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The spatial distribution of multiple elements in the Kanto region of Japan: Transport of chalcophile elements from land to sea

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ABSTRACT

The transport of particles in the Kanto region of Japan is discussed, using comprehensive geochemical maps of 53 elements in terrestrial and marine areas, generated by the Geological Survey of Japan (AIST). This study investigates the transport processes of elements (Cu, Zn, Mo, As, Cd, Sn, Sb, Hg, Pb, and Bi), the concentrations of which are highly increased as a result of mining and anthropogenic activities. The Kanto region was selected as a study area, because it includes large-scale economic mines, as well as the metropolis of Japan with its associated densely populated and industrial areas. Although metalliferous deposits typically enhance the concentrations of chalcophile elements, and Mo and Sn, marine sediments located adjacent the mining areas show no significant enrichment in these elements. Other elements show that their concentrations are mainly controlled by lithology, and display discontinuous spatial distribution patterns across the land and sea. The coastal sea adjacent to the mining area faces the open sea on the Pacific side. It is, therefore, assumed that sediments supplied from the land would be dispersed by wave and coastal sea currents in the coastal sea environment. In contrast, chalcophile elements, P, Mo, and Sn are highly abundant in both the stream sediments of metropolitan areas and the coastal sea sediments of the adjoining inner Tokyo Bay. The contaminated sediments in the bay appear not to extend into the outer sea. In Tokyo Bay, sea water flows along the bottom from the outer sea towards the inner bay, while surface water in the bay flows out steadily. Accordingly, the spatial distribution patterns of contaminated sediments supplied from the nearby urban areas are controlled by water circulation in the bay.

1. Introduction

Geochemical maps provide basic information for mineral exploration and environmental assessment, and in this respect many countries have produced national geochemical atlases or collections of regional distribution maps (Andersson et al., 2014; Fauth et al., 1985; Gustavsson et al., 2001; Koljonen, 1992; Lahermo et al., 1990, 1996; Lis and Pasieczna, 1995; Shacklette and Boerngen, 1984; Thalmann et al., 1989; Weaver et al., 1983; Webb et al., 1978; Xie et al., 1997; Zheng, 1994). Darnley et al. (1995) set guidelines for the development of a global geochemical database, and more recently cross-boundary and continental- and sub-continental-scale geochemical mapping projects have been actively conducted (e.g., Bølviken et al., 1986; Caritat and de Cooper, 2011a, 2011b; De Vos, 2006; Reimann et al., 2003, 2014a,b; Salminen et al., 2005; Smith et al., 2013, 2014).

The Geological Survey of Japan, National Institute of Advanced Industrial Science and Technology conducted comprehensive research into the spatial distribution of 53 elements in terrestrial and marine environments during 1999–2008 (Imai et al., 2004, 2010). Japan is surrounded by sea and, therefore, gaining an understanding of the background elemental abundances in both terrestrial and marine areas is considered important. The production of a comprehensive geochemical atlas, covering the land and the sea, could be used as a powerful tool for examining particle transport processes, particularly the diffusion of pollutants (Ohta and Imai, 2011). However, previous studies in relation to this work have focused mainly on the system of sediment dispersal from terrestrial areas to the coastal sea, in terms of erosion, transport, and deposition of sediments (Ohta et al., 2004, 2007, 2010).

It is also recognised that inner bays often sustain damage from anthropogenic activities from the adjacent terrestrial area. A number of studies have focused on specific areas, such as conducting the environmentally oriented geochemical mapping on soil substances in urbanised areas (Cicchella et al., 2008; Jarva et al., 2008; Johnson and Ander, 2008; Johnson et al., 2011; Li et al., 2004; Thornton et al., 2008). The spatial distribution of pollutants in the marine environment, including within harbours, inner bays, and coastal seas has been examined by Buckley and Winters (1992), Fang et al. (2009), Leoni and Sartori (1996), Li et al. (2001), and Whalley et al. (1999).

However, few comprehensive geochemical surveys have been carried out with respect to anthropogenic activities across both terrestrial and marine environments. Therefore, this study is focused on the Kanto Region of Japan, which includes the metropolis of Japan, highly populated areas, industrial areas, and mining areas, and reveals the transport of

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chalcophile elements (Cu, Zn, As, Cd, Sb, Hg, Pb, and Bi), Mo, and Sn from terrestrial to marine areas related to mining and anthropogenic activities.

2. Study area

A schematic map of the study area and a land use map with geographical names are shown in Fig. 1a and b, respectively. The Kanto region, is located on the Pacific side of Japan, and has a population of approximately 40 million. It consists of large tracts of flat land, and is an important industrial area that has been affected by pollution, especially during the 1960–1970s. Tokyo Bay, in particular is surrounded by highly populated and industrial areas, and major rivers (the Edo, Ara, and Tama) flow through urban areas to the bay. In addition, the Sagami River flows to Sagami Bay, where the sea floor slopes steeply from the coast and reaches a water depth of 1000 m at a location only 10–20 km offshore. Kashima-Nada is the continental shelf.

Fig. 1c is a 1:1,000,000 scale geological map (Geological Survey of Japan, 1992), which shows that more than half of the study area is covered by Pleistocene–Holocene unconsolidated sediments. Tokyo, Yokohama, Kawasaki, and Chiba cities, each with a population of more than 800,000, are located on coastal plains. The mountainous region is mostly underlain by rocks that formed before the Neogene. The accretionary complexes here consist of mélange, mudstone, and sandstone, associated with chert, limestone, metabasalt, and ultramafic rock blocks. Granitic rocks bearing K-feldspar and biotite are distributed in the north-eastern, north-western, and western parts of the study area. The mafic volcanic rocks trend in a NE–SW direction, and are composed of andesitic lava, tuff, and welded tuff. The minor lithologies in the study area are felsic volcanic rocks composed of dacitic lava and tuff, and metamorphic rocks. Fig. 1c also shows the location of some of the major economically mined deposits (Omori et al., 1986). The Hitachi and Ashio mines contain Kieslager-type (Besshi-type) massive sulphide and the vein and massive metasomatic deposits, respectively. These mines are the largest copper mines in Japan. In addition, Takatori mine is a polymetallic W, Sn, Cu, and As deposit. Tochigi mine is a small-scale hydrothermal copper deposit.

3. Sampling locations and sample types

The sampling locations with their respective particle sizes are presented in Fig. 2. In 1980, 65 marine sediment samples were collected using a grab sampler off the Boso Peninsula, and these were subsequently stored in a refrigerating room. In 2004, 125 samples were collected using a grab sampler from Kashima-Nada, Tokyo Bay, and Sagami Bay, with a mean sampling density of one sample per 80 km^2. The samples were classified into six categories according to their grain size, as determined by visual inspection on board the ship, namely gravel, very coarse–coarse sand, medium sand, fine–very fine sand, sandy silt, and silt. The

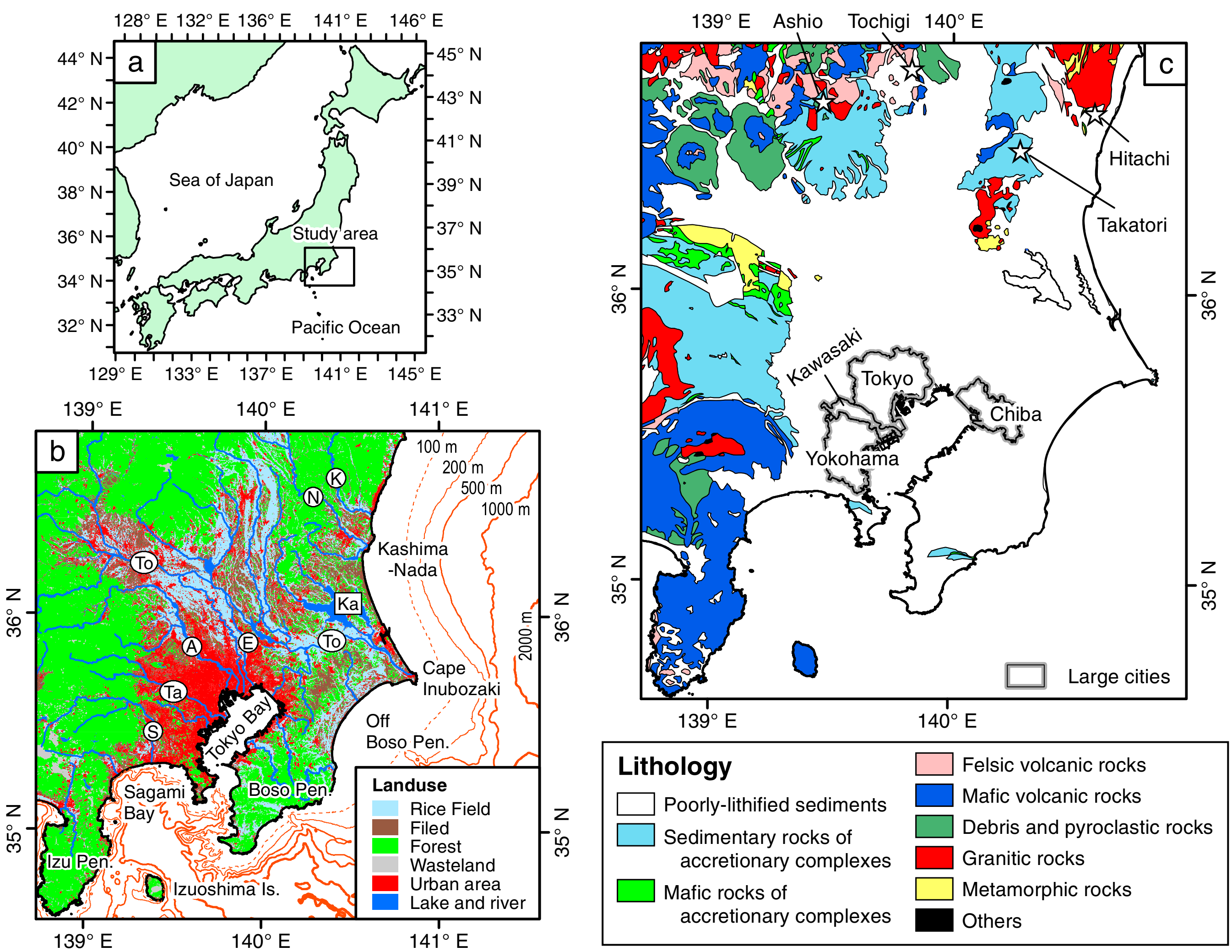

Fig. 1. Schematic maps of the study area: (a) overview map; (b) land use map with geographical names; (c) lithology, major metalliferous mines (indicated by stars) and location of large cities (Geological Survey of Japan, 1992). The abbreviations A, E, Ka, N, Ta, To, and S respectively signify the Ara River, Edo River, Kasumigaura Lake, Naka River, Tama River, Tone River, and Sagami River.