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Micromorphology of basalt alterite and its implications on the geological processes during quiescence period of the Deccan volcanism, Kharghar hill, Maharashtra, India

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ABSTRACT

Palaeoweathering unearths hidden mysteries of the previously weathered (paleo) surfaces. Researchers have shown that each mineral weathers/alters in a particular manner and is process-specific. Micromorphology is the most reliable and well-established technique to identify process-specific features imparted in an alterite under a given set of conditions. The Indian Deccan traps form one of the world's largest flood basalt volcanic provinces and has numerous exposures. Notwithstanding, systematic micromorphological studies of Deccan flood basalts are lacking compared to such flood basalts of global occurrences. The episodic nature of Deccan volcanism provided subsequent phases of interaction with the Earth's surface processes, thereby making the basalt alterites an ideal repository of surficial conditions and subsequent duration. Deccan basalt alterite exposed in the Kharghar hill of Mumbai (Maharashtra) has been selected for detailed micromorphology. Micromorphological results from the top to bottom of >70 cm thick, buried basalt alterite show changes in specific pattern of primary mineral alteration, formation of secondary minerals, development and patterns of secondary porosity. For example, the top of studied alterite (i.e. top 30 cm) has irregular, speckled and patchy patterns of mineral alteration, intramineral secondary pores, dominance of secondary products and only isolated alteromorphs that too with large elongate patches. Whereas towards the bottom (i.e. below 30 cm), the alterite shows planar patterns of mineral alteration, which is preceded at places by a linear/speckled pattern and most distinct is the dominance of intermineral pore system connected with transmineral fractures. Therefore, the basalt alterite can be subdivided from top to bottom into two distinct layers namely, alloterite and isalterite. This distinction significantly indicates a change in process with time as well as duration of basalt interaction with then prevailing surficial conditions. Thus, it can be concluded that alteroplasmation was progressively and gradually replaced with pedoplasmation resulting in dominance of supergene processes over hypogene processes.

Keywords: Deccan Basalt; alterite; micromorphology; pedoplasmation

INTRODUCTION

Palaeoweathering studies are significant to understand past sub-aerial geologic processes comprising dominance of surficial processes, past climates, continental environments and evolution (e.g., Reimink and Smye, 2024). Perhaps the simplest way for palaeoweathering studies in varied weathered mantle is the geochemical approach. However, different geochemical proxies have limitations in specific rock types. Nonetheless these are commonly used as powerful approach. Continental flood basalt eruptions have captivated the scientific community for long period of geologic time, driven by their paramount significance as elucidated by Ross et al. (2005). In particular Ross et al. (2005) showed that continental flood basalt eruptions had potential atmospheric impacts and catastrophic influence on biodiversity, including mass extinction events. Self et al. (2014) rightly stated continental flood basalt provinces as the subaerial expression of large igneous province volcanism. Earth's geologic history is rich in large igneous provinces comprising numerous flood basalt eruptions, which formed through multiple volcanic eruptions within a short geologic time (Self et al., 2008).

The Deccan flood basalt is an excellent example of continental flood basalt in Indian context forming longest lava flow known (Mukherjee et al., 2017), which mainly comprises pahoehoe lava flows erupted within a period of < 1 Ma (Courtillot et al., 1988). Krishnan (1953) estimated its original extent ~ 1.5 million km^2 when extended beneath the Arabian Sea. It covers an area of > ~ 500,000 km^2 (Watts et al., 1989 and others) across western and central India. Self et al. (2022) documented typical Deccan eruption rates as ~ 50–250 km^3 y^{-1} of lava with individual eruptions lasting for a few hundred to thousand years, separated by hiatuses of 3,000–6,000 yrs that makes them significant repositories for understanding of supergene processes. Deccan volcanic province is also rich in vertebrate biodiversity remains and vertebrate fauna (e.g., Khosla et al., 2003; Prasad et al., 2014). The Deccan

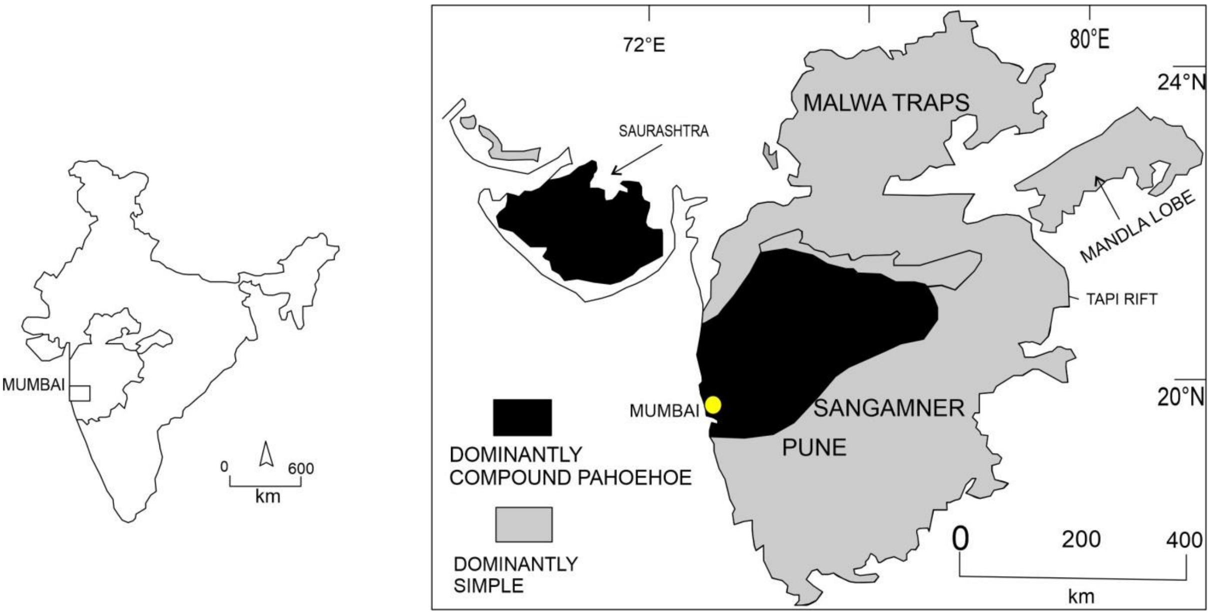

Fig. 1. Map showing the extent of Deccan Volcanic Province, India (After Bondre et al., 2004). Broad location of the study area is shown by yellow colour filled circle.

flood basalt has been extensively investigated geochemically (e.g., Alexander et al., 1977; Peng et al., 1998; Sano et al., 2001; Basu et al., 2020), petrographically (e.g., Shrivastava et al., 2002, 2008; Paul et al., 2008) and by isotopic means (Alexander et al., 1977; Lightfoot et al., 1988; Peng et al., 1998; Ravizza et al., 2003).

What remained a due was the systematic micromorphologic studies of the Deccan flood basalts. Such studies have alredy been performed in continental flood basalts across the globe (Paisani et al., 2013; Spinola et al., 2017; Zhang et al., 2022). Various Deccan basalt alterite outcrops are available in India and the episodic nature of Deccan volcanism serve excellent archives of prevalent surficial/palaeoweathering conditions before the next volcanic phase.

The term *'alterite'* refers to weathered mantle that is the result of weathering/supergene processes (Delvigne, 1998). Researchers have shown that each mineral alters in a particular manner and is process-specific. Systematic micromorphology is the essential technique to identify process-specific features imparted in an alterite under a given set of conditions. Therefore, buried Deccan basalt alterites have been explored in and around Mumbai (Maharashtra) with the major objective of systematic micromorphological studies. The aim of this study is to understand the geologic processes during the quiescence period of the Deccan volcanism.

STUDY AREA

DECCAN TRAPS: GEOLOGY AND STRATIGRAPHY

Several researchers have documented the geology and stratigraphy of Deccan Volcanic Igneous Province, DVIP (Beane et al., 1986; Jay et al., 2008 and others). Detailed account of lithostratigraphy of Deccan traps has been done by Godbole et al. (1996); Solanki et al. (1996) and others (also see Misra and Mukherjee 2017). Whereas the chemostratigraphic advances were presented by Beane et al. (1986) and Peng et al. (1994). Mahoney et al. (1982) deduced chemostratigraphy of lava piles by studying changes in major and trace elements and Sr-Nd ratios. Detailed trace element studies were done by Cox and Hawkesworth (1984). DVIP constitutes of simple and compound flows with western part dominated by compound lava flows (Mahoney, 1988; Bondre et al., 2004; Duraiswami et al., 2012; Fig.1).

Various other researchers documented the magnetostratigraphy of the DVIP (Deutsch et al., 1958; Sahsrabudhe, 1963; Wensink and Klootwijk, 1971) . Absolute ages or chronostratigraphy/ geochronology has been done in detail (Courtillot et al., 1986; Vandamme et al., 1991; Chenet et al., 2007; Schoene et al., 2015 and others). Beane et al. (1986) divided the DVIP of the Western Ghats (India) into three subgroups and 10 formations. Beginning with the lowermost (i.e. stratigraphically oldest) the Kalsubai Subgroup includes five formations- Jawhar, Igatpuri, Neral, Thakurvadi and Bhimashankar. The Lonavala Subgroup overlies The Kalasubai Subgroup and comprises an older Khandala Formation and a younger Bushe Formation. The Wai Subgroup is the youngest of the three subgroups and consists of Poladpur, Ambenali and Mahabaleshwar Formation from bottom to top.

LOCATION OF THE STUDY AREA

The Deccan basalt outcrops in and around Mumbai have been explored for weathered/

pedogenised profiles/units through fieldwork and the interest was to find a buried unit. A buried, Deccan basalt alterite exposed in Kharghar hills of Mumbai was selected for the present study (Fig. 2). This section forms part of the Bhimashankar Formation (= Upper Ratangarh Formation) of the Kalsubai Subgroup. It comprises of dense aphyric to phyric flows, with moderately porphyritic pahoehoe flows intermingling (Misra et al., 2014 and references therein). The selected buried profile in the Kharghar hill was recognised in the field based on morphologic criteria as per Hencher and Martin (1982), Retallack (1988) and Ollier et al. (1996). The preliminary weathering stages in the field have been identified following Hencher and Martin (1982) and Ollier et al. (1996). In general, alterite and soil features have been recognized in the field on the basis of obliteration of basalt rock fabric and texture, which resulted in changes in colour, texture and/or structure.

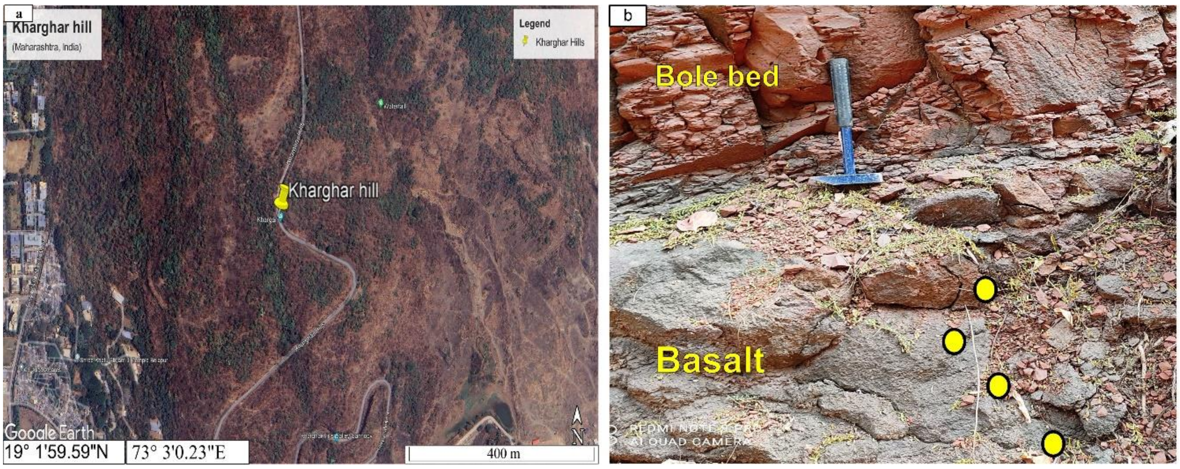

Fig. 2 a). Google Earth image showing the Kharghar hill location (Mumbai), wherefrom basalt alterite was sampled. b): Representative field photograph of the studied basalt alterite. The yellow-coloured circles show sampling locations. Geological hammer used as scale is ~ 30 cm long.

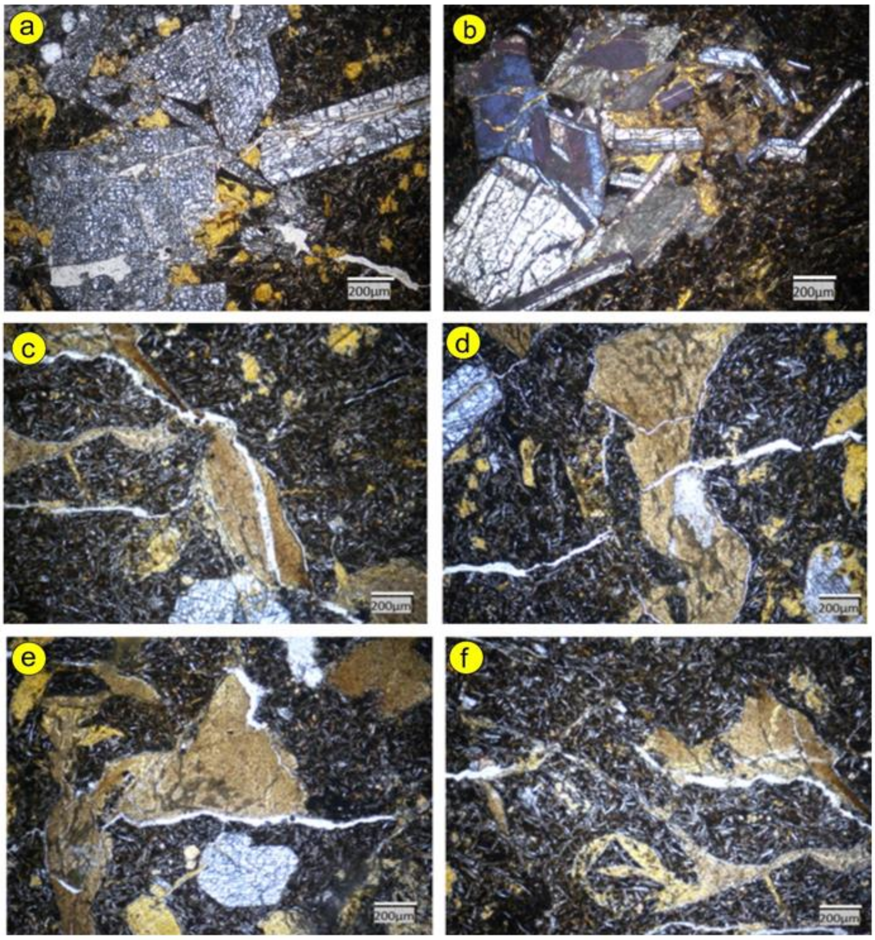

Fig. 3: From the bottommost basalt alterite, representative photomicrographs showing fractured plagioclase laths and secondary products/clay minerals deposited around the mineral grains in (a-b); trans-mineral pore system connected with inter-mineral pores in (c-d) and inter-mineral pore space surrounding the mineral grains in (e-f).

METHODOLOGY

The studied basalt laterite is >70cm thick and has been carefully examined in the field based on changes in morphological features from top to bottom. A total of four representative samples of basalt alterite were collected for micromorphology. For thin-section studies, undisturbed *in-situ* samples have been collected in Kubiena tin boxes of dimension 10 cm * 12 cm * 16 cm and 5 cm* 6 cm * 8 cm and were prepared as per Miedema et al. (1974) and Jongerius and Heintzberger (1975). These were described by following Delvigne (1998), and Stoops (2003). All the micromorphological/ thin-section observations have been done under Carlz Zeiss and Radical polarizing microscopes at the Department of Geology (Panjab University, Chandigarh, India).

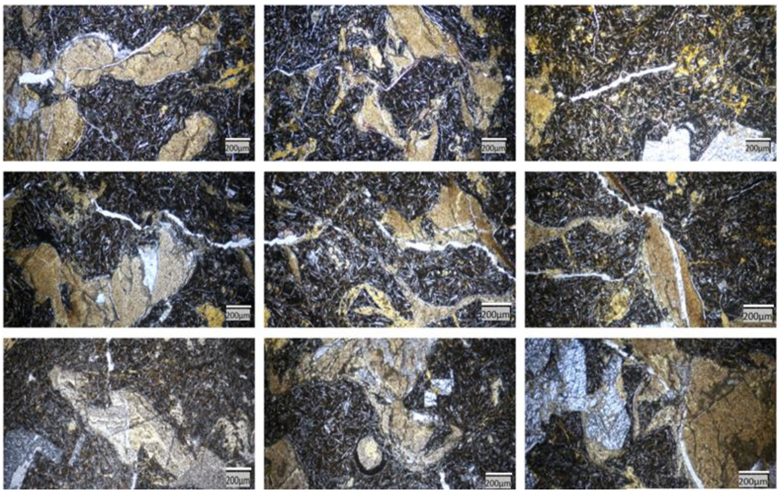

Fig. 4. From the bottommost basalt alterite, representative photomicrographs showing moderate connectivity between inter-mineral pore network.

RESULTS

The investigated, > 70 cm thick, buried basalt alterite, below the bole bed unit, shows distinct micromorphological characterstics from top (i.e. ~ 30 cm thick) part to bottom part of alterite. For example, micromorphological results from the top to bottom of basalt alterite show changes in specific pattern of primary mineral alteration, formation of secondary minerals and development of secondary porosity. Representative photomicrographs showing changes in micromorphologic features (Figs. 3-6). The bottom extent of basalt alterite is unexposed whereas the top part has clear and irregular boundary contact with the overlying bole bed. A number of process-specific micromorphologic features indicative of *in-situ* weathering/pedogenesis have been identified in the logged basalt alterite.

The bottom part of basalt alterite (below ~ 30 cm) shows predominant mineral grains e.g., plagioclase, secondary clay minerals and a fine grained groundmass composed primarily of plagioclase laths and opaques (Fig. 3). Large well developed crystals (phenocrysts) are embedded in fine- grained matrix/ groundmass, and serves distinct primary porphyritic texture. Majority of plagioclase grains are fractured and are bordered by secondary deposition of clay minerals (Fig. 3). Also, the alterite shows development of secondary porosity. Prominent presence of trans-mineral pore space is observed in the bottom alterite traversing the rock and cutting the mineral without following rock boundaries (Fig. 3). Further, the transmineral pores are seen connected with intermineral pores that surrounds the mineral grains without cutting through them (Fig. 3). Furthermore, this bottom part of basalt alterite shows not only intermineral porosity but moderate connectivity has been observed between the inter-mineral pores (Fig. 4).

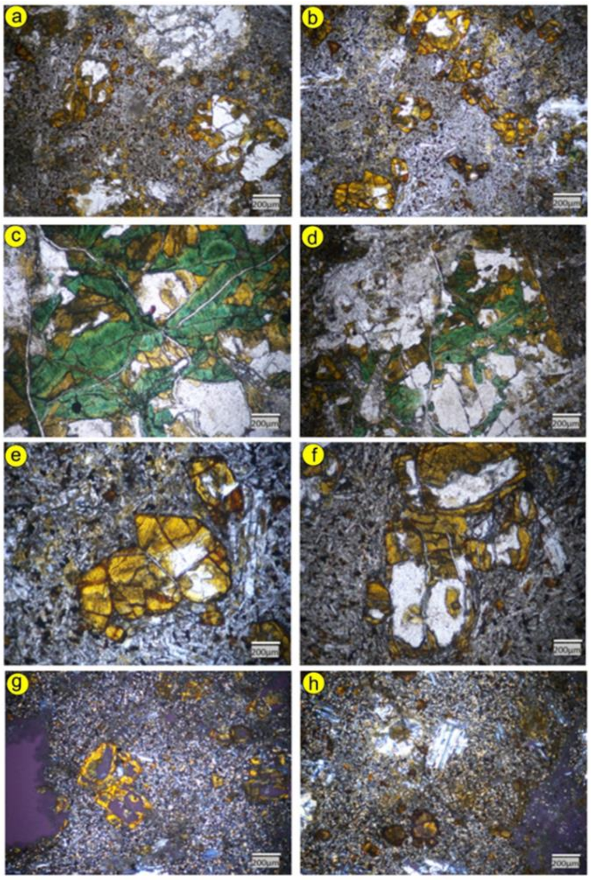

Fig. 5: From the topmost basalt alterite, representative photomicrographs showing patchy pattern of mineral alteration in (a-b); planar radial voids in (c-d); chemical weathering phenomenon by alteration of mineral from outward to inward in (e-f); and dominance of weathered micromass (g-h)

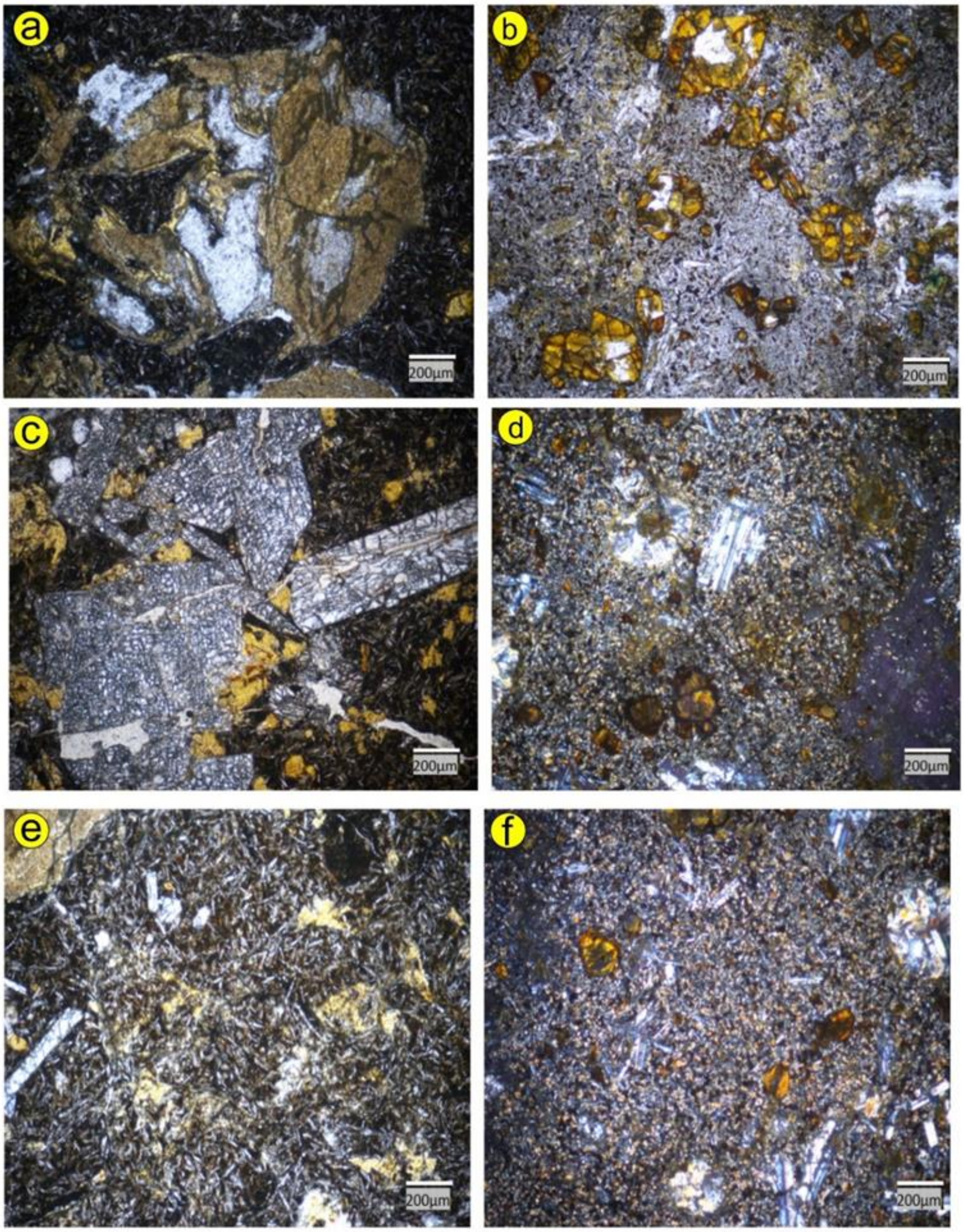

Fig. 6. Representative photomicrographs showing complete disappearance of original rock fabric from bottom (a) to top (b) alterite; Reduction in mineral grain size and increase in porosity from bottom (c) to top (d) alterite; (e-f) shows the relative increase in percentage of opaques from bottom (e) to top (f) alterite.

Towards the top, the basalt alterite shows extensive alteration of primary minerals, where olivine and plagioclase form the major primary minerals alongwith some secondary infillings and amydgules (Fig. 5). The groundmass is fine-grained and consists primarily of plagioclase laths and opaque minerals (Fig. 5). Large well-developed crystals (phenocrysts), primarily altered olivines are embedded in fine- grained matrix (groundmass) clearly indicate porphyritic texture. These mineral grains are partially to completely altered. The alteration is from outward to inward of the mineral grains (Fig. 5). Also, patchy alteration of minerals have been identified along with planar radial voids (Fig. 5). The micromass is more weathered than the bottom alterite and isolated alteromorphs are commonly present (Fig. 5).

Thus, a change in micromorpologic features have been observed from bottom towards the top of the investigated basalt alterite. There is almost complete disappearance of original fabric of the rock in the top when compared with the bottom part of the basalt alterite (Fig. 6). As compared to bottom, the top alterite shows more isolated alteromorphs (Fig. 6). There is significant reduction in grain size due to extensive fractures in mineral such as plagioclase from bottom towards the top of basalt alterite (Fig. 6). Altered micromass with porosity/voids is common in top alterite than the bottom one and there is greater percentage of opaques in top alterite than the bottom part of alterite (Fig. 6).

INTERPRETATIONS AND DISCUSSIONS

Micromorphology acts as an apropriate tool to study the peculiar patterns of mineral alteration. Each mineral species weathers uniquely under given set of conditions and the patterns of alteration are controlled largely by the nature and characteristics of primary mineral (Delvigne, 1998; Delvigne et al., 2000).

In the studied basalt alterite, the bottom alterite (i.e. below 30 cm) shows presence of transmineral pore system that primarily results from fracturing and fissuring of mineral grains. The pore network in a mineral grain facilitates the movement of fluids for better facilitation of weathering processes. The moderate interconnectivity between intermineral pores observed in the bottom alterite connotes that it is a less weathered portion. Whereas towards the top (i.e. 30 cm), alterite shows irregular, speckled and patchy patterns of mineral alteration. Isolated alteromorphs with large elongate patches are observed that shows the intensity of weathering processes that has operated over the top alterite. The weathering progression of minerals from outward to inward is a strong signature of chemical weathering process, which is documented prominently in the top alterite. The presence of planar radial voids indicates dominance of supergene processes.

The micromorphologic features observed at the top part of basalt alterite suggest pedoplasmation. For example, disappearance of original rock fabric, reduced grain size, dominance of alteration products comprising clays, opaques and extensively altered micromass resulting in isolated alteromorphs and voids. Therefore, micromorphology aids in understanding that the transition from alteroplasmation to pedoplasmation that occurred gradually, resulting in the prevalence of supergene processes over hypogene processes.

CONCLUSIONS

1. Based on systematic micromorphological studies, the investigated basalt alterite can be subdivided in to top alterite designated as *alloterite* and the bottom alterite as *isalterite*.
2. Alteroplasmation was progressively and gradually replaced with pedoplasmation resulting in dominance of supergene processes over hypogene processes.

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