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Thermochronology of Mesozoic Sandstone from the Beipiao Basin and Its Implication to Meso-Cenozoic Tectonic Evolution of the Eastern Yan-Liao Orogenic Belt

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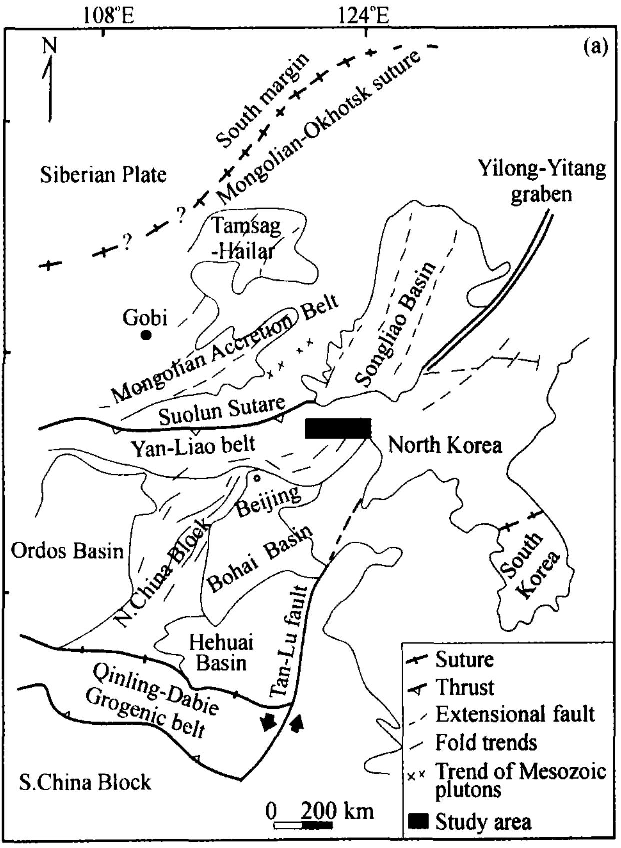
Abstract Combining the single-grain low-temperature apatite fission track with high-temperature zircon U-Pb dating of sandstone can better reveal the temporal association between the source and depositional site, and identify both the age component of the source terrain and subsequent thermo-tectonic events after deposition. This paper introduces the single-grain zircon U-Pb dating and fission track (FT) dating of sediments from the Beipiao basin in Northeast China. The U-Pb ages of 18 single zircon grains collected from the early Jurassic Beipiao Formation range from 194.3±2.9 to 233.8±4.2 Ma and most of apatite FT ages are about 30-40 Ma, indicating that the eastern part of the Yan-Liao orogenic belt experienced an obvious tectonic seesawing during Meso-Cenozoic time. The eastern part of Liaoning Province (the Liaodong block) uplifted in the early Mesozoic (230-190 Ma) and formed a geological landscape of high mountains, while the western part of the province (the Liaoxi area) subsided relatively and thousand-meter-scale sediments were deposited. During the Cenozoic (30-40 Ma), the Liaoxi area uplifted as a whole, and the Xialiaohe Basin sank intensively. The topographic landscape had a great change: high mountains in the west and east of Liaoning Province and low plains in the central area.

Key words: Yan-Liao orogenic belt, single-grain zircon U-Pb dating, apatite fission track (FT) dating

1 Introduction

The Yan-Liao orogenic belt lies in the northern segment of the North China Block (NCB) (Fig. 1). During Mesozoic to Cenozoic time, it experienced intense tectono-magmatic activation, accompanied by the formation of intracontinental basins and widespread magmatism and is a very important area to study continental dynamics and Meso-Cenozoic tectonic evolution in eastern China. Most of previous work in this area has focused on the formation of basement, structural style and volcano-sedimentary strata since the early 20th century (Weng, 1929), e.g., Zhao (1990) summarized the major tectonic characteristics of the Meso-Cenozoic Yan-Liao intracontinental orogenic belt, Davis et al. (1998a) discovered ductile nappes in Yunmengshan and large overthrust structure belts in northern Hebei Province. The evolution of the Yanshan deformation was clarified by dating Mesozoic plutons and volcanic strata using U-Pb and ^{40}Ar-^{39}Ar methods respectively and discovered a complicated history of major superposed contractional deformation. But because the Yan-Liao belt has been influenced by many tectonic events since Mesozoic, there are still some different viewpoints about the tectonic evolution and structural style. The main points of controversy are: (1) When did the tectonic activation start, in the early Yanshanian (Zhao et al., 1994; Wang, 1996) or during the Indosinian (Cui and Li, 1983)? (2) What caused the tectonic activation, a far-field effect (Cheng, 1994) or the deep-seated basaltic underplating process (Chen, 1956; Shao et al., 2000)? (3) How many contractional events have occurred in the Yan-Liao belt (Zhao, 1990; Davis et al., 2001)? (4) What is the likely uplifting sequence, inhomogeneous or coincident (Wu et al., 2000)? The lack of precise thermo-chronology data and insufficient study of the coupling between the sedimentation in a basin and the unroofing-erosion in the surrounding orogens are the main reasons causing the above-mentioned controversy.

Basin sediments contain two kinds of information about source areas. One is the information of material composition (including the detritus composition, heavy mineral and geochemical component) (Yan et al., 2002) and the other is the information of chronological composition of source rocks. It is difficult to quantitatively estimate the proportion of each possible source to the basin sediments only through the detritus composition, heavy mineral and geochemical analyses. In recent years, some studies have been conducted by means of sediment geochronology, such as the single-grain zircon U-Pb age analysis to trace the basin provenance (Bruguier and Lancelet, 1997; Brendan



and Michael, 2000). The major significance of applying geochronological data to tracing the basin provenance lies in that the chronological information of the basin sediments can be extracted and the thermo-tectonic events that source rocks have experienced can be identified.

Detrital zircon is resistant to physical and mechanical degradation and can preserve much useful information of source rocks. Since the zircon U-Pb systematics is undisturbed by temperatures below 700°C, the zircon U-Pb age represents the time that zircon is generally formed in igneous or high-grade metamorphic environments. Therefore, these ages can provide the information about basin source rocks and the coupling between the sedimentation in a basin and the unroofing-erosion in the surrounding orogens when a basin is formed and sediments are deposited. Compared with the zircon U-Pb systematics, the advantage of the apatite FT technique lies in that it can provide low-temperature (partial annealing zone temperature: 70-120°C) data that record the thermo-tectonic events after deposition. Through analyses of the distribution of the age and the confined track lengths of single-grain apatite, the information about the subsequent thermo-tectonic

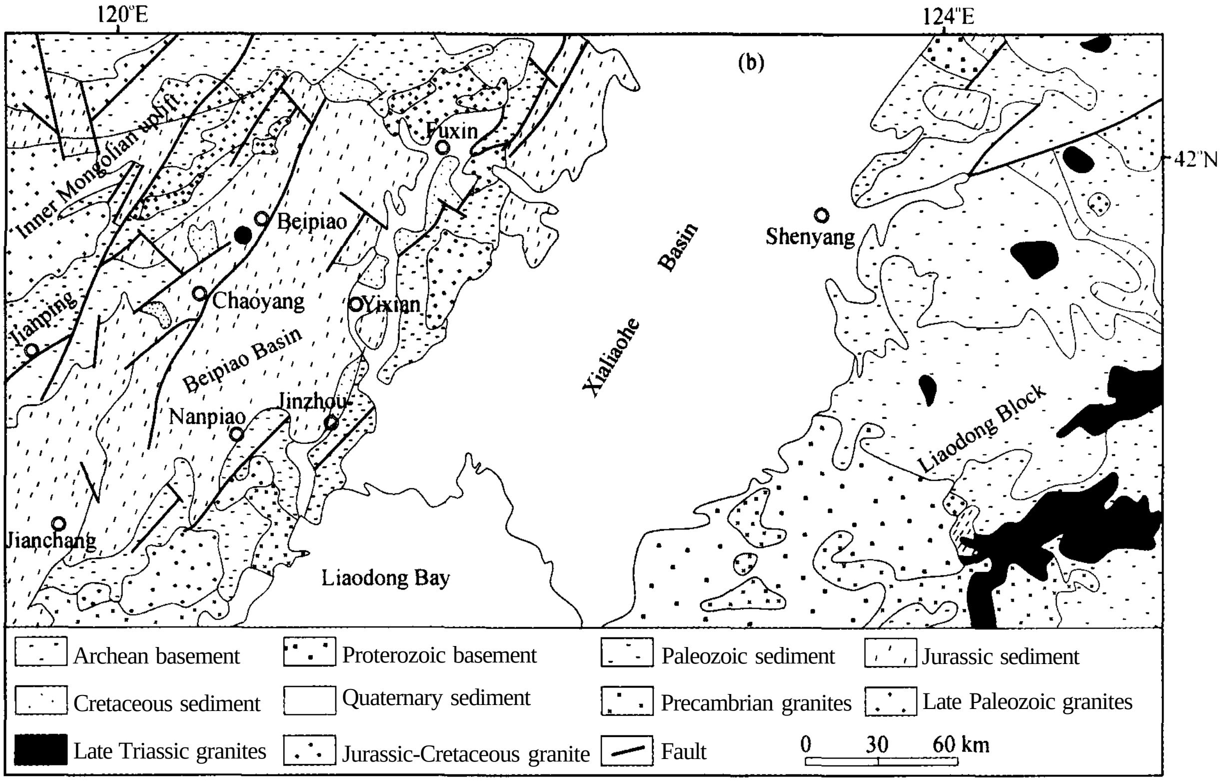


Fig. 1. Tectonic setting of the North China Block. (a) Location of the study area; (b) regional tectonic map of the eastern part of the Yan-Liao orogenic belt.

• Location of the sample.

events after deposition can be obtained. Combining low-temperature FT with high-temperature single-grain U-Pb dating of sandstone can better reveal the temporal association between the source and depositional site, and identify both the underlying age structure of the source and subsequent thermo-tectonic events after deposition. The whole orogenic process can be well reconstructed (Yan et al., 2003).

The Beipiao Basin lies in the eastern part of the Yan-Liao orogenic belt. As one of the largest intracontinental basins, the sediments contain a great deal of information about the tectonic evolution of the Yan-Liao orogenic belt. In this paper, we present analyses of the single-grain zircon U-Pb age dating and apatite FT ages of sandstone collected from Jurassic strata in the basin. The aim of this study is to reveal the uplift process of the Meso-Cenozoic Yan-Liao orogenic belt and rebuild the Meso-Cenozoic basin-mountain evolution history in the eastern part of the Yan-Liao orogenic belt.

2 Geological Setting

The regional metamorphic basement is composed of Archean crystalline basement rocks with the oldest recorded crustal ages of 3.8 Ga (Liu, 1991). Paleoproterozoic neritic sediments (ca. 1850-1800 Ma) are widespread, but with variable thickness (from 0 m to over 10 km). Neoproterozoic strata (ca. 800-615 Ma) are absent. Paleozoic strata on the craton are represented by: (1) Cambrian-middle Ordovician sediments dominated by neritic carbonates; (2) upper Carboniferous-lower Permian alternating marine and terrestrial sequences respectively characterized by carbonates and coal-bearing clastics; (3) upper Permian-Triassic red beds and conglomerates. By the end of the middle Triassic, due to the Indosinian movement, N-S -trending compression resulted in the deformation of pre-Mesozoic strata and the formation of a series of NE-trending fold and fault belts as well as some small-sized intracontinental basins. From the early Jurassic to early Cretaceous, the regional structural style is composed of complex folds, overthrust and reverse faults as a consequence of the Yanshanian events.

The Beipiao Basin has experienced three volcano-sedimentary cycles and is deposited with thousand-meter-thick Jurassic-Cretaceous volcano-sedimentary sequences. Jurassic coal-bearing clastics and continental volcano-sedimentary units unconformably overlie the Archean basement or the younger Phanerozoic sedimentary covers. Late Triassic volcanic activity has been identified, but is geographically restricted. During Jurassic time, intermediate-acidic volcanism was widespread in the basin and the total thickness of Jurassic sediments was about 4000 m, including the lower Jurassic (Xinglonggou and Beipiao formations), middle Jurassic (Haifanggou and Lanqi formations) and upper Jurassic (Tuchengzi Formation). The Xinglonggou Formation was deposited during the first volcanic cycle and was composed of 181-403 m thick intermediate volcanic rocks. The Lanqi Formation was deposited during the second volcanic cycle and comprised of andesite, basalt and agglomerate rocks and the thickness was about 132-975 m. Regional volcanism reached its maximum intensity in the early Cretaceous and lower Cretaceous, and the volcanic rock series included the Yixian, Jiufutang and Fuxin formations. Strata intercalated with the Jurassic and, locally, lower Cretaceous volcanic rocks include coal, conglomerate, sandstone, tuff and other volcaniclastic rocks. The Yixian Formation was composed of intermediate-acidic volcanic rocks with a thickness of about 713-4000 m.

The Jianping uplift neighbors the basin at the northwest, which is the eastern part of the Inner Mongolia uplift belt and is comprised of Archean Xiaotazigou and Dayingzi groups (2500-3000 Ma) and Late Paleozoic plutons (400-250 Ma). The Liaodong uplift consisted of Paleoproterozoic metamorphic rocks (2300-1800 Ma) and late Triassic plutons (230-190 Ma).

In order to illustrate the Meso-Cenozoic Yanshan Mountain uplift process, we applied apatite FT and zircon U-Pb dating to the sandstone collected from the early Jurassic Beipiao Formation. The yellow-brown sandstone was collected at the SW of Beipiao Town. The location of the sample is shown in Fig. 1.

3 Analytical Technique

The separation of zircon and apatite grains was performed at the laboratory of Changsha Institute of Geotectonics, Chinese Academy of Sciences. The sandstone sample was ground to 0.1-0.2 mm. Zircon and apatite grains were handpicked at random under a binocular after fractionation through magnetic, electric-magnetic, dielectric and heavy liquid processes. Zircon and apatite grains were selected and sorted carefully. Other grains, such as those of rutile, were eliminated firstly. The zircon grains were analyzed for their morphologic features and were sorted according to their color, size, idiomorphic grade (e.g. uhedral, half-uhedral or xenomorphic) and crystal shape (e.g. prismatic, round or grainy). The pure, transparent grains without cracks, wraps and catagenesis were selected from different types of zircon for analysis.

Because the zircons in sandstone are derived from different sources and may consist of several age groups, U-Pb ages of single zircon grains were measured. Different types of zircon grains were analyzed according to their proportions in the sample.

The Pb and U isotopic data were obtained at the Tianjin Institute of Geology and Mineral Resources. Single-grain zircon U-Pb age measurement was determined by using the isotopic dissolution method. The procedure was after Krough's (1973). The techniques of zircon decomposition and U and Pb extraction were improved upon that the 208Pb-235U mixing spike was taken as the dissolution dose (Li et al., 1995). After the solution was evaporated, U and Pb were mixed with silica gel-phosphoric acid solution and put on a single-rhenium band. U-Pb isotopic ratios were measured with a VG-354 thermionic mass spectrometer with a high-precision Daly detector. Mass discrimination and system error of all U-Pb data were corrected and total Pb blanks over the period of the analysis ranged from 0.030 ng to 0.050 ng and uranium blanks from 0.002 ng to 0.004 ng. The isotopic composition of radiogenic Pb was determined by subtracting first the blank Pb and then the remainder, assuming a common Pb composition at the time of initial crystallization, determined from the global single stage model. Calculation was performed using the computer software PBDAT (Ludwig, 1993).

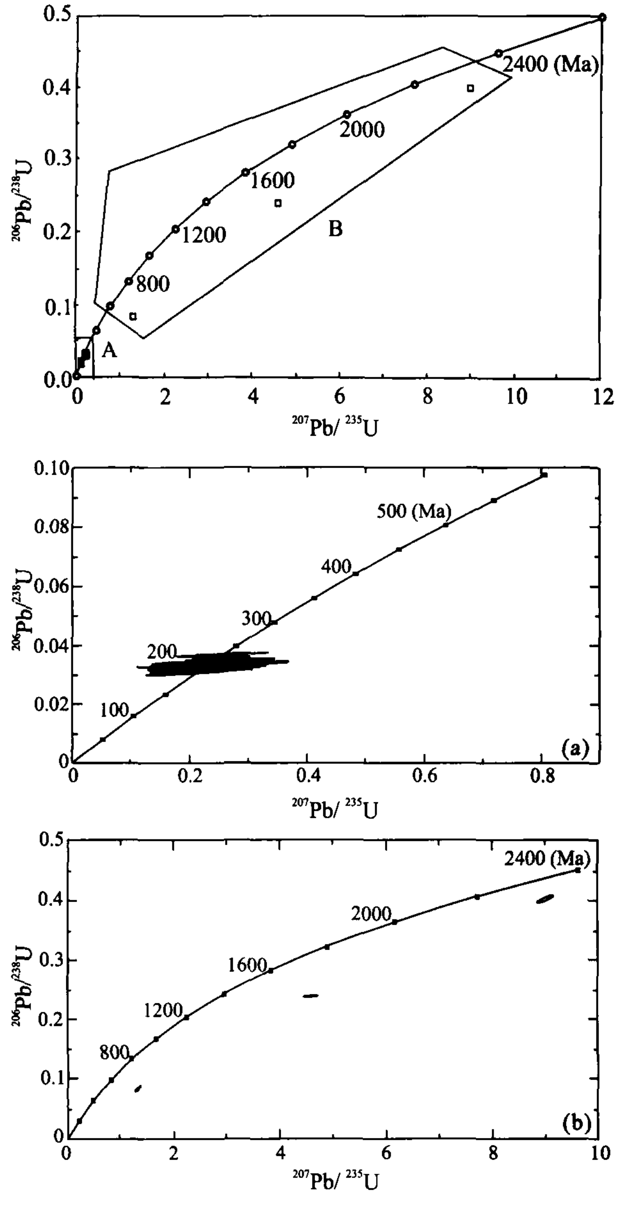


Fig. 2. Concordia plot for detrital zircons of the sample.
Insets (a) and (b) are enlargements between 0 and 600, and 800 **and** 2400 Ma, respectively. Polygons are of 2c error.

The fission track analysis of apatite was made at the Fission Track Laboratory of Changsha Institute of Geotectonics, Chinese Academy of Sciences.

Apatite grains were put into sample moulds containing polysaccharid and arranged into well-distributed strips. Epoxy was used to cement the apatite grains before they were put into an oven at 70°C for 24 h. Corundum powder of M24, M7 and M3.5 was used to wet-rub the inside surface and Cr_2O_3 to polish. Then the slices were etched by 1% HNO_3 for 3 minutes.

Apatite FT ages in this study were measured by using the external detector method. Low-U muscovite slips were pasted on the slices before being radiated by a heavy water reactor tube together with the standard U glass (UB2) under a neutron flux of 5×10^{15} cm^{-2}. The radiated muscovite slips were then etched by 40% HF at 25°C for 55 minutes so that the induced fission tracks can be clearly observed. The track density and length were determined using an AUTOSCAN system. Apatite FT ages are calculated with the ξ method taking the U-glass UB2 (U content is 11.2×10^{-6}) and apatites from volcanic ash in the Fish Canyon as the standards (ξ=381.8±7.3).

4 Analytical Results

4.1 Zircon U-Pb age

The analytical results of single zircon U-Pb dating are shown in Table 1 and Fig. 2.

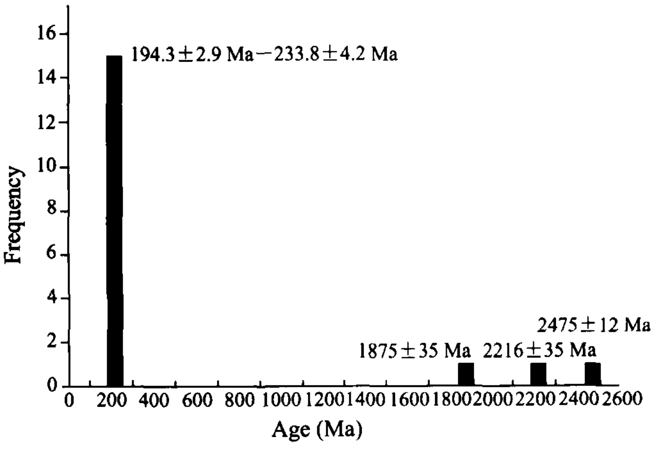


Fig. 3. Frequency diagram for apparent ages of detrital zircons.
Major age peak 194.3±2.9 to 233.8±4.2 Ma is shown.

Table 1 Detrital zircon U-Pb data

Sample Description	Weight (μg)	U (ppm)	Pb (ppm)	^{204}Pb (ppb)	Radios corrected for common lead					Apparent age (Ma)		
					^{206}Pb/^{204}Pb	^{208}Pb/^{206}Pb	^{206}Pb/^{238}U (2 σ error)	^{207}Pb/^{235}U (2 σ error)	^{207}Pb/^{206}Pb (2 σ error)	^{206}Pb/^{238}U	^{207}Pb/^{235}U	^{207}Pb/^{206}Pb
1. Ly, pr	12	45	25	0.035	249	0.1768	0.4035 0.0048	9.005 0.128	0.1618 0.0012	2185 22	2339 13	2475 12
2. Pur, spr	11	150	38	0.015	879	0.03189	0.2393 0.0012	4.590 0.102	0.1391 0.0028	1383 6.2	1748 19	2216 35
3. Ly, pr	12	127	15	0.028	193	0.1552	0.0839 0.0040	1.326 0.028	0.1147 0.0022	519.1 24	857.0 12	1875 35
4. Ly, pr	12	57	6	0.027	52	0.1583	0.0369 0.0007	0.259 0.064	0.0509 0.0117	233.8 4.2	234.1 52	237.3 530
5. Y, spr	12	133	10	0.040	71	0.1209	0.0356 0.0004	0.250 0.044	0.0509 0.0084	225.7 2.6	226.4 36	234.1 380
6. Ly, spr	11	89	9	0.043	53	0.1922	0.0349 0.0004	0.284 0.045	0.0590 0.0084	221.1 2.8	253.9 36	568.8 310
7. Y, gr	12	56	6	0.030	48	0.09834	0.0346 0.0007	0.241 0.066	0.0505 0.0132	219.0 4.4	219.0 54	219.8 610
8. Ly, pr	15	84	15	0.130	34	0.1852	0.0345 0.0007	0.241 0.084	0.0507 0.0166	218.7 4.5	219.3 69	226.6 760
9. Ly, lpr	10	183	12	0.030	97	0.1889	0.0341 0.0003	0.238 0.030	0.0507 0.0061	216.1 1.8	216.9 25	226.0 280
10. Ly, spr	12	59	6	0.034	50	0.2387	0.0340 0.0007	0.238 0.075	0.0508 0.0151	215.8 4.4	217.1 62	230.3 690
11. Y, pr	12	50	8	0.048	34	0.1871	0.0340 0.0007	0.237 0.082	0.0505 0.0166	215.6 4.7	215.8 67	218.5 760
12. Y, spr	15	59	13	0.110	30	0.2089	0.0340 0.0004	0.258 0.044	0.0551 0.0088	215.5 2.8	233.6 36	416.3 360
13. Ly, spr	11	54	8	0.048	37	0.1627	0.0334 0.0009	0.234 0.094	0.0507 0.0192	212.0 5.4	213.1 77	225.6 880
14. Ly, pr	12	61	4	0.013	86	0.2229	0.0334 0.0009	0.238 0.104	0.0516 0.0213	211.9 5.4	216.7 85	269.6 950
15. Ly, spr	10	74	5	0.021	73	0.1858	0.0328 0.0006	0.228 0.048	0.0505 0.0099	208.2 3.8	208.9 40	216.8 450
16. Ly, spr	12	69	4	0.015	85	0.1678	0.0324 0.0007	0.229 0.082	0.0505 0.0173	205.6 4.4	209.4 68	218.8 790
17. Ly, pr	12	52	5	0.025	48	0.1817	0.0309 0.0008	0.215 0.074	0.0505 0.0163	196.1 4.8	198.0 62	220.0 750
18. Ly, lpr	13	71	5	0.025	67	0.1268	0.0306 0.0005	0.212 0.039	0.0503 0.0088	194.3 2.9	195.3 33	207.9 410

Note: Pur – purple; Y – yellow; Ly – light yellow; Pr – prismatic; Lpr – long primatic; Spr – short primatic; Gr – grainy.

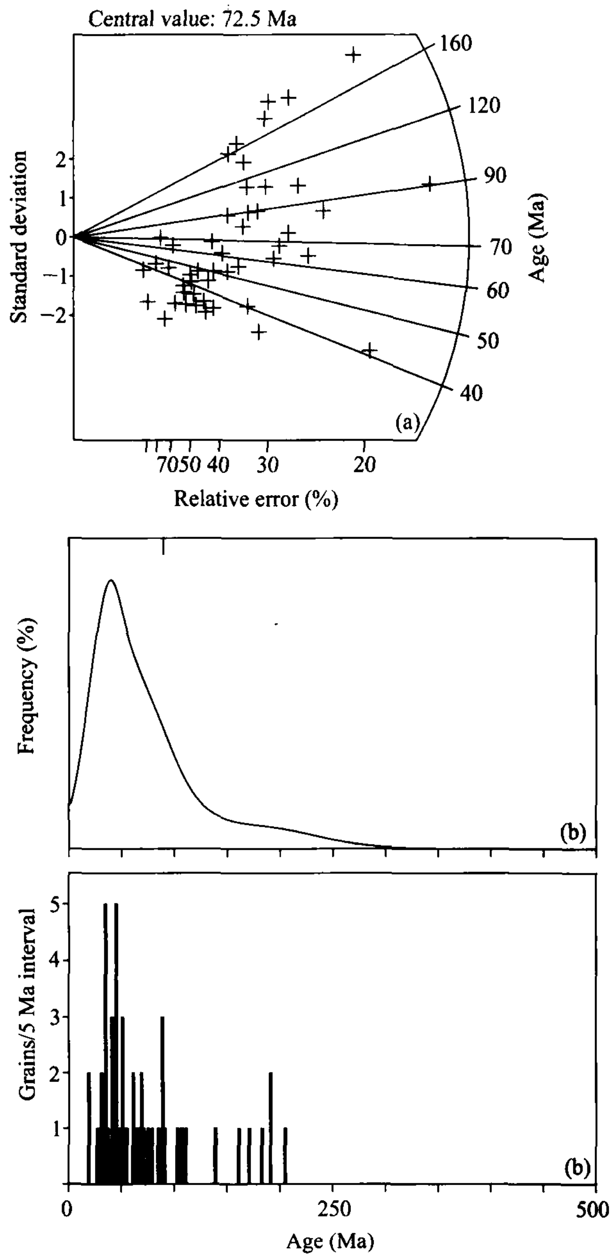


Fig. 4. Apatite FT age decomposition results of the sample.
(a) radial plot; number of grains measured (n), strata age, single-grain FT ages and relative errors are shown.
(b) Gaussian peak-fitting curve (upper) and histogram (lower).

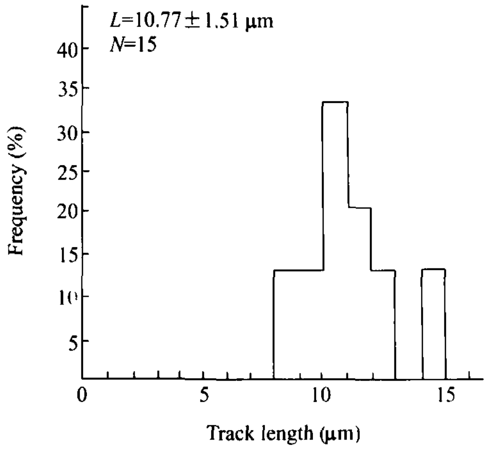


Fig. 5. Frequency diagram of apatite fission track (AFT) lengths.
The sample number, number of track lengths measured *(N)*, mean track length and standard deviation are shown.

In order to reduce the effect of Pb loss, the $^{207}Pb/^{206}Pb$ age was used to represent the ages of old zircons with higher Pb contents (>1200 Ma). Because the $^{206}Pb/^{238}U$ age of younger zircons has a relatively higher precision in the isotope dilution method using Pb spike H208 and U spike H235 than the $^{207}Pb/^{235}U$ and $^{207}Pb/^{206}Pb$ ages, it was taken as the age of younger zircons with relatively lower radioactive Pb contents (<1200 Ma). Due to the lower Pb content (mostly below 10 ppm) and the uncertainty of common Pb corrected, many younger zircons (e.g. analyses 4-18) show large errors in single-grain zircon $^{207}Pb/^{206}Pb$ age. In this situation, the $^{206}Pb/^{238}U$ age with higher precision is more reliable (Sircombe, 1999; Cawood et al., 2000). Shown in the concordia plot, the low level discordance of younger zircons also supports the view that the $^{206}Pb/^{238}U$ age is more significant than the $^{207}Pb/^{235}U$ and $^{207}Pb/^{206}Pb$ ages.

The software Origin was used to analyze the U-Pb ages and yielded the U-Pb age spectrum as shown in Fig. 3.

4.2 Apatite FT ages

The age (T_{sample}) and error *(2σ)* of the sample are respectively calculated by the equations mentioned by Yan et al. (2003) and the analytical results are listed in Table 2.

We used the Gaussian peak-fitting method improved by Brandon to analyze these single-grain apatite ages (Brandon and Vance, 1992; Brandon and Garver, 1994). The decomposition results of apatite FT ages of the sample are shown in Fig. 4. In order to better interpret the measured single-grain FT ages, we also conducted the confined track lengths of some single-grain apatites. The distribution of track lengths is shown in Fig. 5.

5 Discussion

5.1 The indication of zircon U-Pb ages to tectonic evolution

The eastern Asian Bplate was amalgamated by many small blocks in the Triassic and formed thick lithosphere (Dong et al., 2000). The North China Block and the Siberian Plate started to collide and amalgamate in the late Permian, and tectono-magmatic events occurred in the northern margin of the NCB (Davis et al., 1998). Several E-W-trending magmatic belts formed from south to north and

Table 2 Apatite fission track data

No.	Spontaneous $\rho_s\times10^5$cm^{-2} (N_s)	Induced $\rho_i\times10^5$cm^{-2} (Ni)	$T\pm2\sigma$ (Ma)	No.	Spontaneous $\rho_s\times10^5$cm^{-2} (N_s)	Induced $\rho_i\times10^5$cm^{-2} (Ni)	$T\pm2\sigma$ (Ma)
1	2.40 (3)	11.20 (14)	19.25±12.26	27	8.80 (11)	12.80 (16)	61.57±24.16
2	1.60 (2)	7.20 (9)	19.97±15.62	28	8.00 (20)	11.60 (29)	61.77±18.01
3	1.60 (4)	5.20 (13)	27.63±15.81	29	4.00 (5)	5.60 (7)	63.96±37.48
4	4.00 (5)	12.00 (15)	29.93±15.47	30	8.96 (28)	12.48 (39)	64.29±16.00
5	5.60 (7)	16.00 (20)	31.42±13.82	31	17.60 (22)	23.20 (29)	67.91±19.27
6	4.80 (6)	13.60 (17)	31.68±15.06	32	8.00 (10)	10.40 (13)	68.85±29.01
7	5.60 (14)	14.80 (37)	33.96±10.69	33	8.00 (10)	10.40 (13)	68.85±29.01
8	4.27 (8)	11.20 (21)	34.19±14.23	34	6.40 (4)	8.00 (5)	71.59±48.06
9	4.00 (5)	10.40 (13)	34.52±18.18	35	13.33 (25)	16.00 (30)	74.56±20.27
10	5.60 (7)	14.40 (18)	34.90±15.57	36	12.80 (16)	14.40 (18)	79.50±27.38
11	4.80 (6)	12.00 (15)	35.90±17.36	37	14.40 (36)	15.20 (38)	84.69±19.80
12	3.20 (2)	8.00 (5)	35.90±30.04	38	10.67 (20)	10.67 (20)	89.37±28.34
13	4.00 (5)	9.60 (12)	37.39±19.92	39	14.40 (18)	14.40 (18)	89.37±29.86
14	6.93 (13)	15.47 (29)	40.21±13.46	40	11.20 (14)	11.20 (14)	89.37±33.84
15	7.60 (38)	16.60 (83)	41.07±8.10	41	30.40 (76)	30.00 (75)	90.55±14.89
16	2.40 (6)	5.20 (13)	41.40±20.46	42	17.07 (32)	14.93 (28)	102.03±26.51
17	6.40 (8)	12.80 (16)	44.84±19.44	43	19.20 (24)	16.00 (20)	107.09±32.52
18	3.20 (6)	6.40 (12)	44.84±22.44	44	16.00 (20)	12.80 (16)	111.52±37.50
19	3.20 (4)	6.40 (8)	44.84±27.48	45	35.20 (22)	22.40 (14)	139.88±47.94
20	2.40 (3)	4.80 (6)	44.84±31.72	46	32.00 (20)	17.60 (11)	161.59±60.77
21	2.40 (3)	4.80 (6)	44.84±31.72	47	18.40 (23)	9.60 (12)	170.21±60.75
22	5.60 (7)	10.40 (13)	48.27±22.66	48	26.40 (33)	12.80 (16)	182.98±55.91
23	4.80 (9)	8.53 (16)	50.42±21.04	49	34.40 (43)	16.00 (20)	190.63±51.79
24	7.20 (9)	12.80 (16)	50.42±21.04	50	29.20 (73)	13.60 (34)	190.38±39.78
25	8.80 (11)	15.20 (19)	51.89±19.70	51	29.60 (37)	12.80 (16)	204.81±61.47
26	10.40 (13)	16.80 (21)	55.47±19.62	Statistics	10.58 (846)	12.74 (1018)	74.35±3.88

Late Paleozoic granite rocks widely intruded into the Archean metamorphic rocks. The isotopic ages of these granite rocks ranged from ca. 285 Ma to ca. 250 Ma, e.g., the ages of granite rocks in the Hejialing-Yaohuazi area are about 272±5.4 Ma (Zircon U-Pb age) (Bureau of Geology and Mineral Resources of Liaoning Province, 1989).

Influenced by the amalgamation of the NCB and the Siberian Plate in the late Permian, polycrystalline quartz increased and more feldspar and lithic fragment grains appeared in Permian sediments. The contents of feldspar and lithic fragments reached 9% and 20% respectively (Bureau of Geology and Mineral Resources of Liaoning Province, 1989). According to sedimentary filling sequence, the evolution of the NCB had been transformed from a stable cratonic basin to the squeezed foreland basin, and the sediments were mainly derived from the north margin of the NCB (Meng and Ge, 2001).

The Indosinian event influenced the tectonic evolution of the NCB remarkably. Zhao (1990) recognized the importance of the "Indosinian" south-directed thrusting in the northern part of the NCB, and pre-Jurassic E-W-trend thrusting fault and fold were also discovered in the region (Davis et al., 2001). Some small E-W-trending intracontinental basins developed along fault belts, and red conglomerates with shale and coal-bearing layers were deposited. The tectonic and sedimentary filling style was similar to that of the Permian. Sedimentary detritus migrated coarsening upward and sedimentary sequence became thicker towards the direction of the northern margin of the NCB (Wang et al., 1999). This indicates that Archean rocks, Paleoproterozoic rocks and Late Paleozoic granite rocks in the northern margin of the NCB and Mongolian accretion belt were eroded continually and were probably the main source of the basin during the late Triassic.

The NCB and the South China block (SCB) collided from east to west during the Triassic (Zhou et al., 2000), the eastern part of China uplifted to form a high plateau and reached the highest in the middle-late Jurassic, and the paleo-stream in eastern China flowed from east to west during the Jurassic (Dong et al., 2000).

The basement rocks of the Liaodong block are composed of the Paleoproterozoic Liaohe Group (2300-1800 Ma). Influenced by the Indosinian movement in the Triassic, the Liaodong block activated and a great deal of granite rocks intruded in. The ages of plutonic rocks ranged from ca. 200 to ca. 228 Ma, e.g., the age of alkaline rocks in the Saima area is about 230 ±5.5 Ma (Zircon U-Pb) (Jing et al., 1995) and the ages of granite rocks in the Shuangyashan area is about 200±4.0 Ma (Zircon U-Pb) (Bureau of Geology and Mineral Resources of Liaoning Province, 1989). The crystals of zircons from the Indo-Chinese granite rocks in the Liaodong block are light yellow in color and euhedral and half-prismatic euhedral in shape. Furthermore, the mica K-Ar age of the Saima alkaline rocks is also about 230±7 Ma and most of the mica K-Ar ages of the granite rocks in the Shuangtazhen-Xiuyan area are about 222±4.5 to 225±6.5 Ma (Bureau of Geology and Mineral Resources of Liaoning Province, 1989). All of the ages indicated that the plutons in the Liaodong block intruded and cooled fast during the Indosinian movement.

The U-Pb ages of 18 single zircon grains in the Beipiao Formation range from 194.3±2.9 to 233.8±4.2 Ma and most are little yellow and yellow transparent euhedral, half-prismatic euhedral crystals. Their euhedral and half-prismatic euhedral shapes indicate a plutonic/volcanic igneous source (Kroner et al., 1994; Jian et al., 2001; Xiu et al., 2001). The zircon U-Pb ages are similar to those of late Triassic plutonic rocks distributed widely in the Liaodong block and the lack of Late Paleozoic detrital grains (400-250 Ma) indicates that the sediments in the Beipiao Basin are mainly derived from the interior of the Yan-Liao orogenic belt, especially from the Liaodong block.

The difference of basin provenance during the late Triassic and early Jurassic reflects the change of tectonic settings. During the late Permian-late Triassic, the northern margin of the NCB and Mongolian accretion belt were eroded continually and were probably the main source of the basin and the E-W-trending thrust fault and fold illuminated the influence of the collision between the NCB and the Siberian plate. In the early Jurassic, the sediments in the Beipiao Basin were mainly derived from the interior of the Yan-Liao orogenic belt, especially from the Liaodong block, indicating that the influence of the amalgamation of NCB and SCB, and perhaps the subduction of the old Pacific plate increased.

5.2 The indication of apatite FT age to tectonic evolution

When plotted in the radial plot (Fig. 4), the FT ages show a scattered distribution pattern. The confined apatite fission track length of the sample spans from 8.48 to 14.13 μm with amean length of **10.77±1.51 μm** (n=15) (Fig. 5). Most of the FT ages (Table 2) are younger than the strata age. It can be concluded that the apatites have experienced a post-depositional thermal history that causes the track to reset partially. A remarkable feature of the FT ages is that most of the ages fall in a range of 30-40 Ma, which indicates that the Liaoxi area experienced an important thermo-tectonic event during or shortly after 30-40 Ma. Previous studies reveal that the circum-Bohai basins subsided quickly at about 30-40 Ma and were deposited with km-thick clastic sediments (Wang et al., 1999), and the Yan-Liao belt experienced inhomogeneous uplift in the Cenozoic (Wu et al., 2000). At that time, intensive rifting and rapid subsidence as well as strong basaltic magmatism occurred in the North China Block, e.g., the formation of the Feng-Wei graben, intensive sedimentation and formation of oil-bearing basins around the Bohai Bay and widespread tholeiitic volcanism in these rift basins (Xu et al., 1995). All these facts reflect a Cenozoic thermo-tectonic overprinting throughout the Yan-Liao belt and possibly the whole NCB. So it can be deduced that the Liaoxi area experienced a tectonic event and began to uplift since 30-40 Ma. The paleo-geothermal gradient in the Liaoxi area is about 30-35°C/km in the Meso-Cenozoic (Ren, 1999), which indicates that the Liaoxi area has uplifted about 3 km (AFT partial annealing zone temperature: 70-120°C) since 30—40 Ma and the average uplift rate is about 0.1 mm/a. According to other research work (Wu et al., 2000), the uplift process of the Yan-Liao orogenic belt is inhomogeneous, the middle sector uplifted rapidly during 35 to 96 Ma, earlier than the western uplift during 20 to 0 Ma, and followed by the rapid uplift of the southwestern Yanshan Mountains. It can thus be deduced that the eastern Yan-Liao orogenic belt uplifted (30-40 Ma) earlier than the western (0-20 Ma) and later than the middle (35-96 Ma).

6 Conclusion

Through analyses of zircon U-Pb ages and apatite FT of sediments from the Beibiao Basin in western Liaoning Province, the eastern Yan-Liao orogenic belt experienced an obvious tectonic seesawing during the Meso-Cenozoic. The eastern Liaoning Province uplifted rapidly in the early Mesozoic (190—230 Ma) and formed a geological landscape of high mountains, while the western of Liaoning Province subsided relatively and deposited with km-scale sediments. In the (30-40 Ma), western Liaoning Province uplifted as a whole, and the North China fault basin sank intensively, and the topographic landscape had a great change: with high mountains in western and eastern Liaoning Province and low plains in the middle. According to other research work, the rapid uplift of the eastern Yan-

Liao orogenic belt occurred earlier than that of the western sector and somewhat earlier than the middle one.

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