阿尔金断裂带东段古生代花岗岩浆作用及其大陆动力学意义

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造山带花岗岩浆作用一直是地学的重要研究方向, 它记录了地球动力学深部过程的信息, 开展深入的研究工作可以更好的了解板块汇聚环境的陆壳生长和再造以及壳幔之间的相互作用。北祁连造山带是一典型的早古生代造山带, 先后经历了洋盆的打开到闭合, 敦煌地块则是主要由前寒武纪 TTG 片麻岩和变质表壳岩组成。北祁连造山带和敦煌地块分别位于阿尔金断裂带东段的东南侧和西北侧, 且均出露有大面积的古生代花岗岩体。本文以阿尔金主断裂两侧产出的花岗岩类为研究对象, 涉及北祁连造山带中的赵家庄二长花岗岩, 石包城复式岩体(花岗岩、正长花岗岩和花岗闪长岩)和红柳河花岗岩, 敦煌地块中的党河水库花岗闪长岩、沙枣园二长花岗岩、安盆沟复式岩体(正长花岗岩和花岗岩)以及小草湖似斑状花岗岩。通过对上述花岗岩体的岩相学、锆石 U-Pb 年代学、地球化学和锆石 Hf 同位素的研究, 取得了新的认识:

(1)根据锆石 U-Pb 年代学结果, 本文选取的北祁连造山带内典型花岗岩体形成时代分别为: 石包城花岗岩为 464 Ma, 花岗闪长岩为 460~447 Ma, 正长花岗岩为 447 Ma; 红柳河花岗岩为 453 Ma; 赵家庄二长花岗岩为 440 Ma。敦煌地块三危山地区的党河水库花岗闪长岩形成于 462~438 Ma, 沙枣园中-细粒二长花岗岩形成于 458~434 Ma, 而敦煌地块南部的安盆沟正长花岗岩形成于 431 Ma, 花岗岩形成于 360 Ma 和 339 Ma, 小草湖似斑状花岗岩形成于 344~340 Ma。年代学结果表明, 阿尔金断裂带东段两侧块体中的花岗岩均具有不同的期次。

(2)岩石地球化学数据显示, 北祁连造山带内石包城花岗岩属钙碱性系列, 具强过铝质特征; 稀土配分模式为右倾型, $(La/Yb)_N$ 比值为 13.99~20.44, 具有中度-轻度的负 Eu 异常, 富集大离子亲石元素(LILE)Rb、Ba、K、Sr 等, 相对亏损高场强元素(HFSE)Nb、Ta、P、Ti 等; 锆元素饱和浓度温度 t_{Zr} 平均为 760℃, 稀土元素饱和浓度温度 t_{REE} 为 732℃。石包城花岗闪长岩属钙碱性-高钾钙碱性系列, 具准铝质-弱过铝质特征; 稀土配分模式为右倾型, $(La/Yb)_N$ 比值为 6.51~64.78, 不同样品分别具有轻微的 Eu 负异常和较强的正 Eu 异常, 富集 Rb、Th、U、K 等元素, 亏损 Ni、Ta、P、Ti 等高场强元素, 并且还表现出一定程度的 Sr 正异常; t_{Zr} 和 t_{REE} 平均温度分别为 746℃和 685℃。石包城正长花岗岩属高钾钙碱性系列, 具过铝质特征; $(La/Yb)_N$ 比值为 4.52, 具有强烈的负 Eu 异常和明显的 Ba、Sr、Ti 负异常; t_{Zr} 和 t_{REE} 温度分别为 678℃和 676℃。红柳河花岗岩属钙碱性-高钾钙碱性系列, 具过铝质特征; $(La/Yb)_N$ 为 20.99~42.89, 具中度-轻度的负 Eu 异常和明显的 K 和 Sr 正异常, 富集大离子亲石元素 Rb、Ba、K、Sr 等, 相对亏损高场强元素 Nb、Ta、P、Ti 等; t_{Zr} 和 t_{REE} 平均温度分别为 760℃和 742℃。赵家庄二长花岗岩属钙碱性系列和高钾钙碱性系列, 具准铝质到弱过铝质特征; 稀土配分模式为右倾型, $(La/Yb)_N$ 为 11.61~12.97, 具有弱的负 Eu 异常, 富集 Rb、Ba、Th、U、K 等元素, 亏损 Nb、Ta、P、Ti 等元素; t_{Zr} 和 t_{REE} 平均温度分别为 769℃和 673℃。敦煌地块中, 党河水库花岗闪长岩属钙碱性-高钾钙碱性系列, 具过铝质特征; 稀土配分模式为右倾型, $(La/Yb)_N$ 为 11.55~41.95, 具中度-轻度的负 Eu 异常, 富集大离子亲石元素 K、Rb、Ba, 亏损高场强元素 Nb、Ta、P 和 Ti; t_{Zr} 和 t_{REE} 平均温度分别为 785℃和 793℃。沙枣园二长花岗岩多属高钾钙碱性系列, 同样具过铝质特征; $(La/Yb)_N$ 为

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10.86~70.36，并表现出中度的负 Eu 异常，富集大离子亲石元素 K、Rb、Ba，相对亏损高场强元素；t_{Zr} 和 t_{REE} 平均温度均为 752℃。安盆沟正长花岗岩和花岗岩为高钾钙碱性系列，具过铝质特征；稀土配分模式为右倾型，$(La/Yb)_N$ 比值为 6.52~30.3，具中度-强烈的负 Eu 异常，富集大离子亲石元素 K、Rb，亏损高场强元素 Nb、Ta、P 和 Ti；t_{Zr} 和 t_{REE} 平均温度分别为 799℃、763℃和 829℃、784℃。小草湖似斑状花岗岩为高钾钙碱性系列，具准铝质-弱过铝质特征；$(La/Yb)_N$ 比值为 15.96~51.05，具中度-弱的负 Eu 异常和明显的正 Eu 异常，富集 Rb、Ba、K 等强不相容元素，具有明显的 Ba、K 正异常，以及 U、Ta、Nb、P、Ti 负异常；t_{Zr} 和 t_{REE} 平均温度分别为 787℃和 796℃。

(3)上述地球化学特征表明，北祁连造山带中 I 型花岗岩和 S 型花岗岩均有出露。其中，石包城花岗岩、花岗闪长岩和红柳河花岗岩为 I 型花岗岩，形成于北祁连洋的北向俯冲阶段。石包城花岗岩的残留相为麻粒岩，石包城花岗闪长岩和红柳河花岗岩的残留相可能为麻粒岩，甚至是不含斜长石的榴辉岩。并且，石包城花岗闪长岩和红柳河花岗岩还具有较高的 Sr/Y 比值和明显的埃达克质岩石特征，地球化学特征表明为加厚下地壳部分熔融的产物。岩相学和地球化学特征表明，石包城正长花岗岩为 S 型花岗岩，而赵家庄二长花岗岩为典型 I 型花岗岩，二者形成于同碰撞阶段。赵家庄二长花岗岩的残留相为不含石榴石的角闪岩。北祁连造山带中花岗岩类具有一定的时空分布规律，>470 Ma 的花岗岩类主要出露于北祁连与中祁连的交界处，465~440 Ma 的花岗岩则分布与北祁连与阿拉善地块的交界处，<435 Ma 的花岗岩同样出露于北部，分别对应着北祁连洋的南向俯冲、北向俯冲-闭合-同碰撞以及造山后调整阶段，整体上由南向北逐渐年轻。

(4)敦煌地块中同样出露有 I 型花岗岩和 S 型花岗岩。三危山地区的党河水库花岗闪长岩为 I 型花岗岩，残留相为石榴石、角闪石和斜长石为主的麻粒岩，沙枣园中-细粒二长花岗岩为 S 型花岗岩，并且敦煌地块早古生代的造山活动可能提前至 462 Ma。安盆沟正长花岗岩和花岗岩为 S 型花岗岩，但小草湖似斑状花岗岩为加厚下地壳部分熔融成因的埃达克质岩石，具 I-S 过渡型特征。三者的残留相分别为麻粒岩、角闪岩和麻粒岩-角闪榴辉岩，反映了形成深度和变质程度的不同。敦煌地块中早古生代花岗岩主要产于三危山地区和南截山断裂地区，晚古生代花岗岩主要产于三危山断裂中部、以及敦煌地块南部，整体上有由北向南年轻的趋势。

(5)石包城花岗岩、花岗闪长岩，红柳河花岗岩和赵家庄二长花岗岩的 $\varepsilon_{Hf}(t)$和二阶段模式年龄 T_{DM2} 分别变化于+7.6 ~ +12.7、+6.4 ~ +13.4、+0.8 ~ +12.4、+5.7 ~ +11.0 和 0.6~1.0 Ga、0.57~1.0 Ga、0.58~1.0 Ga、0.7~1.0 Ga 之间，源岩主要为新元古代新生基性下地壳，可能与 Rodinia 超大陆的聚合和裂解有关。石包城正长花岗岩的 $\varepsilon_{Hf}(t)$和二阶段模式年龄 T_{DM2} 分别为–2.9 ~ +1.2 和 1.35~1.6 Ga，源岩主要为含部分新生地壳物质的中元古代-新元古代的泥质岩。党河水库花岗闪长岩和沙枣园二长花岗岩的 $\varepsilon_{Hf}(t)$和二阶段模式年龄 T_{DM2} 分别为–5.5 ~ +2、–8.6 ~ –0.9 和 1.3~1.7 Ga、1.5~1.9 Ga，党河水库岩体的源岩以中元古代古老地壳为主，同时含部分新生地壳的(变)基性岩，而沙枣园岩体的源岩是以古元古代晚期到中元古代早期的古老地壳为主的富长石贫黏土的(变)杂砂岩。安盆沟复式岩体的 Hf 同位素特征相似，$\varepsilon_{Hf}(t)$和 T_{DM2} 分别为–12.3 ~ –5.5 和 1.7~2.2 Ga，来源于古元古代–中元古代时期的古老地壳，源岩为含泥质成分的(变)砂质岩。小草湖岩体的 $\varepsilon_{Hf}(t)$和 T_{DM2} 分别为–16.7 ~ –4.9 和 1.8~2.4 Ga，源岩为古元古代古老地壳物质。敦煌地块中花岗岩体的部分源岩可能与 2.0~1.6 Ga 期间的 Columbia 超大陆聚合和裂解事件有关。

(6)总体上，阿尔金断裂带东段两侧地体中花岗岩类有较大的区别。阿尔金—祁连造山带基本于晚奥陶世结束了造山活动，而敦煌地块时代整体较晚，~400 Ma 仍存在造山活动，敦煌地块和中央造山带于早古生代和晚古生代可能经历了不同的地质演化历史，但与北侧的天山—北山造山带的花岗岩类具有时空对应关系，因此，敦煌地块可能在古生代期间卷入了中亚造山带的造山活动中。

关键词： 阿尔金断裂带；北祁连造山带；敦煌地块；花岗岩类；岩石成因；时空分布；动力学意义
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The Paleozoic Granitic Magmatism of the Eastern Altyn Tagh Fault Belt and Its Continental Dynamic Significance

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As an important research direction in earth science, granitic magmatism of the orogenic belt contains abundant information about the geodynamic process at depths. Research work about granitoids can provide more information for understanding the growth and reconstruction of continental crust in plate convergence environment and the crust-mantle interaction. The North Qilian orogenic belt was a typical Early Paleozoic orogenic belt through opening and closing of an ocean basin, while Dunhuang block was mainly composed of Precambrain TTG gneisses and metamorphosed supracrustal rocks. The two tectonic units were located on the northeast side and southwest side of the eastern Altyn tagh fault belt, respectively, with numerous Paleozoic granitoids emplaced in. Aiming to better understand the tectonic evulotion and the geodynamic significance of North Qilian orogenic belt and Dunhuang block, in this thesis, granitoids exposed along the Altyn tagh fault were selected as the research subjects, involving Zhaojiazhuang monzogranite, Shibaocheng composite granites (granite, syenogranite and granodiorite) and Hongliuhe granite in North Qilian orogenic belt and Danghe reservoir granodiorite, Shazaoyuan monzogranite, Anpengou composite granites(syenogranite and granite) and Xiaocaohu porphyritic granite in Dunhuang block. On the basis of petrography, zircon U-Pb geochronology, geochemistry and zircon Hf isotope for the granitoids mentioned above, new understandings have been achieved:

(1) According to the results from zircon U-Pb geochronology, among the typical granitoids of North Qilian orogenic belt, Shibaocheng granite, granodiorite and syenogranite were emplaced in 464 Ma, 460~447 Ma and 447 Ma, respectively. Hongliuhe granite and Zhaojiazhuang monzogranite were emplaced in 453 Ma and 440 Ma, respectively. While Danghe reservoir granodiorite and Shaozaoyuan monzogranite in Sanweishan area of Dunhuang block were emplaced in 462~438 Ma and 458~434 Ma, respectively. The syenogranite of Anpengou composite granites in southern Dunhuang block was emplaced in 431 Ma, and the Late Paleozoic granite was emplaced in 360 Ma and 339 Ma. Xiaocaohu porphyritic granite was emplaced in 344~340 Ma. Geochronological results show that the granitoids of the two tectonic units in eastern Altyn tagh fault belt were formed in multiple magmatic events.

(2) The geochemical data reveals that Shibaocheng granite in North Qilian orogenic belt belongs to calc-alkaline series with strong peraluminous features. Chondrite-normalized rare earth elements (REE) patterns reveals significant enrichment of light REE (LREE) relative to heavy(HREE) with medium-slight negative Eu anomalies, and $(La/Yb)_N$=13.99~20.44. In the primitive mantle-normalized trace diagram, Shibaocheng granite is enriched in large-ion lithophile elements (LILEs)(e.g., Rb, Ba, K, Sr) but depleted in high field strength elements(HFSEs)(e.g., Nb, Ta, P, Ti). The average t_{Zr} and t_{REE} are 760℃ and 732℃,respectively. Shibaocheng granodiorite belongs to calc-alkaline to high-K calc-alkaline series with metaluminous to weak peraluminous features. Chondrite-normalized REE patterns are right-leaning type with different $(La/Yb)_N$ ratios (6.51~64.78) and slight negative Eu to relative strong Eu positive anomalies. In the primitive mantle-normalized trace diagram, Shibaocheng granodiorite is enriched in LILEs (e.g., Rb, Th, U, K) but depleted in HFSEs (e.g., Ni, Ta, P, Ti), and shows obvious positive Sr anomalies. The average t_{Zr} and t_{REE} are 746℃ and 685℃, respectively. Shibaocheng syenogranite belongs to high-K calc-alkaline series with peraluminous features. $(La/Yb)_N$ ratio is equal to 4.52 with strong negavite Eu anomalies and obvious negative Ba, Sr, Ti anomalies. The t_{Zr} and t_{REE} are 678℃ and 676℃, respectively. Hongliuhe granite belongs to calc-alkaline to high-K calc-alkaline series with peraluminous features. Chondrite-normalized REE patterns and primitive mantle-normalized trace diagrams show medium-slight negative Eu anomalies and obvious positive K and Sr anomalies with high$(La/Yb)_N$ ratios(20.99~42.89), and the enrichment in LILEs(e.g., Rb, Ba, K, Sr) and losses of HFSEs(Nb, Ta, P, Ti). The average t_{Zr} and t_{REE} are 760℃ and 742℃, respectively. Zhaojiazhuang monzogranite belongs to calc-alkaline to high-K calc-alkaline series with metaluminous to weak peraluminous features. Chondrite-normalized REE patterns show right-leaning type with slight negative Eu anomalies. Zhaojiaz-

huang monzogranite is enriched in Rb, Ba, Th, U, K elements but depleted in Nb, Ta, P, Ti elements. The average t_{Zr} and t_{REE} are 769℃ and 673℃,respectively. In Dunhuang block, Danghe reservoir granodiorite belongs to calc-alkaline to high-K calc-alkaline series with peraluminous features. Chondrite-normalized REE patterns show right-leaning type with medium-slight negative Eu anomalies and different $(La/Yb)_N$ ratios(11.55~41.95). In the primitive mantle-normalized trace diagram, Danghe reservoir granodiorite is enriched in LILEs(e.g.,Rb, Ba, Th, U, K) but depleted in HFSEs(Nb, Ta, P, Ti). The average t_{Zr} and t_{REE} are 785℃ and 793℃, respectively. Shazaoyuan monzogranite belongs to high-K calc-alkaline series with peraluminous features. Chondrite-normalized REE patterns show medium negative Eu anomalies with different $(La/Yb)_N$ ratios (10.86~70.36). Besides that, Shazaoyuan monzogranite is enrichment in LILEs(e.g., K, Rb, Ba) but depleted in HFSEs, and both average t_{Zr} and t_{REE} is 752℃. Both Anpengou syenogranite and granite belongs to high-K calc-alkaline series with peraluminous features. Chondrite-normalized REE patterns show right-leaning type with medium-strong negative Eu anomalies. Primitive mantle-normalized trace diagram indicates that Anpengou composite granites are enriched in LILEs but depleted in HFSEs. The average t_{Zr} and t_{REE} of Anpengou syenogranite and granite are 799℃, 763℃ and 829℃, 784℃, respectively. Xiaocaohu porphyritic granite belongs to high-K calc-alkaline series with metaluminous to weak peraluminous features. $(La/Yb)_N$ ratios are ranging from 15.96 to 51.05, and chondrite-normalized REE patterns show medium-weak negative Eu anomalies and obvious positive Eu anomalies for different samples. Primitive mantle-normalized trace diagram reveals that Xiaocaohu porphyritic granite is enriched in LILEs(e.g., Rb, Ba, K) with obvious positive Ba and K anomalies, but depleted in U, Ta, Nb, P, Ti elements. The average t_{Zr} and t_{REE} are 787℃ and 796℃, respectively.

(3) The geochemical characteristics mentioned above indicate that both I- and S- type granites outcroped in North Qilian orogenic belt. Among them, Shibaocheng granite, granodiorite and Hongliuhe granite showed the features of I-type granite, and were formed in the northward subduction and closure stage of North Qilian Ocean. The residual rocks of Shibaocheng granite were granulite, while the residual rocks of Shibaocheng granodiorite and Hongliuhe granite were granulite and even the eclogite without plagioclase. In addition, Shibaocheng granodiorite and Hongliuhe granite also showed the features of adakitic rocks with high Sr/Y ratios, and the geochemistry characteristics indicated that the two granites were generated by partial melting of thickened crust. Both Shibaocheng syenogranite and Zhaojiazhuang monzogranite were formed in the syn-collision stage, and Zhaojiazhuang monzogranite showed the features of I-type granite while Shibaocheng syenogranite showed the features of S-type granite by means of petrography and geochemistry. The residual rocks of Zhaojiazhuang monzogranite was the amphibolite without garnet. The granitoids in North Qilian orogenic belt exhibited a certain temporal-spatial regulation. >470 Ma granitoids were outcroped in the conjuction area between Qilian block and North Qilian orogenic belt, while 465~440 Ma and <435 Ma granitoids were dispersed in the conjuction area between Alax block and North Qilian orogenic belt. These three groups of grantoids were corresponding with the southward subduction, north subduction of North Qilian Ocean and syn-collision stage, respectively. In general, the formation age was younger from south to north.

(4)Similarly, Both I- and S- type granite outcroped in Dunhuang block. Danghe reservoir granodiorite and Shazaoyuan monzogranite in Sanweishan area showed the features of I-type and S-type, respectively. And the residual rocks of the former granite were the granulite mainly consisted of garnet, hornblende and plagioclase. In combination with previous study, we propose that the Early Paleozoic orogenic activities in Dunhuang block can be advanced to 462 Ma. Syenogranite and granite of Anpengou composite granites showed the features of S-type granite, but Xiaocaohu porphyritic granite was considered as the thicken-lower crust-derived adakitic rocks with features of I-S transitional type. The residual rocks of Anpengou syenogranite, Anpengou granite and Xiaocaohu porphyritic granite were granulite, amphibolite and granulite-amphibole eclogite, which reflected the differences in the formation depth and degree of metamorphism. In Dunhuang block, the Early Paleozoic granitoids mainly exposed in the areas nearby Sanweishan fault and Nanjieshan fault, while the Late Paleozoic granitoids outcroped in the middle area of Sanweishan fault and southern of Dunhuang block. In general, the age of granitoids gradually get younger from north to south.

(5)Shibaocheng granite and granodiorite, Hongliuhe granite and Zhaojiazhuang monzogranite showed similar Hf isotopic characteristics, with $\varepsilon_{Hf}(t)$ of the granites mentioned aboved ranging from +7.6 ~ +12.7、+6.4 ~ +13.4、+0.8 ~ +12.4 and +5.7 ~ +11.0, and two stage model age T_{DM2} were varied in 0.6~1.0 Ga、0.57~1.0 Ga、0.58~1.0 Ga and 0.7~1.0 Ga, indicating that the source rocks of these granites were derived from Neoproterozoic juvenile mafic crust, and may have a relationship with the assemblage and break-up of the Rodinia supercontinent. But the Hf isotopic characteristics of Shibaocheng syenogranite showed a great difference with other granites in North

Qilian orogenic belt, with $\varepsilon_{Hf}(t)$ ranging from –2.9 ~ +1.2, and T_{DM2} was varied in 1.35~1.6 Ga, indicating that the source rocks was mainly Mesoproterozoic pelite-derived components, perhaps with some juvenile crustal materials. In Dunhuang block, $\varepsilon_{Hf}(t)$ of Danghe reservoir granodiorite and Shazaoyuan monzogranite were ranged from –5.5 ~ +2 and –8.6 ~ –0.9, and T_{DM2} varied in 1.3~1.7 Ga and 1.5~1.9 Ga. Under the consideration of geochemical characteristics, we propose that the source rocks of Danghe reservoir granodiorite mainly derived from Mesoproterozoic ancient crustal materials with part of the juvenile crustal meta-basic rocks, while the source rocks of Shazaoyuan monzogranite derived from meta-greywacke of late Paleoproterozoic to early Mesoproterozoic ancient crust. Anpengou syenogranite and granite showed similar Hf isotopic characteristics, with $\varepsilon_{Hf}(t)$ ranging from –11.7 ~ –6.3 and –12.3 ~ –5.5, and T_{DM2} were varied in 1.8~2.2 Ga and 1.7~2.1 Ga, respectively. Both source rocks of the Early Paleozoic syenogranite and the Late Paleozoic granite mainly derived from meta-greywacke with part of metapelitic materials of Paleoproterozoic to Mesoproterozoic ancient crust. $\varepsilon_{Hf}(t)$ of Xiaocaohu porphyritic granite was ranging from –16.7 ~ –4.9 and T_{DM2} was varied in 1.8~2.4 Ga, indicating that the source rocks of Xiaocaohu porphyritic granite derived from the Paleoprpterozoic crustal materials. In addition, some of the source rocks of the granites emplaced in Dunhuang block may be related to the assemblage and break-up of Columbia supercontinent during 2.0~1.6 Ga.

(6)Overall, granitoids exposed in the two block of eastern Altyn tagh fault belt show great differences with each other. The orogenic activities of Altyn tagh-Qilian orogenic belt were basically ended in Late Ordovician, while the orogenic activities of Dunhuang block ended much later (~400 Ma). Dunhuang block and North Qilian orogenic belt may undergo two different histories of tectonic evolution in Early Paleozoic and Late Paleozoic, but the granitoids in Dunhuang block have a temporal-spatial coupled relationship with the Tianshan-Beishan orogenic belt which lies to the north of Dunhuang block. Therefore, Dunhuang block may involve in the orogenic activities of Central Asian orogenic belt.

Key words: Altyn tagh fault belt; North Qilian orogenic belt; Dunhuang block; granitoids; genesis; temporal-spatial distribution; dynamic significance

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