

北阿尔金喀孜萨依二长花岗岩成因及其构造意义

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内容提要:喀孜萨依二长花岗岩出露于北阿尔金蛇绿混杂岩带北缘, 为探讨其成因、源区特征及构造环境, 本文对其进行了岩石学、锆石 U-Pb 定年、Hf 同位素及岩石地球化学等方面的研究。研究结果表明, 喀孜萨依二长花岗岩主要由石英、斜长石、钾长石、角闪石、黑云母等矿物组成, 岩体侵位时代为 425~423 Ma, 铝饱和指数 A/CNK 为 0.97~1.07, 属弱过铝质钙碱性-高钾钙碱性岩石, P_2O_5 与 SiO_2 含量呈负相关, 具 I 型花岗岩特征。轻稀土富集而重稀土亏损, Eu 异常不明显, 岩石富集 Rb、Ba、Th、U、K 等元素, 相对亏损 Nb、Ta、P、Ti 等元素。锆石 $\epsilon_{HF}(t)$ 值为 +2.65 ~ +6.23, 二阶段模式年龄 t_{DM2} 为 1015~1243 Ma, 其源岩主要来自新生地壳。结合区域构造背景, 喀孜萨依二长花岗岩体可能形成于碰撞后伸展环境。

关键词:二长花岗岩; 地球化学; 锆石 U-Pb 定年; 岩石成因; 北阿尔金

阿尔金造山带地处青藏高原的北缘, 东临祁连西接昆仑, 延伸近 1000 km。北阿尔金蛇绿混杂岩带是阿尔金造山带的次级构造单元之一, 混杂岩带内主要出露有蛇绿岩块、高压变质岩、中酸性侵入岩和火山岩以及复理石沉积。前人研究表明, 区内蛇绿岩形成于早古生代 (Liu Liang, 1999; Wu Jun et al., 2002; Yang Jingshui et al., 2008), 红柳泉一带出露榴辉岩 (513±5 Ma) 和蓝片岩 (497±10 Ma) 等高压变质岩, 被认为与洋壳俯冲作用有关 (Zhang Jianxin et al., 2007), 混杂岩带东段报道了许多与俯冲有关的火山岩 (517~482 Ma) (Hao Ruixiang et al., 2013; Li Songbin, 2013)。此外, 混杂岩带内广泛出露有与俯冲有关的中酸性侵入岩 (520~460 Ma) (Qi Xuexiang et al., 2005a; Wu Cailai et al., 2007; Kang Lei et al., 2011; Han Fengbin et al., 2012; Meng Lingtong et al., 2016, 2017)。而混杂岩带西段地区的 S 型花岗杂岩体及埃达克质花岗岩的研究, 暗示本区在 450~430 Ma 间可能为碰撞环境 (Wu Cailai et al., 2005, 2007, 2009; Yu Shengyao

et al., 2018)。Yu Shengyao et al. (2018) 根据红柳沟一带的高 Mg 埃达克质花岗岩 (425~422 Ma) 的研究, 认为本区从碰撞挤压环境向伸展环境的转变可能发生在 425~422 Ma。

喀孜萨依二长花岗岩体出露于北阿尔金蛇绿混杂岩带的北缘, Qi Xuexiang et al. (2005b) 对其进行了锆石 U-Pb 年代学及地球化学研究, 获得其侵位年龄为 404.7 Ma, 并认为其来自地幔楔的部分熔融, 与阿尔金地块和塔里木地块间的斜向碰撞引发的大规模走滑作用有关 (Qi Xuexiang et al., 2005b)。然而, 地幔部分熔融难以产生花岗岩, 且现有的研究表明北阿尔金洋壳俯冲可能发生在 520~460 Ma (Qi Xuexiang et al., 2005a; Wu Cailai et al., 2007; Kang Lei et al., 2011; Han Fengbin et al., 2012; Meng Lingtong et al., 2016, 2017), 喀孜萨依岩体不可能来自地幔楔的部分熔融。喀孜萨依岩体作为北阿尔金地区花岗质岩浆活动晚期产物, 其岩石成因、物质来源及形成环境尚不清楚。因此, 本文选取该岩体作为研究对象, 从岩石学、岩石地球

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化学、锆石 U-Pb 年代学及 Hf 同位素等方面对其进行研究,以探讨其成因及构造环境。

1 岩体地质及岩相学特征

阿尔金造山带位于青藏高原的北缘,为塔里木盆地与柴达木盆地的地理分界,是一条经历了复杂地质构造演化的复合造山带,自北向南可分为 5 个次级构造单元:阿北地块、北阿尔金蛇绿混杂岩带、中阿尔金地块、南阿尔金超高压变质带以及南阿尔金蛇绿混杂岩带(Xu Zhiqin et al., 1999; Liu Liang et al., 2009; Yang Wenqiang et al., 2012; Gai Yongsheng et al., 2015)。北阿尔金蛇绿混杂岩带为阿尔金造山带重要的次级构造单元之一(图 1a),处在阿北地块与中阿尔金地块之间,呈近东西向带状延伸,主要由蛇绿岩块、高压变质岩、早古生代中酸性侵入岩和火山岩、具复理石特征的深海-半深海碎屑岩及碳酸盐岩等组成。

喀孜萨依二长花岗岩体出露于北阿尔金蛇绿混杂岩带西段北缘,岩体呈近东西向带状分布(图 1b),与岩体南北两侧的断层走向一致,出露面积近 70 km²,岩体围岩主要是早古生代的俯冲碰撞杂岩。二长花岗岩体南侧出露少量肉红色中粒花岗闪长岩(481.5 Ma, Qi Xuexiang et al., 2005b),二长花岗岩体边缘有时可见肉红色花岗闪长岩捕掳体。喀孜萨依二长花岗岩呈灰白色,块状构造,中粒花岗结构,岩石主要由石英、斜长石、钾长石、角闪石、黑云母等矿物组成(图 2b)。石英,它形粒状,含量 25%~30%;斜长石,半自形宽板状,含量 35%~40%,有绢云母化现象;钾长石含量 20%~25%;角闪石呈绿色,含量 3%~5%;黑云母含量为 2%~3%。副矿物有锆石、磷灰石、榍石、磁铁矿等。

2 分析测试方法

锆石的分选在河北廊坊区调院完成,锆石 U-Pb 测年在中国地质科学院地质研究所完成,所用仪器为 Thermo Fisher 公司最新一代 Neptune Plus 型多接收等离子体质谱仪和美国 Coherent 公司的 GeoLasPro 193 nm 激光剥蚀系统(LA-MC-ICP-MS)。激光剥蚀以 He 为载气,剥蚀束斑直径为 32 μm,频率为 8 Hz。在开始测试分析之前,先用国际上通用的锆石标样 91500 作为参考物质进行仪器的最佳化,并用 GJ-1 作为辅助标样对数据的准确性进行验证。测试数据的处理采用中国地质大学刘勇胜教授研发的 ICPMSDataCal 程序(Liu Yongsheng et

al., 2010)和 Ludwig(2003)的 Isoplot 程序。

锆石 Hf 同位素分析在中国地质科学院地质研究所完成,所用仪器为 Neptune Plus 多接收等离子体质谱和 Compex Pro193nm 激光剥蚀系统(LA-MC-ICP-MS),实验过程中采用 He 作为剥蚀物质载气,剥蚀束斑直径为 44 μm,使用国际上通用的锆石标样 GJ-1 作为参考物质,测试过程中锆石标准 GJ-1 的¹⁷⁶Hf /¹⁷⁷Hf 测试加权平均值为 0.282007 ± 0.000025 (2σ)。初始¹⁷⁶Hf /¹⁷⁷Hf 计算,Lu 的衰变常数采用 $1.865 \times 10^{-11} \text{ y}^{-1}$ (Scherer et al., 2001)。计算 $\epsilon_{\text{Hf}}(t)$ 时采用的球粒陨石 Hf 同位素值¹⁷⁶Lu /¹⁷⁷Hf = 0.0336,¹⁷⁶Hf /¹⁷⁷Hf = 0.282785(Bouvier et al., 2008)。

岩石样品的粉末碎样、化学全分析分别在河北廊坊区调院和河北廊坊物化探研究所实验室完成,主量元素分析使用 X 荧光光谱仪 3080E 进行分析测试,分析的相对标准偏差小于 2%~8%。稀土元素 La、Ce、Pr、Nd、Sm、Eu、Gd、Tb、Dy、Ho、Er、Tm、Yb、Lu、Y 和微量元素 Cu、Pb、Th、U、Hf、Ta、Sc、Cs、V、Co、Ni 使用等离子质谱(ICP-MS)Excell 进行测试。而微量元素 Sr、Ba、Zn、Rb、Nb、Zr、Ga 等用 X 荧光光谱仪 2100 进行分析测试,分析的相对标准偏差小于 10%。

3 分析测试结果

3.1 锆石 U-Pb 定年及 Hf 同位素特征

样品 16CL220:锆石呈长柱状,长约 120~200 um,具有清晰的岩浆振荡环带,锆石 Th 含量为 333×10^{-6} ~ 3195×10^{-6} , U 含量为 675×10^{-6} ~ 2801×10^{-6} , Th/U 比值为 0.5~1.1,为典型的岩浆锆石(Koschek, 1993; Corfu et al., 2003)。本文对样品中的 15 颗锆石进行了年龄测定,测点的²⁰⁶Pb/²³⁸U 加权平均年龄为 425 ± 3 Ma,代表岩体的侵位年龄(表 1,图 3a)。选择以上用于锆石 U-Pb 定年的测点进行原位 Hf 同位素分析,15 个测点的分析结果显示,锆石 $\epsilon_{\text{Hf}}(t)$ 值为 +2.65 ~ +6.23,二阶段模式年龄 t_{DM2} 为 1015~1243 Ma(表 2)。

样品 16CL221:锆石呈长柱状,长约 110~210 um,具岩浆振荡环带,锆石 Th 含量为 178×10^{-6} ~ 1540×10^{-6} , U 含量为 298×10^{-6} ~ 1857×10^{-6} , Th/U 比值为 0.4~1.2,为典型岩浆锆石(Koschek, 1993; Corfu et al., 2003)。本文对样品中的 15 颗锆石进行了年龄测定,测点的²⁰⁶Pb/²³⁸U 加权平均年龄为 423 ± 3 Ma,代表岩体的侵位年龄

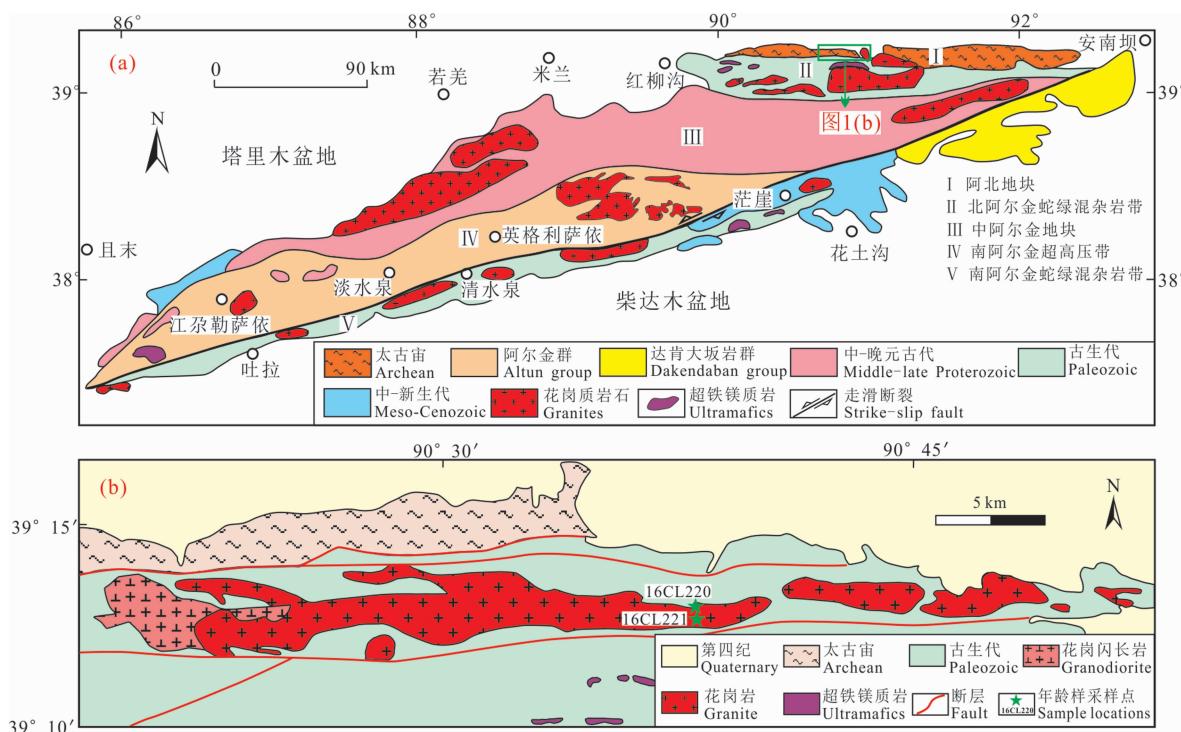


图 1 阿尔金造山带构造单元划分图(a)(据 Wu Callai et al., 2016 修改)及喀孜萨依地区地质简图(b)
(据 1/20 万巴什考供幅地质图修编)

Fig. 1 Geological map showing the tectonic units of the Altun orogenic belt(a)(modified after Wu Callai et al., 2016) and geological sketch map of the Kazisayi area(b)(modified after 1/200000 regional geological map of Bashikaogong region)

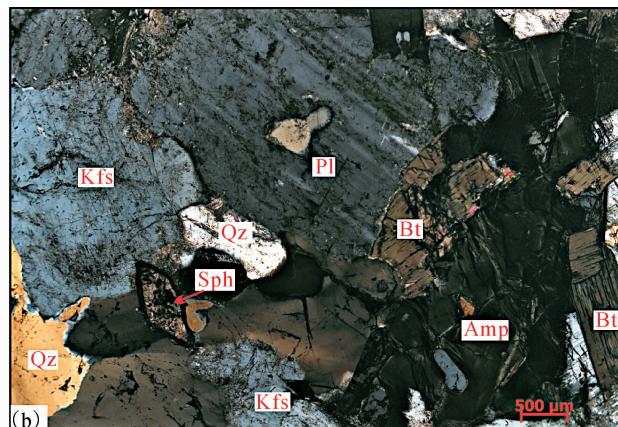


图 2 喀孜萨依二长花岗岩野外露头照片和显微照片(正交偏光)

Fig. 2 Field photographs and micrographs of the Kazisayi monzogranites

Qz—石英; Pl—斜长石; Kfs—钾长石; Amp—角闪石; Bt—黑云母; Sph—榍石

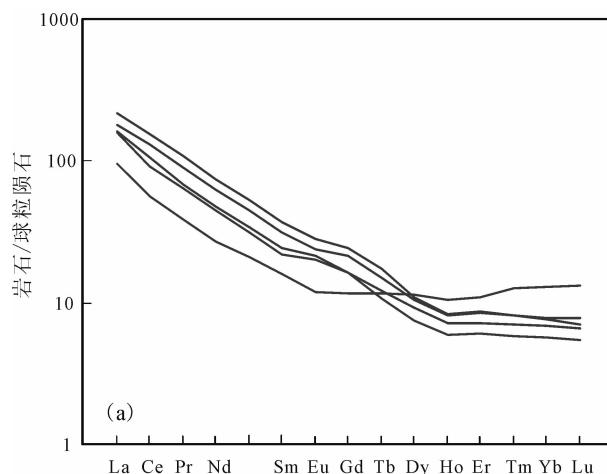
Qz—quartz; Pl—plagioclase; Kfs—K-feldspar; Amp—amphibole; Bt—biotite; Sph—sphene

(表 1, 图 3b)。选择以上用于锆石 U-Pb 定年的测点进行原位 Hf 同位素分析, 15 个测点分析结果显示, 锆石 $\epsilon_{\text{Hf}}(t)$ 值为 $+2.79 \sim +5.24$, 二阶段模式年龄 t_{DM2} 为 1076~1232 Ma(表 2)。

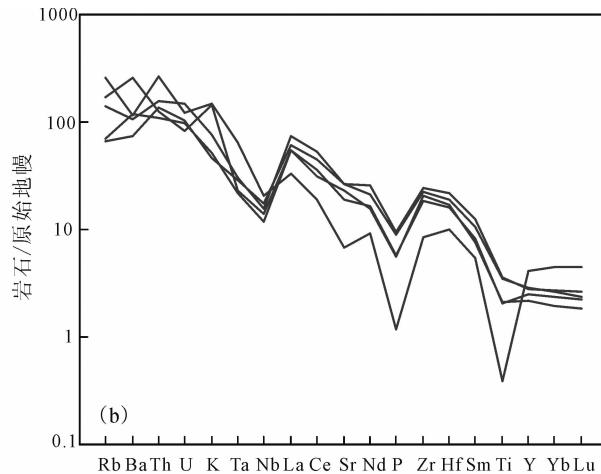
3.2 地球化学特征

喀孜萨依二长花岗岩样品中, SiO_2 含量为 $64.87\% \sim 75.09\%$, Al_2O_3 含量为 $13.39\% \sim$

16.77% , 全铁含量 FeO^{T} 为 $0.92\% \sim 3.31\%$, MgO 含量为 $0.30\% \sim 1.76\%$, TiO_2 含量为 $0.08\% \sim 0.78\%$, Na_2O 含量为 $3.63\% \sim 4.87\%$, K_2O 含量为 $1.37\% \sim 4.42\%$, $\text{Na}_2\text{O}/\text{K}_2\text{O}$ 比值为 $0.82 \sim 3.36$ 。岩石呈弱过铝质, 铝饱和指数 A/CNK 为 $0.97 \sim 1.05$, 平均为 1.02, 样品在 $\text{K}_2\text{O}-\text{SiO}_2$ 图解中落入钙碱性-高钾钙碱性区域, 以上特征表明喀孜萨依二长



(a)



(b)

图 5 二长花岗岩稀土元素球粒陨石标准化配分模式和微量元素蛛网图(标准化值据 Sun et al., 1989)

Fig. 5 Chondrite-normalized REE patterns and trace element spider diagram for the monzogranites
(normalized values after Sun et al., 1989)

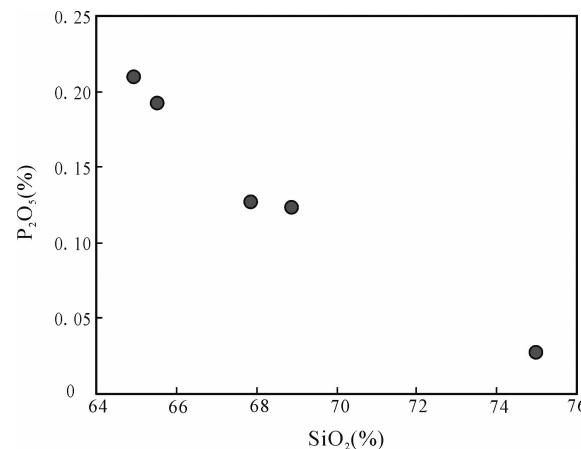
4 讨论

4.1 岩体侵位时代及成因

Qi Xuexiang et al. (2005b) 曾报道了喀孜萨依二长花岗岩体侵位时代为 404.7 Ma, 属 I 型花岗岩, 岩浆来自地幔楔部分熔融。但地幔部分熔融难以产生花岗岩, 岩体的成因及其产出的构造环境仍不明确。近来, 笔者在对该岩体开展了岩石学、地球化学、锆石 U-Pb 定年及 Hf 同位素等方面的研究, 锆石 U-Pb LA-ICP-MS 定年结果显示, 该岩体侵位时代为 425~423 Ma, 为北阿尔金地区早古生代岩浆活动晚期产物。

花岗岩通常被划分为 I 型、S 型、M 型或 A 型。A 型花岗岩中常缺少含水矿物, 具较高的碱含量和 REE 总量, 高的 Ga/Al 和 Fe/Mg 比率, 低的 Ba、Sr、Eu 含量, 明显的负 Eu 异常 (Whalen et al., 1987; White et al., 1983)。S 型花岗岩常呈过铝质, 含有石榴子石、白云母、堇青石等富铝矿物, A/CNK > 1.1, K₂O > Na₂O (Sylvester, 1998)。而 I 型花岗岩常含有角闪石、磷灰石、榍石等矿物, A/CNK 通常小于 1.1。另外, 有研究表明, 在准铝质-弱过铝质 I 型花岗岩中 P₂O₅ 与 SiO₂ 含量呈负相关, 而在 S 型花岗岩中 P₂O₅ 含量随 SiO₂ 含量的增加而增加或基本不变 (Chappell, 1999)。喀孜萨依二长花岗岩中不含石榴子石、白云母、堇青石等富铝矿物, A/CNK < 1.1。岩石样品中基本没有继承锆石, 且锆石 ε_{Hf}(t) 值均为正值, 上述这些特征均表明其并不属于 S 型花岗岩。喀孜萨依二长花岗岩含有角闪石、磷灰石、榍石、磁铁矿等矿物, REE 总量 (86.6 ×

10⁻⁶ ~ 208.8 × 10⁻⁶) 不高, Eu 异常不明显, 且 10000 × Ga/Al < 2.6, 与 A 型花岗岩明显不同 (Whalen et al., 1987)。另外, 岩石中 P₂O₅ 与 SiO₂ 含量呈明显负相关关系 (图 6), 上述这些特征均表明喀孜萨依二长花岗岩属 I 型花岗岩 (Chappell, 1999)。

图 6 二长花岗岩 SiO₂-P₂O₅ 图解Fig. 6 SiO₂-P₂O₅ plot for the monzogranites

I 型花岗岩成因一直存在争论, 一般认为是来自下地壳火成岩石的部分熔融 (Chappell et al., 1988; White et al., 1983)。近些年来的研究显示, 许多 I 型花岗岩来自壳幔岩浆的混合 (Barbarin, 2005; Kocak et al., 2011)。另外, 一些研究表明, 幕源铁镁质岩浆的结晶分异可以产生花岗岩 (Dessimoz, 2012; Grove et al., 2003; Jagoutz et al., 2012)。通过幕源铁镁质岩浆分异形成的花岗岩常与大规模同时代的铁镁质岩有关 (Turner et al.,

al., 2008)。混杂岩带西段的贝克滩及红柳泉一带出露有高压泥质变质岩、榴辉岩及蓝片岩,被认为与洋壳俯冲有关,其中榴辉岩多硅白云母³⁹Ar-⁴⁰Ar等时线年龄为513 Ma,蓝片岩钠白云母³⁹Ar-⁴⁰Ar年龄为497 Ma,暗示北阿尔金地区在早古生代发生过洋壳俯冲(Zhang Jianxin et al., 2007)。此外,区内还出露有大量与俯冲有关的侵入岩和火山岩,这些火成岩的年代学研究表明北阿尔金地区洋壳俯冲可能发生在520~460 Ma(Qi Xuexiang et al., 2005a; Wu Cailai et al., 2007; Kang Lei et al., 2011; Han Fengbin et al., 2012; Li Songbin, 2013; Meng Lingtong et al., 2016, 2017)。

北阿尔金蛇绿混杂岩带基质(即绿片岩相变质岩系)中的绢云母⁴⁰Ar/³⁹Ar定年结果表明蛇绿岩构造侵位时间为455 Ma,暗示俯冲结束和碰撞开始可能在450 Ma左右(Hao Jie et al., 2006)。Wu Cailai et al.(2005, 2007, 2009)报道了混杂岩带西段巴什考供盆地南北两侧的S型花岗杂岩体,获得杂岩体的主要侵位时代为(446~431 Ma),并认为形成于碰撞环境(Wu Cailai et al., 2005, 2007, 2009)。Yu Shengyao et al.(2018)报道了红柳沟一带的高Mg和低Mg两种类型的埃达克质花岗岩,并认为低Mg型埃达克质花岗岩(445~439 Ma)形成于陆陆碰撞加厚环境,而高Mg型埃达克质花岗岩(425~422 Ma)则形成于碰撞后伸展阶段。本文研究的喀孜萨依二长花岗岩体(425~423 Ma),与红柳沟高Mg型埃达克质花岗岩(425~422 Ma, Yu Shengyao et al., 2018)及混杂岩带东段的阿北岩体(417 Ma, Han Fengbin et al., 2012)形成时代相近,均为北阿尔金早古生代花岗岩浆作用晚期的产物,可能形成于碰撞后伸展环境。

5 结论

(1) 喀孜萨依二长花岗岩主要由石英、钾长石、斜长石、角闪石和黑云母等矿物组成,岩体侵位时代为425~423 Ma,岩石铝饱和指数A/CNK为0.97~1.07,属弱过铝质钙碱性-高钾钙碱性岩石,P₂O₅与SiO₂含量呈负相关,具I型花岗岩特征。轻稀土富集而重稀土亏损,Eu异常不明显,微量元素特征显示富集Rb、Ba、Th、U、K等元素,相对亏损Nb、Ta、P、Ti等元素。

(2) 喀孜萨依二长花岗岩锆石ε_{Hf}(t)值为+2.65~+6.23,二阶段模式年t_{DM2}为1015~1243 Ma,其源岩主要来自新生地壳。结合区域构造背

景,喀孜萨依二长花岗岩体可能形成于碰撞后伸展环境。

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Petrogenesis of the Kazisayi monzogranite from North Altun and its tectonic implications

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Abstract

Kazisayi monzogranite pluton crops out at the northern margin of the North Altun ophiolitic mélange belt. In this paper, we present petrological, geochemical, and zircon U-Pb and Lu-Hf isotopic data of the Kazisayi monzogranites to constrain their petrogenesis, source and tectonic setting. The Kazisayi monzogranites consist of mainly quartz, alkali feldspar, plagioclase, amphibole and biotite. Zircon U-Pb dating yielded ages of 425~423 Ma. The rocks have high K₂O with A/CNK varying from 0.97 to 1.07. The granites are weakly peraluminous and plotted within the medium-K to high-K calc-alkaline fields. These rocks show a negative correlation between P₂O₅ and SiO₂ and show significant features of I-type granite. The REE patterns show a significant depletion in HREE, relative to LREE, and lack Eu anomalies. In the primitive mantle-normalized trace-element diagram, the samples show highly enrichments in Rb, Ba, Th, U and K and depletions in Nb, Ta, P and Ti. The $\epsilon_{\text{Hf}}(t)$ values range from 2.65~6.23 with T_{DM2} (two-stage model ages) from 1015 Ma to 1243 Ma. These characteristics indicate that Kazisayi monzogranites derived mainly from the juvenile crust. Considering the regional tectonic setting, the Kazsayi monzogranites may have formed in a post-collision extensional setting.

Key words: monzogranite; geochemistry; zircon U-Pb dating; petrogenesis; North Altun