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Contrasting mobilization of elements in contact with sediment from Lake Roosevelt and the Upper Columbia River, Washington, USA

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ABSTRACT

Trace element contamination is known to be widely present in sediment of Lake Roosevelt and the riverine reach of the Columbia River in Washington State, USA due to discharges from several smelters and numerous mines dating back to the mid-1800's. In this study, the concentrations of aqueous elements in contact with bed sediment from the lake and river were examined under varying degrees of physical mixing and time scales. Contrasting geochemical processes affecting aqueous concentrations were inferred from the release of major ions (Ca and Si), elements enriched in metallurgical smelter slag (Cu and Sb), and redox-sensitive species (Fe, Mn, Mo and U). Releases of major ions reflect the contrasting sediment substrates along the length of the river and large reservoir. Calcium released from carbonate minerals and slag particles was most pronounced in regions of carbonate bedrock and near sediment deposits with a large component of slag material, while Si released from unconsolidated glacial/fluvial sediment increased with increasing distance downstream. Sb release was a consistent indicator of slag presence and weathering, possibly because its anionic nature inhibits readsorption onto metal oxides. In contrast, Cu release was quite variable, likely due to varying degrees of copper readsorption or co-precipitation onto metal oxides. The release of Mo and U appeared to be affected by redox conditions, which were assessed using aqueous Fe and Mn concentrations.

1. Introduction

Widespread trace-element contamination in bed sediment of the 240-km long reach of Franklin D. Roosevelt Lake and the Columbia River upstream of Grand Coulee Dam in Washington State, USA (Fig. 1) has been previously described (Johnson et al., 1990; Bortleson et al., 2001; Majewski et al., 2003; Cox et al., 2005; US EPA, 2006). Trace elements of concern include arsenic (As), cadmium (Cd), copper (Cu), lead (Pb), and zinc (Zn). The historic discharge of water-granulated fumed slag, liquid effluent, and spills from the smelter complex in Trail, British Columbia, Canada is the single largest known and documented source of metals enrichment in sediment of Franklin D. Roosevelt Lake and the upstream reach of the Columbia River in Washington State (US EPA, 2006), which together are referred to herein as Lake Roosevelt.

The release of elements from the accumulated sediment into interstitial (pore) waters of sediment or into the overlying water column provides one important pathway for elements to enter the food web or to affect the survival or growth of aquatic organisms (Luoma and Rainbox, 2005). In a companion paper using aliquots of the composite samples collected for this study, Besser et al. (2008) measured survival and growth of amphipods and midges, and bioaccumulation of trace elements oligochaetes in Lake Roosevelt sediment. The sediment from the riverine reach nearest the Canadian border exhibited the lowest amphipod survival, while midge growth in sediment from four of seven sites throughout the lake was less than growth in sediment from a nearby reference site. Bioaccumulation of Cu in oligochaetes inhabiting sediment from five of seven sites was significantly higher than bioaccumulation from the reference site having lower element concentrations. In a follow-up study, Fairchild et al. (2012) examined toxicity and invertebrate colonization in five sediment samples from three locations in Lake Roosevelt. One sediment sample collected from the riverine reach near Canadian border exhibited toxicity in three of the four tests. Recolonization in one sediment sample at the southern-most site within the lake was significantly higher than the other four sites. Little et al. (2014) focused on the toxicity to white sturgeon (*Acipenser transmontanus*) by Cu in leachates (0.19 µM maximum Cu concentration) from five sediment samples collected from Lake Roosevelt at varying distances from the Canadian border. Leachates from three of the five samples were toxic to white sturgeon at 30 day post-hatch, but leachates from all five samples were nonlethal at 8 days post-hatch. Vardy et al. (2014) measured acute toxicity in white sturgeon in laboratory water and Columbia River water at 8 and 40 days post-hatch. At 8 and

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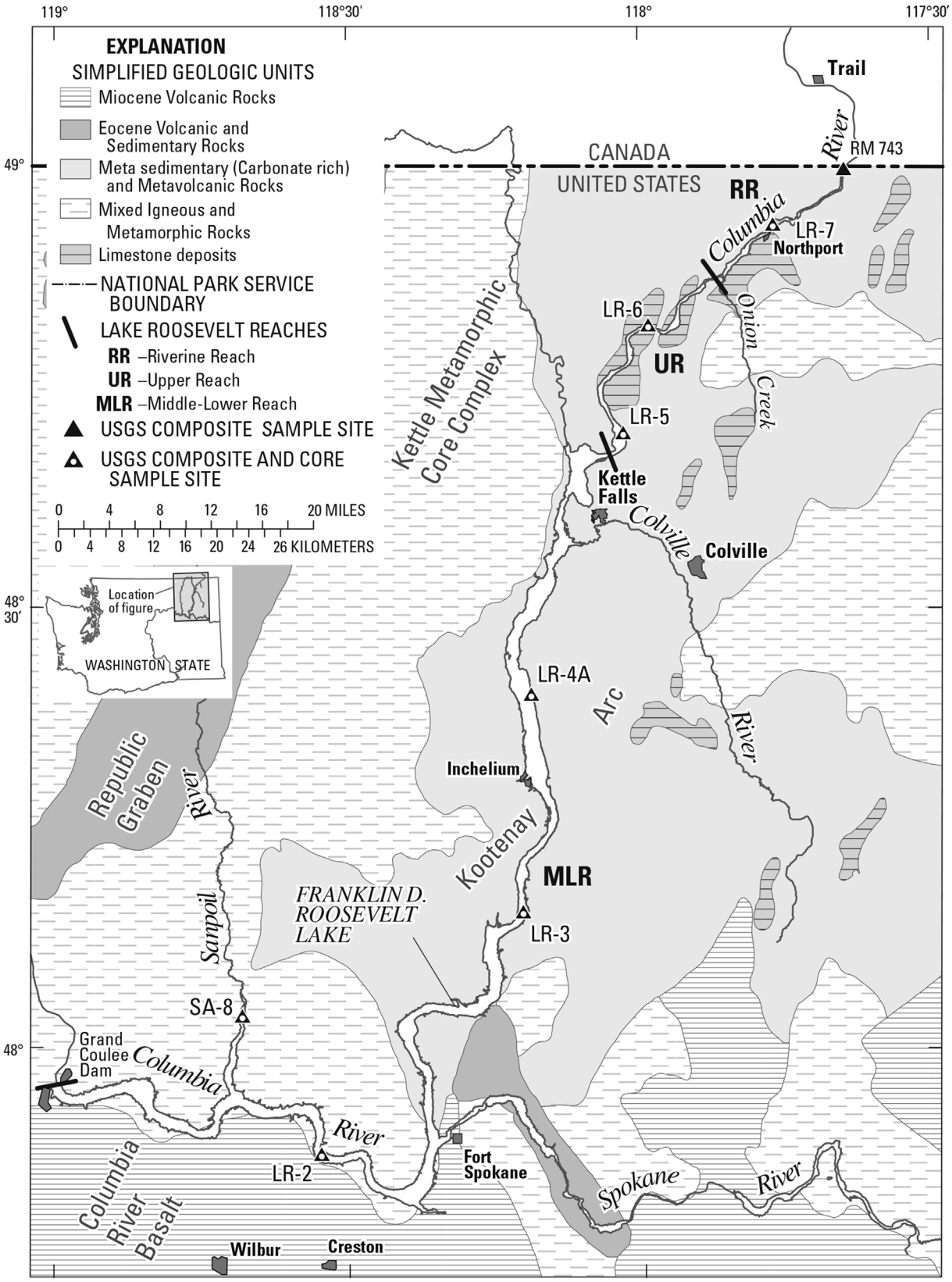

Fig. 1. Lake Roosevelt study area and sampling site locations. Study reaches: the riverine reach (RR) of the Columbia River; and the upper reach (UR), the middle and lower reaches (MLR), and Sanpoil River arm (REF) of Lake Roosevelt with simplified geology of the watershed (Stoffel et al., 1991) and carbonate deposits (Jenkins, 1992). Alternative site LR-5A was within the triangles of the primary site LR-5. Replicate core and composite samples were collected at LR-7.