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Journal of Asian Earth Sciences 26 (2006) 669–681

Journal of Asian Earth Sciences

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U–Pb dating of single detrital zircon grains from Mesozoic sandstone in the Beipiao Basin in the eastern Yan-Liao Orogenic Belt, China: provenance and correlation of tectonic evolution

Yi Yan[a,*], Ge Lin[a], Bin Xia[a], Zian Li[a], Xeujun Cui[a], GuiBang Yuan[b]

[a] *Key Laboratory of Marginal Sea Geology, Guangzhou Institute of Geochemistry and South China Sea Institute of Oceanology Chinese Academy of Sciences, Wuhan, Guangzhou 510640, People's Republic of China*

[b] *Tianjin Institute of Geology and Mineral Resources, China Geological Survey, Tianjin 3000170, People's Republic of China*

Received 2 December 2004; accepted 18 January 2005

Abstract

Single grain U–Pb ages of sediments from the Beipiao Basin, Northeast China were conducted to determine the evolution of basin provenance. Zircons from a sandstone in the Upper Triassic Laohugou Formation yield a wide range of ages and, according to their U–Pb ages, fall into four groups: 209.3 ± 4.0–304.2 ± 4.9, 1565.5 ± 71–2154 ± 50, 2400 ± 35–2499 ± 9, 2512 ± 11–2557 ± 74 Ma. These ages indicate that the zircons were principally derived from Late Archean, Proterozoic and Late Paleozoic plutonic rocks. Intrusions in the Mongolian Accretion Belt and the northern margin of the North China Block (NCB) were probably the main source of the sediments in the basin, but the easterly Liaodong Block also provided minor detrital material, with lower U–Pb ages, during the Late Triassic. Most of the U–Pb ages from zircons collected from a sandstone in the Lower Jurassic Beipiao Formation range from 194.3 ± 2.9 to 233.8 ± 4.2 Ma, reflecting the major sediment source during the Early Jurassic. Zircons derived from Late Indosinian plutonic rocks increased, which suggests that the detritus was supplied mainly from the interior of the Yan-Liao Orogenic Belt, especially from the Liaodong Block. Late Indosinian zircons (200–230 Ma) were eroded and deposited in the Lower Jurassic Beipiao Formation, and this implies that intensive tectonic activation and uplift of the Yan-Liao Orogenic Belt in the Mesozoic commenced in the Late Indosinian.

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1. Introduction

The Yan-Liao Orogenic Belt lies in the northern segment of the North China Block (NCB), and extends westwards at about latitude 40 °N from Bohai Bay and Liaoning Province to the border between Hebei Province and Inner Mongolia (Fig. 1). In the 1800s and early 1900s it was the first major mountain belt in China to be studied from a structural and stratigraphic standpoint (e.g. Wong, 1929). The Yan-Liao system lies along the northern margin of the Archean-floored NCB, but during the Jurassic and Cretaceous time it lay within an amalgamated Mesozoic North China-Mongolian Plate. That plate, as defined here, consisted of two major elements: the Archean North China Block and the Mongolian Accretionary Belt to the north. The timing and style of the amalgamation of the two elements of the Mesozoic North China-Mongolian Plate are controversial. Zhang et al. (1984) believed that the Mongolian Accretionary Belt was a middle Paleozoic subduction zone because of the occurrence of Early to Middle Proterozoic ophiolites, blueschists and magmatic rocks along it. Many workers favor the Late Permian to early Triassic amalgamation of the Mongolian Belt with the Archean Block along the Suolin-Linxi Suture (Wang and Liu, 1986; Wang and Mo, 1995; Yin and Nie, 1996). The amalgamated plates experienced intense intracontinental tectonic activation during the Mesozoic–Cenozoic. Terrestrial sedimentation, magmatism and deformation, including multiple phases of folding, contractional, extensional and strike-slip faulting, characterise the Yan-Liao fold-and-thrust belt. This belt is a key component of the eastern Asian tectonic collage and an important area for the study of Mesozoic–Cenozoic continental dynamics and the tectonic evolution of East China.

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* Corresponding author. Tel.: +86 20 85290504; fax: +86 20 85290130.
E-mail addresses: yanyi@gig.ac.cn (Y. Yan), yycarl@sina.com (Y. Yan).

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doi:10.1016/j.jseaes.2005.01.002

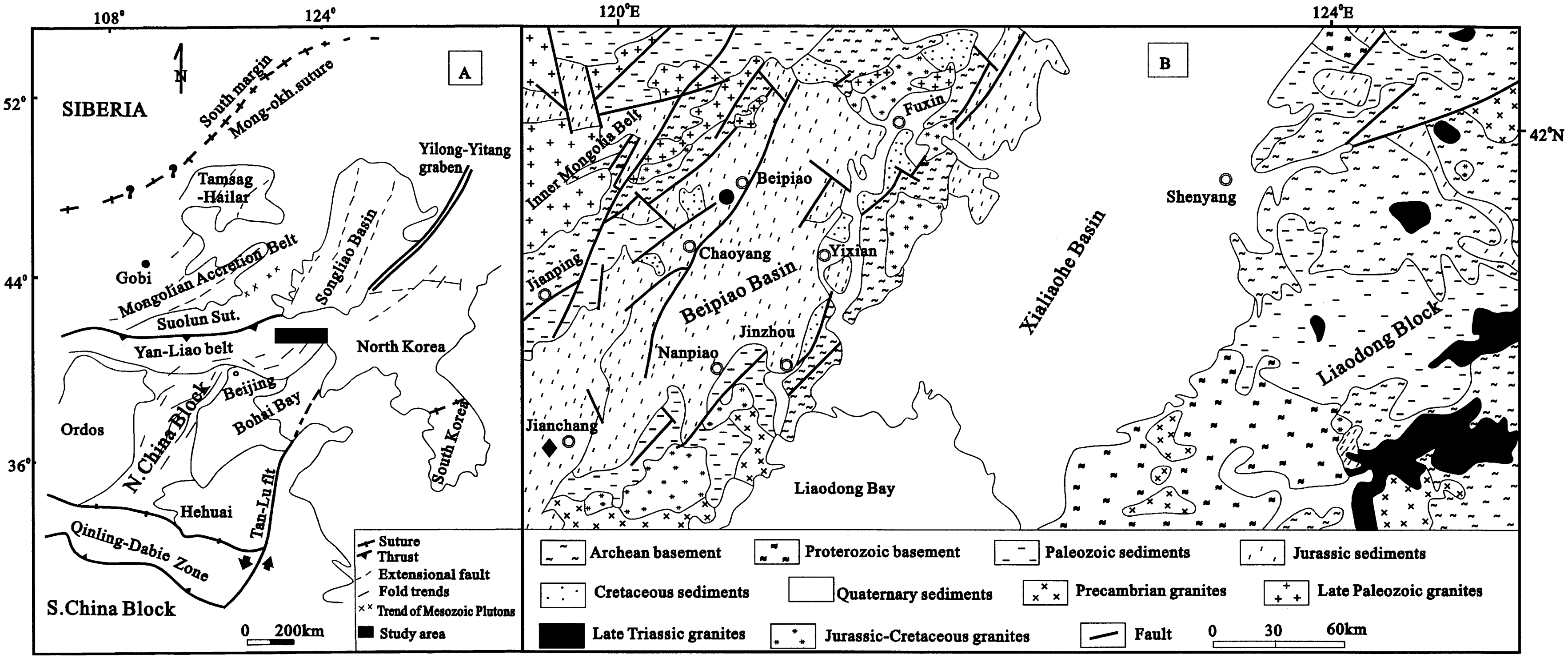


Fig. 1. Tectonic setting of the North China Block. (A) Location of the study area. (B) Regional tectonic map of the eastern part of the Yan-Liao Orogenic Belt. (◆) Location of sample from the Upper Triassic. (●) Location of sample from the Lower Jurassic.

Any proper understanding of Late Paleozoic and Mesozoic assembly and continental dynamics of Asian tectonic elements requires an improved understanding of the tectonic history of the Yan-Liao Belt.

Most of the previous work in this area has concentrated on the formation of the basement rocks, structural styles and volcano-sedimentary strata. Since the early 1900s, Wong (1929) and Cui et al. (1996) have summarised the major characteristics of the Mesozoic–Cenozoic Yan-Liao Orogenic Belt. Davis et al. (1996, 1990) discovered ductile nappes in Yunmengshan, and a large overthrust belt in northern Hebei Province. Chen (1998) studied the Mesozoic tectonic evolution and deformation processes. But because the Yan-Liao Belt has been influenced by many tectonic events since the Mesozoic, there are still some different viewpoints about its tectonic evolution and structural style: 1. When did Mesozoic tectonic activation start, in the Early Yanshanian (Zhao et al., 1994; Wang, 1996), or during their Indosinian (Cui and Li, 1983)? 2. How many contractional events occurred in the Yan-Liao Belt (Davis et al., 1998; Zhao, 1990)? 3. What is the likely uplift sequence and was uplift synchronous, or did it occur in different areas at different times (Wu et al., 2000)? The lack of precise thermo-chronologic data and studies of the relationship between sedimentation in the basin and erosion in the surrounding orogenic belts are the main reasons for these controversies.

Two kinds of information about source rocks can be obtained from basin sediments: material composition (i.e. clast composition, heavy mineral content and geochemistry) and chronological information about the source rocks. It is difficult to estimate quantitatively the contribution of possible sources for the basin sediments through mineral composition, heavy minerals and geochemical analysis, alone. In recent years, many studies have been conducted by means of sediment geochronology, such as single zircon U–Pb age analysis, to determine sediment provenance (Brendan and Michael, 2000; Bruguier and Lancelet, 1997). The major advantage in using geochronological data to determine the provenance of basin sediments is that the thermo-tectonic events experienced at the sediment source can be identified and dated.

The Jurassic-Cretaceous Beipiao Basin lies in the eastern part of the Yan-Liao Orogenic Belt. As one of the largest intra-continental basins in North China, the sediments contain a great deal of information about the tectonic evolution of the Mesozoic Yan-Liao Orogenic Belt. This paper reports a study in which zircon U–Pb ages were determined on grains collected from sediments in the Beipiao Basin. The interpretation of the results provides new insight into the Mesozoic tectonic evolution of the Yan-Liao Orogenic Belt.

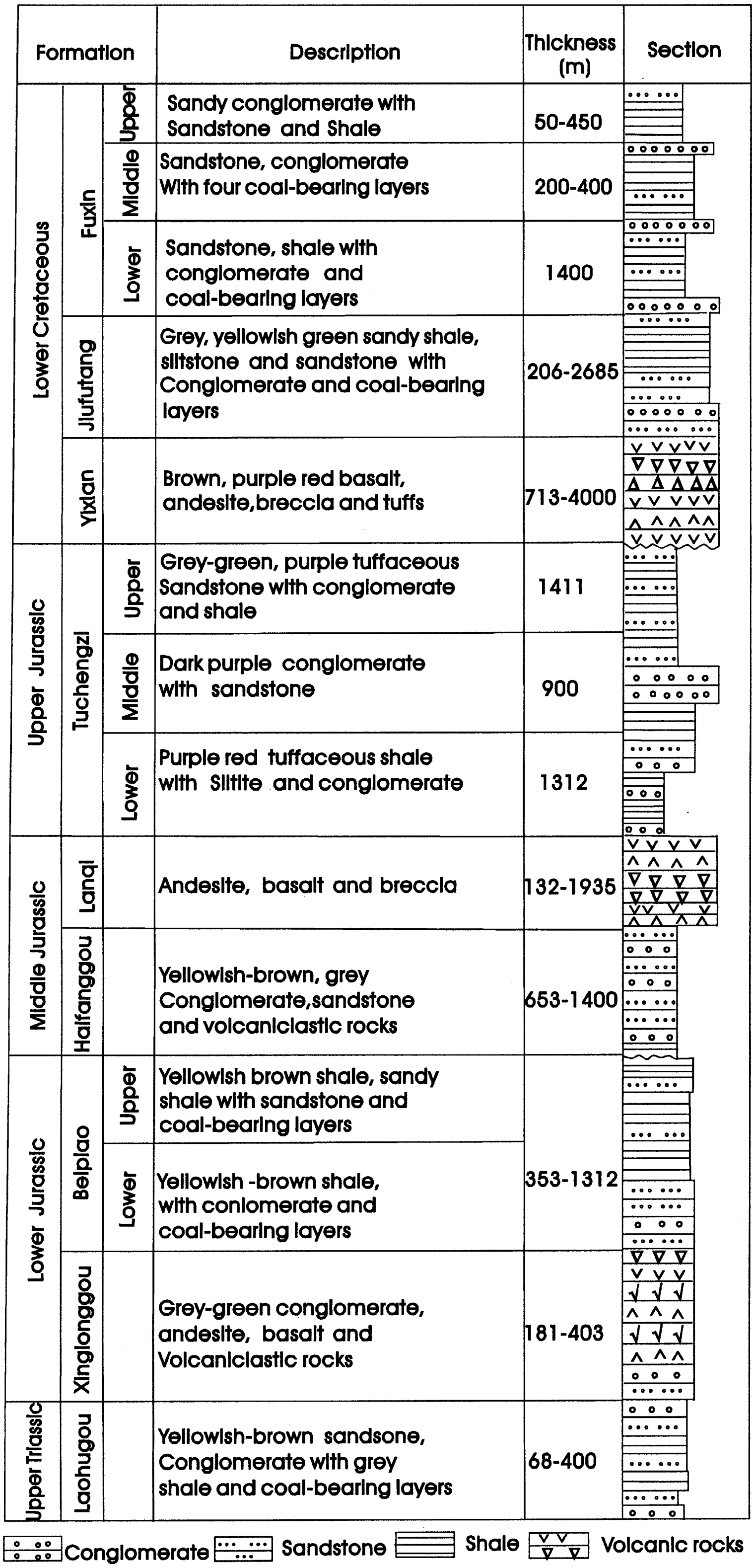
2. Geological background and sampling

The regional metamorphic basement is composed of Archean crystalline rocks, with oldest recorded crustal ages of 3.8Ga (Liu, 1991). Early Proterozoic neritic sediments (ca. 1850–1800 are widespread, but of variable thickness (0 –> 100 m). Upper Proterozoic (Sinian) strata ca. 800–615 Ma are missing. Paleozoic strata on the NCB Craton are represented by: 1. Cambrian-Middle Ordovician deposits dominated by neritic carbonates; 2. Upper Carboniferous–Lower Permian alternating marine and terrestrial sequences are characterised by carbonates and coal-bearing clastics, respectively; 3. Upper Permian-Triassic red beds and conglomerates.

By the end of the Middle Triassic, N–S contraction due to Indosinian movements had led to the deformation of pre-Mesozoic strata and the formation of a series of fold-and-fault belts, as well as the formation of some small sedimentary basins. From the Early Jurassic to the Early Cretaceous the Yanshanian Event formed complex folds, overthrusts and reverse faults. At the same time, kilometer-scale terrestrial volcanic and clastic sediments were deposited in the intra-continental basins. The Beipiao Basin experienced several volcano-sedimentary cycles. Volcanic sediments thousands of metres thick were deposited (Fig. 2). Coal-bearing clastics and continental volcano-sedimentary units overlie either Archean basement or younger Paleozoic rocks unconformably. Late Triassic volcanic activity has also been identified, but it is geographically restricted.

The Upper Triassic Laohugou Formation is composed of yellowish-brown sandstone, conglomerate with grey shale, and coal-bearing layers. Jurassic intermediate-acid volcanics are widespread in the basin and the total thickness of Jurassic sediments is about 4000 m, including the Lower Jurassic (Xinglonggou and Beipiao Formations), Middle Jurassic (Haifanggou and Lanqi formations) and Upper Jurassic (Tuchengzi Formation).

The Lower Jurassic Xinglonggou Formation consists mainly of intermediate-basic volcanic rocks with a thickness of 181–403 m. The Beipiao Formation is the main coal-bearing unit and consists of alternating fluvial lacustrine shale, sandy shale with sandstone, conglomerate and coal-bearing layers. The Middle Jurassic overlies the Beipiao Formation unconformably, commencing with the Hiafanggou alluvial deposits. Volcanism became more intense and the Lanqi formation is composed mainly of andesite, basalt and agglomerates with a thickness of 132–1975 m. The Upper Jurassic Tuchengzi Formation is widespread, and characterised by purple-red terrestrial coarse detritus. The sedimentation rate was higher (between 20.4 and 387 m/my) (Yan and Lin, 2001). Regional volcanism reached its maximum intensity in the Early Cretaceous, and the tectonic setting changed from contraction to extension, with reactivation of thrusts as normal faults and strike-slip movements. Alternating fluvial-lacustrine coal-bearing sediments were deposited. The Lower Cretaceous consists of the Yixian, Jiufutang and Fuxin formations. Strata intercalated with Jurassic, and locally Lower Cretaceous volcanic rocks, include



Formation			Description	Thickness (m)	Section
Lower Cretaceous	Fuxin	Upper	Sandy conglomerate with Sandstone and Shale	50-450	
		Middle	Sandstone, conglomerate With four coal-bearing layers	200-400	
		Lower	Sandstone, shale with conglomerate and coal-bearing layers	1400	
	Jiufutang		Grey, yellowish green sandy shale, siltstone and sandstone with Conglomerate and coal-bearing layers	206-2685	
	Yixian		Brown, purple red basalt, andesite,breccia and tuffs	713-4000	
Upper Jurassic	Tuchengzi	Upper	Grey-green, purple tuffaceous Sandstone with conglomerate and shale	1411	
		Middle	Dark purple conglomerate with sandstone	900	
		Lower	Purple red tuffaceous shale with Siltite and conglomerate	1312	
Middle Jurassic	Lanqi		Andesite, basalt and breccia	132-1935	
	Haifanggou		Yellowish-brown, grey Conglomerate,sandstone and volcaniclastic rocks	653-1400	
Lower Jurassic	Beipiao	Upper	Yellowish brown shale, sandy shale with sandstone and coal-bearing layers	353-1312	
		Lower	Yellowish -brown shale, with conlomerate and coal-bearing layers		
	Xinglonggou		Grey-green conglomerate, andesite, basalt and Volcaniclastic rocks	181-403	
Upper Triassic	Laohugou		Yellowish-brown sandsone, Conglomerate with grey shale and coal-bearing layers	68-400	

Fig. 2. Stratigraphic section of the Jurassic-Early Cretaceous in the Beipiao Basin.

coal, conglomerate, sandstone, tuffs and other volcaniclastic rocks. The Yixian Formation comprises intermediate-basic volcanic rocks with a thickness of 713–4000 m. The Jiufutang and Fuxin formations are restricted, and characterised by coal-bearing yellowish-green sandstone and clay.

The samples used in this study were collected from the Upper Triassic Laohugou and the Lower Jurassic Beipiao formations which are the major stratigraphic units in the Beipiao Basin and record the initial Mesozoic tectonic development of the eastern part of the Yan-Liao Orogenic Belt. Two samples were collected, a yellowish-brown sandstone from the Laohugou Formation to the southwest of Jianchang Town, and another yellowish-brown sandstone from the Beipiao Formation to the southwest of Beipiao Town. The locations from which the samples were collected are shown in Fig. 1. Zircons from these sandstones were dated by U–Pb analysis to elucidate the progress of uplift of the Mesozoic–Cenozoic Yan-Liao Orogen.

3. Analytical technique

Zircon grains were separated at the laboratory of the Changsha Institute of Geotectonics, Chinese Academy of Science. The sandstone samples were ground to 0.1–0.2 mm. The grains were separated by magnetic, electromagnetic, dielectric and heavy liquid processes, and then hand-picked at random under a binocular microscope. Determination of the U–Pb ages of single grains were performed in the Isotopic laboratory of the Tianjin Institute of Geology and Mineral Resources, Geological Survey of China.

Zircon grains were selected and carefully sorted. Other grains such as apatite and rutile were first eliminated. The morphological features of the zircon grains were observed and the grains were sorted according to their color, size, idiomorphic grade (euhedral, half-euhedral, xenomorphic) and crystal shape (e.g. prismatic, round, grainy). Pure transparent zircon grains without cracks, inclusions and metamict were selected for analysis.

Because zircons in sandstones may be derived from different sources and may include several age groups the U–Pb ages of individual mineral grains were measured. Different types of zircon grains were analysed according to their proportion in the sample.

Measurement of the single grain zircon U–Pb ages was determined by the isotopic dissolution method using the procedure of Krough (1973). The techniques of zircon solution and U and Pb extraction were improved upon. The ^{208}Pb–^{235}U 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 placed on a single rhenium band. U–Pb isotopic ratios were measured by a VG-354 thermionic mass spectrometer with a high precision Daly detector. Mass discrimination and system errors of all U–Pb data were corrected and total Pb blanks over the period of the analysis ranged from 0.002 to 0.004 ng. The isotopic composition of radiogenic Pb is determined by subtracting first the blank Pb and then the remainder, assuming a common Pb composition at the time of initial crystallisation, determined from the global single stage model. Calculations were performed using computer software program PBDAT (Ludwig, 1993).

4. Results of analysis

Zircon grains show a wide range in size and morphology. Old grains in the sample from the Laohugou Formation are dominated by purple translucent crystals, and most of the younger grains are light yellow translucent crystals, the morphology of the zircons ranges from euhedral prismatic crystals to rounded grains showing abrasion. Zircons from the sample from the Beipiao Formation are dominated by light yellow translucent euhedral prismatic crystals. Crystals with well-preserved shapes are likely to indicate short distances of sedimentary transport. Conversely the occurrence of rounded grains indicates transport over long distances and/or that they may have survived more than one cycle of erosion and deposition. The U–Pb analytical results for single zircon grains are shown in Tables 1 and 2 and Figs. 3 and 4.

Zircon is the mineral most widely used for U–Pb age determinations. Since zircon U–Pb systematics is undisturbed by temperatures below 700 °C, zircons can record complex evolutionary histories. At the same time zircon from metamorphic rocks may suffer from Pb diffusion loss, metamictisation from lattice radiation damage, overgrowth mixing and recrystallisation. All of these processes may affect the accuracy and validity of zircon ages to some extent. In order to reduce the effect of Pb loss, ^{207}Pb/^{206}Pb age was used to represent the ages of old zircons with a higher Pb content (>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 age, the ^{206}Pb/^{238}U age was taken as the age of younger zircons with a relatively lower radioactive Pb content (<1200 Ma). Due to the lower Pb content (mostly <10 ppm) and the uncertainty of common Pb correction, many younger zircons (e.g. analyses 4–18 from the Beipiao sample, and analyses 22–32 from the Laohugou sample) show a large error in single grain zircon ^{20t}Pb/^{206}Pb age. In this situation, ^{206}Pb/^{238}U age with a higher precision is the more reliable (Sircombe, 1999; Cawood and Nemchin, 2000). Shown in Concordia plot, the low level discordance of younger zircons also supports the conclusion that the ^{206}Pb/^{238}U age is more significant than the ^{207}Pb/^{235}U or the ^{207}Pb/^{206}Pb age.

According to their U–Pb ages zircon grains separated from the Laohuguo Formation fall into four groups: 209.3±4.0–304.2±4.9; 1565.5±71–2154±50; 2400±35–2499±9; and 2512±11–2557±74 Ma. Almost half of the grains have ^{207}Pb/^{206}Pb ages ranging from 2400±35 to 2557±74 Ma. The relatively high degree of discordance exhibited by some grains with low U contents indicates that these grains have suffered Pb loss during a metamorphic/tectonic event. Detrital zircons constitute a mixture of grains of different ages and the time of Pb loss is difficult to determine. Eight zircon grains have ^{206}Pb/^{238}U ages ranging from 230.4±2.5 to 304.2±4.9 Ma and there are three younger zircons with ages ranging 209.3±4.0–219±1.6 Ma.

Table 1
Detrital zircon U–Pb data from the sample from the Upper Triassic Laohugou Formation in the Beipiao Basin

Sample	Weight (μg)	U (ppm)	Pb (ppm)	^{204}Pb (ppb)	Radios corrected for common lead					Apparent ages Ma		
					^{206}Pb/^{204}Pb	^{208}Pb/^{206}Pb	^{206}Pb/^{238}U (±2δerror)	^{207}Pb/^{235}U (±2δerror)	^{207}Pb/^{206}Pb (±2δerror)	^{206}Pb/^{238}U	^{207}Pb/^{235}U	^{207}Pb/^{206}Pb
1. Pur, pr	8	72	76	0.170	74	0.2733	0.4829±0.0076	11.21±0.52	0.1683±0.0072	2540±49	2541±43	2541±72
2. Pur, rd	12	82	49	0.032	498	0.2018	0.4591±0.0028	10.37±0.14	0.1638±0.0019	2435±18	2468±13	2495±20
3. Pur, rd	16	27	17	0.028	268	0.1948	0.4576±0.0063	10.28±0.17	0.1629±0.0014	2429±41	2460±15	2486±15
4. Pur, er	19	65	34	0.011	1918	0.1539	0.4570±0.0026	10.09±0.11	0.1601±0.0015	2426±17	2443±10	2457±15
5. Pur, lpr	15	29	17	0.022	324	0.1453	0.4551±0.0066	10.52±0.28	0.1677±0.0037	2418±42	2482±25	2535±37
6. Pur, pr	15	137	70	0.026	1294	0.1258	0.4456±0.0016	10.23±0.67	0.1666±0.0009	2376±10	2456±52	2524±9
7. Pur, lpr	15	37	19	0.013	704	0.1258	0.4451±0.0054	9.499±0.233	0.1548±0.0032	2373±35	2387±21	2400±35
8. Pur, rd	14	60	32	0.017	672	0.1181	0.4367±0.0026	9.886±0.082	0.1642±0.0009	2336±17	2424±8	2499±9
9. Lb, rd	16	43	23	0.013	791	0.1460	0.4361±0.0043	10.14±0.20	0.1687±0.0028	2333±28	2448±18	2545±27
10. Ly, rd	14	130	66	0.002	17573	0.1997	0.4332±0.0018	9.661±0.075	0.1617±0.0010	2320±12	2403±7	2474±11
11. Pur, pr	15	99	47	0.006	3216	0.1126	0.4247±0.0016	9.685±0.074	0.1654±0.0011	2282±10	2405±7	2512±11
12. Pur, pr	16	13	12	0.064	61	0.2745	0.4046±0.0127	8.943±0.499	0.1603±0.0071	2190±81	2332±51	2459±75
13. Pur, lpr	16	16	26	0.190	35	0.3102	0.3968±0.0096	7.343±0.286	0.1342±0.0038	2154±62	2154±35	2154±50
14. Pur, rd	14	41	24	0.033	265	0.3930	0.3859±0.0046	7.881±0.224	0.1481±0.0037	2104±30	2218±26	2324±43
15. Pur, rd	10	18	15	0.051	60	0.1495	0.3706±0.0120	8.233±0.359	0.1611±0.0045	2033±77	2257±39	2467±47
16. Pur, pr	9	14	11	0.022	87	0.4271	0.3679±0.0164	9.087±0.61	0.1792±0.0090	2019±105	2347±61	2645±83
17. Ly, lpr	15	124	50	0.024	1086	0.1342	0.3430±0.0017	7.326±0.100	0.1549±0.0019	1901±11	2152±12	2401±21
18. Ly, rd	16	30	12	0.016	379	0.1203	0.3179±0.0047	7.325±0.185	0.1671±0.0034	1780±30	2152±23	2529±34
19. Pur, rd	11	80	30	0.028	361	0.1876	0.2899±0.0020	4.506±0.057	0.1128±0.0011	1641±13	1732±11	1844±18
20. Ly, spr	16	64	17	0.038	182	0.2031	0.1771±0.0023	4.151±0.199	0.1700±0.0075	1051±15	1664±39	2557±74
21. Ly, pr	19	178	24	0.003	4710	0.1487	0.1217±0.0005	1.626±0.066	0.09689±0.00367	740.6±3.2	980.5±26	1565±71
22. Ly, lpr	13	221	17	0.044	149	0.2202	0.04834±0.00077	0.3497±0.0738	0.05249±0.01044	304.2±4.9	304.5±56	306.6±450
23. Ly, pr	19	65	3	0.004	514	0.2070	0.04155±0.00094	0.2958±0.1154	0.05162±0.01900	262.5±6.0	263.1±90	268.7±840
24. Ly, lpr	15	264	12	0.010	763	0.1282	0.04142±0.00024	0.2940±0.0284	0.05148±0.00469	261.6±1.5	262±22	262.5±210
25. Ly, lpr	16	621	28	0.031	499	0.1208	0.03989±0.00019	0.2821±0.0062	0.05130±0.00106	252.1±1.2	252.3±6.3	254.1±48
26. Y, spr	18	111	12	0.087	54	0.1201	0.03985±0.00075	0.2816±0.0298	0.05126±0.00505	251.9±4.7	252±24	252.3±230
27. Ly, lpr	12	154	9	0.024	126	0.1007	0.03885±0.00024	0.2742±0.0268	0.05120±0.00475	245.7±1.5	246.1±21	249.8±210
28. Ly, spr	18	125	7	0.022	176	0.1576	0.03760±0.00032	0.2642±0.0365	0.05096±0.00668	237.9±2.0	238.0±29	239.0±300
29. Ly,spr	20	93	9	0.072	55	0.1707	0.03639±0.00039	0.2549±0.0441	0.05079±0.00828	230.4±2.5	230.5±36	231.5±380
30. Ly, lpr	17	125	6	0.013	232	0.2038	0.03462±0.00025	0.2415±0.0283	0.05059±0.00556	219.4±1.6	219.6±23	222.3±240
31. Ly, lpr	12	150	9	0.033	99	0.1625	0.03461±0.00057	0.2413±0.0685	0.05056±0.01355	219.4±3.6	219.5±56	221.0±620
32. Ly, pr	18	61	5	0.028	73	0.2705	0.03300±0.00064	0.2298±0.0756	0.05052±0.01571	209.3±4.0	210.1±62	218.9±720

Pur, purple; Lb, light brown; Y, yellow; Ly, light yellow; Pr, Prismatic; Lpr, long Primatic; Spr, short Primatic.

Table 2
Detrital zircon U–Pb data from the sample from the Lower Jurassic Beipiao Formation in the Beipiao Basin

Sample	Weight (μg)	U (ppm)	Pb (ppm)	^{204}Pb (ppb)	Radios corrected for common lead				Radios corrected for common lead			
					^{206}Pb/^{204}Pb	^{208}Pb/^{206}Pb	^{206}Pb/^{238}U ($\pm 2\delta$error)	^{207}Pb/^{235}U ($\pm 2\delta$error)	^{207}Pb/^{206}Pb ($\pm 2\delta$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

Pur, purple; Y, yellow; Ly, light yellow; Pr, prismatic; Lpr, long Primatic; Spr, short Primatic; Gr, grainy.

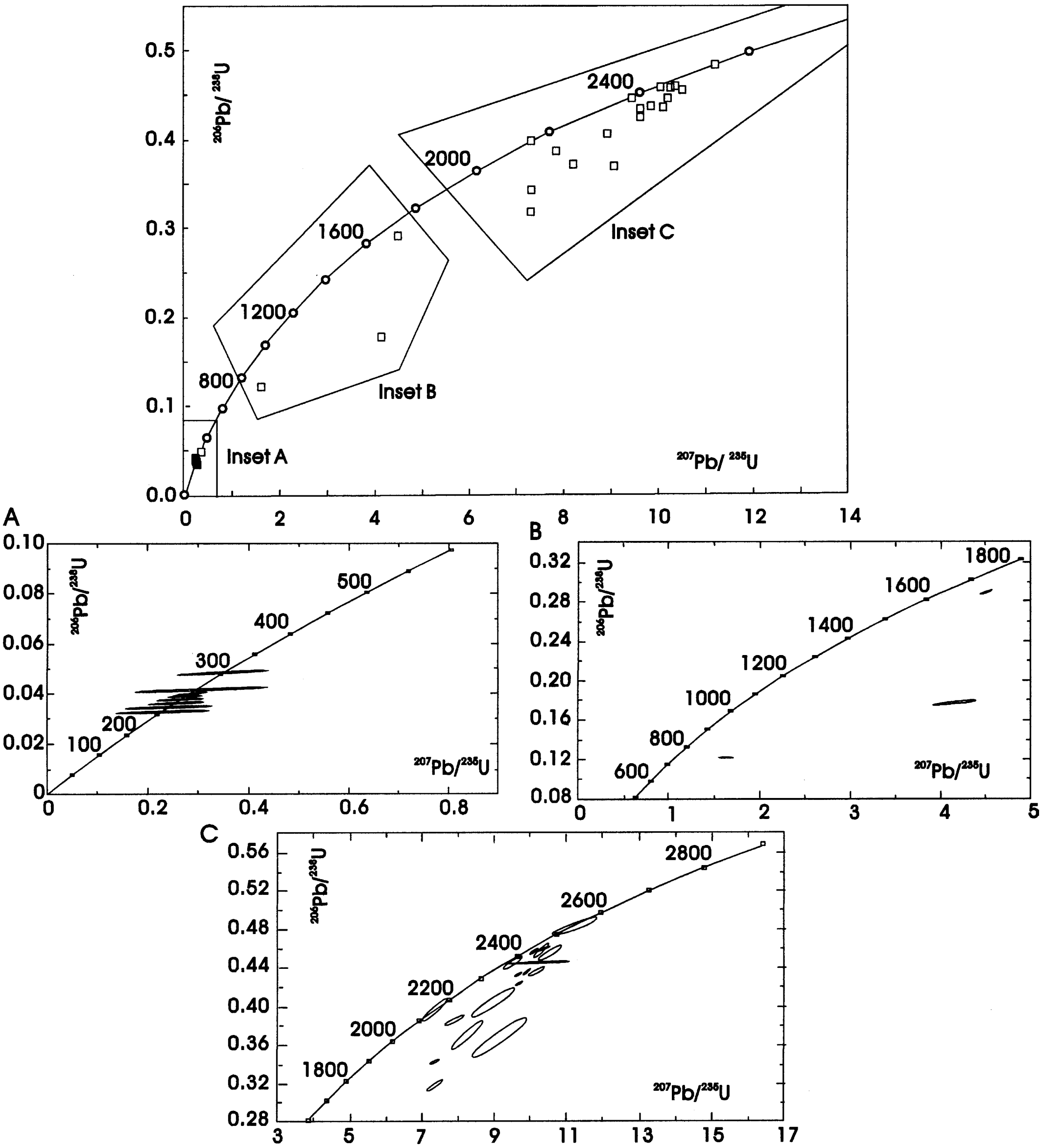


Fig. 3. Concordia plot of detrital zircons from the Upper Triassic Laohugou Formation sample. A, B and C are enlargements between 0–600, 800–1800 and 2000–2600 Ma, respectively. Polygons are 2δ error.

Most of the zircon ^{206}Pb/^{207}Pb ages from the sample collected in the Beipiao Formation range from 194.3 ± 2.9 to 233.8 ± 4.2 Ma. Their euhedral, semi-prismatic euhedral shapes are consistent with a plutonic/volcanic igneous source (Kröner et al., 1994; Jian et al., 2001; Xiu et al., 2001). The results from the three older grains (analyses 1, 2 and 3) are difficult to assess. Analysis 1 has ^{207}Pb/^{206}Pb age of ca. 2500 Ma, which suggest an origin from a Late Archean source; analyses 2 and 3 have ^{207}Pb/^{206}Pb age of ca. 2000 Ma indicating derivation from Early Proterozoic rocks.

5. Discussion

U–Pb spectrums of the zircon samples which were analysed are illustrated in Figs. 5 and 6. The differences of the zircon U–Pb ages in the Upper Triassic and Lower Jurassic can be linked to the provenance of the sediments in the Beipiao Basin, and to the evolution of its tectonic setting during the Mesozoic. The new data set provides insight into the ages of the source rocks and permits the reconstruction of a reasonable picture of the geology of the source region.

The East Asia Plate had a thick lithosphere and was formed by the amalgamation of many small crustal blocks during the Indosinian epoch. In the Paleozoic a wide Old Asiatic Ocean lay between the North China Block (NCB) and the Siberian Plate and some microcontinents (e.g. Xingkai, Bulein and Songliao) occupied the intevening ocean. In the Late Permian the NCB and the Siberian Plate started to collide and amalgamated from west to east, and in

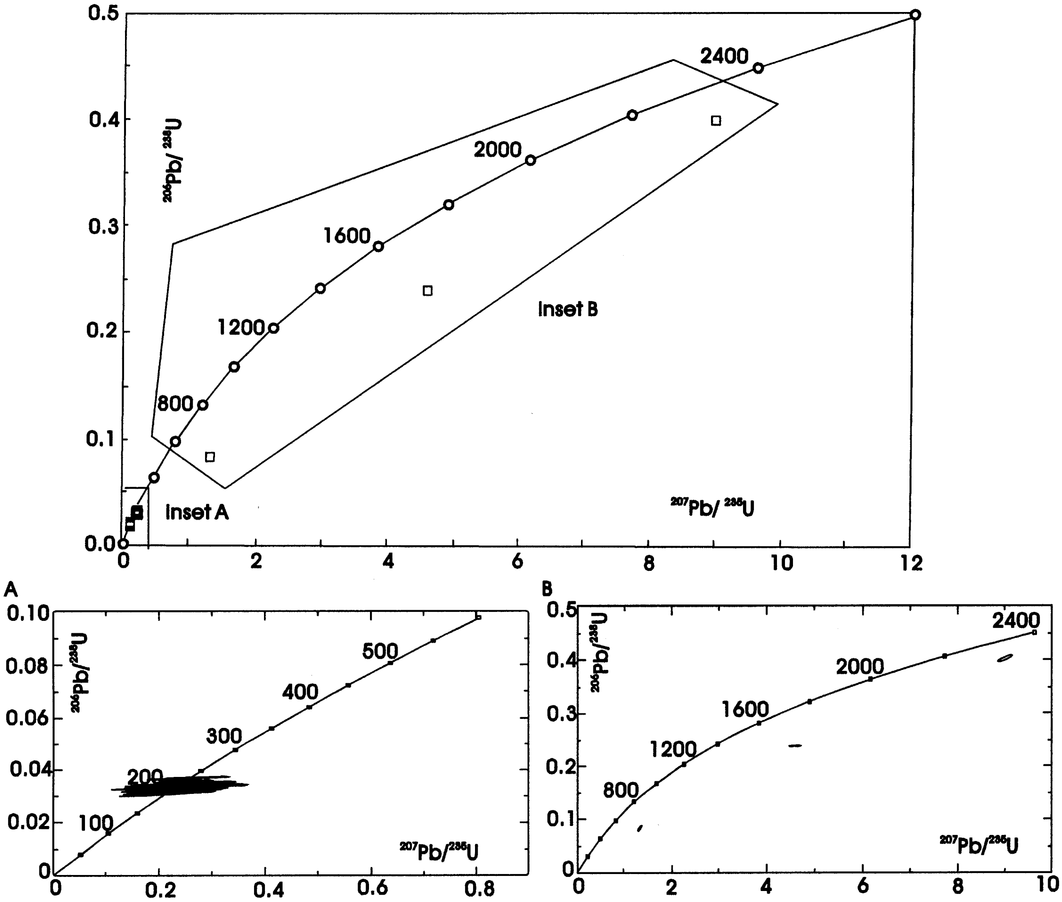


Fig. 4. Concordia plot for detrital zircons from the Lower Jurassic Beipiao Formation sample. A and B are enlargements between 0–600 and 800–2400 Ma, respectively. Polygons are 2*δ* error.

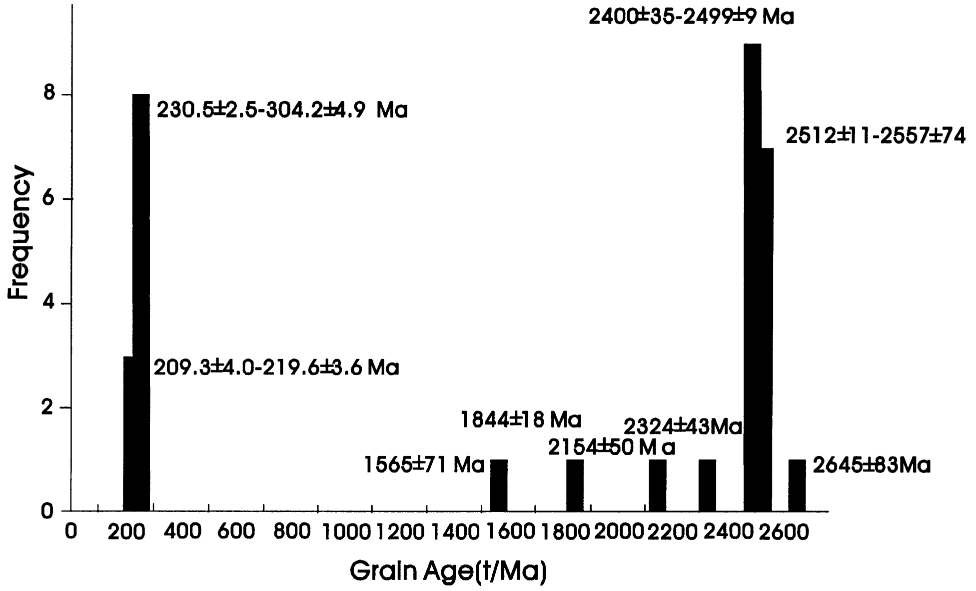


Fig. 5. Frequency diagram for apparent ages of detrital zircons from the sample from the Upper Triassic Laohugou Formation. Four zircon groups are distinguished: 209.3 ± 4.0–304.2 ± 4.9; 1565.5 ± 71–2154 ± 50; 2400 ± 35–2499 ± 9; and 2512 ± 11–2557 ± 74 Ma.

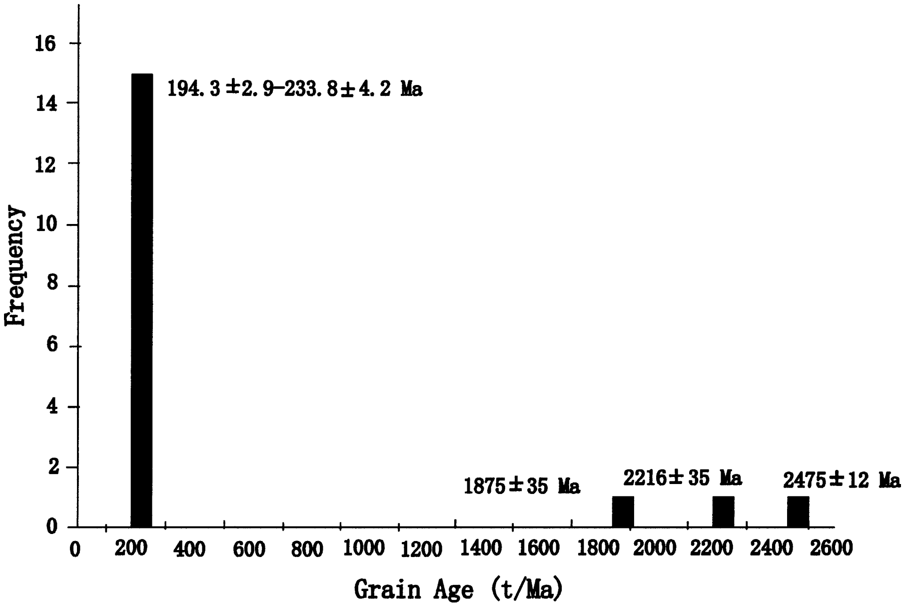


Fig. 6. Frequency diagram for apparent ages of detrital zircons from the sample from the Lower Jurassic Beipiao Formation.

the Late Jurassic the Okhotsk Ocean closed (Zonenshain et al., 1990). Intense tectono-magmatic events occurred along the northern margin of the NCB. Several E–W magmatic belts formed from south to north, and granitic rocks were intruded widely in the Archean metamorphic rocks in the Late Paleozoic. The isotopic ages of these granitic rocks range from ca. 285–250 Ma (zircon U–Pb ages) (Bureau of Geology and Mineral Resources of Liaoning Province, 1989).

The sedimentary sequence in the NCB was controlled by the tectonic evolution of the Old Asiatic Ocean. From the Late Carboniferous to the Early Permian, stable cratonic basins developed on the NCB and sequential thin sedimentary layers, comprised mainly of littoral-neritic quartz sandstones were deposited. In the Late Permian, influenced by the amalgamation of the NCB and the Siberian Plate, polycrystalline quartz increased and more feldpar and lithic fragments, reaching 9 and 20% of the grains, respectively, appear in the Permian sediments (Bureau of Geology and Mineral Resources of Liaoning Province, 1989). According to cyclic sequence stratigraphy the NCB was transformed from a stable cratonic basin into a squeezed foreland-basin thrust orogenic wedge, and sediments were derived mainly from the northern margin of the NCB (Meng and Ge, 2001).

The Indosinian Event influenced the tectonic evolution of the NCB remarkably. Zhao (1990) recognised the importance of the 'Indosinian' south-directed thrusting in the northern part of the NCB, and pre-Jurassic E–W-trending thrust-faults and folds have also been discovered in this region (Davis et al., 1998). Some small E–W-trending intra-continental basins developed along fault belts, and red conglomerates with shale and coal-bearing layers were deposited. The style of the tectonics and the sedimentary infilling was similar to that in the Permian. The sediments of the Laohugou Formation are rich in sedimentary and metamorphic lithic fragments and polycrystalline quartz. Conglomerates are composed mainly of sandstone, carbonate and gneiss clasts (Yan and Lin, 2001). Most clasts are rounded, indicating that they were transported from a distant source and/or survived more than one cycle of erosion and deposition. The sedimentary succession coarsens upwards and the sequence becomes thicker and coarser towards the margins of the NCB (Wang et al., 1999).

Zircons with U–Pb ages of 2400±35–2499±9 and 2512±11–2557±74 Ma are identical to those from the Archean and Early Proterozoic rocks of the NCB, and zircons with U–Pb ages from 230.6±2.5 to 304.2±4.9 Ma are similar to those from the Late Paleozoic plutonic rocks along its northern margin. The Inner Mongolian Uplift belt lies along the northern margin of the NCB, and comprises the Archean Xiaotazigou (3100 Ma) and Dayingzi groups (2500–2400 Ma) with Late Paleozoic plutonic intrusions (400–250). Granulite facies metamorphism in this area occurred at about 2500 Ma. This indicates that the Archean, Early Proterozoic rocks and Late Paleozoic granitic rocks along the margins of the NCB and the Mongolian Accretion Belt were continually eroded, and were probably the main source of sediments for the Beipiao Basin. The occurrence of zircons with U–Pb ages of 1565.5±71–2154±50 Ma implies that there was a minor derivation of sediment from the Liaodong Block. The basement rocks of the Liaodong Block and the Xialiaohe Basin are composed of the Early Proterozoic Liaohe Group (2300–1800 Ma) with minor Late Archean rocks, and metamorphism occurred in the Early Proterozoic at about 2000 Ma. The youngest concordant grains of the sample from the Laohugou Formation have, within margins of error, overlapping $^{206}Pb/^{238}U$ ages, from 209.3±4.0 to 219.6±3.6 Ma. Their euhedral shapes are consistent with a plutonic/volcanic igneous source, and the coincidence with the age of deposition of the sediments supports a volcanic origin.

After intense Indosinian thrusting and folding, weak extension and uplift-subsidence occurred within the Yan-Liao Belt during the Early Jurassic, and NE and ENE tectono-magmatic belts were developed, distinct from those of the Indosinian movements. In the eastern part of the Yan-Liao Belt, small volcanic basins developed along NE and ENE faults, sedimentary basins and areas of erosion alternated. The upward fining sedimentary succession of the Lower Jurassic Beipiao Formation reflects an environment of stable subsidence (Yan and Lin, 2001, 2002). The basin expanded and coal-bearing clastics and continental volcano-clastic sediments were deposited. The sedimentary facies and paleogeography of the Biepiao Formation are illustrated in Fig. 7.

No fluvial deposits occur along the Longtan Fault because it did not exist and did not form the margin of the Beipiao Basin during the Early Jurassic. During the Middle-Late Jurassic the fault was reactivated and thrust towards the SE, so that Archean metamorphic rocks were overthrust onto the Beipiao Formation. The Niantianmen Fault was also activated at the same time (Zhou and Zhao, 1999). Coarser fluvial sediments and conglomerates, consisting mainly of volcanic clasts, are found at Mayouyingzi, Changheyingzi and Liulongtai towns in the eastern part of the basin. The sediments become finer towards the west and the pebbles in the conglomerates are imbricated with the dip to the NE, indicating that the currents flowed from the NE towards the SW (Yan and Lin, 2001).

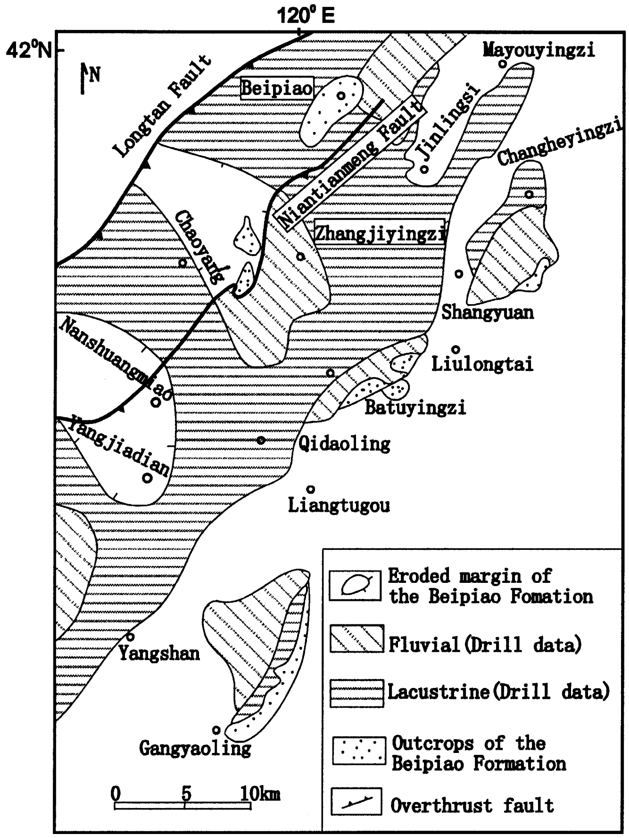


Fig. 7. Sedimentary facies and paleogeography of the Beipiao Formation.

Most of the zircon ^{206}Pb/^{238}U ages of the sample collected from the Beipiao Formation range from 194.3 ± 2.9to 233.8 ± 4.2 Ma, which are similar to those of the Late Triassic plutonic rocks distributed widely in the Liaodong Block. Influenced by the Indosinian Movements, intense tectono-magmatism occurred in the eastern part of China and many granitic rocks were intruded. Tectono-magmatism became stronger towards the east. Late Triassic plutonic rocks (230–200 Ma) are restricted to the northern margin of the NCB, fewer than in the easterly Liaodong Block (Wang, 1996). The isotopic ages of these granitic rocks range from ca. 200–228 Ma, e.g. the age of the alkaline rocks in the Saima area is ca. 230 ± 5.5 Ma (zircon U–Pb age) (Jing et al., 1995) and the ages of the granitic rocks in the Shuangyashan area are ca. 200 ± 4.0 Ma (zircon U–Pb age). Furthermore, the mica K/Ar age of the Saima alkaline rocks is also ca. 230 ± 7 Ma, and most of the mica K/Ar ages of the granitic rocks in the Shuangtazhen-Youyan area range from 222 ± 4.5 to 225 ± 6.5 Ma (Bureau of Geology and Mineral Resources of Liaoning Province, 1989). These ages indicate that the plutonic rocks were intruded and cooled quickly during the Indosinian Movements.

East China was uplifted and formed a landscape of high mountains. The topographic relief was greatest during the Middle to Late Jurassic and paleocurrents were from east to west (Dong et al., 2000). The mass occurrence of Late Triassic zircons and the lack of Late Paleozoic detrital grains (400–250 Ma) suggest that the detritus from the interior of the Yan-Liao Orogenic Belt, and especially the Liaodong Block, increased, and the northern margin of the NCB became a minor source of sediment for the basin. Late Triassic plutonic rocks were eroded and the erosion products deposited as Lower Jurassic sediments indicating that intense uplift occurred and that the Meso-Cenozoic tectonic reactivation of the Yan-Liao Orogenic Belt commenced during the Late Indosinian.

6. Conclusions

Through the analysis of the zircon U–Pb ages of the sediments from the Beipiao Basin in the eastern part of the Yan-Liao Belt, it can be concluded that in the Late Triassic the main sources of the sediments were the northern margin of the NCB and the northerly Mongolian Accretion Belt. A major influx of sediments took place during the Early Jurassic, this detrital material was derived from the interior of the Yan-Liao Orogenic Belt, especially from the Liaodong Block to the east, which became the main source for the sediments in the basin. Erosion of Indosinian rocks during the Early Jurassic implies that intense uplift occurred in East China during the Early Mesozoic and that the Meso-Cenozoic tectonic activation of the Yan-Liao Belt commenced during the Late Indosinian.

Acknowledgements

This work was supported financially by the National Natural Science Foundation of China (No 40306010) and the Chinese Academy of Sciences (No. KZCX2-SW-117). We are grateful to Prof. Randall Parrish (Isotope Unit, British Geological Survey) for his critical and constructive comments on an early version of the manuscript and to Dr A.J. Barber for the improvement of the English.

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