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华南沿海莲花山断裂带控矿构造变形时限:来自锆石U-Pb年龄与地层时代的约束

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提要:莲花山断裂带是中国东南沿海广东省境内一条重要的NE向断裂构造带,同时也是一条重要的锡、钨、铜、铅锌多金属成矿带。本文通过莲花山断裂带和典型矿区野外地质观测及断裂带内发生剪切变形作用的花岗岩体锆石U-Pb年龄测定,初步探讨了莲花山断裂带内韧性变形时限、脆性边界断裂发育时限,以及韧性剪切变形与成矿的关系。研究表明莲花山断裂带内韧性变形时限在129~127 Ma,脆性的边界断裂发育于官草湖组和合水组地层沉积时限之间,莲花山断裂带中韧性剪切变形早于成矿发生时间,韧性剪切变形为成矿提供了容矿空间。

关键词:莲花山断裂带;韧性剪切变形;控矿构造;锆石U-Pb年龄;矿产勘查工程;广东

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Deformation time limit of ore-controlling structures in Lianhuashan fault zone along the South China coast: Constraints from zircon U-Pb age and stratigraphic age

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Abstract: The Lianhuashan fault zone is not only an important NE-striking fault zone in Guangdong Province but also a significant tin, tungsten, copper, lead-zinc polymetallic metallogenic belt. Based on geological field observation of the Lianhuashan fault zone and the typical mining area as well as the measurement of the zircon U-Pb age of the granite intrusive with ductile deformation, the authors preliminarily investigated the time of ductile deformation and boundary fault and the relationship between deformation and

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mineralization in this paper. The result indicates that the ductile deformation time in the Lianhuashan fault zone is around 129−127 Ma, and the brittle boundary fault was developed between the sedimentary time of Guancaohu Formation and the Heshui Formation. The age of ductile shear deformation in the Lianhuashan fault zone was earlier than the mineralization time, and the ductile shear deformation provided the ore−bearing space for mineralization.

Key words: Lianhuashan fault zone; ductile shear deformation; ore−controlling structure; zircon U−Pb age; mineral exploration engineering; Guangdong

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1 引 言

广东莲花山断裂带是中国东南沿海地区一条重要的断裂构造带，为丽水—海丰断裂南西段，其区域构造格架总体呈NE向展布，主要由两条相间约50 km的大致平行的断裂束及夹持于其间的一系列疏密相间、略作等距式多字型展布的断裂构造带、复式褶皱带、岩浆岩带和断裂变质带组成(邱元禧等，1991)。作为北东向的复合构造带，莲花山断裂带印支运动以来经历了多次的挤压与拉张作用，造就了其异彩纷呈的锡铜钨铅锌多金属成矿作用(邱元禧等，1988，1991；徐晓春等，1999；丘增旺等，2016a，b；易其森等，2017；汪礼明等，2018；许汉森等，2018；闫庆贺等，2018；钱龙兵等，2018；朱沛云等，2018)。近年来，随着国家整装勘查项目的实施，莲花山断裂带内不断取得找矿突破，已经逐渐成为广东省最重要的锡铜多金属成矿带(Mao et al., 2013; 丘增旺等, 2014; 钱龙兵等, 2017; 朱沛云等, 2018; 汪礼明等, 2018)，同时在成矿岩体年龄、成矿时代等矿床成因研究方面也取得重要进展(Qiu et al., 2017; 闫庆贺等, 2018; Yan et al., 2018)。但目前，与成矿作用密切相关的构造变形时限及其与多金属成矿之间的关系尚无深入探讨，这限制了对整个断裂带内多金属矿床成矿作用的理解。本文即通过野外地质观察，发生韧性变形的花岗岩体的时代测定，莲花山断裂带内及两侧中生代沉积地层穿切关系来约束变形的时代，并进一步探讨了莲花山断裂带内构造变形与成矿作用的关系，构造变形时限对成矿作用理解的影响，深化了对粤东莲花山成矿带多金属矿床成因认识，以期指导找矿工作。

2 区域地质概况

斜跨粤东地区的莲花山断裂带是中国东南沿海地区海丰—丽水断裂的南西段，属新华夏系和华夏系的复合构造带，是广东省内一条重要的锡、钨、铅锌多金属矿带、构造岩浆带、动热−动力变质带、地热异常带和地震构造带(邱元禧等，1991)(图1)。该带由120多条断裂所组成，广泛发育韧性剪切和脆性变形，据不完全统计，该带已发现的矿床达200多处，其中锡石、硫化物矿床和斑岩型矿床100多处(王军，2018)。

2.1 区域地层

莲花山断裂带南西段发育有古生代、中生代及新生代地层。由老到新有，高滩组($\epsilon_2 g$)变质石英杂砂岩，变粉砂岩与千枚岩、板岩互层；老虎头组($D_2 l$)中细粒、细粒砂岩夹粉砂岩，泥岩；春湾组($D_3 c$)以砂、泥、钙质碎屑岩为主局部夹灰岩；小坪组($T_3 x$)砾岩、砂砾岩、含砾砂岩及石英砂岩；红卫坑组($T_3 hw$)紫灰、灰黑色薄层、中厚层状含砾粗砂岩、细砂岩、粉砂岩夹粉砂质页岩、炭质页岩、煤层(线)；头木冲组($T_3 t$)灰白色中厚层状粗—细粒长石石英砂岩、粉砂岩、粉砂质泥岩为主，夹少量炭质页岩、煤线及煤层，与下伏层位呈整合接触；银瓶山组(TJy)浅灰、黄灰、紫灰、灰白、灰色中厚层−厚层状细−中粒长石石英砂岩夹粉砂质泥岩，与下伏层位呈整合接触；上龙水组($J_1 sl$)灰、深灰、黑色中厚层状粉砂质泥岩、泥岩和泥质粉砂岩互层，夹中细粒长石石英砂岩，与下伏层位呈整合接触；长埔组($J_1 c$)以灰白、浅灰、灰色中厚层及厚层状细粒长石石英砂岩为

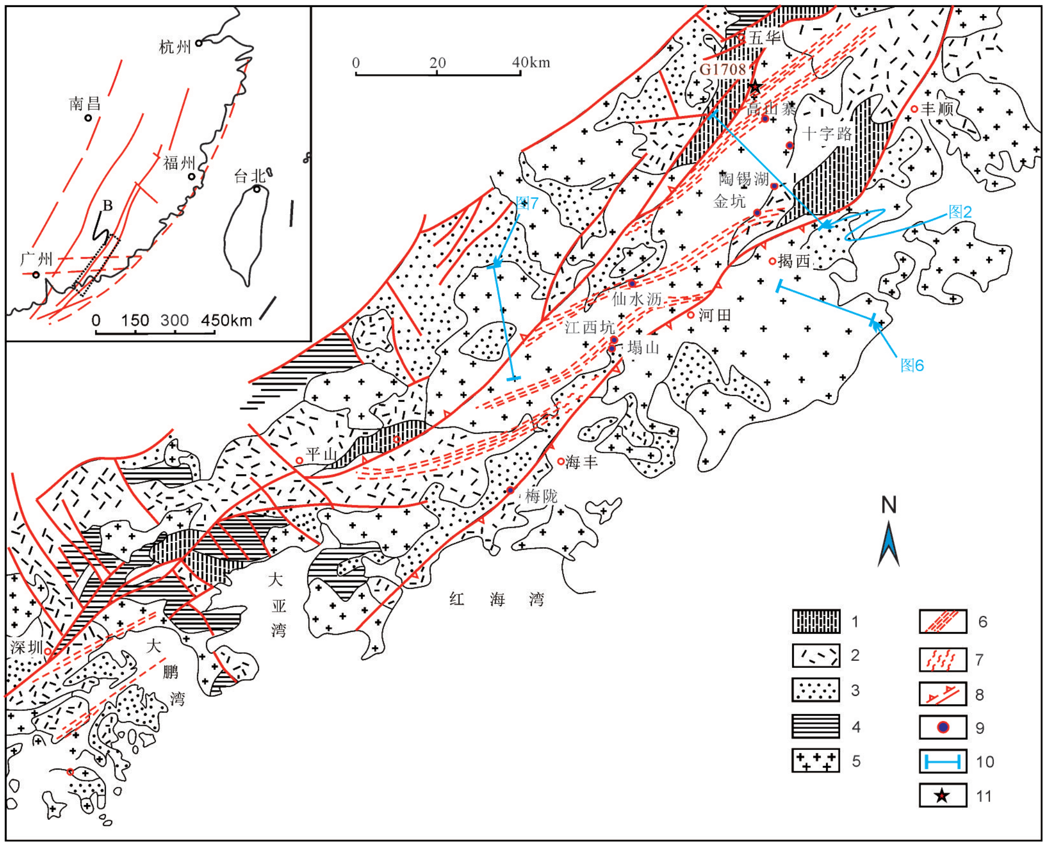

图1 莲花山断裂带构造地质图(据邱元禧等,1988修编)

1—白垩系—新近系;2—上侏罗统火山岩;3—上三叠—下侏罗统砂页岩;4—古生代地层;5—燕山期花岗岩;6—糜棱岩化和糜棱岩;7—片理化和片岩;8—脆性或脆塑性断层;9—多金属矿床/矿点;10—剖面线位置;11—采样点

Fig.1 Structural geological map of the Lianhuashan fault zone (after Qiu Yuanxi et al., 1988)

1−Cretaceous−Neogene; 2−Upper Jurassic volcanic rocks; 3−Upper Triassic−Lower Jurassic sand shale; 4−Paleozoic strata; 5−Yanshanian granite; 6−Mylonitization and myionite; 7−Foliation and schist; 8−Brittle or brittle plastic fault; 9−Polymetallic deposit/mine; 10−Section line; 11−Sampling position

主,夹粉砂岩、泥岩、含炭质泥岩及少量含砾砂岩、砂砾岩,与下伏沉积层呈整合接触;吉水门组(J_1js)以浅灰、灰、灰黑色中厚层—厚层状泥岩为主,夹少量长石石英砂岩、粉砂岩、粉砂质泥岩和含炭质泥岩,与下伏沉积层呈整合接触;漳平组(J_2z)中细粒石英砂岩、泥质粉砂岩夹粉砂质泥岩;热水洞组($J_{2-3}r$)流纹质火山碎屑岩及熔岩,夹少量凝灰质熔岩,与下伏地层不整合接触;水底山组(J_3sd)浅灰、灰黑色泥质岩、凝灰质砂岩、沉凝灰岩、泥岩夹凝灰岩,与下伏沉积层呈整合接触;南山村组(JKn)灰、深灰色流纹质、英安流纹质凝灰岩,熔结凝灰岩,顶部为流纹岩及熔岩,与下伏地层不整合接触;官草湖组(K_1g)灰紫色凝灰砾岩、凝灰质砂砾岩、砂质砾岩夹泥质粉砂岩、凝灰质粉砂岩,与下伏地层呈角度不整合接触;合水组(K_1h),为紫红色厚层状复成分砾岩、含钙质细砂岩、含钙质页岩,夹泥质粉砂岩,与下伏地层呈不整合接触;叶塘组(K_2yt)砂砾岩,与下伏地层角度不整合接触;上覆第四系(Q)砂砾、含砾砂、含砂黏土等。

2.2 岩浆活动

粤东南沿海大陆边缘,岩浆活动十分频繁,莲花山断裂带燕山期火山活动强烈,表现为热水洞组、水底山组、南山村组与官草湖组火山岩地层,主体呈北东向展布,与区域构造线方向一致。莲花山断裂带多期次的构造活动,伴随规模不等的岩浆侵入活动,空间上受区域断裂构造制约,并显示多期活动的特征。中侏罗世为黑云母花岗闪长岩;晚侏罗世有花岗闪长岩,黑云母二长花岗岩及部分花岗

斑岩;早白垩世侵入岩主要为黑云母二长花岗岩,其他为黑云母花岗岩,石英闪长岩,花岗斑岩;晚白垩世侵入岩主要为细粒斑状黑云母二长花岗岩和花岗斑岩,少量基性、超基性岩。

2.3 区域构造

莲花山断裂带总体呈NE向展布,主要由两条大致平行的张性断裂束及夹持于期间的一系列韧性剪切带组成,两条主干断裂在剖面上,倾向相反,倾角相近(图1,图2)。带内主要发育北东东、北东、北西向构造。北东东向构造为韧性剪切构造,总体呈60°左右走向,倾向北西,其韧性变形带的展布具有分段产出,强弱不均的特点。表现为条带状,韧性变形的花岗岩与未变形花岗岩交替出现;在韧性变形花岗岩的中心部位,岩石韧性变形明显,石英发生明显的拉长定向。莲花山断裂南西段南部地层中表现为强片理化带。北东向构造与边界断裂具有相似的性质。北西向构造为一系列走向300°左右的以张扭性为主的断裂构造,往往破坏矿体。

2.4 区域矿产

莲花山断裂带南西段是广东省最重要的成矿带之一,带内构造复杂,导致多期次的岩浆侵位,并为成矿流体提供良好通道和赋矿场所,在不同的围岩条件下形成不同类型的、丰富多彩的内生金属矿床。矿床(点)密集分布,类型复杂,已发现中大型矿床1处,中型矿床6处,小型矿床12处,矿点30多处。以Cu、Sn、Pb、Zn、Ag、W、Mo为主,Au、Fe、Ti、S、As次之。多金属矿床以金坑、陶锡湖、高山寨、仙水沥、江西坑、梅陇和吉水门较为典型。

3 样品及分析方法

对莲花山断裂带中发生韧性剪切变形的粗粒花岗岩岩体进行LA-ICP-MS锆石U-Pb同位素年龄测定。样品采自G1708点(图1,图3)。花岗岩样品,灰白色,石英波状消光,石英和黑云母定向拉长。锆石单矿物挑选在廊坊地科勘探技术服务有限公司完成,制靶、阴极发光图像北京锆年领航科技有限公司完成,LA-ICPMS锆石U-Pb定年分析在中国地质调查局西安地质调查中心完成。将样品破碎至矿物自然粒度后,通过磁选和重液等选矿技术,将矿物初步分离,在双目镜下挑选出晶形完好,透明度和色泽较好的锆石单矿物黏在载玻片的双面胶上,然后用无色透明的环氧树脂固定,待环氧树脂充分固化后,抛光至锆石颗粒露出1/3以上;用配有阴极发光(CL)探头的电子显微镜对锆石进行鉴定并拍照,分析测试前分别用酒精轻擦样品表面,激光剥蚀系统为GeoLas Pro,ICPMS为Agilent 7700x。详细仪器参数和测试过程参见文献(李艳广等,2015)。锆石标准91500作外标进行同位素分馏校正。对于与分析时间有关的U-Th-Pb同位素比值漂移,利用91500的变化采用线性内插的方式进行了校正。锆石样品的U-Pb年龄谐和图绘制和年龄权重平均计算采用Isoplot完成。

4 测试结果

变形的花岗岩样品共选取20颗锆石、共有20个测点。锆石为透明柱状,晶型较好,显示出岩浆

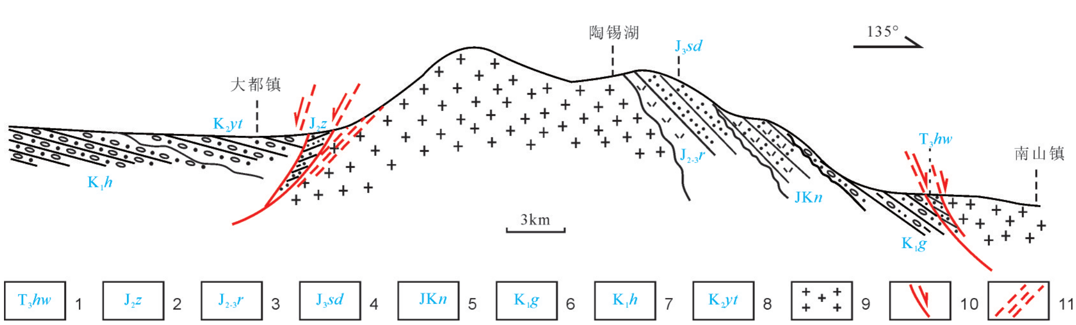

图2 莲花山断裂带大都镇-南山镇剖面图

1—红卫坑组;2—漳平组;3—热水洞组;4—水底山组;5—南山村组;6—官草湖组;7—合水组;8—叶塘组;9—燕山期花岗岩;10—正断层;11—韧性剪切带

Fig. 2 The profile of Dadu Town-Nanshan Town, Lianhuashan Fault Zone

1-Hongweikeng Formation; 2-Zhangping Formation; 3-Reshuidong Formation; 4-Shuidishan Formation; 5-Nanshancun Formation; 6-Guancaohu Formation; 7-Heshui Formation; 8-Yetang Formation; 9-Yanshanian granite; 10-Normal fault; 11-Ductile shear zone

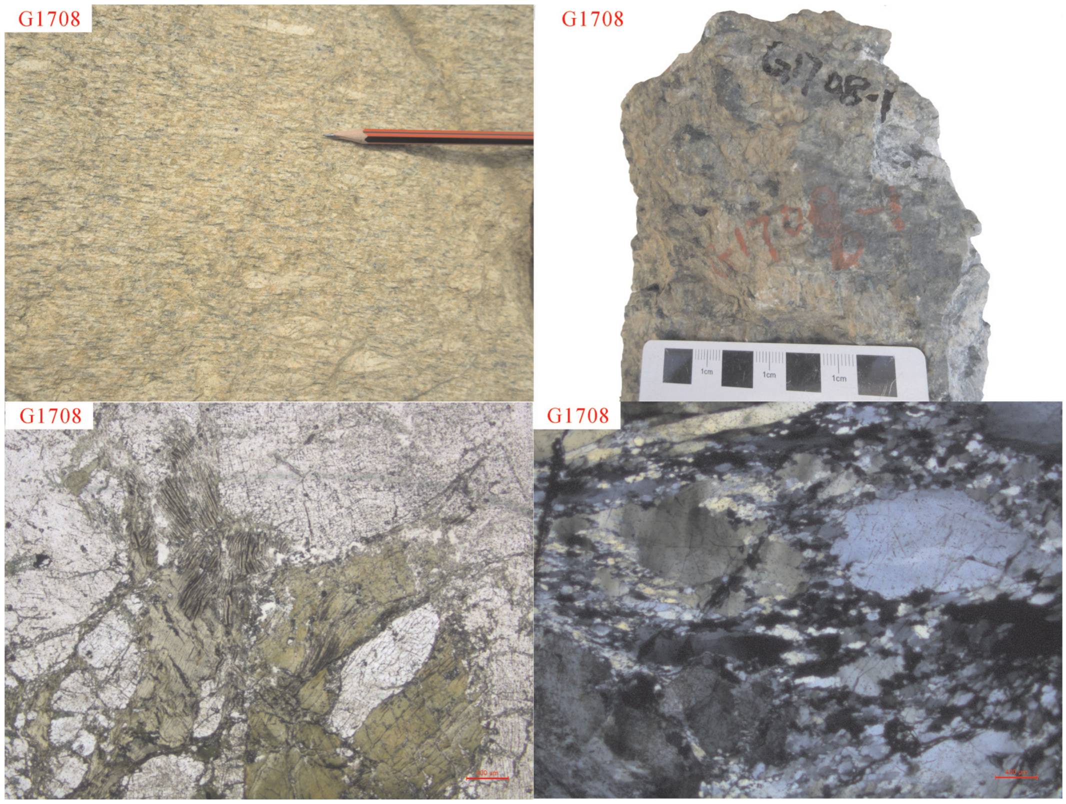

图3 花岗岩野外露头、手标本及显微镜下照片

Fig.3 The photographs of granite in different scales

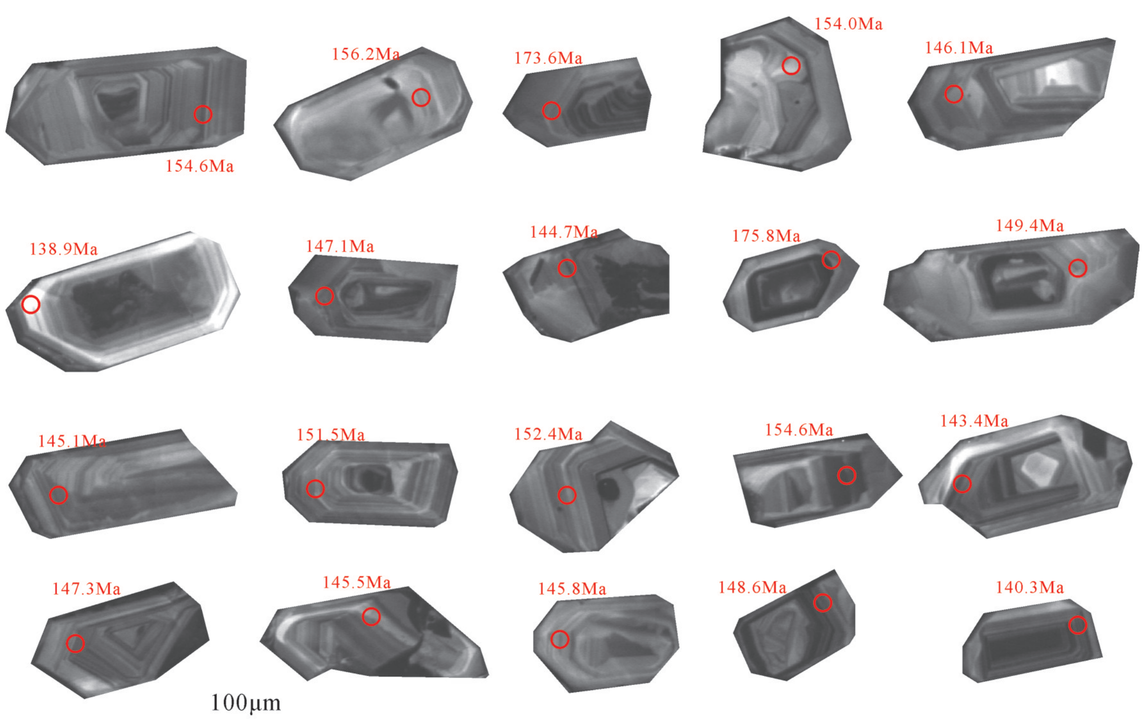

图4 锆石阴极发光及测点图

Fig.4 CL images and measuring point position of the zircons

表1 莲花山断裂带韧性剪切变形花岗岩LA−ICP−MS锆石U−Pb同位素年龄结果

Table 1 Zircon LA−ICP−MS U−Pb analytical results of granite with ductile deformation in Lianhuashan fault zone

点号	^{204}Pb	^{206}Pb	^{207}Pb	^{208}Pb	^{232}Th	^{238}U	$^{238}U/^{232}Th$	同位素比值						年龄/Ma					
								$^{207}Pb/^{206}Pb$	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
135BC01	<1.99	115.74	7.98	0.483	8.32	281.12	33.79	0.04873	0.00496	0.16311	0.01623	0.02427	0.0006	135	223.25	153.4	14.17	154.6	3.78
136BC02	1.78	38.15	1.85	3.3	225.69	390.68	1.73	0.04304	0.00523	0.14552	0.01733	0.02452	0.00067	0.1	112.52	138	15.36	156.2	4.23
137BC03	<3.27	70.37	3.91	3.11	218.38	647.16	2.96	0.04933	0.00519	0.18569	0.01907	0.0273	0.00069	163.3	228.86	172.9	16.33	173.6	4.35
138BC04	<2.78	28.81	1.54	1.3	92	299.31	3.25	0.04744	0.00614	0.15811	0.02004	0.02417	0.00071	70.8	282.65	149.1	17.57	154	4.44
139BC05	<2.36	44.76	2.42	2.97	213.98	490.49	2.29	0.04787	0.00552	0.15124	0.01704	0.02291	0.00061	91.6	253.37	143	15.03	146.1	3.88
140BC06	<2.34	106.42	5.58	7.73	609.91	1226.81	2.01	0.04646	0.00447	0.13954	0.01311	0.02178	0.00052	21.6	216.14	132.6	11.68	138.9	3.27
141BC07	2.02	74.08	4.12	6.3	432.4	805.77	1.86	0.04932	0.00502	0.15698	0.01561	0.02308	0.00057	163	222.04	148.1	13.7	147.1	3.61
142BC08	0.67	48.8	3.17	3.32	238.68	539.61	2.26	0.05757	0.00619	0.18025	0.01891	0.02271	0.0006	513	220.63	168.3	16.27	144.7	3.78
143BC09	2.8	145.69	8.03	12.69	867.93	1323.52	1.52	0.04889	0.00451	0.18632	0.01678	0.02764	0.00064	142.4	203.29	173.5	14.36	175.8	4.03
144BC10	1.55	57.55	2.89	2.39	237.32	616.17	2.60	0.04459	0.00507	0.14419	0.01602	0.02345	0.00062	0.1	178.98	136.8	14.22	149.4	3.89
148BC11	413.3	413.3	413.3	413.3	450.6	457.1	1.01	0.04969	0.00546	0.156	0.01674	0.02277	0.0006	180.3	237.58	147.2	14.71	145.1	3.76
149BC12	0.69	43.99	2.59	4.09	292.89	464.56	1.59	0.0522	0.00594	0.17116	0.01903	0.02378	0.00064	294.3	240.41	160.4	16.5	151.5	4.06
150BC13	<1.89	43.52	2.55	2.76	190.32	456.82	2.40	0.05187	0.00589	0.17109	0.01898	0.02392	0.00065	279.8	240.87	160.4	16.46	152.4	4.08
151BC14	<3.06	187.95	10.45	26.91	2048.77	1944.58	0.95	0.04928	0.00492	0.1649	0.01609	0.02427	0.0006	161	218.2	155	14.02	154.6	3.75
152BC15	2.06	116	6.6	7.18	534.36	1295.14	2.42	0.05047	0.00485	0.15652	0.01467	0.02249	0.00054	216.9	208.23	147.7	12.88	143.4	3.39
153BC16	<1.75	65.23	3.64	4.32	296.19	708.68	2.39	0.04951	0.00526	0.15776	0.01637	0.02311	0.00059	171.9	230.77	148.7	14.36	147.3	3.73
154BC17	0.7	48.9	2.7	5.95	453.44	537.73	1.19	0.04894	0.00552	0.15407	0.01699	0.02283	0.00061	144.9	245.13	145.5	14.94	145.5	3.83
155BC18	<2.72	31.14	1.73	2.78	219.93	341.92	1.55	0.0492	0.0063	0.15514	0.01945	0.02287	0.00067	157.1	274.97	146.4	17.1	145.8	4.21
156BC19	<2.86	108.62	5.96	7.08	517.78	1169.71	2.26	0.04864	0.00467	0.15638	0.01465	0.02332	0.00056	130.5	211.41	147.5	12.87	148.6	3.5
157BC20	<0.00	166.3	9.06	9.61	773.44	1897.21	2.45	0.04828	0.00441	0.14653	0.01306	0.02201	0.00051	113.1	202.36	138.8	11.56	140.3	3.2

锆石振荡环带（图4）。数据见表1。在年龄谐和图上，数据点均在谐和线上或附近。谐和年龄为（147.3±0.8）Ma（n=16，MSWD=0.033）（图5）。

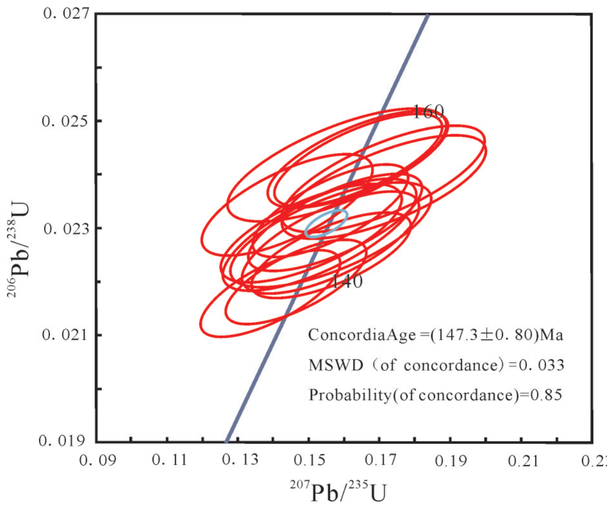

图5 锆石U-Pb年龄谐和图

Fig.5 U-Pb Concordia diagram of zircons in granite with ductile deformation

5 讨 论

5.1 中生代以来莲花山断裂带构造变形时限

印支运动以来莲花山断裂带经历了多次挤压和拉张作用，具体可划分为4个变形变质期：（1）印支期，形成北东向复式褶皱和断裂，并发生轻微的区域动力变质；（2）燕山二幕（中侏罗世），带内地层再次褶皱和断裂，并形成3条近雁列的北东东向递进变质带；（3）燕山三幕（晚侏罗世），断裂再次发生强烈左行压扭，受北东向基底断裂控制，在断裂带内形成一系列与主断裂斜交，走向北东东，产状平缓，以强烈塑性递进形变为特征的韧性剪切带；（4）燕山晚期（白垩纪）以来，发生过多次拉张与挤压，在挤压期，带内地层发生宽缓褶皱，沿断裂带发生碎裂变形为主的动力作用（邱元禧等，1991）。已有的研究表明莲花山断裂带内成矿作用和燕山三幕形成的一系列与主断裂斜交，走向北东东的韧性剪切带关系密切（梁敦杰和谢佑才，1988；邱元禧等，1988，1991）。目前，韧性剪切的时代还缺乏精确的约束。本次工作采集了五华县城附近发生韧性剪切变形的花岗岩，其锆石U-Pb的LA-ICPMS定年结果显示花岗岩的侵位年龄为（147.3±0.8）Ma，而韧性变形发生于花岗岩体内，说明其韧性变形发生在147 Ma之后，在单颗粒锆石年龄中岩体最小的年龄值为138.9 Ma，更进一步说，韧性变形应该发生于138.9 Ma之后。燕山运动以来，莲花山断裂带发生多期次构造活动，从莲花山断裂带形态上看，莲花山断裂带韧性剪切变形不越过边界断裂，同时在莲花山断裂带外围地层和岩体中未见韧性剪切变形（图1，图6，图7），NE向边界断裂晚于韧性剪切变形时代，莲花山断裂带西部边界断裂控制了白垩纪沉积盆地，盆地地层合水组和叶塘组（图2），虽然官草湖组在边界断裂内，但从野外观测来看，官草湖组地层没有发生韧性剪切变形，合水组复成分砾岩和叶塘组砂砾岩也没有发生韧性变形（图8），所以莲

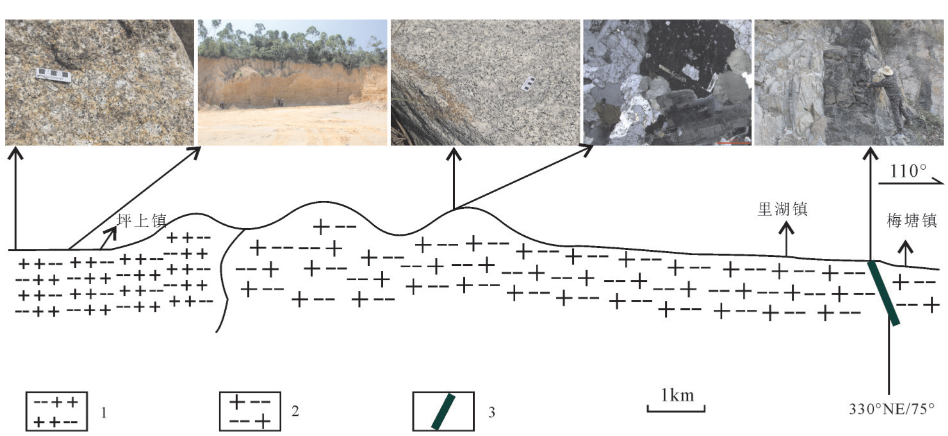

图6 莲花山断裂带外围坪上—里湖剖面图

1—中粒黑云母二长花岗岩；2—粗粒黑云母二长花岗岩；3—辉绿岩脉

Fig. 6 The profile of Pingshan Town-Lihu Town in the outside of Lianhuashan fault zone

1-Medium grained biotite adamellite; 2-Coarse grained biotite adamellite; 3-Diabase dike

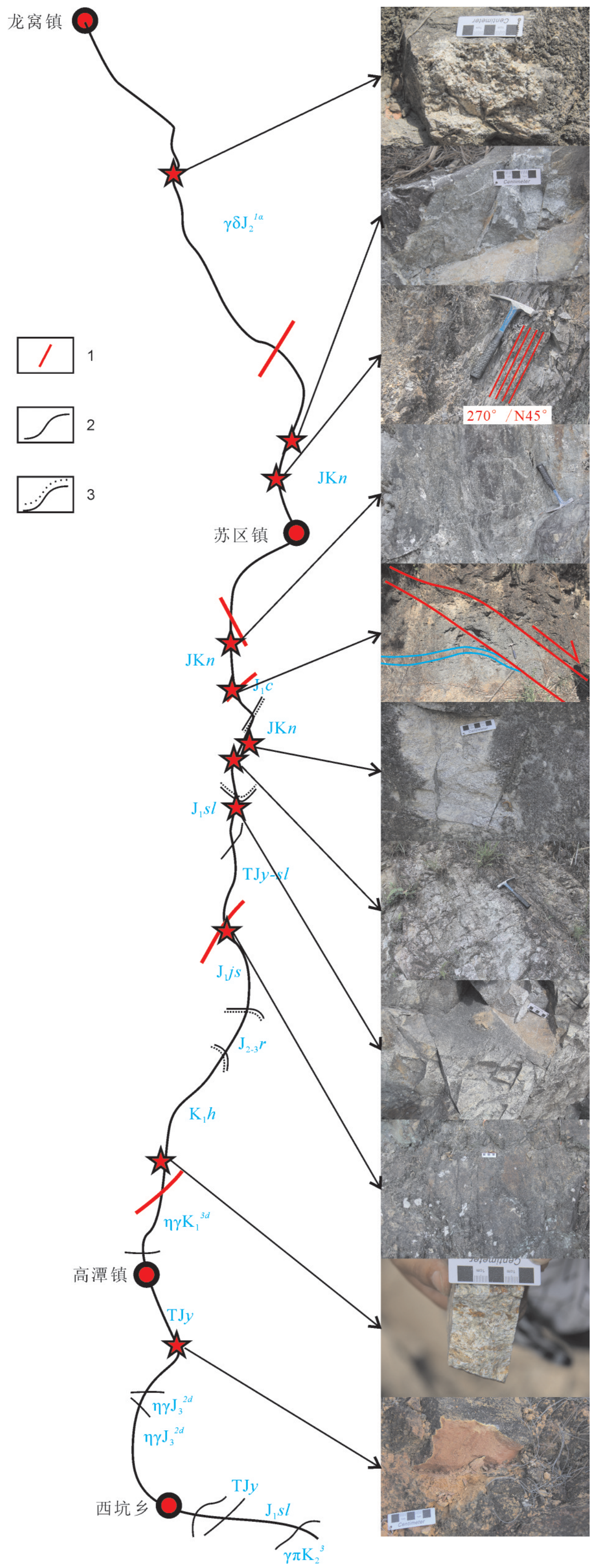

图7 莲花山断裂带外围龙窝—高潭路线观测图

1—断层；2—地层界线；3—不整合面；TJ*y*—银屏山组；TJ*y*–*sl*—银屏山—上龙水组并层；J_1sl—上龙水组；J_1c—长埔组；J_1js—吉水门组；$J_{2-3}r$—热水洞组；JK*n*—南山村组；K_1h—合水组；$\gamma\delta J_2^{1a}$—中细粒斑状角闪黑云母花岗闪长岩；$\eta\gamma J_3^{2d}$—中细粒斑状黑云母二长花岗岩；$\eta\gamma K_1^{3d}$：细粒斑状黑云母二长花岗岩；$\gamma\pi K_2^3$—花岗斑岩

Fig. 7 Observation map of Longwo Town–Gaotan Town route around the Lianhuashan fault zone

1–Fault; 2–Stratigraphic boundary; 3–Unconformity; TJ*y*–Yinpingshan Formation; TJ*y*–*sl*–Yinpingshan–Shanglongshui combination Formation; J_1sl–Shanglongshui Formation; J_1c–Changpu Formation; J_1js–Jishuimen Formation; $J_{2-3}r$–Reshuidong Formation; JK*n*–Nanshancun Formation; K_1h–Heshui Formation; $\gamma\delta J_2^{1a}$–Medium–fine–grained porphyritic hornblende biotite granodiorite; $\eta\gamma J_3^{2d}$–Medium–fine–grained porphyritic biotite adamellite; $\eta\gamma K_1^{3d}$–Fine–grained porphyritic biotite adamellite; $\gamma\pi K_2^3$–Granitic porphyry

花山断裂带内韧性剪切变形发生于岩体侵入之后，官草湖组地层沉积之前。前人通过白云母和透长石的Ar–Ar年龄约束了莲花山断裂带韧性变形时限在129.7~117.5 Ma(邹和平等，2000)，官草湖组火山岩Rb–Sr等时线年龄为127.4~122 Ma(黎汉明，1995)。据此约束莲花山断裂带内的韧性变形时间在129.7~127.4 Ma，这与长乐—南澳断裂中同构造变形花岗石闪长岩和闪长岩包体的锆石U–Pb年龄(~130 Ma，李武显等，2013)较为接近，同时推断莲花山断裂带NE向边界断裂发育时间在管草湖组与合水组沉积时限之间(图2)。

5.2 韧性剪切变形时限对成矿的意义

在莲花山断裂带，矿床的分布产出严格受韧性剪切带及其控矿的次级断裂控矿，带内矿体可以产出于不同的地层与岩性。在金坑锡铜铅锌多金属矿床，出露层为中—上侏罗统热水洞组火山熔岩与火山碎屑岩。矿体受区域断裂构造及其派生的次一级断裂控矿，矿体形态产状变化随剪切变形构造的变化而变化。矿脉由多个连续的或间断的扁豆状、透镜状体组成，厚大矿脉与围岩界线清晰(图9a、b)，矿脉充填于韧性变形产生的裂隙中(图9c、d)，矿脉充填后基本没有受到后期扰动，未发生韧性变形，流体出溶是在稳定的条件下完成(图10)，韧性剪切带为热液充填提供了容矿空间。

近年来研究表明，莲花山断裂带内侵入岩体锆

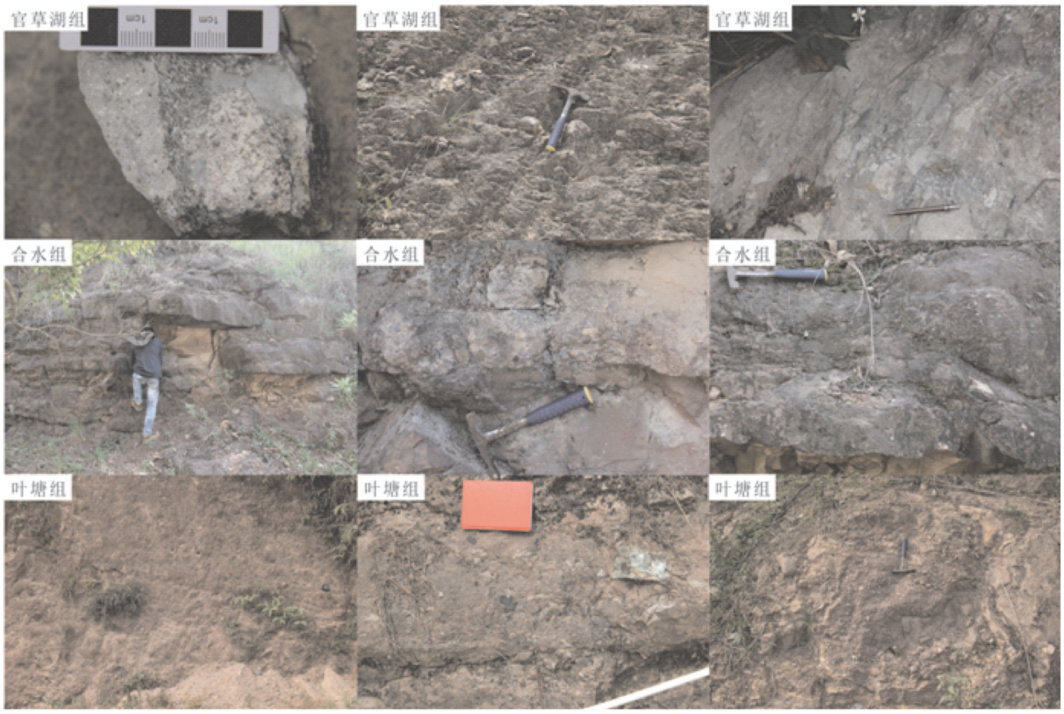

图8 官草湖组、合水组和叶塘组地层特征

Fig.8 Statigraphic photographs of Guancaohu, Heshui and Yetang Formations

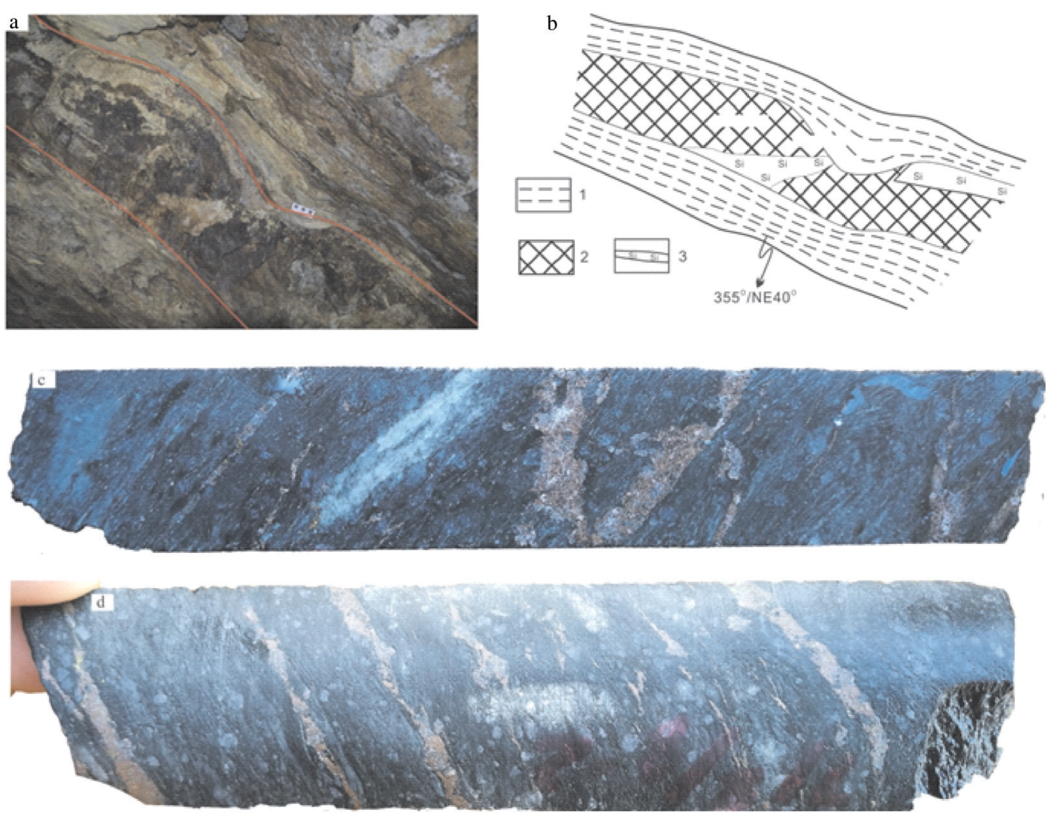

图9 金坑矿床矿体充填与闪锌矿脉充填特征

1—韧性变形凝灰岩;2—矿体;3—石英脉;a-d说明见正文

Fig.9 Characteristics of orebody filling and vein filling in the Jinkeng ore deposit

1-Ductile deformed tuff;2-Orebody;3-Quartz vein;a-d explanation see text

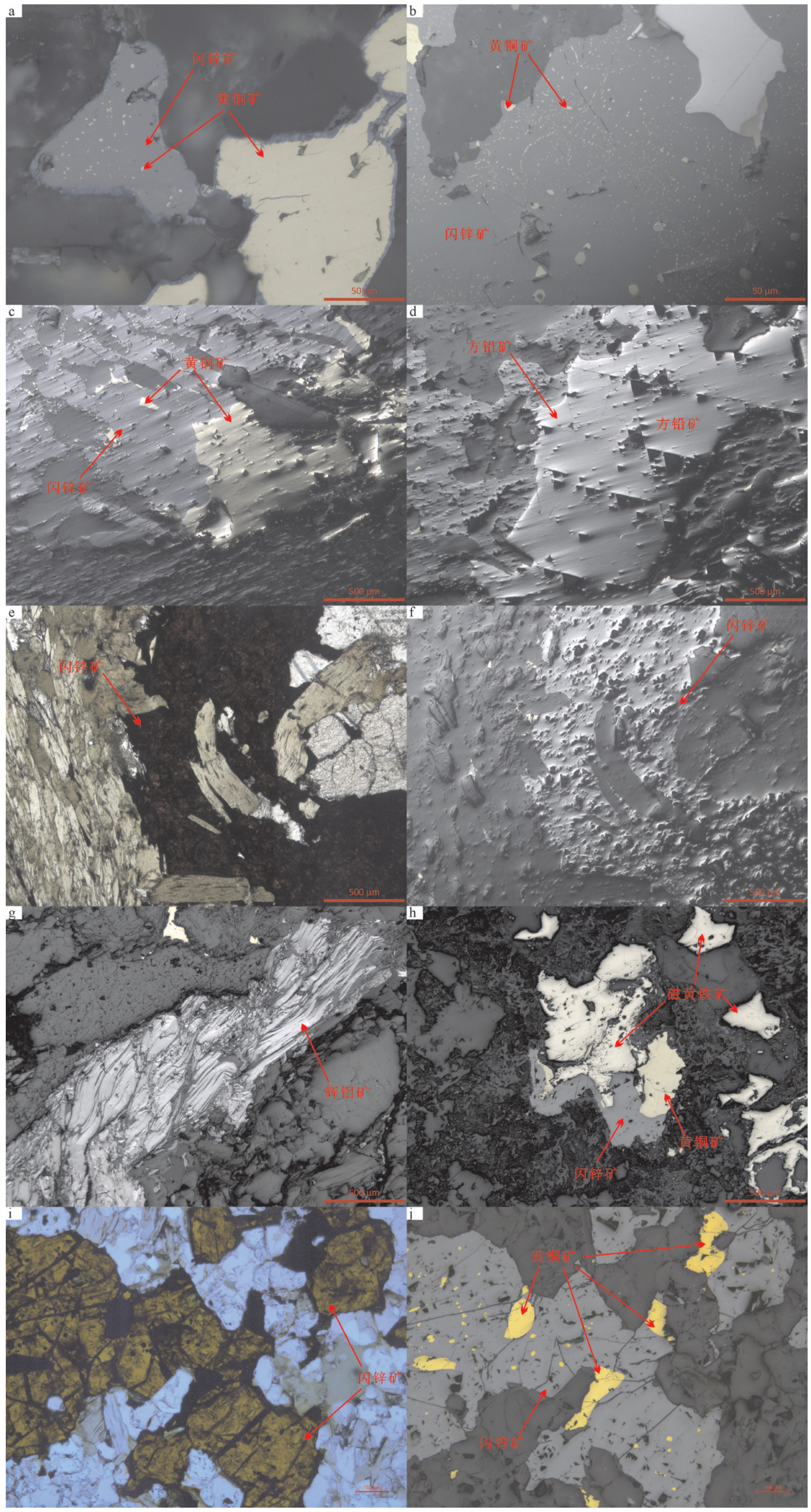

图10 莲花山断裂带不同矿床中矿物镜下特征

a–g—金坑矿床；h—陶锡湖矿床；i–j—仙水沥矿床

Fig.10 Microphotographs of minerals in different deposits of the Lianhuashan fault zone

a–g–Jinkeng deposit; h–Taoxihu deposit; i–j–Xianshuili deposit

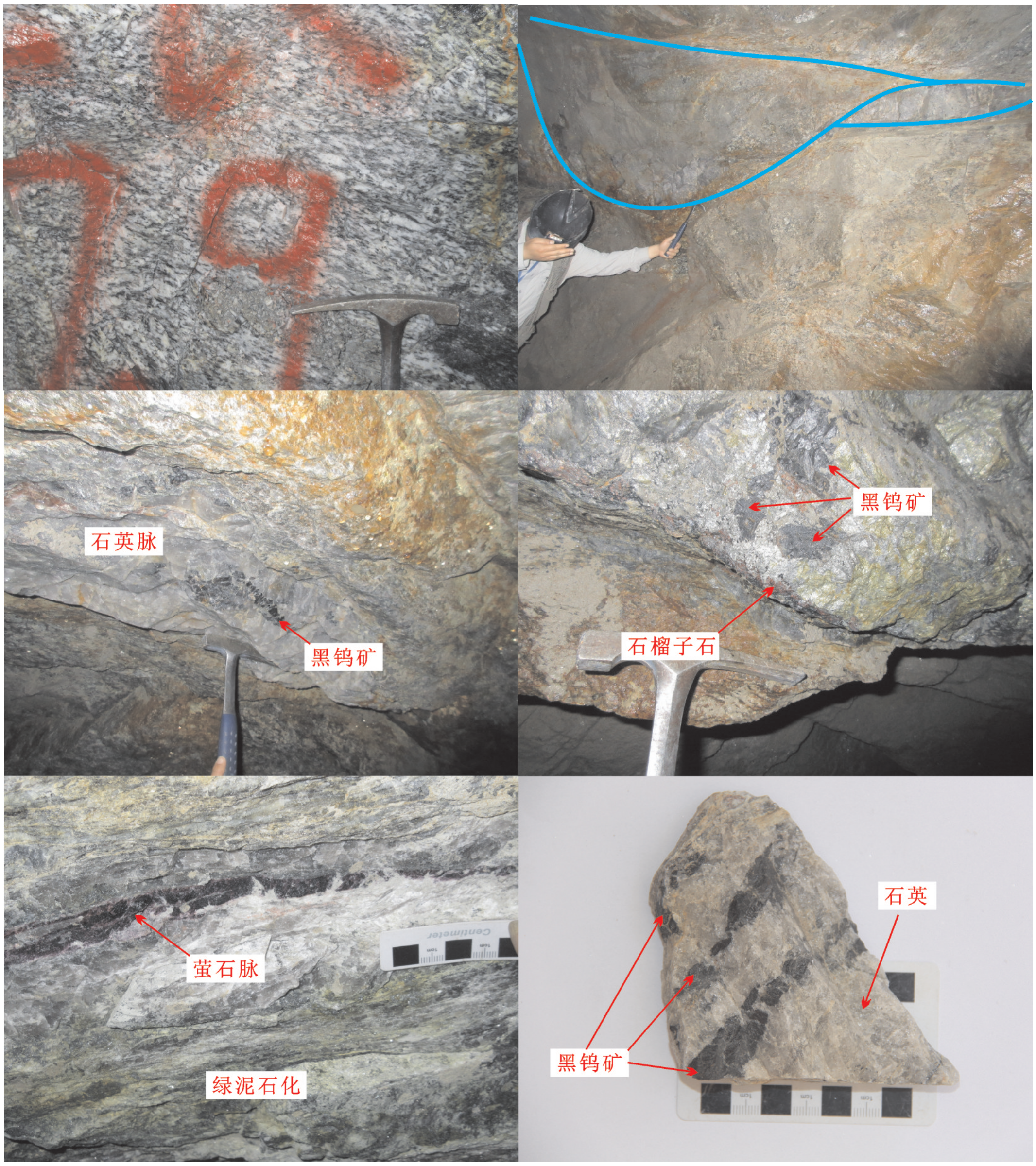

图11 高山寨钨多金属矿体及矿石特征
Fig.11 Characteristics of the orebody and ore from the Gaoshanzhai tungsten polymetallic deposit

石U-Pb年龄多介于146~141 Ma，如陶锡湖锡多金属矿床含锡花岗斑岩(141.8±1.0)Ma，黑云母花岗岩(145.5±1.6)Ma(Yan et al., 2017)，金坑锡多金属矿床黑云母花岗岩和细粒花岗岩年龄分别为(144.7±0.8)Ma和(141.1±1.3)Ma(Qiu et al., 2017)，以辉钼矿Re-Os年龄代表的锡多金属成矿年龄多在139 Ma左右，如金坑矿床的(139.3±2.5)Ma(Qiu et al., 2017)，陶锡湖的(139.0±1.1)Ma(Yan et al., 2017)，三角窝锡矿锡石U-Pb年龄139 Ma(Yan et al., 2018)。从本文看，莲花山断裂带中与成矿有关的韧性变形在129~127 Ma，本次研究镜下观察到的金坑矿床矿物组合为黄铜矿+闪锌矿+方铅矿，陶锡湖矿床矿物组合为黄铜矿+闪锌矿+磁黄铁矿，仙水沥矿床闪锌矿+黄铜矿，这些矿脉充填于韧性剪切带裂隙内(图9, 图10, 图11)，且矿物并未发生成矿后的变形，而高山寨矿床以黑钨矿+白钨矿+辉钼矿组合为主，与前面提到的矿床成矿方式不同。同时，由韧性剪切变形时限约束的铜铅锌成矿时代与陶锡湖矿床和金坑矿床得到的辉钼矿Re-Os年龄并不一致，而且，钨锡钼成矿并不局限于莲花山断裂带内，如

飞鹅山钼矿，出现在断裂带以东，前人测定辉钼矿Re−Os年龄分别为(139.4±2.2)Ma和(140.6±1.9)Ma(李海立等, 2016; Liu et al., 2017)，由此，笔者推断莲花山断裂带内以钨锡钼为主的成矿作用和以铜铅锌为主的成矿作用不是同一期成矿，反映莲花山断裂带内中生代以来至少发育两类多金属成矿作用。

6 结 论

(1)莲花山断裂带内发生韧性剪切变形的花岗岩体，其侵位年龄为(147.3±0.8)Ma。约束莲花山断裂带内的韧性变形时间为129.7~127.5 Ma，NE向边界断裂发育时间在管草湖组与合水组沉积时限之间。

(2)成矿流体充填于韧性剪切带裂隙中，莲花山断裂带中韧性剪切变形为燕山期多金属成矿作用提供了容矿空间。莲花山断裂带内钨锡钼和铜铅锌可能不是同期成矿。

References

Li Haili, Xiao Huiliang, Fan Feipeng, Chen Lezhu, Liu Jianxiong, Chen Xutao. 2016. Molybdenite Re−Os isotopic age of Fei'eshan tungsten and molybdenum polymetallic deposit in Chao'an, Guangdong[J]. Acta Geologica Sinica, 90(2): 231−239(in Chinese with English abstract).

Li Hanming. 1995. Lithostratigraphic division of the Cretaceous in Guangdong[J]. Guangdong Geology, 10(1): 61−68(in Chinese with English abstract).

Li Wuxian, Zhou Xinmin and Li Xianhua. 2003. U−Pb and Ar−Ar datings of deformed igneous rocks from the Changle−Nan'ao fault[J]. Chinese Journal of Geology, 38(1): 22−30(in Chinese with English abstract).

Li Yanguang, Wang Shuangshuang, Liu Minwu, Meng En, Wei Xiaoyan, Zhao Huibo, Jin Mengqi. 2015. U−Pb dating study of Baddeleyite by LA−ICP−MS: Technique and application[J]. Acta Geologica Sinica, 89(12): 2400−2418(in Chinese with English abstract).

Liang Dunjie, Xie Youcai. 1988. Geological structural characteristics of the southwestern sector of the Lianhuashan fault zone, Guangdong province[J]. Regional Geology of China, 2: 126−131 (in Chinese with English abstract).

Liu Peng, Mao Jingwen, Chen Yanbo, Yao Wei, Wang Xiaoyu, Hao Di. 2017. An Early CretaceousW−Sn deposit and its implications in southeast coastal metallogenic belt: Constraints from U−Pb, Re−Os, Ar−Ar geochronology at the Feie'shanW−Sn deposit, SE China[J]. Ore Geology Reviews, 81: 112−122.

Mao Jingwen, Cheng Yanbo, Chen Maohong, Pirajno F. 2013. Major types and time−space distribution of Mesozoic ore deposits in South China and their geodynamic settings[J]. Mineralium Deposita, 48(3): 267−294.

Qian Longbing, Yu Qingliang, Guo Lirong, Yan Lunming, Wen Hui. 2018. On ore−forming grantite of the Taoxihu tin−polymetallic deposit in Jiexi County, Guangdong Province[J]. East China Geology, 39(3): 218−226(in Chinese with English abstract).

Qiu Yuanxi, Qiu Jinsong, Li Huairen. 1988. Basic characteristics and formation mechanism of the Lianhuashan ductile shear zone[J]. Collection of Geomechanics, (8): 19−30(in Chinese).

Qiu Yuanxi, Qiu Jinsong, Li Jianchao, Zhong Hongping. 1991. Deformational and metamorphic features of Lianhuashan fault zone during Meso−Cenozoic time and mechanism of their formation[J]. Bulletin of the Institute of Geomechanics, CAGS, (14): 93−106(in Chinese with English abstract).

Qiu Zengwang, Wang He, Li Shasha, Li Pei, Wei Xiaopeng, Mu Shenglu. 2014. New Progress in exploration and research of Jinkeng Copper−Tin−Lead−Zinc Deposit in Jiexi County, Guangdong Province[J]. Mineral Deposits, (S1): 955−956(in Chinese with English abstract).

Qiu Zengwang, Wang He, Yan Qinghe, Li Shasha, Wang Liming, Bu An, Mu Shenglu, Li Pei, Wei Xiaopeng. 2016a. Zircon U−Pb geochronology and Lu−Hf isotopic composition of quartz porphyry in the Changpu Sn polymetallic deposit, Guangdong Province, SE China and their geological significance[J]. Geochimica, 45(4): 374−386(in Chinese with English abstract).

Qiu Zengwang, Wang He, Yan Qinghe, Li Shasha, Wang Liming, Bu An, Wei Xiaopeng, Li Pei, Mu Shenglu. 2016b. Zircon U−Pb geochronology, geochemistry and Lu−Hf isotopes of granite porphyry in Taoxihu Tin polymetallic deposit, Guangdong Province, SE China and its geological significance[J]. Geotectonica et Metallogenia, 41(3): 516−532(in Chinese with English abstract).

Qiu Zengwang, Yan Qinghe, Li Shasha, Wang He, Tong Laixi, Zhang Rongqing, Wei Xiaopeng, Li Pei, Wang Limin, Bu An, Yan Lunming. 2017. Highly fractionated Early Cretaceous I−type granites and related Sn polymetallic mineralization in the Jinkeng deposit, eastern Guangdong, SE China: Constraints from geochronology, geochemistry, and Hf isotopes[J]. Ore Geology Reviews, 88: 718−738.

Wang Jun. 2018. New progress of basic geology and comprehensive research in the tin−copper polymetallic ore−deposit in the Lianhuashan fault zone integrated exploration area, Guangdong Province[J]. Resources Environment & Engineering, 32(2): 209−211(in Chinese with English abstract).

Wang Liming, Wang Jun, Wang He, Bu An, Li Shasha, Qian Longbing, Wang Wei. 2018. Dynamic metamorphism origin for the Tin−Copper polymetallic mineralization in the Lianhuashan fault, Eastern Guangdong Province[J]. Geotectonica et Metallogenia, 42 (5): 908−917(in Chinese with English abstract).

Xu Hansen, Wang Jianrong, Li Rui, Ling Ken, Zeng Junyue, Yu Deyan.

2018. LA-ICP-MS zircon U-Pb isotopic age, petrogeochemistry characteristics and its metallogenic effect of Guanyinshan pluton, eastern Guangdong Province[J]. Geology and Mineral Resources of South China, 34(1):22-30(in Chinese with English abstract).

Xu Xiaochun, Yue Shucang, Pan Chengrong. 1999. Controlling factors of the metallogenetic time-space distribution of the ore deposits in southeastern China coast[J]. Geology in Anhui, 9(1): 42-44(in Chinese with English abstract).

Yan Qinghe, Li Shasha, Qiu Zengwang, Wang He, Wei Xiaopeng, Li Pei, Dong Rui, Zhang Xiaoyu. 2017. Geochronology, geochemistry and Sr-Nd-Hf-S-Pb isotopes of the Early Cretaceous Taoxihu Sn deposit and related granitoids, SE China[J]. Ore Geology Reviews, 89: 350-368.

Yan Qinghe, Wang He, Qiu Zengwang, Wang Min, Mu Shenglu, Wang Liming, Bu An, Wang Saimeng, Li Shasha, Wei Xiaopeng, Li Pei. 2018. Zircon and cassiterite U-Pb ages and Lu-Hf isotopic Compositions of Tashan Tin-bearing porphyry in Guangdong Province, SE China and its geological significance[J]. Geotectonica et Metallogenia, 42(4): 718-731(in Chinese with English abstract).

Yan Qinghe, Wang He, Qiu Zengwang, Wei Xiaopeng, Li Pei, Dong Rui, Zhou Kailin. 2018. Origin of Early Cretaceous A-type granite and related Sn mineralization in the Sanjiaowo deposit, eastern Guangdong, SE China and its tectonic implication[J]. Ore Geology Reviews, 93: 60-80.

Yi Qisen. 2017. Geological characteristics and genesis of the Shizilu tin-polymetallic deposit in Guangdong Province[J]. Western Resources, (2): 78,103(in Chinese).

Zhu Peiyun, Yan Lunming, Bu An, Xu Diankui, Qian Longbing, Guo Lirong. 2018. Research on the mineralization geological body in Jinkeng copper-tin-lead-zinc deposit, Guangdong[J]. Mineral Exploration, 9 (1): 33-44(in Chinese with English abstract).

Zou Heping, Wang Jianhua, Qiu Yuanzhang. 2000. $^{40}Ar/^{39}Ar$ ages of the Nan'ao shear zone and the Lianhuashan shear zone in Guangdong Province and their geological significance[J]. Acta Geoscientia Sinica, 21(4): 356-364(in Chinese with English abstract).

附中文参考文献

黎汉明. 1995. 广东白垩纪岩石地层划分[J]. 广东地质, 10(1): 61-68.

李海立, 肖惠良, 范飞鹏, 陈乐柱, 刘建雄, 陈叙涛. 2016. 广东潮安飞鹅山钨钼多金属矿床辉钼矿Re-Os同位素定年[J]. 地质学报, 90(2): 231-239.

李武显, 周新民, 李献华. 2003. 长乐—南澳断裂带变形火成岩的U-Pb和Ar-Ar年龄[J]. 地质科学, 38(1): 22-30.

李艳广, 汪双双, 刘民武, 孟恩, 魏小燕, 赵慧博, 靳梦琪. 2015. 斜锆石LA-ICP-MS U-Pb定年方法及应用[J]. 地质学报, 89(12): 2400-2418.

梁敦杰, 谢佑才. 1988. 广东莲花山断裂带西南段地质构造特征[J]. 中国区域地质, 2: 126-131.

钱龙兵, 余庆亮, 郭丽荣, 颜伦明, 温辉. 2018. 广东省揭西县淘锡湖锡多金属矿床成矿花岗岩研究[J]. 华东地质, 39(3): 218-226.

丘增旺, 王核, 李莎莎, 李沛, 魏小鹏, 慕生禄. 2014. 广东揭西县金坑铜锡铅锌矿床勘查和研究新进展[J]. 矿床地质, (S1): 955-956.

丘增旺, 王核, 闫庆贺, 李莎莎, 汪礼明, 卜安, 慕生禄, 李沛, 魏小鹏. 2016a. 广东长埔锡多金属矿床石英斑岩锆石U-Pb年代学、Hf同位素组成及其地质意义[J]. 地球化学, 45(4): 374-386.

丘增旺, 王核, 闫庆贺, 李莎莎, 汪礼明, 卜安, 魏小鹏, 李沛, 慕生禄. 2016b. 广东陶锡湖锡多金属矿床花岗斑岩锆石U-Pb年代学、地球化学、Hf同位素组成及其地质意义[J]. 大地构造与成矿学, 41(3): 516-532.

邱元禧, 邱津松, 李怀仁. 1988. 莲花山韧性剪切带的基本特征及其形成机制[J]. 地质力学文集, (8): 19-30.

邱元禧, 邱津松, 李建超, 钟宏平. 1991. 广东莲花山断裂带中、新生代多期复合变形变质带的基本特征及其形成机制的探讨[J]. 中国地质科学院地质力学研究所所刊, (14): 93-106.

汪礼明, 王军, 王核, 卜安, 李莎莎, 钱龙兵, 王玮. 2018. 粤东莲花山断裂带动力变质作用与动力变质热液成矿[J]. 大地构造与成矿学, 42(5): 908-917.

王军. 2018. 广东莲花山断裂带南西段锡铜多金属矿整装勘查区基础地质与综合研究新进展[J].资源环境与工程, 32(2): 209-211.

徐晓春, 岳书仓, 潘成荣. 1999. 中国东南沿海金属矿床时空分布的控制因素[J]. 安徽地质, 9(1): 42-44.

许汉森, 王建荣, 李瑞, 凌恳, 曾均跃, 余德延. 2018. 粤东观音山岩体LA-ICP-MS锆石U-Pb年龄、岩石地球化学特征及其成矿作用[J]. 华南地质与矿产, 34(1): 22-30.

闫庆贺, 王核, 丘增旺, 王敏, 慕生禄, 汪礼明, 卜安, 王赛蒙, 李莎莎, 魏小鹏, 李沛. 2018. 粤东塌山斑岩型锡多金属矿床锆石及锡石U-Pb年代学、Hf同位素组成及其地质意义[J]. 大地构造与成矿学, 42(4): 718-731.

易其森. 2017. 广东十字路锡多金属矿地质特征及成因初探[J]. 西部资源, (2): 78,103.

朱沛云, 颜伦明, 卜安, 许典葵, 钱龙兵, 郭丽荣. 2018. 广东金坑铜锡铅锌矿床成矿地质体研究[J]. 矿产勘查, 9 (1): 33-44.

邹和平, 王建华, 丘元禧. 2000. 广东南澳和莲花山韧性剪切带$^{40}Ar/^{39}A$年龄及其地质意义[J]. 地球学报, 21(4): 356-364.