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Visible and infrared properties of unaltered to weathered rocks from Precambrian granite-greenstone terrains of the West African Craton

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ABSTRACT

In situ and laboratory 0.35 μm–2.5 μm spectra of rocks from a Paleoproterozoic granite-greenstone terrain along with its Neoproterozoic sedimentary cover and derived regolith materials were examined in western Burkina Faso. The reflectance spectra show the influence of typical arid to semi-arid weathering with the formation of desert varnish, iron films, and dust coatings. Fe and Mg–OH absorption features related to chlorite, amphibole, pyroxene, epidote, and biotite are observable in the mafic and intermediate meta-volcanic rocks as well as in the granodiorites and tonalites. Al–OH absorption caused by kaolinite, smectite, illite/muscovite are typical for meta-volcano-sedimentary schists, Tarkwaian-type detrital meta-sediments, sandstones of the Taoudeni basin, all of the weathered surfaces and regolith materials. Ferric and ferrous iron absorptions related to both primary rock-forming minerals and secondary weathering minerals (goethite, hematite) were observed in most of the sampled materials. The results show that although weathering alters the spectral signature of the fresh rock, indicative absorption features located in the short wave infrared region remain detectable. In addition, spectra of soils partially reflect the mineral composition of the weathered rock surfaces. The analysis of the hyperspectral data shows the potential of differentiating between the sampled surfaces. The library presents a primary database for the geological and regolith analysis of remote sensing data in West Africa.

1. Introduction

The majority of the rocks exposed on the Earth surface are affected by weathering to a greater or lesser extent, depending on the climatic zone, surface dynamics and biological activity. Visible to infrared spectroscopy data have been used to map mineral content and subsequently lithology or alteration patterns in a variety of environments around the globe (Rowan et al., 2004; Amer et al., 2010, Bertoldi et al., 2011; Graettinger et al., 2013). Infrared spectroscopic in situ measurements form an important component of any multispectral or hyperspectral remote sensing analysis regardless of the scientific discipline involved, providing vital data for calibration, ground truth assessment and modeling input parameters (Hueni et al., 2009; Milton et al., 2009). The growing need for spectral data is highlighted by several spectral library projects e.g. ASTER spectral library (Baldridge et al., 2009), ASU Thermal Emission Spectral Library (Christensen et al., 2000), USGS spectral library (Clark et al., 2007), or Specchio (Hueni et al., 2009), DLR spectral archive (Becvar et al., 2008), and the globally distributed soil spectral library ICRAF-ISRIC (2010). Many of these libraries contain laboratory measurements, which have standardized procedures of acquisition and the purity of materials used is well determined; however, such pure materials are difficult to compare with those found in complex natural settings. Moreover, most of the sampled materials are powders or chips of non-altered rocks. Spectral signatures of these materials differ from the weathered exposed surfaces (Cloutis, 1992; Rivard et al., 1992; Younis et al., 1997; Rowan et al., 2004). The thickness and character of the

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modified coating depends on the lithology, type, and intensity of weathering. In granite-greenstone terrains, ferromagnesian minerals such as amphibole, chlorite and biotite are preferentially transformed to iron oxyhydroxides, clays, and other secondary minerals (Tardy, 1997; Delvigne, 1998; Taylor and Eggleton, 2001). The mafic minerals are more susceptible to surface weathering compared to feldspar, quartz and epidote/zoisite, which are altered to clays, gibbsite or not altered at all. To correctly assess and interpret spectral data of rock surfaces there is a need for better understanding of the changes occurring in the spectra of weathered rocks. Data describing the weathered surfaces of rocks may be now found in the Auscope National Virtual Core Library (http://nvcl.csiro.au) that provides spectral information on more than 2 km of rock core samples from the Australian continent and will probably grow in the next few years. The availability of similar data for Africa is nevertheless limited.

Although several remote sensing related studies including spectral in situ measurements have been published for West Africa (Epema and Bom, 1994; Tromp and Steenis, 1996; Tromp and Epema, 1999), none of them focused on the description of spectral properties of the surface materials. Our study presents a spectral library created during the 2008 field campaign of the AMIRA P934 project, the “West African Exploration Initiative”, and documents the effects of rock weathering on the spectral properties of rock surfaces while discussing the derived regolith material as well. The dataset includes spectra of rocks, their weathering crusts, regolith materials (soils, iron rich duricrusts, lags), and vegetation, covering the visible through short wave infrared region 0.3–2.5 μm. The Paleoproterozoic greenstone belts, where greenschist metamorphism affected most of the lithologies, provide the opportunity to obtain novel spectral information. In the current spectral libraries, such as the ASTER spectral library 2.0 (Baldridge et al., 2009), data on greenschist metamorphosed rocks are very sparse and data on regolith materials are absent although applications of imaging spectroscopy to granite greenstone terrains or regolith have already been reported and are not uncommon (Drury and Hunt, 1989; Dehaan and Taylor, 2002; Rowan et al., 2004; Hewson et al., 2005; Deller, 2006). The presented measurements were acquired in the semi-arid zone of western Burkina Faso. This spectral library of 110 sampled locations represents the first publicly available data for West Africa. The results are relevant both to geological and regolith interpretation of remote sensing data in West Africa as well as for the understanding of lithological controls on weathering of Precambrian granite-greenstone terrains in semi-arid environments. The dataset is available as supplementary material.

2. Description of sampling area and sampled materials

All of the samples originate from western Burkina Faso encompassing an area of about 21,000 km^2 (Fig. 1). The study area consists of typical west African lateritic landscape (Grandin, 1976; Brown et al., 1994; Bamba et al., 2002) dominated by a stepped etchplain (Thomas, 1994) with characteristic duricrust plateaus and inselbergs (Butt and Zeegers, 1992) developed over most of the rock types present. The average height of the studied terrain attains 300 m a.m.s.l. (230–570 m). The climatic conditions are Sahelo-Sudanese with a mean annual rainfall of 900 mm. The land cover type consists primarily of open wood savannah; however, increasing agricultural activity means that more than 50 percent of the total area has been turned to cultivated land (IGN, 2005). Vegetation cover is substantial and changes both from south to north as well as according to the season (dry season/rainy season) from nearly total cover (>80% cover) to moderate cover (<40% cover). The field campaign was conducted between February and March of 2008 in the dry period. Weather conditions during the sampling were favorable with clear skies and only few scattered cumulus clouds on some days. Visibility was estimated to be between 10 and 15 km while daytime temperatures oscillated between 30 and 45 °C.

The distribution of samples aimed at covering all of the lithological units and their weathering products. Samples of soils were at all times gathered near the source rock to avoid sampling of transported material except for soils developed over iron-rich duricrusts and soils on agricultural fields. The samples represent mostly poorly developed mineral soils with residual weathered rock material. Samples located on agricultural fields or on planation surfaces developed over granitic terrains may represent soils with deeper weathering profiles as they are sampled further from outcrop and weathering fronts on granite are generally deeper.

The macroscopic description of mineral composition and the type of metamorphic and/or hydrothermal alteration (if present) is available for all of the samples. Mineral assemblages of selected samples were confirmed by microscopic study and microprobe analyses. Throughout the study region, weathering crusts and desert-like coatings can be observed. Mineral composition of the weathering crusts of selected rock samples was determined by X-ray diffraction. Both dry and green vegetation was sampled, because of the substantial vegetation cover in the area of interest.

3. Observed lithological and soil units

Western Burkina Faso represents a typical granite-greenstone terrain of the Leo-Man Shield (Fig. 1) in the West African Craton (Bessoles, 1977) where Paleoproterozoic meta-volcanic and meta-volcano-sedimentary rocks (the prefix meta-will be omitted in the following text) form elongated N–S to NE–SW oriented belts (Houndé belt and Boromo belt) separated by tonalite–-trondhjemite–granodiorite (TTG) and late granite intrusions (Castaing et al., 2003; Béziat et al., 2000). All of the lithologies of the greenstone belts including the Tarkwaian-type sediments (Bossière et al., 1996) were subject to greenschist and locally amphibolite facies metamorphism during the Eburnean orogenesis (~2.15–2.06 Ga). The sediments of the Neoproterozoic Taoudeni basin unconformably overlay the Paleoproterozoic rocks in the western part of the study area (Fig. 2a). The studied rock outcrops include metamorphosed basalts, gabbros, andesites, and andesitic pyroclastic flows, volcano-sedimentary rocks of andesitic to dacitic composition, and detrital sediments of variable grain size, as well as unmetamorphosed TTGs, granites, and sandstones of the Taoudeni basin. Granitoids will be divided into two groups according their geochemical signature: Na-rich low K tonalites and granodiorites vs. K-rich granites. A summary of the sampled lithological units with petrographic description is given in Table 1. The volcanic and subvolcanic units including gabbros, basalts, andesites, and andesitic pyroclastic flows show similar exposures in the field. They usually form massive non-foliated rock outcrops with only localized high strain zones. Together with some of the volcano-sedimentary rocks, they build up erosional ridges, which are occasionally capped by iron rich duricrusts. The weathering surfaces vary from those thickly varnished or coated with iron films and dust films to only slightly weathered ones. Unlike the massive volcanic rocks, the volcano-sedimentary sequences show a higher degree of deformation and are usually strongly foliated. They weather more easily and disintegrate into sheet-like debris. Rock coatings vary depending on the original rock composition. The more resistant layers with higher content of quartz may display both rock varnish and iron coating films while the more easily weathered chlorite and sericite rich layers display only Fe and Mn rich fissuresol coatings that may occasionally be exposed. The