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Major Elements in Soils Along a 2.8-km Altitudinal Gradient on the Tibetan Plateau, China

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ABSTRACT

There are a series of special mountain soils on the Tibetan Plateau of China in an alpine environment for the high altitude. However, very few studies have focused on major soil elements in relation to soil formation in this area. Aluminum (Al), iron (Fe), calcium (Ca), sodium (Na), potassium (K) and magnesium (Mg) contents of 237 topsoil samples covering a 2.8-km altitudinal gradient in uncultivated areas along the Qinghai-Tibet Railway of China were measured using inductively coupled plasma atomic emission spectroscopy. The spatial distribution of the elements and its relationship to the parent rocks and climatic parameters were analyzed. Soils along the gradient are derived from a range of parent materials, but most are less than 30 cm deep with little development (Cambisols). Soil Al, Fe and Mg contents showed a decreasing trend from the start station (Xining Station) to end station (Lhasa Station) of the Qinghai-Tibet Railway, whereas soil K and Na contents were relative stable from Xining Station to the Kunlun Mountains and then increased gradually. Soil Ca content was lower in the southern part of the Tanggula Mountains. The major soil element contents clearly reflected the parent rock and climatic influences. Soils with higher Ca content appeared in areas with Ca-Mg carbonate rocks, soils with higher Al were found in areas with silicate-rich and high-Al silicate clastic rocks and silicate-rich aluminosilicate loose sediments. Soils with higher K and Na contents appeared in areas with high-K, high-Na and silicate-rich aluminosilicate rocks. Soil Na and K contents were affected by temperature, whereas the contents of Mg, Fe, Ca and Al were more affected by precipitation. Soil Na and K contents increased with increasing temperatures, whereas the contents of Mg, Fe, Ca and Al decreased with increasing precipitation. This analysis provides a relationship between soil properties and rapidly changing environmental conditions. The data can be used to investigate the effect of the climate or land use change on soil properties.

Key Words: alpine environment, climate, mountain soil, parent material, precipitation, temperature, pedogenesis, soil formation

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Soil is the result of parent material, topography, biology and climate interacting over time. Parent material is a key determinant for soil formation, and the rock or sediment composition affects soil texture, permeability, and a range of chemical properties including major soil elements such as aluminum (Al), iron (Fe), calcium (Ca), potassium (K), sodium (Na) and magnesium (Mg). Climate affects the soil hydrothermal condition, which is an important factor for weathering, plant growth and microbial activities (Shen *et al.*, 2014). Climate also influences the migration and transformation of minerals and organic matter (Alvarez and Lavado, 1998; Ganuza and Almendros, 2003; Dai and Huang, 2006; He *et al.*, 2014). Saussure had suggested in his book "Voyages dans les Alpes (Travel into the Alps)" that climate was responsible for variations in soil organic matter content. Jenny (1980) had developed the theory of lixiviation or leaching in relation to soil formation and climate. Most soil properties could reflect the environment. For example, Na_2O/K_2O (Chen *et al.*, 2001), Al_2O_3-($CaO+Na_2O$)-K_2O ternary diagrams (Nesbitt and Young, 1984; Nesbitt *et al.* 1997) reflect chemical weathering, from which we can infer palaeoclimatic changes (Chen *et al.*, 1997). Du *et al.* (2013) investigated palaeoclimatic changes in Sichuan Basin of China by analyzing the major elements in soils and rocks.

The soils of the Tibetan Plateau in China are relatively young. Soil-forming slowed down when the plateau started to rise. Most soils are about 30 cm deep, gravelly and have simple soil profiles with low mineral weathering (Zheng *et al.*, 1985); most soils

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have not been cultivated since there are few people living on the plateau because of thin air and cold climate.

Soil studies have been carried out on the Tibetan Plateau since the late 1970s (Zhang *et al.*, 1982; SETQP, 1985). Cheng and Tian (1993) and Zhang *et al.* (2002) analyzed the distribution of trace elements (Cu, Pb, Zn and Cd) in the Tibetan Autonomous Region of China. Zhang *et al.* (2007) studied the trace element distribution in the soils on the northern slope of Mount Qomolangma and Li *et al.* (2008) analyzed the trace and rare earth elements in the soils of the Nam Co Basin of the Tibetan Plateau. Lu *et al.* (2004) and Zhang *et al.* (2012, 2013) analyzed heavy metal elements in the soils along the Qinghai-Tibet Railway. However, very few studies have focused on soil major elements in relation to soil formation in this area.

The Qinghai-Tibet Railway crosses the Tibetan Plateau from northeast to southwest over a wide range of environments. The large altitudinal gradient of the Tibetan Plateau allows for research on the effect of environmental conditions on the soils. In this study, total major soil elements were measured along the Qinghai-Tibet Railway and the relationships between major soil elements and climatic parameters and parent materials were analyzed. The main purpose of this study was to quantify the effect of climatic factors on soil properties and their variation on the Tibetan Plateau along a 2.8-km altitudinal gradient.

MATERIALS AND METHODS

Study area

The Qinghai-Tibet Railway (90.544°–101.787° E, 29.626°–37.292° N), located on the Tibetan Plateau, is the highest-elevation railway and the longest highland railway on the earth, extending over 1956 km from the start station (Xining Station) to the end station (Lhasa Station) (Peng *et al.*, 2007) (Fig. 1). The highest point is 5 072 m above sea level (a.s.l.) at Tanggula Station, and the lowest point is 2 240 m a.s.l. at Xining Station. The range in altitude is 2 832 m a.s.l. (Fig. 2).

According to the Chinese Soil Resource Map and the Environmental Database of China (scale: 1: 4 000 000; 1996) provided by Institute of Soil Science, Chinese Academy of Sciences, the Qinghai-Tibet Railway crosses 22 soil subgroups of the soil genesis classification. The main soil types are Hapli-Gelic Cambosols (alpine grass soils) and Matti-Gelic Cambosols (alpine meadow soils) according to the Chinese Soil Taxonomy (CRG-CST, 2006), and both are the main soil types on the Tibetan Plateau. The railway crosses 11 vegetation types and the main vegetation types are alpine steppe and alpine meadow. The dominant vegetation is *Stipa purpurea*, *S. basiplumosa*, *Carex moorcroftii*, *Kobresia littledalei*, *K. pygmaea*, *K. tibetica* (Zheng and Zhang, 2009).

The parent materials along the Qinghai-Tibet Railway are silicate-rich and high-Al silicate clastic rocks intersected with Ca-Mg carbonate rocks, silicate-rich aluminosilicate loose sediments, high-K, high-Na and silicate-rich aluminosilicate rocks (Fig. 1). Most of these rocks are Quaternary deposits.

The climate on the Tibetan Plateau is cold and arid because of the high altitude. Under the influence of the prevailing western winds and the southwest monsoon, the winter is dry and cold; the summer is relative warm and short. The diurnal temperature range of the Tibetan Plateau is twice as high as that in the lowlands at the same latitude, but the annual temperature range is similar in these areas. The mean annual temperature of sampling sites differs from −7.2 to 8.9 °C (Fig. 2). The temperature is higher at the beginning and the end of the Qinghai-Tibet Railway and lower in the middle of the railway because of its higher altitude. The average annual precipitation differs from 90 to 553 mm. Under the influence of the warm wet southwest monsoon, there is a general decrease in precipitation from the south to the north. Precipitation is only 90 mm in Xitieshan in the north of the Kunlun Mountains.

Most of the areas along the Qinghai-Tibet Railway are sparsely populated (Dong *et al.*, 2005). Unused land occupies 42.03% in the county area along the Qinghai-Tibet Railway, the proportion of grassland is 49.97%, and cultivated land is only 0.68% (Zheng and Zhang, 2009).

Soil sampling and analysis

In total 28 soil sampling sites were selected along the Qinghai-Tibet Railway (Fig. 1). The distance between each of the sampling sites was 50 to 80 km. In order to decrease rail and roadbed influences, the sample points at each site were located more than 50 m from the railroad track. Topsoil samples (0–10 cm) at 50, 80, 100, 500 and 1 000 m distance to the railroad track were collected. Three samples were collected at each point of typical sampling sites with wide land and uniform vegetation and land slope, and one sample at each point of the other sites. At 5 sites (Xidatan North, Tanggula Station, Damxung West, Yangbajain South and Lhasashan), samples at 500 and 1 000 m distance to the railroad track could not be collected because of rivers or mountains. In total, 237 topsoil samples were