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Evolving flux of Asian dust in the North Pacific Ocean since the late Oligocene

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ABSTRACT

The aeolian deposits in the North Pacific Ocean (NPO) serve as important archives for the surface processes in the arid Asian interior. Aeolian flux, which is usually based on the 'operationally defined aeolian dust' (ODED) extracted from the pelagic sediments, is a widely used paleo-proxy that reflects aridity of the source regions. However, such reconstruction of aeolian flux is subject to large uncertainty associated with the age model due to the low sedimentation rate and lack of calcareous nannofossil of the pelagic sediments. Precipitation of authigenic minerals and contribution of volcanic ash also complicate interpretation of the reconstructed ODED flux. This work extracts ODED from the sediments recovered at Ocean Drilling Program (ODP) site 1208 on the Shatsky Rise in NPO. The high sedimentation rate at ODP site 1208 enables a high-resolution age model. The resulting ODED flux, which shows a progressive increasing trend over the past 25 Ma, is very different from the previous reconstructions. The study indicates that authigenic phillipsite contribute a significant portion to the sediment of 25–18 Ma, but the relative contribution of Asian dust to the ODED is roughly constant (60–80%) over the past 18 Ma. Thus, the progressive increasing trend of ODED flux at the ODP site 1208 is not contributed by authigenic phillipsite and volcanic ash but reflect the increasing flux of Asian dust. We propose that the increasing flux of Asian dust in NPO reflects the progressive aridification of Asian interior in response to global cooling and/or regional mountain building.

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1. Introduction

Asia interior is the second largest center of dust emission in the world (Engelbrecht and Derbyshire, 2010). The aeolian deposits of Asian dust in the Chinese loess, the pelagic sediments of NPO, and the Greenland ice cores serve as important archives for the late Cenozoic climate changes (Biscaye et al., 1997; Guo et al., 2002; Rea et al., 1998). Aeolian flux is one of the mostly used proxies that is believed to reflect the aridity of Asian interior (e.g., Sun and An, 2005). The best records for the long-term changes in flux of Asian dust is in the central NPO, where the pelagic sediment can extend back to the early Cenozoic Era (Pettke et al., 2002).

The pelagic sediment in NPO is mainly composed of the mineral dust from the Asian interior and volcanic ash from the circum-Pacific volcanoes with precipitates of authigenic minerals, hydrothermal products, and biogenic organic carbon, opal and carbonate (Nakai et al., 1993; Ziegler et al., 2007). A chemical procedure, which involves sequential leaching by weak acid, reductive and oxidative reactants, and alkaline solution, has been employed to remove the carbonate minerals, amorphous Fe-Mn hydroxides, organic matter, and biogenic opal in the pelagic sediment (Rea and Janecek, 1981). The leaching residue, which is mainly detrital silicates, is regarded as 'operationally defined aeolian dust' (ODED) (Olivarez et al., 1991; Rea and Janecek, 1981). Flux of the ODED (F_{ODED}, g/cm^2/ka) is then can be calculated from the faction of ODED in the bulk sample (f_{ODED}, g/g) given that dry bulk density (D, g/cm^3) and deposition rate (R, cm/ka) of the sediments were known (Rea and Janecek, 1981):

$$F_{ODED} = f_{ODED} \times D \times R \qquad (1)$$

The reconstructed fluxes of ODED in NPO show a dramatic increase since 3–4 Ma (Janecek, 1985; Janecek and Rea, 1983; Rea et al., 1998). However, the detailed evolutions of F_{ODED} are very different among different sites. For example, the F_{ODED} reconstructed from ODP 885/886 sites shows a pronounced increase at ~8 Ma, and then a decreasing trend until the second increasing step at ~3.6 Ma (Rea et al., 1998). The first increasing step of F_{ODED} has not been registered in the site LL44-GPC3 and DSDP site 576 (Janecek, 1985; Janecek and Rea, 1983). However, the first increasing step of F_{ODED} recorded in ODP site 885/886 has been frequently

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referred to reflect the increasing aridity of Asian interior regardless the inconsistence with the other records (Guo et al., 2004; Pettke et al., 2000; Sun and An, 2002; Zheng et al., 2004).

It is unlikely that the flux of Asian dust evolves differently among the different sites in the NPO because Asian dust has been largely dispersed after long-range transportation. Geochemical signature for the contribution of Asian dust in the pelagic sediments has been detected all cross the NPO (Nakai et al., 1993; Olivarez et al., 1991; Pettke et al., 2000, 2002; Seo et al., 2014; Serno et al., 2014; Stancin et al., 2006; Weber et al., 1996). The limited changes in position of the depositional sites associated with seafloor spreading also cannot explain the inconsistent record of F_{ODED} among the different sites (Snoeckx et al., 1992). One of the major errors in calculating the F_{ODED} in Eq. (1) is sourced from the sedimentation rate (R). The pelagic sediments in NPO are characterized by low deposition rate of several meters per million years (Janecek and Rea, 1983; Rea et al., 1993, 1998). The slow deposition rate and the early recovery (before 1990s) of the ODP and DSDP cores prevent high-resolution magnetic reversal stratigraphy (Janecek and Rea, 1983; Rea et al., 1993, 1998). The pelagic sediments in the deep NPO are mostly deposited below the carbonate compensation depth, and thus are subject to extensive dissolution of carbonate. Therefore, the widely used biotic stratigraphy based on calcareous nannofossil is generally inapplicable (Janecek and Rea, 1983; Rea et al., 1993, 1998).

Contribution of volcanic ash and authigenic minerals may also influence the reconstructed F_{ODED} (Weber et al., 1996; Ziegler et al., 2007). The sites that are close to the margin of NPO receive much higher input of volcanic ash from the circum-Pacific volcanoes than the sites in the central NPO (Nakai et al., 1993). Authigenic mineral has been found to contribute a significant portion to the silicate component in the sediments of eastern NPO (Hyeong et al., 2005; Rea et al., 1993; Ziegler and Murray, 2007; Ziegler et al., 2007). Contribution of authigenic mineral, volcanic ash, and Asian dust to the ODED can be resolved by trace element composition and the radiogenic Nd and Sr isotopic ratios (Jiang et al., 2013; Nakai et al., 1993; Weber et al., 1996; Ziegler et al., 2007). Authigenic mineral precipitated from seawater is characterized by high concentration of total REE, LREE depletion, and negative Ce anomaly (Piepgras and Jacobsen, 1992). The volcanic ash, which is in basaltic and andesitic composition, is characterized by low $^{87}Sr/^{86}Sr$ ratio, high ε_{Nd} value, and high contents of mafic elements such as Sc, Ni, Co, Cr (Defant et al., 1990; Nakai et al., 1993; Olivarez et al., 1991; Weber et al., 1996). The Asian dust show similar composition to the upper continental crust with high $^{87}Sr/^{86}Sr$ ratio, low ε_{Nd} value, and high contents of lithophile elements such as Th, Rb, and U (Nakai et al., 1993; Olivarez et al., 1991; Taylor and McLennan, 1985; Weber et al., 1996).

This study reconstructs aeolian flux in NPO based on the sediments recovered from ODP site 1208 on the Shatsky Rise. The age model of the sediments from ODP site 1208 has been well constrained by magnetic reversal stratigraphy and biotic stratigraphy benefited from the high sedimentation rate and the well preserved biogenic carbonate and opal (Shipboard Scientific Party, 2002). Contribution of Asian dust, volcanic ash, and authigenic minerals in the ODED will be resolved by the trace element compositions and the radiogenic Nd and Sr isotopic ratios.

2. Samples and method

2.1. Materials

Bulk sediments of the past 25 Ma were collected from ODP site 1208 and core LL44-GPC3 in the NPO. Core-top samples of late Pleistocene age were also collected from fourteen DSDP/ODP sites in the northwest Pacific Ocean (Fig. 1). In addition, the <5 μm silicate fractions of three loess samples and twenty-six surface sand samples from the ten major deserts in Asian interior (Supplementary Fig. S1) were split from the same samples that were used to constrain the Nd and Sr isotopic composition of Asian dust in our previous studies (Chen et al., 2007; Li et al., 2009).

ODP site 1208 (36°7.6301′N, 158°12.0952′E) is located on the center of the central high of the Shatsky Rise at a water depth of 3346 m (Shipboard Scientific Party, 2002). Coring at site 1208 has recovered an expanded, apparently complete upper Miocene to Holocene section of nannofossil ooze and nannofossil clay between 0 and 251.6 mbsf (meter below sea floor), below which lies almost 60 m of a less expanded lower and middle Miocene section (Shipboard Scientific Party, 2002). A high-resolution age model has been established by biochronologic and magnetic stratigraphy applied onboard to the research vessel (Shipboard Scientific Party, 2002) (Fig. 2a). Two sets of samples have been collected from the ODP 1208 core. A low-resolution sample set that covers the past 25 Ma was collected at proximately equal time interval at resolution of about 3 samples per million years. A high-resolution sample set spanning 250 kyr of time at approximately 2.75 Ma ago was collected at resolution of about 2.5 k.y. per sample. The chronologic

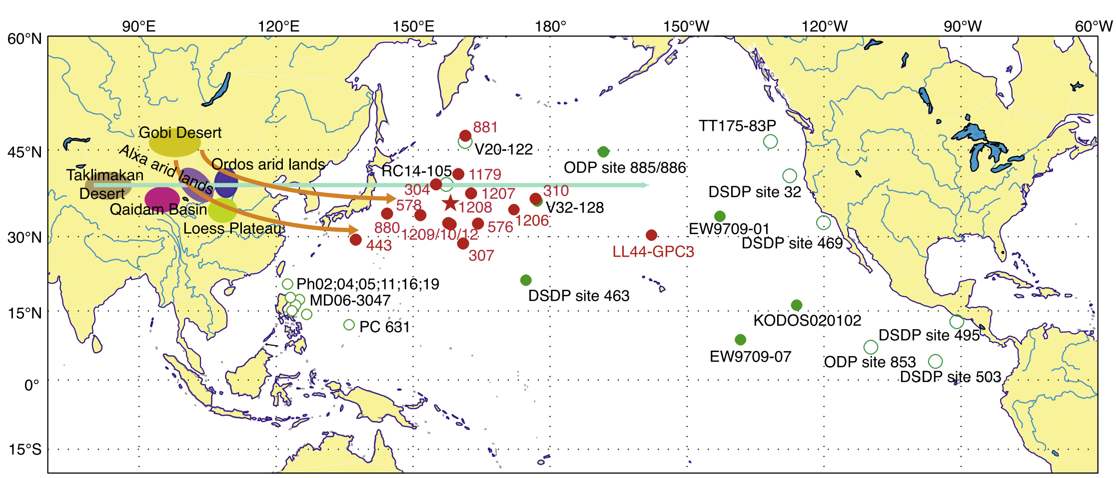

Fig. 1. Map showing the locations of ODP Site 1208 and other sites in North Pacific Ocean. Sites labeled with red-filled circles are the sites studied in this work. Sites labeled with open green and green-filled circles are those with published Nd-Sr isotopic data in circum-Pacific and north central Pacific regions, respectively. The shaded areas in the Asian Interior are the potential source regions of Asian dust. Yellow and green arrows indicate transportation of Gobi and Taklimakan dust by the East Asian winter monsoon and westerly wind, respectively. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

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