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Research Paper

Manifestations of Weathering on Granitic Rocks in the Himalaya and Bundelkhand Regions: A Field-based Observation

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Weathering is controlled by factors such as lithology, geological structures, topography climate, tectonics and biota. The present study aims to highlight the manifestations of weathering in two contrasting settings- the Himalaya and Bundelkhand. The study area in the Himalayan region is characterised by active tectonics, steep topography, rugged landscape, cold and semi-arid climate, and sparse vegetation cover. The Bundelkhand region, however, is characterised by stable, undulatory topography, warm and sub-humid climate, and tropical dry deciduous forest. This study mainly presents field observations made during field campaigns to Gemur and Jispa (Lahul Valley) and Rohtang in the Himalaya; Jhansi, Orchha and Lidhora in the Bundelkhand region. Contrasting features about weathering, erosion and sediment generation in the Himalaya and the Bundelkhand were observed. Weathering through physical heterogeneities are common in the Himalaya as water is lost through surface run off due to steep slopes. Presence of large fragmented materials weathered in the Himalaya is relatable to the erosion dominated regime corresponding to the tectonically active steep topography. On the other hand, gently sloping areas in the Bundelkhand, experience lower surface runoff and higher infiltration. Therefore, weathering in the Bundelkhand proceeds to a greater depth contributing to deep weathering profiles characterized by weathering layers such as sap rock, saprolite and soil. Series of events like the exposure of parent granite, development of physical openings along joints and fractures, erosional activities, transport of eroded materials, and chemical weathering due to longer residence time and longer interaction with water would have supported the development of deep weathering profiles in the Bundelkhand region.

Keywords: Weathering; Sediment Generation; Tectonism; Himalaya; Bundelkhand Craton

Introduction

Weathering is the alteration of rock or minerals *in situ*, under the prevailing conditions at or near the surface of the earth (Yatsu, 1988), which is relevant to life-supporting system such as soil formation, water quality, environment and climate regulation, and mineral resources (Pope *et al*., 1995; Buss *et al*., 2013). Traditionally, weathering has been classified as mechanical and chemical weathering processes corresponding to the physical disintegration of rock into smaller pieces and chemical decomposition of minerals of the rock, respectively (Ollier, 1984; Boggs, 2014). Biological weathering involves biological agents, although ultimately manifested as chemical or physical weathering of rocks (Brady and Weil, 2016). Though classified separately, all types of weathering usually work together, but they appear to be of particular type depending on the prevailing conditions. Lithology, climate, tectonism and vegetation are the major factors that control weathering (Jenny, 1941). Weathering operates on rocks, exposed due to tectonism and uplift and is usually initiated through physical processes, and subsequently worked upon by hydrolysis, solution and dissolution, and mineral decay by organic molecules. Weathering contributes significantly towards transforming massive rocks into saprolite of lower density. Therefore, a continental block with lowered density may result in continental uplift for isostatic compensation (Millot, 1964; Perrodon, 1972; Nahon, 1991). Topography has a significant effect on the rate of chemical weathering and the nature of the

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weathered products as it controls the rate of surface runoff, sub-surface drainage and erosion of the weathered products (Raymo and Ruddiman, 1992). Biological activities, invisible at microscales, play a major and important role in weathering processes (White and Brantley, 1995). Vegetation cover has been reported to have complex effects on the rates of chemical weathering (Berner, 1992; Stallard, 1992) by the increase of soil CO_2 content, stabilizing soil cover and producing organic acids (Keeney, 1983; Drever, 1994; Caldeira, 2006).

The landform of an area is the function of climate, tectonism, and geological formations. The Himalayan region is characterized by active tectonics, steep topography, rugged landscape, cold and semi-arid climate, and sparse vegetation cover. The Bundelkhand craton, however, is characterized by stable, undulating topography, warm and sub-humid climate, and tropical dry deciduous forest. The present study evaluates the critical role of tectonics and climate on weathering based on the field observations in the Himalaya and the Bundelkhand regions. Tectonically induced uplift, uplift induced precipitation and precipitation induced erosional unloading is the characteristic of the Himalaya (Avouac, 2008; Owen, 2010; Godard *et al.*, 2014). The stable, sub-humid setup of Bundelkhand craton provides ideal condition to study *in situ* weathering profiles. The present study aims to understand the manifestations of weathering under contrasting settings of the Himalaya and Bundelkhand region. The study relies on the field observations made during field campaigns in the Himalaya and Bundelkhand regions.

Study Area

The cold and semi-arid Himalaya and hot and sub-humid Bundelkhand craton provide the contrasting settings for weathering studies in India. Though these are large areas and contain different lithologies, only granitoid rocks were chosen for this study. Field visits were made to the Lahul Valley (Gemur and Jispa) and Rohtang in Himachal Pradesh; Jhansi in Uttar Pradesh; Orchha and Lidhora in Madhya Pradesh. Geological settings, physiography, climate and vegetation of the study sites are presented in the next section. Field sites, average climate indices, altitude and bedrock lithologies are listed in Table 1.

Geological Setting

The Jispa granite occurs about 3 km from Jispa village. The lithologies of the Lahul Himalaya is dated to Proterozoic-Cambrian (Sorkhabi and Stump, 1993). The Jispa pluton of granitoids form an anticlinal body within the geosyncline of Batal formation of the Haimanta group (Rao and Sharma, 1995). Saxena and Pande (1968) reported the existence of a broad migmatised zone of Precambrian age in the area around Rohtang which occurs in association with quartzites, limestones, calc-silicates, phyllites and slates. Mineralogically these rocks are similar to Jispa granite.

The Bundelkhand massif is dated to late Archean to early Proterozoic. It lies between the Aravallis and the Satpura orogenic belts. The massif is composed mainly of granitic rocks dated to 2492±10 Ma (Mondal *et al.*, 2002). It is overlain by the Bijawar Group comprising of sediments of Vindhyan Supergroup (Late Proterozoic). The northern portion is covered by Quaternary Indo-Gangetic Alluvium. The Bundelkhand craton lies to the east of the Aravalli-Delhi Fold Belt.

Physiography, Climate and Vegetation

The Himalayan region is characterized by active tectonics with rugged and steep topography. Cold and semi-arid climate prevails in northwest part of the Himalaya whereas in some parts particularly the southern Himalaya receives good rainfall during monsoon. The vegetation in the Lahul region is very sparse characterized by dry temperate to dry alpine type vegetation. The reasons for dry vegetation is scanty rainfall, great variation in temperature, heavy snowfall, topography, soil texture, low moisture, high wind velocity, etc. Average precipitation in Lahul valley and Rohtang is around 700 mm whereas mean annual temperature in Jispa and Rohtang are 7.0 °C and 3.9 °C, respectively.

The Bundelkhand region is characterized by undulating topography. The fieldwork was concentrated mainly in the Betwa river catchment which drains the region and eventually merges with the Yamuna river. The climate of the region is sub-humid with mean annual rainfall of 1041 mm in Tikamgarh and 955 mm in Jhansi. Mean annual temperature is 25.4 °C in Tikamgarh and 26.1 °C in

Table 1: Altitude, average climate indices, and lithologies of the study sites

Site name	Location	Altitude (m)	Average precipitation (mm)	Mean annual temperature (ºC)	Rock type	Geological history/age
Lahul Valley, Himachal Pradesh	Jispa	3266	734	7.0	Granite	Proterozoic-Cambrian (Sorkhabi and Stump, 1993)
	Gemur	3340	719	6.5		
	Rohtang	3978	710	3.9		
Bundelkhand Craton	Lidhora, Tikamgarh in Madhya Pradesh	350	1041	25.4	Granite	Late Archean to Early Proterozoic (Mondal *et al.*, 2002)
	Orchha	215	882	26.3		
	Jhansi, Uttar Pradesh	285	955	26.1		

Jhansi. The vegetation of the Bundelkhand region is of the tropical dry deciduous type.

Field Observations

Field observations were made to Gemur and Jispa (Lahul Valley) and Rohtang in the Himalaya in October 2016. Jhansi, Orchha and Lidhora in the Bundelkhand were surveyed in December 2015 and June 2017. Unlike the Jispa granite and granitoids around the Rohtang pass, typical deep weathered profiles were developed on granites of the Bundelkhand Craton. Contrasting features pertaining to denudation, weathering and sediment generation processes in the Himalaya and Bundelkhand were observed.

The Himalaya

The collision of the Indian and Eurasian plates led to the Himalayan uplift around 50 million years ago. After attaining sufficient relief, orographic precipitation was induced, which favoured erosion (Gabet *et al.,* 2008). Accelerated erosion induced by climate progressively unroofed the Himalaya. In the Himalaya, tectonically and isostatically driven uplift at major lithologic discontinuities existing as terrane boundaries and zones of high seismicity are the causal factor for mass movement or slope failures (Summerfield and Nulton, 1994; Hurtrez *et al.,* 1999; Montgomery and Gran, 2001). Glaciers and rivers are the main eroding and transporting medium for the sediments produced by denudation caused by mass wasting (Fig. 1). Denudation chiefly relates to the mobilization of debris for a short-distance by the mass movement, for intermediate-distance by glaciers and long-distance by fluvial processes (Shroder, 1998). Glacial erosion

Fig. 1: Glacier-fed Bhaga river valley through the Jispa granite, Lahul Valley. Glaciated Zanskar mountain range seen in the background is the source of the Bhaga river

and mass wasting ubiquitous in the Himalaya are perhaps the major processes shaping the Himalayan landscape. Therefore, the Himalaya can be appropriately termed as a huge "sediment factory". The study area of Rohtang gives a live demonstration of various stages involved in sediment production such as tectonism, upliftment, exfoliation, "butchering" of massive rocks into pieces, mass movement along slopes, erosional activities, and induction of weathering through geological structures (Fig. 2). Weathering, as a synergistic phenomenon to erosion, proceeded through geological structures. The weak zones provided by structural features developed due to metamorphism, folding and faulting in the Himalaya during the tectonic evolution. Weathering is promoted along the weak zones such as foliation, cracks, fractures and joints which provides accessibility to water and weathering proceeds (Fig. 2). Although

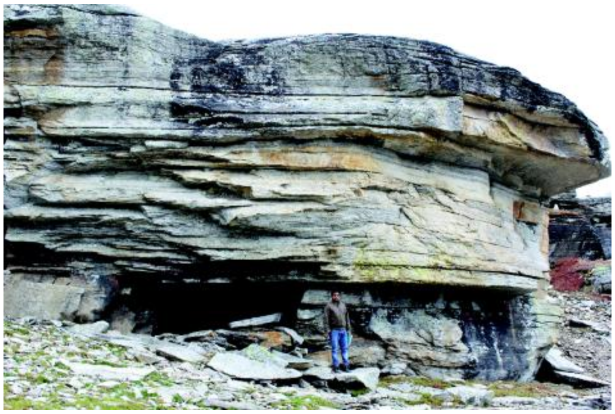

Fig. 2: Parallel alignment of textural and structural features of a rock promote weathering along the weak zones, through foliation planes as well as through the cracks, fractures, and joints

Fig. 3: Presence of large fragments in the Himalaya are relatable to the erosion dominated regime due to the tectonically active steep topography. The loose material moves along the steep unstable slopes resulting from slope failure or mass movement, accumulates on the slope of the hills

physical heterogeneities are common in the Himalayan rocks, due to steep slopes a large part of the water is lost through surface runoff. The water percolated into the rock heterogeneities and pores are the major cause of increasing pore pressure and mass wasting. Presence of large fragmented material in the Himalaya is relatable to the erosion dominated regime corresponding to the tectonically active steep topography (Fig. 3). In general, climate and tectonics operate synergistically and complimenting each other during weathering and erosion processes. Godard (2014) suggested the dominance of tectonics over climate in the Himalayan denudation. Whereas, Thiede *et al.* (2004) suggested climatic control on rapid exhumation along the Southern Himalayan Front.

The Himalaya has an immature topography and characterized by deep valleys and high structural mountain ranges. As discussed earlier, mass wasting is a major process in the Himalaya. The products of mass wasting are deposited as valley fills, which include fluviatile deposits. Mass wasting also exposes fresh rock surfaces for ecological succession to begin. Lichens are the pioneer species to colonize the freshly exposed rock (Fig. 4). The effects of lichens on the mineral substrates of rocks can be attributed to both physical and chemical processes. Organic acids produced by lichens, particularly oxalic acid, can effectively dissolve minerals and chelate metallic cations (Chen *et al.*, 2000). Roots of the small plants induce weathering and the herbs and shrubs help in temporarily stabilizing the soil activity of the area (Fig. 5).

The Bundelkhand

The Bundelkhand craton is composed mainly of granitic rocks, which includes hornblende granite, biotite granite, and leucogranite (Mondal and Ahmad, 2001). Resistant quartz and weatherable alkali and plagioclase feldspars are the predominant minerals in these granites. The time of exposure of bedrock is not exactly known and which remains to be estimated but the formation of topsoil as a weathering product of the granite could not have been older than the Quaternary as the tectonic rejuvenation of peninsular India took place during the Quaternary (Radhakrishna, 1993). The development of physical openings such as the joints and fractures could have supported percolation of water under sub-humid climate. Although, limited availability of water in the sub-humid climate, the larger residence time of regolith on flat topography helped more rock-water interaction and chemical weathering which led to the differentiation of regolith and formation of secondary minerals in different layers. Weathering profiles characterized by topsoil, regolith, saprolite, saprock, least altered rock, are found to be common in the Bundelkhand region.

Topography has a significant effect on the rate of weathering and nature of weathered products and consequently control the thickness of the weathering profile. On very steep slopes such as that of the Himalaya, most of the rainwater is lost through surface runoff and little penetrates the hard rock

Fig. 4: Granitic rocks covered with multicolored lichens. Lichens (a symbiotic relationship between algae and fungi) accelerate the weathering processes by secreting organic acids, hence altering the Eh-pH conditions

Fig. 5: Recent soils developed in the weathering limited/ erosion dominated conditions in the Rohtang area supports vegetation. The herbs and shrubs help in temporarily stabilizing the erosion activity of the area

preventing the formation of deep weathering profile. Flat, stable and gently sloping areas in the Bundelkhand region, alternatively, experience little surface runoff and infiltration of rain-water is at the maximum. Therefore, weathering proceeds to a greater depth contributing to the formation of deep weathering profile, which can also act as a reservoir of water in the initial stages, accelerating the rate and extent of weathering. Exfoliation is the most noticeable feature of weathering processes where curved, concentric and parallel shells of rock break away in succession, somewhat analogous to the way layers of an onion separate (Fig. 6). However, mega-scale exfoliation weathering induced by parallel horizontal

Fig. 6: Concentric and parallel shells of rock exfoliations breaking away as onion peels

foliations are also present in the region (Fig. 7). The sharp boundary of the regolith with the bedrock may be due to unloading by erosion and expansion of bedrocks to give rise to porous exfoliations. The initial stage of weathering produces thin regolith cover of around l m (Fig. 7), where water can be stored and seep through the exfoliations. Further weathering increases the thickness of regolith cover promoting more weathering with 3-4 m thick regolith cover (Fig. 8). Green deciduous forests are dominant vegetation type of the Bundelkhand region. Weathering due to root penetration is a very common feature in the Bundelkhand region. Fig. 8 shows life induced weathering by plant roots. Penetration of plant roots in the rock through fractures enhance the gap, as well

Fig. 7: Parallel foliation plane leading to initial stage of regolith induced weathering withthin regolith cover (~1m) in which the water seeps through the surface parallel foliations

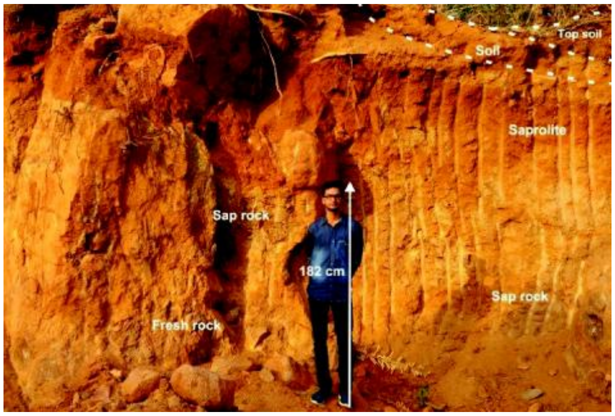

Fig. 8: A typical deep weathering profile showing regolith-soil, saprolite and saprock, above the fresh rock. Plant roots promoting and enhancing weathering are visible in the picture

as form new fractures providing an opportunity for water to move in and promote weathering.

Conclusions

The present study provides some important observations on the weathering of granitoids in the contrasting settings of the Himalaya and Bundelkhand. The study sites in Lahul valley and Rohtang in tectonically active Himalaya exhibit "butchering" of massive granitic rocks, where weak zones such as foliations, fractures, cracks and joints play an important role in weathering. In the erosion dominated regime of the Himalaya, mass wasting is the prime factor for weathering and sediment generation. The Bundelkhand craton, on the other hand, is characterized by stable, undulatory topography, warm and sub-humid climate, and tropical dry deciduous type vegetation. In comparison to the Himalaya, weathering in the Bundelkhand proceeds to a greater depth contributing to the development of deep weathering profiles characterized by layers such as the sap rock, saprolite and soil.

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