中国阿尔泰早古生代后碰撞花岗岩的发现及其地质意义*

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Abstract Baihaba intrusion, located in Habahe County, Xinjiang Province, is mainly composed of biotite plagiogranite, and minor granodiorite. Baihaba rocks with higher SiO_2 and K_2O contents can be classified as high-K calc-alkaline series rock and considered as weakly per-aluminous rocks (SiO_2: 65.58% ~ 65.79%, Na_2O/CaO: 1.73 ~ 3.43, Shand index ≤ 1.05). The intrusion is characterized by high REE abundance($\sum REE = 174.1 \times 10^{-6} \sim 210.6 \times 10^{-6}$), strong negative Eu anomalies($\delta Eu = 0.54 \sim 0.63$), medium REE fractionation [$(La/Yb)_N = 4.46 \sim 5.56$], enrichments in Rb, Th, U, K, La, Ce, Nd, Hf, Zr and Sm, but strong depletions of Ba, Nb, Ta, Sr, P and Ti. These characteristics of major, REE and trace elements indicate that the intrusion was formed in a transitional tectonic setting from compression to extensional regime, which can be classified as post-collisional granitoids. SHRIMP U-Pb zircon analyses yield ages of 413.8 ± 6.4Ma. The discovery of Early Paleozoic post-collisional granites in Altay supports the presence of Altay-Mongolia microcontinent.

Key words Post-collisional granite; SHRIMP U-Pb dating; Geochemistry; Altay; Xinjiang

摘 要 新疆哈巴河县白哈巴岩体主要岩石类型为黑云母斜长花岗岩,另有少量花岗闪长岩。SiO_2 含量介于 65.58% ~ 65.79%之间,A/CNK≤1.05,为弱过铝质岩石,属高钾钙碱性系列。稀土元素总量为 $174.1 \times 10^{-6} \sim 210.6 \times 10^{-6}$,具明显的 Eu 负异常(0.54 ~ 0.63),稀土元素分馏中等($(La/Yb)_N$ 值为 4.46 ~ 5.56),稀土配分曲线为轻稀土富集型,富集 Rb,Th,U,K,La,Ce,Nd,Hf,Zr 和 Sm 等元素,而强烈亏损 Ba,Nb,Ta,Sr,P 和 Ti 等元素。主量元素、稀土元素和微量元素特征表明,白哈巴岩体形成于挤压体制向拉张体制转换的构造环境,属后碰撞花岗岩类。SHRIMP 锆石 U-Pb 年龄为 413.8 ± 6.4Ma。白哈巴岩体后碰撞花岗岩的发现,支持阿尔泰-蒙古微大陆的存在,丰富了对新疆北部构造演化的认识。

关键词 后碰撞花岗岩;SHRIMP U-Pb 年龄;地球化学;阿尔泰;新疆

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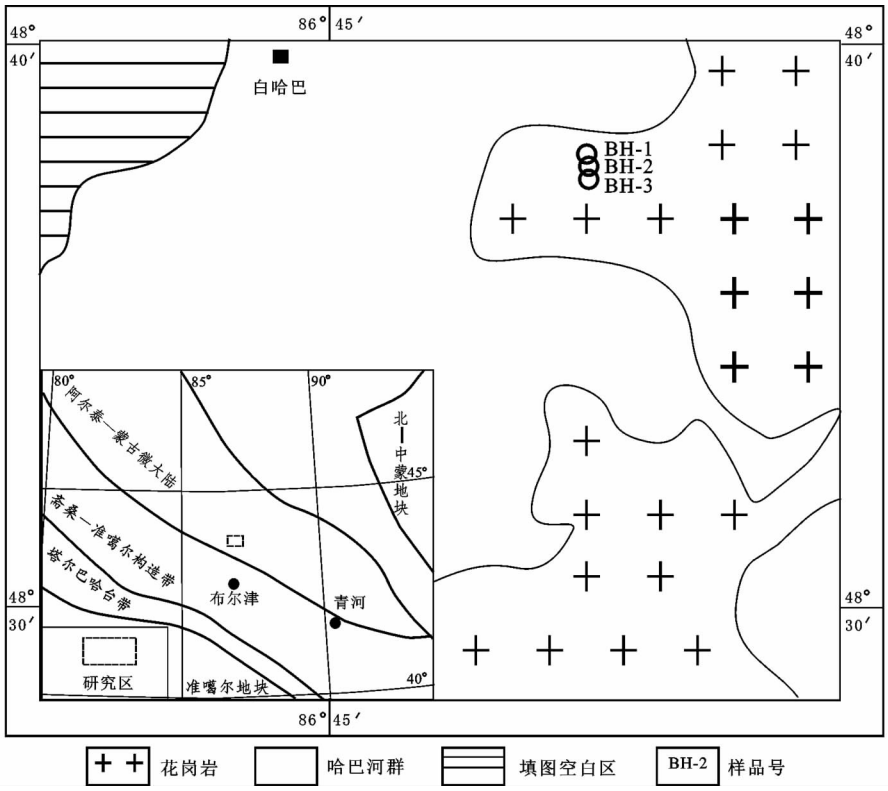


图 1 白哈巴及邻近区域地质简图

Fig. 1 Sketch geological map of Baihaba and adjacent area

1 区域地质特征

中国阿尔泰是目前新疆自治区地质研究程度较高、矿产资源十分丰富的地区,与哈萨克斯坦和蒙古阿尔泰在地质构造上为一个整体,具有类似的成矿地质条件和良好的成矿前景。阿尔泰地区是新疆亦是全国重要的有色金属、贵金属、稀有金属成矿带,如可可托海稀有金属白云母伟晶岩矿床闻名于世,阿舍勒铜矿床、喀拉通克铜镍矿床、可可塔勒铅锌矿床、蒙库铁矿床等均是国内有名矿床。由于该区矿产资源潜力巨大,正确地解释其构造演化过程无疑有助于矿产资源的探查。

阿尔泰地区自前寒武纪以来发生了多期次的构造-岩浆事件,形成了大面积花岗岩,这些花岗质岩体是研究阿尔泰地区显生宙以来构造演化、地壳增生和造山作用的重要对象(王广耀和许培春,1983;邹天人等,1988;刘伟,1990,1993;赵振华等,1993;王中刚等,1998;袁峰等,2001;Wang *et al.*, 2006,2007;Zhu *et al.*,2006;Yuan *et al.*,2007)。然而,由于以往所做的同位素年龄测定在方法、对象还是样品代表性上均存在较大的局限性(张湘炳等,1996),致使所获得的花岗岩类年龄数据跨度大,精确度不高,甚至有些结果并不代表岩体的侵位年龄,这在一定程度上制约了对阿尔泰地区构造环境、构造演化、造山作用及地壳增生的进一步认识。近年来,对阿尔泰花岗质类岩石的锆石 SHRIMP U-Pb 方法精确定年(王涛等,2005;袁超等,2005; Sun *et al.*,2006; Yuan *et al.*,2007;曾乔松等,2007;刘锋等,2008;周刚等,2007;童英等,2007)对阿尔泰构造演化的认识起到了很大的促进和深化作用。

阿尔泰曾被认为是古生代褶皱带或造山带(任纪舜,1997)、晚古生代的活动陆缘(李春昱等,1982)、构造堆叠的古生代岛弧(Sengör and Natal'in,1996)。何国琦于 20 世纪 80 年代后期在完成 IGCP283 项目的过程中首次提出"震旦纪-中奥陶世在阿尔泰南西(现代方位)存在一个大规模古陆"(图 1)(何国琦等,1990),当时称之为"准噶尔古大陆板块";Berzin and Dobretsov(1993)对于独立划出阿尔泰-蒙古地块做了进一步论证; Dobretsov *et al.* (1995)、Dobretsov (2001)、Buslov *et al.* (2003)在近年的工作中则称之为阿尔泰-蒙古地体。

李会军等(2006)称这一古陆为"阿尔泰-蒙古微大陆",认为对白哈巴花岗岩时代及其构造环境的研究是确定阿尔泰-蒙古微大陆存在的重要依据之一。

2 白哈巴岩体岩相学特征

样品采自新疆哈巴河县白哈巴村附近的白哈巴岩体,岩体面积约 600km^2,呈近南北向延伸,贯穿了哈巴河群地层。岩体主要为黑云母斜长花岗岩, 另有少量花岗闪长岩, 二者

表 1 白哈巴岩体常量(wt%)、稀土和微量元素($\times 10^{-6}$)分析结果

Table 1 Major (wt%), REE and trace element ($\times 10^{-6}$) composition of Baihaba granite

样品号	SiO_2	TiO_2	Al_2O_3	FeO^T	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	LOI	Total	A/CNK
BH-1	65.76	0.64	15.11	4.37	0.09	1.65	2.45	3.38	4.06	0.17	0.95	98.63	1.05
BH-2	65.58	0.66	15.63	4.58	0.09	1.68	2.63	3.53	4.08	0.19	0.84	99.49	1.04
BH-3	65.79	0.71	14.84	4.79	0.09	1.80	2.59	3.34	3.73	0.18	0.90	98.76	1.04
样品号	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	
BH-1	32.07	67.30	8.68	31.59	7.66	1.49	6.75	1.20	6.93	1.41	4.05	0.57	3.81	
BH-2	34.00	71.24	9.72	34.74	8.24	1.55	7.38	1.36	8.85	1.62	4.71	0.68	4.63	
BH-3	37.35	78.89	10.23	37.24	9.42	1.63	9.14	1.54	10.18	2.05	5.71	0.84	5.53	
样品号	Rb	Sr	Ba	Zr	Nb	Th	Y	Pb	Co	Cu	Lu	ΣREE	Eu/Eu^*	$(La/Yb)_N$
BH-1	138	144	452	198.28	12.55	12.04	36.31	20.6	11.64	17.9	0.59	174.1	0.63	5.56
BH-2	132	145	449	205.19	12.45	13.3	42.91	21.8	11.05	17.32	0.72	189.4	0.60	4.85
BH-3	135	140	470	190.41	12.4	14.8	51.64	18.7	12.56	20.57	0.83	210.6	0.54	4.46

$A/CNK = Al_2O_3/(CaO + Na_2O + K_2O)$分子数

呈渐变过渡关系。黑云母斜长花岗岩呈灰色,中粗粒结构,块状构造,主要矿物为斜长石 50% ~60%,石英 25% ~30%,黑云母 10% ~15%,副矿物主要有榍石、磷灰石、锆石等。花岗闪长岩呈灰绿色,中粗粒结构,主要矿物为斜长石 40% ~45%,石英约 25%,钾长石 8% ~10%,黑云母 10% ~15%,角闪石 5% ~10%,副矿物主要有锆石、榍石、磷灰石等。采样具体位置如图 1 所示。

3 白哈巴岩体地球化学特征

本文常量、微量、稀土元素测试在北京大学造山带与地壳演化教育部重点实验室完成,采用 ICP 系统测试,稳定性为 RSD <1%(短期)和 RSD <5%(长期)。

3.1 主量元素特征

本次工作选取 3 件样品进行了主量元素、稀土元素及微量元素分析,SiO_2 含量介于 65.58% ~65.79% 之间,为中酸性侵入岩;A/CNK≤1.05,为弱过铝质岩石(表 1)。在 SiO_2-K_2O 图解中(图 2),属高钾钙碱性系列。主量元素特征表明,白哈巴岩体主要形成于构造体制转换时期。

3.2 稀土元素特征

由表 1 可知,稀土元素总量为 174.1×10^{-6} ~ 210.6×10^{-6},具明显的 Eu 负异常(0.54 ~0.63),稀土元素分馏中等($(La/Yb)_N$ 值为 4.46 ~5.56),稀土配分曲线为轻稀土富集型(图 3)。

研究表明,典型岛弧、山弧环境下的钙碱性安山岩和英安岩 HREE 较富集($Yb \geq 2.50 \times 10^{-6}$),REE 分异程度较低($(La/Yb)_N < 10$),具有 Eu 的负异常。白哈巴岩体稀土元素配分曲线特征与典型岛弧、山弧环境下的钙碱性中酸性火成岩相似,但其稀土总量却明显高于岛弧、山弧环境下的钙碱性中酸性火成岩,说明该岩体成因复杂。

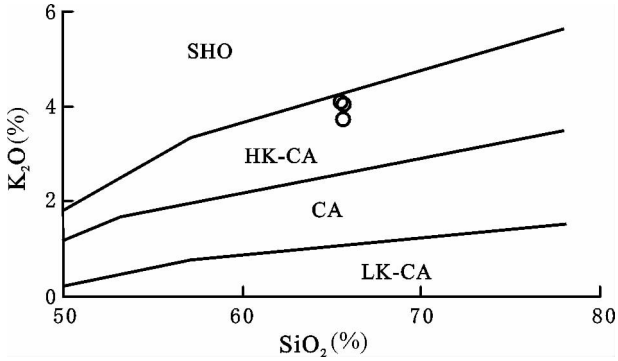


图 2 岩石 SiO_2-K_2O 图(据 Peccerillo and Taylor,1976)

SHO-橄榄安粗岩系列;HK-CA-高钾钙碱系列;CA-钙碱系列;LK-CA-低钾拉斑系列

Fig. 2 SiO_2-K_2O diagram of rock (after Peccerillo and Taylor,1976)

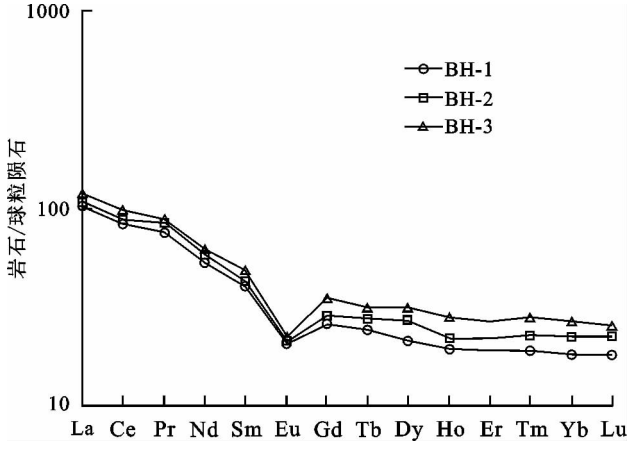


图 3 白哈巴岩体稀土元素配分型式图(球粒陨石值据 Taylor and Gorton, 1977)

Fig. 3 Chondrite-normalized REE distribution patterns of Baihaba granite (Chondrite normalization values are from Taylor and Gorton, 1977)

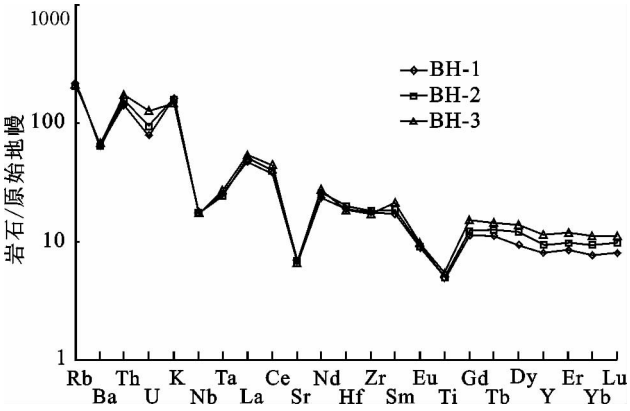


图 4 微量元素原始地幔标准化蛛网图(标准化数值据 Sun and McDonough, 1989)

Fig. 4 Primitive mantle-normalized trace element spider diagram (primitive mantle data from Sun and McDonough, 1989)

3.3 微量元素特征

从微量元素丰度(表 1)来看,白哈巴岩体的大离子亲石元素如 Sr 和 Ba 等含量较低(平均值分别为 143×10^{-6},457×10^{-6}),与安第斯活动大陆边缘火成岩微量元素特征明显不同。白哈巴岩体微量元素特征与 Tuareg 地盾后碰撞花岗岩类微量元素特征(Zen, 1988; Liégeois *et al.*, 1998)相似。在微量元素蛛网图(图 4)上,富集 Rb, Th, U, K, La, Ce, Nd, Hf, Zr 和 Sm 等元素,强烈亏损 Ba, Nb, Ta, Sr, P 和 Ti 等元素,表明白哈巴岩体为与陆-陆碰撞有关的后碰撞花岗岩类。

4 白哈巴岩体 SHRIMP 锆石 U-Pb 年龄

SHRIMP 样品锆石按常规重力和磁选方法分选,最后在双目镜下挑纯。将锆石样品与数粒 RSES 参考样 TEM 置于环氧树脂中,然后磨至约一半,使锆石内部暴露,用于阴极发光(CL)研究及随后的 SHRIMP U-Pb 分析。锆石阴极发光研究在北京大学电子学系完成。SHRIMP U-Pb 分析在北京离子探针中心 SHRIMP II 上完成,详细分析流程和原理见宋彪等(2002)及简平等(2003)。应用 RSES 参考锆石 TEM(417Ma)进行元素间的分馏校正,Pb/U 校正公式采用 $Pb/U = A(UO/U)^2$(Claoue-Long *et al.*, 1995)。应用 SL13 标样(572Ma;U 含量,238×10^{-6})标定样品及 TEM 的 U,Th 和 Pb 含量。数据处理采用 Ludwig SQUID 1.0 及 ISOPLOT 程序(Ludwig, 1999, 2001)。应用实测 ^{204}Pb 校正锆石中的普通铅。所列单个数据点的误差均为 1σ,采用年龄为 $^{207}Pb/^{206}Pb$ 年龄,其加权平均值的误差为 2σ。

锆石 SHRIMP 分析结果见表 2。样品中锆石阴极发光图像显示,大多数锆石晶体形态较好,呈单锥或双锥状,具清楚的生长韵律环带(图 5a),为岩浆成因锆石的反映。U 和 Th 含量分别介于 $107\times10^{-6}\sim1376\times10^{-6}$ 和 $39\times10^{-6}\sim1009\times10^{-6}$ 之间。经计算,白哈巴岩体的 Th/U 比值变化较小,且都大于 0.1(介于 0.13 ~ 0.94 之间)。研究表明岩浆型锆石的 Th/U 比值大于 0.1。根据锆石阴极发光特征和 Th/U 比值,白哈巴岩体中的锆石为岩浆型锆石。

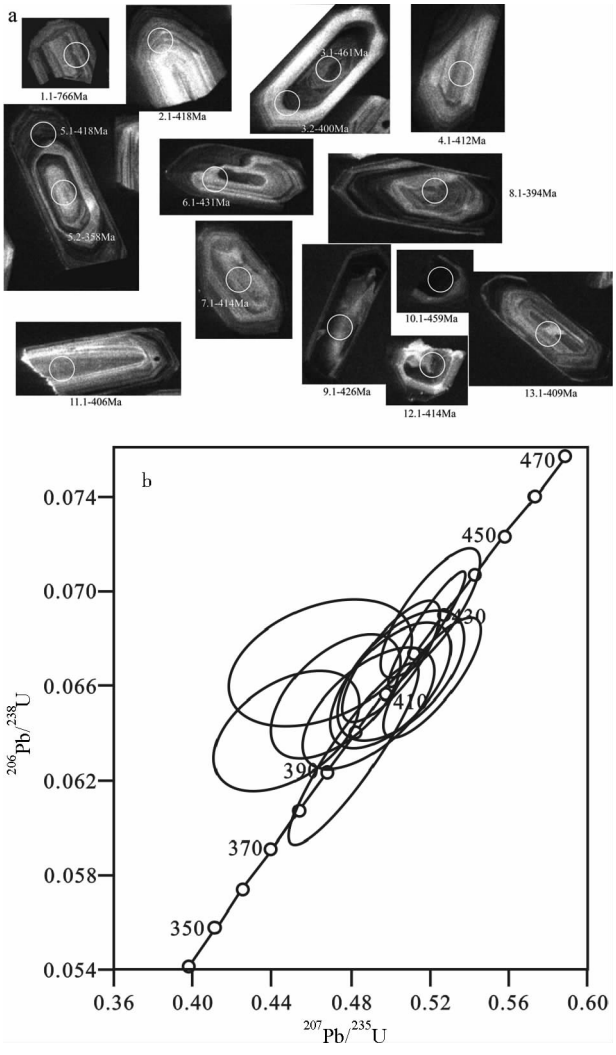


图 5 白哈巴岩体年龄图

(a)-锆石阴极发光照片(圆直径 30μm);(b)-锆石 SHRIMP U-Pb 年龄谐和图

Fig. 5 Age plot of Baihaba granite

锆石 SHRIMP U-Pb 测年结果显示,样品中锆石 15 个点的 $^{206}Pb/^{238}U$ 年龄的加权平均值为 413.8 ± 6.4Ma(图 5b),代表白哈巴岩体的结晶年龄。

5 讨论

Liégeois(1998)把主大洋闭合,两个或多个"大陆"板块发生的碰撞称之为主碰撞(初始主碰撞),以主逆冲带和高压变质作用发育为标志;后碰撞发生在主碰撞之后,通常为陆内环境,但仍有较大的地体位移;当汇聚的大陆板块完全焊

表 2 白哈巴岩体锆石 SHRIMP U-Pb 年龄分析结果

Table 2 Zircon SHRIMP U-Pb data of Baihaba granite

测点号	$^{206}Pb_c$ (%)	U ($\times10^{-6}$)	Th ($\times10^{-6}$)	$^{232}Th/^{238}U$	$^{206}Pb^*$ ($\times10^{-6}$)	$^{207}Pb^*/^{206}Pb^*$ (%)	$^{207}Pb^*/^{235}U$ (%)	$^{206}Pb^*/^{238}U$ (%)	$^{206}Pb/^{238}U$ (Ma)
B11-1.1	0.12	168	146	0.90	18.2	0.0642 ± 1.7	1.118 ± 3.1	0.1262 ± 2.6	766 ± 18
B11-2.1	0.56	152	44	0.30	8.82	0.0503 ± 6.1	0.465 ± 6.6	0.0670 ± 2.6	418 ± 11
B11-3.1	0.06	437	412	0.97	27.9	0.0560 ± 1.9	0.573 ± 3.5	0.0742 ± 3.0	461 ± 13
B11-3.2	0.61	122	71	0.60	6.78	0.0507 ± 4.8	0.448 ± 5.5	0.0641 ± 2.6	400 ± 10
B11-4.1	0.63	107	61	0.59	6.13	0.0550 ± 3.2	0.500 ± 4.2	0.0660 ± 2.6	412 ± 11
B11-5.1	0.31	373	116	0.32	21.6	0.0542 ± 2.2	0.500 ± 3.3	0.0670 ± 2.5	418 ± 10
B11-5.2	0.07	182	76	0.43	8.94	0.0550 ± 2.1	0.433 ± 5.0	0.0571 ± 4.5	358 ± 16
B11-6.1	0.27	233	80	0.35	13.9	0.0546 ± 2.0	0.520 ± 3.3	0.0691 ± 2.5	431 ± 11
B11-7.1	0.33	137	53	0.40	7.86	0.0552 ± 3.4	0.505 ± 4.4	0.0664 ± 2.7	414 ± 11
B11-8.1	0.30	252	39	0.16	13.7	0.0554 ± 2.0	0.482 ± 4.5	0.0631 ± 4.0	394 ± 15
B11-9.1	0.09	1376	1009	0.76	80.7	0.05498 ± 0.78	0.517 ± 2.6	0.0682 ± 2.5	426 ± 10
B11-10.1	0.10	478	81	0.17	30.3	0.05436 ± 1.5	0.553 ± 2.9	0.0738 ± 2.5	459 ± 11
B11-11.1	0.49	126	111	0.91	7.07	0.0545 ± 3.7	0.489 ± 4.5	0.0650 ± 2.6	406 ± 10
B11-12.1	0.22	592	76	0.13	33.8	0.0570 ± 1.9	0.521 ± 3.1	0.0663 ± 2.5	414 ± 10
B11-13.1	0.58	170	74	0.45	9.60	0.0523 ± 3.8	0.472 ± 4.7	0.0655 ± 2.6	409 ± 10

样品测试在中国地质科学院北京离子探针中心完成，表内年龄值为 1σ 绝对误差，其余为 1σ 相对误差. $^{206}Pb_c$ 表示总体铅中普通铅百分含量，Pb^* 表示放射性成因铅，普通铅用测量的^{204}Pb 校正

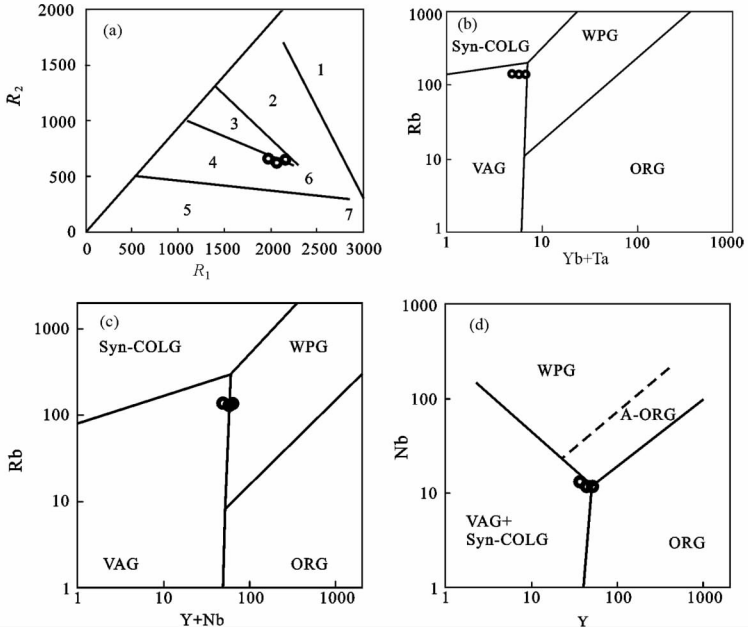


图 6 白哈巴花岗岩构造环境判别图

(a)-R_1-R_2 判别图(据 Batchelor and Bowden,1985)：1-地幔分异；2-板块碰撞前；3-碰撞后隆起；4-造山晚期；5-非造山；6-同碰撞；7-造山后. (b)-Rb-Yb + Ta 判别图、(c)-Rb-Y + Nb 判别图、(d)-Nb-Y 判别图(据 Pearce *et al.*，1984)：ORG-洋脊花岗岩；VAG-火山弧花岗岩；Syn-COLG-同碰撞花岗岩；WPG-板内花岗岩；A-ORG-异常洋中脊花岗岩

Fig. 6 Tectonic setting determinant diagram of Baihaba granite

接在一起，开始围绕一个统一的旋转轴运动时，就进入板内构造体制，标志后碰撞阶段的结束。青藏高原是现今正在进行的后碰撞作用实例。

白哈巴岩体属高钾钙碱性岩系，与后碰撞阶段形成的高

钾钙碱性花岗岩(KCG)岩石组合(Searle *et al.*,1997;Liégeois *et al.*, 1998;Sylvester,1998)相一致。微量元素原始地幔标准化蛛网图上富集 LILE,贫化 HFSE,强烈亏损 Nb,Ta,Sr 和 Ti 等元素,显示后碰撞高钾钙碱性 I 型花岗岩微量元素特征(Searle *et al.*,1997;Ferre *et al.*,1998)。

在花岗岩类形成环境的 R_1-R_2 判别图解(图6a)中,白哈巴岩体投影点落入碰撞后隆起(3 区)和造山晚期(4 区)的界限附近;在 Rb-Yb + Ta(图 6b)和 Rb-Y + Nb 判别图(图 6c)中,在火山弧花岗岩与板内花岗岩的的界限附近,这一区域被 Pearce(1996)圈定为后碰撞花岗岩叠加的区域;在 Nb-Y 判别图(图 6d)中,样品正好落在 VAG + Syn COLG、ORG 和 A-ORG 三区的交点附近。综上所述,白哈巴岩体属后碰撞花岗岩类。

研究结果具有以下几方面的意义:(1)对白哈巴岩体的形成时期及构造环境的研究支持存在阿尔泰-蒙古微大陆,白哈巴岩体形成于阿尔泰-蒙古微大陆与西伯利亚板块增生-碰撞-造山过程的后碰撞时期;(2)王京彬和徐新(2006)认为新疆北部后碰撞阶段的主体时限为早石炭世维宪期-晚二叠世。根据白哈巴岩体的形成时期及构造环境提出阿尔泰晚奥陶世-末志留世处于后碰撞阶段,对于正确认识新疆北部的构造演化可能具有重要意义。

6 结论

(1)白哈巴岩体为高钾钙碱性岩系,根据主量、微量、稀土元素确认属后碰撞花岗岩类。

(2)白哈巴岩体 SHRIMP 锆石 U-Pb 年龄为 413.8 ± 6.4Ma,代表白哈巴岩体的结晶年龄。

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