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Giant impacts and the origin and evolution of Archean cratons

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The Moon's surface preserves evidence of the impact flux that affected the inner rocky planets in our solar system. Compared to endogenic (mantle plume or plate tectonic) processes, the role of exogenic (impact-driven) processes in the development of Earth's cratonic crust has received less consideration. Unambiguous evidence of large impacts is furnished by spherule layers in greenstone sequences and numerical models demonstrate that these events could cause instantaneous massive partial melting of the lithosphere and upper mantle. To evaluate the potential role of impacts, we investigate isotope time series that track crust production during the Archean in the context of the local environment of the Solar System in a simplified model of mass density for the Milky Way—a 4-arm barred spiral galaxy (Kirkland et al., 2022, Geology). For many cratons, we identify a c. 190 Ma period between step changes in zircon Hf isotope composition, which is similar to the period between galactic spiral arm passage with a statistically significant correlation, suggesting enhanced juvenile crust production and reworking occur during arm transit. Zircon oxygen isotopes show a similar periodicity, with less normal distribution of $\delta^{18}O$ during spiral arm entry, indicating shallow and deep melting during episodes of enhanced bombardment. These correlations imply that episodes of production and reworking of continental crust could have been initiated by giant impacts. Oxygen isotope compositions of dated magmatic zircons from the Pilbara Craton (Johnson et al., 2022, Nature), which was built in three stages, support this conjecture. Stage 1 (3.6–3.4 Ga) zircons form two age clusters, with the younger cluster being contemporaneous with spherule beds; one-third of the zircons record sub-mantle $\delta^{18}O$, indicating crystallization from evolved magmas derived by shallow melting of hydrothermally-altered basaltic crust. These features are consistent with impacting. Stage 2 (3.4–3.0 Ga) zircons, which mostly have mantle-like $\delta^{18}O$, crystallized from TTG-like magmas formed at depth in the evolving craton. Stage 3 (<3.0 Ga) zircons have above-mantle $\delta^{18}O$, indicating efficient recycling of supracrustal rocks. That the oldest surviving felsic crust on Earth formed at 3.9–3.5 Ga, towards the end of the late heavy bombardment, was not a coincidence.