Environmental Effects of Large Igneous Provinces

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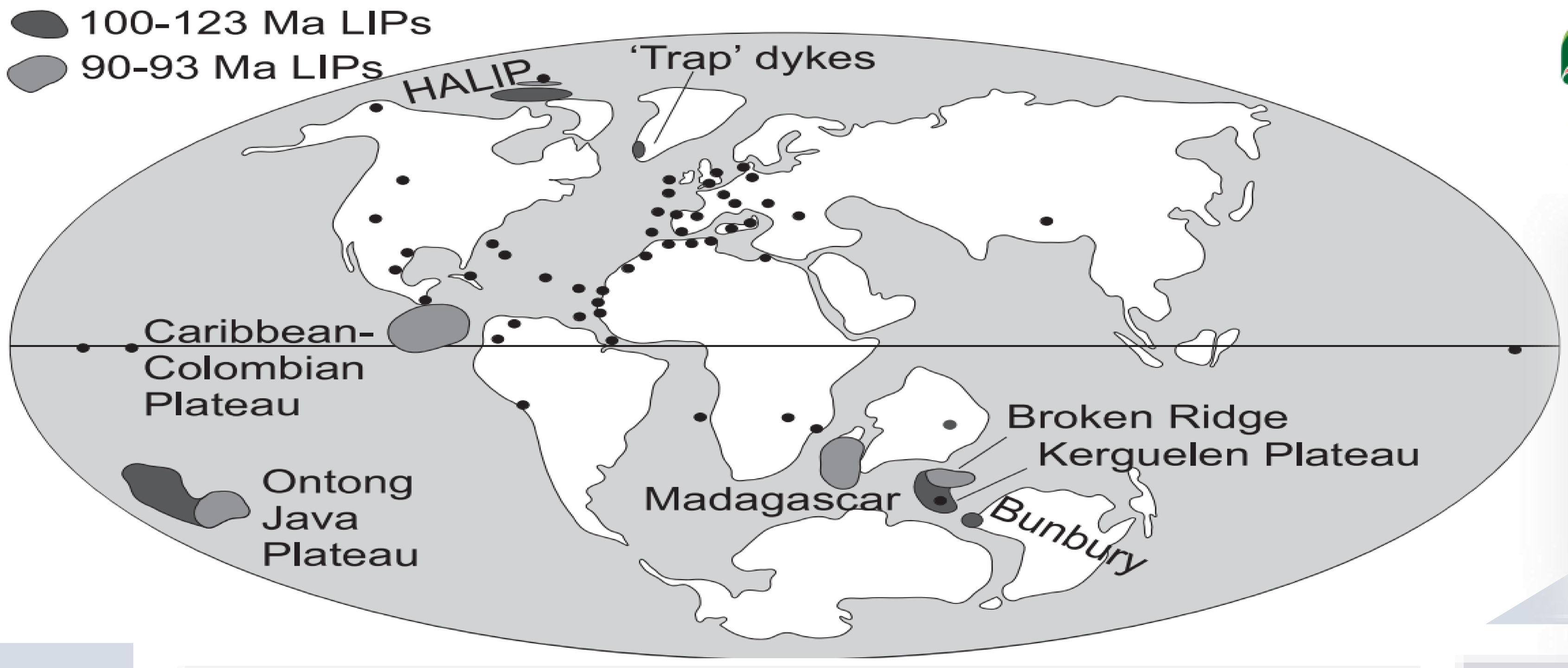
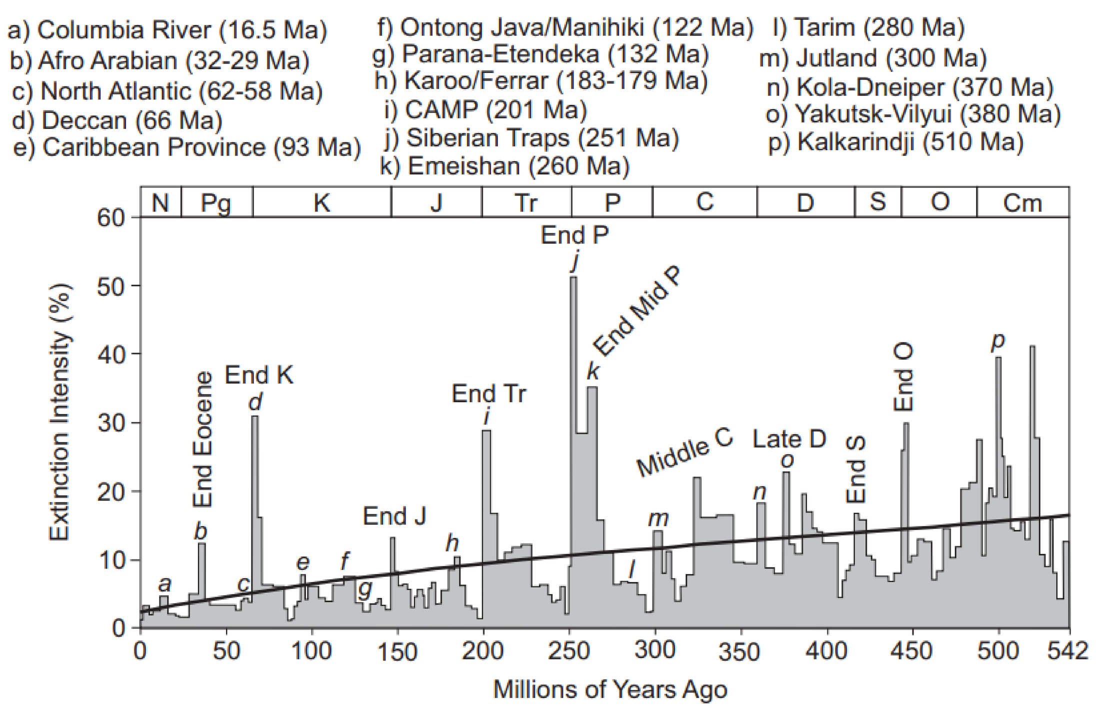
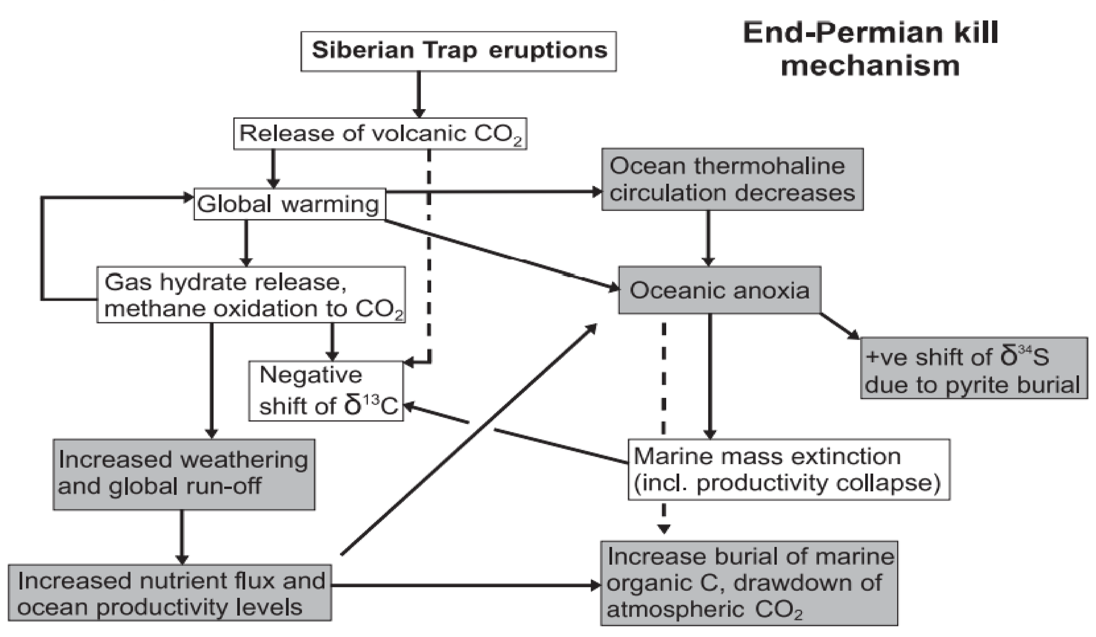


The distribution of life through the Phanerozoic is highly variable, primarily as a result of environmental changes. The most dramatic and sudden changes are associated with extinction events; these define many of the boundaries in the biostratigraphic time scale. Less extreme environmental changes are also recorded by excursions in the isotopic composition of seawater and in the distribution of anoxia events, and by sea-level changes. This investigative study provides a snapshot of the fast changing field and introduce the environmental impact of Large Igneous Provinces (LIPs) on climate change, and as catalysts for faunal and floral collapse and extinction events.

The temporal link between LIPs and extinction events appears robust. Many major, and some minor, LIP events occur within several million years or less of global extinctions. For example, the Deccan (c. 65 Ma), Central Atlantic Magmatic Province (CAMP; 201 Ma), and Siberian Trap (252 Ma) LIPs match in age to the Cretaceous–Tertiary, Triassic–Jurassic, and Permian–Triassic boundary extinctions, respectively. Only the major Ordovician–Silurian boundary extinction has not been correlated with a LIP event, although recent research has identified a c. 440 Ma dolerite Suordakh event in eastern Siberia, but the scale of this event remains unknown pending dating of additional mafic units in the region. Although several LIP–extinction correlations have been identified, the eruption volume of the LIP appears to be unrelated to the intensity of the extinction event. Most dramatically, the largest LIP event, the reconstructed c. 120 Ma Ontong Java–Manihiki–Hikurangi oceanic plateau at c. 80 Mkm3, is not associated with an extinction event, but is associated with an anoxia event, the Aptian-aged Selli event. The absence of a strong relationship between LIP size and magnitude of extinction event underlines the complexity of this relationship. Other parameters besides volume presumably have a very important role in determining the environmental impact of a LIP.

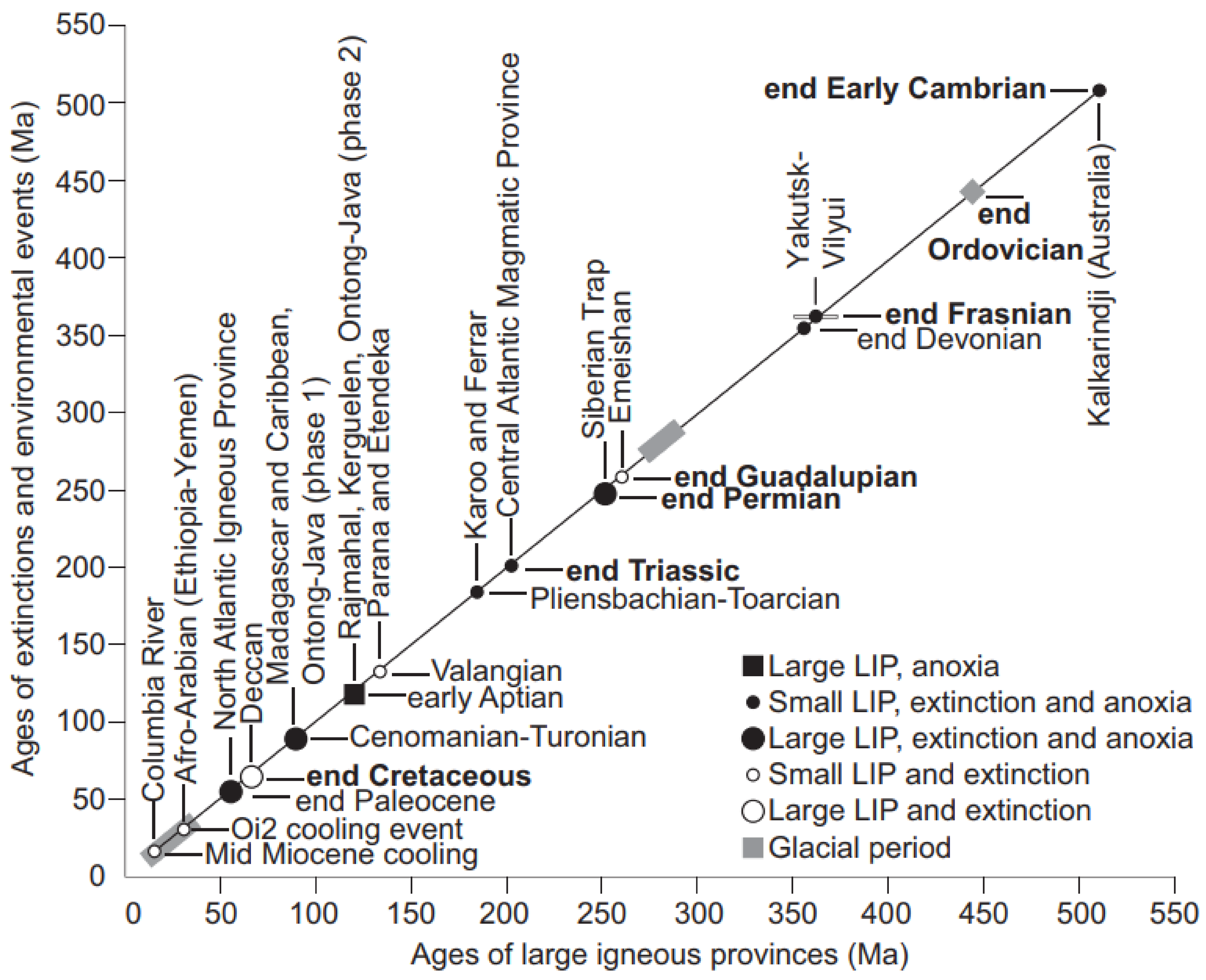


Correlation of volcanic eruption events with extinction events. This figure shows the genus extinction intensity, i.e., the fraction of genera that are present in each interval of time but do not exist in the following interval.



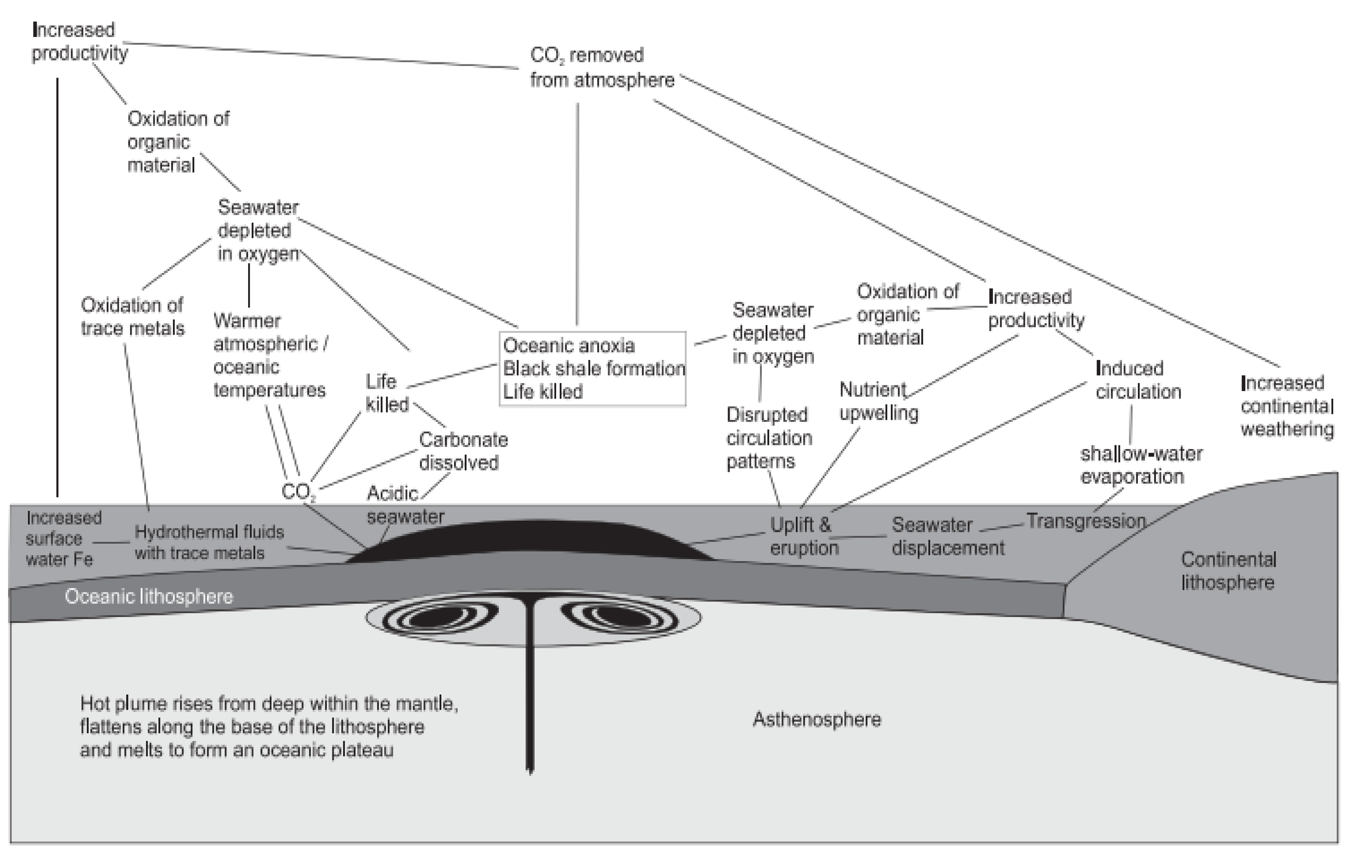
Web of events caused by the eruption of the Siberian Trap LIP which could serve as a model for the effect of continental LIPs on the environment. These indicate the effects linked to the end-Permian mass-extinction event associated with the Siberian Trap LIP. Boxes with gray fill indicate effects which are not part of the end-Triassic extinction

There is clearly a broad link in time between LIP events and extinction events and anoxia events, and also with seawater isotopic compositions. But in order to infer a causal relationship the time matches must be exact. So, for instance, if a LIP event entirely postdates the onset of extinction, then the link will be less likely. Nearly all LIP events have been isotopically dated, frequently to a resolution of a few million years or less. However, much of the seawater isotope data and Phanerozoic sea-level, impact, and extinction data are assigned ages based on interpolation from dated horizons. Unfortunately, there can be distinct differences between the ages assigned to stage boundaries. However, these concerns are becoming less significant given the recent advances in comparing biostratigraphic and isotopic dating, and it is probable that the most recent versions of the biostratigraphic time scale are converging to the isotopically correct ages for most stage boundaries.



Correlation between timing of major volcanic eruptions and global environmental effects

There has been a heated debate for more than two decades over whether global extinctions are caused by meteorite impacts or LIP events. Those supporting the impact connection cite the close correspondence in age between the large Chicxulub impact, associated with a large iridium anomaly, and the K–T extinction event. Other correlations between large impacts and extinctions are less clear because of the uncertainty in the ages of most large impacts or, in some cases, because of uncertainty in the age of the extinction events. In some cases, it has been proposed that multiple impacts are required for an observable effect, and that the extinction event itself lags the impacts by several million years. It is also proposed that global extinctions may be caused by more than one mechanism, and that even individual extinction events may have multiple causes. For instance, the combined "one–two punch" of a bolide impact and a LIP may be required for the largest extinctions.



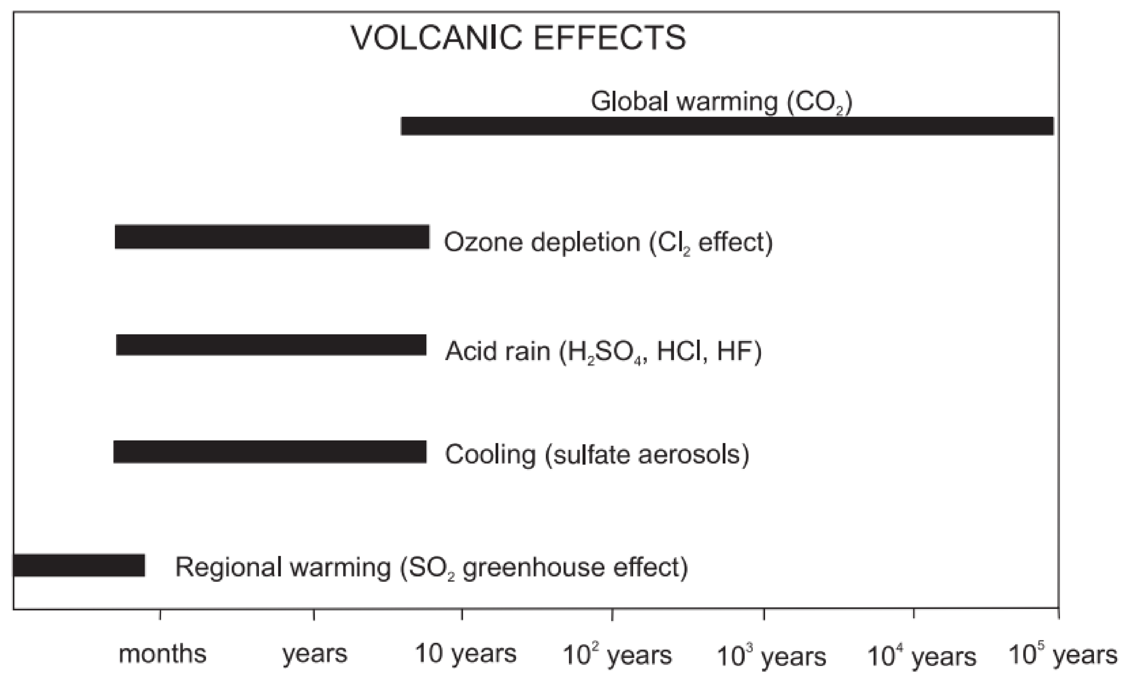
Physical and chemical environmental effects of oceanic-plateau formation.

Discussion

A mechanism proposed for linking the effects of impacts and LIPs in time (ensuring a one–two punch) is through the genetic model of impact-triggered LIPs. However, the ability of an impact to cause flood-basalt magmatism has been questioned by the analyses of Loper and McCartney (1990) and Ivanov and Melosh (2003).

The link between LIPs and extinction events has become remarkably robust. At the same time the only bolide impact with a robust link to an extinction is the Chicxulub impact in Yucatan, Mexico, linked with the Deccan LIP in a one–two "punch" to cause the end Cretaceous extinction. Individual volcanic eruptions can dramatically affect the climate system on a range of time scales from days to years.

An important factor is the release altitude, since gases and particles that are released into the stratosphere as aerosols will have a greater and longer lasting effect on climate (1– 3 years) than material reaching only the tropospheric level (1–3 weeks). Also, aerosol clouds produce cooling at the surface but heating in the stratosphere.



Effects of volcanic gases and the intervals over which they operate. Apart from CO2, most gases are rapidly removed from the atmosphere

Conclusion

LIPs can have a significant environmental effect as monitored by sedimentary isotopic compositions that record seawater composition, and numerous LIP events are temporally correlated with extinction events.

The environmental effects that can contribute to the extinction effectiveness of LIPs include rapid temperature changes due to greenhouse-gas emission, release of clathrates, cooling due to CO2 drawdown by weathering, sea-level changes, and oceanic anoxia events, amongst other effects.

The size of the LIP is not a dominant control, although some of the largest LIPs (e.g., the Siberian Trap) have larger environmental effects. However, the largest LIP (the reconstructed Ontong Java–Manihiki–Hikurangi oceanic plateau) only had a modest extinction effect, indicating that other aspects of LIPs, besides size alone, are also important.

Arguably the most important factor in determining the environmental impact of a LIP event is terrane, both the local terrane with which the intrusive magma is interacting and, more globally, the rock types exposed at the surface that interact with the atmosphere during the LIP event.

Another more widespread effect is the causal relationship between global warming and the destabilization of clathrates; the consequent release of great volumes of greenhouse gases acts to further increase global warming.

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