Continental-Scale Prospectivity Modelling of Volcanogenic Massive Sulphide Deposits in Europe Using a Mineral-System and Explainable ML Framework

Maria Dekavalla[1], Sergio Tenorio Matanzo[2], Martin López Del Río[2], Chrysoula Papathanasiou[1], Angelos Amditis[1]

[1]Institute of Communication and Computer Systems, Athens, Greece, [2]Tharsis Mining, Pueblo Nuevo SN, Minas de Tharsis, Huelva, Spain

Introduction

Why this matters

- Europe needs secure, local sources of **critical raw materials (Cu, Zn, Pb, Au, Ag)**.
- Current exploration projects are **fragmented** and **continental-scale prospectivity models are lacking**.

Objective: Develop a **continental-scale prospectivity model** for **Volcanogenic Massive Sulphide (VMS) deposits in Europe** that is **explainable and geologically informed**.

Workflow

Mineral systems analysis: Identify regional-scale VMS-forming processes and translate them into mappable geological features

Positive Unlabelled Training

50% of known deposits were selected as positive training samples via farthest-point sampling for diversity.

Equal number of unlabeled samples were selected using spatially stratified sampling per training loop.

Input Data: Geological & geophysical layers

ML Model Training (Decision Trees)

1000 training & sampling iterations

Built-in & permutation feature importance

Feature Importance & SHAPLEY Values

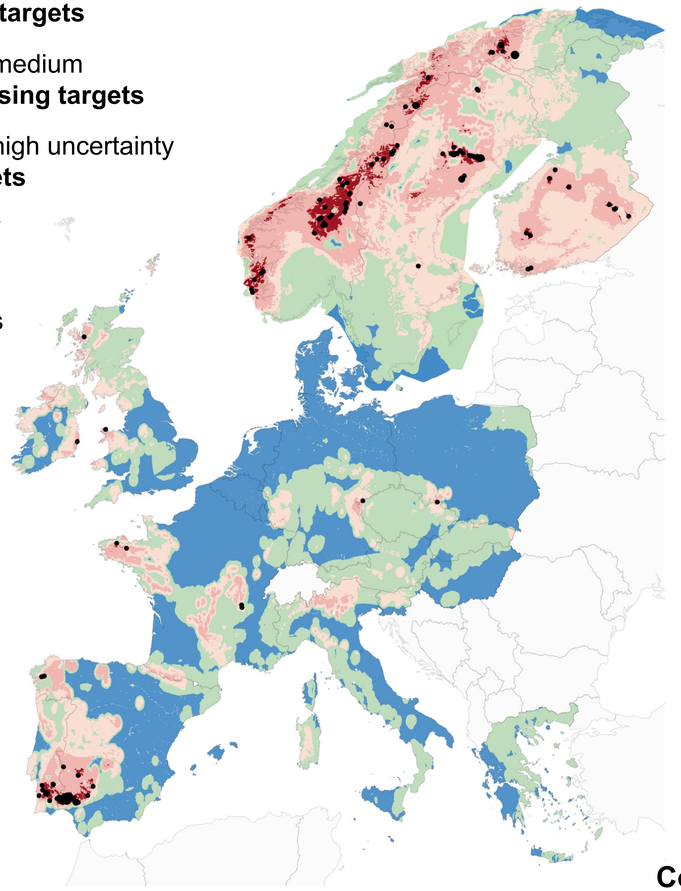
Prospectivity & Uncertainty Maps

VMS Prospectivity Map in Europe

Legend

- High prospectivity + low uncertainty → **High confidence targets**
- High prospectivity + medium uncertainty → **Promising targets**
- High prospectivity + high uncertainty → **Exploration targets**
- Medium prospectivity
- Low prospectivity
- Known VMS deposits and occurrences

High prospectivity areas align with major metallogenic belts across Europe



Interpretation

An explainable, mineral-system-informed ML model reveals new VMS exploration targets at a continental scale in Europe, while preserving geological interpretability.

Important Features	Geological Meaning
Proximity to igneous rocks	Volcanic activity
Proximity to siliciclastic sedimentary rocks	Sedimentation overlap
Tectonic plate margin proximity	Subduction zones
Depth to Mohorovicic discontinuity	Shallow depths indicate extensional settings
Depth to lithosphere-asthenosphere boundary	

Conclusions

- The identification of metallogenic zones with limited known deposits **highlights promising greenfield exploration targets at a continental scale**.
- The input features selected through the mineral systems approach help to **identify crustal-scale structures and tectonic domains** associated with **ancient submarine volcanic activity** - a **key requirement for VMS formation**.
- More broadly, the framework **can be applied to other deposit types** and **supports the use of explainable, geologically informed ML**.

Contact: Maria Dekavalla
Email: maria.dekavalla@iccs.gr
Website: https://terravision-project.eu

Co-funded by the European Union

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or HADEA. Neither the European Union nor the granting authority can be held responsible for them.