东准噶尔老爷庙地区碱性花岗岩锆石U-Pb定年、地球化学及其地质意义

熊双才,张征峰,李广,刘润泽,华叙登,赵富庄,周鹏飞,李关禄
新疆地矿局第一地质大队,新疆昌吉,831100

内容提要:老爷庙地区位于东准噶尔东部,是中亚造山带的重要组成部分。老爷庙碱性花岗岩具有高硅(SiO_2 63.58%~69.92%);富碱(Na_2O+K_2O 9.38%~9.81%)、贫钙(CaO 0.44%~2.47%)、低钛(TiO_2 0.52%~0.97%)的特征,与典型A型花岗岩相似,成因类型上属A2型花岗岩,产于后造山环境。富集大离子亲石元素Rb、Ba、K、Th及高场强元素Zr,相对亏损P、Ti、Nb、Ta。轻稀土富集明显(LREE/HREE=7.62~8.31),且轻稀土元素内部分馏相对较强,重稀土元素元素内部分馏较弱,弱的Eu负异常(δEu =0.52~0.91)。锆石温度饱和温度819~890℃,属于高温花岗岩,中等压力。LA-ICP-MS锆石U-Pb年龄显示其结晶年龄为两期,分别为297.0±6.5 Ma和310.0±2.0 Ma,表明其形成时代为晚石炭世—早二叠世。综合本文数据及区域地质特征,老爷庙地区在早二叠世早期297.0±6.5 Ma时已经拼贴到西伯利亚板块,进入后造山向板内转化的过渡期,结束了该地区地壳的侧向增生,但由于大量幔源岩浆底侵到下地壳,使该区仍在垂向增生。

关键词:东准噶尔;碱性花岗岩;后造山环境;锆石U-Pb定年;岩石地球化学;晚石炭—早二叠世

碱性花岗岩与某些特殊的构造环境相关联,既可以产于非造山环境(Madhavan et al.,1999;Kumar & Rathna,2008),也可以产于碰撞后或后造山环境(Bonin et al.,1998;White et al.,2006),这对区域构造演化,特别是造山带的研究提供了重要的约束(洪大卫等,1995;Tong Ying et al.,2012)。新疆碱性花岗岩发育,主要分布在古生代岛弧、弧后盆地及隆起区,与板块缝合线、深大断裂密切相关,与蛇绿岩带耦合(王中刚等,1993;Zhao Zhenhua et al.,2000;朱笑青等,2006)。东准噶尔岩浆构造发育(李锦轶等,1990;冯京等,2009;杨高学等,2015;邓晋福等,2015a)是研究中亚造山带的有利地段。老爷庙位于东准噶尔造山带东部,该区出露大量碱性正长岩,前人开展的研究工作较少,仅对该区部分古生代地层(马雪等,2005;张超等,2005;张冀等,2016)和老爷庙金矿(王军等,2016)做了少量研究。前人在研究区东侧相邻1∶5万图幅开展区调工作时测得3个碱长花岗岩年龄分别374 Ma、0 Ma、369 Ma,其形成时代应为泥盆纪,但根据岩石的时空分布特征、岩石化学特征和地球化学特征,将其时代定为石炭纪-二叠纪[1]。本次研究结合“新疆巴里坤县1∶5万六幅区域地质调查”项目成果,通过高精度的锆石U-Pb定年、岩石地球化学综合研究,结合区域对比,确定其成岩时代,探讨其形成环境,为研究区域晚古生代构造岩浆作用提供年代学及岩石地球化学约束。

1 区域地质背景

研究区大地构造位置属天山兴蒙造山系—准噶尔弧盆系—唐古巴勒—卡拉麦里古生代复合沟弧带—三塘湖晚古生代弧间盆地(图1a)。地层区划属北疆—兴安地层大区—北疆地层区—北准噶尔地层分区—北塔山地层小区。研究区出露的地层由老到新有:上泥盆统卡希翁组(D_3kx)海陆交互相火山碎屑岩夹少量熔岩、上石炭统巴塔玛衣内山组(C_2b)陆相双峰式火山熔岩、上更新统新疆群(Qp_3X)砂砾石层。各时代的地层的展布方向为NW—SN向(图1b)。区内断裂极其发育,由于长期受NE—SW向挤压,形成大量的NW—SE向逆断裂,及NE、NW向平移断裂。区内断裂极其发育,控

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作者简介:熊双才,1987年生,硕士研究生,工程师,主要从事成矿规律与成矿预测研究及区域地质矿产调查,Email:sc_Xiong@163.com。

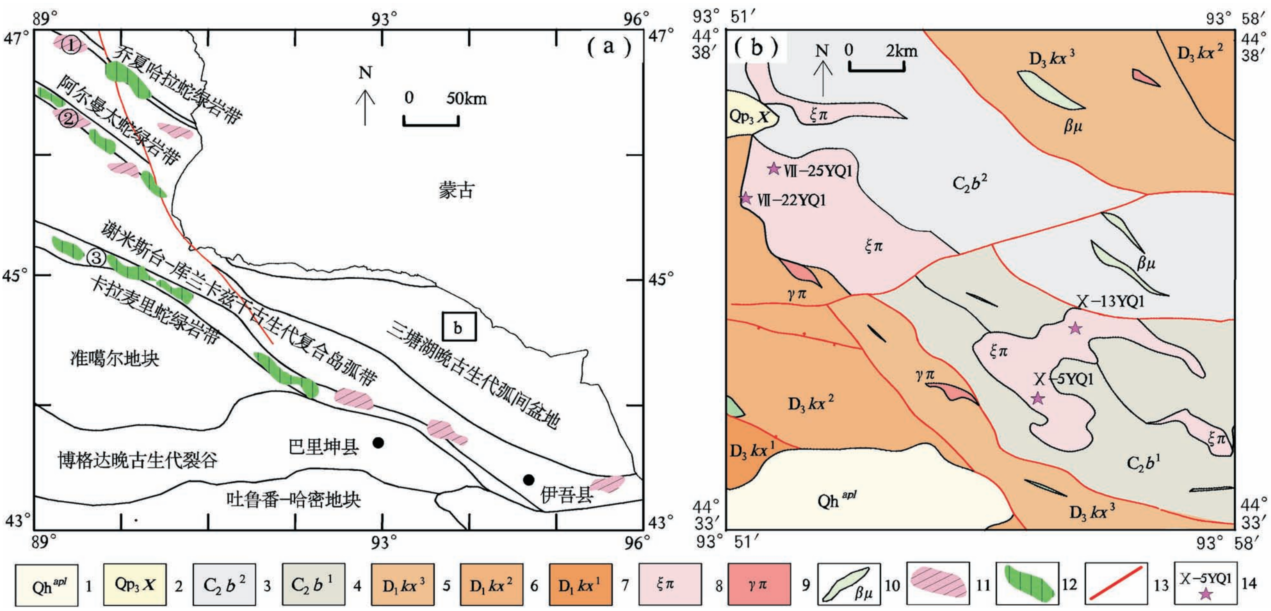

图 1 东准噶尔老爷庙地区大地构造位置(a)(构造据❷;蛇绿岩据徐兴旺等,2013;碱性花岗岩据朱笑青等,2006)及地质简图(b)

Fig. 1 Geotectonic location (a) (structure from❷; ophiolite from Xu Xingwang et al., 2013#; alkaline granite from Zhu Xiaoqing et al.,2006&) and geological map (b) of Laoyemiao area, eastern Junggar

1—全新统冲洪积物;2—上更新统新疆群;3—上石炭统巴塔玛衣内山组第二岩性段;4—巴塔玛衣内山组第一岩性段;5—上泥盆统卡西翁组第三岩性段;6—卡西翁组第二岩性段;7—卡西翁组第一岩性段;8—正长斑岩;9—花岗斑岩;10—辉绿玢岩脉;11—碱性花岗岩;12—蛇绿岩;13—断层;14—采样位置及编号

1—Holocene alluvium and proluvial; 2—Upper Pleistocene Xinjiang Group; 3—the Second Lithologic Member of the Batamane Mountains Formation, Upper Carboniferous; 4—the First Lithologic Member of the Batamane Mountains Formation; 5~7—the Casio Formation, Upper Devonian: 5—the Third Lithologic Member, 6—the Second Lithologic Member, 7—the First Lithologic Member; 8—syenite porphyry; 9—granite porphyry; 10—diabase—porphyrite dike; 11—alkaline granite; 12—ophiolite; 13—fault ;14—sampling position and serial number

制不同时代地层的分布和侵入体的产状、形态。侵入岩较发育,主要为石英碱长正长斑岩、石英正长斑岩,呈不规则小岩株产出。少量花岗斑岩和辉绿玢岩脉分布于岩体边部及周围。岩体产于老爷庙大断裂及玫瑰泉大断裂之间,整体呈 NW—SE 分布,与区域构造方向一致。

2 岩石学特征及岩石全分析

石英碱长正长斑岩(Ⅶ-25YQ1):岩石呈灰褐色—红褐色,斑状结构状、似粗面结构,块状构造、流动构造。斑晶中主要为正长石(46%~52%):他形—半自形板柱状,环带结构、熔蚀结构、条纹结构常见,多为条纹长石,常含不透明矿物包体;石英(3%~6%):他形粒状,不均匀分布;辉石(2%):半自形—自形柱状。基质中条纹长石(22%~28%):他形—半自形板柱状,见条纹结构,部分集合体具流动构造;石英(9%~12%):他形粒状;辉石(1%~3%):显微—半自形粒状、柱状,具闪石化;角闪石(2%~4%):显微—半自形粒状、柱状,具绿泥石化;磷灰石(1%~2%):半自形—自形粒状、柱状,偶见钾长石包体;黑云母(1%):半自形—他形片状,蚀变析出铁质。副矿物锆石、榍石、钛铁矿、赤褐铁矿、绿帘石、磁铁矿等。

石英正长斑岩(Ⅹ-13YQ1):岩石呈浅红褐—红褐色,斑状结构,块状构造。斑晶中钾长石(10%),自形—半自形板状,具条纹结构及卡氏双晶,部分呈聚斑;斜长石(3%),自形—半自形板状,具卡钠复合双晶。基质中石英(13%),他形粒状,具波状消光;斜长石(12%),微晶状—板条状,具卡钠复合双晶;钾长石(57%),微晶状;黑云母(4%),显微鳞片—片状。副矿物:锆石、黄铁矿、磷灰石、榍石、赤褐铁矿、钛铁矿、磁铁矿、角闪石等。

采集石英碱长正长斑岩 2 件(图 1b),分别为Ⅶ-22YQ1、Ⅶ-25YQ1、采集石英正长斑岩 2 件 Ⅹ-

5YQ1、Ⅹ-13YQ1,岩石全分析在广州澳实矿物实验室测试,样品经过破碎、缩分、研磨至 200 目后,采用 ME-MS81 熔融法电感耦合等离子体质谱测定稀土元素含量,ME-XRF26X 荧光光谱仪熔融法精密分析岩石主微量元素,Fe-VOL05 滴定法测定氧化铁。测试结果见表 1。

由表可见岩体具有较高 SiO_2(63.58% ~ 69.92%);富碱(Na_2O+K_2O 9.38% ~ 9.81%);Na_2O/K_2O 为 0.86 ~ 1.22)特征。CaO (0.44% ~ 2.47%)、P_2O_5(0.12% ~ 0.35%)、Fe_2O_3(1.67% ~ 2.49%)、MgO(0.47% ~ 1.21%)及 TiO_2(0.52% ~ 0.97%)含量均较低,分异指数 *DI*(82.12 ~ 92.33)反映岩石经历了高程度分异的特征。里特曼指数 δ3.53 ~ 4.48(>3.3)为碱性岩。在侵入岩 TAS 图解(图 2a)中落入碱性线上方的石英二长岩区域。在 K_2O—SiO_2 图解(图略)中投入钾玄岩系列。铝过饱和程度 A/NK 指数为 1.09 ~ 1.18,A/CNK 值为 0.85 ~ 1.03,在铝饱和图解(图 2b)中主要落入准铝质范围。在岩浆岩 SiO_2—*A. R* 图解中,样品投影在碱性区域(图 2c)。综上,调查区石英(碱长)正长斑岩属酸性、高钾富钠、碱性、准铝质的侵入岩(邓晋福等,2015b)。

在原始地幔标准化图解中(图 3a),大离子亲石元素 Rb、Ba、K、Th 的富集明显,高场强元素 P、Ti 相

表 1 老爷庙地区碱性花岗岩主量(%)、微量及稀土元素($\times10^{-6}$)分析结果表

Table 1 Whole-rock major(%), rare earth and trace elements ($\times10^{-6}$) concentrations of the alkali granites in Laoyemiao area

样号	Ⅶ-22 YQ1	Ⅶ-25 YQ1	Ⅹ-5 YQ1	Ⅹ-13 YQ1	样号	Ⅶ-22 YQ1	Ⅶ-25 YQ1	Ⅹ-5 YQ1	Ⅹ-13 YQ1	样号	Ⅶ-22 YQ1	Ⅶ-25 YQ1	Ⅹ-5 YQ1	Ⅹ-13 YQ1
岩性	石英碱长正长斑岩		石英正长斑岩		岩性	石英碱长正长斑岩		石英正长斑岩		岩性	石英碱长正长斑岩		石英正长斑岩	
SiO_2	63.58	64.19	64.45	69.92	La	54.4	55.7	54.5	60.7	Sr	340	226	261	50.5
TiO_2	0.97	0.93	0.93	0.52	Ce	110.5	114	112	124.5	K	36609	36610	37191	43583
Al_2O_3	15.30	15.37	15.06	14.37	Pr	14.05	14.9	14.3	15.25	Rb	68.1	61.5	69.5	84.4
TFe_2O_3	4.73	4.57	4.67	3.19	Nd	54.6	58.2	56.7	56.3	Ba	1605	1530	1425	724
Fe_2O_3	2.40	2.49	1.67	2.32	Sm	10.25	10.9	10.95	10.7	Th	4.8	4.63	4.59	6.47
FeO	2.1	1.87	2.7	0.78	Eu	2.91	3.16	2.84	1.76	Ta	1	1	0.9	1.3
MnO	0.13	0.14	0.13	0.09	Gd	9.36	9.88	9.42	9.51	Nb	16.2	16	16	20
MgO	1.21	1.06	1.18	0.47	Tb	1.38	1.51	1.42	1.55	Ce	110.5	114	112	125
CaO	2.29	2.47	2.4	0.44	Dy	7.74	8.3	7.96	9.39	P	1527	1527	1527	523
Na_2O	4.97	5.40	5.05	4.54	Ho	1.55	1.66	1.59	1.91	Zr	337	400	413	505
K_2O	4.41	4.41	4.48	5.25	Er	4.36	4.59	4.6	5.61	Hf	7.5	8.4	9	11.4
P_2O_5	0.35	0.35	0.35	0.12	Tm	0.66	0.7	0.71	0.89	Sm	10.3	11	11	11
烧失	1.87	1.35	1.22	0.98	Yb	4.02	4.45	4.32	5.6	Ti	5814	5574	5574	3117
总和	99.58	100.03	99.62	99.8	Lu	0.62	0.67	0.68	0.89	Ga	21.6	21.9	21.8	22.4
DI	82.12	83.57	82.47	92.33	Y	44.6	47.6	45.8	54.8	Sr/Y	7.62	4.75	5.7	0.92
$Mg^{\#}$	33.63	31.48	33.36	22.59	ΣREE	276.4	288.62	281.99	304.56	Nb/Ta	16.2	16.2	17.78	15.54
A.R	3.29	3.44	3.40	4.9	LREE	246.71	256.86	251.29	269.21	Zr/Hf	44.93	47.62	45.89	44.3
δ	4.17	4.48	4.17	3.53	HREE	29.69	31.76	30.7	35.35	Th^*	0.45	0.45	0.42	0.5
A/CNK	0.89	0.85	0.86	1.03	LREE/HREE	8.31	8.09	8.19	7.62	K^*	1.15	1.12	1.17	1.21
A/NK	1.18	1.13	1.14	1.09	La_N/Yb_N	9.71	8.98	9.05	7.78	Nb^*	0.14	0.14	0.14	0.15
Na/K	1.13	1.22	1.13	0.86	La_N/Sm_N	3.43	3.3	3.21	3.66	Sr^*	0.17	0.11	0.13	0.02
R1	1327	1206	1333	1747	Gd_N/Yb_N	1.93	1.84	1.8	1.4	Zr^*	1.41	1.61	1.66	2.73
R2	620	627	621	357	δEu	0.89	0.91	0.83	0.52	Ti^*	0.12	0.11	0.11	0.06
Fe^*/MgO	3.52	3.88	3.56	6.11	δCe	0.96	0.95	0.96	0.98	T_{Zr}	819	826	833	890

$T_{Zr}/K=\dfrac{12900}{2.95+0.85M+\ln\dfrac{496000}{Zr_{melt}/10^{-6}}}$ (Watson et al., 1983),其中 T 为绝对温度,表中已换算为摄氏温度;M 为全岩 $\dfrac{n(Na)+n(K)+2n(Ca)}{n(Al)*nSi}$,计算中令 $n(Si)+n(Al)+n(Fe)+n(Mg)+n(Ca)+n(Na)+n(K)+n(P)=1$;$Zr_{melt}$ 为熔体中 Zr 含量(参见王楠等,2017)。

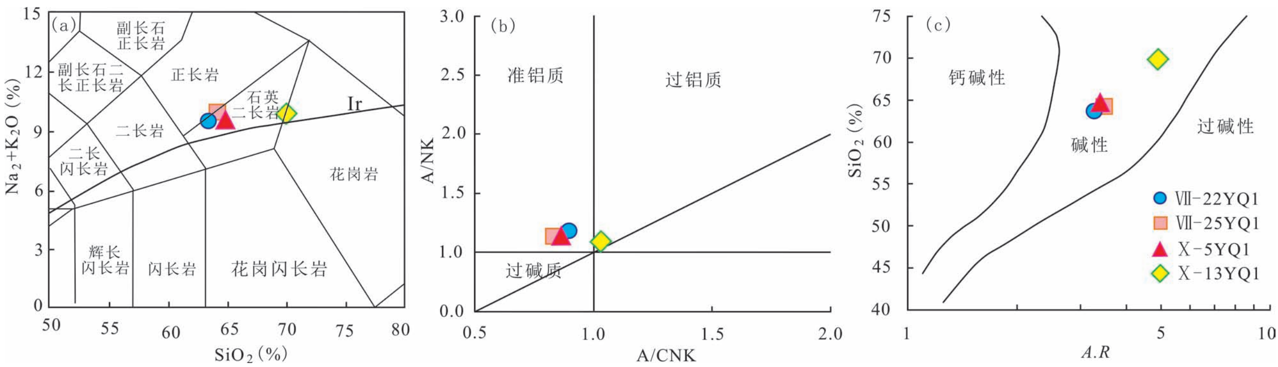

图 2 东准噶尔老爷庙岩体 TAS 分类(a)(底图据 Middlemost,1994)、铝饱和度(b)(底图据 Maniar and Piccoli,1989)及 $A.R$—SiO_2(c)(底图据 Wright,1969)图解

Fig. 2 TAS classification(a)(after Middlemost,1994), aluminum saturation (b) (after Maniar and Piccoli,1989) and $A.R$—SiO_2(c) (after Wright,1969) diagrams of the Laoyemiao granite, eastern Junggar

对亏损及 Nb、Ta 槽指示与消减作用或者壳源深熔有关。Zr 富集及 Ti 贫化表明岩浆可能起源于地壳，Nb/Ta 值 15.54～17.78、Zr/Hf 值 44.30～47.62 表明岩浆具有消减带玄武岩特征，即岩浆可能来源于俯冲的洋壳。

稀土元素特征如下：$\sum$REE = 276.4～304.56×10^{-6}，平均值为 287.89×10^{-6}，稀土元素总量较高。LREE/HREE = 7.62～8.31，平均值 8.05；La/Yb_N = 7.78～9.71，平均值为 8.88；La/Sm_N = 3.21～3.66，平均值为 3.40；Gd/Yb_N = 1.40～1.93，平均值为 1.74，反映轻稀土相对富集，重稀土亏损，且轻稀土元素内部分馏相对较强，重稀土元素元素内部分馏较弱。δEu = 0.52～0.91，平均值 0.79，具较弱的 Eu 负异常。δCe = 0.95～0.98，平均值 0.96，无明显负异常(图 3b)。

3 锆石 LA-ICP-MS 分析

锆石单矿物挑选在河北省区域地质矿产调查研究所实验室，在南京大学内生金属矿床成矿机制研究国家重点实验室进行制靶、CL 拍照、透反射光照相、锆石测年和数据校正。锆石 U-Pb 测试使用 193 nm 激光取样系统连接的 Agilient7500a 型 ICP-MS 上进行，激光剥蚀束斑直径为 32 μm，频率为 6 Hz，采用 He 气作为剥蚀物质的载气，再和 Ar 气混合后

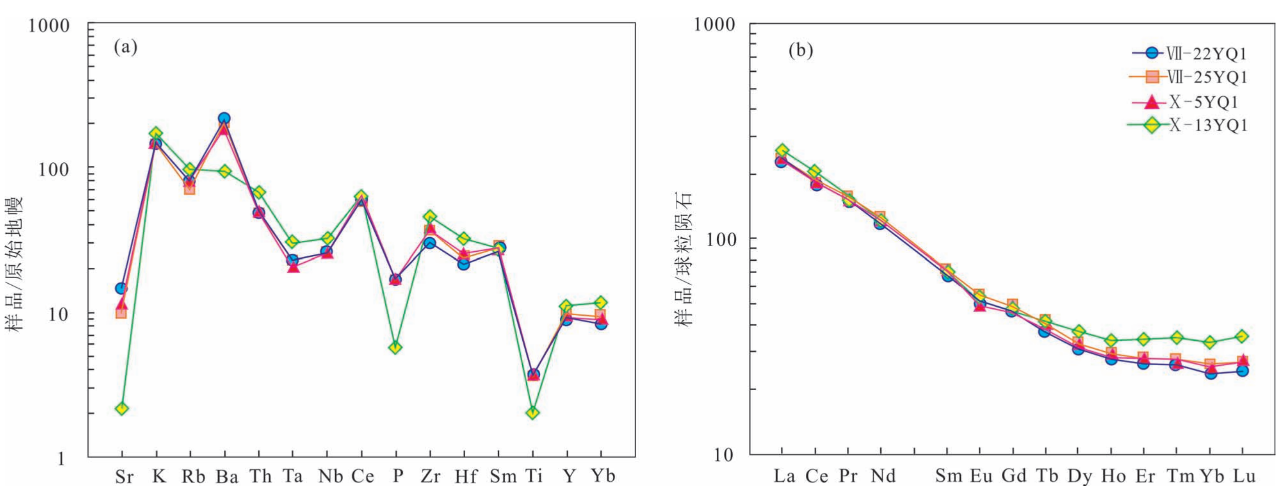

图 3 东准噶尔老爷庙地区碱性花岗岩微量元素原始地幔标准化图(a)及稀土元素球粒陨石标准化图(b)(标准化值据 Sun and Mc Donough,1989)

Fig. 3 Chondrite-normalized REE distribution patterns (a) and primitive mantle-normalized trace element spider diagrams (b) for the alkali granites in Laoyemiao area, Eastern Junggar (values for standardization from Sun and Mc Donough,1989)

表 2 东准噶尔老爷庙地区碱性花岗岩锆石 U-Pb LA-ICP-MS 定年结果表

Table 2 LA-ICP-MS U-Pb isotope data of the zircons from the alkali granites in Laoyemiao area, eastern Junggar

测点号	元素含量($\times10^{-6}$)			$\frac{^{232}Th}{^{238}U}$	同位素比值						同位素年龄(Ma)						谐和度(%)
	总 Pb	^{232}Th	^{238}U		$n(^{207}Pb)/n(^{206}Pb)$		$n(^{207}Pb)/n(^{235}U)$		$n(^{206}Pb)/n(^{238}U)$		$n(^{207}Pb)/n(^{206}Pb)$		$n(^{207}Pb)/n(^{235}U)$		$n(^{206}Pb)/n(^{238}U)$		
					测值	1σ	测值	1σ	测值	1σ	测值	1σ	测值	1σ	测值	1σ	
1	13.11	115.25	151.40	0.76	0.05631	0.00091	0.50236	0.00792	0.06496	0.00049	464.9	35.2	413.3	5.4	405.7	3.0	102
3	5.44	39.77	83.27	0.48	0.05530	0.00179	0.39698	0.01295	0.05257	0.00057	433.4	72.2	339.5	9.4	330.3	3.5	103
4	4.93	42.15	85.24	0.49	0.05655	0.00164	0.35873	0.01022	0.04616	0.00053	476.0	95.4	311.3	7.6	290.9	3.3	107
6	3.99	31.81	63.67	0.50	0.05667	0.00169	0.38321	0.01120	0.04936	0.00048	479.7	64.8	329.4	8.2	310.6	3.0	106
7	28.92	338.99	439.61	0.77	0.05888	0.00086	0.38954	0.00534	0.04802	0.00034	561.1	31.5	334.0	3.9	302.3	2.1	110
10	4.18	28.52	68.58	0.42	0.05476	0.00139	0.36901	0.00910	0.04925	0.00043	466.7	55.6	318.9	6.8	309.9	2.6	103
11	6.20	48.76	93.17	0.52	0.07137	0.00183	0.49270	0.01244	0.05034	0.00042	968.5	51.9	406.7	8.5	316.6	2.6	128
12	5.71	50.25	92.35	0.54	0.05504	0.00127	0.36545	0.00819	0.04847	0.00040	413.0	51.8	316.3	6.1	305.1	2.5	104
13	4.60	39.98	74.09	0.54	0.07738	0.00339	0.51803	0.02457	0.04785	0.00068	1131.5	87.0	423.8	16.4	301.3	4.2	141
14	6.73	61.51	107.15	0.57	0.06564	0.00158	0.43628	0.01032	0.04852	0.00044	794.4	56.5	367.6	7.3	305.4	2.7	120
16	5.58	41.12	88.77	0.46	0.07924	0.00247	0.54820	0.01831	0.04984	0.00052	1188.9	61.1	443.8	12.0	313.5	3.2	142
17	7.61	74.82	122.52	0.61	0.05587	0.00144	0.37901	0.01035	0.04913	0.00042	455.6	55.6	326.3	7.6	309.2	2.6	106
19	6.66	60.82	112.13	0.54	0.05534	0.00143	0.35491	0.00912	0.04678	0.00041	433.4	57.4	308.4	6.8	294.7	2.5	105
20	22.57	203.20	389.76	0.52	0.05240	0.00071	0.34442	0.00505	0.04774	0.00039	301.9	36.1	300.5	3.8	300.6	2.4	100
21	6.34	62.38	102.39	0.61	0.05302	0.00128	0.35835	0.00861	0.04933	0.00040	327.8	55.6	311.0	6.4	310.4	2.4	100
22	4.45	37.83	75.78	0.50	0.05328	0.00140	0.34664	0.00931	0.04747	0.00044	338.9	59.3	302.2	7.0	299.0	2.7	101
23	3.62	24.06	59.50	0.40	0.05294	0.00150	0.35722	0.00975	0.04970	0.00045	327.8	64.8	310.1	7.3	312.7	2.7	99
24	9.04	98.03	148.63	0.66	0.07086	0.00228	0.46719	0.01697	0.04711	0.00044	953.7	65.6	389.2	11.7	296.8	2.7	131
25	3.85	26.86	63.68	0.42	0.05425	0.00156	0.36946	0.01077	0.04988	0.00048	388.9	66.7	319.3	8.0	313.8	3.0	102

进行分析。实验获得的同位素比值采用 GLITTER 程序处理,并进行普通铅校正采,测试结果如表 2。年龄谐和曲线及加权平均值计算采用 Isoplot(3.0)软件处理。

锆石样品岩性为石英碱长正长斑岩(Ⅶ-25YQ1, E93°51′37″, N44°36′31″)。锆石为无色—浅黄色,呈短柱状和近等粒状(图 4),锆石粒度整体偏小,粒径集中在 60~100 μm 之间。根据 CL 图像,锆石可分为 2 类:① 发育典型岩浆成因的生长振荡环带,无晶核和增生边(如锆石 3、21、22);② 具有核边结构,具微弱环带晶核被新生岩浆锆石包裹(如锆石 4、6)。所测锆石 U 和 Th 含量分别为 60×10^{-6}~440×10^{-6}和 24×10^{-6}~339×10^{-6},含量变化较大,Th/U 值为 0.42~0.77,比值变化较小。

19 个分析点中除点 6 个点(点号 7、11、13、14、16、24)的谐和率误差较大,无法呈现在谐和图中之外,余下 13 个点给出了较好的谐和年龄。其中 11 个测点龄范围集中在两个区域,且数据点在谐和图中成群分布在一致曲线上及附近,一个区域是 4 个点的$^{206}Pb/^{238}U$ 年龄介于 291±3~301±2 Ma,加权平均年龄为 297.0±6.5 Ma (MSDW = 2.4)(图 5c);另一个区域 7 个点的$^{206}Pb/^{238}U$ 年龄介于 305±2~314±3 Ma,加权平均年龄为 310.0±2.0 Ma (MSDW = 1.11)(图 5b),这两个年龄应代表石英碱长正长斑岩岩体两个期次的成岩年龄。另外 2 个测点的$^{206}Pb/^{238}U$ 年龄(330±3 和 406±3 Ma)集中分布在谐和图中一致曲线附近,偏离年集中区

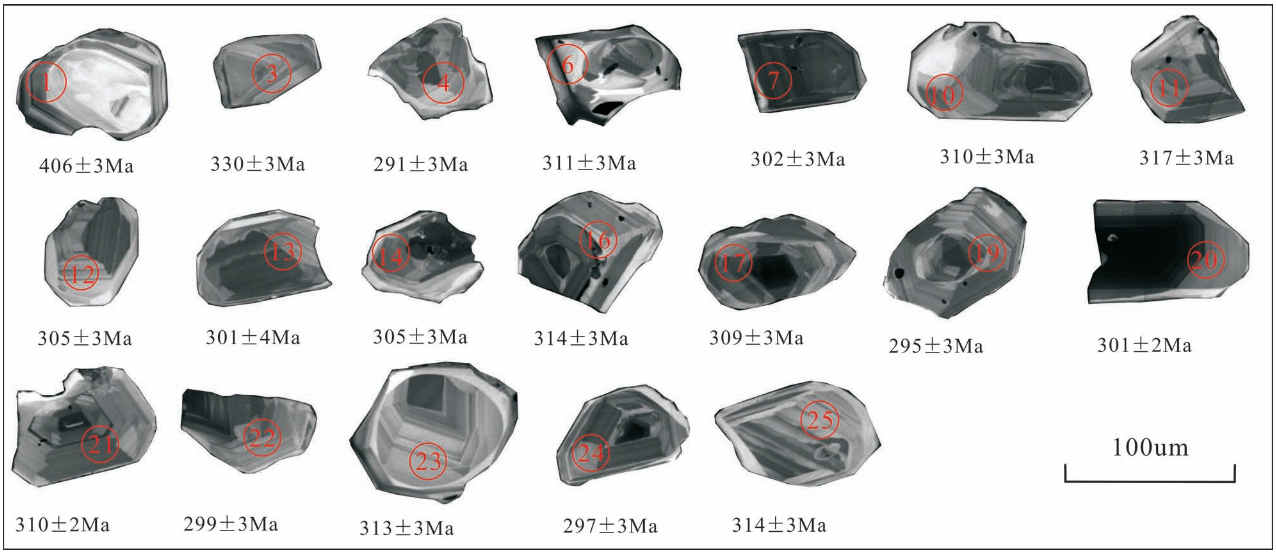

图 4 东准噶尔老爷庙岩体锆石形态和阴极发光(CL)图像

Fig. 4 Zircon morphology and cathodoluminescence (CL) images of the Laoyemiao granite in eastern Junggar

较远(图 5a),为继承锆石,该年龄应代表深部围岩的年龄。

综上,石英碱长正长斑岩 LA-ICP-MS 锆石 U-Pb 年龄分别为(297.0±6.5) Ma 和(310.0±2.0) Ma,属晚石炭世—早二叠世。

4 讨论

人们习惯于把碱性花岗岩等同于 A 型花岗岩,A 型花岗岩原本有 3 个含义(Loiselle et al., 1979)即碱性的(Alkaline)、无水的(Anhydrous)和非造山的(Anorogenic),近年来不少研究者发现很多碱性花岗岩不符合无水和非造山的含义,而把碱性花岗

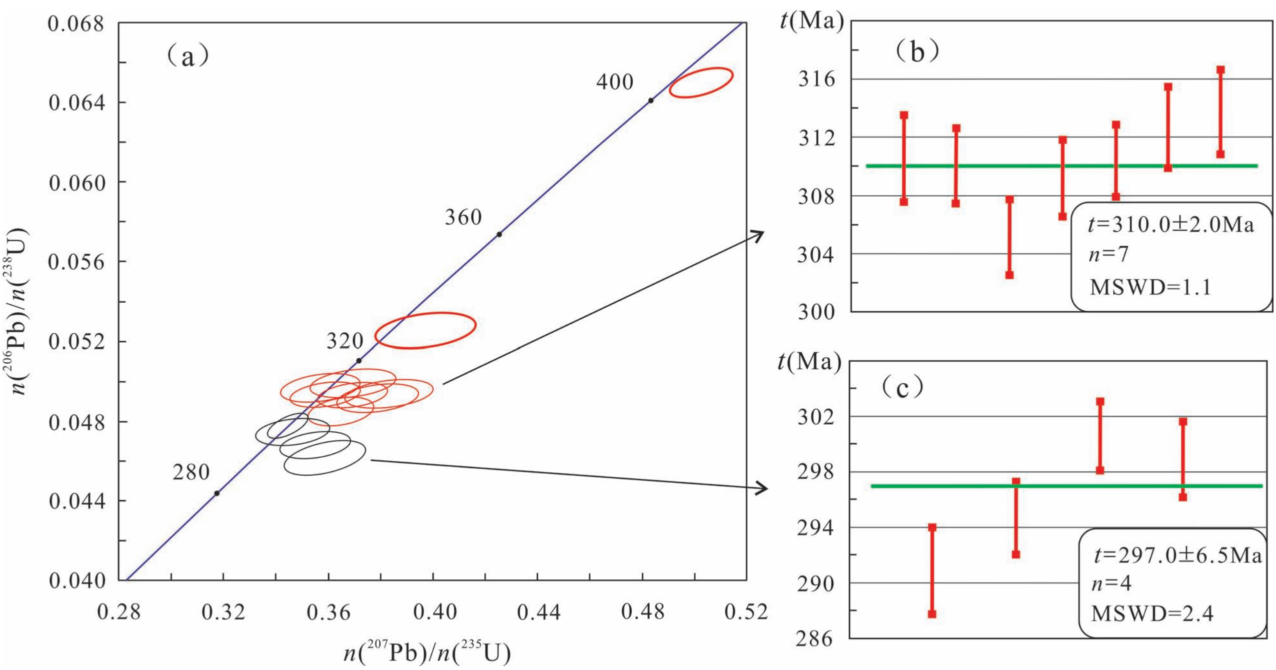

图 5 东准噶尔老爷庙岩体 LA-ICP-MS 锆石 U-Pb 年龄谐和图

Fig. 5 LA-ICP-MS Zircon U-Pb age concordiat diagram of the Laoyemiao granite in eastern Junggar

岩再分为非造山和后造山两类（Eby，1990；Bonin，1998；洪大卫等，1995）。典型 A 型花岗岩相比 S 型、I 型花岗岩，具有高 SiO_2、Na_2O+K_2O、Fe/Mg、Ga/Al、Zr、Nb、Ga、Y 和 Ce，低 CaO、Sr，明显亏损 Eu，并富含碱性矿物的特征（王强等，2000；吴锁平等，2007），老爷庙碱性花岗岩除了 Eu 亏损不明显和未见典型碱性暗色矿物外，其它特征与典型 A 型花岗岩相似。高分异 I、S 型花岗岩和 A 型花岗岩在地球化学特征及矿物学特征方面十分相似（King et al.，1997），常常难以区分，判别 A 型花岗岩的 Whalen 等（1987）的指标仍是最有效的方法（吴福元等，2007）。

老爷庙碱性花岗岩在一系列 A 型花岗岩岩石成因类型判别图中（图 6）落入 A 型花岗岩内。进一步对该 A 型花岗岩细分落入 A2 型（后造山或造山后环境）中（图 7）。在微量元素构造环境判别图（图 8）中落入板内花岗岩与火山弧花岗岩边界，属后碰撞花岗岩。在花岗岩 R1—R2 构造环境判别图（图略）上落入造山晚期的花岗岩中。

东准噶尔及阿勒泰地区 A 型花岗岩多形成于 320～260 Ma（刘家远等，1996；王涛等，2010；童英等，2006；苏玉平等，2008），早石炭世东准噶尔北缘已开始了由后碰撞向板内环境转换（梁培等，2017），中亚地区 A 型花岗岩应该是晚期增生事件的记录（Coleman，1989）。A 型花岗岩在北疆地区广泛而有规律地发育表明至少存在显著的地壳增生现象（毛启贵等，2008）。结合老爷庙地区地质特征，上泥盆统卡希翁组为海陆交互相，上石炭统巴塔玛衣内山组为陆相，表明老爷庙地区在早二叠世早期（297.0±6.5 Ma）时已拼贴到西伯利亚板块，进入后碰撞向板内转化的过渡期，结束了地壳的侧向增生。

岩体锆石温度饱和温度 819～890℃，平均 842°（>840°）属于高温花岗岩，远高于该区 650℃±的莫霍面温度（汪洋等，2013）在 Sr—Yb 图中投入浙闽型花岗岩（图略），属于中等压力（张旗等，2010），结合该区的后碰撞背景推测岩浆的产生与后造山伸展体制下导致的软流圈上涌、幔源岩浆的底侵作用有关（吴福元等，2007）。东准地区，尤其是夹持研究区的阿尔曼太及卡拉麦里碱性岩带普遍具有正的 $\varepsilon_{Nd}(T)$ 和 $\varepsilon_{Hf}(T)$ 值表明有大量幔源岩浆底侵到下地壳（朱笑青等，2006；梁培等，2017）。因此，老爷庙地区在石炭纪末期然处于地壳的垂向增生阶段。

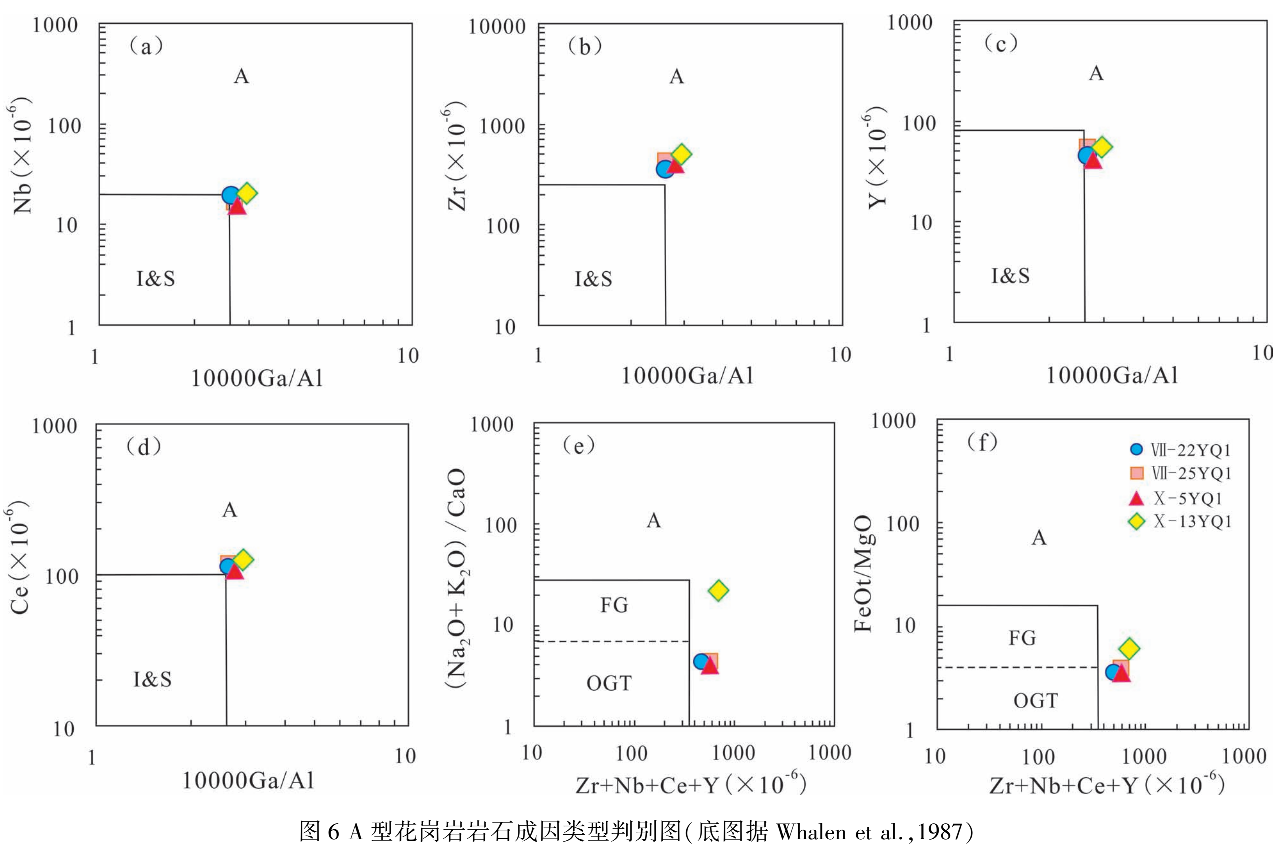

图 6 A 型花岗岩岩石成因类型判别图（底图据 Whalen et al.，1987）

Fig. 6 Classification diagrams of the A-type granites (after Whalen et al.，1987)

I、S、M 和 A—I 型、S 型、M 型和 A 型花岗岩区；OGT—未分异的 I、S 和 M 型花岗岩区；FG—分异的 I 型花岗岩区

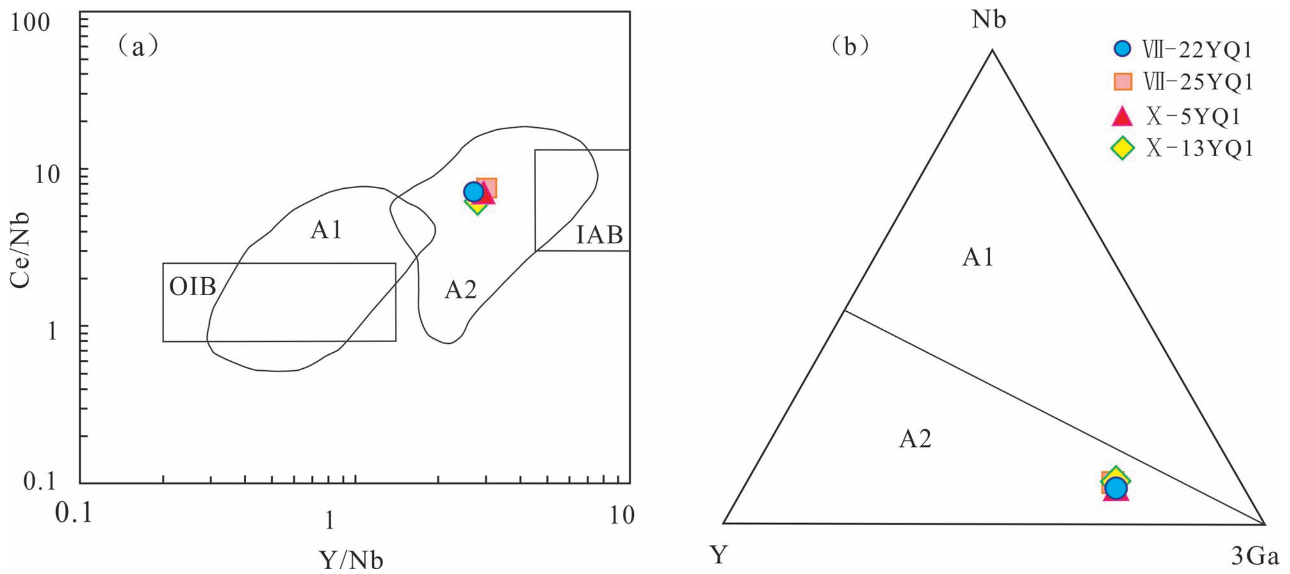

图 7 A 型花岗岩 Y/Nb—Ce/Nb (a)和 Nb—Y—3×Ga (b)图解(底图据 Eby,1 992)

Fig. 7 Y/Nb vs. Ce/Nb(a) and Nb—Y—3×Ga (b) diagrams of the A type granites(after Eby, 1992)

A1、A2—A1、A2 型花岗岩区;OIB—洋岛玄武岩区;IAB—岛弧玄武岩区

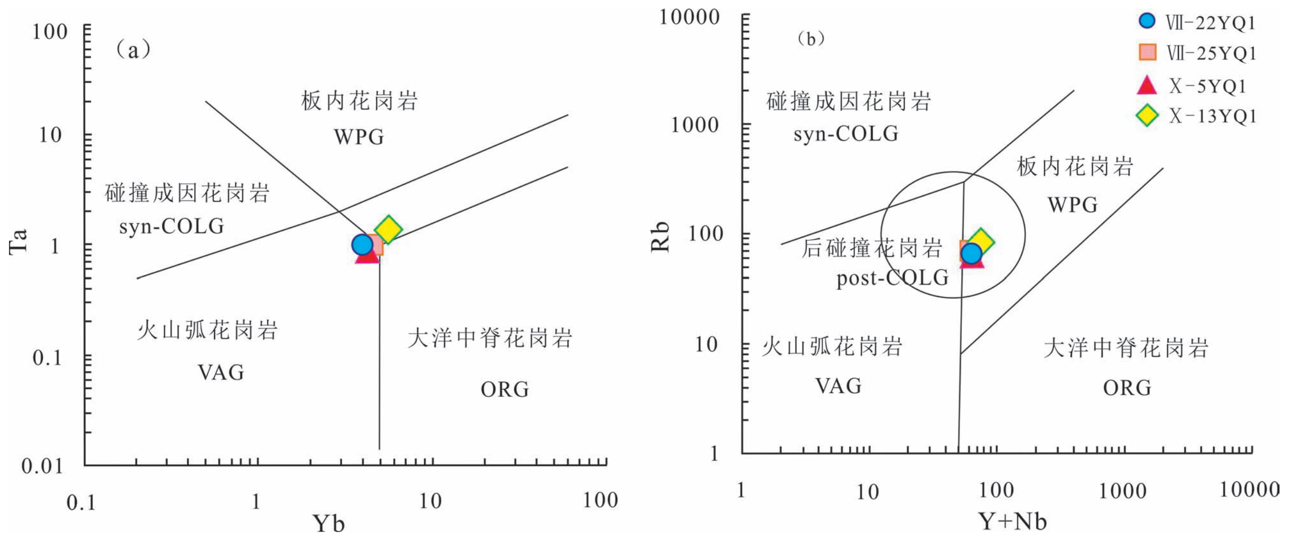

图 8 微量元素构造环境判别图(底图据 Pearce et al.,1984)

Fig. 8 Trace element discrimination diagrams for tectonic settings(after Pearce et al.,1984)

5 结论

(1)老爷庙碱性花岗岩是具有高硅、富碱、贫钙、低钛的特征的高温高分异侵入岩。锆石温度饱和温度 819~890℃,属于高温花岗岩,中等压力。具有 A 型花岗岩特征,成因类型上属 A2 型花岗岩,产于后造山环境。

(2)LA-ICP-MS 锆石 U-Pb 年龄显示岩体结晶年龄为两期,分别为 297.0±6.5 Ma 和 310.0±2.0 Ma,表明其形成时代为晚石炭世—早二叠世。

(3)老爷庙地区在早二叠世早期已经拼贴到西伯利亚板块,进入后碰撞向板内转化的过渡期,结束了地壳的侧向增生。但由于大量幔源岩浆底侵到下地壳,使该区仍在垂向增生。

注 释 / Notes

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Zircon U-Pb Dating, Geochemical Characteristics of Alkali-granites in Laoyemiao Area, Eastern Junggar, and Geological Significance

XIONG Shuangcai, ZHANG Zhengfeng, LI Guang, LIU Runze,
HUA Xudeng, ZHAO Fuzhuang, ZHOU Pengfei, LI Guanlu

No. 1 *Geological Party, Xinjiang Bureau of Geology and Mineral Resources, Changji, Xinjiang*, 831100

Objectives: Laoyemiao area is located in east of East Junggar, known as the important tectonic metallogenic belt of the Central Asian Orogenic Belt (CAOB). Through high-precision zircon U-Pb dating and comprehensive research on rock geochemistry, combined with regional comparison, the diagenetic age was determined and its formation environment was discussed to provide chronology and petro-geochemical constraints for the study of Late Paleozoic tectonic magmatism.

Methods: The full analysis of the rock was tested in the Aussie Minerals Laboratory in Guangzhou. After the sample was crushed, shrunk and ground to 200 mesh, the content of rare earth elements was determined by ME-MS81 fusion inductively coupled plasma mass spectrometry. ME-XRF26X fluorescence spectrometer was used for precise analysis. Determination of iron oxide by the main trace element of rock and Fe-VOL05 titration.

Zircon single minerals were selected in the laboratory of the Institute of Regional Geology and Mineral Resources Research ofHebei Province, and the target, CL photographing, transflective photography, zircon dating and data were carried out in the State Key Laboratory of Mineral Deposits Research Mechanism of Endogenous Metal Deposits, Nanjing University. Correction. The zircon U-Pb test was carried out on an Agilient 7500a ICP-MS connected by a 193 nm laser sampling system. The laser ablation beam spot diameter was 32 μm and the frequency was 6 Hz. He gas was used as the carrier gas for the ablation material, and then mixed with the Ar gas. Analyze. The isotope ratios obtained by the experiment were processed by the GLITTER program and subjected to ordinary lead calibration. The test results are shown in Table 2. The age harmonic curve and the weighted average calculation were processed using Isoplot (3.0) software.

Results: Laoyemiao alkali granites are characterized by high SiO_2(63.58%~69.92%), high alkaline(Na_2O+K_2O: 9.38%~9.81%), low CaO (0.44%~2.47%) and low TiO_2(0.52%~0.97%), Similar to typical A-type granites, which genesis type belongs to the A2-type granites and produced in the post-orogenic environment. The alkali granites are enriched Rb、Ba、K、Th、Zr and relatively depleted in P、Ti、Nb、Ta. Obvious enrichment light rare earth elements(LREE/HREE = 7.62 ~ 8.31), the internal fractionation of light rare earth elements is relatively strong, but weak in heavy rare earth elements , and lack in Eu anomaly(δEu =0.52~0.91).Zircon temperature saturation temperature of 819~890℃, belonging to high-temperature granite, moderate pressure. The zircon U-Pb age of LA-ICP-MS shows that its crystallographic age is two phases, which are 297.0±6.5 Ma and 310.0±2.0 Ma, respectively, indicating that the age of its formation is Late Carboniferous.

Conclusions: Laoyemiao area was tiled into the Siberian plate at the end of the Late Carboniferous period (297.0±6.5) Ma and entered the transitional period of post-orogenic conversion into the plate.The lateral growth of the crust in the area was ended, but the area was still vertically proliferated due to the intrusion of a large amount of mantle-derived magma to the lower crust.

Keywords: east Junggar; alkali granite; post-orogenic environment; zircon U-Pb dating; petrogeochemistry; Late Carboniferous — Early Permian

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First author: XIONG Shuangcai, male, born in 1987, master´s degree, engineer, mainly engaged in metallogenic regularity and metallogenic prediction and regional geological mineral investigation, Email: sc_Xiong@163.com

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