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On the emergence of continents during the early evolution of the Earth's mantle: insights from analogue modeling

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The mantle convective pattern during the first half of Earth history is still debated, and major questions such as whether plate tectonics was already operating and the timing of continental growth remains unresolved. The difficulty stems from the complex rheology of mantle rocks (from viscous to brittle as temperature decreases), the presence of partial melt, and the physics of thermal convection, all of which are poorly understood in such materials. We recently discovered a material, -aqueous dispersions of colloidal nanoparticles-, that has rheological properties analogue to those of the mantle. We therefore undertook a systematic laboratory study of convection in such fluids, using an apparatus in which the fluid was continuously cooled and evaporated from above, with or without heating from below.

Our experiments always show an evolution through different regimes, as a plastic skin ("lithosphere") forms and thickens at the surface while its rheological behaviour changes through time. An initially very soft lithosphere produces a stagnant lid regime of convection, which then evolves in episodic, and finally continuous, recycling of the surface layer. This sequence corresponds to the transiton from episodic to continuous subduction that characterizes the initiation of plate tectonics. We observe that pre-existing continents (i.e. buoyant rafts), as well as hot plumes are very influential in triggering subduction, usually on their edges. In the absence of hot plumes, continuous plate tectonics was never observed. On Earth, the association between plumes and subduction may be instrumental in the nucleation and growth of cratons. Moreover, strong plume episodes are seen to enhance the formation of the first supercontinents.

We use this new fluid dynamics framework to interpret the geochemical, geological and petrological data and propose a scenario of evolution of the Earth in the first two billion years of its evolution.