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Frontiers in Large Igneous Province research

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Abstract

Earth history is punctuated by events during which large volumes of mafic magmas were generated and emplaced by processes distinct from "normal" seafloor spreading and subduction-related magmatism. Large Igneous Provinces (LIPs) of Mesozoic and Cenozoic age are the best preserved, and comprise continental flood basalts, volcanic rifted margins, oceanic plateaus, ocean basin flood basalts, submarine ridges, ocean islands and seamount chains. Paleozoic and Proterozoic LIPs are typically more deeply eroded and are recognized by their exposed plumbing system of giant dyke swarms, sill provinces and layered intrusions. The most promising Archean LIP candidates (apart from the Fortescue and Ventersdorp platformal flood basalts) are those greenstone belts containing tholeiites with minor komatiites. Some LIPs have a substantial component of felsic rocks. Many LIPs can be linked to regional-scale uplift, continental rifting and breakup, climatic shifts that may result in extinction events, and Ni–Cu–PGE (platinum group element) ore deposits.

Some current frontiers in LIP research include:

(1) Testing various mantle plume and alternative hypotheses for the origin for LIPs.
(2) Characterizing individual LIPs in terms of (a) original volume and areal extent of their combined extrusive and intrusive components, (b) melt production rates, (c) plumbing system geometry, (d) nature of the mantle source region, and (e) links with ore deposits.
(3) Determining the distribution of LIPs in time (from Archean to Present) and in space (after continental reconstruction). This will allow assessment of proposed links between LIPs and supercontinent breakup, juvenile crust production, climatic excursions, and mass extinctions. It will also allow an evaluation of periodicity in the LIP record, the identification of clusters of LIPs, and postulated links with the reversal frequency of the Earth's magnetic field.
(4) Comparing the characteristics, origin and distribution of LIPs on Earth with planets lacking plate tectonics, such as Venus and Mars. Interplanetary comparison may also provide a better understanding of convective processes in the mantles of the inner planets.

In order to achieve rapid progress in these frontier areas, a global campaign is proposed, which would focus on high-precision geochronology, integrated with paleomagnetism and geochemistry. Most fundamentally, such a campaign could

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help hasten the determination of continental configurations in the Precambrian back to 2.5 Ga or greater. Such reconstructions are vital for the proper assessment of the LIP record, as well as providing first-order information related to all geodynamic processes.

Keywords: Large igneous province; Flood basalt; Oceanic plateau; Greenstone belt; Komatiite; Dyke swarm

1. Introduction

Large Igneous Provinces (LIPs) have been defined by Coffin and Eldholm (1994) as "massive crustal emplacements of predominantly mafic (Mg and Fe rich) extrusive and intrusive rock which originate via processes other than "normal" seafloor spreading. . . . [and] include continental flood basalts, volcanic passive margins, oceanic plateaus, submarine ridges, seamount groups and ocean basin flood basalts". For the present paper, we explicitly exclude large magmatic events associated with 'normal' subduction processes. We also note that some LIPs may have substantial felsic components (Campbell and Hill, 1988; Bryan et al., 2002).

LIPs occur throughout Earth's history (Isley and Abbott, 1999; Ernst and Buchan, 2001a, 2002; Isley and Abbott, 2002; Fig. 1). Those of Mesozoic and Cenozoic age are the best studied. They most prominently include both continental and oceanic flood basalts, and the former are commonly associated with volcanic rifted margins (e.g., Cox, 1980; White and McKenzie, 1989; Coffin and Eldholm, 1994, 2001; Storey, 1995; Menzies et al., 2002a). Important examples include the 62–56 Ma North Atlantic Igneous Province (NAIP), the 182 Ma Karoo–Ferrar event, the 250 Ma Siberian Traps (Fig. 2A) and the 122 Ma 'greater' Ontong Java event in the Pacific Ocean (Fig. 2B). Paleozoic and Proterozoic LIPs are typically more deeply eroded, exposing their plumbing system of giant dyke swarms, sill provinces and layered intrusions (e.g., Baragar, 1977; Fahrig, 1987; Ernst and Buchan, 1997a,b; 2001a,b; Pirajno, 2000; Condie, 2001). For example, the 1270 Ma Mackenzie giant radiating dyke swarm of the Canadian Shield fans over 100° of arc and extends for more than 2300 km from its focal point (Fig. 3A). In other cases (e.g., Fig. 3B), the distribution of sills, layered intrusions, dykes and volcanics appears less systematic. Flood basalts also occur in the Archean (e.g., Fortescue, Fig. 4A, and Ventersdorp volcanics; e.g., Eriksson et al., 2002). However, most Archean mafic–ultramafic magmatism occurs as deformed and fragmented packages termed greenstone belts. Those Archean greenstone belts that contain thick tholeiite sequences with minor komatiites (Campbell et al., 1989; Nelson, 1998; Arndt, 1999; Kerr et al., 2000; Tomlinson and Condie, 2001; Bleeker, 2002; Arndt, 2003) are excellent candidates for LIPs. An example in the Rae craton of northern Canada (Fig. 4B) extends for more than 1000 km and consists of 2730–2700 Ma komatiite-bearing greenstone belts of the Woodburn Lake, Prince Albert, and Mary River groups (e.g., Schau, 1997; Aspler et al., 1999; Zaleski et al., 2001; Skulski et al., 2003). LIPs have been recognized on Mars, Venus and the Moon where they provide complementary information to that from Earth (Head and Coffin, 1997; Ernst and Desnoyers, 2004).

Coffin and Eldholm (2001) defined the minimum size of a LIP in terms of an areal extent of at least 0.1 Mkm^2, thus including small continental flood basalts (e.g., Columbia River) and small oceanic plateaus (e.g., Shatsky Rise, Magellan Rise, Maud Rise, Wallaby Plateau). However, most Cenozoic and Mesozoic LIPs (Eldholm and Coffin, 2000; Courtillot and Renne, 2003) originally covered >1 Mkm^2. Courtillot and Renne (2003) estimated the volume of the extrusive components of most Mesozoic and Cenozoic continental flood basalts at 2–4 Mkm^3 and that of the Ontong Java oceanic plateau at 6 Mkm^3 (compared with 44.4 Mkm^3 for combined extrusive and intrusive components of Ontong Java). In the ocean basins, a LIP is manifested as oceanic crust that covers an area >0.1 Mkm^2 and has a thickness of at least 10 km, in contrast to the 7-km thickness of normal oceanic crust. In older LIPs where much or all of the volcanic component of the LIP has been lost to erosion, the area encompassed by the exposed plumbing system (i.e., dykes, sills and layered intrusions) is used as the measure of event size