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Geochemical patterns of trace metal and rare earth element distribution in the subarctic Estuary and Gulf of St. Lawrence

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The Estuary and Gulf of St. Lawrence (EGSL), the world's largest estuary, encompasses a marine system shaped by strong environmental gradients, complex circulation patterns, and sustained human activities. Despite extensive research in the region, the geochemical behavior of fine-grained surface sediments, carriers of trace metals, remains partially understood. Improving knowledge of trace metal concentrations is essential to distinguishing natural from anthropogenic inputs and assessing ecological risks. This study investigates the spatial distribution of major, minor and trace elements: metals, metalloids, and rare earth elements (REEs) in 161 fine-grained (fraction <63 µm) surface sediments from the EGSL collected between 2018 and 2022. We also analyze the <5 µm, 2-10 µm, and 10-63 µm fractions from five representative samples across the upper estuary, lower estuary, and gulf to characterize any potential grain-size dependent variations in elemental concentrations. The main objectives of this study are to establish regional patterns of concentrations, identify environmental and/or anthropogenic controls on metal distributions, and assess potential contamination and associated ecological risks through index calculations. Grain-size separations were performed by wet sieving at 5, 10, and 63 µm using Linker mesh, combined with settling following Stokes' law. Sediment samples were digested using microwave-assisted aqua regia, and elements quantified by ICP-MS. Enrichment factors (EF) and geoaccumulation indices (Igeo) were calculated, and concentrations were compared with pre-industrial basal core sediments from the EGSL, the Post-Archean Australian Shale values (PAAS), as well as with values from Québec sediment-quality criteria. Most metal and metalloid trace elements (including Cr, Cu, Zn, and As) show no enrichment based on EF and Igeo values and fall within threshold and occasional ecological effect level (TEL-OEL) ranges, indicating a predominantly natural origin. Cr reaches probable effect values (PEL), suggesting an ecological risk linked to lithological, estuarine, and redox processes rather than recent anthropogenic inputs. Increasing hypoxia and spatial variability in total organic carbon (TOC) and bioturbation may further mobilize and recycle trace metals, producing naturally derived concentrations that may be ecologically sensitive under present oceanographic conditions.

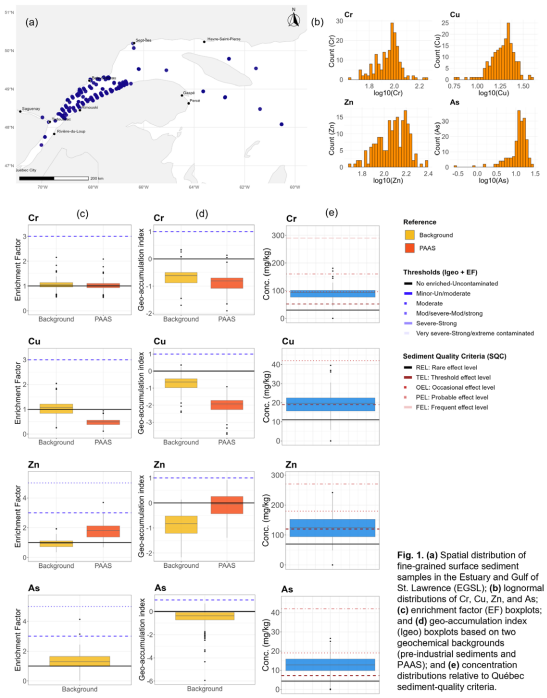


Fig. 1. (a) Spatial distribution of fine-grained surface sediment samples in the Estuary and Gulf of St. Lawrence (EGSL); **(b)** lognormal distributions of Cr, Cu, Zn, and As; **(c)** enrichment factor (EF) boxplots; and **(d)** geo-accumulation index (Igeo) boxplots based on two geochemical backgrounds (pre-industrial sediments and PAAS); and **(e)** concentration distributions relative to Québec sediment-quality criteria.