



# 湘中包金山矿区花岗闪长斑岩的锆石 U-Pb 年龄、Hf-O 同位素组成及其地质意义

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**摘要:** 包金山金矿床是近年在湘中地区探获的以金为主的多金属矿床, 其成矿与印支晚期岩浆活动关系密切。利用高精度 SIMS 锆石 U-Pb 定年方法得到矿区两条花岗闪长斑岩年龄分别为  $(225.1 \pm 1.5)$  Ma 和  $(223.3 \pm 1.4)$  Ma, 在误差范围内一致, 属印支晚期大规模岩浆活动的产物; 矿区两条花岗闪长斑岩的  $^{176}\text{Hf}/^{177}\text{Hf}$  值均集中分布在 0.2825 附近, 对应的  $\epsilon_{\text{Hf}}(t)$  值介于 -5.9~3 之间, 平均为 -3.98, 两阶段模式年龄  $T_{\text{DM2}}$  为 0.96~1.45 Ga, 平均为 1.35 Ga;  $\delta^{18}\text{O}$  值为 0.824‰~0.973‰; Hf-O 同位素研究表明花岗闪长斑岩主要为中元古代下地壳岩石重熔形成, 且有部分幔源物质参与成岩作用; 与紫云山花岗岩体对比分析, 表明两者为同源岩浆演化的产物, 且间接指示包金山金矿成矿时间为 227~223 Ma; 花岗闪长斑岩形成于多板块汇聚的动力学背景, 为印支地块向北挤压和太平洋板块向西俯冲共同作用的结果。

**关键词:** SIMS 锆石 U-Pb 年龄; Hf-O 同位素示踪; 花岗闪长斑岩; 包金山矿床; 湘中

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随着一系列典型印支期成矿年龄的确认, 如荷花坪锡多金属矿  $(224 \pm 1.9)$  Ma<sup>[1]</sup>、云头界钨钼多金属矿  $(216.8 \pm 7.5)$  Ma<sup>[2]</sup>、锡田锡铅锌多金属矿  $(212.8 \pm 3.0)$  Ma<sup>[3]</sup>, 华南印支期的成矿作用越来越值得重视。在湘中地区, 金属(多金属)矿床多分布于印支期花岗岩体周边, 如白马山杂岩体附近的古台山石英脉型金锑矿<sup>[4]</sup>和高家坳微细浸染型金矿床<sup>[5-6]</sup>; 天龙山岩体附近的大新破碎蚀变岩夹石英脉型金矿<sup>[7]</sup>; 芙蓉岩体附近的廖家坪金锑钨矿; 紫云山岩体附近的包金山金矿等; 其成矿与印支期的岩浆活动有着密切的关系。

白马山-龙山-紫云山隆起带为湘中重要的金多金属成矿带, 其上的金属矿床主要赋存于受岩浆上侵穹窿作用形成的放射状或环状断裂中<sup>[7-11]</sup>。包金山金矿位于该成矿带的东段(见图 1(b)), 为典型的受紫云山穹窿环状断裂和地层联合控制的矿床, 以石英脉型为主, 其成矿流体属岩浆期后热液, 与矿区内的花岗闪长斑岩有着密切联系<sup>[12-19]</sup>。但是以往地质工作对于区内花岗闪长斑岩的研究还处于空白, 严重制约了对该区成矿作用的认识。

本文作者在野外实地调查的基础上, 通过高精度 SIMS 锆石 U-Pb 测年及锆石原位 Hf-O 同位素分析, 精确构建区内花岗闪长斑岩脉的年代学格架, 深入探讨了花岗闪长斑岩的源区特征及其形成的动力学背景, 不仅为研究紫云山地区成岩成矿作用奠定了基础, 而且有助于进一步研究华南地区早中生代构造-岩浆演化过程。

## 1 矿区地质概况

包金山金矿床位于湘中盆地的东缘, 紫云山岩体北侧 3 km 处。在大地构造位置上, 该区处在扬子地块与华夏地块的对接带(见图 1(a)), 长期以来经历了复杂的构造岩浆活动, 并伴有大规模的金属成矿活动。矿区出露的地层为元古代板溪群马底驿组浅变质岩系, 赋矿地层为第二段倾向北的钙质板岩夹钙质条带状板岩及灰岩透镜体。矿区主构造线方向为近东西向(见图 2), 以断裂构造为主, 近东西向断裂为紫云山穹窿环

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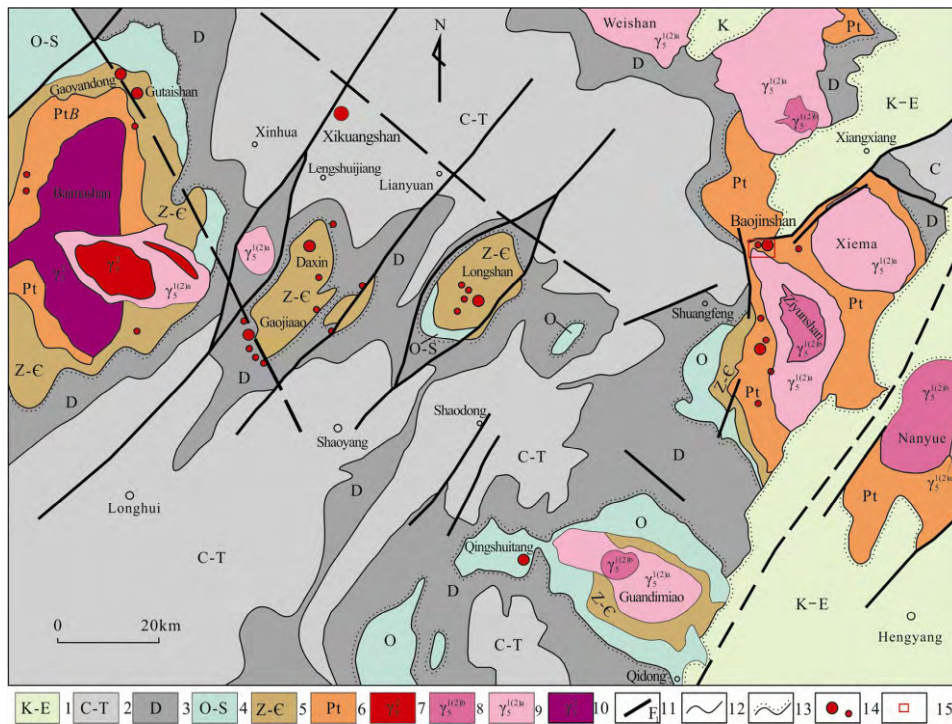


图1 湘中区域地质略图

**Fig. 1** Regional geological map of central Hunan Province: 1—Cretaceous-Paleogene; 2—Carboniferous- Triassic; 3—Devonian; 4—Ordovician-Silurian; 5—Sinian- Cambrian; 6—Neoproterozoic; 7—Yanshanian granite; 8—Late Indosinian biotite (two-mica) granite; 9—Late Indosinian porphyroid monzonitic granite; 10—Caledonian granite; 11—Major deep fracture; 12—Geological boundary; 13—Unconformable boundary line; 14—Ore deposit(ore spot); 15—Study area

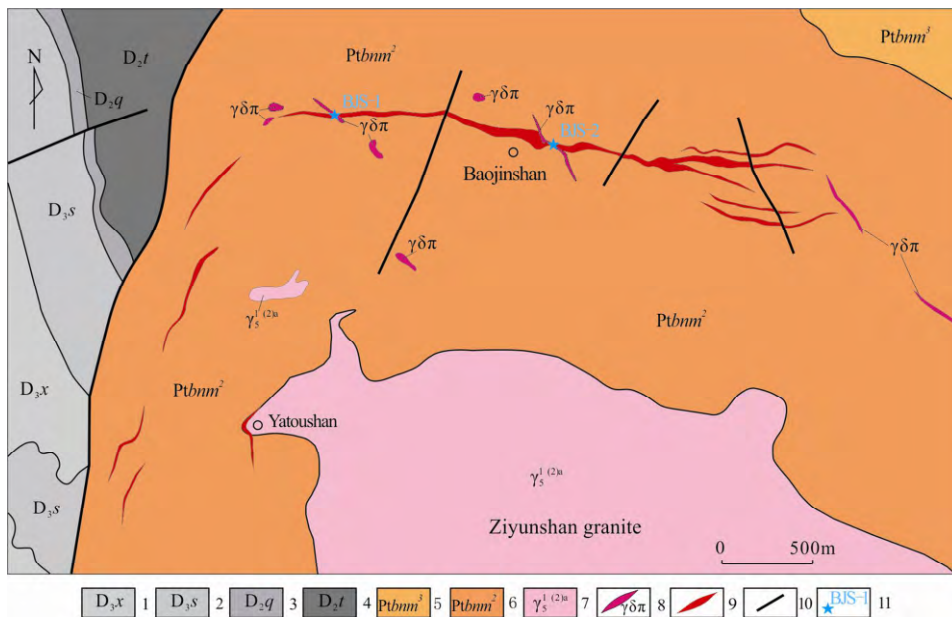


图2 包金山矿区地质略图

**Fig. 2** Regional geological map of Baojinshan gold deposit: 1—Xikuangshan formation, Devonian group; 2—Shetianqiao formation, Devonian group; 3—Qiziqiao formation, Devonian group; 4—Tiaomajian formation, Devonian group; 5—Third member of Madiyi formation, Banxi group; 6—Second member of Madiyi formation, Banxi group; 7—The late Indosinian granite; 8—Granodiorite –porphyry; 9—Ore belt; 10—Fault; 11—Sampling position and number

状断裂的一部分; 近南北向、北东向及北西向破矿断裂。区内花岗闪长斑岩分布广泛, 但产出面积较小, 多为脉状, 呈 NW 走向, 倾向北东。本区主成矿期与印支晚期中酸性岩浆的热液活动有关<sup>[16-18]</sup>。矿区内的花岗闪长斑岩与矿体相互穿插, 在其转弯处常有富矿体存在, 其对成矿具有重要的叠加改造作用, 并为成矿物质活化运移及矿体的进一步富集提供了热量和能量, 并提供了部分的成矿物质<sup>[13, 17-19]</sup>。围岩蚀变以绢云母化、硅化、黄铁矿化与金成矿的关系最为密切。

本区金矿以石英脉型为主, 主要有脉状和筒状两类矿体。其中脉状矿体多呈群脉雁形排列, 走向 NW, 倾向 SW, 倾角 45°~67°。该类矿体走向延伸较短, 一般在 20 m 左右, 倾向延深相对较长, 矿体厚度 0.2~2.0 m。筒状矿体的走向和倾向与脉状矿体相近, 但规模相对较大, 厚度几米到十几米, 倾向延深可达百米。金矿化主要位于石英脉与围岩的接触部位, 近围岩的石英脉内常见明金, 金品位变化较大。

## 2 岩石岩相学特征

通过系统的野外地质观察及镜下显微鉴定分析, 本次所采集的样品均为花岗闪长斑岩。岩石呈灰黑色, 斑状结构, 块状构造(见图 3(a)和(b)), 其浅色矿物为长石、石英, 暗色矿物以黑云母为主, 斑晶含量约 20%~25%, 主要由长石(15%~20%)和石英(5%~8%)组成, 基质含量约 75%~80%, 主要由它形粒状石英、长石和黑云母。副矿物主要为锆石、磁铁矿等。长石主要是斜长石、次为正长石。长石常沿边缘、粒间发生不同程度的绢云母化, 整体蚀变强烈, 长石可呈残余状产出, 局部甚至全部蚀变为绢云母而保留原长石的晶体外形(见图 3(d)、(e)和(f)); 石英分布零星, 主要呈椭圆状、圆状以斑晶的形式分布, 集合体粒度一般 0.5~1.5 mm(见图 3(c)和(e))。

## 3 样品采集及测试分析

用于锆石测年研究的花岗闪长斑岩样品共有 2 件, 样品 BJS-1 采自钻孔, 样品 BJS-2 采自 10 中段的 44 线附近, 样品均未发生风化。

### 3.1 锆石 U-Pb 年龄测定

锆石的挑选由河北省廊坊市诚信地质服务有限公司完成, 样品破碎至 0.3 mm 以下, 用人工淘洗和电

磁选方法富集锆石, 再在双目镜下精选锆石, 未使用任何化学药剂。将精选的锆石用无色透明环氧树脂固定并进行抛光, 使内部暴露, 进行透射光和反射光下照相, 并用阴极发光扫描电子显微镜照相, 以了解锆石的内部结构, 系统对比的基础上选出最理想的供分析的锆石颗粒。锆石阴极发光(CL)内部结构照相在中国科学院地质与地球物理研究所 Cameca 电子探针仪器上完成, 分析电压为 50 kV, 电流为 15nA。锆石 U-Pb 定年在中国科学院地质与地球物理研究所离子探针实验室的 Cameca IMS-1280 型二次离子质谱仪(SIMS)上进行, 详细的分析流程见文献[20]。锆石样品的 Pb/U 比值用标准锆石 TEMORA 2(417 Ma)<sup>[19]</sup>的  $\ln(^{206}\text{Pb}/^{238}\text{U})$  与  $\ln(^{238}\text{U}^{16}\text{O}_2/^{238}\text{U})$  之间的线性关系校正<sup>[22]</sup>; Th 和 U 含量用标准锆石 91500<sup>[23]</sup>计算; 普通 Pb 用测量的  $^{204}\text{Pb}$  进行校正; 用现代地壳的平均 Pb 同位素组成<sup>[24-25]</sup>作为普通 Pb 组成进行校正。单点分析的同位素比值及年龄误差为  $1\sigma$ ( $\sigma$  为绝对误差), U-Pb 平均年龄误差为 95%置信度。

### 3.2 锆石原位 Hf、O 同位素分析

锆石微区原位 Hf 同位素分析在中国地质大学(武汉)地质过程与矿产资源国家重点实验室(GPMR) 利用激光剥蚀多接收杯等离子体质谱(LA-MC-ICP-MS)完成。激光剥蚀系统为 GeoLas 2005 (Lambda Physik, 德国), 配备了信号平滑装置, 使用氦气作为载气, 并引入少量氮气来提升元素的灵敏度<sup>[26]</sup>。详细仪器操作条件和分析方法参照文献[27]。锆石样品自身的  $\beta_{\text{Yb}}$  用于干扰校正<sup>[28]</sup>;  $^{179}\text{Hf}/^{177}\text{Hf} = 0.7325$  和  $^{173}\text{Yb}/^{171}\text{Yb} = 1.132685$ <sup>[29]</sup>用于计算 Hf 和 Yb 的质量分馏系数  $\beta_{\text{Hf}}$  和  $\beta_{\text{Yb}}$ ;  $^{179}\text{Hf}/^{177}\text{Hf}$  和  $^{173}\text{Yb}/^{171}\text{Yb}$  的比值用于计算 Hf( $\beta_{\text{Hf}}$ ) 和 Yb ( $\beta_{\text{Yb}}$ ) 的质量偏差; 使用  $^{176}\text{Yb}/^{173}\text{Yb} = 0.79639$ <sup>[29]</sup>来扣除  $^{176}\text{Yb}$  对  $^{176}\text{Hf}$  的同量异位干扰; 使用  $^{176}\text{Lu}/^{175}\text{Lu} = 0.02656$ <sup>[30]</sup>来扣除干扰程度相对较小的  $^{176}\text{Lu}$  对  $^{176}\text{Hf}$  的同量异位干扰; 采用 Yb 的质量分馏系数  $\beta_{\text{Yb}}$  来校正 Lu 的质量分馏行为。分析数据的离线处理(包括对样品和空白信号的选择、同位素质量分馏校正)采用软件 ICP-MS Data Cal 完成<sup>[31]</sup>。

锆石微区原位 O 同位素分析在中国科学院地质与地球物理研究所离子探针实验室的 Cameca 进行。将做过 SIMS 锆石 U-Pb 定年的样品靶再次磨去约 5  $\mu\text{m}$ , 以消除前期在 U-Pb 定年时造成的氧污染, 详细的分析流程参见文献[20]。仪器质量分馏校正采用 91500 锆石标准, 其中 91500 标准锆石的  $\delta^{18}\text{O} = 0.99\%$ <sup>[32]</sup>, 测量的  $^{18}\text{O}/^{16}\text{O}$  比值通过 VSMOW 值 ( $^{18}\text{O}/^{16}\text{O} = 0.0020052$ )校正后, 加上仪器质量分馏校正

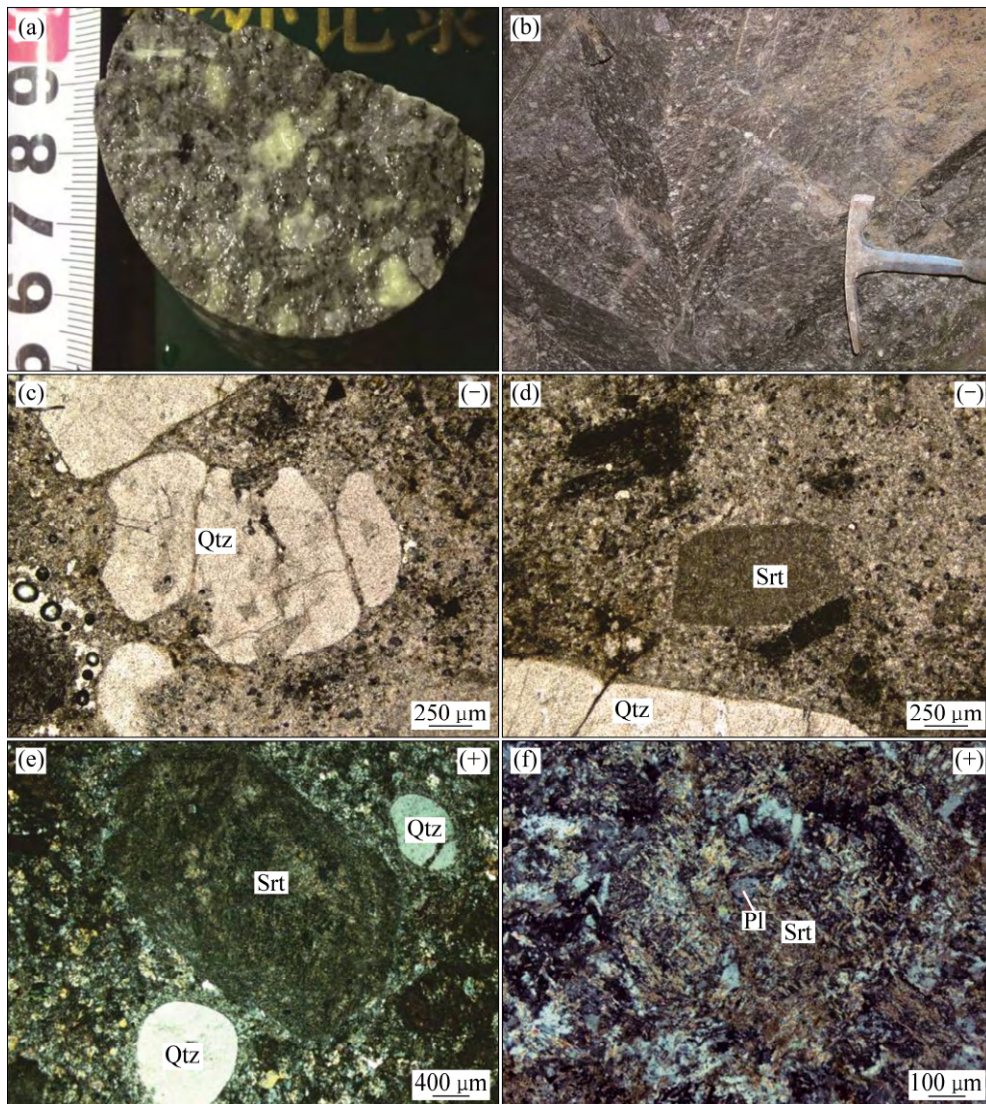


图3 花岗闪长岩岩相学特征

**Fig. 3** Petrographies of granodiorite-porphry: (a) Granodiorite-porphry of BJS-1; (b) Granodiorite-porphry of BJS-2; (c) Spherical quartz(BJS-1); (d) Spherical quartz and sericitization of plagioclase(BJS-2); (e) Spherical quartz and sericitization of plagioclase(BJS-1); (f) Sericitization of plagioclase(BJS-2). Qtz- Quartz; Pl- Plagioclase; Srt-Sericite

因子 IMF 即为该点的  $\delta^{18}\text{O}$  值：

$$(\delta^{18}\text{O})_M = ((^{18}\text{O}/^{16}\text{O})_M / 0.0020052 - 1) \times 100\% \quad ; \quad \text{IMF} = (\delta^{18}\text{O})_{M(\text{standard})} - (\delta^{18}\text{O})_{\text{VSMOW}} \quad ; \quad \delta^{18}\text{O}_{\text{Sample}} = (\delta^{18}\text{O})_M + \text{IMF}.$$

## 4 分析结果

### 4.1 锆石 U-Pb 年龄

供 U-Pb 同位素定年的 2 件花岗闪长斑岩样品中的锆石呈灰色长柱状或短柱状，颗粒较大，长度 100~200  $\mu\text{m}$ ，长宽比一般为 1.5~4，晶体自形程度较好，大部分具有清晰韵律环带结构(见图 4)，并且锆石

的 Th/U 比值主要介于 0.10~0.90 之间(见表 1 和表 2)，具有岩浆锆石的特点<sup>[33]</sup>。利用 Isoplot<sup>[34]</sup>绘制锆石的谐和曲线及谐和年龄的投影图(见图 5)，数据点多分布在谐和线上或在谐和线附近呈线状分布，表明所测的锆石颗粒在形成后 U-Pb 同位素体系是封闭的，基本未发生 U 或 Pb 的加入和丢失<sup>[35-37]</sup>。

样品 BJS-1 进行了 25 个点的定年分析，其中有 4 个测点(8、15、17、18)年龄为离群值，其余 21 个测点  $^{206}\text{Pb}/^{238}\text{U}$  数据得到加权平均年龄(225.5  $\pm$  3.3) Ma(95% 置信度，MSWD=0.21)，谐和年龄为(225.1  $\pm$  1.5) Ma(95% 置信度，MSWD=0.40)(见图 5(a))。

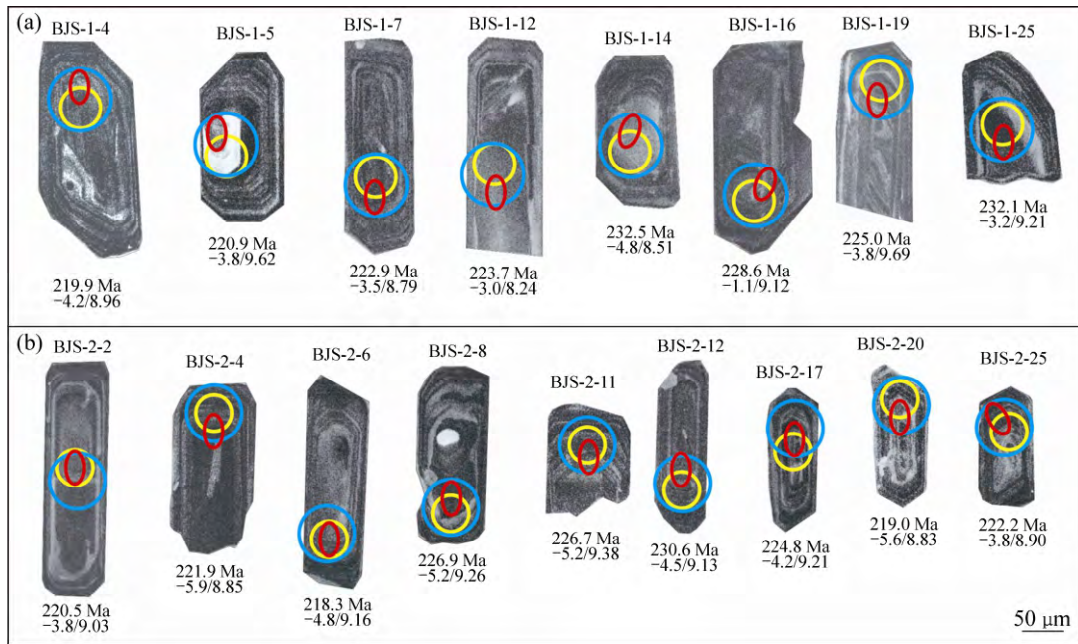


图 4 包金山金矿床花岗闪长斑岩锆石 CL 图像及分析点位图

Fig. 4 Zircon cathodoluminescence (CL) images and analytical point bitmaps of granodiorite -porphyry in Baojinshan gold deposit: (a) BJS-1; (b) BJS-2

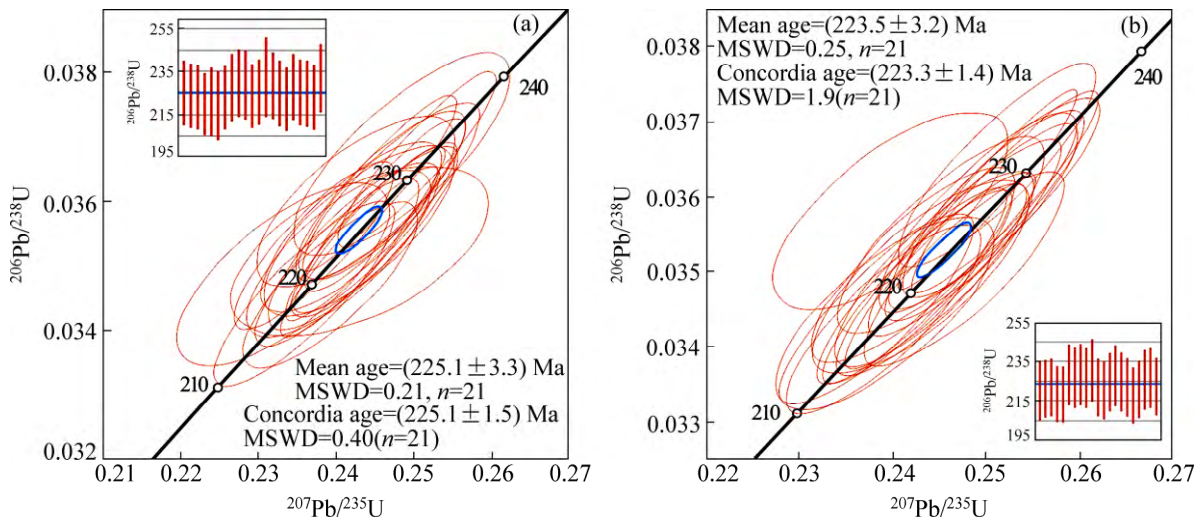


图 5 包金山金矿床花岗闪长斑岩锆石 U-Pb 年龄谐和图

Fig. 5 Zircon U-Pb concordia age diagrams of granodiorite -porphyry in Baojinshan gold deposit: (a) BJS-1; (b) BJS-2

样品 BJS-2 进行了 25 个点的定年分析, 其中有 4 个测点(1、9、18、21)年龄为离群值, 其余 21 个测点  $^{206}\text{Pb}/^{238}\text{U}$  数据得到的加权平均年龄为  $(223.5 \pm 3.2)$  Ma(95% 置信度,  $\text{MSWD}=0.25$ ), 谐和年龄为  $(223.3 \pm 1.4)$  Ma(95%置信度,  $\text{MSWD}=1.9$ )(见图 5(b))。

因此, 包金山矿区两条花岗闪长斑岩的形成年龄分别为  $(223.3 \pm 1.4)$  Ma 和  $(225.1 \pm 1.5)$  Ma, 其形成时间在误差范围内一致, 属印支晚期的产物。

#### 4.2 锆石的 Hf、O 同位素组成特征

对样品 BJS-1 的锆石进行微区原位 Hf 同位素分析, 初始  $^{176}\text{Hf}/^{177}\text{Hf}$  比值为 0.282494~0.282729 之间, 平均为 0.282538, 对应的  $\epsilon_{\text{Hf}}(t)$  为  $-5.3 \sim 3$ (见图 6(a)), 平均为  $-3.4$ , 两阶段模式年龄  $T_{\text{DM}2}$  为 0.96~1.41 Ga, 平均为 1.32 Ga。锆石微区原位 O 同位素分析,  $\delta^{18}\text{O}$  为 0.824%~0.973%(见图 6(b)), 平均为 0.907%。

对样品 BJS-2 的锆石进行微区原位 Hf 同位素分

析, 初始  $^{176}\text{Hf}/^{177}\text{Hf}$  比值为 0.282286~0.282592, 平均为 0.282498, 对应的  $\varepsilon_{\text{Hf}}(t)$  为 -5.9~-2.3(见图 6(a)), 平均值 -4.5, 两阶段模式年龄  $T_{\text{DM2}}$  为 1.25~1.45 Ga, 平均为 1.37 Ga。锆石微区原位 O 同位素分析,  $\delta^{18}\text{O}$  为 0.866%~0.948%(见图 6(b)), 平均为 0.916%。

对花岗闪长斑岩样品 BJS-1 和 BJS-2 的锆石颗粒(包括定年的锆石)进行了微区原位 Hf-O 同位素测定, 分析结果分别见表 3 和 4。

## 5 讨论

### 5.1 成岩年代及意义

本实验中采用高精度 SIMS 锆石 U-Pb 测年方法获得的包金山矿区花岗闪长斑岩年龄为  $(225.1 \pm 1.5)$  Ma

和  $(223.3 \pm 1.4)$  Ma, 在误差范围内一致。其与临近的紫云山花岗岩体(锆石 SIMS U-Pb  $(227.0 \pm 2.2)$ ~ $(225.2 \pm 1.7)$  Ma<sup>[38]</sup> 锆石 LA-ICP-MS U-Pb  $(222.5 \pm 1.0)$  Ma~ $(222.3 \pm 1.8)$  Ma<sup>[39]</sup>)、歇马花岗岩体(锆石 SHRIMP U-Pb  $(218 \pm 3)$  Ma<sup>[40]</sup>; 锆石 SHRIMP U-Pb  $(214.1 \pm 5.9)$  Ma<sup>[41]</sup>) 以及与区域上的南岳花岗岩体(锆石 LA-ICP-MS U-Pb  $(215.5 \pm 1.5)$  Ma<sup>[42]</sup>、沱山花岗岩体(黑云母 Rb-Sr  $(227.0 \pm 13)$  Ma 和  $(221.9 \pm 5.8)$  Ma<sup>[43]</sup>)、大神山花岗岩体(锆石 LA-ICP-MS  $(224.3 \pm 1.0)$  Ma<sup>[44]</sup>)、白马山花岗岩体(锆石 LA-ICP-MS U-Pb  $(224.3 \pm 2.4)$  Ma、 $(221.4 \pm 4.0)$  Ma 和  $(226.6 \pm 4.1)$  Ma<sup>[45]</sup>) 的成岩时限基本一致, 表明矿区内花岗闪长斑岩属于印支晚期(230~200 Ma)大规模岩浆活动的组成部分<sup>[37, 46]</sup>。该类花岗闪长斑岩在区域上广泛发育, 在紫云山岩体主体花岗岩中也偶见出露, 其与紫云山岩体应属同期不同

表 1 包金山矿区花岗闪长斑岩样品 BJS-1 锆石 U-Pb(SIMS)分析结果

Table 1 Zircon U-Pb (SIMS) analytical results of No. BJS-1 sample from granodiorite-porphyry in Baojinshan gold deposit

Analytical position	Th/ 10 <sup>-6</sup>	U/ 10 <sup>-6</sup>	Th/U	<sup>207</sup> Pb/ <sup>206</sup> Pb	1 $\sigma$	<sup>207</sup> Pb/ <sup>235</sup> U	1 $\sigma$	<sup>206</sup> Pb/ <sup>238</sup> U	1 $\sigma$	<sup>207</sup> Pb/ <sup>206</sup> Pb/		<sup>207</sup> Pb/ <sup>235</sup> U/		<sup>206</sup> Pb/ <sup>238</sup> U/	
										Ma	1 $\sigma$	Ma	1 $\sigma$	Ma	1 $\sigma$
BJS-1-1	831	3180	0.26	0.05058	0.00067	0.24791	0.00499	0.0355	0.00054	221.7	30.4	224.9	4.1	225.2	3.3
BJS-1-2	476	1894	0.25	0.04973	0.00044	0.24219	0.00421	0.0353	0.00053	182.4	20.3	220.2	3.4	223.8	3.3
BJS-1-3	599	2093	0.29	0.05107	0.00116	0.24806	0.00678	0.0352	0.00054	243.8	51.6	225.0	5.5	223.2	3.3
BJS-1-4	365	1552	0.23	0.05106	0.00057	0.24428	0.00459	0.0347	0.00052	243.4	25.6	221.9	3.7	219.9	3.3
BJS-1-5	227	633	0.36	0.04954	0.00082	0.23814	0.00558	0.0349	0.00058	173.3	38.1	216.9	4.6	220.9	3.6
BJS-1-6	350	1720	0.20	0.05055	0.00052	0.24092	0.00476	0.0346	0.00059	220.4	23.4	219.2	3.9	219.1	3.6
BJS-1-7	1078	3257	0.33	0.05054	0.00064	0.24523	0.00482	0.0352	0.00053	220.0	29.0	222.7	3.9	222.9	3.3
BJS-1-8	718	1812	0.40	0.05378	0.00380	0.21302	0.01831	0.0287	0.00141	361.7	152.1	196.1	15.4	182.6	8.8
BJS-1-9	253	2621	0.10	0.05070	0.00036	0.25128	0.00422	0.0359	0.00055	227.4	16.2	227.6	3.4	227.6	3.4
BJS-1-10	614	2826	0.22	0.05005	0.00033	0.25039	0.00415	0.0363	0.00055	197.4	15.0	226.9	3.4	229.7	3.4
BJS-1-11	351	1712	0.21	0.05056	0.00050	0.25200	0.00462	0.0361	0.00056	220.8	22.6	228.2	3.7	228.9	3.5
BJS-1-12	1099	1228	0.90	0.05077	0.00051	0.24715	0.00449	0.0353	0.00053	230.5	23.2	224.3	3.7	223.7	3.3
BJS-1-13	368	1707	0.22	0.05030	0.00059	0.24696	0.00473	0.0356	0.00054	208.7	27.1	224.1	3.9	225.6	3.3
BJS-1-14	619	942	0.66	0.05003	0.00070	0.25335	0.00567	0.0367	0.00064	196.4	32.2	229.3	4.6	232.5	4.0
BJS-1-15	465	1074	0.43	0.05269	0.00139	0.24480	0.00894	0.0337	0.00085	315.3	58.8	222.3	7.3	213.7	5.3
BJS-1-16	282	1205	0.23	0.05039	0.00049	0.25078	0.00448	0.0361	0.00054	213.2	22.3	227.2	3.6	228.6	3.4
BJS-1-17	1439	6454	0.22	0.05035	0.00834	0.24595	0.04092	0.0354	0.00056	211.1	344.4	223.3	33.9	224.4	3.5
BJS-1-18	265	726	0.36	0.05014	0.00098	0.26432	0.00778	0.0382	0.00084	201.6	44.6	238.1	6.3	241.9	5.2
BJS-1-19	504	1892	0.27	0.05101	0.00043	0.24985	0.00436	0.0355	0.00054	241.2	19.3	226.5	3.5	225.0	3.4
BJS-1-20	356	1088	0.33	0.05070	0.00045	0.24511	0.00430	0.0351	0.00053	227.1	20.4	222.6	3.5	222.2	3.3
BJS-1-21	491	1420	0.35	0.04986	0.00073	0.24744	0.00520	0.0360	0.00054	188.4	33.7	224.5	4.2	228.0	3.4
BJS-1-22	485	1705	0.28	0.05096	0.00037	0.25003	0.00424	0.0356	0.00054	239.1	16.7	226.6	3.4	225.4	3.4
BJS-1-23	607	2376	0.26	0.05079	0.00033	0.24860	0.00417	0.0355	0.00055	231.4	14.7	225.4	3.4	224.9	3.4
BJS-1-24	811	2285	0.35	0.05106	0.00032	0.24788	0.00410	0.0352	0.00054	243.5	14.5	224.9	3.3	223.1	3.4
BJS-1-25	856	2234	0.38	0.05054	0.00032	0.25544	0.00416	0.0367	0.00055	220.0	14.6	231.0	3.4	232.1	3.4

表 2 包金山矿区花岗闪长斑岩样品 BJS-2 锆石 U-Pb(SIMS)分析结果

Table 2 Zircon U-Pb (SIMS) analytical results of No. BJS-2 sample from granodiorite-porphry in Baojinshan gold deposit

Analytical position	Th/ 10 <sup>-6</sup>	U/ 10 <sup>-6</sup>	Th/U	<sup>207</sup> Pb/ <sup>206</sup> Pb	1σ	<sup>207</sup> Pb/ <sup>235</sup> U	1σ	<sup>206</sup> Pb/ <sup>238</sup> U	1σ	<sup>207</sup> Pb/ <sup>206</sup> Pb/ Ma	1σ	<sup>207</sup> Pb/ <sup>235</sup> U/ Ma	1σ	<sup>206</sup> Pb/ <sup>238</sup> U/ Ma	1σ
BJS-2-1	439	1820	0.24	0.05093	0.00096	0.23342	0.00643	0.0332	0.00067	237.7	42.7	213.0	5.3	210.8	4.2
BJS-2-2	627	1898	0.33	0.05057	0.00038	0.24263	0.00409	0.0348	0.00052	221.3	17.4	220.6	3.3	220.5	3.3
BJS-2-3	221	733	0.30	0.05045	0.00063	0.24296	0.00475	0.0349	0.00053	215.8	28.5	220.8	3.9	221.3	3.3
BJS-2-4	356	1644	0.22	0.05129	0.00050	0.24774	0.00445	0.0350	0.00053	254.0	22.2	224.7	3.6	221.9	3.3
BJS-2-5	367	1327	0.28	0.05010	0.00046	0.23829	0.00420	0.0345	0.00052	199.5	21.1	217.0	3.4	218.6	3.2
BJS-2-6	379	1251	0.30	0.05033	0.00067	0.23906	0.00480	0.0344	0.00052	210.3	30.5	217.7	3.9	218.3	3.2
BJS-2-7	1151	3021	0.38	0.05067	0.00031	0.25195	0.00409	0.0361	0.00054	226.0	14.3	228.2	3.3	228.4	3.4
BJS-2-8	445	1533	0.29	0.05060	0.00042	0.24998	0.00430	0.0358	0.00054	222.8	19.0	226.6	3.5	226.9	3.4
BJS-2-9	865	2170	0.40	0.04725	0.00563	0.22243	0.02671	0.0341	0.00053	61.6	261.6	203.9	22.4	216.4	3.3
BJS-2-10	1073	5127	0.21	0.05027	0.00023	0.25012	0.00393	0.0361	0.00054	207.5	10.6	226.7	3.2	228.5	3.4
BJS-2-11	592	2282	0.26	0.05046	0.00044	0.24904	0.00433	0.0358	0.00054	216.2	20.1	225.8	3.5	226.7	3.3
BJS-2-12	866	2629	0.32	0.05003	0.00043	0.25121	0.00437	0.0364	0.00055	196.4	19.7	227.6	3.6	230.6	3.4
BJS-2-13	420	1163	0.36	0.05060	0.00049	0.24443	0.00437	0.0350	0.00053	222.7	22.2	222.0	3.6	222.0	3.3
BJS-2-14	534	1817	0.29	0.05044	0.00039	0.24202	0.00416	0.0348	0.00053	215.1	18.0	220.1	3.4	220.5	3.3
BJS-2-15	693	2393	0.28	0.05067	0.00042	0.24769	0.00424	0.0355	0.00053	225.9	18.9	224.7	3.5	224.6	3.3
BJS-2-16	390	1460	0.26	0.05070	0.00043	0.25158	0.00435	0.0360	0.00054	227.3	19.7	227.9	3.5	227.9	3.4
BJS-2-17	656	1621	0.40	0.05012	0.00053	0.24522	0.00452	0.0355	0.00053	200.4	24.5	222.7	3.7	224.8	3.3
BJS-2-18	586	1096	0.54	0.05037	0.00253	0.25214	0.01325	0.0363	0.00055	212.1	112.6	228.3	10.8	229.9	3.4
BJS-2-19	647	2207	0.29	0.05074	0.00036	0.24500	0.00413	0.0350	0.00054	229.1	16.4	222.5	3.4	221.9	3.3
BJS-2-20	392	1155	0.34	0.05212	0.00161	0.24839	0.00854	0.0346	0.00052	290.7	69.1	225.3	7.0	219.0	3.2
BJS-2-21	1128	3768	0.30	0.05044	0.00049	0.23904	0.00427	0.0344	0.00052	215.4	22.3	217.6	3.5	217.8	3.2
BJS-2-22	567	1750	0.32	0.05076	0.00042	0.24419	0.00420	0.0349	0.00052	230.0	19.2	221.8	3.4	221.1	3.3
BJS-2-23	823	1834	0.45	0.05074	0.00040	0.24955	0.00422	0.0357	0.00054	229.2	18.0	226.2	3.4	225.9	3.3
BJS-2-24	1105	2808	0.39	0.04854	0.00074	0.23974	0.00512	0.0358	0.00054	125.8	35.3	218.2	4.2	226.9	3.3
BJS-2-25	509	1495	0.34	0.05006	0.00054	0.24214	0.00447	0.0351	0.00053	197.6	24.7	220.2	3.7	222.3	3.3

Test method: SIMS; Test unit: Beijing Nano SIMS Lab, Institute of Geology and Geophysics, Chinese Academy of Sciences.

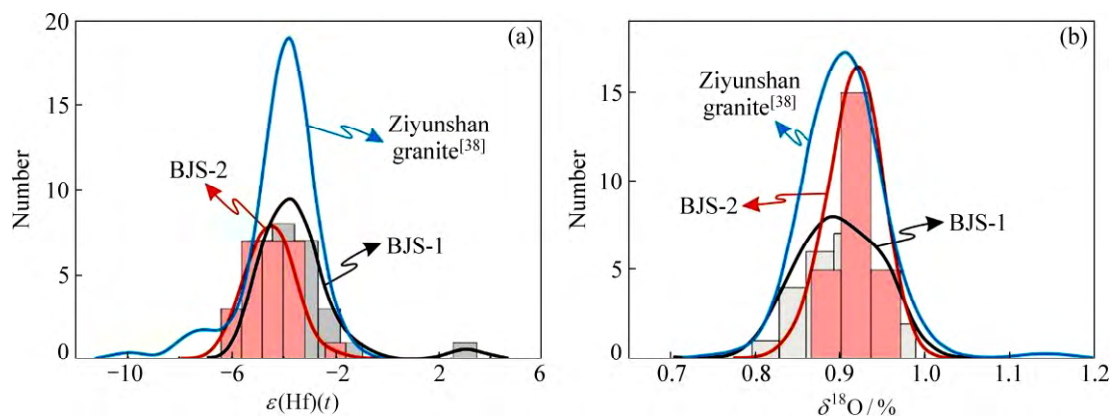


图 6 包金山金矿床花岗闪长斑岩的 Hf 和 O 同位素组成

Fig. 6 Hf isotope compositions (a) and O isotope compositions (b) for granodiorite-porphry of Baojinshan gold deposit

表3 包金山金矿床花岗闪长斑岩 BJS-1 锆石 Hf-O 同位素分析结果

Table 3 Zircons Hf-O isotopic analytical results of No. BJS-1 sample from granodiorite-porphry in Baojinshan gold deposit

Analytical position	Age/Ma	$^{176}\text{Hf}/^{177}\text{Hf}$	$1\sigma$	$^{176}\text{Yb}/^{177}\text{Hf}$	$1\sigma$	$^{176}\text{Lu}/^{177}\text{Hf}$	$1\sigma$	$\epsilon_{\text{Hf}}/t$	$1\sigma$	$T_{\text{DM2}}/\text{Ma}$	$\delta^{18}\text{O}/\%$	$2\sigma$
BJS-1-1	225.2	0.282495	0.000009	0.022826	0.000162	0.000948	0.000007	-5.0	0.6	1403	0.910	0.32
BJS-1-2	223.8	0.282507	0.000009	0.019328	0.000199	0.000791	0.000007	-4.6	0.6	1379	0.937	0.26
BJS-1-3	223.2	0.282500	0.000009	0.027605	0.000672	0.001132	0.000026	-4.9	0.6	1397	0.906	0.43
BJS-1-4	219.9	0.282521	0.000010	0.020444	0.000324	0.000841	0.000013	-4.2	0.6	1354	0.896	0.28
BJS-1-5	220.9	0.282532	0.000010	0.024769	0.000606	0.001023	0.000024	-3.8	0.6	1334	0.962	0.20
BJS-1-6	219.1	0.282558	0.000011	0.024579	0.001142	0.001018	0.000046	-2.9	0.7	1283	0.859	0.27
BJS-1-7	222.9	0.282539	0.000009	0.027212	0.000138	0.001101	0.000003	-3.5	0.6	1321	0.879	0.34
BJS-1-8	225.1	0.282532	0.000012	0.027327	0.000424	0.001107	0.000016	-3.7	0.7	1333	0.885	0.25
BJS-1-9	227.6	0.282544	0.000011	0.024410	0.000400	0.000994	0.000017	-3.2	0.7	1307	0.964	0.21
BJS-1-10	229.7	0.282540	0.000010	0.021444	0.000811	0.000912	0.000033	-3.3	0.6	1313	0.893	0.41
BJS-1-11	228.9	0.282541	0.000010	0.023967	0.000636	0.000977	0.000023	-3.3	0.6	1313	0.879	0.37
BJS-1-12	223.7	0.282729	0.000012	0.072467	0.003883	0.002795	0.000146	3.0	0.7	961	0.824	0.26
BJS-1-13	225.6	0.282535	0.000010	0.023423	0.001205	0.000976	0.000047	-3.6	0.6	1326	0.903	0.25
BJS-1-14	232.5	0.282495	0.000009	0.023008	0.000551	0.000980	0.000021	-4.8	0.6	1401	0.851	0.28
BJS-1-15	213.7	0.282494	0.000010	0.027248	0.000643	0.001096	0.000024	-5.3	0.6	1411	0.886	0.33
BJS-1-16	228.6	0.282604	0.000011	0.037229	0.001713	0.001463	0.000065	-1.1	0.7	1193	0.912	0.28
BJS-1-17	224.4	0.282528	0.000010	0.033934	0.001877	0.001351	0.000072	-3.9	0.7	1343	0.925	0.31
BJS-1-18	241.9	0.282567	0.000010	0.034057	0.001626	0.001343	0.000061	-2.1	0.6	1259	0.853	0.23
BJS-1-19	225.0	0.282528	0.000009	0.022449	0.000215	0.000920	0.000008	-3.8	0.6	1339	0.969	0.33
BJS-1-20	222.2	0.282515	0.000010	0.019815	0.000697	0.000794	0.000027	-4.3	0.6	1364	0.973	0.32
BJS-1-21	228	0.282558	0.000010	0.026795	0.001427	0.001094	0.000054	-2.7	0.6	1281	0.861	0.42
BJS-1-22	225.4	0.282510	0.000010	0.033483	0.000362	0.001349	0.000014	-4.5	0.6	1378	0.957	0.36
BJS-1-23	224.9	0.282526	0.000010	0.024462	0.000193	0.001001	0.000007	-3.9	0.6	1343	0.913	0.39
BJS-1-24	223.1	0.282510	0.000010	0.022526	0.000835	0.000912	0.000032	-4.5	0.6	1374	0.959	0.41
BJS-1-25	232.1	0.282543	0.000012	0.025537	0.000606	0.001014	0.000024	-3.2	0.7	1308	0.921	0.33

阶段的产物,形成时间应略晚于后者。

包金山金矿产于紫云山岩体入侵形成的环状断裂内,那么其成矿时间不会早于紫云山岩体的侵位时间;而花岗闪长斑岩脉穿插包金山矿脉,表明包金山成矿不会晚于花岗闪长斑岩的形成时间。因此,包金山成矿时间应介于紫云山岩体((227.0 ± 2.2)~(225.2 ± 1.7) Ma<sup>[38]</sup>)和包金山花岗闪长斑岩((225.1 ± 1.5) Ma 和 (223.3 ± 1.4) Ma)侵位时间之间,即 227~223 Ma。

## 5.2 岩浆源区及意义

对花岗闪长斑岩锆石原位 Hf-O 同位素数据统计(见图 6),其 Hf-O 同位素的组成基本相似,基本可以重叠。初始  $^{176}\text{Hf}/^{177}\text{Hf}$  值均集中分布在 0.2825

附近,对应的  $\epsilon_{\text{Hf}}(t)$  值在 -5.9~3.0 之间,平均为 -3.98; 两阶段模式年龄  $T_{\text{DM2}}$  为 0.96~1.45 Ga,平均为 1.35 Ga;  $\delta^{18}\text{O}$  值为 0.824~0.973% 之间,均大于地幔  $\delta^{18}\text{O}$  值((0.53 ± 0.03)%<sup>[47]</sup>); 在  $\epsilon_{\text{Hf}}(t)$ -U/Pb Age 图解中(见图 7(a)),样品点主要落于下地壳区域,表明花岗闪长斑岩为中元古代下地壳岩石重熔形成。而在  $\delta^{18}\text{O}$ - $\epsilon_{\text{Hf}}(t)$  图解中(见图 7(b)),Hf-O 同位素完全落在以大容量过铝质花岗岩为代表的地壳端元区域以外,表明源区有幔源岩浆的加入,且加入地幔物质的比例至少可达 20%<sup>[48-49]</sup>。样品 BJS-1 的 12 号测点,初始  $^{176}\text{Hf}/^{177}\text{Hf}$  比值较大,对应其年龄计算的  $\epsilon_{\text{Hf}}(t)$  值为 3.0(见表 3 和 4),其可能为幔源物质参与的结果。与临近的紫云山岩体相比,两者的 Hf 同位素组成基



表 4 包金山金矿床花岗闪长斑岩样品 BJS-2 锆石 Hf-O 同位素分析结果

Table 4 Zirons Hf-O isotopic analytical results of No. BJS-2 sample from the granodiorite-porphry in the Baojinshan gold deposit

Analytical position	Age/Ma	$^{176}\text{Hf}/^{177}\text{Hf}$	$1\sigma$	$^{176}\text{Yb}/^{177}\text{Hf}$	$1\sigma$	$^{176}\text{Lu}/^{177}\text{Hf}$	$1\sigma$	$\epsilon_{\text{Hf}}/t$	$1\sigma$	$T_{\text{DM2}}/\text{Ma}$	$\delta^{18}\text{O}/\%$	$2\sigma$
BJS-2-1	223.3	0.282487	0.000011	0.016702	0.000381	0.000700	0.000016	-3.8	0.6	1337	9.19	0.30
BJS-2-2	220.5	0.282511	0.000010	0.030778	0.001362	0.001219	0.000051	-3.8	0.7	1335	9.03	0.34
BJS-2-3	221.3	0.282544	0.000011	0.025340	0.001246	0.001009	0.000047	-4.8	0.7	1392	9.31	0.25
BJS-2-4	221.9	0.282494	0.000010	0.023034	0.000061	0.000956	0.000002	-5.9	0.7	1449	8.85	0.23
BJS-2-5	218.6	0.282539	0.000010	0.015681	0.000263	0.000663	0.000010	-4.8	0.6	1389	8.86	0.22
BJS-2-6	218.3	0.282537	0.000011	0.019808	0.000212	0.000817	0.000009	-4.8	0.6	1389	9.16	0.25
BJS-2-7	228.4	0.282471	0.000011	0.032466	0.000760	0.001312	0.000029	-5.2	0.7	1419	8.66	0.29
BJS-2-8	226.9	0.282592	0.000012	0.021845	0.000197	0.000917	0.000009	-5.2	0.6	1418	9.26	0.21
BJS-2-9	223.3	0.282539	0.000011	0.027870	0.000758	0.001145	0.000029	-5.7	0.7	1439	9.30	0.21
BJS-2-10	228.5	0.282544	0.000013	0.034676	0.000578	0.001407	0.000026	-3.9	0.7	1344	9.12	0.28
BJS-2-11	226.7	0.282545	0.00001	0.023038	0.000109	0.000938	0.000004	-5.2	0.7	1419	9.38	0.29
BJS-2-12	230.6	0.282514	0.000011	0.022905	0.000110	0.000941	0.000004	-4.5	0.6	1380	9.13	0.23
BJS-2-13	222.0	0.282433	0.000010	0.019175	0.000180	0.000793	0.000007	-4.5	0.7	1375	9.48	0.24
BJS-2-14	220.5	0.282525	0.000010	0.021314	0.000102	0.000873	0.000004	-4.3	0.6	1363	9.31	0.33
BJS-2-15	224.6	0.282509	0.000010	0.022285	0.000183	0.000915	0.000007	-4.0	0.6	1346	9.40	0.27
BJS-2-16	227.9	0.282425	0.000009	0.015069	0.000386	0.000637	0.000015	-4.1	0.7	1354	9.39	0.25
BJS-2-17	224.8	0.282411	0.000010	0.039812	0.001206	0.001568	0.000045	-4.2	0.7	1362	9.21	0.20
BJS-2-18	229.9	0.282453	0.000014	0.023493	0.000288	0.000955	0.000012	-4.2	0.7	1366	9.11	0.30
BJS-2-19	221.9	0.282525	0.000012	0.020411	0.000192	0.000841	0.000007	-4.7	0.7	1385	9.23	0.35
BJS-2-20	217.8	0.282556	0.000010	0.029296	0.001034	0.001186	0.000041	-5.6	0.7	1432	8.83	0.39
BJS-2-21	219.0	0.282524	0.000012	0.032111	0.001688	0.001288	0.000064	-2.3	0.7	1252	9.35	0.27
BJS-2-22	221.1	0.282286	0.000010	0.022139	0.000119	0.000908	0.000005	-3.9	0.6	1343	9.25	0.28
BJS-2-23	225.9	0.282538	0.000011	0.013333	0.000223	0.000569	0.000009	-5.1	0.6	1411	9.11	0.24
BJS-2-24	226.9	0.282529	0.000010	0.027524	0.000113	0.001133	0.000004	-3.6	0.6	1327	9.15	0.25
BJS-2-25	222.3	0.282428	0.000012	0.021802	0.000321	0.000903	0.000012	-3.8	0.6	1338	8.90	0.25

Zirons Hf isotopic: LA-MC-ICP-MS, State Key Laboratory of Geological Processes and Mineral Resources, China University of Geosciences (Wuhan) Airon Hf Isotopic; Beijing nano SIMS Lab, Institute of Geology and Geophysics, Chinese Academy of Sciences.

本相同,分布范围和峰值基本一致(见图 6(a));两者的 O 同位素组成也基本相似,不过花岗闪长斑岩  $\delta^{18}\text{O}$  值的峰值略高一些(见图 6(b)),这可能是由于花岗闪长斑岩后期发生蚀变的结果。在图 7 中,花岗闪长斑岩与紫云山花岗岩落于同一区域,表明两者为同源的特征。

因此,本文作者认为区内花岗闪长斑岩由中元古代下地壳岩石熔融,与幔源岩浆形成的壳、幔混合岩浆源区演化而来,其与紫云山花岗岩体应属于同源岩浆不同演化阶段的产物。

### 5.3 动力学背景探讨

在华南地块内印支晚期花岗岩的逐渐确认,尤其是一系列印支晚期 A 型花岗岩的发现,如湖南的锡田岩体、浙江的大爽岩体、江西蔡江岩体和福建高溪岩体等<sup>[39, 50-55]</sup>,对于华南印支晚期花岗岩形成于地壳伸展构造体制的认识已经成为共识。但对于华南印支晚期花岗岩形成的动力学背景还存在分歧,部分学者<sup>[44, 53-60]</sup>认为印支运动期间(约 260 Ma),印支地块向北挤压,与华南地块发生碰撞,导致地层加厚,之后 10~20 Ma 发生热-应力松弛作用,进入伸展阶段,

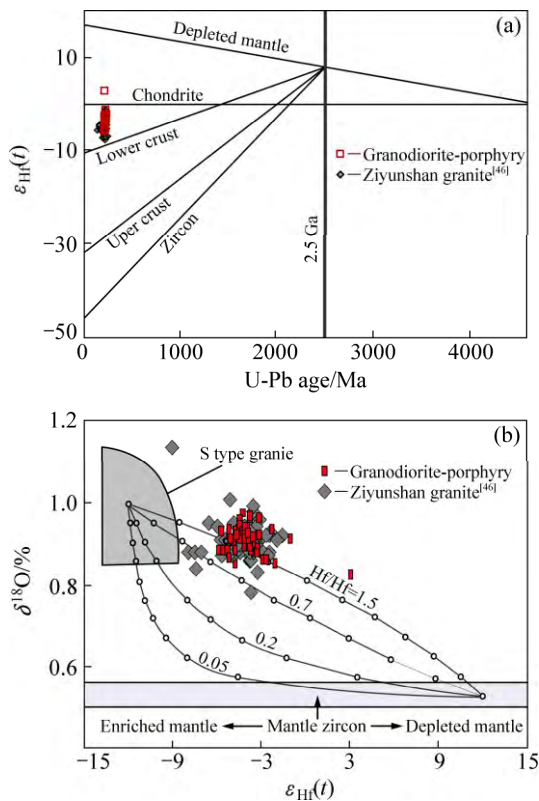


图 7 包金山金矿床花岗闪长斑岩  $\varepsilon_{\text{Hf}}(t)$ -U/Pb 图解(a)和  $\delta^{18}\text{O}$ - $\varepsilon_{\text{Hf}}(t)$ 图解(b)

Fig. 7 Plot of  $\varepsilon_{\text{Hf}}(t)$ -U/Pb (a) and  $\delta^{18}\text{O}$ - $\varepsilon_{\text{Hf}}(t)$  (b) for granodiorite-porphphyry of Baojinshan gold deposit

地壳减压熔融,进而形成花岗岩。LI 等<sup>[61]</sup>认为,在中二叠世(约 280 Ma)太平洋板块西缘转为活动大陆边缘,开始向华南地块俯冲,到三叠世华南地块发生造山运动,之后进入伸展-减薄构造背景,地壳熔融形成花岗岩<sup>[62]</sup>。从印支期华南地块内的构造变形来分析,其以 NE-NNE 向的褶皱及逆冲推覆构造为主,单纯印支地块引起的南北向的挤压应力很难解释这些构造的形成。这些构造的形成应与同期东部太平洋板块的俯冲有着密切的关系。

所以,本文作者认为华南印支期应该属于多板块汇聚的动力学背景,其构造变形和同期花岗岩的形成应为印支地块向北挤压和太平洋板块向西俯冲共同作用的结果。

## 6 结论

1) 包金山矿区两条花岗闪长斑岩锆石 SIMS U-Pb 年龄分别为(225.1 ± 1.5) Ma 和(223.3 ± 1.4) Ma,在误差范围内一致,其与印支晚期(230~200 Ma)大规

模的岩浆活动时限一致,并间接的指示了包金山成矿时间为 227~223 Ma,属典型印支晚期成矿。

2) 花岗闪长斑岩由中元古代下地壳岩石重熔与部分幔源岩浆组成的壳、幔混合岩浆源区演化而来,其与紫云山岩体为同源不同演化阶段的产物。

3) 花岗闪长斑岩形成于多板块汇聚的动力学背景,为印支地块向北挤压和太平洋板块向西俯冲共同作用的结果。

## REFERENCES

- [1] 蔡明海, 陈开旭, 屈文俊, 刘国庆, 付建明, 印建平. 湖南荷花塘锡多金属矿床地质特征及辉钼矿 Re-Os 测年[J]. 矿床地质, 2006, 25(3): 263-268.  
CAI Ming-hai, CHEN Kai-xu, QU Wen-jun, LIU Guo-qing, FU Jian-ming, YIN Jian-ping. Geological characteristics and Re-Os dating of molybdenites in Hehuaping tin-polymetallic deposit, southern Hunan Province[J]. Mineral Deposits, 2006, 25(3): 263-268.
- [2] WU Jing, LIANG Hua-ying, HUANG Wen-ting, WANG Chun-long, SUN Wei-dong, SUN Ya-li, LI Jing, MO Ji-hai, WANG Xiu-zhang. Indosinian isotope ages of plutons and deposits in southwestern Miaoershan-Yuechengling, northeastern Guangxi and implications on Indosinian mineralization in South China[J]. Chinese Science, 2012, 57(9): 1024-1035.
- [3] 姚远, 陈骏, 陆建军, 章荣清. 湘东锡田 A 型花岗岩的年代学、Hf 同位素、地球化学特征及其地质意义[J]. 矿床地质, 2013, 32(3): 467-488.  
YAO Yuan, CHEN Jun, LU Jian-jun, ZHANG Rong-qing. Geochronology, Hf isotopic compositions and geochemical characteristics of Xitian A-type granite and its geological significance[J]. Mineral Deposits, 2013, 32(3): 467-488.
- [4] 戴长华. 古台山-高家坳金矿带北西向构造控矿特征及找矿意义[J]. 湖南地质, 2000, 19(2): 105-110.  
DAI Chang-hua. Deposit-controlled characteristics of NW-trending structure and prospecting significance about Au ores zone of Gutaishan-Gaojiaao[J]. Hunan Geology, 2000, 19(2): 105-110.
- [5] 陈贻旺. 新邵高家坳微细浸染型金矿床构造控矿特征[J]. 湖南地质, 2002, 21(2): 26-29.  
CHEN Yi-wang. The deposit-controlled characteristics of Au-deposit in Gaojiaao mecro-impregnation, Xinshao[J]. Hunan Geology, 2002, 21(1): 26-29.
- [6] 李福顺, 康如华, 陈贻旺, 吴迎春, 袁卫. 湖南高家坳金矿床成矿地质条件及找矿方向[J]. 黄金, 2002, 22(5): 1-3.  
LI Fu-shun, KANG Ru-hua, CHEN Yi-wang, WU Ying-chun, YUAN Wei. The metallogenic geological condition of Gaojia'ao Hunan province and its ore-prospecting or ientation[J]. Gold, 2002, 22(5): 1-3.

- [7] 龚贵伦, 陈广浩, 戴建斌, 陈西, 李武毅. 湖南大新金矿床构造控矿特征及矿床成因[J]. 大地构造与成矿学, 2007, 31(3): 342-347.  
GONG Gui-lun, CHEN Guang-hao, DAI Jian-bin, CHEN Xi and LI Wu-yi. Tectono-controlling characteristics and genesis of Daxin gold deposit in Hunan Province[J]. Geotectonica et Metallogenia, 2007, 31(3): 342-347.
- [8] 陈泽吕. 湖南龙山老窿矿富集规律及找矿方向[J]. 黄金科学技术, 2000, 8(2): 30-35.  
CHEN Ze-lu. Enrichment laws and prospecting direction at the ancient workings ore deposit, Longshan, Hunan[J]. Gold Science and Technology, 2000, 8(2): 30-35.
- [9] 康如华. 湖南白马山-龙山东西向构造带金锑矿找矿前景分析[J]. 华南地质与矿产, 2002(1): 57-61.  
KANG Ru-hua. Analysis of exploration perspectives of gold-antimony deposits in Baimashan-Longshan EW-striking structural zone, Hunan Province[J]. Geology and Mineral Resources of South China, 2002(1): 57-61.
- [10] 李己华, 吴继承, 周遗军. 湘中白马山-龙山金矿带穹隆控矿规律分析[J]. 黄金地质, 2004, 10(4): 32-36.  
LI Ji-hua, WU Ji-cheng, ZHOU Yi-jun. Ore-control rules of dome structure in Baimashan-Co-Longshan gold belt, Central Hunan[J]. Gold Geology, 2004, 10(4): 32-36.
- [11] 李己华, 吴继承, 李永光. 湖南白马山-龙山金锑矿带控矿因素与成矿预测[J]. 资源环境与工程, 2007, 21(S): 33-36.  
LI Ji-hua, WU Ji-cheng, LI Yong-guang. The ore-controlling factors of Baimashan-Longshan gold-stibium belt and metallogenic prognosis[J]. Resources Environment & Engineering, 2007, 21(S): 33-36.
- [12] 孙海清, 贺业军. 双峰县金坑冲金矿地质特征及找矿前景[J]. 湖南地质, 1993, 12(4): 234-276.  
SUN Hai-qing, HE Ye-jun. Geological properties and the prospect of Jinkengchong gold deposit, Shuangfeng County[J]. Hunan Geology, 1993, 12(4): 234-276.
- [13] 戚学祥. 湖南双峰紫云山隆起区金矿成矿机制探讨[J]. 黄金地质, 1998, 4(1): 50-56.  
QI Xue-xiang. Discussion on the mechanism of gold metallogeny in the uplift of Ziyunshan, Shuangfeng County, Hunan[J]. Gold Geology, 1998, 4(1): 50-56.
- [14] 王滨清. 湘中铃山金矿床富集规律与成矿机理研究[J]. 黄金, 2005, 26(3): 14-17.  
WANG Bin-qing. Enrichment pattern and ore-forming mechanism of Lingshan gold deposit in central Hunan Province[J]. Gold, 2005, 26(3): 14-17.
- [15] 周兴良, 毛卫红, 胡世明. 湖南双峰金矿带成矿地质特征及控矿因素[J]. 广西质量监督导报, 2008(7): 190-196.  
ZHOU Xing-liang, MAO Wei-hong, HU Shi-ming. Ore-forming geological characteristics and ore-controlling factors of Shuangfeng gold belt, Hunan Province[J]. Guangxi Quality Supervision Guide Periodical, 2008(7): 190-196.
- [16] 鞠培姣, 赖健清, 莫青云, 陶诗龙. 湖南省包金山金矿流体包裹体特征[J]. 矿物学报, 2015(S1): 586.  
JU Pei-jiao, LAI Jian-qing, MO Qing-yun, TAO Shi-long. Characteristics of fluid inclusion of Baojinshan gold deposit, Hunan Province[J]. Acta Mineralogica Sinica, 2015(S1): 586.
- [17] 张利军, 邵拥军, 赖健清, 石坚, 徐志彬. 湘中包金山-金坑冲金矿床构造控岩控矿分析[J]. 矿产勘查, 2015, 5(3): 245-253.  
ZHANG Li-jun, SHAO Yong-jun, LAI Jian-qing, SHI Jian, XU Zhi-bin. Analysis on ore-controlling alteration rocks and structures in the Baojinshan-Jinkengchong gold deposit, Hunan[J]. Mineral Exploration, 2015, 5(3): 245-253.
- [18] 陶诗龙, 赖健清, 张建东, 鞠培姣. 湘中包金山金矿床地质特征及成因简析[J]. 矿物学报, 2015(S1): 620.  
TAO Shi-long, LAI Jian-qing, ZHANG Jian-dong, JU Pei-jiao. Geological characteristics and genesis analysis of Baojinshan gold deposit, central Hunan province[J]. Acta Mineralogica Sinica, 2015(S1): 620.
- [19] 莫青云, 赖健清, 鞠培姣, 徐质彬, 张利军, 石坚, 王照宇, 潘欣. 湖南双峰包金山金矿床成因初步研究[J]. 南方金属, 2015(5): 22-26.  
Mo Qing-yun, LAI Jian-qing, JU Pei-jiao, XU Zhi-bin, ZHANG Li-jun, SHI Jian, WANG Zhao-yu, PAN Xin. Preliminary study on ore genesis of Baojinshan gold deposit in Shangfeng county of Hunan Province[J]. Southern Metals, 2015(5): 22-26.
- [20] LI Xian-hua, LIU Yu, LI Qiu-li, GUO Chun-hua, CHAMBERLAIN K R. Precise determination of Phanerozoic zircon Pb/Pb age by multicollector SIMS without external standardization[J]. Geochemistry Geophysics Geosystems, 2009, 10: 1-21.
- [21] BLACK L P, KAMO S L, ALLEN C M, DAVIS D W, ALEINIKOFF J N, VALLEY J W, MUNDIL R, CAMPBELL I H, KORSCHE R J, WILLIAMS I S. Improved  $^{206}\text{Pb}/^{238}\text{U}$  microprobe geochronology by the monitoring of a trace-element-related matrix effect; SHRIMP, ID-TIMS, ELA-ICP-MS and oxygen isotope documentation for a series of zircon standards[J]. Chemical Geology, 2004, 205: 115-140.
- [22] WHITEHOUSE M J, CLAESON S, SUNDE T, VESTIN J. Ion-microprobe U-Pb zircon geochronology and correlation of archaean gneisses from the Lewisian complex of Gruinard Bay, north-west Scotland[J]. Geochim Cosmochim Acta, 1997, 61: 4429-4438.
- [23] WIEDENBECK M, ALLE P, CORFU F, GEIFFIN W L, MEIER M, OBERLI F, VONQUADT A, RODDICK J C, SPIEGEL W. Three natural zircon standards for U-Th-Pb, Lu-Hf, trace element and REE analyses[J]. Geostandards and Geoanalytical Research, 1995, 19: 1-23.
- [24] IRELAND T R, WILLIAMS I S. Considerations in zircon geochronology by SIMS[J]. Reviews in Mineralogy & Geochemistry, 2003, 53: 215-241.

- [25] STACEY J S, KRAMERS J D. Approximation of terrestrial lead isotope evolution by a two-stage model[J]. *Earth and Planetary Science Letters*, 1975, 26: 207–221.
- [26] HU Zhao-chu, GAO Shan, LIU Yong-sheng, HU Sheng-hong, CHEN Hai-hong, YUAN Hong-lin. Signal enhancement in laser ablation ICP-MS by addition of nitrogen in the central channel gas[J]. *Journal of Analytical Atomic Spectrometry*, 2008, 23: 1093–1101.
- [27] HU Zhao-chu, LIU Yong-sheng, GAO Shan, LIU Wen-gui, ZHANG Wen, TONG Xi-run, LIN Lin, ZONG Ke-qing, LI Ming, CHEN Hai-hong, ZHOU Lian, YANG Lu. Improved in situ Hf isotope ratio analysis of zircon using newly designed X skimmer cone and Jet sample cone in combination with the addition of nitrogen by laser ablation multiple collector ICP-MS[J]. *Journal of Analytical Atomic Spectrometry*, 2012, 27: 1391–1399.
- [28] WOODHEAD J, HERGT J, SHELLEY M, EGGINS S and KEMP R. Zircon Hf-isotope analysis with an excimer laser, depth profiling, ablation of complex geometries, and concomitant age estimation[J]. *Chemical Geology*, 2004, 209: 121–135.
- [29] FISHER C M, VERVOORT J D, HANCHAR J M. Guide lines for reporting zircon Hf isotopic data by LA-MC-ICPMS and potential pitfalls in the interpretation of these data[J]. *Chemical Geology*, 2014, 363: 125–133.
- [30] BLICHERT T J, CHAUVEL C, ALBAREDE F. Separation of Hf and Lu for high-precision isotope analysis of rock samples by magnetic sector-multiple collector ICP-MS[J]. *Contributions to Mineralogy and Petrology*, 1997, 127: 248–260.
- [31] LIU Yong-sheng, GAO Shan, HU Zhao-chu, GAO Chang-gui, ZONG Ke-qing, WANG Dong-bing. Continental and oceanic crust recycling-induced melt-peridotite interactions in the Trans-North China orogen: U-Pb dating, Hf isotopes and trace elements in zircons of mantle xenoliths[J]. *Journal of Petrology*, 2010, 51: 537–571.
- [32] WIEDENBECK M, HANCHAR J M, PECK W H, SYLVESTER P, VALLEY J, WHITHOUSE M, KRONZ A, MORISHITA Y, NASDALA L, FIEBIG J, FRANCHI I, GIRARD J P, GREENWOOD R C, HINTON R, KITA N, MASON P R D, NORMAN M, OGASAWARA M, PICCOLI P M, RHEDE D, SATOH H, SCHULZ-DOBRICK B, SKAR O, SPICUZZA M J, TERADA K, TINDLE A, TOGASHI S, VENNEMANN T, XIE Q, ZHENG Y F. Further characterisation of the 91500 zircon crystal[J]. *Geostandards and Geoanalytical Research*, 2004, 28: 9–39.
- [33] BELOUSOVA E, GRIFFIN W L, O'REILLY S Y, FISHER N I. Igneous zircon: Trace element composition as an indicator of source rock type[EB/OL]. [2002]. <http://www.researchgate.net/publication/225471090>.
- [34] LUDWIG K R. Users Manual for Isoplot/Ex Rev. 2.49[M]. Berkeley Geochronology Centre Special Publication, 2001: 56.
- [35] 徐夕生, 邓平, O'REILLY S Y, GRIFFIN W L, 周新民, 谭正中. 华南贵东杂岩体单颗粒锆石激光探针 ICPMS U-Pb 定年及其成岩意义[J]. *科学通报*, 2003, 48(12): 1328–1334.
- XU Xi-sheng, DENG Ping, O'REILLY SY, GRIFFIN W L, ZHOU X M, TAN Z Z. Single-grained zircon laser probe ICPMS U-Pb dating of the Guidong rock complex in southern China and its significance[J]. *Chinese Science Bulletin*, 2003, 48(12): 1328–1334.
- [36] 袁洪林, 吴福元, 高山, 柳小明, 徐平, 孙德有. 东北地区新生代侵入体的锆石激光探针 U-Pb 年龄测定与稀土元素成分分析[J]. *科学通报*, 2003, 48(14): 1511–1520.
- YUAN Hong-lin, WU Fu-yuan, GAO Shan, LIU Xiao-ming, XU Ping, SUN De-you. Zircon laser probe U-Pb dating of the cenozoic intrusions in northeast region and componential analysis of the REE elements[J]. *Chinese Science Bulletin*, 2003, 48(14): 1511–1520.
- [37] 丁兴, 陈培荣, 陈卫锋, 黄宏业, 周新民. 湖南沅山花岗岩中锆石 LA-ICPMS U-Pb 定年: 成岩启示及意义[J]. *中国科学(D 辑)*, 2005, 37(7): 606–616.
- DING Xing, CHEN Pei-rong, CHEN Wei-feng, HUANG Hong-ye and ZHOU Xin-min. Zircon LA-ICP-MS U-Pb dating for granite in Weishan, Hunan: the interference and significance of diagenism[J]. *Science in China (Series D)*, 2005, 37(7): 606–616.
- [38] 鲁玉龙, 彭建堂, 阳杰华, 胡阿香, 李玉坤, 谭辉跃, 肖秋越. 湘中紫云山岩体的成因: 锆石 U-Pb 年代学、元素地球化学及 Hf-O 同位素制约[J]. *岩石学报*, 2017, 33(6): 1705–1728.
- LU Yu-long, PENG Jian-tang, YANG Jie-hua, HU A-xiang, LI Yu-kun, TAN Hui-yue, XIAO Qiu-yue. Petrogenesis of the Ziyunshan pluton in central Hunan, South China: Constraints from zircon U-Pb dating, element geochemistry and Hf-O isotopes[J]. *Acta Petrologica Sinica*, 2017, 33(6): 1705–1728.
- [39] 刘凯, 毛建仁, 赵希林, 叶海敏, 胡青. 湖南紫云山岩体的地质地球化学特征及其成因意义[J]. *地质学报*, 2014, 88(2): 208–227.
- LIU Kai, MAO Jian-ren, ZHAO Xi-lin, YE Hai-min and HU Qing. Geological and geochemical characteristics and genetic significance of the Ziyunshan pluton in Hunan Province[J]. *Acta Geologica Sinica*, 2014, 88(2): 208–227.
- [40] WANG Yue-jun, FAN Wei-ming, SUN Min, LIANG Xin-quan, ZHANG Yan-hua and PENG Tou-ping. Geochronological, geochemical and geothermal constraints on petrogenesis of the Indosinian peraluminous granites in the South China block: A case study in the Hunan Province[J]. *Lithos*, 2007, 96: 475–502.
- [41] PENG Bing-xia, WANG Yue-jun, FAN Wei-ming, PENG Tou-ping and LIANG Xin-quan. LA-ICP-MS zircon U-Pb dating for three indosinian granitic plutons from central Hunan and western Guangdong provinces and its petrogenetic implications[J]. *Acta Geologica Sinica*, 2006, 80(5): 660–669.

- [42] 马铁球, 李彬, 陈焰明, 周柯军, 查建章. 湖南南岳岩体 LA-ICP-MS (锆石)U-Pb 年龄及其地球化学特征[J]. 中国地质, 2013, 40(6): 1712-1724.  
MA Tie-qiu, LI Bin, CHEN Yan-ming, ZHOU Ke-jun and CHA Jian-zhang. LA-ICP-MS zircon U-Pb age and geochemical characteristics of Nanyue granites in Hunan Province[J]. Geology in China, 2013, 40(6): 1712-1724.
- [43] 丁兴, 孙卫东, 汪方跃, 陈林丽, 李秋立, 陈福坤. 湖南沅山岩体多期云母的 Rb-Sr 同位素年龄和矿物化学组成及其成岩成矿指示意义[J]. 岩石学报, 2012, 28(12): 3823-3840.  
DING Xing, SUN Wei-dong, WANG Fang-yue, CHEN Lin-li, LI Qiu-li, CHEN Fu-kun. Single-grain mica Rb-Sr isochron ages and mineral chemistry for the Weishan pluton in Hunan Province and implications on petrogenesis and mineralization of Mesozoic composite granite in South China[J]. Acta Petrologica Sinica, 2012, 28(12): 3823-3840.
- [44] 张龙升, 彭建堂, 张东亮, 胡阿香, 阳杰华. 湘西大神山印支期花岗岩的岩石学和地球化学特征[J]. 大地构造与成矿学, 2012, 36(1): 137-148.  
ZHANG Long-sheng, PENG Jian-tang, ZHANG Dong-liang, HU A-xiang and YANG Jie-hua. Geochemistry and petrogenesis of the Indosinian Dashenshan granite, Western Hunan, South China[J]. Geotectonica et Metallogenia, 2012, 36(1): 137-148.
- [45] 陈卫锋, 陈培荣, 丁兴, 孙涛. 湖南白马山岩体花岗岩及其包体的年代学和地球化学研究[J]. 中国科学(D 辑), 2007, 37(7): 873-893.  
CHEN Wei-feng, CHEN Pei-rong, DING Xing, SUN Tao. The geochronology and geochemistry studies on the Baimashan granites, Hunan[J]. Science in China (Series D), 2007, 37(7): 873-893.
- [46] 蔡杨, 陆建军, 马东升, 黄卉, 张怀峰. 湖南邓阜仙印支期二云母花岗岩年代学、地球化学特征及其意义[J]. 岩石学报, 2013, 29(12): 4215-4231.  
CAI Yang, LU Jian-jun, MA Dong-sheng, HUANG Hui and ZHANG Huai-feng. Chronology and geochemical characteristics of late indosinian Dengfuxian two-mica granite in eastern Hunan Province, China, and its significance[J]. Acta Petrologica Sinica, 2013, 29(12): 4215-4231.
- [47] VALLEY J W, KINNEY P D, SCHULZE D J, SPICUZZA M J. Zircon megacrysts from kimberlite: oxygen isotope variability among mantle melts[J]. Contributions to Mineralogy & Petrology, 1998, 133: 1-11.
- [48] 陶继华, 李武显, 李献华, 岑涛. 赣南龙源坝地区燕山期高分异花岗岩年代学、地球化学及锆石 Hf-O 同位素研究[J]. 中国科学(地球科学), 2013, 43(5): 760-778.  
TAO Ji-hua, LI Wu-xian, LI Xian-hua, CEN Tao. Petrogenesis of early Yanshanian highly evolved granites in the Longyuanba area, southern Jiangxi Province: Evidence from zircon U-Pb dating, Hf-O isotope and whole-rock geochemistry[J]. Science China (Earth Sciences), 2013, 56: 760-778.
- [49] 李献华, 李武显, 王选策, 李秋立, 刘宇, 唐国强. 幔源岩浆在南岭燕山早期花岗岩形成中的作用: 锆石原位 Hf-O 同位素制约[J]. 中国科学(地球科学), 2009, 39(7): 872-887.  
LI Xian-hua, LI Wu-xian, WANG Xuan-ce, LI Qiu-li, TANG Guo-qiang. Role of mantle-derived magma in genesis of early Yanshanian granites in the Nanling range, South China: in situ zircon Hf-O isotopic constraints[J]. Science China (Earth Sciences), 2009, 39(7): 872-887.
- [50] 周新民. 对华南花岗岩研究的若干思考[J]. 高校地质学报, 2003, 9(4): 556-565.  
ZHOU Xin-min. My thinking about granite geneses of South China[J]. Geological Journal of China Universities, 2003, 9(4): 556-565.
- [51] 陈卫锋, 陈培荣, 周新民, 黄宏业, 丁兴, 孙涛. 湖南阳明山岩体的 La-ICP-MS 锆石 U-Pb 定年及成因研究[J]. 地质学报, 2006, 80(7): 1065-1077.  
CHEN Wei-feng, CHEN Pei-rong, ZHOU Xin-min, HHUANG Hong-ye DING Xing. Single-zircon La-ICP-MS U-Pb dating of the Yangmingshan granitic pluton in Hunan, South China and its petrogenetic study[J]. Acta Geologica Sinica, 2006, 80(7): 1065-1077.
- [52] 于津海, 王丽娟, 王孝磊, 邱检生, 赵蕾. 赣东南富城杂岩体的地球化学和年代学研究[J]. 岩石学报, 2007, 23(6): 1441-1456.  
YU Jin-hai, WANG Li-juan, WANG Xiao-lei, QIU Jian-sheng and ZHAO Lei. Geochemistry and geochronology of the Fucheng complex in the southeastern Jiangxi province, China[J]. Acta Petrologica Sinica, 2007, 23(6): 1441-1456.
- [53] 郭春丽, 郑佳浩, 楼法生, 曾载淋. 华南印支期花岗岩类的岩石特征、成因类型及其构造动力学背景探讨[J]. 大地构造与成矿学, 2012, 36(3): 457-472.  
GUO Chun-li, ZHANG Jia-hao, LOU Fa-sheng and ZENG Zai-lin. Petrography, genetic types and geological dynamical settings of the Indosinian granitoids in South China[J]. Geotectonica et Metallogenia, 2012, 36(3): 457-472.
- [54] MAO Jian-ren, TAKAHASHI Y, KEE W S, LI Zilong, YE Hai-min, ZHAO Xi-lin, LIU Kai, ZHOU Jie. Characteristics and geodynamic evolution of Indosinian magmatism in South China: A case study of the Guikeng pluton[J]. Lithos, 2011, 127: 535-551.
- [55] MAO Jian-ren, YE Hai-min, LIU Kai, LI Zi-long, TAKAHASHI Y, ZHAO Xi-lin, KEE W S. The Indosinian collision-extension event between the south China block and the palaeo-pacific plate: Evidence from Indosinian alkaline granitic rocks in Dashiung, eastern Zhejiang, South China[J]. Lithos, 2013, 127/173: 81-97.
- [56] LEPVRIER C, MALUSKI H, VAN V N, ROQUES D, AXENTE V, RANGIC C. Indosinian NW-trending shear zones within the Truong Son belt (Vietnam):  $^{40}\text{Ar}/^{39}\text{Ar}$  Triassic ages and Cretaceous to Cenozoic overprints[J]. Tectonophysics, 1997, 238: 105-128.

- [57] NAM T N. Thermotectonic events from early Proterozoic to Miocene in the Indochina craton: implication of K-Ar ages in Vietnam[J]. *Journal of Asian Earth Sciences*, 1998, 16: 475–484.
- [58] CARTER A, ROQUES D, BRISTTOW C. Understanding Mesozoic accretion in southeast Asia: significance of Triassic thermotectonism (Indosinian orogeny) in Vietnam[J]. *Geology*, 2001, 29: 211–214.
- [59] 张伯友, 张海洋, 赵振华, 杨树锋, 陈汉林, 石满全. 两广交界处岑溪二叠纪岛弧型玄武岩及其古特提斯性质的讨论[J]. *南京大学学报(自然科学版)*, 2003, 39(1): 46–54.  
ZHANG Bo-you, ZHANG Hai-yang, ZHAO Zhen-hua, YANG Shu-feng, CHEN Han-lin, SHI Man-quan. Permian Island-arc basalt in West Guangdong and East Guangxi tectonic belt, South China: Implications for the paleotethys[J]. *Journal of Nanjing University (Natural Sciences)*, 2003, 39(1): 46–54
- [60] LIU Xin, LI San-zhong, SUO Yan-hui, LIU Xiao-chun, DAI Li-ming, SANTOSH M. Structural anatomy of the exhumation of high-pressure rocks: Constraints from the Tongbai collisional orogen and surrounding units[J]. *Geological Journal*, 2011, 46: 156–172.
- [61] LI Zheng-xiang and LI Xian-hua. Formation of the 1300-km-wide intracontinental orogen and postorogenic magmatic province in Mesozoic South China: A flat-slab subduction model[J]. *Geology*, 2007, 35: 179–182.
- [62] 刘清泉, 邵拥军, 张智慧, 张宇, 李冰, 张驰. 大别山姚冲花岗岩锆石 U-Pb 年龄、Hf 同位素及地质意义[J]. *中国有色金属学报*, 2015, 25(2): 479–491.  
LIU Qing-quan, SHAO Yong-jun, ZHANG Zhi-hui, ZHANG Yu, LI Bing, ZHANG Chi. Zircon U-Pb ages, Hf isotope characteristics and its implication of granite from Yaochong, Dabie Orogen, China[J]. *The Chinese Journal of Nonferrous Metals*, 2015, 25(2): 479–491.

## Zircon U-Pb ages and Hf-O isotopes of granodiorite -porphyry in Baojinshan mining area and their geological significance

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**Abstract:** Baojinshan gold deposit is Au-dominated polymetallic deposit discovered recently in central Hunan, its mineralization is considered to be closely related to the magmatic activities in late Indosinian. High accuracy SIMS zircon U-Pb age determination was used in this study to obtain the ages of two granodiorite-porphyry dykes at  $(225.1 \pm 1.5)$  Ma and  $(223.3 \pm 1.4)$  Ma, indicating that this deposit was the product of extensive magma activity in late Indosinian. The  $^{176}\text{Hf}/^{177}\text{Hf}$  values of two granodiorite-porphyry dykes intensively distributed around 0.2825, with the corresponding  $\epsilon_{\text{Hf}}(t)$  ranged from  $-5.9$  to  $3$ , averaging  $-3.98$ . The  $T_{\text{DM2}}$  model age was estimated from 0.96 GPa to 1.45 Ga, averaging 1.35 Ga; the  $\delta^{18}\text{O}$  value of granodiorite-porphyry ranged from 0.824% to 0.973%. Hf-O isotope analysis shows that the granodiorite-porphyry is mainly formed by the rock remelting of Mesoproterozoic lower crust, and mantle-sourced materials are considered to participate the diagenesis. Contrastive analysis on the granodiorite-porphyry in Baojinshan with Ziyunshan granite suggests that both of them are the products of comagmatic evolution, which indirectly indicates that the metallogenic time of Baojinshan gold deposit ranges in 227–223 Ma. The granodiorite-porphyry is formed under the multi-plates convergent dynamics background, and affected by the northward squeeze of Indochina Block and westward subduction of Pacific Plate.

**Key words:** SIMS U-Pb zircon dating; Hf-O isotopes tracing; granodiorite-porphyry; Baojinshan gold deposit; central Hunan Province

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