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The Colossal Nature of Past Volcanic Activity on Earth

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Evidence of volcanic activity is seen at various levels of the geologic column. Examples include lava flows from effusive eruptions, pyroclastic deposits from explosive eruptions, magmatic veins or bodies that intruded and cooled deeper down in the earth's crust, or reworked volcanic sediments. Volcanic activity today is linked predominantly to two settings: plate tectonic boundaries and mantle anomalies associated with upwelling of hotter mantle material. Conventionally, the process of plate tectonics is held to be continuous and relatively uniform; however, the emergence of mantle anomalies is often envisaged as sporadic, rapid, and catastrophic. The source of mantle anomalies is still disputed, but plate tectonics is believed to be the main driver, either triggering shallow mantle upheaval or generating deep mantle plumes from subduction and accumulation of crustal slabs at the core-mantle boundary. Meteorite impacts have also been suggested to create mantle anomalies.

Large Igneous Provinces

The surface expression of mantle anomalies that push through the crust are large volcanic areas. Volcanism associated with these anomalies occur both in continental and oceanic settings and may be located within plates (intraplate) or coincide with plate boundaries. The volcanics include predominantly widespread and voluminous basaltic lava flows but also include some silicic rocks. Massive volcanic areas of this type have been termed Large Igneous Provinces (LIPs),[1] and some of the best known examples include the Deccan traps, Paraná-Etendeka Basalts, Columbia River Basalts, Siberian traps, North Atlantic Igneous Province, Ontong Java Plateau, and Karoo Basalts.

LIPs are found throughout the entire geological record. Although difficult to assess because of preservational bias, activity appears to have been high in the Precambrian, with production of rare primitive magmas as komatiites, often interpreted as associated with a stage when the earth was hotter. Also within the Precambrian, we find gigantic dike swarms thousands of kilometers long, such as the Mackenzie dike swarm in Canada, that testify of volcanic events on scales of continental proportions. A few LIPs can be found in the lower Paleozoic, but LIPs are abundant again in the Mesozoic rock record, with massive outpourings of lava in every continent. Although less common in Cenozoic rocks, a few LIPs of significant size formed in the Neogene. This stratigraphic distribution can be ascertained independently from the time frame adopted for the formation of the geologic column.

Flood Basalt Volcanism

Early researchers were quick to realize that volcanism in LIPs represented eruptions of much larger scale than modern activity has produced. In fact, this volcanism was conventionally termed "flood basalt volcanism" because it gave the appearance of "flooding events" in lava terms. The lava flows covered hundreds of thousands of square kilometers with volumes of thousands of cubic kilometers, whereas modern activity has formed flow fields in the range of tens of square kilometers and volumes usually much less than 10 km^3. One of the smallest LIPs but the best studied, the Columbia River Basalt Group in the northwestern United States, includes individual lava fields with estimated areas of more than 40,000 km^2 and flows with volumes in excess of 2,000 km^3.[2] One of the largest fissure eruptions in modern times, the Laki eruption of Iceland in 1783–1784, formed a lava field of about 600 km^2 with volume of 15 km^3, which is dwarfed by these lava flows in flood basalt provinces.

Flood basalts can be clearly differentiated from modern lava flows by their numerous extensive sheet flows, which are kilometers in length and relatively thick and flat, forming what are called "tabular flows" or "simple flows."[3] A great number of extensive sheets in a particular lava field suggests events with high effusion rates, which is the amount of lava erupted at a given time, and calculations for eruptions forming flood basalts have ranged in the order of 10,000 to 10,000,000 m^3 per second. For comparison, the Amazon River has average flow rates of about 200,000 m^3 per second. Modern lava flows, on the other hand, are composed of numerous lava lobes of varying sizes and shapes, usually only decimeters to meters thick and tens to hundreds of meters long, that reflect much smaller eruptions on the order of 10 to 1,000 m^3 per second.

To better understand the relationship between the architecture of the flows and their effusion rates, imagine opening the water tap lightly: the flux of water is low, and water will flow gently, controlled by the micro topography, and form separate little streams. As you open the tap further, water flux increases and begins to form larger sheets. Similarly, lava flows can form lava fields with numerous small units or lobes at low rates of effusion, while the size of the lava flows gradually increases to form large continuous sheets as effusion rates increase until the entire area is flooded, corresponding to what we see in flood basalts. Lava flows can also thicken as they pond, channelize, or inflate during emplacement, and some flows in flood basalt areas reach over 100 m of thickness this way, which are extraordinary thicknesses for lava flows.

Implications for Models of Origins

The colossal nature of the volcanism associated with LIPs is unambiguous. Recent studies are beginning to link the mantle turmoil and volcanism that form LIPs with other major geological phenomena such as mass extinctions, the breakup of continents, and even the frequency of magnetic reversals. Long-held uniformitarian presuppositions are being replaced with catastrophic models, interestingly shifting the geological thinking back toward a catastrophic paradigm. Careful examination of the tectono-magmatic origin, timing, and synergic effects of this past volcanism is encouraged for proper reconstruction of Earth's past history to account for colossal magmatism of this type.

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