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东昆仑—西秦岭造山带对接处三叠纪花岗质岩石时空演化、物源特征对比及其大地构造意义

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造山带组成与演化是大地构造研究的主要课题, 造山带之间的对接关系更是造山带研究的重要节点。在两大造山带对接地带, 构造-岩浆演化的对比, 特别是深部物质组成结构和基底属性的对比, 可为完整认识造山带的物质组成和构造演化提供重要的依据。基于花岗质岩石同位素填图(Sm-Nd、Lu-Hf)在其年代学、区域性大面积展步和易于示踪等方面的优势, 区域性的同位素填图逐步成为一项重要的技术方法, 应用于探讨造山带深部组成结构, 对比造山带基底属性异同。

作为中央造山系的主要组成部分, 昆仑与秦岭造山带在共和盆地处的东西向构造转换衔接关系, 历来为中国地质学界所关注和争议。共和盆地地理位置介于东昆仑东端和西秦岭西端之间, 其两侧的东昆仑和西秦岭造山带, 均为典型的多旋回复合造山带。在多期构造-岩浆热事件和造山作用中, 印支期花岗质岩石在这两大造山带内均出露面积最大, 分布范围最广。

本文选择东昆仑和西秦岭造山带对接地带, 以共和盆地东西两侧的三叠纪花岗质岩石为研究对象, 进行 Nd-Hf 同位素填图, 以期示踪深部物质结构, 系统对比共和盆地两侧秦—昆造山带印支期的构造岩浆演化过程和基底性质, 试图为深刻认识东昆仑—西秦岭两大造山带三叠纪构造岩浆演化、造山带基底物质组成特征提供新的依据。

在目前研究阶段, 众多研究者对东昆仑东段和西秦岭西段大面积出露的花岗质岩石已做了大量研究工作, 取得了众多研究成果, 奠定了区域性三叠纪岩浆作用年代学格架和 Nd-Hf 同位素填图的基础。但是, 对东昆仑东端和西秦岭西端部分重要岩体的研究甚弱, 如毗邻共和盆地东西两侧的虽根尔岗、满丈岗、热血日等花岗质岩体, 缺乏相关的年代学、主微量地球化学和 Nd-Hf 同位素等研究, 直接制约东昆仑与西秦岭两大造山带在共和盆地处的东西向构造对接。在系统收集东昆仑东段-西秦岭西段已公开发表文献中印支期花岗质岩石锆石 U-Pb 年代学数据、Lu-Hf 同位素组分(全岩、锆石)数据和全岩 Sm-Nd 同位素组分数据等资料的基础上, 结合东昆仑东端和西秦岭西端花岗质岩体的年代学、岩石学、地球化学和 Nd-Hf 同位素等实测数据, 本文系统对比共和盆地两侧秦-昆造山带印支期构造岩浆演化过程和造山带基底性质, 主要取得以下成果和认识:

(1)在东昆仑东端和西秦岭西端, 即毗邻共和盆地东西两侧处, 获得 12 个花岗质岩体 14 件锆石 U-Pb 年龄介于 252~224 Ma。结合研究区内公开发表文献中系统收集的 136 件锆石 U-Pb 年龄, 分析对比认为: 共和盆地两侧, 东昆仑东段-西秦岭西段三叠纪花岗质岩浆作用时限基本相似, 介于 252~203 Ma, 可整体进一步划分为早(252~238 Ma)、中(238~226 Ma)、晚(226~203 Ma)三期, 两大造山带三叠纪岩浆活动峰值均为早期 252~238 Ma 阶段。略有不同的是, 早三叠世(252~247 Ma)岩浆活动在东昆仑东段更为强烈。在中央造山系更大范围来看, 自西向东, 从东昆仑东段到西秦岭西段再到东秦岭, 早期(252~238 Ma) 岩浆活动在东昆仑东段-西秦岭西段发育强烈, 晚期(226~203 Ma)岩浆活动在东秦岭发育强烈, 即, 自西向东, 印支期岩浆活动在中

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央造山系范围内向东变年轻并增强。此外, 自共和盆地北部向南部, 印支期岩浆活动也有变年轻的趋势迹象。印支期岩浆岩年代学格架的建立和岩浆期次的划分与对比, 为分析东昆仑—西秦岭造山带三叠纪构造岩浆演化提供了年代学依据, 同时也为系统开展 Nd-Hf 同位素组分分析奠定了年代学基础。

(2)东昆仑造山带东端, 从早(252~237 Ma)到晚(234~232 Ma), 岩石类型从花岗闪长岩、闪长岩和流纹斑岩转变为正长花岗岩; 在西秦岭西端, 从早(245~238 Ma)到晚(232~224 Ma), 岩石类型从花岗闪长岩、英云闪长岩和闪长岩转变为闪长岩、二长花岗岩和花岗闪长岩。上述岩石地球化学整体显示富硅、高钾、高碱(K_2O+Na_2O)、低 P_2O_5 和低 TiO_2 的特征, 亏损 Ba、Sr、P、Ti 元素, 富集 U、Hf、Zr 等元素。除西秦岭西端热血日二长花岗岩(228 Ma)显示 S-型花岗岩的特点外, 其余岩石均显示 I-型花岗岩的特征。从岩浆活动早期到晚期, 在东昆仑东端和西秦岭西端, 岩石地球化学特征总体显示由火山弧区(或俯冲-碰撞前)向碰撞及板内(或碰撞后)构造环境转变的趋势。

(3)东昆仑东端和西秦岭西端测试的 23 件全岩 Nd 同位素组分显示, 早期初, $\varepsilon_{Nd}(t)$值较高、Nd 模式较年轻, 中期和晚期, Nd 同位素组分基本相似, 以较低的 $\varepsilon_{Nd}(t)$值和较古老的 Nd 模式年龄为主。结合系统收集的 193 件全岩 Nd 同位素组分数据, 统计表明, 东昆仑东段和西秦岭西段三叠纪花岗质岩石 $\varepsilon_{Nd}(t)$值主体为负, 集中于–8.5 ~ –2.5, Nd 模式年龄($T_{DM(Nd)}$)集中于 1.8~1.0 Ga。Nd 同位素组分演化特征显示, 在岩浆作用早期(252~238 Ma), 随侵位年龄变小, $\varepsilon_{Nd}(t)$值降低, 模式年龄变老, 显示古老壳源组分逐步增多; 中期(238~226 Ma), 高低 $\varepsilon_{Nd}(t)$并存, 新老物源组分共存; 晚期, $\varepsilon_{Nd}(t)$值逐步升高, 年轻物质组分逐步增多。

东昆仑东端和西秦岭西端测试的 14 件锆石 Hf 同位素组分显示, 早期初以高正 $\varepsilon_{Hf}(t)$值、年轻的 Hf 模式年龄为特征, 中期 $\varepsilon_{Hf}(t)$值主体为负、模式年龄最老, 晚期 $\varepsilon_{Hf}(t)$值正负相间、模式年龄较为年轻。结合系统收集的 56 件 Hf 同位素组分数据, 统计表明, 共和盆地两侧, 东昆仑东段和西秦岭西段印支期花岗质岩体的 $\varepsilon_{Hf}(t)$值主体一致, 均介于–5.5 ~ +5.5 之间。整体而言, 从早期(252~238 Ma)到中期(238~226 Ma)再到晚期(226~210 Ma), Hf 同位素参数似乎有一定的演变: 早期初, 以年轻组分为主, 随侵位年龄变年轻, 在早期末, $\varepsilon_{Hf}(t)$值低、模式年龄老, 古老壳源组分逐步增多; 中期, 高低 $\varepsilon_{Hf}(t)$值并存, 新老物源组分共存; 晚期, $\varepsilon_{Hf}(t)$值逐步升高, 模式年龄变年轻, 且相对年轻的物质组分比例逐步增多。

(4)216 套全岩 Nd 同位素组分(实测 23 套, 收集 193 套)统计分析表明, 东昆仑东段和西秦岭西段三叠纪岩浆岩 Nd 模式年龄主体范围基本一致, 均集中于 1.8~1.0 Ga。通过 Nd 同位素填图进一步揭示, 共和盆地东西两侧, Nd 模式年龄介于 1.2~1.0 Ga 的岩体面积最大, 1.8~1.6 Ga 其次, 1.6~1.4 Ga 再其次, 年轻物质 1.2~0.8 Ga 面积均很小, 并且, 最古老的物质(> 2.0 Ga)只出现在西秦岭。70 件锆石 Hf 同位素数据(实测 14 件, 收集 56 件)统计分析表明, 东昆仑东段和西秦岭西段三叠纪岩浆岩 Hf 模式年龄主体也基本一致, 均集中于 1.7~1.0 Ga。Hf 同位素填图揭示, 共和盆地两侧, Hf 模式年龄介于 1.4~1.2 Ga 和 1.6~1.4 Ga 的岩体面积占主导, 1.2~1.0 Ga 岩体众多但面积均较小, 最古老的物质(> 2.0 Ga)只出现在西秦岭。Nd-Hf 同位素组分统计分析结果和 Nd-Hf 同位素填图均表明, 印支期, 共和盆地两侧, 东昆仑和西秦岭具相似的深部地壳物质组成, 表明这两大造山带基底属性相同或相似。略有不同的是, 东昆仑东段基底更为均一, 且略微偏年轻一点。这提供了东昆仑和西秦岭两大造山带可能连接的深部物质组成证据。

(5)在前人研究基础上, 综合上述成果, 可以证实, 中央造山系中部东昆仑与西秦岭造山带交界地区即共和盆地东西两侧, 印支期, 秦—昆造山带具相似的构造岩浆过程和相似的深部地壳物质组成结构。这揭示, 早中生代, 东昆仑和西秦岭造山带实质上可能为同一个造山带, 都是在中特提斯洋北向俯冲增生(252~238 Ma)到碰撞(238~226 Ma 同碰撞, 226~203 Ma 后碰撞)的动力学背景下, 在相同或相似的古老块体基底上发育的早中生代造山带。

上述成果的重大意义在于: 花岗岩年代学、地球化学及 Nd-Hf 同位素物源研究, 揭示了构造岩浆演化特点, 特别是示踪了深部地壳物质组成结构和基底属性, 为东昆仑和西秦岭两大造山带构造单元划分与对比, 提供了新的证据。

关键词: 花岗质岩石; 锆石年代学; Nd-Hf 同位素填图; 岩浆演化作用; 东昆仑东段和西秦岭西段
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Temporal-spatial Variations, Sources and Tectonic Significances of the Triassic Granitic Rocks in the Junction Part of the East Kunlun and West Qinling Orogen, Central China

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The composition and evolution of orogen is the main subject of tectonic study, and the connection relationship between orogens is an important node in orogenic study. In the junction part of two orogenic belts, the contrast of tectonic-magmatic evolution between two orogens, especially contrast of deep crustal composition structure and basement affinity, can provide an important basis to completely understand the basement nature and tectonic affinity of the orogen. Based on its advantages in geochronology, regional widely distributed and easily tracing, Nd-Hf isotopic mapping for granitic rocks has gradually become an effective approach to delineate tectono-thermal evolution of the orogen, elucidate orogenic composition and contrast basement nature between two orogens.

As major units of the Central China Orogenic Belt (CCOB), the east-west trending tectonic connection relationship between the Kunlun and Qinling orogen around the Gonghe basin, has always been an interesting and controversy issue to Chinese geologists in a long time. The famous Gonghe basin, located in the junction region of the easternmost segment of the East Kunlun Orogen (EKO) and the westernmost segment of the West Qinling orogen (WQO), was considered as a crucial region to explore the tectonic relationship between the Kunlun and Qinling orogen. It is well known that both of the Kunlun and Qinlin orogens are typical composite orogen in central China, and underwent multi-cycle orogenic processes in geological time. Correspondingly, multi-stage magmatism and tectonic-thermal event occurred. Among the multi-stage magmatism, early Mesozoic granitic rocks, especially Triassic granitic rocks, are maximally exposed and most widely distributed in the EKO and WQO, which provide an important research role to explore the tectonic connection relationship between the two orogens.

This paper takes the voluminous Triassic granitic rocks as a research object to produce Nd-Hf isotopic mapping in order to trace the deep crustal compositional structure, and systematically contrast the tectonic-magmatic evolution and basement affinity of the Qinling and Kunlun orogen. It will provide a new basis to deeply understand the Triassic tectonic-magmatic evolution, orogenic process and basement nature of the Qinling and Kunlun Orogens on both sides of the Gonghe Basin.

At present study stage, a large number of previous research works have been carried out and plentiful achievements obtained for the Triassic granitic rocks outcropped in the eastern part of East Kunlun orogen (EEKO) and western part of West Qinling orogen (WWQO), which laid a regional framework of Triassic magmatic chronology and foundation of Nd-Hf isotopic mapping for EEKO and WWQO. However, the research work for some important granitic intrusions in the easternmost segment of EKO and the westernmost segment of WQO, such as Suigen'ergang, Manzhanggang, Rexue'ri plutons adjacent to Gonghe basin, is also very weak. The scarce of geochronology, geochemistry and Nd-Hf isotopic research for these intrusions directly restrict the east-west trending tectonic connection relationship between the EKO and WQO. Based on published data (zircon U–Pb ages and Nd–Hf isotopes) that systematically collecting from literatures for the Triassic granitic rocks in EEKO and WWQO, integrating with our new data (zircon U–Pb ages, bulk-rock major oxides, trace elements, Nd–Nd isotopic compositions) for the Triassic granitic rocks from the easternmost segment of the EKO and the westernmost segment of WQO, this paper systematically contrast the tectonic-magmatic evolution and isotopic composition of the EKO and WQO on both sides of Gonghe basin. The major achievements and new recognitions in this study listed as follows:

(1) U–Pb analysis of 14 zircons from 12 granitic plutons in the easternmost segment of EKO and the westernmost segment of WQO yielded 252~224 Ma. Integrated with the 138 zircon U-Pb ages collected from published literatures, we conclude that the Triassic magmatism in the EEKO and WWQO are roughly similar, ranging from 252 to 203 Ma, and can be integrally divided into the early- (252~238 Ma), middle- (238~226 Ma) and late-stage (226~203 Ma). The peak magmatism of the EEKO and WWQO on both sides of the Gonghe basin is in the early-stage (252~238 Ma). Slightly different, the early Triassic(252~247 Ma) magmatism in EEKO is more intensive than in WWQO. In a large scale in the CCOB, it

can be seen from the EEKO to WWQO and then to the East Qinling orogen (EQO) in an E-W trending, the early-stage (252~238 Ma) magmatism is more intensive in EEKO and WWQO, and the late-stage (226~203 Ma) magmatism is more intensive in EQO. In other words, in the CCAO range, the Triassic magmatism migrated from west to east and became more intensive and younger in its eastern part. In addition, from the northern part of Gonghe basin to its southern part, the Triassic magmatism seems demonstrated a minor trend to become younger. The establishment of geochronology and division of the Triassic magmatism in EEKO and WWQO provide a basis for us to analyze the tectonic-magmatic evolution of the Triassic magmatic rocks in the EEKO and WWQO, but also supply a chronology basis to further analyze the Nd-Hf isotopic composition of the deep crustal structure for EEKO and WWQO on both sides of the Gonghe Basin.

(2) From 252~237 Ma to 234~232 Ma, the main rock types of these granitic rocks in the easternmost segment of EKO change from granodiorite, diorite and rhyolite porphyry to syenogranite; and in the westernmost segment of WQO, from 245~238 Ma to 232~224 Ma, the main rock types changes from granodiorite, tonalite and diorite to granodiorite, monzogranite and diorite. Geochemically, these rocks are mainly high in SiO_2, K_2O and K_2O+Na_2O contents, low in P_2O_5 and TiO_2 contents, depleted in Ba, Sr, P, Ti contents and enriched in U, Hf, Zr contents. Most granitoids are calc-alkaline, and a few are high-K calc-alkaline rocks. Except the Late Triassic Rexue'ri monzogranites (228 Ma) in the westernmost segment of the WQO show some features of S-type granites, the other granitic rocks are all I-type granites. Besides, from early (252~237 Ma) to late (234~224 Ma), the geochemical characteristics of these granitic rocks in the easternmost segment of EKO and the westernmost segment of WQO, show an evolution trend from a subduction-collision setting to a post-collision or within-plate setting.

(3) 23 new whole rock Nd isotopes in the easternmost segment of EKO and the westernmost segment of WQO show that in the beginning of the early-stage (252~238 Ma), the $\varepsilon_{Nd}(t)$ value is higher and Nd model age is younger, and in the middle-stage (238~226 Ma) and late-stage (226~203 Ma), Nd isotopic composition shows similar in low $\varepsilon_{Nd}(t)$ values and old Nd model ages. Combination with 179 whole-rock Nd isotopic data systematically collected from published literatures, the statistical analysis of Nd isotopes for Triassic granitic rocks on both sides of Gonghe basin are predominately negative and mainly ranged from –8.5 to –2.5. Besides, the Nd model ages (T_{DM}) mainly concentrate between 1.8~1.0 Ga. As a whole, from the early- (250~237 Ma) to middle- (238~226 Ma) and then to late-stage (226~210 Ma), Nd isotopic evolution trend shows that in the early-stage, with the pluton's emplacement age became younger, the $\varepsilon_{Nd}(t)$ values decrease and Nd model ages is more older, meaning ancient crustal proportion gradually increased. In the middle-stage, high and low values of the $\varepsilon_{Nd}(t)$ is coexisted together, and the old crustal material and younger mantle component also coexisted in this period. In the late-stage, the $\varepsilon_{Nd}(t)$ values is gradually increased slightly, and the Nd model age is also gradually became more younger.

14 new zircon Hf isotopes in the easternmost segment of EKO and the westernmost segment of WQO show that in the beginning of the early-stage, $\varepsilon_{Hf}(t)$ value is positive and higher, and correspondingly, Hf crustal model age is younger. In the middle-stage, the major component of $\varepsilon_{Hf}(t)$ value is negative and the $T_{DM(Hf)}$ is old, and then in the late-stage, the $\varepsilon_{Hf}(t)$ value coexist with the positive and negative, and the $T_{DM(Hf)}$ is younger. Integrated with 56 Hf isotopic data systematically collected from published literatures, the statistical analysis of the $\varepsilon_{Hf}(t)$ values for Triassic granitic rocks on both sides of Gonghe basin are roughly similar and mainly ranged from -5.5 ro +5.5. As a whole, from the early- (250~237 Ma) to middle- (238~226 Ma) and then to late-stage (226~210 Ma), Hf isotopic evolution trend shows that in the beginning of the early-stage, the major proportion of $\varepsilon_{Hf}(t)$ value is positive and high. With the pluton's emplacement age became younger, in the end of early-stage, the $\varepsilon_{Hf}(t)$ values is negative and $T_{DM(Hf)}$ is more older, indicating that ancient crustal proportion gradually increased. In the middle-stage, the high and low values of the $\varepsilon_{Hf}(t)$ is coexisted together, and the old and younger component also coexisted in this period. In the late-stage, the $\varepsilon_{Hf}(t)$ values is gradually increased slightly, and the $T_{DMC(Hf)}$ is also gradually became younger, indicating that the younger component increased in late-stage.

(4) Statistical analysis of 216 Nd isotopic data (measured 23 and collected 193) show that the main range of Nd model ages for the Triassic magmatic rocks in EEKO and WWQO are consistent, and concentrate in the 1.8~1.0 Ga. From the Nd isotopic mapping, it further reveals that on both sides of the Gonghe basin, the granitic plutons with Nd model ages ranged from 1.2 to 1.0 Ga occupied the largest area. The granitic plutons ranged from 1.8~1.6 Ga ranked secondly, and the granitic plutons ranged from 1.6 ~ 1.4 Ga ranked thirdly. The area of numerous granitic plutons with youngest Nd model ages (1.2~0.8 Ga) are very small, and the oldest Nd model ages (> 2.0 Ga) only occurred in the West Qinling orogen.

Statistical analysis of 70 Hf isotopic composition data (measured 14 and collected 56) show that the main range of Hf model ages of the Triassic granitic rocks from EEKO and WWQO are basically same and concentrate in the 1.7~1.0 Ga. From the Hf isotopic mapping, it further reveals that on both sides of the Gonghe basin, the granitic intrusions with Hf model

ages ranged from 1.4 Ga to 1.2 Ga and 1.6 Ga to 1.4 Ga dominated the largest area, the area of numerous tiny intrusions with Hf model ages ranged from 1.2~1.0 Ga is very small, and the intrusions with oldest Hf model ages (>2.0 Ga) only occurred in the West Qinling orogen.

Both the statistical analysis of Nd - Hf isotopic compositions and Nd - Hf isotopic mapping show that in the Triassic period, on both sides of Gonghe basin, the EEKOE and WWQO share a similar or same deep crustal composition structure, which demonstrate that the two orogens have a similar or same basement affinity. Slightly different, the EEKO's basement is more uniform and slightly younger. This provides the deep material evidence that the Kunlun and Qinling orogen may connect in Triassic period.

(5) Based on the comprehensive results mentioned above and integrated with previous researchers' achievements, it can confirm that on both sides of the Gonghe basin, the Qinling and Kunlun orogen has a similar tectonic-magmatic evolution trend in Triassic period and share a same or similar deep crustal composition structure. This indicates that the EKO and WQO may be a same orogenic belt essentially, and constituted a continuous orogenic belt system in the early Mesozoic. Under the dynamic background of Meso-Tethys' northward subduction- accretion stage (252~238 Ma) to collision stage ((syn-collision (238~226 Ma), and then to post-collison stage (226~203 Ma)) in Triassic period, the EKO and WQO constituted a continuous orogenic belt that developed on the same or similar ancient block basement.

The significance of the above-mentioned achievements are: geochronology, geochemistry, isotopic composition, especially the Nd-Hf isotopic mapping for granitic rocks, can reveals tectonic-magmatic evolution process and trace the deep crustal composition structure as well as the basement nature for the EKO and WQO. This work provides a new basis to divide and contrast the tectonic affinity between the EKO and WQO, and constrain the tectonic relationship between the two orogens.

Key words: granitic rocks; zircon geochronology; Nd-Hf isotopic mapping; magmatism evolution; the eastern part of East Kunlun and the western part of West Qinling

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