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NOTE

Sediment erosion revealed by study of Cs isotopes derived from the Fukushima Dai-ichi nuclear power plant accident

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Deltaic sediments of the Mekong River delta sampled from a tidal beach in Vietnam during the wet season (late October 2011) showed strong ^{137}Cs and ^{134}Cs activities reflecting radionuclides released from the Fukushima Dai-ichi nuclear power plant (FDNPP) after the March 2011 Tohoku-oki earthquake and tsunami, but samples from the same site taken about three months later during the dry season (early February 2012) showed weak activities. This finding indicates that soil from the Mekong drainage basin was deposited along the delta front in the wet season and then removed in the dry season during the winter monsoon. Thus, seasonal changes in the sedimentary environment of sediment supply and accumulation were elucidated by Cs isotopes from the FDNPP accident. This finding may expand the usefulness of radionuclides for obtaining important information about geochemical events.

Keywords: Fukushima Dai-ichi nuclear power plant accident, Cs isotopes, erosion, Vietnam, mega-delta

INTRODUCTION

The large magnitude-9.0 Tohoku-oki earthquake occurred in eastern Japan on March 11, 2011, and the subsequent tsunami struck the Fukushima Dai-ichi nuclear power plant (FDNPP), causing emission of radionuclides into the atmosphere and ocean. Radionuclides from these emissions have been observed worldwide at many observatory stations (Leon *et al*., 2011; Manolopoulou *et al*., 2011; Pittauerova *et al*., 2011; Kanai, 2012). The activities of these nuclides are of great concern for assessing the radiation dose to the public.

Among the radionuclides in the environment, ^{137}Cs is an artificial radionuclide with a half-life of 30.2 y that is produced in nuclear explosions and nuclear reactors. The amount of ^{137}Cs in atmospheric fallout increased in the 1950s and 1960s and reached its maximum in 1963, the year the Nuclear Test Ban Treaty took effect (Peirson, 1971). Although the radionuclide decreased gradually thereafter, its activity remains detectable in sediment. Thus, geochronology of sediment using ^{137}Cs is based on the fact that the depth of the peak concentration in the sediment column corresponds to the year 1963; ^{137}Cs is also used to estimate rates of soil loss from agricultural land (He and Walling, 2003). Note that ^{134}Cs is produced mainly by the neutron activation reaction of ^{133}Cs in nuclear reactors and is not produced during nuclear explosions. Therefore, ^{134}Cs in the environment results from its release from a nuclear power plant during an accident. Furthermore, the half-life of ^{134}Cs is 2 y, too short to allow detection of the isotope's activity after several decades; thus, its presence clearly represents a recent accident.

We are currently engaged in ongoing research on the sedimentary environment in the Mekong River delta to assess the deltaic environment and its conservation status (Saito *et al*., 2012). During a survey of the deltaic sediment in October 2011, we conducted a geomorphological study and also took core samples. We were surprised to detect Cs isotopes released from the FDNPP in the core, and surveyed the same station the next year. The present study focuses on the Cs isotopes in the core in order to study the seasonal variations of this deltaic environment.

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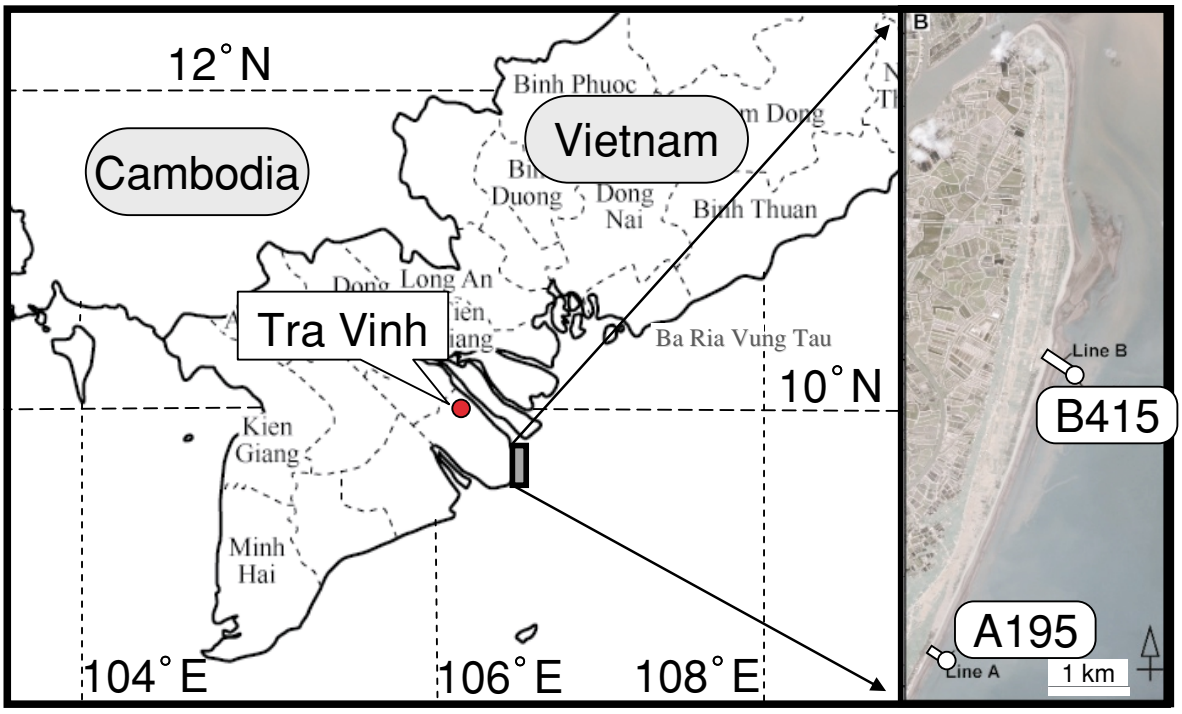

Fig. 1. Sampling locations in the Mekong River delta, Vietnam.

Samples and Analytical Method

Core sediment samples were taken from the coastal zone of the Mekong River delta in Tra Vinh Province, Vietnam (Fig. 1), on October 29–31, 2011, and February 7–8, 2012 (about 3 months later). Samples A195 (core lengths were 66 cm and 54 cm) and B415 (core lengths were 44 cm and 3 cm) were obtained at a point 195 m along line A (trough in a tidal beach) and at the 415-m point of line B (lower tidal flat) by pushing a polyvinyl chloride tube (i.d.: 58 mm) into the sediment. The topography of these lines was described by Tamura *et al*. (2010) as line A and line BN, respectively. The samples were cut at intervals of 3–6 cm, put into polyethylene bags, and brought to the laboratory for gamma spectrometry.

About 6 g of dried powdered sample was analyzed using a multichannel analyzer (7600 MCA, Seiko EG&G Co., Chiba, Japan) with a well-type Ge detector (Ortec International, Oak Ridge, Tennessee, USA). ^{137}Cs and ^{134}Cs were determined from the 662 keV and 605 keV peaks, respectively.

Results and Discussion

Both ^{134}Cs and ^{137}Cs were detected in the A195 core sediment taken in October 2011. Activities were as high as 0.025–0.035 Bq/g at depths of 5–15 cm (Fig. 2a). All other samples contained levels of Cs isotopes near or below the detection limit. The average ^{137}Cs content in surface lake deposits in East Asia ranges from 0.01 to 0.03 Bq/g (recalculated from Kanai, 2009), so the ^{137}Cs concentration in core A195 is a little higher than the East Asian average. However, the high activity of ^{134}Cs means that the Cs isotopes represent radionuclides emitted in the FDNPP accident of March 2011 and that the upper sediments with high contents of Cs isotopes were deposited after the FDNPP accident, more precisely, after March 27, when Long *et al*. (2012) observed ^{131}I, ^{137}Cs, and ^{134}Cs in aerosols at three monitoring stations in Vietnam. The radioactive plume from the FDNPP moved in a southwestern direction, crossed Okinawa, and reached Vietnam. Activities reached a maximum around April 10, 2011, and decreased below the detection limit after April 23 (Long *et al*., 2012). The main fallout period was during the month of April 2011, when Cs isotopes fell on the surface of the hinterland. Most of the Cs isotopes detected in the core sediment would have been derived from inland soils of the drainage basin because Cs adsorbs strongly onto soil and clay particles. At Fukushima, ^{137}Cs was strongly adsorbed onto soil particles in the surface layer and very little (<1%) was taken up by water (Tanaka *et al*., 2012).

In the Mekong River watershed, most rain falls in the wet season from April to October. In 2011, the water level of the Mekong River at Tan Chau, upstream from our study site, increased to 3–5 m during August to October

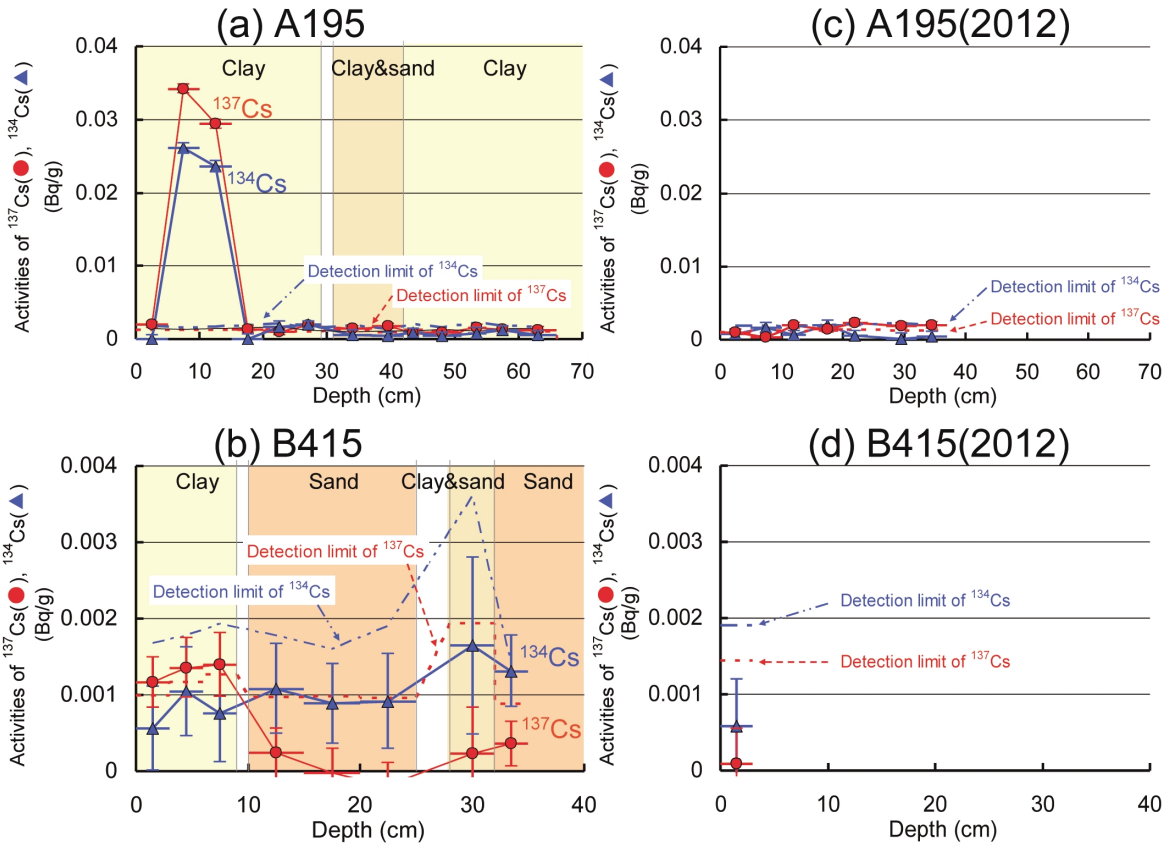

Fig. 2. Activities of ^{137}Cs and ^{134}Cs in core sediments sampled in October 2011 at (a) A195 and (b) B415 and in February 2012 at (c) A195 and (d) B415. The vertical error bars indicate counting statistic error (1σ), and the detection limit is calculated as 3σ.

(MRC, 2012). This increase is consistent with the erosion of a large amount of surface soil with adsorbed Cs isotopes from the hinterland, its subsequent transport to the coast by the Mekong River, and its deposition around the river mouth to form the Cs-rich layer between the depths of 5 and 15 cm in the core. The surface (0–5 cm) sample with small amounts of Cs isotopes may derive from older, deeper soil with low Cs content that was eroded after the surface soil was removed. It might have taken more than one month for these soil particles to be transported to the delta.

The profile of Cs isotopes in the sediment of core B415 (Fig. 2b) differed somewhat from that of core A195. The only activities that were above the detection limit were those of ^{137}Cs in the samples above 10 cm depth, and these were very low compared with those of core A195. Core B415 was extracted from the tidal flat near the mouth of the Mekong River, whereas core A195 came from the trough line in the tidal beach. Consequently, the difference in the Cs profiles probably reflects the difference in location and respective sedimentary environments.

Our second survey at the same stations, conducted in February 2012, about 3 months later, revealed that the activities of ^{137}Cs and ^{134}Cs at A195 were low, near or below the detection limit (Fig. 2c), and that those at B415 were below the detection limit (Fig. 2d). The result for A195 means that the upper layer of sediment with high ^{137}Cs and ^{134}Cs activities that was deposited during the 2011 wet season had been removed from the tidal beach by February 2012. February occurs during the dry season when only a small amount of sediment is delivered from the river and erosion by strong waves during the winter monsoon may exceed sedimentation (Tamura *et al.*, 2010).

Our results have demonstrated seasonal changes of sediment supply and accumulation in the sedimentary environment by measuring Cs isotopes released from the FDNPP. Other short-term geological events may be similarly clarified by using radionuclides. The behavior of Cs isotopes from the FDNPP has not yet been clearly elucidated. The flux and the fate of these radionuclides in the environment (sediment, seawater, fish, plants, and crops) are important subjects for future study.

Conclusion

Mekong Delta sediments in Vietnam were sampled

twice, late in October 2011 and early in February 2012. The samples collected in October, during the wet season, showed strong ^{137}Cs and ^{134}Cs activities due to fallout from the FDNPP accident several months earlier. The samples taken about three months later, during the dry season, showed no strong ^{137}Cs or ^{134}Cs activities. We interpret these results as indicating that soil from the hinterland was transported to the delta front by the river during the wet season and that these sediments were then eroded from the top layer during the following dry season. Thus, seasonal changes in the sedimentary environment of sediment supply and accumulation were elucidated by Cs isotopes that were released from the FDNPP. This finding may serve to expand the usefulness of radionuclides for obtaining important information about geochemical events.

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