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The lateritic profile of Balkouin, Burkina Faso: Geochemistry, mineralogy and genesis

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ABSTRACT

This study reports on the geochemical and mineralogical characterization of a lateritic profile cropping out in the Balkouin area, Central Burkina Faso, aimed at obtaining a better understanding of the processes responsible for the formation of the laterite itself and the constraints to its development. The lateritic profile rests on a Paleoproterozoic basement mostly composed of granodioritic rocks related to the Eburnean magmatic cycle passing upwards to saprolite and consists of four main composite horizons (bottom to top): kaolinite and clay-rich horizons, mottled laterite and iron-rich duricrust. In order to achieve such a goal, a multi-disciplinary analytical approach was adopted, which includes inductively coupled plasma (ICP) atomic emission and mass spectrometries (ICP-AES and ICP-MS respectively), X-ray powder diffraction (XRPD), scanning electron microscopy with energy dispersive spectrometry (SEM-EDS) and micro-Raman spectroscopy.

The geochemical data, and particularly the immobile elements distribution and REE patterns, show that the Balkouin laterite is the product of an *in situ* lateritization process that involved a strong depletion of the more soluble elements (K, Mg, Ca, Na, Rb, Sr and Ba) and an enrichment in Fe; Si was also removed, particularly in the uppermost horizons. All along the profile the change in composition is coupled with important changes in mineralogy. In particular, the saprolite is characterized by occurrence of abundant albitic plagioclase, quartz and nontronite; kaolinite is apparently absent. The transition to the overlying lateritic profile marks the breakdown of plagioclase and nontronite, thus allowing kaolinite to become one of the major components upwards, together with goethite and quartz. The upper part of the profile is strongly enriched in hematite (+kaolinite). Ti oxides (at least in part as anatase) and apatite are typical accessory phases, while free aluminium hydroxides are notably absent. Mass change calculations emphasize the extent of the mass loss, which exceeds 50 wt% (and often 70 wt%) for almost all horizons; only Fe was significantly concentrated in the residual system.

The geochemical and mineralogical features suggest that the lateritic profile is the product of a continuous process that gradually developed from the bedrock upwards, in agreement with the Schellmann classic genetic model. The laterite formation must have occurred at low pH ($\leqslant$4.5) and high Eh ($\geqslant$0.4) values, i.e., under acidic and oxidizing environments, which allowed strongly selective leaching conditions. The lack of gibbsite and bohemite is in agreement with the compositional data: the occurrence of quartz (±amorphous silica) all along the profile was an inhibiting factor for the formation of free aluminium hydroxides.

1. Introduction

More than 200 years ago Francis Buchanan, a surgeon travelling in southern India, coined the term laterite (from the Latin *later-eris*, i.e., brick) to describe "*an indurated clay*" which "*is one of the most valuable materials for building. It is diffused in immense masses... and is placed over the granite.... It contains a very large quantity of iron in the form of yellow and red ochres...*" (Buchanan, 1807, pp. 440–441). Since then, the term "laterite" has been widely used for describing a rock deriving from extreme superficial weathering, generally under tropical climatic conditions. As assessed by abundant studies, the severe weathering conditions of tropical regions trigger strong transformations – involving selective leaching processes – leading to the formation of "lateritic rocks". These rocks are often used as building materials but can also be exploited

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for other types of mineral resources (e.g., Al, Ni, Fe, Au: Robb, 2005, and Refs. therein). As pointed out by Eggleton and Taylor (1999), Buchanan's original definition was actually abandoned and the term "laterite" is nowadays used by different authors with different meanings, indicating a specific material (i.e., as a rock term) or a group of materials organized in a particular way (i.e., "lateritic profile"), often with a genetic connotation.

An important attempt to re-define laterite was done about 30 years ago by Schellmann (1983, 1986), who proposed a new definition and classification based on rock chemistry – namely, on the Si/(Al + Fe) ratio – in comparison to the chemical composition of the underlying parent rock. Though widely used, such an approach was strongly criticized by several authors (e.g., Bourman and Ollier, 2002, 2003; reply in Schellmann, 2003), who proposed that the term "laterite" should have been abandoned. Such a term, however, is so widely used nowadays that its abandonment seems at least unrealistic. The "laterite problem" is largely based on the fact that when studied in detail (e.g., Dahanayake, 1982; Théveniaut and Freyssinet, 1999; Hieronymous et al., 2001; Kasthurba et al., 2005, 2007; Ollier and Sheth, 2008; Fernández-Caliani and Cantano, 2010), in spite of apparent similarities each lateritic profile is unique because of its development depending on several factors, such as climate, morphology, bedrock composition, and hydrogeology. The in-depth understanding of the lateritic materials needs therefore detailed multidisciplinary studies, which involve both field and laboratory investigations (Bourman, 1993).

To achieve a better understanding of the multiple processes involved in laterite formation and the eventual constraints limiting its development, a detailed geological, mineralogical and geochemical characterization of a lateritic profile cropping out in the Balkouin area, Central Burkina Faso (Giorgis, 2012), was performed. The investigated profile rests on a Paleoproterozoic basement mostly composed of granodioritic rocks, related to the Eburnean magmatic cycle, passing upwards to saprolite and consisting of four composite levels, including (bottom to top) kaolinite and clay-rich horizons, mottled laterite and iron-rich duricrust. The study, conducted *via* an in-depth, multidisciplinary analytical approach, is part of a project coordinated by LEMC (Laboratoire d'Eco-Matériaux de Construction) of the Institut International d'Ingénierie de l'Eau et de l'Environnement (2iE), whose purpose is the contribution to the development of eco-sustainable materials – including laterite as a building material (Lawane et al., 2011). Several studies were performed in Western and Central Africa, focused on the geotechnical and mechanical characteristics of the lateritic *soils* (or "lateritic gravels") and their possible use in the construction of roads and trails, especially in Ghana (Gidigasu, 1971, 1974, with Refs.) and more recently in Burkina Faso (Millogo et al., 2008). Studies focused, instead, on lateritic *rocks*, aimed at developing a standard for their use for building purposes, were performed recently, particularly in India (Kasthurba et al., 2005, 2007). In spite of their widespread diffusion, these rocks did not apparently receive so far great attention, especially in Western and Central Africa, and only recently some projects started in order to possibly valorize them as potential building materials (Lawane et al., 2011; Lecomte-nana et al., 2009). Within the circles of the above mentioned project, the data presented in this paper will hopefully also contribute to understand the influence of the chemical and mineralogical features of laterite on its engineering properties.

2. Geological setting and climate

2.1. Regional geology

Burkina Faso is mainly composed of precambrian rock sequences belonging to the West-African craton, made of a Paleoproterozoic basement and its sedimentary covers (Sattran and Wenmenga, 2002; Castaing et al., 2003a and Refs. therein). The basement is characterized by the occurrence of the Birimian greenstone belts (2238–2170 Ma: Castaing et al., 2003a), volcano-sedimentary and plutonic sequences mostly oriented NNE–SSW, affected by a greenschist to (locally) amphibolite facies metamorphic overprint. The greenstone belts are intruded by abundant acidic magmatic bodies (Eburnean magmatism), that have been divided into a tonalite (2210–2100 Ma) and a generally younger granite suite (2150–1819 Ma: Castaing et al., 2003a). The basement is unconformably covered by a Neoproterozoic to Lower Paleozoic sequence in the far West and South-East of the country, as part of the Taoudenni and Volta sedimentary basins respectively. Some terrigenous formations of Cenozoic age also occur in the far North-West and East areas (Sattran and Wenmenga, 2002).

Most of the country is covered by a relatively flat peneplain, which forms a gently undulating landscape. Isolated hills are generally rests of Precambrian massifs, apart from the steeply-sided Paleozoic sandstone massif where the Tena Kourou peak (749 m) stands.

2.2. Geology of the Balkouin area

The Balkouin village is located in Central Burkina Faso, ca. 20 km South-East of the capital Ouagadougou (Fig. 1), at a height of 304 m a.s.l. This area is mainly composed of Paleoproterozoic acidic to intermediate magmatic rocks belonging to the Birimian basement, related to the Eburnean magmatic cycle. They are represented by different varieties of granitic rocks (biotite ± amphibole medium-grained granite; biotite + amphibole porphyritic granodiorite; biotite ± muscovite medium-fine grained granite), which intrude bodies of locally foliated granodiorite, tonalite and quartz-diorite ("tonalitic suite"), dated at 2140 ± 6 Ma (Castaing et al., 2003a,b). Remnants of older volcano-sedimentary and plutonic formations, metamorphosed by the Eburnean event, are represented by scattered bodies of amphibole gneiss (one cropping out at Balkouin according to Castaing et al., 2003b; Fig. 1), volcano-sedimentary schists and rhyolitic rocks within the granites. Rocks belonging to a "leptynite-granodiorite complex" also crop out in the South-East. The Birimian basement is crosscut by WNW–ESE trending dolerite dykes and affected by minor fracture/fault systems, mostly oriented NE–SW (Fig. 1).

As in most of the country, the basement outcrops are relatively rare. In fact, the peneplain developed on the Paleoproterozoic basement is covered by a 5–15 m thick blanket of laterite, which is often mined as a building material. Only locally the basement is visible, in the form of rounded outcrops surrounded by a residual laterite mantle.

2.3. Climate and drainage conditions

Burkina Faso is classified as an intertropical country displaying a strong Sudano-Sahelian climate (Sattran and Wenmenga, 2002). The alternation, all year round, of dry and wet seasons whose length varies from South to North allows the distinction of three climatic zones: (i) the South-Western (wettest) Sudanese zone; (ii) the Northern (driest) Sahelian zone and (iii) the Sudano-Sahelian zone, in the central part of the country, which shows intermediate characters. About 40 years ago the limits among different zones started to move southwards as a consequence of climate changes.

The study area falls within the central Sudano-Sahelian zone, where the pluviometric values range between 900 and 600 mm, the dry season lasts from October to May with average monthly temperatures ranging from 13 °C to 40 °C. The average annual con-