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Thermal Evolution of Plutons and Uplift Process of the Yanshan Orogenic Belt

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Abstract Thermochronological dating was used to study the thermal evolution of the Mesozoic plutons and uplift history of the Yanshan orogenic belt. The results show that the cooling history of the plutons is complicated, corresponding to the inhomogeneous uplift process of the Yanshan orogenic belt. The Panshan granite cooled fast during 226.48–204.95 Ma at a rate of 10.22°C/Ma after its emplacement at a depth of about 10 km, and its fast uplift occurred in about 96–35 Ma at an average rate of 0.115 mm/a. The Wulingshan pluton cooled fast during 132–127.23 Ma at a rate of 94.34°C/Ma, and its rapid uplift occurred in 86–45 Ma at an average rate of 0.186 mm/a. The Yunmengshan granite cooled fast during 143–120.99 Ma at a rate of 19.51°C/Ma, and its rapid uplift occurred in 106–103.95 Ma and 20–0.0 Ma at a rate of 1.06 mm/a and 0.15 mm/a respectively. The Sihetang granite-gneiss uplifted rapidly since 13 Ma at an average rate of 0.256 mm/a. The Badaling granite uplifted rapidly since 6 Ma at an average rate of 0.556 mm/a. The Cenozoic uplift of the Yanshan Mountains can be well correlated to the rifting process of the surrounding basins.

Key words: thermal evolution, uplift process, thermochronological dating, Yanshan orogenic belt

1 Introduction

The Yanshan Mountains are an uplifted orogenic belt in the north of the North China Plain. The typical Mesozoic intracontinental orogenesis is marked by many periods of folding, thrusting, volcanic eruption, plutonism and metallogenesis which occurred in the Yanshan and its adjacent areas after the formation of the Meso-Neoproterozoic and the Palaeozoic sedimentary strata overlying the Archaean-Palaeoproterozoic metamorphic rock series, followed by uplift of mountains and rifting of basins since the end of the Mesozoic (Fig. 1).

Significant progress has been made in the study of the Mesozoic tectonics of the Yanshan orogenic belt in recent years (Cui et al., 1996, 1997; Davis et al., 1996, 1998; Chen, 1998; Wu et al., 1998). However, few geologists have studied in detail the cooling history of the Mesozoic plutons and the Cenozoic uplift process of the Yanshan Mountains by thermochronological dating up to the present.

2 Sampling and Thermochronological Dating

Samples were collected from 5 Mesozoic plutons in different parts of the Yanshan orogenic belt (Fig. 1). Samples S-1-1, S-1-2, S-1-3 and S-1-4 are from the Panshan granite in the central section of the Yanshan orogenic belt at altitudes of 840, 560, 275 and 70 m above sea level. Samples S-2-1 and S-2-2 are from the centre and the east of the Badaling granite on the southwest margin of the Yanshan orogenic belt. Sample S-3 is from the Yunmengshan granite and sample S-4 is from the Sihetang gneiss granite in the west section of the Yanshan orogenic belt. Sample S-5 is from the Wulingshan syenite-porphyry in the central section of the Yanshan orogenic belt. All the samples are fresh and have no evident alteration after their emplacements.

All the samples were crushed, washed and baked. Then pure zircon and apatite grains 0.09–0.15 mm in size were selected for fission-track dating and pure hornblende, biotite, orthoclase and K-feldspar grains

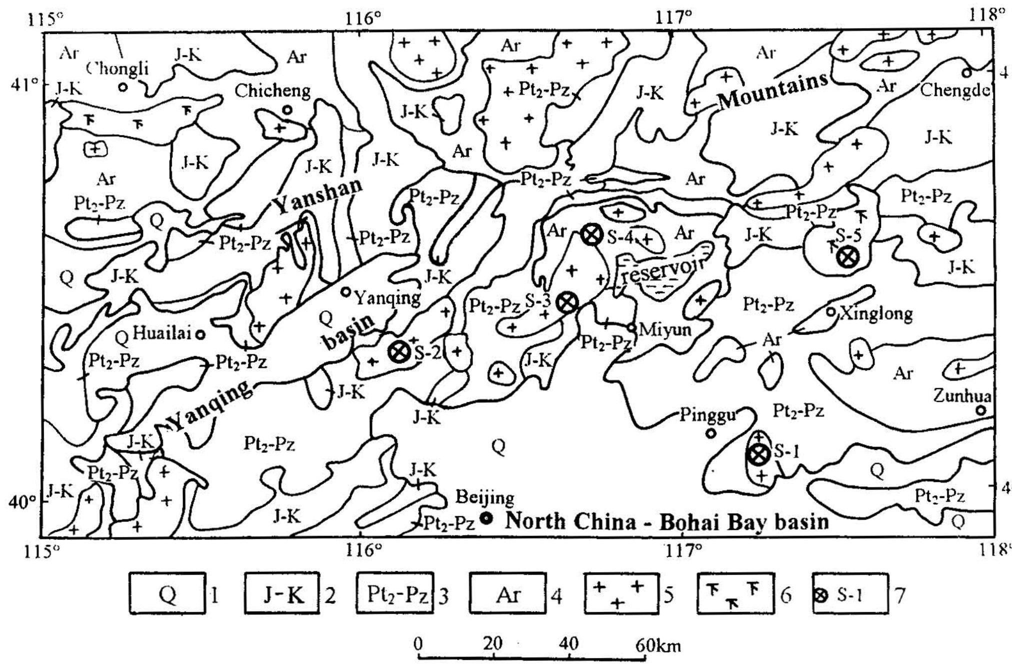

Fig. 1. Geological map of the Yanshan orogenic belt.

1. Quaternary sediments; 2. Jurassic-Cretaceous intracontinental volcanic-sedimentary rocks; 3. Meso-Neoproterozoic and Palaeozoic clastic-carbonate rocks; 4. Archaean-Palaeoproterozoic metamorphic rock series; 5. Mesozoic granite; 6. Mesozoic syenite; 7. sampling location: S-1 is in the middle of the Panshan granite; S-2 in the middle of the Badaling granite; S-3 in the middle of the Yunmengshan granite; S-4 at the northern end of the Yunmengshan granite and S-5 in the south part of the Wulingshan syenite-porphyry.

0.2–0.5 mm in size were selected for K-Ar isotopic dating. The dating results are shown in Tables 1, 2 and 3.

Isotopic ages from references of the paper are used in the following analysis, e.g. 126–129 Ma of K-Ar dating and 129 Ma of Rb-Sr dating of the biotite of the Badaling granite (Beijing Bureau of Geology and Mineral Resources, 1991), 132 Ma of U-Pb dating of the zircon (Davis et al., 1998) and 131.1 Ma of Rb-Sr dating of the whole rock of the Wulingshan syenite-porphyry (Wang et al., 1994) and 142–143±2 Ma of U-Pb dating of the zircon of the Yunmengshan granite (Davis et al., 1996, 1998).

3 Thermal Evolution and Uplift History of Typical Plutons

3.1 Closing temperatures of chronometers and geothermal gradient

Many researches and experiments have been made on the closing temperatures of chronometers, but different closing temperatures were given by different authors for the same chronometer. The closing temperatures adopted here are as follows: 700°C for the U-Pb chronometer of zircon (Harrison et al., 1980), 650°C for the Rb-Sr chronometer of whole rock (Harrison et al., 1979), 520±20°C for the K-Ar chronometer of hornblende (Steiger, 1966), 300±50°C for the K-Ar chronometer of biotite (Turner et al., 1976; Hurford et al., 1991), 250±20°C for the K-Ar chronometer of plagioclase and high-temperature orthoclase of volcanic rocks and porphyry emplaced at shallow depths (Dudson, 1973), 160±30°C for K-Ar chronometer of K-feldspar (Dudson, 1973; Harrison et al., 1979), 225±25°C for the fission-track chronometer of zircon and 100±25°C for the fission-track chronometer of apatite (Naeser et al., 1980; Hurford et al., 1991). Suppose the Meso-Cenozoic geothermal gradient of the Yanshan orogenic belt is 30°C/km, similar to the present geothermal gradient of the surrounding rift basins. Based on the ages of different mineral, the closing temperatures of different chronometers and

Table 1 K-Ar dating results of the Mesozoic plutons of the Yanshan orogenic belt

Sample	Pluton	Mineral	K (%)	$^{40}Ar_{rad}$ (moles/g)	$^{40}Ar_{rad}$ (%)	Age (Ma)
S-1-1	Panshan granite	hornblende	0.51	2.1343×10^{-10}	94.8384	226.48±5.72
S-1-1	Panshan granite	biotite	6.66	2.5069×10^{-9}	97.5044	204.95±3.01
S-3	Yunmengshan granite	biotite	7.07	1.5343×10^{-9}	96.6077	120.99±1.83
S-3	Yunmengshan granite	K-feldspar	3.59	6.6622×10^{-10}	90.0773	103.95±1.59
S-4	Sihetang granite-gneiss	biotite	6.91	1.8023×10^{-9}	97.4815	144.46±2.17
S-5	Wulingshan syenite-porphyry	orthoclase	3.18	7.2697×10^{-10}	95.0327	127.23±2.54

$\lambda_e = 0.581\times10^{-10}/a$, $\lambda_\beta = 4.962\times10^{-10}/a$ and $^{40}K/K = 1.167\times10^{-10}$ are adopted in the calculation of ages.

Table 2 Fission-track dating results of apatite of the Yanshan orogenic belt

Sample	Pluton	Neutron flux ($\times10^{16}$n/cm^2 • s)	Natural track density ρ_s ($n\times10^7cm^{-2}$)	Induced track density ρ_I ($n\times10^7cm^{-2}$)	ρ_s/ρ_i	Age (Ma)
S-1-1	Panshan granite	0.740	0.0273	0.1870	0.1440	63.4± 4
S-1-2	Panshan granite	0.740	0.0384	0.3300	0.1160	50.5± 3
S-1-3	Panshan granite	0.740	0.0398	0.3780	0.1053	49.0± 3
S-1-4	Panshan granite	0.740	0.0332	0.2957	0.1115	48.5± 2
S-2-1	Badaling granite	0.964	0.0022	0.1893	0.0116	6.6± 0.8
S-2-2	Badaling granite	0.964	0.0040	0.3960	0.0100	5.6± 1.5
S-3	Yunmengshan granite	0.740	0.0076	0.0951	0.0799	34.8± 2
S-4	Sihetang granite-gneiss	0.740	0.0016	0.0517	0.0300	13.0± 2
S-5	Wulingshan syenite	0.740	0.0036	0.0247	0.1470	63.7± 8

The neutron flux was determined by comparing to the standard 612# uranium-glass of the United States.

Table 3 Fission-track dating results of zircon of the Yanshan orogenic belt

Sample	Pluton	Neutron flux ($\times10^{16}$n/ cm^2 • s)	Number of grains	Average age (Ma)
S-1-1	Panshan granite	0.06427	10	118± 7
S-1-2	Panshan granite	0.06427	10	114± 7
S-1-3	Panshan granite	0.06427	9	108± 7
S-1-4	Panshan granite	0.06427	9	96± 6
S-2-1	Badaling granite	0.96385	11	78± 5
S-2-2	Badaling granite	0.96385	10	92.5± 5
S-3	Yunmengshan granite	0.06427	10	106± 6
S-4	Sihetang granite-gneiss	0.06427	8	84± 4
S-5	Wulingshan syenite	0.06427	8	86± 6

The neutron flux was determined by comparing to the standard 612# uranium-glass of the United States.

the supposed geothermal gradient, the cooling history and uplift process of plutons of the Yanshan orogenic belt can be analyzed.

3.2 Panshan pluton

Figure 2 shows the thermal evolution and uplift process of the Panshan granite. After its emplacement, the Panshan pluton cooled fast at the rate of 10.22°C/Ma in 226.48–204.95 Ma. This fast cooling process was caused by temperature difference between the pluton and its country rocks. In about 204.95 Ma, thermal balance between the pluton and country rocks occurred with the balance temperature of about 300°C, indicating the depth of emplacement of about 10 km. Then the Panshan pluton cooled very slowly at the rate of 0.86°C/Ma in the period of 204.95–118 Ma, corresponding to the slow uplift of the pluton at an average rate of 0.028 mm/Ma. In 118-63.4 Ma, the Panshan pluton cooled at a rate of 2.29°C/Ma, corresponding to the uplift at an average rate of 0.076 mm/a. Figure 3 shows that the Panshan pluton uplifted at a rate of 0.035 mm/a during 118-80 Ma and at a rate of 0.052 mm/a during 63.4–48.5 Ma. It can be further inferred that the rapid uplift of the Panshan pluton at a rate of 0.15 mm/a occurred during 95–35 Ma (Figs. 2 and 3).

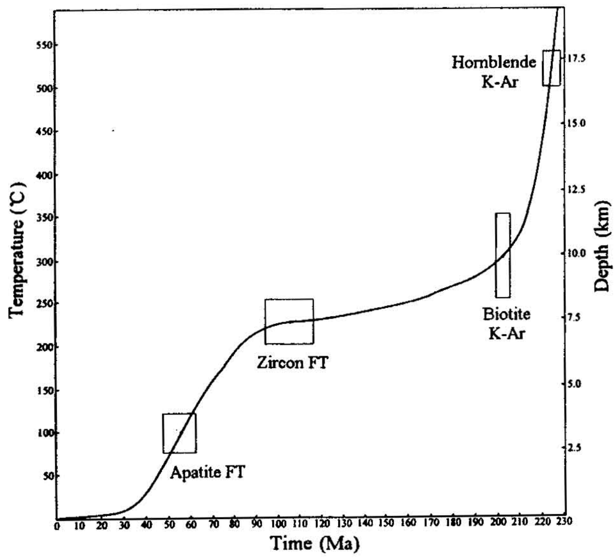

Fig. 2. Diagram of the thermochronological evolution of the Panshan pluton of the middle Yanshan orogenic belt.

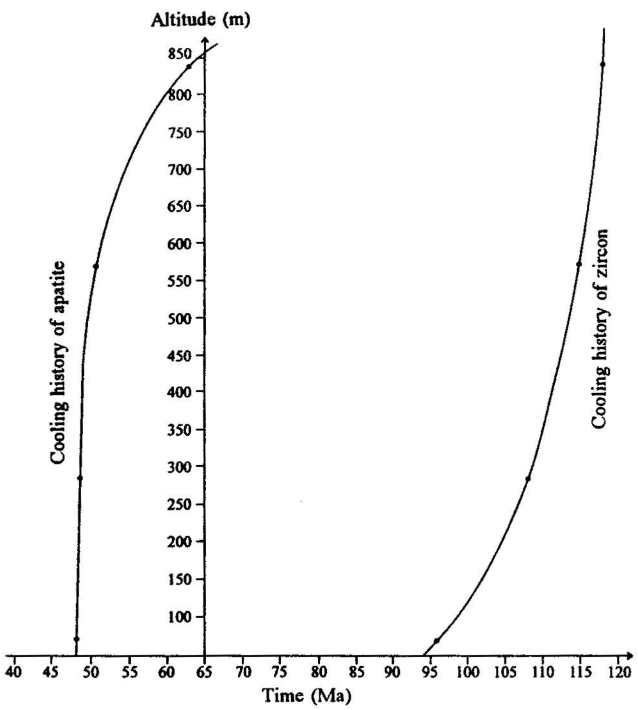

Fig. 3. Diagram of fission-track age vs. altitude of the Panshan pluton of the central Yanshan orogenic belt.

3.3 Badaling pluton

The fast cooling process of the Badaling granite caused by the temperature difference between the pluton and country rocks ended before 129 Ma. Then the Badaling pluton cooled slowly at a rate of 1.626°C/Ma until 6 Ma, corresponding to the slow uplift at an average rate of 0.054 mm/a. Since 6 Ma the Badaling pluton rapidly uplifted at a rate of 0.556 mm/a, resulting in temperature decrease at a rate of 16.67°C/Ma (Fig. 4). The rate and beginning time of the rapid uplift of the Badaling granite are correlated well to the sedimentation rate and beginning time of the rifting of the Yanqing basin in the adjacent areas to the south (Wu Zhenhan et al., 1996).

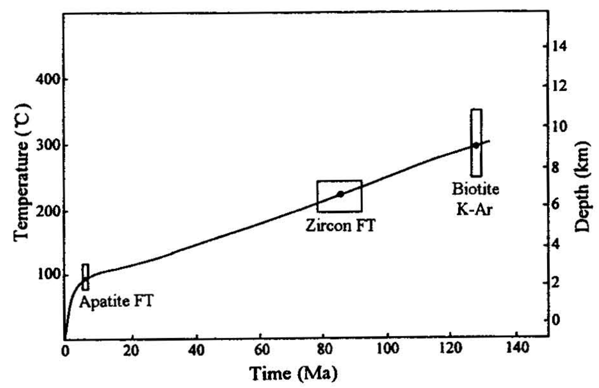

Fig. 4. Diagram of the thermochronological evolution of the Badaling granite on the south margin of the Yanshan orogenic belt.

3.4 Yunmengshan pluton

Figure 5 shows the cooling history and uplift process of the Yunmengshan pluton after its emplacement. The Yunmengshan granite was emplaced in about 143 Ma (Davis et al., 1996, 1998), followed by fast cooling at a rate of 19.51°C/Ma in 129–120.99 Ma mainly caused by thermal balance between the pluton and country rocks. Then the pluton rapidly uplifted at an average rate of 0.167 mm/a, resulting in temperature decrease at a rate of 5°C/Ma in 120.99–106 Ma. During 106–103.95 Ma, the Yunmengshan pluton cooled at a rate of 31.7°C/Ma, corresponding to the rapid uplift at a rate of 1.06 mm/a. This period of rapid uplift was possibly caused by the low-angle normal faulting of the Shuiyu metamorphic core complex discovered by Davis et al. (1996). A slow-uplift process occurred in about 100–20 Ma when the temperature of the pluton decreased at a rate of 0.75°C/Ma.

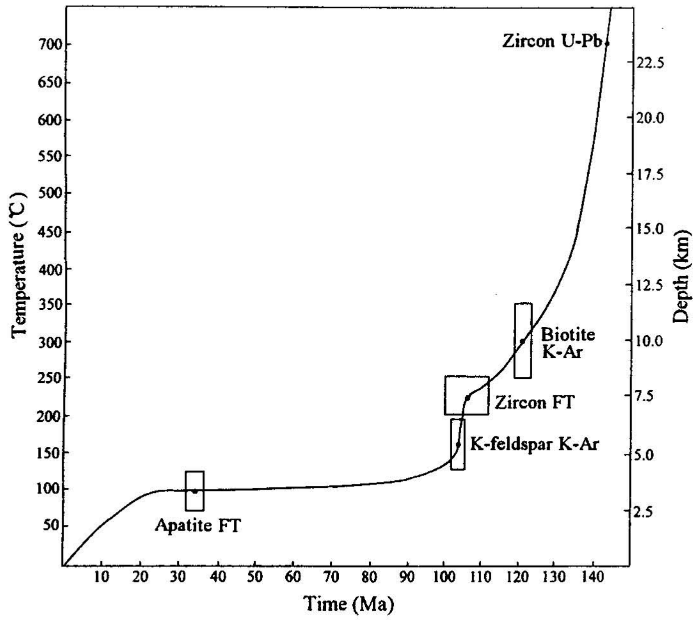

Fig. 5. Diagram of the thermochronological evolution of the Yunmengshan granite of the west Yanshan orogenic belt.

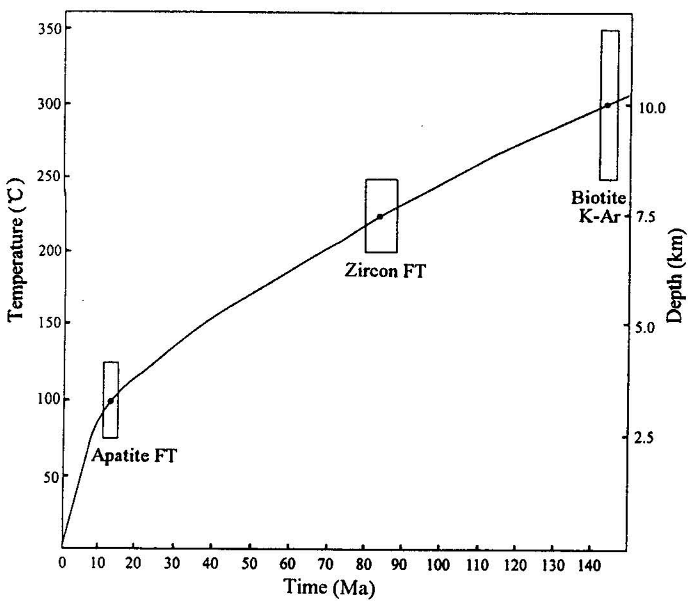

Fig. 6. Diagram of the thermochronological evolution of the Sihetang gneiss-granite of the central Yanshan orogenic belt.

Since about 20 Ma, the Yunmengshan pluton uplifted at an average rate of 0.15 mm/a up to the present, resulting in temperature decrease at a rate of 4.45°C/Ma.

3.5 Sihetang granite-gneiss

The Sihetang granite-gneiss is located in the north of the Yunmengshan pluton (Fig. 1). Its thermal evolution is affected by the Yunmengshan granite. The zero retention temperature of biotite in gneiss occurred before 144.46 Ma when the temperature was higher than 300°C. Then the granite-gneiss cooled at a rate of 2.89°C/Ma in 144.46–84 Ma, corresponding to the uplift at a rate of 0.096 mm/a. The granite-gneiss slowly uplifted in 84–13 Ma at a rate of 0.059 mm/a, yielding temperature decrease at a rate of 1.76°C/Ma. Since 13 Ma, the Sihetang granite-gneiss rapidly uplifted at an average rate of 0.256 mm/a, resulting in rapid cooling at a rate of 7.69°C/Ma (Fig. 6).

3.6 Wulingshan pluton

Figure 7 shows the thermochronological evolution of the Wulingshan pluton. The Wulingshan syenite-porphyry was emplaced in about 132 Ma, followed by fast cooling at a rate of 94.34°C/Ma until 127.23 Ma. Then the pluton cooled slowly at a rate of 0.61°C/Ma in 127.23–86 Ma, corresponding to the slow uplift at a rate of 0.02 mm/a. During 86–63.7 Ma, the Wulingshan pluton uplifted rapidly at an average rate of 0.186 mm/a, yielding temperature decrease at a rate of 5.61°C/Ma. This rapid uplift process lasted until about 45 Ma. Since 45 Ma the pluton has uplifted very slowly at a rate of 0.02 mm/a up to the present.

4 Geodynamic process of uplift of the Yanshan Mountains

The thermochronological dating provided important information of the thermal evolution of plutons of the Yanshan orogenic belt, illustrating the complicated and inhomogeneous uplift process of the Yanshan Mountains (Figs. 2-7).

The earlier uplifts of plutons related to intracontinental orogenesis of the Yanshan orogenic belt were denuded in the Mesozoic. The present Yanshan

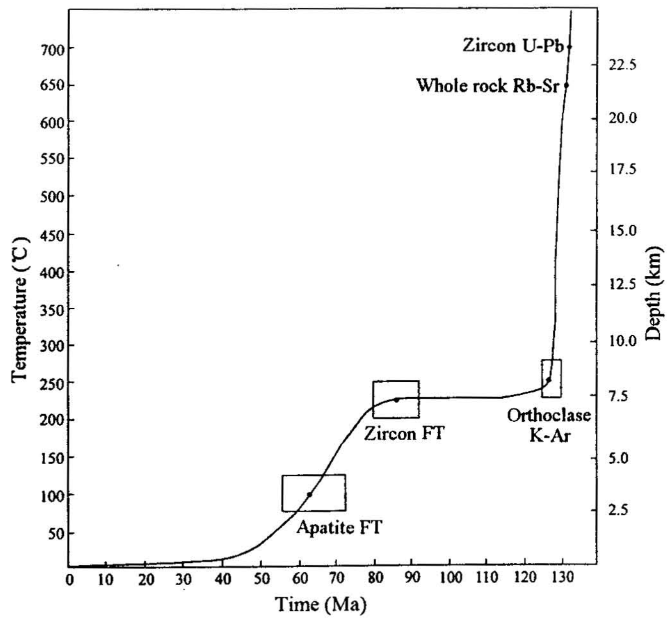

Fig. 7. Diagram of the thermochronological evolution of the Wulingshan pluton of the central Yanshan orogenic belt.

Mountains uplifted section by section since the end of the Mesozoic. The central section of the Yanshan Mountains, e.g. the Panshan and the Wulingshan Mts., uplifted rapidly in 96–35 Ma at average rates of 0.115–0.186 mm/a (Figs. 2, 3 and 7). The west section, e.g. the Yunmengshan and the Sihetang Mts., uplifted rapidly since 20–13 Ma at average rates of 0.15–0.256 mm/a (Figs. 5 and 6). And the southwest margin of the Yanshan Mountains, e.g. the Badaling Mts., uplifted rapidly since 6.0 Ma at an average rate of 0.556 mm/a (Fig. 4).

The geodynamic process of the uplift of the Yanshan Mountains since the end of the Mesozoic can be well correlated to the rifting process of the surrounding basins. The beginning of the rapid uplift of the Yanshan Mountains in about 96 Ma corresponds to the transition from a strong compression to a regional extension (Zhu, 1990; Wu et al., 1998). The rapid uplift of the central Yanshan Mountains during 96–35 Ma is correlated to the rapid rifting of the Songliao basin in the north and the early-stage rifting of the North China basin in the south (Ma et al., 1990; Hu et al., 1990). The rapid uplift of the west Yanshan Mountains since 20–13 Ma is correlated to the rapid subsidence of the North China-Bohai Bay basin in the south and the east (Hu et al., 1990) and Datong basin in the southwest. The rapid uplift on the southwest margin of the Yanshan Mountains is well correlated to the rapid subsidence of the Yanqing rift basin (Wu et al., 1996; Cui et al., 1997). It can be further inferred that the active rifting of the surrounding basins resulted in the passive uplift of the Yanshan Mountains.

5 Discussion

The difference of thermal history and uplift process of plutons in different sections of the Yanshan orogenic belt depends on regional tectonic settings and deep geological processes. From the Late Triassic to Early Cretaceous, inhomogeneous thrusting and folding accompanied by magmatism occurred widely in the Yanshan area (Cui et al., 1997; Davis et al., 1998; Wu et al., 1998), resulting in inhomogeneous denudation and uplift process of plutons in the Mesozoic. Since the Late Cretaceous, regional extension dominated in the Yanshan and its adjacent areas, forming a basin-range tectonic framework (Cui et al., 1997; Wu et al., 1998). The inhomogeneous uplifting and depression of the blocks in the Cenozoic controlled by extensional and shear-extensional faults and deep process finally resulted in the formation of present geomorphic features of the Yanshan orogenic belt (Yi et al., 1993; Cui, 1997). The Meso-Cenozoic tectonic processes of the Yanshan orogenic belt were constrained by crustal movement and geodynamics of the east Asian Peri-Pacific region (Cui et al., 1990; Cui et al., 1997; Wu et al., 1997).

The thermochronological dating is useful to know the cooling history of the Mesozoic plutons and presents constraints on the uplift process of the Yanshan Mountains. However, the thermal gradient of the Mesozoic and the Cenozoic of the Yanshan area is poorly defined because of lack of data. The relations among tectonic events, thermal history and uplift process of plutons based on the thermochronological dating need to be proved by more detailed studies and more data are needed to better understand the geodynamics of the uplift of the Yanshan Mountains.

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