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Zircon and melt inclusion evidence for hydrous, low-pressure partial melting of Hadean crust forming Eoarchaean TTGs

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The formation of Earth's earliest continental crust is central to understanding the evolution of our planet and its habitable environment. Eoarchaean tonalite–trondhjemite–granodiorite (TTG) suites, the oldest surviving felsic crust on many cratons, preserve essential clues to these processes, yet debate continues regarding their genesis, particularly with respect to their magmatic H_2O content and oxygen fugacity (fO_2). Here we investigate Eoarchaean granodioritic and trondhjemitic gneisses from the Eastern Hebei and Anshan nuclei of the North China Craton and present the first integrated dataset combining zircon U–Pb ages, $\delta^{18}O_{(zrn)}$, and trace elements, whole-rock major and trace element compositions, and zircon melt inclusions (MIZs) characterized for major elements, $\delta^{18}O_{(MIZ)}$ and H_2O contents. Zircons were heated in an internally heated pressure vessel to 1100ºC for 6 hours at 0.4 GPa in an Ar atmosphere to remelt devitrified MIZs. Zircon U-Pb ages indicate these TTGs formed at ~3.8 Ga. The MIZs are dominantly granitic, with high SiO_2 and K_2O/Na_2O ratios and low MgO and FeO contents, and are interpreted as evolved interstitial melts trapped during zircon crystallization. Combined MIZ major elements, fractionation-crystallization thermodynamic modelling, and host whole-rock geochemistry indicate that variable melt–crystal segregation within a crystal-mush system accounts for the compositional diversity of the trondhjemites. SIMS analyses reveal high H_2O contents (3.9–8.6 wt%) in the MIZs, representing upper limits on the water contents of their parental magmas unless partial H loss occurred by volume diffusion through host zircon. Zircon trace-element oxybarometry indicates that these Eoarchaean magmas were relatively reduced, with fO_2 of –1.1 to –0.6 relative to the fayalite–magnetite–quartz buffer (ΔFMQ). The least evolved Eoarchaean granodiorites display low-pressure-type TTG geochemical signatures (<1.0 GPa). Zircon Hf & O isotopes, zircon trace-element compositions, and thermodynamic modelling of partial melting collectively suggest that these hydrous, low-fO_2, and low-pressure granodioritic magmas were generated by hydrous partial melting of long-lived Hadean mafic crust under high thermal gradients (>900 °C/GPa). Together with evidence from other cratons, our results support a tectonic regime characterized by the coexistence of plume and subduction, which best explains efficient recycling of hydrated Hadean crust, high T/P gradients, and the global geological record of the Eoarchaean.