The Paleoproterozoic Ni-Zn-Cu-Co-(Mo-V-U) –Enriched Talvivaara Formation, Finland: GOE-Related Coastal Acid Sulfate Soil Drainage and Tidal Resedimentation of Estuarine Metalliferous Monosulfidic Black Muds—A New Ore Forming Process?

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The Paleoproterozoic Talvivaara formation (ca. 2.1–1.95 Ga), Finland, contains a world-class Ni-Zn-Cu-Co deposit (2053 Mt ore; Ni 4.5 Mt, Zn 10.3 Mt), consisting of two 2-km-long metamorphically upgraded orebodies. The 12-km-long metal-enriched Talvivaara fm represents one of the earliest known sediment-hosted base metal accumulations following the Great Oxygenation Event (GOE). The highly C-S-Fe–rich mudstones were deposited in a narrow craton-margin seaway during the Shunga Event. Recent evidence implies rapid sedimentation in a chemically and redox-stratified near-estuarine paleo-environment, and a tidally dominated, fluvially influenced deeper-water proximal offshore setting is suggested. Well preserved samples display element ratios and iron sulfide in situ isotope data indicating hydrogenous clay-organic associated metal enrichment and metal retention in (metamorphically recrystallized) bacterially fractionated syngenetic marine sulfides. No support for the previously promoted SEDEX-model can be found.

We present here our new conceptual genetic model, and we propose that the Talvivaara fm records downstream effects from the Earth's oldest known acid sulfate soil drainage. In the catchment area, continental 2.1 Ga plateau basalts formed a major component of subaerially weathered lithologies. Warm seasonal climate with rainfall events controlled the hydrology and sediment transport of the river system. We hypothesize that both continental and marine sulfate was stored in the estuarine–coastal lowlands muddy floodplains, forming extensive sulfidic soils (potentially acid sulfate soils). Lowering of groundwater tables during drought periods resulted in oxidation of the sulfidic soils producing acidic drainage and heavy metal discharge, ultimately reaching the fluvial–marine mixing zone. Also rainfall flushing likely mobilized metals from these areas. Based on sedimentological observations, we infer that abundant microbial biomass and Fe-oxyhydroxides promoted forming of black monosulfidic muds in the riverine-estuarine system, and material from the estuarine mudflat was tidally resedimented into deeper environment.

Stratigraphically, the Talvivaara fm grades from pyrrhotitic mudstones-siltstones to pyrite-rich lithologies upsection, transitioning from shallower ferruginous–manganiferous conditions to mildly euxinic and finally to strongly euxinic conditions. Precambrian nearshore environments affected by estuarine-coastal lowlands acid sulfate soil (ECLASS) drainage are previously unrecognized, but our emerging "naturally metal-contaminated paleoestuarine" model may find close analogies from recent Australian acid sulfate soil and monosulfidic black-ooze environments. We propose that drainage from ECLASS –areas concentrated sulfate and metals in euxinic near-estuarine environment to ore levels, and this model likely has wider significance for Paleoproterozoic coastal marine settings.