Chinese Science Bulletin 2006 Vol. 51 No. 15 1877—1883

DOI: 10.1007/s11434-006-2035-y

Zircon SHRIMP U-Pb dating of meta-diorite from the basement of the Songliao Basin and its geological significance

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Received December 26, 2005; accepted March 27, 2006

Abstract The basement of the Songliao Basin mainly contains low-grade metamorphic rocks and granites. It has been long disputed whether the basin has Precambrian metamorphic basement. This is a report of zircon SHRIMP U-Pb dating results of a meta-diorite sample, which was taken from the Si-5 drilling hole in the southern portion of the Songliao Basin. The SHRIMP analyses indicate that the meta-diorite with a weighted mean $^{207}Pb/^{206}Pb$ age of 1839±7 Ma (2σ, $n = 8$) was emplaced during Paleo-Proterozoic time. Additionally, the meta-diorite has old Nd model ages (T_{DM1}: 2999Ma; T_{DM2}: 2849Ma). These data suggest that the southern part of the Songliao Basin do possess Precambrian basement.

Keywords: zircon, SHRIMP dating, meta-diorite, Precambrian basement, Songliao Basin.

Located in the east portion of the North Orogenic Belt, the Songliao Basin is bounded by the Da Hinggan Mountains in the west, the Xiao Hinggan Mountains in the north, the Zhangguangcai Range in the east, and the North China Craton (NCC) in the south (Fig. 1)[1]. The basin is one of the biggest and most important petroleum- and natural gas-producing areas in east China. Furthermore, because of its specific location, the inference on the components, genesis, and formation time is crucial not only for understanding the evolutionary history of the basin itself, but also for reconstructing the pre-Mesozoic tectonic evolution of the North Orogenic Belt. However, previous studies on the basement of the basin are relatively poor, and it has long been controversial regarding the nature and formation age of the basin. For example, some researchers suggested, mainly based on conventional zircon U-Pb ages, that there was no Precambrian basement beneath the basin, but a late paleozoic to early Mesozoic composite basement generated by accretion of several micro-plates[1,2]1), other authors proposed that the basin had Precambrian basement, chiefly according to gravity and magnetic characteristics, which were consistent with those of Precambrian terranes[3−6], but the latter is lack of reliable isotopic dating evidence. In this paper, we report reliable isotopic dating data, obtained by using the sensitive high resolution ion microprobe (SHRIMP), of a meta-diorite sample collected from the Si-5 drilling core in southern portion of the Songliao Basin. The results combining with previous geochronological data are helpful to understanding the components and tectonic nature of the basement of the Songliao Basin.

1 Geological background and sample description

The Songliao Basin can be divided into two parts by the Songhua River: the north and the south parts. The latter is administratively straddled on Jilin, Inner Mongolia and Liaoning. Like the strata occurring in other basins of east China, those within the Songliao Basin are predominated by Jurassic, Cretaceous, and Cenozoic sediments. Of the Jurassic strata, the Late Jurassic ones are characterized by coarse sandstones and glutenites with volcanic rocks occurring within nearly the whole basin, whereas the Middle-Jurassic strata are only locally distributed. The Cretaceous strata mainly comprise claystones and fine-grained sedimentary rocks, which are the main cover of the Songliao Basin. The Cenozoic strata consist mainly of clay stones, with minor sandstones and glutenites in the bottom. It is normally considered that the basement of the Songliao Basin refers to the pre-Jurassic formations, which is mainly composed of Carboniferous to Permian sedimentary and magmatic rocks.

1) Shao Mingli *et al*. Deep strata program of Jilin Oilfield, 2000

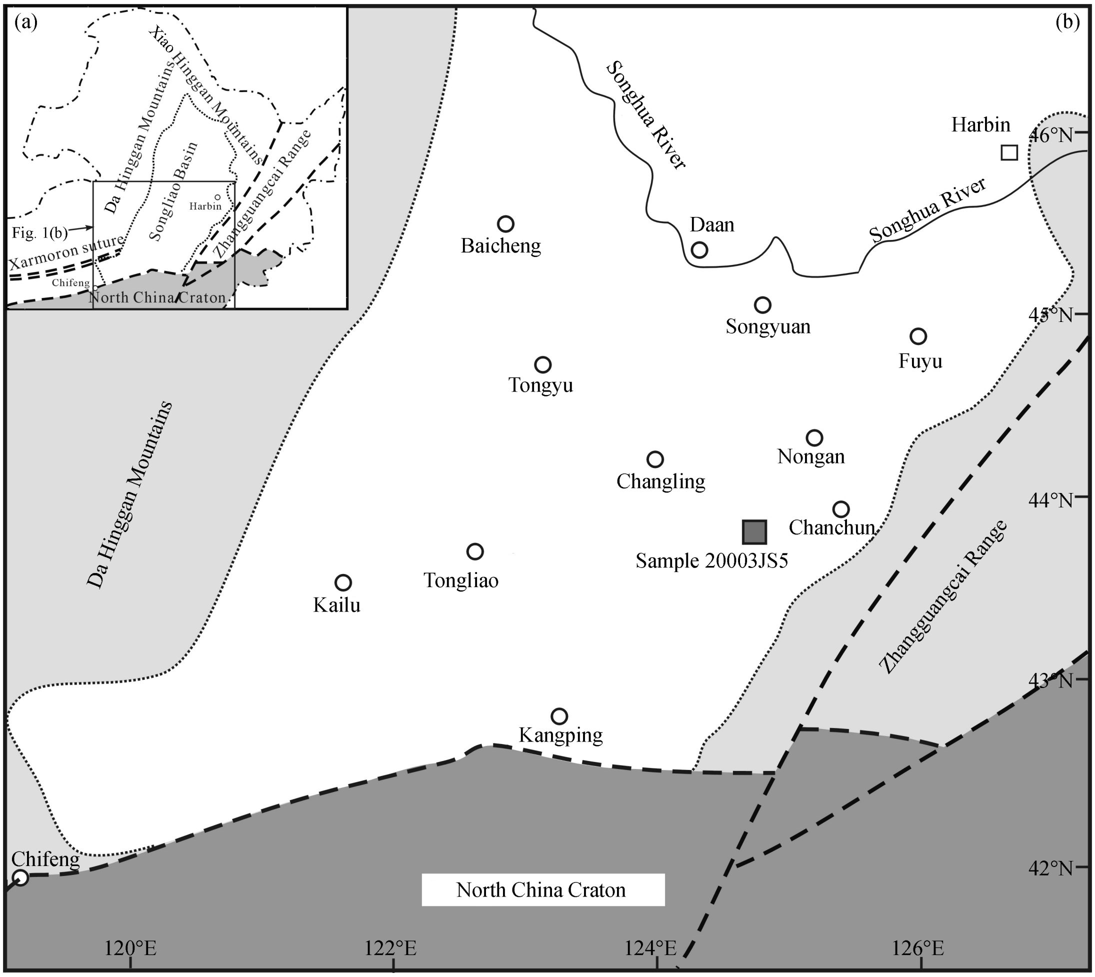

Fig. 1. Simplified map showing the location of the Songliao Basin and the studied sample (modified from Wu *et al*., 2001[1]).

Up to present, there are over 60 drilling holes reaching to the basement in the south Songliao Basin, of which only 30 drilling holes were collected by the oilfield for basement rocks. From observation on cores, the rock types presented beneath the basin are mainly low-grade metamorphic rocks and granites without solid ages.

The sample 2003JS5 was taken from Si-5 well which is located at about 800 m east of Weijiajie Village, Bawu Township, Gongzhuling City, Jilin Province, with coordinates of 124°31′54″E and 43°50′22″N, and is structurally situated on the southeast uplift of the Songliao Basin. The drilling hole is totally 1512.2 m deep, and intersects the basement at a depth of 1385.5 m, which is characterized by an unconformity between the basement and the overlying Lower Cretaceous Denglouku Formation. The thickness of the drilled basement is 126.7 m, and the sample was collected at the depth of 1511 m.

The sample 2003JS5 is dark-grey-green, with a weak gneissic structure and a porphyritic texture. The major minerals include plagioclase (45 vol.%—50 vol.%), hornblende (30 vol.%—40 vol.%), biotite (10 vol.%±), and quartz (less than 3 vol.%). The plagioclase occurs not only as phenocryst but within the martrix. The phenocryst plagioclase is 2—5 mm in size, whereas that in the matrix is 0.5—2 mm. This sample has experienced intense alteration, with the plagioclase entirely replaced by sericite, and the hornblende and biotite displaced by chlorite. Some leached magnetite is distributed along the cleavage of the biotite. Moreover, carbonation has also been observed in the sample. Electronic probe analyses suggest that the plagioclase is oligoclase, with An numbers between 16 and 21. According to the texture and the mineral compositions, the sample is nominated by chlorite-biotite-hornblende-plagioclase gneiss, and its protolith should be diorite.

2 Geochemistry

The sample is analyzed for major and trace element concentrations (Table 1). The results show that the meta-diorite has a high LOI (8.4%), which is consistent with the nature of the strong alteration of the sample. After reduction of the LOI, the contents of SiO_2, MgO, Fe_2O_3* (whole Fe) and CaO are 51.76%, 5.38%, 8.59% and 9.46%, respectively. Another feature of the meta-diorite is that the content of Na_2O is much higher than that of K_2O. In general, the major element compositions of the sample are similar to those of typical diorites.

The total REE concentration of the diorite is 121 ppm. Chondrite-normalized REE patterns are characterized by relative enrichment of light rare earth elements (LREE) to heavy REE (Fig. 2(a))[7], with a high $(La/Yb)_N$ ratio (7.5), indicative of an obvious differentiation between the LREE and HREE, and with a significant negative Eu anomaly (δEu = 0.57), although the sample contains relatively more plagioclase. Flynn and Brunham (1978) have demonstrated that the F- and Cl-bearing fluid would cause the decrease of REE concentration, and the Cl-rich fluid alteration would selectively lead Eu out and, thus, lowering the δEu value, but the F-rich fluid has no this kind of selective leaching. Therefore, we explain the contradiction between the high plagioclase content and the significant negative Eu anomaly as a result of fluid alteration.

In primitive mantle-normalized trace element spidergram (Fig.2 (b))[7], the meta-diorite is characterized by high contents of large ion lithophile elements (LILE), such as K, Rb, Ba and Th, and negative anomalies of high field intensity elements (e.g., Nb, Ta, P, Ti). The P and Ti negative anomalies are probably related to the crystallization separation of apatite and ilmenite, while those of Nb and Ta call for an addition of continental materials. These characteristics of the trace elements are of affinity of arc or continental margin magmatic rocks.

Sr-Nd isotopic data are given in Table 2. The age of 1839 Ma has been used for calculation of initial Sr and Nd isotopic compositions. The calculated initial $^{87}Sr/^{86}Sr$ ratio is 0.7144, and the $\varepsilon_{Nd}(t)$ value is -6.58. The single- and two-stage Nd model ages (T_{DM1} and T_{DM2}) are 2999 Ma and 2849 Ma, respectively. These isotopic data indicate that the meta-diorite has either crustal origin or the mixture of crustal and mantle. According to previous studies, the Paleo-Proterozoic mantle-derived basic rocks in the NCC are also characterized by negative $\varepsilon_{Nd}(t)$ values, and therefore we prefer

Table 1 Chemical data of major elements (wt.%) and trace elements (ppm) of the sample 2003JS5

SiO_2	TiO_2	Al_2O_3	Fe_2O_3*a)	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	LOI	Total
47.61	0.72	15.52	7.91	0.11	4.95	8.71	5.41	0.94	0.18	8.40	100.46
Li	Be	Sc	V	Cr	Co	Ni	Ga	Rb	Sr	Y	Tb
32.42	2.47	20.90	112.28	99.28	19.67	54.71	21.63	29.93	646.65	19.30	0.70
Zr	Nb	Cs	Ba	La	Ce	Pr	Nd	Sm	Eu	Gd	Dy
113.73	11.22	2.76	327.08	20.27	46.87	6.46	26.85	5.22	0.90	4.47	3.80
Ho	Er	Tm	Yb	Lu	Hf	Ta	Tl	Bi	Th	U	ΣREE
0.76	2.03	0.31	1.94	0.30	3.46	0.96	0.16	0.03	6.29	0.68	113

a) Fe_2O_3* is the whole Fe.

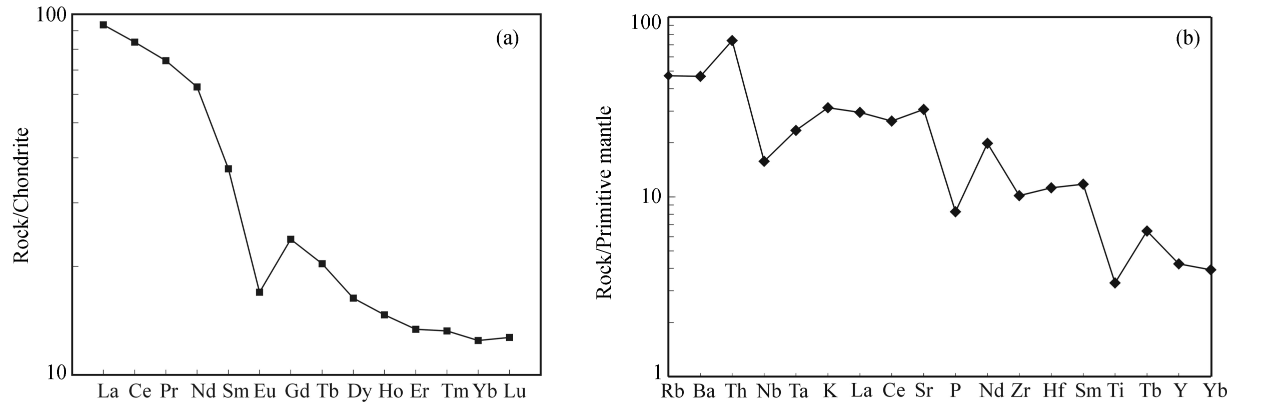

Fig. 2. Chondrite-normalized REE patterns (a) and primitive-mantle normalized spidergrams (b) for the sample 2003JS5 (the normalization values are from Sun and McDonough, 1989[7]).

Table 2 Sr-Nd isotopic data for the meta-diorite (sample 2003JS5)

Sample	Rb (ppm)	Sr (ppm)	$^{87}Rb/^{86}Sr$	$^{87}Sr/^{86}Sr$	2σ	Isr	Sm (ppm)	Nd (ppm)
2003JS5	29.11	672.5	0.1254	0.717700	11	0.7144	5.388	25.02
Sample	$^{147}Sm/^{144}Nd$	$^{143}Nd/^{144}Nd$	2σ	$f_{Sm/Nd}$	$\varepsilon_{Nd}(0)$	$\varepsilon_{Nd}(T)$	T_{DM1} (Ma)	T_{DM2} (Ma)
2003JS5	0.1304	0.511500	13	−0.34	−22.2	−6.58	2999	2849

to the second possibility for the origin of the diorite. Besides, the meta-diorite has model ages T_{DM1} and T_{DM2} of Archaean time, implicating that Precambrian basement exists in the south Songliao Basin. Moreover, the model ages (T_{DM1} and T_{DM2}) are obviously older than the emplacement age of the meta-diorite. This is similar to that of NCC where the rocks younger than 2.5—2.6 Ga have these characteristics[8].

3 Geochronology

3.1 Analytical method

Following crushing to 80—120 mush and screening, zircons were separated from about 10 kg unweathered sample using conventional heavy-liquid and magnetic techniques, then we observed and noted the characters of zircons using a binocular microscope; finally, selected zircons were mounted together with the zircon standard TEM (417 Ma) and were polished nearly to half. The mounted zircons were graphed under an optical microscope (including transmitted and reflected lights), and were imaged using cathodoluminescence (CL) under an electronic probe to show the internal structures of zircons and to guide the SHRIMP analyses. After being gold-coated, the U-Th-Pb analyses were performed on the SHRIMP II ion microprobe at Beijing SHRIMP Center. Standard SL13 (572 Ma, 238×10^{-6} U) was used to calibrate the U, Th and Pb contents of the standard TEM and the unknown, and the standard TEM was used to calibrate the inter-elemental fractionation, The ^{204}Pb methods of Compston et al. were used to make common Pb correction. More detailed descriptions of the SHRIMP analytical procedure have been contained in refs. [9—11].

Analytical data treatment is carried out using the SQUID and ISOPLOT programs of Ludwig[12]. During analytical process, scan is made 5 times on each spot. Uncertainties on individual analyses are quoted at 1σ level, whereas those on the weighted mean age of samples is at 2σ level.

3.2 Analytical results

Relatively more zircons are separated from the meta-diorite sample, and zircon varies from 30 μm to 150 μm in size, mostly between 70 μm and 80 μm. The grains are either stubble (Fig.3(d),(e), (g)) or elongated (Fig. 3(b),(c),(h)) prisms, with length to width ratios mostly less than 2. Some of them have very thin overgrowths (Fig. 3(a), (b),(f), (h)), probably a result of late metamorphism. Core-mantle structures (Fig. 2(g)) and oscillatory zoning (Fig. 2(a)) can be locally observed in some zircons.

A total of 14 spots (Table 3) are analyzed on 13 zircons, and the results are listed in Table 3 and shown in Fig. 4. Of these, spots 9.1 and 9.2 are situated on the core and rim of same zircon, which yield $^{207}Pb/^{206}Pb$ ages of 1840±9 Ma and 1871±34 Ma, respectively, which are similar if the analytical errors are considered. Of the 14 analyses, except for two spots (spots 2.1 and 3.1) that give relatively old $^{207}Pb/^{206}Pb$ ages of 2152±19 Ma and 1996±10 Ma, respectively, which are interpreted as the age of inherited or xenocrystal zircons, the remaining 12 analyses give $^{207}Pb/^{206}Pb$ ages ranging from 1782±22 Ma to 1858±13 Ma, with a weighted mean $^{207}Pb/^{206}Pb$ age of 1822±12 Ma and an MSWD of 5.0. Due to this high MSWD value, further regression is done for the 12 analyses. The more coherent 8 analyses yield a weighted mean age of 1839±7 Ma with an MSWD value of 1.5. This age is interpreted as emplacement age of the diorite.

4 Discussion and conclusions

Many studies have shown that zircons with different origins have distinct Th/U ratios. For example, the ratios of magmatic zircons are relatively high (mostly >0.4), and those of metamorphic zircons are relatively low (<0.1)[13−17]. The Th/U ratios of zircons in the measured meta-diorite are mostly higher than 0.4 (Table 3), which indicates that these zircons are of magmatic but not metamorphic origin. This is supported by the oscillatory zonation of the zircons shown by the CL images. Therefore, the weighted mean age of 1839±7 Ma is interpreted as emplacement age of the meta-diorite. This suggests that the Precambrian basement do exist beneath the south Songliao Basin.

Table 3 SHRIMP U-Th-Pb analyses of zircons from the meta-diorite (sample 2003JS5) a)

Spot	$^{206}Pb_c$ (%)	U (ppm)	Th (ppm)	$^{232}Th/^{238}U$	$^{206}Pb^*$ (ppm)	$^{238}U/^{206}Pb^*$	±%	$^{207}Pb^*/^{206}Pb^*$	±%	$^{207}Pb^*/^{235}U$	±%	$^{206}Pb^*/^{238}U$	±%	$^{206}Pb/^{238}U$ age (Ma)	$^{207}Pb/^{206}Pb$ age (Ma)
JS5-1.1	0.01	513	501	1.01	132	3.34	3	0.11229	0.51	4.63	3.1	0.2992	3	1687 ±45	1836.9 ±9.3
JS5-2.1	0.08	233	117	0.52	74.8	2.68	4.5	0.1341	1.1	6.9	4.6	0.373	4.5	2045 ±78	2152 ±19
JS5-3.1	0.02	1425	563	0.41	401	3.052	3	0.12269	0.59	5.54	3	0.3276	3	1827 ±47	1996 ±10
JS5-4.1	0.03	981	146	0.15	263	3.202	3	0.11113	0.42	4.79	3	0.3123	3	1752 ±46	1818.1 ±7.6
JS5-5.1	0	2004	220	0.11	500	3.44	3	0.11015	0.27	4.41	3	0.2904	3	1644 ±43	1801.9 ±4.9
JS5-6.1	0.01	682	576	0.87	171	3.42	3	0.11266	0.45	4.55	3	0.2926	3	1655 ±44	1842.8 ±8.1
JS5-7.1	0.02	603	552	0.95	149	3.47	3	0.11248	0.5	4.47	3.1	0.2883	3	1633 ±43	1839.9 ±9.1
JS5-8.1	0.01	841	803	0.99	214	3.38	3	0.1089	1.2	4.44	3.2	0.2958	3	1670 ±44	1782 ±22
JS5-9.1	0.02	586	534	0.94	159	3.174	3	0.11247	0.5	4.89	3	0.3151	3	1766 ±46	1839.7 ±9.0
JS5-9.2	0.04	212	170	0.83	55.9	3.27	3.2	0.1144	1.9	4.83	3.7	0.3061	3.2	1722 ±48	1871 ±34
JS5-10.1	0	601	344	0.59	148	3.49	3	0.1102	0.48	4.35	3	0.2862	3	1623 ±43	1802.7 ±8.7
JS5-11.1	0.03	286	271	0.98	71.7	3.43	3	0.1136	0.7	4.57	3.1	0.2916	3	1649 ±44	1858 ±13
JS5-12.1	0.04	626	661	1.09	158	3.41	4.2	0.11193	0.48	4.53	4.2	0.293	4.2	1659 ±61	1830.9 ±8.6
JS5-13.1	0.01	1385	217	0.16	361	3.3	3.1	0.11126	0.32	4.65	3.1	0.3032	3.1	1707 ±46	1820.2 ±5.7

a) $^{206}Pb_c$ is the percent of the whole ^{206}Pb; Pb^* represents radicalized Pb. Analytical errors are last digits and are at one-sigma level

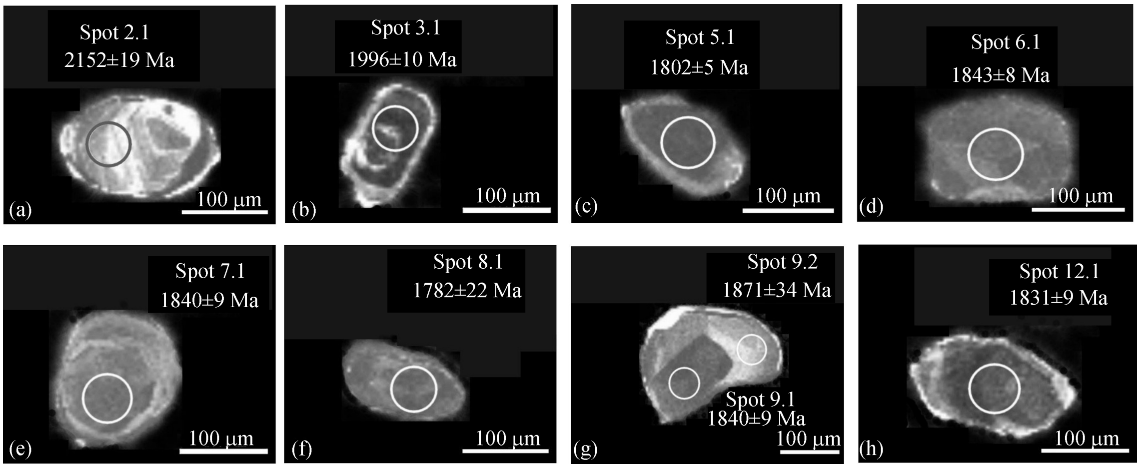

Fig. 3. Selected CL images of dated zircons from the meta-diorite (sample 2003JS5).

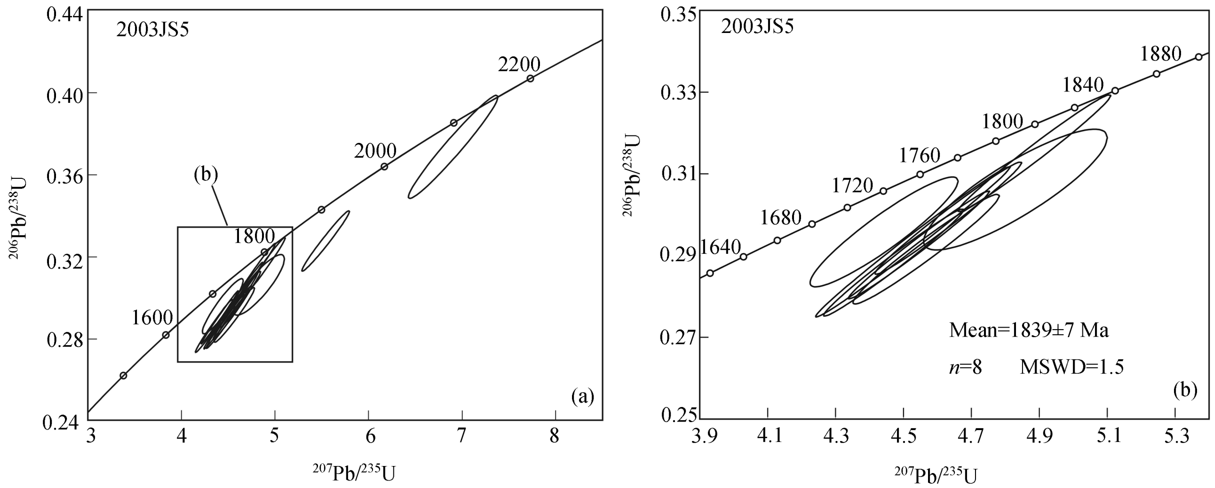

Fig. 4. Concordia diagram showing the SHRIMP analytical data for the meta-diorite (sample 2003JS5).

Wu *et al*.[1,2] dated by using conventional zircon U-Pb method on two gneissic granites from western and eastern sides of the Changyuan uplift beneath the central-north Songliao Basin, and obtained $^{206}Pb/^{238}U$ ages of 305±2 Ma (sample DuI-4) and 165 Ma (sample Ershen-1), respectively. The authors interpreted these ages as the emplacement ages of the two granites. According to geochemical data of ref.[2], the two granites both show significant HREE depletion indicating a residual phase of garnet in their source regions, resemble to typical adakitic rocks [18, 19]. The granite with the age of 305±2 Ma is coeval with the Late-Paleozoic accretion of arc complexes in the North Orogenic Belt[20], whereas the 165Ma granite is generally coeval with the Mesozoic granites formed in an extension regime in eastern China[21, 22]. The SHRIMP dating results of this paper clearly indicate a definite location where an Early-Precambrian basement exists beneath the Songliao Basin, although further work is needed to determine the whole nature of the basement of the basin. From present data, the early Precambrian basement should be located around the southeast uplift zone in the basin, which is coupled with the Changling high positive magnetic anomaly beneath the Songliao Basin (referring to the 1/400000000 Areo Magnetic Anomaly Map of China and Adjacent Coastal Zones). However, whether the whole magnetic anomaly region belongs to Precambrian basement is needed to verify. At present data level, we suggest that the basement of the Songliao Basin is not a single one, that is, it is neither only a Paleozoic orogenic basement nor just a Precambrian one. The basement should be a combination of Paleozoic orogenic formations with (early) Precambrian terrane.

It has been demonstrated that two major tectonic events took place in the NCC during Precambrian at ca 2.5 Ga and ca 1.8 Ga[23−25], respectively. The south Songliao Basin is located to north of the NCC and the age of ca 1.84 Ga of the meta-diorite reported in this paper is consistent with the latter event. This suggests that there is probably an intimate relation between the Precambrian basement beneath the south Songliao Basin and the NNC. Nd isotopic signature of the meta-diorite also supports this postulation. Nevertheless, further studies would be needed to confirm whether the southeast uplift zone in the Songliao Basin is a part of the NCC, which is greatly important to delineate the northern boundary of the NCC.

From present study, the following conclusions can be reached:

(1) Zircon SHRIMP U-Pb dating results show that the meta-diorite emplaced at 1839±7 Ma, suggesting that Precambrian basement do exist beneath the south Songliao Basin;

(2) In combination with previous studies, we propose that the basement beneath the Songliao Basin is a composite one including at least two components: early Precambrian basement of the Lüliang period (ca 1.85 Ga) and orogenic formations of Paleozoic time (ca 305 Ma).

Acknowledgements The authors would like to thank Beijing SHRIMP Center for the SHRIMP analyses on the SHRIMP II, and Zhang Yuhai, Shi Yuruo, Tao Hua, Yang Zhiqing and Song Biao for their support during analytical process. Sun Jiafu is appreciated for his help in collecting the drilling core samples. Miss Xu Yawen is thanked for her assistance in preparing the data. This work was supported by the National Natural Science Foundation of China (Grant Nos.40473030 and 40234045) and Chinese Academy of Sciences (Grant No: KZCX2-104).

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