OCCURRENCE OF TRACE ELEMENTS AND METALLURGICAL SLAG IN SEDIMENT CORES FROM LAKE ROOSEVELT, WASHINGTON STATE

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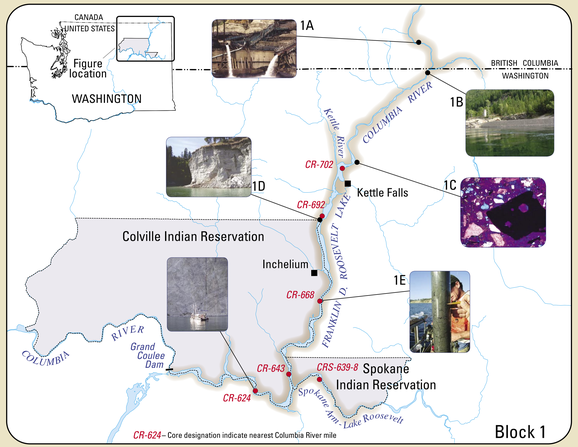
Study conducted in cooperation with the Confederated Tribes of the Colville Indian Reservation



Occurrence of Trace Elements in Sediment Core

The profile of trace-element concentrations in bed sediments of Lake Roosevelt were determined from gravity cores collected from locations in Lake Roosevelt in September 2002 (block 1). Lake Roosevelt is the 217-km-long impoundment of the Columbia River upstream of Grand Coulee Dam. Elevated concentrations of trace elements have been widely observed in the surficial sediments that have been accumulating in the reservoir since its completion in 1941. Slag and other wastes from a lead-zinc smelter have been discharged into the Columbia River (block 1A) upstream of the reservoir. While these discharges have occurred for nearly a century they have been substantially reduced since the mid-1990s.

Cores, ranging in length from 45 to 164 cm (block 1E) were obtained from locations near the pre-reservoir river channel. The cores were sectioned into 2 to 5 cm intervals that were analyzed to determine the concentration of 39 trace elements and cesium-137. The analysis of trace elements included arsenic, cadmium, copper, lead, mercury, and zinc, which had previously been found in surficial bed sediments at concentrations ranging from 4 to 220 times larger than corresponding concentrations determined for reference sediments (block 2). The reference sediments were collected upstream of the smelter and from adjacent bank material. Selected samples of core sediments that contained relatively larger concentrations of zinc, silver, and antimony were analyzed for the presence of slag, a glassy trace-element-rich byproduct of metal smelting processes.

Analysis of cesium-137 data indicates that the sedimentary record in all cores extended as far back as the early 1960s and in two cores the sedimentary record extended to the initial reservoir filling in 1941. Overall, the range of trace-element concentrations observed in core profiles and the distribution of trace elements within the reservoir sediments were similar in range to that observed in surficial sediments by previous studies. Median concentrations of zinc, lead, and copper in the sediment cores were 930, 230 and 52 mg/kg, respectively. Concentrations of arsenic, cadmium, and mercury were smaller with median concentrations of 13, 7.5, and 0.44 mg/kg, respectively. The concentration of trace elements within the core sediments typically showed a spatial trend of decreasing concentrations in the down reservoir direction. However, the concentration of arsenic generally was higher in core CR-643 (upstream of the Spokane Arm of the reservoir).

The concentration profiles for each core provide a historical record of the changing depositional concentrations at locations within the reservoir. Within sediment profiles, the concentrations of trace elements were highly variable and for many of the trace elements of concern, the concentrations at depth were often 2 to 5 times larger than those observed near the upper surface of the core (block 2). In some profiles, short-term decreases in the concentration of trace elements and cesium-137 were observed suggesting the episodic influx of sediments from landslides or bank erosion occurring along the lake margin (block 1D). For many trace elements, decreasing concentrations in recent sediments of the upper 20 to 30 percent of the sediment core profiles, likely indicate a reduction in the input of trace elements to the reservoir. However, an increasing trend in arsenic concentration was apparent in the upper 40 cm of core CR-639-8 and slight increases in the concentration of copper were observed in cores CR-643, CR-688, and CR-702. The concentration profiles of lead and zinc in the cores collected along the Columbia River were similar to one-another, in sections almost parallel, as were the concentration profiles of arsenic and cadmium (block 2). The ratios of lead to zinc and arsenic to cadmium also generally were consistent among cores collected along the Columbia River Channel. These patterns were not observed in the core taken from the Spokane Arm of the reservoir, which likely reflects differences in the primary source of trace elements within those sediments.

Trace-element profiles in cores

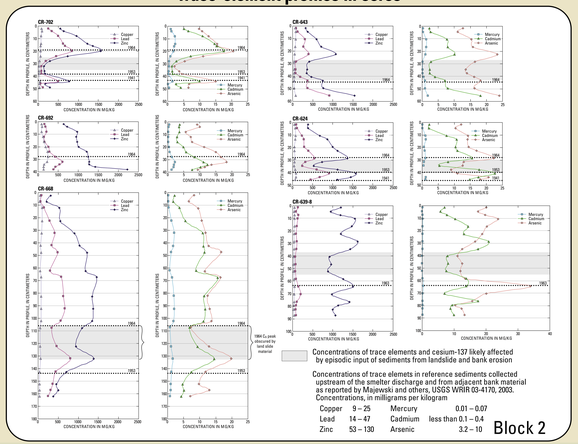
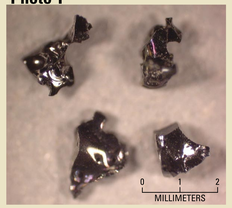


Photo 1

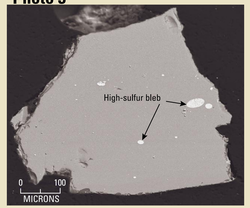


Reflected light micrograph of slag from Columbia River gage

Photo 2

SEM micrograph of slag from Columbia River gage

Photo 3



SEM micrographs of polished cross sections of slag from Columbia River gage*

Concentration of elements in slag

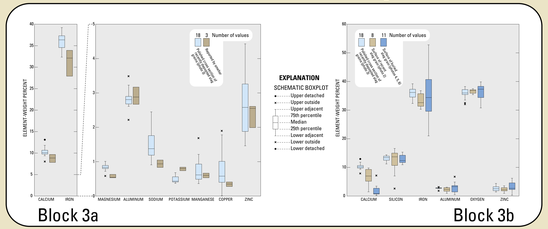


Photo 4

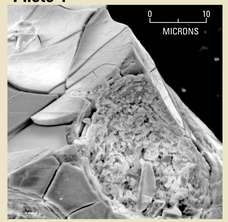
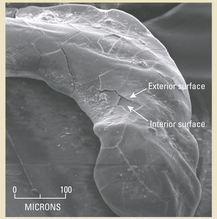


Photo 5

Scanning electron micrographs of slag grains from CR-668

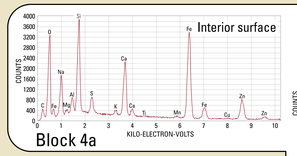
Photo 6

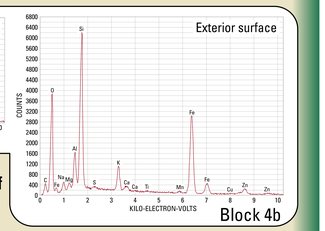


X-ray spectrum of the matrix of a slag grain from Core CR-668

Slag in Sediments of Lake Roosevelt

Prior to 1995, 100,000 tons or more of granulated slag and other metallurgical wastes were discharged annually to the Columbia River from the smelter at Trail, British Columbia (block 1A). Slag particles, typically sand-sized or smaller, were transported by the Columbia River and deposited along its banks and in the quiescent waters of Lake Roosevelt. Slag grains collected from a sand bar at the auxiliary Columbia River gaging station at the International Boundary (block 1B) have a distinctive smooth, glassy, lustrous appearance, often with an iridescent sheen and were angular to rounded in shape often with conchoidal fractures (photo 1). In petrographic thin section, slag grains were opaque and often contained voids (block 1C). The density of slag grains varied but generally exceeded 2.9 gm/cm3. When examined using a scanning electron microscope equipped with an energy-dispersive X-ray spectrometer (SEM/EDS), the chemical composition of the glassy matrix interior of polished cross-sections of slag grains closely approximated the elemental concentrations of fresh slag as reported by the smelter at Trail (block 3A). High-sulfur blebs and other internal features (photo 3) were not included in measurement of the chemical composition of slag matrix. The median element-weight percentage of iron, calcium, aluminum, zinc, sodium, magnesium, manganese, and copper in the interior matrix of slag grains (photo 3) was 37, 10, 2.8, 2.6, 1.3, 0.8, 0.6, and 0.5 respectively.





Sediment grains isolated from selected sample intervals from the three upstream cores were classified as slag based on density, physical characteristics including opacity to plane-polarized light, and chemical composition relative to that of recently deposited slag grains at the Columbia River gage. Slag grains were identified in cores CR-668, CR-692, and CR-702. The largest grains most similar to those from the Columbia River sand bar were from the interval 85 to 90 cm below the top of CR-668. Although these grains had similar color, shape, and optical properties to slag material from the gage location, the surface appearance was typically more weathered, without a glassy-lustrous appearance or iridescent sheen. The chemical composition of slag grains from core CR-668 closely matched that observed in slag grains from the recent beach deposit except that the concentration of calcium typically was much lower in slag grains found in core CR-668 (block 3B). In the weathering of basaltic-volcanic glass, calcium is often the most readily leached major element (Eggleton and others, 1987, Clay and Clay Minerals 35:161-169). The surface of slag grains from the core sample also appeared cracked and flaky (photos 4, 5, and 6). In places where a flake had been removed to expose an inner surface (photo 6), the concentrations of calcium, and to a lesser degree zinc, were larger on the inner surface compared to the outer surface (blocks 4a and b). These observations suggest that glassy slag deposited within the sediments of Lake Roosevelt is undergoing hydration and chemical weathering.

*These images are recorded using a backscattered electron detector on a scanning electron microscope. The grayscale represents atomic number differences.