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SHRIMP U-Pb zircon dating of the Triassic Ermaying and Tongchuan formations in Shanxi, China and its stratigraphic implications

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Abstract　Sensitive High Resolution Ion Microprobe (SHRIMP) U-Pb dating was carried out using zircons from tuffs in the Ermaying and Tongchuan formations of Shanxi, China. The results show weighted mean ages of 245.9 ± 3.2 Ma for a sample from Member II of the Ermaying Formation, 243.1 ± 3.9 Ma for a sample from Member I of the Tongchuan Formation, and 238.6 ± 2.6 Ma and 234.6 ± 6.5 Ma for two samples from the upper part of Member II of the Tongchuan Formation. These ages indicate that the lower part of the Ermaying Formation, which contains the *Shaanbeikannemeyeria* assemblage, is mostly likely Lower Triassic in age, whereas, the Tongchuan Formation is likely late Anisian to Ladinian, Middle Triassic.

Key words　Triassic, tuff, zircon dating

1　Introduction

Correlating sedimentary strata from different facies, especially between the terrestrial and marine realms, poses a difficult challenge to geologists. Biochronology, which depends on the shared presence of particular fossils in the different strata to be correlated, is a common and useful method for approaching this problem. In some cases, however, no fossil that is useful for correlation exists in both sets of strata. For example, tetrapod biochronology is useful in correlating nonmarine strata from the Triassic (e.g., Lucas, 1998; Rubidge, 2005), but tetrapod-based schemes of correlation are hard to apply to marine strata. In contrast, radioisotopic dating makes it possible to directly determine the age of strata, but sedimentary rocks generally do not yield reliable radiometric dates. For example, two Triassic Global Standard Sections and Points, the base of the Ladinian and Carnian stages, still have no reliable absolute ages (International Commission on Stratigraphy, 2012). Only a limited number of absolute ages associated with tetrapods have been reported for the entire non-marine Triassic, and none of these pertain to the Middle Triassic (Rogers et al., 1993; Riggs et al., 2003; Irmis et al., 2011).

In the Ordos Basin of northern China, the Middle Triassic is represented by the Ermaying and Tongchuan formations, and two regional stages have been proposed based on them

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(National Commission on Stratigraphy of China, 2001). The Ermaying Formation is divided into lower and upper members, which respectively contain *Shaanbeikannemeyeria* and *Sinokannemeyeria* assemblages (Sun, 1980). The age of the Ermaying Formation is uncertain mostly because different correlations are possible for the *Shaanbeikannemeyeria* assemblage. The age of this assemblage is generally regarded as either early Middle Triassic (Yang et al., 2000), roughly corresponding to the Anisian (Rubidge, 2005), or late Early Triassic (Olenekian/Spathian)(Sun, 1980; Lucas, 2001, 2010). The Tongchuan Formation is also divided into two members, the upper of which is further divided into two parts. However, the entire formation is considered to date to the late Middle Triassic (Yang et al., 2000). Many tuff layers have been found in the Ermaying and Tongchuan formations of Shanxi, China, and they provide a chance for radioisotopic dating. In this paper, we present the first absolute date from these two geological units and discuss their stratigraphic implications.

2 Samples and analytical techniques

The four samples included in this study were collected from Yonghe and Liulin counties, Shanxi Province, China (Fig. 1): YH1 from Sangbi (36°37′28.9″N, 110°38′07.1″E), YH2 from Jiaokou (36°39′54.2″N, 110°36′23.9″E), SJ1 from Xiasanjiao (37°17′12″N, 110°42′00″E), and SJ4 from Shixi (37°26′15″N, 110°39′06″E). Samples YH1 and YH2 were collected from the lower portion of Second Part of Member II of the Tongchuan Formation (from beds 9 and 3 respectively, in figure 3 of Liu et al., 2001), whereas SJ1 was collected from Member I of the Tongchuan Formation. Sample SJ4 came from Member II of the Ermaying Formation (Fig. 2).

Zircon separation was operated by a laboratory of the Langfang Regional Geological Survey. The rocks were crushed and sieved to about 100 μm for separation. Zircon separation was carried out by a combination of magnetic and heavy liquid methods, finally followed by hand-picking under a binocular microscope. Thousands of zircon grains were collected, but

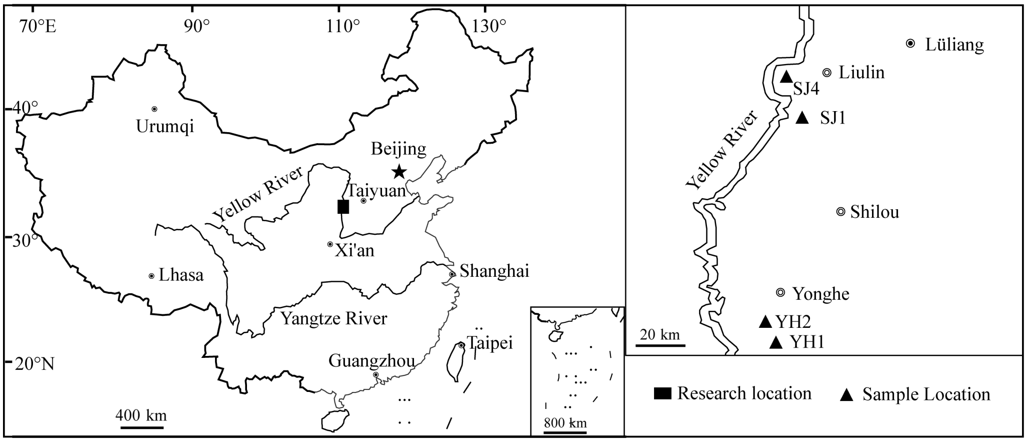

Fig. 1 Map showing the four locations where radiometric samples were collected

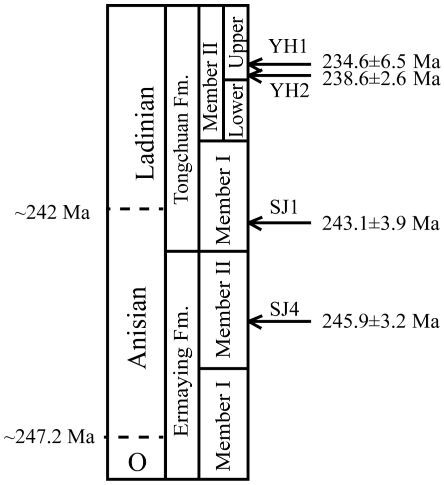

Fig. 2 Stratigraphic positions of the four analyzed samples
O: Olenekian

only the large grains in each sample were prepared for dating. The zircon grains collected for this study were mostly euhedral, transparent, and colorless to light brown, and mostly show concentric zoning. The zircons were analyzed for U, Th and Pb content using SHRIMP at the Beijing SHRIMP Center, Institute of Geology, Chinese Academy of Geological Sciences. Standard instrument settings were used, and all measurement procedures were carried out under standard operating conditions (Williams, 1998; Black et al., 2003). The measured $^{206}Pb/^{238}U$ ratio in the samples was corrected using zircon standard TEM (417 Ma) from Australia. The standard zircon was analyzed every fourth analysis. The common Pb component was estimated from ^{204}Pb counts, and the final age estimates were based on weighted means with 2 σ errors calculated using isoplots at the 95% confidence level. We tried to select the target points on the individual zircon crystals according to the criteria suggested in reference (Liu et al., 2011).

3 Analytical results

Analysis of some selected target points was unsuccessful, in that these points yielded discordant ages that cannot be used in age calculation.

Ages were obtained for 15 zircons in sample SJ1 from the Tongchuan Formation, but tests SJ1-1 and SJ1-2 were taken from anomalously old zircons (~1800 Ma) and are excluded from the U-Pb concordia diagram (Fig. 3). The 13 remaining zircon grains from sample SJ1 had moderately high and variable concentrations of U (260–644 ppm) and Th (100–479 ppm), and their Th/U ratios varied from 0.4 to 0.9. Among them, test SJ1-15 yielded a clearly excessive $^{206}Pb/^{238}U$ age of 300.1 ± 7.2 Ma, possibly because of inherited radiogenic Pb. However, the remaining 12 analyses produced $^{206}Pb/^{238}U$ ratios that were indistinguishable within analytical error, and which corresponded to a single age population with a weighted mean $^{206}Pb/^{238}U$ age of 243.1 ± 3.9 Ma (95% confidence level, MSWD = 1.4).

Ages were obtained for 14 zircons in sample SJ4 from the Ermaying Formation, but tests SJ4-7 and SJ4-12 were taken from anomalously old zircons (>1800 Ma) and are excluded from the U-Pb concordia diagram (Fig. 3). These 12 remaining zircon grains had high and variable concentrations of U (441–1492 ppm) and Th (215–1603 ppm), and their Th/U ratios varied from 0.5 to 1.11. These tests, other than SJ4-2, SJ4-11, and SJ4-14, produced $^{206}Pb/^{238}U$ ratios that were indistinguishable within analytical error, and which corresponded to a single age population with a weighted mean $^{206}Pb/^{238}U$ age of 245.9 ± 3.2 Ma (95% confidence level, MSWD = 0.95).

Ages were obtained for 12 zircons in sample YH1 from the Tongchuan Formation, and are shown on the U-Pb concordia diagram (Fig. 3). These 12 zircon grains had moderately high and variable concentrations of U (153−1475 ppm) and Th (99−752 ppm), and their Th/U ratios varied from 0.52 to 0.98. Tests YH1-1 and YH1-8 produced ages that were clearly too old. By contrast, test YH1-10 produced an anomalously young age, probably because of excess ^{204}Pb. All three anomalous values were excluded in calculating the mean age for the sample. The remaining 9 tests gave a weighted mean $^{206}Pb/^{238}U$ age of 234.6 ± 6.5 Ma (95% confidence level, MSWD = 2.7).

Ages were obtained for 15 zircons from sample YH2 from the Tongchuan Formation, and are shown on the U-Pb concordia diagram (Fig. 3). These 15 zircon grains had moderately high and variable concentrations of U (152−342 ppm) and Th (106−368 ppm), and their Th/U ratios

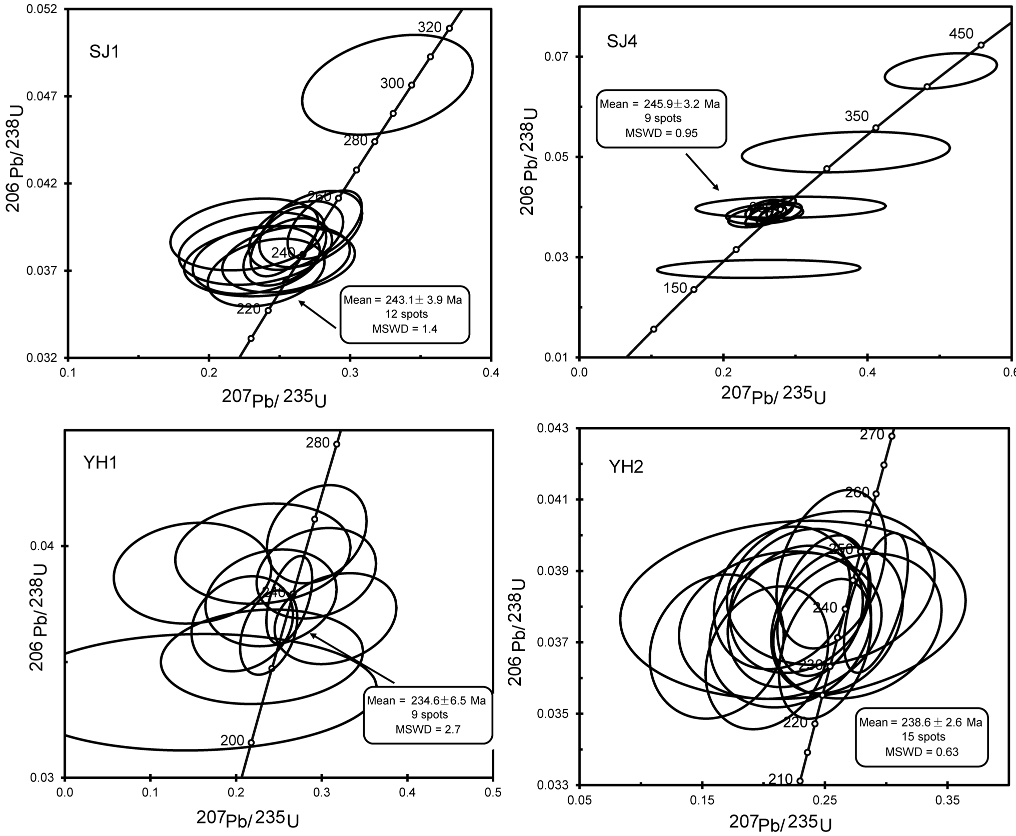

Fig. 3　U-Pb zircon concordia plots for four samples
SJ1 from Member I of the Tongchuan Formation, SJ4 from Member II of the Ermaying Formation, YH1 and YH2 from the upper part of Member II of the Tongchuan Formation

varied from 0.46 to 1.11. The 15 analyses produced $^{206}Pb/^{238}U$ ratios that were indistinguishable within analytical error, and which corresponded to a single age population with a weighted mean $^{206}Pb/^{238}U$ age of 238.6 ± 2.6 Ma (95% confidence level, MSWD = 0.63).

4 Geological implications

No GSSP has been ratified for the base of the Anisian, and the age given for this boundary varies from ~245 to ~247 Ma in recent international stratigraphic charts (2004, 2010, 2012). Regardless of the exact age of the boundary, the current age estimate obtained in this study for sample SJ4 is close to the possible dates for the base of the Anisian, the Lower-Middle Triassic boundary (Lehrmann et al., 2006; Mundil et al., 2010). Sample SJ4 comes from a layer well above the boundary between the lower and upper parts of the Ermaying Formation, so the lower part and the *Shaanbeikannemeyeria* assemblage it contains could be referred to the Lower Triassic.

This date also confirms the age of Heshanggou Formation, which underlies the Ermaying Formation, is Lower Triassic, and that the poposauroid *Xilousuchus sapingensis* is the oldest known member of crown group Archosauria (Nesbitt et al., 2011). This dating provides a minimum age for *Xilousuchus sapingensis*, and thus for divergence for the bird-crocodile split (Parham et al., 2012).

No absolute age is available at the base of the Tongchuan Formation, but the age of sample SJ1 from within Member I of this formation is close to the accepted age of the base of Ladinian (~242 Ma). This result indicates that the lowest part of the Tongchuan Formation could extend into the Anisian.

The beginning of the Carnian was placed at ~235 Ma on 2012 stratigraphic chart, a date more than 6 million years older than those appearing on 2010 chart. Although the age estimate obtained for sample YH1 (234.6 ± 6.5 Ma) has a wide error bar, this age together with that of sample YH2 (238.6 ± 2.6 Ma) indicates the sampled layers are likely Ladinian in age. Because samples YH1 and YH2 came from the middle of Member II of the Tongchuan Formation, this formation is mostly Middle Triassic in age.

The error bars attached to the estimated dates obtained in this study are relatively large for various reasons, including the limitations of current dating methods. We intend to pursue research that will result in more precise ages in the future.

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山西三叠系二马营组和铜川组SHRIMP锆石铀-铅年龄及其地质意义

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摘要：采集了山西省二马营组和铜川组共4个层位的火山凝灰岩，在高灵敏度高分辨率二次离子质谱仪上以铀-铅法测定其中锆石的年龄。二马营组上部的样品测年结果为245.9 Ma ± 3.2 Ma, 铜川组一段样品测年结果为243.1 Ma ± 3.9 Ma, 二段上部两个样品年龄为238.6 Ma ± 2.6 Ma和234.6 Ma ± 6.5 Ma。结果表明出产陕北肯氏兽动物群的二马营组下部极有可能属于下三叠统，而铜川组时代可能从安尼期晚期到拉丁期。

关键词：三叠纪，凝灰岩，锆石测年
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