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Magnetic variations in surface soils in the NE Tibetan Plateau indicating the climatic boundary between the Westerly and East Asian summer monsoon regimes in NW China

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ABSTRACT

Two atmospheric circulation systems, i.e., the mid-latitude Westerlies and the East Asian summer monsoon (EASM), dominate climate change in the NE Tibetan Plateau. However, controversy remains with regard to the climatic boundary between these westerly and monsoon regimes. In this paper, detailed rock magnetic and geochemical Rb/Sr analyses for a larger number of surface soils from a wide area in the NE Tibetan Plateau are presented. They show that surface soils in this region evince relatively significant regional variations in magnetic properties and geochemical characteristics. The magnetic parameters χ_{fd}, χ_{ARM} and geochemical Rb/Sr ratios exhibit higher values in EASM-controlled (humid) areas, and lower values in Westerlies-influenced (arid) areas. These characteristics indicate that such variations in χ_{fd}, χ_{ARM} and Rb/Sr ratios can be regarded as effective indicators of the degree of pedogenesis and weathering in the NE Tibetan Plateau. Our results also demonstrate that the climatic boundary between the westerly and monsoon regimes approximately overlaps with the boundary of highland meadow and temperate steppe desert/desert in NW China.

1. Introduction

In the NE Tibetan Plateau (TP), the East Asian winter monsoon does not directly influence the region because of the high elevation of the TP (An et al., 2012). Consequently, two other important atmospheric circulation systems, namely the mid-latitude Westerlies and the East Asian summer monsoon (EASM), dominate climate change in the NE TP (Fig. 1a) (Gao, 1962; Zhao et al., 2007; Chen et al., 2008; An et al., 2012; Li et al., 2012). It has been suggested that the EASM-controlled (humid) and the Westerlies-influenced (arid) areas of Central Asia display distinct meteorological characteristics, but are tied to one another by the exchange of energy, moisture, and momentum of the atmosphere (Gao, 1962; Chen et al., 2008; An et al., 2012). In this context, identification of the climatic boundary between these two regions is essential both to reconstruct the past climates in the NE TP and to understand present climatic conditions. However, due to the region's formidable natural conditions and vast area, meteorological stations have only been established in a few specific areas in the NE TP. A shortage of generic meteorological data has made it difficult to study the climatic boundary between the EASM-controlled (humid) and Westerlies-influenced (arid) areas of NW China. As a result, many scholars have had to use regional climate models to establish the climatic boundary, though there remains considerable debate over the present limits of EASM influence on the NE TP (Gao, 1962; Zhao et al., 2007; Chen et al., 2008; An et al., 2012; Li et al., 2012) (Fig. 1b).

Recently, systematic rock magnetic studies of surface soils from NW China have demonstrated that topmost soil samples from the EASM-controlled (humid) areas and the Westerlies-influenced (arid) areas exhibit distinct magnetic characteristics. In the EASM-controlled (humid) areas, soil weathering and pedogenesis are generally strong, due to abundant precipitation. Variations in the magnetic susceptibility (χ) of surface soils exhibit a strong, positive correlation with mean annual precipitation (MAP), and ultrafine superparamagnetic (SP) and single domain (SD) magnetite/maghemite grains (<100 nm) produced during pedogenesis are considered to be mainly responsible for enhancements in χ (Han et al., 1996; Liu et al., 2007; Nie et al., 2010; Song et al., 2014). In contrast, in Westerlies-dominated inland China, westerly air currents from the North Atlantic and the Mediterranean are the chief determinants of moisture content. Due to the high topography of the northern TP, these westerly winds generally release their moisture on the windward side of the mountains, and little westerly moisture penetrates into Westerlies-dominated inland China. This limited precipitation generally yields more weakly developed soils. Thus, changes in the concentrations of pedogenically-produced SP and SD magnetic particles do not control the magnetic properties of topmost sediments in these regions. Rather, changes in the concentrations of larger pseudo-single domain (PSD) and multidomain (MD) detrital magnetic minerals derived from source regions appear to be the controlling factors (Zan et al., 2011, 2012, 2015; Xia et al., 2012).

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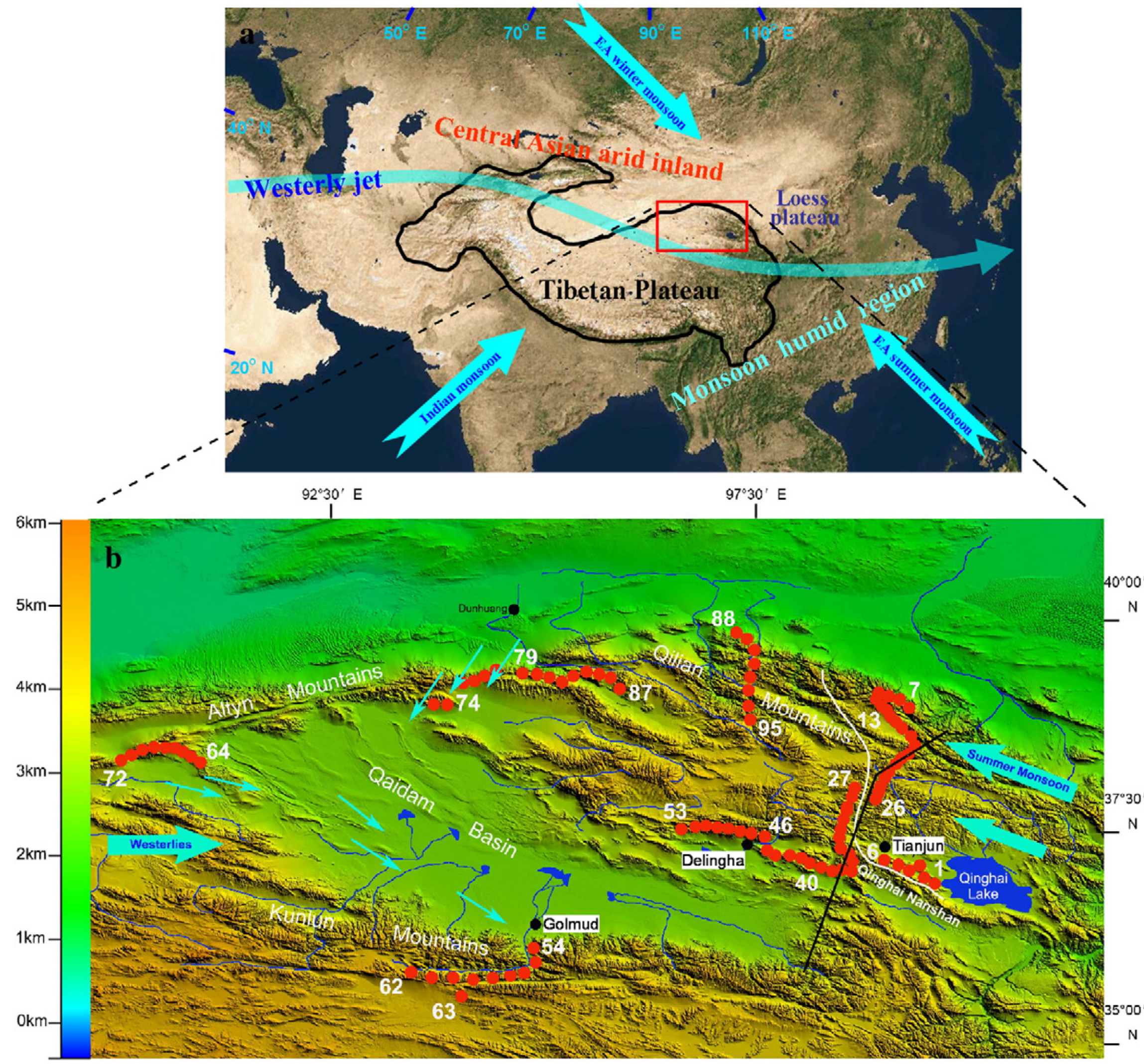

Fig. 1. (a) Satellite image and geographic map showing the location of the study area within the Asian arid inland and East Asian monsoon-moistened regions. (b) Digital elevation map of the NE TP showing sampling locations. Red solid circles show the locations of surface soil samples. The black line shows the present limit of the EASM in NW China (Chen et al., 2008). The white line approximately represents the boundary of highland meadow and temperate steppe desert/desert (Zhao et al., 2007), which is regarded as an indication of precipitation levels. The narrow arrows indicate the main wind directions observed in the Qaidam Basin.

Regional variations in the magnetic properties of surface soils between the EASM-controlled (humid) and the Westerlies-influenced (arid) areas imply that systematic rock magnetic studies of surface soils from the NE TP may provide new information about the climatic boundary between these two regions. In this paper, we present detailed rock magnetic and geochemical Rb/Sr ratio analyses for a larger number of surface soils from a wide area of the NE TP. Our aim is to improve greatly our understanding of the climatic boundary between EASM humid areas and Westerlies-dominated arid areas in NW China.

2. Materials and methods

A total of 95 surface soil samples were collected from A soil horizons across the NE TP, at elevations between 2000 and 4500 m asl (Fig. 1b). The study area, extending from longitude 90°E to 100°E and latitude 35°N–40°N, covers the Qaidam Basin and the adjacent East Kunlun Mountains, Altyn Mountains and Qilian Mountains (Fig. 1a). The regional climate is characterized by a marked gradient in MAP: from 300 to 500 mm in EASM-controlled (humid) areas, to <50 mm in Westerlies-influenced (arid) areas (Gao, 1962). In order to minimize the effect of parent material and geomorphology on the magnetic properties of surface soil samples, all samples were taken from surface soils developed on eolian loess deposits and on flat geomorphic surfaces. In addition, the samples were taken 5 cm from the surface far away from industry and villages to avoid anthropogenic iron contamination.

The samples were air-dried, then were weighed and packed in a nonmagnetic plastic box. Low-frequency and high-frequency magnetic susceptibilities were measured with an AGICO MFK1-FA Kappabridge at frequencies of 976 Hz and 15,616 Hz, respectively. Mass-specific values (χ) in this paper represent low-frequency measurements. From these data, two measurements of frequency-dependent magnetic susceptibility (χ_{fd}%, defined as $(\chi_{976Hz}-\chi_{15616Hz}) / \chi_{976Hz} \times 100\%$, and χ_{fd}, defined as $\chi_{976Hz}-\chi_{15616Hz}$) were then calculated (Forster et al., 1994). Anhysteretic remanent magnetization (ARM) was imparted using a 100 mT peak-alternating field with a superimposed 0.05 mT direct current bias field. The ARM was normalized by the bias field to obtain ARM susceptibility (χ_{ARM}). Saturation isothermal remanent magnetization (SIRM) was imparted in a 1.5 T field using a Magnetic