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VOLCANOLOGY

Flood basalt buildup warms climate

Flood basalts are connected to Earth's most extreme environmental crises, yet warming is sometimes observed before surface eruptions. Modelling reveals that a complex buildup of basalt intrusions into the crust releases enough CO_2 to cause this pre-eruptive warming.

Jennifer Kasbohm

Flood basalts and other large igneous provinces (LIPs) are Earth's most extreme magmatic events. They can erupt millions of cubic kilometres of lava in a few million years or less and their ages can be correlated with biotic and climatic crises[1]. However, the mechanisms linking LIP emplacement and the ensuing crises are not well understood. Writing in *Nature Geoscience*, Tian and Buck[2] show that the formation of subsurface sills and dykes prior to the extrusive flood basalt eruption at the surface triggers the release of greenhouse gases and explains evidence of global warming preceding surface eruptions (Fig. 1).

As LIPs intrude the crust or erupt onto Earth's surface, they release gases that cool the climate on short timescales and cause global warming on long timescales[3]. The Deccan Traps and Columbia River Basalt Group, two of Earth's best-studied LIPs, show broad temporal correlation with Cretaceous/Palaeogene warming and boundary extinction that resulted in the death of the dinosaurs[4] and the global warming of the Miocene Climate Optimum[5], respectively. However, ascribing a causal role for the LIPs is complicated by the fact that analytical and modelling efforts have suggested that greenhouse gases contained in the flood basalts themselves would be insufficient to cause either the end-Cretaceous[6] or the Miocene[7] environmental disruption. Indeed, comparisons of carbon cycle modelling to palaeotemperature records have suggested that Deccan Traps volcanism was not relevant to the Cretaceous/Paleogene extinction, because the bulk of CO_2 appears to have been released prior to surface eruptions and long before the extinction itself[8].

Tian and Buck model the path of the flood basalt magma from a mantle plume to the surface and propose that a complex subsurface sill architecture is required for LIP eruption. They show that for molten basaltic lava to reach the surface, it must be less dense than the crust through which it travels, a condition that is not initially met because the Earth's crust is typically less dense than basalt. The magma therefore pools 20 km below the surface in a horizontal sheet called a sill. This sill warms the crust and alters its density such that subsequent sills can be emplaced closer to the surface. Eventually, when the entire upper crust is packed with cool basalt, warm lava may erupt to the surface.

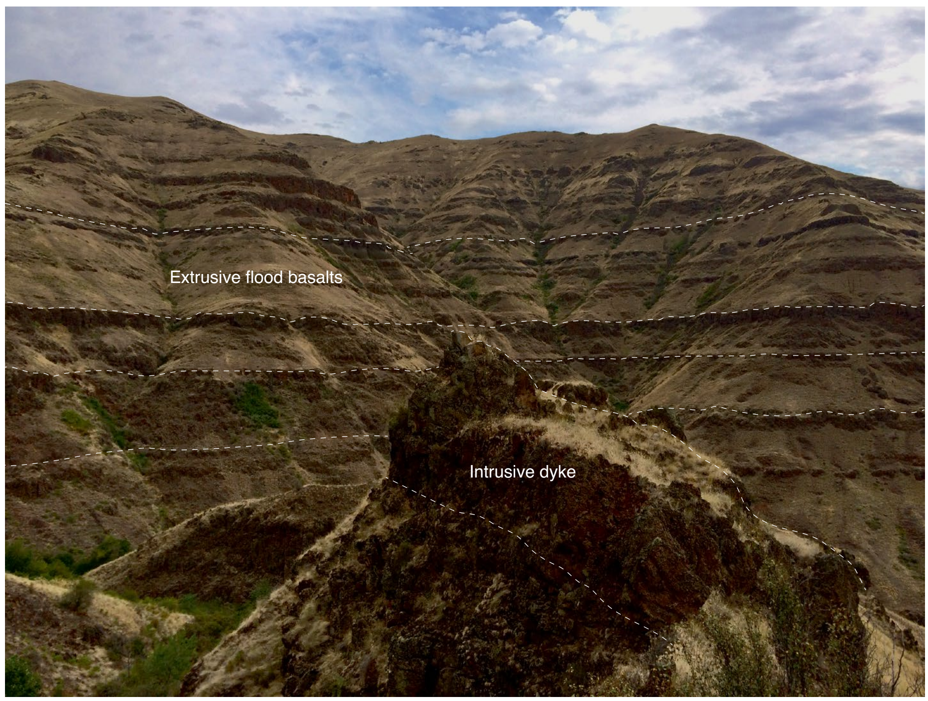

Fig. 1 | Columbia River Basalt Group, WA, USA. Tian and Buck[2] model the emplacement of large igneous province intrusive sills and suggest that the development of a complex subsurface sill architecture can emit sufficient greenhouse gases to explain the temporal mismatch between climate warming and the extrusive eruption of flood basalt lavas (as seen in the background). Feeder dykes (as seen in the foreground) are intrusive units that carried magma from sills to surface lava flows. Credit: Jennifer Kasbohm.

Crucially, Tian and Buck find that this process takes hundreds of thousands of years, and that crystallization in the sills releases an enormous quantity of CO_2 that far exceeds the amount expected from the flood basalt lava flows alone. Using the case studies of the Deccan Traps and Columbia River Basalt Group, Tian and Buck feed the timing and quantity of CO_2 outgassing calculated by their multi-sill model into a climate model. They are able to replicate both the end-Cretaceous warming and the onset of warming in the Miocene, both of which preceded flood basalt surface eruptions by a few hundred thousand years. The study therefore makes a critical connection between the solid Earth processes that lead to the construction of a LIP, and the paleoclimate records of its hypothesized effects.

Tian and Buck's model provides a useful framework for understanding the requirements for flood basalt eruptions. However, as is the case with any model, it cannot account for all geologic complexity. For example, it is unclear how Tian and Buck's framework explains recent geochronology from the Deccan Traps[4] that suggests that surface eruptions were already beginning at the onset of sill emplacement, or the formation of the largest continental flood basalts, the Siberian Traps, where extrusive volcanism was followed, rather than preceded, by widespread sill intrusion[9]. Variable chemistry of lavas through a flood basalt pile and model sensitivity to background CO_2 and other environmental conditions are also not addressed by their work.

With anthropogenic release of CO_2 driving modern climate change, it behooves us to better understand the processes that drove environmental and biotic crises in the past. Contributing to this endeavour, Tian and Buck show that the lag between observed warming and surface eruptions may be explained by the outgassing of CO_2 as subsurface sills developed over hundreds of thousands of years before the onset of volcanism. Ultimately, understanding the causes and consequences of LIP emplacement and, crucially, how the Earth's system recovered, will require similarly cross-disciplinary and quantitative work. ❐

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Competing interests

The author declares no competing interests.