东秦岭栾川铅锌银矿田辉长岩锆石 SHRIMP U-Pb 年龄及成矿时代*

包志伟 李创举 祁进平
BAO ZhiWei, LI ChuangJu and QI JinPing

中国科学院广州地球化学研究所成矿动力学重点实验室, 广州 510640
Key Laboratory for Metallogenic Dynamics, Guangzhou Institute of Geochemistry, Chinese Academy of Sciences, Guangzhou 510640
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Abstract Luanchuan area, located in eastern Qinling orogen, is famous for its Mo-W and Pb-Zn-Ag mineralizations. The Pb-Zn-Ag mineralization and its relationship with the intensive late Mesozoic tectonic-magmatic activities have long been a debate issue, which mostly due to lack of precise isotopic ages. The Pb-Zn-Ag deposits are mainly hosted in the Mesoproterozoic to Neoproterozoic carbonate strata, and field observation shows that the coarse-grained carbonate-sulfide veins and fine-grained pyrite occur along the fractures of gabbro dykes. The zircons from the gabbro are colorless prism crystals showing clear magmatic oscillatory zoning and are dated at 147.5 ±1.7 Ma (MSWD = 1.5) by SHRIMP U-Pb method. Considering the geological relationship of the gabbro and the ore-veins, the vein-type Pb-Zn-Ag mineralization is undoubtedly postdate the intrusion of the gabbro, i.e., the vein-type Pb-Zn-Ag mineralization in Luanchuan area took place no earlier than 147.5 ±1.7 Ma.
Key words Gabbro; Pb-Zn-Ag mineralization; Late Mesozoic; Luanchuan; East Qinling

摘 要 东秦岭栾川地区是著名的钼钨和铅锌多金属矿田。矿田内铅锌银矿床的成因及其与晚中生代构造岩浆活动关系一直存在诸多争论,其症结之一就是缺少可靠的同位素定年数据。铅锌银矿床赋存于中-晚元古代浅变质碳酸盐建造,野外地质观察发现碳酸盐-硫化物脉体及细粒黄铁矿呈细脉或浸染状沿辉长岩裂隙分布。辉长岩中锆石为无色透明柱状晶体,阴极发光图像显示清晰的震荡韵律环带,SHRIMP U-Pb 年龄为 147.5 ±1.7 Ma, MSWD = 1.5。根据铅锌矿脉与辉长岩穿插关系,断定成矿作用晚于辉长岩结晶年龄,即不早于 147.5 ±1.7 Ma。
关键词 辉长岩; 铅锌银矿; 晚中生代; 栾川; 东秦岭
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秦岭-大别造山带是一个经历了多阶段构造演化的复杂的大陆碰撞造山带,包括了中元古代-古生代期间多次陆缘裂解、增生和碰撞,三叠纪华北与扬子大陆板块之间的对接,三叠纪-侏罗纪期间造山带地壳缩短(拆离、推覆、A 型俯冲)和白垩纪造山带伸展(陈衍景和富士谷,1992; Chen *et al.*, 2004, 2009; Meng and Zhang, 2000; Ratschbacher *et al.*, 2003; Zheng *et al.*, 2008)。其中,东秦岭造山带构造岩浆活动强烈,有色金属和贵金属成矿作用特别发育,是中国最重要的多金属矿集区之一,最近发现了铁炉坪、冷水北沟、百炉沟、西沟和银洞沟等脉状铅锌银矿床(陈衍景等, 2003; 燕长海,2004; 张静等, 2004,2005,2009; 陈衍景, 2006; 吕文德等,2006; 祁进平等,2006,2007)。

东秦岭钼矿带与中生代花岗质岩浆活动具有密切的时空和成因联系(Chen *et al.*, 2000; 李永峰等,2004; 李诺等,2007; 包志伟等,2009),钼矿带内发育众多铅锌银矿床,后者既可产于中生代花岗岩体的外接触带,呈矽卡岩型矿化,如后窑峪、曲里、银家沟、骆驼山等矿床,也可呈脉状矿化产于远离岩体的断裂破碎带、不整合面等有利构造部位,如银家沟黑山、冷水北沟、西灶沟、老代丈沟、裂子山等矿床。关于该区铅锌银矿床成因,目前争议较大,栾川铅锌银矿田

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第一作者简介: 包志伟, 男, 1963 年生, 博士, 副研究员, 从事岩石及矿床地球化学研究, E-mail: baozw@gig.ac.cn

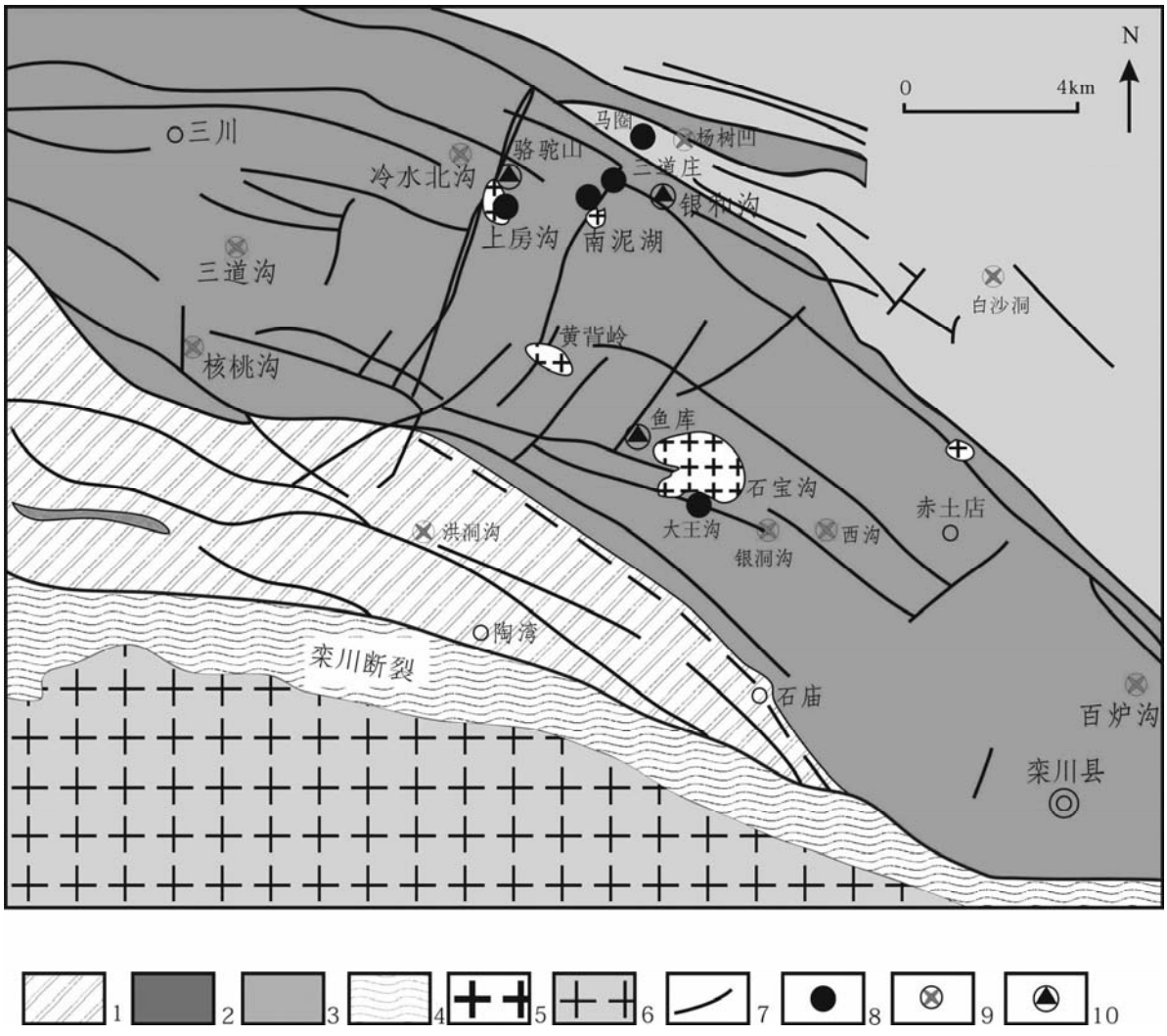

图 1 栾川地区铅锌银矿床分布简图(据毛景文等,2009 修改)

1. 新元古宙陶湾群碳酸盐岩和碎屑岩; 2. 新元古宙栾川群碳酸盐岩、碎屑岩和粗面岩; 3. 中元古宙官道口群含燧石条带状大理岩; 4. 中元古宽坪群大理岩和玄武质岩石; 5. 晚侏罗世花岗岩类; 6. 早白垩世花岗岩类; 7. 断层; 8. 斑岩-矽卡岩型钼(钨)矿床; 9. 矽卡岩型黄铁矿床; 10. 脉状铅锌银矿床

Fig. 1 Distribution of the Pb-Zn-Ag deposits in Luanchuan area, eastern Qinling (Modified from Mao *et al.*, 2009)

1. Neoproterozoic Taowan group carbonate and detrital rocks; 2. Neoproterozoic Luchuan group carbonate, detrital rocks and trachyte; 3. Mesoproterozoic Guandaokou group chert bearing banded marble; 4. Mesoproterozoic Kuanping group marble and basaltic rocks; 5. Late Jurassic granitoids; 6. Early Cretaceous granitoid; 7. Fault; 8. Porphyry-skarn Mo-(W) deposit; 9. Skarn-type pyrite deposit; 10. Vein-type Pb-Zn-Ag deposit.

的主要观点有三种: 1)认为这些矿床形成于燕山期,属于岩浆热液型(王长明等,2005; 吕文德等,2006; 毛景文等,2009)或热液脉型-矽卡岩型(王长明等,2007); 2)强调矿床的层控特征(矿床常赋存于地球化学活性较高的碳酸盐岩地层中,如栾川群煤窑沟组中的碳酸盐岩), 认为矿床主要形成于中-晚元古代,成因类型包括热水沉积型、密西西比河谷型或沉积-叠加改造型(燕长海,2004; 刘国印等,2007; 严海麒等,2007); 3)主要从流体包裹体中含量大量 CO_2 包体及其构造对脉状矿体的控制认为这些矿床应为造山型铅锌银矿(陈衍景,2006)。

栾川铅锌银矿田成矿年龄的准确界定对于查明区内铅锌银矿矿床成因以及对深部和外围找矿具有重要意义,前人试图运用热液矿物(包括脉石矿物和金属硫化物)Ar-Ar 或 Rb-Sr 等时线方法确定铅锌银矿形成年龄(燕长海,2004; 祁进平等,2009)。然而,所测矿物中不同期次流体共存、过剩 Ar 普遍存在、水/岩相互作用过程对流体同位素体系的影响以及同位素体系平衡性等问题, 所获年龄数据存在诸多不确定因素。本文报道了栾川赤土店地区辉绿岩 SHRIMP 锆石 U-Pb 定年结果,根据脉状铅锌银矿与辉绿岩的地质关系较可靠地给出了成矿年龄上限。

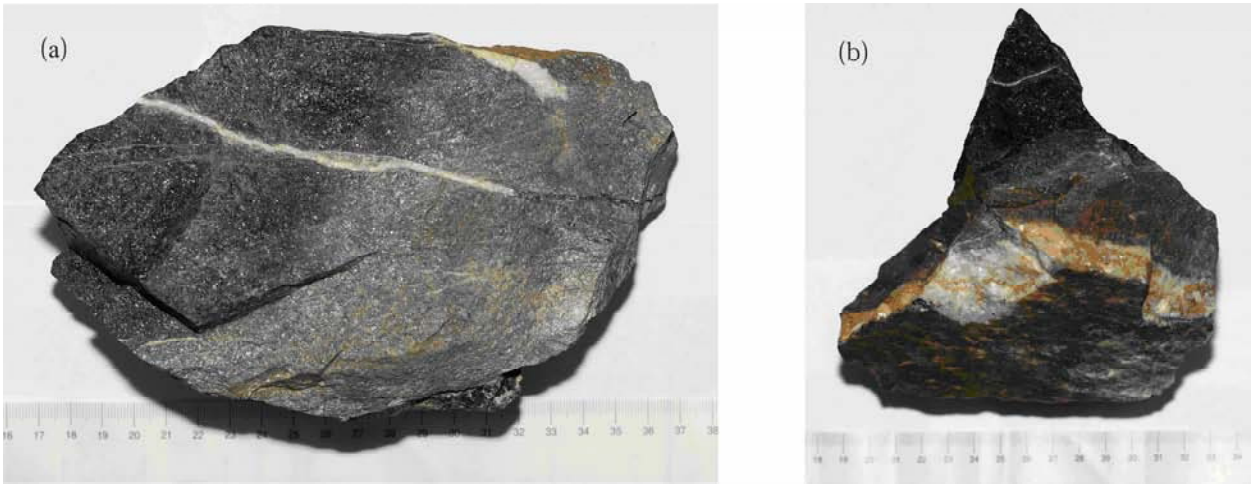

图 2 西沟铅锌银矿区辉长岩中的碳酸盐硫化物细脉

(a)沿裂隙分布的碳酸盐、方铅矿细脉及浸染状的细粒黄铁矿；(b)沿裂隙分布的较粗大颗粒的碳酸盐、闪锌矿矿

Fig. 2 Carbonate-sulfide veins in the gabbro from the Xigou Pb-Zn-Ag deposit

(a) carbonate-galena vein-let and disseminated fine-grained pyrite occurring along the fractures of the gabbro; (b) course-grainded carbonate-sphalerite vein in the gabbro

1 栾川铅锌银矿田地质特征

栾川铅锌银矿田位于东秦岭多金属成矿带的东段，主要矿床包括杨树凹、冷水北沟、西沟、银洞沟、百炉沟等多处铅锌银矿床。这些矿床在空间上与花岗质侵入体及其相关的斑岩-矽卡岩型钼矿床非常接近，如上房沟、南泥湖-三道超大型斑岩-矽卡岩钼矿床（图 1）。脉状铅锌银矿与钼矿床密切的空间关系这一地质现象已引起不少地质学家的重视，毛景文等(2009)明确提出这些脉状铅锌银矿与斑岩钼矿互为找矿勘查的标志。

矿田铅锌矿体多沿北东向和/或北西向断裂分布，容矿岩石为新元古宙栾川群白云母片岩、炭质千枚岩、石英岩和大理岩和中元古宙官道口群含燧石条带大理岩。矿田内发育数条侵入于新元古宙栾川群南泥湖组地层中的北西-北西西走向的辉长岩，岩石呈灰黑色，辉长-辉绿结构，具有不同程度的绢云母化、绿泥石化蚀变。在赤土店附近的西沟矿区见有脉状碳酸盐、方铅矿、闪锌矿脉及细粒黄铁矿沿辉长岩裂隙分布(图 2)。

冷水北沟矿区主要脉体走向为 NNE，倾向 SE，矿体呈脉状、透镜状产于断裂带内。在百炉沟-西沟矿区，矿脉走向 NW，倾向 NE，矿石类型石英脉型和蚀变岩型。成矿过程大致可分为 4 个阶段，即细粒黄铁矿阶段、闪锌矿-白云石阶段、多金属硫化物阶段和石英-碳酸盐阶段。矿石中金属矿物主要有黄铁矿、方铅矿、闪锌矿，含少量黄铜矿、毒砂和辉银矿等，脉石矿物主要有石英、白云石、方解石、绢云母、绿泥石等。围岩蚀变有硅化、绢云母化、碳酸盐化和黄铁矿化。有学者根据栾川地区铅锌矿床(包括骆驼山矽卡岩型和冷水北沟热液脉型铅锌矿)与矿内斑岩-矽卡岩型钼钨矿床密切的空间关系及对成矿流体盐度、H、O 同位素组成、温度变化特征提出脉状铅锌矿与斑岩-矽卡岩钼矿属于同一成矿体系，且均与燕山期岩浆作用有关(吕文德等，2006；叶会寿等，2006；张毅星等，2006)。

2 辉长岩脉锆石年龄测定及铅锌银成矿时间

燕长海(2004)曾报道冷水北沟构造破碎带蚀变岩型铅锌矿的石英 Ar-Ar 坪年龄为 137.2 ± 2.5 Ma。该样品 9 阶段^{40}Ar-^{39}Ar 年龄谱呈马鞍型，可能存在流体包裹体捕获时带来的过剩氩或含钾矿物如绢云母的干扰(Lanphere and Dlrymple, 1976; Kelley, 2002)，使年龄数据的不确定因素难以排除。祁进平等(2009)尝试了黄铁矿、闪锌矿单颗粒 Rb-Sr同位素体系定年，但未能获得等时线年龄。

赤土店西沟铅锌矿区发育辉长岩脉，而且辉长岩脉内发育碳酸盐-硫化物网脉，据此判断辉长岩脉的形成早于铅锌银成矿作用，因此可利用辉长岩锆石 U-Pb 年龄确定成矿年龄的上限。

通过对西沟中粗粒辉长岩样品进行破碎、处理，挑选出无色透明柱状锆石晶体。在中国科学院广州地球化学研究所同位素年代学和地球化学重点实验室对晶体较完整的锆石颗粒进行阴极发光分析，在北京离子探针中心运用 SHRIMP II 对锆石进行 SHRIMP U-Pb 年龄分析(分析方法和流程见：宋彪等，2002)。测试过程中应用标准锆石 TEM(年龄值为 417 Ma)进行元素间的分馏校正，应用 SL13 标准锆石(年龄值为 572 Ma，U 含量为 238ppm)。

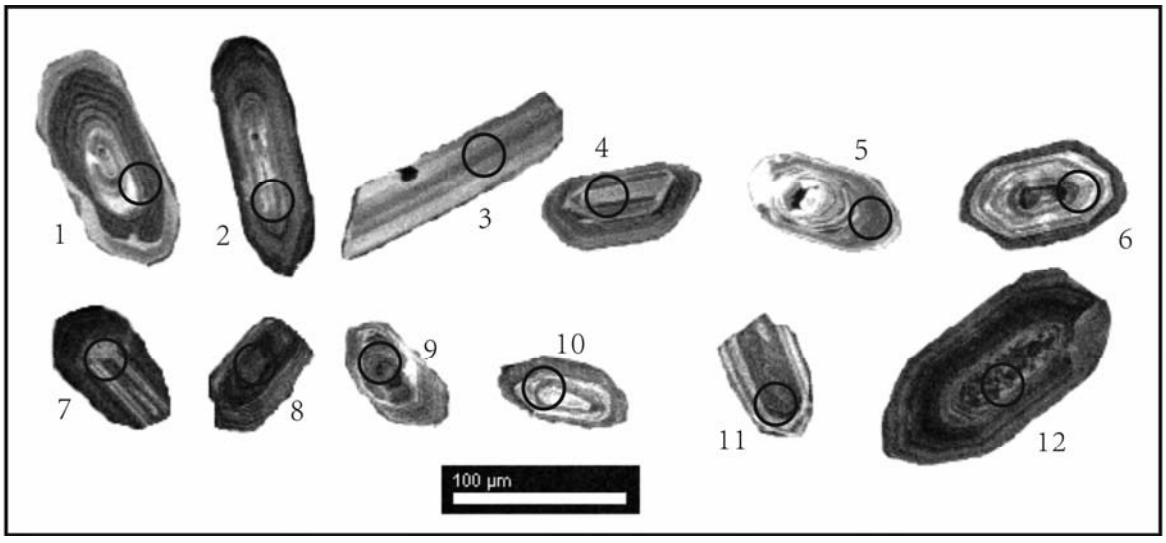

图 3 栾川西沟矿区辉长岩中锆石阴极发光图像及 SHRIMP U-Pb 测试点

Fig. 3 Cathodoluminescence images of zircons of the gabbro from Xigou deposit and the locus for SHRIMP U-Pb determination

表 1 栾川赤土店辉长岩中锆石 SHRIMP U-Pb 同位素分析结果

Table 1 SHRIMP U-Pb analysis results of zircons from the gabbro in the Xigou mine

测点号	Pb^* ($\times10^{-6}$)	Pb_{com} (%)	U ($\times10^{-6}$)	Th ($\times10^{-6}$)	Th/U	$^{206}Pb/^{238}U$ Age (Ma)	$^{207}Pb^*/^{235}U$ 测定值	$^{207}Pb^*/^{235}U$ 1σ	$^{206}Pb^*/^{238}U$ 测定值	$^{206}Pb^*/^{238}U$ 1σ	误差相关系数
HN-7-1	13.8	0.65	698	527	0.78	146.0 ± 2.3	0.1546	4.3	0.0229	1.6	0.375
HN-7-2	17.0	0.24	865	605	0.72	145.8 ± 2.9	0.1595	3.2	0.0229	2.0	0.632
HN-7-3	6.7	1.71	330	439	1.38	148.8 ± 2.9	0.1490	12.4	0.0233	2.0	0.158
HN-7-4	21.2	0.11	1089	504	0.48	144.0 ± 2.2	0.1590	2.4	0.0226	1.6	0.640
HN-7-5	19.9	0.73	981	543	0.57	149.5 ± 2.9	0.1553	6.2	0.0235	2.0	0.318
HN-7-6	13.7	0.35	723	475	0.68	140.2 ± 2.2	0.1528	3.6	0.0220	1.6	0.434
HN-7-7	17.5	0.33	869	517	0.62	148.9 ± 2.5	0.1671	3.5	0.0234	1.7	0.485
HN-7-8	29.2	0.16	1449	719	0.51	149.4 ± 2.3	0.1630	2.1	0.0234	1.5	0.714
HN-7-9	113.7	0.01	1031	1440	1.44	778.1 ± 11.2	1.2387	1.7	0.1283	1.5	0.882
HN-7-10	23.0	0.22	1116	238	0.22	152.7 ± 2.3	0.1642	2.8	0.0240	1.6	0.559
HN-7-11	28.8	0.14	1486	570	0.40	143.8 ± 2.4	0.1597	2.4	0.0226	1.7	0.690
HN-7-12	79.3	0.11	1341	216	0.17	428.8 ± 6.1	0.6806	1.7	0.0688	1.5	0.873

注：Pb^* 和 Pb_{com} 分别代表放射性成因铅和普通铅，以 ^{204}Pb 进行校正。

锆石阴极发光图像韵律环带清晰，应为岩浆成因锆石(图 3)。SHRIMP U-Pb 测试结果见表 1。锆石 Th/U 比值在 0.17 ~ 1.38，具有岩浆锆石特征；锆石普通铅含量较低，说明锆石 U-Pb 体系受后期热液活动影响甚微(Breeding *et al.*, 2004, Bao *et al.*, 2009)。除 3 个数据点(HN-7-9 和 HN-7-12 的 $^{206}Pb/^{238}U$ 年龄偏大，可能为捕获锆石；HN-7-6 的年龄偏低)外，其余 9 个颗粒/测点的年龄较为一致，9 个测试数据在和谐图上非常接近，给出 $^{206}Pb/^{238}U$ 加权平均年龄为 147.5 ± 1.7Ma (MSWD = 1.5)(图 4)，应代表辉长岩结晶年龄。根据碳酸盐-硫化物脉穿插辉长岩脉的事实，确定 147.5 ± 1.7Ma 为脉状铅锌银矿成矿年龄上限，即成矿时间晚于 147.5 ± 1.7Ma。

栾川矿田石宝沟岩体中粗粒黑云母花岗岩和细粒石英正长斑岩的锆石 SHRIMP U-Pb 年龄分别为 147.2 ± 1.7 Ma(MSWD = 1.5)和 145.3 ± 1.7 Ma(MSWD = 1.6)(作者未发表数据)，南泥湖花岗斑岩锆石 LA-ICPMS U-Pb 年龄为 149.56 ± 0.36 Ma(MSWD = 1.5)、上房沟花岗斑岩锆石 LA-ICPMS U-Pb 135.38 ± 0.29 Ma(MSWD = 1.4)(包志伟

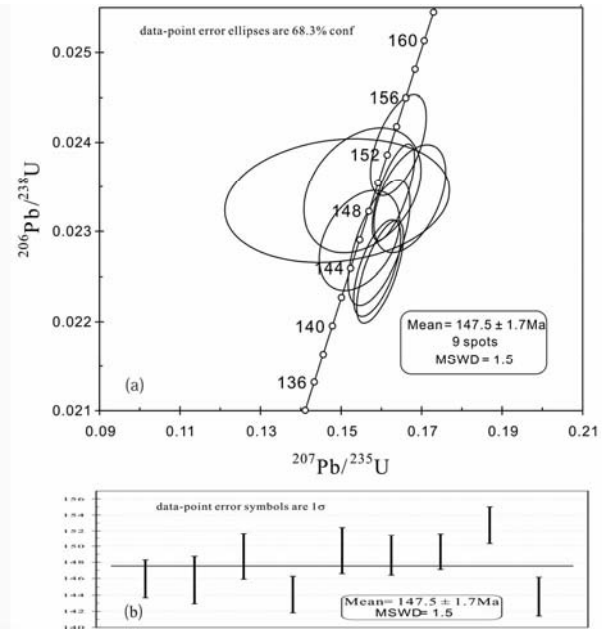

图 4　栾川西沟矿区辉长岩中锆石的 SHRIMP U-Pb 和谐图(a)及$^{206}Pb/^{238}U$年龄加权平均图(b)

Fig. 4　U-Pb concordia diagram (a) and weighted average of $^{206}Pb/^{238}U$ age (b) for zircons of the gabbro from the Xigou deposit

等, 2009)；相邻的合峪花岗岩岩体及其鱼池岭钼矿床(李诺等,2009)等的形成时代亦集中在 130 ~ 150Ma。上述表明,矿田晚侏罗世-早白垩世花岗质岩浆活动及相关成矿作用强烈,与辉长岩近乎同时,可能与铅锌银成矿作用有内在成因联系。

无论如何,本文获得的矿前辉长岩脉锆石铀铅年龄排除了栾川矿田铅锌银矿床作为 SEDEX 型的可能性,应为后生热液矿床。

3　结论

栾川西沟铅锌银矿区内辉长岩锆石 SHRIMP U-Pb 年龄为 147.5 ± 1.7Ma, MSWD = 1.5, 此年龄为代表辉长岩的结晶年龄。根据中粗粒碳酸盐-硫化物脉与辉长岩的穿插关系及细粒黄铁矿沿辉长岩裂隙分布的地质事实,可以断定脉状铅锌银矿的成矿时代应晚于 147.5 ± 1.7Ma。

致谢　野外工作期间得到河南省地质调查院宋要武工程师的大力支持；中国科学院广州地球化学研究所张绍立帮助进行锆石分选。

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