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Exploration of Critical Mineral Resources in the North Estonian Basement, Eastern Fennoscandia: A Geochemical and Geophysical Investigation of a Region Akin to the Southern Svecofennian Finnish Terranes and the Swedish Bergslagen Province

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The Precambrian crystalline basement of Northern Estonia, part of the East European Craton, lies beneath 100–780 meters of sedimentary cover. This study integrates geochemical, petrological, and geophysical analyses—including drill-core data, Bouguer and magnetic potential interpretations—refining the region's tectonic and metallogenic framework, with implications for critical mineral exploration [1,2].

Structural-petrological analysis delineates six basement zones: Tallinn, Alutaguse, Jõhvi, West-Estonian, Tapa, and South-Estonian, each exhibiting distinct geochemical signatures and potential field anomalies. Major deformation zones, including the NW-trending Paldiski-Pskov Deformation Zone (PPDZ) and the E-W Middle-Estonian Fault Zone (MEFZ), significantly influence basement architecture, metamorphic evolution, and mineralization. Fault systems and deformation corridors provide important structural pathways for fluid migration, playing a crucial role in ore-forming processes.

A comparative analysis of Paleoproterozoic metasedimentary and metavolcanic units from Alutaguse with South Svecofennian (SS) terranes—including Ladoga, Saimaa, the Häme Belt, and the Uusimaa Belt—identifies structural and compositional links, enhancing understanding of the Svecofennian Orogeny [3]. The metasedimentary units, primarily micaceous gneisses (garnet, cordierite, sillimanite-bearing), display felsic and intermediate-mafic geochemical signatures akin to the Upper Continental Crust (UCC) and Post-Archean Australian Shale (PAAS). The metavolcanic rocks, consisting of amphibolites and pyroxenic gneisses, exhibit subalkaline affinities, suggesting an asthenospheric mantle origin for Alutaguse, while SS terranes show subducted-oceanic-crust signatures [2,3].

Alutaguse evolved as a back-arc to the Tallinn-Uusimaa Belt(s) ~1.90–1.89 Ga [4], followed by the accretion of the Uusimaa and Häme belts ~1.87 Ga, marking the Svecofennian Ocean's closure. Gravity and magnetic anomalies correlate with Zn-Pb-Fe mineralization, resembling Bergslagen's volcanogenic massive sulfide (VMS) deposits. Sulfide mineralization—including chalcopyrite, arsenopyrite, sphalerite, and galena—suggests a multiphase history with episodes of remobilization. The Jõhvi zone shows metallogenic affinities to Bergslagen and Finland's Orijärvi district. Siderophile- and graphite-bearing gneisses contain up to 5.6% Cu-Pb-Zn, emphasizing their economic potential.

This research, part of Horizon-EU: DEXPLORE [4], advances deep-seated mineral exploration through geophysical and geochemical integration, offering insights for sustainable resource development and economic geology.

[1] Solano-Acosta et al. (2023), *Tectonophysics* 846, 229656.
[2] Soesoo et al. (2020), *Proc. Karelian Res. Centre RAS* 18–33.
[3] Solano-Acosta et al. (2025), *Estonian J. Earth Sci.* 74, 61–82.
[4] Graul et al. (2024), *Lithosphere 2024*, Espoo, Finland.