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Mafic volcaniclastic deposits in flood basalt provinces: A review

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Abstract

Flood volcanic provinces are assumed generally to consist exclusively of thick lavas and shallow intrusive rocks (mostly sills), with any pyroclastic rocks limited to silicic compositions. However, mafic volcaniclastic deposits (MVDs) exist in many provinces, and the eruptions that formed such deposits are potentially meaningful in terms of potential atmospheric impacts and links with mass extinctions. The province where MVDs are the most voluminous—the Siberian Traps—is also the one temporally associated with the greatest Phanerozoic mass extinction. A lot remains to be learned about these deposits and eruptions before a convincing genetic link can be established, but as a first step, this contribution reviews in some detail the current knowledge on MVDs for the provinces in which they are better known, i.e. the North Atlantic Igneous Province (including Greenland, the Faeroe Islands, the British Isles, and tephra layers in the North Sea basin and vicinity), the Ontong Java plateau, the Ferrar, and the Karoo. We also provide a brief overview of what is known about MVDs in other provinces such as the Columbia River Basalts, the Afro-Arabian province, the Deccan Traps, the Siberian Traps, the Emeishan, and an Archean example from Australia.

The thickest accumulations of MVDs occur in flood basalt provinces where they underlie the lava pile (Faeroes: >1 km, Ferrar province: $\geq$400 m, Siberian Traps: 700 m). In the Faeroes case, the great thickness of MVDs can be attributed to accumulation in a local sedimentary basin, but in the Ferrar and Siberian provinces the deposits are widespread ($>3\times10^5$ km^2 for the latter). On the Ontong Java plateau over 300 m of MVDs occur in one drill hole without any overlying lavas. Where the volcaniclastic deposits are sandwiched between lavas, their thickness is much less.

In most of the cases reviewed, primary MVDs are predominantly of phreatomagmatic origin, as indicated by the clast assemblage generally consisting of basaltic clasts of variable vesicularity (dominantly non- to poorly-vesicular) mixed with abundant country rock debris. The accidental lithic components often include loose quartz particles derived from poorly consolidated sandstones in underlying sedimentary basins (East Greenland, Ferrar, Karoo). These underlying sediments or sedimentary rocks were not only a source for debris but also aquifers that supplied water to fuel phreatomagmatic activity. In the

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Paraná–Etendeka, by contrast, the climate was apparently very dry when the lavas were emplaced (aeolian sand dunes) and no MVDs are reported.

Volcanic vents filled with mafic volcaniclastic material, a few tens of metres to about 5 km across, are documented in several provinces (Deccan, North Atlantic, Ferrar, Karoo); they are thought to have been excavated in relatively soft country rocks (rarely in flood lavas) by phreatomagmatic activity in a manner analogous to diatreme formation.

Keywords: flood basalts; phreatomagmatism; pyroclastic; tuff; volcaniclastic; mafic

1. Introduction

Flood basalt volcanism remains a popular explanation for the cause of certain Phanerozoic mass extinctions because of apparent temporal links (e.g., Rampino and Stothers, 1988; Stothers, 1993; Courtillot, 1994; Rampino and Self, 2000; Courtillot and Renne, 2003; White and Saunders, 2005). However, as Wignall (2001) writes, "the [physical] link between large igneous province formation and [mass] extinctions remains enigmatic". One of the mechanisms by which flood basalts can affect the global environment is the cooling effect of huge amounts of sulphate aerosols generated by injection of volcanic SO_2 into the stratosphere (e.g., Devine et al., 1984; Sigurdsson, 1990; Campbell et al., 1992; Renne et al., 1995). Degassing of flowing lava is unlikely to have more than regional atmospheric impacts (haze), but very vigorous basaltic fire fountaining, invoked for example for the Roza eruption in the Columbia River Basalts, might be capable of injecting SO_2 into the stratosphere (Thordarson and Self, 1996).

Attention has turned recently to caldera-forming ignimbrite eruptions for their potential to inject volatiles high in the atmosphere (e.g. Bryan et al., 2002; Jerram, 2002), but generally dacitic and rhyolitic magmas are relatively sulphur-poor, at least compared to mafic magmas (e.g., Devine et al., 1984; Wallace and Anderson, 2000). Consequently, unless silicic magmas in flood volcanic provinces are unusually rich in sulphur (which there is no suggestion of so far), or are erupted in the course of highly explosive eruptions occurring in quick succession, they seem unlikely candidates for extensive and prolonged environmental impacts if sulphur is indeed the culprit.

One possible means of injecting potentially high amounts of SO_2 into the stratosphere would be explosive mafic eruptions. At the present time, there exists a perception that "with the notable exception of the Siberian traps, [mafic] pyroclastics are conspicuously absent from flood basalts" (Cordery et al., 1997). However, recent studies focusing specifically on mafic volcaniclastic deposits (MVDs) within a number of flood basalt provinces, including the Ferrar (Hanson and Elliot, 1996; Elliot, 2000; Elliot and Hanson, 2001), and North Atlantic (Heister et al., 2001; Ukstins Peate et al., 2003a; Larsen et al., 2003), have shown that MVDs are a common and often important component of flood basalt volcanism (Table 1, Fig. 1). In extreme cases such as the Siberian Traps, MVDs are thought to represent about a quarter of the total volume of the province, at least on the Siberian platform (Viswanathan and Chandrasekharam, 1981).

The potential environmental impact of mafic explosive eruptions associated with flood basalts cannot be properly assessed without: (1) understanding the role and timing of MVDs in such provinces, their mechanisms of formation and emplacement, lateral distribution and volumetric contribution to flood volcanism; (2) acquiring more data on the pre-eruptive volatile contents of the involved magmas; and (3) modelling the eruption plumes for individual eruptions of known volume and dispersion, and in particular the height of release of volatiles in the atmosphere. This paper contributes towards the first of these goals especially by reviewing the occurrence of explosively-generated MVDs in the flood basalt provinces where they are so far best documented, i.e. the North Atlantic Igneous Province, the Ontong Java plateau and the Ferrar and Karoo provinces. We also provide, for the sake of completeness, a brief overview of the little that is known about MVDs in other provinces such as the Columbia River Basalts, the Afro-Arabian province, the Deccan Traps, the