Geophysical Applications for Environmental & Tailings Issues in Mining

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Tailings Dam Stability and Integrity

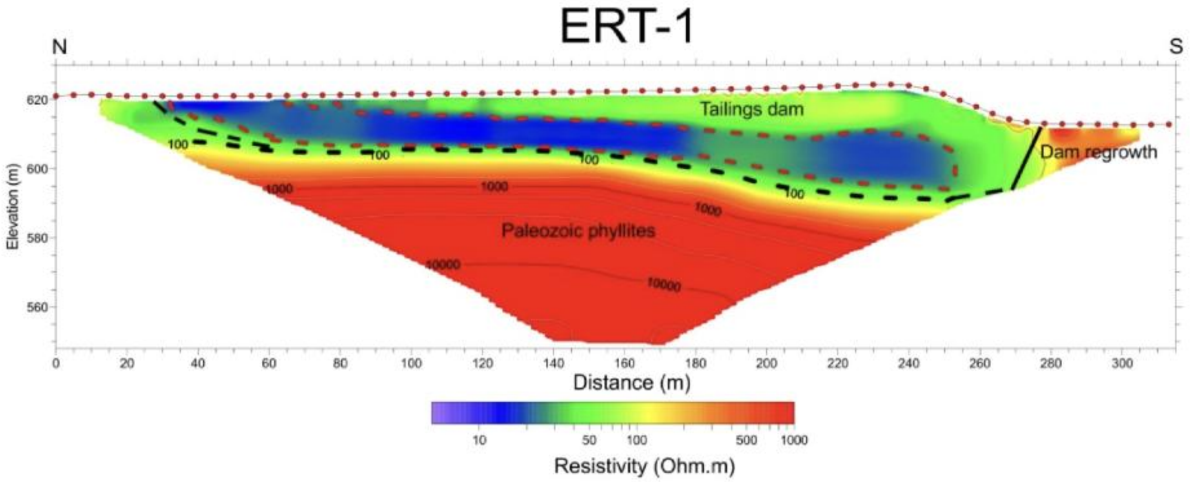
- Key environmental & safety concerns
  - Internal erosion (piping)
  - Seepage through embankments or foundations
  - Weak zones, fractures, or construction defects
  - Liquefaction potential
- Value of geophysics
  - Identifies anomalous seepage before surface expression
  - Images internal conditions between boreholes
  - Enables repeated monitoring over time

- Geophysical methods used
  - Electrical Resistivity Tomography (ERT)
    - Maps moisture distribution, seepage paths, and potential piping zones
  - Seismic methods (refraction, MASW)
    - Characterize stiffness, compaction, and shear-wave velocity of dam materials
  - Self-Potential (SP)
    - Detects electrokinetic signals associated with fluid flow
  - Ground-penetrating radar (GPR) (site-specific)
    - Images shallow layering and internal structures

Case Study – Gold Mine: Federico Mine, La Carolina Mining District, Spain (Historic Underground Gold Mine with Surface TSF)

- ERT cross-sections image strong vertical and lateral resistivity contrasts that distinguish:
  - saturated vs dry tailings,
  - tailings vs bedrock,
  - internal heterogeneity affecting stability.

Martínez, J., Mendoza, R., Rey, J., Sandoval, S., & Hidalgo, M. C. (2021)

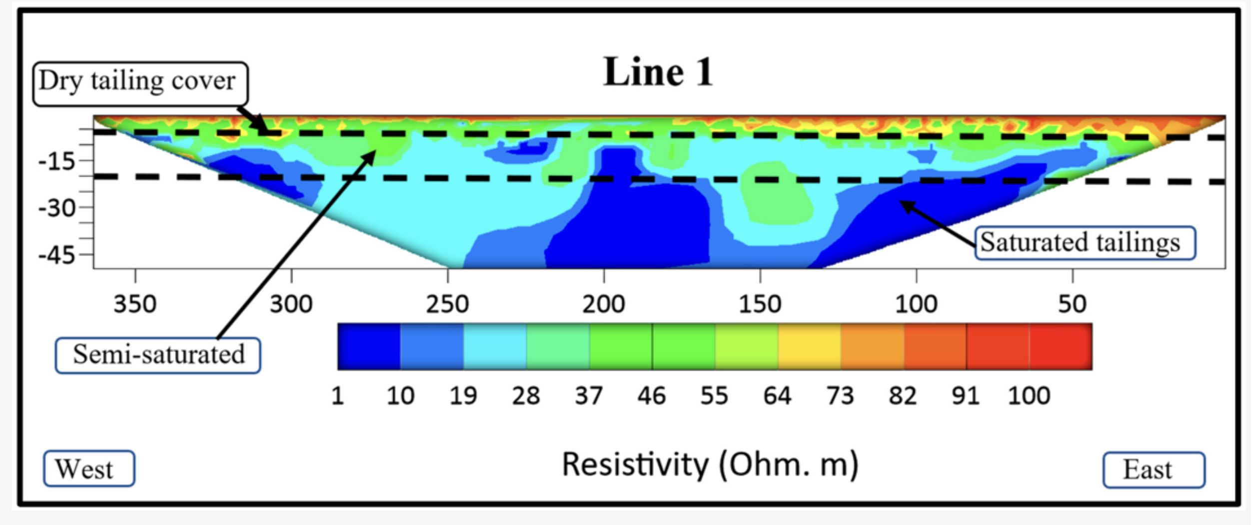


Seepage, Leakage, and Groundwater Protection

- Key environmental concerns
  - Migration of contaminated pore water
  - Impact to shallow aquifers and surface water
  - Undetected leakage from TSFs or waste rock piles
- Value of geophysics
  - Maps plume geometry without dense drilling
  - Monitors plume evolution through time
  - Supports remediation design and compliance monitoring
- Geophysical methods used
  - ERT / Time-lapse ERT
    - Tracks movement of conductive leachate plumes
  - EM methods (frequency or time-domain)
    - Rapid mapping of subsurface conductivity related to dissolved ions
  - SP
    - Identifies preferential flow paths

Case Study: Copper Mine – El Mochito, Honduras (Underground Copper Mine with Surface TSF)

- **Problem addressed:** Detection of seepage and leachate migration from an aging tailings pond into surrounding groundwater.
- **Geophysical method illustrated:** 2D Electrical Resistivity Tomography
- **Key result:** ERT cross-sections show laterally continuous low-resistivity zones (1–30 Ω·m) beneath the TSF, interpreted as active leachate pathways extending into the subsurface.



Ali, M. A. H. et al. (2023)

Acid Rock Drainage and Geochemical Risk

- Key environmental concerns
  - Sulfide oxidation
  - Acid generation
  - Metal mobilization
- Value of geophysics
  - Non-intrusive screening of large waste volumes
  - Targeting of high-risk zones for sampling or encapsulation
  - Supporting ARD prediction and closure planning

- Geophysical methods used
  - ERT / Induced Polarization (IP)
    - Identify sulfide-rich or reactive tailings zones
  - EM
    - Map altered or chemically conductive zones
  - Magnetics (indirect)
    - Map sulfide-bearing waste units where pyrrhotite/magnetite remains

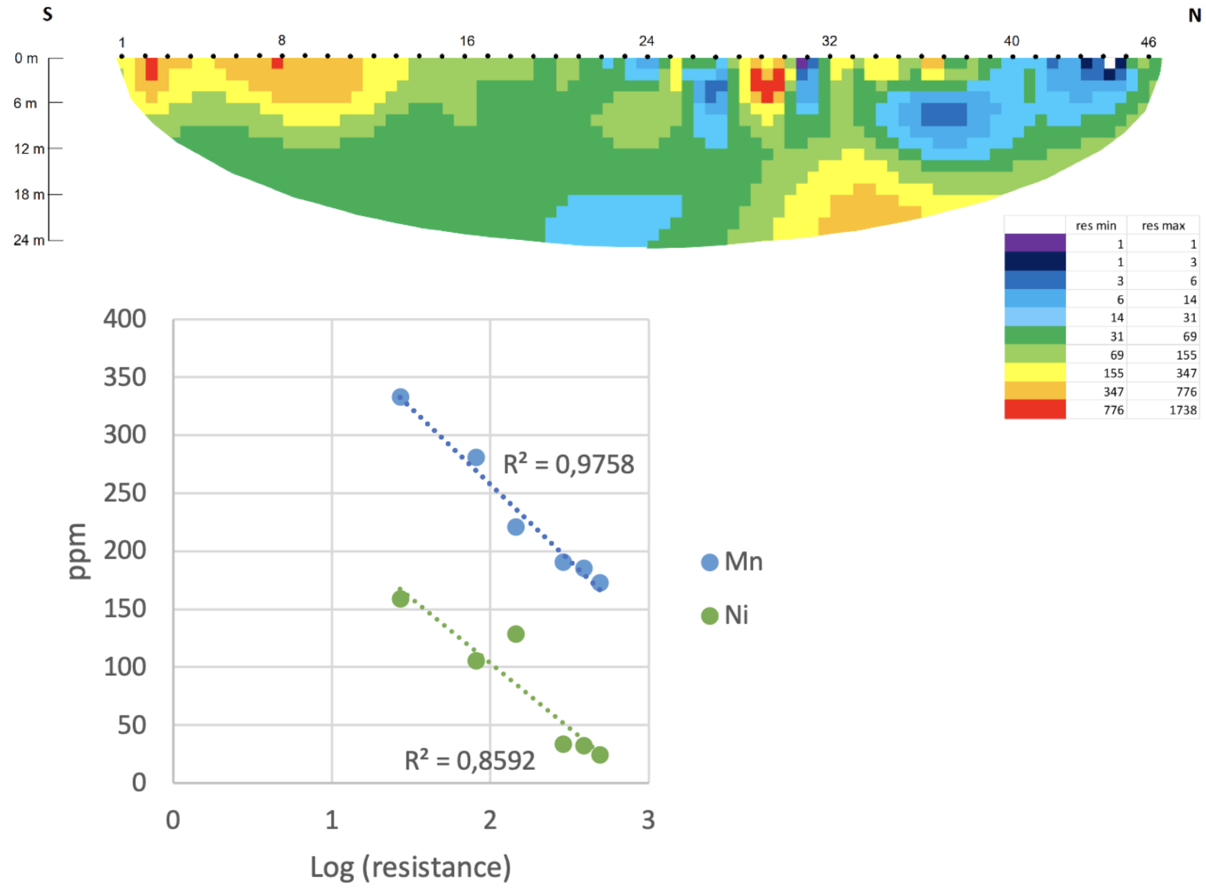
Tailings Re-Mining, Reprocessing, and Resource Recovery

- Key drivers
  - Recovery of residual metals or critical minerals
  - Volume reduction
  - Improved long-term environmental performance
- Value of geophysics
  - Rapid characterization of legacy tailings
  - Reduces drilling and sampling costs
  - Supports techno-economic evaluations for reprocessing
- Geophysical methods used
  - ERT / IP
    - Estimate spatial variability in mineralogy and moisture
  - Seismic methods
    - Map density and consolidation differences
  - EM
    - Delineate zones enriched in conductive minerals

Gold Mine – Witwatersrand Basin, South Africa (Historic Gold Tailings Dumps)

- **Problem addressed:** Identifying spatial distribution of sulfide-rich, potentially acid-generating zones within legacy gold tailings.
- **Geophysical method illustrated:** Electrical Resistivity Tomography (ERT) calibrated to physicochemical properties
- **Key result:**
  - ERT images, combined with limited geochemical data, map zones of higher moisture, salinity, and metal content—key indicators of ARD risk in gold tailings
  - Also demonstrates geophysics as a cost-effective screening and characterization tool for tailings valorization.

Manuel, M. et al. (2023)



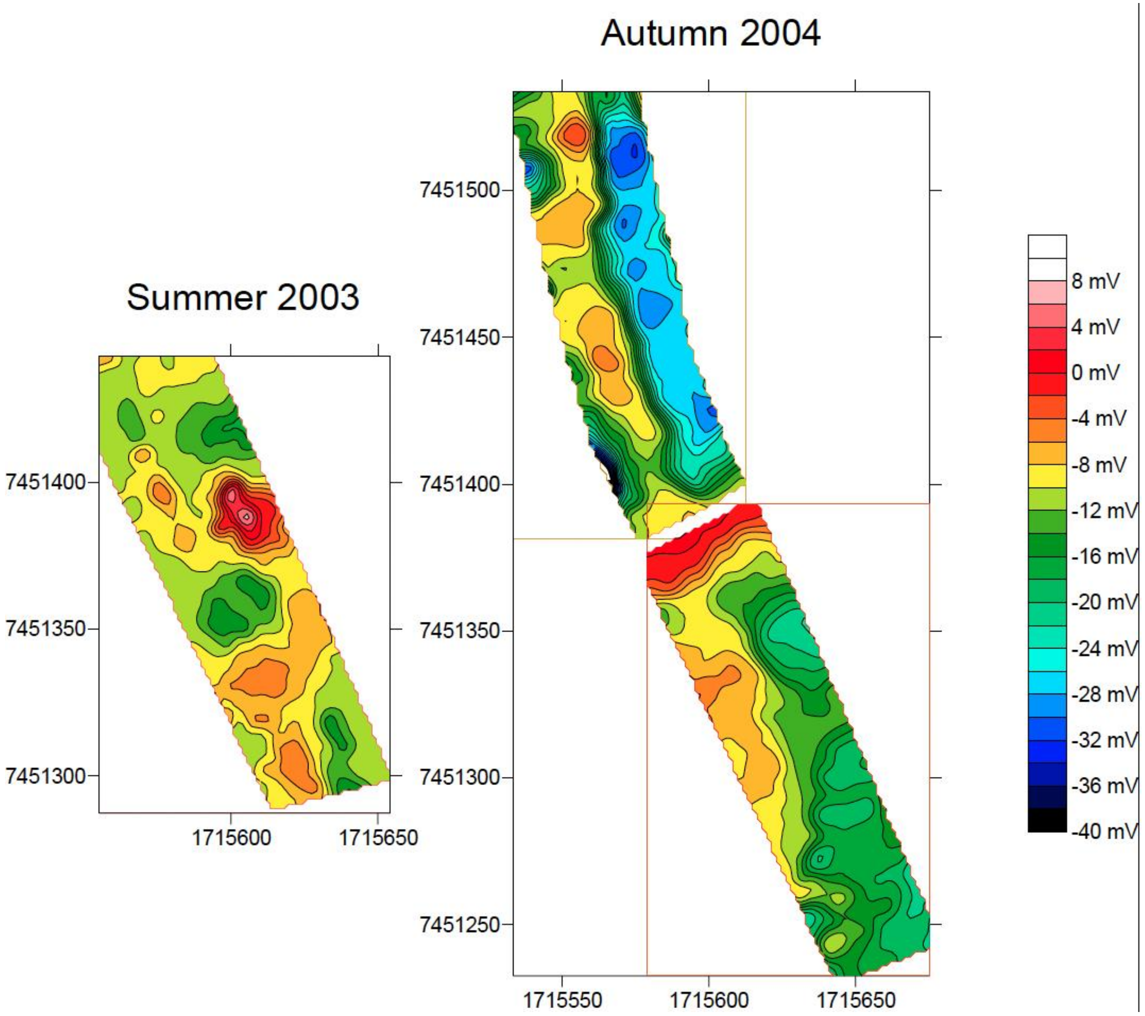
Closure, Reclamation, and Long-Term Monitoring

- Key concerns
  - Post-closure seepage
  - Settlement and deformation
  - Long-term stability under changing climate conditions
- Value of geophysics
  - Establishes baseline conditions at closure
  - Enables non-invasive, cost-effective long-term surveillance
  - Supports regulatory assurance and community confidence
- Geophysical methods used
  - Repeat ERT / SP surveys
  - Seismic monitoring
  - Integration with geotechnical instrumentation

Case Study: Copper Mine – Aitik, Sweden (Large Open-Pit Copper Mine with Downstream TSF)

- **Problem addressed:** Long-term monitoring of internal structure, seepage, and seasonal effects in a closed-loop copper tailings dam.
- **Geophysical methods illustrated**
  - Time-lapse Electrical Resistivity Tomography
  - Self-Potential (SP)
- **Key result:** Repeated ERT profiles image stable internal resistivity structure over time, while SP data verify the absence of evolving seepage paths in the copper TSF.

Mainali, G. (2006)



Geophysics for Mine Safety

Case Study: Radar imaging of fractures and voids behind the walls of an underground mine

Abbasi-Baghbadorani et al. (2021), Geophysics

Study objective & setting

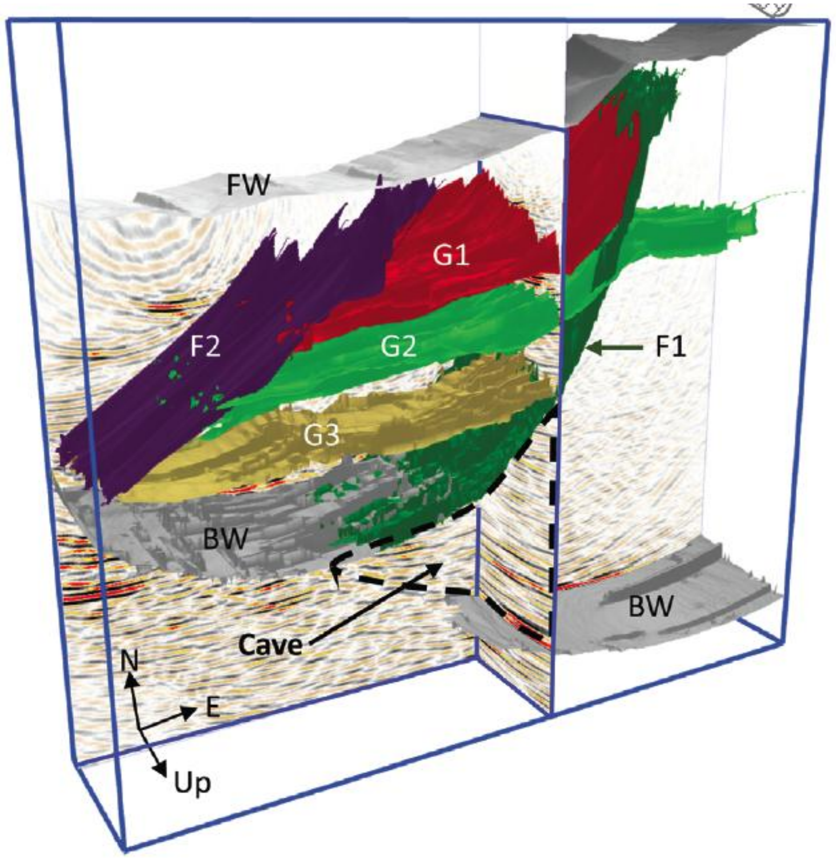
- Image fractures and karst voids behind mine walls in an underground limestone mine, where collapse and water-inrush hazards are common.
- Acquire 2D and 3D GPR data on a rough vertical pillar wall, with known exposed fractures and a large cave for validation.

Geologic & mining context

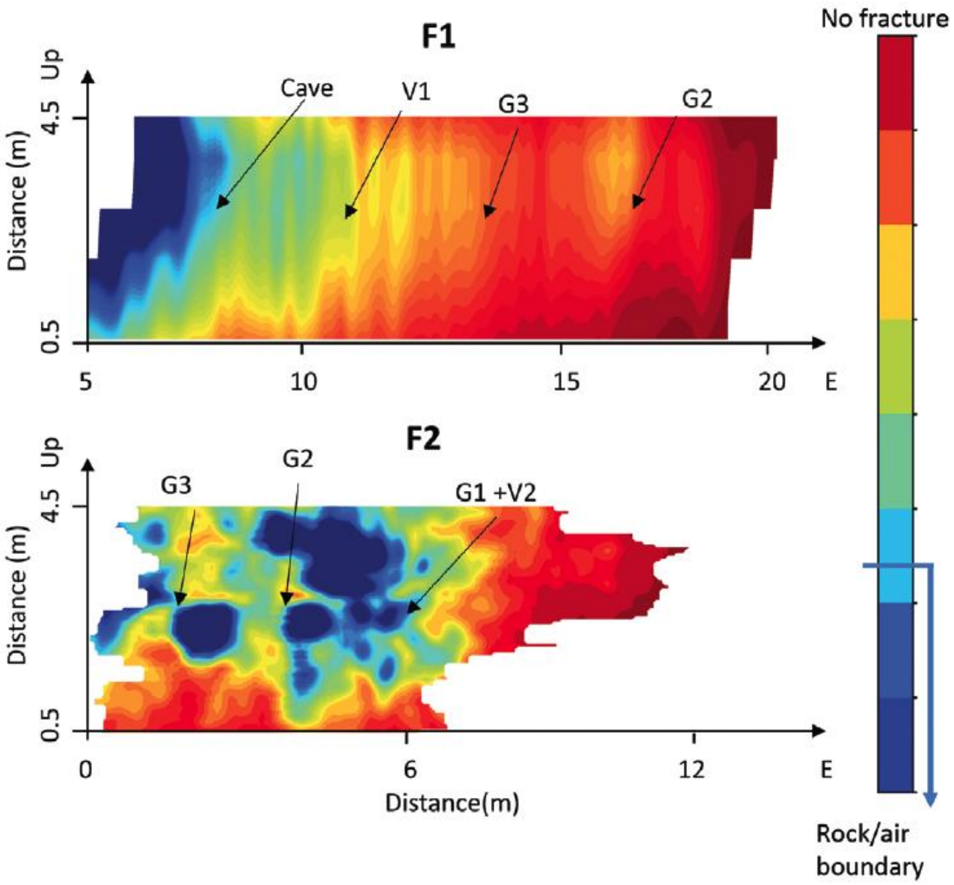
- Massive limestone (>97% $CaCO_3$) with karst development.
- Fractures and voids are the primary mechanical weakness and groundwater pathways.
- Study pillar chosen because it contains:
  - Known fractures (F1–F3),
  - A large cave intersecting the pillar

Fracture and Void Imaging Results

- Radar images:
  - Known fracture set F1–F3,
  - Previously unknown conjugate fracture set G1–G3,
  - Two major voids (V1, V2) (Figures 7 & 10).
- All large voids occur at intersections of fracture sets, indicating preferential dissolution and flow.



Aperture Estimation



- Converted amplitudes to indicative fracture aperture
  - Cm-scale if air-filled,
  - Mm-scale if water-filled.
- Aperture increases:
  - Upward in the pillar,
  - At fracture intersections

Mining Relevance

- GPR detects hazardous features >5× further ahead than probe drilling.
- Enables:
  - Early identification of collapse and flood hazards,
  - Hazard mitigation before blasting,
  - Improved ground control modeling.
- Demonstrates strong value of GPR for operations.