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New insights into the magnetic variations of aeolian sands in the Tarim Basin and its paleoclimatic implications

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ABSTRACT

The Tarim Basin, where aeolian activity is widespread, has been regarded as a major source for global dust production. Therefore, knowledge about variation of magnetic parameters in aeolian sands from the Tarim Basin has a global significance. Systematic rock magnetic studies of aeolian sands from this region are still scarce because of the vast area and poor accessibility of the basin. In this paper, multi-parameter rock magnetic investigations of a larger number of aeolian sand samples from a wide area in the Tarim Basin have been conducted. We find that magnetic properties of aeolian sands are controlled by changes in the concentration of larger pseudo-single domain and multidomain magnetite grains, which are produced by weathering and erosional processes in the surrounding mountain regions. In addition, aeolian sands, collected from different geographic regions of the Tarim Basin, exhibit different magnetic properties, suggesting that selective wind and river transport and low-temperature oxidation might play a critical role for the magnetic properties of aeolian sands in the Tarim Basin. Our study also provides a better understanding of the complex relationships between magnetic properties and source materials for Pliocene deposits in the basin.

1. Introduction

The Tarim Basin, located in northwestern China, is one of the largest inland basins in the world. At present, as much as 70–80% of the basin is covered by the Taklimakan desert and the Gobi. It has been suggested that huge amounts of dusts generated from the Tarim Basin are transported to the Pacific Ocean (Duce et al., 1980; Rea et al., 1998), western North America (Jaffe et al., 1999; Gong et al., 2003), and even farther to Greenland (Biscaye et al., 1997; Bory et al., 2002) by westerlies. In this context knowledge about the magnetic properties of aeolian sands in the Tarim Basin has a global significance.

Previous rock magnetic studies of surface soils across the Tarim Basin (Lü et al., 1994; Zan et al., 2011) suggest that pedogenic processes in the Tarim Basin are weak and pedogenically produced ultrafine ferrimagnetic minerals do not play a significant role for variation of magnetic concentration. Source materials appear to provide the main control on the magnetic properties of these surface sediments (Zan et al., 2011). Aeolian sands, located at different geographic regions of the Tarim Basin, generally correspond to different wind directions and distances from rivers, which will result in variation of magnetic minerals supply and therefore it is expected that they exhibit different magnetic properties.

The Tarim Basin is still one of the most difficult regions to perform comprehensive sample collections because of its vast area and poor accessibility. At present, rock magnetic studies of aeolian sands in the Tarim Basin are relatively scarce, and the existing investigations focus mostly on limited areas (Torii et al., 2001; Zan et al., 2011). This paper intends to provide new data for deciphering the mechanism causing variation of magnetic properties of aeolian sands in the Tarim Basin and then discuss its paleoclimatic implications. The study is based on a larger number of aeolian sand samples from a wide geographical area of the basin.

2. Materials and methods

Fifty-six aeolian sands samples were taken from the Tarim Basin (Fig. 1). Samples 1–29 were collected in the Taklimakan desert. Samples 30–50 were collected along the East–West road transect connecting Ruoqiang and Shache and most of them are located at the margin of desert. Samples 51–56 were collected in some local aeolian dunes, at the northwestern margin of the Tarim Basin. In addition, 9 surface samples (57–65) were collected from the Gravel

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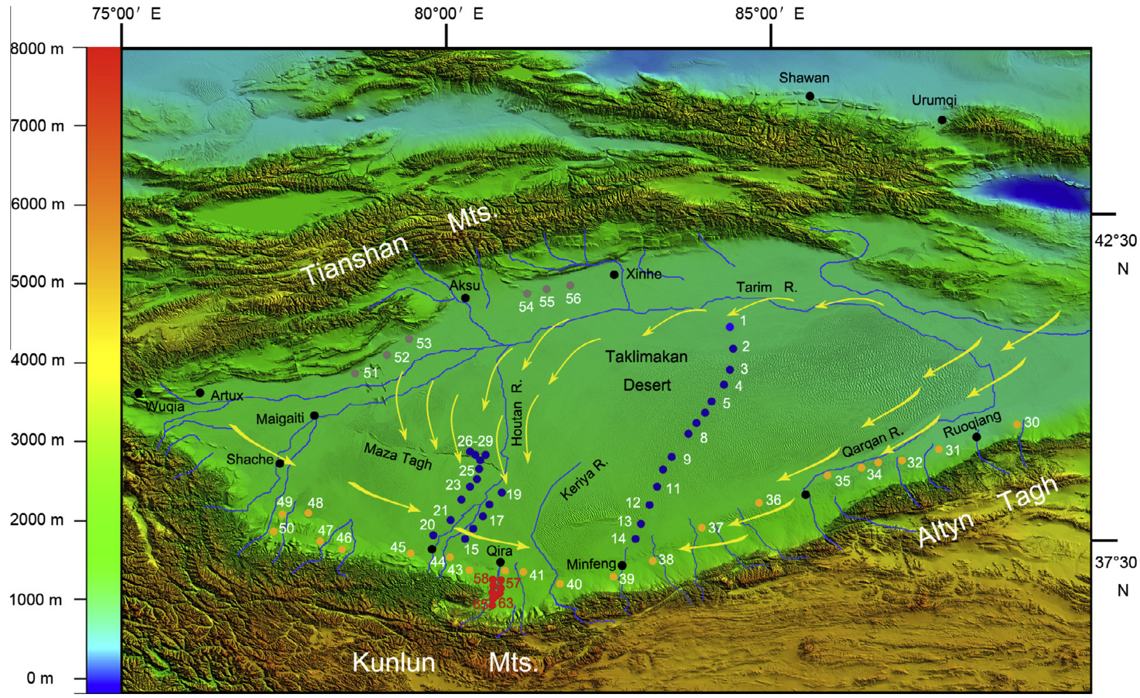

Fig. 1. Digital elevation map of the Tarim Basin showing the sampling locations. Solid circles show the locations of 56 aeolian sands samples and 9 Gobi samples. Yellow arrows indicate the main wind directions in the Tarim Basin. Blue lines show the fluvial systems in the Tarim Basin. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Gobi zones for comparison with the aeolian sands (Fig. 1). All these samples were taken 2 cm from the surface and they are far away from industries and villages to avoid anthropogenic iron contamination.

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 measurements, frequency dependent susceptibility (χ_{fd}%, defined as $(\chi_{976Hz} - \chi_{15616Hz})/\chi_{976Hz} \times 100\%$) were then calculated. 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 T field using an ASC pulse magnetizer, and was measured with a Molspin Minispin magnetometer. A back-field was imparted at 0.3 T by reversing the orientation of the samples. The S ratio and "hard" isothermal remanent magnetization (HIRM) were calculated from these data, defined as $-\mathrm{IRM}_{-300mT}/\mathrm{SIRM}$ and $(\mathrm{SIRM} + \mathrm{IRM}_{-300mT})/2$ (King and Channell, 1991), respectively. Thermomagnetic runs of magnetic susceptilility were performed using the MFK1-FA Kappabridge equipped with a furnace (max. temperature 700 °C) and a CS-4 low temperature (from −190 °C) unit. High temperature dependence of saturation magnetization was measured under an applied field 1 T by a variable field translation balance (VFTB). Bulk grain size analyses were measured using a Microtrac S3500 laser particle sizer following the conventional chemical pre-treatment procedure (Konert and Vandenberghe, 1997).

3. Results

Fig. 2 shows the variations of magnetic parameters and the mean grain size of aeolian sands and Gobi materials in the Tarim Basin. Frequency dependence of magnetic susceptibility (χ_{fd}%) is generally low, with χ_{fd}% varying between 0% and 4% (mean value 2.36%). Ultrafine superparamagnetic particles therefore play a subordinate role in all samples. Magnetic concentration parameters χ, SIRM and χ_{ARM} for the aeolian sand samples (No. 1–29) within the desert are less variable and much lower than for the aeolian sands samples (No. 30–50) and the Gobi samples (No. 57–65) at the southern margin of the Taklimakan desert. The aeolian sands samples (No. 51–56) at the northwestern margin of the basin exhibit the lowermost magnetic concentration values. There is a strong positive linear correlation between χ and SIRM ($R^2 = 0.87$; Fig. 3a) indicating that χ is dominated by ferro(i)magnetic phases. Moreover, the crossplots of SIRM vs. χ (Fig. 3a) and χ_{ARM} vs. χ (Fig. 3c) suggest a change of magnetic mineralogy with higher coercivity phases (such as hematite) in the low magnetic samples. The overall linear regression lines intersect the remanence axes at values >0, which means that the best fit curve would be non-linear and have a steeper slope (higher remanence-to-χ ratio) at lower χ values. The S ratio decreases strongly with lower χ values (Fig. 3b) and therefore confirms that high-coercivity phases become increasingly more important in the lower magnetic samples. Higher HIRM values appear in low magnetic samples (Fig. 3d), proving that this relative increase even corresponds to an absolutely higher amount of high-coercivity phases. The clastic granulometry analysis suggests that all samples consist mainly of coarse silts and fine sands with mean grain size (MZ) larger than 100 μm, and the clay is relatively rare (Fig. 2).

All thermomagnetic curves show a clear Curie temperature at around 580 °C (Fig. 4a and b), indicating that magnetite dominates the magnetic properties of both the aeolian sands and the Gobi materials. The κ–T curves show clear multidomain (MD) behaviors (Deng et al., 2006) (Fig. 4a), strongly supporting the coarse-grained nature of magnetite grains in the Tarim aeolian sands, well consistent with the conclusions reached through other proxies, e.g., the lower values of χ_{fd}% (usually <4%). Some heating curves demonstrate a significant loss of magnetic susceptibility between 300 and 450 °C (Fig. 4a), suggesting the presence of maghemite