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Zircon SHRIMP U-Pb ages of the "Xinghuadukou Group" in Hanjiayuanzi and Xinlin areas and the "Zhalantun Group" in Inner Mongolia, Da Hinggan Mountains

MIAO LaiCheng[1†], LIU DunYi[2], ZHANG FuQin[1], FAN WeiMing[1], SHI YuRuo[2] & XIE HangQiang[1]

[1] Institute of Geology and Geophysics, Chinese Academy of Sciences, Beijing 100029, China;
[2] Beijing SHRIMP Center，Institute of Geology, Chinese Academy of Geological Sciences, Beijing 100037, China

A report is presented of SHRIMP zircon U-Pb dating data of meta-igneous and meta-sedimentary rocks of the Xinghuadukou Group (Xinlin-Hanjiayuanzi area, Heilongjiang Province) and meta-volcanic rocks of the Zhalantun Group (Zhalantun district, Inner Mongolia). The SHRIMP analyses show that the meta-igneous rocks from the Xinghuadukou Group formed at 506±10－547±46 Ma, belonging to Early-Middle Precambrian, whereas the meta-sedimentary rocks yielded detrital zircons, with ages of 1.0－1.2, 1.6－1.8 and 2.5－2.6 Ga, indicative of deposition age at least <1.0 Ga. Meta-basic volcanic rocks from the Zhalantun Group have a formation age of 506±3 Ma. These data suggest that both the Xinghuadukou and Zhalantun Groups formed during Cambrian and/or Neoproterozoic time, rather than Paleoproterozoic time as previously thought. Early Precambrian inherited zircons in the meta-igneous rocks and numerous Precambrian detrital zircons in the meta-sedimentary rocks imply that these rocks were formed proximal to older crust. It is inferred that the Xinghuadukou and Zhalantun Groups represent Cambrian and/or Neoproterozoic volcano-sedimentary sequences formed in an active continental margin setting.

zircon, SHRIMP, metamorphic rock, Xinghuadukou Group, Zhalantun Group, Da Hinggan Mountains

A major endeavor in modern studies of the Central Asian Orogenic Belt is to identify which metamorphic complexes are reworked Precambrian basement and which are latest Neoproterozoic and Phanerozoic assemblages metamorphosed during crustal accretion and collisional orogens. This paper addresses this problem by dating of rocks from far northeastern China (Figure 1).

Metamorphic rocks widely distributed in the northern Da Hinggan Mountains of far northeastern China have previously been designated different metamorphic "stratum" names according to different localities where they outcrop, such as "Xinghuadukou Group", "Luomahu Group", "Xinkailing Group", "Fengshuigouhe Group", "Jiageda Group", and "Zhalantun Group"[1,2] (Figure 1). These have been considered to represent the Precambrian basement of the "Xing'an-Ergun Blocks"[3−9]. Because of lack of fossils in these rocks, previous age determination was mainly based on metamorphic grades and tectonic relationships of the day whereby higher metamorphic grade rocks were generally assumed to be older. As a result, the Xinghuadukou and Zhanlantun Groups were classified as Paleoproterozoic, and the Xinkailing, Luomahu and Fengshuigouhe Groups as Neoproterozoic[1,3,10]. Nevertheless, recent studies indicate that the so-called Neoproterozoic "Xinkailing Group" is a metamorphic complex related to Late Paleozoic to Early Mesozoic Orogenic processes, with a

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†Corresponding author (email: miaolc@mail.igcas.ac.cn)
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protolith age of only 336±2 Ma and a metamorphic age of 216±2 Ma[11]. Consequently, this paper reports the SHRIMP zircon dating results of the so-called Paleoproterozoic Xinghuadukou and Zhalantun Groups, and preliminarily discusses their tectonic implication.

1 Geological setting

The northern Da Hinggan Mountains are dominated by Mesozoic granitic intrusions and their volcanic equivalents that were emplaced into, or overlain onto the pre-Mesozoic metamorphic complexes: the metamorphic rocks outcropping in the area include the Xinghuadukou, Luomahu, Xinkailing, Fengshuigouhe, Jiageda, and Zhalantun Groups (Figure 1).

The Xinghuadukou Group in Mohe, Tahe, Huma, Xinlin, Hanjiayuanzi, and Songling areas has been divided into the Xinghua and Xinganqiao lithological units. The former is characterized by amphibolites, schists, gneisses and migmatites and the latter is composed chiefly of Al-rich schists and gneisses intercalated with marbles, as well as minor magnetite-quarzites. This group has been subjected to high-greenschist to low-amphibolite facies metamorphism. Two contrasting Sm-Nd isochron ages of 1729 Ma and 1157 Ma have been reported[1,10] (unavailable for analytical details). The Luomahu, Xinkailing and Fengshuigouhe Groups, outcropping in the Xiao Hinggan Mountains (Figure 1), are basically similar in lithology and metamorphism to the Xinghuadukou Group, except that no marbles have been recognized. Modern (SHRIMP) zircon dating shows that the Xinkailing Group rocks has zircon (core) ages of 336—290 Ma and metamorphic (zircon overgrowth) age of 216±2 Ma[11]. The Jiageda Group is distributed along the Ergun River in Inner Mongolia, and comprises a meta-volcano-sedimentary sequence dominated by sericite-quartz schists and light green-colored chlorite-quartz schists, which has experienced greenschist-facies metamorphism. No isotopic dates have previously been reported for the rocks of this group. Located around the Zhalantun City, Buhateqi, Inner Mongolia, the Zhalantun Group consists mainly of chlorite-schist, chlorite-quartz schist, biotite-amphibole-plagioclase schist and amphibolite, intercalated with minor meta-sandstone. According to the metamorphism and lithology, the Geology and Mineral Resource Bureau of Inner Mongolia proposed that the Zhalantun Group was compatible with the lower part of the Xinghudukou Group[2].

Granitoids intrusions are widespread in the whole region, and are principally Paleozoic and Mesozoic in age. Although the granites intruding the metamorphic rocks of the Xinghuadukou Group in north of Tahe City, Heilongjiang Province, have been regarded as Proterozoic in age, recent studies demonstrated that the granites emplaced during Early Paleozoic [12]. Similarly, the gabbroic intrusions there have also previously been considered to be Proterozoic in age, but they have zircon U-Pb age of 333±8 Ma[13].

2 Sample description

Four samples (localities shown in Figure 1) from the “Xinghuadukou” and “Zhalantun” Groups were selected for SHRIMP dating. Sample 2002HJY-5 of the “Xinganqiao Unit” was collected from ~15 km north of the Hanjiayuanzi Village (GPS coordinates: 52°07′44.1″N, 125°37′18.4″E). This sample is a schist composed of muscovite (25%—30%), quartz (25%—30%), plagioclase (20%—25%), biotite (10%—15%), and garnet (10%±), with minor staurolite (<5%). The muscovite is flake-shaped, and contains mineral inclusions of quartz, plagioclase and biotite, which shows deformation features, such as wavy extinction and crystal torture; the biotite is characterized by russet-light yellow flakes, and locally contains zircon inclusions with rounded radiogenic aureoles. These micas show distinct orientation arrays parallel to the foliation of the schist. Both the plagioclase and quartz are rounded anhedral grains. The plagioclase without polysynthetic twins has been altered by sericitization; the quartz displays characteristics of undulatory extinction and subgrains, with 3-crystal contacts at a 120° angle locally observed. Garnet is light yellow-colored grains, and contains small quartz inclusions. Staurolite locally sericitized is also light yellow-colored prism, and shows parallel extinction. In addition, this sample contains accessory minerals of zircons and tourmaline. The above-mentioned mineral assemblage suggests that the protolith is likely a pelitic-sandy sedimentary rock.

Sample 2002HJY-20, taken from ~10 km southeast of the Hanjiayunzi Village (GPS coordinates: 51°58′49.7″N, 125°44′48.1″E), is an epidotized plagioclase-hornblende schist, with a fine-grained blastogranular texture and a weakly gneissic structure. Major minerals of the sample

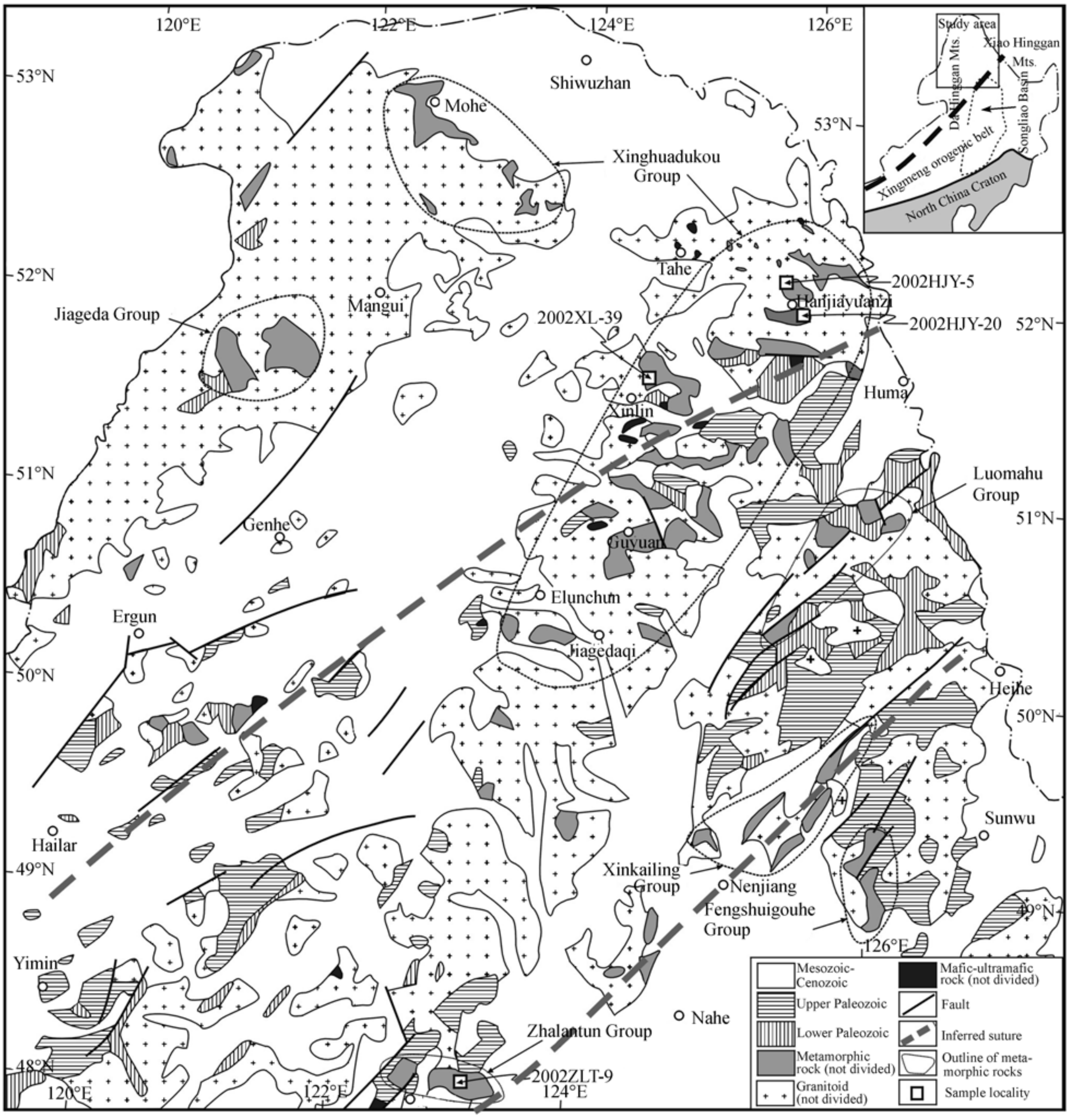

Figure 1 Simplified geological map of the northern Da Hinggan Mountains (modified from refs. [1,2, 5]).

include hornblende (40%), plagioclase (35%), epidote (15%) and quartz (5%—10%), as well as minor diopside (<5%). The hornblende is dark green-light green-colored prisms showing sub-orientated or irregular arrangement, and was mostly replaced by epidote, actinolite and biotite. Some hornblendes contain mineral inclusions of plagioclase, ilmenite and sphene. Plagioclases have been altered for variation degrees: some have only been weekly sericitized and epidotized, but still remain their sub-euhedral platy prisms with zonal texture, whereas others have been completely replaced by epidote. Epidote, as a major alteration mineral, mostly occurs as aggregate heterogeneously distributed within the rock. Quartz occurs as anhedral granular or lumpy grains, and was concentrated to constitute ribbons with distinct undulatory extinction and subcrystalline textures. Diopside is characterized by anhedral grains or stubby prisms, with some replaced by hornblende and actinolite. The accessory minerals of the sample mainly include zircon, apatite, ilmenite and sphene. The protolith of the sample is probably intermediate-basic volcanic rock.

Sample 2002XL-39 is a biotite-K-feldspar-diopside-hornblende schist, which was sampled from the area ~20 km north of the Xinlin Town (GPS coordinates: 51°45′7.7″N, 124°27′54.0″E). This sample has a gneissic structure and a granoblastic texture, and consists principally of hornblende (35%—40%), K-feldspar (25%—30%), biotite (20%), diopside (5%), plagioclase (5%) and epidote (5%), with accessory sphene, zircon and pyrite. The hornblende, being locally with small diopside relicts inside, is dark green-light Kelly-colored elongate prism, and was mostly replaced by biotite, uralite and epidote. The K-feldspar is microcline occurring as euhedral grains without alteration. The biotite is brown-fawn-colored flake, shows undulatory extinction and kink bands, and is locally replaced by chlorite. Diopside is aqua-colored stubby prism with weak polychroism, and occurs mainly as remnants after replacement by hornblende, uralite and carbonate. The plagioclase, as euhedral grains, has strong prehnitization, and was replaced by K-feldspar. Epidote is buff-colored grain, occurring as an alteration mineral. The light-colored plagioclase and dark-colored mafic minerals within the schist display alternative orientated arrangement parallel to the foliation, within which there are small fractures filled by carbonate and chlorite veins. The mineral assemblage and field setting indicates that the protolith was an intermediate-basic volcanic rock or its intrusive equivalent.

Collected from ~20 km northeast of the Zhalantun City, Inner Mongolia, sample 2002ZLT-9 (GPS coordinates: 48°03′51.3″N, 123°07′15.9″E) is a chlorite schist with a schistose structure. The schist is mainly composed of chlorite (>95 %) and epidote (<5 %), with accessory apatite and zircon. The chlorite is characterized by sub-orientated fine scaly flakes (~0.05 mm), with some occurring in fractures to form chlorite veins. Epidote occurs as small grains or prisms (0.02—0.05 mm), and relatively homogeneously distributes within the rock. It is inferred that the protolith was likely a basic volcanic rock or basic tuff.

3 Analytical results

SHRIMP U-Th-Pb analyses were conducted on zircons from the 4 samples aforementioned, see refs. [14—17] for analytical details. SHRIMP analytical sites were selected using cathodoluminescence (CL) images of zircons. Representative CL images of the 4 samples are shown in Figure 2, and the U-Th-Pb analytical results are in Table 1 and Figure 3.

Zircons from metasedimentary sample 2002HJY-5 are mostly rounded or stubby prisms with smooth grain boundary and without oscillatory zonation (Figure 2). Fifty-seven analyses were made on 54 zircons, which yielded ages ranging from 502 Ma to 2824 Ma (Table 1, Figure 3 (a), (b)). In the age probability distribution curve (Figure 3(b)), several age peaks can be identified at about 2800, 2500, 2200, 1800, 1400, 1100 and 600 Ma. This is compatible with this sample being a meta-sedimentary rock, and is suggestive of complex provenance of the detrital zircons.

According to CL images, zircons from intermediate-basic volcanic rock sample 2002HJY-20 can be divided into two groups: one is characterized by elongate euhedral prisms with fine oscillatory zoning, the other is sub-euhedral prisms without oscillatory zonation (Figure 2). Moreover, some zircons have very thin rims (indicated by their strong luminescence), indicating probably a result of overgrowth during late metamorphism or alteration. For this sample, 39 analyses were made on 34 zircons, and yielded ages ranging from 510 Ma to 2646 Ma (Table 1, Figure 3(c)). Except for 10 analyses giving relatively old ages (2600—950 Ma), the remaining 29 analyses can be divided into two coherent groups. The first group consists of 21 analyses, of which 19 analyses give a weighted mean $^{207}Pb/^{206}Pb$ age of 816±27 Ma and an MSWD value of 1.7 after removal of two analyses which are the greatest outliers. The second one comprises 7 analyses. Except for one analysis as a statistic outlier, 6 of these yield a weighted mean $^{206}Pb/^{238}U$ age of 547±46 Ma, with an MSWD value of 0.13 (Figure 3(d)).

Most zircons from intermediate-basic rock 2002XL-39 have similar morphology, such as elongate euhedral prism and oscillatory zonation (Figure 2), although a few have fine rims characterized by strong luminescence. Total 24 analyses were carried out on 19 zircons or zircon fragments from this sample. The analytical results can be divided into two populations. One consists of 18 analyses, giving ages from 477±13 Ma to 547±13 Ma (Table 1, Figure 3(e)), with a weighted mean age of

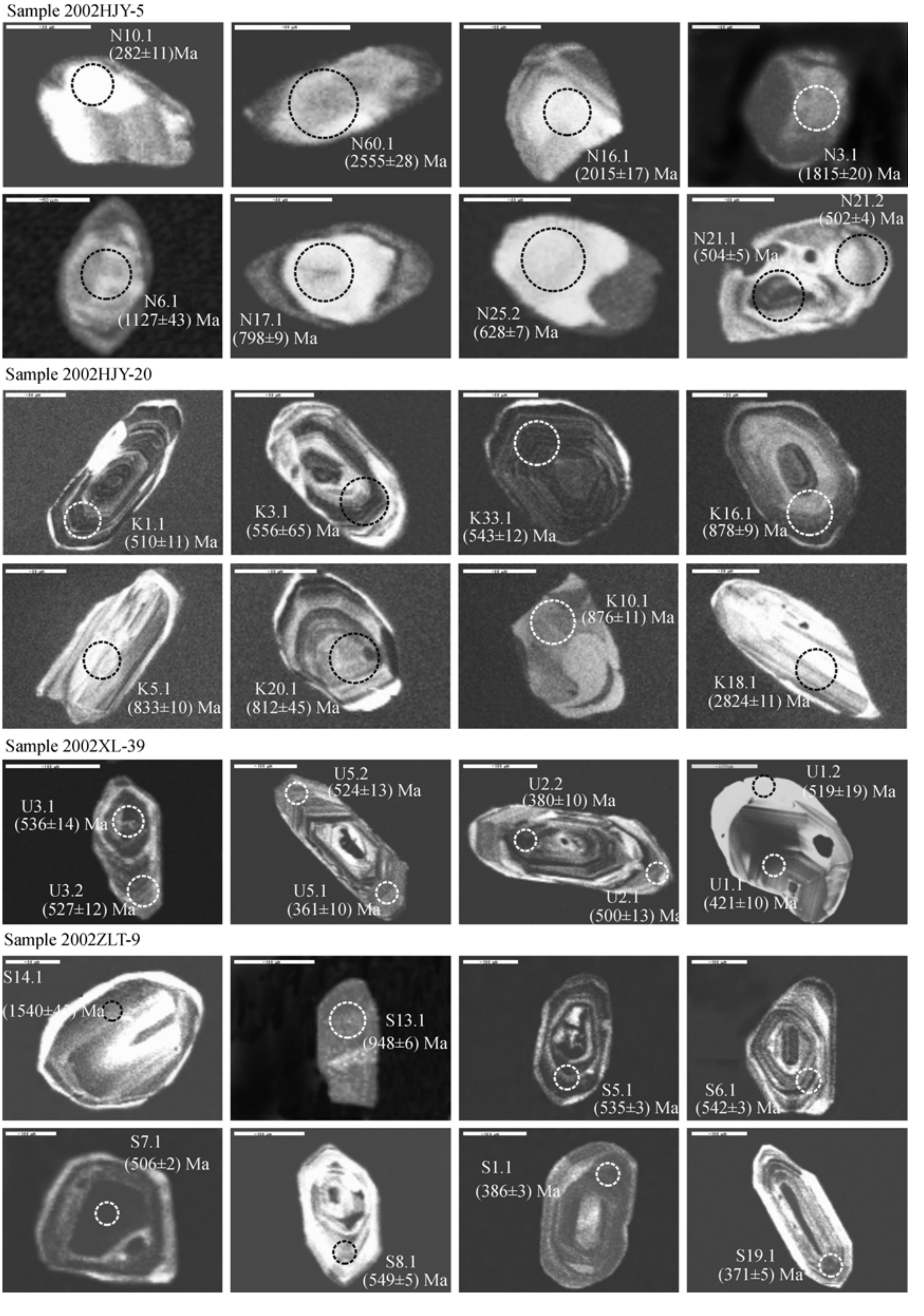

Figure 2 Representative CL images of zircons from dated metamorphic complexes. SHRIMP analytical spots are also shown.

Table 1 SHRIMP U-Pb analyses of zircons from metamorphic complexes in north Da Hinggan Mountains[a)]

Spot	U (ppm)	Th (ppm)	Th/U	f_{206} (%)	$^{206}Pb^*$ (ppm)	$^{207}Pb^*/^{206}Pb^*$		$^{207}Pb^*/^{235}U$		$^{206}Pb^*/^{238}U$		$^{206}Pb/^{238}U$		$^{207}Pb/^{206}Pb$	
						ratio	±(%)	ratio	±(%)	ratio	±(%)	Age (Ma)	±(Ma)	Age (Ma)	±(Ma)
Sample 2002HJY-5															
N1.1	330	66	0.21	0.02	92	0.1130	0.6	5.035	0.9	0.3233	0.6	1806	9	1848	12
N2.1	332	174	0.54	0.05	139	0.1709	0.5	11.500	1.1	0.4882	1.0	2563	20	2566	8
N3.1	135	60	0.46	0.07	37	0.1110	1.1	4.818	1.4	0.3149	0.8	1765	13	1815	20
N5.1	302	7	0.02	0.17	53	0.0787	1.3	2.218	1.5	0.2044	0.6	1199	7	1165	27
N6.1	154	132	0.88	0.31	25	0.0772	2.2	2.017	2.4	0.1894	1.0	1118	10	1127	43
N7.1	237	71	0.31	0.32	35	0.0890	1.5	2.115	1.8	0.1723	1.0	1025	10	1405	29
N8.1	424	122	0.30	0.05	74	0.1056	0.7	2.974	1.0	0.2043	0.7	1199	8	1724	13
N8.2	305	148	0.50	0.13	82	0.1215	1.3	5.259	1.7	0.3138	1.1	1759	17	1979	22
N9.1	199	70	0.36	-0.01	53	0.1087	0.9	4.628	1.1	0.3088	0.7	1735	11	1778	16
N10.1	143	78	0.56	0.21	67	0.1998	0.7	14.933	1.2	0.5422	1.1	2792	24	2824	11
N11.1	97	71	0.77	0.11	36	0.1625	0.9	9.622	1.6	0.4296	1.2	2304	24	2481	16
N12.1	333	105	0.32	0.12	105	0.1403	1.3	7.105	1.4	0.3674	0.6	2017	10	2231	22
N15.1	114	145	1.32	0.23	33	0.1137	1.2	5.280	1.8	0.3368	1.3	1871	21	1859	22
N16.1	196	158	0.83	0.18	62	0.1240	1.0	6.300	1.2	0.3685	0.7	2022	12	2015	17
N17.1	368	87	0.25	-0.13	42	0.0729	1.6	1.323	2.0	0.1317	1.1	798	9	1010	33
N18.1	213	113	0.55	0.18	58	0.1167	0.9	5.080	1.2	0.3158	0.7	1769	11	1906	17
N21.1	300	243	0.84	0.58	21	0.0603	2.9	0.676	3.1	0.0813	0.9	504	5	614	63
N21.2	357	371	1.07	0.25	25	0.0589	2.1	0.657	2.3	0.0809	0.7	502	4	564	47
N25.1	93	61	0.67	0.82	33	0.1607	5.9	9.167	6.2	0.4137	1.7	628	7	733	117
N26.1	119	21	0.18	0.57	20	0.1002	2.5	2.696	2.9	0.1952	1.3	1149	14	1627	47
N27.1	195	168	0.89	0.40	56	0.1093	1.7	5.003	2.0	0.3321	1.0	1849	16	1787	32
N28.1	1180	468	0.41	0.07	266	0.0919	0.8	3.316	1.0	0.2618	0.6	1499	7	1465	15
N29.1	297	175	0.61	0.36	50	0.0755	2.3	2.043	2.4	0.1963	0.9	1156	9	1081	45
N30.1	485	173	0.37	0.18	83	0.0956	1.4	2.609	1.6	0.1981	0.7	1165	8	1539	26
N31.1	792	457	0.60	0.19	162	0.0887	1.1	2.910	1.2	0.2380	0.6	1376	8	1398	21
N32.1	256	144	0.58	0.18	94	0.1912	0.9	11.201	1.4	0.4248	1.1	2282	21	2753	15
N33.1	173	126	0.75	0.23	52	0.1183	1.7	5.665	2.0	0.3474	1.1	1922	18	1930	30
N34.1	133	88	0.69	0.05	59	0.1740	1.2	12.464	1.7	0.5195	1.2	2697	26	2597	20
N35.1	303	109	0.37	0.41	83	0.1072	1.5	4.709	1.8	0.3185	0.9	1783	14	1753	28
N36.1	318	271	0.88	0.44	50	0.0747	2.7	1.877	2.9	0.1822	0.9	1079	9	1062	55
N37.1	169	97	0.59	0.22	42	0.1145	1.9	4.547	2.3	0.2879	1.4	1631	20	1873	34
N38.1	429	126	0.30	0.09	126	0.1125	1.0	5.305	1.2	0.3421	0.7	1897	12	1840	18
N39.1	338	117	0.36	0.09	92	0.1499	1.8	6.543	2.0	0.3166	0.8	1773	12	2345	31
N40.1	192	69	0.37	0.33	69	0.1963	1.1	11.317	1.5	0.4181	1.0	2252	19	2796	18
N41.1	429	128	0.31	0.09	115	0.1132	1.0	4.855	1.2	0.3109	0.7	1745	11	1852	18
N42.1	132	119	0.93	0.49	40	0.1118	2.2	5.402	2.5	0.3505	1.2	1937	19	1828	40
N43.1	305	134	0.46	0.39	77	0.1061	1.6	4.293	1.8	0.2935	0.8	1659	12	1733	29
N44.1	194	104	0.55	0.23	53	0.1110	1.4	4.808	1.9	0.3142	1.2	1761	19	1816	26
N44.1	226	82	0.38	0.76	56	0.1133	2.4	4.433	2.7	0.2838	1.1	1610	16	1853	44
N45.1	1213	300	0.26	0.08	331	0.1106	0.6	4.842	0.8	0.3175	0.5	1777	8	1810	11
N46.1	395	207	0.54	0.10	124	0.1143	0.9	5.758	1.2	0.3655	0.8	2008	14	1868	17
N47.1	239	39	0.17	0.50	42	0.0992	3.1	2.755	3.4	0.2014	1.6	1183	17	1609	57
N48.1	200	108	0.56	0.17	56	0.1155	1.8	5.204	2.1	0.3267	1.1	1822	17	1888	32
N49.1	419	110	0.27	0.25	116	0.1067	1.1	4.728	1.4	0.3214	0.8	1797	12	1743	21
N50.1	558	98	0.18	0.23	95	0.0822	3.0	2.231	3.1	0.1968	0.8	1158	9	1250	59
N51.1	94	44	0.49	0.75	28	0.1125	2.9	5.365	3.3	0.3458	1.4	1914	23	1841	53
N51.2	104	50	0.49	1.20	35	0.1066	3.4	5.626	3.8	0.3829	1.6	2090	29	1741	63
N52.1	120	86	0.74	0.80	35	0.1088	2.6	4.971	2.9	0.3314	1.2	1845	20	1779	47
N53.1	172	120	0.72	0.44	82	0.1690	1.3	12.782	1.6	0.5486	1.0	2819	24	2548	21
N54.1	273	152	0.57	0.13	125	0.1872	0.9	13.785	1.3	0.5341	1.0	2759	23	2718	14
N55.1	143	26	0.19	0.50	38	0.1099	2.2	4.641	2.6	0.3063	1.4	1723	22	1797	40
N57.1	452	323	0.74	0.12	127	0.1128	1.1	5.096	1.4	0.3276	1.0	1827	15	1845	20
N58.1	192	105	0.56	0.15	93	0.1679	1.1	13.057	1.6	0.5639	1.2	2883	28	2537	18

(*To be continued on the next page*)

(*Continued*)

Spot	U (ppm)	Th (ppm)	Th/U	f_{206} (%)	^{206}Pb* (ppm)	^{207}Pb*/^{206}Pb*		^{207}Pb*/^{235}U		^{206}Pb*/^{238}U		^{206}Pb/^{238}U		^{207}Pb/^{206}Pb	
						ratio	±(%)	ratio	±(%)	ratio	±(%)	Age (Ma)	±(Ma)	Age (Ma)	±(Ma)
Sample 2002HJY-5															
N59.1	107	39	0.38	0.13	41	0.1707	1.4	10.389	1.9	0.4415	1.3	2357	25	2564	24
N60.1	234	31	0.14	0.09	117	0.1698	1.7	13.619	2.1	0.5818	1.2	2956	29	2555	28
N61.1	783	418	0.55	0.15	149	0.0805	1.1	2.454	1.3	0.2210	0.6	1287	7	1210	22
N62.1	380	181	0.49	0.37	80	0.0815	1.8	2.726	2.0	0.2425	0.8	1400	10	1235	35
Sample 2002HJY-20															
K1.1	452	256	0.58	0.04	32	0.0610	1.5	0.693	2.8	0.0823	2.3	510	11	639	32
K2.1	565	143	0.26	0.24	67	0.0666	1.3	1.267	10.4	0.1380	10.3	834	80	824	27
K3.1	350	221	0.65	0.19	27	0.0585	2.5	0.726	12.4	0.0900	12.2	556	65	547	55
K4.1	128	80	0.65	0.00	17	0.0680	1.8	1.405	2.0	0.1498	0.9	900	8	869	37
K5.1	77	47	0.63	0.69	9	0.0601	3.4	1.142	3.6	0.1379	1.2	833	10	606	74
K6.1	166	76	0.47	0.24	19	0.0686	3.2	1.272	3.4	0.1345	1.2	814	9	887	66
K6.2	163	82	0.52	0.14	24	0.0672	1.7	1.568	2.0	0.1693	0.9	1008	9	843	36
K7.1	248	168	0.70	0.27	29	0.0642	1.9	1.199	2.0	0.1354	0.6	819	5	749	41
K8.1	101	74	0.76	0.44	13	0.0640	3.3	1.266	3.4	0.1436	1.0	865	8	741	70
K9.1	108	61	0.59	0.17	32	0.1158	1.8	5.525	6.6	0.3459	6.3	1915	104	1893	33
K10.1	58	39	0.69	0.58	7	0.0632	4.5	1.268	4.7	0.1456	1.3	876	11	715	96
K11.1	149	98	0.68	0.09	13	0.0573	2.3	0.782	2.5	0.0989	0.8	608	5	505	51
K12.1	147	63	0.44	0.33	16	0.0643	2.6	1.136	2.7	0.1280	1.0	777	7	753	54
K13.1	63	23	0.37	0.48	7	0.0653	4.9	1.201	5.0	0.1333	1.2	807	9	785	102
K14.1	245	28	0.12	0.06	29	0.0654	1.9	1.246	2.0	0.1381	0.7	834	6	787	40
K15.1	154	85	0.57	0.17	34	0.0967	1.9	3.416	2.1	0.2563	0.9	1471	12	1561	36
K15.2	170	33	0.20	0.00	22	0.0820	1.6	1.726	1.8	0.1526	0.8	916	7	1246	31
K16.1	74	35	0.49	0.65	9.3	0.0617	3.6	1.241	3.8	0.1459	1.1	878	9	664	78
K17.1	102	80	0.81	0.08	14	0.0710	2.1	1.568	2.5	0.1602	1.3	958	11	958	44
K17.2	89	56	0.65	0.47	10	0.0660	3.7	1.224	4.0	0.1345	1.4	813	11	807	78
K18.1	92	64	0.72	0.22	22	0.1009	1.5	3.908	1.7	0.2809	0.9	1596	12	1641	28
K19.1	184	55	0.31	0.35	20	0.0649	2.1	1.124	2.2	0.1257	0.8	763	5	771	44
K20.1	253	16	0.06	0.08	29	0.0686	1.5	1.271	6.0	0.1343	5.8	812	45	887	30
K21.1	248	221	0.92	0.26	28	0.0643	1.9	1.162	2.1	0.1311	0.7	794	6	752	41
K22.1	163	18	0.12	0.30	19	0.0656	2.3	1.249	2.4	0.1381	0.9	834	7	794	48
K23.1	102	37	0.37	0.28	8	0.0577	3.4	0.725	3.5	0.0911	1.1	562	6	517	74
K24.1	169	134	0.82	0.28	23	0.0710	2.0	1.561	2.2	0.1596	0.8	954	7	956	42
K25.1	105	67	0.66	0.28	12	0.0649	3.0	1.172	3.2	0.1310	1.1	794	8	771	63
K26.1	152	73	0.49	0.00	38	0.0822	20.9	3.256	20.9	0.2871	0.8	1627	12	1251	409
K26.1	214	121	0.58	0.13	59	0.1150	2.2	5.111	3.7	0.3224	3.0	1802	46	1879	40
K27.1	242	114	0.49	0.49	18	0.0648	4.6	0.781	5.3	0.0874	2.5	540	13	767	98
K28.1	246	250	1.05	0.08	96	0.1792	2.1	11.270	3.2	0.4561	2.4	2422	48	2646	35
K29.1	1075	220	0.21	0.12	81	0.0574	2.2	0.694	3.2	0.0877	2.3	542	12	509	48
K30.1	322	70	0.23	0.39	34	0.0703	2.6	1.173	4.6	0.1211	3.8	737	27	936	53
K31.1	985	57	0.06	0.15	110	0.0665	1.1	1.195	2.6	0.1303	2.3	790	17	822	24
K32.1	354	46	0.14	0.38	42	0.0733	3.7	1.404	4.4	0.1389	2.5	838	19	1022	75
K33.1	1285	1331	1.07	0.07	97	0.0592	1.1	0.718	2.5	0.0879	2.3	543	12	576	25
K34.1	481	63	0.13	0.00	55	0.0669	1.3	1.239	2.7	0.1343	2.4	812	18	836	28
K34.2	145	171	1.22	0.16	16	0.0696	3.0	1.227	3.9	0.1279	2.6	776	19	917	61
Sample 2002XL-39															
U1.1	259	454	1.75	0.41	15	0.0558	2.2	0.519	3.3	0.0674	2.4	421	10	446	49
U1.2	25	19	0.74	7.09	2	0.1620	9	1.870	9.7	0.0838	3.7	519	19	2478	150
U2.1	208	129	0.62	--	14	0.0635	2.9	0.706	3.9	0.0806	2.7	500	13	726	62
U2.2	446	435	0.98	0.50	23	0.0539	5.2	0.451	5.9	0.0607	2.7	380	10	368	120
U3.1	189	132	0.70	0.27	14	0.0587	3	0.702	4.1	0.0868	2.7	536	14	554	66
U3.2	416	548	1.32	0.18	31	0.0594	1.9	0.698	3.1	0.0851	2.4	527	12	583	41
U4.1	77	28	0.37	1.99	5	0.0515	13	0.474	13.0	0.0668	3.1	417	12	262	300
U4.2	538	717	1.33	0.58	31	0.0530	5.4	0.479	6.0	0.0655	2.5	409	10	329	120

(*To be continued on the next page*)

(*Continued*)

Spot	U (ppm)	Th (ppm)	Th/U	f_{206} (%)	$^{206}Pb^*$ (ppm)	$^{207}Pb^*/^{206}Pb^*$		$^{207}Pb^*/^{235}U$		$^{206}Pb^*/^{238}U$		$^{206}Pb/^{238}U$		$^{207}Pb/^{206}Pb$	
						ratio	±(%)	ratio	±(%)	ratio	±(%)	Age (Ma)	±(Ma)	Age (Ma)	±(Ma)
Sample 2002XL-39															
U5.1	220	180	0.82	0.86	11	0.0546	10	0.433	11.0	0.0575	2.8	361	10	396	230
U5.2	162	78	0.48	0.48	12	0.0556	5.1	0.649	5.7	0.0847	2.6	524	13	436	110
U6.1	583	1458	2.50	--	32	0.0557	1.8	0.484	3.0	0.0631	2.4	395	9	438	40
U7.1	217	167	0.77	0.22	17	0.0573	3.2	0.699	4.0	0.0884	2.5	546	13	503	70
U8.1	359	605	1.68	0.22	27	0.0573	2.1	0.699	3.2	0.0885	2.4	547	13	501	46
U9.1	253	200	0.79	0.38	17	0.0572	2.4	0.615	3.4	0.0779	2.4	484	11	499	52
U10.1	112	63	0.57	1.01	8	0.0550	5.4	0.613	6.0	0.0808	2.6	501	13	414	120
U11.1	130	66	0.51	0.27	9	0.0641	3	0.721	4.0	0.0816	2.5	506	12	745	64
U12.1	309	251	0.81	0.34	22	0.0573	2.7	0.644	3.7	0.0815	2.4	505	12	503	60
U13.1	243	263	1.08	0.66	16	0.0549	3.8	0.592	4.5	0.0783	2.4	486	11	407	84
U14.1	165	118	0.72	1.12	12	0.0535	5.9	0.639	6.4	0.0866	2.5	535	13	350	130
U15.1	144	81	0.56	1.19	10	0.0517	7.1	0.561	7.5	0.0788	2.5	489	12	270	160
U16.1	160	172	1.07	0.95	12	0.0521	6.1	0.609	6.6	0.0847	2.5	524	13	289	140
U17.1	213	132	0.62	0.24	14	0.0589	2.3	0.638	3.3	0.0786	2.4	488	11	562	49
U18.1	137	50	0.37	1.16	10	0.0543	6.3	0.612	6.9	0.0818	2.8	507	14	384	140
U19.1	83	68	0.81	1.17	6	0.0519	13	0.549	14.0	0.0768	2.8	477	13	280	310
Sample 2002ZLT-9															
S1.1	583	71	0.12	0.00	31	0.0570	2.4	0.486	2.5	0.0618	0.81	386	3	492	52
S1.2	201	22	0.11	1.52	11	0.0444	15	0.394	15.0	0.0643	1.9	402	7	-88	370
S2.1	614	303	0.49	0.45	43	0.0552	3.1	0.622	3.1	0.0817	0.57	506	3	422	69
S3.1	468	195	0.42	0.76	35	0.0552	3.5	0.652	3.6	0.0856	0.62	530	3	422	78
S4.1	3171	3520	1.11	0.09	197	0.0571	1.2	0.568	1.9	0.0722	1.5	449	7	494	27
S5.1	462	393	0.85	0.84	35	0.0553	3.4	0.660	3.5	0.0865	0.6	535	3	425	77
S6.1	380	228	0.60	0.44	29	0.0564	2.5	0.681	2.6	0.0876	0.66	542	3	468	55
S7.1	900	197	0.22	0.24	63	0.0564	1.5	0.635	1.5	0.0816	0.42	506	2	467	32
S8.1	185	133	0.72	0.70	14	0.0562	4.2	0.689	4.3	0.0889	1	549	5	460	93
S9.1	618	412	0.67	0.26	46	0.0563	1.8	0.676	1.9	0.0871	0.7	538	4	462	40
S10.1	574	53	0.09	0.39	42	0.0550	2.2	0.643	2.3	0.0848	0.52	525	3	412	50
S11.1	193	105	0.54	0.28	15	0.0591	4.3	0.731	4.8	0.0897	2.2	554	12	572	93
S12.1	395	114	0.29	0.44	30	0.0556	2.6	0.675	2.7	0.0881	0.61	544	3	435	58
S13.1	271	35	0.13	0.27	37	0.0682	1.6	1.488	1.8	0.1584	0.64	948	6	873	34
S14.1	140	15	0.10	0.24	26	0.0956	2.4	2.900	4.0	0.2199	3.2	1281	37	1540	45
S15.1	120	54	0.45	0.73	9	0.0560	7	0.640	7.2	0.0830	1.2	514	6	451	160
S16.1	219	162	0.74	0.90	15	0.0523	4.6	0.571	4.7	0.0791	0.85	491	4	300	110
S17.1	364	256	0.70	0.38	25	0.0552	2.5	0.600	2.6	0.0788	0.65	489	3	422	57
S18.1	342	231	0.67	0.53	24	0.0541	3.3	0.602	3.3	0.0807	0.76	500	4	374	73
S19.1	360	243	0.68	0.56	18	0.0537	4.9	0.438	5.0	0.0592	1.2	371	5	359	110
S20.1	425	148	0.35	0.28	30	0.0566	2	0.647	2.3	0.0829	1.1	513	5	475	45
S21.1	1284	95	0.07	1.75	110	0.0755	1.9	1.017	1.9	0.0977	0.36	601	2	1081	37
S22.1	60	26	0.43	0.00	11	0.0877	3.8	2.640	4.4	0.2180	2.3	1272	26	1375	73
S23.1	237	130	0.55	0.74	17	0.0556	6.5	0.624	6.8	0.0813	2	504	10	437	140
S24.1	699	243	0.35	0.14	53	0.0564	1.2	0.689	1.3	0.0885	0.44	547	2	469	27

a) f_{206} is the percentage of ^{206}Pb attributed to common Pb; Pb^* is radiogenic Pb; errors are at one-sigma level.

509±11 Ma and an MSWD value of 3.1. Because this MSWD value (3.1) is too high to classify these analyses as a single group, further regression is done. Omitted two oldest and one youngest analyses from the group, the remaining 15 analyses give a weighted mean age of 506±10 Ma and an MSWD value of 2.1. The other is composed of 6 analyses, which yield ages ranging from 361±10 Ma to 421±10 Ma, with a weighted mean value of 395±24 Ma (MSWD = 5.4). Rejecting the youngest analysis (spot U5.1; Table 1), the other 5 analyses generate a weighted mean age of 403±21 Ma (MSWD = 2.8).

Zircons from basic volcanic rock 2002ZLT-9 are mostly stubby prisms with magmatic oscillatory zonation; several zircons are rounded grains with or with out oscillatory zoning. Like those of zircons from sample

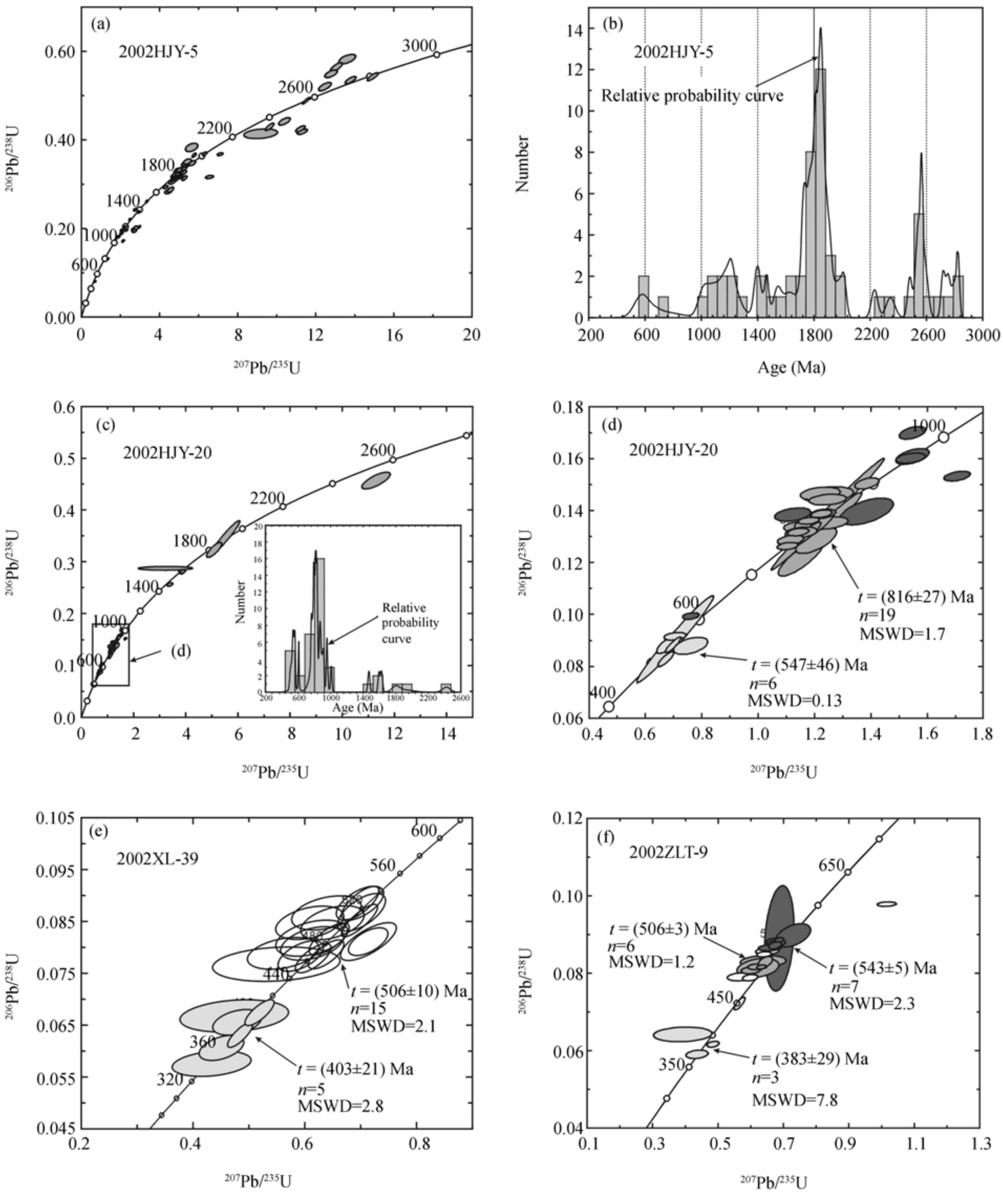

Figure 3 Concordia plots showing SHRIMP U-Pb data of zircons from metamorphic rocks in the north Da Hinggan Mountains. (a) Concordia diagram of sample 2002HJY-5 (staurolite-bearing garnet-two-mica schist of the Xinghuadukou Group); (b) age ($^{207}Pb/^{206}Pb$) histogram and probability curve of sample 2002HJY-5; (c) concordia plot and age ($^{206}Pb/^{238}U$) histogram (insert) of sample 2002HJY-20 (epidotized plagioclase-hornblende schist of the Xinghuadukou Group); (d) amplification of a part of (c); (e) concordia plot of sample 2002XL-39 (biotite-K-feldspar-diopside-hornblende schist of the Xinghuadukou Group); (f) concordia plot of sample 2002ZLT-9 (chlorite schist of the Zhalantun Group; for clarity, 3 analyses yielding ages >900 Ma are not shown).

2002XL-39, some zircons in this sample also have narrow bright overgrowth rims in CL images (Figure 2). Twenty-five analyses were made on 24 zircons from the sample, which yield ages ranging from 371 Ma to 1540

Ma (Table 1). Of these, except for 8 analyses (S13.1, S14.1, S21.1, S22.2, S1.1, S1.2, S4.1 and S19.1), giving relatively old and young ages, the remaining 17 analyses give ages from 489±3 Ma to 554±12 Ma. These 17 analyses can be divisible into two sub-groups (Figure 3(f)). The first sub-group consists of 7 analyses, which give a weighted mean age of 543±5 Ma, with an MSWD value of 2.3; the second one comprises 6 analyses, which yield a weighted mean age of 506±3 Ma and an MSWD value of 1.2. Additionally, 2 analyses (spots S3.1, S10.1) give ages (525±3 Ma and 530±3 Ma) between the 2 sub-groups, and the other 2 analyses (spots S16.1 and S17.1) have relatively young ages (491±4 Ma and 489±3 Ma). For the 4 youngest analyses of the sample, 3 of them yield ages of 371±5 Ma, 386±3 Ma and 402±7 Ma, respectively, with a weighted mean value of 383±29 Ma (MSWD = 7.8; Figure 3(f)).

4 Discussion and conclusions

4.1 Formation ages of the "Xinghuadukou Group" and "Zhalantun Group"

Previous isotope age data for the Xinghuadukou and Zhalantun Groups in the northern Da Hinggan Mountains are restrict to only two Sm-Nd isochron ages of 1729 Ma and 1157 Ma (without information on error or MSWD). The former was interpreted as the formation age, whereas the latter as a metamorphic one[1, 10]. Notwithstanding detailed data of these two analyses are unavailable, which is difficult to evaluate the reliability, and such great differences between the two ages obtained by using similar analytical methods suggest that the dated objects are of either different ages or initial ratios, so that they form meaningless isochrones.

As described in Section 2, the dated sample 2002HJY-5 is a staurolite-bearing garnet-two-mica schist, and its protolith is pelitic-sandy sedimentary rock. As a consequence, the zircons from the schist should be detrital or metamorphic in origin, and therefore their ages represent the ages of their provenances or metamorphism. According to CL images, the morphology of zircons of the sample is characterized by rounded grains and smooth outlines, indicating a detrital origin. Furthermore, the zircons are relatively homogeneous, and lack of typical magmatic oscillatory zonation, but with some bright "patches" of strong luminescence (Figure 2). This suggests that they are likely detrital zircons with a metamorphic origin. Multiple age peaks in this sample indicate that the provenances of the meta-sedimentary rocks probably contain materials with different ages. Generally, the youngest age of the detrital zircons should constrain the lower limit of the formation ages of the sedimentary rocks. The youngest detrital zircon of this sample gives $^{206}Pb/^{238}U$ ages of 502± 4 Ma and 504± 45 Ma, but only one (two analytical spots N21.1 and N21.2) of such zircons was detected in this study, and the ages are not concordant (having $^{207}Pb/^{206}Pb$ ages of 564 ± 47 Ma and 614± 63 Ma, respectively), being possibly a result of Pb-loss during late tectono-thermal events. Therefore, the significance of these results to constrain the age of deposition is uncertain. On the other hand, numerous detrital zircons with ages of 1.0—1.1 Ga in this sample suggest that the deposition age of the sample must be younger than 1.0 Ga, that is, it formed during Neoproterozoic or even Cambrian period, rather than in the Paleoproterozoic time as previously thought[1, 10].

The protoliths of both samples 2002HJY-20 and 2002XL-39 are intermediate-basic igneous rocks, which are from the so-called "Xinghua lithologic unit" of the "Xinghuadukou Group". The sample 2002HJY-20 has two age groups giving weighted mean ages of 816± 27 Ma and 547± 46 Ma, respectively. Because the latter was obtained from zircons with fine oscillatory zonation and the former from those with or without weak zonation, we interpret the latter (547± 46 Ma) as the formation age of the sample and the former as representing zircon inheritance, although the former is more abundant than the latter. Sample 2002XL-39 has a weighted mean age of 506±10 Ma for the main zircon population, with a few of zircons giving sparse younger ages at about 403±10 Ma (n = 5, MSWD = 2.8). Since all zircons of this sample are characterized by typical magmatic oscillatory zonation, we interpret the age of 506±10 Ma of the main zircon population as the formation age of this sample. For the relatively young ages, we preliminarily interpret them as a consequence of variable radiogenic Pb-loss, which is demonstrated by repeated analyses on some individual zircons. For example, analytical spots U1.1 and U1.2 are located on the same zircon (Figure 2): the former on the zircon core with oscillatory zonation yields a younger age of 421±10 Ma, but the latter on the zircon rim without the zonation gives an older age of 519±19 Ma, similar to the ages of the main zircon population. This indicates that the zircon core must have experienced Pb-loss, probably caused by relatively high U content of the zircon core (Table 1). For another example, both spots U5.2 and U5.1 are located on zircon rim domains with oscillatory zonation, (Figure 2), which should have the same or similar ages, but the former gives an age of 524±13 Ma, similar to ages of the main zircon group, whereas the latter gives an age of 361±10 Ma, obviously younger than that of the former, which similarly indicates that spot U5.1 has been subjected to Pb-loss. The U and Th contents (220 ppm and 180 ppm) of spot U5.1 are higher than those of spot U5.2 (162 ppm and 78 ppm), which is a possible cause of the Pb-loss. Another possibility is that the Pb-loss occurred during late metamorphic or tectono-thermal events. Therefore, it is reasonable to interpret the age 506±10 Ma of the main zircon population as the formation age. This age is, within analytical errors, coeval with that of the younger group of the sample 2002HJY-20 (547±46 Ma), suggesting that both of them formed during Cambrian period.

The sample 2002ZLT-90 of the Zhalantun Group is a chlorite schist, whose protolith is likely a basic volcanic or tuff. According to analytical results in combination with CL images of zircons, we interpret the 4 zircons yield ages >600 Ma as being inherited or xenocrystic in origin. The two group zircons, which yield weighted mean ages of 543±5 Ma and 506±3 Ma, respectively, are both morphologically characterized by magmatic oscillatory zonation, and therefore the younger age (506±3 Ma) is interpreted as the formation age of the schist. For the older age (543±5 Ma), there are two possible interpretations: one is that it, like those of the old zircons, is also a result of zircon inheritance; the other is that it represents the initiation of magmatism. Because of volcanic protolith of the rock, we prefer to the first alternative. This is because if the analytical errors are not considered these two ages have a differentiation of ~ 40 Ma, which seems too long for one single volcanism. Similarly, the few younger ages (371—449 Ma) are interpreted as a consequence of disturbance by late metamorphic or magmatic-thermal events. The formation age (506±3 Ma) of the schist sample is comparable with those of samples 2002HJY-20 (547±46 Ma) and 2002XL-39 (506±10 Ma), if the errors are taken into account, suggesting that the "Zhalantun Group" was formed during Middle-Cambrian time.

In summary, current SHRIMP results demonstrate that the dated "Xinghuadukou Group" and "Zhalantun Group", regardless of the meta-sedimentary or meta-igneous rocks, are not Paleoproterozoic in age as previously inferred, but formed in the Early-Middle Cambrian time for the meta-igneous rocks, probably coeval with the meta-sedimentary rocks. Consequently, they are not Precambrian basement of the region.

It is worth noting that both of the two meta-igneous samples of 2002XL-39 and 2002ZLT-9 generate relatively young ages of 380—400 Ma. As discussed above, they are probably caused by Pb-loss, which was possibly related either to metamorphism- deformation the rocks experienced or to late thermal events (e.g. intense Mesozoic granitic magmatism). However, from present amount of data, it is difficult to define exactly the age of metamorphism. Note that outcrops of the "Xinghuadukou Group" are scattered across a large region, and therefore, the conclusions of this paper are probably valid only for the outcrops where the samples were collected. Caution should be taken when these conclusions are extrapolated to other distract outcrops.

4.2 Tectonic implications

There is still debate concerning the crustal architecture and tectonic evolution of the northern Da Hinggan Mountains. Some authors proposed that there were three continental blocks in the region, from north to south, namely Ergun, Hinggan, and Songnen blocks[4,5,18,19], and that the later two were collided along the Hegenshan-Zhalaite-Nenjiang suture during the Late Paleozoic period[20,21]. However, few data are available to constrain the position and timing of the suturing of the first two blocks. Recently, Ge et al.[12] urged, based on studies of granite and gabbro, that these two blocks were sutured during the early Early Paleozoic period (>490 Ma). According to the above classification, all the 3 dated samples of the "Xinghuadukou Group" are located in Ergun block (the southern margin), whereas the sample of the "Zhalantun Group" in the Hinggan block (the southern margin).

The "Xinghuadukou Group", which is characterized by a lithological assemblage of volcanic and clastic sedimentary rocks and marbles, was previously considered as a typical Paleoproterozoic sequence formed in an active margin setting, which was folded and metamorphosed at about the end of the Paleoproterozoic to form a part of the basement of the Ergun block[1, 3,4]. However, our results suggest that the formation age of the group is

Cambrian or Neoproterozoic, i.e. the Xinghuadukou Group represents volcano-sedimentary formations in an active continental margin of Cambrian or slightly earlier age. This is consistent with the feature of old inherited zircons of Precambrian ages detected in the meta-igneous rock samples, especially those (>1.0 Ga) abundant in the meta-sedimentary rock. Thus, the northern Da Hinggan Mountains, in which the Xinghuadukou Group was exposed, should be an active continental margin setting during Cambrian and/or Neoproterozoic period. Combining with recent studies, if the Tahe granitic complex (~490 Ma) was emplaced in a post-colli- sional extension environment[12], the formation of ages of 506－547 Ma the meta-volcanic rocks of the Xinghuadukou Group formed in an active continental margin would constrain the lower limit of the collision to be Late Cambrian (490－506 Ma).

The Zhalantun Group outcropping around the Zhalantun City of Buhateqi, Inner Mongolia, is composed mainly of a sequence of volcanic and volcanoclastic rocks, intercalated with minor clastic sedimentary rocks[2], essentially comparable with the volcanic formation (Xinghua lithologic unit) of the Xinghuadukou Group, indicative of a same or similar environment in which they formed. The SHRIMP data also confirm that they are coeval (Cambrian). Nevertheless, the present location of the Zhalantun Group is in the southern margin of the above-mentioned “Hinggan block, very far from the Xinghuadukou Group, and therefore the relationship of the two groups is uncertain yet. We infer three possibilities for this: 1) the present spatial configuration of the two groups is original — they represent two different Cambrian continental margins of two blocks; 2) the Zhalantun is probably a thrust outlier from north; and 3) they primarily formed in the same active margin or island-arc, but late break-up occurred and the Zhalantun Group possibly represents a fragment drifting away to south. Due to lack of detailed geological data, further work is needed to verify which scenario is more practicable.

From present study, the following conclusions can be reached:

(1) The meta-igneous rocks of the Xinghuandukou Group in the Xinlin-Hanjiayuanzi area, the northern Da Hinggan Mountains, and the Zhalantun Group in Inner Mongolia were formed during Cambrian period, and meta-sedimentary rocks during the same period or slightly earlier, which suggests that the ages of the two groups were not Paleoproterozoic as previously inferred.

(2) The SHRIMP zircon results, in combination with lithological data of the rocks, demonstrated that the dated rocks (Xinghuadukou and Zhalantun Groups) can now be identified as Cambrian or Neoproterozoic active margin assemblages formed early in the evolution of the Central Asian Orogenic Belt, although the relation of the two groups needs further study.

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