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南天山地块塔格拉克地区二长花岗岩锆石 U-Pb 年代学、地球化学特征: 对壳源岩浆成因和构造背景的限定

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提要:【研究目的】西南天山造山带内塔格拉克地区的长条状岩体位于南天山地块, 由二长花岗岩组成。厘定该二长花岗岩的形成机制, 对南天山壳源岩浆成因的限定、洋盆俯冲消减及碰撞闭合时限等问题的研究具有重要意义。【研究方法】本文首次报道了塔格拉克地区二长花岗岩的全岩主量元素、微量元素、锆石 U-Pb 年代学结果。【研究结果】LA-ICP-MS 锆石年代学研究揭示出塔格拉克地区二长花岗岩成岩年龄为(284.0±1.9)~(284.3±3.2)Ma, 为早二叠世花岗岩。岩石主量元素和微量元素分析结果揭示该二长花岗岩具有 A 型花岗岩特征: (1) SiO₂ (70.92%~72.78%) 含量高, 碱质(K₂O+Na₂O=7.91%~8.44%) 含量较高, A/CNK(0.89~0.99) 较高, 表明二长花岗岩为准铝质岩石, 属于高钾钙碱性系列; (2) LREE(196×10⁻⁶~280×10⁻⁶) 相对富集, HREE(22.8×10⁻⁶~28.2×10⁻⁶) 相对亏损, 负 Eu 异常(δEu 为 0.51~0.64) 明显, 球粒陨石标准化配分模式呈右倾 V 型特征; (3) 富集 Rb、Th 和 K 等大离子亲石元素, 相对亏损 Nb、Ta、Zr、P 和 Ti 等高场强元素。【结论】结合区域构造演化, 认为塔格拉克地区二长花岗岩形成于后碰撞构造背景。

关键词: 锆石 U-Pb 年代学; 地球化学; 二长花岗岩; 地质调查工程; 塔格拉克地区; 南天山地块

创新点: 从野外地质特征、岩石地球化学及 LA-ICP-MS 锆石 U-Pb 年代学等方面, 查明了南天山地块塔格拉克地区二长花岗岩地球化学特征及其成岩年代, 恢复形成时的构造背景, 为南天山古洋盆闭合、碰撞造山时限、后碰撞板块构造特征等洋-陆格局的演化等问题提供了新的科学依据。

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Zircon U-Pb geochronology and geochemistry of the Tagelake monzogranites in South Tianshan block: Constraints on crustal magmatic origin and tectonic setting

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

[Objective] The Tagelake strip pluton, outcropped at the south Tianshan terrane in Southwestern Tianshan orogenic belt, is composed of monzogranites. Determining the formation mechanism of the monzogranites has important implications for the crust-derived magma origin and the time limit of subduction and ocean basin closure in South Tianshan Mountains. **[Methods]** In order to determine the formation mechanism of the monzogranites, detailed zircon U-Pb geochronology, major elements and trace elements were firstly conducted. **[Results]** LA-ICP-MS zircon geochronology study reveals that the monzogranites in the Tagelake area crystallized at $(284.0\pm 1.9)-(284.3\pm 3.2)$ Ma, indicative of an Early Permian pluton. The results of major elements and trace elements reveal that the monzogranites display the characteristics of A-type granite: (1) The contents of SiO_2 (70.92%–72.78%), $\text{K}_2\text{O}+\text{Na}_2\text{O}$ (7.91%–8.44%) and A/CNK (0.89–0.99) are high, indicating that monzogranites are metaluminous rock and belongs to the high potassium calcium alkaline series; (2) The monzogranites are enriched in LREE (196×10^{-6} – 280×10^{-6}) and depleted in HREE (22.8×10^{-6} – 28.2×10^{-6}). Negative Eu anomaly is obvious, with δEu values of 0.51–0.64, and the monzogranites are characterized by fractionated chondrite-normalized REE patterns; (3) The monzogranites are enriched in Rb, Th, K and other large ion lithophile elements and depleted in Nb, Ta, Zr, P, and other high field strength elements. **[Conclusions]** Combined with the regional tectonic evolution, it is considered that the Tagelake monzogranites were formed in the post-collision tectonic setting.

Key words: zircon U-Pb geochronology; geochemistry; monzogranite; geological survey engineering; Tagelake area; South Tianshan Block

Highlights: On the basis of field geological characteristics, geochemistry with zircon LA-ICP-MS U-Pb dating, we clarified the geochemical characteristics and the formation age, and recovered the formation environment of the monzogranites in Tagelake, south Tianshan terrane. It provides new evidence for the evolution of the ocean basin closure, the time of collision orogeny, and the character of post-collision tectonic setting in the southern Tianshan.

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1 引言

天山造山带不仅是中亚造山带的组成部分,也是中国西北部古生代岩浆活动的集中区,并蕴含着丰富的古亚洲洋演化信息(徐学义等,2005;李平等,2018;计文化等,2020),成为近年来研究中亚造山带的形成与演化、陆壳生长和深部组成结构的有利地区之一(秦切,2017;余吉远,2018;耿全如等,2021)。20世纪80年代以来,众多学者对于南天山造山带古生代地质体开展了大量工作,包括高压—超高压变质岩(张立飞等,2005;蒲晓菲,2011;Xiao et al., 2012;郝国杰等,2020;Wu et al., 2021;姜雪薇和吕增,2021)、蛇绿岩发现和研究(刘本培等,1996;李曰俊等,2005)、古生物与地层(Li et al.,

2002;朱永峰等,2005;Qin et al., 2021;王庆同等,2021)、南天山造山带各种构造演化模式(Coleman, 1989;高俊等,2006;Long et al., 2008;Konopelko et al., 2009;黄河等,2011;Huang et al., 2013;周振菊等,2022)、古生代岩浆岩(刘楚雄等,2004;王超等,2007;黄河等,2011;刘春花等,2014;秦切,2017;孟令华等,2022)等。南天山造山带中广泛发育晚古生代侵入体(张招崇等,2009;陈士海等,2020;刘桂萍等,2021),以花岗质侵入岩为主,以闪长质侵入岩、辉长质侵入岩为次(图1)。前人已从南天山造山带晚古生代侵入体的岩石学、地球化学、年代学等方面探讨了南天山的区域构造格局和演化过程(Konopelko et al., 2007, 2009; Long et al., 2008; Huang et al., 2012; Biske et al., 2013; 刘春花等,

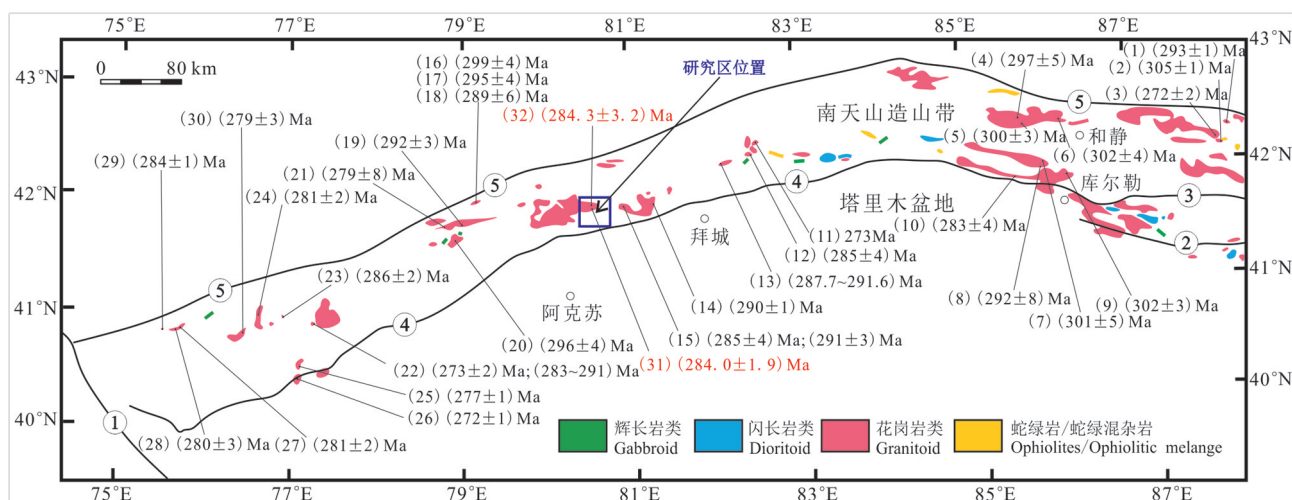


图1 南天山晚古生代侵入岩分布简图(据秦切,2017修改)

①—塔拉斯—费尔干纳右旋走滑断裂;②—兴地断裂;③—辛格列断裂;④—南天山南缘断裂带;⑤—南天山北缘断裂带

Fig.1 Distribution of the Late Paleozoic intrusive rocks in South Tianshan Mountains (modified from Qin Qie, 2017)

①—Talas—Fergan dextral strike-slip fault; ②—Xingdi fault; ③—Xinggir fault; ④—Fault belt in the southern margin of South Tianshan; ⑤—Fault belt in the northern margin of South Tianshan

2014; Ma et al., 2015; 秦切, 2017)。

但对南天山洋盆俯冲消减及碰撞闭合时限问题仍存争议,目前不同观点有:早石炭世末、晚石炭世末、中二叠世以前、晚二叠世之后、二叠纪末—三叠纪初等(李曰俊等, 2001; 夏林圻等, 2002; 高俊等, 2006; Zhang et al., 2007; 朱志新等, 2008; Su et al., 2010; Xiao et al., 2013; 毛友亮等, 2014; 黄河等, 2015; 王宗秀等, 2017; 林涛等, 2019; 李智佩等, 2021)。此外,对南天山后碰撞阶段中酸性岩体的形成过程中是否有幔源物质加入等问题仍未达成共识(黄河等, 2010)。

本文选择南天山塔格拉克地区二长花岗岩为研究对象,在详细的岩石地球化学及LA-ICP-MS锆石U-Pb年代学研究基础上,旨在查明其岩石地球化学特征及其成岩年代,恢复其成岩环境,为进一步探讨南天山古洋盆闭合、碰撞造山时限、后碰撞板块构造特征等洋-陆格局的演化问题提供新的科学依据。

2 区域地质背景及岩石学特征

塔格拉克地区位于中亚造山带之西天山造山带(图2a),属于卡拉库姆—塔里木板块(I)、南天山陆块群(II)、木扎尔特陆块(III),北邻南天山南缘晚古生代弧后盆地,南邻塔里木盆地(图2b)(王

宗秀等, 2017)。研究区出露的地层有长城系、寒武系、石炭系、二叠系、三叠系、侏罗系、白垩系、古近系、新近系、第四系(图2c),其中长城系阿克苏群岩性为灰绿色绢云绿泥石英片岩、绿帘绿泥石英片岩、绿泥石英片岩,寒武系肖尔布拉克组岩性为碳酸盐岩夹少量细碎屑岩,石炭系阿衣里河组和康克林组岩性为深灰色灰岩夹碎屑岩,二叠系小提坎立克组岩性为浅灰黑色晶屑凝灰岩、岩屑凝灰岩、英安质晶屑凝灰岩,三叠系、侏罗系岩性为碎屑岩夹煤层、煤线,白垩系岩性为碎屑岩,古近系、新近系岩性为碎屑岩夹石膏层,第四系岩性为冲洪积物和冰碛物。研究区火山岩分布较少,主要分布于二叠系小提坎力克组中,以中酸性火山碎屑岩为主。研究区出露晚古生代二叠纪岩浆岩(图2c),属塔吉克—塔里木一级构造岩浆带,呈巨大的岩基侵入长城系阿克苏群、上石炭统康克林组中,岩性主要为中粗粒二长花岗岩、粗粒二长花岗岩(图2d)。研究区变质岩主要为区域变质岩,分布于长城系阿克苏群中,以石英片岩为主;在岩体接触带部位,发育接触变质岩,岩性为角岩、矽卡岩。研究区区域深大断裂发育,由中部丹津苏大断裂(F_2)及南部帕喀勒克—提坎库鲁克大断裂(F_3)贯穿整个研究区(图2c)。

塔格拉克地区二长花岗岩,出露面积约112.9 km²(图2c),主要位于研究区的北部,侵入于长城系

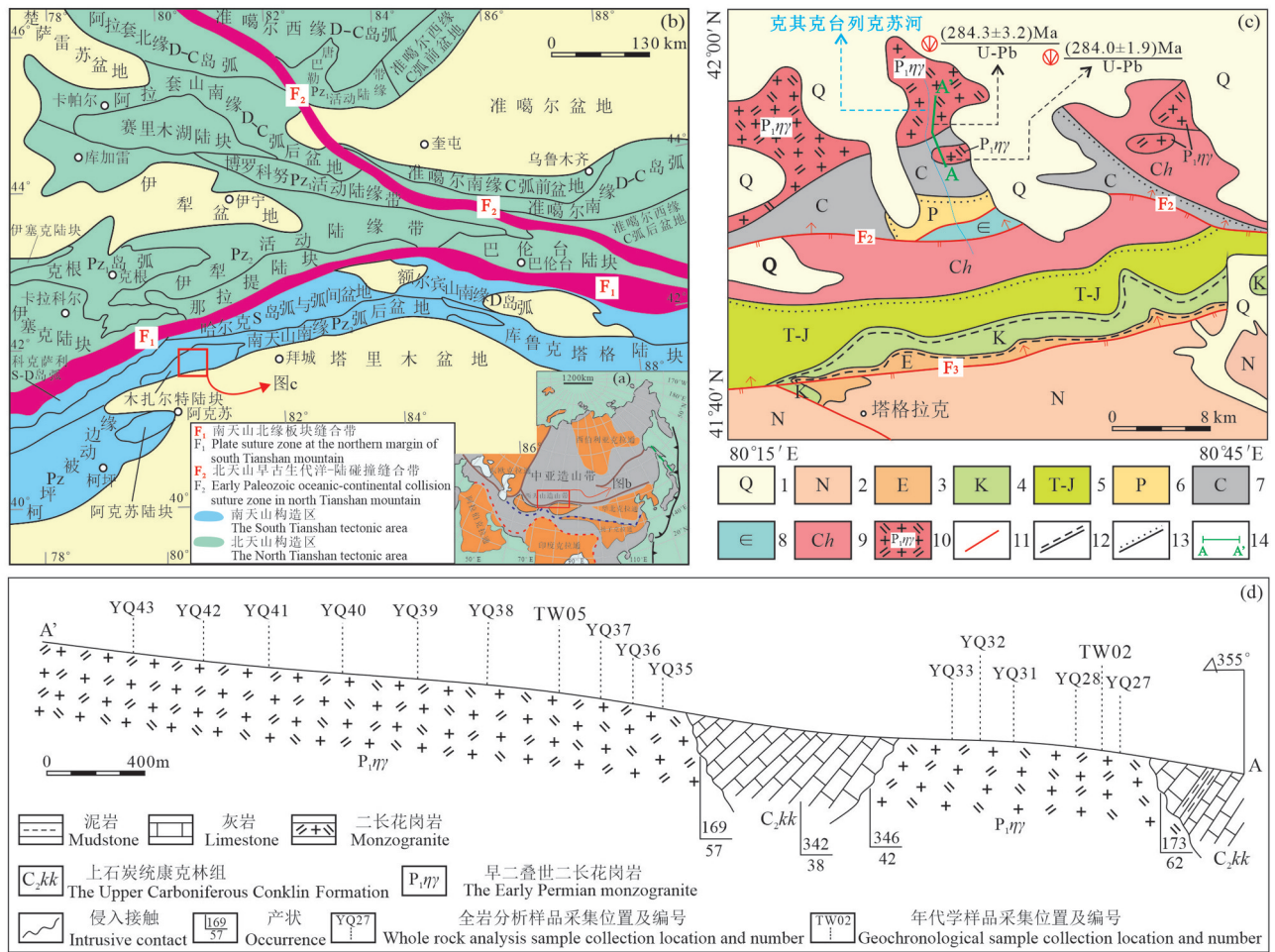


图2 西天山造山带构造单元划分图(a、b,据王宗秀等,2017)和塔格拉克地区地质简图及采样位置图(c、d,据甘肃省地质矿产勘查开发局第二地质矿产勘查院,2018^①)

1—第四系;2—新近系;3—古近系;4—白垩系;5—侏罗系—三叠系;6—二叠系;7—石炭系;8—寒武系;9—长城系;10—早二叠世二长花岗岩;11—断层;12—平行不整合;13—角度不整合;14—剖面位置

Fig.2 Tectonic division in Western Tianshan Orogen (a, b, after Wang Zongxiu et al., 2018) and geological map of Tagelake area with sampling locations (c, d, modified from the Second Institute of Geology and Minerals Exploration Team, Gansu Provincial Bureau of Geology and Minerals Exploration and Development, 2018^①)

1—Quaternary; 2—Neogene; 3—Paleogene; 4—Cretaceous; 5—Jurassic—Triassic; 6—Permian; 7—Carboniferous; 8—Cambrian; 9—Changcheng System; 10—Early Permian monzogranite; 11—Fault; 12—Parallel unconformity; 13—Angular unconformity; 14—Section position

阿克苏群及石炭系中,呈近东西向长条状展布,与围岩接触界线清楚,呈侵入接触。岩石为浅肉红色和浅灰白色,粗中粒结构,块状构造。该二长花岗岩(图3a、b)的主要矿物为斜长石(±40%)、钾长石(±35%)、石英(±20%)、黑云母(±4%)、白云母(微)、锆石(微)(图3e)、榍石(微)(图3c)和磷灰石(微)等;斜长石(图3c、d、e、f)呈自形板条状、短柱状和柱粒状,晶体棱边平直,斜长石的自形程度强于钾长石,斜长石晶体为粗中粒级,粒径为2.0~7.0 mm,斜长石发育绢云母化、黏土化、绿帘石化,为

酸性斜长石,见环带构造和聚片双晶;钾长石(图3d、e、f)呈他形粒状,为条纹长石、正长石和微斜长石,条纹长石具条纹结构,微斜长石具格子双晶,微高岭土化,粒径为2.0~6.5 mm;石英(图3c、d、e、f)多为不规则的他形粒状,呈锯齿状镶嵌分布,分布于其他矿物的空隙中,单体粒径相对长石较细小,消光不均匀,单体粒径在5.0 mm以下;暗色矿物为黑云母(图3d、f),部分已绿泥石化,杂乱分布,粒径在0.2 mm×0.5 mm以下;见少量的白云母分布,粒径在0.5 mm以下。

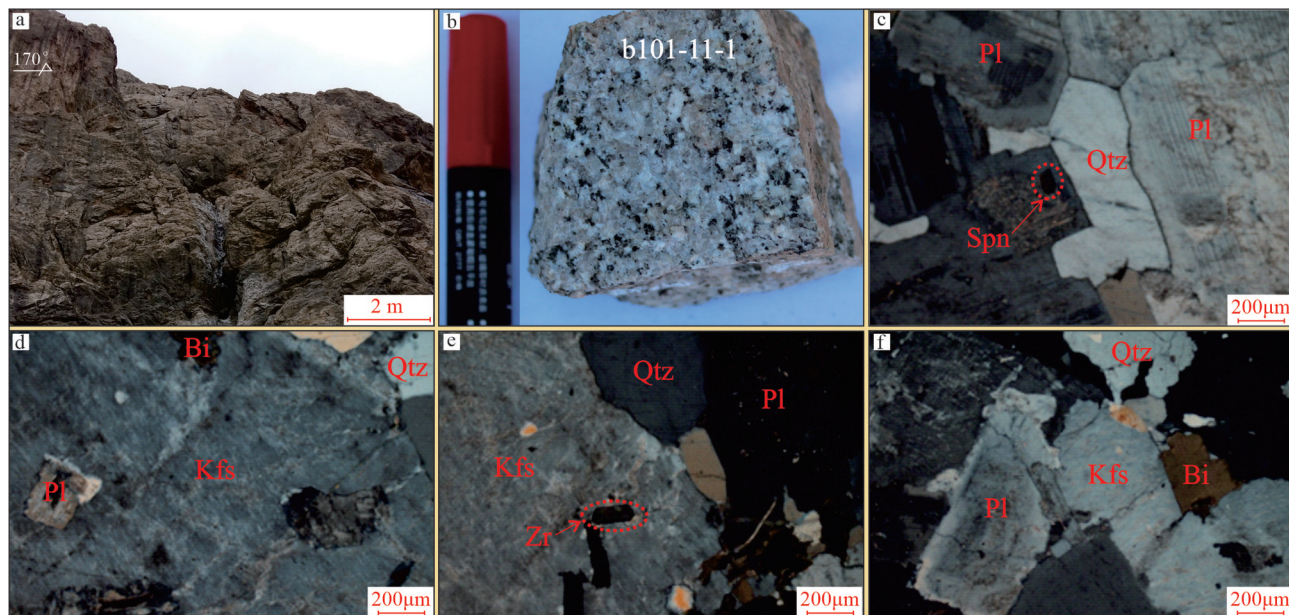


图3 塔格拉克地区二长花岗岩的岩石标本和镜下特征

Qtz—石英;Pl—斜长石;Kfs—钾长石;Bi—黑云母;Zr—锆石;Spn—榍石

Fig.3 Scanned photo of specimens and photomicrographs of the monzogranites in Tagelake area

Qtz—Quartz; Pl—Plagioclase; Kfs—K-feldspar; Bi—Biotite; Zr—Zircon; Spn—Sphene

3 分析方法

为了精确厘定南天山二长花岗岩的形成年代,在塔格拉克地区采集了2件典型的二长花岗岩新鲜样品,采样位置见图2d,样品编号为TW02、TW05,每件重约5 kg,小心排除和避免任何相邻层位和外来物质的污染。从中挑选锆石,经过手工挑选、制靶、剖光和照相观察。锆石的挑选在河北省廊坊市区域地质调查研究所实验室完成,采用标准重矿物技术分选锆石。锆石的制靶、显微镜照相、阴极发光(CL)图像分析在南京聚谱检测科技有限公司完成。将双目镜下挑选的表面平整光洁且具有不同长宽比例、不同柱锥面特征、不同颜色的锆石颗粒粘在双面胶上,用无色透明环氧树脂固定,待固化后对其表面抛光至锆石中心。用反射光和透射光对待测锆石进行照相,然后镀金,进行阴极发光照相,以检查锆石的内部结构和裂隙分布情况,选取锆石U-Pb测试点。本次的锆石测年采用LA-ICP-MS方法,测试工作在南京大学内生金属矿床成矿机制研究国家重点实验室完成。测试使用与相干193 nm激光取样系统连接起来的Agilent 7500a ICP-MS完成。分析过程中,激光束斑直径

采用32 μm,频率为5 Hz。样品经剥蚀后,由He气作为载气,再和Ar气混合后进入ICP-MS进行分析。U-Pb分馏根据澳大利亚锆石标样GEMOC GJ-1来校正,锆石标样Mud Tank作为内标,控制分析精度;采用专用软件ICP-MS Data Cal完成锆石样品的数据处理工作,包括对样品和空白信号的选择、仪器灵敏度漂移校正、元素含量计算等,并最终给出合理年龄,分析结果见表1。

在塔格拉克地区采集了14件典型的二长花岗岩新鲜样品进行全岩地球化学分析,采样位置见图2d,全岩地球化学分析在华北有色地质勘查局燕郊中心实验室完成。主量元素采用Axios PW4400型X射线荧光光谱玻璃熔片法分析,稀土元素和微量元素均采用电感耦合等离子体质谱法(ICP-MS)分析,分析结果见表2。

4 锆石U-Pb年龄

2件样品中所挑选的锆石颗粒主要呈自形—半自形棱柱状晶体,长100~300 μm,宽40~100 μm,长宽比在2:1~4:1。研究表明,岩浆成因锆石多具有特征性的韵律环带(Corfu, 2003; 吴元保和郑永飞, 2004; 李长民, 2009),研究区锆石颗粒在CL图像上

表1 塔格拉克地区二长花岗岩LA-ICP-MS锆石U-Pb年龄测定结果
Table 1 LA-ICP-MS U-Pb data of the monzogranites in Tagelake area

测点号	含量/ 10^{-6}			Th/U	同位素比值						年龄/Ma					
	Pb	Th	U		$^{207}\text{Pb}/^{206}\text{Pb}$		$^{207}\text{Pb}/^{235}\text{U}$		$^{206}\text{Pb}/^{238}\text{U}$		$^{207}\text{Pb}/^{206}\text{Pb}$		$^{207}\text{Pb}/^{235}\text{U}$		$^{206}\text{Pb}/^{238}\text{U}$	
					比值	误差/ 1σ	比值	误差/ 1σ	比值	误差/ 1σ	年龄	误差/ 1σ	年龄	误差/ 1σ	年龄	误差/ 1σ
TW02-14	36.75	178.14	727.96	0.24	0.0514	0.0007	0.3139	0.0042	0.0442	0.0003	257.5	26.9	277.2	3.3	279.0	1.8
TW02-24	16.57	155.76	307.18	0.51	0.0532	0.0010	0.3254	0.0061	0.0445	0.0003	344.5	44.4	286.0	4.7	280.6	2.1
TW02-12	16.05	127.55	300.86	0.42	0.0516	0.0010	0.3165	0.0063	0.0446	0.0004	264.9	44.4	279.2	4.9	281.4	2.2
TW02-23	10.76	115.16	192.09	0.60	0.0525	0.0011	0.3253	0.0070	0.0450	0.0004	305.6	48.1	286.0	5.4	283.8	2.2
TW02-06	6.35	46.50	119.26	0.39	0.0525	0.0015	0.3233	0.0089	0.0451	0.0004	309.3	64.8	284.5	6.9	284.2	2.6
TW02-18	19.81	217.88	351.22	0.62	0.0523	0.0010	0.3262	0.0061	0.0451	0.0003	298.2	42.6	286.7	4.7	284.4	2.0
TW02-05	22.85	208.86	412.46	0.51	0.0519	0.0008	0.3243	0.0054	0.0453	0.0003	283.4	32.4	285.2	4.1	285.4	1.9
TW02-03	12.35	120.20	221.83	0.54	0.0526	0.0011	0.3275	0.0070	0.0453	0.0004	322.3	48.1	287.6	5.3	285.9	2.2
TW02-01	13.21	89.27	244.98	0.36	0.0528	0.0011	0.3290	0.0067	0.0454	0.0003	320.4	15.7	288.8	5.1	286.1	1.9
TW02-09	15.01	84.08	289.70	0.29	0.0542	0.0012	0.3375	0.0072	0.0456	0.0004	388.9	48.1	295.3	5.5	287.2	2.6
TW02-02	27.68	245.92	495.84	0.50	0.0513	0.0008	0.3228	0.0050	0.0456	0.0003	253.8	39.8	284.1	3.9	287.7	2.0
TW05-18	24.49	289.59	434.43	0.67	0.0516	0.0009	0.3133	0.0051	0.0441	0.0003	333.4	37.0	276.7	4.0	277.9	2.0
TW05-01	37.28	241.70	731.15	0.33	0.0533	0.0007	0.3245	0.0047	0.0441	0.0003	342.7	26.9	285.4	3.6	278.3	2.1
TW05-07	16.84	169.61	307.15	0.55	0.0536	0.0011	0.3267	0.0071	0.0442	0.0003	353.8	80.5	287.0	5.4	278.6	2.0
TW05-24	23.75	249.98	423.78	0.59	0.0520	0.0010	0.3212	0.0065	0.0447	0.0003	283.4	44.4	282.8	5.0	281.9	2.1
TW05-13	27.88	302.37	501.58	0.60	0.0543	0.0009	0.3394	0.0066	0.0450	0.0004	387.1	37.0	296.7	5.0	283.7	2.7
TW05-20	30.29	285.14	547.65	0.52	0.0523	0.0008	0.3253	0.0053	0.0450	0.0003	298.2	41.7	286.0	4.0	284.0	2.0
TW05-19	24.42	255.94	429.96	0.60	0.0527	0.0009	0.3294	0.0057	0.0453	0.0003	322.3	38.9	289.1	4.3	285.5	2.2
TW05-16	29.91	303.99	518.11	0.59	0.0537	0.0008	0.3382	0.0053	0.0456	0.0003	366.7	35.2	295.8	4.0	287.3	1.8
TW05-08	18.47	158.43	335.31	0.47	0.0530	0.0010	0.3333	0.0059	0.0457	0.0003	331.5	36.1	292.1	4.5	288.2	2.0
TW05-02	25.98	212.15	469.51	0.45	0.0528	0.0009	0.3375	0.0061	0.0460	0.0004	320.4	41.7	295.3	4.7	290.2	2.3
TW05-22	28.69	325.85	485.60	0.67	0.0525	0.0008	0.3350	0.0052	0.0462	0.0003	309.3	35.2	293.4	4.0	291.4	2.1

具有明显的岩浆韵律环带(图4);同时,岩浆锆石的Th、U含量较高,且Th/U比值一般大于0.1(Simon and Nigel, 2007),研究区2件样品Th/U比值分别介于0.24~0.62(平均值为0.45)、0.33~0.67(平均值为0.55),均大于0.1,化学成分上也进一步表明锆石均为岩浆成因。TW02样品的11个测点的U-Pb年龄在误差范围内具有较好的一致性,其 $^{206}\text{Pb}/^{238}\text{U}$ 年龄的加权平均年龄为(284.0±1.9)Ma(图4b);TW05样品的11个测点的U-Pb年龄在误差范围内也具有较好的一致性,其 $^{206}\text{Pb}/^{238}\text{U}$ 年龄的加权平均年龄为(284.3±3.2)Ma(图4d)。塔格拉克地区岩体的结晶年龄为(284.0±1.9)~(284.3±3.2)Ma,时代为早二叠世。

5 岩石地球化学

5.1 主量元素

本文在研究区取14个样品进行主量元素分析,结果见表2。二长花岗岩的 SiO_2 含量集中于70.92%~72.78%,平均为71.64%,属酸性岩类(图5a); Al_2O_3 含量在13.12%~14.22%,岩石中碱质含量高, $\text{K}_2\text{O}+\text{Na}_2\text{O}$ 含量为7.91%~8.44%,且 $\text{K}_2\text{O}/\text{Na}_2\text{O}$ 均大于1,相对富钾;相对贫 TiO_2 (0.27%~0.33%)、 MgO (0.26%~

0.37%), MnO (0.04%~0.07%)和 P_2O_5 (0.07%~0.11%)。 TFe_2O_3 含量在1.19%~5.11%,平均值为2.79%,可能与岩石中黑云母有关。

SiO_2 - K_2O 图解(图5b)显示,二长花岗岩样品属于高钾钙碱性系列岩石。二长花岗岩的A/CNK为0.89~0.99,属于准铝质岩石(图5c)。

5.2 稀土元素特征

塔格拉克地区二长花岗岩球粒陨石稀土元素标准化配分图像(图6a)显示,其稀土总量高,在 219×10^{-6} ~ 305×10^{-6} ;轻重稀土分馏明显(LREE/HREE=8.60~11.17, $\text{La}_N/\text{Yb}_N=10.08$ ~14.61),轻稀土元素相对富集(LREE=196×10⁻⁶~280×10⁻⁶),重稀土元素相对亏损(HREE=22.8×10⁻⁶~28.2×10⁻⁶),其配分模式呈右倾V型特征,岩石中 δEu 为0.51~0.64,负Eu异常明显,说明岩浆演化过程中存在一定程度的斜长石的结晶分离或源区斜长石的残留。

5.3 微量元素特征

在原始地幔标准化微量元素蛛网图(图6b)中,二长花岗岩的微量元素变化特征基本一致,样品具有相对一致的配分型式,表明它们在成因上有一定的亲缘关系。样品均表现为富集Rb、Th、K等大离

表2塔格拉克地区二长花岗岩全岩主量元素(%)和微量元素(10^{-6})组成及有关参数Table 2 Analytical results of major elements (%) and trace elements (10^{-6}) of the monzogranites in Tagelake area

样品编号	YQ27	YQ28	YQ31	YQ32	YQ33	YQ35	YQ36	YQ37	YQ38	YQ39	YQ40	YQ41	YQ42	YQ43
岩性	二长花岗岩													
SiO ₂	70.92	71.23	72.16	71.02	72.00	72.00	71.12	72.78	72.23	71.03	72.03	71.65	71.02	71.80
TiO ₂	0.30	0.29	0.31	0.32	0.31	0.29	0.32	0.28	0.27	0.33	0.30	0.27	0.33	0.32
Al ₂ O ₃	13.12	13.85	13.56	14.22	13.41	13.56	13.85	13.30	13.85	13.89	13.45	13.78	13.92	13.68
Fe ₂ O ₃	0.44	0.40	0.20	0.44	0.49	0.44	0.24	0.34	0.16	0.69	0.40	0.40	0.40	0.24
FeO	3.12	2.63	2.72	2.60	2.74	2.45	3.00	2.36	2.36	2.74	2.36	2.36	2.60	2.75
TFe ₂ O ₃	3.26	2.96	1.48	3.26	3.63	3.26	1.78	2.52	1.19	5.11	2.96	2.96	2.96	1.78
MnO	0.07	0.05	0.05	0.05	0.05	0.04	0.06	0.05	0.04	0.05	0.05	0.05	0.05	0.05
MgO	0.32	0.30	0.36	0.35	0.34	0.26	0.33	0.31	0.30	0.34	0.33	0.29	0.37	0.35
CaO	2.22	2.11	1.85	1.97	1.75	1.80	2.06	1.95	1.90	2.03	1.98	2.00	2.03	1.91
Na ₂ O	3.27	3.36	3.16	3.30	3.16	3.26	3.36	3.26	3.32	3.36	3.26	3.39	3.59	3.23
K ₂ O	4.91	4.85	4.75	5.00	5.00	5.01	4.72	4.65	4.78	4.85	4.74	4.92	4.85	4.79
P ₂ O ₅	0.10	0.07	0.10	0.08	0.09	0.09	0.09	0.07	0.11	0.09	0.09	0.08	0.09	0.09
LOI	0.94	0.94	0.90	0.68	0.69	0.75	0.88	0.73	0.68	0.61	1.07	0.57	0.74	0.73
Total	99.73	100.07	100.11	100.03	100.03	99.95	100.03	100.08	100.00	100.01	100.06	99.75	99.98	99.94
Mg ^f	18.6	19.1	36.2	20.0	17.9	15.7	30.2	22.3	37.1	13.4	20.6	18.6	22.5	31.4
Na ₂ O+K ₂ O	8.18	8.21	7.91	8.30	8.16	8.27	8.08	7.91	8.10	8.21	8.00	8.31	8.44	8.02
K ₂ O/Na ₂ O	1.50	1.44	1.50	1.52	1.58	1.54	1.40	1.43	1.44	1.44	1.45	1.45	1.35	1.48
A/NK	1.23	1.29	1.31	1.31	1.26	1.26	1.30	1.28	1.30	1.29	1.28	1.26	1.25	1.30
A/CNK	0.89	0.95	0.99	0.99	0.97	0.97	0.96	0.95	0.98	0.96	0.95	0.95	0.94	0.98
La	57.6	74.6	54.6	63.0	73.5	58.9	70.9	67.0	51.3	49.3	49.6	66.7	75.9	60.9
Ce	107	129	101	111	127	110	121	122	95.8	91.3	90.2	116	130	110
Pr	11.9	14.1	11.0	12.4	13.8	12.4	13.6	13.1	10.4	10.0	10.0	12.9	13.9	12.3
Nd	45.0	49.7	41.2	46.4	48.5	45.4	48.7	47.6	39.0	37.4	38.4	46.6	50.1	46.2
Sm	8.11	8.74	7.89	8.42	7.84	8.31	8.68	8.83	7.63	7.14	7.11	8.57	8.75	8.36
Eu	1.45	1.50	1.42	1.54	1.41	1.38	1.46	1.43	1.43	1.35	1.46	1.41	1.42	1.42
Gd	7.89	7.70	6.82	7.93	7.36	7.90	7.50	7.48	6.46	6.34	6.56	7.18	7.39	7.12
Tb	1.36	1.30	1.15	1.33	1.19	1.34	1.24	1.27	1.07	1.09	1.13	1.22	1.22	1.18
Dy	7.22	6.93	6.63	7.53	6.50	7.41	6.69	6.93	6.06	6.03	6.41	6.56	6.44	6.20
Ho	1.41	1.40	1.32	1.54	1.31	1.52	1.34	1.43	1.26	1.27	1.23	1.34	1.36	1.27
Er	3.85	3.93	3.79	4.34	3.61	4.23	3.84	4.02	3.57	3.59	3.52	3.76	3.81	3.54
Tm	0.61	0.62	0.60	0.68	0.58	0.66	0.59	0.65	0.55	0.56	0.56	0.58	0.60	0.52
Yb	3.85	3.82	3.70	4.24	3.62	3.97	3.76	3.89	3.43	3.51	3.52	3.55	3.73	3.41
Lu	0.55	0.54	0.52	0.61	0.52	0.57	0.52	0.56	0.49	0.49	0.49	0.51	0.56	0.48
Y	39.6	38.8	36.5	41.5	35.5	41.5	36.9	38.8	34.0	33.6	36.0	36.0	36.8	34.9
Rb	185	202	212	213	202	205	204	213	207	196	189	210	201	175
P	424	286	439	355	399	382	383	325	483	382	401	334	373	373
Th	36.0	24.9	20.8	22.1	23.1	21.6	23.8	24.3	19.1	18.2	20.5	24.5	24.2	23.0
U	6.63	3.87	3.89	4.31	3.29	3.50	3.50	5.43	3.59	3.06	3.89	4.21	4.42	3.75
K	41260	40614	39742	41778	41783	41924	39521	38853	39951	40505	39750	41179	40568	40081
Nb	19.5	17.5	18.6	19.0	14.8	18.2	16.2	16.7	16.1	16.2	16.1	16.5	15.5	16.2
Sr	113	115	114	122	121	99.0	118	118	117	115	117	109	115	118
Ti	1820	1753	1873	1930	1870	1752	1935	1689	1629	1990	1816	1632	1993	1933
Ta	1.55	1.74	2.08	1.89	1.35	2.17	1.74	1.92	1.60	1.52	1.56	1.55	1.47	1.42
Hf	6.09	5.54	5.54	6.35	5.85	6.49	5.27	5.85	4.96	5.45	5.48	5.87	5.57	5.31
Zr	222	201	196	230	205	231	194	219	181	199	200	214	201	195
TREE	258	304	241	271	297	264	290	286	228	219	220	277	305	263
LREE	231	277	217	243	273	237	264	260	205	196	196	252	280	239
HREE	26.7	26.2	24.5	28.2	24.6	27.6	25.4	26.2	22.8	22.8	23.4	24.7	25.1	23.7
LREE/HREE	8.65	10.59	8.86	8.64	11.06	8.60	10.39	9.93	8.99	8.60	8.40	10.24	11.17	10.10
La _N /Yb _N	10.73	14.02	10.59	10.66	14.58	10.65	13.53	12.37	10.74	10.08	10.11	13.48	14.61	12.82
δEu	0.55	0.55	0.58	0.57	0.56	0.51	0.54	0.52	0.61	0.60	0.64	0.53	0.53	0.55
δCe	0.95	0.91	0.95	0.92	0.92	0.95	0.89	0.95	0.96	0.95	0.94	0.91	0.91	0.93
Nb/Ta	12.58	10.09	8.94	10.10	11.02	8.41	9.36	8.70	10.09	10.66	10.35	10.69	10.60	11.41
La/Nb	2.95	4.25	2.94	3.30	4.94	3.23	4.35	4.01	3.18	3.04	3.07	4.03	4.88	3.76
Th/Nb	1.85	1.42	1.12	1.16	1.55	1.19	1.46	1.46	1.18	1.12	1.27	1.48	1.56	1.42
Th/La	0.63	0.33	0.38	0.35	0.31	0.37	0.34	0.36	0.37	0.37	0.41	0.37	0.32	0.38
Rb/Sr	1.64	1.74	1.85	1.75	1.67	2.07	1.73	1.81	1.76	1.71	1.60	1.92	1.74	1.48
Rb/Nb	9.49	11.51	11.42	11.17	13.61	11.24	12.54	12.76	12.82	12.11	11.70	12.71	12.94	10.80
Nb/U	2.94	4.53	4.78	4.43	4.52	5.21	4.65	3.08	4.50	5.29	4.15	3.94	3.52	4.32
Sm/Nd	0.18	0.18	0.19	0.18	0.16	0.18	0.18	0.19	0.20	0.19	0.18	0.18	0.17	0.18

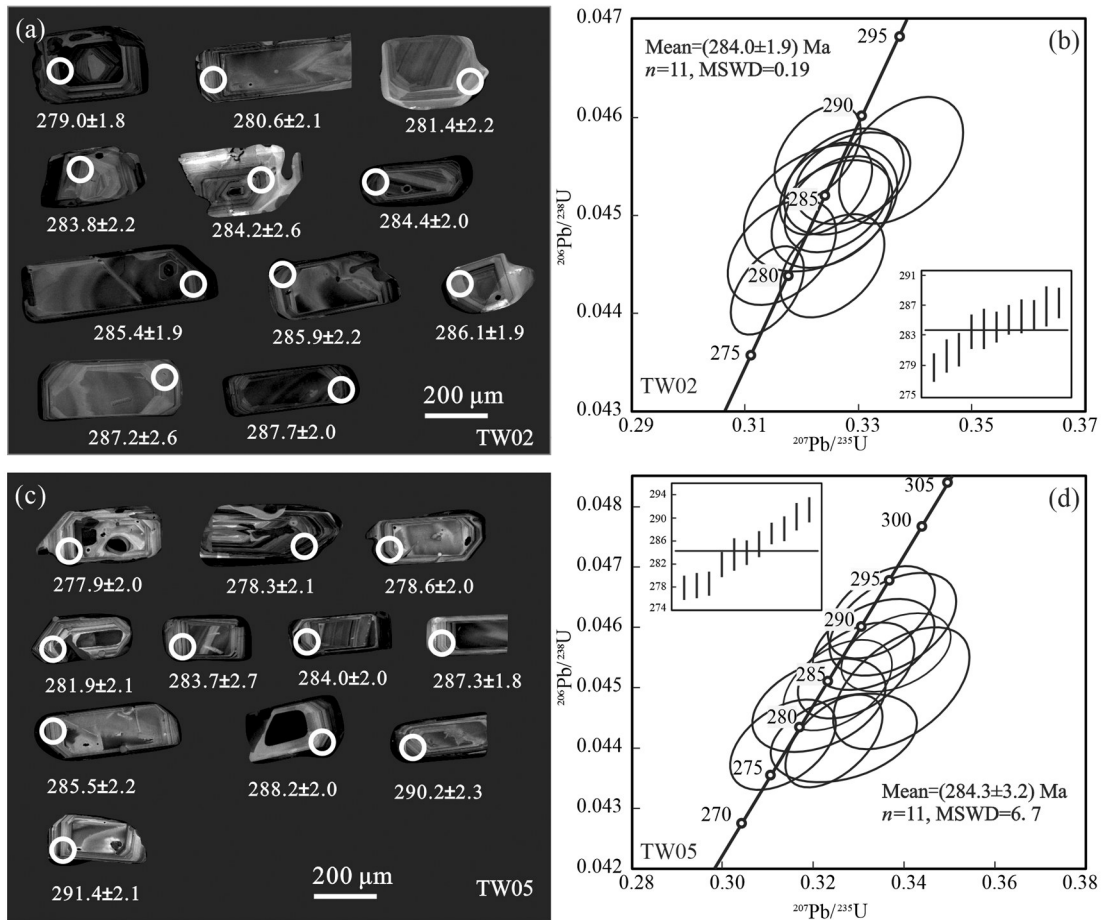


图4 代表性锆石颗粒的CL图像和U-Pb同位素谐和图(a,b为样品TW02,c,d为样品TW05)

Fig.4 Cathodoluminescence images of representative zircon grains and zircon U-Pb isotopic concordia plots for the zircons of sample TW02 (a, b) and TW05 (c, d)

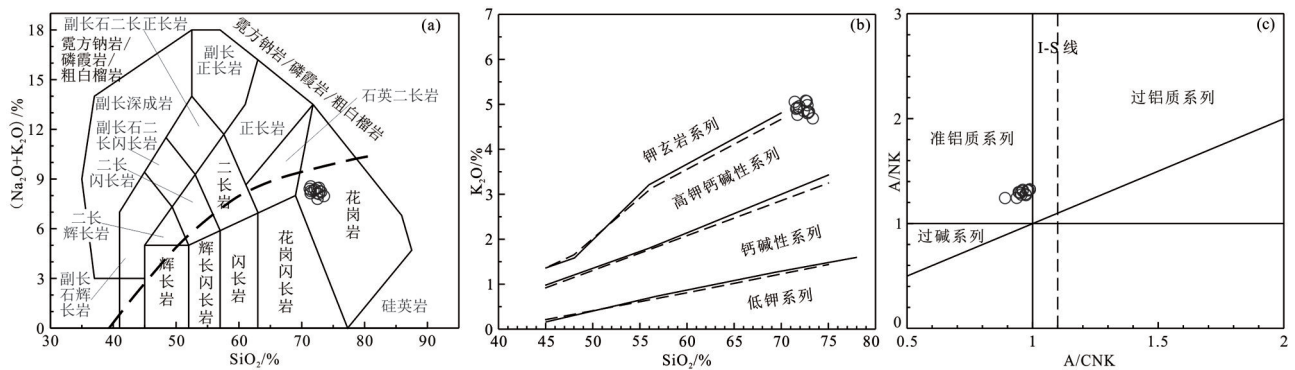


图5 塔格拉克地区二长花岗岩TAS图(a)、SiO₂-K₂O图(b)和A/CNK-A/NK图(c)(a据Mckenzie, 1989; b据Peccerillo and Taylor, 1976; c据Maniar and Piccoli, 1989)

A/CNK—摩尔比[Al₂O₃/(CaO+Na₂O+K₂O)]; A/NK—摩尔比[Al₂O₃/(Na₂O+K₂O)]

Fig.5 TAS (a), SiO₂-K₂O (b) and A/CNK-A/NK (c) diagrams of the monzogranites in Tagelake area (a after Mckenzie, 1989; b after Peccerillo and Taylor, 1976; c after Maniar and Piccoli, 1989)

A/CNK—molar [Al₂O₃/(CaO+Na₂O+K₂O)]; A/NK—molar [Al₂O₃/(Na₂O+K₂O)]

表3 南天山晚古生代花岗质侵入体年代学特征

Table 3 Geochronological data from the granitic plutons at Late Paleozoic in South Tianshan Mountains

岩体编号(图1)	产出位置	岩性	年龄/Ma	数据来源
1	库米什	花岗岩	293±1	黄岗等,2011
2	库米什	花岗岩	305±1	毛友亮等,2014
3	库米什	碱长花岗岩	272±2	Ma et al., 2015
4	盲起苏	花岗闪长岩	297±5	朱志新等,2008
5	盲起苏	二云母二长花岗岩	300±3	秦切,2017
6	盲起苏	花岗闪长岩	302±4	秦切,2017
7	虎拉山	二云母花岗岩	301±5	秦切,2017
8	虎拉山	二云母花岗岩	292±8	秦切,2017
9	七个星	黑云母二长花岗岩	302±3	秦切,2017
10	库尔楚I号	石榴石花岗岩	283±4	秦切,2017
11	依南里克	花岗岩	273	刘楚雄等,2004
12	黑英山	花岗岩	285±4	Long et al., 2008
13	波孜果尔	花岗岩	287.7~291.6	刘春花等,2014
14	波孜果尔	花岗岩	290±1	Huang et al., 2014
15	英买来	花岗岩	285±4; 291±3	马乐天等,2010;黄河等,2011
16	吉尔吉斯斯坦	花岗岩	299±4	Konopelko et al., 2009
17	吉尔吉斯斯坦	花岗岩	295±4	Konopelko et al., 2009
18	吉尔吉斯斯坦	花岗岩	289±6	Konopelko et al., 2009
19	吉尔吉斯斯坦	花岗岩	292±3	Konopelko et al., 2009
20	吉尔吉斯斯坦	花岗岩	296±4	Konopelko et al., 2007
21	吉尔吉斯斯坦	花岗岩	279±8	Konopelko et al., 2007
22	巴雷公	碱长花岗岩	273±2; 283~291	王超等,2007;黄河等,2015
23	川乌鲁	二长岩-正长岩	286±2	Huang et al., 2012
24	吉尔吉斯斯坦	花岗岩	281±2	Konopelko et al., 2007
25	古尔拉勒	花岗岩	277±1	Zhang and Zou., 2013
26	克孜勒	黑云母花岗岩	272±1	Zhang and Zou., 2013
27	吉尔吉斯斯坦	花岗岩	281±2	Biske et al., 2013
28	吉尔吉斯斯坦	花岗岩	280±3	Biske et al., 2013
29	吉尔吉斯斯坦	花岗岩	284±1	Biske et al., 2013
30	吉尔吉斯斯坦	花岗岩	279±3	Konopelko et al., 2007
31	塔格拉克	二长花岗岩	284.0±1.9	本文研究
32	塔格拉克	二长花岗岩	284.3±3.2	本文研究

子亲石元素,相对亏损Nb、Ta、Zr、P和Ti等高场强元素。该岩体具明显的负Eu异常,亏损Sr、Ti、P等元素,相对富集Rb、Th、K、Hf等元素。

6 讨 论

6.1 岩体形成时代

随着锆石高精度测年技术的不断发展,南天山地区新涌出了一批可靠的年代学数据资料,特别是南天山地区晚石炭世—中二叠世(峰期年龄284 Ma)岩浆活动规模相对较大(表3),以花岗质侵入

体为主(秦切,2017),如:库尔楚I号岩体(283 Ma,秦切,2017)、波孜果尔岩体(287.7~291.6 Ma,刘春花等,2014)、川乌鲁岩体(286 Ma, Huang et al., 2012)、英买来岩体(285 Ma,黄河等,2011)、巴雷公岩体(273 Ma,王超等,2007)、黑英山岩体(285 Ma, Long et al., 2008)、依南里克岩体(273 Ma,刘楚雄等,2004)、库米什岩体(272~305 Ma,黄岗等,2011;毛友亮等,2014;Ma et al., 2015)、吉尔吉斯斯坦南天山岩体(279~299 Ma, Konopelko et al., 2007, 2009; Biske et al., 2013)等,这些岩体均形成于南天

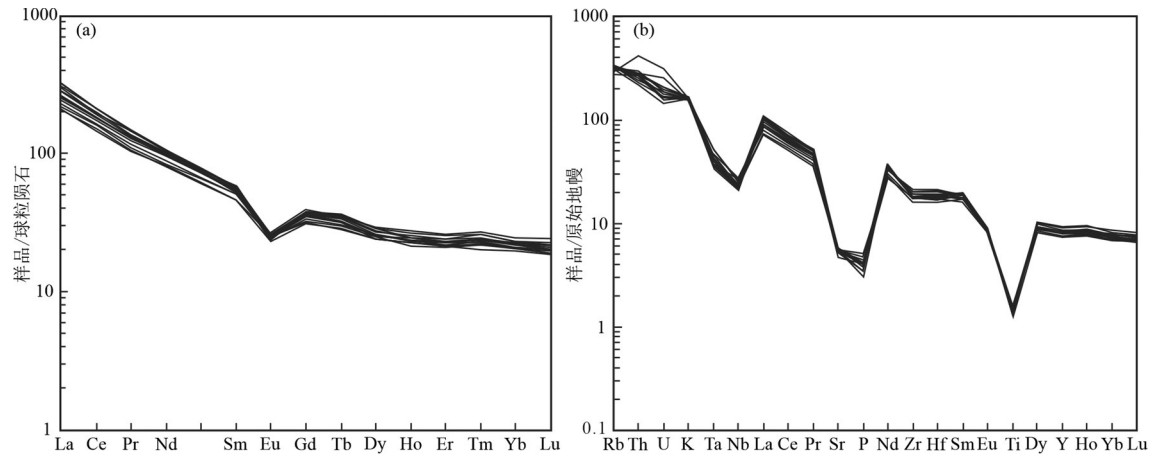


图6 塔格拉克地区二长花岗岩稀土元素球粒陨石标准化配分图(a)与微量元素原始地幔标准化蛛网图(b)(标准化值据Sun and McDonough, 1989)

Fig.6 Chondrite-normalized REE patterns (a) and primitive mantle-normalized trace element spider diagrams (b) of monzogranites in Tagelake area (normalized values are from Sun and McDonough, 1989)

山后碰撞挤压构造背景。本次研究在塔格拉克地区获得2组二长花岗岩的锆石U-Pb年龄分别为 (284.0 ± 1.9) Ma和 (284.3 ± 3.2) Ma,与南天山地区晚石炭世—中二叠世岩浆活动的峰期年龄(284 Ma)高度一致,属于早二叠世。

6.2 岩石成因

关于A型花岗岩的成因主要有以下5种:下地壳岩石的部分熔融和再熔融(Hoskin and Schaltegger, 2003)、幔源拉斑质岩浆高度分异或玄武质岩石部分熔融(Turner et al., 1992;张旗等,2007)、壳幔物质的混合作用(Dickina et al., 1991)、幔源岩浆的分离结晶(Pearce et al., 1984;张旗等,2007)、上地壳钙碱性岩石的低压部分熔融(Spulber and Rutherford, 1983)。因此,A型花岗岩的成因探讨应结合岩体的岩石学、地球化学特征、岩体自身构造和大地构造背景及动力学等多种特征综合分析。

南天山地块塔格拉克地区二长花岗岩具有高硅(70.92%~72.78%)、高碱(K_2O+Na_2O 含量7.91%~8.44%)、富铝(13.12%~14.22%)和低 TiO_2 (0.27%~0.33%)、 MgO (0.26%~0.37%)、 P_2O_5 (0.07%~0.11%),属于高钾钙碱性系列。二长花岗岩球粒陨石标准化分布模式呈右倾V型特征,Eu呈明显负异常,轻重稀土分馏程度不高(La_N/Yb_N 为10.08~14.61),表现为富集Rb、Th、K等大离子亲石元素,明显亏损高场强元素(Nb、Ta、Ti)及Sr、P的特征,反映了地壳源区特点(Mckenzie, 1989),同时也显示出A型花岗岩

的特征。另外,二长花岗岩A/CNK值范围为0.89~0.99,表现出准铝质特征,具有高 Fe^* 值($FeO^T/(FeO^T+MgO)$,0.79~0.93)和具较高的 TiO_2/MgO 比值(0.86~1.12),上述特征与典型A型花岗岩特征一致。在 $(Zr+Nb+Ce+Y)-FeO^T/MgO$ 图解(图7a)及 $(Zr+Nb+Ce+Y)-(Na_2O+K_2O)/CaO$ 图解(图7b)中,几乎所有样品落于分界线上或A型花岗岩区域,落入分界线上的样品可能是由于分异程度较高导致Zr含量的明显降低引起的(Waston and Harrison, 1983);在 K_2O-Na_2O 图解上(图7c),所有样品落于A型花岗岩区域;由于微量元素易受结晶分异的影响,Frost et al. (2001)提出新的判别图解,在 $SiO_2-FeO^T/(FeO^T+MgO)$ 图解中(图8a)和 $SiO_2-(Na_2O+K_2O)-CaO$ 图解中(图8b)中,所有样品均落于A型花岗岩区域。综上所述,南天山地块塔格拉克地区二长花岗岩应属于A型花岗岩。

研究表明:Ta和Nb为强不相容元素,Nb/Ta比值在岩浆分异中不会造成较大的分异,因此,能够指示岩浆源区特征及演化过程(Green, 1995)。研究区14件二长花岗岩样品Nb/Ta比值为8.41~12.58(壳源岩浆的Nb/Ta比值为11~12,幔源岩浆的Nb/Ta比值为 17.5 ± 2 (Green, 1995)),暗示岩浆的壳源属性; La/Nb 比值为2.94~4.94,均大于1,表明岩石也源于壳源(Depaolo and Daley, 2000);MORB(洋中脊玄武岩)和OIB(洋岛玄武岩)中Nb/U比值为 47 ± 10 ,原始地幔中Nb/U平均比值为33.59,但大陆

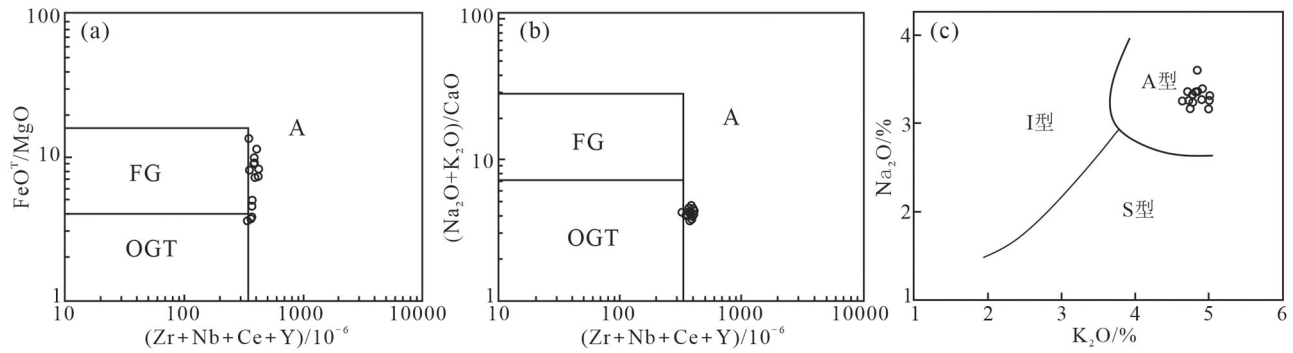


图7 塔格拉克地区二长花岗岩的 $(Zr+Nb+Ce+Y)-FeO^7/MgO$ 图、 $(Zr+Nb+Ce+Y)-(K_2O+Na_2O)/CaO$ 图和 K_2O-Na_2O 图(a, b据 Whalen et al., 1987; c据 Zorpi et al., 1989)

A—A型花岗岩; FG—分异型I、S或M型花岗岩; OGT—未分异的I、S或M型花岗岩

Fig.7 $(Zr+Nb+Ce+Y)-FeO^7/MgO$ (a), $(Zr+Nb+Ce+Y)-(K_2O+Na_2O)/CaO$ (b) and K_2O-Na_2O diagrams (c) of the monzogranites in Tagelake area (a, b after Whalen et al., 1987; c after Zorpi et al., 1989)

A—A-type granites; FG—Fractionated M-, I- and S-type granites; OGT—Unfractionated M-, I- and S-type granites

地壳中该比值很低(Taylor and McLennan, 1985),研究区二长花岗岩低的Nb/U值(2.94~5.29),远低于前两者比值;此外,研究区样品Sm/Nd比值在0.16~0.20,与大陆地壳的Sm/Nd比值(0.17~0.25)相近,反映岩石组分多源于地壳(陈加杰等,2016)。综上所述,塔格拉克地区二长花岗岩的微量元素特征显示出壳源属性。

研究区岩体缺乏详细的Sr-Nd同位素资料,导致不能对塔格拉克地区二长花岗岩的源岩或成因模式进行准确的限制;另外,塔格拉克地区二长花岗岩周围并不存在同期玄武质岩石密切共生,因此,认为其不可能由地幔玄武质岩浆高度结晶分异形成。岩体具有较高的 SiO_2 (70.92%~72.78%)和 K_2O (4.65%~5%)含量及较低的 $Mg^\#$ (13.4~37.1),这些特征基本排除了幔源或壳幔混合成因,而暗示岩体可能起源于古老地壳物质的重融。此外,研究区岩体亏损Nb,进一步表明不可能由地幔基性岩浆结晶分异形成(Green, 1995;杨高学等,2013)。在早二叠世时期,南天山已经进入碰撞后伸展阶段(夏林圻等,2004),塔格拉克地区二长花岗岩可能是在早二叠世后碰撞岩石圈伸展背景下形成。

6.3 构造背景及地质意义

区域地质资料已表明,南天山洋闭合时间不晚于晚石炭世,且在290 Ma已经处于岩石圈伸展背景下后碰撞演化阶段(Chen et al., 1999;夏林圻等,2004;刘楚雄等,2004;高俊等,2006;黄河等,2011;刘春花等,2014;林涛等,2019)。杨蓉(2016)研究

认为早二叠世大量A型花岗岩的涌现揭示晚石炭世—早二叠世西天山地区已进入后碰撞晚期向伸展环境的转化阶段;秦切(2017)认为晚石炭世时南天山地区已进入后碰撞环境;刘楚雄等(2004)研究认为塔里木北缘南天山一带的碱性侵入岩(黑英山克其克果勒霞霞正长岩锆石U-Pb年龄275 Ma、依南里克黑云霞石歪长伟晶岩锆石U-Pb年龄273 Ma)形成于后造山的拉张构造环境;吉尔吉斯南天山地区碱性花岗岩(280~266 Ma)形成于后碰撞构造(Solomovich and Trifonov, 2002);高俊等(2006)在研究南天山造山带的花岗岩类、蛇绿岩、高压变质岩等方面的成果基础上,认为南天山洋在早石炭世闭合,南天山西段造山带(塔里木地块与伊犁地块)开始于早石炭世(345 Ma),结束于晚石炭世末(~300 Ma)(Allen et al., 1993; Carroll et al., 1995; Gao et al., 1998;高俊等,2006);刘春花等(2014)研究南天山拜城县波孜果尔A型花岗岩类(287.7~291.6 Ma)认为南天山古洋盆闭合(碰撞造山)最晚发生在晚石炭世,早二叠世已经进入后碰撞演化阶段。

区域上,大哈拉军山组岛弧型火山岩的最年轻年龄为313 Ma(朱永峰等,2005)、后碰撞火山浅侵位岩浆岩Ar-Ar年龄306~250 Ma(赵振华等,2003),进一步说明南天山碰撞造山事件在石炭世末结束;塔里木地块和伊犁地块的古地磁特征显示早二叠世时期塔里木地块与伊犁地块已联合为一整体(蔡东升等,1995;贾承造,1997;Chen et al., 1999),表明天山的碰撞造山结束时间应早于二叠纪;库车盆

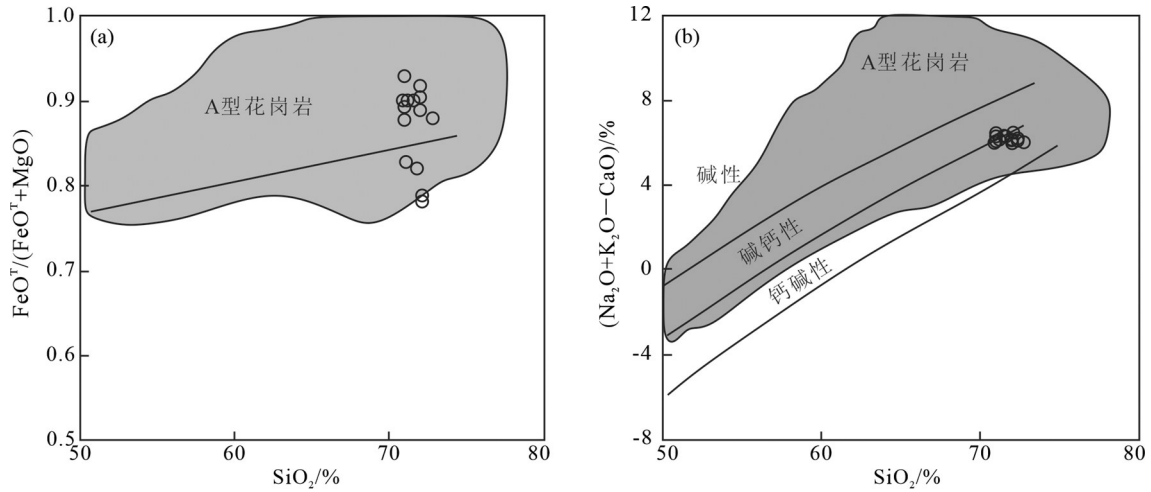


图8 塔格拉克地区二长花岗岩的SiO₂-FeO^T/(FeO^T+MgO)图和SiO₂-(Na₂O+K₂O-CaO)图(据Frost et al., 2001)
 Fig.8 SiO₂-FeO^T/(FeO^T+MgO) and SiO₂-(Na₂O+K₂O-CaO) diagrams of the monzogranites in Tagelake area (after Frost et al., 2001)

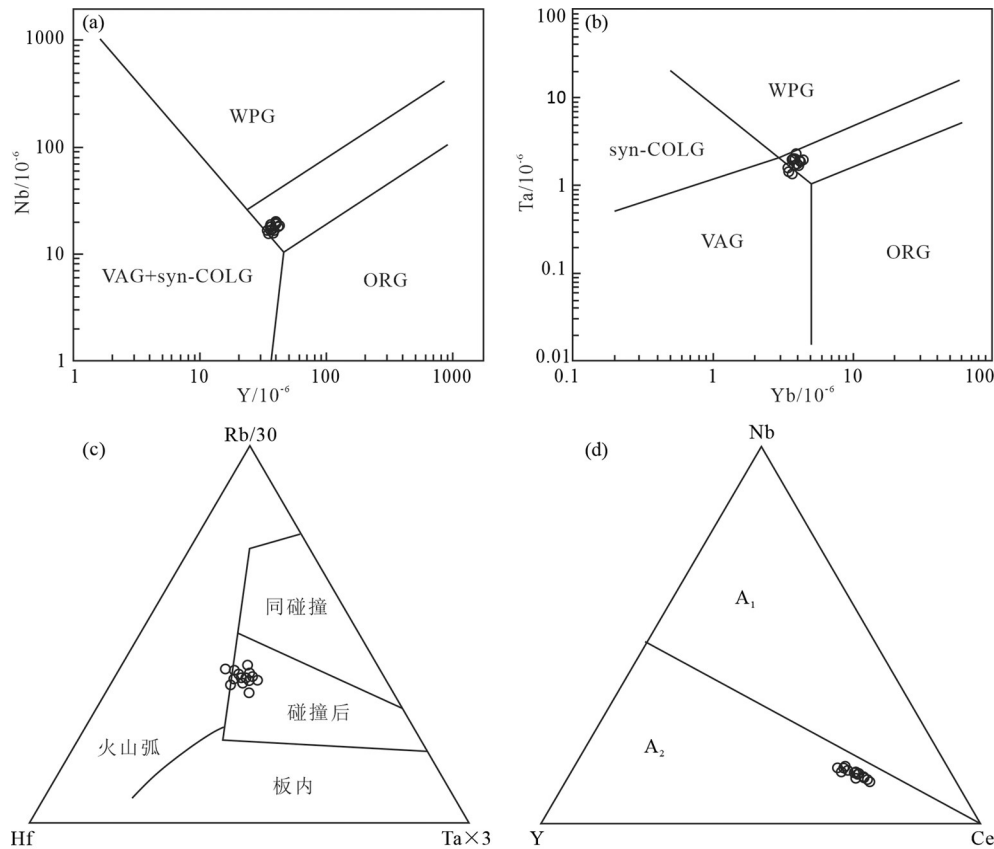


图9 塔格拉克地区二长花岗岩的Y-Nb图(a)、Yb-Ta图(b)、Rb/30-Hf-Ta×3图(c)与Nb-Y-Ce图(d)(a, b after Pearce et al., 1984; c after Harris et al., 1986; d after Eby, 1992)
 syn-COLG—同碰撞型; VAG—火山弧型; WPG—板内型; ORG—洋中脊型; A₁—非造山A型花岗岩; A₂—造山后A型花岗岩
 Fig.9 Y-Nb (a), Yb-Ta (b), Rb/30-Hf-Ta×3 (c) and Nb-Y-Ce (d) diagrams of the monzogranites in Tagelake area (a, b after Pearce et al., 1984; c after Harris et al., 1986; d after Eby, 1992)
 syn-COLG—syn-collision granite; VAG—Volcanic arc granite; WPG—Within plate granite; ORG—Oceanic ridge granite; A₁—Anorogenic A-type granitoids; A₂—Orogenic A-type granitoids

地的沉积地层序列特征揭示了上二叠统比尤勒包谷孜组陆相磨拉石沉积(周宗良等,1999),也指示了南天山造山带为一晚古生代造山带。

南天山塔格拉克地区二长花岗岩富钾(K_2O 为4.65%~5.01%),体现出碰撞后的A型花岗岩特征(张旗等,2012;赵闯等,2021;赵亚云等,2022),A型花岗岩形成于地壳减薄环境,出现在碰撞后和板内构造背景(徐学义等,2005;张旗等,2012)。在Y-Nb和Yb-Ta图解中(图9a、b),几乎所有样品均投入板内花岗岩环境区域,反映了碰撞后的岩浆生成环境;在Rb/30-Hf-Ta \times 3图解中(图9c),几乎全部样品投入碰撞后区域,也体现了碰撞后的构造背景;在Nb-Y-Ce图解上(图9d),样品全部投入A2型花岗岩区域,同样体现出了碰撞后的构造背景,表明花岗岩岩浆起源于地壳(Eby,1992),产于碰撞后的张性构造环境。

综合上述分析,结合区域构造演化,认为塔格拉克地区二长花岗岩(~284 Ma)属于塔里木板块与伊犁板块碰撞后岩石圈伸展背景下的产物,进一步表明南天山塔格拉克地区在早二叠世时期已经进入后碰撞演化阶段,南天山古洋盆闭合(碰撞造山)在早二叠世之前已结束。

7 结 论

通过对南天山地块塔格拉克地区岩体野外地质调查、岩相学、岩石地球化学和锆石U-Pb年代学研究,得出如下结论。

(1)本文获得塔格拉克地区岩体中锆石岩浆振荡环带的LA-ICP-MS U-Pb年龄分别为(284.0 \pm 1.9)Ma、(284.3 \pm 3.2)Ma,属于早二叠世岩浆活动产物,与南天山地块大量早二叠世岩浆活动时间一致。

(2)塔格拉克地区岩体岩性为二长花岗岩, SiO_2 、碱质含量较高,相对富钾,准铝质岩石,属于高钾钙碱性系列,具有高的Fe*值和TiO₂/MgO比值;富集轻稀土,亏损重稀土,负Eu异常明显,球粒陨石标准化配分模式呈右倾V型特征;富集Rb、Th、K等大离子亲石元素,相对亏损Nb、Ta、Zr、P和Ti等高场强元素,分析表明二长花岗岩具有壳源属性,属于A型花岗岩。

(3)结合区域构造演化,认为塔格拉克地区二

长花岗岩形成于塔里木板块与伊犁板块碰撞后的岩石圈伸展背景。

致谢:感谢项目组成员在野外样品采集过程中的大力帮助,以及编辑和两位匿名审稿人认真评阅稿件,并提出许多宝贵意见。

注释

①甘肃省地质矿产勘查开发局第二地质矿产勘查院. 2018. 新疆拜城县塔格拉克-关其特一带铜多金属矿远景调查报告[R]. 94-115.

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