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滇西桃花花岗斑岩中新太古代-古元古代锆石年龄信息:对扬子板块西缘基底时代的约束*

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Abstract　The existence of Paleoproterozoic basement in the western Yunnan area has been a hot topic of debate. In this study, large amounts of inherited zircons of the granite porphyry in the Taohua area were selected to use for the SHRIMP U-Pb dating. The Taohua granite porphyry that has geochemical signatures of island arc granite and was formed in a late orogenic to late-collision-process, which possibly related to remelting magmatism induced by resubduction of the detached Jinshajiang oceanic crust and enriched lithospheric mantle domain or by the partial melting of the thickened crust. Inherited zircons were divided into two types: core inherited zircon presented in cores of magmatic zircons with dense oscillatory zones, and subrounded shape inherited zircon. Based on the dating results, the magmatic zircons have an age of approximately 36.35 ± 0.35Ma, the inherited core zircons have ages ranging from 167Ma to 891Ma, whereas the subrounded shape inherited zircons record two group zircons with mean ages of 1851 ± 22Ma and 2499 ± 32Ma, respectively. The new dating results of the zircons from the Taohua granite porphyry indicate that there are not only records of later Paleozoic arc magmatism related to eastward subduction of the Jinshajiang ocean plate and of the Neoproterozoic rift magmatism, but also Early Proterozoic zircon and magmas in the Taohua area, western Yunnan. Moreover, the 1.8Ga and 2.5Ga zircon groups were originated from the ambient Shigu schist, and the Shigu schist possibly has a 2.5 ~ 1.8Ga crust basement. This is to say that there is Early Paleoproterozoic basement in the western Yunnan area.

Key words　Inherited zircon; SHRIMP U-Pb dating; Precambrian basement; Taohua granite porphyry; Yangtze plate

摘　要　扬子板块西缘滇西地区是否存在古老基底一直存在争议。本文对滇西桃花地区花岗斑岩进行了岩石学、地球化学和锆石 SHRIMP U-Pb 年代学研究。形成于晚造山-后碰撞背景的桃花花岗斑岩具岛弧花岗岩地球化学特征,其成因可能与:1)俯冲折离的洋壳俯冲折离的洋壳或富集地幔重熔作用;2)加厚的地壳部分熔融。花岗斑岩中的继承锆石有两种类型:一类是发育具有密集振荡环带的岩浆锆石;另一类是次浑圆状锆石。测年结果显示,花岗斑岩的岩浆锆石年龄为 36.35 ± 0.35Ma,环带发育的继承锆石年龄介于 167 ~ 891Ma 之间;而次浑圆状继承锆石可以分为两组,其 $^{207}Pb/^{206}Pb$ 加权平均年龄分别为 1851 ± 22Ma 与 2499 ± 32Ma。新的锆石测年结果表明着滇西桃花地区不仅存在古金沙江洋东向俯冲形成的晚古生代弧

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岩浆记录,还发现新元古代岩浆活动信息,及早古元古代和新太古代的锆石记录。推测1.8Ga与2.5Ga锆石可能是捕获自地壳或围岩(石鼓片岩),表明滇西地区可能存在古老基底。

关键词 继承锆石;SHRIMP U-Pb定年;前寒武基底;桃花花岗斑岩;扬子板块

中图法分类号 P588.13; P597.3

1 引言

扬子板块西缘基底特征是中国前寒武纪地质研究的重要科学问题之一(耿元生等, 2008)。滇西地区位于扬子板块西南缘与三江构造带的结合部,对其基底特征一直存在不同的观点。区域内,变质岩系主要出露于石鼓-点苍山-哀牢山地区,其原岩的形成时代存在很大争议。对于点苍山-哀牢山地区的变质岩,部分学者认为属于中生代或新生代花岗质片麻岩,并非前寒武纪变质岩(张玉泉等, 2004; 李宝龙等, 2008; 戚学祥等, 2010);而一些学者认为存在前寒武基底(翟明国和从柏林, 1993; 王义昭和丁俊, 1996; 朱炳泉等, 2001; 李昆琼, 2003; 刘俊来等, 2008),如下元古界的苍山群和哀牢山群,并经历多期多阶段的山脉隆升过程(Schoenbohm *et al.*, 2005; 王二七等, 2006)。石鼓地区变质岩以羊坡岩组为主,这套片岩又被称为石鼓片岩。云南省地质矿产局(1984①, 1985②)在1:20万维西和中甸幅地质图将其划为早寒武世。石鼓片岩中斜长角闪岩Sm-Nd模式年龄结果显示其年龄为1.4~2.0Ga(翟明国和从柏林, 1993; 朱炳泉等, 2001; 李昆琼, 2003),表明石鼓片岩可能为中-古元古界变质岩,但具体时代还不明确。此外,滇西碱性斑岩中的深源包体研究也曾发现存在变质基底(蔡新平, 1992; 赵欣等, 2003, 2004; 魏启荣和王江海, 2004)。同时,一些年代学数据也显示滇西地区存在前寒武纪基底(夏斌等, 2005; 刘俊来等, 2008; 赵甫峰等, 2011),如:桃花村富碱斑岩中继承锆石U-Pb蒸发年龄为1016.1Ma(毛晓长等, 2012)。扬子西缘会理、会东地区、大红山地区古元古代末期-中元古代变质岩与基性岩浆岩中锆石SHRIMP U-Pb年龄介于1694~1710Ma之间(Greentree *et al.*, 2006; Greentree and Li, 2008; Zhao *et al.*, 2010; 关俊雷等, 2011; 杨红等, 2012; 王子正等, 2012; 王冬兵等, 2013)。Sun and Zhou (2008), Sun *et al.* (2009)、朱华平等(2011)和杜利林等(2013)在扬子西缘不同地区发现大量太古代-古元古代碎屑锆石也显示在扬子西缘可能存在古元古代-新太古代地壳。针对石鼓片岩形成时代的争议问题,最近,我们在滇西桃花花岗斑岩中发现大量继承锆石,通过精细的锆石SHRIMP U-Pb定年获得其中两组锆石年龄分别为~1.85Ga与~2.5Ga,其可能揭示了滇西地区的老基底信息。

2 区域地质背景

滇西地区位于青藏高原东南缘三江构造带和扬子板块西缘结合部(图1a),区内包含中-新特提斯洋消减封闭及碰撞造山形成的构造带,其中沿金沙江-红河一带分布的金沙江构造带是晚古生代古金沙江洋盆的俯冲消减带(Tapponnier and Molnar, 1976, 1993; Tapponnier, 1982, 1990; Leloup *et al.*, 1995; Wang *et al.*, 2000; 方维萱等, 2002; Gilley *et al.*, 2003; 戚学祥等, 2010)。古金沙江洋是石炭纪(294~340Ma)特提斯洋的重要分支(Zhang *et al.*, 1985; Mo *et al.*, 1993; Wang *et al.*, 2000),一般认为其在晚三叠世封闭(Tapponnier *et al.*, 1982; 莫宣学等, 1993; Hou *et al.*, 2003a, b; Xu *et al.*, 2009)。从晚白垩世至第三纪,印度板块与欧亚板块碰撞过程沿金沙江构造带形成一系列的大型逆冲与走滑断层,并伴生大量碱性斑岩与火山岩(Wang *et al.*, 2001; 曾普胜等, 2002; Hou *et al.*, 2003a, b; Xu *et al.*, 2009)。

3 桃花地区地质特征

滇西桃花地区位于滇西丽江市石鼓镇西南,金沙江缝合带东侧的扬子板块西南缘(图1a)。区内出露的地层包括古元古界石鼓片岩和始新统云龙组砂岩。其中,石鼓片岩中、下部为灰色石榴斜长二云片岩、石榴斜长黑云片岩;上部为黑云斜长石英片岩。始新统云龙组红色砂岩不整合覆盖于石鼓片岩之上。桃花地区的花岗斑岩(图1b)呈岩株与岩枝状,侵位于古元古界石鼓片岩与始新统云龙组砂岩中。较大侵入体长7~8km、宽4~6km、面积约41km^2;较小侵入体长约7km、宽1~3km、面积约11km^2。我们对临近桃花村的花岗斑岩(本文称其为桃花花岗斑岩)开展了锆石SHRIMP U-Pb定年研究。

4 样品特征和制备、分析方法

4.1 岩石样品特征

桃花斑岩野外呈浅肉红色,块状构造,似斑状结构,斑晶为长石和石英。斑岩中含黑云母斜长片麻岩与石英黑云片岩包体(图2a)。显微镜下,桃花花岗斑岩具典型的斑状结构(图2b),斑晶由更长石、钾长石和石英构成,粒度在0.35~4.75mm之间,含量55%左右,一些更长石斑晶具连晶结构。石英斑晶多呈港湾状,溶蚀结构发育(图2b),基质由微

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① 云南省地质矿产局. 1984. 1:20万维西幅区域地质调查报告

② 云南省地质矿产局. 1985. 1:20万中甸幅区域地质调查报告

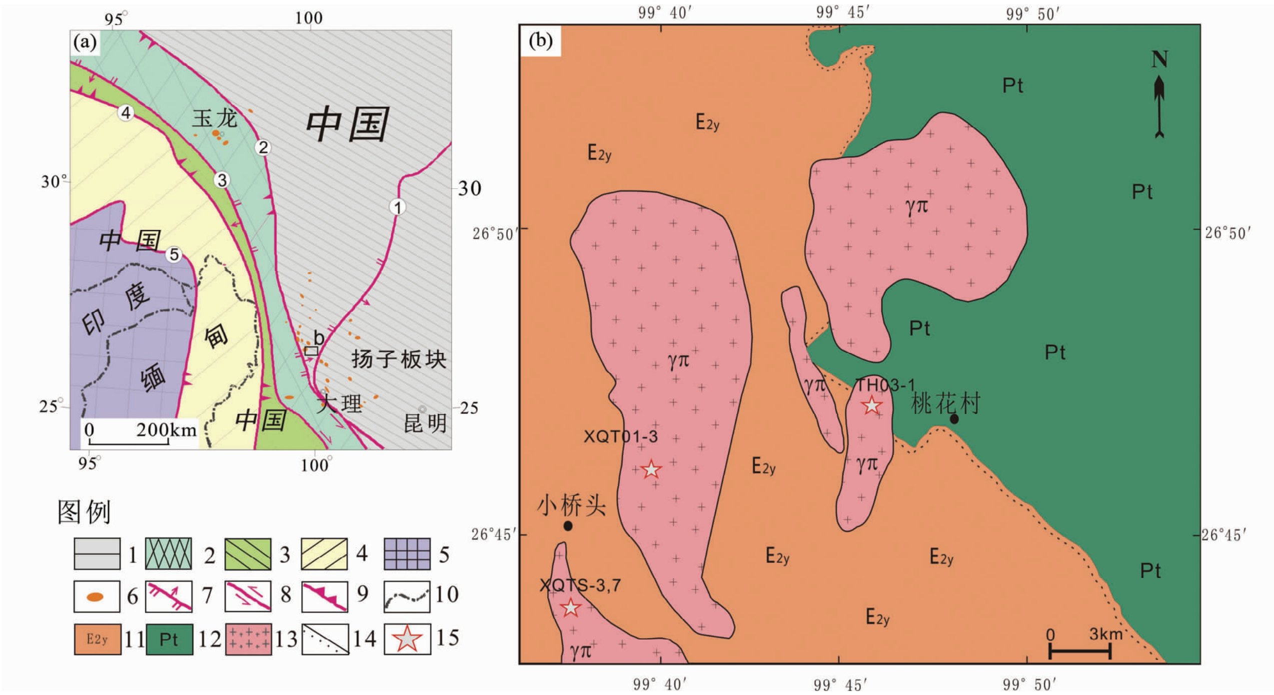

图 1 滇西桃花地区构造位置(a,据 Xu *et al.*, 2007a, b)和地质图(b,据云南省地质矿产局,1984)

1-扬子板块;2-北羌塘-思茅块体;3-南羌塘-思茅块体;4-冈底斯-腾冲块体;5-印度板块;6-喜山期斑岩体;7-逆断层;8-走滑断层;9-缝合带;10-国界;11-始新统云龙组红色砂岩;12-古元古界石鼓片岩;13-花岗斑岩;14-不整合界线;15-采样点;①-龙门山断裂;②-金沙江缝合带;③-澜沧江缝合带;④-怒江缝合带;⑤-雅鲁藏布江缝合带

Fig. 1 Tectonic location (a, after Xu *et al.*, 2007a, b) and geological map (b) of the Taohua area, western Yunnan

1-Yangtze plate; 2-North Qiangtang-Shimao block; 3-South Qiangtang-Shimao block; 4-Gandese-Tengchong block; 5-Indian plate; 6-Tertiary porphyry; 7-thrust fault; 8-strike-slip fault; 9-suture; 10-national boundary; 11-red sandstone of the Yunlong Formation; 12-Paleoproterozoic Shigu schist; 13-granite-porphyry; 14-unconformity; 15-sample collecting location; ①-Rongmenshan thrust fault; ②-Jinshajiang suture; ③-Lanchang jiang suture; ④-Nujiang suture; ⑤-YarlungZangbo suture

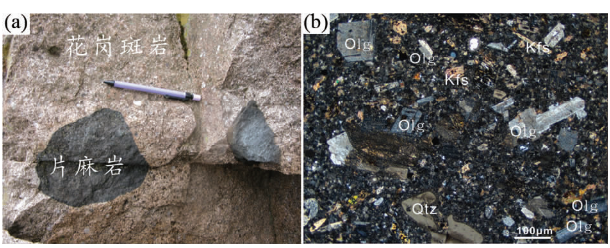

图 2 滇西桃花花岗斑岩野外(a)和镜下照片(b)

Qtz-石英;Olg-更长石;Kfs-钾长石

Fig. 2 Filed (a) and polarized microscopic (b) images of granite-porphyry from the Taohua area, western Yunnan

Qtz-quartz; Olg-oligoclase; Kfs-K-feldspar

晶更长石、钾长石和石英构成。副矿物为锆石、磁铁矿等。

4.2 分析方法

桃花花岗斑岩(TH03-1)及岩性相似的小桥头石英二长斑岩样品(XQT S-3、XQT 01-3、XQT S-7)的主、微量元素测试在中国科学院地质与地球物理研究所成矿年代学实验室完成的。主量元素的测定采用X-射线荧光光谱法(XRF):首先称取0.5g样品,然后加入适量硼酸高温熔融成玻璃片,最后在X射线荧光光谱仪(XRF-1500)上采用外标法测定氧化物含量,分析误差小于5%。并借助Geokit 2012(路远发,2004)计算程序得到岩石的主要岩石化学参数。微量元素测试使用配有耐酸锰耐尔合金钢套和热缩管的Teflon溶样罐,用HNO_3+HF在200℃温度下保温4天溶解,并用ICP-MS ELEMENT仪器进行测试,分析精密度RSD<2.5%(靳新娣和朱和平,2000)。测试结果详情见表1。

桃花花岗斑岩(TH03-1)锆石按常规方法分选,最后在双目镜下挑选。将锆石与一片RSES参考样SL13及数粒TEMORA Ⅰ置于环氧树脂中,然后磨至约一半,使锆石内部暴露,用于阴极发光研究及随后的SHRIMP U-Pb分析。锆石阴极发光照相研究(CL图像)在中国科学院地质与地球物理研究所扫描电镜研究室完成。锆石SHRIMP U-Pb同位素分析在北京离子探针中心SHRIMP Ⅱ上进行。一次粒子流束斑大小为25~30μm。锆石样品分析原理和详细流程参见Williams(1998)和宋彪等(2002)。标样为澳大利亚国立大学(ANU)的SL13和TEMORA1。数据处理采用SQUID和ISOPLOT程序(Ludwig, 2002)。单个数据的误差为1σ,加权平均年龄误差为2σ,置信度为95%。测试结果见表2。

表1 桃花地区岩体主量(wt%)、微量($\times 10^{-6}$)元素数据表

Table 1 Major (wt%) and trace-element ($\times 10^{-6}$) concentrations for igneous rocks from the Taohua area, western Yunnan

样品号	TH03-1	XQT S-3	XQT01-3	XQT S-7
SiO_2	71.40	64.70	66.49	63.93
TiO_2	0.48	0.73	0.36	0.67
Al_2O_3	12.70	15.97	15.78	15.89
Fe_2O_3	1.22	0.12	0.12	1.55
MnO	0.05	1.15	0.79	0.05
MgO	1.56	2.82	1.75	1.10
FeO	1.63	1.82	2.24	2.42
CaO	3.13	3.53	3.12	2.52
Na_2O	3.15	2.60	3.49	4.98
K_2O	3.52	5.65	5.43	4.90
P_2O_5	0.35	0.32	0.01	0.19
烧失量	0.45	0.43	0.36	0.65
总量	99.64	99.84	99.94	98.85
A/CNK	1.30	1.36	1.32	1.28
Rb	240	244	144	243
Sr	502	1489	1635	1468
Y	18.5	33.2	14.6	24.0
Zr	175	387	161	298
Nb	10.5	30.2	8.76	24.1
Ba	1366	2000	1635	1575
La	27.7	61.5	27.9	51.8
Ce	59.5	122.5	55.0	98.2
Pb	27.5	48.6	35.4	94.1
Pr	6.60	14.1	6.20	11.1
Nd	27.1	51.0	23.7	39.4
Sm	5.10	9.70	4.30	7.70
Eu	1.40	2.30	1.40	1.90
Gd	5.10	8.50	4.20	6.60
Tb	0.70	1.20	0.60	0.90
Dy	3.40	5.90	2.60	4.50
Ho	0.60	1.10	0.50	0.80
Er	1.80	3.10	1.20	2.50
Tm	0.20	0.50	0.20	0.30
Yb	1.70	3.10	1.30	2.30
Lu	0.30	0.50	0.20	0.40
Hf	4.50	10.0	4.50	7.70
Ta	0.89	1.80	0.80	1.70
Th	11.5	30.8	10.1	28.2
U	3.94	11.5	3.73	9.05
ΣREE	141.2	284.8	129.3	228.6
$(La/Yb)_N$	12.0	14.1	15.7	15.9
δEu	0.8	0.8	1.0	0.8

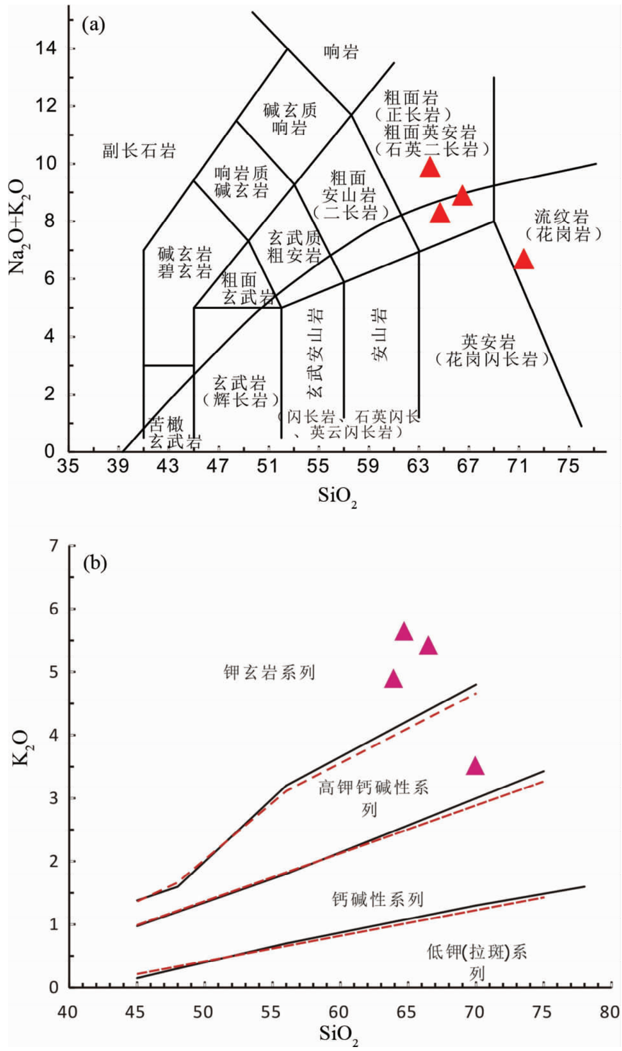

图3 桃花地区花岗岩类岩体TAS图(a,据Middlemost, 1985)和SiO_2-K_2O图(b,据Peccerillo and Taylor, 1976; Le Maitre *et al.*, 1989)

Fig. 3 TAS diagram (a, after Middlemost, 1995) and SiO_2-K_2O diagram (b, after Peccerillo and Taylor, 1976; Le Maitre *et al.*, 1989) of granitoids from the Taohua area, western Yunnan

5 桃花地区岩体岩石地球化学特征

桃花花岗斑岩(TH03-1) SiO_2 含量为71.4%,具高的 K_2O(3.5%)与 Na_2O(3.2%)和相对较高的 K_2O/Na_2O 比值(1.09),为强过铝质(A/CNK=1.30)岩体(数据见表1)。桃花斑岩样品(TH03-1) TAS图和 SiO_2-K_2O 图解投在花岗岩(图3a)和高钾钙碱性系列区域(图3b)。小桥头的3个岩体TAS图和 SiO_2-K_2O 图解中大部分在石英二长岩(图3a)和钾玄岩系列(图3b)区域。

桃花花岗斑岩和小桥头岩体的稀土和微量元素含量见表1,其Rb、Sr、Ba、Pb、U和Th等元素含量较高,亏损Nb、Ta、Ti、Yb、P元素;稀土元素总量中等。原始地幔标准化的微量元素配分图解中(图4a),具明显的Pb正异常和Nb、Ta、P和Ti负异常。在球粒陨石标准化的稀土元素配分图解中(图4b),轻重稀土元素分异较强烈($(La/Yb)_N$ = 12.0~15.9),负异常不明显(δEu=0.8~1.0)。桃花地区花岗岩类的微量和稀土元素特征与临区(北衙、剑川、维西-德钦、临沧等)花

表 2　桃花斑岩(TH03-1)锆石 SHRIMP U-Pb 定年结果

Table 2　Zircons SHRIMP U-Pb dating results for granite-porphyry (Sample TH03-1) from the Taohua area, western Yunnan

测点号	U ($\times10^{-6}$)	Th ($\times10^{-6}$)	$\frac{Th}{U}$	$^{206}Pb^*$ ($\times10^{-6}$)	$^{206}Pb_c$ ($\times10^{-6}$)	同位素比值						年龄(Ma)			
						$\frac{^{207}Pb}{^{206}Pb}$	$\pm\sigma$ (%)	$\frac{^{207}Pb}{^{235}U}$	$\pm\sigma$ (%)	$\frac{^{206}Pb}{^{238}U}$	$\pm\sigma$ (%)	$\frac{^{207}Pb}{^{206}Pb}$	$\pm\sigma$	$\frac{^{206}Pb}{^{238}U}$	$\pm\sigma$
t1	684.7	96.44	0.15	7.3	10.07	0.06	31	0.05	31	0.01	3.5	35.0	±6.6	35.2	±1.2
t2	1115	200.9	0.19	35	5.48	0.04	28	0.03	28	0.01	2.5	36.2	±5.0	36.2	±0.9
t3	1379	162.3	0.12	9.0	8.05	0.03	55	0.02	55	0.01	2.8	36.3	±5.5	36.3	±0.9
t4	1155	225.1	0.20	8.0	6.14	0.04	27	0.03	28	0.01	2.5	36.7	±4.5	36.5	±0.9
t5	1499	247.7	0.17	7.0	6.26	0.05	19	0.04	19	0.01	2.4	36.4	±4.5	36.6	±0.9
t6	943.7	140.2	0.15	749	4.32	0.04	28	0.03	28	0.01	2.6	36.9	±6.2	36.7	±0.9
t7	1345	298.4	0.23	18.0	6.04	0.04	40	0.03	40	0.01	2.8	37.2	±11.0	37.0	±0.9
t8	709.0	746.6	1.09	16.1	12.8	0.03	62	0.03	62	0.01	3.2	38.4	±5.8	37.8	±1.5
t9	465.3	38.75	0.09	12.0	5.92	0.04	20	0.14	20	0.03	2.3	166.7	±9.9	167.4	±3.8
t10	972.2	85.92	0.09	153	0.97	0.05	5.5	0.23	5.8	0.03	2.0	207.1	±13.0	207.7	±4.2
t11	433.2	119.4	0.28	211	3.00	0.04	11	0.22	11	0.04	2.2	225.3	±27.0	226	±5.0
t12	137.7	132.7	1.00	111	5.24	0.05	20	0.25	21	0.04	2.7	225.3	±4.7	227.8	±7.0
t13	527.2	339.9	0.67	263	1.71	0.05	6.2	0.27	6.5	0.04	2.1	235.6	±12.0	236.9	±5.4
t14	472.3	94.81	0.21	272	2.47	0.05	9.2	0.25	9.4	0.04	2.1	246.1	±22.0	246.3	±5.3
t15	478.6	50.36	0.11	132	0.97	0.05	4.6	0.28	5.1	0.04	2.1	250.1	±12.0	250.5	±5.2
t16	210.3	271.5	1.33	123	3.54	0.05	15.0	0.34	15	0.05	2.4	294.4	±33.0	305.5	±8.6
t17	4142	440.5	0.11	3.65	0.14	0.05	1.5	0.46	2.4	0.06	1.9	380.7	±17.0	380.9	±7.1
t18	323.8	72.29	0.23	118	1.77	0.07	3.7	1.08	4.3	0.11	2.1	662	±56.0	665	±14.0
t19	532.4	109.3	0.21	31.6	0.59	0.06	4.0	1.05	4.5	0.12	2.0	717	±85.0	717	±14.0
t20	1139	642.0	0.58	7.84	0.15	0.07	0.9	1.18	2.1	0.13	1.9	784	±18.0	785	±16.0
t21	204.3	93.16	0.47	241	1.43	0.06	4.1	1.18	4.6	0.13	2.1	817	±40.0	819	±18.0
t22	1007	583.9	0.60	34	0.51	0.07	1.1	1.3	2.2	0.14	1.9	846	±22.0	845	±17.0
t23	881.5	247.4	0.29	38	0.57	0.08	1.9	1.62	2.7	0.14	2.0	856	±37.0	868	±17.0
t24	373.5	175.9	0.49	54.2	0.96	0.07	2.3	1.35	3.2	0.15	2.2	890	±48.0	891	±20.0
t25	630.0	98.31	0.16	4.45	0.23	0.07	1.0	1.59	2.2	0.16	1.9	959	±19.0	974	±18.0
t26	1015	318.3	0.32	5.89	0.17	0.05	5.7	0.28	6.1	0.04	2.3	290	±13.0	245.6	±5.7
t27	593.2	100.9	0.18	127	1.50	0.11	3.6	1.25	4.2	0.08	2.2	1770	±66.0	484	±12.0
t28	1020	2186	2.21	8.46	0.07	0.14	0.6	6.28	2.1	0.32	2.0	2246	±11.0	1769	±45.0
t29	305.0	203.5	0.69	54.2	0.38	0.11	1.0	4.95	2.3	0.32	2.1	2499	±17.0	1795	±33.0
t30	462.0	190.0	0.42	122	0.36	0.11	1.4	5.06	2.6	0.33	2.2	1808	±25.0	1851	±37.0
t31	377.7	226.8	0.62	13.6	0.28	0.12	1.0	5.28	2.4	0.33	2.2	2378	±17.0	1855	±37.0
t32	554.5	392.8	0.73	17.2	0.35	0.11	1.5	5.28	2.8	0.34	2.3	2376	±32.0	1876	±39.0
t33	681.2	272.9	0.41	27.6	0.34	0.11	1.0	5.39	2.3	0.34	2.1	1882	±19.0	1894	±36.0
t34	676.2	117.6	0.18	217	0.50	0.11	1.2	5.3	2.4	0.35	2.1	1816	±21.0	1918	±35.0
t35	769.1	180.3	0.24	118	0.43	0.16	1.3	7.99	2.4	0.36	2.0	2448	±23.0	2005	±36.0
t36	453.5	183.7	0.42	4.81	0.24	0.14	1.2	7.77	2.5	0.39	2.2	2275	±21.0	2130	±41.0
t37	1020	2186	2.21	9.1	0.07	0.15	1.0	8.39	2.6	0.4	2.4	2246	±11.0	2165	±47.0
t38	380.7	81.45	0.22	47.8	0.57	0.15	1.9	9.3	2.9	0.44	2.2	1857	±27.0	2372	±47.0
t39	317.5	316.9	1.03	34	0.39	0.16	1.0	10.35	2.4	0.46	2.2	2487	±16.0	2448	±51.0
t40	554.5	392.8	0.73	110	0.35	0.17	0.6	11.13	2.1	0.48	2.1	2376	±32.0	2513	±43.0
t41	675.2	52.13	0.08	7.12	0.15	0.16	1.0	10.16	2.5	0.45	2.2	2552.6	±9.8	2395	±48.0
t42	1781	64.44	0.04	4.13	0.09	0.16	0.4	11.07	2.0	0.49	2.0	2497.9	±6.2	2568	±42.0

岗岩类的地球化学性质一致(图4a, b)(徐兴旺等, 2006；喻学惠等, 2008；高睿等, 2010；孔会磊等, 2012)。桃花花岗斑岩(TH03-1)以及小桥头的岩体(XQTS-3、XQT01-3、XQTS-7)的 Yb-Ta、Rb-(Y+Nb)图解显示落在晚造山-后碰撞过渡的区域(图5)，临区其他岩体(北衙、剑川、维西-德钦、临沧等)也显示相同的趋势(徐兴旺等, 2006；Xu *et al.*, 2007a, b；喻学惠等, 2008；高睿等, 2010；孔会磊等, 2012)(图5)。

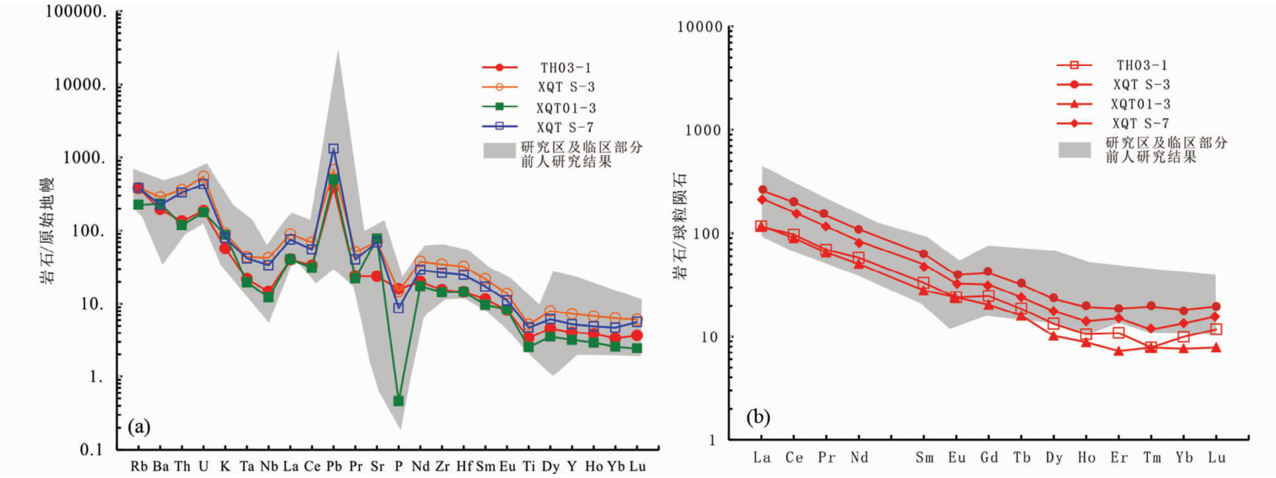

图 4 桃花地区花岗岩类微量元素蛛网图(a,原始地幔值据 Sun and McDonough, 1989)和稀土元素配分图(b,球粒陨石值据 Boynton, 1984)

区域资料据徐兴旺等, 2006; Xu *et al.*, 2007a, b; 喻学惠等, 2008; 高睿等, 2010; 孔会磊等, 2012. 图 5 同

Fig. 4 Trace element spider (a, primitive mantle values after Sun and McDonough, 1989) and REE element (b, chondrite values are after Boynton, 1984) diagrams of granitoids from the Taohua area

Regional data are according to Xu *et al.*, 2006; Xu *et al.*, 2007a, b; Yu *et al.*, 2008; Gao *et al.*, 2010; Kong *et al.*, 2012, also in the Fig. 5

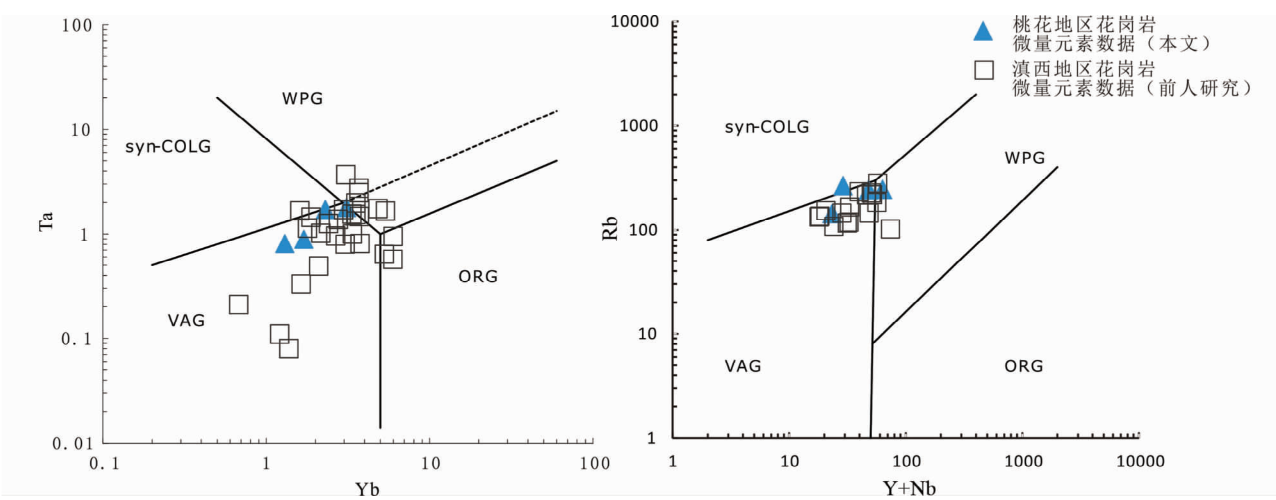

图 5 桃花花岗岩类岩体的 Yb-Ta 与 Rb-(Y+Nb)图解(据 Pearce *et al.*, 1984)

Fig. 5 The Yb-Ta and Rb vs. (Y+Nb) discrimination diagram of granitoids from the Taohua area (after Pearce *et al.*, 1984)

6 锆石特征与 SHRIMP U-Pb 分析结果

桃花花岗斑岩中锆石大多数为典型岩浆锆石(图 6),锆石呈短柱-长柱状,晶形完好,柱面{110}、{100}及锥面{111}均较发育。大部分岩浆锆石中含有继承锆石核。阴极发光图像中,岩浆锆石振荡环带发育,继承性锆石核多呈亮白色,部分见岩浆环带;少量次浑圆状继承锆石,CL 图像整体呈暗灰色。还有部分颗粒发育核-幔-边结构,边为亮白色,核为浑圆状深灰色。

本次研究选择 38 粒锆石开展了 42 个测点分析,分析结果如表 2 所示。岩浆锆石 8 个测点(点 t1-t8)的分析结果显示:Th 含量为 $96\times10^{-6}\sim747\times10^{-6}$、U 含量为 $685\times10^{-6}\sim1499\times10^{-6}$、Th/U 比值 0.12~1.09。锆石 $^{206}Pb/^{238}U$ 年龄介于 35.2±1.2Ma 到 37.8±1.5Ma 之间(图 7a, b、表 2),加权平均年龄为 36.35±0.35Ma(MSWD=3.8)(图 7b、表 2)。

核部继承锆石 16 个测点的分析测试结果显示:Th 含量为 $38.75\times10^{-6}\sim642.0\times10^{-6}$、U 的含量变化范围为 $137.7\times10^{-6}\sim4142\times10^{-6}$、Th/U 比值 0.09~1.33。锆石 $^{206}Pb/^{238}U$ 年龄介于 167.4±3.8Ma 与 891±20Ma 之间,年龄较集中分布在 226~236Ma、246~250Ma 与 845~891Ma 这 3 个年龄段(图 7f)。

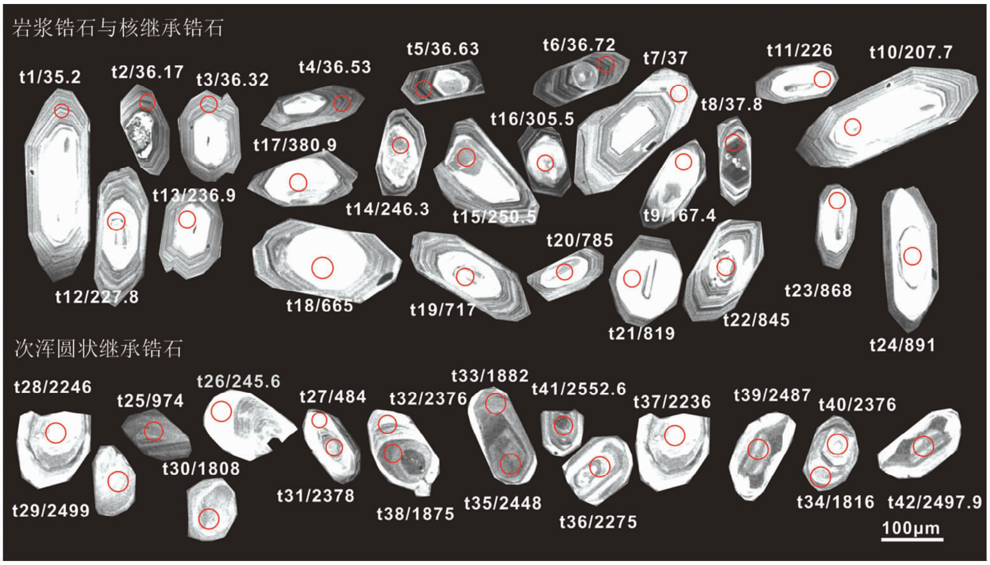

图 6 滇西桃花花岗斑岩(样品 TH03-1)锆石阴极发光图像与 SHRIMP U-Pb 测点位置

t1/35.2,前者是测点号,后者是锆石$^{206}Pb/^{238}U$年龄值,红圈示测点位置;年龄 > 1.0Ga 的锆石,以$^{207}Pb/^{206}Pb$表面年龄表示

Fig. 6 Cathodoluminescence (CL) images and measuring positions of representative zircon grains selected for SHRIMP U-Pb dating analysis from the granite-porphyry (sample TH03-1) in the Taohua area, western Yunnan

The red ellipses show the LA-ICP-MS analysis location with corresponding spot numbers and $^{206}Pb/^{238}U$ ages for each spot are labeled aside the red ellipses; zircons' age > 1.0Ga, was applied in $^{207}Pb/^{206}Pb$ apparent age

次浑圆状继承锆石的亮白色环边的三个测点 t25、t26 与 t27 的分析结果显示:Th 含量 $98.31 \times 10^{-6} \sim 318.3 \times 10^{-6}$、U 含量为 $593.2 \times 10^{-6} \sim 1015 \times 10^{-6}$、Th/U 比值 0.16 ~ 0.32,锆石$^{206}Pb/^{238}U$年龄分别为 245.6 ± 5.7Ma、484 ± 12Ma、974 ± 18Ma,年龄结果可以与部分岩浆核继承锆石的年龄对比。次浑圆状继承锆石其$^{207}Pb/^{206}Pb$年龄介于 1770 ± 66Ma 与 2552 ± 9.8Ma 之间,$^{207}Pb/^{206}Pb$年龄直方图统计可以明显地分出三个峰值区域:1.83Ga、2.2Ga 和 2.50Ga(图 7f),并可明显的分为两个群组 GA 和 GB。其中 GA 由 t29-t34 这六个测点组成,GA 锆石的 Th 含量为 $118 \times 10^{-6} \sim 393 \times 10^{-6}$、U 含量为 $305 \times 10^{-6} \sim 681 \times 10^{-6}$、Th/U 比值范围在 0.18 ~ 0.73,大部分 > 0.4(吴元保和郑永飞, 2004),是典型的岩浆锆石,这六个点谐和年龄为 1850 ± 26Ma(MSWD = 0.71)(图 7e)。测点 t27 年龄($^{207}Pb/^{206}Pb$ = 1770Ma)锆石 Pb 丢失严重;测点 t27 与 GA 组其他锆石构成的不一致线其上交点年龄为 1846 ± 34Ma(MSWD = 2.3)(图 7c),上交点年龄与$^{207}Pb/^{206}Pb$统计直方图峰值年龄 1.83Ga 和谐和年龄为 1850 ± 26Ma (MSWD = 0.71)相近。GB 锆石$^{207}Pb/^{206}Pb$年龄集中在 2448 ± 23Ma 与 2552 ± 9.8Ma 之间(测点 t35-t42),其 Th 含量变化范围为 $52 \times 10^{-6} \sim 2186 \times 10^{-6}$、U 的含量变化范围为 $381 \times 10^{-6} \sim 1781 \times 10^{-6}$、Th/U 比值 0.04 ~ 2.21,部分 < 0.1(吴元保和郑永飞, 2004)(图 7d、表 2),锆石的 CL 图的特征也说明存在变质锆石。GB 锆石年龄多为具有铅丢失,但它们和(t38、t39、t40、t41、t42)不一致线上交点年龄为 2499 ± 32Ma (MSWD = 13.0)(图 7d)与$^{207}Pb/^{206}Pb$年龄直方图峰值 2.5Ga 年龄(图 7f)相近。

7 讨论

桃花花岗斑岩岩浆锆石测点谐和年龄为 36.35 ± 0.35Ma(MSWD = 3.8)(图 7b),与滇西老君山、玉召块、六合、北衙、大理与姚安等地的喜山期碱性花岗斑岩年龄一致(简平等, 2003; 张玉泉等, 2004; 夏斌等, 2005; Chung *et al.*, 2005; 施小斌等, 2006; Hou *et al.*, 2007; Liang *et al.*, 2007; Xu *et al.*, 2009; Huang *et al.*, 2010; 赵甫峰等, 2011; 毛晓长等, 2012),表明桃花花岗斑岩的形成时代为始新世。研究区在内的滇西喜山期碱性斑岩在 Yb-Ta、Rb-(Y + Nb)图解大部分位于晚造山-后碰撞阶段形成的花岗岩区域内,富集 Pb、U、Sr 元素,亏损 Nb、Ta、Yb、P 元素(图 5),却表现出岛弧岩浆的特征(Pearce *et al.*, 1984; Winter, 2001)。古金沙江洋在晚三叠世已经封闭,新生代时该区域已经处于碰撞构造背景(Hou *et al.*, 2003a, b; Xu *et al.*, 2009),其可能与以下过程相关:1)岛弧岩浆的地球化学特征可能与哀牢山-红河断裂走滑作用减压环境下俯冲拆离的洋壳或者早期的富集岩石圈地幔的重熔作用相关,(Guo *et al.*, 2005; 徐兴旺等, 2006; Xu *et al.*, 2007a, b; 邓军等, 2010; 薛传东等, 2010);2)中新世时印度板块向欧亚板块高角度深俯冲过程中板片的断离导致软流圈物质沿着板片窗上涌,上涌底垫的软流圈物质诱发加厚的大陆下地壳部分熔融形成的产物(寇彩化等, 2011; 和文言等, 2013)。

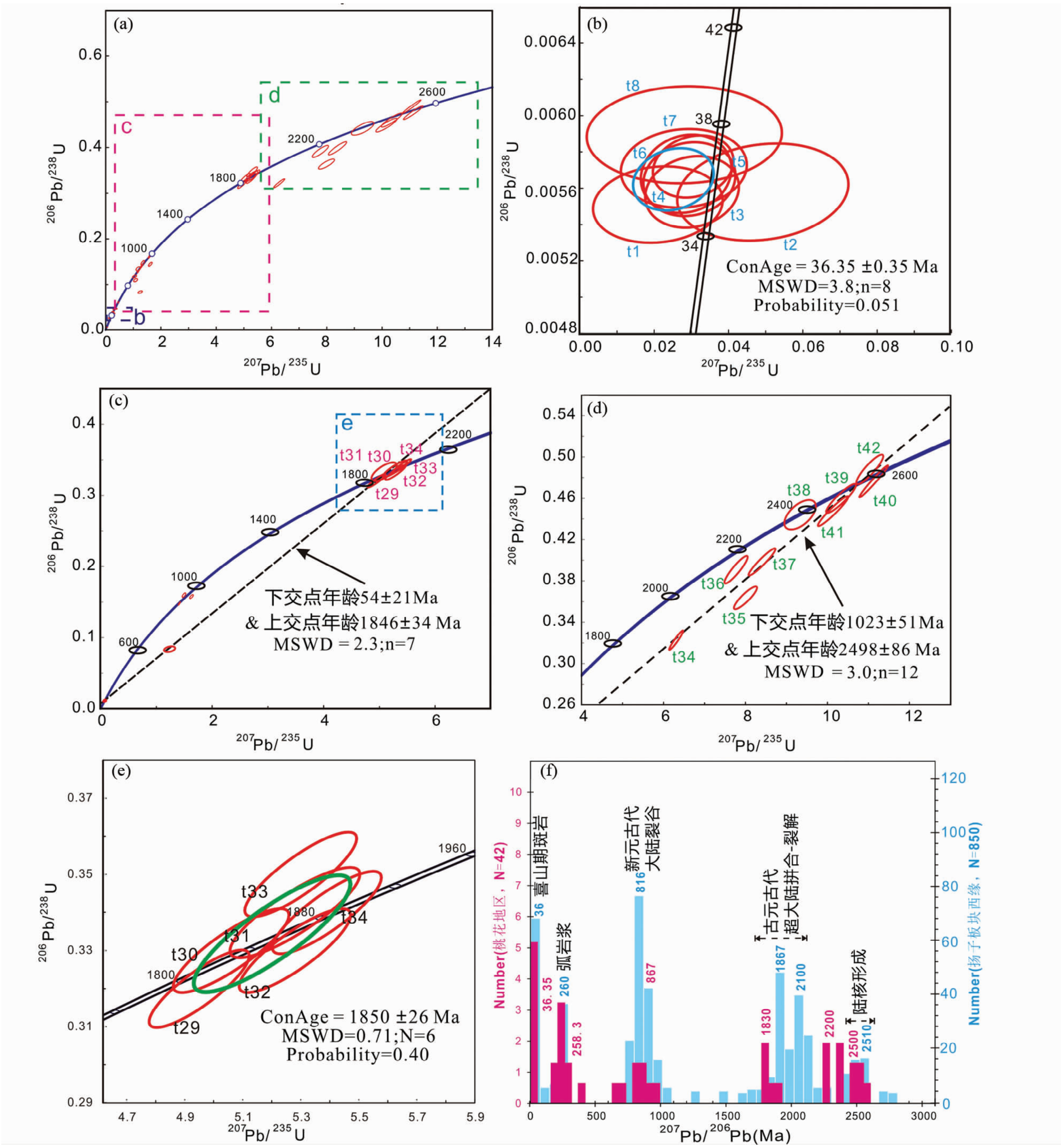

图7 桃花花岗斑岩(样品 TH03-1)锆石 SHRIMP U-Pb 年龄谐和图(a-e)和滇西火成岩中锆石$^{207}Pb/^{206}Pb$表面年龄统计直方图(f)

图 f 中扬子板块西缘区域岩体中锆石$^{207}Pb/^{206}Pb$表面年龄数据引自 Zhang *et al.*, 2006; Greentree and Li, 2008; Zhao *et al.*, 2010; 朱华平等, 2011; 张丽娟等, 2011; 王冬兵等, 2013

Fig. 7 Zircon SHRIMP U-Pb concordia age plots of the granite-porphyry (Sample TH03-1) from the Taohua area (a-e) and histograms of zircon $^{207}Pb/^{206}Pb$ apparent ages for zircons from igneous rocks in the western Yunnan (f)

Data for the statistical of $^{207}Pb/^{206}Pb$ apparent ages are from Zhang *et al.* (2006), Greentree and Li (2008), Zhao *et al.* (2010), Zhu *et al.* (2011), Zhang *et al.* (2011), Wang *et al.* (2013)

岩浆锆石中的继承锆石核(CL 图呈亮白色)U-Pb 年龄集中在 167～891Ma(图 7a)之间,是对研究区中生代-新元古代岩浆事件的响应。该结果可能表明 167Ma 左右研究区存在岩浆活动,与邻近区域(折多山花岗岩、松潘-甘孜褶皱带

中花岗岩、扁路岗角闪二长花岗岩）构造-岩浆热事件（153～197Ma）年龄相吻合，是该地区中生代区域性构造-岩浆作用的有力证据（郭建强等，1998；Roger *et al.*，2004；刘树文等，2006；任光明等，2013）。226～250Ma 的锆石年龄与区域（金沙江德钦鲁春、哀牢山缝合带北部）弧岩浆岩年龄一致（张旗等，1996；王立全等，1999；牟传龙和王立全，2000；王立全等，2001；牟传龙和余谦，2002；王立全，2002a，b；Hou *et al.*，2003a，b；李龚健等，2013），表明研究区存在早三叠世-中三叠世古金沙江洋东向俯冲形成的岩浆弧活动（王立全等，1999，2001；牟传龙和王立全，2000；牟传龙和余谦，2002；王立全，2002a，b；Hou *et al.*，2003a，b）。而785～891Ma 的锆石年龄（峰值年龄 816Ma）（图 7f）与扬子板块西缘大量发育的新元古代岩浆活动的时间（统计峰值年龄867Ma）（图 7f）对应（Zhou *et al.*，2002a；Li *et al.*，2003a；耿元生等，2008；Du *et al.*，2014）。对于这期岩浆活动形成的构造背景，部分学者认为其为双峰式非造山型岩浆活动（830～795Ma，780～750Ma）与导致 Rodinia 超大陆裂解的地幔柱-超级地幔柱活动有关（Li *et al.*，2003b；李献华等，2001；Wang *et al.*，2001；刘俊来等，2008）；另一部分学者认为扬子地台西缘的新元古代（特别是≥800Ma）是与洋壳俯冲消减于扬子地块之下的俯冲造山运动有关，并认为新元古代时期扬子地块是一个被洋壳包围起来的孤立陆块，扬子地块周缘的俯冲造山运动可能持续到 820Ma 或更晚（王康明和阚泽忠，2001；Zhou *et al.*，2002b；耿元生等，2008；裴先治等，2009）。桃花地区花岗斑岩中 7 个锆石年龄范围在 665～891Ma 之间，平均年龄在 798.5±2.3Ma（MSWD=2.4），与扬子地台西缘许多新元古代花岗岩形成时代相近（Zhou *et al.*，2002a；Li *et al.*，2003a；Du *et al.*，2014）。在花岗岩中也缺少由于地幔柱底侵形成的基性幔源岩浆包体，这意味着扬子地台西缘新元古代可能为典型的板块俯冲环境，即在Rodinia 超大陆裂解过程新元古代扬子板块西-北缘可能为活动大陆边缘并存在俯冲作用（王康明和阚泽忠，2001；Zhou *et al.*，2002b；耿元生等，2008；裴先治等，2009；Du *et al.*，2014）。

桃花花岗斑岩中次浑圆状继承锆石中 GA 锆石环带较发育，为岩浆锆石，其谐和年龄 1850±26Ma（MSWD=0.71）与扬子板块古元古代年龄信息统计的 1867Ma 峰值年龄有较好的对应，该年龄亦与点苍山花岗糜棱岩 Sm-Nd 模式年龄（1676～2050Ma；翟明国和从柏林，1993；王义昭和丁俊，1996；朱炳泉等，2001；沙绍礼，2011）、扬子陆块西缘四川会理地区古元古基性辉长岩的 U-Pb 年龄（1.8Ga；王冬兵等，2013）、河口地区辉绿岩 U-Pb 年龄（1.7Ga；关俊雷等，2011）、扬子西南缘碎屑锆石年龄（1.84～1.85Ga；Sun *et al.*，2008，2009；杜利林等，2013）、会理地区通安组变玄武岩（角闪岩）（1.72Ga；任光明等，2014）相近，这表明扬子板块西缘滇西地区存在 1.85～1.7Ga 的岩浆建造与地壳，可能是 Columbia 超级大陆裂解事件在扬子西缘的地质记录有关（焦文放等，2009；张丽娟等，2011；王冬兵等，2013）。而GB 锆石呈次浑圆状、环带不发育，为变质锆石，其不谐和线上交点年龄 2499±32Ma（MSWD=13）（图 7a，d）与扬子板块年龄统计的峰值段 2.5Ga 可对应，推测该区域 2.5Ga 岩浆活动是扬子板块古-中太古代地壳在约 2.5Ga 再造的产物（Rosen，2002；彭澎等，2004；沈其韩等，2005；刘富等，2009；翟明国，2010，2013；胡娟等，2013）。

此外，斑岩作为具有斑状结构的浅成侵入体，其斑晶形成于中间岩浆房，基质在浅部岩浆房晚期快速结晶形成（Xu *et al.*，2009）。而结晶与封闭温度较高（700℃左右）的岩浆锆石（Ortega-Rivera *et al.*，1997；Wu *et al.*，2000；沈渭洲等，2000）形成于中间岩浆房。桃花斑岩中核继承锆石记录了中间岩浆房及深部中生代-新元古代岩浆建造信息。次浑圆状继承锆石不含 36Ma 岩浆锆石的环边（图 6），这意味着浑圆状继承锆石是在岩浆锆石结晶后斑岩岩浆上侵过程被捕获的、源于通道的围岩-石鼓片岩（Winter，2001；Barbey *et al.*，2005；Samuel *et al.*，2007；Xu *et al.*，2009），也就是说，次浑圆状继承锆石可能记录了石鼓片岩年龄的信息，即石鼓片岩可能为 2.5～1.8Ga 变质岩，这与前人测量石鼓片岩的Sm-Nd 年龄是一致的（翟明国和从柏林，1993；Zhai *et al.*，2000；朱炳泉等，2001；李昆琼，2003）。

8 结论

（1）形成于晚造山-后碰撞背景桃花花岗斑岩具岛弧花岗岩地化特征，其成因可能与：一为俯冲拆离的洋壳或富集地幔重熔作用；二为加厚的地壳部分熔融。

（2）桃花花岗斑岩继承锆石有两种类型：一为发育于具密集振荡环带、晶形完好岩浆锆石中的核继承锆石；二为次浑圆状继承锆石。

（3）岩浆锆石谐和年龄为 36.35±0.35Ma，表明桃花斑岩体为喜山期岩体。继承核部锆石年龄在 167～891Ma 之间，表明研究区存在古金沙江洋西缘东向俯冲形成的古生代弧岩浆活动及新元古代岩浆事件响应。

（4）次浑圆状继承锆石中 1.8Ga 与 2.5Ga 锆石群源于斑岩围岩片岩（石鼓片岩），可能代表石鼓片岩的时代，即滇西地区存在早古元古代基底。

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