Attention has recently been drawn to large igneous provinces on Earth, which are defined as regions characterized by transient large-scale intrusive and extrusive activity, including continental flood basalt (CFB) provinces (e.g., the Deccan Traps), volcanic passive margins (e.g., the Voring Margin), oceanic plateaus (e.g., the Ontong Java Plateau), ocean basin flood basalts (e.g., the Carribean Flood Basalts), and large seamount chains (e.g., Hawaiian-Emperor) (1). Commonly analyzed separately in the past, recent studies (2,3) have shown that there are important temporal, spatial, and compositional relationships among terrestrial large igneous provinces, informally referred to as LIPs.

These studies, and numerous others that document individual occurrences, show that the genesis and evolution of LIPs are closely linked to mantle dynamics, that LIPs represent major global events (large volumes of lava and associated intrusives are commonly produced in short episodes, and their emplacement had potentially major effects on the global environment), and that emplacement of some LIPs may be related to changes in rate and direction of plate motion. There is a possible episodicity in their formation but modification and destruction of older examples, and oceanic cover of others, makes this difficult to determine. Although several models have been proposed for the emplacement of LIPs (primarily associated with mantle plumes)(4,5,6), these models are not yet well constrained by observations. At present only a limited, but growing, amount of quantitative data is available to constrain associated mantle and crustal processes, to constrain LIP dimensions, durations, rates of emplacement, crustal structure, and relationship to tectonism, and to reliably predict environmental effects of LIP formation.

Large igneous provinces are also common on the terrestrial planets other than the Earth (7) and their presence, characteristics, and geologic and temporal settings offer a potentially important perspective for LIPs on Earth. For example, unlike the Earth, the majority of which is covered by water and virtually unknown at high resolution, global imaging coverage exists for the solid surface of the Moon and Mars, and Magellan has imaged over 98% of Venus at ~200 m resolution. In addition, exposure and preservation are excellent due primarily to fewer erosional agents, minimal erosional rates, and relatively stable lithospheres. Stable lithospheres also mean that longer time intervals are available for study. The age of two-thirds of the Earth’s surface (the ocean basins) is less than 5% of the age of the planet; the majority of the surface of the Moon and Mars, however, dates to the first half of Solar System history. Terrestrial planetary bodies, by virtue of their number, offer multiple examples for study. Thus, LIPs might be studied in different places on one planet and between several planets. Similarly, the terrestrial planets provide an opportunity to assess how different environmental conditions (e.g., different crustal and thermal structure) might influence the formation and effects of large igneous provinces. Furthermore, the segmented, laterally moving, and constantly renewing terrestrial lithosphere both insulates and obscures the view of many mantle convection processes, and indeed is an active influence on these processes. The perspective offered by one-plate planets (8) such as the Moon, Mars, Mercury, and Venus can illustrate the long-term influences of mantle plumes and their variations under different thermal conditions in space and time. The multiple, well-exposed examples of LIPs on the planets can also help to reveal their relation to tectonic structure. For example, Venus has tens of thousands of km of exposed rift zones (9) which display a wide variety of igneous centers (9, 10), many of which are LIPs. Finally, the planetary record can be instructive in terms of the chronology and episodicity of large igneous events and provinces. The extended historical record permits an assessment of changes in the style of LIPs with time (potentially linked to thermal evolution, for example), and the frequency at any given time. Although there is a paucity of radiometric dates from the planetary record, clues from well-exposed deposit morphology can sometimes even be used to estimate single event duration (11). Finally, the planetary record can offer an end-to-end perspective on many processes associated with LIPs. For example, lateral plate movement on Earth in the case of the Hawaiian-Emperor seamount chain helps to illustrate many of the stages in the development of hot spots by spreading the signature out into a series of volcanic edifices; this same process, however, destroys the signature of the initial event in the
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plume history. On the planets, particularly Venus, the end-to-end process of mantle plumes can be studied (e.g., the relation of thermal uplift, tectonics, and volcanism in a single example and from examples in different stages of formation) (12) and compared to Earth. In summary, the planetary record, in concert with the detailed examination of examples on Earth, should be of use in developing and testing models for the emplacement of LIPs, and in helping to distinguish plate tectonic influences from those linked to deeper interior (mantle and core) processes.

Examples of large igneous provinces from the terrestrial planets illustrate these points. On the Moon, the relatively low density anorthositic crust creates a density trap for rising basaltic magmas which collect in reservoirs at the base of the crust (13); shallow magma reservoirs and large shield volcanoes are not known (14). Reservoir overpressurization causes wall failure and dikes are propagated into the crust and toward the surface. The geometry is such that dikes sufficiently large to reach the surface are likely to result in large-volume, high effusion rate eruptions (15); indeed, single eruptive phases on the Moon are predicted and observed to be in the range of several hundred to over \(10^3\) km\(^3\) (16-18). Indeed some individual eruptions may have been characterized by effusion rates of the order of \(1.2 \times 10^3\) km\(^3\) per year. This record may provide clues to the nature of similar terrestrial eruptions, a number of which combine together over short time periods to form LIPs such as the Columbia River Basalt.

On Mars, massive shield volcanoes are formed on the stable lithosphere over long-duration hot spots; shield heights are up to 25 km above the surrounding plains, which themselves are atop the 10 km high, several thousand km diameter Tharsis rise (19). Volumes of single edifices are of the order of \(1.5 \times 10^6\) km\(^3\), comparable to the volumes for the Columbia River, Karoo, Parana, Deccan and NAVP basalt provinces on Earth. The lower gravity on Mars causes dikes and vents to be wider and eruptions to be characterized by higher effusion rates; compositionally similar cooling-limited lava flows on Mars would be about six times longer than on Earth (20).

On Venus, the high atmospheric pressure influences gas exsolution, rock vesicularity and density, and the presence and distribution of neutral buoyancy zones (21). At low elevations, neutral buoyancy zones are not predicted, a situation favoring the direct ascent and outpouring of lavas, and low intrusion/extrusion ratios. Indeed, extremely large volcanic outflows are observed (22), covering areas of \(1.8-3 \times 10^9\) km\(^2\) (23), and some lava channels are in excess of several thousand km in length (24). In addition, the impact cratering record on Venus has been interpreted to mean that Venus underwent massive planet-wide volcanic resurfacing about 500 my ago (25), an event possibly related to the overturn of a depleted mantle layer resulting from the vertical accretion of a basaltic crust (26). This hypothesized event could be the equivalent of a "planet-wide" large igneous province.