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四川理塘地区花岗闪长岩特征及其增生楔弧岩浆活动

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提要:【研究目的】通过查明理塘地区拉扎嘎山花岗闪长岩的年龄、地球化学特征,探讨花岗闪长岩形成的时代、成因及构造背景,为研究甘孜—理塘洋盆俯冲增生构造演化过程提供依据。**【研究方法】**选取甘孜—理塘蛇绿混杂岩带俯冲增生楔内花岗闪长岩,系统开展岩相学、LA−ICP−MS锆石U−Pb年代学和岩石地球化学研究。**【研究结果】**花岗闪长岩含有大量的角闪石、黑云母等铁镁矿物,局部见大量的闪长质包体和围岩捕掳体。岩体形成于晚三叠世((207.2±1.5)Ma),岩石属I型钙碱性准铝质花岗岩类,具富集大离子亲石元素Rb、Ba、K、Th、U,亏损高场强元素Nb、Ta、P、Zr、Ti,显示轻稀土富集、重稀土亏损的右倾式配分模式,具有Eu的负异常,是典型的火山弧型花岗岩。**【结论】**结合区域地质资料及本文研究成果,认为四川理塘地区拉扎嘎山花岗闪长岩与甘孜—理塘洋向西俯冲致使中咱地块东缘增生楔不断扩大密切相关,是增生楔杂岩熔融成不同类型岩浆混合的产物。

关 键 词:钙碱性岩浆岩;锆石U−Pb年龄;地球化学特征;增生楔;地质调查工程;四川理塘

创 新 点:四川理塘地区拉扎嘎山花岗岩形成于晚三叠世,具典型的火山弧型花岗岩地球化学特征,形成于甘孜—理塘洋西向俯冲致使增生楔杂岩熔融,为甘孜—理塘洋俯冲增生构造演化提供了新的证据。

中图分类号:P588.12+1 **文献标志码:**A **文章编号:**1000−3657(2022)04−1295−14

Characteristics of granodiorite in the Litang area of Sichuan and its volcanic arc magmatism accretionary wedge

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Abstract: This paper is the result of geological survey engineering.

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[Objective] By finding out the age and geochemical characteristics of granodiorites in Lazhagashan area, this paper discusses the age, genesis and tectonic background of granodiorites, so as to provide a basis for the study of subduction−accretion processes in the Ganzi−Litang Ocean Basin. **[Methods]** Our project carried out systematically study the petrography, LA−MC−ICP−MS zircon U−Pb chronology and rock geochemistry from the granodiorites in subduction accretion complex of Ganzi−Litang ophiolite melange belt. **[Results]** The granodiorites contain a large amount of femic mineral such as amphibole, biotite, and a large number of dioritic enclaves and surrounding rock xenoliths. The intrusive rocks were formed in the Late Triassic ((207.2±1.5)Ma), and are I−type calc−alkaline quasi−aluminous granites with enriched in large−ion−lithophile elements (LILE), such as Rb, Ba, K, Th and U, depleted in high−field−strength elements (HFSE), such as Nb, Ta, P, Zr and Ti. It shows a right−leaning pattern of enrichment of light rare earth and depletion of heavy rare earth. It is a typical volcanic arc granite showing strong enrichment of LREE and depletion of HREE, with negative Eu anomaly. **[Conclusions]**Combined with the regional geological data and the research results of this paper, it is considered that the Lazhagashan granodiorite in Litang area is closely related to the westward subduction of the Ganzi−Litang Ocean resulted in the expansion of the accretionary complex in the eastern margin of the Zhongza block, which is the product of melting accretionary complex into different types of magma mixing.

Key words: calc−alkaline magmatic rock; zircon U−Pb age; geochemistrical characteristics; accretionary wedge; geological survey engineering; Litang County in Sichuan Province

Highlights: The Lazhagashan granite in Litang area was formed in Late Triassic with typical geochemical characteristics of volcanic arc granite. It was formed in the melting of accretionary complex due to westward subduction of the Ganzi−Litang Ocean, which provides new evidence for the subduction and accretionary tectonic evolution of the Ganzi−Litang Ocean.

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1 引　言

增生楔形成于汇聚板块边缘并位于大陆边缘弧或岛弧与海沟之间，是俯冲过程（包括洋-洋、洋-陆俯冲体系）中被刮削下来的远洋沉积物、大洋板块残片和海沟浊积岩在上驮板块前端共同堆积形成的、以逆冲断层为边界的楔形地质体（Karig et al., 1975; 闫臻等, 2018）。随着海沟的后退，构造堆积形成的增生楔持续扩大，当增生楔扩大到一定规模时，早期形成的增生楔上可能会发生弧岩浆活动。此现象在南美安第斯、东南亚爪哇—苏门答腊造山带以及中国北祁连、天山、东西昆仑、雅鲁藏布江造山带均可见到（许志琴等，1994；Müller et al., 1998；张建新等, 1998；肖文交等，2000；Chiaradia et al., 2004；李继亮，2004；Marschik et al., 2006；Laznicka, 2006；高俊等，2009；Vallance et al., 2009；耿全如等，2011；李奋其等，2016）。

甘孜—理塘蛇绿混杂岩带处于欧亚板块与印度板块结合部位的特提斯构造域东段，与西侧的义敦—沙鲁里岛弧带和勉戈—青达柔弧后盆地共同组成了甘孜—理塘弧盆系（潘桂棠等,2013, 2017）。现有证据表明，甘孜—理塘洋盆于晚三叠世开始向西俯冲，在中咱地块东缘形成了大规模的火山-岩浆弧，火山-岩浆弧与扬子陆块于晚三叠世/早侏罗世之交发生碰撞（刘宝田等,1983；候立玮等,1983；俞如龙等,1989; 许志琴等,1992；莫宣学等, 1993；候增谦等,1995, 1996, 2003, 2004；潘桂棠等, 1997, 2013, 2017；钟大赉,1998；李兴振等,1999；Hou et al., 2007；李文昌等, 2010）。漫长的俯冲消减过程中在海沟一侧形成了规模宏大的弧前增生楔杂岩带，但迄今未见有甘孜—理塘蛇绿混杂岩带内关于弧岩浆活动内容的报道。本次研究以甘孜—理塘蛇绿混杂岩带中段四川理塘地区拉扎嘎山花岗闪长岩体为研究对象，通过岩相学、同位素年代学、岩石地球化学研究，对该岩体的形成时代、岩石成因及构造环境进行探讨研究，为甘孜—理塘蛇绿混杂岩带

晚三叠世末期构造演化提供新的约束。

2　地质背景

甘孜—理塘蛇绿混杂岩带北西自邓柯，向南东经甘孜转向南，经理塘至川滇交界处的三江口，然后向西折转沿哈巴雪山、玉龙雪山西侧南延至剑川，该带北西端和南段分别在青海玉树和云南乔后与金沙江蛇绿混杂岩带相接（潘桂棠等,2013）。研究区位于甘孜—理塘蛇绿混杂岩带中段四川省理塘县—新龙县一带（图1a），理塘地区增生杂岩主要由基质和岩块组成，其中基质主要由三叠纪深水—半深水细碎屑沉积物组成；块体的组成较为复杂，包含晚泥盆世—三叠纪理塘洋残片、奥陶纪陆源裂离块体、晚三叠世洋内残弧块、二叠纪—三叠纪洋岛（海山）残块以及一系列不同时代的硅质岩、灰岩岩块等，代表了晚古生代—中生代发育的理塘洋盆现今残余。

本文所研究的拉扎嘎山岩体出露于理塘县亚火乡拉扎嘎山—下坝村一带，呈不规则椭圆状北西—南东向展布于理塘增生杂岩带东侧，长约7.8 km，出露面积约12.5 km²，在新龙县竹青村和理塘县下坝村一带围岩中零星出露数个小型岩枝（图1b）。岩石类型

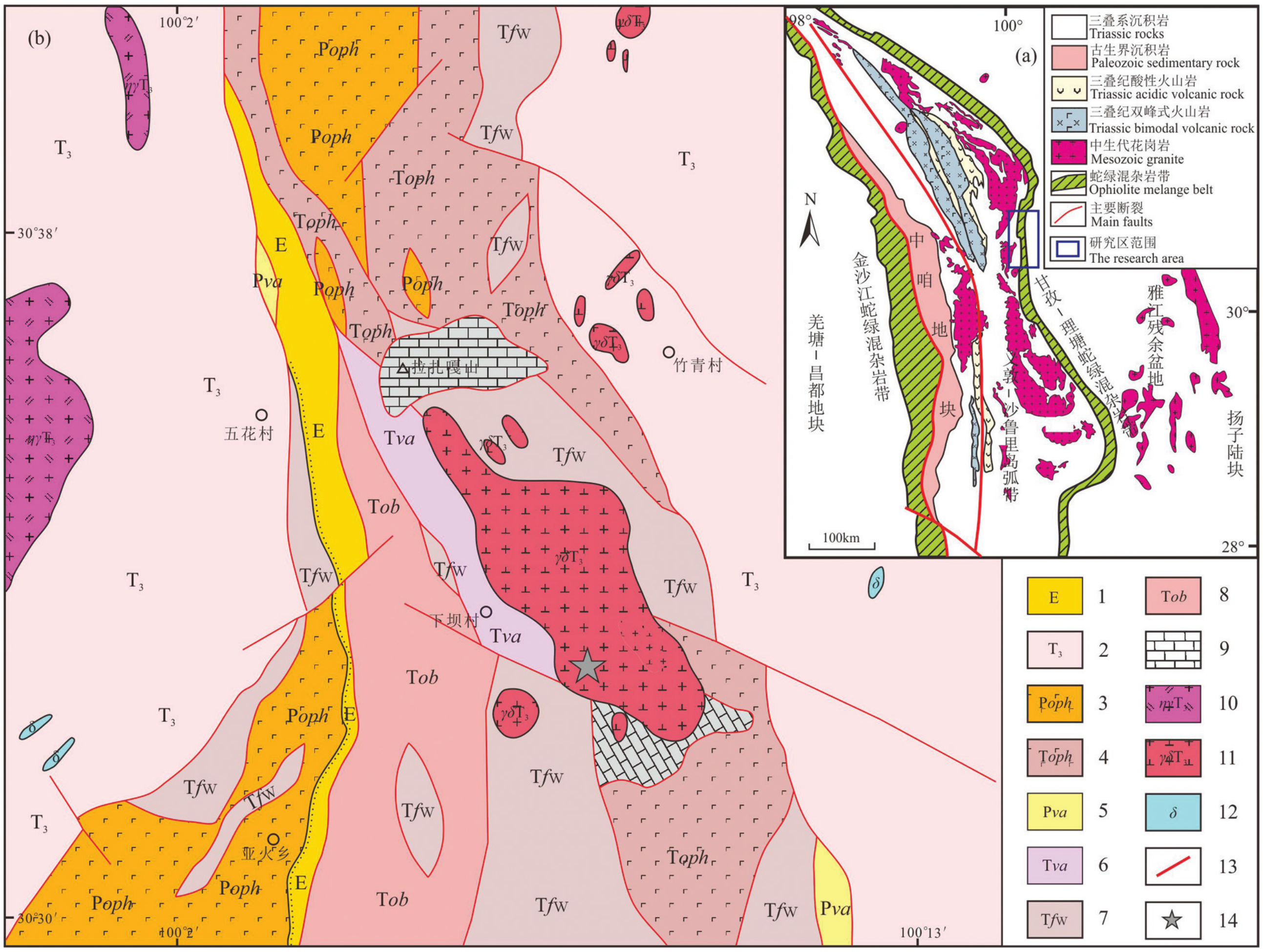

图1 理塘蛇绿混杂岩带大地构造位置图（a, 据Hou et al., 2007修改）和理塘地区区域地质简图（b）

1—古近纪地层；2—晚三叠世地层；3—二叠纪蛇绿岩岩片；4—三叠纪蛇绿岩岩片；5—二叠纪洋岛岩片；6—三叠纪洋岛岩片；7—三叠纪复理石岩片；8—三叠纪深海沉积岩片；9—灰岩岩块；10—二长花岗岩；11—花岗闪长岩；12—闪长岩；13—断层；14—采样位置

Fig.1 Simplified geological map of the Ganzi—Litang ophiolite mélange belt(a, modified from Hou et al., 2007) and simplified regional geological map in Litang area(b)

1–Paleogene strata; 2–Late Triassic strata; 3–Permian ophiolite schist; 4–Triassic ophiolite schist; 5–Permian oceanic island schist; 6–Triassic oceanic island schist; 7–Triassic flysch; 8–Triassic deep sea sedimentary schist; 9–Limestone block; 10–Monzogranite; 11–Granodiorite; 12–Diorite; 13–Fault; 14–Sampling location

主要为灰白色中细粒花岗闪长岩(图2a),局部见中粗粒花岗闪长岩及少量的中粒黑云母二长花岗岩,相互之间均呈涌动式侵入接触关系(图2b)。花岗闪长岩中见大量的不规则状闪长质包体(图2c)。拉扎嘎山花岗闪长岩体与围岩呈明显的侵入接触关系,其西侧为蛇绿混杂岩洋岛残片,灰岩普遍热接触变质为透辉石榴大理岩,东侧为蛇绿混杂岩复理石岩片,岩石普遍发育角岩化或石英岩化,在内外接触带见有明显的砂岩捕掳体(图2d)和烘烤边(图2e)。

花岗闪长岩为灰白色,呈中细粒花岗结构,块状构造。主要矿物成分为斜长石(37%~47%)、石英(23%~26%)、角闪石(15%~20%)、黑云母(12%~14%)、钾长石(2%~3%)及少量的副矿物(图2f)。斜长石为自形—半自形板状,粒度一般为0.7 mm,蚀变见较强的泥化、碳酸盐化等而使表面较为污浊,部分晶粒可见环带结构。石英多为他形粒状,镜下较干净透明,粒度一般为1 mm。角闪石为自形—半自形,较自形者呈近菱形的六边形,粒度大小不等,0.6~2.5 mm,一般为1.2 mm,具明显绿色多色性,较自形晶粒可见特征的闪石式解理,常见简单双晶现象,个别颗粒可见环带构造,蚀变见碳酸盐化、绿泥石化等。黑云母为红褐色,板状,见弱绿泥石化,具细长密集解理缝。钾长石多为他形粒状,见泥化等而使表面呈土褐色。斜长石与暗色矿物角闪石自形程度较高,钾长石与石英多为他形粒状,石英呈不规则状充填构成花岗结构。副矿物见半自形柱粒状锆石,粒度约为0.08 mm。

3 年代学

本次研究样品采于理塘县亚火乡那曲河沿岸小道,编号为PM011-43DN1,地理坐标:30°34′23″N,100°07′52″E。锆石分选是在河北省廊坊地质研究所实验室进行的,将重约10 kg岩石样品粉碎成200目,利用常规的浮选和电磁方法分离出锆石。在双目镜下挑选出晶形和透明度较好的锆石,将其黏在树脂台上,经打磨、抛光后并镀金,在进行激光剥蚀测试前,进行反射光、透射光和阴极发光照相,分析锆石内部的结构,分选点力求避开内部裂隙和包裹体。样品测试在中国地质科学院矿产资源所激光剥蚀多接收电感耦合等离子体质谱仪(LA-MC-ICP-MS)实验室完成的。锆石U-Pb测试分析仪器为Finnigan Neptune型LA-MC-ICP-MS,并配备有与之配套的Newwave UP 213激光剥蚀系统。LA-MC-ICP-MS激光剥蚀以He为载气、束斑直径为30 μm,采用单点剥蚀的方式,数据分析前用锆石GJ-1进行调试仪器,使之达到最优状态,锆石U-Pb定年以锆石GJ-1为外标,U、Th含量以锆石M127为外标进行校正。为保证测试精度,在测试过程中每测定5~7个样品点后,重复测定2个锆石GJ1和一个锆石Plesovice进行校正。实验数据前期处理采用ICP-MS Data Cal 4.3程序完成,锆石年龄谐和图以及频率直方图均采用Isoplot 3.0程序绘制。实验测试过程详见侯可军等(2009),样品的分析测试结果见表1。

本次挑选的花岗闪长岩锆石呈自形—半自形长柱状晶体,颗粒长136~290 μm,宽68~119 μm,长宽比为1.3~2.6。阴极发光(CL)图像显示锆石均发育清晰的岩浆振荡环带(图3),属于典型的岩浆作用形成的锆石。

分析结果表明,锆石的Th和U含量分别为50×10^{-6}~477×10^{-6}和161×10^{-6}~701×10^{-6},Th/U比值为0.27~0.68,这同样表明这些锆石属典型的岩浆锆石(Weave,1991;Hoskin and Black,2000;吴元保等,2004;孙转荣等,2017;菅坤坤等,2018)。样品26个测点的^{206}Pb/^{238}U年龄变化范围为203~212 Ma,表明年龄值分布较为集中,年龄数据投影均在U-Pb谐和曲线上或附近(图4),其^{206}Pb/^{238}U加权平均年龄为(207.2±1.5)Ma(MSWD=0.35,n=26),为晚三叠世末期,代表了拉扎嘎山花岗闪长岩侵位年龄。

4 地球化学

用于岩石地球化学研究的样品采自理塘县亚火乡拉扎嘎山山坡,样品采集过程中避开脉体发育地段。7件样品经清洗表面杂质后破碎,经多次清洗后将样品烘干研磨至200目。主量元素、微量和稀土元素分析是在四川冶金地质勘查局六〇五大队分析测试中心完成的。其中主量元素使用X-射线荧光光谱仪(XPF-1500)法测试,精度优于2%~3%,微量元素及稀土元素利用酸溶法制备样品,使用ICP-MS(Element Ⅱ)测试,分析精度一般优于5%。7件拉扎嘎山花岗闪长岩的分析结果见表2。

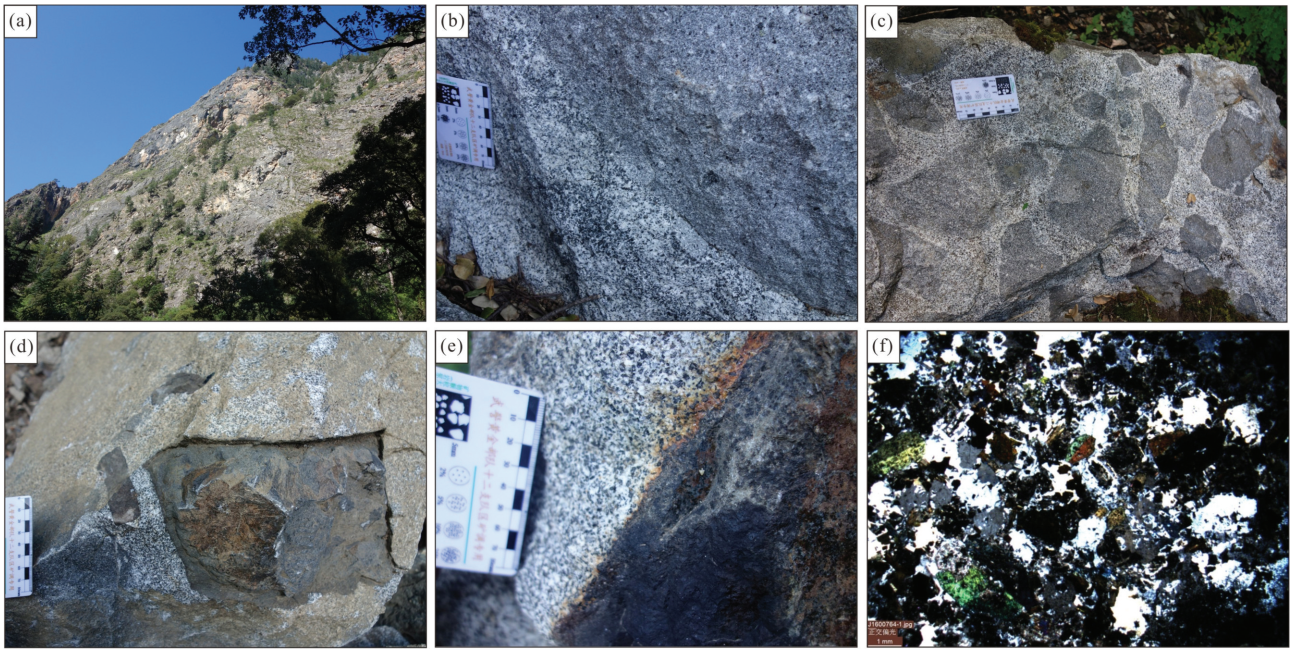

图2 拉扎嘎山花岗闪长岩野外露头及显微镜下照片

a—拉扎嘎山花岗闪长岩;b—中细粒花岗闪长岩与中粗粒花岗闪长岩呈涌动式接触关系;c—闪长质包体;d—花岗闪长岩中砂岩捕掳体;e—围岩烘烤边;f—花岗闪长岩显微镜下照片

Fig.2 Field outcrop and microstruction photos of granodiorites in Lazhagashan area

a−Lazhaga mountain granodiorite; b−Medium−fine−grained granodiorite and medium−coarse−grained granodiorite show a surging contact relationship; c−Dioritic inclusion; d−Sandstone traps in granodiorite; e−Roasting edge of surrounding rock; f−Microscopic photographs of granodiorite

拉扎嘎山花岗闪长岩SiO_2含量变化于63.46%~64.70%,Al_2O_3含量为15.46%~16.03%,CaO含量为5.81%~6.20%,(Na_2O + K_2O)含量较低(4.46%~4.91%),平均为4.66%,K_2O/Na_2O值为0.93~1.06。里特曼指数(*σ*)为0.98~1.11,均小于3.3,岩石属于钙碱性岩类。铝饱和指数(A/CNK)为0.89~0.92,属准铝质花岗岩范畴。MgO含量为1.96%~2.45%,TiO_2含量为0.61~0.68。

在侵入岩TAS图解(图5)上,7件样品均落入花岗闪长岩区域内,与岩相学观察特征一致。在SiO_2-K_2O图解(图6a)上,样品均落入钙碱性系列。在铝饱和指数图解(图6b)中,样品都落入准铝质区域内。

样品的稀土元素总量(ΣREE)为135.80×10^{-6}~168.42×10^{-6}, LREE/HREE=6.21~8.31,$(La/Yb)_N$=6.47~10.20,表明轻重稀土元素分馏程度强烈。除LZGA−46FX样品Eu异常高达5.06外,其余6件样品均具中等程度的Eu负异常(δEu=0.71~0.79),暗示在岩浆源区有斜长石残留或经历了较强的斜长石、钾长石的分离结晶(Cullers and Graf, 1984),LZGA−46FX样品出现Eu正异常可能是该样品中含有斜长石斑晶导致Eu元素的富集。在球粒陨石标准化稀土元素配分曲线图(图7a)上,样品均显示出轻稀土元素富集、重稀土元素相对平缓的右倾型特征,是板块汇聚边缘岩浆岩共有的特征。微量元素原始地幔标准化蛛网图(图7b)中,样品具富集大离子亲石元素Rb、Ba、K、Th、U,亏损Nb、Ta、P、Zr、Ti等高场强元素特征,明显不同于MORB和OIB,而具典型的岛弧岩浆岩特征,特别是Nb、Ta的亏损是板块俯冲产生岛弧环境岩浆岩的显著特征,这种亏损反映了岩浆形成过程中有俯冲带流体的参与。P、Ti、Nb、Ta的负异常也表明源区可能有磷灰石和钛铁矿、金红石、角闪石的残留或存在结晶分异;Sr的负异常说明岩石经历了斜长石的分离结晶作用或源区有斜长石的残留,与稀土元素所反映的特征相一致;强烈的Ti负异常则反映了岩浆中钛铁

表1 拉扎嘎山花岗闪长岩(PM011−43DN1)LA−ICP−MS锆石U−Pb同位素测试结果

Table 1 LA−ICP−MS Zircon U−Pb isotope data of granodiorites(PM011−43DN1) from the Lazhagashan area

分析点	含量/10^{-6}			Th/U	同位素比值							年龄/Ma					
	Pb*	Th	U		^{207}Pb/^{206}Pb	1σ	^{207}Pb/^{235}U	1σ	^{206}Pb/^{238}U	1σ	rho	^{207}Pb/^{206}Pb	1σ	^{207}Pb/^{235}U	1σ	^{206}Pb/^{238}U	1σ
PM011-43DN1-1	14	125	372	0.34	0.0536	0.0035	0.2343	0.0144	0.0321	0.0006	0.3071	354	148	214	12	204	4
PM011-43DN1-2	7	55	178	0.31	0.0500	0.0035	0.2246	0.0150	0.0331	0.0008	0.3804	195	158	206	12	210	5
PM011-43DN1-3	14	114	349	0.33	0.0512	0.0034	0.2320	0.0161	0.0329	0.0006	0.2769	256	154	212	13	209	4
PM011-43DN1-4	7	61	181	0.34	0.0593	0.0040	0.2599	0.0179	0.0324	0.0008	0.3656	576	142	235	14	205	5
PM011-43DN1-5	6	51	165	0.31	0.0529	0.0040	0.2320	0.0165	0.0329	0.0008	0.3604	324	174	212	14	208	5
PM011-43DN1-7	15	130	377	0.35	0.0484	0.0033	0.2172	0.0152	0.0326	0.0008	0.3403	117	156	200	13	207	5
PM011-43DN1-8	17	204	419	0.49	0.0489	0.0025	0.2188	0.0109	0.0326	0.0005	0.3355	146	120	201	9	207	3
PM011-43DN1-9	10	91	248	0.37	0.0476	0.0038	0.2142	0.0159	0.0335	0.0006	0.2298	80	178	197	13	212	4
PM011-43DN1-10	12	101	305	0.33	0.0554	0.0034	0.2492	0.0146	0.0330	0.0006	0.3179	432	137	226	12	209	4
PM011-43DN1-11	13	117	335	0.35	0.0545	0.0033	0.2379	0.0134	0.0324	0.0005	0.2999	391	135	217	11	205	3
PM011-43DN1-12	12	99	306	0.32	0.0484	0.0026	0.2207	0.0115	0.0333	0.0005	0.2986	120	122	203	10	211	3
PM011-43DN1-14	11	107	304	0.35	0.0540	0.0033	0.2414	0.0152	0.0324	0.0005	0.2498	372	136	220	12	205	3
PM011-43DN1-15	14	127	366	0.35	0.0504	0.0026	0.2237	0.0113	0.0326	0.0005	0.3178	213	114	205	9	207	3
PM011-43DN1-16	7	54	199	0.27	0.0558	0.0051	0.2423	0.0195	0.0324	0.0007	0.2808	456	202	220	16	205	5
PM011-43DN1-17	9	75	241	0.31	0.0538	0.0033	0.2368	0.0140	0.0324	0.0006	0.2967	365	137	216	11	205	4
PM011-43DN1-19	8	74	223	0.33	0.0527	0.0033	0.2269	0.0132	0.0322	0.0006	0.3455	317	141	208	11	204	4
PM011-43DN1-20	28	446	693	0.64	0.0546	0.0023	0.2418	0.0102	0.0322	0.0006	0.4668	394	94	220	8	204	4
PM011-43DN1-21	10	80	282	0.28	0.0528	0.0034	0.2336	0.0151	0.0323	0.0007	0.3462	317	146	213	12	205	5
PM011-43DN1-22	7	57	195	0.29	0.0571	0.0047	0.2473	0.0185	0.0323	0.0008	0.3409	494	180	224	15	205	5
PM011-43DN1-23	9	79	249	0.32	0.0540	0.0036	0.2366	0.0149	0.0326	0.0006	0.2991	369	156	216	12	207	4
PM011-43DN1-24	11	97	287	0.34	0.0509	0.0032	0.2369	0.0160	0.0332	0.0006	0.2844	235	144	216	13	210	4
PM011-43DN1-25	13	116	356	0.32	0.0510	0.0032	0.2314	0.0155	0.0328	0.0008	0.3421	239	151	211	13	208	5
PM011-43DN1-26	20	229	530	0.43	0.0508	0.0025	0.2301	0.0116	0.0328	0.0007	0.4175	232	111	210	10	208	4
PM011-43DN1-27	9	86	254	0.34	0.0530	0.0039	0.2425	0.0195	0.0327	0.0008	0.2969	328	167	220	16	207	5
PM011-43DN1-28	11	103	299	0.34	0.0564	0.0040	0.2498	0.0163	0.0329	0.0008	0.3520	478	159	226	13	208	5
PM011-43DN1-29	8	72	230	0.31	0.0528	0.0046	0.2289	0.0173	0.0327	0.0007	0.2703	320	200	209	14	207	4

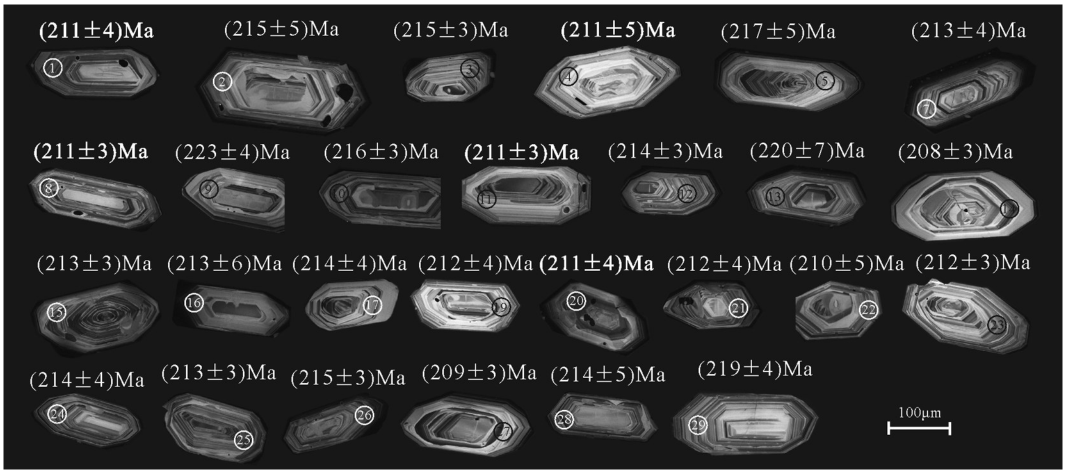

图3 拉扎嘎山花岗闪长岩锆石阴极发光(CL)图像

Fig.3 Cathodeluminescence images of analyzed zircon from granodiorites of the Lazhagashan area

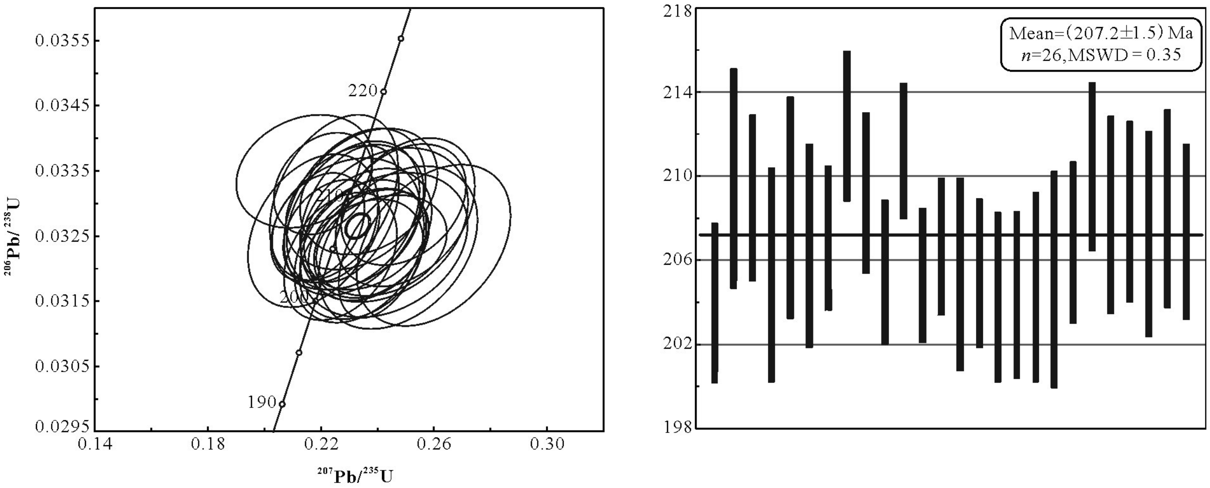

图4 拉扎嘎山花岗闪长岩LA-ICP-MS锆石U-Pb年龄谱和图
Fig.4 LA-ICP-MS age concordia diagram and weighted average ages of granodiorites from the Lazhagashan area

矿的结晶分离作用(Li Fenqi et al.,2016)。

5 讨　论

5.1 岩浆源区及成因

拉扎嘎山花岗闪长岩从造岩矿物方面看，岩石均含有角闪石、黑云母等铁镁矿物，副矿物含磷灰石，未见白云母、堇青石等过铝质矿物，CIPW标准矿物中未见刚玉分子；从地球化学方面看，岩石具高硅铝、低镁钛的特征，铝饱和指数为0.89~0.92，均小于1.1，属于钙碱性准铝质花岗岩类。以上矿物学和元素地球化学特征均表明拉扎嘎山花岗闪长岩属于I型花岗岩类。

样品富集大离子亲石元素(LILE)、亏损高场强元素(HFSF)以及Eu具中等程度负异常，暗示岩浆不可能由软流圈部分熔融直接产生，而应该来自于地壳或壳幔混染(Dungan et al., 1986; Mckenzie, 1989; Foley et al., 1992; 胡芳芳等,2005)。Barbarin(1999)将A/CNK<1的准铝质花岗岩分为富钾钙碱性花岗岩类(KCG)、含角闪石钙碱性花岗岩类(ACG)和洋中脊拉斑玄武质花岗岩类(RTG)。研究区拉扎嘎山花岗闪长岩富含角闪石和黑云母，具低钾高硅特征，A/CNK=0.89~0.92，属钙碱性系列，为典型的含角闪石钙碱性花岗岩类(ACG)。Barbarin(1999)指出ACG是壳幔混合源的钙碱性花岗岩类，且在富CaO和贫K_2O的ACG中，地幔成分是主要的(Depaolo, 1981; Depaolo et al., 1984; Pitcher, 1993; 肖庆辉等, 2002)。研究区花岗闪长岩CaO含量为5.81%~6.20%，K_2O含量为2.16%~3.37%，反映拉扎嘎山岩体属壳幔混合源，且地幔组分多于地壳组分。

现代弧环境中，板片流体的加入或俯冲沉积物的部分熔融可以使与俯冲有关的岩浆交代富集(Elburg et al., 2002; Guo et al.,2005)，当Th/Yb比值小于1时，为流体占主导的弧环境；当Th/Yb大于2时，表明存在大量沉积物。拉扎嘎山花岗闪长岩的Th/Yb比值介于2.65~3.95(平均3.36)，表明其源区有沉积物的贡献。一般来说，幔源岩浆的Nb/Ta比值为17.5±2，而壳源岩浆的Nb/Ta比值为11~12(Taylor and McLennan, 1985; McDonough and Sun, 1995; 管琪等,2010)，花岗闪长岩Nb/Ta=10.5~40.9，变化范围很大，表明岩体源区物质组成不均一，或是镁铁质岩浆和长英质岩浆混染作用所致。实地观察中，拉扎嘎山花岗闪长岩中可见大量的暗色微粒包体，也证实了岩浆演化过程中确实存在幔源岩浆与壳源岩浆之间的岩浆混合作用。

5.2 构造环境

花岗质岩浆活动伴随着威尔逊旋回的各个阶段，并记录着相应地质过程的重要信息(Whalen, 1985,1987; Chappell and White, 2001; Clemens, 2003; Bonin, 2007)。岩石、构造及地球动力学的研究结果指出，不同类型的花岗岩类的成因明显受到地球动力学环境的制约(肖庆辉等,2002)。

如上所述，研究区拉扎嘎山花岗闪长岩为典型

表2 拉扎嘎山花岗闪长岩常量元素(%)和微量元素(10^{-6})分析结果

Table 2 Major(%) and trace elements(10^{-6}) contents of granodiorites from the Lazhagashan area

测试项目	LZGA-42FX	LZGA-43FX	LZGA-44FX	LZGA-45FX	LZGA-46FX	LZGA-47FX	LZGA-48FX
SiO_2	63.66	64.46	63.46	64.70	64.44	64.64	64.40
Na_2O	2.29	2.37	2.35	2.21	2.45	2.34	2.54
CaO	6.01	5.81	6.20	6.00	6.09	5.84	5.94
FeO	4.43	4.21	4.32	4.12	4.26	3.98	4.11
Fe_2O_3	0.88	0.80	0.90	0.65	1.08	1.13	0.88
Al_2O_3	15.76	15.48	15.59	15.49	16.03	15.46	15.64
MgO	2.14	2.37	2.45	1.97	2.28	2.26	1.96
K_2O	2.16	2.30	2.19	2.34	2.37	2.30	2.37
P_2O_5	0.11	0.11	0.12	0.12	0.12	0.11	0.13
MnO_2	0.12	0.12	0.13	0.13	0.12	0.13	0.13
TiO_2	0.67	0.67	0.66	0.61	0.68	0.66	0.62
LOI	1.09	0.60	0.96	1.10	0.71	1.05	0.85
Total	98.24	98.71	98.37	98.34	99.93	98.85	98.71
La	39.8	31.3	30.2	34.3	36.4	35.2	37.4
Ce	67.8	54.6	51.5	63.5	59.6	57.5	66.5
Pr	6.70	5.45	5.66	6.15	7.04	6.30	6.84
Nd	26.3	23.9	24.1	25.3	26.9	24.9	28.3
Sm	4.34	4.11	4.32	5.08	5.04	4.67	5.43
Eu	1.11	1.06	1.13	1.13	8.50	1.14	1.26
Gd	4.23	4.22	4.30	4.39	5.13	4.89	4.90
Tb	0.78	0.74	0.83	0.80	0.94	0.87	0.96
Dy	4.90	4.96	5.14	5.31	5.87	5.32	6.17
Ho	0.96	0.97	1.08	1.10	1.23	1.18	1.26
Er	2.98	3.08	3.17	3.17	3.84	3.44	4.12
Tm	0.46	0.49	0.50	0.53	0.57	0.50	0.59
Yb	2.80	3.04	3.35	3.23	3.64	3.63	4.05
Lu	0.44	0.44	0.48	0.48	0.61	0.49	0.61
Y	32.1	31.6	36.0	33.1	34.0	31.4	37.4
Li	28.9	39.9	30.7	21.9	36.2	26.7	35.6
Sc	14.6	16.3	16.8	15.1	17.2	18.0	17.6
V	49.8	53.3	48.1	45.4	54.3	53.4	46.2
Cr	37.2	41.0	41.9	38.1	38.9	39.6	39.6
Co	12.0	12.1	12.1	11.5	13.4	13.0	13.4
Ni	4.16	2.37	3.61	3.84	2.26	3.32	1.02
Cu	3.72	10.0	3.42	8.36	3.32	3.82	6.57
Zn	66.6	71.6	66.7	67.4	67.7	67.1	69.1
Ga	16.9	17.2	18.6	17.1	18.3	19.0	20.2
Rb	83.5	94.0	87.4	88.8	91.1	84.1	103
Sr	230	224	232	220	240	233	220
Zr	19.3	24.0	23.8	32.9	30.4	22.7	29.1
Nb	11.6	10.7	10.8	11.2	11.7	4.29	13.0
Ba	493	494	493	480	503	512	478
Hf	1.13	1.42	1.33	1.65	2.56	1.54	2.00
Ta	0.64	0.57	0.43	0.61	1.11	0.10	1.12
Pb	10.92	18.27	22.86	16.53	10.41	18.44	19.66
Th	11.1	9.73	8.87	11.1	12.6	12.6	13.7
U	0.86	0.89	1.01	1.54	1.65	1.47	1.49

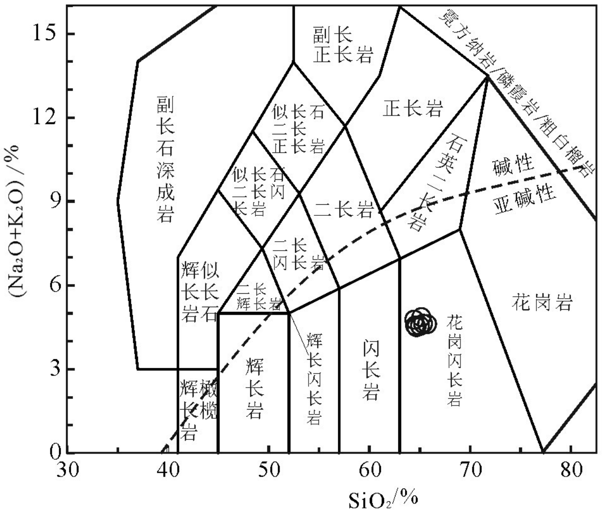

图5 拉扎嘎山花岗闪长岩TAS图解（据Middlemost, 1994）
Fig.5 TAS diagramof granodiorites in Lazhagashan area (after Middlemost, 1994)

的含角闪石钙碱性花岗岩类（ACG），Barbarin（1999）认为含角闪石钙碱性花岗岩类（ACG）总是定位在俯冲带之上，在活动大陆边缘，ACG形成了巨大岩基，平行海沟方向延伸，并指出比较丰富的ACG与比较成熟度的俯冲带有关。主量元素特征表明，拉扎嘎山花岗闪长岩属钙碱性准铝质花岗岩类，稀土元素特征表明岩石轻重稀土元素分馏明显，且富集轻稀土、重稀土相对亏损的特征；岩石的微量元素地球化学特征表明，岩石富集大离子亲石元素（LILE）、亏损高场强元素（HFSF），Ta、Nb、P、Ti的明显亏损，表明岩石具岛弧花岗岩的特征，说明源岩可能来自岛弧型火山岩的部分熔融或是岛弧型的火山岩同源岩浆演化的产物。在Pearce（1984）给出的构造环境判别图解（图8）中，拉扎嘎山花岗闪长岩均落入火山型花岗岩区域。

5.3 地质意义

现有研究表明，在大洋板块与大陆板块缓慢而复杂的俯冲、碰撞过程中，仰冲板块前端因刮削作用、底侵作用、前端剥蚀作用等，使洋壳物质（包括蛇绿岩、洋岛和复理石沉积）在海沟内壁发生增生，增生楔逐渐形成和增长，具体表现为随着俯冲过程的持续，海沟逐渐向洋一侧后退，大陆弧逐渐向洋一侧迁移（李继亮,2004; 范建军等,2018）。拉扎嘎山花岗闪长岩属于岛弧型钙碱性花岗岩类，一般而言，岛弧型岩浆岩多产于俯冲带的后方，与俯冲带前缘形成的增生楔有一定距离。但基本未变形的拉扎嘎山花岗闪长岩直接侵位于强烈变形的理塘蛇绿混杂岩之中，说明在（207.2±1.5）Ma时随着甘孜—理塘洋盆的持续向西俯冲消减，中咱地块东缘的增生楔已经增长到足够的规模和宽度，伴随着海

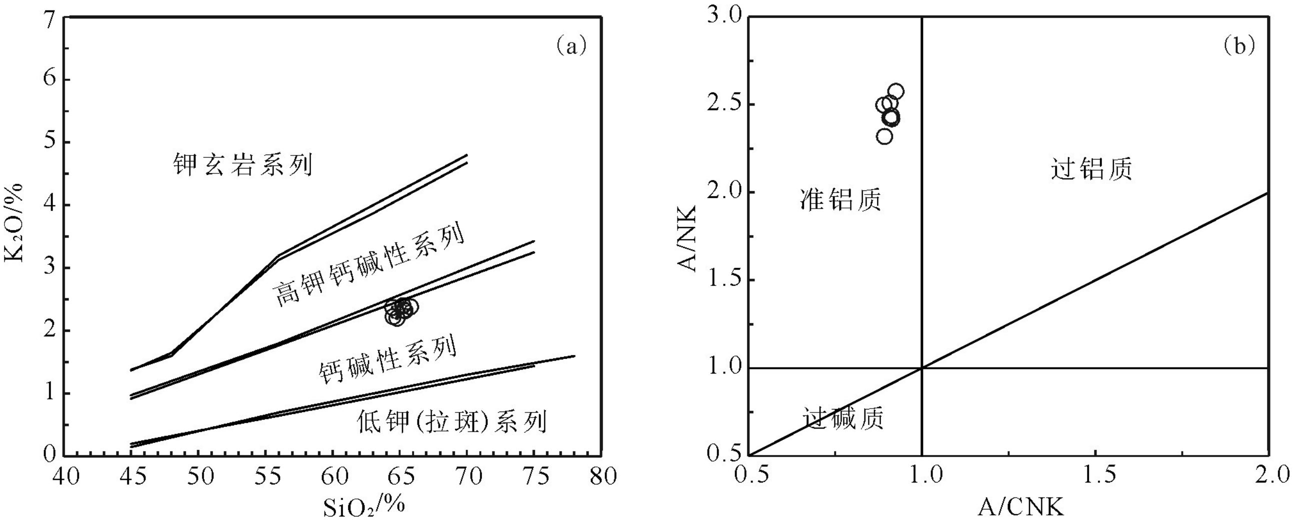

图6 拉扎嘎山花岗闪长岩SiO_2−K_2O图解（a, 据Peccerillo and Taylor, 1976）和A/CNK−A/NK图解（b, 据Maniar and Piccoli, 1989）
Fig.6 SiO_2−K_2O diagram(a, after Peccerillo and Taylor, 1976) and A/CNK−A/NKdiagram(b, after Maniar and Piccoli, 1989) of granodiorites in Lazhagashan area

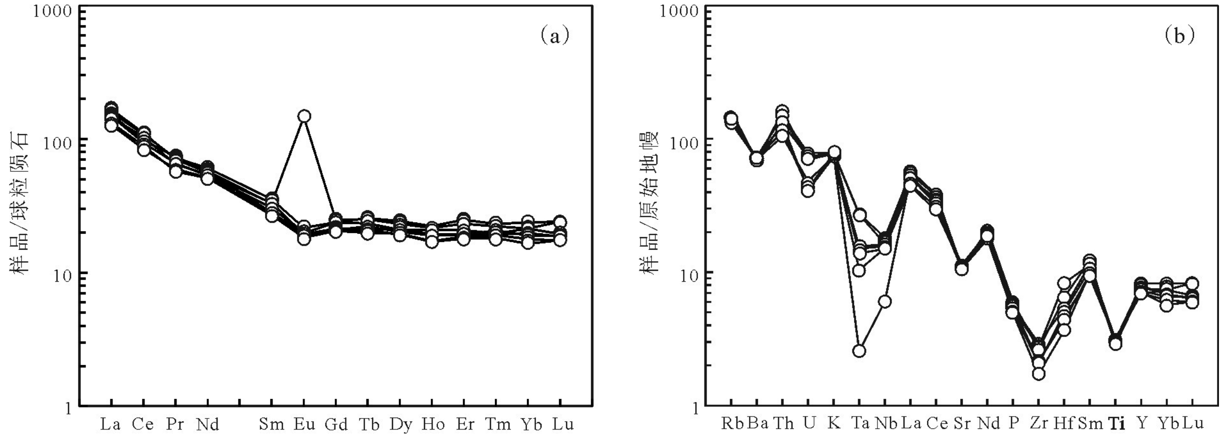

图7 拉扎嘎山花岗闪长岩稀土元素球粒陨石标准模式化配分曲线图(a)和原始地幔标准化微量元素蛛网图(b)
(球粒陨石及原始地幔标准化值均来自Sun and McDonough,1989)
Fig.7 Chondrite-normalized REE patterns(a) and primitive mantle-normalized trace pattrens(b) of granodiorites in Lazhagashan area(Chondrite and primitive mantle values are from Sun and McDonough,1989)

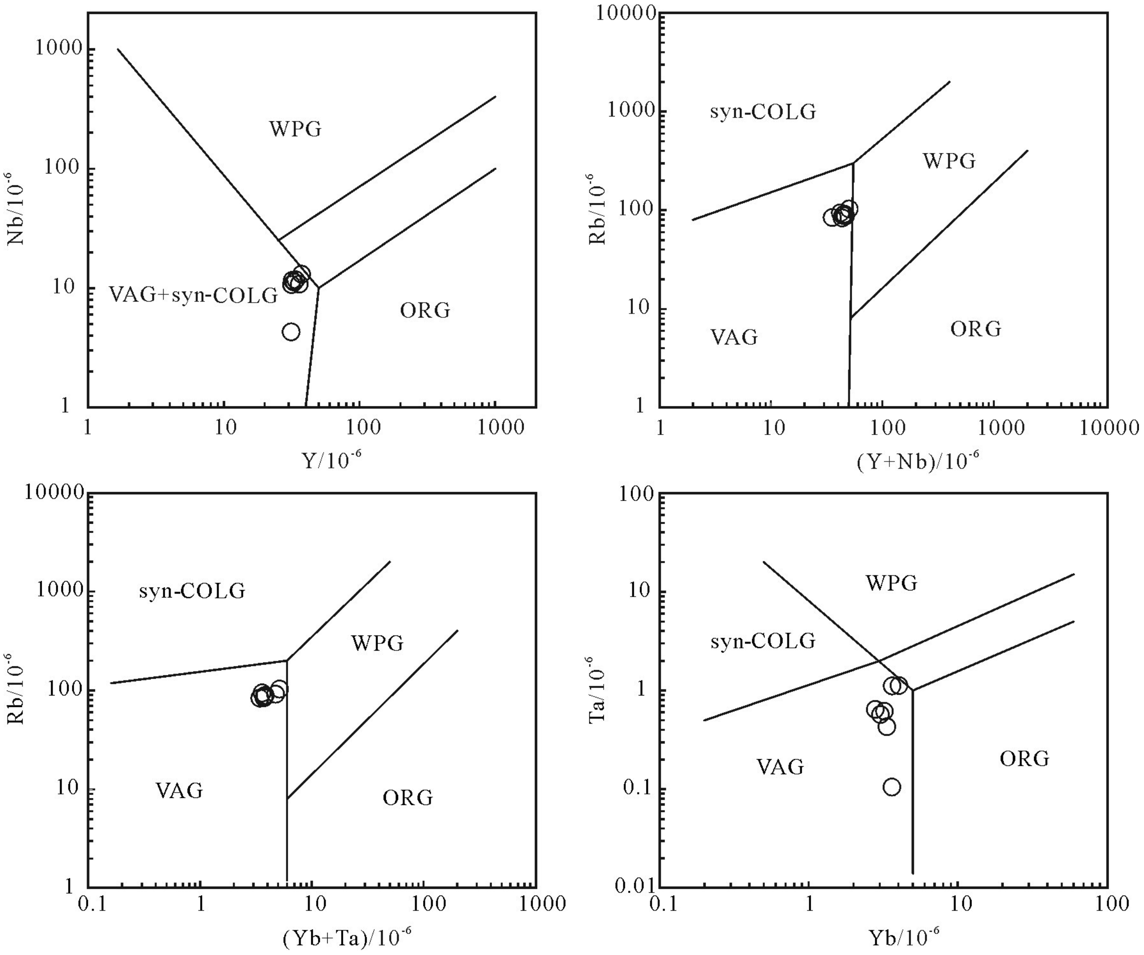

图8拉扎嘎山花岗闪长岩微量元素构造环境判别图解(底图据Pearce et al.,1984)
VAG—火山弧花岗岩;ORG—洋中脊花岗岩;WPG—板内花岗岩;Syn—COLG—同碰撞花岗岩
Fig.8 Tectonic discrimination diagrams of granodiorites in Lazhagashan area(diagram after Pearce et al.,1984)
VAG-Volcanic arc granite; ORG-Mid-ocean ridge granite; WPG-Intraplate granite; Syn-COLG-Collisional granite

沟的不断后退，增生楔的持续扩大，新的岩浆弧已经前进至原先形成的增生楔之上，造就了晚三叠世末期的岛弧型钙碱性花岗闪长岩直接侵入于理塘蛇绿混杂岩带内的现象。侯增谦等（2004）依据义敦岛弧碰撞造山带花岗岩时空坐标、岩浆组合、地球化学特征，认为俯冲造山期弧花岗岩活动时限为237~206 Ma，碰撞造山期同碰撞花岗岩活动时限为206~138 Ma。LA−ICP−MS锆石U−Pb测年显示研究区花岗闪长岩的侵位年龄为（207.2±1.5）Ma，此时正处于甘孜—理塘洋盆俯冲末期，即将进入碰撞造山的转折节点，也正是甘孜—理塘增生楔规模最大的时期。

李继亮（2004）在研究增生型造山带基本特征时曾指出，在海沟后退、增生楔增生过程中，大陆地幔楔不可能追随着海沟一直处于消减带之上的位置，因此，增生弧中的大量钙碱性岩浆岩不可能来源于大陆地幔楔。既然这些岩浆不能由大陆地幔楔提供，那么，它们必然来自增生楔物质的重熔。可以提供重熔的物质可能是复理石，也可能是蛇绿岩的镁铁质组分。甘孜—理塘蛇绿混杂岩带复杂的物质组成为拉扎嘎山花岗闪长岩壳幔混合源提供了岩浆混合的物质来源，大量的复理石熔融为其提供壳源组分，蛇绿岩熔融为其提供幔源组分。

据此笔者分析认为甘孜—理塘洋盆于晚三叠世末期进入俯冲的尾声，此时中咱地块东缘已形成规模宏大的增生楔杂岩，在俯冲背景之下的拉张体制，软流圈或拆沉的岩石圈发生部分熔融，岩浆沿深大断裂上升所提供的热量促使地幔楔杂岩熔融成不同类型的岩浆，岩浆上升侵位过程中发生混合作用形成了拉扎嘎山花岗闪长岩。

6　结　论

（1）拉扎嘎山岩体侵位于理塘蛇绿混杂岩之中，岩石类型主要为花岗闪长岩，含有大量的角闪石、黑云母等铁镁矿物，局部见大量的闪长质包体和围岩捕掳体。

（2）LA−ICP−MS锆石U−Pb同位素测年研究表明，拉扎嘎山花岗闪长岩岩体的年龄为（207.2±1.5）Ma，为晚三叠世末期，该时期甘孜—理塘洋盆处于俯冲/碰撞之交。

（3）拉扎嘎山花岗闪长岩属I型钙碱性准铝质花岗岩类，富集轻稀土及大离子亲石元素，亏损重稀土及高场强元素，具明显的Eu负异常，是典型的火山弧型花岗岩。

（4）晚三叠世末期甘孜—理塘洋盆趋于关闭，中咱地块东缘形成规模宏大的增生杂岩，在俯冲背景之下的拉张体制，软流圈或拆沉的岩石圈发生熔融形成玄武质岩浆，岩浆上涌促使增生楔杂岩发生熔融，不同类型熔融岩浆混合形成了拉扎嘎山花岗闪长岩岩浆。

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