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Magnetic properties of a soil from Southeastern Brazil in the presence of magnetic biomineralization by social insects

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ABSTRACT

It is known that the migratory ant *Pachycondyla marginata*, and its prey, the termite *Neocapritermes opacus*, synthesize magnetic minerals which may contribute to the magnetic characteristics of soil. A comparative study of the magnetic properties of the minerals found in those species, as well as their nests and surrounding soil aimed at investigating the contribution of the biogenic minerals to the magnetization of the soil. Partially oxidized magnetite ($T_v \approx 120$ K) was found in the *Pachycondyla marginata* as shown by the Verwey transition in the ZFC/FC and RTSIRM curves. Low-temperature remanence measurements of the *Neocapritermes opacus* indicated the presence of maghemite and/or titanomaghemite, while partially oxidized pseudo-single domain magnetites and/or titanomaghemite were recognized in the soil and insect nests. Based on the similarity in the magnetic characteristic of the samples it is concluded that there is significant influence of biogenic mineralization upon the pedogenic contribution.

1. Introduction

Biogenic magnetic minerals have been identified in a great variety of animals like salmon (Quinn, 1980), honeybees (Gould et al., 1978; Gould et al., 1980), birds (Wiltschko and Wiltschko, 1972; Walcott et al., 1979; Walcott, 1980; Wiltschko and Wiltschko, 1996; Wiltschko and Wiltschko, 2002; Beason, 2005), field mice (Mather and Baker, 1981) among others. The magnetic minerals may be present in different parts of the animal's bodies, and are probably used for migration and homing following the orientation of the Earth's magnetic field. Some species of social insects like ants and termites were also identified as producers of magnetic phases, and their uses have already been investigated in the ant species *Solenopsis invicta* (Anderson and Vander Meer, 1993), *Formica rufa* (Çamlitepe and Stradling, 1995), *Oecophylla smaragdina* (Jander and Jander, 1998), *Atta colombica* (Banks and Srygley, 2003; Riveros et al., 2013; Alves et al., 2014), *Pachycondyla marginata* (Leal and Oliveira, 1995; Acosta-Avalos et al., 1999; Wajnberg et al., 2000; Acosta-Avalos et al., 2001; Alves et al., 2004; Esquivel et al., 2004), *Solenopsis* sp. (Sandoval et al., 2012), *Solenopsis interrupta* (Abraçado et al., 2012), as well as in the termite *Nasutitermes exitiosus* and *Amitermes meridionalis* (Maher, 1998).

The migratory ant *Pachycondyla marginata* has a typical predatory behavior carrying out well organized predatory raids towards the nests of its prey, the termite *Neocapritermes opacus*. The species *P. marginata* changes its nest from time to time and a preferred migration in a south-north direction has been noticed by Leal and Oliveira (1995). This migratory behavior of *Pachycondyla marginata* is influenced by geomagnetic field changes (Acosta-Avalos et al., 1999), which is highly effective for insect orientation and long-distance migration to exploit food sources. Using magnetic measurements and electron microscopy, Maher (1998) reported that biomineralization in termites produces particles in the ultrafine range (around 10 nm) which falls in the superparamagnetic threshold. It is well known that these fine particles are not able to carry stable magnetization. Differently from the two species studied by Maher (1998), the termite found in Brazil, *Neocapritermes opacus* (Alves et al., 2004; Esquivel et al., 2004; Oliveira et al., 2005; Oliveira et al., 2008), seems to produce a magnetite that falls in the range of pseudo-single to multi-domain size and, therefore, once released to the environment those grains could significantly contribute to the magnetic properties of soils.

The magnetic mineralogy of soils depends primarily on the parent rock and pedogenesis (Igel et al., 2012). Other factors to be considered are the anthropogenic influence (Gautam et al., 2004; Chaparro et al., 2006; Blaha et al., 2008) and biogenic minerals produced by bacteria

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(Fassbinder et al., 1990; Karande et al., 2014). Here we will consider the influence of the biogenic minerals produced by the ant *Pachycondyla marginata* and the termite *Neocapritermes opacus* to the magnetization of soil. The *Neocapritermes opacus* has some housing characteristics that may contribute to concentrate the biogenic minerals in the mound. The nests are subterranean at shallow depths of 10 to 25 cm (Krishna and Araujo, 1968); the irregular galleries or tunnels are built using soil particles, excrement, plant remains, and saliva (Lee and Wood, 1971). The dead individuals and those showing abnormal behavior are ingested by the labor termites of the colony although the voluminous parts like the jaws and the head (which present more chitin) are not ingested, being discarded or used in constructions. When the ant *Pachycondyla marginata* organizes raids to a termite nest nearly 1600 insects are captured over a period of nine hours, and this may occur twice a day (Leal and Oliveira, 1995). Therefore, it is reasonable to expect a magnetic signal inside and around that insect nest with similar characteristics and influenced by the biogenic minerals.

However, the detection and characterization of biogenic magnetic minerals is not a straightforward task, especially when the grains are mixed to others of non-biogenic origin. In this work we analyze results from various rock-magnetic techniques, including: (i) high and low temperature magnetism (e.g., Moskowitz et al., 1993; Moskowitz et al., 2008; Weiss et al., 2004; Chang et al., 2013) for identifying minerals by means of their unblocking temperatures or other low-temperature characteristics; (ii) magnetic susceptibility response to alternating fields of different frequencies, which helps in the characterization of different single domain grain populations (Eyre, 1997); (iii) isothermal remanent magnetization (IRM) acquisition curves for coercivity analysis (e.g., Kruiver et al., 2001; Egli, 2004a, 2004b); and (iv) ferromagnetic resonance (FMR) spectroscopy (e.g., Weiss et al., 2004) which provides key magnetic parameters to characterize ensembles of magnetic single-domain nanoparticles. It is largely used in the detection of magnetite produced by magnetotactic bacteria, and has been already applied to the study of the magnetic minerals in both ants and termites (Wajnberg et al., 2010; Riveros et al., 2013). The field-cooled and zero-field-cooled (FC/ZFC) protocols are important to examine the thermal dependence of magnetization in nanoparticles, as are the biogenic minerals (Moskowitz et al., 1993).

2. Experimental procedures

2.1. Sampling and sample preparation

Samples of soil, insects (*Pachycondyla marginata* and *Neocapritermes opacus*) and nests were collected inside a conservation area (Mata Santa Genebra; 22°49′20″S 47°06′40″W) set on the granitoids and gneisses of the Pre-Cambrian basement (Perrota et al., 2005) in Campinas city, Southeast Brazil. The insects of interest in this study do not occur widely spread in the area but are found in specific places. The soil samples were taken at 5 m (site JF40) and 10 m (site JF41) from the termite nest (Fig. 1). From each site samples were taken at surface, 25 cm and 45 cm depth, and labeled as a, b, and c, respectively, from top to bottom. Samples were also collected from the termite (JF42) and ant (JF43) nests. For the magnetic measurements samples from soil and nests were crushed into powder. The insects were submitted to magnetic analyses without any previous iron free diet, only extensively washed in 2.5% glutaraldehyde solution to become free of residues.

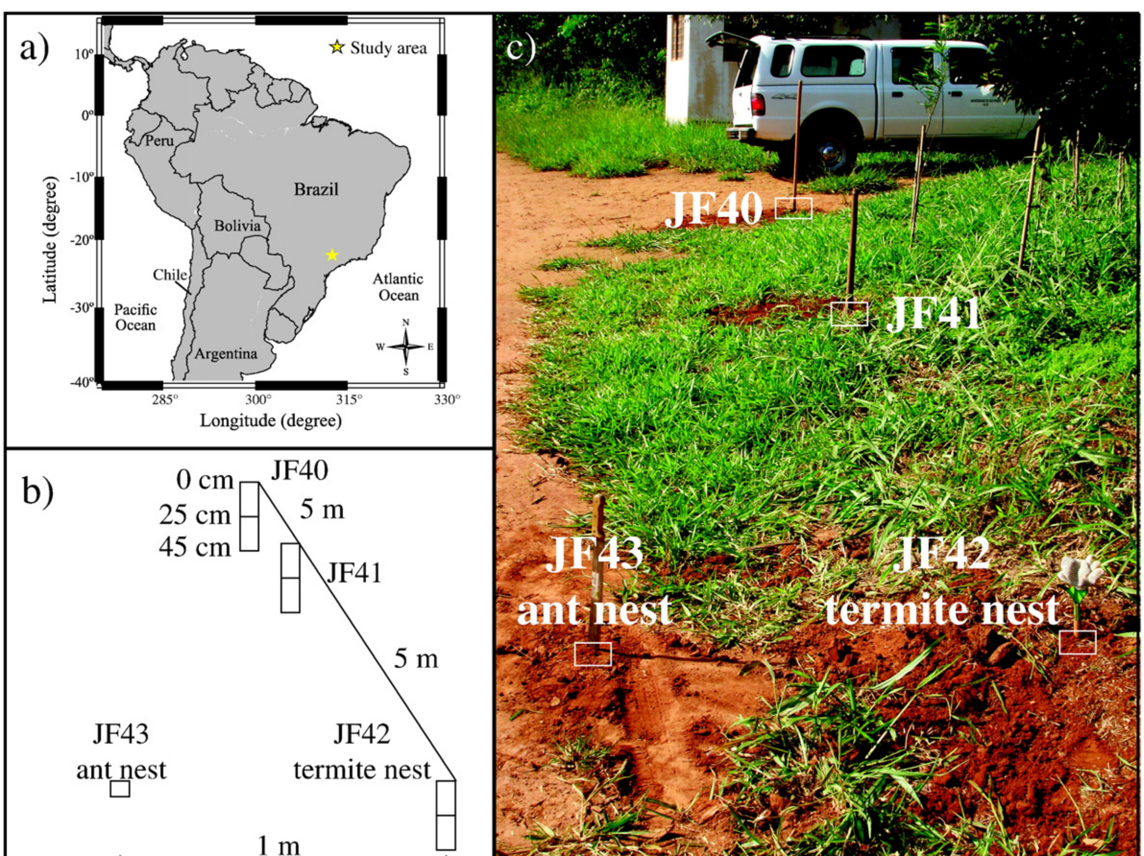

Fig. 1. Study area map for the field experiment. (a) Map of South America with study area location (yellow star). (b) Photo of relative position of the sampling sites from Mata Santa Genebra, Southeast Brazil. (c) Schematic diagram of sampling sites distribution with depths and distance between sites. The nest of *Pachycondyla marginata* is located on the ground, has one entrance hole and consists of several chambers connected by galleries. The nest chambers are distributed from 5 cm to 1.5 m below the ground surface. *Neocapritermes opacus* termite prey nests within roots or rotting wood, and occurs at approximate density of one nest at every 3 m. The soil samples have no significant differences in terms of color, dominated by red soil.