MINE.IO
A Holistic Digital Mine 4.0 Ecosystem

UNIVERSITY OF OULU

Environmental management
Reliable surveillance operations

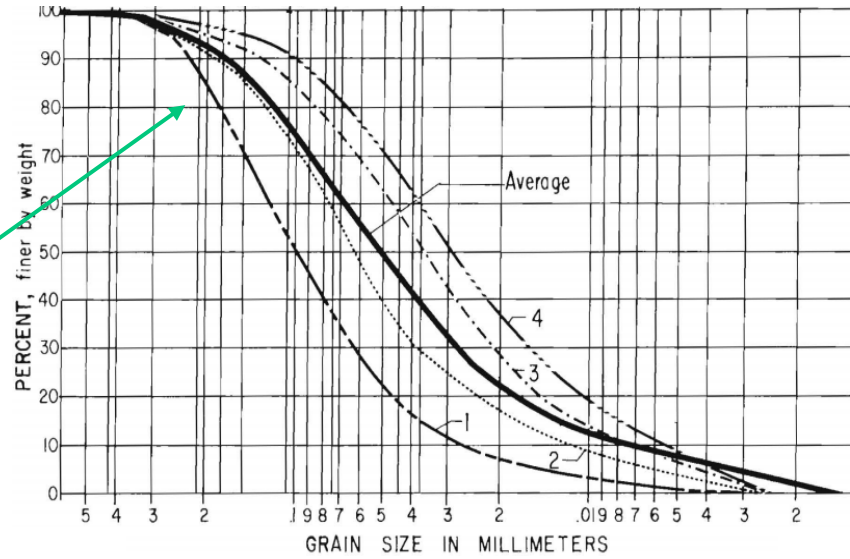
Multi-source geophysical data fusion and interpretation for monitoring, assessment and management of tailings facilities

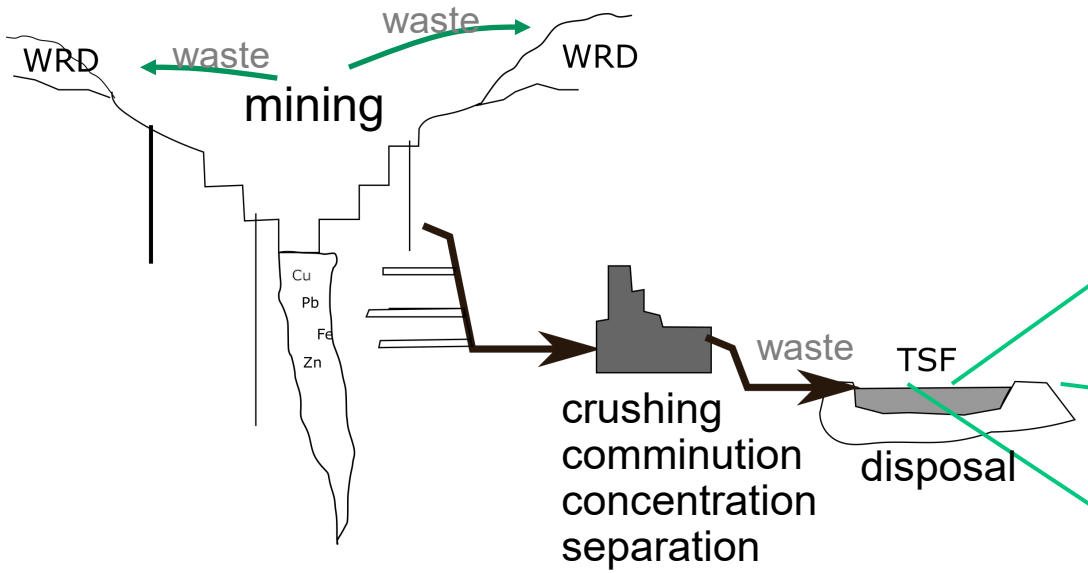
Mining Workshop – Sustainable Mining Practices in the Future
21.11.2024

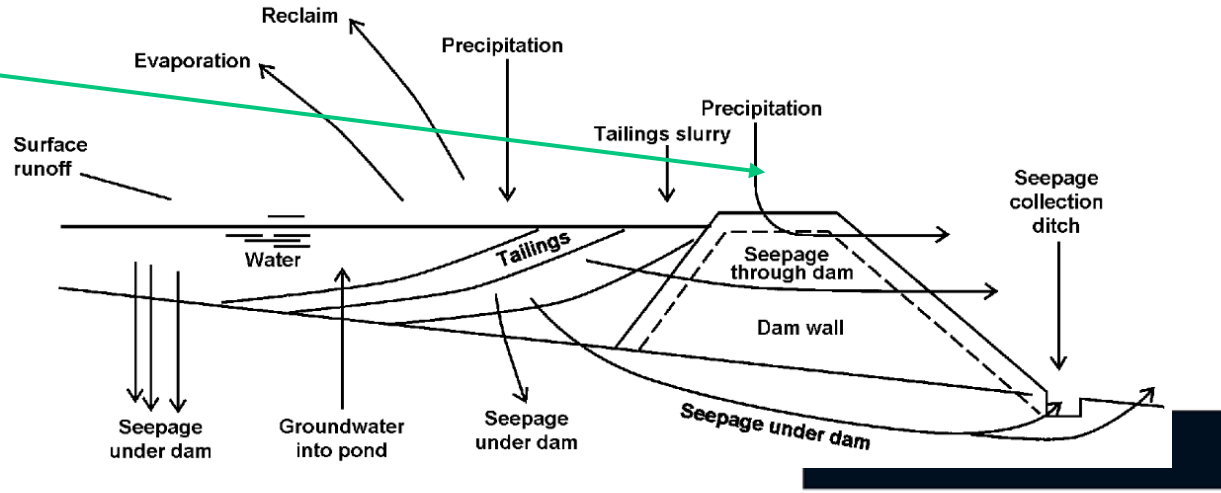
Co-funded by the European Union

Tailings and Tailings Storage Facility (TSF)

Tailings is the reject of a mineral enrichment process







Water management

Freeboard

Seepage

Pipe bursts

Erosion

Dust

When a tailings storage facility (TSF) collapse

Mariana Dam failure (5 Nov 2015):

- 19 people dead, two villages devastated.
- Nine years after, Vale and BHP have agreed to a monumental USD30.36 billion settlement. Payments will span two decades until 2043.

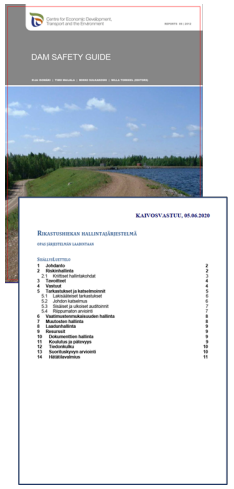
Brumadinho tailings dam failure (27 Jun 2019):

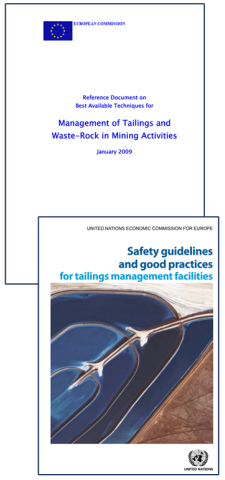
- 270 people dead
- environmental and social damage
- USD 6.79 billion deal agreement for Vale mining company to compensate.

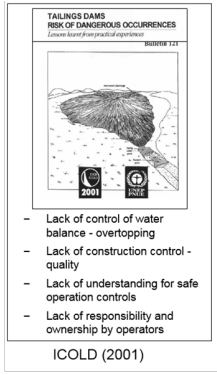
Social movements influencing political parties for revision and amendment of settlement agreement.

+30 years of guidelines and reviews

(…)

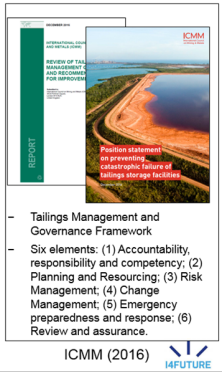






- Lack of control of water balance - overtopping
- Lack of construction control - quality
- Lack of understanding for safe operation controls
- Lack of responsibility and ownership by operators

ICOLD (2001)

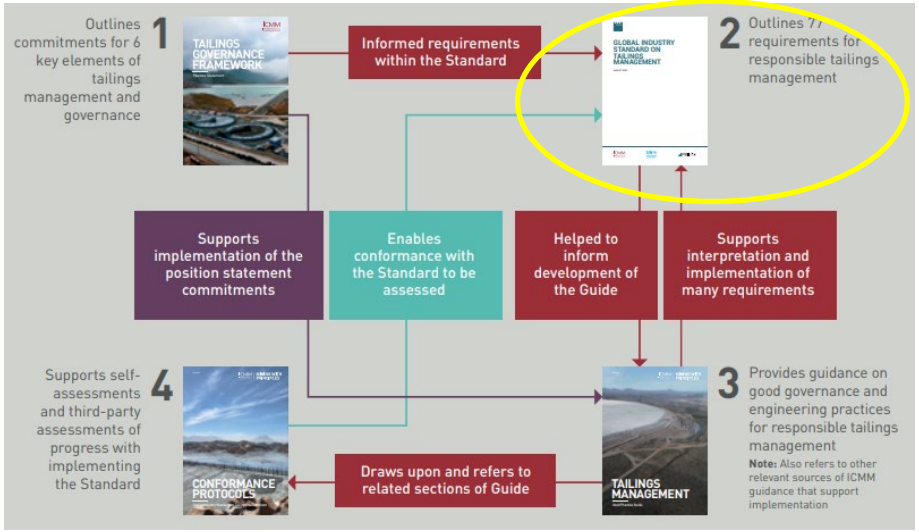


- Tailings Management and Governance Framework
- Six elements: (1) Accountability, responsibility and competency; (2) Planning and Resourcing; (3) Risk Management; (4) Change Management; (5) Emergency preparedness and response; (6) Review and assurance.

ICMM (2016)

(…)

Tailings management framework (ICMM, 2019-2020)



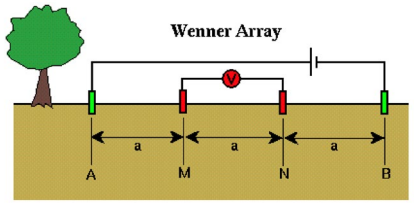
ICMM engagement for TSF Monitoring Technologies (June, 2021)

- Piezometers
- Inclinometers / Shape Acceleration Arrays (SAA)
- Surveying pins / monuments
- Field inspections

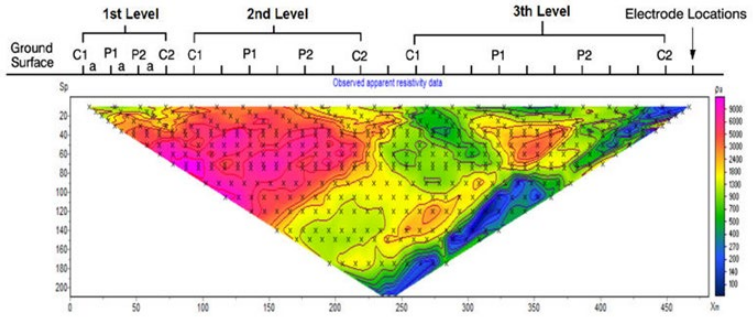
- Laser scanning
- Terrestrial-based radar
- Satellite-based Interferometric Synthetic-Aperture Radar (InSAR)
- Satellite-borne photogrammetry, hyperspectral imaging or other techniques
- Drone optic and photogrammetric surveys
- Bathymetry drone survey
- Survey geophysics
- Thermal imaging
- Time-Domain Reflectometry (TDR)
- Passive seismic tomography
- Core sampling autonomous vehicles

Can we use near-surface geophysics to map the subsurface structure and conditions of TSFs?

Electrical resistivity imaging (ERI)



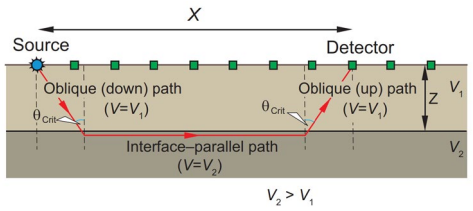
$$\rho_a = 2\pi a \frac{\Delta V}{i}$$



And many other arrays and combinations of them…
… and geometric factors for different arrays

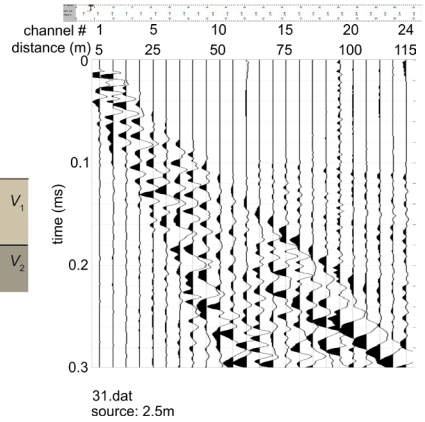
Seismic refraction & MASW

Schematic raypath at a horizontal planar surface



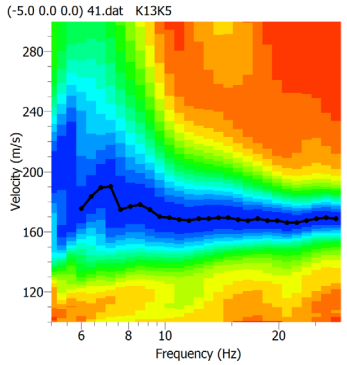
Mudge (2014)

Travel time records



31.dat
source: 2.5m

Fundamental mode dispersion curve



What relationship exist between geophysical signature of tailings and the hydrogeological and elastic properties in the subsurface?

Petrophysical approach

Tailings physics approach

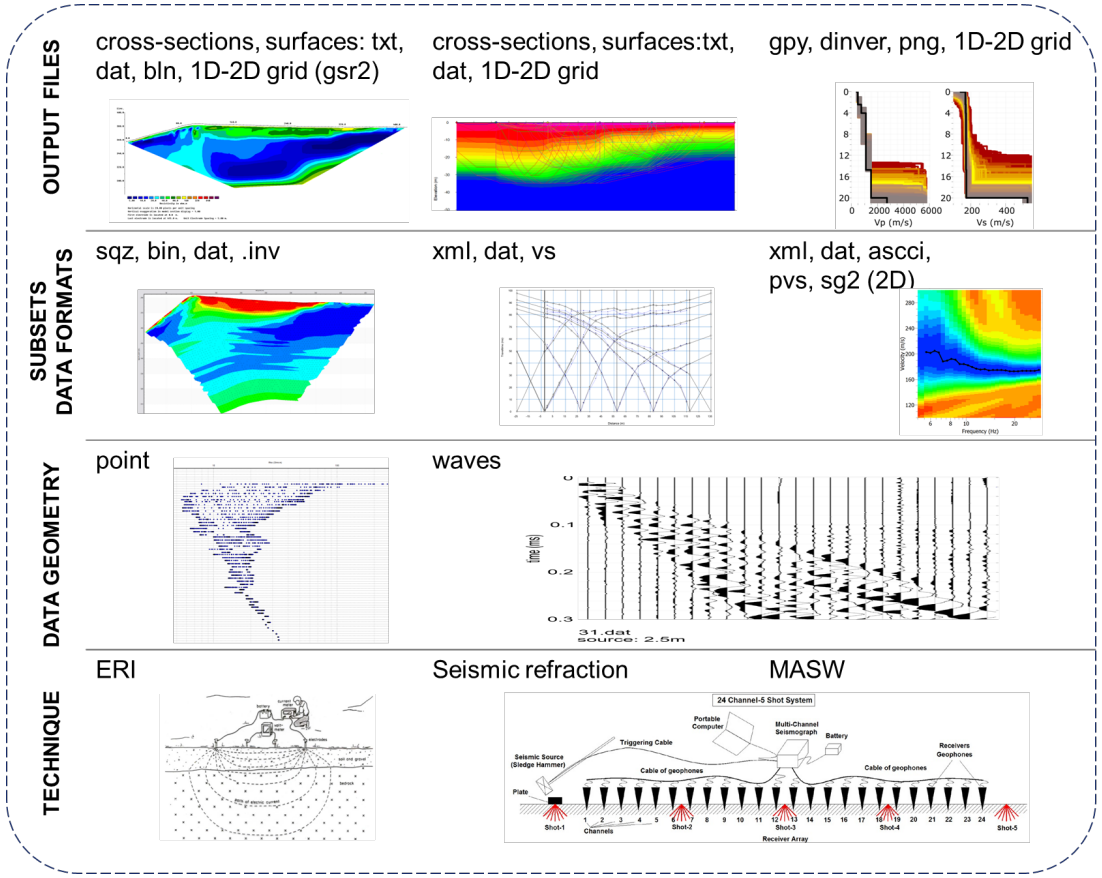
Can we interpret geophysical dataset in terms of:

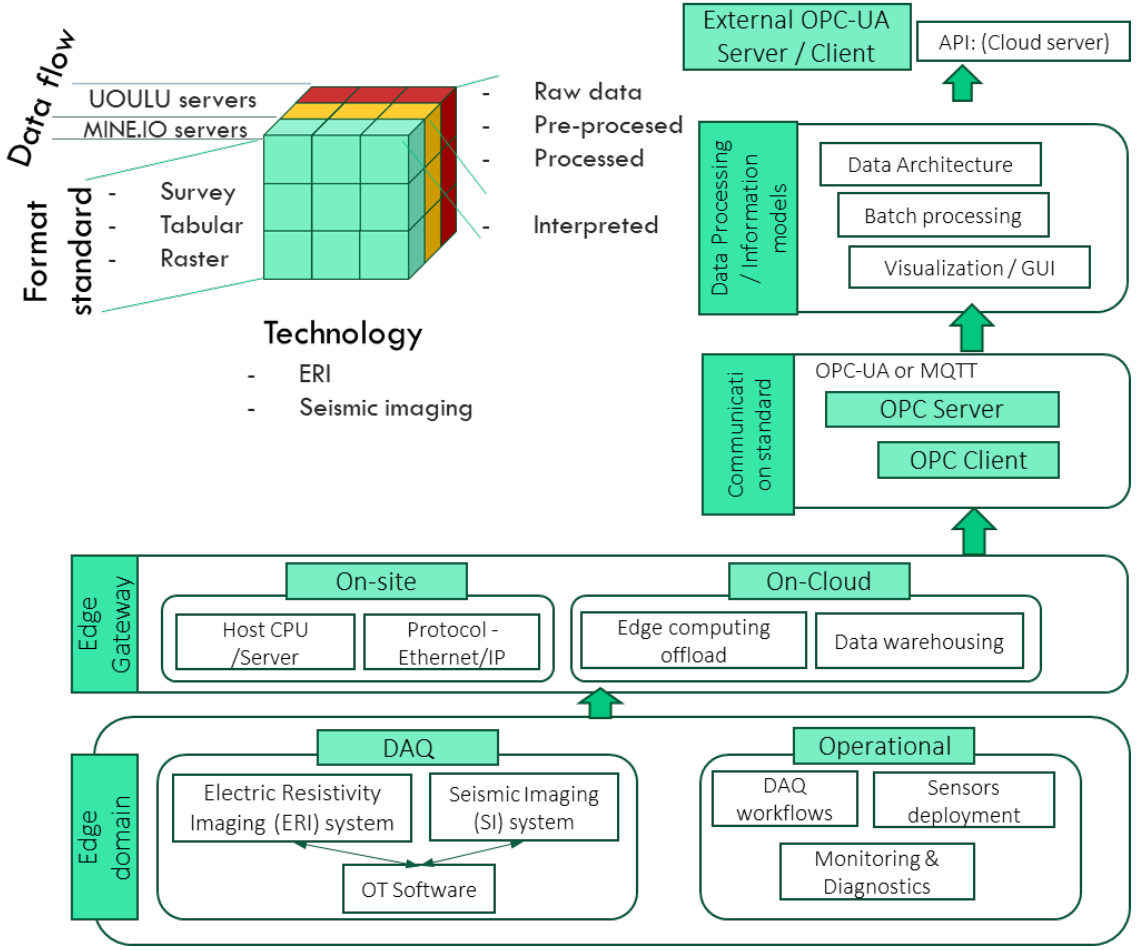
hydrogeological conditions?
- Water saturation
- Porosity

and elastic properties?
- Elastic moduli (geomechanical strength)

Digitalisation - Data workflow

Multi-source geophysical data fusion and interpretation for monitoring, assessment and management of tailings facilities



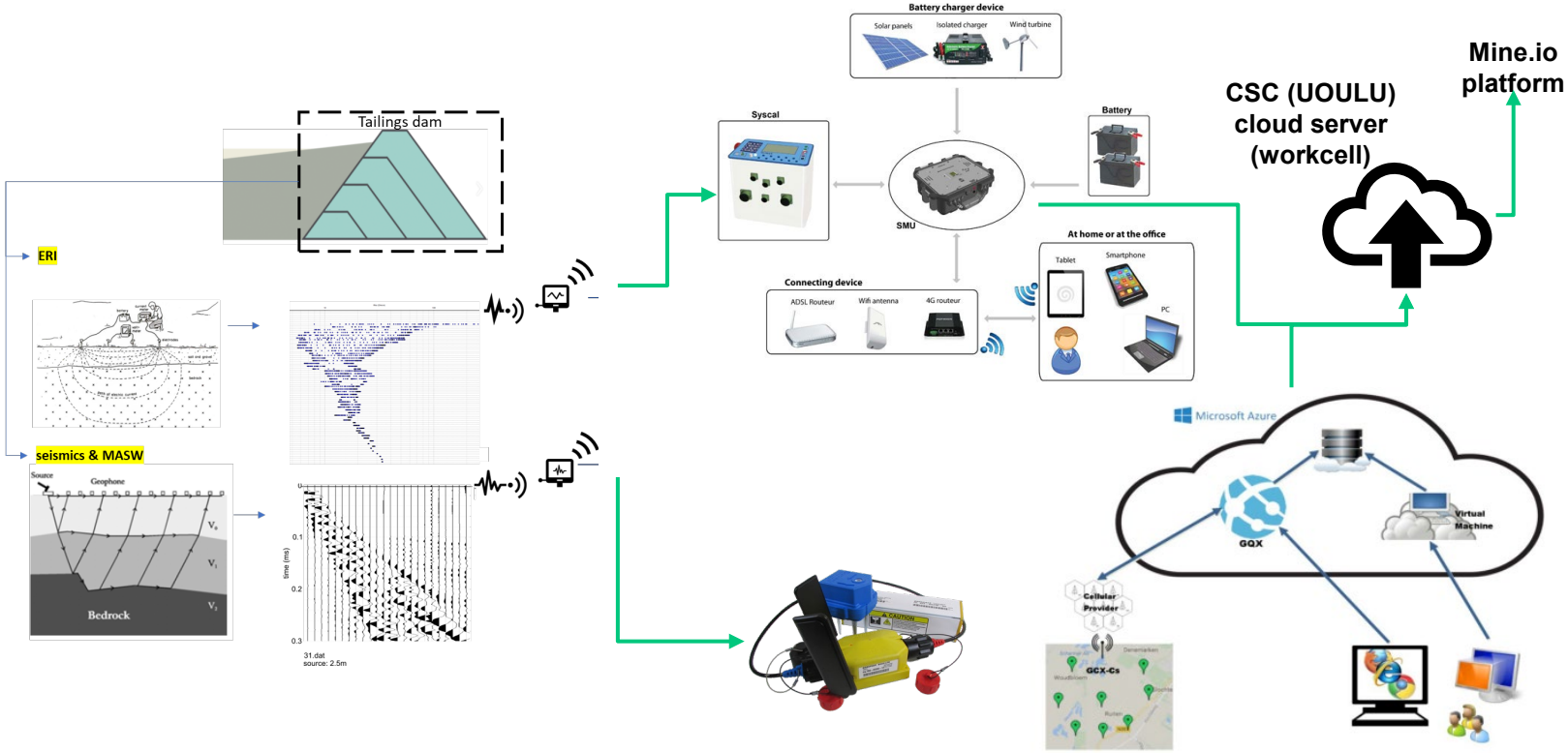


Technology overview

Multi-source geophysical data fusion and interpretation for monitoring, assessment and management of tailings facilities

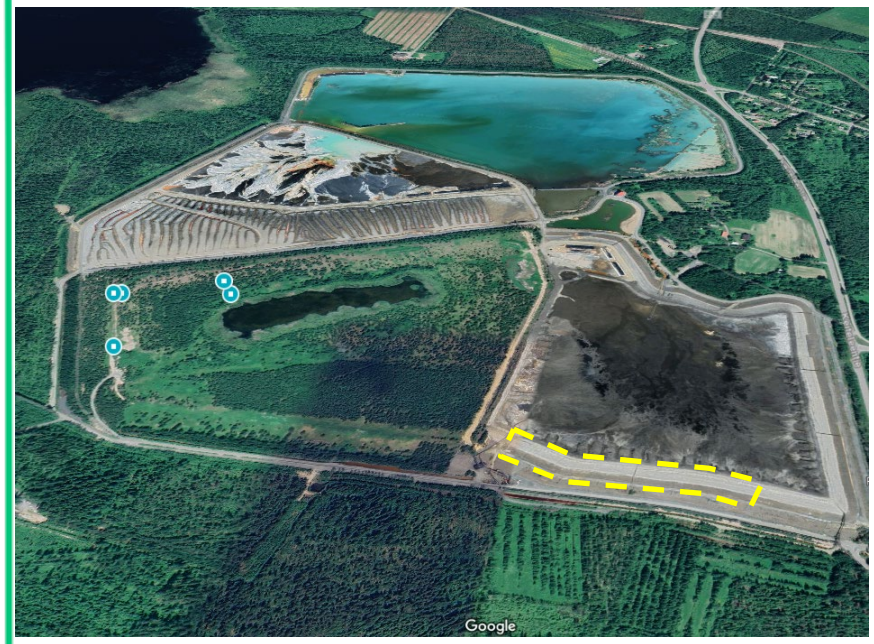
Project objectives and tasks

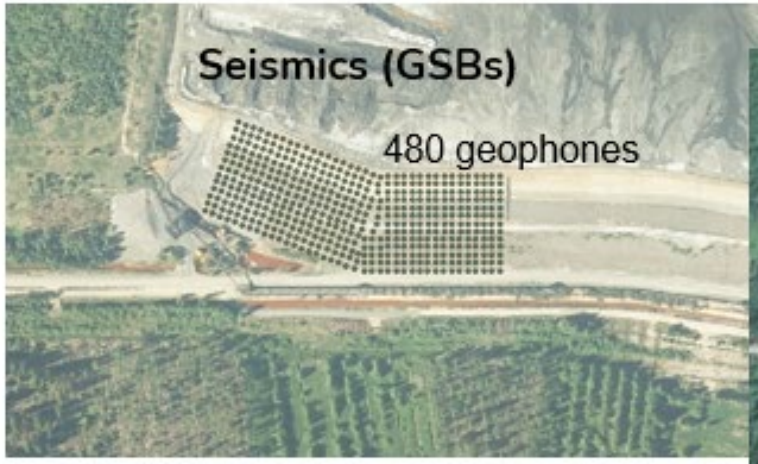
- Digitalisation of geophysical surveys with application to surveillance of tailings structures.
- Design of a geophysical data acquisition system (ERI and Seismics) for subsurface investigations and surveillance of structural elements in tailings facilities.
- Modelling and interpretation of geophysical dataset in tailings structures in terms of hydrogeological and elastic conditions.

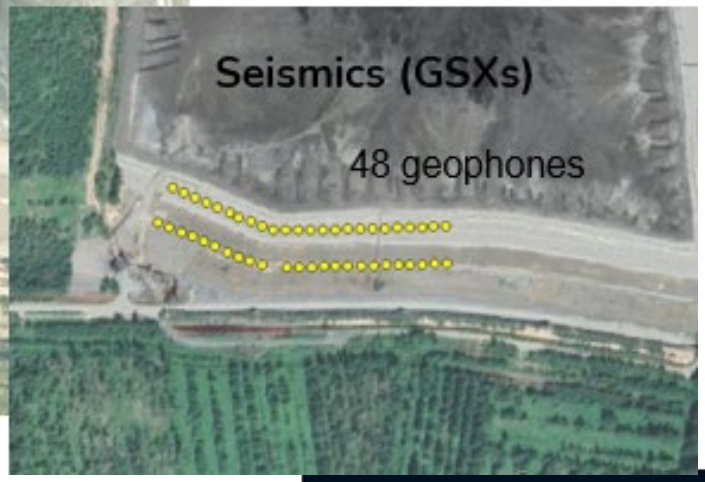


Pilot Trial 1 (May 2024)

Pilot site Finland: Pyhäsalmi mine site / Tailings facilities







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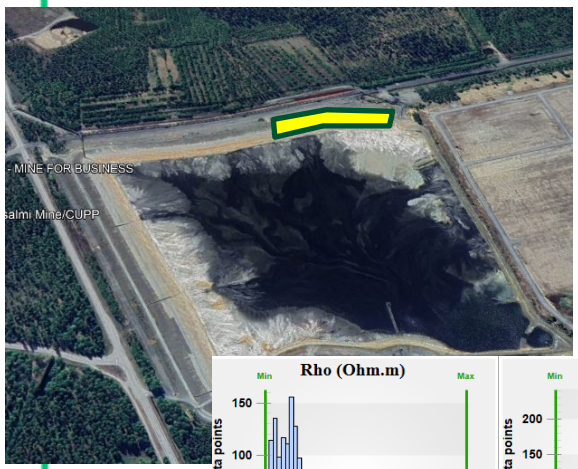
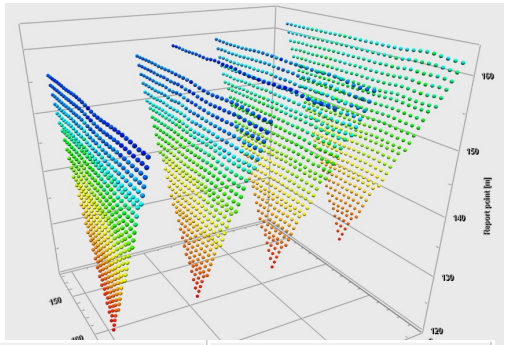
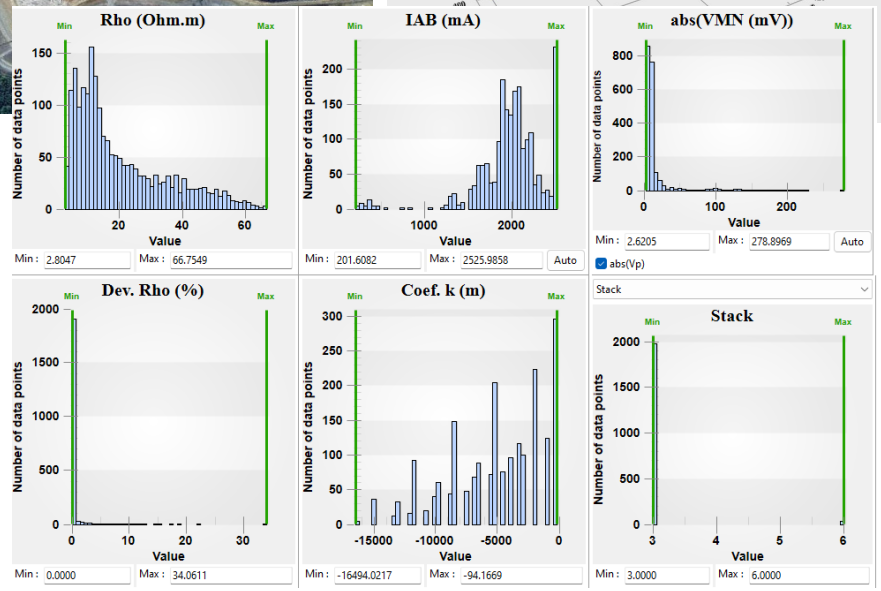
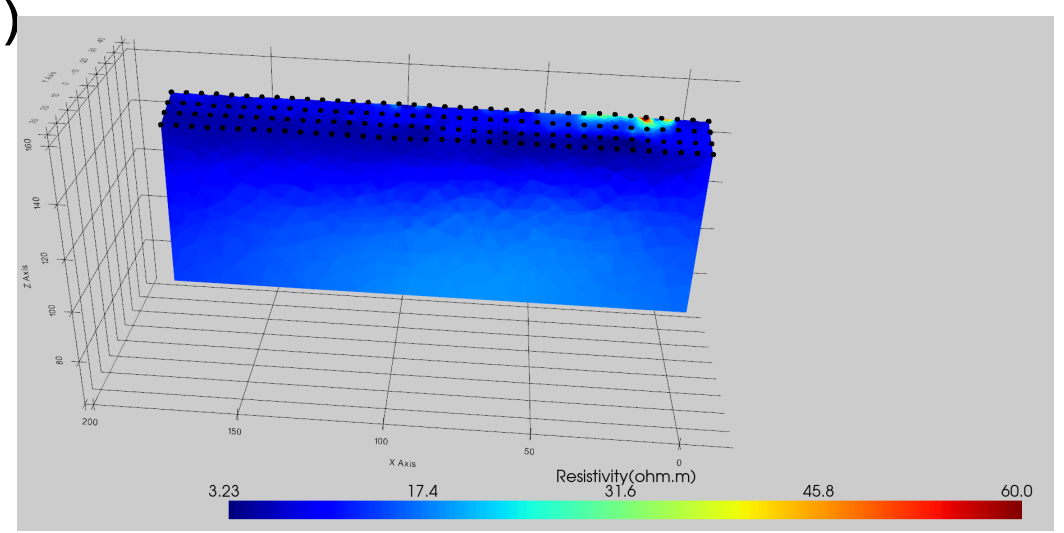
Pilot Trial 1 (Spring 2024) – ERI imaging (9.5.2024 sample)



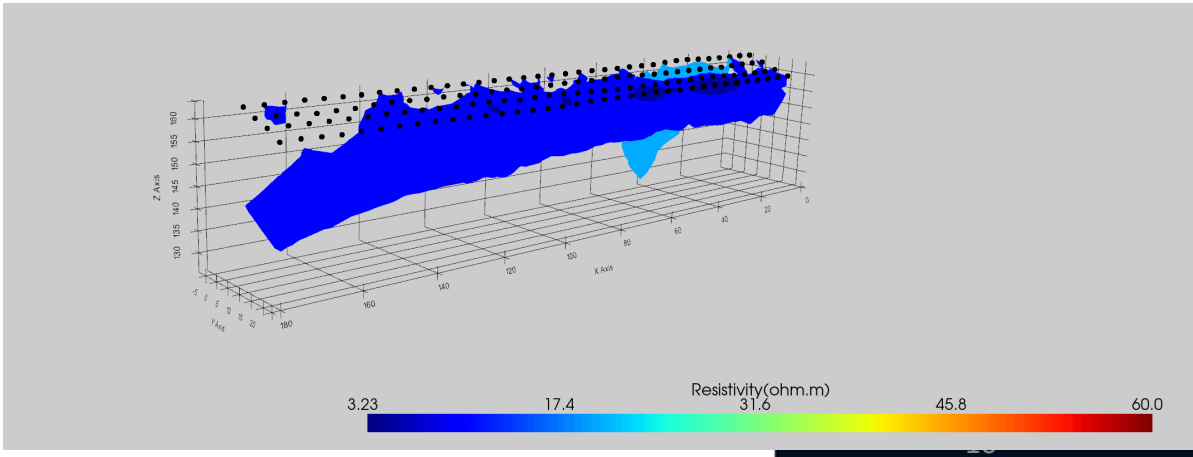




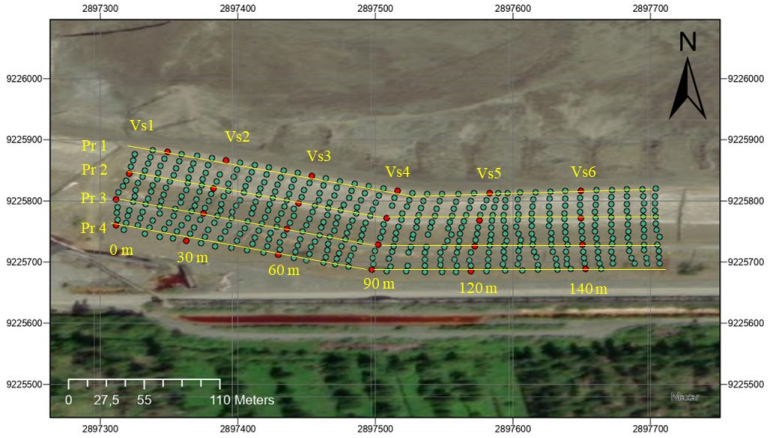
3D inversion model (ResIPy open source)



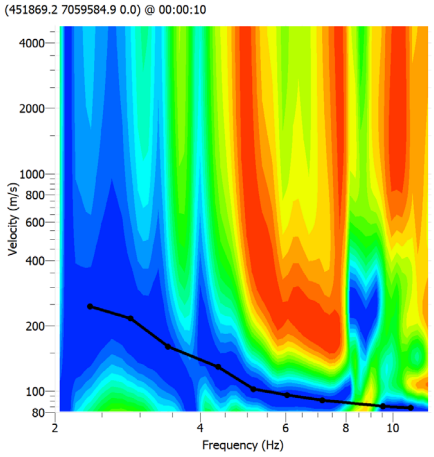
Isosurfaces 5-10-20 ohm.m



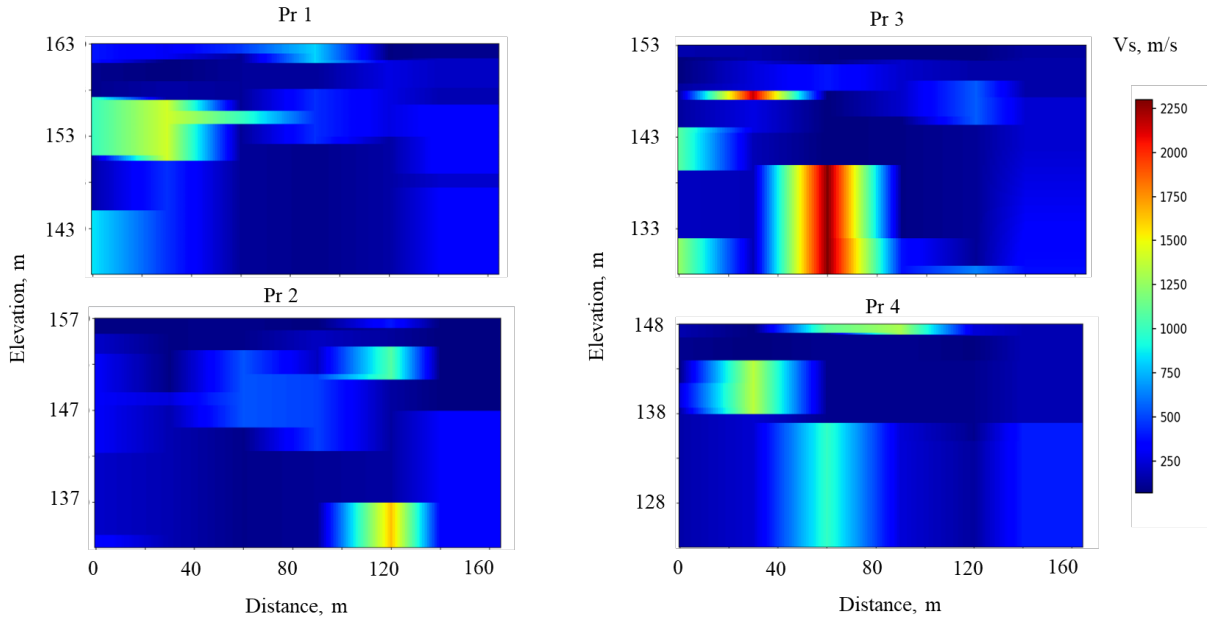
Pilot Trial 1 (Spring 2024) – Seismic imaging (preliminary)



Pr – profile; red dots – virtual sources; Vs – lines of virtual sources



Dispersion curve extraction by MASW for Vs3 Pr4

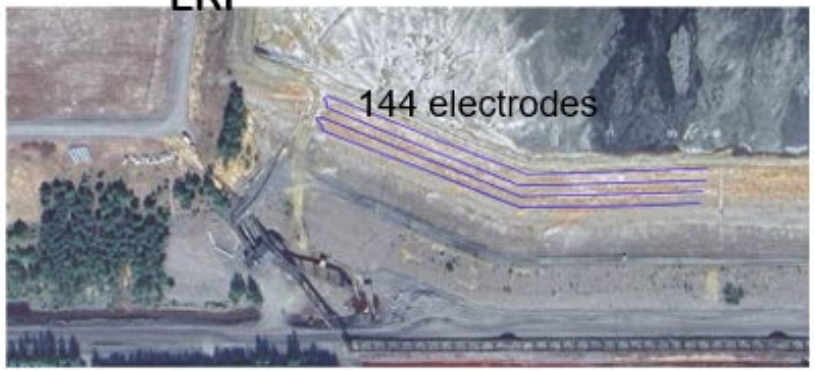


2D Vs models, obtained by inversion of surface waves dispersion curves

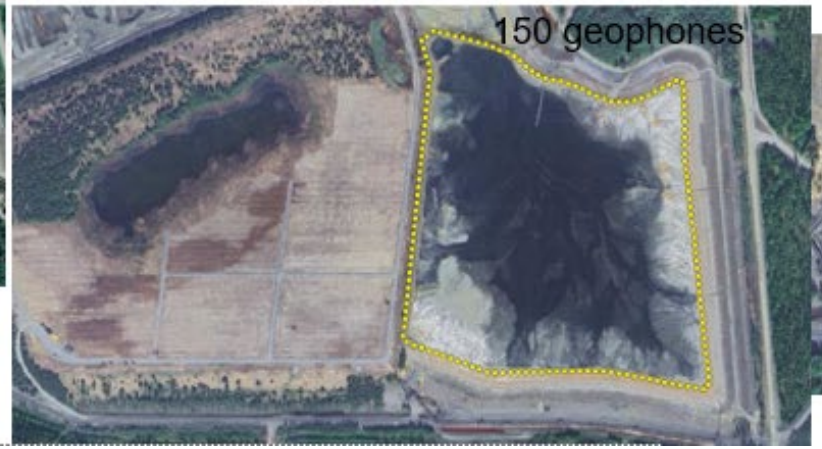
Pilot Trial 2 (Nov2024-Apr2025)

Pilot site Finland: Pyhäsalmi mine site / Tailings facilities

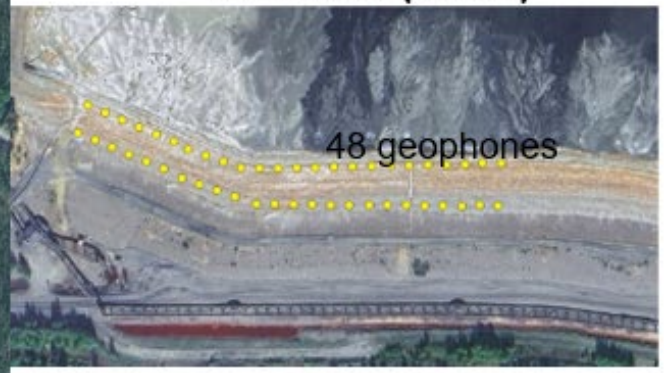
ERI



Seismics (GSBs + SmartSolo)



Seismics (GSXs)



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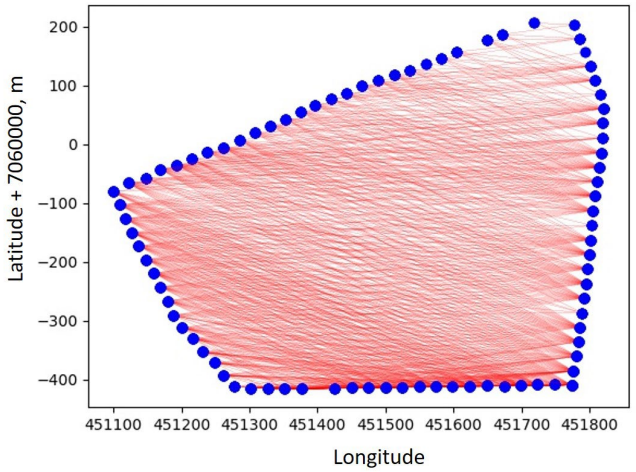
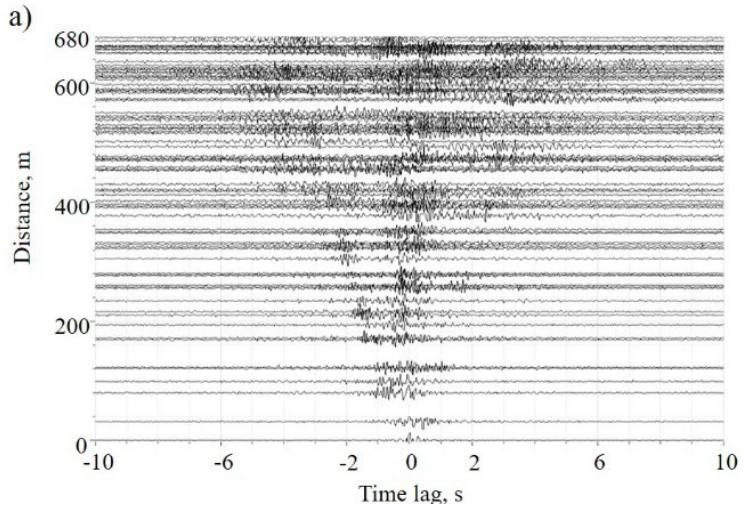
Passive seismic surface wave tomography for structural health monitoring of tailings storage facilities (a case study of Pyhäsalmi tailing)

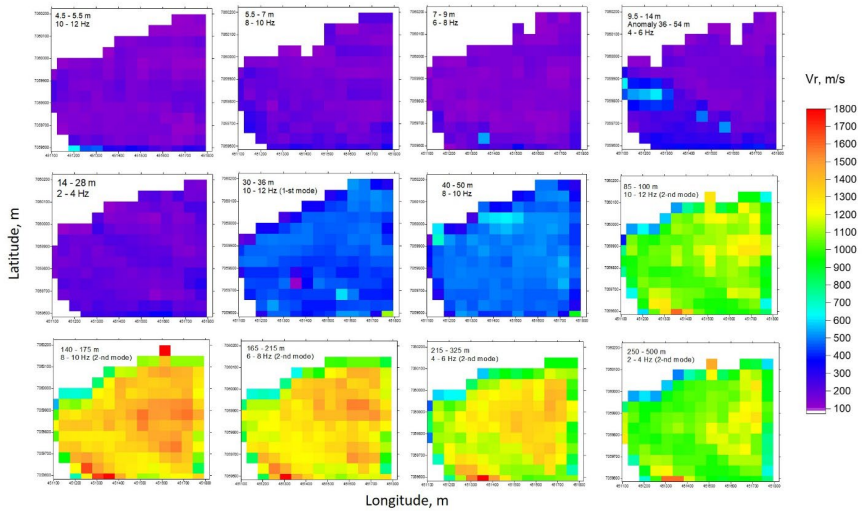
Passive seismic measurements on tailings embankment



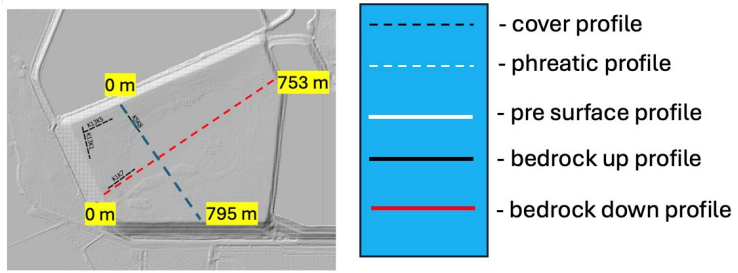
Selecting rays

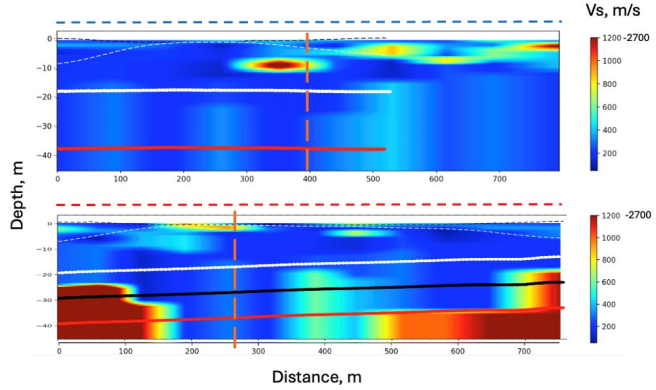


Converting ambient seismic noise to signal by seismic interferometry



Tomographic inversion of surface waves

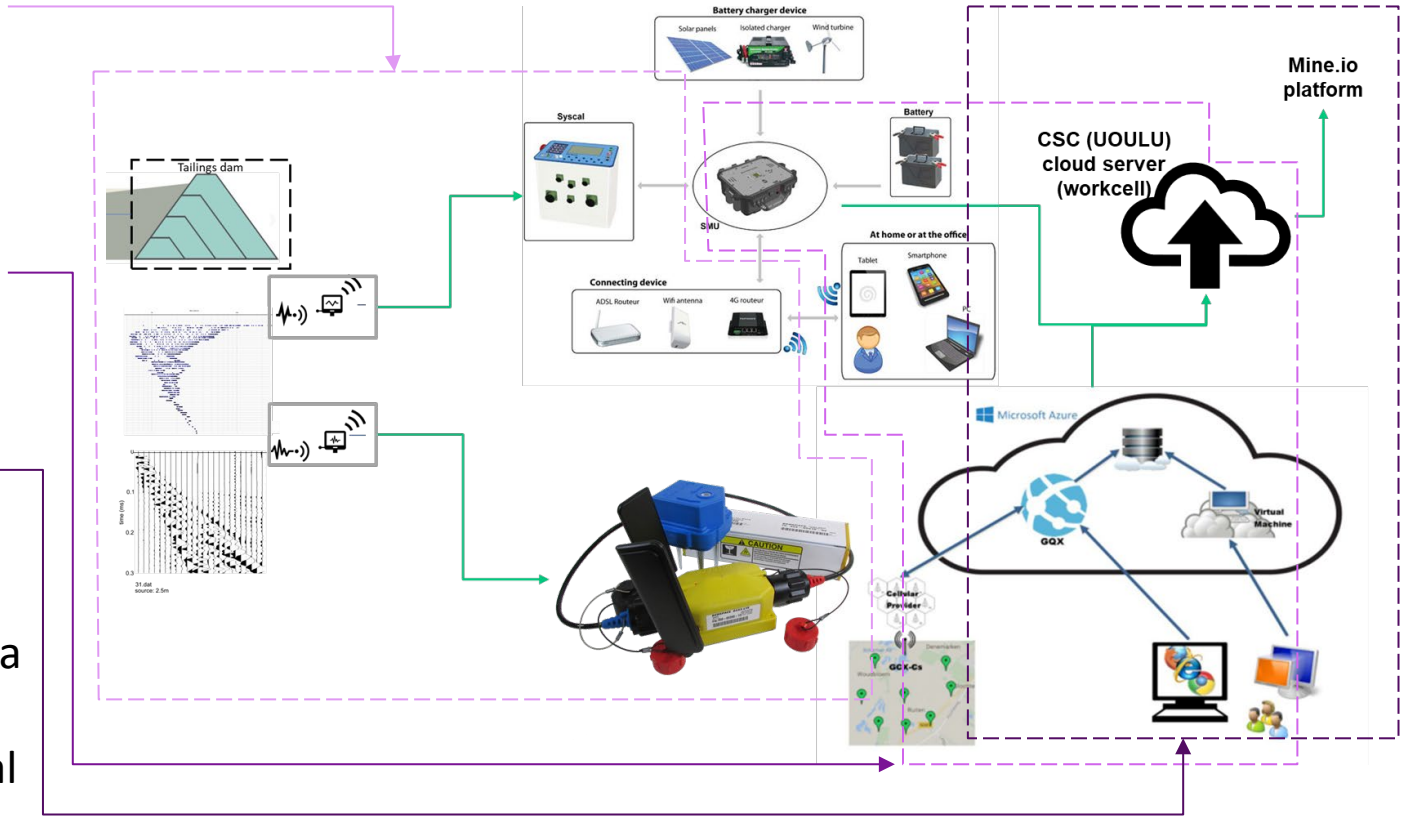




Obtaining 2D or 3D S-wave velocity models along “virtual” profiles (inaccessible parts of tailing)

Work coming – Integration

- Pilot Trial 2 (Winter 2025). Deployment and piloting DAQ, pre-processing, processing in near real time. (Nov2024 – Apr2025)
- Data workflow infrastructure – **From** DAQ cloud server **To** CSC HPC cloud services (UOULU) (Sep 2024 – Nov 2024)
- Data workflow infrastructure – **From** CSC cloud services (UOULU) **To** Mine.io infrastructure (Oct2024 – Apr 2025)
- Developing automated workflows and data fusion from the geophysical dataset to predict the embankment's hydrogeological and elastic conditions.



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Impact and significance of a digitalised and reliable environmental surveillance and monitoring

	Industry	Government	Community	Scientific Research
Need / gap	Fast and cost-effective techniques for characterization of mining waste repositories.	accessible and transparent surveillance and monitoring platform for regulated structures	Transparent information to answer community perceptions regarding mining waste structures	Non-invasive methods for system characterization of tailings structures
Challenges	Suitability and reliability of data for planning and/or engineering	Uncertainties regarding subsurface structures and long-term performance of mining waste repositories	access to technical information and models throuhg friendly imagery	Multidisciplinary integration. Access to reference sites and data transparency
Opportunities	High-resolution (spatial & temporal) dataset to support performance criteria and regulatory compliance.	Technological development for assisting regulatory, permitting and compliance assessments.	Confidence and trust on cutting-edge technology and industry practices	Leverage advances in mining geophysics. R&D in controlled field scale environment
Value / Benefit	Surveillance and monitoring of mining repositories (TSFs, leaching pads, rehabilitated land).	Decission support related to mining regulation; and water and land management.	Support to industry. Social licence to operate	Observed and calibrated models for geophysical, geotechnical and hydrogeological characterisation

Questions?

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