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# Geochemical insights into the origins of compositionally distinct Early Permian Panjal Traps basalts: Implications for the transition from continental lithospheric to sub-lithospheric mantle melting regimes

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ABSTRACT

The Early Permian Panjal Traps in northwestern Himalaya are the by far largest continuous expression of the Panjal-Qiangtang large igneous province (LIP). The eruption of the Panjal Traps is connected with the rifting at the northern continental margin of Gondwana, leading to the formation of the ribbon-shaped continent 'Cimmeria' and the opening of the Neo-Tethys Ocean. This study presents geochemical investigations on the lava flows from the Sonmarg area in the Kashmir Valley, representing the northeastern extremity of the Panjal Traps, to understand the spatio-temporal variations in the compositions of the traps and to constrain their petrogenesis and tectonic implications. The upper and lower flows show distinct geochemical characteristics, with the lower flows (classified as Group I basalts) showing negative high-field strength elements (Nb, Ta, Ti) anomalies similar to arc-related basalts and melts derived from the sub-continental lithospheric mantle (SCLM), and the upper flows (classified as Group II basalts) having geochemical traits similar to enriched mid-ocean ridge basalts (E-MORB). The geochemical affinity of the Group I basalts with arc-related basalts is interpreted as a result of significant assimilation of continental crust during ascent of these melts while undergoing fractionation of a gabbroic assemblage. It is inferred that the Group I basalts erupted during continental extension when continental crust was thinned and available for the uprising magma for assimilation. In contrast, the petrogenesis of the upper Group II basalts is inferred to occur in an extended rift where hot convecting sub-lithospheric mantle underwent adiabatic decompression melting. The transition from the eruption of Group I basalts to Group II basalts reflects the progressive evolution of mantle sources from sub-continental lithospheric mantle to sub-lithospheric mantle melting regimes during the passive continental extension at the northern margin of Gondwana in the Early Permian.

## 1. Introduction

Throughout its geological history, the Earth has experienced intermittent voluminous lava eruptions on the continents. These extensive volcanic outbursts, known as Large Igneous Provinces (LIPs) or Continental Flood Basalts (CFBs), involve volumes >1 million km$^3$ erupting mainly (>75 % volume) within a short time frame of <5 million years (Bryan and Ernst, 2008). They play a significant role in supercontinent fragmentation, forming sedimentary basins, global environmental and climate changes, mass extinctions, metallogeny, and the development of oil and natural gas systems (Ernst et al., 2021). The origin of flood basalt provinces is attributed to several processes: partial melting of mantle plumes originating from either the core-mantle boundary or the mantle transition zone (e.g., Campbell and Griffiths, 1990; White and McKenzie, 1995; Trela et al., 2017); extraction of voluminous melts from an enriched asthenospheric (sub-lithospheric) mantle without the involvement of mantle plumes (e.g., Anderson, 1994, 2000; King and Anderson, 1995; Sheth, 1999a, 1999b); and volatile influx-induced hydration melting of the mantle (e.g., Ivanov, 2015; Wang et al., 2015; Xia et al., 2016; Liu et al., 2017).

Although large-scale volcanic eruptions occurred episodically throughout the Phanerozoic, flood basalt provinces are most frequently

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