

新疆中天山科克苏地区高钾钙碱性花岗岩 地球化学特征、成因及形成环境

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摘要:以新疆中天山科克苏地区高钾钙碱性花岗岩为研究对象,分析该花岗岩全岩主微量元素及Sr-Nd同位素,发现该花岗岩具高Si, Na, K, Al, 低Fe, P, Ti, Mg[#]特征;富集Rb等大离子亲石元素(LILE)元素,亏损Nb, Ti等高场强(HFS)元素;主量元素(Fe, Mg, Ca, P, Ti)及部分微量元素(Ba, Sr)多与SiO₂呈负相关。地球化学特征表明,科克苏地区高钾钙碱性花岗岩岩浆经历了结晶分异过程。该花岗岩 $\epsilon_{Nd}(T)$ 为负值, Mg[#], Ce, Pb, U, Nb等指示岩浆来源为地壳物质的部分熔融。Rb, Y, Nb, Ta等揭示该高钾钙碱性花岗岩形成于后碰撞环境。

关键词:高钾钙碱性花岗岩;地球化学;地壳部分熔融;后碰撞

中亚造山带位于亚洲腹地,大地构造上北邻西伯利亚克拉通,南接塔里木克拉通^[1-3],又称为阿尔泰拼接体^[4],由众多构造属性不相同的地体拼合而成。这些地体具不同的构造性质,包括古老陆块、古生代岛弧、蛇绿岩套残片、海山和增生杂岩体等^[4-7]。目前普遍认为中亚造山带是全球最大的显生宙增生型造山带^[7-10]。在显生宙漫长的地质演化过程中,中亚地区形成大批世界级金属矿床^[11-13]。因此,对中亚造山带的研究具有重要的科学意义和经济意义。在中亚造山带漫长的地质演化过程中,南天山及毗邻地区在早古生代和晚古生代发育有大量花岗岩,前人对其时空分布、年代学、岩石地球化学及成因等方面进行了研究,取得一定成果。针对该区花岗岩岩石类型,有学者认为属I型花岗岩^[14-15],也有认为应划为S型花岗岩^[16]。该区花岗岩虽不含S型花岗岩标志矿物堇青石,但部分学者认为其特征矿物并不能很好地区分花岗岩类型^[17]。本文对该区花岗岩进行研究,将其定义为高钾钙碱性花岗岩,揭示了该种花岗岩地球化学特征及成因,为高钾钙碱性花岗岩的研究提供实例。

1 区域地质背景及岩相学

新疆科克苏地区位于特克斯县南部、中天山地块南缘和那拉提北坡断裂间的科克苏河流经区域

(图1-a),北部为伊犁地块,南部为南天山碰撞带,再往南为塔里木板块。区内花岗岩发育广泛,主要有二长花岗岩、黑云母花岗岩、斜长花岗岩、花岗斑岩和石英闪长岩。本次采集样品主要为二长花岗岩和黑云母花岗岩。研究区主要出露前寒武纪和少量石炭纪大哈拉军山组火山岩(图1-b),前寒武纪为古元古代木扎尔特岩群,由片麻岩和混合岩,夹大理岩、石英岩及云母石英岩等组成^[15]。石炭纪由安山玢岩、流纹岩、凝灰岩、凝灰质砂岩、灰岩和砾岩组成。该区二长花岗岩主体呈面状分布并侵入石炭系中,出露面积约60 km²,分布于区内中部和南部,被黑云母花岗岩和英云闪长岩侵入体隔成两段。黑云母花岗岩出露面积约12 km²,分布于中西部并侵入二长花岗岩中。英云闪长岩出露面积约24 km²,分布于中东部,侵入黑云母花岗岩和二长花岗岩中。因此,黑云母花岗岩较二长花岗岩形成时期晚,英云闪长岩最晚形成。二长花岗岩(KX05-11)为似斑状构造,钠长石约占40%,石英占25%,黑云母占5%,内有玄武岩包体。黑云母花岗岩(KX01-04)主要组成矿物为碱性长石(45%)、石英(34%)、斜长石(15%)和少量黑云母(1%)。英云闪长岩由角闪石(35%)、长石(55%)、石英(5%)、云母(5%)组成。已有资料表明科克苏地区花岗岩形成时代约在341~355 Ma^[14,18]。

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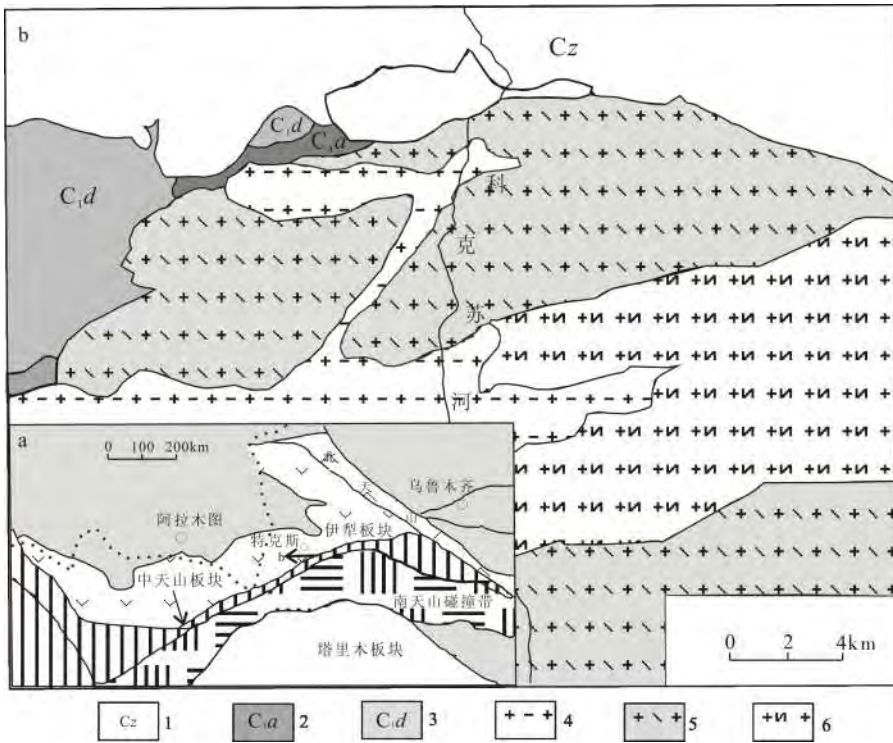


图1 中天山科克苏地区地质简图

Fig.1 Geological sketch map for Kekesu region in Central Tianshan

(据李平, 2011)

1.新生界;2.阿克沙克组;3.大哈拉军山组;4.黑云母花岗岩;5.二长花岗岩;6.英云闪长岩

2 分析方法

样品经清除表面杂质后破碎成岩屑,实验室用纯净水反复冲洗至清洁后用5%的盐酸溶液浸泡10分钟,再加入去离子水在超声波洗槽中清洗15分钟,重复2~3次,样品经烘干后用玛瑙研钵磨至200目供化学分析。主元素和微量元素分析在中国科

学院地球化学研究所矿床地球化学国家重点实验室分别采用X射线荧光法(XRF)和电感耦合等离子体质谱法(ICP-MS)完成,主元素分析精度大多优于5%,微量元素分析精度多优于8%。Sr-Nd同位素在核工业北京地质研究院测定。同位素采用ISOPROBE-T热电离质谱仪分析,测试条件:相对湿度20%,温度20℃。¹⁴³Nd/¹⁴⁴Nd比值据¹⁴⁶Nd/¹⁴⁴Nd=0.721 9标准化,Nd同位素国际标准样品JNdi-1测试值为0.512 096±5。

3 地球化学特征

3.1 主元素特征

新疆科克苏地区花岗岩主元素分析结果见表1。该区花岗岩具有高SiO₂、K₂O、Al₂O₃特征,在K₂O-SiO₂图解上(图2)^[9],样品均落在高钾钙碱性区域,并具低的TF₂O₃、P₂O₅、CaO、TiO₂。K₂O+Na₂O=8.29%~9.37%,属钙碱性。A/CNK(Al₂O₃/(CaO+Na₂O+K₂O))为1.08~1.12,属弱过铝质(图3)。Mg[#]较低,Mg[#]-SiO₂图解指示该区花岗岩为地壳熔体形成(图2)。

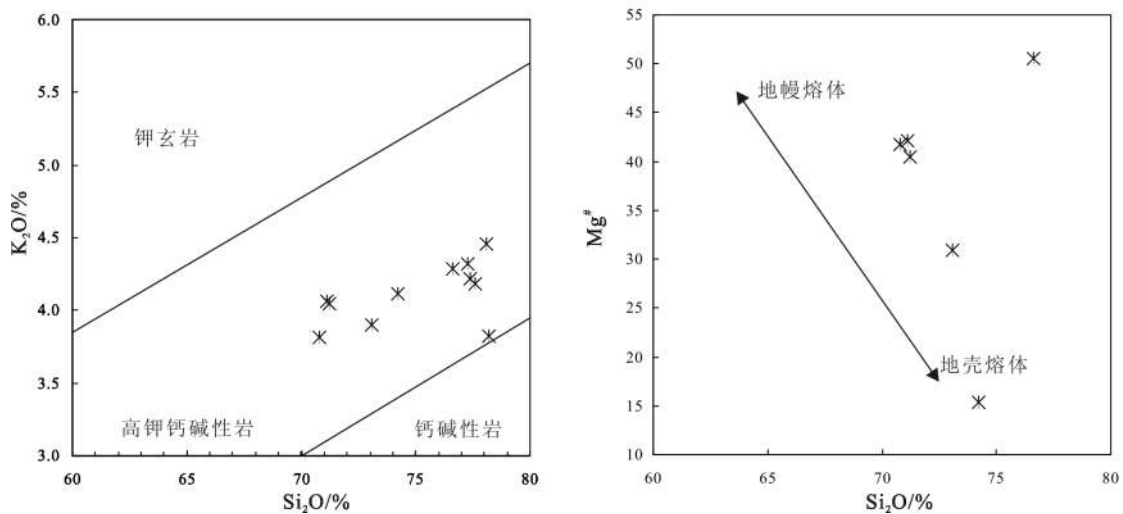


图2 K₂O-SiO₂、Mg[#]-SiO₂图解

Fig.2 Major elements and some trace elements K₂O-SiO₂、Mg[#]-SiO₂ diagrams

(据 Rapp and Watson, 1995)

表1 科克苏地区花岗岩主量元素和微量元素分析结果
Table 1 The major elements and trace element analytical results of granitoids from Kekesu area

样品	KX01	KX02	KX03	KX04	KX05	KX06	KX07	KX08	KX09	KX10	KX11
SiO ₂	77.300	77.400	76.600	78.200	73.100	71.200	70.800	71.100	77.600	78.100	74.200
TiO ₂	0.110	0.110	0.110	0.090	0.280	0.370	0.350	0.340	0.040	0.090	0.370
Na ₂ O	4.560	4.430	3.990	4.680	4.940	5.050	5.560	4.940	4.790	4.030	4.510
K ₂ O	4.320	4.220	4.290	3.820	3.900	4.050	3.810	4.060	4.180	4.460	4.110
Al ₂ O ₃	12.550	12.220	12.170	12.970	13.860	15.190	15.100	15.040	12.940	12.570	13.600
TFe ₂ O ₃	0.440	0.420	0.380	0.330	1.350	2.060	2.060	2.030	0.550	0.670	2.250
MnO	0.020	0.030	0.050	0.010	0.030	0.060	0.060	0.060	0.040	0.020	0.050
MgO	—	—	0.200	—	0.310	0.720	0.760	0.760	—	—	0.210
CaO	—	0.050	0.050	—	0.590	0.440	0.320	0.590	—	—	0.270
P ₂ O ₅	0.020	0.020	0.020	0.020	0.050	0.090	0.060	0.090	—	—	0.070
LOI	0.320	0.540	0.300	0.350	0.620	1.270	1.090	1.060	0.290	0.530	0.880
TOTAL	99.730	99.470	98.760	100.470	98.680	100.580	100.050	100.060	100.520	100.460	100.540
Na ₂ O/K ₂ O	1.060	1.050	0.930	1.230	1.270	1.250	1.460	1.220	1.150	0.900	1.100
K ₂ O+Na ₂ O	8.880	8.650	8.290	8.500	8.840	9.100	9.370	8.990	8.980	8.490	8.630
A/CNK	—	1.020	1.080	—	1.030	1.120	1.090	1.110	—	—	1.100
Mg [#]	—	—	50.580	—	30.870	40.470	41.780	42.130	—	—	15.360
Li	0.980	0.340	0.820	1.270	6.210	9.380	8.890	9.440	6.720	2.170	5.700
Be	2.730	2.740	2.300	1.860	1.570	2.750	2.500	2.280	14.300	3.230	4.150
Sc	4.580	3.670	3.550	2.020	2.980	4.740	4.750	3.070	2.780	2.170	5.170
V	2.000	1.680	1.910	2.010	18.500	27.000	25.400	22.400	0.770	1.320	15.300
Cr	4.400	3.120	6.160	5.340	7.230	3.180	4.871	5.000	3.890	4.100	5.610
Co	34.500	27.800	27.200	38.200	24.900	26.300	28.900	18.200	33.100	46.000	32.400
Ni	7.600	3.870	4.650	4.700	4.870	3.670	4.360	4.020	3.710	4.570	5.350
Cu	5.550	3.150	7.180	4.690	2.030	2.960	3.730	2.240	2.380	2.140	3.510
Zn	44.500	30.900	33.400	23.400	38.300	43.500	49.700	55.600	30.300	22.200	60.500
Ga	11.600	10.200	11.300	12.800	11.600	16.100	15.100	14.800	19.000	12.400	17.200
Ge	1.260	1.100	1.240	0.910	0.880	0.900	1.030	1.030	2.950	1.050	1.120
As	9.890	9.030	9.090	8.990	10.700	10.900	10.600	10.100	10.500	9.690	10.700
Rb	138.000	129.000	157.000	105.00	95.500	110.000	97.700	114.000	245.000	133.000	145.000
Sr	16.600	16.500	11.700	21.100	64.000	170.000	102.000	193.00	2.200	10.700	81.300
Y	26.300	16.900	18.100	21.300	13.100	16.100	16.300	14.000	40.800	18.000	29.900
Zr	80.000	64.500	70.800	76.700	101.000	124.000	101.000	91.000	181.000	77.400	229.000
Nb	16.000	12.600	11.100	12.100	10.300	13.100	12.700	9.900	58.900	9.800	32.100
Mo	0.360	3.300	0.630	0.350	0.320	0.140	0.250	0.260	0.490	0.820	0.450
Ag	0.230	0.200	0.150	0.180	0.150	0.170	0.170	0.150	0.680	0.120	0.380
Cd	0.080	0.120	0.090	0.060	0.040	0.070	0.060	0.050	0.160	0.050	0.130
In	0.020	0.030	0.030	0.018	0.009	0.017	0.0130	0.018	0.057	0.028	0.048
Sn	3.110	3.420	3.110	2.410	1.620	2.680	2.130	1.750	6.880	2.470	4.740
Sb	0.470	0.260	0.460	0.260	0.830	0.450	4.830	0.480	1.120	0.370	0.480
Cs	0.940	1.190	1.480	0.970	0.680	1.760	0.750	1.180	32.100	0.810	1.410
Ba	214.000	272.000	242.000	261.000	529.000	580.000	451.000	491.000	21.000	88.000	321.000
La	11.800	11.400	9.400	12.100	13.100	39.800	28.100	27.700	14.000	25.900	35.500
Ce	36.200	34.000	27.500	35.600	30.600	82.500	63.700	63.600	46.700	62.100	86.500
Pr	3.900	3.600	2.900	3.800	3.200	7.700	6.500	5.900	4.800	6.100	8.100
Nd	14.200	12.800	10.200	13.900	12.900	26.400	23.700	21.100	16.400	20.800	30.100
Sm	4.020	3.170	2.560	3.540	3.140	4.360	4.020	3.440	4.180	3.540	5.720
Eu	0.410	0.360	0.350	0.370	0.730	1.000	1.030	0.920	0.060	0.280	0.820
Gd	4.170	3.050	2.750	3.190	2.640	3.780	3.750	3.170	4.390	3.240	5.690
Tb	0.750	0.540	0.530	0.610	0.400	0.560	0.520	0.430	0.860	0.500	0.890
Dy	4.560	3.150	3.240	3.650	2.250	2.790	2.760	2.330	5.590	2.940	5.260
Ho	0.968	0.642	0.715	0.813	0.469	0.590	0.609	0.485	1.330	0.685	1.140
Er	2.650	1.790	2.000	2.350	1.370	1.670	1.730	1.490	4.250	2.060	3.270
Tm	0.403	0.277	0.283	0.355	0.229	0.267	0.251	0.222	0.785	0.305	0.523
Yb	2.860	1.870	2.080	2.450	1.570	1.860	1.900	1.540	6.560	2.100	3.950
Lu	0.398	0.262	0.295	0.372	0.217	0.299	0.273	0.231	0.988	0.307	0.537
Hf	3.920	3.170	3.410	3.800	2.880	3.770	2.890	2.730	16.400	3.210	7.460
Ta	1.820	1.570	1.480	1.640	1.080	1.180	1.150	0.847	9.160	1.270	2.990
W	179.000	149.000	139.000	296.000	237.000	259.000	235.000	156.000	222.000	284.000	250.000
Tl	0.886	0.842	0.982	0.706	0.461	0.488	0.514	0.498	1.130	0.618	0.656
Pb	15.680	10.720	22.800	7.410	3.060	7.120	5.210	9.460	47.160	11.500	13.100
Bi	0.1930	0.092	0.088	0.035	0.020	0.042	0.026	0.028	1.200	0.031	0.064
Th	14.300	11.600	11.400	14.100	10.900	14.300	14.800	10.500	32.900	15.200	25.000
U	3.630	3.190	2.150	4.850	1.840	2.850	1.940	1.730	10.200	2.990	5.290

注:主量元素单位:%;微量元素单位: $\times 10^{-6}$

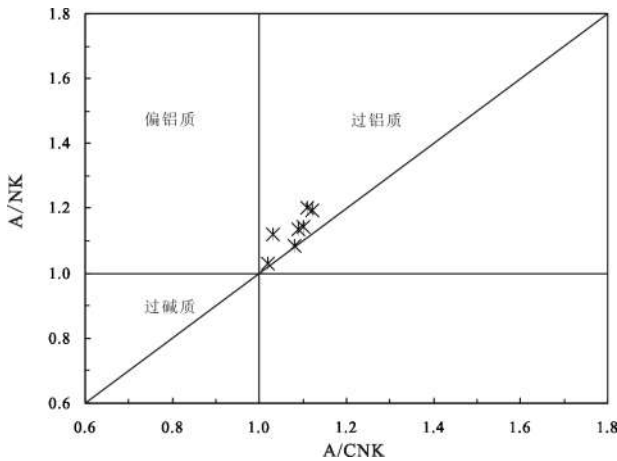


图3 A/NK-A/CNK图解
Fig.3 A/NK-A/CNK diagram

3.2 微量元素特征

科克苏地区花岗岩稀土元素及微量元素蛛网图见图4^[20,21],科克苏地区花岗岩具中等稀土总量(Σ REE),为 $60 \times 10^{-6} \sim 188 \times 10^{-6}$ 。在稀土元素球粒陨石标准化图上(图4),显示轻稀土(LREE)富集,重稀土平坦分布,具轻度REE分异, $(La/Yb)_n$ 为1.5~12.9。样品具明显的Eu负异常($Eu/Eu^* = 0.02 \sim 0.84$)。该区花岗岩在微量元素蛛网图上表现为高场强元素HFS(Nb, Zr, Eu, Ti等)亏损,大离子亲石元素LILE(Rb、

Nd等元素)富集(图4)。

3.3 Sr-Nd 同位素特征

科克苏地区花岗岩具特别高的 $^{87}Sr/^{86}Sr$ (0.718 977~0.877 835)比值及低的 $\epsilon_{Nd}(T)$ (-1.7~-3.9)值(表2)。由于 $^{87}Sr/^{86}Sr$ 过高(岩浆岩强演化具极高的Rb),失去成因意义,可通过Nd同位素特征说明科克苏地区花岗岩来自地壳物质的部分熔融。

4 讨论

4.1 岩浆来源

科克苏地区高钾钙碱性花岗岩具负的 $\epsilon_{Nd}(T)$ (-1.7~-3.9)值, $Mg^{\#}$ 表现出趋向地壳熔体特征(图2),表明该花岗岩来源趋向于壳源物质的部分熔融。Ce/Pb及Nb/U比值的分布很好地反映了花岗岩来源^[22],科克苏地区花岗岩在Ce/Pb与Ce、Nb/U与Nb的图解上(图5),均分布于壳源物质区,也说明该区花岗岩来源为地壳物质。此外,Ba,Nb,Ti的亏损及LILE的富集都是地壳熔体的典型特征^[23]。因此,判断该区花岗岩来源为地壳源岩的部分熔融。Ba/Th与 $^{143}Nd/^{144}Nd$ 及Sr/Th与 $^{143}Nd/^{144}Nd$ 的相关关系,很好地反映了岩浆来源的物质组成^[22]。该区花岗岩在Ba/Th与 $^{143}Nd/^{144}Nd$ 及Sr/Th与 $^{143}Nd/^{144}Nd$ 的图解上均

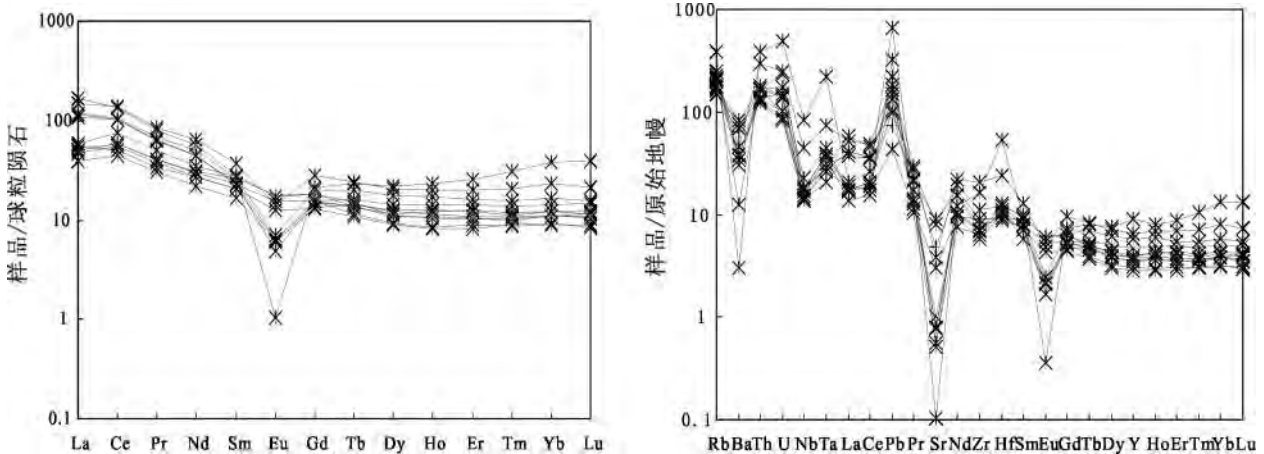


图4 微量元素标准化图及稀土元素

Fig.4 Primitive mantle-normalized trace element spidergrams and chondrite-normalized REE patterns
(据 Sun and McDonough, 1989; Boynton, 1984)

表2 科克苏地区花岗岩Sr-Nd同位素分析结果

Table 2 The Sr-Nd isotopic analytical result of Kekesu granitoids

样品编号	$^{87}Sr/^{86}Sr$	Std Err	$^{143}Nd/^{144}Nd$	Std Err	$\epsilon_{Nd}(T)$
KX01	0.812 294	0.000 008	0.512 476	0.000 005	-3.1
KX03	0.877 835	0.000 011	0.512 488	0.000 006	-3.0
KX04	0.774 359	0.000 010	0.512 460	0.000 005	-3.5
KX05	0.725 413	0.000 011	0.512 551	0.000 006	-1.7
KX07	0.718 977	0.000 008	0.512 466	0.000 004	-3.4
KX11	0.731 304	0.000 007	0.512 444	0.000 004	-3.9

位于混合源区曲线上(图6),靠近变质火成岩一端,远离变质沉积岩一端,说明该区花岗岩物质来源为变质火成岩或火成岩。因此推断该地区花岗岩是由古老的基底(变质火成岩或火成岩)发生部分熔融,产生高钾钙碱性的熔体,熔体在构造的作用下向上运移,最终形成科克苏地区花岗岩。

4.2 岩浆的分离结晶

如上所述,科克地区花岗岩从全岩主量、微量元素和同位素数据看都为壳源。该区花岗岩具有较高的SiO₂含量,属高分异钙碱性花岗岩。花岗岩中不相容元素反映岩浆演化过程中的分离结晶作用,如Sr元素的亏损及LILE的富集和HFS的亏损都说明岩浆经历了强烈的分离结晶过程。

4.3 构造环境

前人研究认为高钾钙碱性花岗岩可在活动大陆边缘及后碰撞的环境形成^[24-26],但大陆活动边缘形成的高钾钙碱性花岗岩具低的Rb与Y+Nb及低的Yb+Ta^[27]。科克苏地区高钾钙碱性花岗岩具高的Rb与Y+Nb及高的Yb+Ta值,Rb-Y+Nb和Rb-(Yb+Ta)图解上均落入后碰撞范围(图7),说明科克苏地区高钾钙碱性花岗岩为后碰撞花岗岩。除科克苏地区高钾钙碱性花岗岩所反映出的碰撞环境外,汤耀庆和Liu Y通过分布于南天山碰撞带中的蛇绿岩证明南天洋一直存在于早石炭世^[28-29],早石炭世后南天洋可能已闭合。刘斌、周鼎武、高俊等通过对南天山碰撞带中高压变质带的研究^[30-33],判断变质带中的榴辉

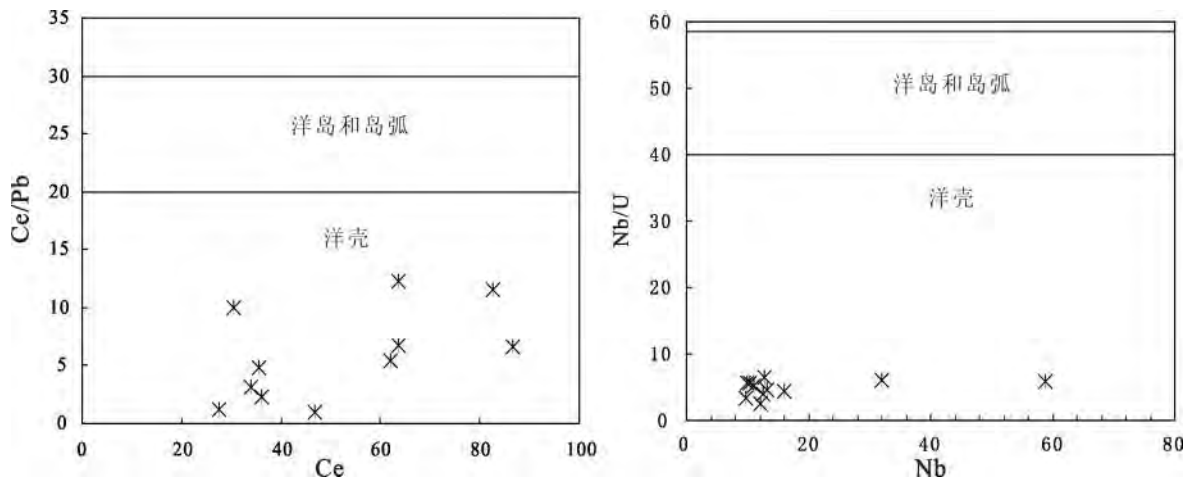


图5 Ce/Pb-Ce、Nb/U-Nb图解
Fig.5 Ce/Pb-Ce and Nb/U-Nb diagrams
(据 Guo et al ,2012)

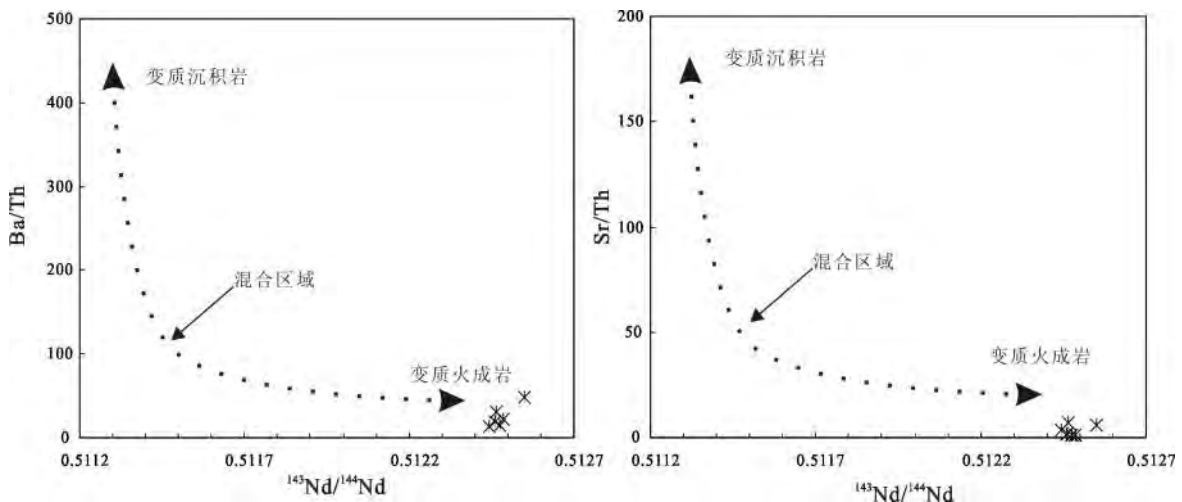


图6 Ba/Th-¹⁴³Nd/¹⁴⁴Nd、Sr/Th-¹⁴³Nd/¹⁴⁴Nd图解
Fig.6 Ba/Th-¹⁴³Nd/¹⁴⁴Nd and Sr/Th-¹⁴³Nd/¹⁴⁴Nd diagrams
(据 Guo et al ,2012)

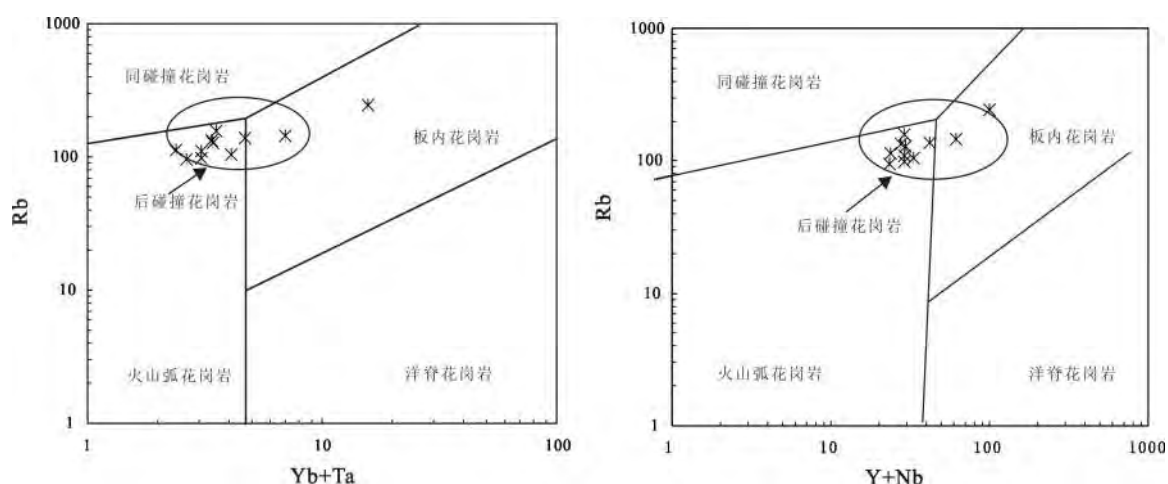


图7 $\lg(Y+Nb)-\lg Rb$ 和 $\lg(Yb+Ta)-\lg Rb$ 图解
 Fig.7 The diagrams of $\lg(Y+Nb)-\lg Rb$ and $\lg(Yb+Ta)-\lg Rb$
 (Pearce, 1984)

岩变质可能发生于早石炭世,证明了科克苏地区在350 Ma左右存在后碰撞花岗岩的合理性。

5 结论

(1) 新疆科克苏地区高钾钙碱性花岗岩具高的Si, Na, K, Al, 低Fe, P, Ti, Mg[#], 微量元素LILE富集, HFS亏损, LREE富集而HREE平坦分布的特征。

(2) 该区花岗岩形成时经历了岩浆结晶分异过程。

(3) 科克苏地区高钾钙碱性花岗岩的来源为地壳物质的部分熔融。

(4) 科克苏地区高钾钙碱性花岗岩的形成环境为后碰撞的构造环境。

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High-Potassic Calc-Alkaline Granitoids from Kekesu Area in Central Tianshan, Xinjiang: Petrogenesis, Geochemical and Tectonic Setting

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Abstract: The granitoids from Kekesu area in central Tianshan Xinjiang belong to the high-potassic calc-alkaline series and exhibit high Si, Na, K, Al and low Fe, P, Ti, Mg[#] characteristics. These granitoids are all enriched in Rb and depleted in Nb, Ti and have lower $\epsilon_{\text{Nd}}(T)$ values. Most of the major elements (such as Fe, Mg, Ca, P, Ti) and some trace elements (such as Ba, Sr) show a negative correlation with SiO_2 , indicating that the granitoids from Kekesu area underwent the fractional crystallization. The value of $\epsilon_{\text{Nd}}(T)$ is negative, besides the element of Mg[#], Ce, Pb, U, Nb which could indicate the source of granitoids all show the granitoids from Kekesu area come from the crust (including metaigneous or igneous), so the source of granitoids is crust partial melting. Those elements, such as Rb, Y, Nb, Ta, indicate the granitoids formed in post-collision setting.

Key words: High-potassium calc-alkaline granitoids; Geochemical; Crust partial melting; Post-collision