INDIAN JOURNAL OF GEOGRAPHY & ENVIRONMENT 15-16 (2018)
Indian Journal of Geo. and Env. Mang. 15-16 (2018) 130-136
April 2018, Vidyasagar University, West Bengal, India
(http://vidyasagar.ac.in/journal) **ISSN:0972-7388**

VIDYASAGAR UNIVERSITY
Dept. of Geo. and Env. Mang.

Scientific Communication

Rock to Regolith: A Synthesis of Physico-chemical Processes in Purulia District, West Bengal

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Article History:
Received 15 January 2018
Received in revised form 20 April 2018
Accepted 29 April 2018

ABSTRACT

The present study is trying to identify the existing nature and processes of weathering and regolith development in the studied weathering profile in Raghunathpur-I block, Purulia district, West Bengal. The thin section analysis of collected samples has been carried out for mineral identification and recognizing micro-fractures and their propagation. The major elemental composition in the samples from different weathering grades has been measured by XRF technique. The open-system mass change ($\tau_{j,w}$) and CIA have been calculated for understanding mineralogical transformations and the degree of weathering respectively. The result shows that quartz, feldspar, and micas composed granitic bedrock is gradually fragmented and altered into Fe-oxides and secondary clay by progressive microfractures development and hydro-chemical weathering. But the chemical analysis of major elements indicates poor depletion of SiO_2 than other elements (Si, Al, Fe, Na and K) which denote the lower degree of transformation of quartz and silicate minerals. Therefore, the potentiality for both physico-chemical weathering is recognized to develop more mature regolith.

Keywords:
Weathering; XRF; Elemental transformation; Chemical index of alteration; Regolith

Introduction:

Most of the landscape of the Earth surface is covered with a transportable layer of different substances including soil which are mainly originated from the underlying bedrock. Sometimes those surface materials are immobile in character and may be eroded and transported by different geomorphic processes (Anderson, and Anderson, 2010). These overlying materials are developed by the physical and chemical alteration of underlying parent rocks through several geomorphic processes in different degrees depending on the local environment (Dolui et al., 2016). Therefore, a complex interaction has been found in the critical zone (Anderson et al., 2007) which is the adjoining part of bedrock and weathered saprolite. This critical zone is extended up to the top surface from the deepest part of the protolith including several functional layers with active weathering zone (Brantley et al., 2007). The boundaries between unweathered parent rock, weathered saprolite, and overlying soil are created by weathering processes with the interaction among geology, geomorphology, geochemistry, hydrology and biology (Heimsath et al., 2009; Rempe and Dietrich, 2014; Fisher, 2016).

Determine the landscape and landforms relationship in the Earth surface including subsurface features developed by different geomorphic processes is still interesting to study. To understand the landscape evolution and to identify the zone of alteration of bedrocks are still challenging (Fisher et al., 2017). Similarly, understanding the degree and intensity of weathering and the elemental transformation for the development of rock to regolith is often difficult in different environmental conditions (McQueen and Scott, 2008; Vyshnavi and Islam, 2015). The functional

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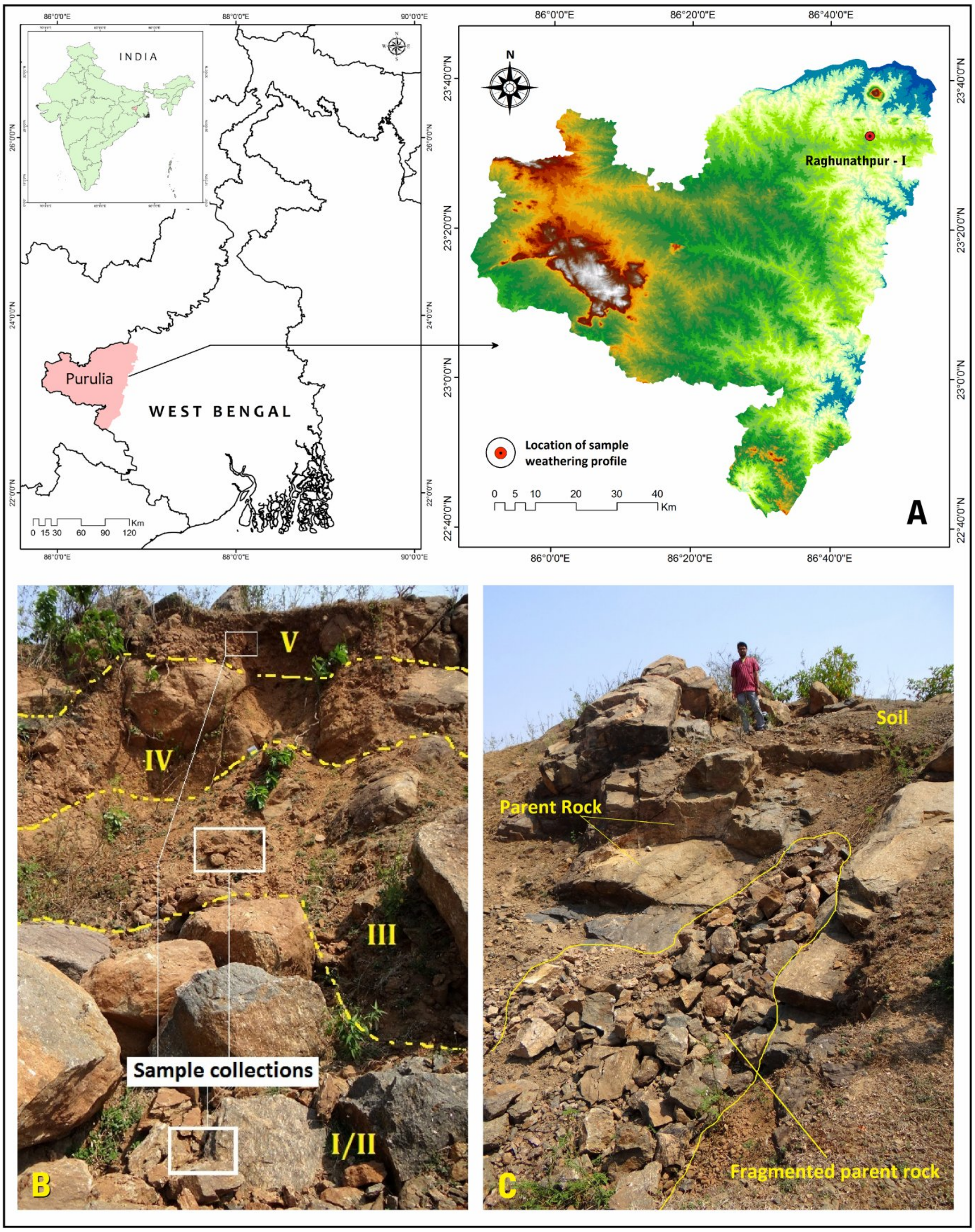

Fig. 1: A) Location of the sample weathering profile, B) Samples collection from different weathering grades: I-II indicates Fresh rock; III – Moderately weathered materials; IV – Highly weathered materials and V – Completely weathered materials (soil) and C) Nature of weathering: showing physical fragmentation of parent rocks.

mass transformation calculation has been widely used to characterize weathering of rocks and identify the pedogenic alteration of elements (Jin et al., 2010; Heimsath and Burke 2013; Yoo et al., 2015 and Fisher et al., 2017). Mass change approach evaluates elemental concentrations and their transformation either negative or positive in different weathering grades of weathering profiles. Mass transformation calculations make us understand the gains or losses of elements from fresh rock to weathered materials for illustrating the processes of regolith formation. In this perspective, current work tries to understand the existing stage of regolith development by analyzing the physical and chemical transformation of minerals in the studied weathering profile.

2. Study location and sample collection

The present study is based on a granitoid weathering profile in Raghunathpur-I block, Purulia district, West Bengal. The area is under the Chotanagpur Gneissic Complex, a part of peninsular of eastern India situated in the north of Singhbhum Craton. Therefore, the district is habitually associated with most of the granitic substance and Meta sedimentary rock formed in Precambrian age (Dolui et al., 2016). Environmentally the studied profile appears under the hot and humid sub-tropical climate and therefore, surface topography and subsurface lithology experience an intense hydro-thermal activity. Sample weathering profile has been selected from a natural exposure associated with underlying granitic bedrock (Figure 1). The samples have been collected from different weathering grades of the profile and the observed characteristics of the materials such as fresh unweathered rock (as parent rock), slightly to highly weathered rock (as saprolite) and completely weathered materials (as soil) are considered. In this research communication, only one sample profile is taken into consideration as it is an initial experiment for fulfilling the broader aspects to understand the landscape evolution of the Purulia district. Therefore, limited numbers of samples are used here for analyses.

3. Materials and Methods

3.1. Laboratory analysis

The samples were analyzed with a petrographic microscope for mineral identification, mineral alteration phase identification, and microfractures observation to understand their propagation. For this investigation, petrographic image assessment of thin sections of the samples was carried out by NIKON polarised electronic microscope in the geophysical lab at the department of Geology, Presidency University, Kolkata. The wavelength-dispersive x-ray spectrometry of this same department was used for major elemental analysis of the samples from different weathering grades. The aluminium cups were used to pack those powder samples which mixed with boric acid and cellulose powder. Then the samples were pelletized with manual compress machine in the sample preparation laboratory.

3.2. Elemental analysis

Open-system mass change ($\tau_{j,w}$) calculation using geochemical mass balance approach is adopted between the existing parent rock and weathered materials of this apparent parent rock in the profiles (Figure 1). The ratio of major element concentration (Si, Al, Fe, Na, Ca and K) in the samples is used to measure the mobility of the elements with changing weathering grades within the profile (Brimhall and Dietrich, 1987; Chadwicket al., 1990). To explore the mass transfer ($\tau_{j,w}$) of the mobile element (j), elemental concentration, volume and bulk density of the materials have been incorporated in the calculation as proposed by Chadwick et al. (1990). To determine this transformation titanium (Ti)was selected as it is an essential immobile element in granitic rock (Brimhall et al., 1991). The formulation of open system mass transfer of Chadwick et al. (1990) is given as:

$$V_p \rho_p C_{j,p} + m_{j,flux} = V_w \rho_w C_w \qquad (1)$$

Where, V_p and V_w are the volume of parent rocks and soil/regolith, respectively, ρ_p and ρ_w and are the bulk density of rock and soil/regolith, respectively. Variable m_j describes inputs and losses of element j to the system where positive values represent inputs and negative values represent losses.

Major six important elements were selected in the mass balance equation, and the equation of mass transfer of immobile elements (i) is

$$V_p \rho_p C_{j,p} = V_w \rho_w C_w \qquad (2)$$

By combining these equations, the final open system mass transformation ($\tau_{j,w}$) of any elements can be measured as given below:

$$\tau_{j,w} = \frac{m_{j,flux}}{m_{j,p}} = \left(\frac{C_{j,w}}{C_{i,w}} \Big/ \frac{C_{j,p}}{C_{i,p}} \right) - 1 \qquad (3)$$

From this equation, if the calculated value is negative (<0 to -1), losses of elements from one grade to another grade is expected (Chadwick et al. 1990). Whereas, if the value is positive (>0 to +1), gains of elements and mineral enrichment in the next grade is proposed (ibid). The value '0' means no transformation of elements along the weathering profile (ibid).

In this context, the Chemical Index of Alteration (CIA) proposed by Nesbitt and Young (1982) is used to understand the stages and process of mineral alteration as well as the intensity of weathering rate. To estimate CIA, the concentration of major elements is used in the calculation which is given as:

$$CIA = \left[\frac{Al_2O_3}{(Al_2O_3 + CaO + Na_2O + K_2O)} \right] \times 100 \qquad (4)$$

This equation measured the conversion intensity of feldspar to clay minerals, and used extensively in the literature (Sutton et al., 1990; Sutton and Maynard, 1992, 1993; Gall, 1994).

4. Results and discussion

The petrographic images from the thin section analysis reveals that parent rock of the sample weathering profile is composed with mainly quartz and feldspar (both plagioclase and orthoclase) minerals associated with some micas (both muscovite and biotite; Figure 2). Several microfractures developed in the initial phase of weathering and those fractures gradually propagated across and/or along the minerals boundaries (Figure 2A-B). Extreme thermal stress and compaction with rainwater activity increase the intensity of fracture propagation and fragmentations. As a result, underlying parent rocks are open for hydro-chemical activity and therefore, geophysical and geochemical processes act together for extreme fragmentation and mineralogical alteration of the parent rocks. By this process secondary clay (mainly kaolinite) is produced including some newly formedFe-oxides in the grains boundaries (Figure 2C-D). In most cases, biotite minerals are easily hydro-oxidized to form this kind of oxide contents

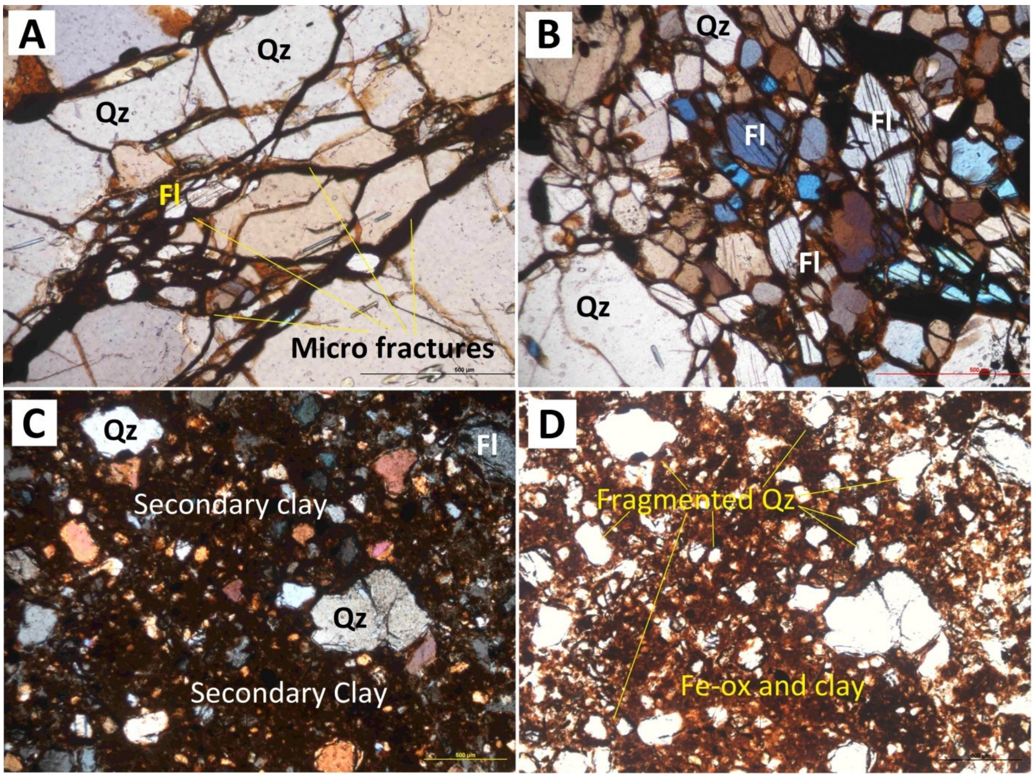

Fig. 2: Petrographic images of changing phases of minerals alteration: A) Parent materials with micro fracture development, B) Intense weathering and fragmentation of minerals, C-D) Fe-oxides and secondary clay formation with highly fragmented primary minerals C) – Cross polarized microscopic image; D) – Plane polarized microscopic image. Qz - quartz and Fl – feldspar

which gradually help to generate secondary clay such as kaolinite, montmorillonite, and illite. Consequently, this neo-formed clay including fragmented and altered primary mineral scan help to developed more mature and thick overlying soil surface.

On the other hand, open system mass transfer ($\tau_{j,w}$) of the major elements indicates elemental losses in the profile. Most of the mobile elements (Si, Al, Fe, Na, and K) show their negative transformation with changing weathering grades that means losses of elements are evident in this profile except Ca (Figure 3). Therefore, an insignificant transformation of Ca-rich minerals is identified in the studied profile. But the higher depletion of Al, Fe, Na, and K illustrate the immense alteration of plagioclase feldspar and muscovite rather than quartz because the depletion of Si element is not very significant (-0.5) and indicates the lower transformation of quartz and silicate

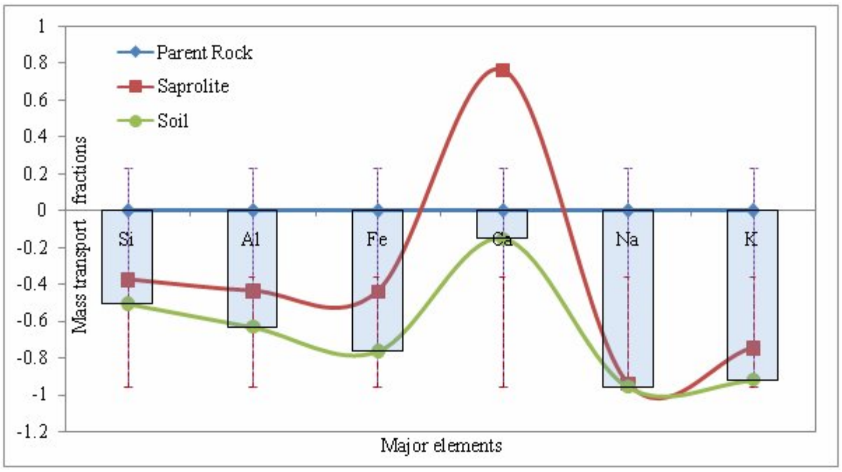

Fig. 3: Open-system mass transport fractions ($\tau_{i,w}$) of major elements (Si, AL, Fe, Ca, Na and K) in different weathering grades

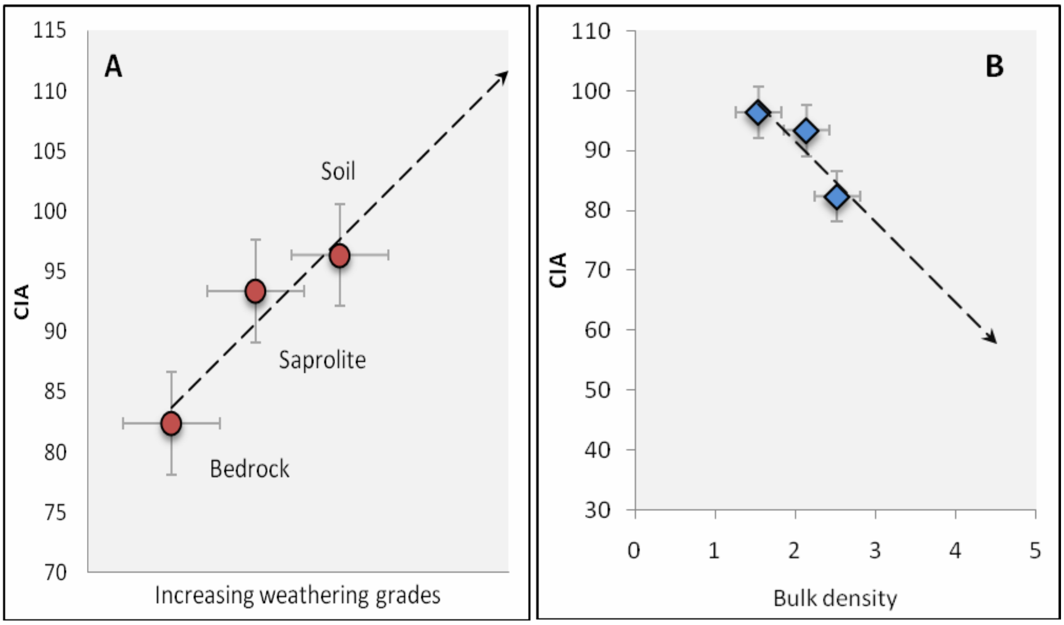

Fig. 4: A) Increasing trend of CIA along with progressive weathering grades; B) Inverse relationship between bulk density and CIA in the studied weathering profile

minerals in upper weathering grades. Elemental transformation ($\tau_{j,w}$) values of Si, Al, and Fe are under -0.7 which indicates further depletion and more intense weathering potentiality in this profile. Additionally, the result from the calculation of CIA is compared with the bulk density of three different weathering grades and it shows that there is an inverse relationship between these two aspects in the studied weathering crust (Figure 4B). The extreme fragmentation and alteration of parent rock of the profile were found during field observation, which is supposed to develop a complete regolith. Thus, reduction in bulk density is reasonable with increasing weathering grades but at the same time, CIA shows the increasing trend in weathering degree (Figure 4A). So, parent rock disintegration and chemical alteration are highly active simultaneously. As the studied profile is a typical reflection of the underlying lithology and weathering characteristics of that region, so the overall experiment indicates an intense weathering of granitic rocks which have the possibility for further chemical transformation and complete dissolution of parent materials for extending the regolith thickness in the study area.

5. Conclusion

Analyses from the petrographic thin sections make us understand that quartz, feldspar and micas composed granitic parent rock beneath the surface which are gradually fragmented and altered by micro fracture development and propagation and continuously hydro-chemically altered into Fe-oxides and secondary clay to developa regolith crust. But the chemical analysis of major elements and their mass transformation along the weathering profile indicate present characteristics of weathering and future potentiality for physico-chemical alteration. Similarly, reducing bulk density and growing weathering intensity along the increasing weathering grades simultaneously occur in this landscape. Therefore, active physico-chemical weathering on parent rock and its future erosional potentiality can develop more mature regolith and overlying soil in this area.

Acknowledgements

Authors are thankful to the Department of Geology, Presidency University, Kolkata for providing the opportunity to use their laboratory. Authors are also grateful to the anonymous reviewer for their valuable comments and suggestions to improve the quality of this article.

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