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粤北大宝山铜多金属矿区赋矿地层时代及对矿床成因的指示

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摘要: 广东大宝山铜多金属矿床是中国著名的大型矿床之一, 主要由斑岩型−矽卡岩型钼−钨矿和层状—似层状铜−铅−锌多金属矿组成。矿区内层状—似层状多金属矿的成因一直存在古生代喷流沉积成因或属于侏罗纪斑岩−矽卡岩成矿系统之争, 关键问题之一是赋矿地层的时代及与层状火山岩的关系未得到很好的约束。通过对赋矿地层碎屑锆石进行 LA−ICP−MS U−Pb 测年和 Hf 同位素研究表明, 2 件样品的碎屑锆石最小年龄分别为 430±8 Ma 和 431±4 Ma, 2 件层状火山岩底板碎屑岩中最年轻且谐和的锆石年龄分别为 239±3 Ma 和 189±3 Ma, 将矿区层状—似层状矿体的赋矿地层、层状火山岩底板砂岩的沉积时代分别限定在中泥盆世和早侏罗世。碎屑源区主要为中—新元古代（1200~750 Ma）和早古生代（440~420 Ma）的物质, 并有少量古元古代（2500~1600 Ma）甚至泛非期（650~520 Ma）物质来源, 后者还有少量晚古生代—早中生代（340~210 Ma）物质记录, 它们是华夏地块早期微陆块聚合演化、扬子和华夏地块拼合及其显生宙演化过程的响应。Hf 同位素特征暗示这些物质主要源自再循环的古老地壳物质及元古宙新生地壳。综合分析认为, 矿区赋矿的泥盆纪地层不整合覆盖在志留纪层状火山岩之上, 后被推覆在侏罗纪碎屑岩之上, 层状—似层状矿体先经历了泥盆纪海底喷流沉积成矿作用, 后受到燕山期岩浆热液叠加成矿。

关键词: 赋矿地层; 碎屑锆石; U−Pb 年龄; Hf 同位素; 铜多金属矿; 大宝山; 广东
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Abstract: The Dabaoshan deposit is a large−sized polymetallic deposit in northern Guangdong province, South China, and consists mainly of porphyry− and skarn−type Mo–W mineralization and adjacent stratiform Cu–Pb–Zn mineralization. It has been debated for a long time whether the stratiform Cu–Pb–Zn mineralization is related to a Jurassic porphyry Cu–Mo system, or to a Devonian exhalative event with Jurassic overprinting. One of the key issues is that the depositional age of the ore−hosting strata and petrogenetic

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relationship to the layered volcanic rocks were not well constrained. In this paper, we conducted LA−ICP−MS zircon U−Pb dating and Hf isotope study for the ore−hosting strata in the Dabaoshan deposit. The results show that the youngest ages of detrital zircon from two ore−hosting strata samples yield 430±8 Ma and 431±4 Ma, whereas those from two footwall rocks samples of the layered volcanic rocks yield 239±3 Ma and 189±3 Ma, respectively. It suggests that the depositional age of the ore−hosting strata and footwall rocks of the layered volcanic rocks belongs to the Middle Devonian and the Early Jurassic, respectively. They were mainly derived from Neo− to Meso−proterozoic (1200~750 Ma) and Paleozoic (440~420 Ma) crust with minor input of Paleo−proterozoic (2500~1600 Ma) and Pan−African (650~520 Ma) material. In addition, the footwall rocks include the Late Paleozoic to the Early Mesozoic detrital zircons (340~210 Ma). The Hf isotopic signature suggests that these materials were mainly originated from recycled ancient crust and the Proterozoic juvenile crust. All above mentioned were the response to the early micro−continental evolution of the Cathaysia Block, amalgamation between the Yangtze Craton and the Cathaysia Block and their Phanerozoic evolution. The layered volcanic rocks were unconformable overlaid by the ore−hosting Devonian rocks, and they were both thrusting on the Jurassic clastic rocks. The stratiform Cu−Pb−Zn orebodies were suffering from the Devonian sedimentary exhalative, then overprinted by the Yanshanian magmatic−hydrothermal activity.

Key words: ore−hosting strata; detrital zircon; U−Pb age; Hf isotope; copper polymetallic; Dabaoshan; Guangdong Province

粤北大宝山矿床位于钦杭成矿带中部(图 1−a),是由层状—似层状铜–铅–锌多金属矿、脉状铜–铅–锌矿、层状菱铁矿、斑岩型–矽卡岩型钼–钨矿,以及风化淋滤型褐铁矿组成的大型多金属矿床。该矿床的成因长期存在争议,目前对燕山期斑岩型–矽卡岩型钼–钨矿成因认识趋于一致,但对层状—似层状铜–铅–锌多金属矿成因仍未达成共识,主要有泥盆纪海底喷流沉积成矿(刘孝善等, 1984, 1985; 葛朝华等, 1987; 徐克勤等, 1996; 宋世明等, 2007; Gu et al.,2007)、志留纪火山块状硫化物成矿(伍静等, 2014)和燕山期岩浆热液成因(刘妬群等, 1985; 蔡锦辉等, 1993;祝新友等, 2011; 王磊等, 2012)3 种不同认识。葛朝华等(1987)认为,矿区发育一套泥盆纪含矿火山−沉积建造,其上部为层状—似层状矿体,下部为层状火山岩,层状火山岩底板仍属于该火山−沉积建造。但部分学者认为层状火山岩为燕山期英安岩或英安斑岩(汤吉方等, 1992; 蔡锦辉等 1993)。最近研究表明,矿区层状火山岩属于火山碎屑熔岩类,主要有英安质凝灰熔岩、流纹质凝灰熔岩及角砾熔岩,形成时代为志留纪(伍静等, 2014; Su et al., 2019; Wang et al., 2019)。伍静等(2014)进一步提出矿区层状火山岩与下伏炭质页岩及上部页岩夹灰岩整合接触,同为志留纪地层的一部分,且认为与上覆的层状—似层状矿体有成因联系。而刘武生等(2022)在层状火山岩底板石英砂岩中获得的最年轻碎屑锆石 U−Pb 年龄属于印支期,黑色炭质泥岩样品 Re-Os 等时线年龄为 195±28 Ma。可以看出,造成争议的主要原因之一是赋矿地层的时代及与层状火山岩的关系未得到很好的约束。

本次研究根据层状—似层状矿体的赋矿地层、层状火山岩底板岩石中最年轻碎屑锆石 U−Pb 年龄,重新限定了它们的沉积时代;结合碎屑锆石原位 Hf 同位素数据,分析了赋矿地层和层状火山岩底板岩石的物质来源;综合已有研究资料,探讨了层状—似层状矿体的成因。

1 地质背景

钦杭结合带作为扬子和华夏地块新元古代的拼合带,是华南地区最重要的铜–铅–锌–金–银多金属成矿带,不仅分布有元古宙海底喷流型铜矿床,还有更多与中生代中—酸性花岗岩类有关的铜多金属矿床和钨锡多金属矿床(蒋少涌等, 2008; 毛景文等, 2011; Mao et al., 2013)。发育于该成矿带中部的大宝山矿床位于北东向吴川−四会断裂与近东西向大东山−贵东构造岩浆带的交会部位(图 1−b)。矿区出露地层主要有寒武系高滩组浅变质砂页岩及板岩,中—下泥盆统老虎头组砂岩及砂砾岩,中泥盆统棋梓桥组下段砂泥质碳酸盐岩沉积、上段中酸性火山碎屑沉积岩,上泥盆统天子岭组灰岩,下侏罗统金鸡组砂页岩。断裂主要有近东西向船肚−大宝山断裂,北东—南北向九曲岭断裂和徐屋断裂及北北西向大宝山断裂和丘坝断裂(图 1−c)。矿区内岩浆活动较强烈,主要有大宝山花岗闪长斑岩和船肚花岗闪长岩,大宝山、九曲岭、丘坝及徐屋英安岩,其中,大宝山和九曲岭英安岩呈岩墙产出,即矿区的层状火山岩。花岗闪长(斑)岩高精度锆石 U−Pb 年龄为 175~160 Ma

(王磊等, 2010; Wang et al., 2011; Li et al., 2012a; 刘莎等, 2012; Mao et al., 2013; 何国朝等, 2016), 英安岩高精度锆石 U-Pb 年龄介于 450~426 Ma 之间(毛伟等, 2013; 潘会彬等, 2014; 伍静等, 2014; 傅晓明等, 2016; Su et al., 2019; Wang et al., 2019)。此外, 矿区还出露少量的辉绿岩脉和玄武岩脉, 形成时代为

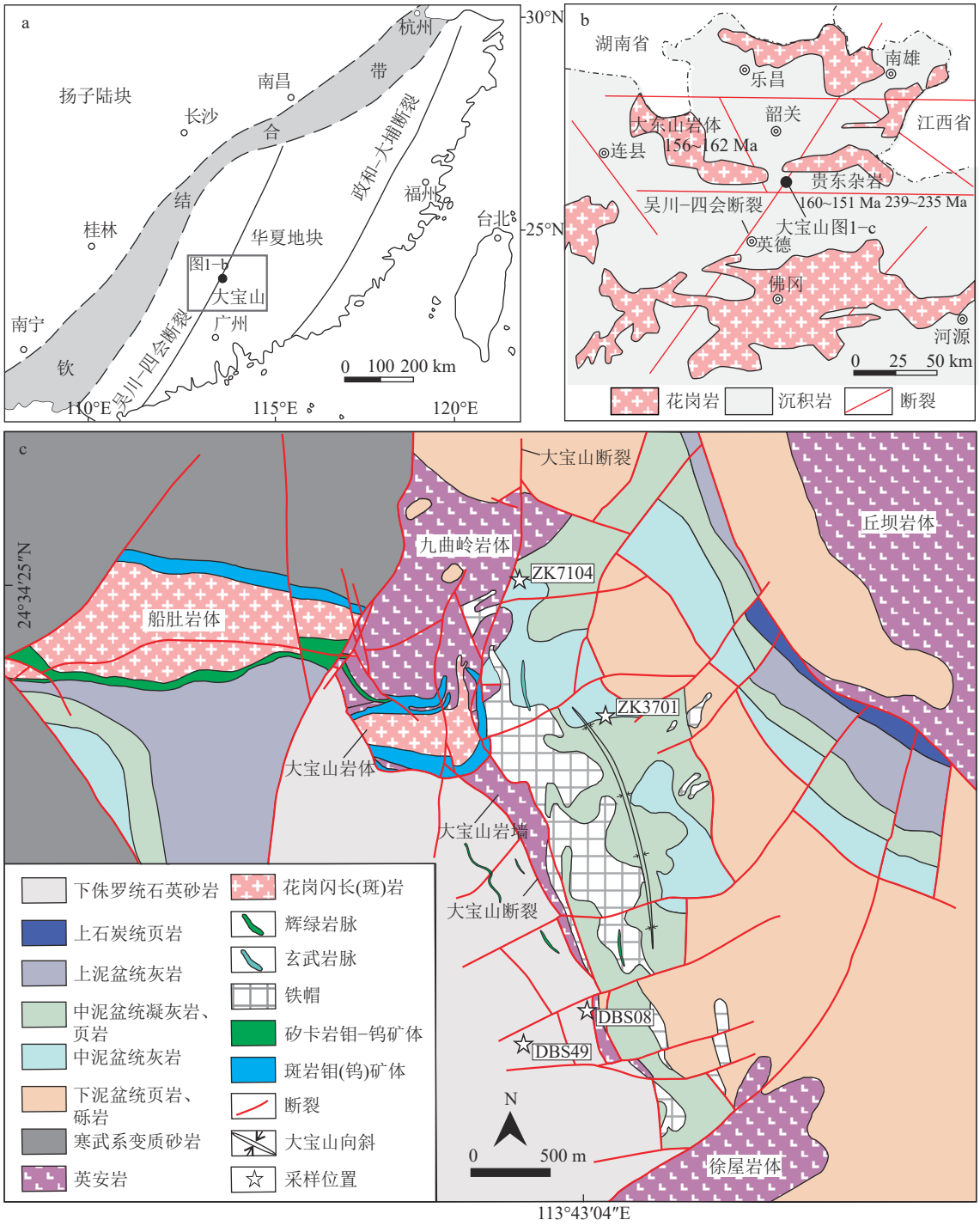


图 1　华南大地构造略图(a, 据 Gu et al., 2007; 毛景文等, 2011)、粤北区域地质简图(b, 据葛朝华等, 1987)和大宝山矿床地质图(c, 据 Wang et al., 2019)

Fig. 1　Simplified tectonic map of South China (a), regional geological map of North Guangdong Province (b) and geological map of the Dabaoshan deposit (c)

燕山期和/或印支期(毛伟等, 2013; Wang et al., 2019)。

大宝山矿床的矿体产出特征及成因类型多样。其中, 斑岩型钼(钨)矿体主要围绕大宝山花岗闪长斑岩体呈环形分布或沿船肚花岗闪长岩体北接触带分布, 而矽卡岩型钼–钨矿体则分布在船肚花岗闪长岩体南侧呈东西向产出(图 1–c)。这 2 类矿体代表性的矿石矿物主要为辉钼矿、白钨矿、辉铋矿和黄铁矿。层状—似层状铜–铅–锌多金属矿体主要赋存于中泥盆世棋梓桥组碳酸盐岩地层中, 呈层状、似层状、透镜状和脉状分布, 矿石矿物主要为黄铜矿、黄铁矿、磁黄铁矿、方铅矿和闪锌矿。层状—似层状矿体上部的晚泥盆世碎屑岩中发育似层状、透镜状菱铁矿体, 顶部为风化淋滤而成的褐铁矿(图 2)(刘妬群等, 1985; 汤吉方等, 1992; 蔡锦辉等, 1993; 王磊等, 2012)。此外, 层状火山岩底板中发育少量脉状铜–铅–锌矿体。

2 样品采集及测试

本次研究中, 共采集 4 件样品用于碎屑锆石 U–Pb 定年及原位 Hf 同位素分析(图 1–c)。其中, 2 件层状火山岩底板岩石样品(以往划为下侏罗统金鸡组)采自矿区南采场及其外围, 岩性为细粒石英砂岩(样品 DBS08 和 DBS49, 图版 Ⅰ–a~c, e)。2 件层状—似层状矿体的赋矿地层样品(以往划为中—下泥盆统棋子桥组和老虎头组)分别采自钻孔

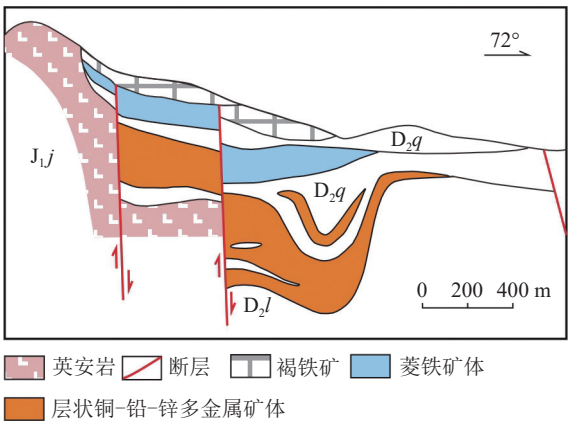


图 2 大宝山矿床勘探线 27 线剖面图(据庄明正, 1986 修改)

Fig. 2 Cross-section map along Exploration Line No. 27 at the Dabaoshan deposit

J_1j—下侏罗统金鸡组; D_2q—中泥盆统棋子桥组; D_2l—中泥盆统老虎头组

ZK7104 岩心 476.5~477.5 m 处和钻孔 ZK3701 岩心 538~540 m 处(图 3), 岩性分别为石英粉砂细砂岩和石英细砂质砾岩(图版 Ⅰ–d, f~h)。

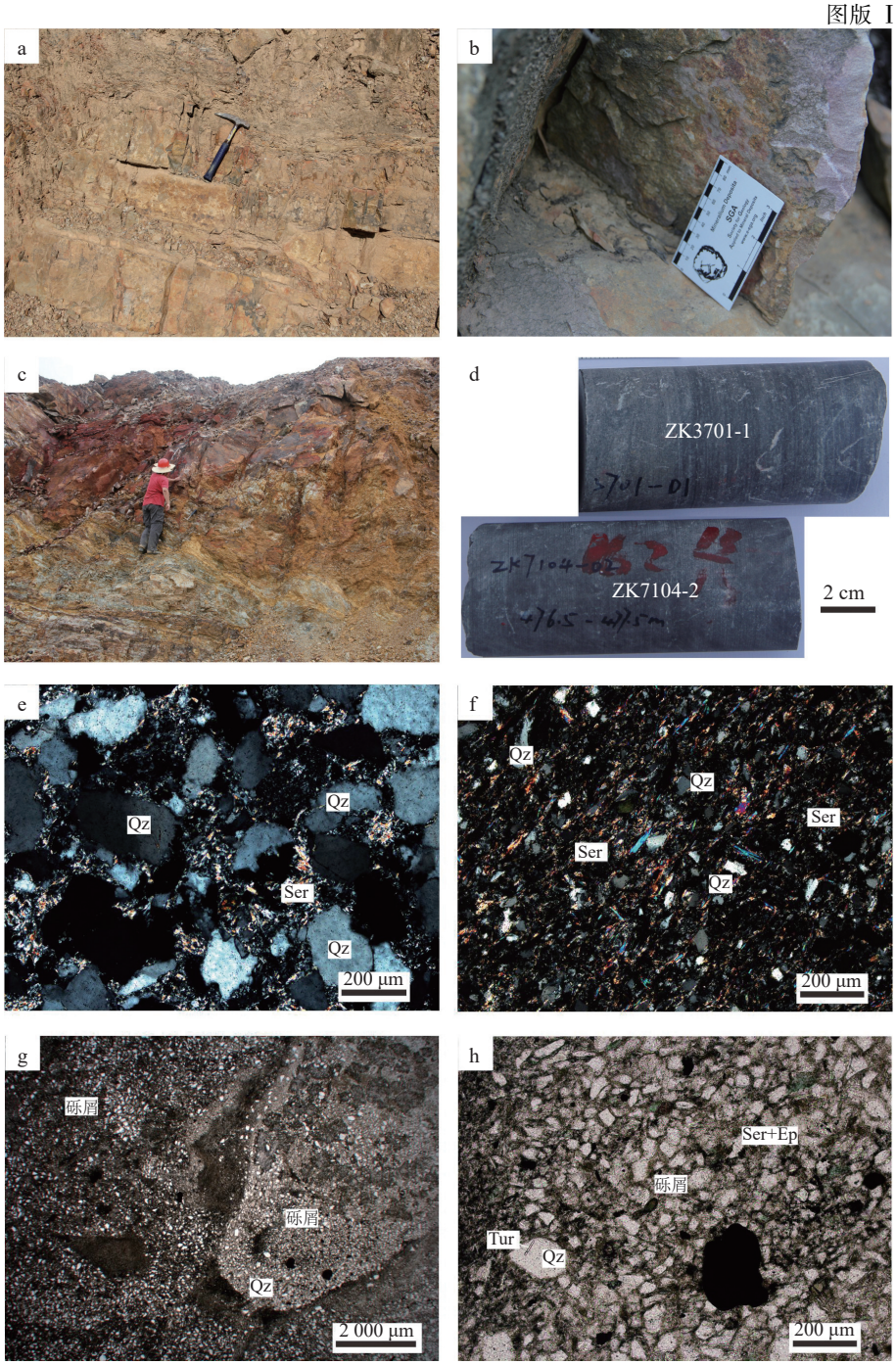
锆石在河北省廊坊市宇能岩石矿物分选技术服务公司完成分选后, 送武汉上谱科技有限公司进行制靶、透射、反射光拍照及阴极发光(CL)照相, 在中国地质大学(武汉)地质过程与矿产资源国家重点实验室(GPMR)利用激光剥蚀电感耦合等离子质谱仪(LA–ICP–MS)进行 U-Th-Pb 同位素分析。激光剥蚀系统为 GeoLas 2005, ICP-MS 为 Agilent 7500a。U–Pb 同位素定年中剥蚀束斑直径为 32 μm; 采用锆石标准 91500 作外标进行同位素分馏校正。分析数据的离线处理采用软件 ICPMSDataCal 完成(Liu et al.,2008, 2010a)。详细的仪器操作条件和数据处理方法同 Liu et al.(2008, 2010a, b)。锆石 U–Pb 年龄计算及谐和图绘制采用 Isoplot ver4.13 软件(Ludwig, 2003)。

锆石 Lu-Hf 同位素分析在中国地质调查局武汉地质调查中心完成, 仪器为配备 Resolution 193nm ArF 准分子激光剥蚀系统与 Neptune plus 型 MC-ICP-MS 联机系统。样品 DBS49 的剥蚀束斑直径为 29 μm, 其余样品为 43 μm, 分析点位于 U–Pb 年龄测试点附近。剥蚀时间为 60 s, 激光频率为 6 Hz, 激光能量密度为 4 J/cm^2。测定时采用锆石 91500 和 Plesovice 作为标样。^{176}Lu 对^{176}Hf 的干扰采用 ^{176}Lu/^{175}Hf=0.02656 进行校正(Blichert-toft et al., 1997)。^{176}Yb 对^{176}Hf 的干扰采用实施无干扰^{173}Yb 进行校正, 同时设定^{176}Yb/^{173}Yb 值为 0.78696 来进行计算(Thirlwall et al., 2004)。锆石 Hf 同位素原始数据采用 ICPMSDataCal 软件进行处理(Liu et al., 2008)。

3 分析结果

4 件样品中分选出的锆石颗粒自形程度较好, 多为长柱状、短柱状或椭圆状, 粒径小于 250 μm, 长宽比 3∶1~1∶1, 有明显的韵律环带; 少数呈板状, 发育宽缓环带或无明显环带(图 4); Th/U 值集中于 0.01~4.17 之间, 其中约 98% 锆石颗粒的 Th/U>0.1(表 1; 图 5), 且这些锆石 CL 图像均显示出明显的振荡环带, 表明其主要为岩浆锆石(Hoskin et al., 2003; 吴元保等, 2004)。本次随机挑选 328 颗锆石进行 U–Pb 年龄测试, 并对谐和度大于 93% 的

图版 Ⅰ　Plate Ⅰ



a,b.野外露头, 细粒石英砂岩 (DBS49); c.野外露头, 细粒石英砂岩 (DBS08); d. 钻孔 ZK7104 岩心, 石英粉砂–细砂岩 (ZK7104-2), 以及钻孔 ZK3701 岩心, 石英细砂质砾岩 (ZK3701-1); e.正交偏光显微镜下, 细粒石英砂岩 (DBS08); f. 正交偏光显微镜下, 石英粉砂细砂岩 (ZK7104-2); g,h.单偏光显微镜下, 石英细砂质砾岩 (ZK3701-1)。Qz—石英; Ser—绢云母; Ep—绿帘石; Tur—电气石

285 颗锆石进行原位 Hf 同位素分析(表 2), 少数年龄谐和但因锆石粒径较小未进行 Hf 同位素分析。

对样品 ZK7104-2(石英粉砂细砂岩)中 70 颗锆石的 70 个点进行 U–Pb 测年, 得到 66 个谐和年龄, 年龄范围为 2502~430 Ma(图 6–a、图 7–a)。碎屑锆石年龄主要集中于 443~430 Ma(17 个)、1461~720 Ma(34 个)和 1914~1606 Ma(9 个)之间, 主要峰值年龄为 438 Ma, 次要峰值年龄为 989 Ma、830 Ma 和 767 Ma; 2 颗最老的锆石年龄约 2500 Ma, 还有 4 颗锆石年龄为 627~527 Ma。17 颗最年轻且谐和的锆石 $^{206}Pb/^{238}U$ 年龄加权平均值为 438.1±2.3 Ma (MSWD=0.37)。对该样品 62 个谐和年龄点进行了

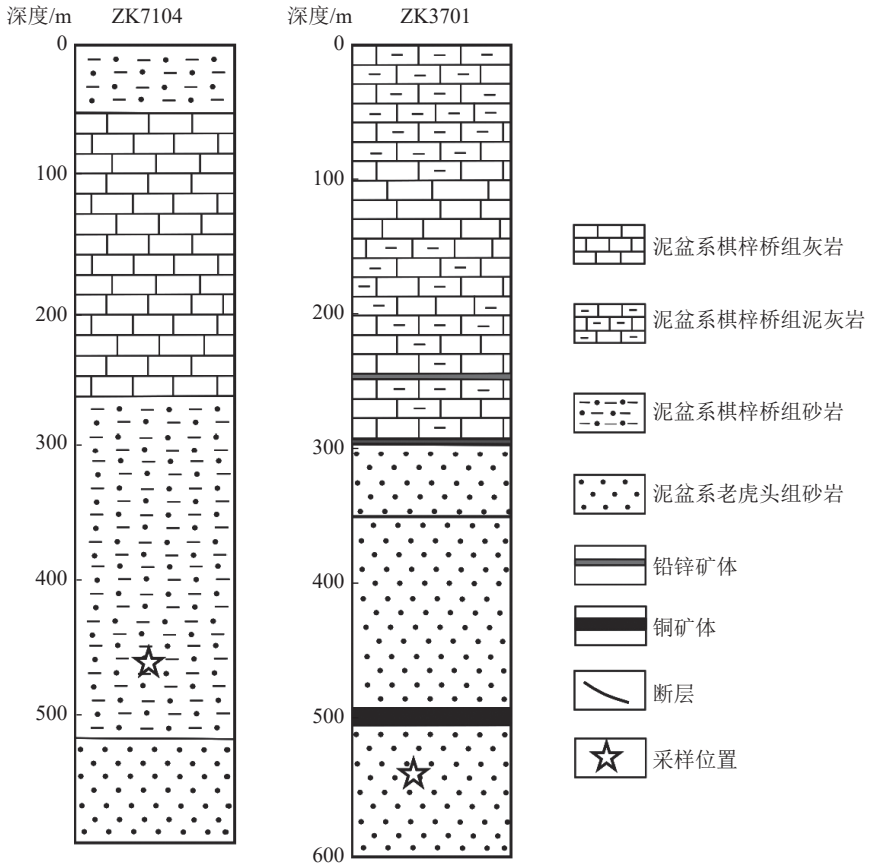


图 3 大宝山矿床钻孔 ZK7104 和 ZK3701 剖面图(据广东省地质局第三地质大队, 2016 修改)

Fig. 3 Sections of drill holes ZK7104 and ZK3701 in the Dabaoshan deposit

原位 Hf 同位素分析, $\varepsilon_{Hf}(t)$ 值为−51.8~+12.8, 单阶段模式年龄(T_{DM1})为 3178~1034 Ma, 二阶段模式年龄(T_{DM2})为 4223~1111 Ma。

对样品 ZK3701-1(石英细砂质砾岩)中 64 颗锆石的 65 个点进行 U−Pb 测年, 得到 63 个谐和年龄, 年龄范围为 2654~431 Ma(图 6–b、图 7–b)。碎屑锆石年龄主要集中于 442~431 Ma(16 个)、1431~738 Ma(33 个)和 2654~2102 Ma(8 个)之间, 主要峰值年龄为 439 Ma, 次要峰值年龄为 953 Ma 和 750 Ma。还有 4 颗锆石年龄为 665~553 Ma, 2 颗锆石年龄分别为 1544 Ma 和 1577 Ma。16 颗最年轻且谐和的锆石 $^{206}Pb/^{238}U$ 年龄加权平均值为 438.5±2.2 Ma (MSWD=0.65)。对该样品 63 个谐和年龄点进行了 51 个原位 Hf 同位素分析, $\varepsilon_{Hf}(t)$ 值为−40.4~+14.0, 单阶段模式年龄(T_{DM1})为 3254~828 Ma, 二阶段模式年龄(T_{DM2})为 3905~839 Ma。

对样品 DBS49(细粒石英砂岩)中 116 颗锆石的 116 个点进行 U−Pb 测年, 得到 103 个谐和年龄, 年龄范围为 3016~239 Ma(图 6–c、图 7–c)。碎屑锆石年龄主要集中于 389~261 Ma(10 个)、469~422 Ma(18 个)、705~518 Ma(10 个)、1587~735 Ma(39 个)和 2502~1726 Ma(19 个), 主要峰值年龄为 437 Ma、968 Ma 和 262 Ma; 最老的 4 颗锆石年龄为 2698~3016 Ma, 3 颗锆石年龄为 1587~1561 Ma, 最年轻且谐和的 1 颗锆石年龄为 239 Ma。对该样品 103 个谐和年龄点进行了原位 Hf 同位素分析, $\varepsilon_{Hf}(t)$ 值为−26.9~+14.0, 单阶段模式年龄(T_{DM1})为 3560~382 Ma, 二阶段模式年龄(T_{DM2})为 4118~410 Ma。

对样品 DBS08(细粒石英砂岩)中 77 颗锆石的 77 个点进行 U−Pb 测年, 得到 69 个谐和年龄, 年龄范围为 3059~189 Ma(图 6–d、图 7–d)。碎屑锆石年龄主要集中于 329~251 Ma(9 个)、444~429 Ma (14 个)、902~734 Ma(17 个)和 2535~1789 Ma (27 个), 主要峰值年龄为 435 Ma 和 262 Ma。最老的 2 颗锆石年龄为 2665 Ma 和 3059 Ma, 最年轻且谐和的 3 颗锆石年龄为 189 Ma、214 Ma 和 226 Ma。

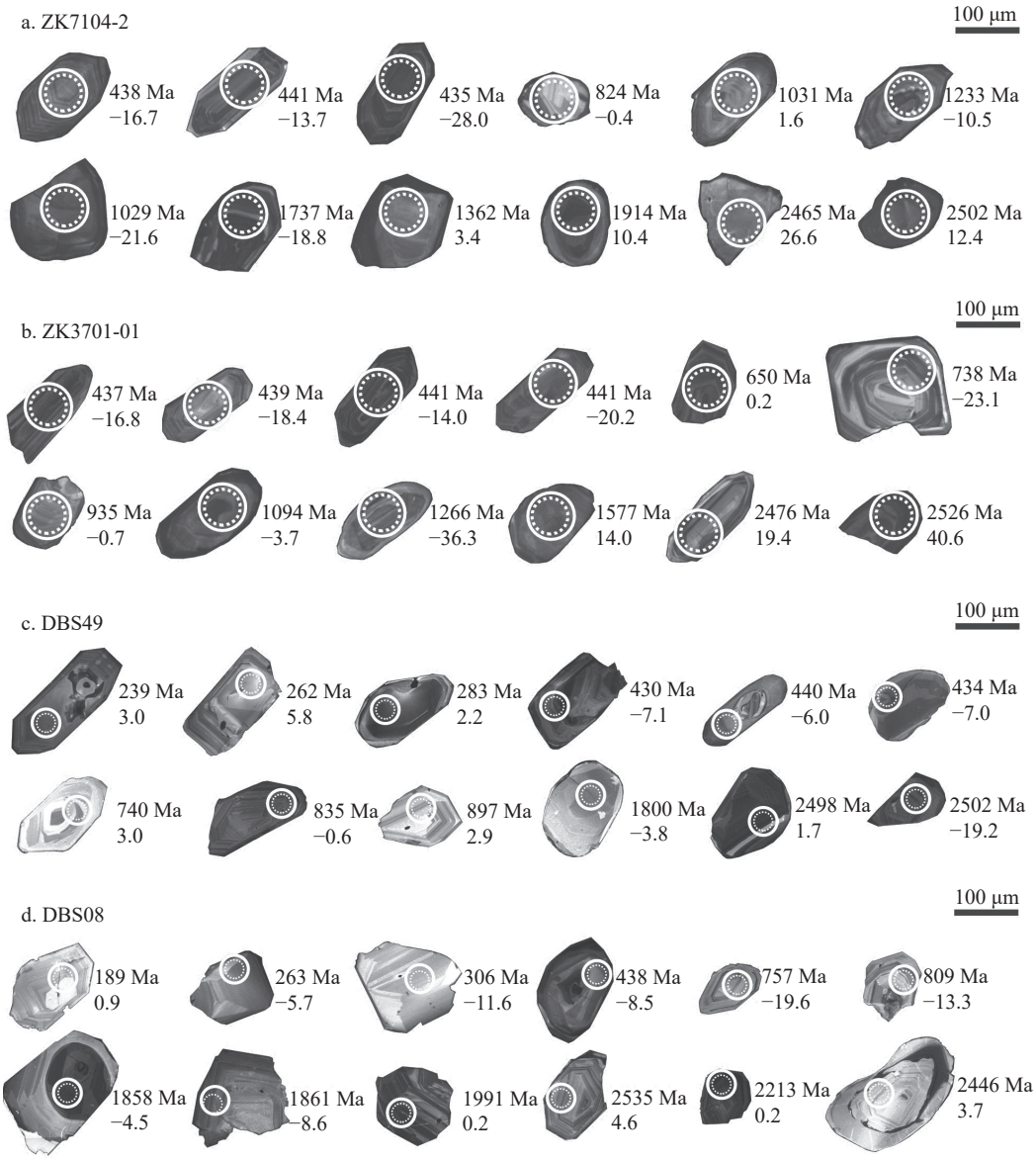


图 4　大宝山矿床赋矿地层样品中典型锆石阴极发光图像(实线圈代表 U−Pb 同位素测试点位; 虚线圈代表 Lu−Hf 同位素分析点位)

Fig. 4　Representative zircon cathodoluminescence images from the ore-hosting strata samples in the Dabaoshan deposit

对该样品 69 个谐和年龄点进行原位 Hf 同位素分析, $\varepsilon_{Hf}(t)$ 值为−23.5~+5.5, 单阶段模式年龄(T_{DM1})为 3524~772 Ma, 二阶段模式年龄(T_{DM2})为 3849~973 Ma。

4　讨　论

4.1　沉积时代

通过区域地层对比研究, 前人将大宝山矿区内层状—似层状矿体赋矿地层的形成时代划归为中泥盆世(刘孝善等, 1984)。然而, 其确切的时代仍缺乏精确的厘定。伍静等(2014)认为, 矿区志留纪层状火山岩与下伏炭质页岩及上部页岩夹灰岩整合接触。刘武生等(2022)获得的层状火山岩底板石英砂岩中最年轻碎屑锆石年龄为 236±4.8 Ma 和 247±4.9 Ma, 6 件黑色炭质泥岩样品 Re-Os 等时线年龄为 195±28 Ma, 认为其形成时代为早侏罗世。

本次在矿区层状—似层状矿体赋矿地层中采集 2 件石英粉砂细砂岩、石英细砂质砾岩样品用于碎屑锆石 U−Pb 年龄分析, 最年轻且谐和的锆石年龄加权平均值分别为 438.1±2.3 Ma 和 438.5±2.2 Ma, 限定了赋矿地层沉积时代的下限。样品中最年轻碎屑锆石 U−Pb 年龄及年龄谱系特征(图 7), 与前人对区

表 1 大宝山矿床赋矿地层 LA−ICP−MS 碎屑锆石 U−Pb 年龄分析结果

Table 1 LA−ICP−MS detrital zircon U−Pb dating results from the ore-hosting strata samples in the Dabaoshan deposit

序号	元素含量/10^{-6}			Th/U	同位素比值						年龄/Ma						谐和度
	Pb	Th	U		$^{207}Pb/^{206}Pb$	1σ	$^{207}Pb/^{235}U$	1σ	$^{206}Pb/^{238}U$	1σ	$^{207}Pb/^{206}Pb$	1σ	$^{207}Pb/^{235}U$	1σ	$^{206}Pb/^{238}U$	1σ	
ZK7104-2																	
1	427	1291	2027	0.64	0.0531	0.0028	0.5118	0.0423	0.0690	0.0013	345	120	420	28	430	8	97%
2	88	242	436	0.55	0.0554	0.0017	0.5391	0.0159	0.0699	0.0007	428	64	438	10	435	4	99%
3	206	603	998	0.60	0.0560	0.0014	0.5464	0.0134	0.0699	0.0007	450	56	443	9	435	4	98%
4	124	412	432	0.95	0.0549	0.0015	0.5337	0.0142	0.0700	0.0008	409	66	434	9	436	5	99%
5	33	103	117	0.88	0.0564	0.0026	0.5463	0.0259	0.0700	0.0010	478	104	443	17	436	6	98%
6	199	562	1151	0.49	0.0543	0.0015	0.5317	0.0145	0.0700	0.0007	383	68	433	10	436	4	99%
7	118	372	373	1.00	0.0581	0.0020	0.5643	0.0201	0.0701	0.0009	532	74	454	13	437	5	96%
8	119	396	292	1.36	0.0589	0.0021	0.5719	0.0202	0.0701	0.0008	561	80	459	13	437	5	94%
9	104	291	532	0.55	0.0573	0.0016	0.5570	0.0166	0.0701	0.0007	502	61	450	11	437	4	97%
10	405	1276	1208	1.06	0.0564	0.0012	0.5513	0.0119	0.0702	0.0007	478	44	446	8	438	4	98%
11	59	187	230	0.81	0.0537	0.0022	0.5237	0.0213	0.0704	0.0008	367	97	428	14	438	5	97%
12	92	251	463	0.54	0.0591	0.0015	0.5775	0.0141	0.0707	0.0007	572	58	463	9	441	4	95%
13	61	185	288	0.64	0.0568	0.0019	0.5570	0.0181	0.0708	0.0009	483	79	450	12	441	6	98%
14	129	385	488	0.79	0.0560	0.0016	0.5486	0.0158	0.0709	0.0008	450	67	444	10	441	5	99%
15	197	578	748	0.77	0.0581	0.0014	0.5709	0.0137	0.0709	0.0007	532	52	459	9	442	4	96%
16	93	261	429	0.61	0.0568	0.0017	0.5561	0.0161	0.0710	0.0008	483	67	449	11	442	5	98%
17	29	82	138	0.60	0.0585	0.0027	0.5729	0.0285	0.0712	0.0011	546	106	460	18	443	7	96%
18	431	1232	535	2.30	0.0574	0.0015	0.6800	0.0174	0.0852	0.0007	509	57	527	11	527	4	99%
19	78	212	51	4.17	0.0583	0.0035	0.7332	0.0431	0.0921	0.0014	543	164	558	25	568	8	98%
20	163	363	383	0.95	0.0606	0.0016	0.8018	0.0220	0.0957	0.0010	633	57	598	12	589	6	98%
21	111	163	633	0.26	0.0609	0.0013	0.8650	0.0188	0.1022	0.0009	635	44	633	10	627	6	99%
22	124	186	504	0.37	0.0647	0.0015	1.0553	0.0250	0.1181	0.0010	765	48	731	12	720	6	98%
23	107	196	192	1.02	0.0621	0.0019	1.0336	0.0305	0.1201	0.0013	676	65	721	15	731	7	98%
24	129	225	276	0.82	0.0666	0.0019	1.1209	0.0326	0.1213	0.0013	828	57	763	16	738	8	96%
25	536	1014	598	1.70	0.0642	0.0013	1.1199	0.0235	0.1261	0.0011	748	44	763	11	765	6	99%
26	131	150	624	0.24	0.0631	0.0015	1.1119	0.0250	0.1262	0.0009	709	49	759	12	766	5	99%
27	114	198	254	0.78	0.0625	0.0018	1.1040	0.0314	0.1265	0.0014	700	59	755	15	768	8	98%
28	56	91	159	0.57	0.0651	0.0022	1.1608	0.0382	0.1284	0.0017	776	75	782	18	779	9	99%
29	43	66	69	0.96	0.0713	0.0031	1.3243	0.0541	0.1363	0.0019	965	88	856	24	824	11	96%
30	1789	3162	2164	1.46	0.0748	0.0017	1.4166	0.0329	0.1369	0.0012	1065	46	896	14	827	7	92%
31	34	58	42	1.39	0.0692	0.0038	1.2774	0.0718	0.1375	0.0025	903	114	836	32	830	14	99%
32	125	144	506	0.29	0.0681	0.0016	1.2975	0.0307	0.1377	0.0011	870	49	845	14	832	7	98%
33	301	465	592	0.79	0.0661	0.0013	1.2658	0.0243	0.1378	0.0011	809	41	831	11	832	6	99%
34	143	216	354	0.61	0.0668	0.0017	1.2822	0.0308	0.1378	0.0013	831	47	838	14	832	8	99%
35	325	420	802	0.52	0.0727	0.0017	1.4001	0.0340	0.1384	0.0021	1006	42	889	14	835	12	93%
36	126	213	251	0.85	0.0651	0.0017	1.2566	0.0318	0.1386	0.0014	789	54	826	14	837	8	98%
37	161	205	471	0.44	0.0702	0.0014	1.3828	0.0290	0.1422	0.0012	1000	38	882	12	857	7	97%
38	336	427	938	0.46	0.0780	0.0014	1.6126	0.0295	0.1486	0.0013	1147	36	975	11	893	7	91%
39	57	64	128	0.50	0.0776	0.0028	1.6737	0.0685	0.1542	0.0018	1144	72	999	26	925	10	92%
40	89	91	383	0.24	0.0811	0.0018	1.7577	0.0438	0.1565	0.0020	1233	38	1030	16	937	11	90%
41	257	249	923	0.27	0.0715	0.0013	1.6337	0.0312	0.1646	0.0017	972	5	983	12	982	9	99%

续表 1-1

序号	元素含量/10^{-6}			Th/U	同位素比值						年龄/Ma						谐和度
	Pb	Th	U		$^{207}Pb/^{206}Pb$	1σ	$^{207}Pb/^{235}U$	1σ	$^{206}Pb/^{238}U$	1σ	$^{207}Pb/^{206}Pb$	1σ	$^{207}Pb/^{235}U$	1σ	$^{206}Pb/^{238}U$	1σ	
42	145	177	337	0.53	0.0735	0.0015	1.6816	0.0373	0.1648	0.0016	1029	43	1002	14	983	9	98%
43	186	236	384	0.62	0.0698	0.0014	1.5995	0.0347	0.1648	0.0017	924	43	970	14	984	9	98%
44	304	350	732	0.48	0.0712	0.0018	1.6490	0.0395	0.1659	0.0017	963	45	989	15	989	10	99%
45	135	186	227	0.82	0.0716	0.0017	1.6537	0.0403	0.1672	0.0018	976	53	991	15	997	10	99%
46	382	548	480	1.14	0.0711	0.0017	1.6485	0.0407	0.1676	0.0016	961	50	989	16	999	9	99%
47	241	260	609	0.43	0.0726	0.0014	1.6935	0.0352	0.1684	0.0015	1006	39	1006	13	1003	8	99%
48	90	110	152	0.73	0.0730	0.0021	1.6948	0.0496	0.1686	0.0017	1013	59	1007	19	1004	10	99%
49	95	119	185	0.64	0.0725	0.0019	1.7558	0.0479	0.1744	0.0023	1011	53	1029	18	1036	13	99%
50	322	368	727	0.51	0.0752	0.0017	1.9046	0.0417	0.1811	0.0015	1076	46	1083	15	1073	8	99%
51	258	307	383	0.80	0.0752	0.0015	1.9429	0.0394	0.1869	0.0021	1072	45	1096	14	1104	12	99%
52	136	157	188	0.83	0.0760	0.0019	2.0084	0.0507	0.1906	0.0023	1094	44	1118	17	1125	12	99%
53	149	174	165	1.05	0.0805	0.0021	2.1625	0.0551	0.1949	0.0021	1209	50	1169	18	1148	11	98%
54	740	973	448	2.17	0.0770	0.0016	2.1465	0.0467	0.2008	0.0022	1120	41	1164	15	1180	12	98%
55	365	355	545	0.65	0.0819	0.0015	2.3536	0.0480	0.2070	0.0021	1244	36	1229	15	1213	11	98%
56	151	161	178	0.90	0.0831	0.0019	2.3926	0.0583	0.2077	0.0019	1272	42	1240	17	1216	10	98%
57	208	118	501	0.24	0.0876	0.0019	2.8709	0.0632	0.2358	0.0028	1373	42	1374	17	1365	14	99%
58	137	110	250	0.44	0.0871	0.0019	2.8954	0.0635	0.2382	0.0024	1362	41	1381	17	1377	13	99%
59	136	116	137	0.84	0.0917	0.0030	3.1060	0.0946	0.2437	0.0024	1461	61	1434	23	1406	13	98%
60	219	180	191	0.94	0.0990	0.0023	3.8348	0.0922	0.2804	0.0031	1606	44	1600	19	1593	15	99%
61	1709	1468	971	1.51	0.1010	0.0017	3.9282	0.0719	0.2809	0.0026	1643	30	1620	15	1596	13	98%
62	404	264	520	0.51	0.1050	0.0021	4.2187	0.0850	0.2884	0.0028	1715	37	1678	17	1633	14	97%
63	152	61	405	0.15	0.1050	0.0022	4.3757	0.0978	0.3000	0.0034	1714	38	1708	19	1691	17	99%
64	100	78	55	1.42	0.1115	0.0033	4.7574	0.1397	0.3098	0.0035	1824	54	1777	25	1740	17	97%
65	212	120	306	0.39	0.1127	0.0022	5.0789	0.1008	0.3226	0.0028	1843	37	1833	17	1802	14	98%
66	311	228	212	1.08	0.1089	0.0023	4.8695	0.1067	0.3228	0.0028	1783	39	1797	19	1803	14	99%
67	332	159	549	0.29	0.1172	0.0025	5.3427	0.1086	0.3263	0.0025	1914	39	1876	17	1821	12	97%
68	196	55	481	0.11	0.1154	0.0023	5.3134	0.1043	0.3299	0.0029	1887	36	1871	17	1838	14	98%
69	218	116	66	1.75	0.1643	0.0038	10.5093	0.2503	0.4592	0.0054	2502	39	2481	22	2436	24	98%
70	315	153	153	0.99	0.1608	0.0032	10.4041	0.2084	0.4669	0.0043	2465	33	2471	19	2470	19	99%
ZK3701-1																	
1	127	419	415	1.01	0.0571	0.0020	0.5466	0.0183	0.0692	0.0006	498	76	443	12	431	4	97%
2	114	392	376	1.04	0.0564	0.0019	0.5430	0.0179	0.0693	0.0007	478	72	440	12	432	4	98%
3	57	161	309	0.52	0.0573	0.0021	0.5544	0.0209	0.0698	0.0009	502	84	448	14	435	5	97%
4	116	355	592	0.60	0.0543	0.0018	0.5295	0.0179	0.0702	0.0007	383	76	431	12	437	4	98%
5	138	400	561	0.71	0.0569	0.0023	0.5504	0.0213	0.0702	0.0008	487	91	445	14	437	5	98%
6	60	183	280	0.66	0.0613	0.0022	0.6024	0.0213	0.0704	0.0007	650	76	479	14	439	4	91%
7	221	666	1112	0.60	0.0574	0.0017	0.5605	0.0166	0.0704	0.0007	506	65	452	11	439	4	97%
8	71	225	288	0.78	0.0581	0.0027	0.5599	0.0239	0.0705	0.0009	532	102	451	16	439	5	97%
9	148	512	438	1.17	0.0557	0.0018	0.5446	0.0173	0.0706	0.0006	439	70	441	11	440	4	99%
10	141	469	501	0.94	0.0550	0.0017	0.5372	0.0166	0.0707	0.0009	413	69	437	11	440	5	99%
11	90	287	327	0.88	0.0577	0.0022	0.5606	0.0212	0.0708	0.0009	520	90	452	14	441	6	97%
12	178	544	813	0.67	0.0553	0.0013	0.5417	0.0138	0.0708	0.0008	433	54	440	9	441	5	99%
13	86	255	389	0.66	0.0552	0.0018	0.5416	0.0178	0.0708	0.0008	420	77	439	12	441	5	99%

续表 1-2

序号	元素含量/10^{-6}			Th/U	同位素比值						年龄/Ma						谐和度
	Pb	Th	U		$^{207}Pb/^{206}Pb$	1σ	$^{207}Pb/^{235}U$	1σ	$^{206}Pb/^{238}U$	1σ	$^{207}Pb/^{206}Pb$	1σ	$^{207}Pb/^{235}U$	1σ	$^{206}Pb/^{238}U$	1σ	
14	54	162	318	0.51	0.0566	0.0023	0.5536	0.0223	0.0708	0.0009	476	87	447	15	441	5	98%
15	60	165	341	0.48	0.0572	0.0020	0.5610	0.0185	0.0709	0.0008	502	71	452	12	442	5	97%
16	109	334	521	0.64	0.0576	0.0021	0.5653	0.0207	0.0710	0.0007	522	81	455	13	442	4	97%
17	126	383	406	0.94	0.0569	0.0021	0.5656	0.0220	0.0710	0.0008	487	80	455	14	442	5	97%
18	137	299	622	0.48	0.0598	0.0016	0.7420	0.0196	0.0896	0.0008	594	26	564	11	553	5	98%
19	789	2418	642	3.77	0.0603	0.0018	0.7864	0.0232	0.0936	0.0008	613	63	589	13	577	5	97%
20	83	75	818	0.09	0.0593	0.0016	0.8822	0.0287	0.1062	0.0020	589	61	642	15	650	12	98%
21	191	417	462	0.90	0.0639	0.0020	0.9632	0.0305	0.1087	0.0011	737	233	685	16	665	7	97%
22	82	158	162	0.98	0.0705	0.0028	1.1778	0.0466	0.1213	0.0016	943	81	790	22	738	9	93%
23	171	322	446	0.72	0.0661	0.0016	1.1114	0.0280	0.1216	0.0013	809	47	759	13	740	8	97%
24	178	339	370	0.92	0.0640	0.0019	1.1011	0.0313	0.1237	0.0011	743	62	754	15	752	7	99%
25	34	67	35.9	1.88	0.0717	0.0057	1.2027	0.0882	0.1243	0.0024	976	162	802	41	755	14	94%
26	430	678	745	0.91	0.0647	0.0014	1.1288	0.0329	0.1246	0.0022	765	46	767	16	757	12	98%
27	156	282	217	1.30	0.0696	0.0027	1.2234	0.0463	0.1274	0.0014	917	80	811	21	773	8	95%
28	131	199	486	0.41	0.0646	0.0016	1.1512	0.0291	0.1283	0.0012	763	52	778	14	778	7	99%
29	107	137	507	0.27	0.0688	0.0019	1.2548	0.0335	0.1314	0.0011	894	56	826	15	796	6	96%
30	446	801	698	1.15	0.0658	0.0017	1.2479	0.0305	0.1359	0.0013	798	52	822	14	822	7	99%
31	106	186	199	0.94	0.0677	0.0019	1.2977	0.0377	0.1384	0.0017	861	142	845	17	835	10	98%
32	270	397	778	0.51	0.0700	0.0018	1.4043	0.0353	0.1448	0.0016	928	56	891	15	872	9	97%
33	126	200	172	1.16	0.0719	0.0024	1.5542	0.0532	0.1560	0.0018	983	68	952	21	935	10	98%
34	516	666	1376	0.48	0.0788	0.0017	1.7331	0.0405	0.1581	0.0016	1166	43	1021	15	946	9	92%
35	159	158	651	0.24	0.0702	0.0015	1.5496	0.0339	0.1587	0.0015	933	45	950	14	949	8	99%
36	180	163	761	0.21	0.0717	0.0014	1.5919	0.0327	0.1591	0.0013	976	8	967	13	952	7	98%
37	401	567	615	0.92	0.0724	0.0017	1.5961	0.0376	0.1593	0.0014	996	46	969	15	953	8	98%
38	146	151	538	0.28	0.0708	0.0015	1.5698	0.0341	0.1593	0.0014	950	44	958	13	953	8	99%
39	118	174	225	0.77	0.0715	0.0018	1.5975	0.0401	0.1610	0.0014	972	58	969	16	963	8	99%
40	234	349	379	0.92	0.0723	0.0017	1.6420	0.0396	0.1637	0.0016	994	48	986	15	977	9	99%
41	87	122	142	0.86	0.0746	0.0027	1.7249	0.0598	0.1663	0.0018	1057	72	1018	22	992	10	97%
42	109	150	165	0.90	0.0730	0.0021	1.7469	0.0493	0.1720	0.0018	1017	53	1026	18	1023	10	99%
43	92	81	314	0.26	0.0744	0.0019	1.7849	0.0474	0.1732	0.0017	1054	53	1040	17	1030	9	99%
44	117	97	510	0.19	0.0754	0.0018	1.8192	0.0455	0.1737	0.0020	1081	47	1052	16	1032	11	98%
45	102	86	384	0.22	0.0752	0.0018	1.8194	0.0446	0.1744	0.0014	1076	45	1052	16	1036	8	98%
46	464	675	560	1.20	0.0775	0.0019	1.9508	0.0518	0.1813	0.0021	1133	50	1099	18	1074	12	97%
47	258	367	229	1.60	0.0755	0.0020	1.9027	0.0500	0.1826	0.0016	1083	58	1082	18	1081	9	99%
48	470	530	872	0.61	0.0743	0.0015	1.9296	0.0417	0.1868	0.0018	1050	45	1091	14	1104	10	98%
49	117	106	373	0.28	0.0759	0.0023	2.0200	0.0620	0.1918	0.0024	1094	61	1122	21	1131	13	99%
50	228	262	227	1.16	0.0763	0.0019	2.1271	0.0559	0.2010	0.0022	1106	50	1158	18	1181	12	98%
51	114	110	232	0.47	0.0887	0.0060	2.5140	0.1725	0.2038	0.0019	1398	131	1276	50	1196	10	93%
52	62	65	101	0.64	0.0804	0.0024	2.3257	0.0723	0.2074	0.0023	1207	60	1220	22	1215	12	99%
53	229	266	280	0.95	0.0825	0.0019	2.4142	0.0592	0.2101	0.0024	1257	46	1247	18	1229	13	98%
54	91	82	215	0.38	0.0828	0.0021	2.4212	0.0613	0.2103	0.0020	1266	49	1249	18	1230	11	98%
55	108	106	104	1.02	0.0902	0.0028	3.1074	0.0978	0.2483	0.0028	1431	65	1435	24	1430	14	99%
56	217	104	527	0.20	0.0953	0.0020	3.5646	0.0709	0.2695	0.0022	1544	39	1542	16	1538	11	99%

续表 1-3

序号	元素含量/10^{-6}			Th/U	同位素比值						年龄/Ma						谐和度
	Pb	Th	U		$^{207}Pb/^{206}Pb$	1σ	$^{207}Pb/^{235}U$	1σ	$^{206}Pb/^{238}U$	1σ	$^{207}Pb/^{206}Pb$	1σ	$^{207}Pb/^{235}U$	1σ	$^{206}Pb/^{238}U$	1σ	
57	126	114	108	1.06	0.0975	0.0026	3.6362	0.0972	0.2697	0.0030	1577	50	1557	21	1539	15	98%
58	318	233	173	1.34	0.1303	0.0032	6.6405	0.1677	0.3661	0.0035	2102	43	2065	22	2011	16	97%
59	249	131	261	0.50	0.1347	0.0031	7.3533	0.1675	0.3931	0.0036	2161	40	2155	20	2137	17	99%
60	332	187	290	0.65	0.1358	0.0026	7.5279	0.1527	0.3970	0.0039	2176	34	2176	18	2155	18	99%
61	239	82	291	0.28	0.1639	0.0032	9.8889	0.1925	0.4332	0.0030	2498	32	2424	18	2320	14	95%
62	184	66	231	0.28	0.1620	0.0051	9.5558	0.2901	0.4348	0.0079	2476	47	2393	28	2327	35	97%
63	79	23.1	116	0.20	0.1574	0.0036	9.8781	0.2306	0.4522	0.0048	2428	39	2423	22	2405	21	99%
64	228	79	251	0.32	0.1668	0.0036	11.0460	0.2432	0.4755	0.0045	2526	36	2527	21	2508	20	99%
65	737	346	435	0.80	0.1799	0.0039	12.6821	0.2914	0.5075	0.0052	2654	36	2656	22	2646	22	99%
DBS49																	
1	67.3	1156	932	1.24	0.0544	0.0010	0.2842	0.0061	0.0378	0.0005	387	41	254	5	239	3	94%
2	46.6	443	772	0.57	0.0976	0.0073	0.5936	0.0550	0.0408	0.0009	1589	140	473	35	258	5	41%
3	17.0	127	239	0.53	0.0713	0.0031	0.4099	0.0216	0.0411	0.0006	969	89	349	16	259	4	70%
4	7.30	77.4	96.4	0.80	0.0543	0.0013	0.3095	0.0081	0.0414	0.0006	383	52	274	6	261	4	95%
5	8.98	106	108	0.99	0.0533	0.0015	0.3045	0.0087	0.0415	0.0006	343	94	270	7	262	4	97%
6	22.7	296	301	0.98	0.0517	0.0013	0.2958	0.0076	0.0416	0.0006	333	57	263	6	263	4	99%
7	86.1	525	1645	0.32	0.0515	0.0008	0.3186	0.0061	0.0448	0.0007	261	33	281	5	283	4	99%
8	4.78	31.0	62.9	0.49	0.0554	0.0018	0.3429	0.0118	0.0449	0.0008	432	74	299	9	283	5	94%
9	13.86	119	228	0.52	0.0538	0.0017	0.3331	0.0111	0.0451	0.0009	365	66	292	8	284	6	97%
10	70.3	675	1084	0.62	0.0590	0.0007	0.3691	0.0066	0.0452	0.0007	565	26	319	5	285	4	88%
11	3.30	15.9	34.4	0.46	0.0540	0.0023	0.3644	0.0161	0.0492	0.0009	372	96	315	12	309	6	98%
12	7.13	45.5	90.7	0.50	0.0540	0.0013	0.4079	0.0109	0.0548	0.0009	372	58	347	8	344	5	98%
13	7.38	39.0	78.4	0.50	0.0582	0.0020	0.4863	0.0179	0.0607	0.0012	539	74	402	12	380	7	94%
14	135.9	471	2109	0.22	0.0565	0.0006	0.4844	0.0095	0.0622	0.0014	478	19	401	7	389	8	97%
15	43.6	209	480	0.44	0.0611	0.0011	0.5549	0.0103	0.0659	0.0009	643	35	448	7	412	5	91%
16	45.6	222	521	0.43	0.0556	0.0009	0.5202	0.0097	0.0676	0.0009	439	3	425	6	422	6	99%
17	101.1	392	1382	0.28	0.0559	0.0005	0.5238	0.0091	0.0679	0.0011	456	19	428	6	424	7	99%
18	15.63	83.2	175	0.48	0.0563	0.0013	0.5366	0.0144	0.0690	0.0011	465	55	436	9	430	7	98%
19	67.1	520	620	0.84	0.0554	0.0009	0.5291	0.0103	0.0691	0.0009	428	33	431	7	431	6	99%
20	39.1	252	366	0.69	0.0567	0.0010	0.5461	0.0126	0.0696	0.0010	480	37	442	8	434	6	97%
21	38.96	54.6	555	0.10	0.0558	0.0006	0.5363	0.0068	0.0697	0.0008	456	29	436	5	434	5	99%
22	43.9	194	521	0.37	0.0572	0.0006	0.5526	0.0086	0.0701	0.0009	498	26	447	6	436	5	97%
23	101.1	345	1288	0.27	0.0555	0.0007	0.5378	0.0094	0.0702	0.0010	432	(3)	437	6	437	6	99%
24	22.3	175	179	0.98	0.0556	0.0015	0.5408	0.0153	0.0707	0.0011	435	59	439	10	440	7	99%
25	16.73	71.9	179	0.40	0.0563	0.0014	0.5516	0.0148	0.0711	0.0012	465	54	446	10	443	7	99%
26	24.0	139	241	0.57	0.0552	0.0008	0.5452	0.0110	0.0715	0.0011	420	35	442	7	445	6	99%
27	39.5	266	380	0.70	0.0564	0.0008	0.5577	0.0102	0.0717	0.0009	465	31	450	7	446	6	99%
28	60.7	105	859	0.12	0.0558	0.0005	0.5541	0.0084	0.0719	0.0009	456	16	448	6	447	6	99%
29	41.1	143	527	0.27	0.0560	0.0006	0.5619	0.0112	0.0727	0.0013	454	22	453	7	452	8	99%
30	18.5	122	151	0.81	0.0566	0.0009	0.5689	0.0119	0.0727	0.0011	476	40	457	8	453	7	98%
31	161.5	359	2130	0.17	0.0580	0.0007	0.5913	0.0114	0.0738	0.0011	532	32	472	7	459	7	97%
32	34.1	192	348	0.55	0.0567	0.0010	0.5799	0.0144	0.0739	0.0013	480	37	464	9	460	8	98%
33	14.28	63.9	122	0.52	0.0569	0.0017	0.5925	0.0193	0.0755	0.0013	487	58	472	12	469	8	99%

续表 1-4

序号	元素含量/10^{-6}			Th/U	同位素比值						年龄/Ma						谐和度
	Pb	Th	U		$^{207}Pb/^{206}Pb$	1σ	$^{207}Pb/^{235}U$	1σ	$^{206}Pb/^{238}U$	1σ	$^{207}Pb/^{206}Pb$	1σ	$^{207}Pb/^{235}U$	1σ	$^{206}Pb/^{238}U$	1σ	
34	34.4	157	301	0.52	0.0578	0.0010	0.6671	0.0123	0.0837	0.0012	520	42	519	7	518	7	99%
35	32.1	292	154	1.89	0.0578	0.0008	0.6771	0.0124	0.0851	0.0013	520	25	525	8	526	8	99%
36	20.6	143	124	1.16	0.0589	0.0010	0.7298	0.0177	0.0895	0.0018	561	35	556	10	553	11	99%
37	95	1059	186	5.68	0.0653	0.0013	0.8294	0.0181	0.0917	0.0012	783	44	613	10	566	7	91%
38	43.7	282	291	0.97	0.0584	0.0008	0.7553	0.0142	0.0939	0.0015	543	25	571	8	578	9	98%
39	21.8	120	131	0.92	0.0598	0.0010	0.7873	0.0159	0.0956	0.0014	598	35	590	9	588	8	99%
40	19.79	2.25	238	0.01	0.0576	0.0011	0.7685	0.0183	0.0976	0.0022	517	47	579	10	600	13	96%
41	79.3	150	698	0.21	0.0612	0.0008	0.8910	0.0157	0.1052	0.0013	656	27	647	8	645	8	99%
42	58.6	335	306	1.09	0.0601	0.0010	0.8804	0.0189	0.1061	0.0018	606	37	641	10	650	10	98%
43	52.3	174	332	0.52	0.0629	0.0010	0.9869	0.0199	0.1136	0.0017	702	3	697	10	694	10	99%
44	68.5	181	472	0.38	0.0630	0.0007	1.0088	0.0154	0.1155	0.0016	709	31	708	8	705	9	99%
45	57.5	216	306	0.71	0.0638	0.0009	1.0637	0.0178	0.1207	0.0015	744	31	736	9	735	9	99%
46	46.9	182	247	0.74	0.0641	0.0007	1.0927	0.0174	0.1235	0.0017	746	24	750	8	751	10	99%
47	86.5	201	555	0.36	0.0648	0.0009	1.1306	0.0215	0.1261	0.0020	769	30	768	10	766	11	99%
48	38.4	152	174	0.87	0.0728	0.0010	1.2654	0.0195	0.1264	0.0015	1009	23	830	9	767	9	92%
49	128	560	612	0.92	0.0672	0.0008	1.1876	0.0219	0.1277	0.0018	843	31	795	10	775	10	97%
50	39.6	64.4	268	0.24	0.0731	0.0016	1.3321	0.0437	0.1308	0.0028	1017	44	860	19	792	16	91%
51	113.5	428	543	0.79	0.0665	0.0006	1.2629	0.0182	0.1376	0.0016	820	(180)	829	8	831	9	99%
52	32.6	112	148	0.76	0.0671	0.0008	1.2813	0.0204	0.1386	0.0018	839	24	837	9	836	10	99%
53	20.9	78.0	80.3	0.97	0.0713	0.0013	1.4687	0.0363	0.1493	0.0028	966	41	918	15	897	16	97%
54	85.7	217	447	0.49	0.0693	0.0007	1.4499	0.0248	0.1515	0.0022	909	20	910	10	909	13	99%
55	64.4	142	338	0.42	0.0695	0.0009	1.4676	0.0304	0.1530	0.0028	922	26	917	13	918	16	99%
56	122.2	230	654	0.35	0.0716	0.0006	1.5295	0.0194	0.1548	0.0016	973	12	942	8	928	9	98%
57	36.8	59.4	200	0.30	0.0684	0.0007	1.4638	0.0231	0.1550	0.0018	880	22	916	10	929	10	98%
58	39.7	153	145	1.06	0.0711	0.0010	1.5238	0.0267	0.1550	0.0020	961	29	940	11	929	11	98%
59	26.0	128	69.1	1.86	0.0733	0.0014	1.5651	0.0385	0.1550	0.0031	1021	39	956	15	929	17	97%
60	64.02	16.2	423	0.04	0.0706	0.0009	1.5190	0.0275	0.1558	0.0023	946	25	938	11	933	13	99%
61	70.7	134	358	0.37	0.0706	0.0009	1.5390	0.0259	0.1574	0.0020	946	26	946	10	942	11	99%
62	22.8	52.6	104	0.51	0.0687	0.0009	1.5060	0.0228	0.1591	0.0019	900	27	933	9	952	11	97%
63	99.7	379	338	1.12	0.0700	0.0006	1.5421	0.0234	0.1593	0.0021	931	20	947	9	953	12	99%
64	25.3	66.4	137	0.48	0.0713	0.0014	1.5714	0.0457	0.1598	0.0037	965	40	959	18	955	20	99%
65	184	461	848	0.54	0.0713	0.0005	1.5841	0.0198	0.1608	0.0018	965	16	964	8	961	10	99%
66	144	588	451	1.30	0.0743	0.0010	1.6641	0.0281	0.1619	0.0022	1050	22	995	11	967	12	97%
67	145.8	214	795	0.27	0.0710	0.0006	1.5892	0.0226	0.1620	0.0023	967	17	966	9	968	13	99%
68	51.1	96.0	245	0.39	0.0739	0.0013	1.6530	0.0324	0.1630	0.0029	1039	32	991	12	973	16	98%
69	45.2	69.3	241	0.29	0.0716	0.0010	1.6143	0.0307	0.1633	0.0025	976	28	976	12	975	14	99%
70	48.2	101.8	236	0.43	0.0720	0.0008	1.6299	0.0292	0.1639	0.0023	987	22	982	11	978	13	99%
71	59.0	55.6	329	0.17	0.0718	0.0011	1.6354	0.0329	0.1648	0.0026	989	30	984	13	984	15	99%
72	111.4	100.8	645	0.16	0.0718	0.0007	1.6338	0.0233	0.1649	0.0022	981	19	983	9	984	12	99%
73	74.7	193	328	0.59	0.0723	0.0011	1.6502	0.0283	0.1655	0.0024	994	31	990	11	987	13	99%
74	73.1	174	326	0.54	0.0714	0.0006	1.6540	0.0248	0.1677	0.0023	969	16	991	10	1000	13	99%
75	68.9	174	313	0.56	0.0723	0.0009	1.6790	0.0357	0.1685	0.0033	994	26	1001	14	1004	18	99%
76	79.2	133	399	0.33	0.0725	0.0007	1.6940	0.0247	0.1689	0.0022	1011	20	1006	9	1006	12	99%

续表 1-5

序号	元素含量/10^{-6}			Th/U	同位素比值						年龄/Ma						谐和度
	Pb	Th	U		$^{207}Pb/^{206}Pb$	1σ	$^{207}Pb/^{235}U$	1σ	$^{206}Pb/^{238}U$	1σ	$^{207}Pb/^{206}Pb$	1σ	$^{207}Pb/^{235}U$	1σ	$^{206}Pb/^{238}U$	1σ	
77	67.1	93.7	362	0.26	0.0717	0.0007	1.6823	0.0319	0.1700	0.0029	989	20	1002	12	1012	16	98%
78	41.6	77.5	185	0.42	0.0765	0.0010	1.8898	0.0294	0.1787	0.0021	1109	25	1078	10	1060	11	98%
79	40.7	142	118	1.21	0.0766	0.0015	1.8908	0.0406	0.1790	0.0025	1122	39	1078	14	1061	14	98%
80	37.4	89.2	148	0.60	0.0760	0.0008	1.8917	0.0288	0.1801	0.0024	1095	20	1078	10	1068	13	99%
81	80.5	130	361	0.36	0.0760	0.0007	1.9161	0.0309	0.1827	0.0024	1094	23	1087	11	1082	13	99%
82	52.5	145	157	0.92	0.0884	0.0022	2.2425	0.0670	0.1828	0.0027	1391	48	1194	21	1082	15	90%
83	97.9	240	356	0.67	0.0748	0.0010	1.9003	0.0319	0.1839	0.0024	1065	32	1081	11	1088	13	99%
84	99.8	45.7	455	0.10	0.0829	0.0009	2.4648	0.0382	0.2154	0.0029	1266	16	1262	11	1257	15	99%
85	167	336	396	0.85	0.0967	0.0012	3.3908	0.0613	0.2540	0.0040	1561	22	1502	14	1459	20	97%
86	127.9	215	346	0.62	0.0921	0.0011	3.3287	0.0580	0.2619	0.0043	1469	27	1488	14	1500	22	99%
87	74.4	144	164	0.88	0.0980	0.0011	3.6734	0.0622	0.2707	0.0042	1587	22	1566	14	1544	21	98%
88	326.4	148	988	0.15	0.1514	0.0015	5.7335	0.0792	0.2735	0.0032	2363	17	1936	12	1558	16	78%
89	93.8	127	245	0.52	0.0979	0.0009	3.8283	0.0646	0.2827	0.0041	1587	17	1599	14	1605	21	99%
90	134.4	88.9	365	0.24	0.1460	0.0012	5.9036	0.1008	0.2929	0.0046	2302	13	1962	15	1656	23	83%
91	117.5	77.1	372	0.21	0.1110	0.0009	4.6501	0.0985	0.3033	0.0059	1817	10	1758	18	1708	29	97%
92	229.1	153	607	0.25	0.1144	0.0013	4.8964	0.0693	0.3086	0.0035	1872	20	1802	12	1734	17	96%
93	217.1	214	519	0.41	0.1118	0.0014	4.9118	0.0802	0.3181	0.0040	1828	23	1804	14	1780	20	98%
94	109.5	85.8	322	0.27	0.1061	0.0008	4.6546	0.0892	0.3181	0.0062	1800	14	1759	16	1780	31	98%
95	135.2	52.9	362	0.15	0.1166	0.0012	5.2448	0.0819	0.3247	0.0050	1906	19	1860	13	1813	24	97%
96	65.9	100.8	132	0.76	0.1056	0.0011	4.7630	0.0769	0.3266	0.0046	1726	21	1778	14	1822	22	97%
97	197.03	15.9	574	0.03	0.1133	0.0010	5.2434	0.0868	0.3340	0.0054	1853	15	1860	14	1858	26	99%
98	301	334	600	0.56	0.1467	0.0014	6.9888	0.1103	0.3444	0.0046	2309	17	2110	14	1908	22	89%
99	188.8	75.0	484	0.16	0.1158	0.0011	5.5618	0.0849	0.3474	0.0044	1894	17	1910	13	1922	21	99%
100	99.6	90.4	218	0.41	0.1388	0.0036	7.3249	0.4229	0.3557	0.0163	2213	44	2152	52	1962	78	90%
101	128.0	24.1	443	0.05	0.1167	0.0014	5.9928	0.1756	0.3708	0.0100	1907	21	1975	26	2033	47	97%
102	387.4	137	864	0.16	0.1626	0.0019	8.6624	0.1413	0.3849	0.0052	2482	20	2303	15	2099	24	90%
103	574.6	128	1327	0.10	0.1369	0.0010	7.7903	0.1825	0.4099	0.0079	2189	13	2207	21	2215	36	99%
104	249	215	365	0.59	0.1601	0.0018	9.6420	0.1494	0.4358	0.0058	2457	19	2401	14	2332	26	97%
105	271	178	421	0.42	0.1657	0.0011	10.4759	0.1325	0.4577	0.0053	2517	11	2478	12	2429	23	98%
106	248	230	342	0.67	0.1644	0.0013	10.4377	0.1494	0.4599	0.0059	2502	14	2474	13	2439	26	98%
107	144	194	159	1.22	0.1614	0.0013	10.3121	0.1493	0.4634	0.0064	2472	14	2463	14	2455	28	99%
108	120.2	137	145	0.95	0.1640	0.0020	10.5814	0.2078	0.4666	0.0079	2497	21	2487	18	2469	35	99%
109	406	302	603	0.50	0.1607	0.0018	10.4415	0.1679	0.4691	0.0068	2463	19	2475	15	2480	30	99%
110	29.2	28.5	36.1	0.79	0.1577	0.0017	10.2286	0.1943	0.4694	0.0073	2431	19	2456	18	2481	32	98%
111	110.5	41.2	187	0.22	0.1640	0.0017	10.8404	0.1690	0.4792	0.0072	2498	17	2510	15	2524	32	99%
112	244	300	265	1.13	0.1616	0.0016	10.7699	0.1649	0.4822	0.0064	2473	21	2503	14	2537	28	98%
113	111.1	88.5	145	0.61	0.1850	0.0016	13.3022	0.2653	0.5207	0.0102	2698	14	2701	19	2702	43	99%
114	161.1	38.3	242	0.16	0.1999	0.0016	14.6268	0.2486	0.5279	0.0081	2826	13	2791	16	2733	34	97%
115	334.3	59.0	525	0.11	0.1806	0.0015	13.1978	0.1894	0.5289	0.0068	2658	8	2694	14	2737	29	98%
116	184	137	198	0.69	0.2249	0.0021	16.7922	0.2405	0.5412	0.0063	3016	15	2923	14	2788	26	95%
DBS08																	
1	7.88	134	207	0.65	0.0511	0.0034	0.2065	0.0132	0.0297	0.0004	256	156	191	11	189	3	98%
2	25.81	251	648	0.39	0.0496	0.0018	0.2316	0.0081	0.0337	0.0003	176	79	212	7	214	2	99%

续表 1-6

序号	元素含量/10^{-6}			Th/U	同位素比值						年龄/Ma						谐和度
	Pb	Th	U		$^{207}Pb/^{206}Pb$	1σ	$^{207}Pb/^{235}U$	1σ	$^{206}Pb/^{238}U$	1σ	$^{207}Pb/^{206}Pb$	1σ	$^{207}Pb/^{235}U$	1σ	$^{206}Pb/^{238}U$	1σ	
3	4.85	94.2	101	0.93	0.0545	0.0046	0.2510	0.0202	0.0357	0.0007	391	189	227	16	226	4	99%
4	24.67	92.0	568	0.16	0.0491	0.0017	0.2697	0.0091	0.0397	0.0003	153.8	76.8	242	7	251	2	96%
5	3.35	78.5	57.8	1.36	0.1118	0.0984	0.8827	0.0925	0.0400	0.0014	1828	1079	642	50	253	9	13%
6	9.28	106	181	0.58	0.0542	0.0029	0.3072	0.0159	0.0415	0.0006	389	122	272	12	262	3	96%
7	11.59	133	219	0.61	0.0510	0.0027	0.2909	0.0152	0.0417	0.0005	239	129	259	12	263	3	98%
8	16.13	238	305	0.78	0.0551	0.0043	0.3071	0.0226	0.0421	0.0007	417	176	272	18	266	4	97%
9	2.28	26.2	46.2	0.57	0.0567	0.1060	0.7763	0.0931	0.0426	0.0017	480	2004	583	53	269	11	26%
10	51.9	516	1021	0.51	0.0523	0.0022	0.3122	0.0130	0.0437	0.0005	298	96	276	10	276	3	99%
11	8.19	125	132	0.94	0.0529	0.0032	0.3313	0.0194	0.0457	0.0006	324	134	291	15	288	4	99%
12	3.40	47.6	50.9	0.94	0.0571	0.0080	0.3535	0.0488	0.0487	0.0011	494	312	307	37	306	7	99%
13	28.4	380	421	0.90	0.0527	0.0028	0.3772	0.0207	0.0515	0.0006	317	122	325	15	324	4	99%
14	23.78	326	324	1.01	0.0540	0.0021	0.3919	0.0145	0.0524	0.0005	372	87	336	11	329	3	98%
15	58.3	490	651	0.75	0.0559	0.0014	0.5347	0.0131	0.0687	0.0005	456	56	435	9	429	3	98%
16	7.98	51.1	94.1	0.54	0.0541	0.0036	0.5119	0.0330	0.0688	0.0009	372	150	420	22	429	5	97%
17	15.72	116	170	0.68	0.0562	0.0025	0.5426	0.0234	0.0692	0.0008	461	96	440	15	431	5	97%
18	19.91	214	210	1.02	0.0552	0.0023	0.5245	0.0208	0.0695	0.0007	420	99	428	14	433	4	98%
19	12.81	81.1	143	0.57	0.0562	0.0026	0.5429	0.0238	0.0696	0.0009	461	97	440	16	434	5	98%
20	52.6	406	613	0.66	0.0580	0.0024	0.5510	0.0218	0.0696	0.0008	532	89	446	14	434	5	97%
21	52.3	701	476	1.47	0.0558	0.0021	0.5434	0.0191	0.0697	0.0007	456	81	441	13	435	4	98%
22	12.93	86.9	149	0.58	0.0585	0.0027	0.5627	0.0246	0.0703	0.0009	546	94	453	16	438	5	96%
23	52.2	288	625	0.46	0.0550	0.0014	0.5356	0.0138	0.0703	0.0007	409	56	436	9	438	4	99%
24	60.7	392	723	0.54	0.0619	0.0020	0.6064	0.0199	0.0704	0.0008	733	70	481	13	438	5	90%
25	13.85	42.9	176	0.24	0.0542	0.0026	0.5191	0.0239	0.0705	0.0008	389	111	425	16	439	5	96%
26	28.20	118	343	0.35	0.0596	0.0021	0.5845	0.0206	0.0707	0.0007	587	76	467	13	440	4	94%
27	4.35	22.1	50.5	0.44	0.0593	0.0043	0.5608	0.0408	0.0709	0.0013	576	159	452	27	441	8	97%
28	17.86	167	188	0.89	0.0565	0.0023	0.5537	0.0222	0.0713	0.0008	478	95	447	14	444	5	99%
29	9.97	23.6	69.1	0.34	0.1005	0.0071	1.5562	0.1038	0.1171	0.0026	1635	131	953	41	714	15	71%
30	36.6	142	241	0.59	0.0690	0.0031	1.1394	0.0529	0.1206	0.0019	898	-105	772	25	734	11	94%
31	31.4	201	175	1.15	0.0644	0.0021	1.1052	0.0354	0.1233	0.0014	754	68	756	17	749	8	99%
32	11.59	83.2	62.9	1.32	0.0675	0.0033	1.1651	0.0569	0.1246	0.0015	854	100	784	27	757	9	96%
33	10.43	58.5	62.4	0.94	0.0680	0.0033	1.1527	0.0521	0.1246	0.0018	878	101	779	25	757	11	97%
34	16.5	134	84.7	1.58	0.0639	0.0028	1.1021	0.0462	0.1251	0.0015	739	93	754	22	760	9	99%
35	7.26	33.2	42.7	0.78	0.0690	0.0038	1.1851	0.0635	0.1270	0.0021	898	110	794	30	771	12	97%
36	4.86	11.4	32.6	0.35	0.0855	0.0059	1.4544	0.0937	0.1273	0.0029	1328	133	912	39	772	16	83%
37	4.99	41.9	23.6	1.77	0.0777	0.0057	1.3019	0.0929	0.1299	0.0030	1139	146	847	41	787	17	92%
38	28.4	141	157	0.90	0.0684	0.0023	1.2354	0.0398	0.1302	0.0013	883	70	817	18	789	7	96%
39	4.82	33.3	23.5	1.42	0.0707	0.0059	1.2540	0.1033	0.1332	0.0031	950	171	825	47	806	18	97%
40	13.35	95.5	65.3	1.46	0.0736	0.0035	1.3424	0.0613	0.1337	0.0018	1031	62	864	27	809	11	93%
41	17.28	77.6	99.1	0.78	0.0690	0.0026	1.2788	0.0485	0.1344	0.0014	898	80	836	22	813	8	97%
42	24.31	111	139	0.80	0.0684	0.0038	1.2522	0.0685	0.1354	0.0019	880	115	824	31	819	11	99%
43	17.30	71.1	100.2	0.71	0.0693	0.0025	1.2954	0.0463	0.1357	0.0015	907	79	844	20	820	9	97%
44	11.02	47.4	60.6	0.78	0.0848	0.0045	1.6204	0.0927	0.1378	0.0022	1311	102	978	36	832	12	83%
45	39.4	169	219	0.77	0.0656	0.0018	1.2610	0.0347	0.1390	0.0012	794	53	828	16	839	7	98%

续表 1-7

序号	元素含量/10^{-6}			Th/U	同位素比值						年龄/Ma						谐和度
	Pb	Th	U		$^{207}Pb/^{206}Pb$	1σ	$^{207}Pb/^{235}U$	1σ	$^{206}Pb/^{238}U$	1σ	$^{207}Pb/^{206}Pb$	1σ	$^{207}Pb/^{235}U$	1σ	$^{206}Pb/^{238}U$	1σ	
46	84.4	308	477	0.65	0.0656	0.0016	1.2679	0.0326	0.1396	0.0014	791	52	831	15	842	8	98%
47	65.25	89.8	414	0.22	0.0621	0.0016	1.2044	0.0312	0.1401	0.0011	676	56	803	14	845	6	94%
48	39.14	81.8	223	0.37	0.0713	0.0017	1.4874	0.0369	0.1502	0.0014	965	49	925	15	902	8	97%
49	406.7	116	1335	0.09	0.1175	0.0024	4.4340	0.0899	0.2724	0.0019	1918	37	1719	17	1553	9	89%
50	299.4	402	775	0.52	0.1101	0.0020	4.6543	0.0853	0.3046	0.0019	1811	33	1759	15	1714	9	97%
51	275.9	634	655	0.97	0.1175	0.0022	5.0260	0.0968	0.3094	0.0022	1920	35	1824	16	1738	11	95%
52	73.6	102	188	0.55	0.1087	0.0029	4.7462	0.1173	0.3174	0.0032	1789	48	1775	21	1777	16	99%
53	51.7	82.0	123	0.66	0.1123	0.0024	4.9756	0.1061	0.3195	0.0024	1837	39	1815	18	1787	12	98%
54	146.8	218	352	0.62	0.1194	0.0031	5.3361	0.1513	0.3213	0.0036	1947	48	1875	24	1796	18	95%
55	196.2	460	435	1.06	0.1144	0.0026	5.0868	0.1118	0.3218	0.0023	1872	47	1834	19	1799	11	98%
56	253.7	363	595	0.61	0.1259	0.0035	5.6980	0.1904	0.3229	0.0027	2043	49	1931	29	1804	13	93%
57	39.3	65.6	92.5	0.71	0.1145	0.0029	5.1250	0.1315	0.3229	0.0035	1872	46	1840	22	1804	17	98%
58	380	665	909	0.73	0.1133	0.0020	5.0734	0.0895	0.3231	0.0021	1854	32	1832	15	1805	10	98%
59	107.7	133	267	0.50	0.1115	0.0026	5.0433	0.1171	0.3277	0.0026	1833	42	1827	20	1827	13	99%
60	68.4	106	165	0.64	0.1141	0.0035	5.1689	0.1576	0.3286	0.0035	1866	56	1848	26	1832	17	99%
61	409.6	378	1053	0.36	0.1153	0.0021	5.2584	0.1009	0.3290	0.0027	1885	32	1862	16	1833	13	98%
62	68.9	151	148	1.02	0.1138	0.0026	5.2221	0.1176	0.3309	0.0032	1861	41	1856	19	1843	16	99%
63	100.5	225	208	1.08	0.1282	0.0027	5.8987	0.1205	0.3313	0.0026	2074	37	1961	18	1845	12	93%
64	88.0	50.4	215	0.23	0.1104	0.0030	5.1744	0.1322	0.3353	0.0031	1806	44	1848	22	1864	15	99%
65	345	679	751	0.90	0.1153	0.0022	5.4570	0.1067	0.3417	0.0026	1884	35	1894	17	1895	12	99%
66	247.4	291	584	0.50	0.1136	0.0021	5.4073	0.1001	0.3436	0.0027	1858	29	1886	16	1904	13	99%
67	219.7	311	478	0.65	0.1223	0.0022	5.8606	0.1032	0.3447	0.0022	1991	31	1955	15	1909	11	97%
68	32.58	14.3	63.5	0.23	0.1476	0.0048	8.5175	0.3136	0.4236	0.0099	2320	56	2288	33	2277	45	99%
69	69.7	74.2	124	0.60	0.1591	0.0038	9.4595	0.2146	0.4316	0.0041	2446	41	2384	21	2313	19	96%
70	261.5	324	416	0.78	0.1534	0.0034	9.4895	0.1974	0.4422	0.0034	2384	38	2387	19	2360	15	98%
71	187.5	205	313	0.65	0.1388	0.0027	8.6650	0.1703	0.4483	0.0034	2213	34	2303	18	2388	15	96%
72	53.2	43.9	89.7	0.49	0.1677	0.0036	10.5616	0.2234	0.4538	0.0043	2535	37	2485	20	2412	19	97%
73	173.8	82.7	292	0.28	0.1663	0.0040	10.7547	0.2451	0.4623	0.0040	2521	41	2502	21	2450	18	97%
74	111.7	181	168	1.08	0.1641	0.0033	10.5012	0.2156	0.4636	0.0044	2498	33	2480	19	2455	19	99%
75	142	416	152	2.74	0.1591	0.0029	10.6318	0.1971	0.4815	0.0040	2446	31	2491	17	2534	17	98%
76	94.7	124	127	0.98	0.1813	0.0041	13.0737	0.3059	0.5220	0.0058	2665	37	2685	22	2708	24	99%
77	75.8	56.3	89.6	0.63	0.2310	0.0052	19.0606	0.4317	0.5932	0.0060	3059	30	3045	22	3002	24	98%

域上泥盆纪地层中碎屑锆石 U–Pb 年代学研究结果基本一致, 如赣南地区中泥盆世跳马涧组(440 Ma, 向磊等, 2010), 湘东南中泥盆世跳马涧组(440~430 Ma, 陈家驹等, 2021), 粤西阳春地区早泥盆世桂头群(447 Ma、433 Ma, 王志宏等, 2018), 说明矿区赋矿地层以往划为中泥盆世棋子桥组和老虎头组是符合事实的。采自层状火山岩底板地层中 2 件石英砂岩样品, 最年轻且谐和的锆石年龄分别为 189±3 Ma 和 239±3 Ma, 限定了层状火山岩底板岩石沉积时代的下限。这一结果与刘武生等(2022)(炭质泥岩 Re–Os 等时线年龄, 195 Ma)对矿区该层位的研究结果基本一致, 也与前人在粤东盆地早侏罗世金鸡组(196 Ma, 刘念等, 2018), 粤东地区下侏罗统(180 Ma, 杨宗永等, 2013), 赣中早侏罗世水北组(200 Ma, Meng et al., 2015), 东坑盆地早侏罗世余田群(196 Ma, 李武显等, 2013), 闽西早侏罗世梨山组(198 Ma, 许中杰等, 2018), 东南沿海早侏罗世金鸡组和梨山组(200~190 Ma, Kong et al., 2021)等地层中获得的最年轻碎屑锆石 U–Pb 年龄及年龄谱系特征类似, 说明层状火山岩底板砂岩的沉积时代为早侏罗世。

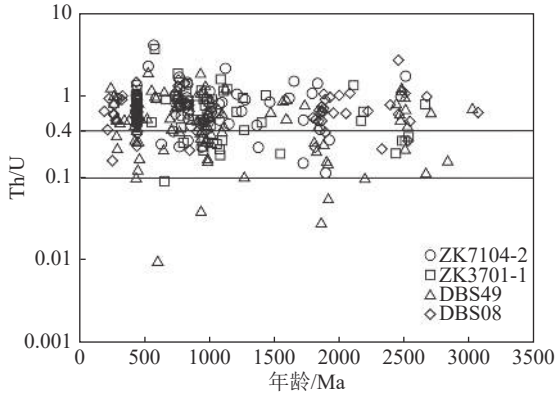


图 5 大宝山矿床赋矿地层样品中碎屑锆石 Th/U 值分布图

Fig. 5 Th/U value distribution of detrital zircons from the ore-hosting strata samples in the Dabaoshan deposit

4.2 源区分析

前人研究工作表明，区域上泥盆纪地层碎屑锆石 U−Pb 年龄主要峰值为 2500 Ma、1900 Ma、1000 Ma、800 Ma、600 Ma 和 440 Ma(向磊等, 2010; 王志宏等, 2018; 陈家驹等, 2021)；早侏罗世地层碎屑锆石 U−Pb 年龄除出现上述峰值年龄外，还出现 200 Ma 和 260 Ma 的峰值(李武显等, 2013; 杨宗永等, 2013; Meng et al., 2015; 许中杰等, 2018; Kong et al., 2021)。从表 1 和图 7 可见，本次研究的 4 件样品分别与前人获得的中泥盆世和早侏罗世地层具有类似的年龄谱图，主要分为 5 组：440~420 Ma，650~520 Ma，870~750 Ma，1200~900 Ma，2500~1600 Ma。此外，2 件层状火山岩底板中有少量的早侏罗世—晚石炭世(344~189 Ma)和中—新太古代(3059~2654 Ma)锆石。

2500~1600 Ma 之间，尤其是 2200~1700 Ma 的地质事件主要与哥伦比亚超大陆的聚合−裂解有关，华夏地块武夷地区发现有 1800 Ma 左右的地质体(汪相等, 2008; Yu et al., 2010)，它们可能提供该时期的物源。这些锆石的 $\varepsilon_{Hf}(t)$ 值介于−26.9~+10.4 之间，$\varepsilon_{Hf}(t)$ 为负值的 T_{DM2} 为 4118~2475 Ma，$\varepsilon_{Hf}(t)$ 为正值的 T_{DM1} 为 2739~1706 Ma，反映前者为更古老地壳物质的再循环，而后者可能暗示存在太古宙—古元古代的地壳增生。6 颗锆石(3059~2654 Ma)为中—新太古代的物质记录，它们的 $\varepsilon_{Hf}(t)$ 值介于−7.9~−0.8 之间，T_{DM2} 为 3766~3317 Ma，暗示为始—古太古代地壳物质的再循环。

1200~900 Ma 的锆石记录了华夏地块内部新元古代早期微陆块的聚合，前人在云开和武夷地区报道有该时期的花岗岩、流纹岩、玄武岩等地质体(舒良树等, 2008; Wang et al., 2014; 王磊等, 2015; 周岱等, 2017)，并提出华夏地块新元古代幕式拼合的演化模式(Wang et al., 2014)。这些碎屑锆石的 $\varepsilon_{Hf}(t)$ 值介于−36.3~+12.8 之间，$\varepsilon_{Hf}(t)$ 为负值的 T_{DM2} 为 3905~1724 Ma，$\varepsilon_{Hf}(t)$ 为正值的 T_{DM1} 为 1086~1706 Ma，说明它们部分为太古宙—古元古代的再循环物质，部分来自华夏地块内部早期微陆块聚合时的新生地壳物质，如云开和武夷地区 1000 Ma 的岩浆岩(舒良树等, 2008; Wang et al., 2014; 王磊等, 2015; 周岱等, 2017)。

870~750 Ma 的锆石为扬子和华夏地块的拼合记录，该时期形成了扬子陆块东南缘大面积的新元古代花岗岩、褶皱基底(冷家溪群、梵净山群等)及其中的基性岩(Wang et al., 2006, 2007, 2008)。这些碎屑锆石的 $\varepsilon_{Hf}(t)$ 值介于−38.4~+13.4 之间，$\varepsilon_{Hf}(t)$ 为负值的 T_{DM2} 为 3626~1618 Ma，少数 $\varepsilon_{Hf}(t)$ 为正值的 T_{DM1} 集中于 1402~991 Ma，说明它们主要为始太古代—古元古代的再循环物质，少部分源自格林威尔期初生地壳物质。

650~520 Ma 的锆石记录华夏这些物质来自泛非造山带。区域上古生代地层中普遍发育该时期碎屑锆石，但地质体仅报道有福建政和蛇绿岩(约 520 Ma; Li et al., 2022)，它们大部分可能来自冈瓦纳大陆。这些碎屑锆石的 $\varepsilon_{Hf}(t)$ 值介于−51.8~+5.8 之间，$\varepsilon_{Hf}(t)$ 为负值的 T_{DM2} 为 4223~1447 Ma，$\varepsilon_{Hf}(t)$ 为正值的 T_{DM1} 为 1237~942 Ma，反映前者主要为太古宙—元古宙甚至可能有冥古宙的再循环物质，后者来自华夏地块内部的新生地壳物质。

430~440 Ma 的锆石年龄记录了华南加里东造山事件(或武夷−云开造山事件)，该时期沿武夷—云开一带形成了大量的花岗岩及少量的中酸性火山岩和基性岩(Wang et al., 2012; 王磊等, 2012; Shu et al., 2014)。这些碎屑锆石的 $\varepsilon_{Hf}(t)$ 值介于−40.4~+5.5 之间，$\varepsilon_{Hf}(t)$ 为负值的 T_{DM2} 为 3496~1331 Ma，$\varepsilon_{Hf}(t)$ 为正值的 T_{DM1} 为 1048~825 Ma，说明它们主要为古—中元古代及少量新太古代地壳物质的再循环，少量为元古宙新生地壳物质。这与华南加里东期花岗岩主要源自古老地壳重熔一致，而元古宙新生地壳物质很可能来自扬子和华夏地块新元古代早期拼合形成的新生地壳物质。

表 2　大宝山矿床赋矿地层碎屑锆石 Hf 同位素组成

Table 2　Hf isotopic compositions of detrital zircons from the ore-hosting strata samples in the Dabaoshan deposit

序号	年龄/Ma	$^{176}Yb/^{177}Hf$	$^{176}Lu/^{177}Hf$	$^{176}Hf/^{177}Hf$	1σ	$\varepsilon_{Hf}(0)$	1σ	$\varepsilon_{Hf}(t)$	1σ	T_{DM1}/Ma	T_{DM2}/Ma	$f_{Lu/Hf}$
ZK7104-2												
1	430	0.072209	0.001988	0.282459	0.000015	−11.1	0.7	−2.2	0.8	1151	1410	−0.94
2	435	0.044536	0.001025	0.281720	0.000015	−37.2	0.7	−28.0	0.8	2149	2825	−0.97
3	435	0.122668	0.003166	0.282180	0.000025	−20.9	1.0	−12.3	1.1	1602	1969	−0.90
4	436	0.052931	0.001342	0.282284	0.000015	−17.3	0.7	−8.1	0.8	1379	1739	−0.96
5	436	0.030693	0.000707	0.282051	0.000010	−25.5	0.6	−16.1	0.6	1677	2181	−0.98
6	436	0.032645	0.000544	0.282094	0.000085	−24.0	3.1	−14.6	3.1	1612	2096	−0.98
7	437	0.087015	0.001980	0.281948	0.000175	−29.1	6.2	−20.1	6.2	1881	2399	−0.94
8	437	0.047389	0.001197	0.281863	0.000014	−32.1	0.7	−22.9	0.7	1960	2551	−0.96
9	437	0.065858	0.001698	0.282329	0.000013	−15.7	0.7	−6.6	0.7	1328	1657	−0.95
10	438	0.116135	0.003106	0.282052	0.000019	−25.4	0.8	−16.7	0.9	1787	2215	−0.91
11	438	0.080019	0.002058	0.282015	0.000017	−26.8	0.8	−17.7	0.8	1790	2271	−0.94
12	441	0.046614	0.001127	0.282246	0.000012	−18.6	0.7	−9.2	0.7	1424	1807	−0.97
13	441	0.050291	0.001309	0.282122	0.000016	−23.0	0.8	−13.7	0.8	1604	2050	−0.96
14	441	0.057291	0.001422	0.282039	0.000011	−25.9	0.6	−16.7	0.7	1726	2214	−0.96
15	442	0.100705	0.002392	0.282263	0.000014	−18.0	0.7	−9.0	0.7	1448	1793	−0.93
16	442	0.114965	0.002672	0.282079	0.000015	−24.5	0.7	−15.6	0.8	1727	2154	−0.92
17	443	0.097886	0.002299	0.281950	0.000205	−29.1	7.3	−20.0	7.3	1895	2398	−0.93
18	527	0.058703	0.001427	0.282091	0.000014	−24.1	0.7	−13.0	0.7	1653	2080	−0.96
19	568	0.035006	0.000857	0.282055	0.000011	−25.4	0.6	−13.2	0.7	1679	2124	−0.97
20	589	0.032810	0.000762	0.280949	0.000044	−64.5	1.6	−51.8	1.7	3178	4223	−0.98
21	627	0.043902	0.001065	0.281916	0.000025	−30.3	1.0	−16.9	1.1	1881	2373	−0.97
22	720	0.030243	0.000830	0.281349	0.000012	−50.3	0.7	−34.9	0.7	2643	3415	−0.97
23	731	0.057609	0.001457	0.281835	0.000013	−33.1	0.7	−17.7	0.7	2013	2497	−0.96
24	738	0.051001	0.001269	0.281863	0.000013	−32.2	0.7	−16.5	0.7	1965	2437	−0.96
25	765	0.016523	0.000527	0.282216	0.000012	−19.6	0.7	−3.0	0.7	1442	1722	−0.98
26	766	0.042089	0.001171	0.282258	0.000018	−18.2	0.8	−1.9	0.9	1409	1658	−0.96
27	768	0.070531	0.001779	0.282113	0.000017	−23.3	0.8	−7.3	0.8	1638	1957	−0.95
28	779	0.049663	0.001365	0.282029	0.000014	−26.3	0.7	−9.8	0.8	1738	2104	−0.96
29	824	0.109186	0.002834	0.282291	0.000018	−17.0	0.8	−0.4	0.9	1425	1621	−0.91
30	830	0.082760	0.002039	0.281994	0.000013	−27.5	0.7	−10.3	0.7	1819	2172	−0.94
31	832	0.040411	0.001050	0.281425	0.000011	−47.6	0.6	−29.9	0.7	2555	3232	−0.97
32	832	0.018571	0.000397	0.281946	0.000009	−29.2	0.6	−11.1	0.6	1807	2214	−0.99
33	832	0.075774	0.001994	0.282285	0.000012	−17.2	0.7	0.0	0.7	1402	1606	−0.94
34	835	0.041756	0.001136	0.282524	0.000011	−8.8	0.6	9.1	0.7	1034	1111	−0.97
35	837	0.119701	0.003045	0.282303	0.000020	−16.6	0.9	0.2	0.9	1416	1601	−0.91
36	857	0.030544	0.000844	0.281864	0.000010	−32.1	0.6	−13.7	0.7	1942	2376	−0.97
37	982	0.105745	0.002708	0.282134	0.000016	−22.6	0.8	−2.6	0.8	1650	1871	−0.92
38	983	0.042907	0.001101	0.282055	0.000012	−25.4	0.7	−4.3	0.7	1689	1965	−0.97
39	984	0.045199	0.001186	0.282141	0.000011	−22.3	0.6	−1.3	0.7	1573	1802	−0.96
40	989	0.015927	0.000357	0.282033	0.000010	−26.1	0.6	−4.5	0.7	1687	1979	−0.99
41	997	0.068429	0.001652	0.282161	0.000014	−21.6	0.7	−0.6	0.8	1564	1774	−0.95
42	999	0.038268	0.000846	0.282014	0.000011	−26.8	0.6	−5.3	0.7	1735	2030	−0.97

续表 2-1

序号	年龄/Ma	$^{176}Yb/^{177}Hf$	$^{176}Lu/^{177}Hf$	$^{176}Hf/^{177}Hf$	1σ	$\varepsilon_{Hf}(0)$	1σ	$\varepsilon_{Hf}(t)$	1σ	T_{DM1}/Ma	T_{DM2}/Ma	$f_{Lu/Hf}$
43	1006	0.067724	0.001763	0.282465	0.000014	−10.9	0.7	10.2	0.8	1136	1184	−0.95
44	1013	0.038532	0.000984	0.281547	0.000016	−43.3	0.7	−21.6	0.8	2384	2927	−0.97
45	1011	0.033065	0.000798	0.281249	0.000010	−53.8	0.6	−32.1	0.7	2777	3487	−0.98
46	1076	0.052278	0.001299	0.282101	0.000011	−23.7	0.6	−0.8	0.7	1633	1847	−0.96
47	1072	0.074109	0.001753	0.281898	0.000012	−30.9	0.7	−8.4	0.7	1940	2259	−0.95
48	1094	0.042081	0.001144	0.282156	0.000012	−21.8	0.7	1.6	0.7	1550	1727	−0.97
49	1209	0.058056	0.001604	0.282314	0.000012	−16.2	0.7	9.3	0.8	1346	1396	−0.95
50	1120	0.063649	0.001640	0.282217	0.000020	−19.6	0.9	4.0	0.9	1484	1619	−0.95
51	1244	0.045151	0.001364	0.281727	0.000010	−36.9	0.6	−10.5	0.7	2158	2507	−0.96
52	1272	0.069081	0.001786	0.282259	0.000016	−18.1	0.8	8.6	0.8	1431	1489	−0.95
53	1373	0.149927	0.003722	0.282235	0.000071	−19.0	2.6	8.1	2.7	1545	1596	−0.89
54	1362	0.034541	0.000821	0.282034	0.000011	−26.1	0.6	3.4	0.7	1706	1845	−0.98
55	1461	0.070895	0.001752	0.282263	0.000175	−18.0	6.2	12.8	6.3	1424	1410	−0.95
56	1606	0.036595	0.000875	0.282035	0.000015	−26.1	0.7	8.8	0.8	1706	1747	−0.97
57	1715	0.037836	0.000935	0.281660	0.000012	−39.3	0.7	−2.2	0.8	2226	2429	−0.97
58	1824	0.014728	0.000372	0.281246	0.000015	−54.0	0.7	−13.8	0.8	2751	3139	−0.99
59	1783	0.004581	0.000101	0.281122	0.000008	−58.4	0.6	−18.8	0.7	2897	3374	−1.00
60	1914	0.063204	0.001621	0.281915	0.000015	−30.3	0.7	10.4	0.9	1910	1909	−0.95
61	1887	0.034761	0.000845	0.281413	0.000012	−48.1	0.7	−7.1	0.8	2558	2827	−0.97
62	2502	0.092295	0.002075	0.281632	0.000497	−40.3	17.6	12.4	17.7	2334	2274	−0.94
ZK3701-1												
1	431	0.118994	0.002684	0.282113	0.000089	−23.3	3.2	−14.6	3.2	1678	2093	−0.92
2	432	0.033184	0.000797	0.282196	0.000014	−20.4	0.7	−11.1	0.7	1480	1902	−0.98
3	435	0.008374	0.000180	0.281362	0.000011	−49.9	0.6	−40.4	0.7	2582	3496	−0.99
4	437	0.091247	0.002034	0.281835	0.000019	−33.1	0.9	−24.1	0.9	2045	2618	−0.94
5	437	0.143781	0.002961	0.282050	0.000208	−25.5	7.4	−16.8	7.4	1783	2217	−0.91
6	439	0.135740	0.002601	0.282555	0.000095	−7.7	3.4	1.2	3.5	1030	1228	−0.92
7	439	0.068272	0.001732	0.281993	0.000015	−27.5	0.7	−18.4	0.8	1805	2308	−0.95
8	440	0.049220	0.001160	0.282057	0.000013	−25.3	0.7	−16.0	0.7	1689	2175	−0.97
9	440	0.113414	0.002346	0.282433	0.000137	−12.0	4.9	−3.0	4.9	1200	1463	−0.93
10	441	0.020802	0.000537	0.282106	0.000011	−23.6	0.6	−14.0	0.7	1594	2070	−0.98
11	441	0.029565	0.000740	0.282338	0.000014	−15.4	0.7	−5.9	0.7	1282	1622	−0.98
12	441	0.044296	0.001072	0.281934	0.000009	−29.6	0.6	−20.2	0.6	1855	2410	−0.97
13	442	0.138651	0.002962	0.282550	0.000038	−7.9	1.4	1.0	1.5	1048	1243	−0.91
14	442	0.091145	0.001952	0.282594	0.000027	−6.3	1.1	2.9	1.1	955	1140	−0.94
15	442	0.056412	0.001319	0.282491	0.000026	−9.9	1.1	−0.6	1.1	1085	1331	−0.96
16	553	0.153869	0.003101	0.282624	0.000072	−5.2	2.6	5.8	2.7	942	1065	−0.91
17	577	0.032139	0.000855	0.281543	0.000015	−43.5	0.7	−31.1	0.8	2382	3105	−0.97
18	650	0.069367	0.001748	0.282393	0.000017	−13.4	0.8	0.2	0.8	1237	1453	−0.95
19	665	0.094125	0.002235	0.282308	0.000015	−16.4	0.7	−2.7	0.8	1378	1627	−0.93
20	738	0.024848	0.000616	0.281668	0.000012	−39.0	0.7	−23.1	0.7	2197	2794	−0.98
21	752	0.023243	0.000529	0.281227	0.000014	−54.6	0.7	−38.4	0.8	2787	3626	−0.98
22	755	0.029614	0.000750	0.282235	0.000014	−19.0	0.7	−2.7	0.8	1425	1697	−0.98
23	757	0.046427	0.001171	0.282072	0.000015	−24.8	0.7	−8.7	0.8	1669	2024	−0.96

续表 2-2

序号	年龄/Ma	$^{176}Yb/^{177}Hf$	$^{176}Lu/^{177}Hf$	$^{176}Hf/^{177}Hf$	1σ	$\varepsilon_{Hf}(0)$	1σ	$\varepsilon_{Hf}(t)$	1σ	T_{DM1}/Ma	T_{DM2}/Ma	$f_{Lu/Hf}$
24	773	0.019628	0.000487	0.282001	0.000013	−27.3	0.7	−10.5	0.7	1737	2136	−0.99
25	778	0.053177	0.001263	0.281678	0.000021	−38.7	0.9	−22.2	0.9	2220	2776	−0.96
26	796	0.099407	0.002317	0.282688	0.000024	−3.0	1.0	13.4	1.0	828	839	−0.93
27	822	0.021267	0.000522	0.281856	0.000012	−32.4	0.7	−14.5	0.7	1935	2395	−0.98
28	872	0.039380	0.001017	0.282552	0.000011	−7.8	0.6	10.9	0.7	991	1039	−0.97
29	935	0.077279	0.001506	0.282193	0.000030	−20.5	1.2	−0.7	1.2	1513	1730	−0.95
30	949	0.059808	0.001578	0.282155	0.000016	−21.8	0.8	−1.8	0.8	1569	1801	−0.95
31	952	0.032376	0.000791	0.282242	0.000011	−18.7	0.6	1.8	0.7	1417	1604	−0.98
32	953	0.015723	0.000406	0.281255	0.000011	−53.6	0.6	−32.9	0.7	2741	3487	−0.99
33	953	0.050333	0.001206	0.281915	0.000013	−30.3	0.7	−10.0	0.7	1889	2252	−0.96
34	963	0.054990	0.001503	0.282307	0.000015	−16.4	0.7	3.9	0.8	1351	1497	−0.95
35	977	0.030172	0.000747	0.281816	0.000011	−33.8	0.6	−12.7	0.7	2003	2417	−0.98
36	992	0.037567	0.001096	0.281719	0.000014	−37.2	0.7	−16.1	0.8	2155	2609	−0.97
37	1017	0.079826	0.001993	0.282455	0.000014	−11.2	0.7	10.0	0.8	1157	1207	−0.94
38	1054	0.038581	0.000930	0.282220	0.000010	−19.5	0.6	3.2	0.7	1452	1610	−0.97
39	1081	0.079153	0.001907	0.282428	0.000018	−12.2	0.8	10.4	0.9	1194	1234	−0.94
40	1076	0.029332	0.000686	0.281320	0.000017	−51.4	0.8	−28.1	0.8	2674	3323	−0.98
41	1133	0.054480	0.001588	0.282347	0.000017	−15.0	0.8	8.9	0.8	1298	1360	−0.95
42	1083	0.087653	0.001910	0.282303	0.000021	−16.6	0.9	6.0	1.0	1372	1476	−0.94
43	1050	0.039589	0.000943	0.282040	0.000010	−25.9	0.6	−3.3	0.7	1702	1961	−0.97
44	1094	0.057235	0.001453	0.282013	0.000012	−26.8	0.7	−3.7	0.7	1764	2017	−0.96
45	1106	0.068262	0.001715	0.282242	0.000018	−18.7	0.8	4.5	0.9	1452	1579	−0.95
46	1398	0.061655	0.001717	0.281591	0.000015	−41.8	0.7	−12.3	0.8	2369	2726	−0.95
47	1207	0.079849	0.002053	0.282357	0.000024	−14.7	1.0	10.5	1.1	1300	1333	−0.94
48	1257	0.090961	0.002271	0.281888	0.000015	−31.3	0.7	−5.3	0.8	1983	2235	−0.93
49	1266	0.170863	0.002815	0.281021	0.000952	−61.9	33.7	−36.3	33.9	3254	3905	−0.92
50	1431	0.030138	0.000786	0.281891	0.000011	−31.2	0.6	−0.1	0.7	1901	2091	−0.98
51	1544	0.077773	0.002206	0.282261	0.000033	−18.1	1.3	14.0	1.3	1444	1409	−0.93
DBS49												
1	239	0.052759	0.001505	0.282714	0.000009	−2.1	0.6	3.0	0.6	773	973	−0.95
2	261	0.035293	0.000958	0.282193	0.000011	−20.5	0.6	−14.9	0.7	1491	1979	−0.97
3	262	0.030586	0.000805	0.282777	0.000012	0.2	0.7	5.8	0.7	669	833	−0.98
4	263	0.039053	0.001105	0.282717	0.000011	−1.9	0.7	3.7	0.7	760	954	−0.97
5	283	0.058835	0.001547	0.282598	0.000015	−6.2	0.7	−0.2	0.8	940	1186	−0.95
6	283	0.019576	0.000639	0.282662	0.000010	−3.9	0.6	2.2	0.6	828	1051	−0.98
7	284	0.051142	0.001386	0.282693	0.000012	−2.8	0.7	3.2	0.7	800	996	−0.96
8	309	0.039614	0.001063	0.282983	0.000012	7.5	0.7	14.0	0.7	382	410	−0.97
9	344	0.015197	0.000449	0.282681	0.000011	−3.2	0.7	4.2	0.7	797	986	−0.99
10	380	0.033460	0.000935	0.282877	0.000008	3.7	0.6	11.8	0.6	531	591	−0.97
11	289	0.090660	0.002249	0.282226	0.000010	−19.3	0.6	−13.4	0.6	1496	1916	−0.93
12	422	0.187173	0.004573	0.282373	0.000022	−14.1	0.9	−6.1	1.0	1371	1619	−0.86
13	424	0.045297	0.001269	0.282281	0.000009	−17.4	0.6	−8.4	0.6	1380	1748	−0.96
14	430	0.049141	0.001195	0.282315	0.000011	−16.2	0.6	−7.1	0.7	1330	1678	−0.96
15	431	0.042239	0.001286	0.282562	0.000027	−7.4	1.1	1.7	1.1	984	1196	−0.96

续表 2-3

序号	年龄/Ma	$^{176}Yb/^{177}Hf$	$^{176}Lu/^{177}Hf$	$^{176}Hf/^{177}Hf$	1σ	$\varepsilon_{Hf}(0)$	1σ	$\varepsilon_{Hf}(t)$	1σ	T_{DM1}/Ma	T_{DM2}/Ma	$f_{Lu/Hf}$
16	434	0.076451	0.001807	0.282319	0.000013	−16.0	0.7	−7.0	0.7	1345	1677	−0.95
17	434	0.086600	0.002232	0.282450	0.000014	−11.4	0.7	−2.5	0.7	1172	1430	−0.93
18	436	0.044440	0.001135	0.282243	0.000009	−18.7	0.6	−9.4	0.6	1428	1815	−0.97
19	437	0.047243	0.001203	0.282299	0.000010	−16.7	0.6	−7.5	0.6	1352	1706	−0.96
20	440	0.023664	0.000573	0.282334	0.000011	−15.5	0.6	−6.0	0.7	1281	1627	−0.98
21	443	0.047705	0.001173	0.282340	0.000009	−15.3	0.6	−5.9	0.6	1294	1625	−0.96
22	445	0.029739	0.000735	0.282213	0.000011	−19.8	0.6	−10.2	0.7	1455	1864	−0.98
23	446	0.027664	0.000698	0.282463	0.000010	−10.9	0.6	−1.3	0.7	1107	1375	−0.98
24	447	0.091243	0.002283	0.282282	0.000010	−17.3	0.6	−8.2	0.7	1417	1754	−0.93
25	452	0.049907	0.001204	0.282364	0.000010	−14.4	0.6	−4.8	0.6	1260	1573	−0.96
26	453	0.035761	0.000892	0.282297	0.000010	−16.8	0.6	−7.1	0.7	1344	1699	−0.97
27	459	0.064445	0.001585	0.282350	0.000011	−14.9	0.6	−5.3	0.7	1294	1606	−0.95
28	460	0.037305	0.000979	0.282279	0.000008	−17.5	0.6	−7.6	0.6	1373	1734	−0.97
29	469	0.094543	0.002338	0.282167	0.000014	−21.4	0.7	−11.8	0.7	1585	1971	−0.93
30	518	0.017784	0.000450	0.282189	0.000010	−20.6	0.6	−9.4	0.7	1476	1874	−0.99
31	526	0.030517	0.000678	0.282153	0.000009	−21.9	0.6	−10.6	0.6	1536	1947	−0.98
32	553	0.037119	0.000910	0.282436	0.000010	−11.9	0.6	0.0	0.6	1151	1389	−0.97
33	578	0.016081	0.000417	0.282171	0.000011	−21.3	0.6	−8.7	0.7	1501	1885	−0.99
34	588	0.037551	0.000985	0.281728	0.000011	−36.9	0.6	−24.4	0.7	2136	2748	−0.97
35	600	0.011431	0.000349	0.282390	0.000009	−13.5	0.6	−0.4	0.6	1197	1447	−0.99
36	645	0.027131	0.000640	0.282497	0.000011	−9.7	0.6	4.2	0.7	1057	1225	−0.98
37	650	0.040957	0.000940	0.282073	0.000013	−24.7	0.7	−10.8	0.7	1658	2058	−0.97
38	694	0.042881	0.001005	0.282607	0.000014	−5.8	0.7	9.0	0.8	914	1000	−0.97
39	705	0.069161	0.001452	0.282642	0.000016	−4.6	0.8	10.3	0.8	874	938	−0.96
40	735	0.048856	0.001244	0.282283	0.000011	−17.3	0.7	−1.7	0.7	1377	1624	−0.96
41	751	0.042885	0.001044	0.282094	0.000009	−24.0	0.6	−7.9	0.7	1633	1979	−0.97
42	766	0.073347	0.001749	0.282388	0.000013	−13.6	0.7	2.4	0.7	1245	1421	−0.95
43	775	0.021532	0.000532	0.282003	0.000010	−27.2	0.6	−10.4	0.7	1735	2131	−0.98
44	831	0.021646	0.000532	0.281867	0.000009	−32.0	0.6	−14.0	0.6	1921	2370	−0.98
45	836	0.015589	0.000418	0.282253	0.000011	−18.4	0.6	−0.1	0.7	1388	1618	−0.99
46	897	0.057093	0.001350	0.282315	0.000012	−16.2	0.7	2.9	0.7	1335	1503	−0.96
47	909	0.059302	0.001474	0.282396	0.000012	−13.3	0.7	5.9	0.7	1224	1343	−0.96
48	918	0.024914	0.000568	0.282220	0.000009	−19.5	0.6	0.4	0.7	1439	1653	−0.98
49	928	0.043385	0.001009	0.282106	0.000010	−23.5	0.6	−3.6	0.7	1614	1884	−0.97
50	929	0.089606	0.002213	0.282104	0.000011	−23.6	0.7	−4.5	0.7	1670	1929	−0.93
51	929	0.044398	0.001043	0.282275	0.000014	−17.6	0.7	2.3	0.8	1380	1557	−0.97
52	929	0.024863	0.000557	0.281919	0.000011	−30.2	0.6	−10.0	0.7	1852	2231	−0.98
53	933	0.048681	0.001357	0.281992	0.000013	−27.6	0.7	−7.8	0.7	1788	2115	−0.96
54	942	0.019575	0.000443	0.282000	0.000010	−27.3	0.6	−6.8	0.7	1735	2065	−0.99
55	952	0.095807	0.002261	0.282346	0.000014	−15.1	0.7	4.6	0.8	1323	1452	−0.93
56	953	0.063107	0.001514	0.282193	0.000014	−20.5	0.7	−0.4	0.8	1514	1724	−0.95
57	959	0.053944	0.001144	0.282333	0.000013	−15.5	0.7	5.0	0.8	1303	1437	−0.97
58	961	0.030462	0.000703	0.282066	0.000010	−25.0	0.6	−4.2	0.7	1656	1939	−0.98
59	967	0.042887	0.000952	0.282174	0.000010	−21.2	0.6	−0.4	0.7	1517	1736	−0.97

续表 2-4

序号	年龄/Ma	$^{176}Yb/^{177}Hf$	$^{176}Lu/^{177}Hf$	$^{176}Hf/^{177}Hf$	1σ	$\varepsilon_{Hf}(0)$	1σ	$\varepsilon_{Hf}(t)$	1σ	T_{DM1}/Ma	T_{DM2}/Ma	$f_{Lu/Hf}$
60	968	0.015684	0.000343	0.281992	0.000008	−27.6	0.6	−6.4	0.6	1741	2066	−0.99
61	973	0.015564	0.000414	0.282472	0.000010	−10.6	0.6	10.7	0.7	1086	1132	−0.99
62	975	0.058776	0.001342	0.282481	0.000011	−10.3	0.7	10.4	0.7	1100	1148	−0.96
63	978	0.029871	0.000629	0.282076	0.000010	−24.6	0.6	−3.4	0.7	1639	1909	−0.98
64	984	0.042149	0.000909	0.282126	0.000008	−22.8	0.6	−1.7	0.7	1582	1820	−0.97
65	984	0.032367	0.000762	0.282136	0.000009	−22.5	0.6	−1.2	0.7	1562	1796	−0.98
66	987	0.018791	0.000486	0.282376	0.000010	−14.0	0.6	7.5	0.7	1220	1317	−0.99
67	1000	0.028569	0.000694	0.281938	0.000009	−29.5	0.6	−7.8	0.7	1832	2170	−0.98
68	1004	0.057522	0.001406	0.282132	0.000011	−22.6	0.6	−1.4	0.7	1595	1819	−0.96
69	1011	0.087156	0.002134	0.282158	0.000012	−21.7	0.7	−0.8	0.7	1589	1793	−0.94
70	1012	0.053395	0.001274	0.282077	0.000011	−24.6	0.6	−3.0	0.7	1666	1918	−0.96
71	1109	0.037405	0.000991	0.282199	0.000011	−20.3	0.7	3.6	0.7	1484	1632	−0.97
72	1122	0.062689	0.001533	0.282107	0.000012	−23.5	0.7	0.2	0.7	1635	1828	−0.95
73	1095	0.050768	0.001260	0.282102	0.000011	−23.7	0.6	−0.4	0.7	1631	1837	−0.96
74	1094	0.029649	0.000717	0.282079	0.000010	−24.5	0.6	−0.8	0.7	1639	1860	−0.98
75	1065	0.026806	0.000734	0.282177	0.000010	−21.0	0.6	2.0	0.7	1505	1683	−0.98
76	1266	0.008281	0.000176	0.281972	0.000007	−28.3	0.6	−0.3	0.7	1761	1972	−0.99
77	1561	0.043114	0.001115	0.281525	0.000009	−44.1	0.6	−10.6	0.7	2422	2759	−0.97
78	1469	0.030043	0.000713	0.281668	0.000010	−39.0	0.6	−7.1	0.7	2202	2499	−0.98
79	1587	0.034242	0.000833	0.281416	0.000011	−48.0	0.7	−13.6	0.7	2554	2941	−0.97
80	1587	0.024997	0.000626	0.281645	0.000011	−39.9	0.6	−5.2	0.7	2229	2491	−0.98
81	1817	0.046323	0.001127	0.281486	0.000011	−45.5	0.7	−6.4	0.8	2477	2735	−0.97
82	1872	0.042114	0.000974	0.281636	0.000010	−40.2	0.6	0.4	0.7	2261	2415	−0.97
83	1828	0.037779	0.000970	0.281561	0.000012	−42.8	0.7	−3.3	0.8	2364	2576	−0.97
84	1800	0.036975	0.000878	0.281559	0.000008	−42.9	0.6	−3.8	0.7	2361	2585	−0.97
85	1906	0.054350	0.001289	0.281612	0.000010	−41.0	0.6	−0.1	0.7	2313	2469	−0.96
86	1726	0.028550	0.000705	0.281759	0.000010	−35.8	0.6	1.8	0.7	2077	2220	−0.98
87	1853	0.030933	0.000773	0.281598	0.000010	−41.5	0.6	−1.1	0.7	2301	2482	−0.98
88	1894	0.046174	0.001133	0.281606	0.000008	−41.2	0.6	−0.4	0.7	2312	2475	−0.97
89	1907	0.052776	0.001231	0.281635	0.000010	−40.2	0.6	0.8	0.8	2278	2421	−0.96
90	2189	0.026582	0.000677	0.280657	0.000011	−74.8	0.6	−26.9	0.8	3560	4118	−0.98
91	2457	0.054488	0.001284	0.281136	0.000012	−57.8	0.7	−4.9	0.8	2967	3163	−0.96
92	2517	0.027478	0.000785	0.281028	0.000012	−61.7	0.7	−6.6	0.8	3074	3298	−0.98
93	2502	0.030103	0.000758	0.280680	0.000011	−74.0	0.6	−19.2	0.8	3537	3955	−0.98
94	2472	0.031620	0.000756	0.281106	0.000011	−58.9	0.6	−4.8	0.8	2968	3168	−0.98
95	2497	0.024690	0.000564	0.281018	0.000012	−62.0	0.7	−7.0	0.8	3070	3306	−0.98
96	2463	0.033154	0.000827	0.281249	0.000011	−53.9	0.6	0.0	0.8	2779	2906	−0.98
97	2431	0.026602	0.000646	0.281209	0.000010	−55.3	0.6	−1.8	0.8	2820	2978	−0.98
98	2498	0.006544	0.000142	0.281243	0.000008	−54.1	0.6	1.7	0.7	2739	2842	−1.00
99	2473	0.035054	0.000900	0.281222	0.000010	−54.8	0.6	−0.8	0.8	2821	2960	−0.97
100	2698	0.046630	0.001089	0.280995	0.000012	−62.8	0.7	−4.2	0.8	3143	3317	−0.97
101	2826	0.022560	0.000606	0.280982	0.000008	−63.3	0.6	−0.8	0.8	3121	3242	−0.98
102	2658	0.026464	0.000612	0.280970	0.000010	−63.7	0.6	−5.1	0.8	3137	3334	−0.98
103	3016	0.049774	0.001336	0.280704	0.000014	−73.1	0.7	−7.9	0.9	3558	3766	−0.96

续表 2-5

序号	年龄/Ma	$^{176}Yb/^{177}Hf$	$^{176}Lu/^{177}Hf$	$^{176}Hf/^{177}Hf$	1σ	$\varepsilon_{Hf}(0)$	1σ	$\varepsilon_{Hf}(t)$	1σ	T_{DM1}/Ma	T_{DM2}/Ma	$f_{Lu/Hf}$
DBS08												
1	189	0.062031	0.001743	0.282686	0.000016	−3.0	0.8	0.9	0.8	818	1049	−0.95
2	214	0.032003	0.001035	0.282473	0.000013	−10.6	0.7	−6.0	0.7	1103	1453	−0.97
3	226	0.068045	0.001918	0.282155	0.000015	−21.8	0.7	−17.1	0.7	1584	2073	−0.94
4	251	0.017462	0.000508	0.282574	0.000011	−7.0	0.6	−1.6	0.7	947	1235	−0.98
5	262	0.046650	0.001273	0.282643	0.000018	−4.6	0.8	1.0	0.8	868	1102	−0.96
6	263	0.040883	0.001110	0.282452	0.000014	−11.3	0.7	−5.7	0.7	1134	1474	−0.97
7	266	0.030888	0.000903	0.282706	0.000012	−2.3	0.7	3.4	0.7	772	973	−0.97
8	276	0.042313	0.001258	0.282129	0.000014	−22.7	0.7	−16.9	0.7	1593	2100	−0.96
9	288	0.061470	0.001718	0.282693	0.000016	−2.8	0.8	3.2	0.8	808	999	−0.95
10	306	0.017392	0.000466	0.282258	0.000010	−18.2	0.6	−11.6	0.6	1383	1830	−0.99
11	324	0.034188	0.001025	0.282124	0.000013	−22.9	0.7	−16.0	0.7	1589	2088	−0.97
12	329	0.036615	0.000988	0.282348	0.000011	−15.0	0.6	−8.0	0.7	1277	1651	−0.97
13	429	0.032154	0.000871	0.282275	0.000011	−17.6	0.6	−8.4	0.7	1373	1751	−0.97
14	429	0.029471	0.000897	0.281995	0.000021	−27.5	0.9	−18.3	0.9	1763	2295	−0.97
15	431	0.029346	0.000901	0.282441	0.000011	−11.7	0.6	−2.5	0.7	1143	1426	−0.97
16	433	0.021358	0.000548	0.282151	0.000011	−22.0	0.6	−12.6	0.7	1533	1986	−0.98
17	434	0.038332	0.001103	0.282271	0.000012	−17.7	0.7	−8.5	0.7	1388	1761	−0.97
18	434	0.017541	0.000509	0.282662	0.000010	−3.9	0.6	5.5	0.6	825	987	−0.98
19	435	0.063724	0.001726	0.282552	0.000012	−7.8	0.7	1.3	0.7	1010	1222	−0.95
20	438	0.012692	0.000356	0.282262	0.000012	−18.0	0.7	−8.5	0.7	1373	1765	−0.99
21	438	0.018012	0.000513	0.282433	0.000011	−12.0	0.7	−2.5	0.7	1142	1433	−0.98
22	439	0.007139	0.000184	0.282186	0.000010	−20.7	0.6	−11.1	0.7	1471	1910	−0.99
23	440	0.032014	0.000882	0.282398	0.000012	−13.2	0.7	−3.8	0.7	1203	1507	−0.97
24	441	0.009617	0.000244	0.282433	0.000014	−12.0	0.7	−2.4	0.7	1135	1428	−0.99
25	444	0.049195	0.001379	0.282405	0.000013	−13.0	0.7	−3.6	0.7	1209	1501	−0.96
26	734	0.055222	0.001459	0.282174	0.000015	−21.1	0.7	−5.7	0.8	1537	1841	−0.96
27	749	0.059397	0.001659	0.282045	0.000014	−25.7	0.7	−10.0	0.8	1729	2092	−0.95
28	757	0.040162	0.001162	0.281791	0.000012	−34.7	0.7	−18.6	0.7	2059	2565	−0.97
29	757	0.019631	0.000591	0.281756	0.000009	−35.9	0.6	−19.6	0.6	2076	2617	−0.98
30	760	0.068841	0.001981	0.282148	0.000015	−22.1	0.7	−6.3	0.8	1596	1896	−0.94
31	771	0.066298	0.001676	0.282065	0.000016	−25.0	0.8	−8.8	0.8	1701	2044	−0.95
32	789	0.045925	0.001134	0.281921	0.000012	−30.1	0.7	−13.3	0.7	1876	2300	−0.97
33	806	0.047307	0.001299	0.281861	0.000014	−32.2	0.7	−15.1	0.8	1968	2414	−0.96
34	809	0.062587	0.001795	0.281919	0.000014	−30.2	0.7	−13.3	0.8	1913	2317	−0.95
35	813	0.038978	0.001148	0.282098	0.000011	−23.8	0.6	−6.5	0.7	1631	1950	−0.97
36	819	0.020643	0.000630	0.281992	0.000010	−27.6	0.6	−9.8	0.7	1755	2137	−0.98
37	820	0.051640	0.001516	0.282435	0.000010	−11.9	0.6	5.4	0.7	1171	1303	−0.95
38	839	0.027824	0.000767	0.282246	0.000009	−18.6	0.6	−0.5	0.7	1410	1641	−0.98
39	842	0.029449	0.000820	0.282061	0.000011	−25.1	0.6	−7.0	0.7	1668	1999	−0.98
40	845	0.003149	0.000059	0.281727	0.000008	−36.9	0.6	−18.3	0.6	2086	2620	−1.00
41	902	0.072107	0.001583	0.281749	0.000011	−36.2	0.6	−17.2	0.7	2140	2602	−0.95
42	1811	0.022631	0.000574	0.281438	0.000009	−47.2	0.6	−7.5	0.7	2507	2792	−0.98
43	1920	0.021005	0.000553	0.281434	0.000009	−47.3	0.6	−5.2	0.7	2511	2754	−0.98

续表 2-6

序号	年龄/Ma	$^{176}Yb/^{177}Hf$	$^{176}Lu/^{177}Hf$	$^{176}Hf/^{177}Hf$	1σ	$\varepsilon_{Hf}(0)$	1σ	$\varepsilon_{Hf}(t)$	1σ	T_{DM1}/Ma	T_{DM2}/Ma	$f_{Lu/Hf}$
44	1789	0.019266	0.000504	0.281490	0.000011	−45.3	0.7	−6.1	0.8	2431	2697	−0.98
45	1837	0.017059	0.000469	0.281431	0.000010	−47.4	0.6	−7.1	0.7	2508	2787	−0.99
46	1947	0.030571	0.000787	0.281491	0.000009	−45.3	0.6	−2.9	0.7	2447	2649	−0.98
47	1872	0.008124	0.000171	0.281618	0.000010	−40.8	0.6	0.7	0.7	2239	2396	−0.99
48	2043	0.008855	0.000258	0.281351	0.000012	−50.3	0.7	−5.0	0.8	2603	2839	−0.99
49	1872	0.008676	0.000227	0.281416	0.000010	−47.9	0.6	−6.5	0.7	2513	2784	−0.99
50	1854	0.029363	0.000736	0.281491	0.000010	−45.3	0.6	−4.9	0.7	2445	2685	−0.98
51	1833	0.010443	0.000281	0.281537	0.000007	−43.7	0.6	−3.2	0.7	2355	2574	−0.99
52	1866	0.032055	0.000826	0.281560	0.000010	−42.8	0.6	−2.3	0.7	2356	2553	−0.98
53	1885	0.002072	0.000035	0.281550	0.000009	−43.2	0.6	−1.2	0.7	2322	2511	−1.00
54	1991	0.082710	0.002181	0.281603	0.000013	−41.3	0.7	0.2	0.8	2382	2520	−0.93
55	2074	0.038016	0.001073	0.280842	0.000012	−68.3	0.7	−23.5	0.8	3349	3849	−0.97
56	1806	0.041668	0.001061	0.281508	0.000011	−44.7	0.6	−5.8	0.7	2443	2693	−0.97
57	1884	0.015500	0.000433	0.281347	0.000011	−50.4	0.6	−8.9	0.7	2619	2925	−0.99
58	1858	0.017953	0.000513	0.281491	0.000010	−45.3	0.6	−4.5	0.7	2431	2667	−0.98
59	1861	0.015709	0.000401	0.281370	0.000011	−49.6	0.6	−8.6	0.7	2587	2889	−0.99
60	2320	0.010551	0.000314	0.281350	0.000010	−50.3	0.6	1.2	0.8	2607	2728	−0.99
61	2446	0.022181	0.000670	0.281356	0.000012	−50.1	0.7	3.7	0.8	2624	2696	−0.98
62	2384	0.099973	0.002631	0.281416	0.000015	−47.9	0.7	1.3	0.9	2678	2776	−0.92
63	2213	0.039266	0.001127	0.281425	0.000010	−47.6	0.6	0.2	0.8	2560	2695	−0.97
64	2535	0.018224	0.000541	0.281318	0.000009	−51.4	0.6	4.6	0.8	2666	2720	−0.98
65	2521	0.020470	0.000653	0.281193	0.000012	−55.8	0.7	−0.4	0.8	2842	2972	−0.98
66	2498	0.013841	0.000414	0.281302	0.000008	−52.0	0.6	3.4	0.7	2679	2754	−0.99
67	2446	0.007608	0.000191	0.280842	0.000010	−68.3	0.6	−13.8	0.8	3274	3626	−0.99
68	2665	0.023470	0.000726	0.280983	0.000014	−63.3	0.7	−4.7	0.9	3130	3318	−0.98
69	3059	0.032039	0.000875	0.280698	0.000011	−73.4	0.6	−6.2	0.8	3524	3710	−0.97

344~189 Ma 的锆石年龄记录了华南南缘海西期—印支期造山事件及古特提斯构造域向古太平洋构造域转换, 华南南缘已报道有大量该时期碎屑锆石(Li et al., 2012b; 梁新权等, 2013; Hu et al., 2017; Zhang et al., 2019)及少量地质体(Yu et al.,2013; Li et al., 2016)。这些碎屑锆石的 $\varepsilon_{Hf}(t)$ 值介于−17.1~+14.0 之间, $\varepsilon_{Hf}(t)$ 为负值的 T_{DM2} 为 2073~1186 Ma, $\varepsilon_{Hf}(t)$ 为正值的 T_{DM1} 集中于 818~669 Ma, 说明前者主要为古—中元古代地壳物质的再循环, 后者为扬子和华夏地块新元古代拼合后拉张阶段产物。

因此, 矿区 4 件碎屑锆石的年龄很好地响应了华夏地块早期演化、扬子和华夏地块拼合及其显生宙的演化历史, 同时反映它们的源区主要为新元古代和早古生代的物质, 并有少量古元古代甚至泛非期的物质来源。Hf 同位素特征暗示, 这些物质主要为古老地壳物质的再循环, 以及源自元古宙新生地壳物质(图 8)。其中, 443~430 Ma 的锆石年龄与矿区层状火山岩年龄一致, 二者的 Hf 同位素特征相似(Su et al., 2019; Wang et al., 2019; 瞿泓滢等, 2019), 它们应主要源自矿区层状火山岩。

4.3　矿床成因指示

大宝山矿区内层状—似层状矿体成因目前主要有 3 种不同认识, 包括燕山期岩浆热液成矿(刘妬群等, 1985; 蔡锦辉等, 1993; 祝新友等, 2011; 王磊等, 2012)、志留纪海底火山块状硫化物矿床(伍静等, 2014)及泥盆纪海底喷流沉积成矿(葛朝华等, 1987; 徐克勤等, 1996; Gu et al., 2007; 宋世明等, 2007)。持燕山期成矿观点的学者认为, 层状火山岩与花岗闪长(斑)岩为同源岩浆演化的产物, 矿体是该时期岩浆分异后的含矿热液顺层交代围岩的产物, 与燕山期斑岩–矽卡岩型钼–钨矿为同一成矿系统。高精度定年结果表明, 层状火山岩形成于志留纪

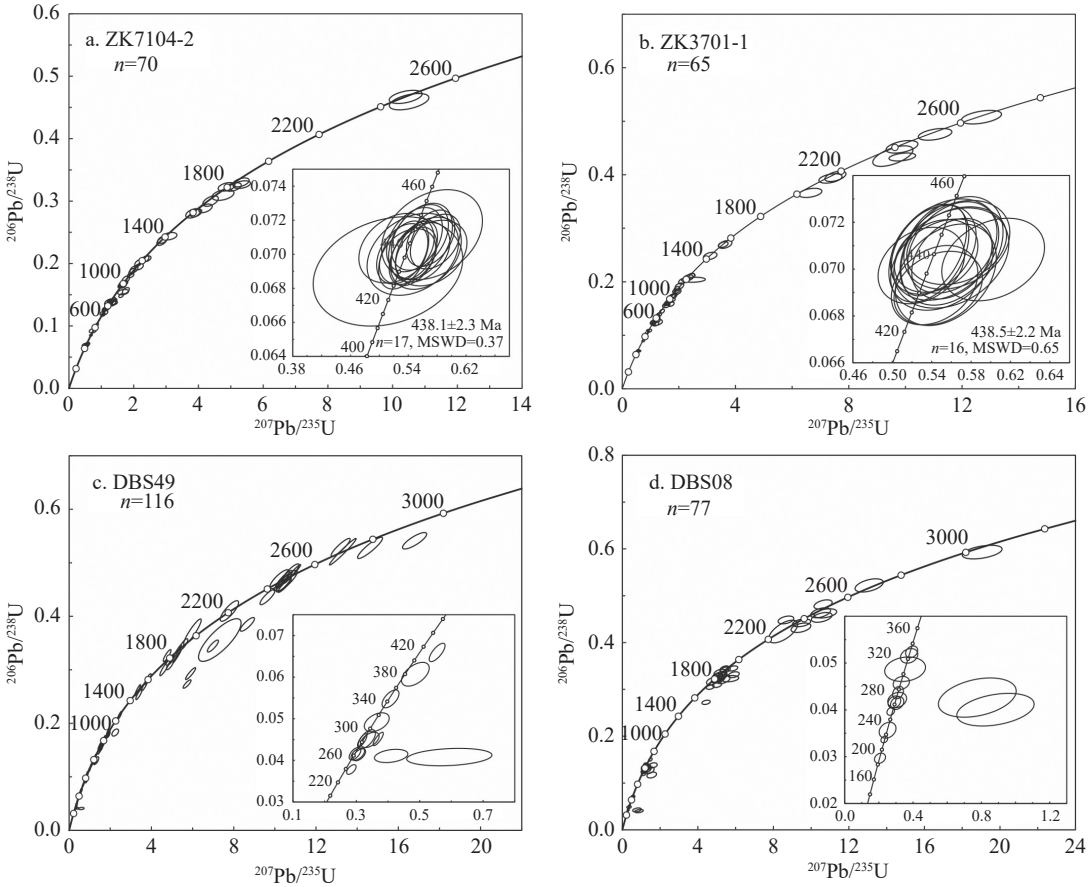


图 6 大宝山矿床赋矿地层样品锆石 U−Pb 年龄谐和图

Fig. 6 Concordia diagrams of the zircon U−Pb ages from the ore-hosting strata samples in the Dabaoshan deposit

(438~425 Ma)(伍静等, 2014; Su et al., 2019; Wang et al., 2019), 与粤北瑶岭志留纪茶园头组火山岩时代一致(Yao et al., 2012)。本次研究确定赋矿地层时代为中泥盆世, 层状火山岩底板为早侏罗世, 它们与志留纪火山岩不是同一套地层, 且形成时代相差太大。因此, 志留纪海底火山块状硫化物型成因模式可以排除。关于大宝山层状—似层状矿体是否存在泥盆纪海底喷流沉积成矿的可能, 葛朝华等(1987)通过钻孔观察, 发现矿区火山熔岩厚达数百米, 夹有最多 3 层具热水沉积特征且厚达数米的微晶钾长石岩, 据此推测粤北大宝山一带泥盆纪海相火山熔岩是多幕火山作用形成的; 刘孝善等(1984)在赋矿地层中发现了多种由硫化物组成的腕足类化石, 并伴生有植物化石碎片及黄铁矿结核等, 认为是沉积−成岩作用的产物。Gu et al.(2007)提出, 大宝山矿区层状—似层状矿体是华南晚古生代盆地或坳陷中产出的大型块状硫化物矿床之一。但是, 由于层状—似层状矿体中缺乏合适的定年矿物, 加之可能受到燕山期岩浆热液叠加的影响, 层状—似层状矿体以往获得的黄铁矿/黄铜矿 Rb-Sr、绢云母 Ar-Ar 年龄介于 167~160 Ma 之间(杜国民等, 2012; 瞿泓滢等, 2014), 与矿区花岗闪长(斑)岩及相关的钼–钨矿化时代一致(Wang et al., 2011), 未能获得泥盆纪成矿年龄。

近年来, 向建华等(2018)对矿区赋矿地层中与菱铁矿−黄铁矿同沉积形成的黑色炭质泥岩进行了 Re-Os 同位素定年, 获得等时线年龄为 387.6±9.9 Ma, 与应立娟等(2017)报道的矿区北部层状矿体中磁黄铁矿 Re-Os 等时线年龄(410±16 Ma)在误差范围内一致。Wang et al.(2018)采用 LA−ICP−MS 微区原位分析了层状—似层状铜–铅–锌多金属矿中的磁黄铁矿成分, 发现 Co/Ni 值几乎均小于 1, 指示其为沉积成因。刘武生等(2019)开展的 LA−ICP−MS 微区原位分析中, 块状、似层状到脉状硫化物中黄铁矿和磁黄铁矿 Co、Zn 和 Se 含量及 Co/Ni 值降低, 其中部分 Co/Ni 值小于 1。傅晓明等(2018)对不

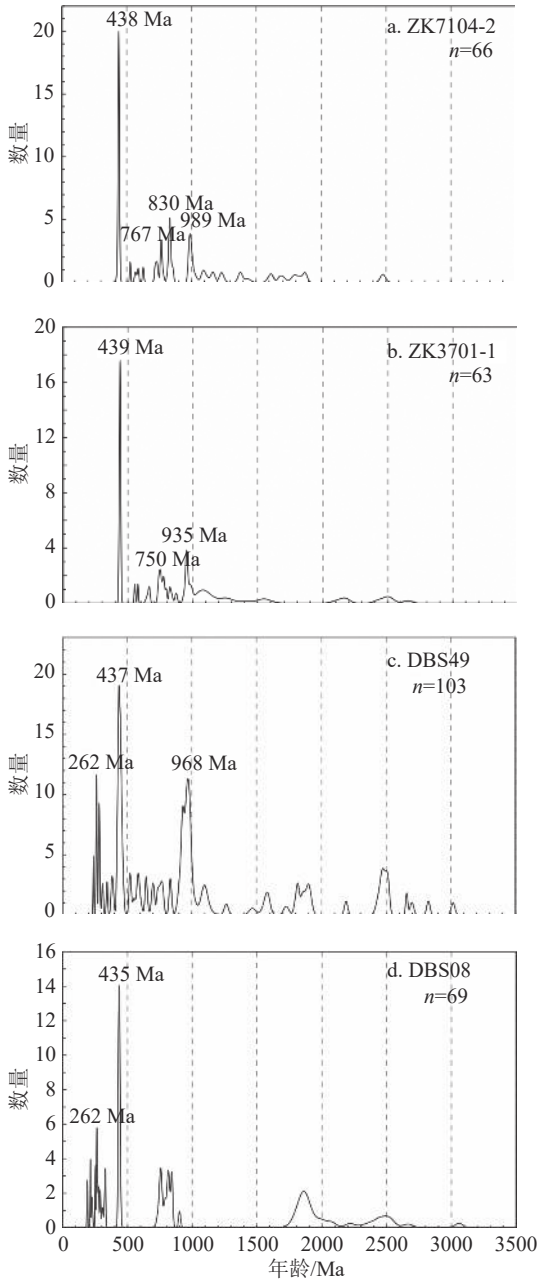


图 7　大宝山矿床赋矿地层样品锆石 U−Pb 年龄谱系图

Fig. 7　Probability density plots of the zircon U−Pb ages from the ore-hosting strata samples in the Dabaoshan deposit

同矿体中的黄铁矿进行了 LA−ICP−MS 微区原位分析, 发现层状—似层状铜−铅−锌多金属矿中黄铁矿相对富集 Ni 和 Ag, 而斑岩−矽卡岩钼−钨矿体中黄铁矿相对富集 Co、Ni、As、Se、Mo。上述研究成果表明, 矿区存在泥盆纪沉积成矿作用, 但受到燕山期岩浆热液成矿事件的叠加。根据前人资料, 中泥盆世棋梓桥组中夹多层火山角砾岩、凝灰岩, 表明该地区在泥盆纪存在火山活动, 具备形成块状硫化物矿

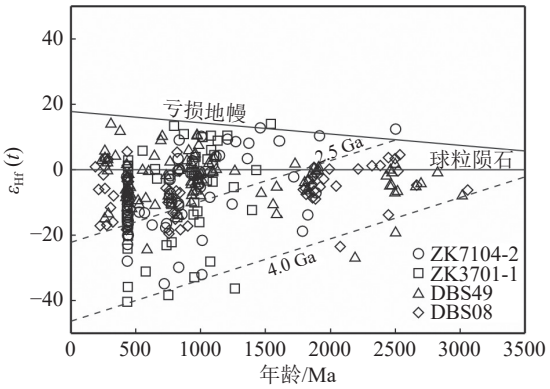


图 8　大宝山矿床赋矿地层样品碎屑锆石年龄−$\varepsilon_{Hf}(t)$ 图解

Fig. 8　U−Pb age vs. $\varepsilon_{Hf}(t)$ diagram of detrital zircons from the ore-hosting strata samples in the Dabaoshan deposit

床的条件(邱世强, 1981; 庄明正, 1986)。以往研究表明, 华南地区有超过 20 个以上的块状硫化物矿床赋存于古生代断陷盆地中, 呈层状—似层状产出, 与泥盆纪—石炭纪海底火山作用相关, 这些矿床多又受到燕山期岩浆热液的改造和叠加(Gu et al., 2007)。赋矿地层主要集中在桂北和粤北盆地的中—上泥盆统, 如泗顶铅锌矿、大宝山铜多金属矿、凡口铅锌矿等; 闽西、萍乡—乐平和信江盆地的中—上石炭统, 如城门山铜矿、武山铜矿、东乡铜矿、永平铜矿等; 下扬子盆地的中石炭统, 如铜官山铜矿、新桥铜多金属矿、冬瓜山铜金矿等(葛朝华等, 1986; 顾连兴等, 2003; Gu et al., 2007)。

综上分析, 矿区志留纪层状火山岩之上为泥盆纪地层及其中赋存的层状—似层状矿体, 之下为侏罗纪金鸡组及其中赋存的脉状矿体(图 9), 这一认识与钻孔编录及野外观察一致。在矿区南采场, 可见层状火山岩与底板侏罗纪地层为断层接触关系, 该断层(F)为一北西向的逆掩断层, 层状火山岩和泥盆系推覆至侏罗系之上, 而侏罗系粉砂岩未见显著的热接触变质作用, 且接触带上可见断层角砾。区域上北西向断层可以穿过广东凡口一直延续到湖南千里山—骑田岭地区, 该断层的准确活动时代尚需要进一步研究。但已有研究表明, 燕山期(153~147 Ma)古太平洋板块向华南板块为低角度俯冲, 可以形成朝北西逆冲的推覆构造(Li et al., 2020)。因此, 本研究认为层状—似层状矿体先经历了泥盆纪海底喷流沉积成矿作用, 后受到燕山期岩浆热液叠加成矿。

5　结　论

(1)大宝山矿区层状—似层状铜−铅−锌矿体的

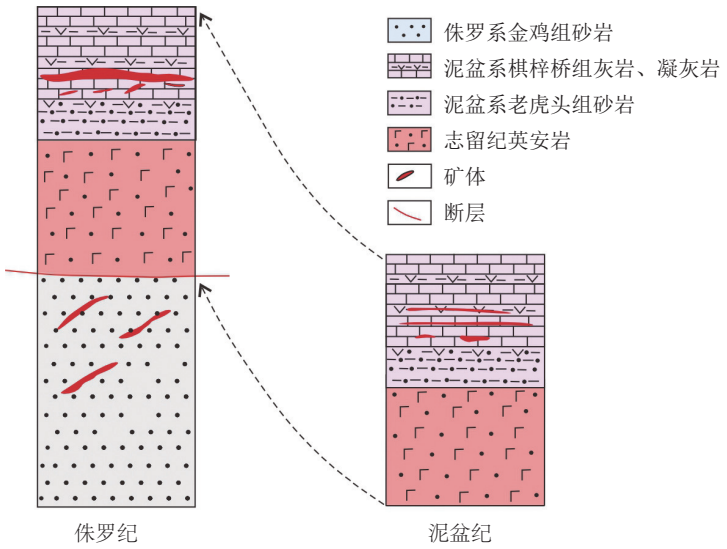


图 9 大宝山矿床赋矿地层与层状火山岩和矿体的关系

Fig. 9 Petrogenetic relationship between the ore-hosting strata and the layered volcanic rocks, orebodies in the Dabaoshan deposit

赋矿地层、层状火山岩底板岩石中最年轻且谐和的碎屑锆石 U-Pb 年龄分别为 438 Ma 和 189 Ma，结合区域地质对比分析，将赋矿地层时代约束在中泥盆世，层状火山岩底板石英砂岩沉积时代限定在早侏罗世。

(2)碎屑锆石 U-Pb 年龄和 Hf 同位素特征显示，岩石源区主要为中—新元古代(1200~750 Ma)和早古生代(440~420 Ma)物质，并有少量古元古代(2500~1600 Ma)甚至泛非期(650~520 Ma)物质，它们主要源自再循环的古老地壳物质及元古宙新生地壳，是华夏地块早期微陆块聚合演化、扬子和华夏地块拼合及其显生宙演化过程的响应。

(3)矿区赋矿的泥盆纪地层不整合覆盖在志留纪层状火山岩之上，后被推覆在早侏罗世金鸡组碎屑岩之上，层状—似层状矿体先经历了泥盆纪海底喷流沉积成矿作用，后受到燕山期岩浆热液叠加成矿。

致谢：野外工作期间得到了广东省大宝山矿业有限公司的帮助；LA-ICP-MS 锆石 U-Pb 测年得到了中国地质大学（武汉）地质过程与矿产资源国家重点实验室胡兆初教授、罗涛副教授的帮助，锆石原位 Hf 同位素分析得到了中国地质调查局武汉地质调查中心童喜润高级工程师的帮助；张维峰副研究员、杨文强高级工程师、邱啸飞研究员仔细阅读了本文初稿，两位审稿专家提出了宝贵的修改意见，在此一并致谢。

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