYG16-5 03	134	0.027416	0.001069	0.282350	0.000012	-14.92	-12.07	1275.73	2717.30	-0.97
QYG16-5 04	134.6	0.024557	0.000951	0.282363	0.000013	-14.48	-11.61	1254.35	2676.13	-0.97
QYG16-5 05	132.2	0.029552	0.001179	0.282356	0.000015	-14.71	-11.91	1271.05	2701.39	-0.96
QYG16-5 06	133.3	0.026149	0.001104	0.282357	0.000014	-14.69	-11.87	1268.00	2698.28	-0.97
QYG16-5 07	132.3	0.033367	0.001468	0.282397	0.000015	-13.27	-10.50	1223.53	2574.96	-0.96
QYG16-5 08	144.4	0.024306	0.001059	0.282308	0.000012	-16.41	-13.34	1334.40	2837.63	-0.97
QYG16-5 09	130	0.026478	0.001065	0.282359	0.000014	-14.60	-11.84	1263.11	2694.05	-0.97
QYG16-5 10	138.4	0.020469	0.000816	0.282318	0.000014	-16.06	-13.10	1312.25	2812.31	-0.98
QYG16-5 11	141.7	0.027350	0.001110	0.282337	0.000015	-15.39	-12.39	1295.81	2750.14	-0.97
QYG16-5 12	134.2	0.028244	0.001159	0.282333	0.000014	-15.51	-12.67	1302.44	2771.09	-0.97
QYG16-5 13	139.3	0.025572	0.001082	0.282324	0.000011	-15.84	-12.89	1312.78	2793.47	-0.97
QYG16-5 14	132.6	0.021569	0.000910	0.282296	0.000012	-16.85	-14.02	1346.43	2890.67	-0.97
QYG16-5 15	131.7	0.018252	0.000842	0.282321	0.000012	-15.95	-13.14	1308.76	2811.07	-0.97
QYG16-5 16	140.3	0.018195	0.000743	0.282363	0.000013	-14.46	-11.46	1246.95	2666.03	-0.98
QYG16-5 17	138.1	0.023531	0.000957	0.282299	0.000015	-16.73	-13.79	1343.58	2873.77	-0.97
QYG16-5 18	137.2	0.025196	0.001156	0.282282	0.000016	-17.33	-14.43	1374.41	2930.03	-0.97
QYG16-5 19	124.6	0.019867	0.000839	0.282347	0.000014	-15.04	-12.37	1272.66	2738.18	-0.97

注:表中锆石 Hf 同位素组成的计算参数为: ^{176}Lu 衰变常数 $\lambda = 1.867 \times 10^{-11}$ (Soderlund *et al.*, 2004); 球粒陨石和亏损地幔的 $^{176}\text{Lu}/^{177}\text{Hf}$, $^{176}\text{Hf}/^{177}\text{Hf}$ 分别为 0.03321、0.282772、0.03842、0.28325 (Bizzarro *et al.*, 2002; Griffin *et al.*, 2000); 下地壳 $f_{\text{Lu/Hf}} = -0.34$ (Vervoort *et al.*, 2000)

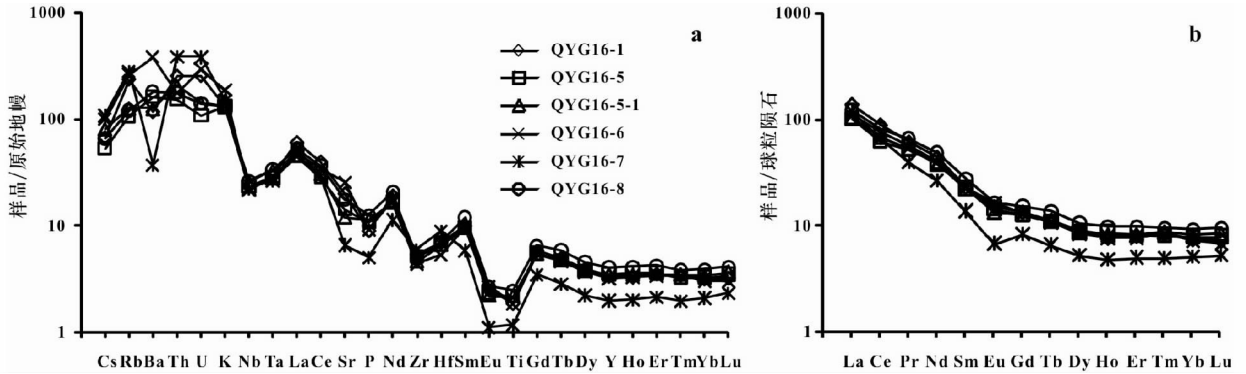


图6 祁雨沟16号角砾岩筒下伏斑岩体微量元素蛛网图(a)和稀土元素配分图(b)

原始地幔和球粒陨石标准值据 McDonough and Sun (1995)

Fig.6 Primitive mantle-normalized trace elements spider plots (a) and Chondrite-normalized REE patterns diagram (b) for the granite porphyry under the No. 16 breccia pipe in Qiyugou

Primitive mantle normalizing values and Chondrite normalizing values are from McDonough and Sun (1995)

表4 祁雨沟7号岩筒辉钼矿 Re-Os 同位素测年数据

Table 4 Molybdenite Re-Os isotopic data for the No. 7 breccia pipe in Qiyugou

样品号	样量(g)	Re		¹⁸⁷ Re		¹⁸⁷ Os		模式年龄	
		(×10 ⁻⁶)		(×10 ⁻⁶)		(×10 ⁻⁹)		(Ma)	
		测定值	1σ	测定值	1σ	测定值	1σ	测定值	1σ
QYG-31	0.01563	521.96	8.92	328.06	5.58	733.65	1.66	134.1	2.3
QYG-30	0.01607	509.83	9.52	320.44	5.96	709.46	2.39	132.7	2.5
QYG-17	0.01601	498.43	7.49	313.27	4.69	729.64	3.01	139.6	2.2
QYG-1	0.2951	19.25	0.24	12.10	0.15	26.56	0.07	131.6	1.7
QYG-2	0.01554	484.78	8.95	304.70	5.60	677.55	1.43	133.3	2.5

注:模式年龄 t 按 $t = 1/\lambda \ln(1 + ^{187}\text{Os}/^{187}\text{Re})$ 计算,其中 $\lambda(^{187}\text{Re}) = 1.666 \times 10^{-11} \text{a}^{-1}$ (Smoliar *et al.*, 1996)

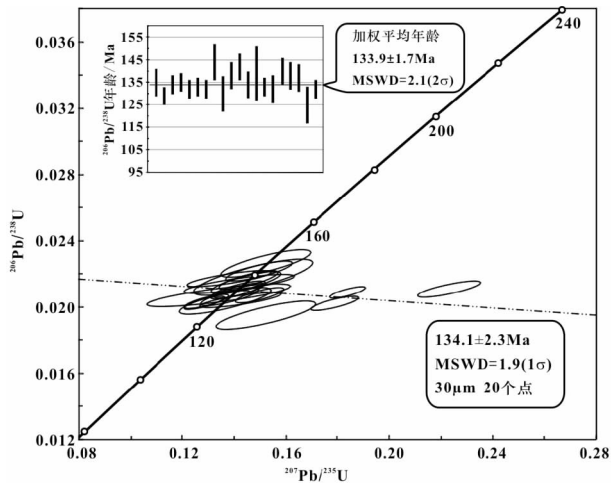


图7 祁雨沟金矿16号角砾岩筒隐伏花岗岩锆石 U-Pb 同位素年龄

Fig.7 Zircon U-Pb isochron plot for the granite porphyry under the No. 16 breccia pipe in Qiyugou

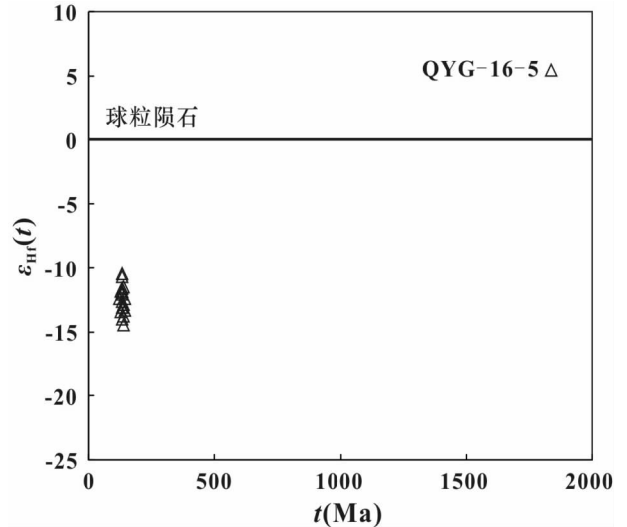


图8 祁雨沟16号角砾岩筒下伏斑岩体锆石 $\epsilon_{\text{Hf}}(t)$ - t 关系图

Fig.8 Correlations between Hf isotopic compositions and U-Pb ages of zircons from the granite porphyry under the No. 16 breccia pipe in Qiyugou

究,样品的原位 Hf 同位素分析数据点都投影于球粒陨石 Hf 同位素演化线之下(图8),具有低的 $\epsilon_{\text{Hf}}(t)$ 值(-10.50 ~ -14.43)和古老的 Hf 模式年龄(2.57 ~ 2.93Ga),表明它们为壳源成因(Chen *et al.*, 2000, 2009; 郭东升等, 2007),成岩岩浆总体来源于古老下地壳的部分熔融。样品模式年龄明显大于锆石结晶年龄,表明其源区物质具有较长的地壳滞留时间。锆石 Hf 同位素两阶段模式年龄为 2.57 ~ 2.93Ga,说明源区物质主要为新太古宙陆壳,与太华超群的形成时代相当(李怀乾等,2002;赵太平等,未刊资料)。

表 5 祁雨沟地区花岗岩及矿床同位素年龄

Table 5 Isotope ages of granites and ore deposits in the Qiyugou area

地区	岩体或矿床	测试矿物	测试方法	年龄 (Ma)	资料来源	
花山花岗岩基	五丈山岩体	钾长石	Rb-Sr 等时线	183	河南地矿局, 1989	
		锆石	SHRIMP U-Pb	156.8 ± 1.2	李永峰等, 2004 ^①	
	蒿坪岩体	钾长石	Rb-Sr 等时线	123	河南地矿局, 1989	
		锆石	SHRIMP U-Pb	130.7 ± 1.4	李永峰等, 2004	
祁雨沟矿区	花山岩体	锆石	SHRIMP U-Pb	132.0 ± 1.6	李永峰等, 2004	
		金山庙岩体	钾长石	Rb-Sr 等时线	105	河南地矿局, 1989
	雷门沟矿床	辉钼矿	Re-Os	131.6 ± 2.0	李永峰等, 2006	
		雷门沟斑岩	锆石	SHRIMP U-Pb	133.1 ± 1.9	李永峰等, 2006
	雷门沟金矿	蚀变钾长石	锆石	SHRIMP U-Pb	136.2 ± 1.5	李永峰等, 2006
			Ar-Ar 坪年龄	125 ± 3	王义天等, 2001	
	摩天岭斑岩	祁雨沟斑岩	锆石	K-Ar	122 ± 0.4	王义天等, 2001
				U-Pb	115 ± 2	王义天等, 2001
		花岗闪长斑岩	钾长石	K-Ar	125.7 ± 7.2	任富根等, 2001
				K-Ar	119.6 ± 7.5	任富根等, 2001
蚀变钾长石		黄铁矿	K-Ar	113 ± 2	陈衍景和富士谷, 1992	
			单颗粒 Rb-Sr 等时线	121 ± 2	陈衍景和富士谷, 1992	
16 号角砾岩筒		锆石	LAICPMS U-Pb	126 ± 11	Han <i>et al.</i> , 2007	
16 号角砾岩筒		锆石	LAICPMS U-Pb	136.6 ± 2.3	本文	
7 号角砾岩筒	辉钼矿	Re-Os	135.6 ± 5.6	本文		

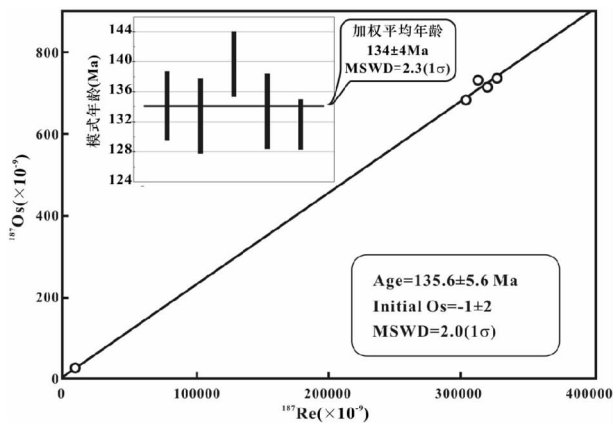


图 9 祁雨沟金矿 7 号角砾岩筒辉钼矿 Re-Os 同位素年龄

Fig. 9 Molybdenite Re-Os isochron plot for the No. 7 breccia pipe in Qiyugou

5.2 祁雨沟金矿成岩成矿时代及成因

李永峰等 (2004) 获得五丈山、蒿坪和花山岩体的 SHRIMP U-Pb 年龄分别为 156.8 ± 1.2 Ma、130.7 ± 1.4 Ma 和 132.0 ± 1.6 Ma; 李永峰等 (2006) 获得紧邻祁雨沟金矿的雷门沟矿床斑岩体锆石的 SHRIMP U-Pb 年龄为 136.2 ± 1.5 Ma, 两个辉钼矿的模式年龄分别为 131.6 ± 2.0 Ma 和 133.1 ± 1.9 Ma (表 5)。

关于祁雨沟金矿的成矿年龄, 前人获得的大量结果介于 126 ~ 115 Ma 之间 (表 5), 成矿作用持续达 10 Ma 以上。单就这些年龄而言, 它们晚于花山花岗岩基的年龄, 似可将祁雨沟爆破角砾岩型成矿系统解释为花山花岗岩基结晶分异的产物 (邵克忠等, 1992)。然而, 本研究获得祁雨沟矿区 16 号

角砾岩筒下伏斑岩体的 LA-ICPMS 锆石 U-Pb 年龄为 134.1 ± 2.3 Ma, 7 号含金爆破角砾岩筒的辉钼矿 Re-Os 等时线年龄为 135.6 ± 5.6 Ma, 不但与雷门沟斑岩的形成年龄一致, 而且均明显大于花山花岩体和蒿坪岩体的锆石 SHRIMP U-Pb 年龄 (表 5), 表明祁雨沟爆破角砾岩、雷门沟花岗斑岩及其成矿系统早于花山、蒿坪岩体发育, 不可能是后者结晶分异的产物 (陈衍景和富士谷, 1992; 郭东升等, 2007)。此外, 这些年龄晚于五丈山岩体 20 Ma, 也很难设想五丈山岩体冷凝固结晶后长达 20 Ma 之后, 才分异出祁雨沟金矿区的岩浆-流体成矿系统。综上所述, 矿床与矿区斑岩、角砾岩筒同时同空间同源形成, 与区域大的花山花岗岩也同时同源, 表明祁雨沟金矿是与岩浆有关的爆破角砾岩型金矿床。

5.3 祁雨沟金矿的成矿动力学背景

一些学者 (李曙光等, 1989; 陈衍景和富士谷, 1992; Chen *et al.*, 1995; 李锦铭, 2001; 张国伟等, 2001) 曾主张扬子克拉通与华北克拉通在 238 ~ 218 Ma 之间实现碰撞对接, 之后进入造山后阶段。但是, 最新研究表明 (Zhu *et al.*, 1998; Zhang *et al.*, 2002; 杨荣生等, 2006; 张静等, 2006; 刘红杰等, 2008; 许成等, 2009), 扬子与华北两大块之间的洋盆最早在 220 Ma 时才最终闭合, 即陆陆碰撞造山作用最早始于 220 Ma, 最强烈的碰撞挤压、地壳缩短加厚 (Yuan, 1996)、隆升造山作用应发生在侏罗纪, 侏罗纪—白垩纪之交发生碰撞挤压向造山带伸展减薄体制的转换, 因此大规模的成岩成矿与流体作用应发生在晚侏罗世和早白垩世, 即 160 ~ 100 Ma。显然, 熊耳地体的热液矿床、花山花岗岩基和祁雨沟—雷门沟斑岩-爆破角砾岩带及其相关矿床等, 均应属于陆陆碰撞过程的挤压向伸展转变体制的产物。

陆陆碰撞导致秦岭造山带内部发育一系列东西走向陆

① 李永峰等. 2004. 小秦岭—熊耳山地区中生代金的大规模流体成矿系统. 国家 973 项目研究报告. 57

内俯冲带,熊耳地体南部的马超营大断裂就属于这组 A 型俯冲带(陈衍景和富士谷,1992)。按照 A 型俯冲成岩成矿与流体作用模型(陈衍景和富士谷,1992),即 CMF 模式(Chen *et al.*, 2007, 2008, 2009; Pirajno, 2008),在沿马超营断裂倾向北的 A 型俯冲过程中,自南而北依次派生了熊耳地体的康山-上官造山型金银矿带、花山花岗岩基带和祁雨沟—雷门沟斑岩-爆破角砾岩及其矿床带。如此,导致花山花岗岩基与其南侧造山型成矿系统和北侧斑岩-爆破角砾岩及其成矿系统近乎同时发育,彼此之间属于“兄弟关系”而非“母子关系”,三者成岩成矿物质总体来自俯冲壳楔和仰冲壳楔。鉴于马超营断裂发育在以太华超群为标志的华熊地块内部,俯冲壳楔和仰冲壳楔均以太华超群或其衍生物为主要物质组成,因此祁雨沟矿区的成矿岩浆显示了源于太华超群的特点。事实上,熊耳地体及其邻区的同位素地球化学研究早已排他性地证明了这一认识(陈衍景等,2003;祁进平等,2005, 2006;郭东升等,2007;Chen *et al.*, 2004, 2005, 2008, 2009)。

6 结论

祁雨沟角砾岩筒下伏斑岩体 SiO₂ 的含量集中在 66.67% ~ 75.17%, 铝饱和指数 A/CNK < 1.1。锆石具有低的 $\varepsilon_{\text{Hf}}(t)$ 值(-10.50 ~ -14.43) 和古老的 Hf 模式年龄(2.57 ~ 2.93Ga), 为壳源成因, 表明花岗岩浆来源于古老的下地壳物质的部分熔融。锆石 Hf 同位素两阶段模式年龄为 2.57 ~ 2.93Ga, 说明源区物质主要为新太古宙陆壳, 与太华超群的形成时代相当。

祁雨沟矿区 16 号角砾岩筒下伏斑岩体的 LA-ICPMS 锆石 U-Pb 年龄为 $134.1 \pm 2.3\text{Ma}$, 7 号含金爆破角砾岩筒的辉钨矿 Re-Os 等时线年龄为 $135.6 \pm 5.6\text{Ma}$, 明显大于花山花岗岩体和嵩坪岩体的成岩年龄, 表明祁雨沟爆破角砾岩及其成矿系统不可能是后者结晶分异的产物。矿床与矿区斑岩、角砾岩筒同时同空同源形成, 与区域大的花山花岗岩也同时同源, 表明祁雨沟金矿是与岩浆有关的爆破角砾岩型金矿床。

熊耳地体的热液矿床、花山花岗岩基和祁雨沟—雷门沟斑岩-爆破角砾岩带及其相关矿床等, 属于陆陆碰撞过程的挤压向伸展转变体制的产物。花山花岗岩基与其南侧造山型成矿系统和北侧斑岩-爆破角砾岩及其成矿系统近乎同时发育, 彼此之间属于“兄弟关系”而非“母子关系”, 三者成岩成矿物质总体来自俯冲壳楔和仰冲壳楔, 可用碰撞造山成岩成矿与流体作用模式解释。

致谢 研究工作得到陈衍景等专家的指导, 感谢陈根文老师在野外采集样品时的帮助。两位审稿人和王焰研究员提出了宝贵的修改意见, 在此表示谢意!

References

Bizzarro M, Simonetti A, Stevenson RK and David J. 2002. Hf isotope

- evidence for a hidden mantle reservoir. *Geology*, 30: 771 - 774
- Bureau of Geology and Mineral Resources of Henan Province. 1989. Regional Geology Henan Province. Beijing: Geological Publishing House, 772 (in Chinese with English abstract)
- Chen JF, Xie Z, Liu SS, Li XM and Folland KA. 1995. Cooling age of Dabie orogen, China; Determined by ⁴⁰Ar-³⁹Ar and fission track techniques. *Science in China (Series B)*, 38: 749 - 757
- Chen YJ and Fu SG. 1992. Gold Mineralization in West Henan. Beijing: Seismological Press, 234 (in Chinese with English abstract)
- Chen YJ, Fu SG and Qiang LZ. 1992. The tectonic environment for the formation of the Xiong'er Group and the Xiyanghe Group. *Geological Review*, 38: 325 - 333 (in Chinese with English abstract)
- Chen YJ and Zhao YC. 1997. Geochemical characteristics and evolution of REE in the Early Precambrian sediments; Evidences from the southern margin of the North China Craton. *Episodes*, 20: 109 - 116
- Chen YJ, Guo GJ and Li X. 1998. Metallogenic geodynamic background of gold deposits in granite-greenstone terrains of North China craton. *Science in China (series D)*, 41(2): 113 - 120
- Chen YJ, Li C, Zhang J, Li Z and Wang HH. 2000. Sr and O isotopic characteristics of porphyries in the Qinling molybdenum deposit belt and their implication to genetic mechanism and type. *Science in China (Series D)*, 43(Supp.): 82 - 94
- Chen YJ, Sui YH and Pirajno F. 2003. Exclusive evidences for CMF model and a case of orogenic silver deposits; Isotope geochemistry of the Tieluping silver deposit, east Qinling orogen. *Acta Petrologica Sinica*, 19: 551 - 568 (in Chinese with English abstract)
- Chen YJ, Pirajno F and Sui YH. 2004. Isotope geochemistry of the Tieluping silver deposit, Henan, China; A case study of orogenic silver deposits and related tectonic setting. *Mineralium Deposita*, 39: 560 - 575
- Chen YJ, Pirajno F and Sui YH. 2005. Geology and D-O-C isotope systematics of the Tieluping silver deposit, Henan, China; Implications for ore genesis. *Acta Geologica Sinica*, 79: 106 - 119
- Chen YJ, Pirajno F, Qi JP, Li J and Wang HH. 2006. Ore geology, fluid geochemistry and genesis of the Shanggong gold deposit, eastern Qinling Orogen. *China. Resource Geology*, 56: 99 - 116
- Chen YJ, Chen HY, Zaw K, Pirajno F and Zhang ZJ. 2007. Geodynamic settings and tectonic model of skarn gold deposits in China; An overview. *Ore Geology Review*, 31: 139 - 169
- Chen YJ, Ni P, Fan HR, Pirajno F, Lai Y, Su WC and Zhang H. 2007. Diagnostic fluid inclusions of different types hydrothermal gold deposits. *Acta Petrologica Sinica*, 23(9): 2085 - 2108 (in Chinese with English abstract)
- Chen YJ, Pirajno F and Qi JP. 2008. The Shanggong gold deposit, eastern Qinling Orogen, China; Isotope geochemistry and implications for ore genesis. *Journal of Asian Earth Sciences*, 33: 252 - 266
- Chen YJ, Pirajno F, Li N, Qi JP, Guo DS, Lai Y and Zhang YH. 2009. Isotope systematics and fluid inclusion studies of the Qiyugou breccia pipe-hosted gold deposit, Qinling orogen, Henan Province, China; Implications for ore genesis. *Ore Geology Reviews*, doi: 10.1016/j.oregeorev.2008.11.003
- Cheng GG. 1994. The genesis, tectonic setting of the Mesozoic granite and its relation to mineralization in MT. Xiong'er, Henan Province. *Geological exploration for non-ferrous metals*, 3(1): 15 - 21, 27 (in Chinese with English abstract)
- Fan HR, Xie YH and Wang YL. 1993. The properties of magmatic hydrothermal fluid of Huashan granitic batholiths in western Henan Province and their relationship to gold mineralization. *Acta Petrologica Sinica*, 9: 136 - 145 (in Chinese with English abstract)
- Fan HR, Xie YH, Zhao R and Wang YL. 1994. Stable isotope geochemistry of rocks and gold deposits in the Xiong'er shan area, western Henan Province. *Contributions to Geology and Mineral Resources Research*, 9(1): 54 - 64 (in Chinese with English abstract)
- Fan HR, Xie YH, Zheng XZ and Wang YL. 2000. Ore-forming fluids in hydrothermal breccia-related gold mineralization in Qiyugou, Henan Province. *Acta Petrologica Sinica*, 16(4): 559 - 563 (in Chinese

- with English abstract)
- Griffin WL, Pearson, NJ, Belousova E, Jackson SE, O'Reilly SY, van Achterberg E and Shee SR. 2000. The Hf isotope composition of cratonic mantle; LAM-MC-ICPMS analysis of zircon megacrysts in kimberlites. *Geochimica et Cosmochimica Acta*, 64: 133 - 147
- Guo DS, Chen YJ and Qi JP. 2007. Isotope geochemistry and ore genesis of the Qiyugou gold deposit, Henan: A synthesis. *Geological Review*, 53(2): 217 - 228 (in Chinese with English abstract)
- Han YG, Li XH, Zhang SH, Zhang YH and Chen FK. 2007. Single grain Rb-Sr dating of euhedral and cataclastic pyrite from the Qiyugou gold deposit in western Henan, central China. *Chinese Science Bulletin*, 52(13): 1820 - 1826
- He YH, Zhao GC, Sun M and Wilde SA. 2008. Geochemistry, isotope systematics and petrogenesis of the volcanic rocks in the Zhongtiao Mountain: An alternative interpretation for the evolution of the southern margin of the North China Craton. *Lithos*, 102: 158 - 178
- Hu SX, Lin QL, Chen ZM, Sheng ZL and Li SM. 1988. *Geology and Metallogeny of the Collisional Belt Between the North and South China Plates*. Nanjing: Nanjing University Press, 558 (in Chinese)
- Li C, Chen YJ and He SD. 2001. East Qinling-Dabieshan lithosphere delaminating age, mechanism and direction; Petrological evidences and stipulation. *Chinese Journal of Geochemistry*, 20(1): 59 - 72
- Li HG, Wang WZ, Liu MG and Ye HN. 2002. Mineralization feature of gold mine to the northeast of Huashan granite mass in the west of Henan. *Mineral Resources and Geology*, 16: 91 - 94 (in Chinese with English abstract)
- Li JY. 2001. Pattern and time of the collision between the Sino-Korean Block and Yangtze Block; Evolution of the Sinian-Jurassic sedimentary settings in the Middle-Lower Reaches of the Yangtze River. *Acta Geologica Sinica*, 75(1): 25 - 34 (in Chinese with English abstract)
- Li N, Chen YJ, Zhang H, Zhao TP, Deng XH, Wang Y and Ni ZY. 2007a. Molybdenum deposits in East Qinling. *Earth Science Frontiers*, 14: 186 - 198 (in Chinese with English abstract)
- Li N, Sun YL, Li J and Li WB. 2007b. Molybdenite Re/Os isochron age of the Wunugetu Shan porphyry Cu/Mo deposit, Inner Mongolia and its implication for metallogenic geodynamics. *Acta Petrologica Sinica*, 23(11): 2881 - 2888 (in Chinese with English abstract)
- Li N, Lai Y, Lu YH and Guo DS. 2008. Study of fluid inclusions and ore genetic type of the Qiyugou gold deposit, Henan. *Geology in China*, 35(6): 1230 - 1239 (in Chinese with English abstract)
- Li SG, Hart SR and Zheng SG. 1989. The collision time of North China Plate and South China Plate; Evidence from Sm-Nd ages. *Science in China (Series B)*, 19(3): 312 - 319 (in Chinese)
- Li YF, Mao JW, Liu DY, Wang YB, Wang ZL, Wang YT, Li XF, Zhang ZH and Guo BJ. 2006. SHRIMP zircon U-Pb and molybdenite Re-Os datings for the Leimengou porphyry molybdenum deposit, western Henan and its geological implication. *Geological Review*, 52(1): 122 - 131 (in Chinese with English abstract)
- Liu HJ, Chen YJ, Mao SD, Zhao CH and Yang RS. 2008. Element and Sr-Nb-Pb isotope geochemistry of granite-porphry dykes in the Yangshan gold belt, western Qinling Orogen. *Acta Petrologica Sinica*, 24(5): 1101 - 1111 (in Chinese with English abstract)
- Ludwig KR. 1991. ISOPLOT: A plotting and regression program for radiogenic-isotope data. US Geological Survey Open-File Report. 39
- McDonough WF and Sun SS. 1995. The Composition of the Earth. *Chemical Geology*, 120: 223 - 253
- Pirajno F. 2008. *Hydrothermal Processes and Mineral Systems*. Geological Survey of Western Australia: Springer, 1250
- Qi JP, Lai Y, Ren KX and Tang GJ. 2006. The Sr-isotope constraint on the origin of the Xiaqingling gold field. *Acta Petrologica Sinica*, 22(10): 2543 - 2550 (in Chinese with English abstract)
- Qi JP, Zhang J and Tang GJ. 2005. Carbon and oxygen isotope composition of the Meso-Neoproterozoic strata south of the Xiong'er terrane; Evidence of the CMF model. *Acta Petrologica Sinica*, 21(5): 1365 - 1372 (in Chinese with English abstract)
- Qi L, Hu J and Gregoire DC. 2000. Determination of trace elements in granites by inductively coupled plasma-mass spectrometry. *Talanta*, 51: 507 - 513
- Ren FG, Ding SY, Zhao JN and Li ZH. 1996. The features of explosive breccias gold deposits and ore-hunting indications in Xiong'er mountain-Weifangshan mountain. *Progress in Precambrian Research*, 22(2): 32 - 38 (in Chinese with English abstract and references)
- Ren FG, Yin YJ, Li SB and Zhao JN. 2001. The coupling character between isotopic geochronology of Indosinian Epoch in Xiong'er fault basin. *Bulletin of Mineralogy Petrology and Geochemistry*, 20(4): 286 - 288 (in Chinese with English abstract)
- Shao KZ, Wang BD and Li SR. 1992. Characteristics of Qiyugou gold deposits and their prospecting perspective geological setting. *Journal of Hebei College of Geology*, 15: 105 - 195 (in Chinese with English abstract)
- Smoliar ML, Walker RJ and Morgan JW. 1996. Re-Os ages of group IA, IIA, IVA and IVB iron meteorites. *Science*, 271: 1099 - 1102
- Soderlund U, Patchett PJ, Vervoort JD and Isachsen CE. 2004. The ¹⁷⁶Lu decay constant determined by Lu-Hf and U-Pb isotope systematics of Precambrian mafic intrusions. *Earth Planetary Science Letters*, 219: 311 - 324
- Song B, Zhang YH, Wan YS and Jiang P. 2002. Target preparation, age determination and discussion about some phenomenon of SHRIMP zircon isotopic analysis. *Geological Review*, 48(supp.): 26 - 30 (in Chinese with English abstract)
- Sun YL, Zhou MF and Sun M. 2001. Routine Os analysis by isotope dilution-inductively coupled plasma mass spectrometry: OsO₄ in water solution gives high sensitivity. *Journal of Analytical Atomic Spectrometry*, 16: 345 - 349
- Vervoort JD, Patchett PJ, Albarede F, Blichert-Toft J, Rudnick R and Downes H. 2000. Hf-Nd isotopic evolution of the lower crust. *Earth Planetary Science Letters*, 181: 115 - 129
- Wang YT, Mao JW and Lu XX. 2001. ⁴⁰Ar-³⁹Ar dating and geochronological constraints on the ore-forming Epoch of the Qiyugou gold deposit in Songxian County, Henan Province. *Geological Review*, 47(5): 551 - 555 (in Chinese with English abstract)
- Wang ZG, Cui B and Xu ML. 1997. *Tectonic evolution and mineralization of the southern margin of the North China Block*. Beijing: Metallurgical Industry Press, 310 (in Chinese).
- Wiedenbeck M, Alle P and Corfu F. 1995. Three natural zircon standards for U-Th-Pb, Lu-Hf, trace element and REE analyses. *Geostand Newsletter*, 19: 1 - 23
- Wu XG and Yang ZS. 1991. Discussion on the ore formation caused and controlled by tectonic dynamic in Qiyugou breccias-type gold deposit. *Henan Geology*, 9(1): 15 - 20 (in Chinese)
- Wu HC, Zhang SH, Li ZX, Li HY and Dong J. 2005. New paleomagnetic results from the Yangzhuang Formation of the Jixian System, North China, and tectonic implications. *Chinese Science Bulletin*, 50: 1483 - 1489
- Xu C, Song WL, Qi L and Wang LJ. 2009. Geochemistry and tectonic setting of Ore-bearing carbonatites in Huanglongpu Mo field, Shaanxi. *Acta Petrologica Sinica*, 25(2): 422 - 430 (in Chinese with English abstract)
- Xu P, Wu F Y, Xie L W and Yang YH. 2004. Hf isotopic compositions of the standard zircons for U-Pb dating. *Chinese Science Bulletin*, 49: 1642 - 1648
- Yang RS, Chen YJ, Zhang FX, Li ZH, Mao SD, Liu HJ and Zhao CH. 2006. The chemical Th-U-Pb ages of monazite from the Yangshan gold deposit, Gansu Province and their geologic and metallogenic implications. *Acta Petrologica Sinica*, 22(10): 2603 - 2610 (in Chinese with English abstract)
- Yuan XC. 1996. Velocity structure of the Qinling lithosphere and mushroom cloud model. *Science in China (Series D)*, 39: 235 - 244
- Zhang GW, Zhang BR, Yuan XC and Xiao QH. 2001. *Qinling Orogenic Belt and Continental Dynamics* Beijing: Science Press, 855 (in Chinese)
- Zhang J, Chen YJ, Shu GM, Zhang FX and Li C. 2002. Compositional study of minerals within the Qinlingliang granite, southwestern Shaanxi Province and discussions on the related problems. *Science in*

- China (Series D), 45(7): 662–672.
- Zhang J, Chen YJ, Chen HY, Wan SQ, Zhang G and Wang JM. 2006. Isotope geochemistry of the Yindongpo gold deposit, Tongbai County, Henan Province, China. *Acta Petrologica Sinica*, 22(10): 2551–2560 (in Chinese with English abstract)
- Zhang JJ, Zheng YD and Liu SW. 1998. Structural Style, Evolution and Genetic Mechanism of the Xiaqingling Metamorphic Core Complex. Beijing: Ocean Press, 120 (in Chinese)
- Zhao GC, Sun M, Wilde SA and Li SZ. 2004a. A Paleo-Mesoproterozoic supercontinent: Assembly, growth and breakup. *Earth-Science Review*, 67: 91–123
- Zhao TP, Zhou MF, Zhai MG and Xia B. 2002. Paleoproterozoic rift-related volcanism of the Xiong'er Group, North China Craton: Implication for the breakup of Columbia. *International Geology Reviews*, 44: 336–351
- Zhao TP, Zhai MG, Xia B, Li HM, Zhang YX and Wan YS. 2004b. Zircon U-Pb SHRIMP dating for the volcanic rocks of the Xiong'er Group: Constraints on the initial formation age of the cover of the North China Craton. *Chinese Science Bulletin*, 49: 2495–2502
- Zhao TP, Xu YH and Zhai MG. 2007. Petrogenesis and tectonic setting of the Paleoproterozoic Xiong'er Group in the southern part of the North China Craton: A review. *Geological Journal of China Universities*, 13(2): 191–206 (in Chinese with English abstract)
- Zhu RX, Yang ZY, Wu HN, Ma XH, Huang BC, Meng ZF and Fang DJ. 1998. Paleomagnetic constraints on the tectonic history of the major blocks of China during the Phanerozoic. *Science in China (Series D)*, 41 (Supp.): 1–19
- 附中文参考文献**
- 陈衍景, 富士谷. 1992. 豫西金矿成矿规律. 北京: 地震出版社, 234
- 陈衍景, 富士谷, 强立志. 1992. 评熊耳群和西洋河群形成的构造背景. *地质论评*, 38(4): 325–333
- 陈衍景, 隋颖慧, Pirajno F. 2003. CMF模式的排他性证据和造山型银矿的实例: 铁炉坪银矿同位素地球化学. *岩石学报*, 19(3): 551–568
- 陈衍景, 倪培, 范洪瑞, Pirajno F, 赖勇, 苏文超, 张辉. 2007. 不同类型热液金矿床的流体包裹体特征. *岩石学报*, 23(9): 2085–2108
- 程广国. 1994. 河南熊耳山地区中生代花岗岩成因及构造环境与成矿关系. *有色金属与勘查*, 3(1): 15–21, 27
- 范宏瑞, 谢奕汉, 王英兰. 1993. 豫西花山花岗岩岩浆热液性质及与金成矿的关系. *岩石学报*, 9: 136–145
- 范宏瑞, 谢奕汉, 赵瑞, 王英兰. 1994. 豫西熊耳山地区岩石和金矿床稳定同位素地球化学研究. *地质找矿论丛*, 9(1): 54–64
- 范宏瑞, 谢奕汉, 郑学正, 王英兰. 2000. 河南祁雨沟热液角砾岩体型金矿床成矿流体研究. *岩石学报*, 16(4): 559–563
- 郭东升, 陈衍景, 祁进平. 2007. 河南祁雨沟金矿同位素地球化学和矿床成因分析. *地质论评*, 53(2): 217–228
- 河南地矿局. 1989. 河南省地质志. 北京: 地质出版社, 772
- 胡受奚, 林潜龙, 陈泽铭, 盛中烈, 黎世美. 1988. 华北与华南古板块拼合带地质与成矿. 南京: 南京大学出版社, 558
- 李怀乾, 王伟忠, 罗明强, 叶惠嫩. 2002. 豫西花山花岗岩东侧金矿成矿特征. *矿产与地质*, 16: 91–94
- 李诺, 陈衍景, 张辉, 赵太平, 邓小华, 王运, 倪智勇. 2007a. 东秦岭斑岩铜矿带的地质特征和成矿构造背景. *地学前缘*, 14: 186–198
- 李诺, 孙亚莉, 李晶, 李文博. 2007b. 内蒙古乌努格吐山斑岩铜矿床辉钼矿铼钨等时线年龄及其成矿地球动力学背景. *岩石学报*, 23(11): 2881–2888
- 李诺, 赖勇, 鲁颖准, 郭东升. 2008. 河南祁雨沟金矿流体包裹体及矿床成因类型研究. *中国地质*, 35(6): 1230–1239
- 李锦轶. 2001. 中朝地块与扬子地块碰撞的时限与方式——长江中下游地区震旦纪—侏罗纪沉积环境的演变. *地质学报*, 75(1): 25–34
- 李曙光, Hart SR, 郑双根. 1989. 中国华北、华南陆块碰撞时代的Sm-Nd同位素年龄证据. *中国科学(B辑)*, 19(3): 312–319
- 李永峰, 毛景文, 刘敦一, 王彦斌, 王志良, 王义天, 李晓峰, 张作衡, 郭保健. 2006. 豫西雷门沟斑岩铜矿 SHRIMP 锆石 U-Pb 和辉钼矿 Re-Os 测年及其地质意义. *地质论评*, 52(1): 122–131
- 刘红杰, 陈衍景, 毛世东, 赵成海, 杨荣生. 2008. 西秦岭梁山金矿带花岗岩元素及 Sr-Nd-Pb 同位素地球化学. *岩石学报*, 24(5): 1101–1111
- 祁进平, 赖勇, 任康绪, 唐国军. 2006. 小秦岭金矿田成因的铀同位素约束. *岩石学报*, 22(10): 2543–2550
- 祁进平, 张静, 唐国军. 2005. 熊耳地体南侧中晚元古代地层碳同位素组成: CMF模式的证据. *岩石学报*, 21(5): 1365–1372
- 任富根, 丁士应, 赵嘉农, 李增慧. 1996. 熊耳山—外方山区爆破角砾岩型金矿床的特征和有关找矿问题. *前寒武纪研究进展*, 22(2): 32–38
- 任富根, 殷艳杰, 李双保, 赵家农. 2001. 熊耳裂陷印支期同位素地质年龄耦合性. *矿物岩石地球化学通报*, 20(4): 286–288
- 邵克忠, 王宝德, 李胜荣等. 1992. 祁雨沟地区爆破角砾岩型金矿成矿条件和找矿方向研究. *河北地质学院学报*, 15: 105–195
- 宋彪, 张玉海, 万渝生, 简平. 2002. 锆石 SHRIMP 样品靶制作、年龄测定及有关现象讨论. *地质论评*, 5(增刊): 26–30
- 王义天, 毛景文, 卢欣祥. 2001. 嵩县祁雨沟金矿成矿时代的⁴⁰Ar-³⁹Ar年代学证据. *地质论评*, 47(5): 551–555
- 王志光, 崔毫, 徐孟罗. 1997. 华北地块南缘地质构造演化与成矿. 北京: 冶金工业出版社, 310
- 吴新国, 杨竹森. 1991. 嵩县祁雨沟式隐爆角砾岩型金矿成矿控矿模式的探讨. *河南地质*, 9(1): 15–20
- 许成, 宋文磊, 漆亮, 王林均. 2009. 黄龙铺铜矿田含矿碳酸岩地球化学特征及其形成构造背景. *岩石学报*, 25(2): 422–430
- 杨荣生, 陈衍景, 张复新, 李志宏, 毛世东, 刘红杰, 赵成海. 2006. 甘肃阳山金矿独居石 Th-U-Pb 化学年龄及其地质和成矿意义. *岩石学报*, 22(10): 2603–2610
- 张国伟, 张本仁, 袁学诚, 肖庆辉. 2001. 秦岭造山带与大陆动力学. 北京: 科学出版社, 855
- 张静, 陈衍景, 陈华勇, 万守全, 张冠, 王建明. 2006. 河南省桐柏县银洞坡金矿床同位素地球化学. *岩石学报*, 22(10): 2551–2560
- 张进江, 郑亚东, 刘树文. 1998. 小秦岭变质核杂岩的构造体制、形成机制及构造演化. 北京: 海洋出版社, 120
- 赵太平, 徐勇航, 翟明国. 2007. 华北陆块南部元古宙熊耳群火山岩的成因与构造环境: 事实与争议. *高校地质学报*, 13(2): 191–206