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News & Views

Discovery of Triassic volcanic-sedimentary strata in the basement of Songliao Basin

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In the Songliao Basin, the existence of lower Mesozoic strata remains a debatable issue. Previous studies indicated the absence of Triassic to Lower and Middle Jurassic strata in northeastern China because of uplift and erosion events associated with the return of geo-synclinal folds and orogenic movement during the Late Permian–Early Jurassic. To date, geochronological studies of intrusive and metamorphic rocks in the basement of the Songliao Basin have also confirmed Carboniferous, Permian, and Late Jurassic ages for the basement formations in general [1–4]. In the International Continental Scientific Drilling Project (ICDP) in the Songliao Basin, radiometric dating has been carried out for the entire drilling core of the SK-2 east borehole. As a result, we have discovered Triassic volcanic-sedimentary strata in the basement of the Songliao Basin.

The International Continental Scientific Drilling Project of the Songliao Basin includes the SK-1 boreholes (the SK-1 south borehole and the SK-1 north borehole) and SK-2 boreholes (the SK-2 east borehole and the SK-2 west borehole). The two SK-1 boreholes are located in the Qijia–Gulong Depression (Fig. 1a). Complete sedimentary records of the Late Cretaceous strata were obtained from these boreholes, and the total length of drilling cores from the SK-1 boreholes is 2,485.89 m [5]. The SK-2 east borehole is located in the Xujiaweizi Fault Depression (Fig. 1a), in the northern part of the Songliao Basin, and is the third scientific borehole of the ICDP in China. The scientific objective of the SK-2 east borehole is to obtain continuous high-resolution terrestrial geological records for the study of greenhouse climate change and basin development during the Cretaceous. The target strata of the SK-2 east borehole are the Lower Cretaceous Yingcheng, Shahezi, and Huoshiling formations, and the basement of the Songliao Basin [6]. The depth of the borehole is 7,018 m. The coring footage is 4,278.73 m. The length of the drilling core is 4,134.8 m, with a core recovery rate of 96.61%. U–Pb isotopic dating of zircons was conducted at the State Key Laboratory of Geological Processes and Mineral Resources and the State Key Laboratory of Continental Dynamics of China University of Geoscience (Wuhan). Samples include andesite from a depth of 6,031.9 m, sandstone from a depth of 6,286.2 m, and andesite from a depth of 6,373.9 m. Laser-ablation inductively coupled plasma mass spectrometry (LA-ICP-MS) U–Pb geochronology was used in this research. Errors in individual analyses by LA-ICP-MS are given at the 1σ level, whereas errors in pooled ages are given at the 95% (2σ) confidence level. The dating results are presented in Table S1 (online) and Fig. 1d.

Triassic volcanic-sedimentary strata revealed by the SK-2 east borehole consist of andesitic volcanic breccias at the bottom; andesites, sandstones, and conglomerates in the middle; and andesites at the top. The total thickness of these strata is over 500 m. The main mineral components of the andesite at 6,031.9 m are magnetite (5% of the total minerals), amphiboles (10% of the total minerals) and plagioclases (85% of the total minerals). The main mineral components of the andesite at 6,373.9 m are magnetite (10% of the total minerals), amphiboles (altered) (15% of the total minerals), and plagioclases (75% of the total minerals). Porphyritic and hyalopilitic textures are developed in the andesites at 6,031.9 and 6,373.9 m. The main components of the sandstone at 6,286.2 m are feldspars (10% of the total minerals), lithic fragments (15% of the total minerals), and quartz (85% of the total minerals). The structure is medium-grained with moderate sorting and poor roundness.

The zircons from the sandstone at 6,286.2 m are euhedral crystals with various diameters from 60 to 150 μm and a range of axial ratio from 1:1 to 2:1. In general, the crystals are sub-angular or sub-rounded. The zircons from the andesites at 6,031.9 and 6,373.9 m are euhedral crystals or subhedral crystals with assorted diameters from 45 to 100 μm and a range of axial ratios from 1:1 to 3:1. In general, these crystals are angular or sub-angular. Zircons from the two andesite samples show clear internal structure and oscillating growth rings under cathode luminescence (Fig. 1d). Based on the relatively high Th/U ratios of the zircon samples (Table S1 online) and the above information, these zircons are of magmatic origin [7,8]. For U–Pb isotope dating, twenty zircon crystals were selected from the andesite at the depth of 6,031.9 m, and twenty zircon crystals were selected from the andesite at 6,373.9 m. In the 6,031.9 m interval, eleven zircons did not demonstrate concordant ages, indicating that their closed isotope system was destroyed, and they did not show reliable ages. The remaining nine zircon samples from this andesite demonstrated concordant ages. Of these nine zircon samples, the isotopic ages of seven zircons showed the weighted average $^{206}Pb/^{238}U$ age of

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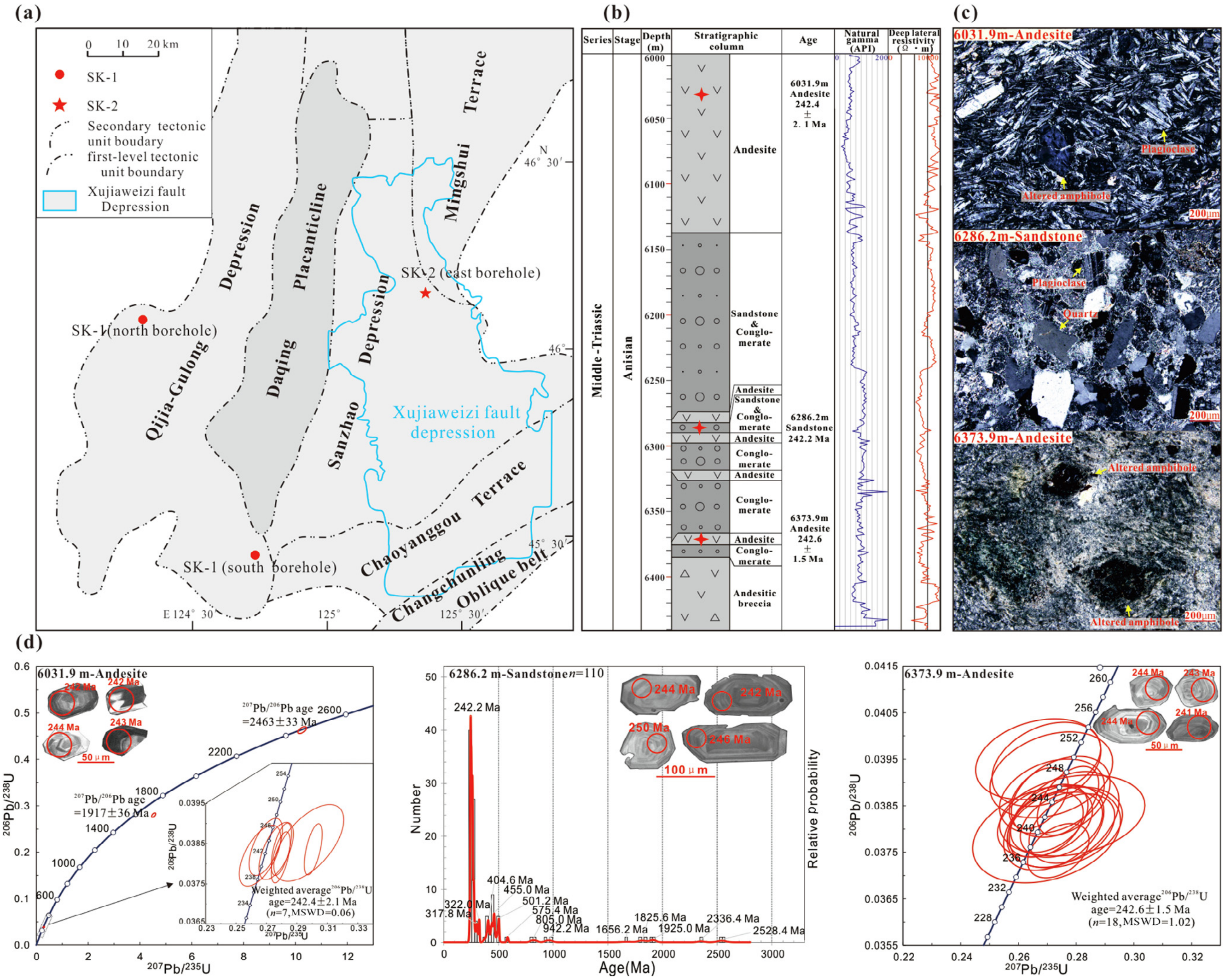

Fig. 1. Triassic volcanic-sedimentary strata and age data of the Songliao Basin revealed by the SK-2 east borehole. (a) Locations of key wells. (b) Triassic volcanic-sedimentary strata revealed by the SK-2 east borehole. (c) Photomicrographs (cross-polarized light) of zircon U–Pb dating samples. (d) Zircon U–Pb dating concordia diagrams and probability density diagrams with histograms.

242.4 ± 2.1 Ma (MSWD = 0.06, n = 7). The $^{207}Pb/^{206}Pb$ ages of the other two zircons revealed the concordant ages of 1,917 ± 36 Ma and 2,463 ± 33 Ma, respectively (Fig. 1d). Among the reliable isotopic age data above, the dominant isotopic age (n = 7) of 242.4 ± 2.1 Ma is inferred to represent the formation age of this interval. The remaining two isotopic age data characterize the ages of zircons captured by the andesite. In the 6,373.9 m interval, eighteen zircon samples from the andesite displayed concordant ages, which showed a weighted average of $^{206}Pb/^{238}U$ age 242.6 ± 1.5 Ma (MSWD = 1.02, n = 18) (Fig. 1d). This date is inferred to represent the formation age of this interval. The isotopic analysis results demonstrate that these two andesite intervals formed during the Triassic. One hundred and ten zircon crystals were randomly selected from the sandstone of the 6,286.2 m interval. All the zircon samples from this sandstone show concordant ages, with an age distribution between 240 and 2,546 Ma (young zircons (<10 Ga) show $^{206}Pb/^{238}U$ ages and old zircons (>10 Ga) show $^{207}Pb/^{206}Pb$ ages in Fig. 1d) with several age peaks. The youngest peak age is 242.2 Ma, which indicates that the Triassic source rocks were the youngest sediment supplier during the development of the sandstone (Fig. 1d). Because the sandstone is sandwiched between the two sets of andesite, we infer that the chronologic age of this interval is likely Triassic. Based on the above data, the volcanic-sedimentary strata discovered in the SK-2 borehole formed during the Triassic.

This study demonstrates that in the Songliao Basin, there are not only Carboniferous and Permian strata, but also a Triassic volcanic-sedimentary succession in the basement of the basin. The SK-2 drilling core reveals that this volcanic-sedimentary sequence has great thickness. These Triassic volcanic-sedimentary strata provide new clues for the study of the origin and development of the Songliao Basin. As both volcanic and sedimentary rocks can be oil and gas reservoirs, this discovery also provides a new target for oil and gas exploration deep in the Songliao Basin.

Conflict of interest

The authors declare that they have no conflict of interest.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.scib.2019.03.020.

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