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# Finnish Metalliferous Black Shales Coeval with Shunga and Pechenga-Onega LIP Events

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The Talvivaara Formation (eastern Finland) is a ~2.0-1.9 Ga metalliferous black shale with resources totaling an estimated 1550 Mt of ore [1]. Anomalously high organic-carbon ($TOC_{avg}$ = 7 wt.%) and metal concentrations (Ni = 0.22%, Zn = 0.49%, Cu = 0.13%, Co = 0.02%) are, in part, the consequence of high rates of organic carbon burial and metal accumulation under anoxic, and likely ferruginous and euxinic, environmental conditions on a post-GOE Earth [1,2].

Imprecise depositional age constraints for the Talvivaara Formation have hampered efforts to identify the geologic triggers responsible for its metal enrichment. It remains unclear whether the Formation's depositional environment reflects merely local conditions or points to more widespread, Phanerozoic-style oceanic anoxic events. It is also uncertain whether Talvivaara mudstones share a genetic link with the ca. 1.98 Ga Shunga Event [3] —a major organic carbon burial episode—and if the Formation's metal endowment stems, in part, from a contemporaneous mantle plume event (the Pechenga-Onega LIP [4]).

Linking the deposition of the Talvivaara Formation to these geologic events is further complicated by post-depositional thermotectonic processes, particularly amphibolite facies metamorphism (ca. 1.89 Ga), which converted sedimentary organic carbon to graphite and locally sheared and desulfurized syn-depositional pyrite. As a result, it has remained uncertain whether syn-depositional age information can be recovered from the Talvivaara Formation or if its age will remain imprecisely constrained within a 100 Myr window between ca. 2.0 and 1.9 Ga.

Here, we report Re-Os dating results alongside major/trace element geochemistry for metalliferous black shale packages from the Talvivaara Formation. Our results provide the first high precision age constrains on the Talvivaara Formation and reveal the temporal pacing of metal-rich shale deposition and the Shunga and Pechenga-Onega LIP Events. These results provide unique insights into the geologic levers controlling critical mineral enrichment at a pivotal time in Earth history.

[1] Loukola-Ruskeeniemi & Lahtinen (2013) Ore Geology Reviews 52, 85-99.

[2] Virtasalo, Laitala, Lahtinen, & Whitehouse (2015) EPSL 432, 449-460.

[3] Martin, Prave, Condon, Lepland, Fallick, Romashkin, Medvedex, & Rychanchik. (2015) EPSL 424, 226-236.

[4] Lubnina, Stepanonva, Ernst, Nilsson, & Soderlund. (2016) GFF 00, 1-25.