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Granulometric and mineralogic investigation for explanation of radionuclide accumulation in different size fractions of the Yenisey floodplain soils

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ABSTRACT

A detailed study of soil fractions of different sizes and their mineralogy was performed to explain the distributions of ^{137}Cs discharged by the Krasnoyarsk MCC in alluvial soils of the near and remote impact zones. Radionuclides were shown to concentrate in fine fractions enriched in hydromica and smectite. However, in natural conditions the dominant size fractions responsible for ^{137}Cs accumulation appeared to belong to sizes from silt (0.010 mm) to clay (0.001 mm). Ultrasonic treatment helped to reveal that this occurs due to natural water-resistant aggregation of smaller particles. Aggregation of fine particles and a considerable contribution of coarse fractions to the total sample mass lead to a smoothing effect in the distribution of ^{137}Cs inventory in different fraction masses constituting the soil layer. However, clay fractions $<$0.001 mm, and aggregates sized 0.05(0.63)–0.010 mm and 0.25–0.125 mm appear to dominate in radiocesium storage in the studied layers supporting the contention that these fractions play a major role in the distribution and accumulation of technogenic contamination in the floodplain soils of the region.

Mineralogical analysis of the samples proved that floodplain sediments are able to fixate cesium due to the presence of smectites, illite, feldspars and micas in fines and coarser fractions. Abundant feldspar transformed to sericite can also contribute to cesium sedimentation. The particle interval from $<$0.001 to 0.010 mm would appear to be crucial for contamination levels of river sediments and floodplain soils as they are comparatively resistant in aqueous solution and prone to easy transport by the river. Therefore the alluvial soil fractions of these sizes are of prime importance in the studies of technogenic contamination of river systems.

1. Introduction

Technogenic radionuclides released to the environment are immediately included in natural processes and thus constitute useful tracers. They enable us to study not only the contamination level but also the behavior of trace elements and the main factors responsible for their migration. Physical and chemical properties of soil particles are crucial in terms of their influence upon the distributions of trace elements in the environment. In this regard, the processes of fixation and transport of trace elements are important in landscape systems and in floodplains in particular. Methodological aspects of studying chemical element distributions between soil micro- and nanoparticles have been recently discussed by Shkinev et al. (2012a).

Soil particle size and particle mineralogy have a distinct relationship. The sand fraction (0.05–2.0 mm in USDA system, Shaeltz and Anderson, 2005) is usually composed of primary minerals while most clay particles are of secondary origin. In our study it is important to stress the difference between the term “clay” as a size fraction and as a set of clay minerals. Clay minerals are mainly phyllosilicates represented by kaolinite, chlorite, vermiculite, smectite and iron compounds such as goethite and hematite, while fine fractions may also include quartz and amorphous compounds.

Since the 1990-ies, a considerable number of publications have focused upon radionuclide contamination in the Yenisey River due to the activities of the Krasnoyarsk Chemical and Mining Combine (KMCC). The main goals of the studies were related to the estimation of the composition and level of contamination, zones of radionuclide accumulation and their transfer to water and terrestrial food chains. Studies were also conducted to establish the extent of contamination in terms of the distance of radionuclide migration downstream from the source. Many studies were devoted to measurements and experimental

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evaluations of radionuclides in soils and sediments at different locations on the Yenisey floodplain (Bolsunovsky et al., 2002; Kuznetsov et al., 1994; Nosov and Martynova, 1996; Nosov et al., 1993; Standring et al., 2009; Sukhorukov et al., 2004; Vakulovsky et al., 1995). It was shown that radionuclides from Krasnoyarsk could migrate as far as the Yenisey delta and estuary but their distribution in floodplain areas was significantly heterogenous due to lithology, geomorphology, vegetation of local landscapes (Linnik et al., 2000) and the hydrological regime in the periods of radionuclide discharges (Linnik et al., 2004a, 2004b, 2005, 2006; Nosov et al., 1993). Particular attention was paid to the fact that up to 50% of ^{137}Cs and more than 60% of ^{60}Co and ^{152,154}Eu were transported in suspended material (Kuznetsov et al., 1994; Vakulovsky et al., 1995).

However, the particle size and composition of the suspended matter that control radionuclide sorption are known to exhibit regional specificity. This phenomenon has been studied to a limited extent in the Yenisey River compared to the more extensive studies conducted on radionuclide migration in river systems elsewhere as exemplified by research on Chernobyl deposition (Comans et al., 1998; Konoplev et al., 1996).

The main goal of our study was to explain the observed radionuclide accumulation in different size fractions (mainly ^{137}Cs since the short-lived radioisotopes of ^{155}Eu and ^{154}Eu were hardly detectable due to decay) by their detailed analysis accounting for the aggregation of particles in soils in natural conditions and the mineralogy of those fractions.

2. Study area and a brief description of the studied soils

The study area is situated in the widened reaches of the Yenisey River floodplain. In the region of set Bol'shoi Balchug the floodplain is formed on the Middle Jurassic parent rocks of the Nazarov suite (J_2nz_{1-2}) (Geologic map of the USSR, 1978). The bottom of the parent rocks consists of pebbles with beds of laminated sandstone covered by coarse-grained sandstone subsequently replaced by fine-grained deposits. In the top layers argillite layers are inter-bedded with aleurolite and medium- small- and fine-grained sandstone. Floodplain in the region of the Mikhin Island is formed in the Early Carboniferous volcanogene-sedimentary rocks. The island and adjacent area lie on the remnants of Paleogene quartz and quartz–feldspar sands with interbeds of aleurolite and clay.

Soil samples were collected from four soil profiles located on the Balchug floodplain 20 km downstream the KMCC and on the Island of Mikhin 180 km away from the discharge point. The position of the sites and description of local landscapes are described elsewhere (Linnik et al., in press, see this issue). Aggregation, granulometry and mineralogy have been studied in selected samples from the key soil profiles MBP-2 and MBP-1 (Balchug floodplain) and KP-11 and KP-28 (the Island of Mikhin) which differed in elevation and radionuclide contamination levels.

Profile MBP-1 characterizes Gleyic Fluvisol (Arenic) (according to soil classification proposed by IUSS working group, 2007) formed under forb-foxtail-fescue meadow with quack-grass and birch and willow sprouts located in the undulated floodplain close to the Balchug channel. It has a rather coarse laminated structure reflecting interbedding of moist layers of medium-grain sand and bluish-gray gleyish silty sand and silt. Red-brown hue and spots mark the location of oxidation conditions. At a depth of 46–53 cm, gley porous loam layer is observed. This is underlain by 3-cm thick medium-size sand and pebbles. A soddy layer abundant in roots and plant debris is 8 cm thick.

Profile morphology

0–8 OA. Dark-gray soddy-humus horizon, loamy sand, crumby, friable, slightly moist, interlaced with roots, with inclusions of organic matter up to 20% and plant debris.
8–22 ACg. Pale-dark-gray horizon, medium-grain sand, with greenish-gray hue, medium dense, with beds of bluish-dark-gray loam that are fragmentary.
22–32 G. Sandy loam, sandy, dense, bluish-dark-gray, abundant in red-brown spots, dense, moist.
32–44 Ia1g. Medium-grain sand, bluish-gray with big red-brown spots, gley, dense, slightly moist.
44–53 IIalg. Loam, bluish-dark-gray with dark brown spots, gley, moist, with few roots, porous, laminated.
53–56 IIIal. Medium-grain sand, red-brownish-dark-pale.
56–58 IVal. Pebbles.

Profile MBP-2 represents Gleyic Fluvisol (Arenic) formed on a ridge top covered by high grass willow and birch stand with currant shrubs. Friable fresh organic layer is 6.5 cm thick. The profile has a finer texture (fine sand, silty) and is abundant in signs of oxidation (red-brown rusty spots). The layers differ in color, density and slight texture variations.

Profile morphology

0–0.5 O. Friable weakly decomposed litter and sod.
0.5–6.5(8) A. Dark gray, loose, soddy, silt to sandy loam, friable, interlaced with roots, fresh.
6.5(8)–13 ACg. Pale-gray with greenish-red spots, crumby, silty fine sand, medium-dense.
13–21 Cg (Ial). Silty fine sand, pale-light-gray, plated, dense, abundant in rusty-red-brown spots. At the depth from 16.5 cm to 17.0 cm and 19.5–21 cm there are two loamy layers with a darker hue.
21–28 IIal. Fine sand with silt, visible pores along the roots, pale-dark-gray with red-brown-rusty spots, thick plated, less dense, gley.
28–31 G. Loamy to clay gley bed.
31–51 IIal. Fine sand, silty, pale-light gray, with rusty spots, fine-laminated.

Profile KP-11 was located on the high floodplain of the Mikhin Island and characterized by shallow Haplic Fluvisol (Oxyaquaic, Dystric, Arenic) with buried humic layers formed under sparse poplar stand with herbaceous-horsetail-reedgrass overground vegetation. The surface was abundant in tree trunks and plant debris. The profile is almost completely sandy with the buried almost black organic (humic) beds 3 mm to >10 mm thick.

Profile morphology

0–3 A. Humic layer, brownish-black, friable, well decomposed plant debris
3–18 AC. Medium-size mottled sand grayish-brownish-pale with brownish-gray and pale particles, friable
18–24 Ab. Buried humus layers: interbedding of humic black and thicker organic layers separated by thin sandy beds.
24–49 C (Ial). Medium-size mottled sand grayish-brownish-pale with brownish-gray and pale particles, friable
49–54 Ial. Less pronounced new series of interbedding sandy layers crossed by brown humic leakage along the former roots.
54–66 IIIal. Brownish-gray moist medium to small-grain sand, mottled.
66–75 IVal. Pale-gray fine dense sand.

Soil profile KP-28 is located in the central part of the slope covered by thin herbaceous-grass association and presents a soil transitional from Gleyic Fluvisol (Arenic). The top horizons having a small-sized friable sandy texture include humus beds indicating burial processes during flooding. Lower layers have also laminated nature despite a rather coarse (sandy, sandy loam) texture.

Profile morphology

0–3 Oi. Soddy layer, grayish-black.
3–8 A. Whitish-gray friable small-grain sandy layer with a black humus bed at the depth of 5–6.5 cm
8–18 ACg. Sandy loam with sand, grayish-dark brown, weakly gley, medium dense, with organic inclusions up to 20%, lower layers are grayish-brown, blackish-brown.