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藏南冈底斯地体中段南缘构造演化

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冈底斯岩浆带位于拉萨地体南缘, 是新特提斯洋盆演化和印度-亚洲陆陆碰撞的岩浆产物, 对冈底斯岩浆带的研究方兴未艾, 但一些基本问题仍然存在着激烈的争论(比如晚三叠世到早—中侏罗世新特提斯洋演化的极性, 冈底斯岩浆带中大型韧性剪切带形成的时代、动力学机制以及冈底斯中段新生代的隆升-剥蚀模式等等), 这都直接影响了对新特提斯域构造和青藏高原形成演化的理解, 以及对冈底斯构造成矿带的资源评价。

本文选择冈底斯岩浆带中段南缘地区作为研究对象, 开展了详细的野外地质调查, 首次在日喀则南木林和拉萨曲水地区发现和厘定了晚三叠世的侵入岩体, 并开展了详细的岩石学、矿物学、地球化学、锆石 Lu-Hf 同位素分析和年代学研究; 对早—中侏罗世的花岗岩类及次火山岩开展了岩石学、年代学和锆石 Lu-Hf 同位素研究; 对冈底斯中段高海拔地区的始新世花岗岩类进行了地球化学和年代学研究; 对冈底斯中段谢通门—曲水韧性剪切带和曲水地区色甫—鸡公韧性剪切带进行了详细的野外地质调查、显微薄片鉴定、EBSD 研究、云母 ^{40}Ar-^{39}Ar 和锆石 U-Pb 定年等; 在前人研究的基础上, 对冈底斯中段进行选择性采样, 补充了新的磷灰石裂变径迹数据; 综合分析上述研究资料, 并结合前人研究成果以及区域地质特征, 试图建立和探讨冈底斯中段南缘的构造演化模式。

(1)南木林卡孜乡糜棱质花岗岩形成于 206~212 Ma 之间, 形成环境为活动大陆边缘, 锆石的 $\varepsilon_{Hf}(t)$值从 8.95 到 12.91, 一阶段模式年龄 326~486 Ma; 曲水其奴角闪辉长岩侵位结晶年龄为~210 Ma, 锆石的 $\varepsilon_{Hf}(t)$值从 9.56 到 14.75, 一阶段模式年龄为 256~459 Ma; 曲水达嘎花岗岩体的侵位结晶年龄为 225~230 Ma, 具有正的 $\varepsilon_{Hf}(t)$值(13.91 到 15.54); 地质年代学、岩石学、矿物学、地球化学以及锆石 Lu-Hf 同位素等显示, 晚三叠世的花岗岩、角闪辉长岩和新特提斯洋的向北俯冲有关, 其中角闪辉长岩和俯冲板片流体交代地幔楔的部分熔融有关, 花岗质岩石和初生地壳的部分熔融有关, 并且地幔物质在花岗质岩石的形成过程中扮演有重要的角色。晚三叠世的岩浆作用暗示了新特提斯洋的俯冲应该不晚于 230 Ma。

(2)通过对冈底斯中段南缘日喀则奴玛地区和尼木地区的闪长岩、花岗闪长岩、花岗岩以及次火山岩的地质年代学、地球化学、矿物岩石学以及锆石 Lu-Hf 同位素等综合研究, 获得了如下认识: 花岗岩类及次火山岩主要形成于 169~191 Ma, 为早—中侏罗世晚期岩浆作用的产物; 在化学组成上, 花岗岩类及次火山岩富集轻稀土(LREEs)和大离子亲石元素(LILEs), 强烈亏损 Nb、Ta 等高场强元素, 具有岛弧型花岗岩的地球化学特征; 花岗岩类为亚碱性, 属中钾钙碱性 I 型花岗岩类; 样品的 $\varepsilon_{Hf}(t)$值为 10.10~15.44, 具有明显亏损锆石的 Hf 同位素组成; 综合研究表明, 早中侏罗世应该和晚三叠世具有相似的大地构造环境, 即藏南冈底斯地区(活动大陆边缘)应属于新特提斯洋板片俯冲的构造背景, 花岗质岩石的形成主要是来自中下地壳物质的部分熔融。

(3)对冈底斯中段始新世的花岗岩类(闪长岩到花岗岩斑岩)进行了锆石 U-Pb 年代学、Lu-Hf 同位素和地球化学分析。分析结果显示, 花岗岩类锆石的 LA-ICP-MS U-Pb 定年结果为 40~55 Ma 之间, 该年龄代表了花岗岩类的侵位结晶年龄; 在地球化学组成上, 花岗岩类富集轻稀土(HREEs)和大离子亲石元素(LILEs), 强烈亏损高场强元素 Nb、Ta、P 等, 样品显示出岛弧型花岗岩的特征。此外, 分析样品还表现为准铝质 I 型花岗岩类的特征, 主要位于钙碱性到高钾钙碱性系列区域。锆石的 Lu-Hf 同位素分析结果显示, 多数样品的 $\varepsilon_{Hf}(t)$以正值为主, 少数锆石为负的 $\varepsilon_{Hf}(t)$值, 结合地球化学成分判别图解,

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花岗岩类主要是新生地壳的部分熔融—由变基性到变英云闪长质岩石的部分熔融以及变砂岩的部分熔融, 在此过程中, 底侵的地幔物质也参与了花岗质岩石的形成和演化。在 Sr-Yb 图解上始新世的样品表现为碰撞期花岗岩类的地球化学特征, 因此也暗示了印度-亚洲在始新世早期时已经完全碰撞。始新世冈底斯地区的岩浆作用可能是由于新特提斯洋板片俯冲到欧亚板片之下, 由于印度-亚洲大陆的碰撞, 致使新特提斯洋板片俯冲角度变陡, 发生了板片断离(slab break off), 引发了始新世冈底斯地区强烈的岩浆-火山作用。

(4)通过野外详细的地质调查、构造解析以及室内薄片鉴定和 EBSD 组构分析, 确定了谢通门—曲水韧性剪切带的构造属性和演化特征。谢通门—曲水韧性剪切带主要由强变形域和弱变形组成, 包括面理化花岗岩、糜棱岩化花岗岩、初糜棱岩、糜棱岩组成, 局部地区可见千糜岩。几何学和运动学研究结果显示谢通门-曲水韧性剪切带具有一致的运动学特征, 表现为以向北的正向滑覆为主。此外, 运动学涡度显示(Wk>0.71)该剪切带为典型的简单剪切为主的一般剪切, 为伸展减薄型剪切带, 平均减薄量为 20%。剪切带的 EBSD 组构分析显示了谢通门—曲水韧性剪切带主要滑移系以柱面<a>、菱面<a>和底面<a>滑移为主, 变形主要以中低温作用为主(550~300℃)。

(5)谢通门—曲水韧性剪切带中的黑云母、绢云母 ^{40}Ar-^{39}Ar 年代学以及锆石 U-Pb 年代学共同限定了剪切带活动的时限。综合年代学结果表明: 谢通门—曲水韧性剪切带形成于中新世早期 21~24 Ma 之间。

(6)经过详细的野外地质调查、室内显微薄片鉴定、EBSD 组构分析等研究认为色甫—鸡公韧性剪切带以右行走滑为主。长石-石英变形矿物对以及石英 EBSD 组构研究结果显示, 鸡公—曲水韧性剪切带发生变形的温度为 500~550℃。其次, 通过对剪切带中发育的同构造长英质脉体的锆石 U-Pb 年代学分析, 获得了色甫—鸡公韧性剪切带活动的时限 35~38 Ma, 即始新世晚期。

(7)通过对冈底斯中段 11 件磷灰石样品的裂变径迹分析, 获得了中段南缘的构造隆升剥蚀史。研究结果显示: 冈底斯中段的隆升是多阶段性的, 渐新世以前的抬升、剥蚀和印度-亚洲板块的碰撞有关, 23 Ma 以来的快速隆升和冈底斯地区逆冲断裂的活动有关, 并且在快速隆升阶段也存在短暂的构造平静期。10 Ma 以来是冈底斯中段南缘地区又一次快速的隆升期, 该次隆升和雅鲁藏布江的快速下切侵蚀有关。第四纪以来在构造活动和气候变化以及地表径流的联合作用下, 共同塑造了现今的冈底斯。

(8)综合结果表明: 冈底斯岩浆带经历了一个长期的演化过程, 从晚三叠世开始俯冲消减(230 Ma), 直到 60~55 Ma 时印度-亚洲大陆的碰撞。始新世印度亚洲的碰撞导致了逆冲断裂和大型走滑断层的形成, 并导致了新生代冈底斯岩基及邻区的第一次整体的隆升剥蚀。23 Ma 以来, 由于藏南地区地壳侧向增厚变化不均匀以及南北向应力挤压的松弛, 导致了拉萨地体发生东西向的崩塌和南北向的伸展, 此时大型正断层以及拆离构造应用而生, 同时加厚的地壳发生部分熔融而形成了具有特殊地球化学属性的花岗质斑岩, 此时也是冈底斯地区成矿大爆发时期。

关键词: 冈底斯; 花岗岩类; 韧性剪切带; 裂变径迹; 构造演化
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Tectonic Evolution of the Southern Region in the Middle Gangdese Batholith, Southern Tibet

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The Gangdese magmatic belt, located in southern margin of the Lhasa terrane, was related to the Neo-Tethys oceanic evolution and Asian-Indian collision. Therefore, the Gangdese magmatic belt is a still research focus of the Tibetan geosciences. However, some basic and essential issues have been under discussion and debated, such as the Triassic–Jurassic evolutionary characteristics or nature of the Neo-Tethys oceanic crust, formation ages and dynamic mechanisms of ductile shear zones and denudation and uplift models of the Gangdese batholith in southern Tibet. These issues cloud the understanding

and tectonic framework of the Tibetan plateau and the Neo-Tethys oceanic evolution, especially in assessing accurately ore deposits and met-allogenic belt for the whole Gangdese magmatic belt.

A series of detailed field surveys were conducted in the southern region of the middle Gangdese batholith, leading to discoveries of the Triassic plutons, which were analyzed by means of petrology, minerology, geochemistry and zircon Lu-Hf isotopes as well as geochronology. Besides, the Early–Middle Jurassic granitoids were studied using petrology, geochronology and Lu-Hf isotopes. We also have selectively taken Eocene granitic samples from the middle Gangdese for geochemistry and geochronology analysis. About geological structures, research group conducted much work, including geological observations and experimental researches (thin section observation, ^{40}Ar-^{39}Ar dating, U-Pb dating and EBSD measurements) for the Xaitongmoin–Quxu and Sefu–Jigong ductile shear zones. Combining with published data of the fission tracks in the Gangdese belt, we supplemented new samples and obtained new data about apatite fission track. Based on those above-mentioned data and regional geological features, we try to establish tectonic framework and discuss evolutionary model in southern Tibet.

(1) Mylonitic granite was generated in an active continental margin during 206~212 Ma, varying from 8.95 to 12.91 for zircon $\varepsilon_{Hf}(t)$ values in Kazi township of Namling county. Zircons from the hornblende gabbros yield crystallization age of ca.210 Ma, and $\varepsilon_{Hf}(t)$ values show highly positive values from 9.56 to 14.75 as well as model ages exhibit t_{DM1} from 256~459 Ma. Zircons from Daga show that granites crystallized during 225~230 Ma, showing a highly positive $\varepsilon_{Hf}(t)$ values (from 13.91 to 15.54) and relatively young model ages. The geochronology, petrology, minerology and geochemistry as well as Lu-Hf isotopes suggest that Late Triassic granites and hornblende gabbros have a close relationship with the northward subduction of the Neo-Tethys oceanic crust, and further indicate that the hornblende gabbros might be generated by the hydrous partial melting of depleted mantle wedge matasomatized by fluids released from down-going oceanic slab. The granites were formed due to partial melting of juvenile crustal materials, and the mantle materials play a significant role in generating granites. These late Triassic magmatic events indicate that the northward subduction of the Neo-Tethys oceanic crust no later than the Norian stage of Triassic and did not terminate until at least the early stage of Cenozoic.

(2) The diorite, granodiorite and granite from Numa and Nyemo areas in the middle Gangdese belt provide an excellent opportunity for further studying rock suites and interactions, by means of geochronology, geochemistry, minerology and Lu-Hf isotopes. The LA-ICP-MS U-Pb dating results demonstrate that the granitoid suites crystallized at 169~191 Ma, belonging to the Early–Middle Jurassic magmatism. Chemically, granitoid suites are enriched in LREEs and LILEs, depleted in HFSEs, such as Nb and Ta et al, revealing a volcanic arc granitic feature. Additionally, granitoids belong to typical sub-alkaline and show dominantly medium K calc-alkaline series. The granitoid suites have highly depleted zircon Hf isotopic compositions, with $\varepsilon_{Hf}(t)$ values of 10.10~15.44. Those data reach a consensus that the Early–Middle Jurassic magmatisms have the same tectonic setting with the Late Triassic, and strengthen the notion that the southern Tibet was typical of an active continental margin. And those granitoid suites were originated from Middle–Lower crustal partial melting.

(3) The granitic complexes developed in the southern region of the middle Gangdese batholith provide a very valuable opportunity to study and assess Eocene magmatisms directly, with aim of supplying new geochronology and geochemical constraints on Asian-Indian collision. In this paper, we take typical samples and conducted experiments, including geochronology, petrology and Lu-Hf isotopes. The LA-ICP-MS U-Pb data demonstrate that granitoids crystallization ages range from 40 Ma to 55 Ma. In geochemical aspects, the samples, enrichment of HREEs and LILEs and depletion of Nb, Ta and P, show a volcanic arc affinities. Moreover, analyzed samples, located in calc-alkaline and high K calc-alkaline fields, are dominantly by metaluminous nature and marked by I-type granitic characteristics. Dominantly positive $\varepsilon_{Hf}(t)$ values and geochemical compositional discrimination diagrams suggest that Eocene granitoids might be generated from partial melting of juvenile crustal materails, which include meta-tonalite partial melting and small amounts of meta-sandstone, with a little mantle materials injection. The Sr-Yb discrimination diagram show that the Eocene granitoid samples plot into collision fields, indicating the collision of Asian-Indian plates at the very early Eocene. According to numerical and geochemical combinations, the Eocene magmatism was related to breakoff of the Neo-Tethys slab.

(4) Detailed geologic survey, structural analysis, thin section observations and EBSD fabric measurements together determined structural nature and evolutionary dynamic process for the Xaitongmoin–Quxu shear zone. The Xaitongmoin–Quxu ductile shear zone, consisted of strong deformational zones and weak deformational zone, includes foliated granite, mylonitic granite, protomylonite, mylonite and small amounts of phyllonite. Structural geometry and dynamics reveal that the shear zone has the same kinematic features, showing a shearing sense top to the north dominately. In addition, kinematic vorticities, over 0.71, demonstrate that the shear zone is marked by simple shear, namely pure shear play a little role in shearing process. According to quantitative formula, we obtained mean thickness reduction value about 20% for the Xaitongmoin–Quxu shear zone. Quartz

EBSD measurements of mylonites reveal that two patters of deformation in the shear zone are observed which are middle-temperature and low-temperature, respectively. Obviously, owing to lacking of high-temperature prismatic <c> fabrics, the slip systems are dominantly by prismatic<a>, rhombohedral<a> and basal <a> glides.

(5) Zircon U-Pb ages of mylonites and un-deformed veins and ^{40}Ar-^{39}Ar ages play significant roles in constraining activity limits of the Xaitongmoin-Quxu shear zone. Integrated results show that the Xaitongmoin-Quxu shear zone was motivated in the late stage of Eocene, namely 35~38 Ma.

(6) Field geological survey, thin sections observed and EBSD measurements arrive at a consensus that shearing sense of Sefu-Jigong ductile shear zone is dominantly dextral strike slip. Mineral deformation thermometer and EBSD measurements suggest that the Sefu–Jigong shear zone mainly experienced middle-temperature structural deformations, indicating about 500~550℃. Zircons from syn-tectonic granitic dykes exposed in the shear zone were conducted by LA-ICP-MS, suggesting activity time during 35~38 Ma.

(7) Eleven samples collected from the Gangdese batholith proposed that denudation and uplift are complex and multiple stages. Early uplift was due to collision of Asian-Indian plates, but quick denudation was caused by major thrusts in the Gangdese since 23 Ma. However, very short non-active phase also existed during active periods. From 10 Ma to present, the significant tectonic and climatic changes occurred in the Gangdese belt, for instance, quick fluvial erosion of the Yarlung Tsangpo drainage systems and formation of the Asian monsoon, which resulted in enhanced erosion in the Gangdese. Consequently, tectonic and climatic interactions have continued to shape southern Tibet to the present.

(8) Integrated studies suggest that the Gangdese magmatic belt have experienced a long evolution from late Triassic to 55 Ma. Due to Asian-Indian collision, many thrusts and strike-slip fauts occurred and southern Tibet began uplift during Eocene and Oligocene. After 23 Ma, the E-W extensional collapse owing to lateral variation of crust thickened gradient in the Lhasa terrane might have contributed to generation of normal faults and formation of granite porphyry (with metallogenic explosion), and quick uplift and denudation occurred in the Gangdese magmatic belt.

Key words: Gangdese; granitoids; ductile shear zone; fission track; tectonic evolution

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