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Full Length Research Paper

Dynamic Weathering in Western Ghats Southern India – How Does Rock Weathering Proceed in Nature

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Abstract

Rock weathering is a fundamental geological process on the surface of the Earth. It acts on a non-living system (rocks) and converts it into a life supporting system (soil) by redistribution of elements therefore rock weathering is the fundamental process for elemental distribution on the surface of the Earth. The rock weathering studies by geochemical method dates back to 50 years. Climate, lithology, topography, biological activity, vegetation and tectonics all seems to play important role in governing the nature and extent of rock weathering, though the relative importance of these factors are not well understood. On the basis of field study, five different modes of water-rock interaction are documented in the present study. It is observed that when one particular rock-type in an area under a given climatic condition undergoes a particular mode of weathering, same rock type in another area but in different climatic condition may be subjected to another set of weathering processes to form regolith/soil therefore the processes of rock weathering are indeed continuous in nature at different levels of exposure with different climatic conditions. This implies the dynamic nature of weathering, herein called as dynamic weathering, which is in contrast to the idea of commonly believed insitu/static weathering process.

Keywords: *Climate, Lithology, Regolith, Tectonics, Weathering*

Introduction

Rock weathering produces first saprolith, than saprolite and finally regolith, which become sediments after erosion, transport and deposition. It is well known that tectonics and denudational processes continuously shape the Earth's surface (Ledley et al, 1999) However, our knowledge of the associated processes is inadequate. The rate and nature of weathering vary widely and are controlled by many variables such as parent rock-type, topography, climate and biological activities. It involves interaction between the lithosphere, hydrosphere, atmosphere and biosphere. Weathering profoundly alters the surface of the Earth and the chemistry of water bodies. We document here five different ways of water entry into the rocks and weathering of hard rocks in the field

1. Physical heterogeneities (i.e. through (a) foliation planes (b) lithological contacts (c) compositional layers (d) joints and fractures and (e) shear zones).
2. Fracture induced weathering. (i.e. through secondary fractures developed during uplift and unroofing)
3. Spheroidal weathering.
4. Regolith induced Weathering (i.e. Regolith accumulating on slopes and foothills)
5. Life induced weathering (i.e. through plant root system, animals etc)

Considerable amount of work on weathering and soil formation has been done for temperate regions of the world. However, little is known for tropical regions, particularly phenomenological aspects of rock weathering in the field setup. Rocks exposed in humid-tropical regions are commonly subjected to a high degree of chemical weathering because of availability of water and higher temperature. Again we know very little on the weathering process in monsoonal climate regions such as the major part of India, where relatively shorter spell of rainy months alternating with longer spell of semi-aridity. A monsoonal climate may actually be an annual analogue of long term humidity and aridity fluctuation, as far as the weathering processes are concerned.

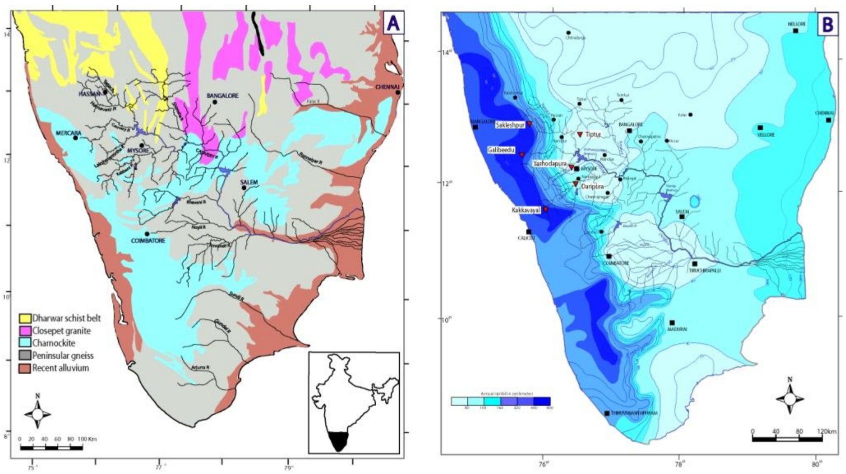

Figure-1[A]: Generalized geological map of southern India (After Radhakrishna, 1993) and [B] Topographical and rain fall map of southern India. (After Gunnel, 1988)

In this study, we discuss some of the field aspects of rock weathering in the Mysore plateau, the catchment area of the Kaveri River. This region has at least three major rock types, granitic gneisses, mafic rocks of amphibolitic to granulitic grade and chanockite (Figure-1A). Steep W-E gradient in rainfall and high relief is observed on the western margin of the plateau (Figure-1B). The region is neo-tectonically active (Radhakrishna, 1993; Gunnel, 2001). In the present study, we show dynamic nature of weathering of rocks in one of the biological hotspot of the world that is Western Ghats, southern India through field photographs. Different modes of weathering what rock undertook for this life sustaining process which starts taking advantage in a feedback manner using products of weathering to different extents and using a combination of various steps mentioned below.

Physical Heterogeneities

It is very common in many old continental terrains (Jayananda et al., 1995; Brandon and Meen, 1995) where strongly deformed and foliated gneissic rocks with zones of variable deformation are exposed to weathering. Gneissic rocks especially migmatitic gneisses with compositional bands, aplitic and pegmatitic veins and dykes provide excellent opportunity for water infiltration and therefore undergo rapid physical disintegration. Thus for a given set of climatic conditions, the intensity of the weathering processes of these gneisses is a function of grain size, nature of the physical discontinuities, their density in a given volume of rocks and their orientation relative to the surface. Physical heterogeneities in rocks are important in semi-arid climatic set-up because under high rainfall regime, these physical heterogeneities will be suppressed by the pervasive action of water. Figure-2 shows field photographs of physical heterogeneities of different kinds present within exposed rocks that provide an excellent example how these heterogeneities promote weathering processes. Banded migmatitic gneisses can be visualized in figure 2a as fractures present in between the compositional bands providing an ample opportunity for water to move in for the process of weathering to proceed. In figure-2b which is a closer view of figure-2a shows that the rock is coarse-grained with higher density of physical discontinuities, all this collectively favor rapid physical disintegration of rocks during weathering. Another kind of physical heterogeneity inherent to the gneisses, which is termed as foliations, can be visualized in figure 2c where foliation planes are parallel to the compositional band whereas in figure- 2d foliation planes occur in a massive rock. These foliation planes provide an opportunity for water to move in and to weather the rock, especially if they are disposed obliquely to the surface. Density, orientation and coarseness of structure control the intensity and rate of weathering. As weathering intensity increases, the rock initially develops a schistose appearance (Figure-2e) and eventually to a zone of featureless, fine grained saprolites with occasional preservation of foliated structure (as marked by resistant quartz) (Figure-2f).

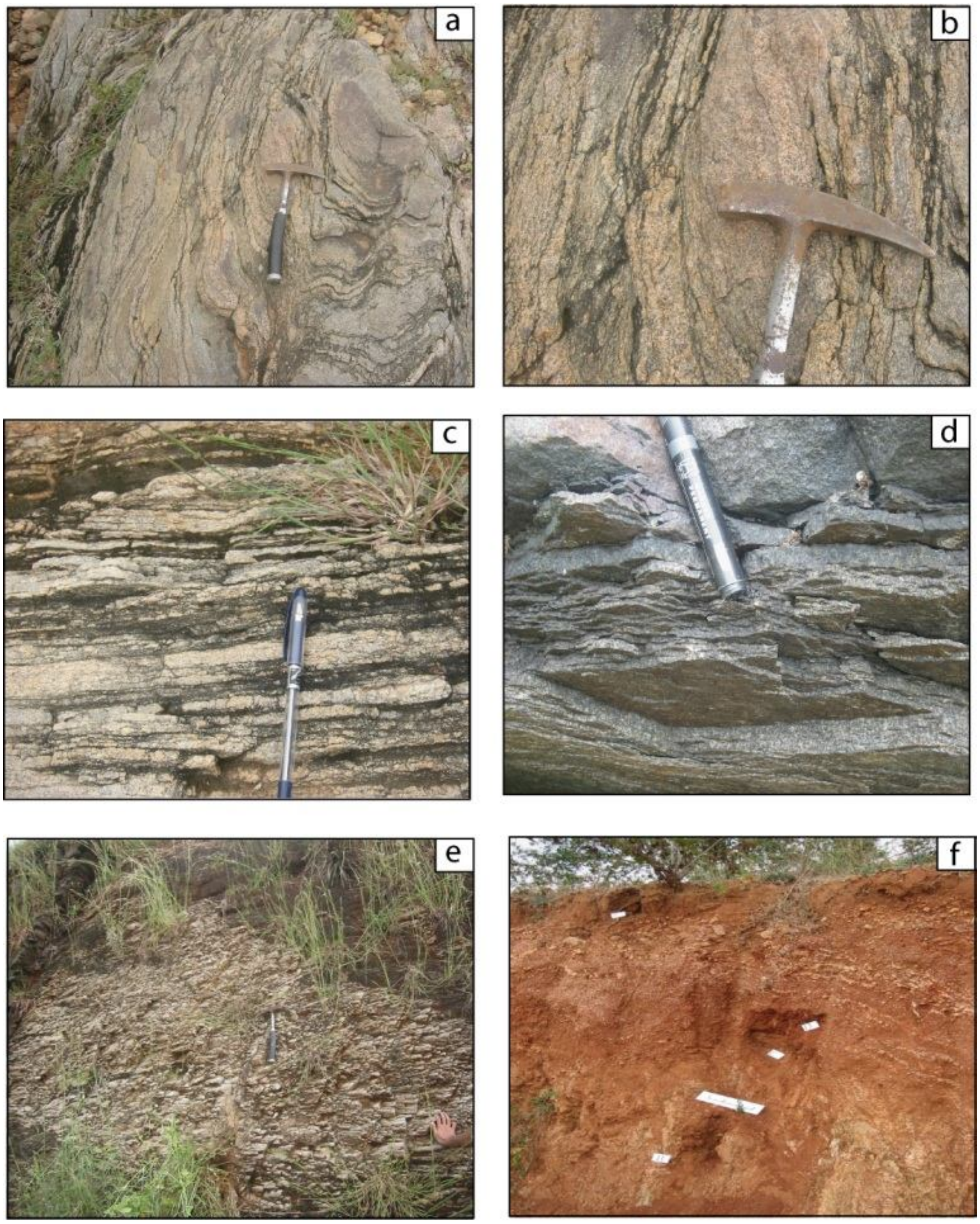

Figure-2: Field photographs showing different modes of physical heterogeneities

Thus the nature and orientation of the physical discontinuities, as well as their distribution density in rocks determine the extent and rate of weathering. A foliated and heterogeneous migmatitic rock undergoes a high rate of physical disintegration and produces chemically less-weathered regolith. We observe that water permeability in hard rocks is as important as water availability in controlling the weathering rates.

Fracture induced weathering

The next important process by which access to water is accomplished in rocks is through fractures developed due to upliftment processes. These fractures which are formed as a result of uplift and unroofing of overlying material are sub-parallel to the surface but some could be at high angle because of cross cutting nature of several fractures.

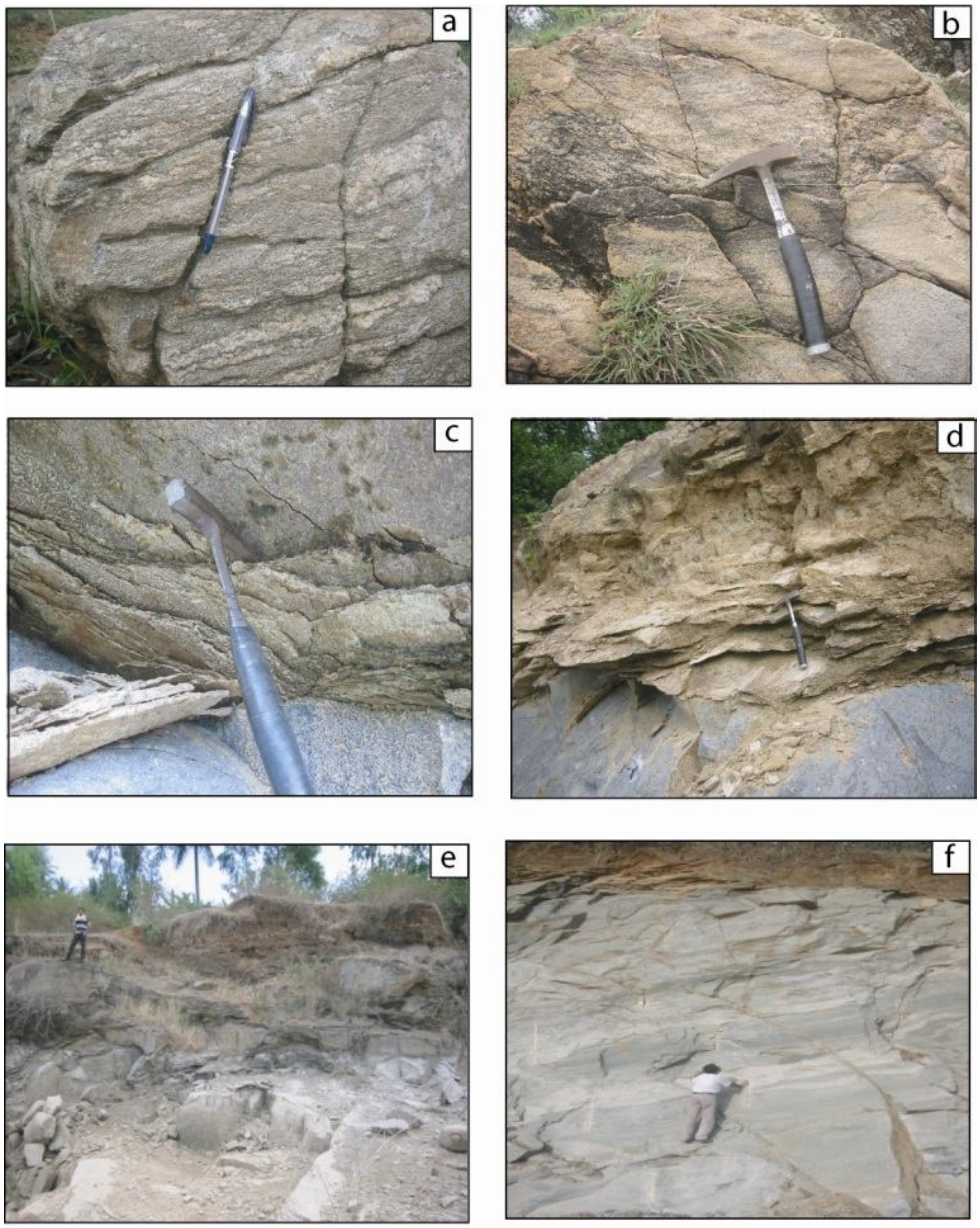

Figure-3: Field photographs showing different modes of fracture induced weathering

It is known that the Western Ghat belt is neo-tectonically active area (Radhakrishna, 1993; Gunnel, 2001). The occurrence of these fractures is very common under semi-arid climatic set-up, because of greater preservation potential. These fractures provide accessibility for water through which weathering proceeds along the fractures. Near the surface where the effect of pressure release is maximum, the fracture intensity is higher, which in turns promotes higher extent of weathering at the surface. The boulders intercalated with regolith are formed by the outcome of fracture induced weathering at relatively higher topographical level (Espinosa et al., 2007). As the extent of weathering along the fractures increases the boulders appear to be embedded within the locally formed regolith. Figure 3 shows field photographs of fracture induced weathering, in figure-3a and b a good illustration of sub-parallel and high angle fracture relative to the surface can be seen in granites. In figure-3c a massive hard rock becomes strongly ex-foliated to different degrees along fractures with accompanying changes in color and hardness (Figure-3d). Figure-3e illustrates thin regolith cover developed at the top due to progressive downward weathering and the formation of clay minerals along the fracture planes. At a later stage due to differential weathering along the fracture plane results in the formation of boulders as observed in figure-3f.

Spheroidal weathering

Spheroidal weathering is the term used if concentric shells completely surround a corestone. The term concentric weathering and onion weathering are generally used as synonyms for spheroidal weathering (Ollier, 1967, 1971). Spheroidal weathering is very common in homogeneous, hard rocks which are well jointed, especially granite, dolerite, basalt and amphibolite. Weathering of rocks proceeds from the outside towards the rock's interior. This is especially evident in spheroidally weathered boulders whose onion-skin morphology of altered layers envelope a core of fresh rock (Augustithis and Ottemann, 1966).

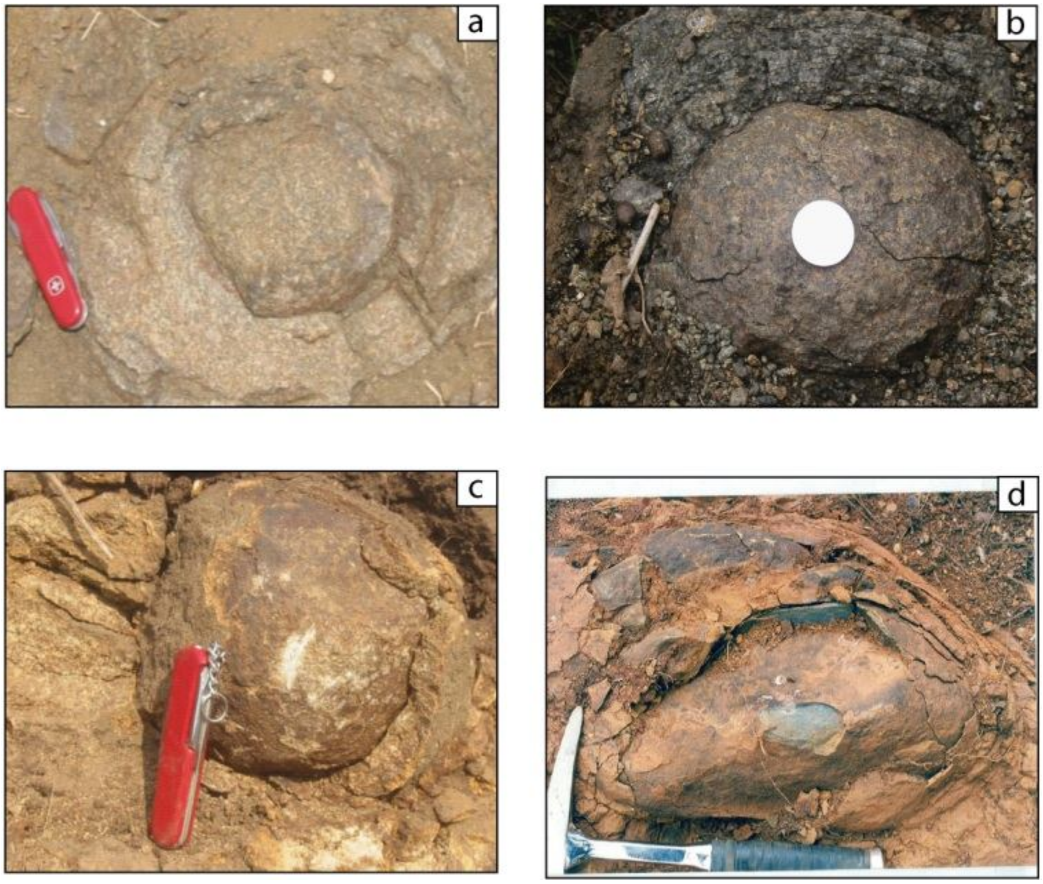

Figure-4: Field photographs showing different modes of spheroidal weathering

The distinction between spheroidal weathering and other forms of exfoliation is significant. Miller (1925) distinguished exfoliation as a mechanical process whereas spheroidal weathering as a chemical process. Figure-4 shows field photographs of spheroidal weathering. Concentric cracks as well as concentric colour zones are common in spheroidal weathering (Figure-4a). The cracks could result from shrinkage following increasing segregation and dehydration of the hydroxides. Thus although the joint block as a whole retains constant volume, local shrinkage causes the concentric cracks (Figure- 4a) where a hard core stone is preserved, there is often a remarkably abrupt change between the fresh rock and the weathered rock. This is known as weathering front (Mabbutt, 1961), (Figure-4b). In some instances even the core stones have suffered granular disintegration or mineral decomposition (Figure- 4b). Spheroidal weathering is sometime preserved adjacent to fresh core stones, although the outer parts of the joint block have broken down to structure less grubs (Figure-4c). Sometime a hard and fresh core stone may be surrounded by much decomposed spheroidal shells showing change in color in adjacent concentric shells (Figure-4d). Spheroidal weathering can occur on boulders within alluvial or regolith deposits (Figure-4e) In some instances the corners of joint blocks are fairly fresh, but are separated from a cores tone by spheroidal cracks, the resulting fragments, which may be termed cornerstones, are roughly tetrahedral in shape.

Core stone shell complexes are common features that develop during spheroidal weathering as water moves through rock fractures and drives weathering reactions in the rock (Ollier, 1967, 1971). Basaltic and andesitic lava flows have cooling features, such as columnar joints, which serve as hydrologic discontinuities, and which functions as a major pathways for water that are the agents of weathering.

Regolith induced weathering

There is tremendous interest in understanding the process that controls the interaction between minerals and aqueous solution in the weathering mantle (i.e regolith cover). Topography has a marked effect on the rate of weathering and also on the nature of weathered product as discussed above which in turn control the thickness of the weathering mantle. On very steep slopes most of the rain water is lost through surface runoff and little penetrates the hard rock and at the same time erosion by running water, wind and other agent is particularly active inhibiting the formation of deep weathering mantle.

Figure-5: Field photographs showing different modes of regolith induced weathering

Flat, or gently sloping areas, on the other hand, experience little surface runoff and infiltration of rain-water is at a maximum, so weathering proceeds to a greater depth contributing to the formation of deep weathering mantle, which can act as a reservoir of water in the initial stages accelerating the rate and extent of weathering. As emphasized by Stallard (1992) and further discussed by Bluth and Kump (1994), weathering rate will decrease as weathering mantle get deeper, isolating the bedrock from precipitation therefore most of the aggressive processes caused by plants are actually more strongly expressed in the upper part of the weathering mantle. Figure 5 shows field photographs of regolith induced weathering. Figure-5a shows the initial stage of weathering with thin regolith cover (1m) in which the water stored seeps through the surface parallel fractures. In the next stage figure-5b the thickness of regolith cover increases promoting more weathering and at a later stage in figure-5c nearly 6-7m thick regolithic cover can be observed. Commonly we observe that thicker the weathering mantle, the higher will be the weathering intensity but after a certain stage this weathering process ceases as water cannot reach to the deeper part (Figure-5d). Because of that, at greater depth of weathering mantle roots are scarce or missing and the biological activity is reduced.

Life induced weathering

The characteristics of soils and weathering mantles reflect the integrated effects of water, atmosphere and life acting on rocks. Plants directly control water dynamics, weathering and the chemistry of weathering solutions, which is clearly exhibited in equatorial areas where old weathering mantles are greatly influenced by biological activity. Soil fauna, plant roots and organic matter directly affect soil structure and porosity. The role of life in determining the rates of weathering at the mineral, was addressed in several studies (Likens et al., 1977; Velbel, 1985; Berner, 1992; Cochran & Berner, 1992; Bluth & Kump, 1994; Drever, 1994; Moulton & Berner, 1998).

Figure-6: Field photographs showing different modes of life induced weathering

Plants absorb soil water through their roots and take in atmospheric CO_2 through their leaves. Vegetation, with its associated fungi and bacteria promotes mineral dissolution by modifying the chemical characteristics of the soil solutions. The root actively excretes H^+ which exchanges for other nutrients(Mg^+, Ca^{2+},NH^{4+}, K^+ and so on) and thus maintain a charge balance (Briskin, 1994).

It takes up basic cations and excretes acid cations Al^{3+} (Andersson, 1988) and organic acids (Jones and Brassington, 1998). The redox potential may be locally changed as the result of depletion of dissolved O_2 through the oxidation of organic matter, which can result in increased dissolution of redox-sensitive elements such as Fe, Al, V, and Cr etc. Biological activity, mainly related to plant growth, may modify rates and especially products of weathering relative to those that would result from abiotic processes. Figure-6 shows field photographs of life induced weathering by plant roots and biological activity. In figure-6a the penetration of plant root in a rock through fractures can be seen to enhance the gap, as well as form new fractures providing an opportunity for water to move in. Weathering process is accelerated and with the passage of time the rock weathers to form soil (Figure-6b). The presence of lichens (a symbiotic relationship between algae and fungi) can be seen in figure-6c, which develops under humid oxidizing condition. These lichens accelerate the weathering processes by secreting organic acids, hence locally changing the Eh-pH conditions. The formation of algal layer (Figure-6d) is common in tropical climate, where longer spells of rainy months alternate with small spells of semi-aridity. During the rainy months these layers develop over the exposed rock surface and enhance the weathering of rocks by changing the redox conditions and by the mobilization of the ions. In the dry summer months this process ceases and the weathered material is removed by erosion and new fresh surface is exposed for further weathering and erosion. The process by which life controls the weathering mantle have thus to be considered, when studying global changes through geological times as well as during the present time.

Discussion

Weathering of rocks starts when they get exposed to the surface or when they get access to the surface water, whichever is earlier surface water can bring with it other agents of weathering such as dissolved air and suspended organics / microbes. The rocks can go through either one of the processes or a combination of processes to weather and to form soil. In different climatic regions different weathering processes are playing a key role in governing the rate and extent of weathering. In semi-arid climatic set-up of our study area (Figure-1B), physical heterogeneities and fracture induced are the major weathering processes by which the rock is locally converted into saprolite and eventually to soil. In the humid climatic set-up of our study area which includes (Figure-1B), regolith-induced and life-induced are the major processes undergone by rocks to weather. The process of spheroidal weathering is common in both semi-arid as well as humid climatic set-up but under semi-arid climatic set-up spheroids are developed at an outcrop scale whereas under humid climatic set-up, spheroids are developed at a local scale, especially on foot hills and gentle slopes. Also we observe that when one rock type in one place undergoes weathering by one of the processes enlisted above, in a place with different climatic condition it is taking another set of processes to form soil. Thus the processes of rock weathering are in continuous motion at different levels with different climatic condition and with different set of processes enlisted above. This process is not operating at one level nor is it static as the materials and the nature of processes are in constant motion. We term this weathering process as dynamic weathering to contrast against the controversial idea of static/in situ weathering. The present study highlights the importance of weathering process which is very much essential to understand the relevance of geoscience education that actually how this process operates at different levels in the field, to hold the concept that "*it is geology what determines biology*". We can expect that closer observations, refined definition and the application of modern analytical methods will soon make rapid advances in on understanding of weathering processes, which are fundamental to sustain life on Earth.

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