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中文摘要

本年度計畫分析東崑崙山脈內斷層活動情形，探討阿爾金斷裂帶第三紀活動演化與印度一歐亞大陸碰撞作用之關係。研究成果已寫就期刊論文(Onset timing of significant unroofing around Qaidam basin, northern Tibet, China: Constraints from $^{40}Ar/^{39}Ar$ and FT thermochronology on granitoids)已為 Journal of Asian Earth Science 接受刊登，其重要內容分別摘錄於下。

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ABSTRACT

$^{40}Ar/^{39}Ar$ and fission track thermochronological results from two granitoid suites in the mountain ranges along the northern and southern edges of Qaidam basin constrain the timing of a Tertiary denudation event and their tectonism association in northern Tibet. The cooling histories based upon $^{40}Ar/^{39}Ar$ and fission track ages suggest a rapid cooling event (7.5-10.7 °C/Ma) during Oligocene-early Miocene. This cooling event is thought to reflect increasing denudation rate associated with the rapid uplifting and denudation of the North Qaidam and Kunlun Shan mountain ranges. With consideration of the field evidences, the sedimentation rate of the Qaidam basin, and the propagation rate along the Altyn Tagh fault, the rapid uplifting and denudation are probably due to crustal thickening associated with the Cenozoic propagation of the Altyn Tagh fault, in accommodating to the convergence of the India-Asia collision.

Keywords: $^{40}Ar/^{39}Ar$, Fission dating, India-Eurasia collision, China

1. INTRODUCTION

Although Murphy et al. (1997) suggested a significant portion of southern Tibet was raised to 3-4km of elevation during Early Cretaceous prior to the India-Asia collision, most features of the Himalayan belt and the Tibetan plateau are results of the Cenozoic India-Asia collision. Cenozoic activities in the Tibetan plateau and adjacent areas have long been the focus of a number of geological studies on lithospheric accommodation mechanisms, particularly the partitioning of thickened homogeneous crust with horizontal compression, and lateral extrusion along major strike-slip faults under continental collision (Tapponnier et al., 1986; Dewey et al., 1988; Avouac, 1991). Tapponnier et al. (1990) suggested local crustal thickening would also occur under lateral extrusion due to (1) progressively filled sedimentary basins, and (2) formation of large anticlines by major thrusts 'branching' from strike-slip faults.

One of the major strike-slip faults associated with the Cenozoic tectonics of this range is the Altyn Tagh fault zone. The Altyn Tagh fault zone separates the Tarim basin to the north from the Qaidam basin, Kunlun Shan, and the Tibetan plateau to the south. Several studies (Peltzer et al., 1989; Tapponnier et al., 1990; Meyer et al., 1998) suggested that the propagation of the Altyn Tagh fault not only control the uplifting and denudation, but also determines the geometry of mountain belts in this area. Thus, if we want to have further understanding of the accommodation mechanism and the tectonic history of this region, precise reconstruction of thermochronological history for the propagation evolution of the Altyn Tagh fault is urgently needed.

Though structural and stratigraphic evidence indicated left-lateral displacement of the Altyn Tagh fault (Molnar and Tapponnier, 1975; Molnar et al., 1987; Gaudemer et al., 1989; Peltzer et al., 1989), no precise timing criteria were seen in the field. Folding of late Cenozoic sediments in adjacent regions, such as the Qaidam basin, implied the presence of active deformation during Neogene (Tapponnier and Molnar, 1977). Chen et al. (1998) suggested syn-depositional thrust faulting of lacustrine sediments during Oligocene (23.7-36.6Ma). Active folding and thrusting is evidenced at the foot of the Kunlun range and in the Qaidam basin further north. However, thrusting is also mapped in the Kunlun range south of Golmud (Mock et al., 1999), making it difficult to determine whether the contacts are actually Tertiary in age. Structural and stratigraphic evidences indicated active slip event occurred on thrust fault along the northern edge of Qaidam (Molnar et al., 1987; Tapponnier et al., 1990; Wang and Coward, 1990). Several studies indicated an important change in crustal thermal state (unroofing event) around 20 Ma affected the Western Kunlun range and the Tarim basin, and also affect the entire Himalayan orogen (Harrison et al., 1992, 1993). However, Mock et al. (1999) reported a cooling/unroofing event around 30Ma from the eastern Kunlun range. In order to clarify if this cooling event is a regional phenomena or just a local one, a combination of $^{40}Ar/^{39}Ar$ and fission track dating on the granitoid complexes around the Qaidam basin was carried out in the present study. Current samples were obtained from the north and the south edges of the Qaidam basin, NW China. It is hoped that the results could provide constraints on the onset timing of the mountain belt unroofing around the Qaidam basin and contribute to clarification of the regional tectonic history.

2. GEOLOGICAL SETTING

The Qaidam basin is a rhombic basin bounded by three fault systems of: the Altyn Tagh fault zone to the northwest, the North Qaidam fault zone (NQ fault zone) to the northeast and the eastern Kunlun fault zone (EKL fault zone) to the south. Among these three fault systems, the north Qaidam and eastern Kunlun fault zones are developed in the North Qaidam orogen belt subparallel to the Qilian Shan-Nan Shan orogen belt. The northeastern border of the Qaidam basin contains Paleocene and Eocene deltaic and shallow lacustrine sandstone overlie unconformably on the Mesozoic strata. The basin strata reaches about 14km thick (Wang and Coward, 1990), and consists of dark colored argillaceous deposits from Middle Oligocene to the end of Miocene (Métivier, 1996) topped by Pliocene fluvial and lacustrine facies deposites (Chen and Bowlar, 1986).

Two mountain ranges surround the Qaidam basin. The 700 km long, NW-SE trending North Qaidam range north of the Qaidam basin firstly formed during Paleozoic-Triassic collision, and was re-deformed during Cenozoic when India collided with Asia (Cui et al., 1999). Similarly, the Kunlun range south of the Qaidam basin is also a reactivated Paleozoic-Triassic collision belt (Matte et al., 1996). These mountain ranges contain a sequence of nappes originated from ramp thrusts (Chen et al., 1998) along a mid-crustal decollement beneath the basin (Burchfiel et al; 1989), and are considered to be formed during the Cenozoic India-Asia collision under northeast-southwest compression (Molnar and Tapponnier, 1978; Molnar and Chen, 1983; Armijo et al., 1986; Molnar et al., 1993).

Geological evidence indicated a left-lateral sense of displacement for the Altyn Tagh fault (Molnar et al., 1975, 1987; Gaudemer et al., 1989; Peltzer et al., 1989) transacting the Kunlun fault systems and resulting in the separation of the EKL (eastern Kunlun) fault zone 500 km apart from the western Kunlun fault zone (Peltzer and Tapponnier, 1988). Along the Altyn Tagh fault, a number of granitoid plutons intruded into Ordovician-Permian sediments around 120-140 Ma (biotite Rb/Sr ages), or 200 Ma (whole rock Rb/Sr ages; Harris et al., 1988). However, recent zircon U-Pb data on granitoid plutons located along the Xidatan fault (a branch of Kunlun fault zone) yield Paleozoic ages (Mock et al., 1999) suggesting that the Mesozoic Rb/Sr ages should be interpreted as for a metamorphic event possibly associated with the accretion, instead of the emplacement, of Triassic-Jurassic Qiangtang block.

3. GEOCHRONOLOGY

3.1. Samples and analytical methods

This study analyzed two gneissic granitoid samples: a biotite granite (NQ9901) collected from the North Qaidam range, and one biotite granite (KL9901) from the southern edge of the eastern Kunlun range. Both samples exhibit gneissic textures, containing almost identical mineral assemblage of biotite, muscovite, K-feldpsar, plagioclase, quartz and oxides. Although micas show euhedral grains mainly lining up along the foliation, most feldspar grains exhibit a significant amount of fractures and weak undulose extinction along subgrain domains under microscope.

^{40}Ar/^{39}Ar step-heating experiments were carried out on biotite and K-feldspar concentrates (grain sizes range between 100-180μm) obtained from mineral separation using heavy liquids, Frantz magnetic separator, and hand picking under microscope. Minerals were irradiated, along with the neutron flux monitor LP-6 biotite (Odin et al., 1982) at the VT-C position in the Tsing-Hua Open-Pool Reactor (THOR) at Tsing-Hua University, Taiwan, for 25 hours with a fast neutron flux of $1.566\times10^{13}n(cm^2s)^{-1}$. After irradiation, the samples were degassed using a 30 minute heating schedule. The isotopic composition was measured using a Varian-MAT GD150 mass spectrometer at National Taiwan University, Taiwan. After corrections for mass discrimination, system blanks, isotope interferences and radiometric decay, ^{40}Ar/^{39}Ar ages were calculated according to ^{40}Ar*/^{39}Ar ratios and the J value obtained by analyses of the monitor standards. A detailed description of analytical and data processing methods is outlined by Lo and Lee (1994). Plateau ages were calculated from adjacent ages agreeing with each other within 2σ ranges. ^{36}Ar/^{40}Ar-^{39}Ar/^{40}Ar isotope correlation diagrams were plotted to examine the possible components of gas reservoirs in minerals.

For fission track (FT) analyses, two apatite separates, obtained via conventional techniques, were mounted in Araldite®, polished and etched in HNO_3 (5 M) for 20 sec. All samples were analyzed using the external detector method (Hurford and Green, 1983) by attaching a low-uranium mica detector to each sample mount. Samples were irradiated at the 49-2 Reactor in Beijing, China for 1 hour. Neutron flux was monitored by mica detectors that attached to CN-5 and SRM-612 glasses with apatites. After irradiation, the mica detectors were etched in 40% HF for 45 min. Mounts were counted using a Zeiss Axioplan® microscope with an automated stage. Age calculations were done using the zeta-calibration approach (Hurford and Green, 1983), based on the IUGS-recommended age standards (Hurford, 1990).

3.2. ^{40}Ar/^{39}Ar geochronological results

Biotite within granite NQ9901 displayed a fairly flat age spectrum with well-defined plateau with an age of 195.5±0.4 Ma over 74% of ^{39}Ar released. Similarly, biotite from KL9901 showed a very flat age spectrum with a much younger plateau age of 120.0±0.3Ma over 80% of ^{39}Ar released. The intercept ages for biotites obtained from the least-squares regressions of the plateau steps are: 194.9±1.0 Ma with MSWD=1.8 for NQ9901, and 119.2±0.5 Ma with MSWD=2.4 for KL9901, which are all consistent with their respective plateau ages. The ^{40}Ar/^{36}Ar intercept values generally agree with the atmospheric composition (^{40}Ar/^{36}Ar=295.5) These biotite plateau ages are generally consistent with previous ^{40}Ar/^{39}Ar, K/Ar and Rb/Sr age results from granitic complexes in the Kunlun range (Harris et al., 1988; Matte et al., 1996; Mock et al., 1999), which indicate the thermal events during the Jurassic-Cretaceous.

Two K-feldspar samples (NQ9901 and KL9901) displayed similar age spectrum profiles characterized by a gradient with apparent age increasing from low values at low temperature steps to high values at high temperature steps. The exception of some abnormally old ages recorded for the first few steps of KL9901 is thought to reflect a small amount of excess Ar present in the sample. The apparent ages for high temperature steps (~215 Ma for NQ9901, and ~138 Ma for KL9901) are generally close to or slightly older than their respective biotite plateau ages. However, the minimum ages (25.2 ± 3.0 Ma for NQ9901 and 36.5 ± 0.5 Ma for KL9901) are much younger than their respective biotite plateau ages. Nevertheless, two flat portions of the K-feldspar age spectrum at the low temperature steps appear to yield ages around ~ 33.5 Ma for NQ9901 and ~ 38.4 Ma for KL9901. Miraculously, similar age ranges and age spectrum profiles have also been reported by Mock et al. (1999) for granitoid samples from eastern Kunlun range.

3.3. Fission track dating results

Apatites from KL9901 and NQ9901 yielded concordant fission track ages concentrated at 15.8 ± 1.1 Ma (KL9901) and 16.7 ± 1.4 Ma (NQ9901). These apatite FT ages are much younger than their correspond biotite and feldspar $^{40}Ar/^{39}Ar$ ages (Figs 2-4). It is not surprising to see such a difference between apatite FT and $^{40}Ar/^{39}Ar$ ages since the apatite fission track exhibit much lower blocking temperature, which is about 110 ± 10°C (Naeser et al., 1989), than those of argon isotope systematics in biotite and K-feldspar (~150-350°C) (see McDougall and Harrison, 1999).

4. THERMOCHRONOLOGICAL INTERPRETATION

The Mesozoic ages interpreted in this study generally agree with previous reported whole rock Rb-Sr ages (100-120 Ma and ~200 Ma; Harris et al., 1988) and mica $^{40}Ar/^{39}Ar$ plateau ages (128 – 257 Ma; Mock et al., 1999) for the granitoids in the same region, suggesting the thermal events is related to the accretion of Lhasa block in Tibet (Allegre et al., 1984). The $^{40}Ar/^{39}Ar$ age ranges and age spectrum profiles of K-feldspars are also in general consistent with those reported ages for granitoids in eastern Kunlun range (Mock et al., 1999). Using multi-domain diffusion (MDD) modeling method (Lovera et al., 1989, 1991), Mock et al. (1999) suggested a Tertiary rapid cooling/unroofing event in eastern Kunlun range. By considering the sample locations, and the similarities of $^{40}Ar/^{39}Ar$ age ranges and K-feldspar age spectrum features between the present study and Mock et al. (1999), we may suggest that this Tertiary rapid cooling/unroofing event had also been registered in the present samples.

The validity of the MDD model has been questioned due to complex microstructures preserved within K-feldspar (Parsons et al., 1999, Reddy et al., 1999, 2001) and potential influence from other diffusion mechanisms (Lee, 1995). In order to compare our results with those in the previous study (Mock et al., 1999), the MDD model and the basic assumption for argon diffusion in K-feldspar, such as volume diffusion in plane slab, which were used in the previous study, were utilized. A slab diffusion geometry is thought to be justified because argon loss from K-feldspar during in-vacuo step-heating experiments can be best described by volume diffusion in a slab geometry (Lovera et al., 1997). After appropriate adjustment of the various model parameters, a model age spectrum can be obtained that closely match the experimental results. Although it may not be necessarily unique, the modeled cooling histories appear to be consistent with the biotite $^{40}Ar/^{39}Ar$ ages and apatite fission-track ages of the same sample. It is shown that the granitoid (NQ9901) in the northern edge of the Qaidam basin may have emplaced much earlier (240-250Ma) than the southern edge (150Ma; KL9901). After the Mesozoic thermal event, both them have experienced a slow cooling stage until Oligocene. Starting from Oligocene, both samples exhibit fast cooling with rates increasing dramatically to about ~7.5-10.7 °C/Ma. These cooling patterns are surprisingly similar to those of the eastern Kunlun region (Mock et al., 1999). The similarity of the cooling patterns may suggest that the Tertiary fast cooling event not only effected the eastern Kunlun range but also effected the whole Kunlun range extending to the North Qaidam range around the Qaidam basin.

5. DISCUSSIONS

Tapponnier et al. (1990) and Meyer et al. (1998) suggested that most of the parallel mountain ranges in northeastern Tibet resulted from sediment accumulation (basin infilling) between rising ranges of large-scale ramp anticlines with south-dipping thrust faults splaying from the sinistral slip of the Altyn Tagh fault. Indeed, rapid cooling of metamorphic/plutonic complexes often reflects the increasing rate of denudation due to uplifting of mountain ranges. Sustained uplifting of a mountain range could also amplify river incision and erosion that leads to the formation of foreland flexural depression (basin). Consequently, increasing denudation could also result in increasing sedimentation rate in basin. In other words, uplift of mountain range and basin formation could be co-dependent to each other.

Many of these Oligocene deformations in northeastern Tibet, appear to be coeval with the great strike slip motion of the Altyn-Tagh fault (Tapponnier et al., 1990; Meyer et al., 1998). Wang (1997) claimed several tertiary back-thrusts branched from the mid-crustal decollement formed by continuous northeastward propagation of the Altyn Tagh fault, and produced northwest-southeast trending basement wedges along the North Qaidam range. These basement wedges were then uplifted by thrusting, and possibly undergone denudation around 30 Ma ago (Wang, 1997). This notation seems to gain supports from thermochronological evidences from the fault slip (East Kunlun fault) in the eastern Kunlun range, which also started at around 30 Ma (Mock et al., 1999). It is also worthy to note that based on the field evidences, the North Qaidam fault branched from the Altyn Tagh fault through an oblique, more easterly striking splay. As discussed above, the North Qaidam range was uplifted rapidly during the mid-Oligocene-Miocene, which implied the activity of the North Qaidam fault during the same period of time. Thus, we concluded that the slip and thrusting of the North Qaidam fault and the Eastern Kunlun fault may have occurred actively in association with the movement of the Altyn Tagh fault during mid-Oligocene – Miocene.

Previous studies showed that the sedimentation rate in the Qaidam Basin increased from 0.017mm/Ma, during late Mesozoic – early Tertiary, to more than 0.07mm/Ma after 36.6Ma, due to slip rate variation along the Althn Tagh fault and the northeastward-extension tectonics of this region (Xu, 1985; Chen et al., 1998; Métivier, 1998; Cui, 1999). As discussed above, the mountain ranges (North Qaidam and Kunlun) around the Qaidam Basin have experienced a similar rapid uplift event starting from mid-Oligocene, which occurs almost synchronically with the increasing sedimentation in the Qaidam Basin. Such a temporal concordance reinforces the notation that there is a close interplay between the uplift of the mountain ranges (Kunlun and North Qaidam), the slip propagation of Altyn Tagh Fault and the development of the Qaidam Basin (Figs 1, 8 and 9) (Tapponnier and Molnar, 1977; Tapponnier et al., 1990; Chen et al., 1998; Meyer et al., 1998; Cui et al., 1999).

6. CONCLUSION

^{40}Ar/^{39}Ar and fission track thermochronological results from two granitoid suites collected from mountain ranges along the northern and southern edges of Qaidam basin suggested these granites may have emplaced in separate events, but experienced a similar rapid cooling event during the Oligocene-Miocene. This event has been found widely in mountain ranges around the Qaidam Basin. By examining the spatial and temporal relationship of fault slips, terrain uplift and basin sedimentation, it is suggested that the significant strike-slip motion along the Altyn Tagh fault starting from the mid-Oligocene may have led to crustal

Lo, C.H. and Lee, C.Y. (1994) ^{40}Ar/39Ar method of K-Ar age determination of geological

thickening and uplifting of the mountain ranges around the Qaidam basin. This reinforces the idea that the India-Asia collision was mainly accommodated by lateral extrusion along great strike-slip faults during the Cenozoic, and that the Altyn Tagh fault was indeed active and propagating along the northern edge of the Tibet since the mid-Oligocene.

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