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THE THERMAL HISTORY OF THE LHASA BLOCK, SOUTH TIBETAN PLATEAU BASED ON FTD AND AR-AR DATING

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ABSTRACT

Twelve basement samples were collected from South Tibet Plateau for FTD and Ar-Ar analysis to demonstrate their uplifting history since Cenozoic era. The preliminary results from different minerals with different closure temperatures, including apatite and zircon for fission-track dating, and K-feldspar, biotite for Ar-Ar dating, show that at least four stages of thermal history can be recognized in the studied area.

KEYWORDS

Tibetan Plateau; Lhasa Block; thermal history; fission-track dating; Ar-Ar dating.

INTRODUCTION

The Tibet Plateau, which is bound by the Jinsha Suture in the North and the Indus Zangbo Suture in the South (Fig. 1A), is regarded as the result of the northward convergence of India into Asia over the past 40 to 50 Ma. Many thermochronologic studies show that rapid uplift and unroofing of southern Tibet began about 20 million years ago and the present elevation of much of the Tibetan plateau was attained by about 8 million years ago (e.g., Harrison *et al.*, 1992; Pan *et al.*, 1993; Coleman and Hodge, 1995; Copeland *et al.*, 1995). Although many models have been proposed to account for its thickened crust and high elevation, the uplift of the Tibetan plateau may be the consequence of the convective removal of the lower portion of the thickened Asian lithosphere (e.g., Platt and England, 1994). Furthermore, Chung *et al.* (1998) argued that there were diachronous uplift events starting 40 Myr ago based on the observation of alkaline magmatic rocks in eastern and western Tibet. Using the fission-track dating (FTD) and Ar-Ar dating technique, we will examine the thermal history of southern Tibet by dating its basement rocks directly in this study.

ANALYSIS AND RESULTS

Representative samples were collected from Lhasa Block of South Tibet and the northern part of the Lhasa Block. Seven samples are from the Gangdese Bothlith (Fig. 1C), meanwhile, the others are from the northern part of the Lhasa Block (Fig. 1B). For comparison, one granodiorite sample (K) was also collected near the Jinsha Suture (Fig. 1A).

Fission-track dating result

Enough zircon and apatite grains separated from the samples were mounted in teflon and epoxy respectively for irradiation. "Grain-by-grain" and mica external detector techniques were adopted to obtain individual grain ages. A zeta value (e.g., Green, 1985) of 27.9 ± 1.5 (1σ) has been obtained for zircons of Fish Canyon Tuff (Yang *et al.*, 1995). The pooled age used in this study is calculated by pooling counts for the counted grains (Tagami *et al.*, 1988). Statistical errors were calculated from

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the Poisson uncertainties in fossil and induced tracks, and in counts used to determine the neutron dose as well (Green, 1981). The detailed analytical procedures are those reported in Yang *et al.* (1995).

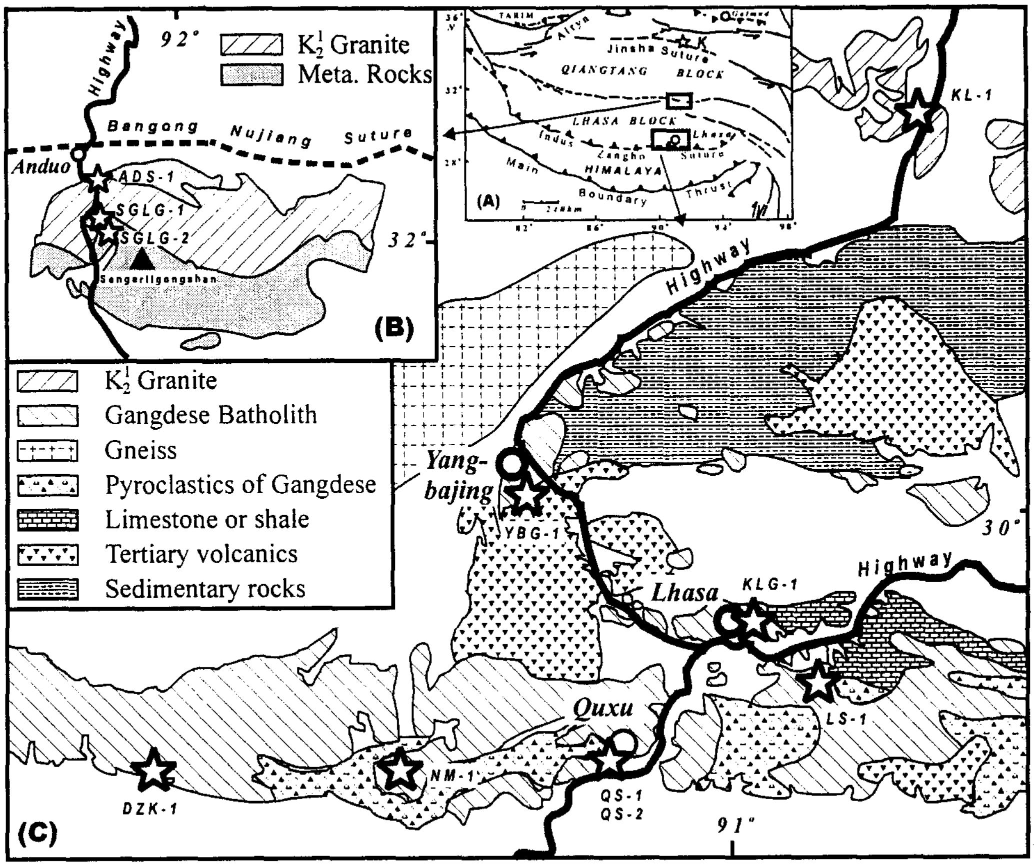

Fig. 1. Sample localities in this study. (A) Simplified tectonic setting of Tibetan plateau; open star (K) is the location of sample HSS-1; (B) Sample localities and geologic map of North Lhasa Block; and South Lhasa Block (C).

Table 1 shows the fission-track dating results of this study and indicate a wide age range of ages (16.7~63.4 Ma) with small errors (3.2~8.6%). Except for the apatite date for sample NM-1, all data are consistent with their peak age and χ^2 age within one standard deviation error and exhibit a symmetric distribution in the composite probability density plot. This implies that the data have ideally recorded the last thermal event. As expected, all the zircon dates are significantly older than the apatite data from the same samples.

Ar-Ar dating

Samples were wrapped in aluminum foil packets and irradiated for 8 hours in the THOR nuclear reactor at Tsing-Hua University, Taiwan. The maximum flux gradient was less than 0.9% within overall sample volume. The irradiated samples were step-heated using a Lindberg resistance furnace and analyzed by a Varian-MAT GD150 mass spectrometer at the National Taiwan University. The monitor standard was the LP-6 biotite (127.7±1.4 Ma) and ages were calculated using the constants recommended by Steiger and Jäger (1977). All errors are quoted at the 1σ level and do not include the uncertainty of the monitor age. Experimental details are given in Lo and Lee (1994).

The Ar-Ar dating results obtained in this study is shown in Table 2. All samples exhibit plateau spectra and are consistent with the inverse isochron ages (e.g., Fig. 2), although some abnormal high values of $(^{40}Ar/^{36}Ar)_0$ are obtained due to the narrow range data set of argon isotopic ratios (e.g., Fig.

2A). The Ar-Ar ages show a wide age spectrum of 49.1~196.0 Ma and can be divided into three groups: (1) ~200Ma, (2) 140~160Ma, and (3) 50~60 Ma respectively. They are much older than the fission-track ages.

Table 1. The Fission-track dating result of representative basement rocks from Tibetan Plateau.

Sample	Locality	G	Min.	Density of tracks (10^6/cm^2)			Pooled age (Ma ± 1σ)	χ^2 age (Ma ± 1σ)	Peak age
				ρ_s (N_s)	ρ_i (N_i)	ρ_d (N_d)			
HSS-1	Kokshili	12	Ap	1.6 (241)	13.1 (937)	1.55 (2038)	63.4 ± 4.6	63.4 ± 4.6	63.1
ADS-1	Anduo	16	Ap	1.8 (414)	14.2 (1609)	0.97 (2000)	39.8 ± 2.2	39.8 ± 2.2	39.2
SGLG-1	Sengerli-	31	Zr	7.8 (3759)	7.1 (110)	1.82 (2021)	56.3 ± 1.8	54.1 ± 2.0	56.3
	gongshan	16	Ap	1.0 (219)	8.5 (48)	0.97 (2000)	34.8 ± 2.6	33.1 ± 2.8	34.0
KL-1	Gulu	18	Zr	5.4 (1145)	9.6 (2029)	3.47 (2103)	54.8 ± 2.3	52.7 ± 2.6	54.0
		18	Ap	1.8 (362)	23.2 (2458)	1.55 (2038)	37.8 ± 2.2	35.8 ± 2.3	35.5
YBG-1	Yang-	18	Zr	3.4 (827)	8.9 (2178)	3.47 (2103)	36.9 ± 1.7	35.6 ± 1.8	35.9
	bajing	11	Ap	1.5 (169)	44.7 (2405)	1.55 (2038)	17.3 ± 1.4	17.3 ± 1.4	16.9
KLG-1	Lhasa	14	Zr	4.2 (920)	4.0 (883)	1.82 (2021)	53.1 ± 2.8	51.2 ± 3.0	52.8
		14	Ap	1.2 (162)	15.1 (73)	0.97 (2000)	24.4 ± 2.1	22.2 ± 2.3	23.4
LS-1	Dagze	30	Zr	7.8 (4343)	7.0 (3887)	1.82 (2021)	57.0 ± 1.8	55.8 ± 1.8	56.9
		18	Ap	1.6 (354)	16.8 (102)	0.97 (2000)	29.6 ± 1.8	26.5 ± 2.1	29.6
QS-1	Quxu	24	Zr	5.4 (3020)	6.1 (296)	1.82 (2021)	43.8 ± 1.5	40.3 ± 1.8	42.9
		17	Ap	1.3 (302)	18.5 (2082)	0.97 (2000)	20.2 ± 1.4	19.2 ± 1.6	19.8
QS-2	Quxu	14	Zr	3.1 (598)	7.8 (1486)	3.47 (2103)	38.2 ± 2.1	36.5 ± 2.3	38.9
		16	Ap	1.5 (273)	40.4 (3702)	1.55 (2038)	18.2 ± 1.1	17.6 ± 1.3	17.9
NM-1	Neymu	33	Zr	2.9 (1391)	3.3 (1594)	1.82 (2021)	44.5 ± 1.9	42.0 ± 2.1	44.2
		21	Ap	1.5 (320)	26.6 (138)	0.97 (2000)	16.7 ± 1.0	13.2 ± 1.2	14.2
DZK-1	Dazuka	16	Zr	4.5 (1017)	9.1 (2043)	3.47 (2103)	48.4 ± 2.1	48.3 ± 2.2	48.1
		14	Ap	2.0 (315)	29.9 (2337)	1.55(2038)	32.6 ± 2.0	31.7 ± 2.1	32.0

External detector grain-by-grain method was used in this study. G is the number of counted grains; N is the number of counted tracks. χ^2 age is the pooled age, which passed the χ^2 test at 5% level. Peak age (Ma) is the highest peak of the composite probability density plot of all grain dates in one sample. Ap=apatite; Zr=zircon.

Table 2. The Ar-Ar dating result of representative basement rocks from Tibetan Plateau.

Sample	Location	Rock type	Mineral dated	Plateau age (Ma ± 1σ)	Isochron age (Ma ± 1σ)	$(^{40}Ar/^{36}Ar)_o$ (± 1σ)	MSWD	N
HSS-1	Kokshili	GD	Biotite	196.0 ± 1.9	192.7 ± 2.2	626.8 ± 162.4*	2.4	11
ADS-1	Anduo	GD	Biotite	157.6 ± 1.6	147.0 ± 2.3	1120 ± 475*	2.7	12
			K-feldspar	141.6 ± 1.4	143.3 ± 1.6	273.6 ± 19.1	6.7	7
SGLG-1	Sengligon-	S	Biotite	142.1 ± 0.1	142.1 ± 2.0	294.5 ± 7.6	1.1	9
SGLG-2	shan	S	Biotite	147.8 ± 1.5	140.8 ± 3.9	1217 ± 373*	1.9	11
KLG-1	Lhasa	SY	Biotite	55.8 ± 0.6	55.7 ± 0.7	297.6 ± 3.3	4.2	12
LS-1	Dagze	GD	Biotite	61.1 ± 0.6	61.0 ± 0.7	304.0 ± 13.6	2.0	10
NM-1	Nyemu	GD	Biotite	49.1 ± 0.5	49.4 ± 0.5	304.6 ± 20.9	3.2	9

Rock type of GD=granodiorite; S=schist; SY=syenite. $(^{40}Ar/^{36}Ar)_o$ is the ratio at intercept, MSWD is the mean squared weighted deviate and N is the number of steps used in the age calculation.
* The abnormally high value of $(^{40}Ar/^{36}Ar)_o$ is not due to the inherited argon, but is due to the difficulty to extrapolate the intercept value from the narrow range of the data set (see Fig. 2A).

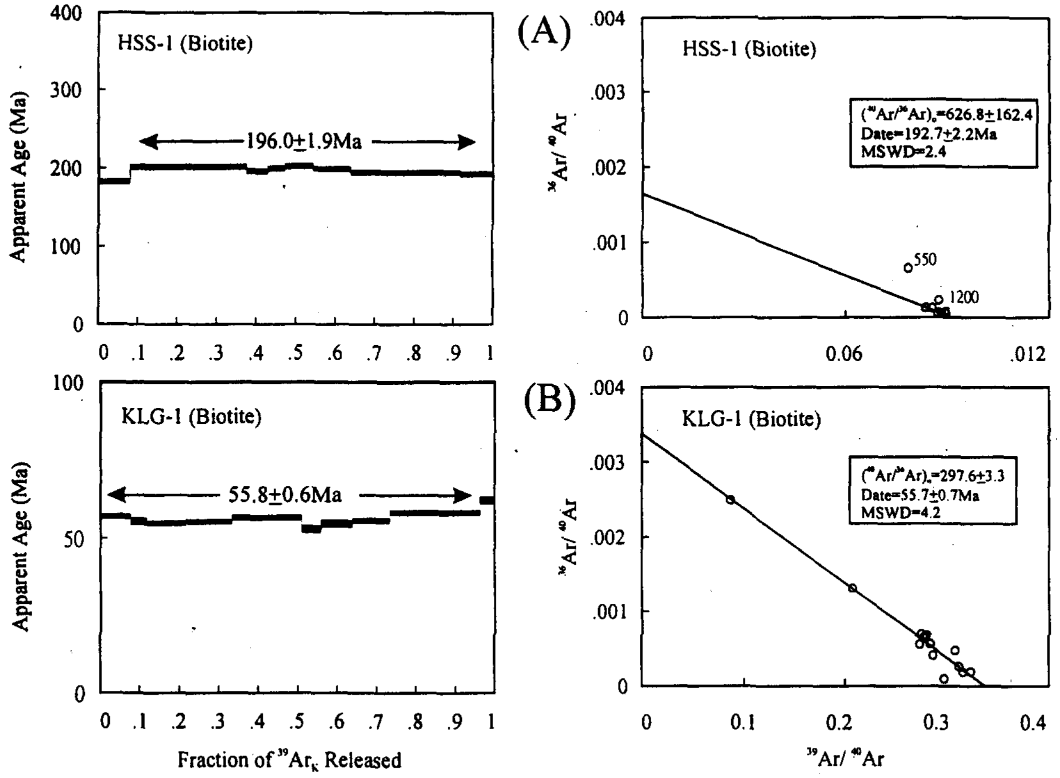

Fig. 2. Representative age spectrum of Ar-Ar date (left side) and the isochron plot (right side): The plateau age of the age spectrum is consistent with inverse isochron age (see also Table 2). The abnormally high $(^{40}Ar/^{36}Ar)_0$ value of sample is due to the narrow range of isotopic ratios (A); however, those samples with wide isotopic ratios can easily extrapolate the intercept of $(^{40}Ar/^{36}Ar)_0$ and obtain the value close to air ratio (B).

DISCUSSION

Thermal history of the studied area

The closure temperature of dated mineral is believed related to the cooling rate, heating time, and the composition of the mineral (e.g., James and Durrani, 1986; Yamada *et al.*, 1995). Sorkhabi (1993) discussed the time-temperature pathways of Himalayan and Trans-Himalayan crystalline rocks using different closure temperatures for different range of apatite FT dates. Wagner and Van de Haute (1992) suggested the track-retention temperatures for zircon is 210±40°C, and 100±20°C for apatite. According to the composition, we can derive the closure temperature of 350±50°C for biotite and 280±25°C for K-feldspar Ar-Ar dates. We will adopt above temperatures in latter discussion. Combining the results of this study, Fig. 3 summarizes the results of our study regarding the thermal history of the Lhasa Block. At least four stages of cooling can be identified in the studied area.

The first stage is > 60 Ma: this stage has only been recorded in the dated minerals from North Lhasa and Tibet. Interestingly, there is one 63.4 Ma of apatite FT date from North Tibet near the Jinsha Suture. Because of the low track stability in apatite, it implies that the Jinsha Suture has been relative stable after 60 Ma even during the time of severe collision. The estimated cooling rate is rather low ca. <2°C/m.y. during this period.

The second stage is about 60~40 Ma: Both south and north of the Lhasa Block, the basement rocks have recorded this stage. However, the cooling rate recorded in South Lhasa Block is much higher (43.7~20.9°C/m.y.) than in the North (5.2°C/m.y.). Such a high cooling rate obviously is related to the severe collision of India and Asia. However, this fast cooling (unroofing) event seems not to be clearly recorded in the basement rocks of North Lhasa Block/Tibet.

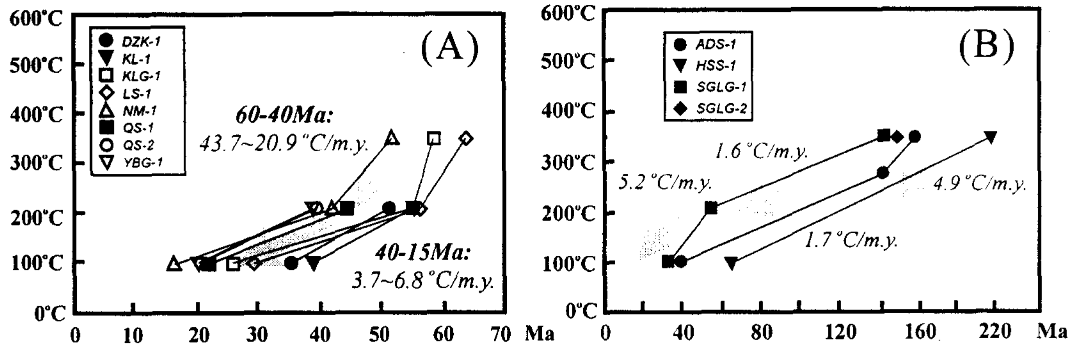

Fig. 3. The thermal history of the Gangdese batholith of the Lhasa Block, S. Tibet (A); and North of Lhasa Block and Tibet (B).

The third stage occurs in the period of 40~15 Ma: The cooling rate is relative low (3.7~6.8°C/m.y.) during this period. It is worth to note that no thermal event has been recorded after 35 Ma in the Northern Tibet Plateau in this study. This implies that North Tibet may have reached its ultimate altitude and no significant thermal events occurred to affect this area.

The last stage is younger than 15 Ma: There is a consensus that the South Tibetan plateau may have started its fast uplift since 20 Ma, and might have reached its ultimate altitude ca. 8 Ma (e.g., Harrison *et al.*, 1992; Coleman and Hodges, 1995). Furthermore, based on apatite fission track thermochronology Pan *et al.* (1993) reported that there was a pulse of rapid cooling (>80°C/m.y.) around 20~15 Ma in the Quxu area, southern Lhasa terrane. Although we do have obtained records of less than 20 Ma in this study, nevertheless, there are not enough data to show the rapid cooling event after 20 Ma. It is necessary to collect more samples from different altitudes and apply some other dating technique with lower blocking temperatures. For instances, U-Th-He dating of apatite with a closure temperature possibly as low as 75±5°C (Wolf *et al.*, 1997) might be a potential method for the purpose of resolving the detailed cooling history in this area after 20 Ma.

Diachronous uplift of Tibet

In addition to the generally accepted fast uplift of the Tibetan plateau which started from 20 Myr ago, Chung *et al.* (1998) suggested that the fast uplift of Tibet commenced much earlier since 40 Myr ago. For lack of the samples from eastern Tibet, we cannot examine if fast uplift in eastern Tibet occurred much earlier than in western Tibet (Chung *et al.*, 1998). However, we can conclude that at least two diachronous uplift events have occurred in Tibet and the first fast thermal cooling (uplift) event occurred at 60~40 Ma. This fast uplift is believed related to the collision event between Indian and Asian. All our collected samples have obtained the thermal event record of this period. This implies that the effect of this event may have been recorded in the entire Tibetan plateau, not only in eastern Tibet. Subsequently, the collision was ongoing, however, only in the southern part of Tibet the second fast uplift event has been recorded (<20 Ma).

CONCLUSION

According to the results of our study, at least four stages of cooling in the Lhasa Block of South Tibet can be recognized. Stage I (>60 Ma): In the northern part of the studied area, some pre-60 Ma thermal events have been recorded and not been reset by the later collision event. It implies that there were some other event occurred before 60 Ma in this area. Stage II (60~40 Ma): A rather fast cooling rate of 20.9~43.7°C/m.y. is calculated for the 60~40 Ma period. The fast cooling may reflect fast unroofing in this area due to the collision between Indian Plate and Eurasian Plate. Stage III (40~15 Ma): Subsequently, a relatively slow cooling rate (3.7~6.9°C/m.y.) is considered to result from a slowdown of unroofing. No obvious tectonic event has been recorded to cause the significant unroofing during the period. Stage IV (< 20 Ma): Some ages have been dated in S. Lhasa samples. Nevertheless, none of sample from northern part of Lhasa Block can obtain this event record in this study. It suggests that the general accepted rapid uplifting event after 20 Ma may only occur in South of Tibetan Plateau.

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