Chin.J.Geochem.(2014)33:001–008
DOI: 10.1007/s11631-014-0655-5

Zircon U-Pb age and Hf isotopic characteristics of the Huangtuliang monzonitic granite, North Hebei Province, China

HU Huabin[1*], NIU Shuyin[1], ZHANG Zhanyang[2], TIAN Ye[1], LIU Xiaoyu[1], CHEN Xicai[1], and CHEN Haijiao[1]
[1] *College of Resources, Shijiazhuang University of Economics, Shijiazhuang 050031, China*
[2] *Congli Zhijin Mining Industry Limited Liability Co., Hebei, Congli 076350, China*
[*] *Corresponding author, E-mail: huhb27@163.com*

Received June 6, 2013; accepted August 5, 2013

Abstract The Huangtuliang monzonitic granite outcrops on the northern side of the Huangtuliang gold mining district, Chicheng, North Hebei Province. Our predecessors only made isotopic age determination using the K-Ar method. Through LA-MC-ICP-MS zircon U-Pb dating and zircon Hf isotopic composition determination, this study acquired the age of 244.8±2.0 Ma (MSWD=0.57) on the basis of the weighed mean $^{206}Pb/^{238}U$ ratio, indicating that the Huangtuliang monzonitic granite was formed during the Middle Triassic period, which is the product of Early Indosinian magmatic activities in the region of North Hebei. εHf(t) values vary relatively evenly, within the range of -10.65− -14.03, with an average of -12.14. The two-stage evolution model ages, t_{DM2}, vary between 1943 and 2144 Ma, implying that the rock-forming materials of the Huangtiliang monzonitic granite mainly came from the Paleoproterozoic recirculated crustal materials, though a small quantity of enriched-mantle materials would have been involved.

Key words Huangtuliang monzonitic granite; zircon U-Pb age; Hf isotope; Hebei landmass

The Huangtuliang gold deposit is located in the Zhaojiagou-Erbaozi ductile-brittle shear zone on the southern side of the Congli-Chicheng ductile-brittle shear zone and the orebodies are hosted in the eastern section of the Shuiquangou-Dananshan monzonite complex. In recent years important advances have been made in research on structurally controlled mineralization, metallogenic rules and ore-search orientation (Niu Shuyin et al., 2003; Fu Fangjian et al., 2006). Under the direction of the newly developed theory of metallogenesis an important breakthrough has been made in geological prospecting of this deposit (Niu Shuyin et al., 2008). However, deep-going research has not yet been conducted on the age and genesis of magmatic rocks in this mining district, for example, only a K-Ar age of 197.68±2.94 Ma has been reported for the monzonitic granite situated on the northern side of the mining district (Liu Haitian, 1999). Due to intense Paleozoic-Mesozoic magmatic activities in this region the K-Ar ages would be easily affected by thermal events after rock mass emplacement, and therefore, the reliability of ages is relatively poor. Through LA-MC-ICP-MS U-Pb dating and Hf isotopic composition determination of zircon, this study explored the formation age and genesis of the Huangtuliang monzonitic granite, as well as their geological significance.

1 Rockbody characteristics and brief sample introduction

The monzonitic granite outcrops on the northern side of the Chicheng-Huangtuliang gold mining district, North Hebei Province (Fig. 1). The southern part of the rockbody is in fault contact with the Devonian syenite and its northern part is in fault contact with the Jiangouhe Formation of the Congli Group. The sampling location is N40°56'32", E115°39'22". The rockbody is light flesh pink in color and exhibits granular texture and massive structure. The rocks are composed mainly of oligoclase, barbierite and quartz. The oligoclase is subhedral clintheriform-anhedral, with sericitization, muscovitization and kaolinization. Some crystals were contaminated by K-feldspar to form creep texture, with the content of about 40%. The barierite is mostly anhedral and irregular in crystal form but subordinately subhedral and clintheriform. It was metasomatized to form oligoclase with the content of 25%−30%. The quartz is euhdral and fills in the cracks, showing wavy extinction, with the content of 20%−25%. The accessory minerals include magnetite (1%), apatite (1%) and zircon (0.5%). Zircon grains sorted from the samples are mostly colorless or light yellowish-brown in color under transmission light and the grains are mostly long prismatic in form with the macro-axes varying between 150−200 μm and the ratios of major axis to minor axis varying between 1.5∶1−3∶1 (Fig. 2).

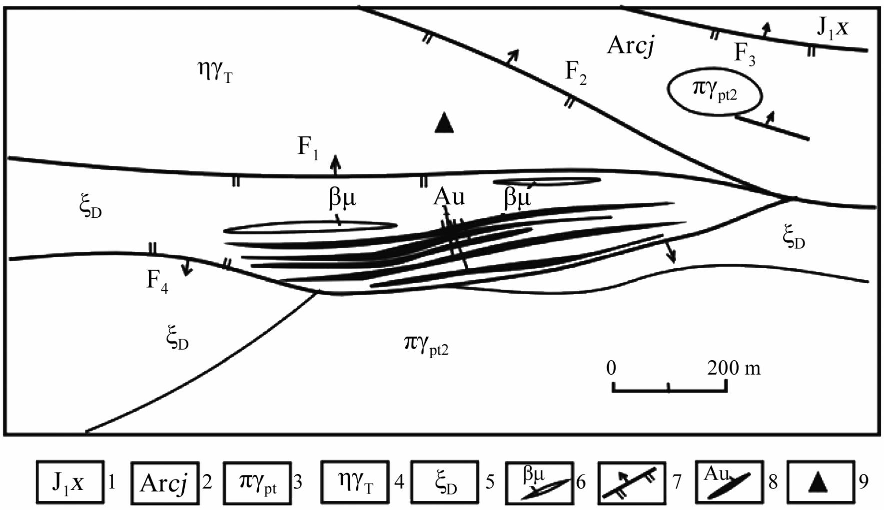

Fig. 1. Geological map of the Huangtuliang gold deposit. 1. Jurassic Xiahuayuan Formation; 2. Congli Group Jiangouhe Formation; 3. Paleoproterozoic porphyritic granite; 4. Triassic monzonitic granite; 5. Devonian syenite; 6.diorite-porphyrite; 7.fault; 8. gold orebody; 9. sampling site.

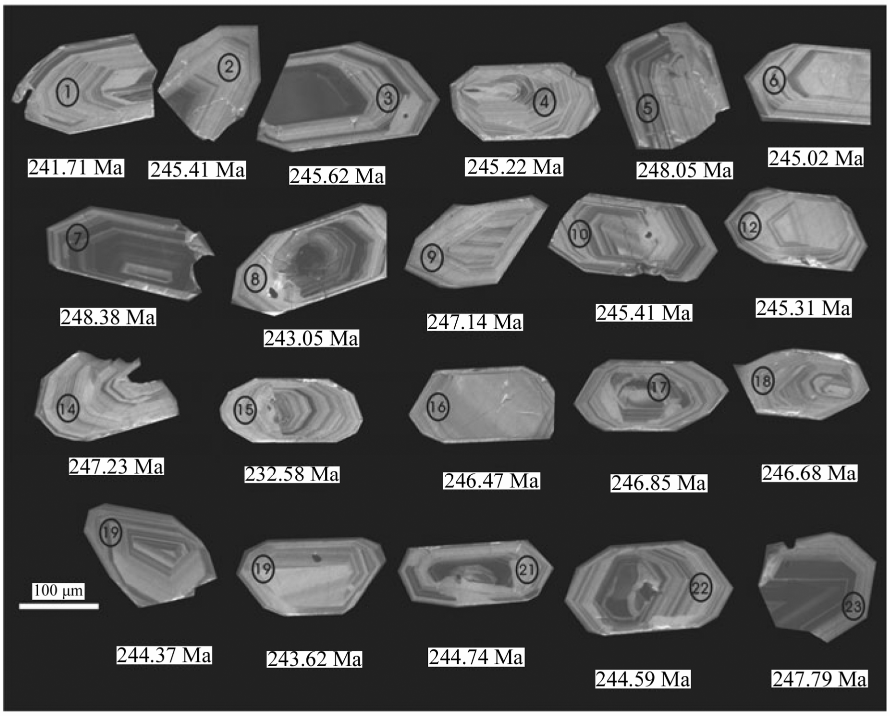

Fig. 2. Cathod luminescence (CL) images of the representative zircon crystals in the Huangtuliang monzonitic granite.

2 Analytical method

LA-MC-ICP-MS zircon U-Pb dating was accomplished at the Laboratory for Isotopic Research, Institute of Mineral Resources, Chinese Academy of Geological Sciences. The analytical instruments are the Finnigan Neptune-Type MC-ICP-MS and the assorted Newwave UP 213 Laser Denudation System. LA-MC-ICP-MS laser denudation sampling was conducted in the mode of single-point denudation. Before data analysis zircon GJ-1 was used for instrumental debugging. In zircon U-Pb dating zircon GJ-1 was used as the external standard and the U and Th contents were corrected by using zircon M127 (U 923×10^{-6}, Th 439×10^{-6}, Th/U 0.475) (Nasdala et al., 2008) as an external standard. In the process of isotopic measurement two zircon GJ-1 samples were repeatedly measured before and after 5 samples were analyzed to correct the measurement results of the samples. Meanwhile, one zircon Plesovice sample was measured. Under this circumstance the operation status of the instrument was carefully observed so as to guarantee the precision of the measurement. The ICPMADataCa 4.3 program was adopted for data processing (Liu Yongsheng et al., 2010). In the test process $^{206}Pb/^{204}Pb>1000$ for the most majority of the analytical points, with no correction for common Pb. ^{204}Pb was tested by means of an ion counter. The analytical points with abnormally high contents of ^{204}Pb would have been affected by common Pb, for instance, from fluid inclusions, and those with abnormally high contents of ^{204}Pb should be rejected in calculation. Zircon age concordant plot was obtained using the Isoplot 3.0 program. The errors involved in the single points listed in the expression are all equal to 1σ, and the weighed mean ages have a 95% confidence coefficient. For the details of the experimental and test processes, please refer to Hou Kejun et al. (2009).

Zircon Hf isotopic measurement was conducted at the Laboratory for Metallogenesis and Resource Evaluation, Ministry of Land and Resources, Institute of Mineral Resources, Chinese Academy of Geological Sciences on the Neptune multi-reception LA-ICP-MS and Newwave UP 231 ultraviolet laser denudation system (LA-MC-ICP-MS). In the experimental process He was taken as denudation-material carrier gas. According to the size of zircon the denudation diameter was taken to be 55 or 40 μm. In the test process the international zircon standards GJ-1 and Plesovice were taken as the reference materials .The analytical points and those for U-Pb dating are located in the same site. For the operation conditions of the related instruments and the details of the analytical procedure, please refer to Hou Kejun et al. (2007). In the analytical process the weighed mean value of $^{176}Hf/^{177}Hf$ was 0.282007±0.000007 (2σ, n=36), completely consistent with the values reported in the literature (Hou Kejun et al., 2007; Morel et al., 2006) within the limit of errors.

3 Results of zircon U-Pb dating and Hf isotopic composition

The U contents of the Huangtuliang monzonitic granite samples vary between $10.59\times10^{-6}-783.17\times10^{-6}$, their Th contents vary between $5.70\times10^{-6}-453.19\times10^{-6}$, their Th/U ratios are 0.42−1.31 (Table 1), and their $^{206}Pb/^{238}U$ apparent ages vary between 232.58 and 248.38 Ma. Twenty-one analysis points are concentrated on the concordant curve and its vicinities (Fig. 3) and the $^{206}Pb/^{238}U$ weighed mean age is 244.8±2.0 Ma (MSWD=0.57), representing the intrusion age of the monzonitic granite.

Micro-area *in-situ* analysis of the Huangtuliang monzonitic granite sample HG-5 was made for zircon Hf isotopic composition, with a total of 18 points analyzed. The $^{176}Lu/^{177}Hf$ ratios of the analyzed zircon vary over a small range, between 0.000233 and 0.000844; the $^{176}Hf/^{177}Hf$ ratios of the sample vary over a relatively small range, between 0.282232 and 0.282320; the εHf(t) values also vary in a relatively small range, between -10.65 and -14.03, with an average of -12.14 and a standard deviation of 1.116; the two-stage evolution model ages (t_{DM2}) vary between 1943 and 2144 Ma (Table 2), i.e., mainly concentrated within the range reported for the Paleoproterozoic period.

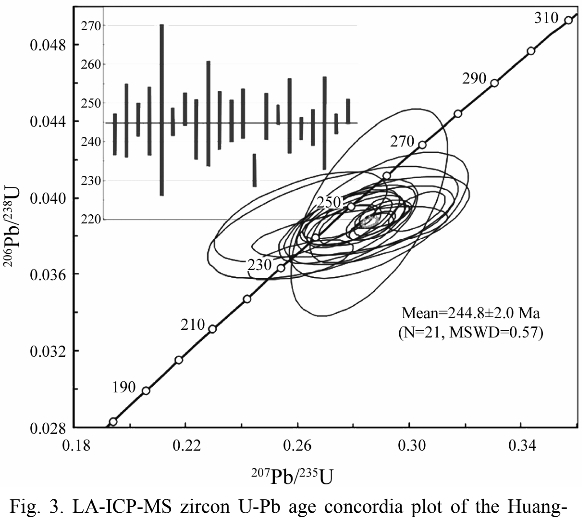

Fig. 3. LA-ICP-MS zircon U-Pb age concordia plot of the Huangtuliang monzonitic granite.

Table 1 Results of LA-ICP-MS zircon U-Pb age determination for the Huangtuliang monzonitic granite

Point No.	Isotopic content (10^{-6})			Isotopic ratio									Apparent age (Ma)							
	Pb	Th	U	$^{207}Pb/^{206}Pb$	1σ	$^{207}Pb/^{235}U$	1σ	$^{206}Pb/^{238}U$	1σ	$^{208}Pb/^{232}Th$	1σ	$^{232}Th/^{238}U$	$^{207}Pb/^{206}Pb$	1σ	$^{207}Pb/^{235}U$	1σ	$^{206}Pb/^{238}U$	1σ	$^{208}Pb/^{232}Th$	1σ
HG-05-1	43.73	19.52	34.48	0.053	0.0034	0.2788	0.023	0.038	0.0009	0.0145	0.0048	0.566	309.32	143.5	249.69	18.32	241.72	5.39	290.19	95.25
HG-05-2	19.48	18.57	23.04	0.054	0.0040	0.2884	0.021	0.039	0.0015	0.0165	0.0031	0.806	383.39	166.65	257.28	17.28	245.42	9.48	330.11	62.00
HG-05-3	37.67	50.78	50.63	0.054	0.0011	0.2892	0.008	0.039	0.0007	0.0059	0.0011	1.003	372.28	46.29	257.94	6.13	245.63	4.28	120.28	22.73
HG-05-4	7.09	13.65	21.96	0.053	0.0019	0.2837	0.013	0.039	0.0014	0.0171	0.0055	0.621	346.35	84.25	253.58	10.03	245.22	8.89	342.86	109.02
HG-05-5	38.80	19.42	31.17	0.053	0.0031	0.2857	0.019	0.039	0.0036	0.0148	0.0099	0.623	346.35	133.32	255.18	14.62	248.05	22.09	296.47	197.38
HG-05-6	21.00	25.99	31.15	0.051	0.0014	0.2748	0.0086	0.039	0.0006	0.0099	0.0018	0.834	261.18	62.95	246.56	6.89	245.02	3.57	199.84	36.47
HG-05-7	49.73	75.64	155.63	0.056	0.0010	0.3027	0.0067	0.039	0.0007	0.0039	0.0007	0.486	450.05	43.52	268.50	5.24	248.39	4.24	78.45	13.40
HG-05-8	44.17	16.37	29.96	0.052	0.0023	0.2759	0.0149	0.038	0.0012	0.0137	0.0028	0.546	283.40	105.54	247.37	11.87	243.06	7.74	274.89	55.19
HG-05-9	0.20	9.48	12.14	0.054	0.0035	0.2890	0.0211	0.039	0.0022	0.0261	0.0072	0.781	383.39	144.43	257.80	16.65	247.15	13.50	520.36	142.00
HG-05-10	0.56	26.69	32.65	0.054	0.0032	0.2879	0.0185	0.039	0.0012	0.0044	0.0010	0.817	364.87	130.54	256.91	14.56	245.42	7.50	88.79	20.28
HG-05-12	20.19	19.31	25.03	0.053	0.0018	0.2831	0.0103	0.0388	0.0009	0.0127	0.0024	0.771	338.95	77.77	253.09	8.17	245.32	5.42	254.32	47.62
HG-05-14	8.05	25.83	28.17	0.052	0.0025	0.2816	0.0138	0.039	0.0010	0.0059	0.0017	0.917	305.62	107.39	251.89	10.90	247.24	6.44	120.33	34.19
HG-05-15	0.46	22.34	28.95	0.052	0.0033	0.2611	0.0125	0.037	0.0007	0.0074	0.0050	0.772	275.99	146.28	235.55	10.04	232.58	4.27	149.31	100.79
HG-05-16	0.55	22.36	32.96	0.052	0.0016	0.2796	0.0112	0.039	0.0009	0.0055	0.0018	0.679	287.1	74.99	250.35	8.92	246.47	6.02	111.76	35.20
HG-05-17	24.49	17.85	31.46	0.054	0.0011	0.2903	0.0065	0.039	0.0004	0.0134	0.0048	0.567	372.28	46.29	258.79	5.12	246.85	2.59	269.46	95.18
HG-05-18	111.16	20.55	30.83	0.049	0.0040	0.2611	0.0204	0.039	0.0016	0.0142	0.0054	0.666	138.98	181.46	235.58	16.44	246.68	9.66	285.87	107.70
HG-05-19	126.14	64.24	49.04	0.054	0.0008	0.2865	0.0051	0.038	0.0005	0.0046	0.0010	1.310	388.94	33.33	255.80	4.07	243.37	2.90	93.14	20.16
HG-05-20	60.75	19.22	30.32	0.052	0.0012	0.2767	0.0088	0.039	0.0008	0.0099	0.0021	0.634	283.40	58.33	248.01	7.01	243.63	4.65	199.59	42.51
HG-05-21	30.94	5.70	10.59	0.052	0.0058	0.2726	0.0295	0.039	0.0019	0.0362	0.0129	0.538	301.91	286.08	244.76	23.62	244.75	12.01	719.98	251.29
HG-05-22	34.97	26.70	62.99	0.054	0.0007	0.2877	0.0048	0.039	0.0004	0.0077	0.0013	0.424	368.57	63.88	256.74	3.80	244.59	2.58	156.04	25.85
HG-05-23	637.73	453.19	783.17	0.053	0.0003	0.2880	0.0038	0.039	0.0005	0.0026	0.0004	0.579	342.65	17.59	257.02	3.02	247.80	3.23	51.90	7.75

Table 2 Results of zircon Hf isotopic measurement for the Huangtuliang monzonitic granite

Sample No.	Age (Ma)	$^{176}Yb/^{177}Hf$	$^{176}Lu/^{177}Hf$	$^{176}Hf/^{177}Hf$	2σ	$^{176}Hf/^{177}Hf_i$	εHf(o)	εHf(*t*)	t_{DM1} (Ma)	t_{DM2} (Ma)	$f_{Lu/Hf}$
HG-05-1	241.72	0.028319	0.000528	0.282244	0.000022	0.282242	-18.67	-13.46	1404	2115	-0.98
HG-05-2	245.42	0.011984	0.000233	0.282288	0.000019	0.282286	-17.13	-11.78	1334	2013	-0.99
HG-05-3	245.63	0.022972	0.000420	0.282250	0.000021	0.282248	-18.45	-13.13	1392	2098	-0.99
HG-05-4	245.22	0.020775	0.000379	0.282316	0.000023	0.282314	-16.13	-10.81	1300	1952	-0.99
HG-05-5	248.05	0.042747	0.000803	0.282304	0.000019	0.282300	-16.56	-11.25	1331	1981	-0.98
HG-05-6	245.02	0.033096	0.000597	0.282316	0.000022	0.282314	-16.11	-10.83	1307	1953	-0.98
HG-05-7	248.39	0.030834	0.000599	0.282320	0.000016	0.282317	-16.00	-10.65	1302	1944	-0.98
HG-05-8	243.06	0.014085	0.000259	0.282320	0.000021	0.282318	-16.00	-10.70	1291	1943	-0.99
HG-05-9	247.15	0.020051	0.000380	0.282308	0.000018	0.282307	-16.39	-11.03	1310	1967	-0.99
HG-05-10	245.42	0.021721	0.000436	0.282290	0.000019	0.282288	-17.04	-11.72	1337	2009	-0.99
HG-05-12	245.32	0.020143	0.000381	0.282317	0.000019	0.282315	-16.08	-10.76	1298	1949	-0.99
HG-05-14	247.24	0.019714	0.000376	0.282238	0.000019	0.282236	-18.89	-13.53	1407	2124	-0.99
HG-05-15	232.58	0.013705	0.000250	0.282232	0.000020	0.282231	-19.09	-14.03	1410	2144	-0.99
HG-05-16	246.47	0.041585	0.000844	0.282271	0.000017	0.282267	-17.72	-12.44	1378	2055	-0.97
HG-05-17	246.85	0.035508	0.000611	0.282288	0.000020	0.282285	-17.12	-11.81	1347	2015	-0.98
HG-05-18	246.68	0.019334	0.000333	0.282244	0.000023	0.282243	-18.66	-13.30	1397	2109	-0.99
HG-05-19	243.37	0.019389	0.000329	0.282249	0.000022	0.282247	-18.51	-13.22	1390	2102	-0.99
HG-05-20	243.63	0.030668	0.000523	0.282260	0.000019	0.282257	-18.11	-12.85	1382	2079	-0.98
HG-05-21	244.75	0.038377	0.000702	0.282248	0.000017	0.282245	-18.52	-13.26	1404	2105	-0.98
HG-05-22	244.59	0.022039	0.000400	0.282285	0.000018	0.282284	-17.21	-11.91	1343	2020	-0.99
HG-05-23	247.80	0.022947	0.000437	0.282266	0.000015	0.282264	-17.88	-12.51	1370	2060	-0.99

4 Discussion

4.1 Formation age and geological significance of the Huangtuliang monzonitic granite

Th/U ratios in zircons from the monzonitic granite studied in this paper are greater than 0.1, varying between 0.42 and 1.31, indicating that the zircons are of magmatic origin. Cathod luminescence research showed that zircons of this type keep a perfect long columnar crystal shape, the magmatic girdles are well developed, further indicating their magmatic origin. Therefore, the weighed mean age of 244.8±2.0 Ma (MSWD=0.57) obtained in this study represents the crystallization age of the monzonitic granite. The International Commission on Stratigraphy (ICS) (2008) prescribed a limit of 228.7−245.9 Ma to the Middle Triassic, indicating that the monozonitic granite in this region was formed during the Middle Triassic epoch.

Messozoic magmatic activities were intense in the Zhang-Xuan region, North Hebei Province, but, as for their time limit, they mostly occurred during the Jurassic-Cretaceous periods. Little report has been made on Triassic, especially Early Triassic magmatic activities. The relatively reliable zircon ages are those U-Pb TIMS ages for hornblende monzonite, course-grained granite and light fresh-pink phenocryst-bearing granite in the Beichagoumen region, North Hebei Province, which vary from 250±3.6 to 246.7±2.5 Ma (Mao Debao et al., 2003; Chen Zhihong et al., 2004). The Huangtuliang monzonitic granite and granitoid rocks in the Beichagoumen region, North Hebei, are the magmatic response to the Early Indosinian tectonic movement in the region of North Hebei. In the middle segment of the northern margin of the North China landmass the Middle-Late Triassic magmatic activities were relatively extensive. For example, the zircon LA-ICP-MS U-Pb age of the Honghualiang granite about 20 km west of the Huangtuliang monzonitic granite is 235±2 Ma (Jiang Neng et al., 2007); the zircon SHRIMP U-Pb age of the Guzuizi granite is 236±2 Ma (Miao Laicheng et al., 2002); the zircon SHRIMP U-Pb age of the Bingshanliang granodiorite at Chicheng is 228.0±3.1 Ma (Liu Kuangyin et al., 2010); the zircon SHRIMP U-Pb ages of the Dushan granite porphyry dykes in the Sanjia gold mining district on the eastern side are 223±2 and 222±4 Ma, respectively (Luo Zhenkuan et al., 2003); Wu Fuyuan et al. (2005) made use of zircon TIMS and LA-ICP-MS U-Pb dating methods and obtained the forming age of 233±1 Ma for the Saima rockbody and the forming age of 231±1 Ma for Bailinchuan rockbody. The Sr-Nd-Pb isotopic characteristics showed that all those rockbodies, more or less, possess the isotopic characteristics of the enriched mantle (Yan Guohan et al., 2000).

The destruction of the North China Craton has become a hot topic in the geological field both at home and abroad in recent ten years, which involves the time, space, mechanism and driving force of the North China Craton destruction (Wu Fuyuan et al., 2008). Some researchers considered that the destruction of the North China Craton started mainly in the Triassic period (Xu Wenliang et al., 2006; Yang Jinhui et al., 2009) and some other scholars held that it started in Late Mesozoic time (Gao Shan et al., 2004; Yang Jinhui et al., 2008). On the basis of their understanding of Triassic magmatism in the Chicheng region, North Hebei Province, Li Yin et al. (2010) suggested that the destruction of the North China Craton started in the Indosinian period. So, whether the Huangtuliang monzonitic granite in the Chicheng region of North Hebei is the product of North China Craton dectruction still needs to be further studied. Because the time at which the North China Craton collided and joined together with the Siberian Plate is 290−234 Ma, i.e., the paleo-Asian Ocean closed finally at 234 Ma (Zhang Shuanhong et al., 2009, Ma Xu et al., 2012), the Huangtuliang monzonitic granite is a constituent part of the Triassic alkaline rock belt which extends nearly as long as 1500 km in the eastern-western direction on the northern margin of the North China landmass, and its formation seems to be more closely related to the extension background of the North China Craton during the time period from late collision to post-orogenesis.

4.2 Magma source region

Zircon Hf isotopic micro-area *in-situ* analysis of 21 points of sample HG-5 of the Huangtuliang monzonitic granite was carried out and $^{176}Lu/^{177}Hf$ ratios in the tested zircons vary over a relatively small range, between 0.000233 and 0.000844. $^{176}Lu/^{177}Hf$ values for all the analytical points are less than 0.002, indicating that almost no radiogenic Hf accumulation occurred after the formation of zircons and the zircons were seldom affected by any later-stage magmothermal event. Therefore, the $^{176}Lu/^{177}Hf$ values for the tested sample may basically represent the Hf isotopic values at the time of formation of the sample. $^{176}Hf/^{177}Hf$ values vary in a relatively small range, between 0.282232 and 0.282320. εHf(t) values also vary over a small range, between -10.65 and -14.03, with an average of -12.14 and a standard deviation of 1.116. The Hf isotopic composition of the Huangtuliang monzonitic granite lies in the range recorded at the time of Paleoproterozoic crust evolution (Fig. 4), just overlapping the distribution range of εHf(t) values for the Yanshanian folded zone, and obviously differing from the distribution range of εHf(t) values for the eastern segment of the Xingmeng orogenic belt (Yang Jinhui et al., 2006). The two-stage model ages (t_{DM2}) stand between 1943 and 2144 Ma, concentrated within the range recorded for the Paleoproterozoic period, implying that the residence time of the granomagmatic material source in the crust is Paleoproterzoic.

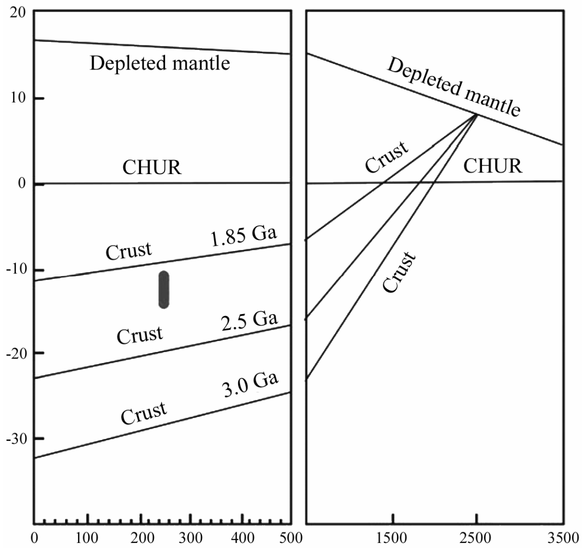

Fig. 4. The Hf isotopic evolution plot of the Huangtuliang monzonitic granite.

The positive εHf(t) values of granitic rocks are thought to be resultant from partial melting of crustal materials from the depleted mantle or of newly proliferative crustal materials derived from the depleted mantle, and the negative εHf(t) values are indicative of ancient crust origin (Wu Fuyuan et al., 2007). It was testified by further studies that εHf(t) may be around -9.0 for the enriched lithospheric mantle (EM) in North China (Yang Jinhui et al., 2006; Chen Bin et al., 2008). As viewed from the Hf isotopic composition, the ancient lower crust has a very low εHf(t) value (about -35) (Zheng Jianping et al., 2004; Chen Bin et al., 2008). The zircon Hf isotopic composition of the Huangtuliang monzonitic granite is slightly lower than the εHf(t) value of the enriched lithospheric mantle (EM), North China, but obviously higher than the Hf isotopic composition of the ancient lower crust, North China. At present, some important achievements have been made in the Hf isotopic study of Mesozoic magmatic rocks in the Zhang Xuan region in the middle segment of the northern margin of the North China landmass, and the obtained εHf(t) values are used to explore the nature of the magma source region. For example, the εHf(t) values of the Xiaozhangjiakou basic-ultrabasic rockbody dated at 220 Ma, corresponding to Late Triassic, vary between -2.9 and 1.66. This is thought to be the result of partial melting caused by interaction and mixing between mantle fluid/melt in the depleted asthenosphere and the enriched lithospherical mantle (Tian Wei et al., 2007); the εHf(*t*) values of the Middle Triassic (235 Ma) Honghuagang granite at Dongping vary between -9.9 and -23.3, the two-stage evolution model ages are mostly within the range of 1892−2321 Ma, and the granomagmatic source region was formed from the Paleoproterzoic lower crust materials (Jiang Neng et al., 2007); the Hf isotopic values of zircons in the Early Cretaceous Houcheng Formation dacite in the Zhangxuan region vary between -15.1 and -18.5; the former is thought to have come mainly from Late Archean crustal materials while the latter is considered to have been derived from the mixture of Archean crustal materials and mantle-source materials (Yang Jinhui et al., 2006). The εHf(*t*) values of zircons in the Huangtuliang monzonitic granite are obviously lower than those of zircons in the mantle-source Xiaozhangjiakou basic-ultrabasic rockbody, slightly higher than those of zircons in the Zhangjiakou Formation rhyolite , falling within the range of εHf(*t*) values for the Middel Triassic Honghuagang granite at Dongping. All this, in conjunction with the zircon two-stage evolution model ages, implies that the monzonitic granite in this region was formed mainly from the Paleoproterozoic recirculated crustal materials, while the involvement of a small amount of enriched mantle material should not be excluded.

5 Conclusions

(1) The weighed mean $^{206}Pb/^{238}U$ age obtained from LA-MC-ICP-MS zircon U-Pb dating (244.8±2.0 Ma） represents the age of magmatic crystallization. The Huangtuliang monzonitic granite was formed during the Middle Triassic, and it was the product of Early Indosinian tectono-magmatic activities. Regionally, the Huangtuliang monzonitic granite is a part of the nearly EW-extending alkaline rock belt on the northern margin of the North China landmass, and its formation may be related to the extension from the late stage of collision to post orogenesis on the northern margin of the North China Craton.

(2) The εHf(*t*) values of samples from the Huangtuliang monzonitic granite vary over a relatively small range, between -10.65 and -14.03, with an average of -12.14, just overlapping the range of εHf(*t*) values for the Yanshanian fold belt. The two-stage evolution model ages (t_{DM2}) stand between 1943 and 2144 Ma, concentrated within the Paleoproterozoic range, indicating that the crustal residence time of material source of granitic magma is Paleoproterozoic, the monzonitic granite was mainly derived from Paleoproterozoic recirculated crustal materials, though there would be involved a minor amount of enriched mantle material.

Acknowledgements The authors wish to cordially thank Engineer Shi Ping of the Huangtuliang Gold Mining Administration for his help with the field work and Doctor Hou Kejun of the Institute of Mineral Resources, Chinese Academy of Geological Sciences, for his instruction in isotopic measurement. This research project was financially supported jointly by the Geological Investigation Item sponsored by the China Geological Survey (No. 1212011220492), the Scientific Research Base of China's Typical Metallic Ores (No. 200911007) and the National Natural Science Foundation of China (40872137).

References

Chen Bin, Tian Wei, Jahn B.M. et al. (2008) Zircon SHRIMP U-Pb ages and *in-situ* Hf isotopic analysis for the Mesozoic intrusions in South Tailing, North China Craton: Magmas and crustal components [J]. *Lithos*. **102**, 118−137.

Chen Zhihong, Mao Debao, Zou Yicheng et al. (2004) The Beichagoumen Mesozoic magmatic intrusion-associated metagenetic system [J]. *Acta Geoscientia Sinica*. **25**, 224−228.

Fu Fangjian, Niu Shuyin, Han Yuchou, Zhang Ge, Sun Aiqun, Wang Baode, and Hu Huabin (2006) Exploration of deep orebodies in Huangtuliang gold deposit, Northwest Hebei [J]. *Journal of Guilin University of Technology*. **26**, 328−333 (in Chinese with English abstract).

Gao Shan, Rudnick R.L., Yuan Hongling et al. (2004) Recycling lower continental crust in the North China Craton [J]. *Nature.* **432**, 892−897.

Hou Kejun, Li Yanhe, and Tian Youyong (2009) *In-situ* U-Pb zircon dating using laser ablation-multi ion couting-ICP-MS [J]. *Mineral Deposits*. **28**, 481−492 (in Chinese with English abstract).

Hou Kejun, Li Yanhe, Zou Tianren, Qu Xiaoming, Shi Yuruo, and Xie Guiqing (2007) Laser ablation-MC-ICP-MS technique for Hf isotope microanalysis of zircon and its geological applications [J]. *Acta Petrologica Sinica*. **23**, 2595−2604 (in Chinese with English abstract).

Jiang Neng, Liu Yongsheng, Zhou Wenge, Yang Jinhui, and Zhang Shuangquan (2007) Derivation of Mesozoic adakitic magmas from ancient lower crust in the North China Craton [J]. *Geochimica et Cosmochimica Acta.* **71**, 2591−2608.

Liu Haitian (1999) Analysis of ore-controlling factors of Huangtuliang gold deposit, northwest Hebei Province [J]. *Journal of Precious Metallic Geology*. **8**, 209−216 (in Chinese with English abstract).

Liu Yin, Ni Zhiyao, Zhai Mingguo, Shi Yuruo, Yan Gang, and Lu Junsheng (2010) Zircon Shrimp U-Pb dating of granite in Chicheng County, northern Hebei Province and its geological implications [J]. *Journal of Mineralogy and Petrology.* **30**, 38−44 (in Chinese with English abstract).

Liu Yongsheng, Gao Shan, Hu Zhaochu et al. (2010) Continental and oceanic crust recycling-induced melt-peridotite interactions in the Trans-North China Orogen: U-Pb dating, Hf isotopes and trace elements in zircons from mantle xenoliths [J]. *Journal of Petrology*. **51** (1−2), 537−571 (in Chinese with English abstract).

Luo Zhenkuan, Miao Laicheng, Guan Kang et al. (2003) SHRIMP U-Pb zircon dating of the Dushan granitic batholith and related granite-porphyry dyke, eastern Hebei Province, China, and their geological significance [J]. *Geochimica*. **32**, 173−180 (in Chinese with English abstract).

Ma Xu, Chen Bin, Chen Jiafu, and Niu Xiaolu (2012) Zircon SHRIMP U-Pb age, geochemical, Sr-Nd isotopic, and *in-situ* Hf isotopic data of the Late Carboniferous-Early Permian plutons on the northern margin of the North China Craton [J]. *Science China: Earth Sciences*. **42**, 1830−1850.

Mao Debao, Chen Zhihong, Zhong Changding et al. (2003) Geochronology and geochemistry of Mesozoic intrusive rocks in the Beichagoumen region, North Hebei [J]. *Acta Petrologica Sinica.* **19**, 661−674 (in Chinese with English abstract).

Miao Laicheng, Qiu Yumin, McNaughton Neal, Luo Zhenkuan, Groves David, Zhai Yusheng, Fan Weiming, Zhai Mingguo, and Guan Kang (2002) SHRIMP U-Pb zircon geochronology of granitoids from Dongping area, Hebei Province, China: Constraints on tectonic evolution and geodynamic setting for gold metallogeny [J]. *Ore Geology Review* **19**, 187−204.

Morel M.L.A., Nebel O., Nebel-Jacobsen Y.J., Miller J.S., and Vroon P.Z. (2008) Hafnium isotope characterization of the GJ-1 zircon reference material by solution and laser-ablation MC-ICPMS [J]. *Chemical Geology*. **255**, 231−235.

Nasdala L., Hofmeister W., Norberg N. et al. (2008) Zircon M257—A homogeneous natural reference material for the ion microprobe U-Pb analysis of zircon [J]. *Geostandards and Geoanalytical Research.* **32**, 247−265.

Niu Shuyin, Sun Aiqun, Wang Baode, Han Yuchou, Wei Minghui, Zhang Hai, Zhang Ge, Shi Ping, and Wang Wenxing (2008) Source of ore-forming material for the Huangtuliang gold deposit, Hebei Province and ore prospecting in the deep periphery [J]. *Chinese Journal of Geochemistry*. **27**, 225−234.

Niu Shuyin, Wang Baode, Sun Aiqun, Li Hongyang, Hou Quanlin, Li Fu, and Wang Wenxing (2003) The study of ore-controlling structures and determination of deep ore bodies in Huangtuliang gold deposit, Northwest Hebei [J]. *Geology and Prospecting*. **39**, 17−20.

Tian Wei, Chen Bin, Liu Chaqun, and Zhang Huafeng (2007) Zircon U-Pb age and Hf isotopic composition of the Xiaozhangjiakou ultramafic pluton in northern Hebei [J]. *Acta Petrologica Sinica*. **23**, 583−590.

Wu Fuyan, Li Xianhua, Zheng Yongfei, and Gao Shan (2007) Lu-Hf isotopic systematics and their applications in petrology [J]. *Acta Petrological Sinica*. **23**, 185−220.

Wu Fuyuan, Yang Jinhui, and Liu Xiaoming (2005) Geochronological framework of the Mesozoic granitic magmatism in the Liaodong Peninsula, Northeast China [J]. *Geological Journal of China Universities*. **11**, 305−317 (in Chinese with English abstract).

Wu Fuyuan, Xu Yigang, Gao Shan, and Zheng Jianping (2008) Lithospheric thinning and destruction of the North China Craton [J]. *Acta Petrologica Sinica*. **24**, 1145-1174.

Xu Wenliang, Yang Chenghai, Yang Debin, Pei Fuping, Wang Qinghai, and Ji Weiqiang (2006) Mesozoic high-Mg diorites in eastern North China Craton: Constraints on the mechanism of lithospheric thinning [J]. *Earth Science Frontiers.* **13**, 120−129 (in Chinese with English abstract).

Yan Guohan, Mu Baolei, Xu Baoliang, He Guoqi, Tan Linkun, Zhao Hui, He Zhongfu, Zhang Renhu, and Qiao Guangsheng (2000) Triassic alkaline intrusives in the Yanliao-Yinshan area: Their chronology, Sr, Nd and Pb isotopic characteristics and their implications [J]. *Science in China* (Series D). **30**, 383−387.

Yang J.H., Wu F.Y., Wilde S.A. et al. (2008) Mesozoic decratonization of the North China Block [J]. *Geology*. **36**, 467−470.

Yang Jinhui and Wu Fuyuan (2009) Triassic magmatism and its relation to decratonization in eastern North China Craton [J]. *Science China Series D-Earth Science* **39**, 910−921.

Yang Jinhui, Wu Fuyuan, Chung Sunlin et al. (2006) A hybrid origin for the Qianshan A-type granite, Northeast China: Geochemical and Sr-Nd-Hf isotopic evidence [J]. *Lithos*. **89**, 89−106.

Yang Jinhui, Wu Fuyuan, Shang Jian, Xie Liewen, and Liu Xiaoming (2006) *In-situ* U-Pb dating and Hf isotopic analyses of zircons from volcanic rocks of the Houcheng and Zhangjiakou Formations in the Zhang-Xuan area, Northeast China [J]. *Earth Science*. **31**, 71−80.

Zhang Shuanhong, Zhao Yue, Song Biao et al. (2009) Contrasting Late Carboniferous and Late Permian-Middle Trassic intrusive suites from the northern margin of the North China Craton: Geochronology, petrogenesis, and tectonic implications [J]. *Geology Society of America Bulletin.* **121**, 181−199.

Zheng Jianping, Griffin W.L., O'Reilly S.Y. et al. (2004) U-Pb and Hf-isotope analysis of zircons in mafic xenoliths from Fuxian kimberlites: Evolution of the lower crust beneath the North China Craton [J]. *Contributions to Mineralogy and Petrology,* **148**, 79−103.