Plate tectonics: When ancient continents collide

Journal Item

[Plate tectonics]

When ancient continents collide

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The geological record preserves scant evidence for early plate tectonics. Analysis of eclogites –rocks formed in subduction zones – in the Trans-Hudson mountain belt suggests modern-style subduction may have operated 1,800 million years ago.

Mountain belts form where tectonic plates collide. The Himalayan mountains, which started forming about 50 million years ago as India rammed into Asia, are Earth's most recent expression of the vast forces involved when two continental plates collide. An outstanding question in Earth history is how far back in time similar modern-style collisional tectonics started. Writing in *Nature Geoscience*, Weller and St-Onge[x] show that the early formation stages of the Trans-Hudson orogen – a 1,800 million year old mountain range that once spanned North America – formed in a similar way to the Himalayas. Their results suggest that the same tectonic processes that bury and deform continental crust during plate collisions today were operating over a billion years earlier than previously thought.

One of the big mysteries of early Earth evolution is when modern-style plate tectonics began. Today plate tectonics involves the formation of oceanic crust at mid-ocean ridges and its destruction in subduction zones at the margins of the ocean basins. Continental crust is a relatively passive bystander in this process – it is created above subduction zones by magmatic activity, yet only rarely destroyed in subduction zones because it is relatively buoyant and doesn't subduct very easily. Continental crust and its underlying mantle (together termed continental lithosphere) only subducts when forced to do so, by being attached to the remnants of oceanic lithosphere as it subducts during the earliest stages of continental collision (Figure 1).

As rocks become buried and deformed, their mineralogy changes to reflect the ambient conditions. These metamorphic minerals provide some of our only clues about how temperature changes with depth deep in the Earth – the geothermal gradient. Specific metamorphic rocks called eclogites form under the cold, high-pressure conditions that characterise modern subduction zons. Ancient eclogites can therefore be used to assess when modern plate tectonics began. Until the discovery by Weller and St Onge, the oldest-known eclogites on Earth were though to have formed 620 million years ago[2]. The dearth of older examples was used to suggest a switch in plate tectonic style from hot, shallow subduction - incapable of producing eclogites - to cold, deep subduction at the start of the Phanerozoic Eon[1].

Weller and St-Onge[x] have identified eclogites exposed in the exhumed roots of the roughly 1,800 million year old Trans-Hudson mountain belt in Canada. These rocks appear to have formed along a similar geothermal gradient to that in modern subduction zones. This discovery implies that relatively cold geothermal gradients existed at least a billion years earlier than previously thought[1]. However because the rocks of the Trans-Hudson orogen have experienced a long and multi-faceted history since their original formation, the researchers needed to prove that the eclogites formed during the early stages of collision and that the history they record was not imprinted during some other tectonic event. This is not trivial, as the minerals that record pressure and temperature are not the same as the minerals that record time, and both can be independently re-set during later tectonic activity.

Weller and St-Onge first show that the eclogites from the Trans-Hudson orogen are exposed in a similar tectonic position to eclogites that formed in the Himalayas. This suggests that they may have formed by similar tectonic processes and at the same relative time in the history of the mountain belt. Furthermore, both Trans-Hudson and Himalayan eclogites formed from continental (rather than oceanic) crust, suggesting that they formed during the very initial stage of continental collision. Weller and St Onge use metamorphic models to predict the mineral compositions expected to form in rocks undergoing subduction. The mineral compositions and amounts observed in the Trans-Hudson eclogites both fit the predictions and are similar to the Himalayan equivalents. Trace-element concentrations in certain minerals, which are sensitive to temperature, provide extra confirmation of the temperature conditions experienced by the eclogites.

To prove the time at which the eclogites formed, Weller and St Onger turned to trace element 'fingerprinting"[3] to link the minerals preserving the time information to the minerals that preserve the pressure-temperature history. Eclogites do not always contain minerals that constrain timing, so Weller and St-Onge instead reconstructed the timing of metamorphism of the host rocks. Specifically, the researchers confirmed that garnet minerals in the host rocks had formed under the same pressure–temperature conditions as garnet in the eclogites. They dated monazite minerals encased in the host rock garnets, thus both constraining the timing of garnet growth and also eclogite formation. Trace element concentrations in the monazites provided further confirmation that they had been growing at the same time as the garnet. The monazite inclusions in the Trans-Hudson garnets were 1,831 million years old, implying both the host rocks and the eclogites experienced peak pressure metamorphism during the early stages of continental collision.

The presence of eclogites – the hallmark of modern-day plate subduction – in the 1,800 million-year old Trans-Hudson orogen implies that tectonic processes operating during the Proterozoic were remarkably similar to those operating on Earth today. The continental collision that created the Trans-Hudson orogen resulted in the subduction of continental lithosphere under geothermal gradients that were as cool as those in present-day subduction zones. The Earth's mantle is therefore unlikely to have experienced dramatic cooling the past one to two billion years. It appears that the previously proposed apparent change in plate tectonic style could simply be an artefact of the ravages of time, erosion, and later reworking and overprinting.

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