Chemosphere 202 (2018) 65–75

Contents lists available at ScienceDirect

Chemosphere

journal homepage: www.elsevier.com/locate/chemosphere

Origin and migration of trace elements in the surface sediments of Majuro Atoll, Marshall Islands

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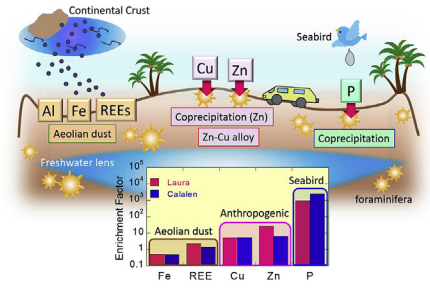
HIGHLIGHTS

- The origins of elements in sediments of Majuro Atoll were identified as the continental crust, anthropogenic, and seabird feces.
- Chemical species of high-content elements at the surface of sediments were revealed by XAFS analysis.
- Zinc was fixed in the upper sedimentary layer by coprecipitation with calcite and apatite.
- Heavy metal such as zinc was hindered to release into groundwater by the characteristic of sediments in the atoll.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 26 September 2017
Received in revised form
14 February 2018
Accepted 11 March 2018
Available online 13 March 2018

Handling Editor: Martine Leermakers

Keywords:
Atoll
Foraminifera
X-ray absorption near edge structure
Heavy metal
Fixation
Apatite

ABSTRACT

The sediments of Majuro Atoll, Marshall Islands, consist of bioclastic materials, including foraminifera and coral debris. The sedimentary depth profiles of elements showed that various elements including zinc (Zn) and copper (Cu) were enriched in the upper layers of the islands of Majuro Atoll. Carbon-14 dating revealed that the sedimentation of the upper layer was completed before 1670 and 542 cal BP in Laura and Calalen, respectively. The enriched elements could be categorized by their origins: (a) terrestrial elements transported as dust (aluminum (Al) and rare earth elements (REEs)); (b) anthropogenic elements (Zn and Cu); and (c) elements supplied by seabirds (phosphorus (P)). From the results of the total amount of Al supplied to sediments for ca. 2000 years, Al in Majuro Atoll was suggested to be airborne origin. The enrichment factors of the elements normalized to Al concentration of continental crust showed that REEs were also transported as dust, while Zn and Cu were mainly of anthropogenic origin. The speciation analysis by X-ray absorption near-edge structure (XANES) showed the presence of Zn–Cu alloys originated from industrial products. It was also revealed that Zn was enriched in the surface due to anthropogenic emission after urbanization on Majuro Atoll and fixed by carbonate and phosphate at the upper layer, which inhibits migration of Zn into the deeper layer and its release to the groundwater and costal water. Hence, the fixation of heavy metals at the surface prevents their exposure to aquatic organisms and residents via fresh groundwater in the island.

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https://doi.org/10.1016/j.chemosphere.2018.03.083
0045-6535/

1. Introduction

Majuro Atoll in Marshall Islands (Fig. 1) has one of the longest human history among other atolls in the world. Still, only approximately 2000 years have passed since islanders first settled on this atoll (Yamaguchi et al., 2005, 2009).

Some studies have investigated the environmental chemistry of atolls. Arimoto et al. (1985) investigated concentrations of trace elements in dry and wet deposits in Enewetak Atoll in Marshall Islands (Fig. 1). This study, however, did not investigate the postdeposition processes of these elements. Osawa et al. (2010) and Fujita et al. (2014) examined the anthropogenic impacts on atolls, but these studies were limited to the water area. Furthermore, few studies have actually investigated the influences of trace elements in sediments on several aspects of human life, such as agriculture and diet. Deenik and Yost (2006) examined the chemical properties of Marshall Islands, but the samples were not systematically collected from various depths. Thus, the initial deposition process of the trace elements and their subsequent migration in the vertical profile after the early stage of island formation to the present were still not well known.

Thus, this study aimed to quantify the total amount of supplied elements, subsequent postdeposition migration, and chemical interactions in the sediments. Especially, Zn has adverse impacts on some aquatic species, such as zooplankton and algae. The diversities and population of zooplankton and algae decrease upon exposure to high concentrations of Zn in water even below 0.05–0.1 mg/L (e.g., Greene et al., 1975; Carlson and Roush, 1985; Clements and Kiffney, 1995). Therefore, migration of heavy metals such as Zn and Cu from the surface to deeper sediments is crucial for their exposure to aquatic organisms and even to the residents, since groundwater is the only natural source of freshwater when rain catchment storage is exhausted in Majuro Atoll (Presley, 2005; Koda et al., 2013; Bailey and Jenson, 2014). Thus, we primarily focused on Zn, which can be regarded as an anthropogenic element given its presence in numerous industrial products (Nakanishi et al., 2008).

Other elements, such as aluminum (Al), rare earth elements

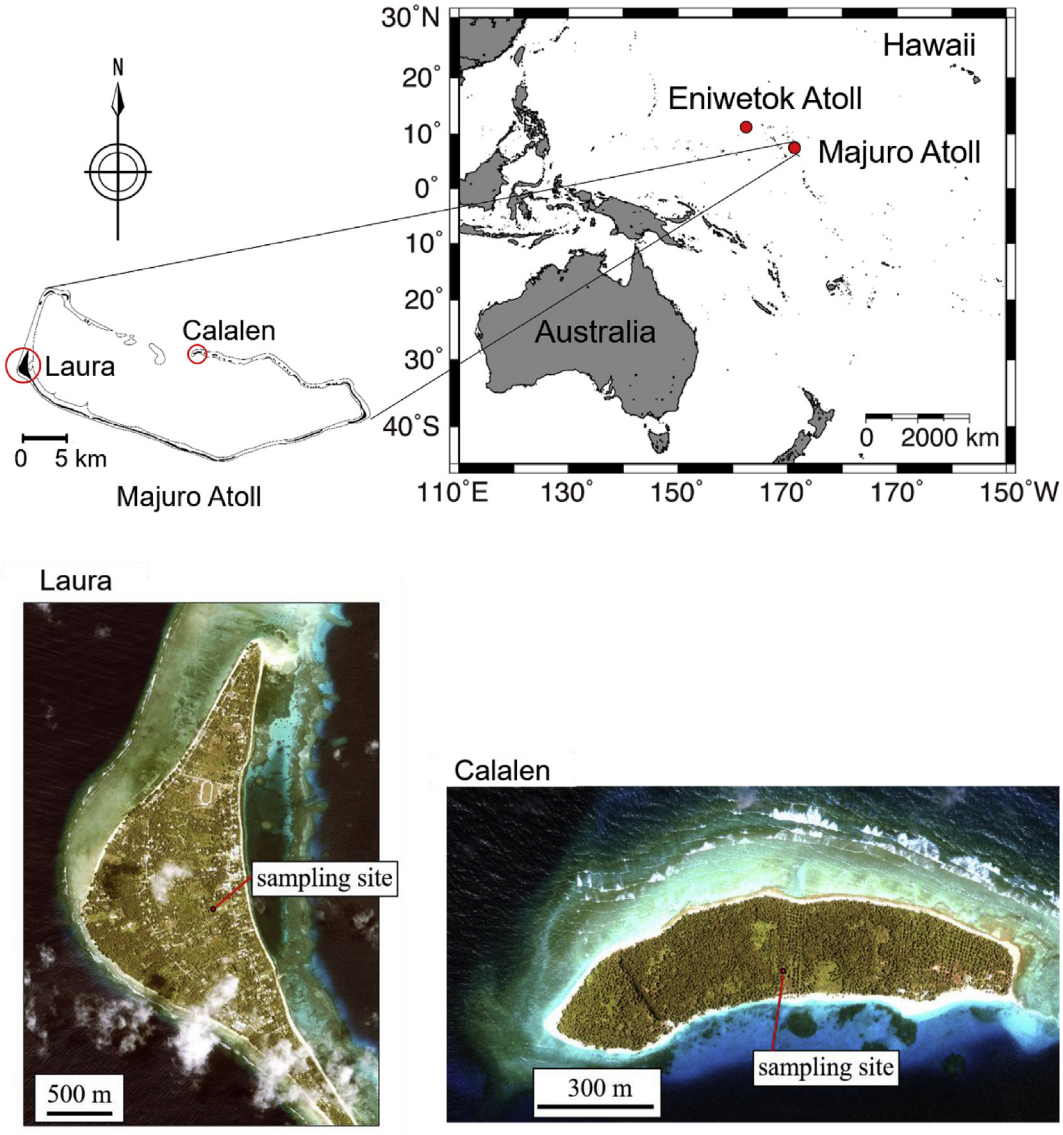

Fig. 1. Location of Majuro Atoll. Majuro is the capital city of Marshall Islands, which consists of 29 atolls and 5 islets. Majuro Atoll is located between Hawaii and Australia near the equator. Laura and Calalen are located on the west side and center of the atoll, respectively.