3D multi-method Geophysical Data Integration Using Self-Organizing Maps: A Case Study in DroneSOM Project with Data from the SeemsDeep Project

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Abstract

Within the DroneSOM project, co-funded by EIT RawMaterials, we developed and applied an advanced workflow for multi-method 3D geophysical data integration using Self-Organizing Maps (SOM). For this purpose, we utilized a comprehensive suite of geophysical datasets provided through the EU-funded (ERA-MIN 3) SeemsDeep (Seismic and Electromagnetic Methods for Deep mineral exploration) project, covering the Koillismaa Layered Igneous Complex in northeastern Finland—an area of high interest for deep mineral exploration.

The dataset includes 3D MT and CSEM resistivity models, 3D ERT/IP resistivity and phase models, a 3D seismic velocity model, and a refined geological model. These are complemented by GTK-provided 3D inversion results for gravimetric density and magnetic susceptibility, as well as lithological logs from the GTK deep borehole, which provide high-value ground truth for validating the SOM results. To enable joint analysis, all datasets were homogenized within DroneSOM to consistent spatial extents and voxel resolutions (100 m and 50 m), resampled onto a unified grid, and normalized.

Using SOM followed by k-means clustering, we extracted coherent and geologically meaningful subsurface domains from the joint multi-parameter voxel space. High-density and high-susceptibility clusters delineate banded iron formations, while dense but weakly magnetic clusters correspond to mafic–ultramafic intrusive bodies. Additional clusters identify resistive intrusive units, conductive alteration zones, and low-velocity, low-density overburden. The interpretation is supported by independent borehole lithologies, which map consistently into specific clusters, validating the SOM-derived structures.

SOM quality metrics, including the U-Matrix and hit-count maps, quantify data variability, cluster separability, and model stability, demonstrating that the integrated SOM space reliably captures geologically meaningful transitions despite the heterogeneity of the input datasets. These findings underscore that SOM-based multi-physics integration significantly enhances subsurface characterization in complex intrusive systems. By fusing diverse geophysical inputs from the SeemsDeep project within the DroneSOM methodological framework, the approach improves geological discrimination and provides a scalable, data-driven foundation for deep mineral exploration.

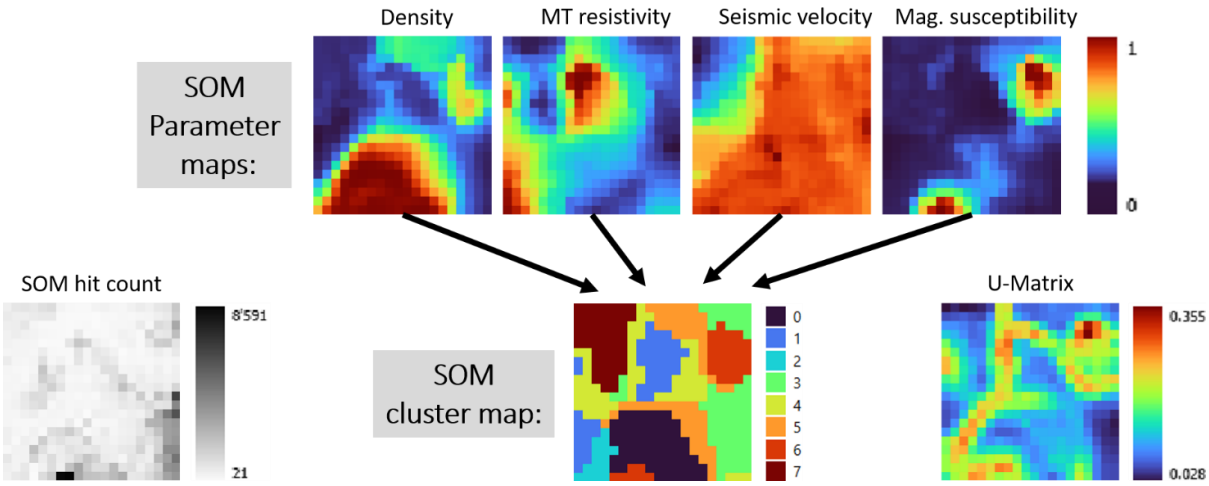

Figure 1: SOM parameter maps and k-means cluster map, as well as quality measures such as the Hit-Count Map and U-Matrix.

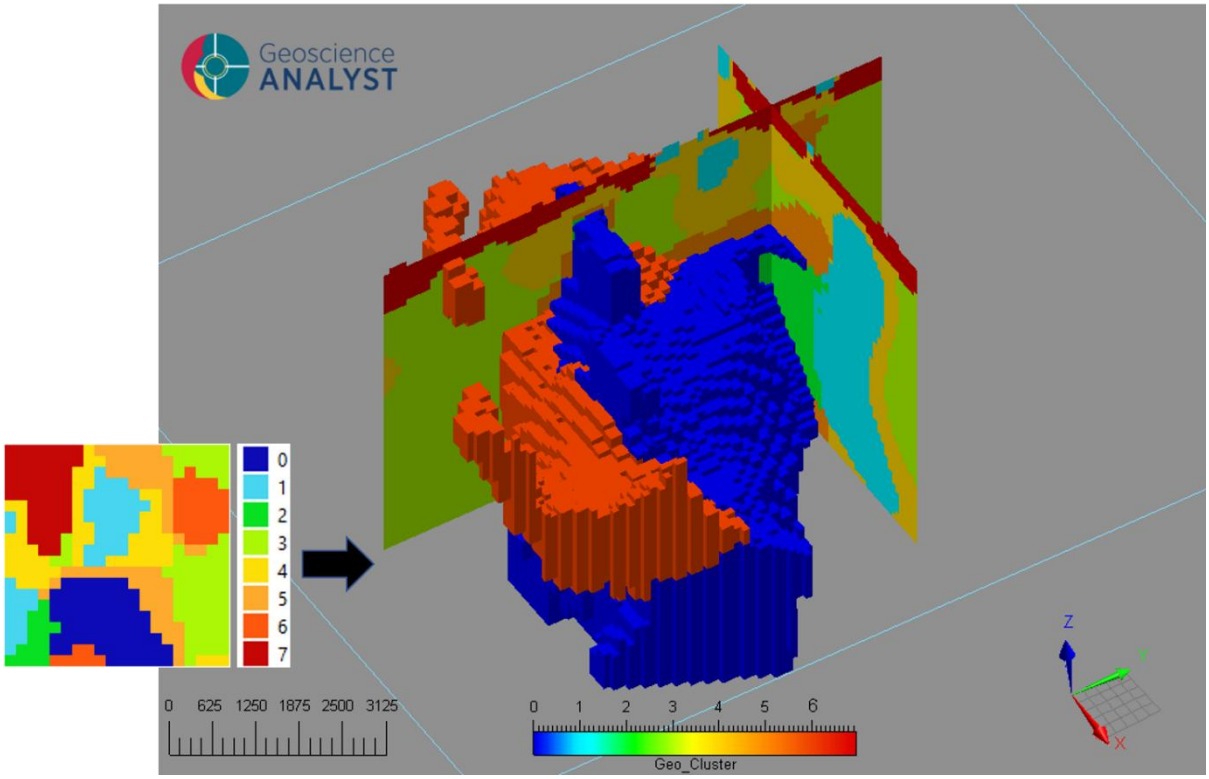

Figure 2: K-means cluster mapped back from SOM into 3D geo-space, illustrated along x–z and y–z slices. In addition, cluster no. 0 (high density and low susceptibility) is shown with blue volumes and cluster no. 6 (high density and low susceptibility) is shown with orange volumes.