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Sr–Nd elements and isotopes as tracers of dust input in a tropical soil chronosequence

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ABSTRACT

Although Hainan Island is located in one of the relative least dusty regions in China, Asian dust has been identified in Hainan soils. We used Sr and Nd isotopes of soils, saprolite, bedrocks and Asian dust to not only identify long-range transported dust but also quantify the dust contribution to Hainan soils. Sr and Nd isotopic compositions of the soils are clearly affected by dust deposition. The soils in near-surface horizons have $^{87}Sr/^{86}Sr$ values as high as 0.7193 that are more radiogenic than the basalts, indicating involvement of Asian dust; whereas deep horizons show a dominantly basaltic signature ($^{87}Sr/^{86}Sr = 0.7038$). The $\varepsilon_{Nd}(0)$ values for Hainan soils range from −6.46 to 1.85. The higher value closely approximates the values measured for the Hainan lava, and the lower value indicates the fingerprint of the Asian dust. The $^{87}Sr/^{86}Sr$ and $\varepsilon_{Nd}(0)$ values for soils also show a progressive trend with time, which implies that dust accumulates with soil age. We calculated the dust accretion rates for Sr-based and Nd-based to quantify the dust contributions to soils. The estimate of dust accreted shows an approximate increasing trend with the ages of soils for Sr-based and Nd-based methods. The soils in the old sites are likely to have undergone long-term dust input and accumulated high dust levels. We also find excellent agreement in the amount of dust present and dust accretion rates based on the two tracers at the 300 ka site and the 1120 ka site, respectively. Besides lower dust deposition in the Pliocene epoch than the late Quaternary over eastern Eurasian, the loss of mineralogical and geochemical tracers over million year time scales also may lead to underestimates of time-averaged dust deposition rates in the old sites. Therefore, the young sites (180 ka and 300 ka) should provide more realistic estimates of average dust accretion rates. The importance of dust in the tropical Hainan soil chronosequence highlights the significance of dust accretion to soils globally.

1. Introduction

Wind-blown dust has a crucial impact on the environment globally (Yaalon and Ganor, 1973; MacLeod, 1980; Derry and Chadwick, 2007; Singer, 2007), even in places far from dust source regions (Simonson, 1995). Asian dust from the desert and loess areas of northern and northwest China and southern Mongolia affects climate, human health and biological activity over the Northern Hemisphere on an event to geological timescale (Duce et al., 1980; Chadwick et al., 1999; Wilkening et al., 2000). Over tens to hundreds of thousands of years, accumulation of Asian dust begins to have a considerable impact on soils. As a result, the continuous addition of new material to soil as dust profoundly affects such soils, and many studies have focused on the effects of chronic dust addition to soils (Borg and Banner 1996; Chadwick et al., 1999; Pett-Ridge et al., 2009).

The migrations of Sr and Nd in the soil profile are often estimated by comparing their concentrations at different depths (Nesbitt, 1979; Middelburg et al., 1988; Marsh, 1991), and these traditional geochemical approaches led to growing comprehension of element migrations. However, minor variations in metal concentrations are frequently overlooked along the soil profile and minor accumulation of them may be difficult to ascertain in deeper soil horizons. Fortunately, Sr and Nd isotopes are powerful fingerprints to palliate these problems (Chadwick et al., 1999; Derry and Chadwick, 2007; Kurtz et al., 2001; Pett-Ridge et al., 2009; Stewart et al., 2001). Dust, soils and rocks have distinctly different $^{87}Sr/^{86}Sr$ and $^{143}Nd/^{144}Nd$ ratios, and these isotope ratios are less altered over time than elemental compositions in soil environments because their isotopic compositions are fundamentally controlled by geological properties and are not altered by weathering, transportation or biological processes (Elderfield et al., 1981; Grousset et al., 1988; Grousset and Biscaye, 2005). Thus, Sr and Nd isotopes have proven to be valuable tracers for understanding earth surface

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processes related to regolith development, watershed processes, and global geochemical fluxes. Many researchers have used Sr and Nd to track the relative contributions of atmospheric input and mineral weathering to soils (Borg and Banner, 1996; Chadwick et al., 1999; Kurtz et al., 2001; Pett-Ridge et al., 2009; Stewart et al., 2001).

Soil chronosequence in Hainan Island provides a good opportunity to study contributions from continental dust in tropical soils. First of all, Hainan Island is isolated from continental sources and the soils have developed on a relatively pure basalt regolith, which facilitates the identification of eolian components. Meanwhile, basalts weather rapidly and congruently, which yields a nearly invariant mantle-sourced isotopic value during extensive weathering in a tropical zone. Thus, there is a strong contrast in the isotopic composition between Hainan basalts and Asian dust, which facilitates easy identification of contributions from dust. Finally, to quantify the long-term rate of dust deposition over time periods remains a challenge as there is no effective method to identify the role of dust additions to soils. Soil chronosequence could provide a condition that facilitates the estimation of fingerprinting elements stored in soils over a long time even up to million years (Chadwick et al., 1999; Pett-Ridge et al., 2009; Stewart et al., 2001).

People have pay more attention to the importance of dust deposition for soil genesis (Herrmann et al., 1996; Inoue and Sase, 1996; Jickells et al., 2005; Kurtz et al., 2001; Ramsperger et al., 1998; Swap et al., 1992; Stewart et al., 1998). And some studies, such as Erel and Torrent (2010), Grousset and Biscaye (2005), Grousset et al. (1998), Miller et al. (1993) and Rognon et al. (1996), have reported quantification methods that contribute to soils to provide fundamental information for studies on dust input, weathering rates, groundwater geochemistry, and biogeochemical cycling in ecosystems. As one of important source region of sand storm, Asian dust has been identified in Hainan Island of China. The importance of dust in the tropical Hainan soil chronosequence highlights the significance of dust accretion to soils globally. Therefore, we report the Sr and Nd concentrations and isotopic compositions of soils and potential parent materials in the Hainan soil chronosequence, in order to identify the important role of chronic dust additions to Hainan Island soils. The second aim of this study is to quantify the dust deposition flux by using Sr and Nd isotopes mass balance.

2. Materials and methods

2.1. Hainan soil chronosequence

Soil chronosequences are often used to illustrate the rate of formation and soil changes in general (Vidic and Lobnic, 1997; Pillans, 1997; Chadwick et al., 1999; Kurtz et al., 2001; Pett-Ridge et al., 2009). They demonstrate the relative degree of soil development under varying duration of soil formation (Stevens and Walker, 1970), if other soil-forming factors are similar. In this study, we sampled soils along a chronosequence, keeping many factors (e.g. climate and parent material) that influence soil development constant and allowed lava flow age to vary; so the changes of soil properties were mainly controlled by the time period of weathering and soil development. Zhang et al. (2007) and He et al. (2008) have established a soil chronosequence that was developed on the basalt in Hainan Island, which provides a useful tool in soil science and ecosystems research. Four soil profiles under study were developed on the basalts, which erupted during the Quaternary in the northern Hainan Island (Zhang et al., 2007). The effect of climate change during the Quaternary was negligible for the northern part of the island because during the late Pleistocene glacial period it remained a warm tropical climate. The amplitude of temperature change was no greater than 2.5 °C (Huang et al., 1999); thus, the changes in soil properties were primarily controlled by the time period of weathering and soil development. Therefore, we established a soil chronosequence derived on basalt in Hainan Island to investigate the role of dust in soil development.

2.2. Study area and pedon description

Hainan Island is the largest tropical island in China. It is located in the South China Sea on the northern fringe of the tropical zone (Fig. 1). This study was conducted in the northern of Hainan Island, which has a mean temperature of 23–24 °C and a mean annual precipitation of 1400 to 1800 mm (Huang et al., 1999). It is a tropical monsoon climate with contrasting seasons. Continental dust from the Loess Plateau in North China is one of the most important sources of aeolian precipitation in South China. In the northern winter season, cold air from high latitudes is controlled by the continental high-pressure system and propagates southward along the eastern margin of the Tibetan Plateau to form the strongest northerly dry and cold winter monsoon in the world (Sun, 2005). The northern winter monsoon can extend to tropical South China, even crossing the Equator to trigger southern summer monsoons (An, 2000). Cold air controlled by the Siberian High migrates southward along the eastern margin of the Tibetan Plateau as anticyclones during winter. Dry, cold air flowing from the Asian landmass passes over the northern South China Sea and controls atmospheric circulation in Hainan Island (Bogdanov and Moroz, 1995). The southward transport of dust from the Loess Plateau in North China is prominent during the dry season from November to April as a winter monsoon (Lina et al., 2007).

The four soil profiles under study (i.e., the HB12, HB04, HB01 and HB06 profiles) are from Xiuying, Lingao, Meilan and Chengmai counties, respectively (Table 1 and Fig. 1). All of the soil profiles were selected on primary shield volcano surfaces, where physical erosion and groundwater influences were minimal (Zhang et al., 2007). Thus, surface runoff and groundwater appear not to contribute much extraneous material to soils. Soil profiles were developed on the basalts. The interruption is not observed in the intergradation from basalt to soils and these profiles are in-situ weathering products developed continuously since the eruption of the basalt (Fig. 2).

The basalt bedrock ages range from 180 ka to 2300 ka (Table 1), which was determined using K–Ar chronology (Ge et al., 1989; Zhang et al., 2007). The differences in basalt age may provide a sequence for the intensity chemical weathering. Chemical and mineralogical data for the basalts studied are outlined in Ho et al. (2000). The younger rocks retain the primary minerals and indicate rapid weathering rates, while soils in the oldest rocks have been deeply weathered and are composed of secondary minerals that weather slowly. In this study, the profiles derived from the basalts were classified as Primosols to Ferralsols (CRGCST, 2001; Zhang et al., 2007), which are equivalent to Entisols to Oxisols (Table 1) according to Soil Survey Staff (2003). Soils were excavated to at least a meter or to rock and sampled from small concavities in an otherwise convex portion of the landscape by genetic horizon (Fig. 2).

2.3. Analytical methods

Soil samples were air-dried, crushed using a wooden pestle and mortar, and then passed through a 2 mm nylon sieve. Samples were dissolved with an acid solution ($HNO_3 + HF$) to measure the Nb, Sr and Nd concentrations using an inductively coupled plasma mass spectrometer (ICP-MS) at the State Key Laboratory of Ore Deposit Geochemistry, Institute of Geochemistry in the Chinese Academy of Science. The standard reference materials were GSR-3, BCR-1, GXR-5 and GXR-6. Analytical uncertainties were less than ±5% for the trace elements. The loss on ignition (LOI wt.%) was determined by ashing soil samples for 5 h at 500 °C and recording the change in weight during this step (Table 1). Soil dry bulk density (ρ) was determined by soil wreath knife based on standard techniques (ISSCAS, 1978).

In addition, the sample powders were first baked at 700 °C, to destroy the organic materials, digested using an HNO_3 and HF mixture and finally dissolved in a 2 N HCl solution. The sample solution was separated and purified on a column filled with AG50-X8 cation resin.