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Rock magnetic properties of lateritic soil profiles from southern India: Evidence for pedogenic processes

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ABSTRACT

We report here data on the pH, electrical conductivity (EC) and environmental magnetic properties (χ_{lf}, χ_{fd}, χ_{ARM}, IRMs at different field strengths) of modern tropical lateritic soils from Aribail, Miyapadavu and Uliyathadka, all in the Kasaragod District of Kerala, southern India. This study aims to characterize the rock magnetic properties of lateritic soils that formed under *tropical* high-rainfall conditions and determine the effects of pedogenesis on soil magnetic properties in comparison with *temperate* soils. The profiles may be divided into two or three zones based on differences in magnetic mineral concentration, grain size and mineralogy. There is no magnetic enhancement of topsoil in any of the profiles studied. As the lateritic rocks in the region are ferruginous, the lateritic soils developed over them contain significant amounts of coarse grained lithogenic magnetite as well as hematite. Because of the presence of this 'laterite-derived' magnetite and hematite, the lateritic soils have much higher susceptibility values when compared to temperate soils. The upper zone is characterized by a higher proportion of lithogenic grains and the lower zone by superparamagnetic (SP) grains. This is probably because of iron reduction and dissolution of fine magnetic grains at the profile-top because of the excessively high rainfall (average = ~3500 mm/year) in the region. The slight increase in χ_{lf} and SIRM values toward the top of the Aribail and Miyapadavu profiles is due to the presence of coarse magnetic grains. This characteristic is common to all the three profiles irrespective of the topography. Compared to pre-monsoon samples, post-monsoon samples exhibit an increase in the proportion of SP grains. However, the magnetic grain size of lateritic soils from the three locations is similar to that of temperate soils.

1. Introduction

Iron in soils is present in the form of oxides (magnetite, titanomagnetite, hematite and maghemite), sulphides (greigite and pyrrhotite) and hydroxides (goethite and limonite) (Thompson and Oldfield, 1986). The major sources of magnetic minerals in soils are (1) anthropogenic input through atmospheric fallout from coal-fired power plants (Blaha et al., 2008a), metallurgical industries (Blaha et al., 2008b), vehicular emissions and cement factories (Gautam et al., 2004; Hoffmann et al., 1999); (2) inorganic *in situ* formation of ultrafine-grained magnetite (Maher and Taylor, 1988; Taylor et al., 1987); (3) precipitation of Fe^{3+} oxides and sulphides by bacterial magnetosomes (Fassbinder and Stanjek, 1994; Fassbinder et al., 1990); (4) transformation of iron-bearing minerals during alternate wetting and drying cycles in soils (Dearing et al., 1996b; Schwertmann et al., 1988 a, b); (5) inheritance of magnetic minerals from parent rocks (Maher, 1986); and (6) production of greigite (Fe_3S_4) in sulphate-reducing environments (Roberts, 1995; Stanjek et al., 1994) under water-logged conditions. The different iron-bearing minerals in soils and their sources may be appraised using environmental magnetic methods. In temperate soils, the study of pedogenic magnetite has been particularly helpful in understanding soil-forming processes in relation to climate. Rainfall enhances the intensity of chemical weathering and hence can increase the production of pedogenic magnetite in soils. The relation between soil magnetic susceptibility and rainfall is established in the Chinese Loess and temperate regions (Geiss et al., 2008; Maher and Thompson, 1995; Maher et al., 2002). However, the relation is not clear in subtropical and tropical regions.

There have been plenty of rock magnetic studies of soil profiles from temperate regions, which are summarized as follows. Magnetic enhancement in topsoils was investigated by Orgeira et al. (2011), Maher (1986), Maher et al. (2002), Geiss et al. (2004) and Geiss and Zanner (2006). Detailed studies on the potential pathways for this magnetic enhancement were carried out by Maher and Taylor (1988), Fassbinder and Stanjek (1993), Kletetschka and Banerjee (1995) and Liu et al. (2004). Many investigations focused on the rock magnetic properties of soil profiles developed on basaltic (Van Dam et al., 2008) and calcareous (Lu et al., 2012) rocks and loess-paleosol sequences (Han et al., 1996; Maher and Thompson, 1991). Soil magnetic studies were carried out to determine the relationship between magnetic properties and parent rock lithology (Fialova et al., 2006; Maher, 1986;

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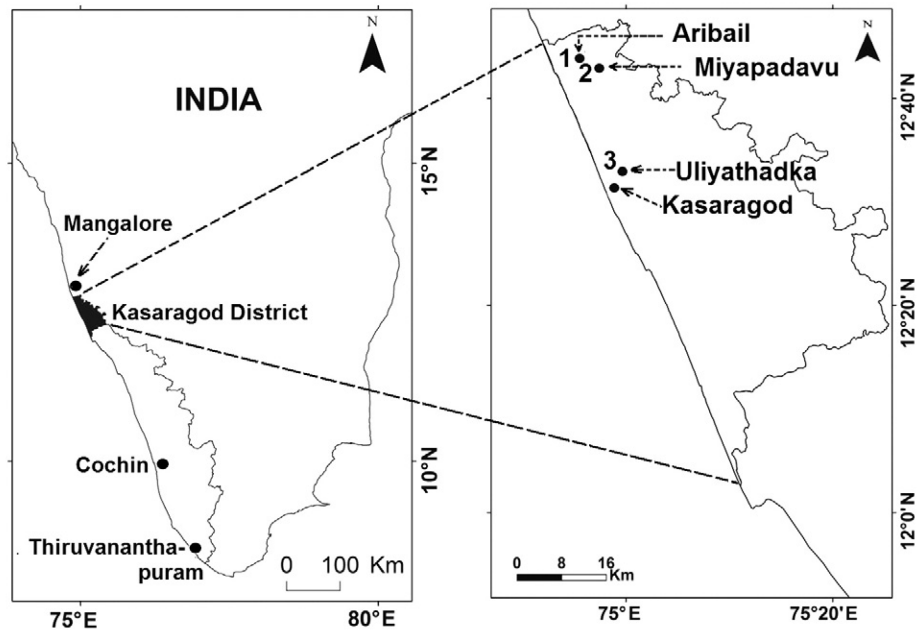

Fig. 1. Map showing the locations of soil profiles from Aribail (1), Miyapadavu (2) and Uliyathadka (3).

Shenggao, 2000), heavy metal and fly-ash pollution (Kapicka et al., 2000; Wang, 2013), archaeology (Jeng et al., 2003) and paleoclimate (Geiss et al., 2008; Maher et al., 2002).

There are some studies on the magnetic properties of soil profiles from tropical regions (Fabris et al., 1998; Fischer et al., 2008; Wiriyakitnateekul et al., 2007), including lateritic soils (Safiuddin et al., 2011). However, only a limited number of studies on such lines have been carried out in India; most of them focused on loess-paleosol sequences (Sangode and Bloemendal, 2004) or pollution aspects (Meena et al., 2011; Sangode et al., 2010). Studies on lateritic soil profiles in tropical southern India from a pedogenic point of view are even more limited (Sandeep et al., 2012). Laterite is produced as a result of intense chemical weathering of parent rocks under a humid, tropical climate, resulting in the enrichment of iron and aluminum hydroxides (Banerjee, 1998; Mitchell and Soga, 2005). According to Safiuddin et al. (2011), physical weathering might affect the granulometry and the concentration of magnetic minerals, but chemical weathering affects the magnetic mineralogy. Hence, the magnetic behavior of tropical lateritic soils may be different from that of temperate soils. At this point in time, there is no conceptual model for lateritic soils based on soil magnetic properties.

Considering the potential of environmental magnetic methods in shedding light on pedogenesis and also the dearth of detailed studies of soil profiles from the *tropics* from a pedogenic point of view, we have investigated the environmental magnetic properties of lateritic soil profiles from the tropical southern India. The main objectives of this paper are: (a) to characterize the rock magnetic properties of lateritic soils that developed under tropical high rainfall conditions with the aim of gaining insights into their pedogenesis, (b) to examine the relationship between topography and magnetic parameters in a typical lateritic terrain, (c) to obtain information regarding the variation in magnetic parameters during pre- and post-monsoon seasons and (d) to bring out the differences between rock magnetic properties of tropical and temperate soils.

1.1. Site description

The area chosen for the present study is the northern most part of Kasaragod District of Kerala State (Fig. 1). Soil samples were collected from exposed soil profiles in Aribail (12°43.85′N; 74°55.46′E), Miyapadavu (12°43.09′N; 74°57.52′E) and Uliyathadka (12°32.47′N; 75°0.36′E) during the pre-monsoon season (May, 2007). These are modern soils which are well drained and developed *in situ* over laterites. Both surface and sub-surface samples were collected. The sites were selected mainly with the objective of understanding the effect of topography on rock magnetic parameters. We ensured that the sampling sites are situated well away from anthropogenic activities and pollution sources. According to Jenny (1941), soil development depends on climate (temperature and rainfall), parent material, topography, micro-organisms and time. The sites were selected so as to keep all soil-forming factors the same except topography. The parent rock in the three sites is charnockite/charnockitic gneiss of Archaean age (Mallikarjuna et al., 1995), which upon weathering, has given rise to thick lateritic profiles. The upper parts of the lateritic rocks are characterized by lateritic soils. The mean annual rainfall in the region is ~3500 mm (India Meteorological Department) and the annual temperature range 16 °C–37 °C (Kerala District Gazetteer: Cannanore, 1972), which does not vary much among the three locations. Hence, the soils have formed under tropical climatic conditions with alternate wet and dry seasons. All the three locations are located in uncultivated land and are sparsely vegetated with shrubs of mixed type. Lateritization of crystalline rocks in the area took place during pre-Oligocene times (Mallikarjuna et al., 1981). Factors like parent material, climate, vegetation and time are almost similar in all the three locations. Hence, topography is the only variable that principally influences the magnetic properties of the soils investigated.

Due to the high rainfall typical of tropical regions followed by a dry season, the area has developed thick laterite profiles, with the parent rock occurring at great depths. It is difficult to identify the soil horizons (Figs. 2–4) as is the case with most lateritic soils of southern India. The laterites in the region are primary, having formed by the *in situ* weathering of parent rocks (Narayanaswamy, 1992). The Aribail soil profile is 190 cm deep whereas the Miyapadavu and Uliyathadka profiles are 170 cm deep each. The lateritic soils grade into hard laterites below these depths. However, it is difficult to mark the exact depth of this gradation. The laterites, in turn, grade into charnockite/charnockitic gneiss—the parent rock. The laterites seen in Kasaragod District are predominantly ferruginous (Soman, 1997). The lateritic soils of Kerala are