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Rock magnetism in modern soils, Buenos Aires Province, Argentina

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ABSTRACT

The influence of climate on the magnetic signal has been investigated assuming it is a first order factor in soil formation. In order to assess the degree of variability of the magnetic signal under different drainage conditions, Mollisols from the Pampean region developed on Pampean loess at varying topographical positions were studied. The sampled sites were located south and north of Buenos Aires in Verónica and Zárate, Pampa Ondulada. The magnetic signal is opposite in the two areas. The generation of superparamagnetic particles (SP) seems to be higher in Zárate. The loss of detrital magnetite could be higher in the less drained soils, in agreement with the hypothesis of loss of detrital magnetite by reductive process. As a simplified interpretation, it is suggested that the differential soil humidity in the studied soils could explain their different magnetic signal. The degree of drainage seems to be the variable that conditions the process of reduction loss.

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1. Introduction

Rock magnetism has been applied to loess-palaeosol sequences from many localities throughout the world in order to analyze Late Cenozoic climate variations (Banerjee and Hunt, 1993; Han et al., 1996; Hunt et al., 1995; Bloemendal and Liu, 2005, among others). Only a few publications have been devoted to modern soils (Dearing et al., 1996; Maher, 1998; Jordanova and Jordanova, 1999; Torrent et al., 2006, among others). In this contribution, two modern soil types from the Pampean plain (Buenos Aires Province, Argentina) were studied using rock magnetism and pedological techniques.

Analysis of processes occurring in recent soil formation can be used to understand ancient soil formation. Futhermore, paleosols can be interpreted as a record of past climatic change. Climate, relief, parent material, vegetation and time are factors that influence the soil formation.

The relief is one of the main constraining factors that conditions the characteristics of the forming soils because it influences the soil drainage. Under similar climate conditions and parent material, different types of soils will develop if the relief is different. Physiochemical changes and/or neo-formation of ferromagnetic minerals in the soil could also be affected by the relief.

This contribution tries to determine the influence of climate on the magnetic signal assuming that it is a very important factor in soil formation.

The aim of this study is to determine the degree of variability of the magnetic signal at different geomorphological positions. Modern soils from a restricted area (which are developed on similar parent material, Pampean loess), coming from different geomorphological zones, are studied.

Additionally, it is important to consider other aspects that could modulate the general climatic conditions of a site, such as mineralogy, granulometry, intensity of illuviation, local drainage, among others. These factors define different soil microenvironments, which must be taken into account as first order variables, together with climate.

2. Hypothetical model of the changes in magnetic minerals during edaphic processes

All the processes that may change the magnetic signal in the soils are correlated to the weathering of magnetic minerals. Hydratation, hydrolysis and dissolution during humid periods can be subsequently followed by either reduction or oxidation. Reductive loss as well as oxidation may be stressed in acid environments as a result of the magnetite instability in such environments (Buol et al., 1991; McBride, 1994; Faure, 1998). During pedogenesis, humic acids may have supplied the required acidity for such dissolution.

The iron released from the magnetic minerals and the iron coming from other minerals that were altered during the pedogenic processes form amorphous complexes with clays or organic

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material. These complexes could migrate or crystallize as different iron minerals depending on the prevailing environmental conditions.

If a reductive environment changes slowly into an oxidating environment, in neutral pH conditions, a Fe^{2+}/Fe^{3+} complex can crystallize as superparamagnetic magnetite, (SP) (Maher, 1998). The input of dissolved oxygen causes rapid oxidation of Fe^{2+} and precipitation of ferric hydroxides if the pH value is higher than 6. Fe^{2+} persists for a few minutes in oxygenated solutions of pH 7 or higher (McBride, 1994).

SP particles can be also generated in soils by the actions of anaerobic bacteria. This is a biological process, and the permanence of the SP mineral will depend on the environmental conditions (Lovley et al., 1987, among others).

If the amorphous Fe complexes were subject to highly oxidant environments, e.g. a climate with warm and distinct dry periods, in well-drained areas, a high coercivity iron oxide, such as hematite, could be formed. Consequently, the presence of a SP magnetite fraction could be an indicator of climatic conditions with periods of increased rainfall and a drier season. The presence of hematite indicates a seasonal and more extreme warm–dry climate.

The pH value is an environmental property that could change fast in soils as it is in dynamic equilibrium, closely correlated with rainfall, nature and changes of the water table and type of parent material.

In any case, successive cycles of formation and depletion of minerals could lead to a net balance of magnetic minerals. This balance can be negative or positive according to the environmental and climatic conditions of each locality.

3. Sampling area

Sampled soils are located in a loessic plain, characterized by a smooth topography. Well-drained soils (R3 and SZ) are located in the upper sectors of the watersheds, while poorly drained soils (R2 and AP) are located in depressions. The loessic plain is dissected by several small fluvial courses, tributaries of the Plate-Paraná river, and it is known as Pampa Ondulada. In the four soils under study, parent material consists of reddish-yellow sandy–silty loess of late Pleistocene age named Buenos Aires Formation. Granulometric data show that Verónica loess is more clayey than Zárate loess. These soils have a typical Pampean grassland plant association.

Both sampled sites are located in Buenos Aires Province, south and north of Buenos Aires City, respectively (Fig. 1). Soils from Verónica (R3 and R2) are located in the southeastern part of Pampa Ondulada (Undulating Pampa) (35°17.5′S–57°38.8′W) in the transition zone to the neighboring Pampa Deprimida (Depressed Pampa) geomorphic unit. Soils from the other sampled site are from the Zárate area (SZ and AP) (34°10′S–59°3′W) situated in the central part of Pampa Ondulada.

Well-drained soils are strongly developed into thick well differentiated horizons. In general, the Zárate soil is texturally coarser than the Verónica soils. High organic matter values are found in superficial horizons of both areas, though they occur slightly higher in the Verónica R3 soil than in the Zárate soil (2.68% and 1.21% C respectively, Table 1). In both soils, A horizons are more than 30 cm thick, have a dark-brown color (10YR3/1) and a strong medium blocky angular structure. The A horizon of R3 is silty loam, whereas the A horizon of SZ is a sandy loam, both defined as mollic horizons.

Bt (argillic) horizons are formed below the mollic horizons. The strong medium prismatic structures grade to weak prismatic structures downwards. In both cases, Bt horizons are more than 50 cm thick and have a brown color (7.5YR3/2). In soil R3, the Bt horizon is clayey and the SZ soil consists of silty-clayey loam. They have abundant clay skins and slicken sides, indicating expanded clay content and vertic properties (Tables 1 and 2).

The Bt horizons are followed by BC transition horizons and, between 100 and 120 cm depth, a C horizon with silty loam (R3) or sandy loam (SZ) is exposed. The loam has a 7.5YR7/6 Munsell soil color.

The above mentioned features allow us to classify these two soils as Argiudolls. The main ongoing pedogenetic processes are melanization and argilluviation. The formation of mollic superficial horizons needs less time to be formed than the argillic horizon.

According to Birkeland (1999), periods between 1 and 10 ka are necessary for Bt formation, which implies the presence of an endopercolative regime and seasonal water excess to make argilluviation possible. The present pH values are slightly acid for A horizons, becoming alkaline for the rest of the soil profiles. They are more basic in the case of Zárate SZ soil, possibly due to a higher content of $CaCO_3$. The Verónica R3 soil has lower C.E.C. (cation exchange capacity) and in both cases divalent cations predominate in the cation exchange complex (Ca and Mg).

In both poorly drained soils (R2 and AP) superficial horizons fulfill all requirements for mollic diagnostic epipedons, even if they are less dark, weakly structured and thinner than in the above mentioned typic Argiudolls.

Below the A horizons, illuvial Bt horizons with a high concentration of exchangeable Na are found. Accordingly, pH is high (such as 9.2 and 8.8), and these horizons fulfill the requirements for natric horizons. The base of A horizons gives evidence for hydromorphic conditions such as mottles and concretions pointing to the presence of at least a seasonal aquic regime. Consequently R2 and AP soils can be classified as typic Natracuolls. In all the four soils, the cation exchange complex is totally saturated in accordance with a neutral to alkaline environment. Though both poorly drained soils (R2 and AP) have well developed profiles, the degree of development is not as high as in the case of well-drained soils.

Semi-quantitative clay mineralogical results by X-ray diffractometry were also carried out selecting three horizons in all sampled soils (A, Bt and C). The results are presented in Table 3. The Verónica soils are more clayey than the Zárate ones. In all cases illite dominates with values ranging between 45% and 70%, with higher figures for A horizons. Less illite in the Bt and BC horizons shows the importance of the argilluviation process and the presence of an ongoing clay formation process in these soils. Probably part of the smectite found in Bt and BC horizons has this origin. Illites are inherited from loess parent material. Smectites are present in all profiles as secondary clay in Bt horizons. In general, soils from Verónica have more smectites possibly owing to a more recent clay formation. Interstratified clays, usually illite–smectite types, are frequent in all profiles, also pointing to an ongoing transformation process. Finally, kaolinites have an amount of less than 10%, with the highest amount in the AP soil of Zarate. In these cases, kaolinites probably are inherited too. Impurities are quartz and potassium-feldspars. Illites have a good cristallinity; smectites and interstratified clays do not have a good cristallinity. Clay characteristics, their amounts and distribution in profiles, are coherent with the existence of humid climates (around 1000 mm total annual precipitation) for longer periods, as evidenced by neutral to alkaline soil environments.

4. Magnetic results

The measurement of the hysteresis parameters was performed with a vibrating sample magnetometer (VSM) MicroMag (Princeton Measurements Corporation). The room temperature measurements of susceptibility were carried out with a Bartington susceptibilimeter at two frequencies (470 and 4700 Hz).

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