Greywacke weathering under tropical climate: Chemical and mineralogical changes (example from central-Brazil)

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Abstract

Greywackes are matrix-rich sandstone, in general, containing chemically unstable minerals, which under tropical weathering conditions give origin to thick weathering profiles, depleted in base cations and rich in metals hydroxides. This work deals with a thin weathering profile developed on a proterozoic greywacke, under tropical conditions in central-Brazil. The rock presents a fine-grained texture and is mainly composed of quartz, feldspars and phyllosilicates. Initial weathering yields expandable clay minerals and opaque minerals (Fe-oxihydroxides), which replace phyllosilicates and form euhedral crystals. From fresh rock to the most altered level, K_2O and Na_2O decrease, Fe_2O_3 increases, but Mg remains almost constant. The fine-grained texture of the rock, and expandable clay minerals produced in the first stage of alteration inhibit water infill in the rock, explaining the narrow level of weathering. This study reinforces the role of the parent rock in the weathering, even under tropical conditions.

Key Words

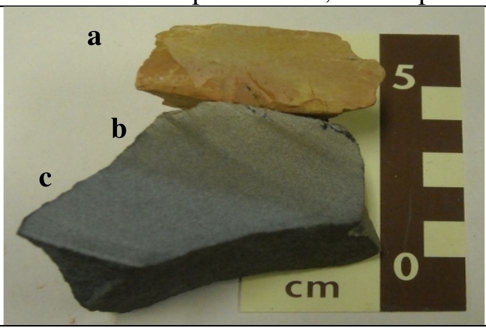
Greyawcke, Fe-oxide, interstratified clay minerals, smectite, electron microprobe, X-ray diffraction

Introduction

In tropical and equatorial climates, soils are very thick and mainly formed of kaolinite combined with Al and Fe-oxihydroxides, even where the composition of parent rocks is different. However, the composition of parent materials is of decisive importance for the beginning of weathering, when mineral composition and water flow control the products of alteration (Meunier, 2005). The mainly chemical and mineralogical transformations lead leaching of base cations and Si, result in formation of kaolinite and oxidation of iron and manganese. Weathering of chlorite is characterized by both Fe oxidation and leaching of Mg yielding vermiculites and smectites (Newman, 1982). On landscape modeled by differential erosion, hills are sustained by resistant rocks. In central Brazil, the tropical climate is characterised by annual precipitation of approximately 1600 mm with a wet season from October to March and a mean temperature ranging from 18 to 22°C. Erosional processes produce plateaus sustained mainly by granites, quartzites, sandstones and lateritic crusts, but some are maintained by greywackes from the proterozoic Três Marias Formation (Bambuí Group). Despite the chloritic matrix and plagioclase content, the alteration profiles on these greywackes are only a few centimeters in depth and the plateau surfaces are covered by sand among boulders, cobbles and pebbles produced by spheroidal weathering. On boulders and cobbles, alteration occurs from the surface to the core, in which parental rock is preserved. In this paper we present the initial mineralogical change on the greywacke and the possible mechanism that limits the weathering on the surface. Indeed, mineralogical studies allow a better understanding of the processes of soils formation and better determine the rate of soil processes (Cornu *et al*., 2009).

Methods

The study was carried out on a representative greywacke cobble (15 cm) from Três Marias Formation collected on a plateau near Cabeceiras town, Goiás, Brazil (S 15° 46’ - W 48°23’). Three samples were selected: a fresh parent rock, an incipient altered rock and an altered level (Figure 1).



Sample	Macroscopic characteristics
EGC 37 II a	Medium yellowish brittle level (2 cm thickness) at surface of the cobble, with strong alteration.
EGC 37 II b	Medium grey brownish level (3 cm thickness with incipient alteration, surrounding the core.
EGC 37 II c	Dark grey greenish hard rock in the 6 cm core without alteration features.

Figure 1. Macroscopic characteristics of greywacke samples.

Polished thin sections of samples were studied by both conventional petrographic microscopy and microprobe. Bulk chemical analyses of major elements were determined after acid digestion (hot, conc. HF, $HClO_4$, HNO_3 and HCl) of finely ground samples. Analyses were performed using ICP-AES for Si, Ti, Fe, Ca and Mg determination and ICP-MS for Na and K. X-ray diffraction (XRD) analyses were performed using a Rigaku D/Max diffratometer with Cu radiation, under 35 kV and 13 mA, on fine earth (< 0,1mm) powders from whole samples and clay-sized fraction isolated by centrifuge and prepared by conventional technics: air-dried, and later solvation by ethylene-glycol for 12 hours. Elemental analysis of the minerals was made on polished thin sections, using a CAMECA/Camebax electron microprobe with operating conditions of 15kV, beam current of 5 to 10 mA and counting time of 10-15 sec. per element with a spot size of about 2 µm. Analyzed phyllosilicates are chlorite and interstratified clay minerals. Structural formulae for chlorite are calculated on the basis of 56 negative charges and assuming all iron as ferrous. Analyses with high Na, Ca and K contents and low octahedral occupancy have been interpreted as intimate intergrowths of mica and chlorite, or even mixed-layer clay minerals.

Results

Mineralogical composition is quite different in three samples (Figure 2). Fresh rock (EGC 37 II c) consists of more than 15% matrix constituted of an intimate intergrowth of illite and chlorite beside opaque minerals. The grains are 35% quartz, 30% feldspar mainly plagioclase, 12% of phyllosilicates (muscovite, biotite, chlorite) and the rest are opaque minerals, tourmaline and zircon. Micas and chlorite occur as clear laminae or are small lamella in lithic grains, with typical pleochroism. Biotite and muscovite are brown and white, respectively and chlorite is green or grey. Opaque minerals are euhedral crystals inside detrital grains, or micro-crystals along cleavage planes in phyllosilicates and somewhere replace partially other minerals.
In the level surrounding the core (EGC 37 II b) the composition is similar to fresh rock, feldspar being preserved, but phyllosilicates present changes: most of them become brownish and some are completely replaced by opaque minerals. In the most altered level (EGC 37 II a), some K-feldspars are still preserved, while all the phyllosilicate have lost their original colour or have been completely replaced by opaque minerals.

X-ray diffratograms from whole samples show typical reflections for quartz, illite and feldspar (Figure 3). The 14 reflection from chlorite is low, the 7 and reflections are high (coincident with kaolinite), while, 4.7 is present in both fresh rock and incipiently altered rock, but do not appear in most altered sample.
In clay fraction, quartz and feldspar reflections are low or missing, while phyllosilicates have high peaks. Fresh rock (EGC 37 II c) presents a distinct 14 Å reflection that does not expand under solvation by ethylene-glycol, characteristic of chlorite. This same reflection in EGC 37 II b displaces to 16 Å, indicating a smectite and it appears a 30 reflection under solvation by glycerol. These reflections indicate both the presence of smectite and an interstratified clay mineral. The most altered sample (EGC 37II a) presents kaolinite peaks and a high background.

Table 1 shows the chemical composition of the whole rock is quite different from one sample to another. Si, Al and Mg contents in the whole rock are almost constant in three samples. From fresh rock to the most altered, Fe_2O_3 increases, while Na_2O and K_2O decrease.

Table 1. Chemical composition of greywacke (whole rock).

Samples	SiO_2	Ti O_2	Al_2O3	Fe_2O_3	MgO	CaO	Na_2O	K_2O	P_2O_5	LOI	Total
ECG-37IIa	73.94	1.06	10.23	5.99	1.32	0.31	0.33	0.62	0.12	6.10	99.83
ECG-37IIb	78.52	0.65	10.07	2.86	1.22	0.46	1.19	1.21	0.12	2.61	98.92
ECG-37IIc	72.91	0.70	10.88	3.36	1.56	0.54	2.34	1.89	0.11	2.73	97.02

Elemental analyses (Table 2) show Fe-chlorite in fresh rock wich low vacance in octahedral site. In incipient altered rock, chlorites like lamelaes have more high octahedral vacance, that is atributed to oxidation state of iron and seems to indicate presence of smectite, or vermiculite, where Mg is high. In the most altered sample, the phyllosilicates like lameleas presents highest vacance in octahedral site (Figure 4) calculated as chlorite and high Fe content, that may be correspond to mixture or interestratified Fe-Kaolin (Ryan & Huerta, 2009).

Table 2. Elemental composition (%) of phyllisilicates calculated as chlorite.

SAMPLES	Si	Al(t)	Al(o)	Fe	Mg	Ti	Oct	Ca	Na	K	Alc
ECG-37IIa	6.2-7.8	1.8-0.2	3.5-4.8	2.1-4.3	1.8-4.0	0.0-0.02	9-10.6	0-0.1	0.1-0.2	0.1-0.5	0.2-0.3
ECG-37IIb	6.0-6.8	2.0-1.2	2.7-3.1	3.4-4.4	3.0-4.8	0.0-0.1	10.7-11.7	0-0.1	0-0.2	0.1-0.3	0.1-0.2
ECG-37IIc	5.8-6.2	2.2-1.8	2.4-2.6	4.2-6.5	3.2-4.2	0-0.1	10.8-11.9	0-0.01	0-0.1	0-0.2	0.07-0.2

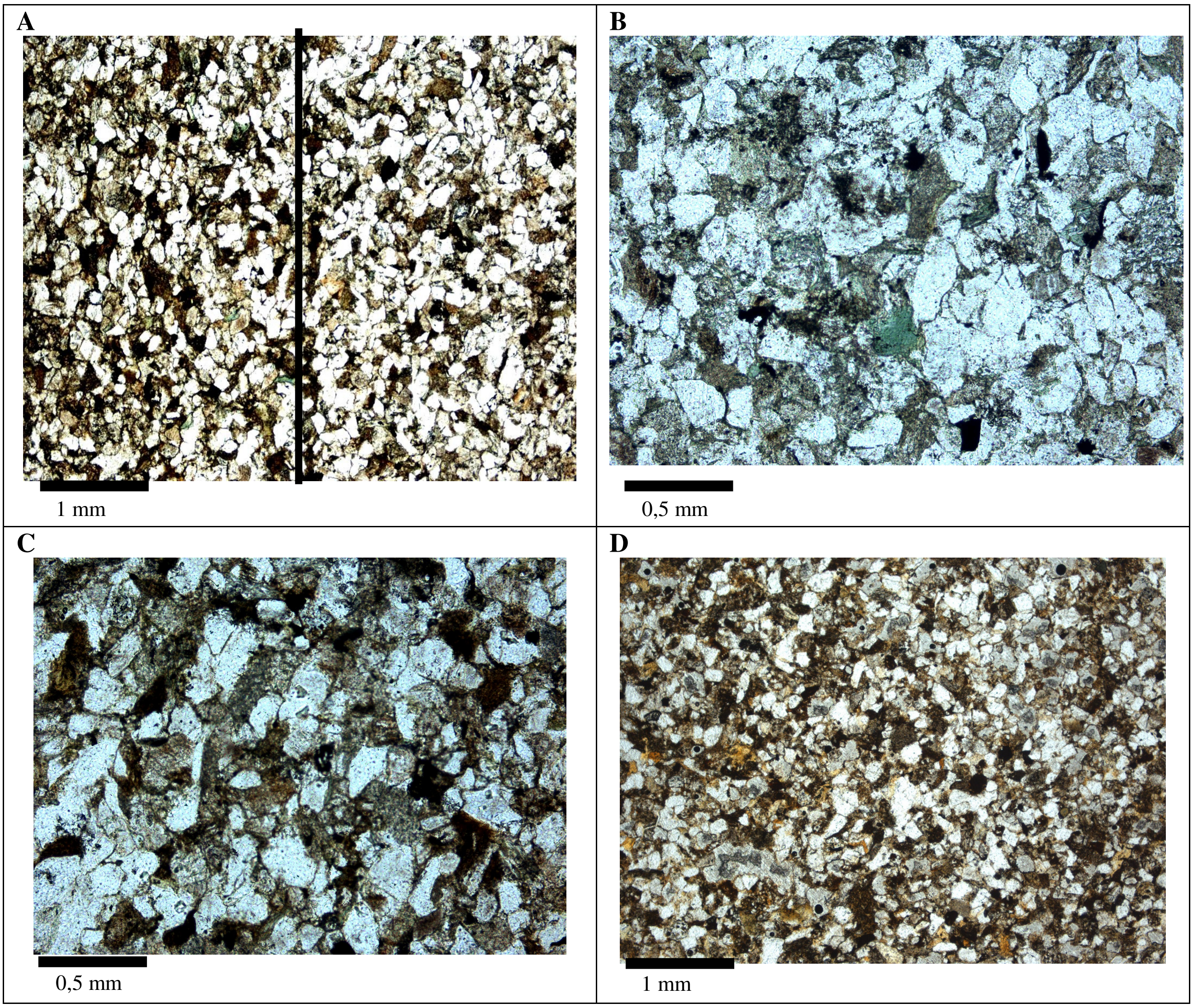


Figure 2. Greywacke under microscope: A) line indicates the contact between EGC 37 II c (fresh rock) and EGC 37 II b (incipient altered rock; B) detail on fresh rock, with green chlorite; C) detail on incipient altered rock: phyllosilicates are brown and some are replaced by opaque minerals; D) most altered rock: opaque minerals replace almost all phyllosilicates.

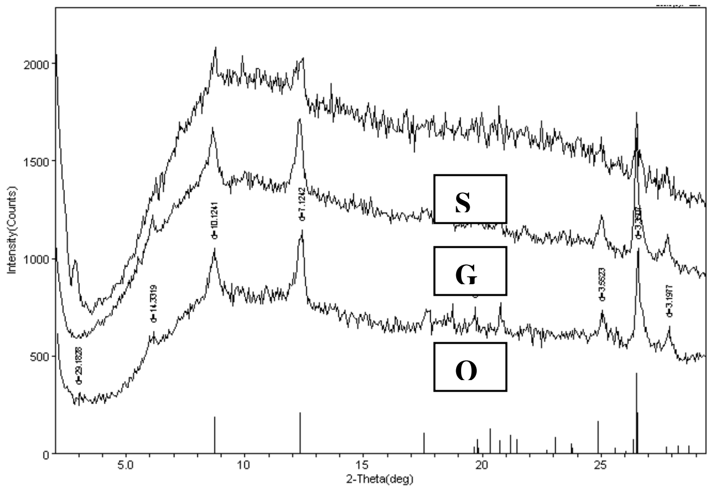


Figure 3. Diffractogram of clay fraction of EGC 37 IIb: O - oriented powder air-dried; G – solvated in ethylene-glycol; S – solvated in glycerol.

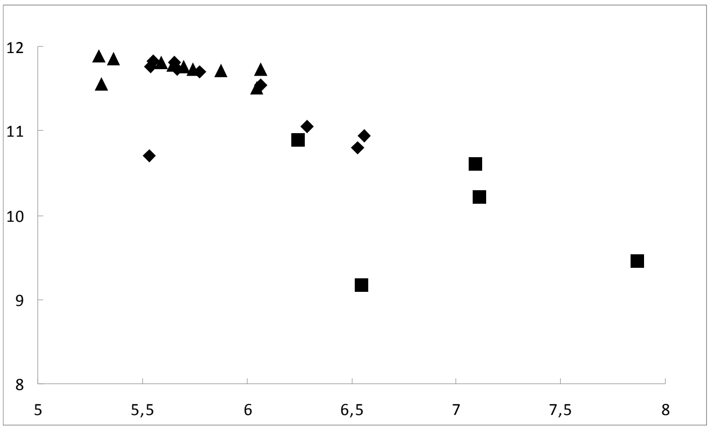


Figure 4. Octahedral occupation (Y axis) and Si content (X axis) in phyllosilicates calculate as chlorites: ▲– fresh rock; ♦– incipient altered rock; ■ – most altered sample.

Conclusion

From the fresh rock to altered one, the studied greywacke behaves as expected in some aspects and is different in others. Smectite and vermiculite are produced in the first stage of alteration and disappear in the surface, where kaolinite remains; Fe_2O_3 increases, while Na_2O and K_2O decrease. However, Mg and Al_2O_3 contents remain almost constant in all samples. Mg content corresponds to vermiculite and interstratified clay minerals calculated by microprobe analyses and identified by XRD. The high background in XRD of most altered sample indicates high content in iron. The thin weathering profile is attributed to fine grained rock and the expansive clay minerals in the first stage of alteration, inhibiting the water infill in the fresh rock. This work shows that the parent rock plays a decisive role in the beginning of weathering and can determines the path of the soil formation.

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