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U-Pb zircon age for the Daohugou Biota at Ningcheng of Inner Mongolia and comments on related issues

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Abstract SHRIMP U-Pb zircon dating was carried out for the Daohugou Biota near Ningcheng of Inner Mongolia and for lavas overlying or underlying salamander-bearing strata at Reshuitang in Lingyuan of West Liaoning. The results suggest that the Daohugou Biota occurred at an interval from 168 Ma to 164—152 Ma. Both the Daohugou Biota and the salamander-bearing fossil assemblage are the same biota and thus developed from 168 to 152 Ma, i.e. from late Middle Jurassic to the early Late Jurassic. The Daohugou Biota-bearing rocks, resting on the Jiulongshan Formation in disconformity and being overlain in unconformity by Late Jurassic Tuchengzi Formation and Early Cretaceous rocks containing the Jehol Biota, are mainly composed of volcanic-sedimentary rocks in a normal sequence. It is recommended that the Daohugou Biota and the related stratigraphy should be correlated with the Tiaojishan Formation (Lanqi Formation in West Liaoning) or its synchronous rocks. It is suggested that the Daohugou Biota and the Jehol Biota would be neither taken into one biota nor considered as the earliest elements of the Jehol Biota. The Daohugou Biota and the related rocks and the Yixian Formation were respectively formed in different periods of volcanic-sedimentary tectonics.

Keywords: Daohugou Biota, U-Pb zircon dating, comment, related issues.

Since discovery of the new biota (the Daohugou Biota) of late Mesozoic at Daohugou of Shantou Township in SE Ningcheng of Inner Mongolia in the early days of this century, a number of geologists and paleontologists have carried out enormous studies of the Late Mesozoic stratigraphies and paleontologies[1−18]. However, age of the Daohugou Biota and related strata has been a controversial issue for a long time. Recent studies have established the type lithological succession and correlation between the late Mesozoic Daohugou Biota-bearing strata and regional Tiaojishan Formation of the Middle Jurassic[13,14]. He *et al*.[16,17] and Wang *et al*.[2], however, suggested that the strata in the Daohugou region are "an inversed sequence", and "the Tiaojishan Formation is covered by the rocks containing the Daohugou Biota". Furthermore, they insisted that "the rocks association hosting the Daohugou Biota and the Yixian Formation were both formed in the same volcanic-sedimentary phase, and the age of the Daohugou Biota is from Late Jurassic to Early Cretaceous other than Middle Jurassic". They even stated that "the fossil assemblage of the Daohugou Biota is well correlated with the vertebrate assemblage of the Jehol Biota and is the earliest element of the Jehol Biota". These conclusions claimed by He *et al*.[16,17] and Wang *et al*.[2] not only arise the questions regarding the age of the Daohugou Biota and the related stratigraphic sequence even more complicated, but also yield serious conflicts with the field evidence and the lately acquired U-Pb zircon age in this paper. Thus they are needed to be seriously scrutinized. In order to give the age of the Daohugou Biota, SHPIMP U-Pb zircon dating was conducted on the basis of our previous studies concerning the volcanic-sedimentary rocks succession and their regional correlation. Comments on the related issues raised by He *et al*.[16,17] and Wang *et al*.[2] are reviewed on the meantime.

1 Location, stratigraphy and volcano-sedimentary succession

The Ningcheng basin, extending along the boundary between Inner Mongolia, Hebei and Liaoning, belongs to one of the Late Mesozoic basins in the volcano-sedimentary basin group in North Hebei and West Liaoning. Study area of this paper covers a region of 41°14′—41°30′N and 118°40′—119°30′E (Fig. 1(a) and (b)). The basement of the Ningcheng basin consisting of Archean or Mesoproterozoic, and the Jurassic-Cretaceous volcanic-sedimentary rocks is filled within it (Fig. 1(b)).

The successive Middle Jurassic sequences are well

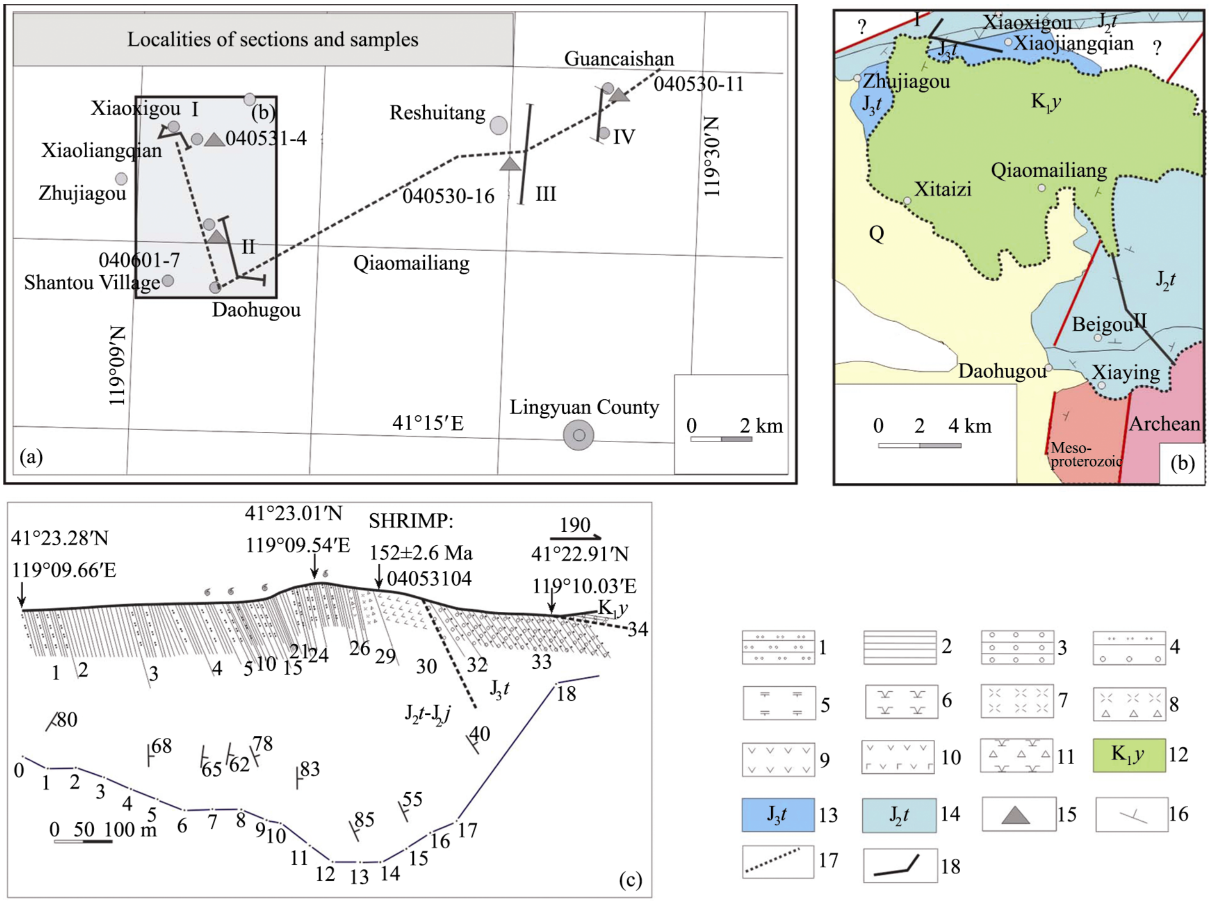

Fig. 1. Location of stratigraphic sections and schematic geological map in the Daohugou area. 1, Siltstone or sandstone; 2, mudstone or shale; 3, conglomerate; 4, rhythmic deposits of sandstone and conglomerate; 5, trachyandesite; 6, dacite; 7, rhyolite; 8, brecciated rhyolite; 9, andesite; 10, basalt; 11, brecciated dacite; 12, Yixian Formation; 13, Tuchengzi Formation; 14, Tiaojishan Formation; 15, sample site; 16, occurrence; 17, formation boundary; 18, measured section.

exposed in the research region (Fig. 1(b), (c); Fig. 2), and they are in the ascending order from the Middle Jurassic Jiulongshan Formation, Tiaojishan Formation, Late Jurassic Tuchengzi Formation to the Early Cretaceous Yixian Formation[13, 14]. The Jiulongshan Formation mainly consists of coarse conglomerates intercalated with sandstone, mudstone or thin-bedded coal layers. The lower part of the Tiaojishan Formation is composed of sedimentary rocks containing the Daohugou Biota while the upper part is medium to acid or alkaline lavas, and a transitional contact with the overlying Tuchengzi Formation is observed. The Tuchengzi Formation is composed of light purple reddish, massive and medium bedded conglomerates, sandstone interbedded with siltstone, and the top of this formation is covered by sandstone and conglomerate of the Early Cretaceous Yixian Formation with an unconformity (Fig. 1(b), (c); Fig. 2).

2 Characteristics of samples and zircons for dating

Samples for dating in this research were respectively collected from the measured sections at Xiaoxigou-Xiaoliangqian, Qiaomailiang-Daohugou in Ningcheng of Inner Mongolia and at Reshuitang in Lingyuan of West Liaoning (Figs. 1 and 2).

In order to acquire the oldest and youngest geochronological ages of the biota correctly, samples for dating are either collected from the lavas underlying the Daohugou Biota-bearing layers or those underlain by the salamander-bearing layers at Reshuitang. In this research, four samples are chosen to be dated and the lithological features of each sample are shown in Table 1.

Selection of zircons are made in a routine way in which the 100% pure zircons are selected under microscope after comminuting these samples to the granularity of 300 μm and panned by hands. The zircon sample

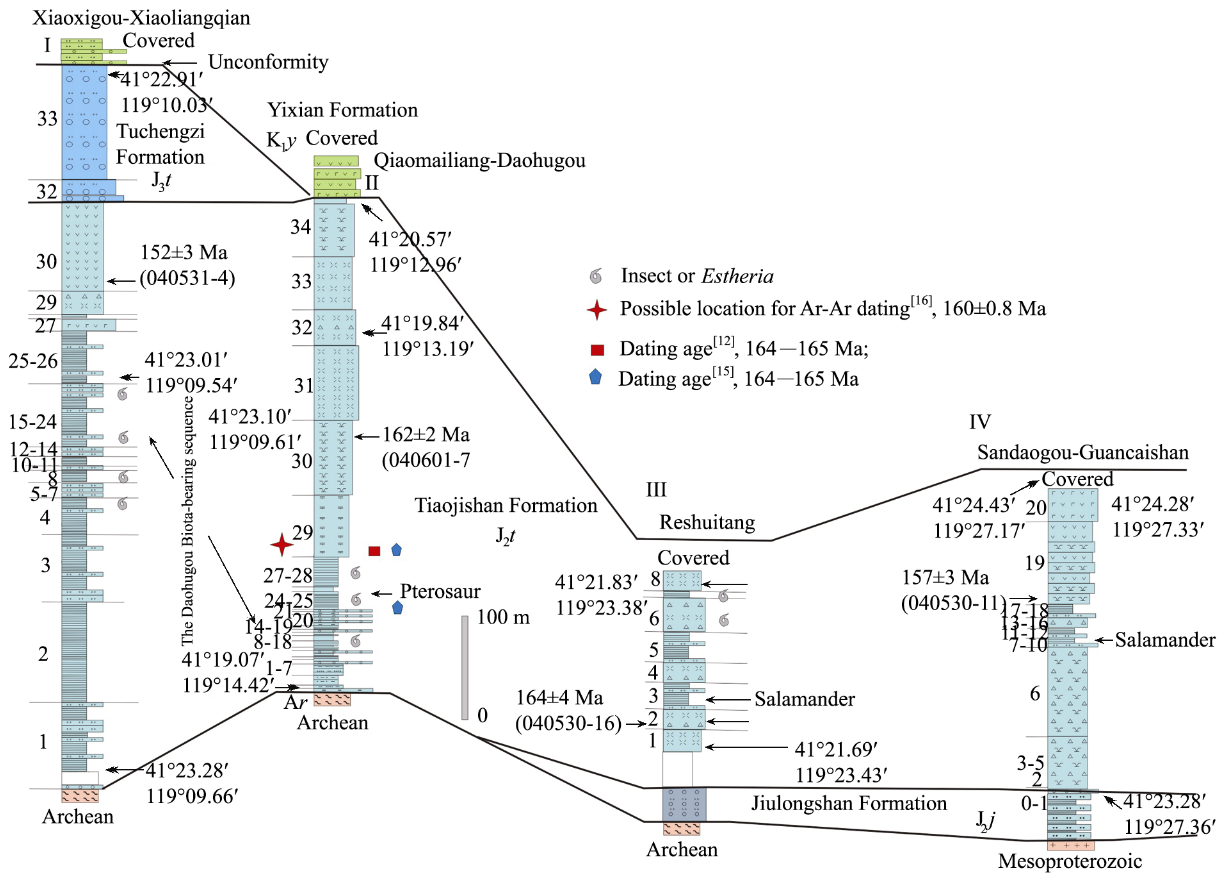

Fig. 2. Correlation and the dating ages of the Daohugou Biota-bearing sequences in the Daohugou area (legends the same as Fig. 1).

Table 1 Lithological characteristics of samples for U-Pb zircon dating by SHRIMP

Samples	Lithology	Rock
040531-4	massive structure, interlocking texture, phenocrystal biotite, matrix plagioclase, K-feldspar and pyroxene	pyroxene trachyandesite
040601-7	massive structure, microcrystalline and felsitic matrix, phenocryst are mainly biotites	quartz trachyandesite
040530-16	ripple bedding, phenocryst and felsitic matrix, phenocryst are mainly euhedral feldspars and biotite	rhyolite
040530-11	massive structure, microcrystalline and felsitic matrix, phenocryst are mainly feldspars and biotite	quartz trachyandesite

is inlaid in the sample target whose surface has been rubbed and polished till the new profile of the zircon shows up. The gilding process is performed after the zircon in the target has been taken picture with “reflected light” and “transmitted light”. Finally, it is put into the SHRIMP mass spectrograph for the preparation of analyzing.

Most of the zircons selected from the samples are shown, under the microscope, to be obviously transparent to translucent, colorless or light yellow and purple with equal axis or column crystals, which are mainly euhedral and crystals. The crystal surfaces of the most zircons are normally kept in good condition with a few being not kept in good condition. The crystal surface of most zircons is level without obvious smelting erosion and rubbing abrasion marks. Moreover, the typical magmatic zonning shown by the cathodoluminescence images suggests that they are magmatic genesis (Fig. 3). In addition, there is a small amount of zircons with rubbing abrasion and smelting erosion, which are inherited ones captured in the process of eruption.

Fig. 3. Cathodoluminescence images of zircons for dating and analyzing spots.

3 Analytical methods

U-Pb zircon dating by SHRIMP is processed on Beijing Center of SHRIMP. A primary ion beam of ca. 4—8 nA with an angle of incidence at 45^{o} bombarding zircons' surface was used. The secondary ions of laser beam are collected by ionic arithmometer after energy focalizing and quality focalizing, and it is modified based on the standard sample SL13 in the reference target.

The analyses on the unknown and standard zircons samples are conducted one after the other to guarantee the accuracy of timely supervision and modified results. Data processing and age calculating are conducted by software Squid 1.0 and Isoplot1.0. In the final results, 1σ is adopted to show data errors of every single survey result. The common lead is deducted by actually surveyed ^{204}Pb. The final adopted age result is the weighted average value of the ratio age of ^{206}Pb/^{238}U. Only one analyzing spot is chosen for every grain of zircons in the dating. For more details of U-Pb zircon dating by SHRIMP, please refer to ref. [19].

4 Results

Results of U-Pb zircon dating by SHRIMP in this research are shown in Table 2 and Fig. 4.

4.1 Xiaoxigou-Xiaoliangqian section

Sample 040531-4 was collected from the Xiaoxigou-Xiaoliangqian section, which is located at the bottom of pyroxene trachyandesite within the top part overlying the Daohugou Biota-bearing volcano-sedimentary rocks (bottom of bed 30 in Xiaoxigou-Xiaoliangqian section: 41°23.06′N, 119°09.84′E). Among the total ^{206}Pb/^{238}U analytic results of 19 spots from 19 zircons, there is one age of 2315 Ma and one age 327 Ma respectively, one spot of 180—190 Ma, two spots of 160—170 Ma, eight spots of 150—160 Ma, six spots 140—150 Ma. Age data are all on the concordant line (Fig. 4(a)) except for one inherited zircon age of 2315 Ma and that of 327 Ma respectively. The weighted average age of ^{206}Pb/^{238}U is 152±2.3 Ma (2σ).

Table 2 Results of U-Pb zircon dating by SHRIMP[a)]

Sample & spot	U (ppm)	Th (ppm)	Th/U	^{206}Pb* (ppm)	^{206}Pb$_{c}$ (%)	^{207}Pb*/^{206}Pb*	±%	^{207}Pb*/^{235}U	±%	^{206}Pb*/^{238}U	±%	^{206}Pb/^{238}U age (Ma)	
040531-4-1.1	170	350	2.12	3.67	3.62	0.0692	13	0.231	14	0.02420	3.3	154.2	± 5.0
040531-4-2.1	519	1117	2.22	10.6	0.29	0.0536	3.9	0.1755	4.7	0.02377	2.5	151.4	± 3.7
040531-4-3.1	420	711	1.75	7.98	1.04	0.0525	7.0	0.158	7.5	0.02188	2.8	139.5	± 3.9
040531-4-4.1	165	252	1.58	3.27	4.56	0.036	33	0.109	33	0.02203	3.2	140.5	± 4.5
040531-4-5.1	118	125	1.10	2.45	1.77	0.0575	13	0.189	14	0.02381	3.1	151.7	± 4.7
040531-4-6.1	175	273	1.61	3.47	3.28	0.042	29	0.129	29	0.02228	3.7	142.1	± 5.2
040531-4-7.1	327	557	1.76	6.69	0.81	0.0510	4.4	0.1662	5.1	0.02364	2.6	150.6	± 3.8
040531-4-8.1	336	595	1.83	6.71	1.03	0.0484	6.0	0.153	6.5	0.02301	2.7	146.7	± 3.9
040531-4-9.1	286	424	1.53	5.93	0.99	0.0496	12	0.163	12	0.02386	2.7	152.0	± 4.1
040531-4-10.1	407	739	1.88	8.27	0.71	0.0504	4.6	0.1632	5.2	0.02347	2.5	149.5	± 3.7
040531-4-12.1	401	146	0.38	18.0	0.19	0.0542	2.7	0.389	3.8	0.0520	2.8	327.1	± 8.8
040531-4-13.1	171	222	1.34	3.73	2.79	0.0419	17	0.143	17	0.02475	2.9	157.6	± 4.5
040531-4-14.1	161	217	1.39	3.36	1.47	0.0593	7.2	0.196	7.8	0.02392	3.0	152.4	± 4.4
040531-4-15.1	194	542	2.89	4.26	1.26	0.0552	6.9	0.192	7.5	0.02527	2.8	160.9	± 4.4
040531-4-16.1	83	87	1.08	1.82	0.00	0.0890	5.6	0.313	6.5	0.02550	3.2	162.3	± 5.2
040531-4-17.1	210	419	2.06	4.61	2.65	0.0472	16	0.162	16	0.02490	3.0	158.5	± 4.7
040531-4-18.1	87	112	1.33	32.5	0.21	0.1640	1.1	9.77	2.9	0.432	2.7	2，315	±52
040531-4-19.1	261	389	1.54	5.11	1.82	0.0529	13	0.163	14	0.02234	2.8	142.4	± 3.9
040531-4-20.1	13	16	1.25	0.336	0.00	0.278	9.1	1.12	11	0.0292	6.4	186.0	±12
040601-7-2.1	245	219	0.92	5.46	1.34	0.0457	14	0.161	14	0.02557	2.7	162.8	±4.4
040601-7-4.1	315	285	0.93	7.09	3.51	0.0282	27	0.098	27	0.02525	3.0	160.8	±4.8
040601-7-5.1	392	443	1.17	8.73	1.70	0.0425	15	0.149	15	0.02549	2.7	162.3	±4.3
040601-7-6.1	361	265	0.76	8.50	0.00	0.0602	3.5	0.2276	4.4	0.02742	2.6	174.4	±4.4
040601-7-7.1	226	176	0.81	5.07	1.63	0.0468	6.3	0.166	6.8	0.02567	2.7	163.4	±4.3
040601-7-8.1	623	773	1.28	13.1	0.63	0.0493	3.5	0.1653	4.3	0.02431	2.5	154.8	±3.8
040601-7-10.1	680	1099	1.67	15.5	1.00	0.0464	6.0	0.168	6.5	0.02618	2.5	166.6	±4.0
040601-7-11.1	185	207	1.16	4.18	2.02	0.0463	12	0.165	12	0.02583	2.8	164.4	±4.6
040601-7-12.1	469	573	1.26	10.4	1.75	0.0377	14	0.132	14	0.02541	2.5	161.8	±4.1
040601-7-13.1	517	850	1.70	11.4	0.48	0.0495	3.8	0.1741	4.5	0.02550	2.5	162.3	±3.9
040601-7-14.1	331	312	0.97	7.01	1.01	0.0489	5.4	0.165	6.1	0.02443	3.0	155.6	±4.5
040601-7-15.1	486	418	0.89	10.1	0.46	0.0497	3.6	0.1660	4.4	0.02421	2.5	154.2	±3.8
040601-7-16.1	526	364	0.71	12.7	2.06	0.0367	16	0.139	16	0.02756	2.7	175.3	±4.7
040601-7-17.1	463	483	1.08	10.1	0.33	0.0454	6.2	0.159	7.0	0.02531	3.2	161.1	±5.1
040601-7-18.1	372	236	0.65	8.54	0.98	0.0515	4.0	0.1880	4.7	0.02646	2.5	168.3	±4.2

(*To be continued on the next page*)

(*Continued*)

Sample & spot	U (ppm)	Th (ppm)	Th/U	$^{206}Pb^*$ (ppm)	$^{206}Pb_c$ (%)	$^{207}Pb^*/^{206}Pb^*$	±%	$^{207}Pb^*/^{235}U$	±%	$^{206}Pb^*/^{238}U$	±%	$^{206}Pb/^{238}U$ age (Ma)	
040601-7-19.1	342	262	0.79	7.83	1.10	0.0460	7.9	0.167	8.4	0.02634	2.6	167.6	±4.3
040530-16-1.1	84	84	1.03	2.06	0.00	0.0763	5.8	0.298	7.5	0.0284	4.8	180.4	± 8.5
040530-16-2.1	264	434	1.70	6.07	1.86	0.0416	11	0.151	11	0.0263	4.0	167.4	± 6.6
040530-16-3.1	120	208	1.80	2.97	2.14	0.088	13	0.346	14	0.0283	4.0	180.2	± 7.0
040530-16-4.1	88	105	1.24	2.15	3.11	0.085	21	0.323	21	0.0276	3.9	175.5	± 6.8
040530-16-5.1	97	157	1.67	2.30	6.56	0.060	34	0.214	34	0.0257	4.0	163.6	± 6.5
040530-16-7.1	148	128	0.89	3.58	5.38	0.041	58	0.149	58	0.0267	4.0	169.6	± 6.8
040530-16-8.1	82	112	1.41	1.90	2.70	0.065	18	0.233	19	0.0261	3.8	165.8	± 6.3
040530-16-9.1	57	62	1.13	1.54	0.00	0.1419	5.9	0.616	7.1	0.0315	4.0	199.8	± 7.8
040530-16-10.1	556	469	0.87	12.0	0.34	0.0505	5.8	0.174	6.4	0.02496	2.6	158.9	± 4.1
040530-16-12.1	97	138	1.47	2.33	5.88	0.052	38	0.186	39	0.0262	4.0	167.0	± 6.6
040530-16-13.1	70	67	0.99	1.70	3.63	0.109	23	0.413	24	0.0274	4.9	174.3	± 8.5
040530-16-14.1	107	158	1.53	2.49	4.89	0.053	32	0.188	32	0.02582	3.7	164.3	± 6.0
040530-16-15.1	39	31	0.84	0.955	12.99					0.0251	7.6	160	±12
040530-16-16.1	57	60	1.08	1.29	10.67	0.038	82	0.12	82	0.0236	6.6	150.1	± 9.9
040530-16-17.1	120	133	1.14	2.85	5.02	0.049	35	0.178	35	0.02615	3.7	166.4	± 6.2
040530-11-1.1	274	299	1.13	5.71	1.13	0.0403	7.3	0.133	7.9	0.02398	2.9	152.8	± 4.4
040530-11-3.1	108	179	1.72	2.49	3.94	0.037	40	0.130	40	0.02588	3.6	164.7	± 5.9
040530-11-4.1	116	100	0.89	2.72	3.95	0.043	25	0.157	25	0.0263	5.8	167.2	± 9.6
040530-11-5.1	151	222	1.52	3.38	1.24	0.0460	17	0.162	18	0.02563	3.2	163.1	± 5.1
040530-11-6.1	214	219	1.06	4.58	2.32	0.0488	15	0.164	15	0.02436	2.8	155.2	± 4.3
040530-11-8.1	63	57	0.94	1.37	6.79	0.037	53	0.122	53	0.0237	4.5	150.7	± 6.7
040530-11-9.1	64	62	1.01	1.36	5.92	0.024	62	0.079	62	0.02336	3.9	148.8	± 5.7
040530-11-10.1	249	257	1.07	5.68	2.92	0.042	30	0.150	30	0.02584	3.3	164.5	± 5.4
040530-11-11.1	81	64	0.82	1.76	3.78	0.055	20	0.185	20	0.02441	3.7	155.4	± 5.7
040530-11-12.1	52	38	0.75	1.06	20.02	-0.101	35	-0.267	36	0.0193	5.2	123.3	± 6.4
040530-11-13.1	109	40	0.38	28.3	0.35	0.1044	1.7	4.35	3.2	0.3021	2.6	1，702	±39.0
040530-11-14.1	270	315	1.21	5.60	0.73	0.0524	4.7	0.173	6.1	0.02395	3.9	152.6	± 5.8
040530-11-15.1	135	170	1.30	3.05	3.38	0.0405	20	0.142	20	0.02542	3.1	161.8	± 5.0
040530-11-16.1	125	157	1.30	3.00	4.64	0.097	21	0.356	22	0.0266	4.3	169.2	± 7.2

a) The isotope ratios are 1σ relative errors, and the $^{206}Pb/^{238}U$ age 1σ absolute errors. $^{206}Pb_c$ is the percentage of common ^{206}Pb in total ^{206}Pb. $^{206}Pb^*$ is radiogenic ^{206}Pb.

4.2 Qiaomailiang-Daohugou section

Sample 040601-7 (Fig. 1. (a) and Fig. 2; 41°23.10′N, 119°09.61′E) was collected from quartz trachyandesite overlying the succession bearing the Daohugou Biota in the of Qiaomailiang-Daohugou section. The $^{206}Pb/^{238}U$ ages of 16 spots of zircons are all in the scope of 175－154 Ma (Table 2) with the data spots located near to the concordant line and the weighted average age of $^{206}Pb/^{238}U$ is 162±2 Ma (2σ) (Fig. 4 (b)). Chen *et al*.[12] published two SHRIMP $^{206}Pb/^{238}U$ ages of 166±1.1 Ma and 165±2.4 Ma, and ^{40}Ar-^{39}Ar age of sanidine 164±2.5 Ma (Fig. 2) in the location corresponding to the trachyandesite or rhyolite about 100 m below the sample 040601-7 in Daohugou. Yang *et al*.[15] also respectively obtained SHRIMP $^{206}Pb/^{238}U$ ages of 164±1.2 Ma and 165±1.2 Ma in the same horizontal lava and tuffs (Fig. 2). He *et al*.[16] reported another feldspar ^{40}Ar-^{39}Ar age of 159.8±0.8 Ma in ignimbrite directly overlying the fossil-bearing layers (Fig. 2). Obviously, these age results keep highly consistency with the results of this paper.

4.3 Reshuitang section

Sample 040530-16 was collected from the lower part of the rhyolitic breccia lavas underlain by the salamanders-bearing rocks (Fig. 2; 41°21.922′N, 119°.55′E). $^{206}Pb/^{238}U$ age of 040530-16 is mainly formed by two cluster forms. Except for three zircons with 180－200 Ma, all the other 13 zircons are between 150 Ma and 175 Ma. The weighted average age is 164±4 Ma (2σ) (Fig. 4(c)). Because of those unconcordant ages,

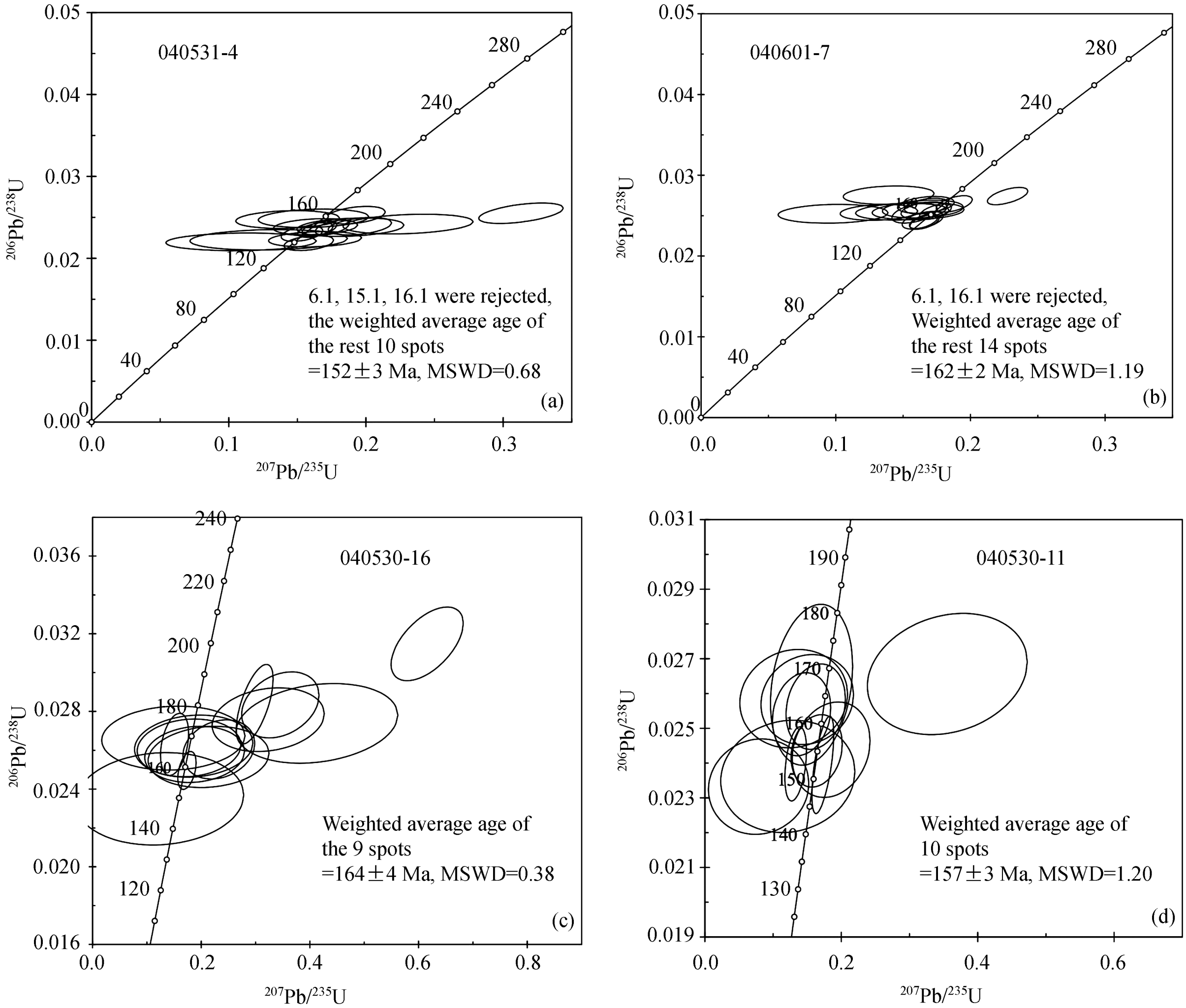

Fig. 4. Concordant diagrams of U-Pb zircon dating by SHRIMP.

meanwhile, a low cross age of 163±5 Ma from this sample was conducted. These samples were collected either from the lavas below the salamander-bearing rocks in Reshuitang or lavas above the Middle Jurassic Jiulongshan Formation, therefore, 164±4 Ma is the oldest geochronological constraint on fossils such as salamander and related rocks.

4.4 Sandaogou-Guancaishan section

Sample 040530-11 was collected from the quartz trachyandesite within the top part of Sandaogou-Guancaishan section (bed 9, 41°24.41′N, 119°27.17′E) (Fig. 2), and in lower part of this section (bed 10) salamanders and *Euestheria* were found. Among analytic results of 15 zircons, there is one age of 1702 Ma and one age of 123 Ma respectively, the other 13 zircons are in the range of 146—169 Ma (Table 2), and age data are all on the concordant line. The weighted average age of $^{206}Pb/^{238}U$ is 157±3 Ma (2σ) except for some unrelated age data (Fig. 4(d)).

5 Analysis and discussion

5.1 Geochronological constraint of the Daohugou Biota

Since samples of 040531-4, 040601-7 and 040530-11 were either collected from the lavas above the Daohugou Biota or within the deposits containing salamanders, an age interval of 162—152 Ma conducted from these samples is the youngest geochronological constraint of the Daohugou Biota. Because 164 Ma was dated from the sample of 040530-16 located in lava under deposits bearing salamanders, it is the oldest geochronological constraint of salamanders, i.e., the

Daohugou biota was mainly developed in a geological period of 164－152 Ma.

5.2 Geochronology and regional correlation of stratigraphy

The International Stratigraphic Chart[20] shows that the chronological boundary of Early and Middle Jurassic lies at 175±2.0 Ma and that of Middle and Late Jurassic is at 161.2±4.0 Ma. Therefore, the Daohugou Biota-bearing stratum with an age of 164－152 Ma was formed between late Middle Jurassic and early Late Jurassic, i.e. Oxfordian-Kimmeridgian to Bathonian-Callovian stages.

In ascending order, the regional stratigraphic successions of Middle to Late Jurassic in North Hebei and West Liaoning are the Jiulongshan Formation/Haifanggou Formation of early Middle Jurassic, and the Tiaojishan Formation/Lanqi Formation of late Middle Jurassic and Tuchengzi Formation of Late Jurassic. Based upon the dating results of the Daohugou Biota and the related rocks in study areas, because of the Daohugou Biota-bearing volcanic-sedimentary rocks either overlying the Jiulongshan Formation in a disconformity or in turn underlain by the Late Jurassic Tuchengzi Formation and the Early Cretaceous Yixian Formation in an unconformity (Fig. 2), this paper concludes that the volcanic-depositional successions bearing the Daohugou Biota are correlated with Tiaojishan Formation/Lanqi Formation.

A number of previous dating results for the Tiaojishan Formation and Tuchengzi Formation were documented. Swisher *et al*.[21] published a ^{40}Ar-^{39}Ar age of 139 Ma from the tuff in the top part of the Tuchengzi Formation at Beipiao of West Liaoning; Zhao *et al*.[22] obtained zircon U-Pb ages of 157 and 158 Ma respectively from andesite at the bottom of the Tiaojishan Formation in West Beijing and brecciaed andesite at the bottom of the Lanqi Formation at Xingzhangzi in Lingyuan, West Liaoning[22]; Davis *et al*[23]. acquired mica ^{40}Ar-^{39}Ar ages of 161,180 Ma and 161－156 Ma respectively from the andesites of Tiaojishan Formation in Chengde and Luanping of North Hebei. A series of zircon U-Pb dating results by LA-ICPMAS from the lavas of the Tiaojishan Formation in North Hebei and West Liaoning were recently published by Zhang *et al*.[24], i.e., 157－154 Ma is the age interval for the top lavas of this formation in Chengde, Lingyuan and Beipiao, and the lavas in the same horizon yielded ages of 163－154 Ma. An age of 164 Ma was acquired from the bottom lavas of the formation in Luanping. Obviously, these previous dating results of the Tiaojishan Formation keep highly consistency with the results of this paper.

6 Comments on related issues

Based upon the survey of a few sections, Wang *et al*.[2] concluded that the direction contact between the sequences bearing the Daohugou Biota and the overlying strata was not outcropped although the bottom boundary and lower part of the sequences containing the Daohugou Biota were well observed in the field. Obviously, it is the key point to use the contact between sequences bearing the Daohugou Biota and the overlying and underlying strata to define the geochronology of the Biota and the related rocks. Actually, a number of complete and successive sections containing the Daohugou Biota were measured and studied by Liu *et al*. in 2004, and at the meantime, the Daohugou Biota-bearing sequence and its contact with overlying strata and a regional stratigraphic correlation were well worked out[13,14]. He *et al*.[17] wondered why no field evidence is observed to support the direct contact relationship. In fact, in ascending order, a number of successive stratigraphic sequences consisting of the Middle Jurassic Jiulongshan and Tiaojishan Formations, the Late Jurassic Tuchengzi Formation are well exposed either in the Xiaoliangqian-Xiaoxigou of Ningcheng or in the Reshuitang and Sanshijiazi of Lingyuan[13,14].

Wang *et al*.[2] thought that the lavas overlying or inter-bedding with the Daohugou Biota-bearing rocks were all underlain by the Daohugou fossil-bearing rock conflict with our field observations. Detailed field survey indicates that medium and acid lavas with a massive thickness resting on the Daohugou fossil-bearing rocks are a common occurrence. The Daohugou Biota and the fauna of salamander in Reshuitang belong to the Middle Jurrasic intermontaneous biota and the sediments bearing-salamander and insects in Reshuitang are interbedded with the lavas, therefore, those lavas with dating ages of 164－152 Ma are either underlain by or interbedded with the Daohugou fossil-bearing rocks other than underlying occurrence as Wang *et al*. insisted[2].

Geological survey made by us and Zhang *et al*.[25] revealed that the Middle Jurassic Jiulongshan Formation exists under the Daohugou Biota-bearing sequences, and a complete and normal stratigraphic sequence of the Middle-Late Jurassic in study areas in ascending order includes the Jiulongshan Formation, Tiaojishan Formation and Tuchengzi Formation. “Underlying strata” or “Reversed sequence” claimed by Wang *et al*.[2] and He *et al*.[16,17] need to be seriously scrutinized. If the Tiaojishan Formation is truly underlain by the Daohugou Biota-bearing sequence or even reversed, the present outcropped sequence containing the the Daohugou Biota should be composed of down to up the Tiaojishan Formation and Jiulongshan Formation, unfortunately, no such evidence was observed in the field.

According to Wang *et al*.[2] and He *et al*.[16,17], some stratigraphic reversions and reversed folds were formed within the Daohugou Biota-bearing sequences because of lately intense tectonic reformation. Various small scale folds and even locally reversed stratigraphy are actually observed in the field, these folds, especially the local reversion of stratigraphy, however, are in small scale and normal occurrence caused from reformation of elastic strata by local faults and all bounded within the strata. These reforms are easily presented with locally reversed occurrences because of the sharp angle of strata of 60°—70°. For example, a multiple syncline extending in a large scale with locally reversed stratigraphic occurrence outcropped in the Daohugou and Datongjianggou areas of Ningcheng. This syncline is constructed by the Tiaojishan Formation and can be traced by the indicator of the Daohugou Biota-bearing sequence. The northwestern part of it dips southeast at an angle greater than 60° locally and toward south the dip angle becomes lowly or nearly 0° while the southeastern part of it dips northwest at an angle of 30°—50°. Pressure faults with locally reversed occurrences were all located at the axis of the syncline, and some subanticline and subsyncline were stacked in the southeastern part of the fault where the stratigraphic reversion or reversed folds exist[2,16,17].

Based upon the stratigraphic sequence, chronology and vertebrate association, Wang *et al*.[2] worked out a series of conclusions that the Daohugou Biota-bearing sequences and Yixian Formation were formed in the same volcano-sedimentary evolutionary interval, the chronological age of the Daohugou Biota occurred between Late Jurassic and Early Cretaceous other than Middle Jurassic, and both the Daohugou Biota and the Rehol Biota share the earliest vertebrate assemblage of the Cretaceous.

As proposed by Shen *et al*.[5] and Ren *et al*.[6], both insects and Estheria fossil associations display a sharp feature of Middle Jurassic. Furthermore, what can the vertebrate associations of the Daohugou Biota be referred to? Three categories and species of *Chunerpeton*[11], *Jeholotriton*[3] and *Liaoxitriton*[4], two categories and species of *Pterorhynchus*[26] and *Jeholopterus*[27], and two categories and species of *Epidendrosaurus*[28] and *Pedopenna*[29] are distinguished from the Daohugou Biota so far. Salamanders are of regional elements, which are dispensable for the chronology of the Daohugou Biota.

Assemblages of pterosaurs within the Daohugou Biota are of clear implications for the chronology of the biota. *Jeholopterus* is an element of Anurognathidae, which was only found in the Oxfordian-Kimmeridgian strata in Kazakhstan or late Tithonian in Germany[30,31]. Additionally, *Dendrorhynchoides* belonging to the same Anurognathidae were also found in the Jianshangou depositional layer at Sihetun, in Beipiao, West Liaoning[32,33]. Based on the individual fact that *Jeholopterus* and *Dendrorhynchoides* belong to the same family, Wang *et al*.[2] insisted that the pterosaur from Daohugou should belong to the Jehol Biota, which ignores obviously that Anurognathidae may occur in Late Jurassic.

Since *Dendrorhynchoides* may live from Late Jurassic to Early Cretaceous, why could not *Jeholopterus* occur in early Middle Jurassic? Wang *et al*.[2] did not make anymore discussion about the comparisons of *Pterorhynchus.* As we known, *Pterorhynchus* is one element of Rhamphorhynchidae[34,35] which is well-known fossil reported from Early Jurassic to Late Jurassic. No rhamphorhynchid pterosaur has been found from the Cretaceous strata so far.

The elements of both Anurognathidae and Rhamphorhynchidae have been found in the associations of the Late Jurassic pterosaurs in Europe and Kazakhstan, which is very similar to those of the Daohugou Biota. The association of *Pterorhynchus* and *Jeholopterus* of the Daohugou Biota suggests that their living age be not later than the Late Jurassic. Even though Wang *et al*.[2] raised some more advanced elements such as *Haopterus*[35] and *Eosipterus*[31,32,36] found in the Jianshangou depositional layer of the lower Yixian Formation, however, these elements have not been found in the Daohugou Biota so far, which further make it clear that the Daohugou Biota is older than the Jehol biota.

Although the other two categories of maniraptorids were found in the Daohugou Biota, in the opinion of Wang *et al*.[2], on the basis of the more occurrences of theropods found in the Yixian Formation, the maniraptorids of the Daohugou Biota resemble theropods of the Jehol Biota are seriously scrutinized.

Epidendrosaurus is much smaller than the maniraptorids of the Jehol Biota, and its third finger of the front limb is much longer than the rest fingers, which is different from the maniraptorids of the Jehol Biota and unknown categories. Further, we do not have much more knowledge now about *Pedopenna* because only its front limb was found and its systematic position is unknown. Therefore, both *Epidendrosaurus* and *Pedopenna* are not unique ground for the geochronology of the Daohugou Biota, and more studies need to be made on the maniraptorids in the future.

At the meantime, Wang *et al*.[2] confirmed that none of fish fossils of the Jehol Biota is discovered in the Daohugou Biota. In fact, fish fossils of the Jehol Biota have never been discovered in the Daohugou Biota because of its lower stratigraphic horrizon than the Jehol Biota, therefore, it is exactly true that those fossils of fish and Estheria,etc. have never be found in the Daohugou Biota.

We never suspected the accuracy of the dating results made by He *et al*.[16,17] and Wang *et al*.[2], whereas, we raised a query about their interpretations. Referring to a misidentification of stratigraphic sequence of the Daohugou Biota (a reversed sequence), a geochronology of the Biota for Late Jurassic/Cretaceous other than Middle Jurassic was logically adopted by He *et al*.[16,17] and Wang *et al*.[2]. Though some researchers never give up the opinion that the Daohugou Biota was formed in the Cretaceous[3,4], more field evidence and dating results suggest that the Daohugou Biota and the related rocks are below the Tuchengzi Formation, and occur in Middle Jurassic and correspond to the Tiaojishan Formation.

We also call Wang *et al*.'s[2] conclusion in question that stratigraphic sequence containing the Daohugou Biota and Yixian Formation shared one volcanic-sedimentary tectonic evolutionary history. On the basis of regional tectonic, magmatic activities and basin evolution, the Daohugou Biota-bearing Tiaojishan Formation are greatly different from the Yixian Formation yielding the Jehol Biota and more achievements supporting this from various branches of geosciences have been documented .

A great change in the tectonic direction from E-W to NE in West Liaoning, North Hebei and Ningcheng of Inner Mongolia happened at 135—136 Ma[37], which made a significant impact on the living environments or promoted extinct evolution for living things. A series of geological events such as molas deposits of the Tuchengzi Formation caused by the mountain building of intraplate after the formation of the Tiaojishan Formation and those large-scale volcanic activities in the Zhangjiakou period within a stretch stress background before formation of the Yixian Formation occurred, which suggest that both biotas are respectively presented in individual geochronological episode. Furthermore, it is these significant geological events that lead to the extinction of the Daohugou Biota in the Late Jurassic and the appearance of the Jehol Biota in Early Cretaceous, and the Daohugou Biota is not considered as the earliest elements of the Jehol Biota.

7 Conclusions

A Middle Jurassic Daohugou Biota-bearing volcano-sedimentary succession in a normal sequence other than an inversed one was well exposed in the research region. The stratigraphic successions containing the Daohugou Biota rest on the Jiulongshan Formation (Haifanggou Formation) , mainly consisting of coarse clastic rocks interbedded with thin-bedded coal layers, with a disconformity covered by the Late Jurassic Tuchengzi Formation or the Early Cretaceous Yixian Formation in an unconformity. A series of results of U-Pb zircon dating by SHRIMP from these lavas above, below or within the rocks containing the Daohugou Biota, suggest that the Daohugou Biota at Xiaoxigou and Daohugou areas together with fossils bearing salamanders in Reshuitang occur in an equal geochronological interval and both share one biota. The Daohugou Biota was thriving in the geochronological period of 168—152 Ma, i.e. from Middle Jurassic to early Late Jurassic. This study indicates that the Daohugou Biota and related rocks may be correlated with the Tiaojishan Formation (Lanqi Formation in West Liaoning) or synchronous rock association. Comparison of vertebrate assemblages between the Daohugou Biota and the Jehol Biota shows that the former does not resemble the latter, and the Daohugou Biota is not the earliest elements of the Jehol Biota. The conclusion of the Late Jurassic to Early Cretaceous age for the Daohugou Biota made by Wang *et al*. is wrong. A lot of evidence indicates that the Daohugou Biota and their host rocks and the Yixian Formation containing the Jehol Biota respectively occur in individual geochronological episodes or at different volcano-sedimentary stages.

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