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Short Communications (Research Advances)

Paleoproterozoic collision in the Yangtze Craton: Constraint from rutile and zircon U-Pb dating of the khondalite series in the Kongling Complex

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1. Objective

Global collisional orogenic events during the Middle to Late Paleoproterozoic (2.1–1.8 Ga) have garnered significant attention due to their potential role in assembling the Columbia supercontinent (also known as Nuna). Having undergone a series of complex subduction-accretion-collision events, the Yangtze Craton (YTC) is critical for understanding the evolution of Columbia supercontinent. However, research remains limited because Paleoproterozoic basement rocks are largely concealed beneath Neoproterozoic to Phanerozoic sedimentary cover. The Kongling Complex, located within the Huangling Dome (HLD) in the northern YTC, preserves evidence of tectonothermal events between 2.1 Ga and 1.8 Ga. Although most scholars agree that a collision event occurred in the YTC during the Paleoproterozoic, the proposed timing varies widely, ranging from 2.15 Ga to 1.95 Ga. The HLD exposes a khondalite series (KS), composed predominantly of metasedimentary rocks, making it a crucial area for investigating the tectonic evolution of the YTC. As a major component of Early Precambrian high-grade metamorphic complexes, the KS provides a distinctive petrological record of collision processes, with its formation directly linked to collisional orogeny. Chronological studies of the KS are thus essential for constraining the timing of collision event. The Kongling khondalite series (KLKS) assemblages are predominantly composed of metapelites (including graphite schists and gneisses), interlayered with metacarbonates (such as marble) and siliceous rocks

(including quartzite and leptynite).

The sedimentary protolith and metamorphic ages preserved in the KLKS provide critical constraints for reconstructing the tectonic evolution of the YTC. Previous studies have constrained the KLKS depositional age to the Paleoproterozoic (2.2–2.0 Ga), based on the youngest concordant detrital zircon ages combined with metamorphic zircon age or the garnet Sm-Nd isochron age. However, discrepancies among these ages highlight the need for alternative geochronological approaches. Metamorphic ages derived from zircon grains whose U-Pb systems were reset during high-grade metamorphism range from 2.08 Ga to 1.94 Ga. Future studies should prioritize more robust geochronological methods (e.g., rutile dating) to refine these constraints. Rutile is a powerful tool for recording ultrahigh-pressure (UHP) and high-pressure (HP) metamorphic histories, as it preserves critical thermobarometric and geochronological information related to orogenic processes. Consequently, rutile dating is widely used to resolve controversies surrounding HP rocks and plays a key role in constructing precise temporal frameworks for complex geological events. In this study, LA-ICP-MS U-Pb dating of rutile and zircon, together with trace elements of rutile from graphite schist in the KLKS was conducted to constrain the timing of collision processes in the YTC.

2. Methods

The graphite-muscovite schist sample analyzed in this study (NKL23-03; GPS: N 31°16'23.34", E 111°07'17.57") was collected from an outcrop of the KLKS in the northern HLD. The analytical methods are summarized in [Supplementary text](#).

3. Results

The graphite-muscovite schist sample is gray to dark gray

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with interspersed granitic material (Figs. 1a–b), while diopside-olivine marble occurs in the surrounding area (Fig. 1c). The schist is fine- to medium-grained, comprising muscovite (50%), graphite (30%), quartz (15%), and plagioclase (5%). Muscovite and graphite occur as elongated flakes with a preferred orientation, forming a well-developed schistose fabric (Figs. 1a–b, d–e). Representative BSE images and U–Pb isotopic data of rutile are shown in Fig. 1g and Supplementary Table 1. Rutile trace element contents are also listed in Supplementary Table 1. Rutiles are euhedral to subhedral, 60–120 μm in diameter, planar, and exhibit no compositional zoning in BSE images, interpreted as metamorphic rutile. Fifteen analyses were carried out on 15 rutile grains, containing lower concentrations in U (3.24×10^{-6} – 11.3×10^{-6}) and Pb (3.24×10^{-6} – 11.3×10^{-6}), respectively. All the measured analyses yield a tightly clustered age of about 2.0 Ga on the Tera-Wasserburg concordia diagram (Fig. 1g). Zr-in-rutile temperatures range from 485°C to 597°C and clustering around 551°C (Supplementary Table 1). Ten grains with concordance values >90% define a weighted mean age of

1958 ± 51 Ma (MSWD = 1.5, $n=10$; Fig. 1g).

Sixteen zircon grains are elliptic or prismatic, ranging from 80 μm to 120 μm in length. CL images reveal no oscillatory zoning (Fig. 1h) in all of the grains, typical of metamorphic zircon. U contents range from 63.9×10^{-6} to 3820×10^{-6} , and Th from 755×10^{-6} to 6156×10^{-6} , with Th/U ratios from 0.01 to 0.94. Most analyses are discordant and scatter along a discordia line intersecting the concordia at 1932 ± 64 Ma, consistent with a concordant zircon age of 1914 ± 27 Ma (Con. = 99%) within error, and are also close to the rutile age.

Previous studies identified a clockwise P–T path for the KLKS, based on metamorphic mineral assemblages and P–T conditions, indicating a collisional orogenic event. Only subduction and collision could have transported the sedimentary precursors of pelitic rocks and marbles to the deep crustal levels required for UHP–HP metamorphism, suggesting that the YTC underwent a complex tectonothermal evolution. The rutile and zircon metamorphic ages of 1.91–1.96 Ga in this study reflect the timing close to peak

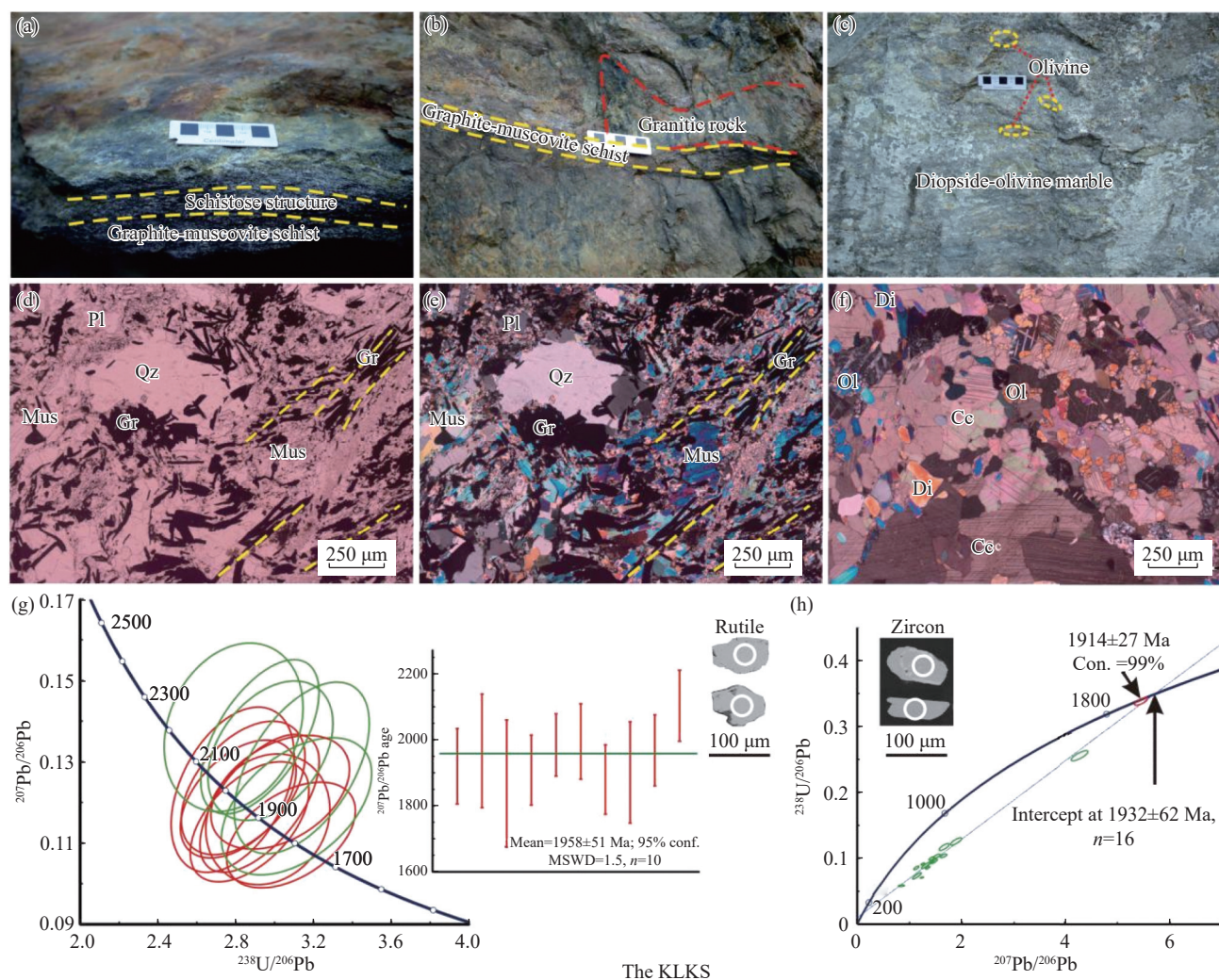


Fig. 1. Field photographs of a–b–schist and c–marble; photomicrographs of d–e–schist and f–marble from the KLKS (Kongling khondalite series) in the Northern Huangling Dome; g–tera-Wasserburg diagram and representative BSE images and weighted mean age diagram of rutiles; h–zircon U–Pb concordia plots with typical zircon CL images. Cc–calcite; Di–diopside; Gr–graphite; Mus–muscovite; Ol–olivine; Pl–plagioclase; Qz–quartz.

metamorphism. This peak records the final stage of collision), suggesting that amalgamation of the YTC may have occurred as early as about 1.91–1.96 Ga.

4. Conclusion

Rutile U-Pb dating yields a metamorphic age of 1958 Ma, consistent with metamorphic zircon ages of 1914–1932 Ma within error, collectively indicating that the KLKS underwent significant tectonothermal overprinting during the Paleoproterozoic. Calculated Zr-in-rutile temperatures range from 485°C to 597°C, clustering around 551°C, reflecting peak metamorphic conditions. Intense metamorphism in the HLD induced recrystallization of both rutile and zircon during collisional orogeny. The metamorphic ages of about 1.91–1.96 Ga provide critical constraints on the timing of collision. Collisional processes in the YTC led to formation of the KLKS. This study thus provides new constraints on the Paleoproterozoic tectonic evolution of the YTC.

CRediT authorship contribution statement

Yu Shi prepared the original manuscript with support from Zhi-xian Tian. Song-bai Peng, Jie Yang and Yuan-yuan Tang collected, analyzed the samples and discussed the results. All authors contributed to the final manuscript.

Declaration of competing interest

The authors declare no conflicts of interest.

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Supplementary dataset

Supplementary data ([Supplementary text](#) and [Supplementary Table 1](#)) to this article can be found online at doi: [10.31035/cg2025091](https://doi.org/10.31035/cg2025091).