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Determining surface magnetic susceptibility of loess-paleosol sections based on spectral features: Application to a UHD 185 hyperspectral image

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ABSTRACT

Magnetic susceptibility (MS) records of loess-paleosol sequences have been considered a measure of the degree of pedogenic activity and are considered to be excellent proxies for terrestrial climatic fluctuations. However, the MS of single (vertical) path variations occasionally represents site-specific influences rather than monsoonal changes (depending on the position of the path). Few studies have used remote sensing techniques to map the surface MS information of loess-paleosol sections. Hyperspectral techniques provide an efficient, economical and quantitative alternative. In this study, stepwise regression was used to build MS estimation models based on spectral features. Six MS models based on spectral features were established. Test datasets indicated that our models are very successful, all resulting in $R^2 > 0.92$ and RMSEs ranging from 4.5736 to 6.80475. The slope change between 810 nm and 880 nm (b880/b810) observed in all models played an important role in MS estimation. Models 5 and 6 have higher RMSEs and relatively lower SAM values, although the R^2 values are both above 0.95. The RMSEs of the first four models are similar. Therefore, the first four models were thought to be more stable and useful.

UHD 185, a new generation of commercial hyperspectral imaging sensor, was used for surface MS mapping of a loess-paleosol section by model 1 and model 2. The MS map corresponded well to the loess sequences. The MS values obtained from the UHD 185 data are convincing and consistent with the measured data ($R^2 > 0.85$). The trend in changing MS values is clear, suggesting that model 1 and model 2 could produce reasonable loess-paleosol section surface maps from the UHD 185 image, although there is a linear offset between the estimated MS and the measured MS. The methodology proposed here can be used to map MS on a much larger scale. Because of the limit of the spectral range, the performances of model 3 and model 4 with the image were not discussed. However, they have been shown to be successful according to the laboratory test data.

1. Introduction

Magnetic susceptibility (MS) records of loess-paleosol sequences have been studied in the past and are considered to be an effective measure of the degree of pedogenic activity and excellent proxies for terrestrial climatic fluctuations (Liu, 1985; An et al., 1991; Verosub et al., 1993; Heller and Liu, 1982, 1984, 1986; Heller and Evans, 1995; Porter et al., 2001; Kohfeld and Harrison, 2003; Maher et al., 2003; Stevens and Lu, 2009; Smith et al., 2011). Usually, low susceptibility implies periods in which the summer monsoon was weak and cold, with reduced pedogenic activity. Conversely, high susceptibility values usually imply periods when the summer monsoon was warm and moist, with strong pedogenic activity (An et al., 1991). MS is an important physical parameter of soils and sediments (Tompson and Oldfield, 1986; Heller and Evans, 1995; Jin et al., 2003). Traditional methods to generate a susceptibility profile for a several-meter-thick sediment section would take an hour or more, while MS profiles are commonly taken along a single (vertical) path. However, typically, the internal consistency of the vertical line MS data is not tested by replicating values along other parallel profiles (Porter et al., 2001).

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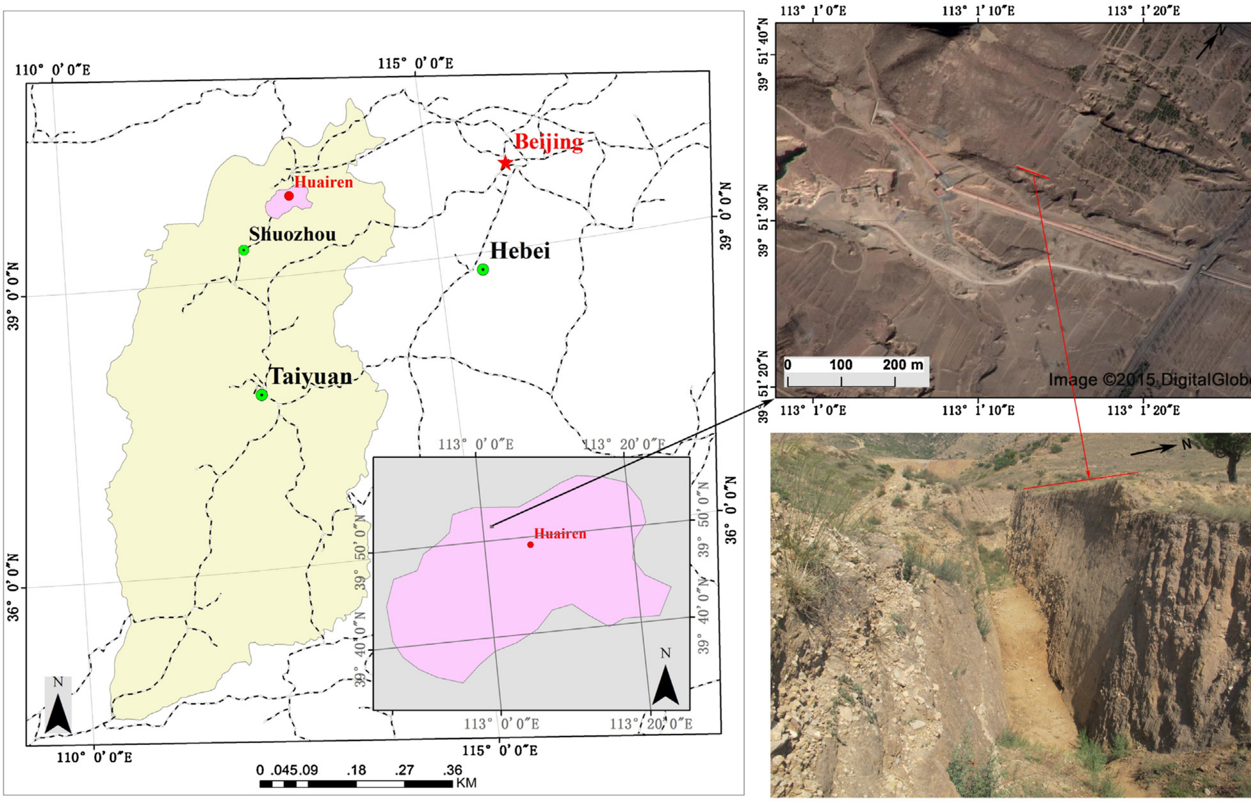

Fig. 1. Location of the study area.

Image source: Digital Globe

The image of the loess-paleosol section could enlarge the datasets covering variation over a wide vertical and lateral range. Grayscale intensity and whiteness data for sections in a range of climatic and latitudinal settings display a high degree of correlation with magnetic susceptibility data (Porter et al., 2001; Chen et al., 2002). Indeed, Ji et al. (2004a,b) first used TM images to estimate the MS of surface soil on the Loess Plateau at a large scale, obtaining good results. Previous laboratory studies focused on correlations between reflectance spectroscopy and MS show the potential of MS mapping with hyperspectral images (Jin et al., 2003; Smith et al., 2011). These works are all based on the premise that reflectance is related to the composition and structure of constituent minerals. However, few studies have used remote sensing techniques to map the surface MS information of loess-paleosol sections, which is useful for rapidly characterizing multiple loess sequences and linking the stratigraphic changes to monsoonal processes (Smith et al., 2011). Further, local and post-depositional effects can cause variation in the response of magnetic susceptibility. Smith et al. (2011) obtained an image of a loess-paleosol profile using a Nikon D80 and first processed the image to a single RGB and NIR file. Their work suggests that the bands used by cameras are too broad for MS estimation.

Hyperspectral remote sensing refers to the use of a very narrow, continuous spectrum of remote sensing image that features continuous channel technology. The abundant spectral information of the hyperspectral image could provide the ability to establish a link between reflectance and MS. The objectives of this study are to define a new model based on spectral features to mapping MS of a loess-paleosol section and to apply this model to a sensor with limited spectral range to see how well it performs.

2. Materials and methods

We aimed to determine the correlation between magnetic susceptibility and reflectance spectra. This required understanding the spectral features of the soils and then choosing those parameters that correlated with MS, allowing us to construct a model for MS estimation.

2.1. Site description and sample collection

The Emaokou section is located to the northwest of the town of Huairen, in Shanxi Province (Fig. 1), centered at longitude 113° 1′ 13.10″E and latitude 39° 51′ 33.04″N. The main landforms in the study area are loess platforms. The cross section shown in Fig. 2 includes Malan Loess (L_1), the Holocene Black Loam paleosol (S_0), a distinct loess layer (L_0) and a gravel layer. For this study, we sampled only the loess-paleosol sequence (between the two dashed yellow lines in Fig. 2), excluding the bottom gravel layer and the top loess layer (L_0). We collected samples from S_0 and L_1 along model line 1, model line 2 and the test line for laboratory analysis (model line 1, 2 and the test line are shown in Fig. 2). The sampling interval was 10 cm from the top to the bottom. Samples from model line 1 (37 samples) and model line 2 (35 samples) were used to build the model. Samples from the test line (55 samples) were used for model testing.

2.2. Magnetic susceptibility measurement

The low-frequency magnetic susceptibility of the samples was measured at 976 Hz using a MFK1-FA Multi-Function Kappabridge magnetic susceptibility meter (Pokorny et al., 2006), a product of the Advanced Geoscience Instruments Company (AGICO) of the