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New material of microfossils from the Ediacaran Doushantuo Formation in the Zhangcunping area, Yichang, Hubei Province and its zircon SHRIMP U-Pb age

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The Zhangcunping area is located at the north limb of the Huangling anticline in Yichang, Hubei Province. Here, the sedimentary succession of the Ediacaran Doushantuo Formation is similar with that in the Weng'an area, Guizhou Province. A large number of new microfossils (mainly acanthoacritarchs) from the Doushantuo Formation in this area are reported in this paper. The fossil assemblage shows similarity as the phosphatized biota of the Doushantuo Formation at Weng'an, Guizhou Province and the silicified biota of the Doushantuo Formation at the Yangtze Gorges, which suggests that the Zhangcunping area is a key for correlation of the Doushantuo Formation between the Weng'an area, Guizhou Province and the Yangtze Gorges. Besides, a new zircon SHRIMP U-Pb age (614.0±7.6 Ma) is first obtained from a horizon underneath the exposed surface in the middle of the Doushantuo Formation in the Zhangcunping area. This age not only provides a new datum for subdivision of the Ediacaran Doushantuo Formation, but also indicates that the age of the exposed surface in the middle of the Doushantuo Formation in the Yangtze Platform should be posterior to 614.0±7.6 Ma. Due to the horizon of the Weng'an biota situated above the exposed surface, the age of the Weng'an biota should be posterior to 614.0±7.6 Ma as well.

Yangtze Gorges, Ediacaran, Doushantuo Formation, microfossils, zircon SHRIMP U-Pb age

The holotype section of the Ediacaran (Sinian) in the Yangtze Gorges, which contains abundant fossils with a long research history, is one of the most important Ediacaran sections in the world. Generally, the Ediacaran (Sinian) Doushantuo Formation in the Yangtze Gorges consists of four members. These members are, in ascending stratigraphic order, (1) cap dolostone overlying glacial diamictite of the Cryogenian (Nanhuan) Nantuo Formation; (2) black shale intercalated with medium-bedded muddy dolostone, with abundant chert nodules; (3) medium-bedded dolostone with chert nodules or lenticles and banded limestone; and (4) black shale with large dolostone concretions. Abundant silicified microfossils (micrometers to millimeters) had been reported from chert nodules or lenticles in both Members II and III[1−6]. In addition, *Chuaria*-like carbonaceous compressions and a dichotomously branching algal thallus were found in black shale of Member II at Jiulongwan[7] (Figure 1) and the black shale in the Member IV at Miaohe (Figure 1) contains abundant algal and possible metazoan macroscopic carbonaceous compressions[8−10]. Besides, the age of the Doushantuo Formation has been constrained between 635.2±0.6 Ma and 551.1±0.7 Ma on the zircon U-Pb ages obtained

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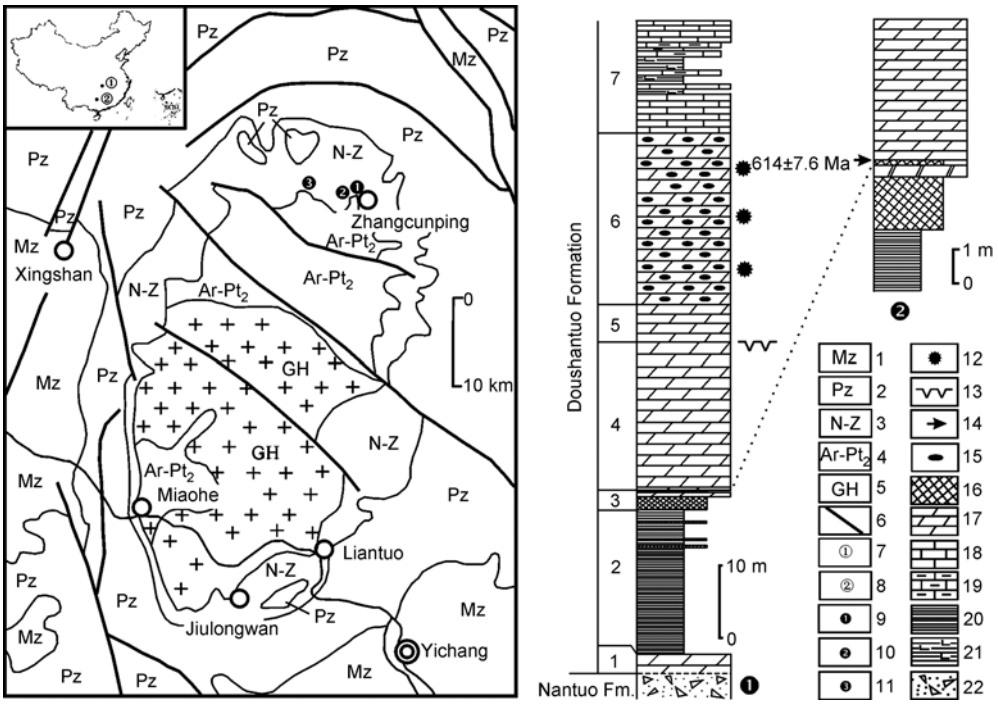

Figure 1 Geological map in the Yangtze Gorges and stratigraphic column of the Doushantuo Formation from the Zhangcunping area. 1, Mesozoic; 2, Paleozoic; 3, Nanhuan (Cryogenian)+Sinian (Ediacaran); 4, Archean to Mesoproterozoic; 5, Huangling granite; 6, fault; 7, Yangtze Gorges; 8, Weng'an area; 9, Wanjiagou section; 10, Wangjiagou section; 11, Yinjiaping section; 12, horizon of microfossils; 13, erosional unconformity; 14, sample for the zircon dating; 15, cherty-phosphatic nodules; 16, phosphorite; 17, dolostone; 18, limestone; 19, muddy limestone; 20, black shale; 21, calcic shale; 22, glacial diamictite.

from the interbedded ash beds[11−14].

The Zhangcunping area is located at the north limb of the Huangling anticline in the Yangtze Gorges. The Doushantuo succession is well developed here and is similar with that in the Weng'an, Guizhou Province[15] (Figure 1). However, only three papers deal with Doushantuo Formation from the Zhangcunping area before this report[15−17]. 2 genus and 2 species of filamentous cyanobacteria (*Siphonophycus sinensis* and *Salome hubeiensis*) were first reported in 1986[16] and more microfossils were found late in 2005[15], including filamentous cyanobacteria *Siphonophycus* sp., *Polytrichoides* sp., *Oscillatoriopsis* sp., *Salome hubeiensis* and multicellular algae *Wengania minuta*, *W. globosa*, *Sarcinophycus* sp., *Paratetraphycus giganteteus* (Zhou *et al*. considered that the genus *Paratetraphycus* is the invalid taxon and as synonymous with coccoidal fossils *Archaeophycus*[17]). In addition, carbon and oxygen isotopic stratigraphy was also studied from the Doushantuo Formation in the Zhangcunping area and was correlated with other sections in the Yangtze Platform[18].

Recently, the authors fortuitously found a large number of microfossils (mainly new types) from thin sections of cherty-phosphatic nodules of the Doushantuo Formation in the Zhangcunping area. Those new microfossils not only enrich the fossils assemblage of the Doushantuo Formation there, but also provide an important new data for stratigraphic correlation with other sections in the Yangtze Platform. Besides, one volcanic bed was first discovered from the lower part of the Doushantuo Formation in the Wangjiagou section (Figures 1 and 3), which gives a zircon U-Pb age of 614.0± 7.6 Ma by SHRIMP II dating. The new microfossils and the zircon U-Pb age (614.0±7.6 Ma) are reported and discussed carefully together in this paper.

1 Stratrigraphic setting

The typical section of the Doushantuo Formation in the Zhangcunping area is located at Wanjiagou phosphorite mine (Figure 1). Here, the Doushantuo Formation overlies on the Cryogenian (Nanhuan) Nantuo glacial diamictite and consists of 7 beds (Figure 1). These beds are, in ascending stratigraphic order, (1) grey cap dolostone in 2.65 m; (2) black shale in 23.1 m, with thin phosphatic interbeds at the upper part; (3) black phos-

phorite in 2.5 m; (4) grey thick-bedded dolostone in 20.0 m, with an erosional unconformity on the top; (5) grey thin- to medium-bedded dolostone in 5.2 m; (6) dark grey thick-bedded dolostone in 24.6 m, with abundant cherty-phosphatic nodules; and (7) grey limestone is >11.7 m in thickness, with calcic shale interbeds. The microfossils, reported in this paper, were collected from both Wanjiagou and Yinjiaping sections (Figure 1) and the sample of zircon U-Pb age was collected from the Wangjiagou section (Figures 1 and 3).

2 New material of microfossils

The most new microfossils were discovered from cherty-phosphatic nodules of the bed 6 of the Doushantuo Formation at the Wanjiagou section, few of them were discovered at the Yinjiaping section (Figure 1). The new microfossils consist of acritarchs (including 6 genera and 7 species, they are *Asterocapsoides sinensis*, *Echinosphaeridium maximum*, *Ericiasphaera speldeaesii*, *Leiosphaeridia tenuissima*, *Meghystrichosphaeridium perfectum*, *Tianzhushania spinosa*, and *T. ornata*), multi-cellular algae (*Sarcinophycus papilloformis*) and filamentous cyanobacteria (*Oscillatoriopsis obtusa*) (Figure 2). All of these new microfossils generally occur in silicified biota from both members II and III of the Doushantuo Formation in the Yangtze Gorges[2,4−6,19−22]. Apart from acritarchs *Ericiasphaera speldeaesii* and multi-cellular algae *Sarcinophycus papilloformis*, others generally occur in the phosphatized biota from the upper part of the Doushantuo Formation at Weng'an, Guizhou Province[23−26]. Besides, the multi-cellular algae *Paratetraphycus giganteus* and *Wengania globosa*, which reported from the Doushantuo Formation in Zhangcunping before[15], also occur from the upper part of the Doushantuo Formation at Weng'an[6]. Thus, the microfossil assemblage of the Doushantuo Formation in the Zhangcunping area shows similarity with both the phosphatized biota at Weng'an and the typical silicified biota in the Yangtze Gorges.

3 The new zircon SHRIMP Ⅱ U-Pb age

The analyzed sample (sample No. 7527) was collected from the Wangjiagou section in the Zhangcunping area, Yichang, Hubei Province (Figures 1 and 3). The horizon of sample is in between bed 3 and bed 4 (Figures 1 and 3). The volcanic bed is 3−5 cm in thickness and extends spasmodically to 50 m in outcrop. The volcanic bed has been weathered as incompact yellow sand-like and consists of transparent minerals. The primal rock may be medium to basic volcanic rock.

Zircons, picked out from sample, are colorless, transparent, euhedral, equant or prismatic in shape, and commonly have well-preserved crystal surfaces without any pronounced corrosion phenomenon. Cathodoluminescence images of zircons usually show distinct uniform zoned structures and most of them range up to about 100 μm in length (Figure 4).

A total of 19 spots of zircons were analyzed (Figure 5 and Table 1). Apart from spot 16.1, all of them fall on the concordia and formed one cluster (Figure 5). The ages of this cluster are between 592 Ma and 639 Ma (Table 1), and it gives a weighted mean $^{206}Pb/^{238}U$ age of 614.0±7.6 Ma (MSWD=2.3). It represents the age of the volcanic rock.

4 Discussion and conclusion

4.1 The signification of new microfossils

The Ediacaran Doushantuo Formation in South China contains two important microfossils biota—phosphatized biota (the typical biota is called the Weng'an biota, which preserved in phosphorites of Upper Doushantuo Formation at Weng'an, Guizhou Province) and silicified biota (it is preserved in cherts of the Doushantuo Formation in the Yangtze Gorges). A closer examination of the silicified and phosphatized biota from the Doushantuo Formation shows that the two taphonomic windows have increasing biodiversity similarity[2]. However, base on the difference of sedimentary facies, the accurately stratigraphic correlation of the Doushantuo Formation between the Weng'an area and the Yangtze Gorges should be difficulty there. Although the Zhangcunping area locates on the north limb of the Huangling anticline in the Yangtze Gorges (Figure 1), the sedimentary succession of the Doushantuo Formation is similar with that in the Weng'an area, and its microfossils assemblage is similar with both the typical Weng'an biota at Weng'an, Guizhou Province and the silicified biota in the Yangtze Gorges. Thus, the new microfossils, which are similar with the Weng'an biota, provided important data for stratigraphic correlation of the Doushantuo Formation between the Weng'an area and typical sections in the Yangtze Gorges. The new material seems to support the view that the horizon of the Weng'an biota in Guizhou

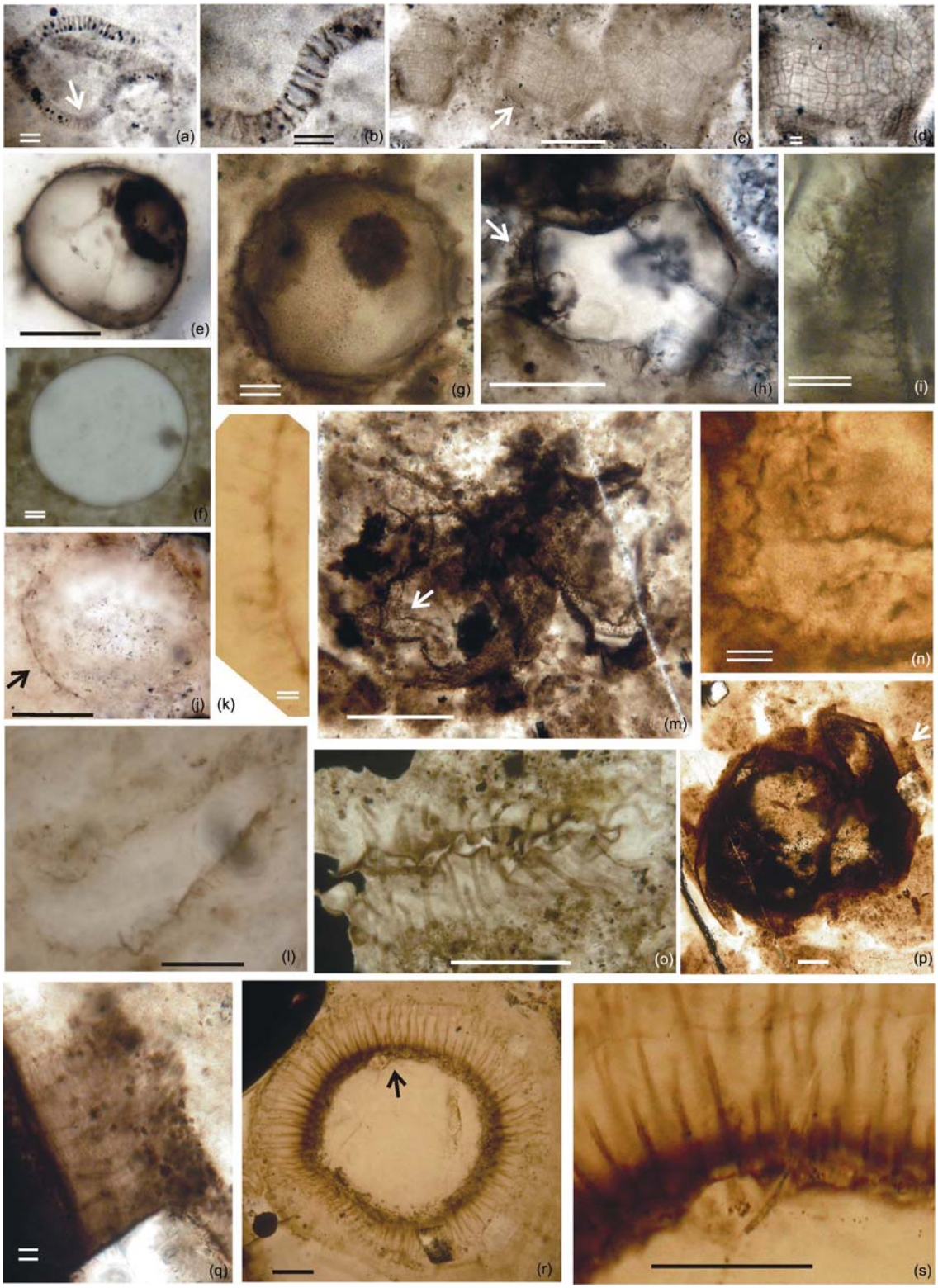

Figure 2 The new microfossils from Doushantuo Formation in the Zhangcunping, Yangtze Gorges. (a), (b) *Oscillatoriopsis obtusa*, (b) is an enlarged view of marked area with arrow in (a); (c), (d) *Sarcinophycus papilloformis*, (d) is an enlarged view of marked area with arrow in (c); (e), (f) *Leiosphaeridia tenuissima*; (g) *Asterocapsoides sinensis*; (h), (i) *Meghystrichosphaeridium perfectum*, (i) is an enlarged view of marked area with arrow in (h); (j)—(l) *Ericiasphaera speldeaesii*, (k) is an enlarged view of marked area with arrow in (j); (m), (n) *Echinosphaeridium maximum*, (n) is an enlarged view of marked area with arrow in (m); (o)—(q) *Tianzhushania spinosa*, (q) is an enlarged view of marked area with arrow in (p); (r), (s) *Tianzhushania ornata*, (s) is an enlarged view of marked area with arrow in (r). Single scale bars = 100 μm. Double scale bars = 10 μm.

Figure 3 Field photographs of the volcanic bed (arrows indicate the volcanic bed) from the Wangjiagou section, Zhangcunping.

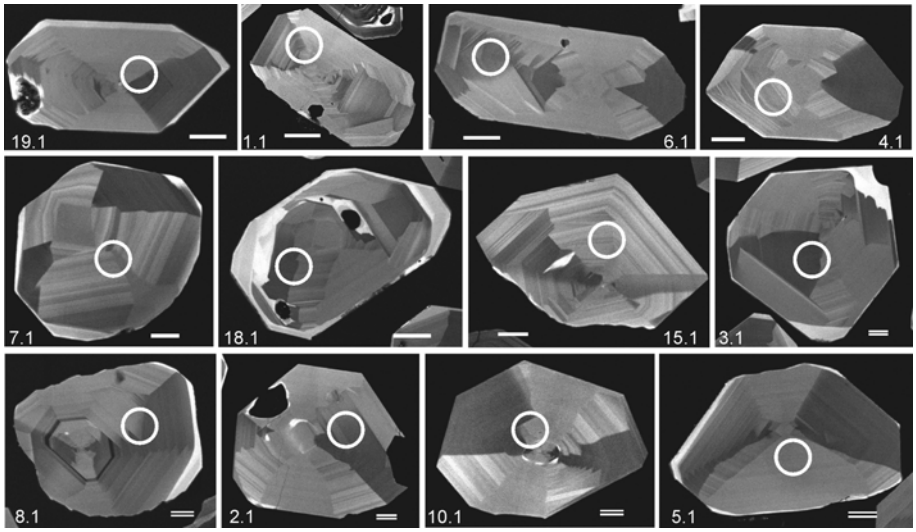

Figure 4 The cathodoluminescence images of zircons. Single scale bars = 20 μm. Double scale bars = 10 μm.

Table 1 SHRIMP U-Pb isotopic data for zircons from sample 7527[a)]

Spot No.	$^{206}Pb_c$ (%)	U ($\times10^{-6}$)	Th ($\times10^{-6}$)	$^{232}Th/^{238}U$	$^{206}Pb^*$ ($\times10^{-6}$)	$^{206}Pb/^{238}U$ age (Ma)	$^{207}Pb/^{206}U$ age (Ma)	$^{207}Pb^*/^{206}Pb^*$	±%	$^{207}Pb^*/^{235}U$	±%	$^{206}Pb^*/^{238}U$	±%	Error corr.
1.1	0.49	162	129	0.82	13.9	611±11	576±61	0.0582	1.8	0.797	2.5	0.0993	1.8	0.714
2.1	0.66	216	196	0.94	18.9	622±9.7	570±59	0.05588	1.6	0.778	2.3	0.1009	1.6	0.710
3.1	0.87	225	211	0.97	20.2	636±10	612±73	0.0617	1.7	0.883	2.4	0.1039	1.6	0.688
4.1	1.58	146	63	0.45	12.7	612±10	460±120	0.0610	2.0	0.842	2.7	0.1002	1.8	0.661
5.1	0.82	178	139	0.81	15.5	618.7±10.0	631±72	0.0612	1.8	0.851	2.5	0.1008	1.7	0.681
6.1	0.78	178	158	0.91	16.1	639±10	561±89	0.05846	1.7	0.840	2.4	0.1042	1.7	0.711
7.1	1.10	119	43	0.37	9.96	592±10	548±99	0.0613	2.2	0.816	2.8	0.0966	1.8	0.643
8.1	0.66	218	250	1.18	18.3	595.7± 9.4	520±57	0.06282	1.5	0.844	2.2	0.0974	1.6	0.739
9.1	1.48	189	176	0.96	16.4	612±12	807±80	0.0605	1.9	0.826	2.8	0.0990	2.0	0.728
10.1	0.62	185	157	0.88	16.5	632±10	698±60	0.0633	1.7	0.901	2.3	0.1032	1.7	0.707
11.1	0.89	173	111	0.67	15.4	630±10	534±75	0.0608	1.7	0.863	2.4	0.1030	1.7	0.716
12.1	1.05	188	155	0.85	15.9	598.4±9.6	458±85	0.0602	1.7	0.812	2.4	0.0978	1.7	0.702
13.1	1.78	191	147	0.80	16.4	605±10	542±110	0.0588	1.9	0.800	2.6	0.0986	1.7	0.662
14.1	0.69	157	129	0.85	13.7	619±10	548±72	0.0543	2.1	0.752	2.7	0.1003	1.7	0.630
15.1	1.15	155	91	0.61	13.2	602.5±9.8	512±90	0.0677	1.6	0.926	2.3	0.0992	1.7	0.716
16.1	0.33	140	97	0.72	11.4	581±12	1,299±36	0.0608	2.5	0.769	3.3	0.0918	2.1	0.654
17.1	0.21	211	192	0.94	17.8	603±11	749±35	0.05732	1.7	0.768	2.5	0.0972	1.9	0.740
18.1	0.61	184	88	0.49	16.3	631±10	616±66	0.0612	1.7	0.868	2.4	0.1029	1.7	0.698
19.1	0.58	198	193	1.01	16.5	594±10	653±86	0.0652	2.4	0.871	3.0	0.0969	1.8	0.598

a) Errors are 1-sigma; Pb_c and Pb* indicate the common and radiogenic portions, respectively. Common Pb corrected using measured ^{204}Pb.

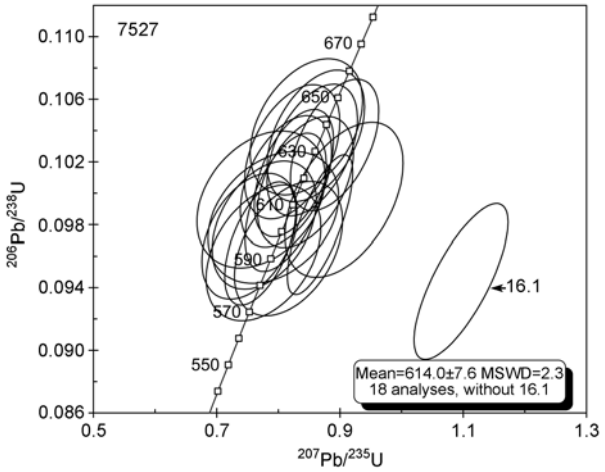

Figure 5 Concordia diagram of zircon analyses from the sample 7527.

Province should be correlated with the upper part of the Member II of the Doushantuo Formation in the Yangtze Gorges[18,21], therefore, the reason that the microfossils can't be found from the Lower Doushantuo Formation in Guizhou Province can be interpreted as the difference of taphonomic facies.

4.2 The signification of the new zircon U-Pb age

Recently, several zircon ages had been obtained from the top and bottom of the Doushantuo Formation in the Yangtze Gorges, including 635.2±0.6 Ma[11] from Member I, 632.5±0.5 Ma[11] , 628.3±5.8 Ma[12] and 621±7 Ma[14] from basal Member II and 551.1±0.7 Ma[11], 549.9±6.1 Ma[13] and 555.2±6.1 Ma[14] from upper Member IV. These ages constrain the age of the Doushantuo Formation between 635.2±0.6 Ma and 551.1± 0.7 Ma and provide important data for establishing Ediacaran chronostratigraphic framework. However, the zircon age never obtained from the middle part of the Doushantuo Formation before this report. So, the new zircon age 614.0±7.6 Ma (SHRIMP II) provides an very important datum for subdivision of the Doushantuo chronostratigraphy and establishing global chronostratigraphic framework of Ediacaran.

In addition, one obvious erosional unconformity in the middle part of the Doushantuo Formation can be seen in many sections in South China[15,18]. Zhou et al.[15] considered that the erosional unconformity in the Zhangcunping section can correlate with that at the Weng'an section and represents an regional exposed event in the middle Doushantuo stage. Zhu et al.[18] took all these erosional unconformities as a boundary of sequence II in Ediacaran that suggested these erosional unconformities are isochronous. The sedimentary succession of the Doushantuo Formation in the Zhangcunping area is similar with that in the Weng'an area. Especially, its microfossils assemblage above the erosional unconformity is analogous to the Weng'an biota. So, the authors consider that it is viable to take the both erosional unconformities in the middle part of the Doushantuo Formation in the Zhangcunping area and in the Weng'an area as isochronous boundary. The present zircon age 614.0±7.6 Ma gained from the base of the thick-bedded dolostone underneath the erosional unconformity (Figures 1, 3) indicates that the erosional unconformity is posterior to 614.0±7.6 Ma. Due to the horizon of the Weng'an phosphatized biota situated above the exposed surface, the Weng'an biota should be posterior to 614.0±7.6 Ma as well.

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