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Rare earth element components in atmospheric particulates in the Bayan Obo mine region

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ABSTRACT

The Bayan Obo mine, located in Inner Mongolia, China, is the largest light rare earth body ever found in the world. The research for rare earth elements (REEs) enrichment in atmospheric particulates caused by mining and ore processing is fairly limited so far. In this paper, atmospheric particulates including total suspended particulate (TSP) matter and particles with an equivalent aerodynamic diameter less than 10 μm (PM_{10}) were collected around the Bayan Obo mine region, in August 2012 and March 2013, to analyze the levels and distributions of REEs in particles. The total concentrations of REEs for TSP were 149.8 and 239.6 ng/m^3, and those for PM_{10} were 42.8 and 68.9 ng/m^3, in August 2012 and March 2013, respectively. Enrichment factor was calculated for all 14 REEs in the TSP and PM_{10} and the results indicated that REEs enrichment in atmosphere particulates was caused by anthropogenic sources and influenced by the strong wind in springtime. The spatial distribution of REEs in TSP showed a strong gradient concentration in the prevailing wind direction. REE chondrite normalized patterns of TSP and PM_{10} were similar and the normalized curves inclined to the right side, showing the conspicuous fractionation between the light REEs and heavy REE, which supported by the chondrite normalized concentration ratios calculated for selected elements (La_N/Yb_N, La_N/Sm_N, Gd_N/Yb_N).

1. Introduction

Rare earth elements (REEs) are a group of metallic elements comprised of yttrium, fifteen lanthanide elements, and sometimes scandium. These elements are typically split into two sub-groups, the cerium sub-group of "Light" rare earth elements (LREEs) which includes La to Eu and the yttrium sub-group of "Heavy" rare earth elements (HREEs) which include the remaining lanthanide elements, Gd to Lu, as well as yttrium (Wang et al., 2011; Jordens et al., 2013). They share similar chemical and physical properties and exist together naturally in a wide range of mineral types, including halides, carbonates, oxides, phosphates and silicates. REEs have been widely used in various areas of industry and agriculture throughout the world (Pang et al., 2001; Hu et al., 2004). The demand for REEs is increasing annually and has led to the excessive exploitation of rare earth minerals (Chen, 2011). China has relatively abundant REE resources and its REE reserve in 2011 was estimated at 18 million tons, accounting for 23% of world's proven reserve (Anonymous, 2012). From 1987 to 2010, more than 1.6 million tons of rare earth reserves (count as oxides) were produced in China (Chen, 2011). It was estimated that REE oxides entering into the soil due to mining activities with low extraction rate of 50% were 119,000 t in 2005 in China, resulting in potential soil pollution because of their persistence and toxicity (Li et al., 2013; Liang et al., 2008). Large-scale and rapid increases of the exploitation activities of REE resources have resulted in environmental pollution and ecological destruction. It also caused the substantial increases of REEs concentration levels in soil, water and air around the mining area. However, researches about environmental pollution caused by REEs are comparatively weak and little information is thus far available about the potential health effects of exposure to REEs on human beings living in the rare earth mining area.

Surface mines generate kinds of pollutants especially the air pollution, primarily particulate matter including total suspended particulate (TSP) matter and particles with an equivalent aerodynamic diameter smaller than 10 mm (PM_{10}), through blasting, wind erosion of exposed areas, and handling of ore at the mines, during transportation, and at processing plants (Chakraborty et al., 2002; Huertas et al., 2012). Over the last decades, there has been a growing concern about atmospheric particulates because evidence has shown that they are associated with respiratory and cardiovascular diseases, severe intestinal upsets, keratosis and skin cancer in humans (Anenberg et al., 2010; Cheng et al., 2013).

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Atmospheric particulate matter contains a mixture of solid particles in the form of organic and inorganic pollutants (Lee et al., 2010; Cheng et al., 2013), which was more harmful to human's health than the particulate matter itself.

It was reported that REEs had the positive effects on the growth performance of farming animals and various plant species (Pang et al., 2001; Hu et al., 2004). Consequently, REEs had been used at low concentrations as feed additives and fertilizers in China for decades (Wang et al., 2008). However, the environmental safety of REEs application has always been controversial in the academic field and human health risk caused by rare earth intake has drawn increasing attention. REEs may be accumulated in organs of human by ingestion, inhalation and dermal contact, and may induce some diseases. Several studies have indicated the harmful effects and health hazards of REEs to human beings and it has already been proven that long-term exposure of REE dust may cause pneumoconiosis in humans (Hirano and Suzuki, 1996). In China, significant decreases in the intelligence quotient were observed in children living on high rare earth containing soil (Zhang et al., 2000), whereas in adults, the conduction time from the median nerve to the thalamus was found to be reduced. Chen et al. (2001) reported that REE could enter the cell and cell organelles and mainly be bound with biological macromolecules. The long-term consumption of food contaminated with REE may cause chronic poisoning (Jiang et al., 2012).

Large amounts of REEs transported and accumulated in the surrounding environment around the mining area and enter into food chain by edible portion in plants to damage the health of human being. In the past decades, considerable work has been devoted to the concentration distribution of REEs in soil and water bodies (Zhang et al., 2001; Wang et al., 2008; Liang et al., 2008; Li et al., 2010), but little work has been done on the concentration of REE in air (Shaltout et al., 2013). REEs in atmosphere not only posed a threat to human health through the food chain, but also directly entered the human body through the inhaled particle matter and resulted in kinds of potential influence on human health. Consequently, it is imperative to continually assess and monitor the levels of REEs in the atmospheric environment around the mining area, for evaluation of human exposure and for sustainable environment.

The Bayan Obo mine, located in Inner Mongolia, China, is the largest light rare earth deposit ever found in the world. After mining and ore processing, a large amount of tailings which is high in REE are discharged into the surrounding environment and more REE have increasingly been emitted into the atmosphere. To assess the potential risk of REEs to ecological environment and human health, it is therefore necessary to investigate their concentrations levels in airborne particulate matter. In this study, we mainly focused on the concentration and distribution of REEs components in the atmospheric particulates in a representative open-air rare earth mining region of northern China. TSP and PM_{10} samples were collected around the Bayan Obo mine region in August 2012 and March 2013, representing the warm and wet season and the cold and dry season in this area, respectively.

2. Materials and methods

2.1. Site description

The Bayan Obo REE–Nb–Fe deposit located in Inner Mongolia, North China (109°59′E, 41°48′N) (Fig. 1). It is the largest light REE deposit ever found in the world and its total reserves have been reported as at least 1.5 billion tonnes of iron

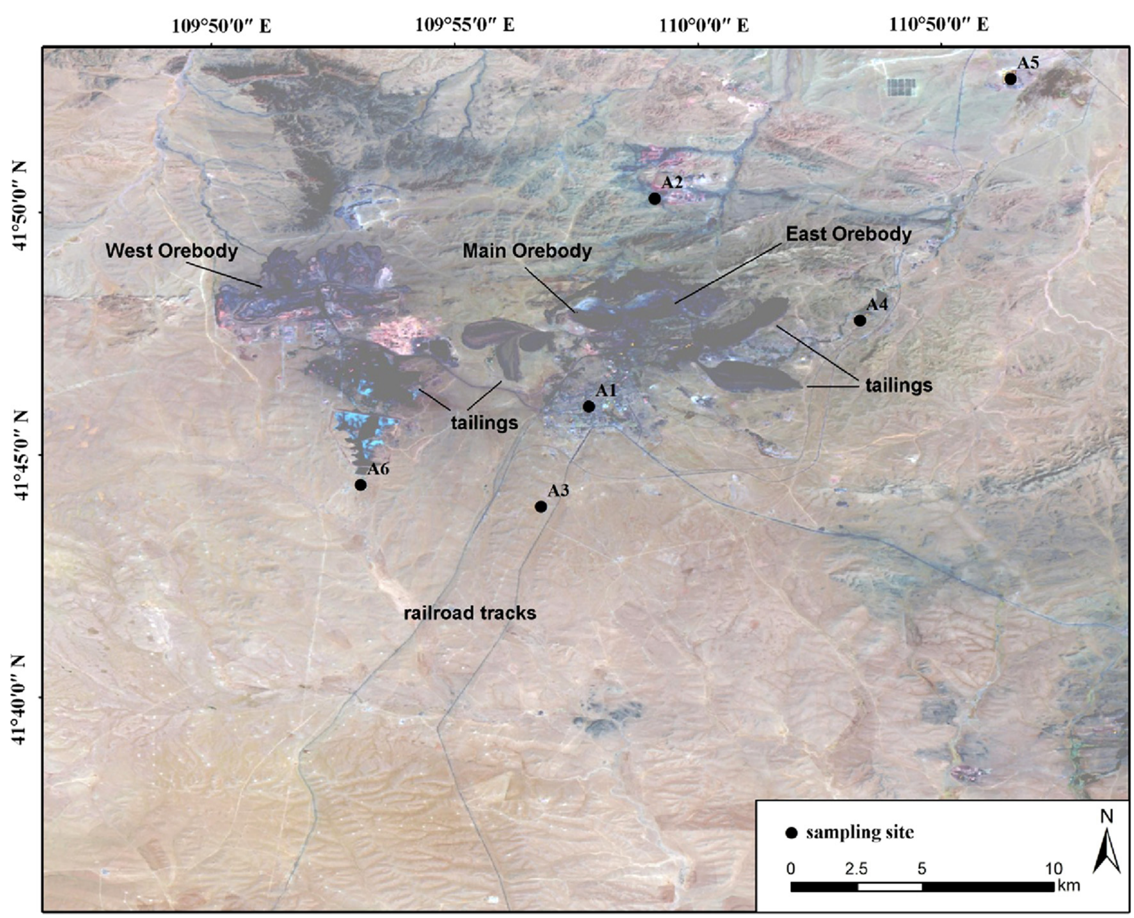

Fig. 1. Map of the study area and sampling site.