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Deformed and dragged red bole horizon near Pune, Maharashtra

The Deccan Volcanic Province (DVP) is unique in the geology of India because of its prodigious volcanism and its pivotal role in studies of volcanology. The Deccan volcanics have erupted close to the Cretaceous–Tertiary (*K*/*T*) boundary at about 65 Ma. It has been estimated that today the Deccan Traps cover an area of 500,000 sq. km in western and Central India, consisting dominantly of subaerial flows of tholeiitic basalts with subordinate picrites, picritic basalts and alkaline basalts[1]. The emplacement of the Deccan Traps was a discontinuous process and the quiescence periods have been recorded by many intrabasaltic bole beds which are the products of weathering during major hiatus[2]. Thus bole beds are indeed paleosols formed over the lava flows they cap and they witness the processes of weathering occurring between emplacements of the successive lava flows. Hence, bole beds can be effectively used to construct the time intervals between successive lava flows in the Deccan Traps[3]. Intrabasaltic paleosols (fossil soils) are preserved in many of the flood basalt provinces of the world throughout the geological time and until recently, they were studied using primary qualitative methods. In recent years, palaeopedology has shifted from a largely qualitative field based on comparisons with modern analogues to an increasingly quantitatively endeavour[4] with the development of a variety of semi-quantitative and quantitative tools to examine past weathering and pedogenesis, which help reconstruct both palaeoenvironmental and palaeoclimatic conditions at the time that the palaeosols formed. According to Sayyed and Hundekari[5], and Ghosh *et al*.[6], the bole beds occur as prominent horizons composed of fine-grained earthy material having colours in shades of red to chocolate brown, green, purple or grey, having formed by pedogenesis of the underlying basalts on the basis of geochemistry of bole beds in

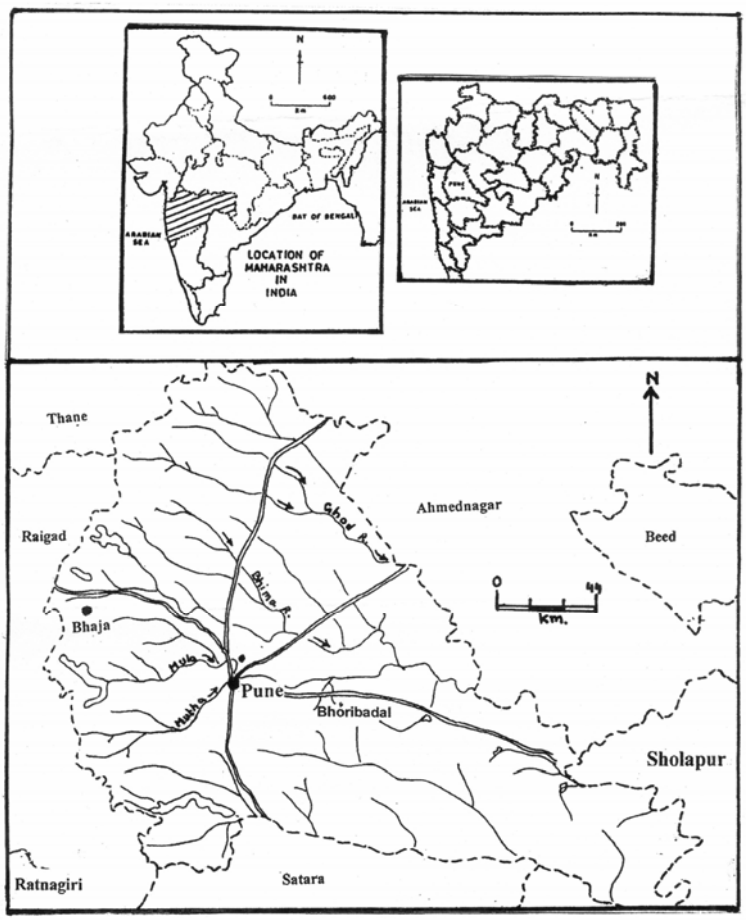

Figure 1. Location map of the study area.

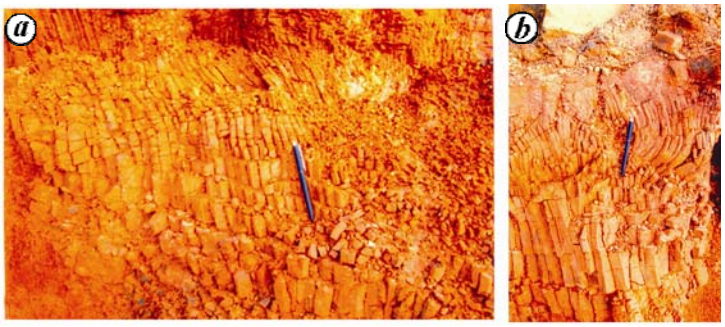

Figure 2. ***a***, Exposed red bole section near the village Bhoribandal. Note the extensively developed columnar jointed pattern of the red bole. ***b***, Plastically deformed (buckled) columns of the red bole into a broad, U-shaped form resembling a mushroom.

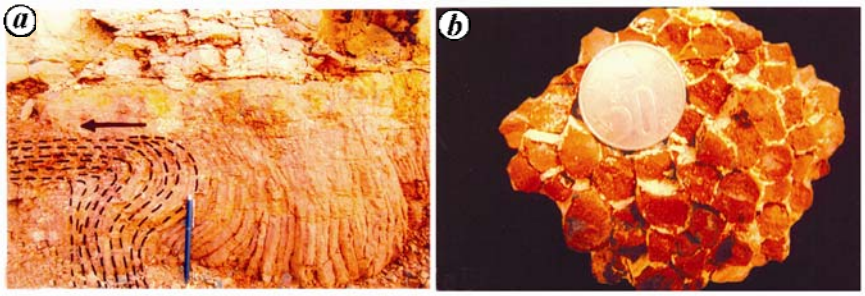

Figure 3. ***a***, Buckling and dragging of the red bole columns almost parallel to the direction of the overlying basaltic flow. ***b***, Transverse section of the hand specimen of the red bole exhibiting hexagonal, pentagonal and four-sided outlines of the columns. Note the joint planes are filled with white-coloured secondary minerals.

comparison with the basaltic modern soils. Sayyed and Hundekari[5] concluded that the bole beds may not have been subjected to intense weathering and long-term pedogenesis, but nonetheless formed under uniform rainfall with surface run-off exceeding evaporation.

The present study area lies about 30 km from Pune on the Pune–Sholapur highway in an abandoned basalt quarry fringing the village Bori Aindi near Uruli Kanchan (Figure 1). According to the District Resource Map, Geological Survey of India[7], the Deccan Traps in this area represent 'aa' and simple basaltic lava flows belonging to the Diveghat Formation. Near Bori Aindi, a 2.615 m thick red bole section is found to be overlain by a more than 2.0 m thick basaltic lava flow. In general, from the base to about 2.0 m, the red bole horizon is found to be friable, loose and powdery in form. The remaining 0.615 m of the red bole horizon exhibits extensive long, thin to medium-sized columnar jointed pattern, which is almost vertical in its attitude (Figure 2 *a*). At the central part of the section, the columnar joints in the red bole are found to be plastically deformed into a broad, U-shaped form, resembling a mushroom (Figure 2 *b*). At the contact between the columnar jointed red bole and the Deccan Traps lava flow, baking, buckling and dragging effects are observed. The dragging of the jointed columns of the red bole at the contact is found to be almost horizontal and parallel to the overlying Deccan Traps lava flow (Figure 3 *a*). In transverse section, these columnar pencil joints exhibit pentagonal, to four-sided forms (Figure 3 *b*). More than 200 diameters of these pencil joints were measured and they were found to vary from 0.7 to 3.5 cm. Thin-section analysis of the columnar jointed red bole reveals reddish to reddish-brown, fine-grained clayey matter rarely embedding highly weathered basalt fragments within them. Minor amounts of magnetite grains are found disseminated within the clayey matter, whereas in the voids and cracks of the red bole crystallization of stilbite is frequently observed.

As mentioned earlier, the red bole horizons are numerous in DVP, occurring as a reddish-brown clayey horizon sandwiched between the lava flows. These are the weathered products (paleosols) made up of fine-grained earthy material during the major hiatus[2,5]. These bole beds are known to retain appreciable amounts of water/moisture during precipitation, without transmitting it (aquitards). The heat provided by the massive, younger overriding lava flow to this moist, weathered, fine-grained clayey material (red bole) caused baking effects with the development of numerous evenly dispersed centres of shrinkage, similar to the hexagonal, polygonal or four-sided cracks that developed when clay-rich sediments are subjected to evaporation[8]. In the present study, the columns of the red boles have attained extensive and unusual lengths, of nearly 0.615 m. The movement and pressure of the overriding younger lava flow not only caused these columns to be plastically deformed (buckled), but they were also shattered and dragged almost parallel to the flow direction (Figure 3 *a*). In general, the columns are found to be dragged by the overlying lava flow from west towards east.

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