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Inter-basaltic clay (bole bed) horizons from Deccan traps of India: Implications for palaeo-weathering and palaeo-climate during Deccan volcanism

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Abstract

Reddened clay-rich horizons between basalt flows have historically been identified as "baked zones" or as zones of lateral groundwater movement. The reddening was interpreted as a form of alteration due to thermal or chemical processes. Many of these zones are referred to as "bole beds" in Deccan traps and occur as prominent horizons showing red to brown, green, purple or grey colors, and are composed of fine-grained clayey material. The red and green colors are caused by the presence of variable amounts of Fe_2O_3 and MgO in the bole samples. The geochemistry of bole beds suggests that they were derived from basalts due to weathering processes. These boles record significant hiatuses in basalt flow emplacement and in some cases resemble incipient palaeosol deposits. Samples have been collected in profiles from the overlying basalt flow, through the bole, down to the underlying flow. Geochemical analyses suggest loss of Ca, Na, Mg, Fe^{2+}, Fe* and P in the boles compared to neighboring basalts, consistent with the weathering patterns observed in present day volcanic islands. The observed high concentration of K and Rb in the green bole samples compared to the adjoining basalts have been argued as features suggesting eolian transportation of volcanic ashes and deposition rather than evidence of metasomatism. The mean δD and $\delta^{18}O$ values of clays from red and green bole outcrops were −83.05‰ and 15.8‰, respectively. Clays analyzed from green boles were marginally more depleted, probably indicating a process of high temperature fractionation during deposition/transformation of ash into green bole. Our estimate of the average meteoric water $\delta^{18}Op$ (−8.1‰) value calculated from measured isotopic data (with the assumption of environmental temperature) is similar to or higher than previous estimate from palaeosol carbonates from Cretaceous central India. The depleted meteoric water composition observed in this study provides independent evidence of intensive precipitation during Deccan trap eruption.

Keywords: Boles; Flood basalt; Weathering; Palaeosol

1. Introduction

The Deccan Volcanic Province (DVP) is one of the largest continental flood basalt provinces in the world, extending over hundreds of kilometers across western

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and central India. Thicknesses of basaltic flows, dominantly tholeiitic in composition, are over 2 km in the western part of the province. Sequences of basalt flows commonly include spectacular red interflow strata widely known as "bole bed", which serve as the marker beds, in between two basaltic flows. Boles are made up of friable earthy clay, and it was suggested that boles are made up of material derived from the weathering of the neighboring basalts and volcanic ashes (Wilkins et al., 1994). Although they are usually recognized based on red color, they also occur in a range of colors varying between brown, green, purple and grey. The coloration and texture of bole bed outcrops suggest processes of chemical weathering similar to what is observed in case of pedogenesis in basalts. The absence of organic matters and biogenic remains made the origin of bole beds controversial. The geochemistry of bole beds and associated rocks suggested that many of the boles are weathered pyroclasts (Wilkins et al., 1994). In a few outcrops, they are characterized by polygonal structures, indicating shrinkage features developed as a result of a loss of fluid after deposition (Sarkar et al., 2000). An escape of fluid may have been triggered by hot magma deposited on top of weathered basalt during repeated eruptions (Sarkar et al., 2000). Interflow boles represent a well-defined time interval due to the fact that they truncate the flow they formed upon, and are, in turn, truncated by the overlying successive flow. In some cases, red boles are similar to lateritic soils in appearance (color) but differ in this in chemical composition from the present day laterite found in the area, whereas green bole bed can be considered as an equivalent of andosols (volcanic ash soil). High concentrations of immobile elements such as Al and Fe^{3+} ions (Widdowson et al., 1997) in red boles provide indirect evidences that they are primitive forms of palaeo-laterite, probably developed during the short periods (hiatus) of weathering following eruption. Many of these red horizons may have geochemical characters which allow them to be interpreted as palaeosol. Similar reddened zones have been described from the Columbia River flood basalt province in the western United States (Sheldon, 2003). These palaeosols are potentially ideal for palaeo-environmental reconstruction because of their primitive character. The hard compact basalt found on top and underneath of a bole horizon provides less chance of diagenetic alteration due to fluid rock interaction and "therefore" offer greater possibility for preservation of the geochemical and isotopic signatures.

The timing of the Deccan Volcanic Episode marks an important phase of earth history, coinciding with extensive volcanic activity and mass extinction during the Late Cretaceous and Early Tertiary time frame. The Cretaceous climate was dominated by global greenhouse conditions with the presence of high levels of pCO_2 in the atmosphere (Ghosh et al., 1995, 2001). Understanding the climate and weathering pattern during the event of the Deccan volcanic activity is possible based on the study of geochemistry of the bole beds (red and green horizons developed during periods of quiescence in volcanic eruption episodes). This paper presents major, trace and REE compositions of different bole bed samples and adjoining basalt layers from the type locality of the bole bed occurrence near Pune and Mahabaleshwar. The results from the geochemical analyses were used for interpreting the origin of the bole beds and their relationship with the basalts. The stable isotope composition of the clay mineral found in the bole bed samples was used for the climatic reconstruction during Deccan volcanism.

1.1. Age of bole beds

The age of bole beds should be similar to the age of over- and underlying basalts. Despite an earlier proposal of 67 to 65 Ma as the age range of the Deccan basalts, a more recent study constrained the age to 65.2±0.4 Ma (Hofmann et al., 2000). The palaeomagnetic age and geo-chronological age of basaltic flow from the Mahabaleshwar suggest an eruption timing of 65.2± 0.4 Ma (Venkatesan et al., 1993; Hofmann et al., 2000). It was also suggested that at least 1800 m out of the 2500 m thick composite trap section was erupted in a relatively short interval, perhaps even within a 1 m.y. time period. Therefore, the intermittent layers of bole beds must record the signature of the environment during relatively short periods of quiescence between these eruptions.

1.2. Study area

The Mahad-Mahabaleshwar section in western India provides a unique opportunity for the study of bole beds. The relatively uniform, undeformed nature of the flood basalts (Fig. 1(A)) provides an exceptional condition for *in-situ* preservation of the bole bed samples. The occurrence of the bole beds was earlier reported from the same area (Wilkins et al., 1994). The basaltic stratigraphy of the area was comprised of 47 horizontal flows, interspersed with red bole beds at places (Sukheswala and Poldervaart, 1958; Beane et al., 1986). Each flow has a thickness ranging from 7 m to 60 m. Distinctions between the individual flows are commonly made on the basis of intervening red and rare