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西天山达巴特A型花岗岩的形成时代与构造背景*

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Abstract The Dabate granitic porphyry pluton is located geographically to the north of the Sayram Lake, western Tianshan and, tectonically, occurs in the orogenic belt between the Junggar plate to the north and the Yli-central Tianshan plate to the south. It mainly consists of biotite-bearing granite porphyries that are geochemically similar to A-type granites. They have high SiO_2 (75.6% ~ 77.6%), alkalis ($Na_2O + K_2O$ = 8.27% ~ 8.70%), Fe/(Fe + Mg) (0.91 ~ 0.98) and (Ga/Al) $\times 10^4$ (3.19 ~ 3.40) values, but low Al_2O_3 (12.04% ~ 12.91%) and CaO (0.28% ~ 0.34%) contents. They are enriched in large ion lithophile elements (Rb, Th and U) and high field strength elements (Nb, Ta, Zr and Hf), but have obvious negative Eu, Ba and Sr anomalies and "sea-gull"-type rare earth element pattern. They also have relatively high Rb/Nb and Y/Nb ratios, indicating A_2-type granite characteristics. Our new zircon LA-ICP-MS U-Pb age data suggest that the Dabate A-type granite porphyries were generated in the Early Permian (288.9 ± 2.3Ma). Some residual zircon cores have a Late Carboniferous (319.0 ± 4.7Ma) age, indicating that the source of the granitic porphyries likely contains Carboniferous magmatic rocks. Taking into account reginoal geological and magmatic rock data, we suggest that the northern Tianshan was in an extensional setting by the Early Permian, which was possibly related to post-collisional evolution of the orogenic belt.

Key words Zircon LA-ICPMS U-Pb dating; A-type granite; Post-collision; West Tianshan

摘 要 达巴特花岗斑岩侵入体位于西天山北部的赛里木湖北部，构造上属于准葛尔板块与伊犁-中天山板块之间的造山带。达巴特花岗岩斑岩具有A型花岗岩的特征，如高硅(SiO_2 = 75.38% ~ 77.61%)、碱($Na_2O + K_2O$ = 8.26% ~ 10.10%)和Fe/(Fe + Mg)(0.91 ~ 0.98)，但低Al_2O_3(12.04 ~ 12.91%)和CaO(0.03% ~ 0.42%)，富集Rb、Th、U等大离子亲石元素和Nb、Ta、Zr、Hf等高场强元素，(Ga/Al) $\times 10^4$值变化于3.19 ~ 3.40之间，具有明显的负Eu、Ba和Sr异常，稀土配分显示"海鸥型"特征。达巴特花岗岩斑岩具有较高的Rb/Nb和Y/Nb比值，显示了A_2型花岗岩的特征。LA-ICP-MS锆石U-Pb测年结果显示达巴特岩体的侵位年龄为288.9 ± 2.3Ma，并且一些锆石具有老的核(319.0 ± 4.7)，暗示花岗岩斑的源岩中可能包含有石炭纪的岩浆岩。结合区域地质和岩浆岩资料，我们认为西天山早二叠世处于伸展的背景中，可能与造山带后碰撞阶段的演化有关。

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关键词 LA-ICPMS 锆石 U-Pb 定年；A 型花岗岩；后碰撞；西天山

中图法分类号 P588.121；P597.3

1 引言

近东西走向的天山造山带位于中亚造山带(Coleman, 1989; Jahn *et al.*, 2000; Khain *et al.*, 2003)或阿尔泰构造拼贴体(Sengor *et al.*, 1993; Yakubchuk, 2004)的最南端，是哈萨克斯坦和塔里木板块的汇聚地带，也是一个重要的 Cu-Au 等多金属成矿带。天山造山带是在古生代由塔里木和西伯利亚板块之间的古亚洲洋的消减闭合，塔里木、准噶尔、哈萨克斯坦等板块的俯冲—碰撞—增生所形成(Allen *et al.*, 1993; Coleman, 1989; Gao *et al.*, 1998; Sengor *et al.*, 1993; Shi *et al.*, 1994; Windley *et al.*, 1990; Xiao *et al.*, 2004a; Liu and Fei, 2006; Qian *et al.*, 2008)。但是，目前对天山造山带的形成与演化，尤其是晚古生代石炭纪—二叠纪的构造动力学背景还存有激烈的争论：一是天山北部石炭纪是岛弧环境(Zhu *et al.*, 2005; Zhang *et al.*, 2006a; Wang *et al.*, 2007b; 王强等, 2006)、碰撞后(Wang *et al.*, 2004a; 韩宝福等, 2004; 王京彬和徐新, 2006)、还是裂谷环境(Xia *et al.*, 2004b, 2008; 车自成和刘良, 1996; 顾连兴等, 2000)或与地幔柱有关(Pirajno *et al.*, 2008; 夏林圻等, 2004)；二是古生代北天山洋或准噶尔洋的闭合时限最终是在晚石炭—早二叠世关闭(Allen *et al.*, 1993; Windley *et al.*, 1990; Xiao *et al.*, 2004b; Wang *et al.*, 2007b; 王强等, 2006)或晚二叠(Xiao *et al.*, 2008)，还是在石炭纪前(Wang *et al.*, 2004a; Xia *et al.*, 2004b; 夏林圻等, 2002; 韩宝福等, 2004)。

达巴特矿区位于西天山赛里木湖北部。一些学者对其矿床成因、构造背景和成矿年代(王志良等, 2004, 2006; 王核和彭省临, 2000; 张作衡等, 2006)进行了研究，认为：(1)达巴特矿主要为铜钼矿床；(2)矿化或矿区岩浆岩的时代为海西中期；(3)矿床和区内岩浆岩的构造背景为阿拉套—科古琴晚古生代岛弧。达巴特矿区出露有许多岩浆岩，通过对其深入研究，有可能对深入了解金属矿床的成因和大地构造背景提供重要的启示。为此，我们近期对达巴特矿区的花岗斑岩体进行了系统的主量、微量元素分析，并对其进行了锆石 LA-ICP-MS U-Pb 同位素定年，发现达巴特花岗斑岩体形成于早二叠世，且显示了 A 型花岗岩的地球化学特征。本文将重点报道这一成果，并来探讨其形成的构造背景。

2 地质背景与岩相学

中国境内天山造山带以乌鲁木齐为界(东经 88°线)分为东天山和西天山。天山造山带分别以南天山和北天山两条晚古生代缝合线将其与塔里木和准噶尔两板块分开

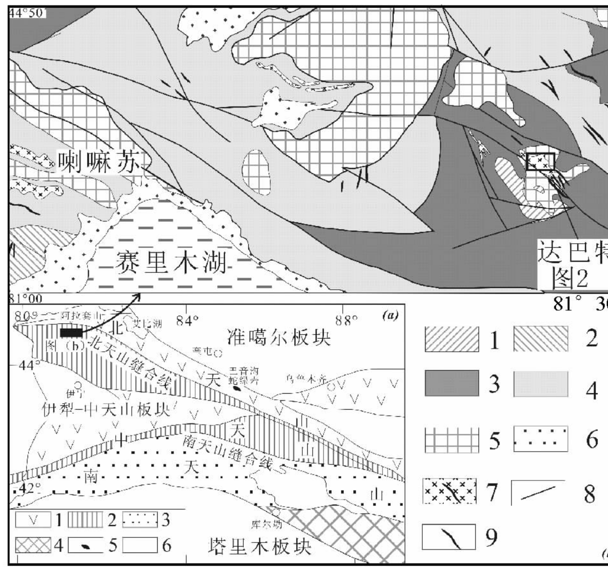

图 1 (a)天山地区大地构造简图(根据 Gao *et al.*, 1998 修改)，1-晚古生代火山岩或火山碎屑岩；2-前寒武基底、古生代花岗岩和地层；3-古生代沉积岩；4-前寒武角闪岩相岩石；5-蛇绿岩；6-中新生带地层；(b)西天山达巴特地区地质简图(根据新疆地矿局第一区调队 1992 年温泉幅 1-20 万地质图改绘)。1-下元古界温泉群，2-中元古界，3-泥盆纪，4-石炭纪，5-二叠纪，6-第四系，7-花岗岩类，8-断层；9-花岗质脉岩

Fig. 1 (a) Simplified geological map of the western Tianshan (modified after Gao *et al.*, 1998); (b) Regional geological sketch map of the Lamasu and Dabate areas, western Tianshan (modified after 1 : 20000 geological map of Wenquan by the Xinjiang Geological Survey Team in 1992

(Windley *et al.*, 1990)。达巴特矿区所在的赛里木湖—博罗科努地区位于伊犁中天山板块的北缘，北天山岛弧带和北天山缝合线的南侧(图 1a)。研究区附近的温泉、赛里木湖地区出露以花岗片麻岩和斜长角闪岩为主的古—中元古(2.1 ~1.7Ga)基底，古元古界的温泉群混合岩化片麻岩中锆石 U-Pb 年龄为 798 ± 8Ma 和 821 ± 11Ma (图 1b)(Hu *et al.*, 2000; 胡霭琴和等, 2001; 陈义兵等, 1999)。

达巴特矿区出露的地层主要为上泥盆统托斯库尔他乌组凝灰岩和凝灰质熔岩，中部出露一长约 2km、宽 120m ~ 500m 的酸性浅成侵入岩体，岩性为流纹质凝灰角砾岩、流纹斑岩、花岗斑岩以及超浅浅成英安斑岩，花岗斑岩和流纹质晶屑凝灰岩呈渐变过渡关系(图 2)。前人报道了达巴特矿区花岗斑岩和英安斑岩中的锆石 SHRIMP U-Pb 年龄分别为 317 ± 8Ma 和 315.9 ± 5.9Ma，但没有原始数据(王志良等,

2006）。矿体一般产于流纹质晶屑凝灰岩和角砾岩的接触带中，一般长 60m ~ 300m，宽 1m ~ 16m，呈细脉浸染状、脉状和透镜状产出（图 2）。辉钼矿 Re-Os 年龄为 301 ± 20Ma（张作衡等，2006）。达巴特英安斑岩在区内东南边出露较多（图 2）。

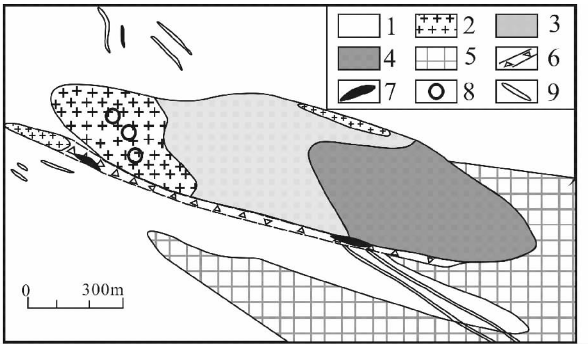

图 2 达巴特矿区地质简图（关明珍等①修改）

1-上泥盆系托斯库尔他乌组；2-花岗岩斑岩；3-流纹质质晶屑凝灰岩；4-流纹质质熔结凝灰岩；5-英安斑岩；6-破碎带；7-铜钼矿体；8-采样点；9-石英斑岩脉

Fig. 2 Geological sketch map of the Dabate copper deposit (after Guan *et al*.)

本文研究的重点是与矿化关系并不密切的花岗斑岩侵入体（图 2）。该侵入体侵入上泥盆系托斯库尔他乌组。花岗斑岩为土红色、砖红色，斑状结构、块状构造，斑晶占 10% ~15%，自形、半自形板状，成分为斜长石、石英、钾长石和少量黑云母，粒径 1mm ~ 3mm，基质 85% ~90%，主要成分为石英、钾长石、斜长石、次为少量黑云母，构成显微花岗结构。

3 分析方法

主、微量元素的分析测试均在中国科学院广州地球化学研究所同位素年代学和地球化学重点实验室完成。主量元素分析是用 Rigaku RIX 2000 型荧光光谱仪（XRF）分析，其详细步骤与 Li *et al*.（2005）所述相同。样品的含量由 36 种涵盖硅酸盐样品范围的参考标准物质双变量拟合的工作曲线确定，基体校正根据经验的 Traill-Lachance 程序进行，分析精度优于 1% ~5%。微量元素的分析则采用 Perkin-Elmer Sciex ELAN 6000 型电感耦合等离子体质谱仪（ICP-MS），具体的流程见 Li（1997）。使用 USGS 标准 W-2 和 G-2 及国内标准 GSR-1、GSR-2 和 GSR-3 来校正所测样品的元素含量，分析精度一般为 2% ~5%。分析数据列于表 1。

为精选锆石样品，先将新鲜的岩石样品粉碎至 120 目以下，用常规的人工淘洗和电磁选方法富集锆石，再在双目镜下用手工方法逐个精选锆石颗粒，未用任何化学试剂。本次锆石定年样品和主元素和微量元素分析的样品相对应。

表 1 达巴特花岗斑岩主量（wt%）、微量元素（$\times 10^{-6}$）组成

Table 1 Major element (wt%) and trace element ($\times 10^{-6}$) compositions of the Dabate granitic porphyries

	06-XJ-08	06XJ-10	06XJ-12	06XJ-13	06-XJ-14	06XJ-15
SiO_2	75.56	75.67	76.92	76.36	75.38	77.61
TiO_2	0.08	0.12	0.09	0.11	0.10	0.10
Al_2O_3	12.80	12.04	12.91	12.72	12.64	12.97
Fe_2O_3	1.16	1.14	0.95	1.28	1.17	0.97
MnO	0.002	0.002	0.003	0.004	0.004	0.003
MgO	0.05	0.05	0.01	0.01	0.06	0.01
CaO	0.03	0.03	0.28	0.34	0.42	0.31
Na_2O	2.47	1.39	3.00	3.56	4.06	3.27
K_2O	7.63	8.08	5.27	5.14	4.92	5.21
P_2O_5	0.01	0.01	0.01	0.01	0.01	0.00
LOI	0.62	0.88	0.79	0.87	0.79	0.00
Total	100.40	99.41	100.21	100.40	99.54	100.14
Sc	0.121	0.0450	2.19	0.0420	0.849	0.137
V	9.09	15.6	3.95	7.98	19.6	7.36
Cr	4.20	8.43	15.6	2.51	7.25	12.2
Co	0.424	0.768	0.518	0.625	0.452	0.652
Ni	1.41	2.63	3.06	2.09	1.83	7.61
Ga	20.8	19.8	21.8	22.8	25.2	23.2
Cs	20.0	18.4	15.3	14.5	17.2	18.6
Rb	316	357	265	264	286	287
Ba	110	209	144	150	107	109
Th	15.4	13.0	20.2	15.3	18.7	12.5
U	3.72	2.92	3.38	2.38	2.50	7.44
Nb	25.2	20.6	24.8	25.6	27.5	24.2
Ta	2.29	1.82	2.18	2.04	2.28	2.10
Sr	35.1	29.3	22.8	27.1	18.6	17.9
Y	40.8	29.6	57.3	52.7	58.7	51.5
Zr	91.6	101	140	128	142	121
Hf	4.08	4.05	5.81	5.29	5.83	5.29
La	8.17	6.63	19.1	15.9	18.8	13.3
Ce	22.5	17.3	46.7	37.4	43.9	31.7
Pb	9.52	6.15	10.1	9.80	14.4	12.5
Pr	3.23	2.40	6.20	4.90	6.04	4.22
Nd	13.6	10.5	23.6	18.5	23.1	15.9
Sm	4.86	3.35	6.65	5.12	6.42	4.64
Eu	0.145	0.154	0.268	0.211	0.225	0.199
Gd	5.26	3.48	7.84	6.08	7.37	5.97
Tb	1.11	0.710	1.61	1.38	1.59	1.39
Dy	6.76	4.44	10.1	8.70	9.62	8.74
Ho	1.39	0.923	2.11	1.78	2.07	1.86
Er	3.74	2.64	5.94	5.06	5.76	5.28
Tm	0.575	0.428	0.919	0.729	0.873	0.787
Yb	3.67	2.73	5.80	4.78	5.47	4.87
Lu	0.517	0.409	0.887	0.687	0.788	0.720

① 关明珍等．新疆赛里木湖铜多金属成矿带地物化探综合研究及靶区优选．新疆 305 项目 N7-1 课题

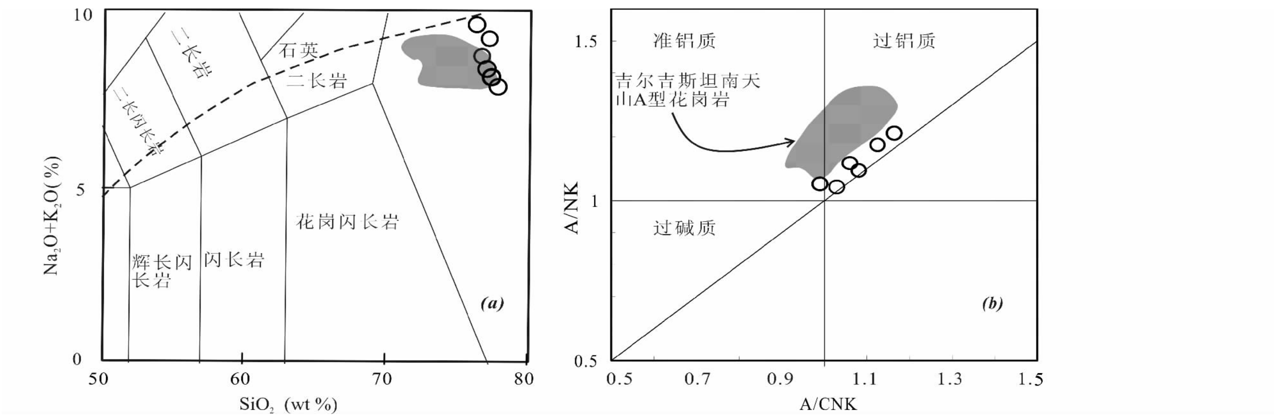

图 3 TAS (a) (Middlemost, 1994) 和 A/CNK-A/NK 图解(b),(A/CNK = molar [Al_2O_3/($CaO + Na_2O + K_2O$)]; A/NK = molar Al_2O_3/(Na_2O + K_2O)) 吉尔吉斯坦南天山 A 型花岗岩来源于(Konopelko *et al.*, 2007)

Fig. 3 TAS (a) and A/CNK-A/NK (b) digrams for the Dabate granite porphyries

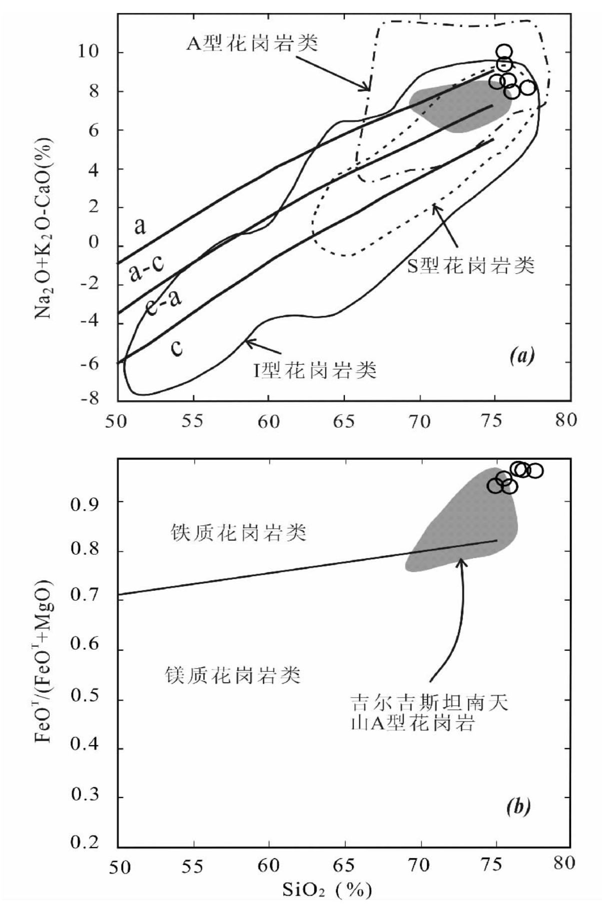

图 4 (a) (Na_2O + K_2O)-(CaO)-SiO_2% 和 (b) (FeO^T)/(FeO^T + MgO)-SiO_2% 图(据 Frost *et al.*, 2001) 吉尔吉斯坦南天山 A 型花岗岩来源于(Konopelko *et al.*, 2007), c-钙性花岗岩类; c-a-钙碱性花岗岩类; a-c-碱钙性花岗岩类; a-碱性花岗类

Fig. 4 (a) ($Na_2O + K_2O$)-(CaO)-SiO_2% and (FeO^T)/(FeO^T + MgO)-SiO_2% (after Frost *et al.*, 2001)

锆石阴极发光图像研究在中国科学院广州地球化学研究所 JXA-8100 电子探针仪上完成。锆石 LA-ICP-MS U-Pb 年龄测定在中国地质大学(武汉)地质过程与矿产资源国家重点实验室完成。ICP-MS 为 Perkin Elmer/SCIEX 公司带有动态反应池的四极杆 ICP-MS Elan6100DRC,仪器依标准模式运行,激光剥蚀系统为德国 Lamda Physik 公司的 GeoLas 200M 深紫外(DUV) 193nm ArF 准分子(excimer)激光剥蚀系统。实验中采用 He 作为剥蚀物质的载气,激光斑束直径为 32μm。参考物质为美国国家标准技术协会研制的人工合成硅酸盐玻璃 NIST SRM610,锆石 U-Pb 年龄的测定采用国际标准锆石 91500 作为外标校正方法,每隔 5 个分析点测一次标准,保证标准和样品的仪器条件完全一致。在样品分析前后以及每隔 20 个测点各测一次 NIST SRM610,以 Si 做内标,测定锆石中的 U, Th, Pb 的含量。详细的分析流程及有关参数见(Yuan *et al.*, 2004)。元素的比率和元素的含量用 GLITTER(4.0 版)来处理,年龄的计算和谐和图用 ISOPLOT (3.00 版)(Ludwig, 2003)来完成。分析数据列于表 2。

4 花岗斑岩的元素地球化学特征

达巴特花岗斑岩高硅,SiO_2 含量变化范围小(75.38% ~ 77.61%),Al_2O_3 含量为 12.04% ~12.91%, $K_2O + Na_2O$ 含量为 8.26% ~ 10.10%, K_2O/Na_2O 为 1.2 ~ 5.8。在 TAS 图解(图 3a)中岩石样品落入花岗岩区,并落入亚碱性区,弱过铝质,铝饱和指数 A/CNK 为 0.99 ~1.12(图 3b)。花岗斑岩具有高的 Fe/(Fe + Mg),约 0.98,根据 Frost *et al.* (2001) 的花岗岩分类,岩石样品落在铁质范围和钙碱性内(图 4)。达巴特花岗斑岩富集高场强元素(Zr、Hf、Nb、Ta、重稀土元素和大离子亲石头(U、Th),稀土元素轻重稀土无分馏,配分模式呈海鸥状(图 5a),$(La/Yb)_N$ 为 2.3 ~2.5,具有明显的负 Eu、Ba、Sr 异常和 Nb 正异常(图 5b)。

表 2　达巴特花岗岩岩锆石 LA-ICPMS 分析结果

Table 2　Zircon LA-ICPMS analyzing results for the granitic porphyries in the Dabate areas

分析点号	元素含量(×10⁻⁶)		元素比值	同位素比值						表观年龄(Ma)					
	Th^{232}	U^{238}	U/Th	$^{207}Pb/^{206}Pb$	1σ	$^{207}Pb/^{235}U$	1σ	$^{206}Pb/^{238}U$	1σ	$^{207}Pb/^{206}Pb$	1σ	$^{207}Pb/^{235}U$	1σ	$^{206}Pb/^{238}U$	1σ
06XJ013-1	61	105	1. 72	0. 05397	0. 00238	0. 37540	0. 01586	0. 05045	0. 00064	370	102	324	12	317	4
06XJ013-2	193	358	1. 86	0. 07118	0. 00116	0. 45377	0. 00749	0. 04623	0. 00052	963	17	380	5	291	3
06XJ013-3	146	290	1. 99	0. 05402	0. 00166	0. 34298	0. 00980	0. 04604	0. 00053	372	71	299	7	290	3
06XJ013-4	302	509	1. 69	0. 05359	0. 00072	0. 34155	0. 00473	0. 04622	0. 00051	354	14	298	4	291	3
06XJ013-5	29	61	2. 08	0. 05311	0. 00138	0. 33785	0. 00873	0. 04614	0. 00056	333	37	296	7	291	3
06XJ013-6	79	155	1. 96	0. 05310	0. 00196	0. 37170	0. 01301	0. 05077	0. 00061	333	86	321	10	319	4
06XJ013-7	50	175	3. 51	0. 05339	0. 00099	0. 33923	0. 00633	0. 04609	0. 00052	345	23	297	5	290	3
06XJ013-8	356	677	1. 90	0. 05327	0. 00077	0. 33625	0. 00501	0. 04578	0. 00050	340	16	294	4	289	3
06XJ013-9	324	545	1. 68	0. 05314	0. 00070	0. 34021	0. 00466	0. 04643	0. 00051	335	14	297	4	293	3
06XJ013-10	455	615	1. 35	0. 06762	0. 00272	0. 41114	0. 01572	0. 04410	0. 00055	857	86	350	11	278	3
06XJ013-11	106	190	1. 79	0. 05341	0. 00107	0. 37410	0. 00751	0. 05079	0. 00058	346	25	323	6	319	4
06XJ013-12	137	221	1. 61	0. 05675	0. 00093	0. 36120	0. 00599	0. 04616	0. 00051	482	19	313	4	291	3
06XJ013-13	256	317	1. 24	0. 05244	0. 00077	0. 33593	0. 00504	0. 04646	0. 00051	305	16	294	4	293	3
06XJ013-14	850	1616	1. 90	0. 06358	0. 00600	0. 33191	0. 03097	0. 03786	0. 00054	728	208	291	24	240	3
06XJ013-15	65	169	2. 61	0. 05196	0. 00094	0. 33400	0. 00612	0. 04662	0. 00053	284	22	293	5	294	3
06XJ013-16	89	167	1. 88	0. 05841	0. 00238	0. 35907	0. 01394	0. 04458	0. 00056	545	91	312	10	281	3
06XJ013-17	645	1253	1. 94	0. 06261	0. 00092	0. 36572	0. 00551	0. 04236	0. 00047	695	15	316	4	267	3
06XJ013-18	139	499	3. 59	0. 05614	0. 00079	0. 39290	0. 00569	0. 05075	0. 00056	458	15	336	4	319	3
06XJ013-19	669	663	0. 99	0. 06496	0. 00090	0. 40648	0. 00580	0. 04538	0. 00050	773	14	346	4	286	3
06XJ013-20	290	460	1. 59	0. 05735	0. 00200	0. 35351	0. 01162	0. 04470	0. 00052	505	79	307	9	282	3
06XJ013-22	199	414	2. 08	0. 06178	0. 00091	0. 39809	0. 00600	0. 04673	0. 00052	667	15	340	4	294	3
06XJ013-23	349	644	1. 84	0. 05353	0. 00078	0. 34120	0. 00509	0. 04622	0. 00051	351	16	298	4	291	3
06XJ013-24	178	365	2. 05	0. 05154	0. 00161	0. 32488	0. 00942	0. 04572	0. 00053	265	73	286	7	288	3
06XJ013-25	139	383	2. 76	0. 05433	0. 00080	0. 34127	0. 00515	0. 04556	0. 00050	385	16	298	4	287	3

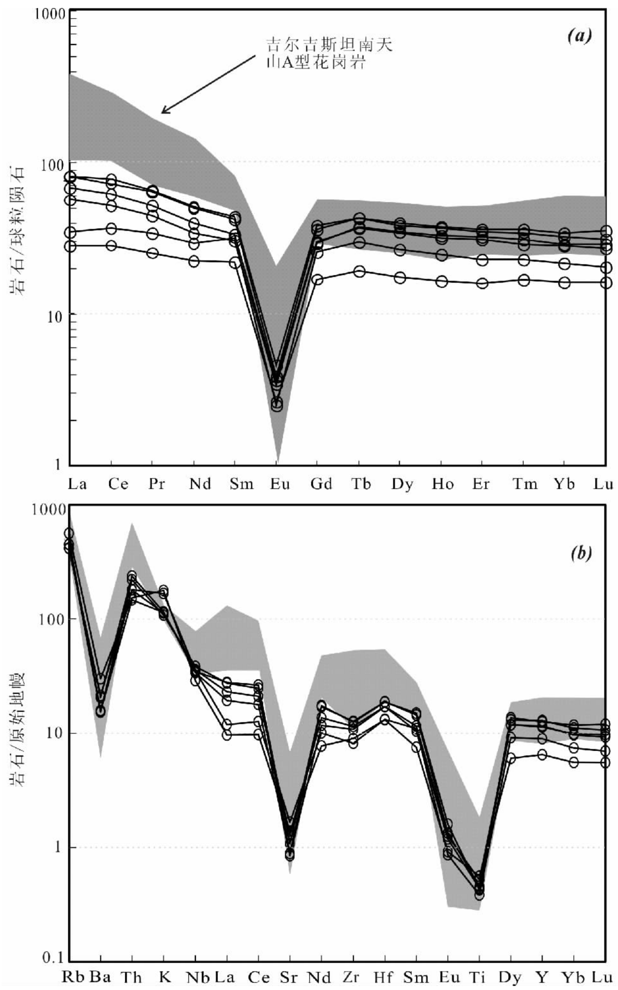

图 5 稀土元素球粒陨石标准化配图(a)和微量元素 NMORB 标准化蛛网图(b)(标准值据(Sun and McDonough, 1989))

吉尔吉斯坦南天山 A 型花岗岩来源于(Konopelko *et al.*, 2007)

Fig. 5 The chondrite-normalized rare earth element (REE) patterns (a) and primitive mantle-normalized multi-element plots (b) (normalized values from (Sun and McDonough, 1989))

5 锆石 LA-ICPMS U-Pb 定年

达巴特花岗斑岩样品 06XJ-013 的绝大多数的锆石呈棱柱状,长约 40μm ~ 130μm,长宽比在 1∶1.5 ~ 3∶1,少量呈浑圆状。阴极发光图像(图 6)显示发育有清晰的韵律结构,为典型的岩浆锆石。锆石的的 U、Th 含量较高,分别可达 1616×10^{-6} 和 850×10^{-6}。锆石具有比较均一的 U/Th 比(0.9 ~ 2.7),大部分在 1 ~ 2 之间,为典型的岩浆锆石。24 个分析点中有 18 个在 278 ~ 294Ma 之间(图 6),其加权平均值为 288.9 ± 2.3Ma,其中有几个点偏离谐和线,这可能是由于不同程度的普通 Pb 的贡献,或者是结晶后 U 和 Pb 同位素的

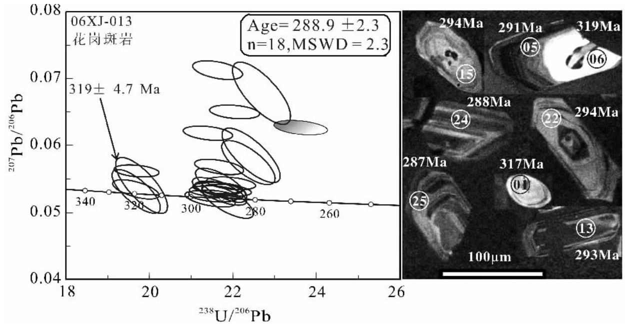

图 6 06XJ-013 U-Pb 年龄谐和图和锆石阴极发光图像

Fig. 6 Concordia diagram showing LA-ICPMS analytical points for zircons from the Dabate granite porphyries and CL images

增加或丢失,这种不一致往往是由于测量时 ^{207}Pb 偏高,但当锆石年龄小于 1000Ma 时一般不影响 $^{206}Pb/^{238}U$ 年龄。另有 4 个分析点落在 320Ma 的谐和线附近,其加权平均值为 319.0 ± 4.7Ma,这组锆石的形态和其它锆石明显不同,或出现于锆石核部(边部时代为 ~290Ma)或呈现出浑圆状,我们把它解释为石炭纪火山岩的捕获晶或花岗斑岩的源岩锆石熔蚀后的残留体(后面详细讨论)。还有两个分析点(14.17)明显偏离谐和线并小于 280Ma,可能反映了锆石在形成过程中有 Pb 丢失。

6 讨论

6.1 形成时代

前人曾对达巴特花岗斑岩和英安斑岩进行了 SHRIMP 锆石 U-Pb 定年,结果分别为 317 ± 8Ma 和 315.9 ± 5.9Ma(无原始数据)(王志良等, 2006; 张作衡等, 2006),这和我们本次定年结果中年龄较老的年龄为 319.0 ± 4.7Ma 一组数据相一致。结合锆石 CL 图像(图 6)可以看出,319Ma 这一组数据的锆石或者为锆石的核部,或者是那些韵律结构模糊并呈现出浑圆状的锆石,如同一颗锆石中核部年龄为 319Ma,边部年龄为 291Ma。因此,我们认为晚石炭世(317 ~ 319Ma)年龄很可能是来自晚石炭世火成岩锆石捕获晶或花岗斑岩源岩锆石熔蚀后的残留体,并且后一种可能性更大。早二叠世(~289Ma)的锆石均为棱柱状,晶型较好,CL 图像中显示有清晰的韵律环带,U/Th 为 0.9 ~ 2.7,为典型的岩浆锆石,所以该组年龄代表了岩体的结晶年龄。该地区广泛发育晚石炭世—二叠世岩浆岩:博罗科努山闪长岩 SHRIMP 锆石 U-Pb年龄为 308.2 ± 5.4Ma(朱志新等, 2006),辉石闪长岩 LA-ICP-MS 锆石 U-Pb 年龄为 301 ± 7Ma,黑云母花岗岩年龄范围为 294 ± 7 ~ 285 ± 7Ma,黑云母钾长花岗岩形成于 280 ± 5 ~ 266 ± 6Ma(王博等, 2007),玉希莫洛盖达坂花岗闪长岩 LA-ICP-MS 锆石 U-Pb 年龄为 315 ± 3Ma 和 309 ± 3Ma(Wang *et al.*, 2006a),哈希勒根达坂黑云母花岗岩 TIMS 锆石 U-Pb

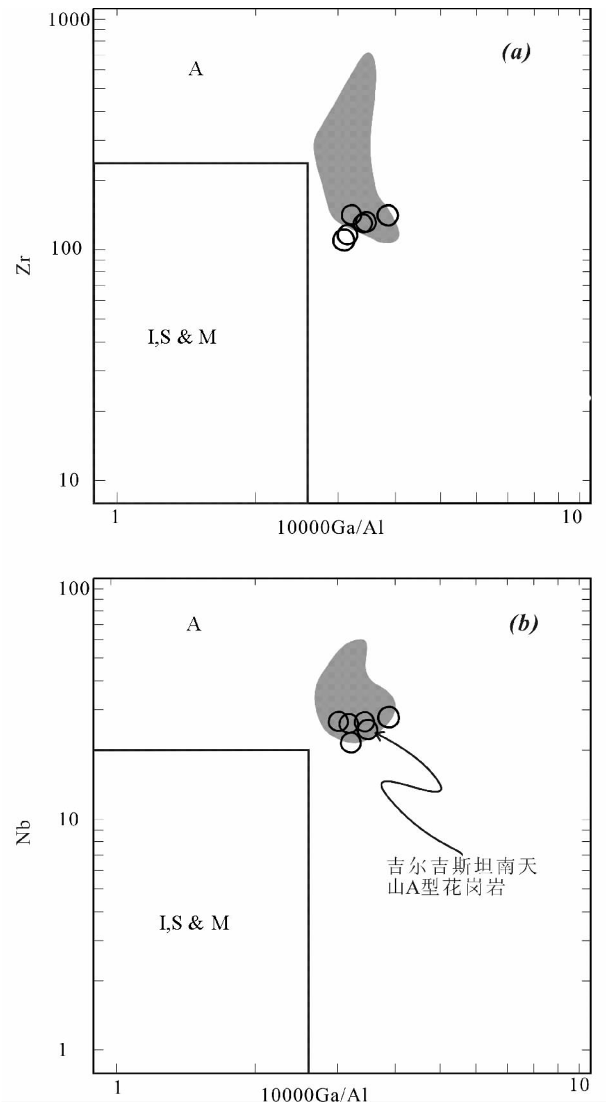

图7　达巴特花岗斑岩10000×Ga/Al对Zr(a)和Nb(b)图解(据(Whalen *et al.*，1987))

吉尔吉斯坦南天山A型花岗岩来源于(Konopelko *et al.*，2007)，I，S & M-未分异的I,S和M型花岗岩,A-A型花岗岩

Fig. 7　10000×Ga/Al versus Zr (a) and Nb (b) digrams for the Dabate granite porphyries (after Whalen *et al.*, 1987)

年龄为286.8±0.8Ma(徐学义等，2006c)。因此,西天山伊犁板块北缘的岩浆岩主要形成于晚古生代,而达巴特岩体形成于古生代晚期的早二叠世。

6.2　岩石类型与成因

达巴特花岗斑岩具有A型花岗岩的特点：(1)富硅、富碱,贫镁,具有高的Fe/(Fe+Mg)；(2)富集Rb、Th、U等大离子亲石元素和Nb、Ta、Zr、Hf等高场强元素,亏损Sr、Ba(图5b),富Ga(图7),$(Ga/Al)\times10^4$ 值变化于3.19~3.40

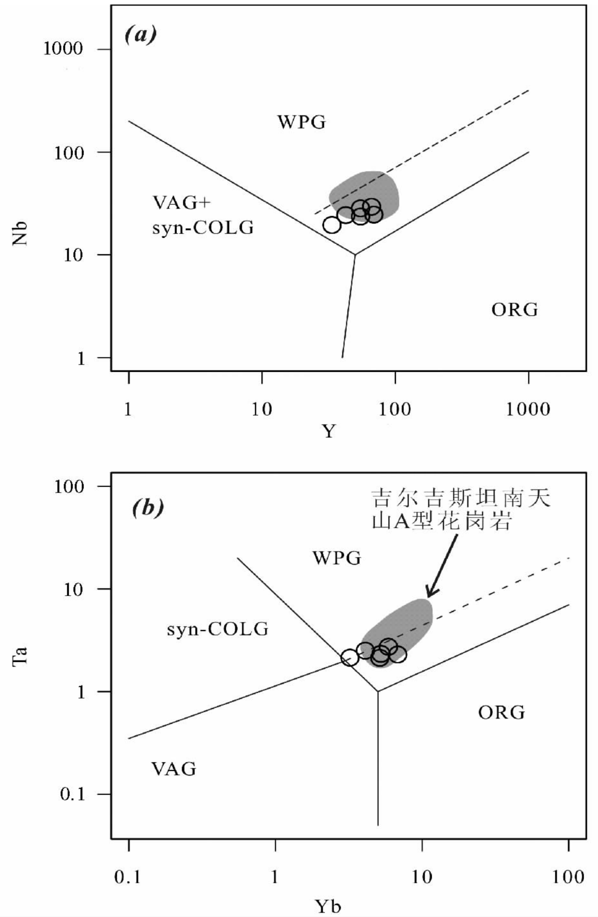

图8　达巴特斑岩Y-Nb (a) 和Yb-Ta (b) 构造环境判别图解(据Pearce *et al.*，1984)

吉尔吉斯坦南天山A型花岗岩来源于(Konopelko *et al.*，2007)，syn-COLG-同碰撞型；VAG-火山弧型；WPG-板块内部型；ORG-洋中脊型

Fig. 8　Y-Nb (a) and Yb-Ta (b) tectonic discriminat-ondiscrimination digrams for the Dabate granite porphyry porphyries (after Pearce *et al.*, 1984)

之间。在Whalen *et al.* (1987)以10 000×Ga/A1比值为标准的花岗岩分类图上,花岗斑岩投影在A型花岗岩区(图7),与铝质A型花岗岩相一致(图3b)(King *et al.*，1997),和吉尔吉斯坦南天山早二叠世(280 ~ 296Ma) A-型花岗岩(Konopelko *et al.*，2007)相似(图3,4,6,7,8,9)。高硅的铝质A型花岗岩经常与高分异的I型花岗岩表现出相似的特点(King *et al.*，1997),二者很难区分(吴福元等,2007)。但达巴特花岗斑岩很可能是A型花岗岩而不是高分异的I型花岗岩：如高分异的I型花岗岩的形成温度为764℃(King *et al.*，1997),而达巴特花岗岩斑岩的锆石饱和温度为783 ~ 822℃；高分异的I型花岗岩的FeO的含量含量往往较低(~0.5%),而达巴特A型花岗岩的FeO的含量较高(0.85 ~1.04%)。在Y-Nb和Yb-Ta判别图(图8)中,同典型A型花岗岩一样,达巴特花岗斑岩落入板内花岗岩区。Eby

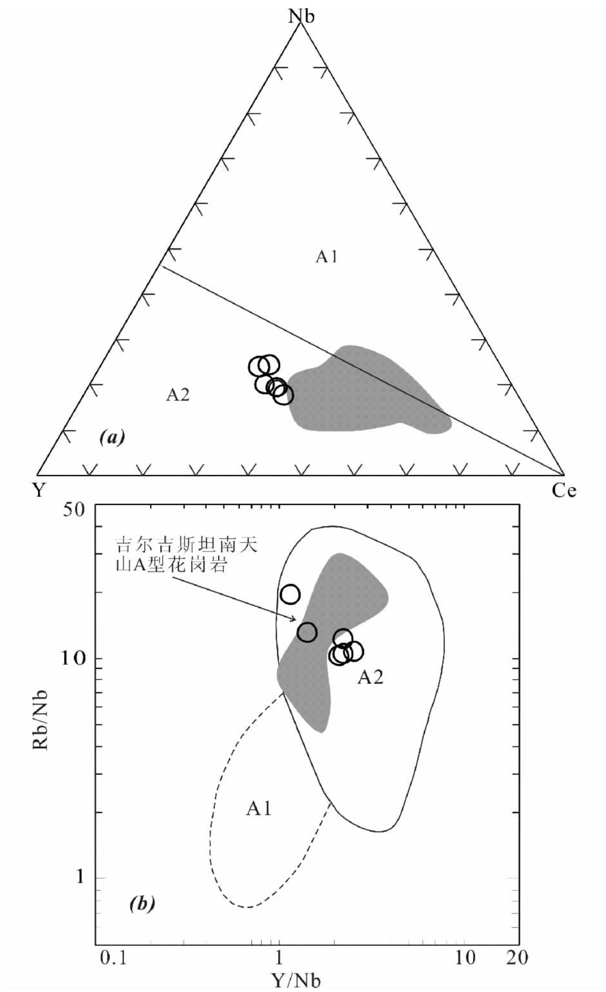

图9 达巴特花岗斑岩 Y-Nb-Ce（a）和 Rb/Nb-Y/Nb（b）图解(据 Eby, 1992)

吉尔吉斯坦南天山 A 型花岗岩来源于(Konopelko *et al.*, 2007)

Fig.9 Y-Nb-Ce (a) and Rb/Nb-Y/Nb (b) digrams for the Dabate granite porphyries (after Eby, 1992)

(1992)根据地球化学特征将 A 型花岗岩分为 A_1 和 A_2 型，并认为 A_1 型是地幔来源，且侵位于大陆裂谷或板内的构造环境，A_2 型来源于大陆地壳或板内下地壳，主要形成于后碰撞环境。达巴特花岗斑岩在 Y-Nb-Ce 和 Y/Nb-Rb/Nb 判别图中均投影于 A_2 区(图9)。

前人对于 A 型花岗岩的成因提出了许多模式：(1)地幔玄武质岩浆高度结晶分异(Beyth *et al.*, 1994; Han *et al.*, 1997; Mushkin *et al.*, 2003; Turner *et al.*, 1992)；(2)各种源岩的部分熔融，如麻粒岩相岩石(Clemens *et al.*, 1986; Collins *et al.*, 1982; King *et al.*, 1997; Whalen *et al.*, 1987)、英云闪长岩-花岗闪长岩(Creaser *et al.*, 1991)和紫苏花岗岩(Landenberger and Collins, 1996)、新生玄武质地壳(Wu *et al.*, 2002)；(3)幔源物质和壳源物质混合(Konopelko *et al.*, 2007; Mingram *et al.*, 2000; Yang *et al.*, 2006a; 邱检生等, 1999)；(4)上地壳钙碱性岩石低压熔融(Patino Douce, 1997)。由于还缺乏详细的 Sr-Nd 同位素资料，我们还不能对达巴特花岗斑岩的源岩或成因模式进行准确的限制。但是达巴特花岗斑岩并不与同期玄武质岩石密切共生，因此我们认为其由地幔玄武质岩浆高度结晶分异形成的可能性较小。此外，达巴特花岗斑岩中存在的晚石炭世(319.0±4.7Ma)的熔蚀残留锆石核，暗示其源区很可能与晚石炭世事件有关。由于石炭纪可能是天山北部地区重要的岛弧岩浆活动时期(Wang *et al.*, 2007b; 王强等, 2006)，如博罗科努、玉希莫洛盖达坂等岩体均为石炭纪岩浆(Wang *et al.*, 2006a; 朱志新等, 2006)。因此斑岩中存在的晚石炭世(319.0±4.7Ma)的年龄可能暗示达巴特斑岩的源岩中包含石炭纪的岛弧岩浆岩。在早二叠世，西天山北部很可能已经进入碰撞后伸展阶段，达巴特花岗斑岩可能是在早二叠世后碰撞岩石圈伸展的背景下形成：岩石圈伸展促使软流圈上涌并加热中下地壳物质，导致石炭纪底侵的岛弧岩浆岩发生熔融形成 A 型花岗岩。这与典型 A_2 型花岗岩的形成模式(Eby, 1992)比较一致。

6.3 动力学意义

中国境内天山造山带以乌鲁木齐为界(东经 88°线)分为东天山和西天山。天山造山带分别以南天山和北天山两条晚古生代缝合线将其与塔里木和准噶尔两板块分开(图1a)(Windley *et al.*, 1990)。南天山缝合线为位于塔里木板块和伊犁中天山板块之间的古南天山洋俯冲于伊犁中天山板块的缝合线，一般认为其在早石炭世闭合(Allen *et al.*, 1993; Carroll *et al.*, 1995; Coleman, 1989; Gao *et al.*, 1998; 高俊等, 2006)，但也有学者认为闭合在石炭世之前(Xia *et al.*, 2004b)或三叠纪(Zhang *et al.*, 2007a, 2007b)，北天山缝合线为准噶尔洋(又称北天山洋)向南俯冲于伊犁中天山板块的缝合线，一般认为闭合于早石炭世或晚石炭世(Allen *et al.*, 1993; Carroll *et al.*, 1995; Coleman, 1989; Gao *et al.*, 1998; Wang *et al.*, 2007b)。北天山和南天山主要由活动增生带、大陆边缘和岛弧组成等组成(Gao *et al.*, 1995, 1998)，中天山主要有各种变质岩和深海和浅海沉积物(Xiao *et al.*, 2008)。

天山造山带是在晚古生代由准噶尔、伊犁中天山和塔里木板块碰撞作用而形成(Gao *et al.*, 1998)。许多学者认为准噶尔洋从奥陶世(龙灵利, 2007)、晚泥盆世(Wang *et al.*, 2006a)、或晚石炭世早期(Wang *et al.*, 2007b)向南俯冲于伊犁中天山板块之下，于晚石炭世闭合(Allen *et al.*, 1993; Carroll *et al.*, 1995; Coleman, 1989; Wang *et al.*, 2007b)。其中西天山北部的岩浆岩主要形成于古生代，在 370～260Ma 之间(图10)，其中分别主要集中在 370～350Ma 和 320～280Ma 两个时间段，其中后者又分为 320～300Ma 和 300～280Ma 两个阶段，所以西天山北部泥盆纪—二叠纪岩浆岩可以分为三期，即晚泥盆世—早石炭世、晚石炭世和早二叠世。其中晚泥盆世—早石炭世形成的如莱历斯高尔岩

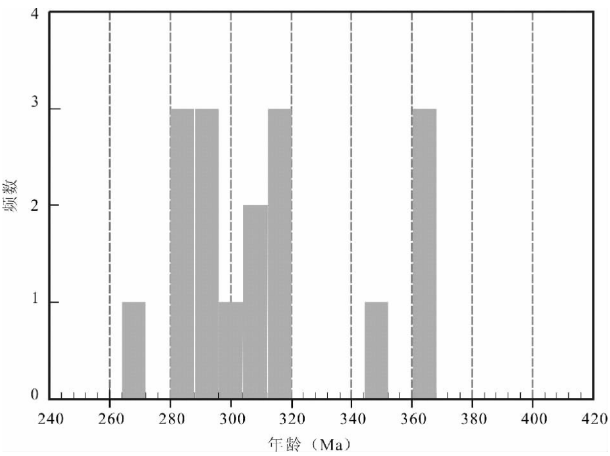

图10 西天山伊犁中天山板块北缘岩浆岩年龄统计图
数据来源于（Wang *et al.*, 2006a; Zhao *et al.*, 2008; 王志良等, 2006; 王博等, 2007; 朱志新等, 2006; 李华芹等, 2006; 唐功建等, 2008; 徐学义等, 2006c; 翟伟等, 2006）

Fig. 10 Age histograms for the igneous rocks in the northern margin of the Yili-central Tianshan Plate

体（李华芹等,2006）；晚石炭世之间形成的如博罗科努山岩体（Wang *et al.*, 2006a; 朱志新等,2006）；早二叠世形成的岩体如达巴特岩体，哈希勒根达坂岩体（徐学义等,2006c）。前两期花岗岩类都具有岛弧或活动大陆边缘型花岗岩类的特点，可能与准噶尔洋的俯冲消减有关，形成于大陆弧或岛弧环境。我们最近发现达巴特以西的40km的喇嘛苏斑岩形成于晚泥盆世（366.3±1.9Ma），且与俯冲洋壳熔融形成的埃达克岩非常类似（唐功建等, 2008），也进一步证实了该区晚泥盆世为岛弧环境。此外，西天山北部的巴音沟蛇绿岩中堆晶辉长岩LA-ICP-MS锆石U-Pb年龄为344.0±3.4Ma（徐学义等, 2006a），侵位于辉长岩中的斜长花岗岩SHRIMP锆石U-Pb年龄为324.7±7.1Ma（徐学义等,2006b），表明该蛇绿岩形成于早石炭世。最近的研究表明，在天山北部地区也存在石炭纪的洋壳俯冲和熔融作用，并且形成了典型的岛弧岩浆岩组合埃达克岩—高镁安山岩—富Nb玄武岩组合（Wang *et al.*, 2007b; 王强等,2006）。所以晚石炭世的岩浆岩可能是由石炭纪北天山洋（准噶尔洋）向南俯冲到伊犁中天山板块作用形成的。早二叠世岩浆岩可能是在石炭纪北天山洋（准噶尔洋）闭合碰撞后的伸展背景下形成的。由于A型花岗岩多形成于拉张伸展的构造环境，并经常出现在非造山或碰撞后伸展阶段（Black *et al.*, 1993; Clemens *et al.*, 1986; Eby, 1990, 1992; Whalen *et al.*, 1987; Wu *et al.*, 2002），所以达巴特A型花岗岩的出现标志着西天山伊犁中天山板块北缘的造山带可能已经进入在早二叠世进入伸展阶段，很可能与造山带后碰撞的演化有关。本文报道的达巴特A型花岗岩的早二叠世的侵位年龄（288.9±2.3Ma）晚于准噶尔洋晚石炭世闭合的时限，除了达巴特A型花岗岩外，还有许多证据说明早二叠世伊犁中天山板块北缘的造山带已经进入伸展阶段，并可能与造山带后碰撞的演化有关：（1）被认为是后碰撞造山环境下哈希勒根达坂的黑云母花岗岩形成时代为286.8Ma±0.8（徐学义等,2006c），吉尔吉斯坦南天山的A型花岗岩的形成时代也形成于早二叠世（280～296Ma）（Konopelko *et al.*, 2007）；（2）在天山地区二叠世也出现了双峰式火山岩（车自成等, 1994）以及陆相磨拉石堆积（龙灵利, 2007）等；（3）塔里木西部的小海子正长岩（A型花岗岩）的SHRIMP锆石U-Pb年龄为277±4Ma（Yang *et al.*, 2007; 杨树锋等, 2006）。

7 结论

（1）达巴特岩体侵位于288.9±2.3Ma，为早二叠世岩体。

（2）达巴特花岗岩斑岩具有A（A_2）型花岗岩的特点，可能是石炭纪底侵于中下地壳中的岩浆岩在伸展的条件下熔融形成。

（3）西天山伊犁中天山板块北缘的造山带在早二叠世为伸展环境，可能与造山带后碰撞的伸展有关。

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