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The environmental implications for dust in high-alpine snow and ice cores in Asian mountains

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ABSTRACT

Dust in ice cores is an excellent proxy for atmospheric dust and can reveal long-term dust history, but the relative contribution from high mountains close to Asian deserts, such as the Tibetan Plateau, remains uncertain. Here we show that dust from high-alpine snow collected from Eastern Tien Shan (Tian Shan), Eastern Pamirs (Muztagata), and Qilian Shan displays a different geochemical composition (e.g. rare earth elements, REEs) to adjacent moraines and neighboring surface soils, but is similar in composition to the upwind remote arid regions. For high-alpine snow dust, the local contribution from moraines and surface soils is minor, with the major source being the Asian deserts. The results have revealed that the snow dust is representative of mid- and upper troposphere dust from Asian deserts, and demonstrates a weak event-based discrepancy but a strong concentration-independent uniformity in composition in the long-term, and confirm the regional environmental implication for the paleo-climatic records from ice cores.

1. Introduction

Atmospheric dust history is pivotal to increasing scientific understanding of its climatic effects over the long-term (e.g. Thompson et al., 1989). The Asian mountain ranges are located adjacent to or even enclosed by the vast Asian arid region, which is one of the major dust sources in the world (Yang et al., 2007a; Wu et al., 2009a). The widely distributed glaciers on these ranges are excellent media to receive and preserve eolian dust from the deserts (Wake et al., 1992, 1994; Wu et al., 2009b). Dust in ice cores recovered from the low- and mid-latitude Asian mountain ranges has important environmental implications. Unlike the glaciers in Greenland and Antarctica that are distant from arid- and semi-arid land, here the neighboring moraines, nearby detrital, alluvial/fluvial deposits, and surface soils can be potential sources of alpine glacier dust in addition to those of the deserts (Hinkley et al., 1997). Therefore, the environmental and climatic implications of the dust found in mountain ice cores might not be as straightforward as those of dust found in polar regions.

The local and background (remote) dusts in Alai-Pamir range have different compositions and concentrations in snow. Although local dust deposition events are common in Central Asia, the deposition of the background dust can be distinguished from the local-source material by its composition (Hinkley et al., 1997). On the glacier surface, especially in the ablation zone, windblown dust particles, often combined with the biogenic materials, can be aggregated to form cryoconite after melting. Cryoconite (glacier surface dust) is common on the Asian alpine glaciers and its source has been discussed (e.g. Takeuchi et al., 2005). Geochemical composition is a powerful and effective tool for atmospheric dust provenance tracing. However, source tracing for dust components of cryoconite by geochemical methods is limited (Li et al., 2011).

Therefore, dust in Asian alpine snow might be a mixture of local and remote sources, as well as natural and anthropogenic source (e.g. Wake et al., 1992; Liu et al., 2011; Dong et al., 2014). This mixture leads to uncertainty regarding the representative dust proxy in snow and ice cores recovered from Asian ranges. The source of dust in ice cores needs to be identified to determine whether there are regional environment implications, and if it represents long-range transported dust. In previous studies, authors have discussed the element composition and provenance of Pamirs ice core dust and aerosol dust, and snow dust from Eastern Tien Shan (Tian Shan) (Wu et al., 2009a, 2010a). For the current study, we took new samples at the two previous sites, and at two new sites from Qilian Shan, to determine the composition of dust in snow or ice cores, and of the nearby moraines and surface soils. The main purpose of this study is to identify snow dust sources from the Tibetan Plateau and Tien Shan ranges, define the climatic implications and to validate use of ice core dust as an indicator of atmospheric dust.

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2. Material and method

In the current paper, three Asian mountain ranges and four sites were chosen for a study of dust in snow and its implications. The Eastern Tien Shan is enclosed by Gurbantunggut to the north, Kazakhstan deserts to the west, Taklimakan to the southwest, and Gobi to the east (Fig. 1). Since March 2006, we have collected surface snow samples weekly or bi-weekly at the Program for Glacier Process Investigation observation site (43°06′N, 86°49′E, 4130 m a.s.l.) in a percolation zone of the eastern branch of Urumqi Glacier No.1 (UG1, Chinese Glacier Inventory No. 5Y730C0029), as described in detail previously (Wu et al., 2010a). Additionally, a total of 25 samples collected from February to December 2008 were used to analyze snow dust composition. The composition of moraine and cryoconite (silt pellet) samples of UG1 were obtained from previous studies (Chang et al., 2000; Li et al., 2011).

The Pamir range is surrounded by Taklimakan to the east, Kara Kum and Kyzyl Kum to the west, Afghanistan and Pakistan to the south. In 2002, we drilled several ice cores at Mt. Muztagata (Muztagh Ata). The lengthways quarter-sections of nine ice tubes (at depths from 31.76 to 40.89 m) from a 93.5 m ice core drilled at 6250 m a.s.l. were cut and grouped into successive subsections at intervals of about 100 cm. Since 2004, we have collected aerosol samples on the terminal moraine of a glacier on a western slope of Mt. Muztagata (Muztagh Ata, 38°70′N, 75°10′E, 4430 m). In this study, new aerosol samples ($n = 7$) collected between 30 June and 13 November, 2011 were used for the element analysis. In the summer of 2010 and 2012, we collected surface soil samples ($n = 15$, 36.88°–38.65°N, 74.92°–75.22°E, altitude ranging from 3051 m to 4576 m a.s.l.) near Mt. Muztagata along the Sino-Pakistan International Highway. The soil samples were mostly collected from the crusted surface soil (mainly fine silts and clays) in dried small depressions.

The Qilian Shan, forming the northern border of Tibetan Plateau, is enclosed by Gobi to the north, Badain Jaran and Tengger to the northeast, Qaidam to the south, and Taklimakan to the west. The Qiyi Glacier (Chinese Glacier Inventory No. 5Y437C18, 39°14′N, 97°46′E) is located in the western part of Qilian Shan. In July 2009, we collected two snow samples at 4800 m, seven cryoconite samples (altitude ranging from 4442 m to 4767 m a.s.l.) on the glacier surface and six moraine samples (altitude ranging from 3944 m to 4868 m a.s.l.) along the valley of Qiyi Glacier. In August 2010, we collected three fresh snow samples (i.e. pristine fallen snow, or snowing when samples were collected) at 4787 m a.s.l., and one aged snow sample at 4856 m a.s.l. at this glacier. The Ningchan River Glacier No. 3 (NCG3, Chinese Glacier Inventory No. 5Y416F003, 37°31′N, 101°49′E) is located at Lenglongling, Eastern Qilian Shan. In July 2009, we collected two fresh snow samples at 4300 m a.s.l. on the NCG3 surface, and three moraine samples (4123 m, 4154 m, and 4186 m a.s.l., respectively) at the glacier terminus. In July 2010, one aged snow sample was collected on the surface on the glacier.

Acid-cleaned wide-mouth Nalgene low density polyethylene (LDPE) bottles were used both as sample scoops and containers. The bottles were kept frozen during transport to the laboratory before filtration. The snow and ice core samples were melted at room temperature and then filtrated with LCR hydrophilic PTFE membrane filters (Millipore Corporation) with the pore size of 0.45 μm (Wu et al., 2010a) in the class 1000 clean room. The aliquots of Qiyi cryoconite samples were sorted by Stokes law to separate the <20 μm fraction, while the Qiyi and NCG3 moraine samples were sieved to separate the <50 μm fraction (Table 1).

The snow dust and aerosol filters, surface soil, moraine and cryoconite samples were digested for inductively coupled plasma mass spectrometry (ICP-MS) (Thermo X-7, Thermo-Elemental Corp.) at the Institute of Tibetan Plateau Research, CAS. The digestion and measurement processes, and detection limit and precision of ICP-MS have been described in detail previously (Wu et al., 2009a). The Sr–Nd isotopic analysis for the UG1 snow dust samples was performed using the same processes described by Wu et al. (2010b). The concentration and grain size of snow dust were analyzed with a Coulter Counter (Beckman MS3, diameter from 1 to 30 μm), and the grain size of cryoconite and moraine with a Microtrac-S3500 laser particle size analyzer (Microtrac Inc.). The analysis of total organic carbon (TOC) and inorganic carbon (IC) content of Qiyi cryoconite was performed using a Shimadzu TOC-VCPH).

3. Results

3.1. Urumqi Glacier No. 1 (UG1), Eastern Tien Shan

In a previous study we discussed the variation of dust concentration and uniformity of dust composition in UG1 snow samples during the period of March 2006 to January 2008 (Wu et al., 2010a). In this study, we carried out further analysis over the period February to

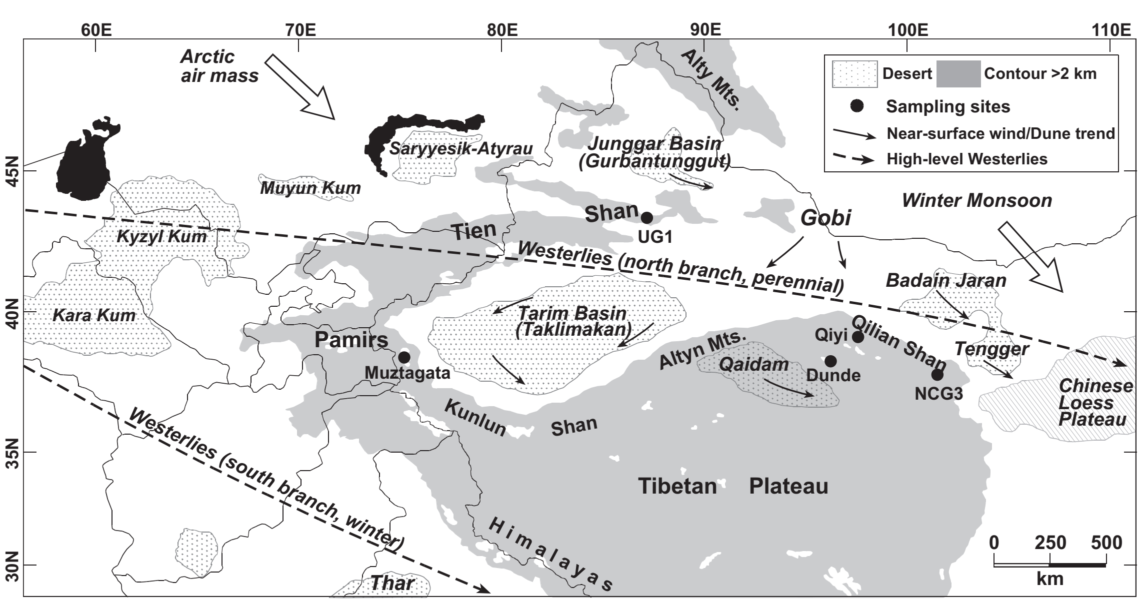

Fig. 1. Sketch map of the location of study sites.