Supplementary materials

Implications for Ediacaran biological evolution from the ~602 Ma Lantian biota in China

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1, X-ray CT Core Imaging

CT Imaging of the Lantian drill core was conducted at the Department of Geography, Durham University using a Geotek X-ray CT core imaging system. Data from the 14-bit digital flat panel were collected as 16-bit grayscale TIFF images with a resolution of 0.1 mm. The images then were used to produce computed tomographic (CT) reconstructions by projecting data perpendicularly to the axis of the cores, and to visualize three-dimensional structures within cores. The x-ray source and detector positions were adjusted during the study in order to ensure optimal image quality and to accommodate the core diameters using Geotek CTQuickView.

2, X-ray Fluorescence Scanning

Major and trace elements imaging was conducted at the Department of Geography, Durham University using a Geotek X-ray Fluorescence instrument. A down-core resolution of 1 mm and a cross-core resolution of 5 mm were used during this study. A wide range of elements (magnesium to uranium) have been detected, and the detection limits typically are better than 20 ppm for most elements, except for Mg (1800 ppm), Al (125 ppm) and Si (190 ppm). The measurement cell is flushed with helium to improve the sensitivity of light element (e.g., magnesium, aluminum and silicon) measurements. The data were processed using a MSCLXYZ Core Workstation.

3, Re-Os isotope composition analysis

A prescreening approach was used to target the best preserved shale with least post-depositional isotope exchange for Re-Os dating (Stein and Hannah, 2014). Fresh core samples without post-formation veining and weathering were selected, and then imaged by a Geotek X-ray CT Core Imaging System and a Geotek X-ray Fluorescence (XRF) at Durham University. Based on the CT imagery and XRF scan, a core interval with well-preserved sedimentary lamination and relative homogenous elemental patterns that suggest no evidence of chemical weathering and indicate a stable depositional environment (e.g., Si, Al, Fe) was used for Re-Os geochronology.

After cutting, drill core samples were polished using a diamond-encrusted polishing pad to remove cutting marks and eliminate any potential metal contamination from the saw blade. The samples were then air dried at 60°C for ~12 hours, broken into chips with no metal contact. Samples were crushed to a fine powder (~70 μm) in an agate mortar. The Re–Os isotope analyses were carried out at the Durham Geochemistry Centre (Laboratory for Sulfide and Source Rock Geochronology and Geochemistry, and Arthur Holmes Laboratory) at Durham University. A Cr^{VI}–H_2SO_4 solution was utilized to preferentially digest the organic fraction of the samples and thus liberate hydrogenous Re and Os budget, minimizing the contamination from detrital Re and Os (Selby and Creaser, 2003; Kendall et al., 2004).

The sample powder (~0.5 g) together with a known amount of mixed $^{190}Os+^{185}Re$ tracer (spike) solution and 8 ml of 0.25 g/g Cr^{VI}–H_2SO_4 solution were digested in a sealed Carius tube for 48 h at 220 °C (Selby and Creaser, 2003). Rhenium was isolated from the solution using NaOH–C_3H_6O solvent extraction and

then purified by anion chromatography. Osmium was purified using solvent extraction ($CHCl_3$) and micro-distillation methods (Cohen and Waters, 1996; Birck et al., 1997). The isolated Re and Os fractions were loaded onto Ni and Pt filaments, respectively (Selby, 2007). Isotopic measurements were conducted using a ThermoElectron TRITON mass spectrometer with the Re measurement in static Faraday collection mode and Os measurement in secondary electron multiplier peak-hopping mode. Total procedural blanks during this study were 18.0±1.0 pg and 0.10±0.05 pg (2SD, n = 4) for Re and Os, respectively, with an average $^{187}Os/^{188}Os$ value of 0.20±0.05 (2SD, n = 4). Long-term mass spectrometry measurements of the in-house Re (ReStd) and Os (DROsS) reference solutions yield $^{187}Re/^{185}Re$ ratio of 0.5986±0.0004 (n=702) and $^{187}Os/^{188}Os$ ratio of 0.1609±0.0002 (n=743) respectively,

The Re-Os isotope data are regressed using an inverse isochron approach (Li and Vermeesch, 2021) and yield an isochron age of 602.0±6.6 Ma (2σ, same below) and an initial $^{187}Os/^{188}Os$ of 1.14±0.03. Including the decay constant uncertainty of ^{187}Re (Smoliar et al., 1996) the age is 602.0±6.9 Ma. As discussed in detail by Davis (2021) and Li and Vermeesch (2021), the inverse isochron approach allows for better data visualization, and is able to give more accurate results when the uncertainties of input isotopic ratios are large (e.g., >5%) and are strongly correlated (e.g., error correlations >0.99). Although our measurements are very precise (0.15-0.77% for $^{187}Re/^{188}Os$ and 0.20-1.2% for $^{187}Os/^{188}Os$) and are only moderately correlated (rho = 0.581-0.690), we still used the inverse isochron approach here to yield the best age constraints for the Lantian biota. When using a Monte Carlo simulation (Li et al., 2019), the results are 601.7±8.9/12.9 Ma (uncertainties are presented as analytical only/model uncertainty included), with an initial $^{187}Os/^{188}Os$ of 1.141±0.025/0.037; and an age of 601.7±9.2/13.0 after adding the decay constant uncertainty of ^{187}Re

(Smoliar et al., 1996). Our Monte Carlo simulation indicates that the final uncertainty of our isochron regression is predominately analytical (84%), this is in line with the small MSWD of the inverse isochron of 0.07.

For the final age of the Lantian biota, though the Monte Carlo approach gives more accurate estimates, we tentatively use the results from the inverse isochron approach to be comparable with literature data. But we report both results to permit future comparisons when the Monte Carlo approach becomes the default approach to Re-Os age determinations.

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