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Geochemistry and paleosedimentology of iron sulfide-rich carbonaceous mudstones in drill core DDKS-010: a tidally resedimented estuarine mudflat origin for surficially Ni-Zn-Cu-Co –enriched Paleoproterozoic Talvivaara formation (2.1–2.0 Ga), Finland

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Abstract

Abstract. The Paleoproterozoic metasedimentary Talvivaara fm (2.1–2.0 Ga) in Sotkamo, Finland, hosts one of the largest sulfidic nickel resources in Europe (2053 Mt ore; Ni 4.5 Mt, Zn 10.3 Mt). Globally, the Talvivaara ore deposit is the largest shale-hosted Ni-(Cu–PGE) sulfide mineralization in production. We report here the preliminary results of our ongoing studies, which contradict the current genetic model relating the polymetallic Ni-Zn-Cu-Co –enrichment of the Talvivaara fm "black shales" to hydrothermal activity in a stratified rift basin. Sedimentology and geochemistry of drill core DDKS-010 (476.40 m) from the Kolmisoppi orebody was studied in detail, also additional trace element and high-resolution isotopic data was obtained. The intersection from 476.40 m to ca. 390 m forms stratigraphically nearly continuous well preserved succession, allowing an integrated study that has not been previously viable. Our results indicate a syn-sedimentary, paleomarine hydrogenous metal-enrichment for the C-S-Fe –rich Talvivaara fm mudstones–siltstones, and we interpret that the Tv fm sediments were mainly tidally resedimented into deeper water, proximal offshore environment from a nearby estuarine mudflat.

Talvivaara Ore Deposit – Europe's Largest Ni-Project

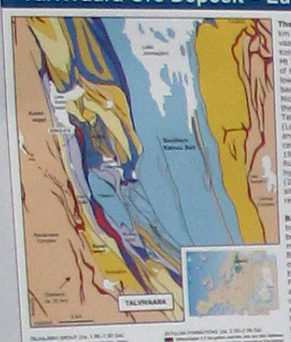

FIG. 1. Geology of the Talvivaara area (map modified from Kontinen 2012; Sedimentary lithologies should be prefixed with "meta-"). Inset map: www.Talvivaara.com

The deposit and mine. The Talvivaara ore deposit is located ca. 25 km from Sotkamo, eastern Finland (Fig. 1). The polymetallic Talvivaara ore deposit (Ni-Zn-Cu-Co-U) is comprised of Kuusilampi and Kolmisoppi orebodies, which together contain ca. 2053 Mt ore @ 4.5 Mt Ni and 10.3 Mt Zn (Talvivaara Plc. 2012, 2014), constituting one of the largest nickel resources in Europe (USGS 2013). The relatively low-grade but large tonnage sulfide ore is being utilized by using bacterially catalyzed bioheapleaching (Riekkola-Vanhanen 2013). Nickel deliveries started in 2009, and when in full-scale production, the mine is aiming at 50,000 t p.a. level (Talvivaara Plc. 2014). The Talvivaara ore deposit is currently genetically classified as SEDEX (Loukola-Ruskeeniemi and Heino 1996; Goodfellow and Lydon 2007), and as recently as 2014, Mudd and Jowitt (2014) included it in the category of hydrothermal Ni-deposits. Jowitt and Keays (2011, p. 194) review the hydrothermal genetic model proposed by Loukola-Ruskeeniemi and Heino (1996), but consider also the syngenetic, hydrogenous seawater scavenging model proposed by Kontinen et al. (2006). Globally, the metamorphically upgraded Talvivaara ore deposit is the largest shale-hosted Ni–(Cu–PGE) sulfide mineralization currently in production (Jowitt and Keays (2011).

Regional geology. The polymetallic Talvivaara ore deposit is hosted by the Paleoproterozoic C-S-Fe –rich Talvivaara formation, which belongs to the Sotkamo group (2.06–1.96 Ga) of primarily metasedimentary Kainuu Belt (Fig. 1). Overview on the geology of the Kainuu Belt is provided by Laajoki (2005). The ca. 200-km-long Kainuu Belt overlies a reactivated Neoarchean suture zone between Archean blocks (Kontinen et al. 2007; Lahtaa and Kautuvaara Complexes in Fig. 1.). Rifting of the Archean Karelian craton margin at 2.22–2.1 Ga and opening of Sveocarelian paleosea at 2.1 Ga on the western side of the Kautavaara Complex led to extensional deepening of the Kainuu basin (Lahtinen et al. 2008; Korja et al. 2006). The initial block faulting phase included chaotic sedimentation in the lower Sotkamo group (Gehör and Havola 1988), and 2.1 Ga mafic tuffite interbeds in clastic shallow-water carbonates at Metalampi, Paltamo (60 km NNW of Talvivaara), indicates local magmatism during the incipient rifting stage (Kärki 1988). Epiclastic, compositionally Fe-phosphate amplified tuffite horizons occur also in siliciclastic-facies iron formation units of Tuomivaara and Tervetti formations (ca. 30 km NNE of Talvivaara), which belong lithostratigraphically to the lower or middle part of the Sotkamo group (Gehör and Havola 1988).

The Paleoproterozoic evolution of supracrustal sequences in nearby Russian Karelia is recently synthesized by Melezhik et al. (2013), and Russian Karelia is adopted here. Lower age for the Sotkamo group is provided by the Fennoscandian Shield