扬子地块西缘Grenville期花岗岩的厘定及其地质意义

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提要:本文在扬子地块西缘的米易垭口地区,从原划分的冷竹关组地层中厘定出一变质变形的侵入体,岩性为二长花岗岩,具有高硅、富钾特征。该岩体具有较高的Rb/Sr(2.66~10.5)和Rb/Zr(0.43~1.12);有明显的Ba、Sr、P、Nb、Ta和Ti的负异常;$^{87}Sr/^{86}Sr$为1.209549;ε Nd(t,1.0Ga)=−0.89,具有壳源碰撞花岗岩的特征。锆石SHRIMP U−Pb年龄测试结果表明该岩体形成于(1014±8)Ma左右,应为扬子地块与华夏地块在Grenville期碰撞拼贴时的产物。本文的研究表明江南造山带向西可能一直延伸到扬子西缘的会理攀枝花一带,而不是经黔滇向南转折。

关　键　词:火山沟花岗岩;格林威尔期;江南造山带;扬子地块

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扬子地块西缘岩浆岩广泛发育,近年来,一直是研究的热点,并取得了一系列的研究进展[1−34]。这些进展主要集中于晋宁期(0.8 Ga左右)岩浆作用的研究,并且产生了岛弧环境[1−12]和地幔柱环境[15−32]的激烈争论。最近,李献华等[34]又提出了"从四堡造山到南华裂谷"的动力学模式。本文在扬子地块西缘从原划康定群地层中厘定出了Grenville期花岗岩,这对探讨华夏陆块与扬子陆块的关系以及Rodinia超大陆的重建都具有重要的意义。

1　地质背景

扬子地块西缘的基底岩系一直被称为"康滇地轴",它包括侵入岩杂岩——康定杂岩和强变形浅变质地层。这些基底岩系被震旦纪地层不整合覆盖。

扬子地块西缘侵入岩的岩石类型众多,从超基性岩—酸性岩、碱性岩均有分布,但最为发育的还是花岗岩类。这些不同类型的前震旦纪侵入岩呈近南北向带状分布,构成了广义的康定杂岩。由北向南出露的分别有彭灌杂岩、宝兴杂岩、狭义的康定杂岩、石棉杂岩、冕宁杂岩、米易—磨盘山杂岩、同德杂岩、攀枝花大田杂岩和元谋杂岩等杂岩体,其南北长800多千米,东西宽度变化比较大,从数千米至50 km(图1)。上述杂岩体均呈独立圈闭状态出露,狭义的康定以南的各杂岩呈南北向断续分布,而宝兴和彭灌杂岩则呈北东向展布,顺其北东延伸方向还相继出露有近东西向展布的米仓山杂岩、汉南杂岩和黄陵杂岩。该带状分布的杂岩构成了扬子地块现今出露的边界,其西侧为松潘—甘孜造山带,其北为秦岭—大别造山带。

康定杂岩的主体是各类晋宁—澄江期的侵入体,笔者在米易−磨盘山杂岩的边缘——米易垭口地区厘定出一套Grenville期的二长花岗岩。磨盘山—米易岩浆杂岩呈长条状分布于德昌磨盘山及米易垭口一线,岩性以花岗岩−英云闪长岩为主,岩体普遍糜棱岩化。在杂岩的两侧发育一套二云石英片岩和二云片岩为主的地层,1:5万撒莲幅地质图❶将其划为古元古代的五马箐岩组。从区域对比看该岩组的时代应与中元古代的会理群相当。前人将杂岩

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❶四川省地质矿产局. 1:5万撒莲幅地质图及说明书,1995.

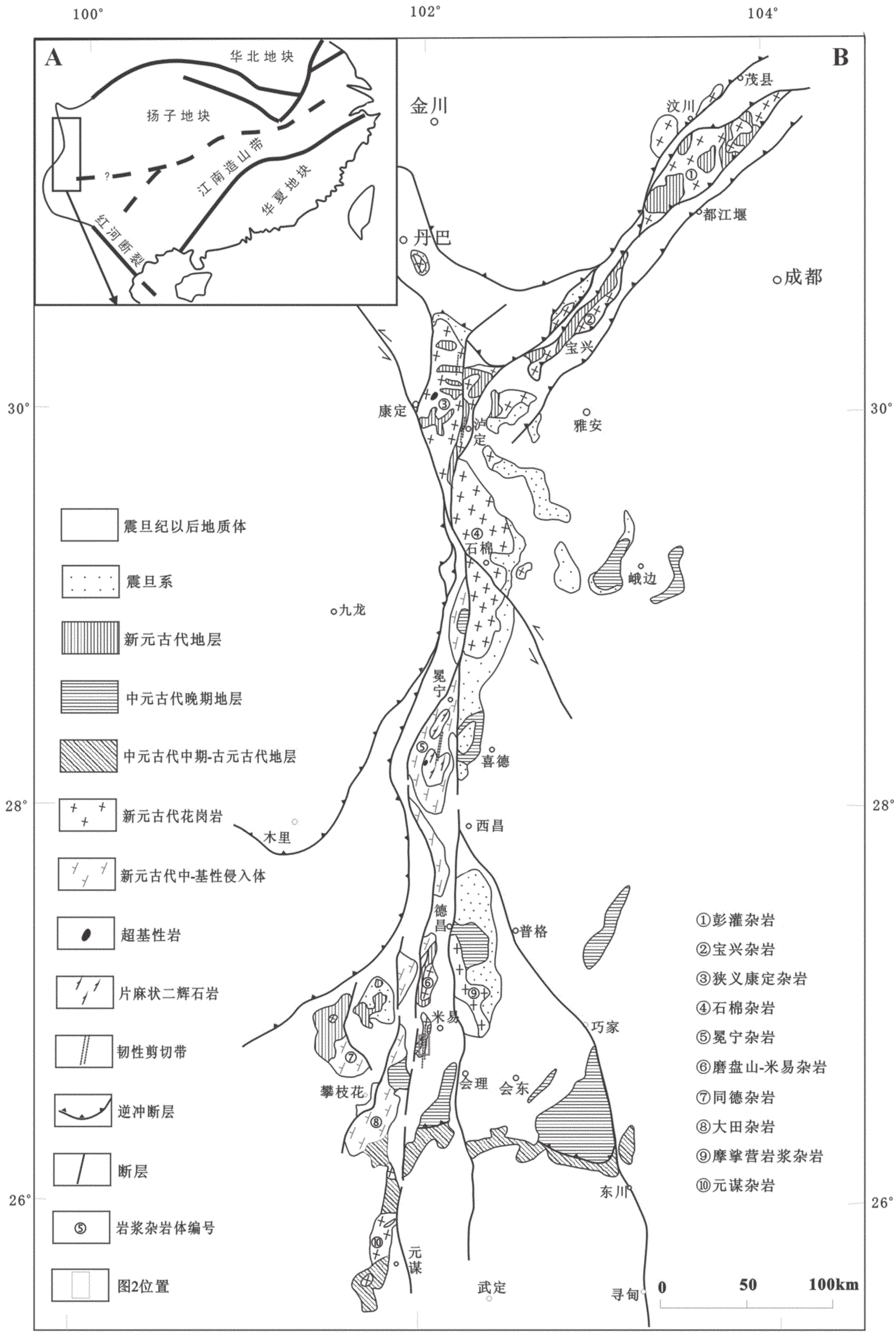


图 1 华南构造分区(A)(据于津海等,2005 资料修改)和扬子地台西缘基底岩系分布(B)
(王新社据 1:20 万和 1:5 万地质图等资料编制)
Fig.1 A Tectonic subdivision of South China (modified from Yu Jinhai et al., 2005) and B distribution of basement rocks in the western margin of Yangtze Block (modified from 1:200000 Geological Map and 1:50000 Geological Map)

边部垭口地区的一套糜棱岩化的片麻状岩石划为康定群冷竹关组。笔者经过详细的野外和室内研究将其厘定为变质变形的侵入岩,暂称为火山沟岩体。

2 火山沟二长花岗岩特征

2.1 野外产状和岩石学特征

火山沟岩体出露于米易县垭口镇火山沟, 位于顶针杂岩与五马箐岩组接触部位(图 2),以往一直被当作康定群冷竹关组的地层。岩体片麻理发育,强烈的糜棱岩化使岩石表现为片麻岩的外貌 (图 3),这也是以往其被当作地层的一个重要原因。其南侧和东侧与五马箐岩组地层为韧性剪切带接触, 片理一致。北侧被顶针杂岩所侵入,西侧与顶针杂岩断层接触。顶针杂岩为一套黄白色片麻状的花岗质-英云闪长质杂岩, 可见五马箐岩组片岩和火山沟片麻状二长花岗岩的包体。前人认为顶针杂岩主体侵位时代为古元古代❶, 笔者测得其锆石 SHRIMP 年龄为(852±7)Ma(另文发表),属新元古代侵入体。

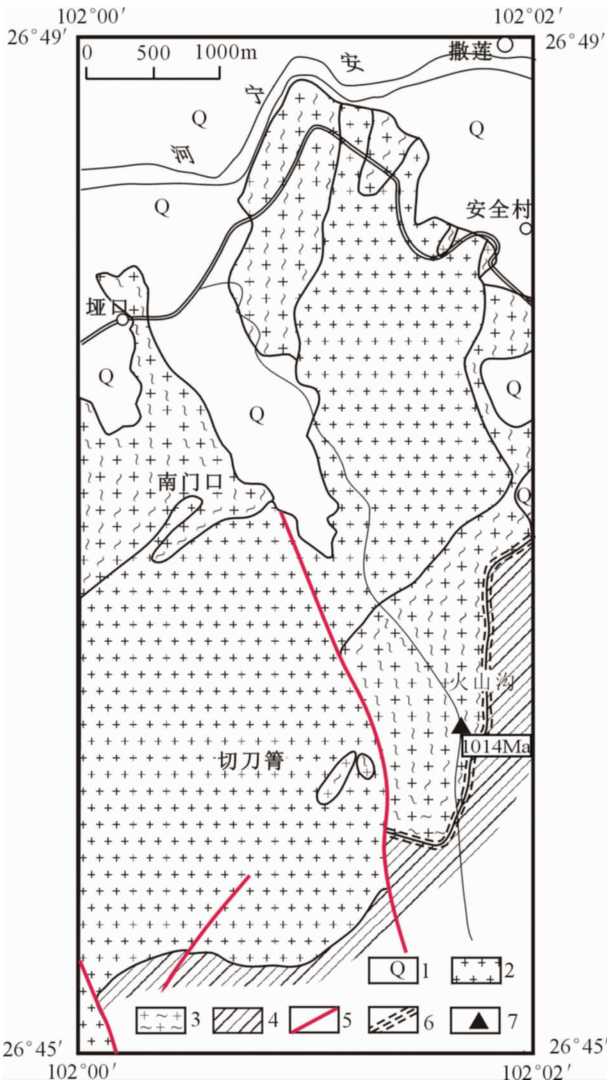


图 2 垭口地区地质简图(据 1:5 万撒莲幅地质图及本文资料修编)

1—第四系;2—顶针杂岩;3—火山沟二长花岗岩;4—五马箐岩组;5—断层;6—韧性剪切带;7—样品位置

Fig.2 Geological sketch map of Yakou area

1-Quaternary; 2-Dingzhen complex; 3-Huoshangou monzogranite; 4-Wumaqing Formation; 6-ductile shear zone; 7- sampling location

图 3 火山沟花岗岩的野外特征

Fig.3 Field features of Huoshangou granite

火山沟岩体岩石新鲜面为灰白色, 风化面黄白色,中粒半自形粒状结构,片麻状构造,条带状构造,黑云母集中成条带分布(图 4-a),局部见有眼球状构造,眼球为钾长石残斑(图 4-b)。岩石中糜棱组构发育,石英等矿物定向拉长呈矩形(图 4-b),构成了矿物线理,而围绕碎斑的基质为细粒的长石和石英,常见自形-半自形板柱状的斜长石晶体残留(图 4-b)。这些结构特征说明原岩应为花岗岩。该岩石主要由石英(25% ±)、微斜长石(35% ±)、斜长石(25% ±)、黑云母(10% ±)、白云母(2% ±)和少量磷灰石等副矿物组成。

2.2 岩石化学特征

从岩石的化学组成(表 1)可以看出,具有明显的高硅(74.31%~78.28%)富钾(4.03%~4.28%)特征,在 QAP 图解中投点于二长花岗岩区, 在 An-Ab-Or 图解中投于狭义的花岗岩区(图 5),全碱含量为 6.8%~8.01%,A/CNK 为 1.14~1.2, 属于过铝的 S 型

❶四川省地质矿产局. 1:5 万米易县幅、撒莲幅会里县幅、关河幅、河口幅区域地质调查报告, 1995.

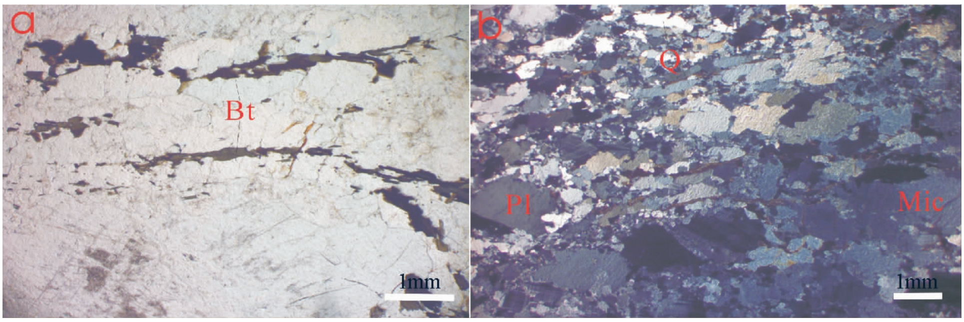


图 4 火山沟花岗岩的显微结构特征

a—单偏光;b—正交偏光;比例尺为 1mmBt−黑云母;Q−石英;Pl−斜长石;Mic−微斜长石

Fig.4 Microphotographs of Huoshangou granite

a−plainlight; b−crossed polars; scale:1mm; Bt−biotite; Q−quartz; Pl−plagioclase; Micro−microcline

表 1 火山沟花岗岩全岩常量元素(%)及稀土和微量元素(10^{-6})组成

Table 1 Major elements(%), trace elements and rare earth elements(10^{-6}) data of Huoshang granite

氧化物	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	FeO	CaO	MgO	K_2O	Na_2O	MnO	P_2O_5	H_2O^+	CO_2
CX126-1	77.05	0.14	11.52	0.52	1.24	0.72	0.10	5.35	2.40	0.02	0.01	0.26	0.21
撒莲幅*	74.32	0.3	12.13	1.02	2.55	2.9	0.45	4.03	2.77	0.029	0.088	0.66	——
撒莲幅	78.28	0.16	14.15	0.35	1.00	0.79	0.40	4.28	3.50	0.017	0.06	——	0.10

稀土元素	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
CX126-1	103	294	24.1	86.2	18.3	0.62	17.9	3.20	18.6	3.29	8.27	0.99	5.51	0.75
撒莲幅	59.6	111	13.9	56.7	14.3	1.59	18.2	2.98	20.4	4.54	12.8	1.73	10.6	1.71

微量元素	Sr	Rb	Ba	Th	Ta	Nb	Zr	Hf	Y	Sc	V	Cr	Co	Ni	Ga	U
CX126-1	24.0	252	141	69.1	1.13	22.9	226	10.5	77.6	2.56	5.2	4.69	0.03	2.00	20.3	5.71
撒莲幅	64	170	597	32.2	1.8	29.3	392	9.0	96.9	8.0	11	5.2	4.15	1.3	22	15.2

注:数据由国家地质实验测试中心分析。主量元素用 X 荧光光谱仪(3080E)测定,分析的相对标准偏差小于 2%~8%;微量元素 Nb、Zr、Rb、Sr、Ba、Ga、Pb、V 用 X 荧光光谱仪(RIX2100)测定,分析的相对标准偏差小于 5%;稀土元素和其他微量元素用 ICP−MS(Excell)测定,分析的相对标准偏差小于 10%。* 数据引自 1:5 万撒莲幅地质图说明书。

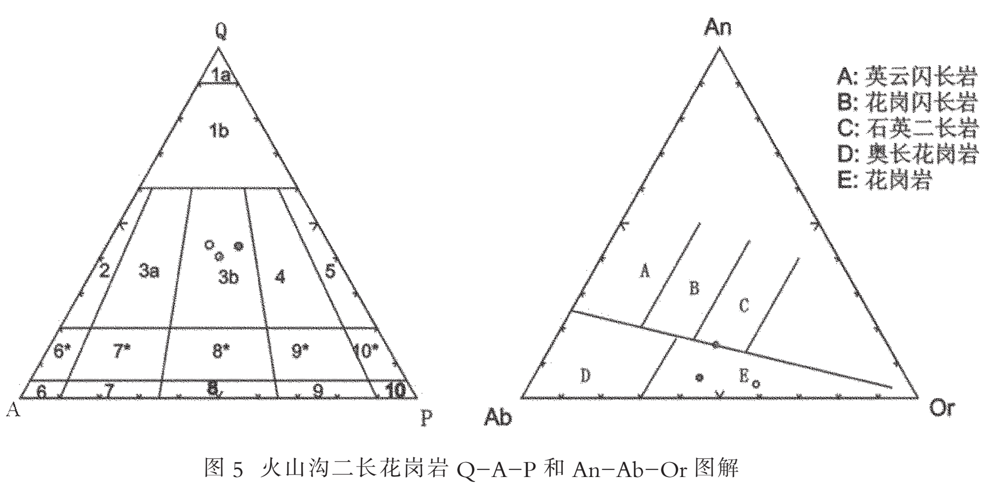


图 5 火山沟二长花岗岩 Q−A−P 和 An−Ab−Or 图解

Fig.5 Q−A−P diagram and An−Ab−Or diagram of Huoshangou granite

花岗岩。

2.3 地球化学特征

该岩石具有非常明显的负铕异常，轻重稀土分馏不强(图 6–a)，表现出富钾花岗岩类的特征。从微量元素组成看该岩石明显富 Rb，低 Sr，具有高的 Rb/Sr(2.66~10.5)，高于大陆地壳的平均值 0.25。微量元素蛛网图具有明显的 Ba、Sr、P、Nb、Ta 和 Ti 的负异常(图 6–b)。Rb/Zr(0.43~1.12)比值高，具有典型的碰撞花岗岩的特征。在 SiO_2–Rb 图解中投于同碰撞花岗岩区(图 7)。

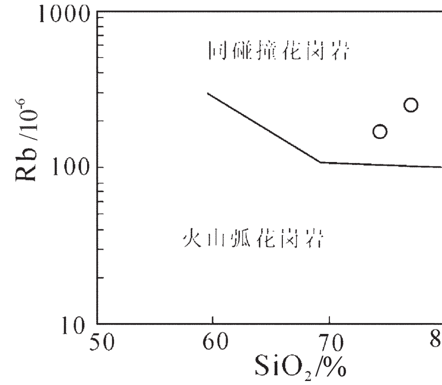


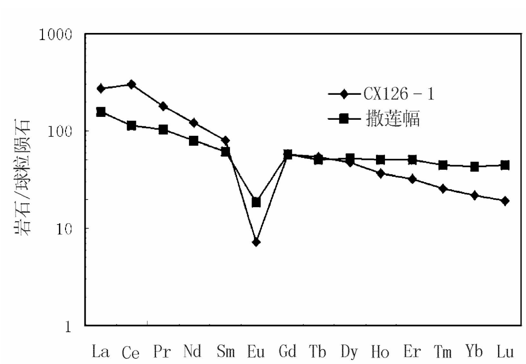
图 7 火山沟花岗岩 SiO_2–Rb 图解

Fig.7 SiO_2–Rb diagram of Huoshangou granite

从同位素组成看(表 2)，二长花岗岩的 $^{87}Sr/^{86}Sr$ 为 1.209549，远高于大陆地壳的 Sr 同位素平均值，可能是花岗岩形成过程中有富 K 流体(熔体)的加入或在后期强变形过程中 Rb、Sr 发生迁移。对具有高 Rb/Sr 比值的岩石来说，经过年龄校正计算出来的 ISr 值会有很大的不确定性，不能用于讨论岩石的成因。二长花岗岩的 εNd(t，1.0Ga)=–0.89，高于扬子地块西缘中元古代成熟地壳，表明其岩浆源区可能有新生地壳或地幔物质的加入。Nd 模式年龄为 1818 Ma，表明该花岗岩可能来源于古元古代的地壳基底。

2.4 锆石 SHRIMP U–Pb 年龄

测年样品采自火山沟，样品的制备与测试方法分别见宋彪等[35]和 Williams[36]文献。锆石阴极发光研



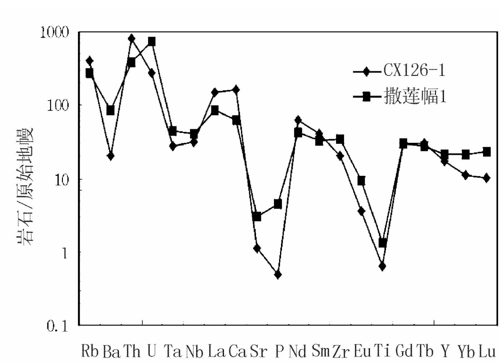


图 6 火山沟二长花岗岩稀土及微量元素图解

Fig.6 Chondrite–normalized REE patterns and mantle–normalized trace elements spidergram of Huoshangou granite

表 2 火山沟花岗岩 Sr–Nd 同位素分析

Table 2 Sr–Nd data of Huoshangou granite

样品号	Rb(10^{-6})	Sr(10^{-6})	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$	$2s_m$	$^{87}Sr/^{86}Sr(t)$
CX126-1	92.17	34.79	7.9728	1.209549	20	1.095527

样品号	Sm(10^{-6})	Nd(10^{-6})	$^{147}Sm/^{144}Nd$	$^{143}Nd/^{144}Nd$	$2s_m$	$^{143}Nd/^{144}Nd_i$	εNd(t)	T_{DM}(Ma)
CX126-1	19.35	89.45	0.1312	0.512163	22	0.511302	-0.89	1818

注:Sr、Nd 同位素分析在中国科学院地质与地球物理研究所固体同位素地球化学实验室完成。Rb–Sr 和 Sm–Nd 用双稀释剂法分离后在 TIMS(MAT262)上测定，Sr、Nd 同位素分馏分别采用 $^{86}Sr/^{88}Sr$=0.1194 和 $^{146}Nd/^{144}Nd$=0.7219 校正。分析流程中实验室本底为:Rb、Sr 小于 100pg，Sm、Nd 小于 50pg。

究由中国科学院地质与地球物理研究所电子探针研究室完成,锆石 SHRIMP U−Pb 分析由北京离子探针中心完成。

锆石的阴极发光图像(图 8)显示自形柱状,内部可见密集的震荡环带,Th/U 比值均大于 0.2 (表 3),属于典型的岩浆锆石。锆石没有明显的变质增生边,也未见变质锆石,从副矿物的角度进一步证明了该岩石是花岗质侵入体,而非变质地层。个别锆石具有核边(幔)结构,但是核和边(幔)均具有密集震荡环带, 只是发光强弱不同 (见图 8 锆石颗粒 8、12、13),边部的 Th/U 比值略低于核部,其年龄也比较接近,只是边(幔)部年龄略微低一点,推测这种核边(幔)结构是由于岩浆期后热液对已结晶的锆石交代造成的,有的锆石内部也见有交代的现象(锆石颗粒 1)。有的锆石边部具有明显的溶蚀现象 (锆石颗粒 3),可能为韧性剪切变形时造成的。

共测试了 16 个锆石颗粒, 获得了 18 个年龄数据。去除偏离谐和线与年龄明显偏离其他锆石群的 3.1、6.1、9.1、13.2、14.1 和 15.1 等 6 个测点,12 个点的 $^{206}Pb/^{238}U$ 加权平均年龄为(1014±8)Ma(图 9),代表了岩浆锆石的结晶年龄,也即岩体的侵位年龄。

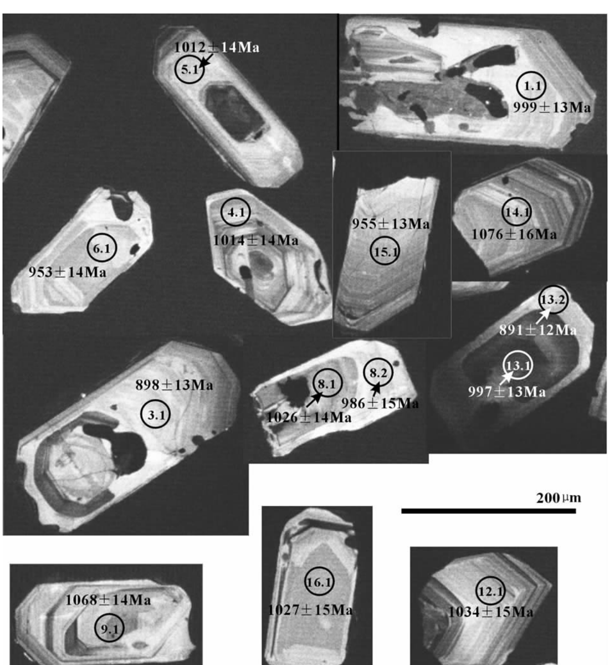


图 8 火山沟花岗岩锆石阴极发光(CL)图像

Fig.8 CL images of zircons from Huoshangou granite

3 讨 论

华南陆块由扬子地块和华夏地块通过江南造山带拼接而成已成为共识, 对江南造山带已有了广泛和深入的研究[5, 8, 9, 17, 20, 37−53],多数学者也都认为是中新元古代造山带(四堡期),与全球性 Grenville 期造山活动有关, 但也有学者根据现有的年龄结果认为扬子与华夏板块的拼合发生在 860~800 Ma,较格林威尔造山期(1190~980 Ma)滞后 330~180 Ma,目前无法确认江南造山带是格林威尔期造山带[49,51]。本文 1.0 Ga 左右花岗岩的厘定为探讨江南造山带的时间提供了重要的限定。Li Zhengxiang 等[17]曾报道过攀枝花北东约 36 km 的回箐沟地区,副片麻岩中存在(1007±14) Ma 的花岗质片麻岩,其时代与本文花岗岩相近。但其并未描述花岗质片麻岩的基本特征,也未给出地球化学数据和特征。笔者通过研究表明火山沟岩体富钾过铝,具有碰撞花岗岩的特征,结合其 1.0 Ga 左右的年龄, 以及区内出露的大量同时代的钙碱性酸性火山岩[54],可以确定在中元古代的末期,该区的构造属性应为俯冲−碰撞造山环境,与 Grenville 期构造运动的时限大体一致。该造山活动应是江南造山带的组成部分, 可能导致了扬子板块在其南部与华夏板块近南北向挤压拼合碰撞。该岩体的年龄和性质为江南造山带的碰撞时间和构造环境提供了重要的依据。

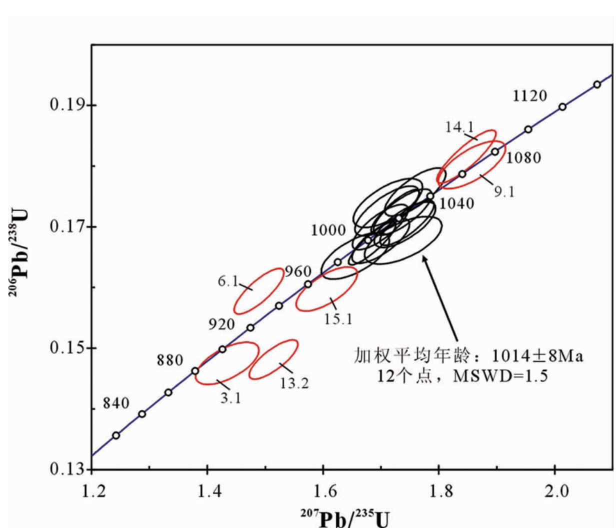


图 9 火山沟花岗岩锆石 U−Pb 年龄谐和图

Fig.9 SHRIMP U−Pb concordant diagram of zircon from Huoshangou granite

表 3 火山沟花岗岩(CX126–1)锆石 SHRIMP 分析结果

Table 3 Zircon SHRIMP analytical data of Huoshangou granite

点号	U (10^{-6})	Th (10^{-6})	Th/U	$^{206}Pb_c$ (%)	同位素比值 $^{207}Pb^*/^{206}Pb^*$	±%	$^{207}Pb^*/^{235}U$	±%	$^{206}Pb^*/^{238}U$	±%	年龄/Ma $^{206}Pb/^{238}U$	±	$^{207}Pb/^{206}Pb$	±	$^{208}Pb/^{232}Th$	±	不谐和性(%)
1.1	193	98	0.52	0.12	0.0735	1.3	1.700	1.9	0.1677	1.4	999	±13	1,028	±26	965	±20	3
2.1	108	55	0.52	0.14	0.0751	2.0	1.738	2.5	0.1678	1.5	1,000	±14	1,072	±40	1,013	±25	7
3.1	128	57	0.46	0.23	0.0705	2.0	1.434	2.5	0.1475	1.6	887	±13	944	±40	993	±24	6
4.1	177	135	0.79	0.25	0.0741	1.4	1.741	2.0	0.1704	1.4	1,014	±14	1,045	±28	969	±18	3
5.1	185	97	0.54	0.10	0.0725	1.2	1.699	1.9	0.1699	1.4	1,012	±14	1,000	±24	1,042	±19	-1
6.1	226	55	0.25	0.22	0.0678	1.1	1.489	1.9	0.1594	1.6	953	±14	862	±23	979	±21	-11
7.1	136	81	0.62	0.06	0.0726	1.3	1.759	2.0	0.1757	1.5	1,044	±14	1,003	±26	1,060	±20	-4
8.1	168	95	0.58	0.21	0.0731	1.2	1.737	1.9	0.1724	1.5	1,025	±14	1,016	±25	1,016	±21	-1
8.2	109	41	0.39	0.23	0.0727	1.8	1.656	2.3	0.1652	1.5	986	±14	1,005	±36	1,104	±25	2
9.1	206	128	0.64	0.06	0.0747	1.5	1.857	2.1	0.1802	1.4	1,068	±14	1,061	±30	1,084	±20	-1
10.1	215	107	0.52	0.03	0.0742	1.0	1.745	1.8	0.1707	1.4	1,016	±13	1,046	±21	1,039	±21	3
11.1	387	189	0.50	0.03	0.0725	0.8	1.725	1.6	0.1725	1.4	1,026	±13	1,000	±16	1,073	±17	-3
12.1	151	82	0.56	0.21	0.0714	1.7	1.712	2.3	0.1739	1.5	1,034	±15	969	±35	1,019	±22	-7
13.1	476	400	0.87	0.03	0.0731	0.8	1.685	1.6	0.1673	1.4	997	±13	1,015	±16	987	±15	2
13.2	244	134	0.57	0.03	0.0741	1.1	1.514	1.8	0.1481	1.4	891	±12	1,045	±23	861	±15	15
14.1	299	164	0.57	0.05	0.0738	0.9	1.848	1.8	0.1816	1.6	1,076	±16	1,036	±18	1,061	±19	-4
15.1	147	68	0.48	0.19	0.0729	1.6	1.606	2.2	0.1598	1.5	955	±13	1,012	±32	1,015	±28	6
16.1	131	96	0.75	0.12	0.0719	1.5	1.710	2.1	0.1726	1.6	1,026	±15	982	±30	1,005	±21	-5

注：$^{206}Pb_c$(%)指普通铅，普通铅中的 ^{206}Pb 占全铅 ^{206}Pb 的百分数；Pb^*代表放射性铅，用实测 ^{204}Pb 校正，表中所有误差均为 1 σ。

江南造山带的东部研究的较为详细，然而其如何西延却不是很清楚，一些学者认为江南造山带的南界向西转为溆浦—黔阳—融安近南北走向，即武陵山重力布格梯度陡变带[38]。其北部边界为长江断裂带[38]，沿贵阳、昆明以南向南西转折[39]。通过本文的研究则提供了另一种可能，江南造山带并没有经黔滇向南转折，而可能是向西延伸至会理一带。姜勇彪等[53]和耿元生等[55]通过构造解析发现攀枝花、会理—东川等地区的早期构造线总体方向为近东西向(局部受后期岩体侵位等影响而发生改变)，说明早期变形构造的运动方向应该为南北向的挤压运动。在会理群与南部河口群的东西向接触带中发育一套大洋拉斑玄武岩–超镁铁质堆积岩建造（目前还缺乏准确的年龄限定)，王康明等[56]称之为菜子园混杂岩，认为代表了陆块拼贴带。上述种种迹象表明江南造山带向西可能一直延伸到扬子地块西缘的会里—攀枝花一带。江南造山带东部和中部由双溪坞群、上溪群、双桥山群、冷家溪群、四堡群等地层和大量的S 型花岗岩等组成，延至川西则由天宝山变质火山岩(1028 Ma)[53]、大小相岭变质火山岩等钙碱性火山岩，以及相应的沉积地层与同时代的花岗岩组成。

4 结 论

(1)火山沟地区原划分的冷竹关组地层实为变质变形的侵入体，其岩性为二长花岗岩，具有同构造花岗岩的属性，形成时间为（1014±8）Ma，与Grenville 期造山活动有关。

(2)江南造山带有可能向西一直延伸到扬子西缘的会里—攀枝花一带。

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The identification of the Grenvillian granite on the western margin of the Yangtze Block and its geological implications

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Abstract: A deformed and metamorphosed monzogranite intrusion was ruled off from the Lengzhuguan Formation at Yakou Town, Miyi County, which is situated on the western margin of the Yangtze Block. The intrusion is high in SiO_2 and K_2O and shows obvious negative anomalies of Ba, Sr, P, Nb, Ta and Ti in the mantle−normalized trace element spidergram. In addition, the rock has high Rb/Sr (2.66~10.5) and Rb/Zr (0.43~1.12) ratios, and the 87Sr/86Sr and εNd (t, 1.0 Ga) values are 1.209549 and −0.89, respectively, suggesting a crust−derived collisional granite. The zircon SHRIMP data give a granite crystallization age of ca 1014±8 Ma. It is proposed that the Huoshangou granite might have resulted form the collision between the Yangtze Block and the Cathysia Block during the Grenvillian event. It can also be deduced that the Jiangnan orogenic belt can probably extend westward to Huili−Panzhihua area on the western margin of the Yangtze Block instead of turning southward from the Guizhou−Yunnan area.

Key words: Huoshangou granite; Grenvillian; Jiangnan orogenic belt; Yangtze block

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