ERA-MIN 2

RESEARCH & INNOVATION PROGRAMME
ON RAW MATERIALS
TO FOSTER CIRCULAR ECONOMY

AMTEG

Project coordinator (Jens Kobow/supracon AG/Germany)

ERA-MIN 2 Final Conference and Final Seminar of Call 2017 projects
18-19th November 2021

Co-funded by the Horizon 2020 programme
of the European Union

Consortium

- Supply of raw materials from exploration and mining, Subtopic: Exploration
- May 1st, 2018 – October 31st, 2021 /42 months
- Project consortium
  - Nordic Iron Ore / Sweden / VINNOVA
  - Geognosia / Spain / CDTI
  - Ingenieur-Gesellschaft für Interfaces mbH / Germany / PT J
  - Leibniz-Institute of Phototnic Technologies , Jena / Germany / PT J
  - Supracon AG / Germany / PT J
- Start – end TRL from TRL 5 up to TRL 7
- Project budget 1.366.733 € / requested funding 952.149 € / 100 % project execution

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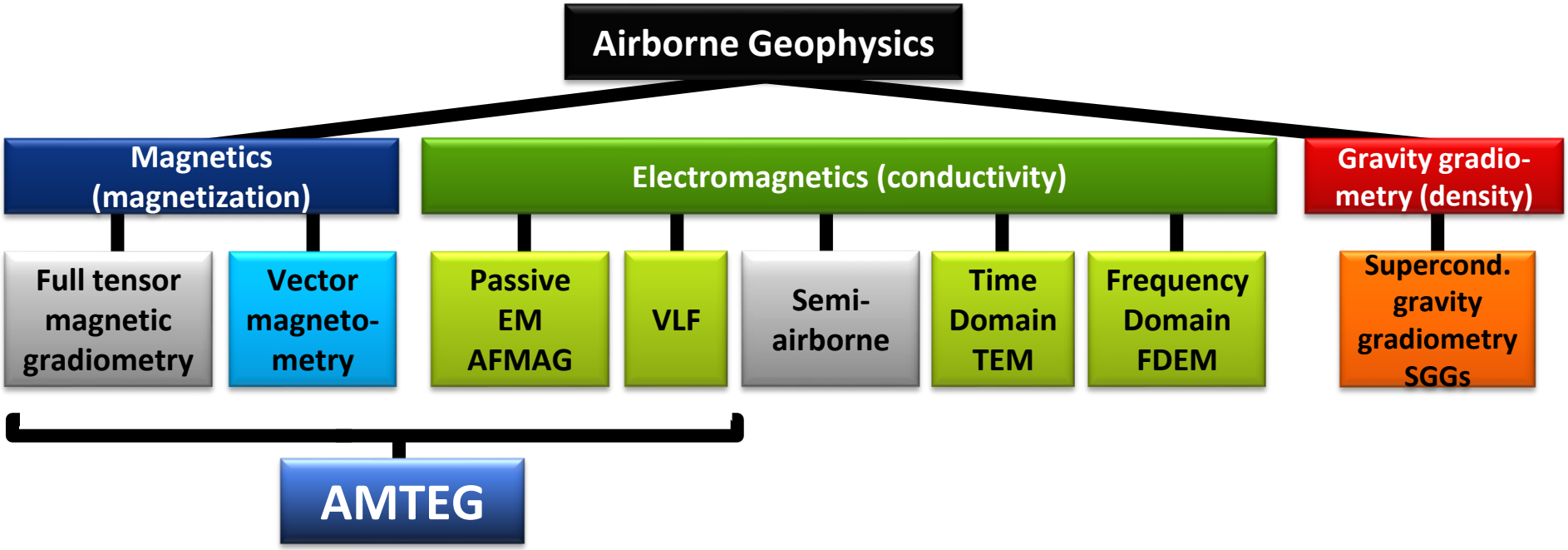
Objectives



- Development of a highly sensitive system to discover formerly undetectable deposits by its geophysical (magnetic) characteristics

  (R&D on new technologies e.g. magnetic field sensing, IMU, data processing, inversion and interpretation)

- **hand over or provide service with innovative tools to European industry, institutions and organizations such as national geological services etc.**
- **Aim: discovery of formerly undetectable deposits to make new resources accessible for the benefit of European industry in a sustainable way**

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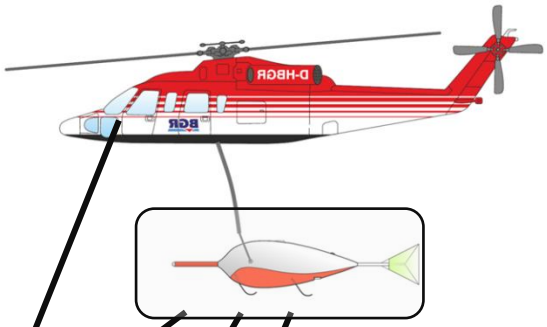
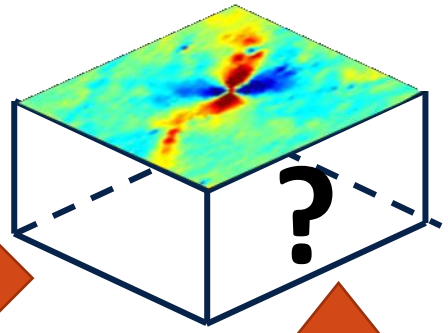
Tasks





- Swedish test site,
- organization of test campaign,
- interpretation,
- performance evaluation and dissemination.

Nordic Iron Ore

- high performance IMU and data processing,
- Flight navigation and planning,
- system integration of sensors and inertial unit,
- successive field testing and optimization.

IGI® www.igi-systems.com

- selection of test site in Spain (pyrite belt),
- organization of test campaign,
- data processing and interpretation,
- performance evaluation and dissemination.

Geognosia

- new hybrid SQUID sensors and optically pumped magnetometers with huge dynamic range and extremely high resolution,
- system integration,
- new data processing & inversion tools,
- various sensor and field tests for evaluation.

Leibniz ipht

- project management and coordination,
- new sensor electronics and data acquisition,
- tests & optimization of electronics with sensors,
- cryostat for sensor and electronics integration
- system integration of sensors and inertial unit,
- integrate demonstrator for airborne field tests,
- successive field testing and optimization.

supracon SQUID and Microfabrication Technologies

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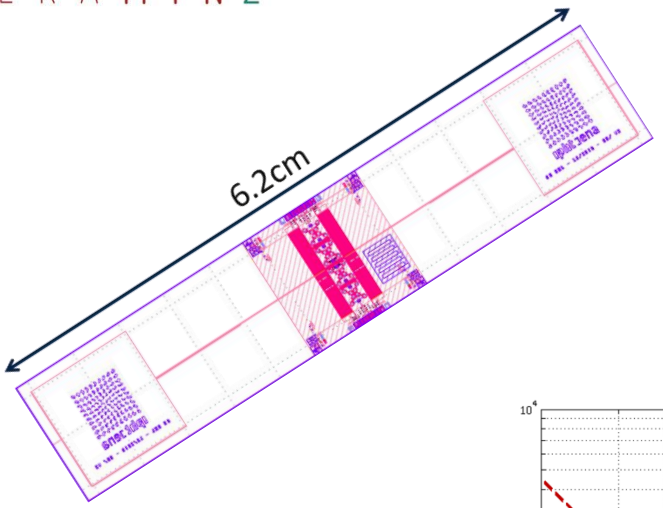
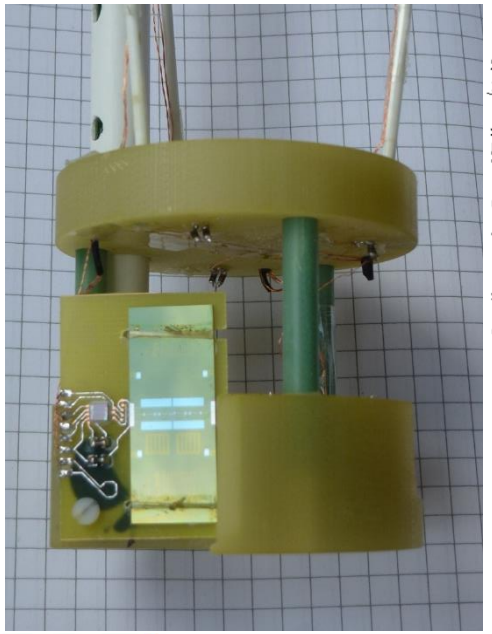
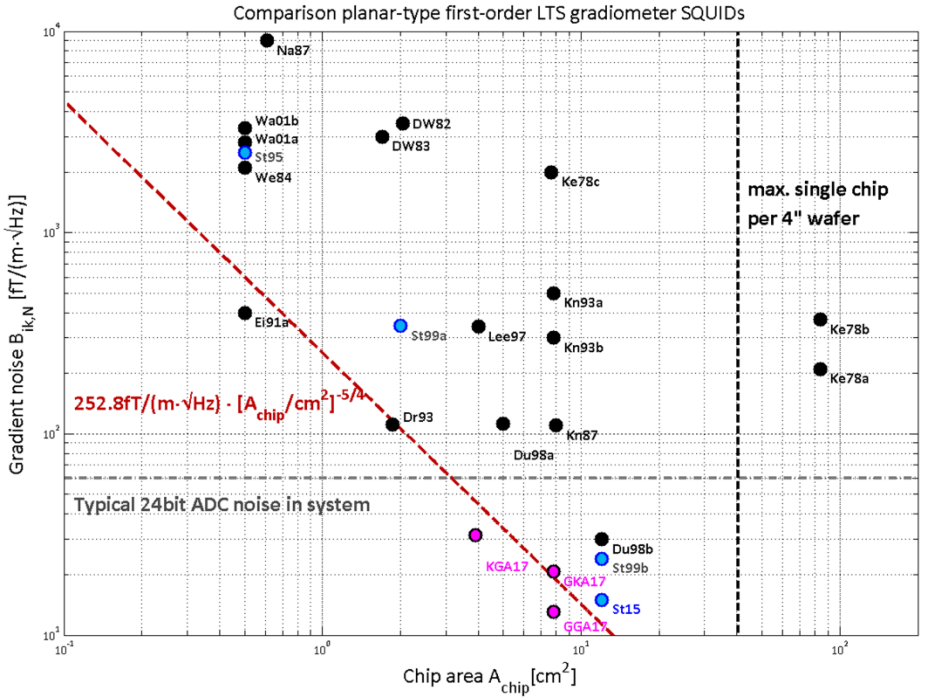
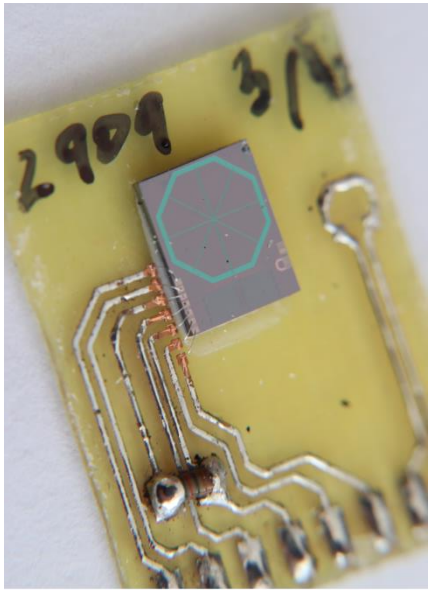
Results: Sensors



- new fabrication technology,
- new SQUID gradiometers with lowest noise measured for planar-type sensors; SQUID magnetometers with extremely low intrinsic noise of $< 1\,\mathrm{fT}/\sqrt{\mathrm{Hz}}$,
- hybrid readout of SQUID with digital output implemented.







Antenna sizes:
GGA: 6.2cm x 1.2cm,
GKA: 4.2cm x 1.2cm
KGA: 3.2cm x 1.2cm

Stolz et al., SuST 33(5), 055002, doi: 10.1088/1361-6668/ab78ba

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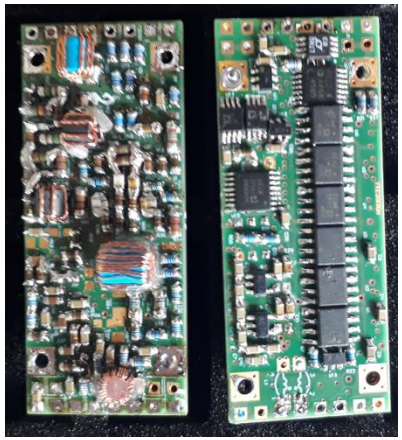
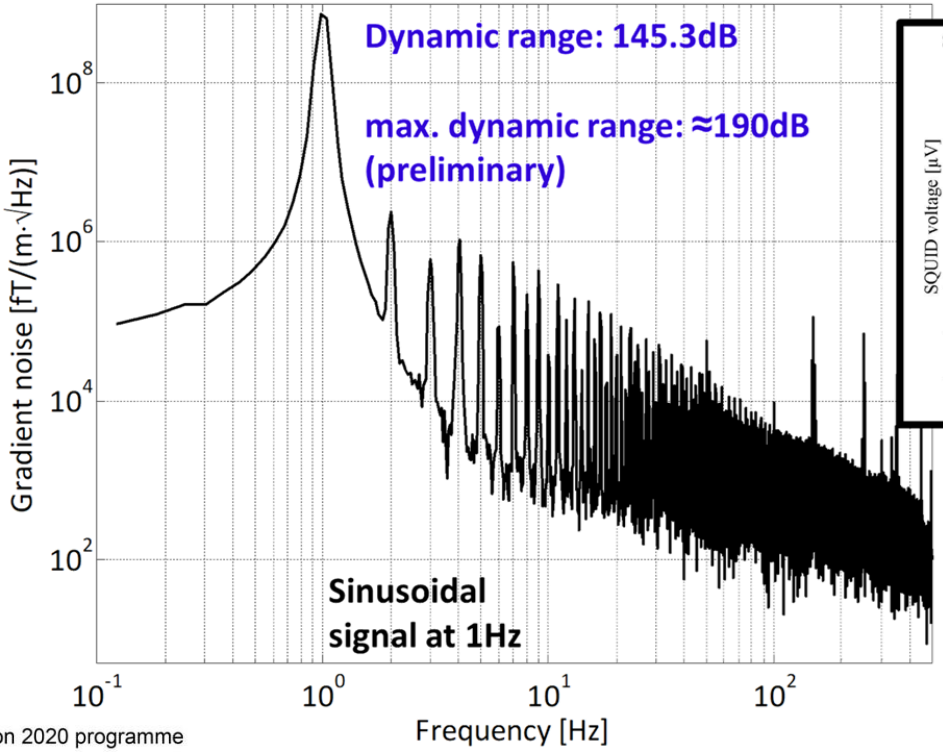
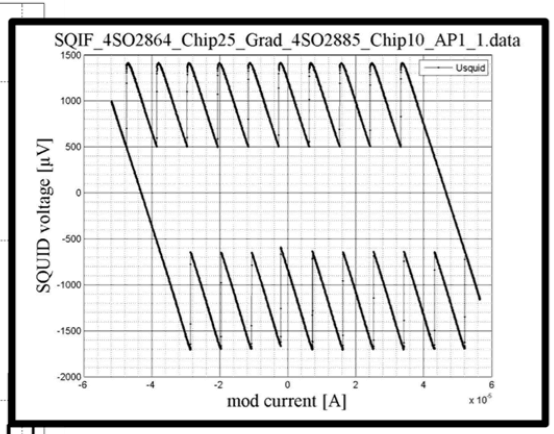
Results: SQUID electronics

- hybrid readout of analogue SQUID with digital output implemented and stable operation proven; sensor dynamic ranges of $> \mathbf{32bit}$ achieved;
  1MHz sample rate with real-time processing and decimation to 32kHz,
- maximum slew rate increased to about $\mathbf{1.5\,M\Phi_0/s}$,
- measured system noise: $< \mathbf{10}\,\boldsymbol{fT/\sqrt{Hz}}$ and $< \mathbf{50}\,\boldsymbol{fT/(m\cdot\sqrt{Hz})}$
  magnetometer gradiometer.







Example: measurement with AMTEG gradiometer.

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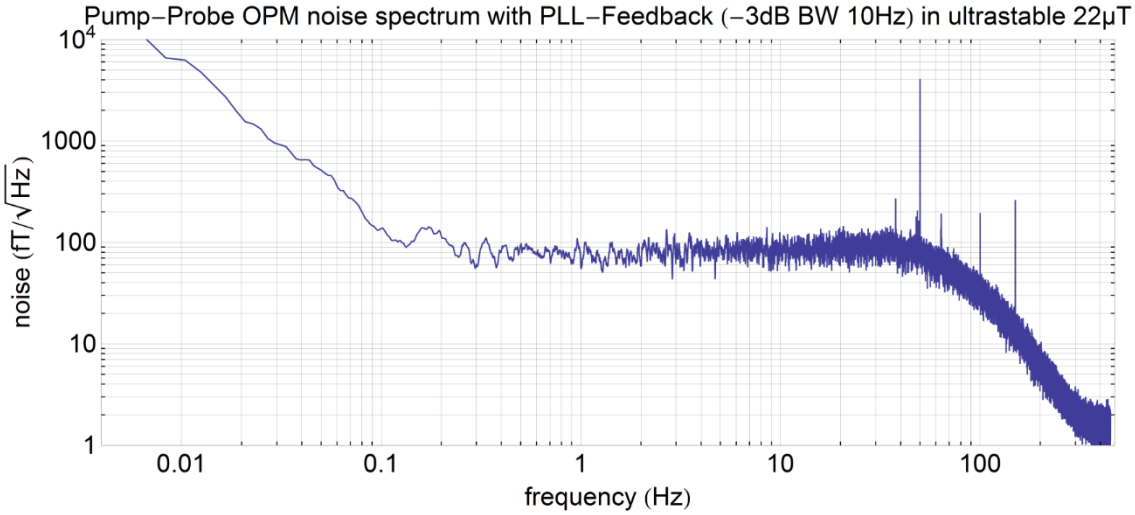
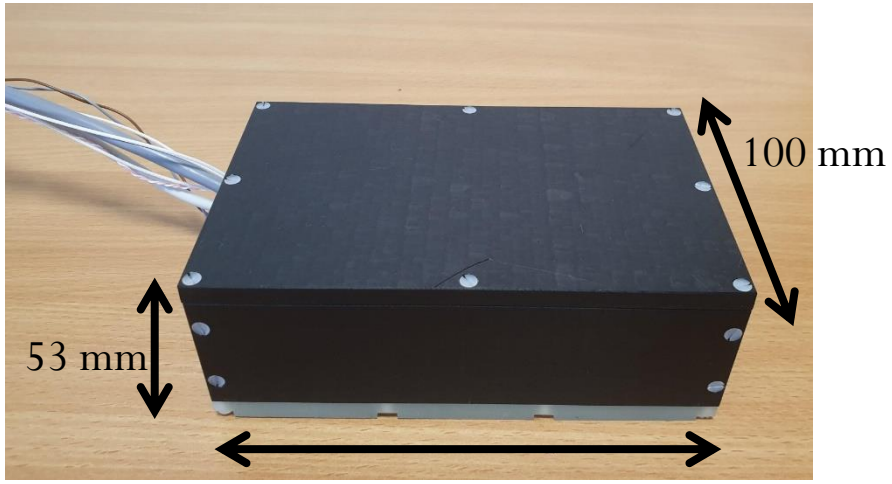
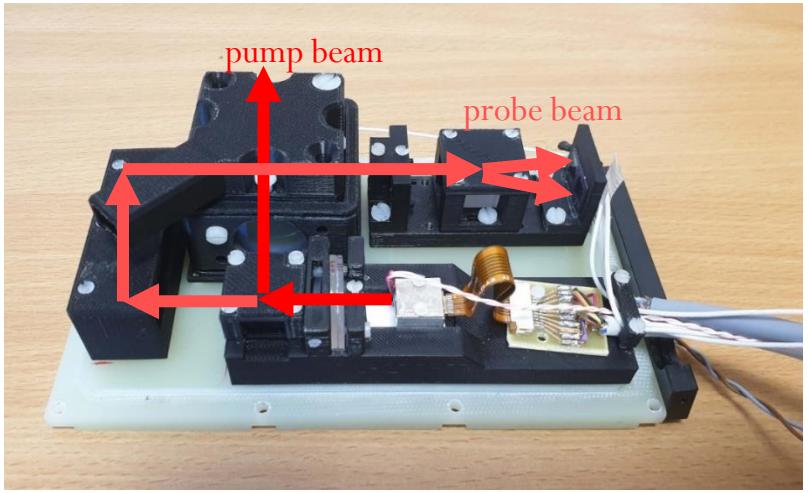
Results: OPM and electronics

- miniaturized, fully-integrated sensor head,
- tailored, compact, energy-efficient, battery-driven electronics unit,
- system noise $> 100\,\mathrm{fT}/\sqrt{\mathrm{Hz}}$,
- further optimization in a post-project phase required.







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Results: Data processing & interpretation

- new algorithms for motion noise compensation implemented, (GNSS path, fast attitude angle calculation, compensation),
- implementation of topography for inversion,
- advanced interpretation tools:
  - development of advanced FTMG inversion (voxel-based) with different options:
    - all five linearly independent elements of the magnetic gradient tensor alternatively **combination with total-field inversion** (better depth definition expected),
    - regularization with minimum support (MS) functional,
    - depth weighting with a weighting parameter of β=0.8.
    - footprint radius of 1 km (FTMG inversion) 10 km (FTMG and TMI combined)
  - application of EM based tools for advanced interpretation,
  - work on joint interpretation ongoing.

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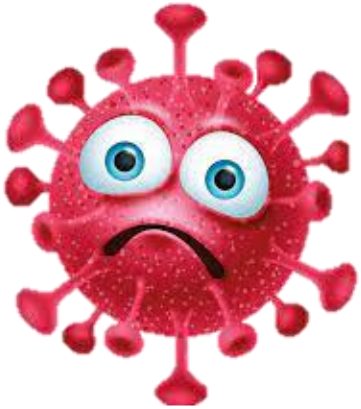
and the came Covid-19…



- no day to day work in presence
  - joint sensor and electronics development and testing strongly delayed,
  - system integration delayed (on top: no or very delayed availability of electronic components, delay in board fabrication and element placement),
  - delays in system integration,
  - field testing almost impossible,
- no travelling to Spain until April 2021
  - no field testing in the pyrite belt possible
  - Geognosia did detailed study of 3 areas under interest in Spanish pyrite belt,
  - Supracon and Leibniz-IPHT provided data acquired in Germany for development and test of advanced interpretation techniques,
- delays in project process:
  - main focus to test at Swedish target (NIO) using two separate instruments to demonstrate the performance of the envisioned combined instrument.

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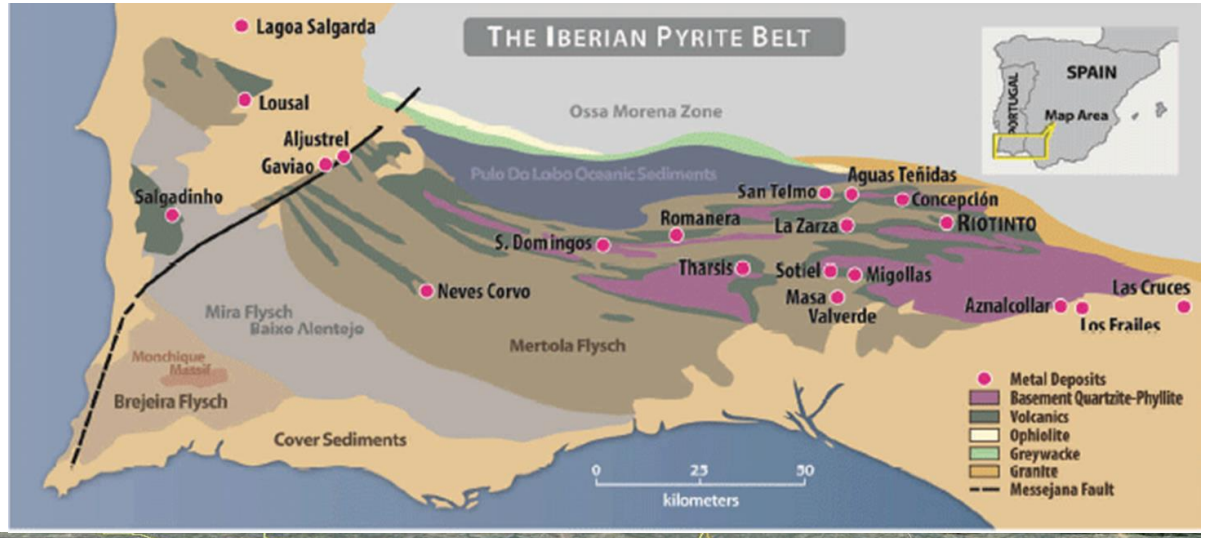
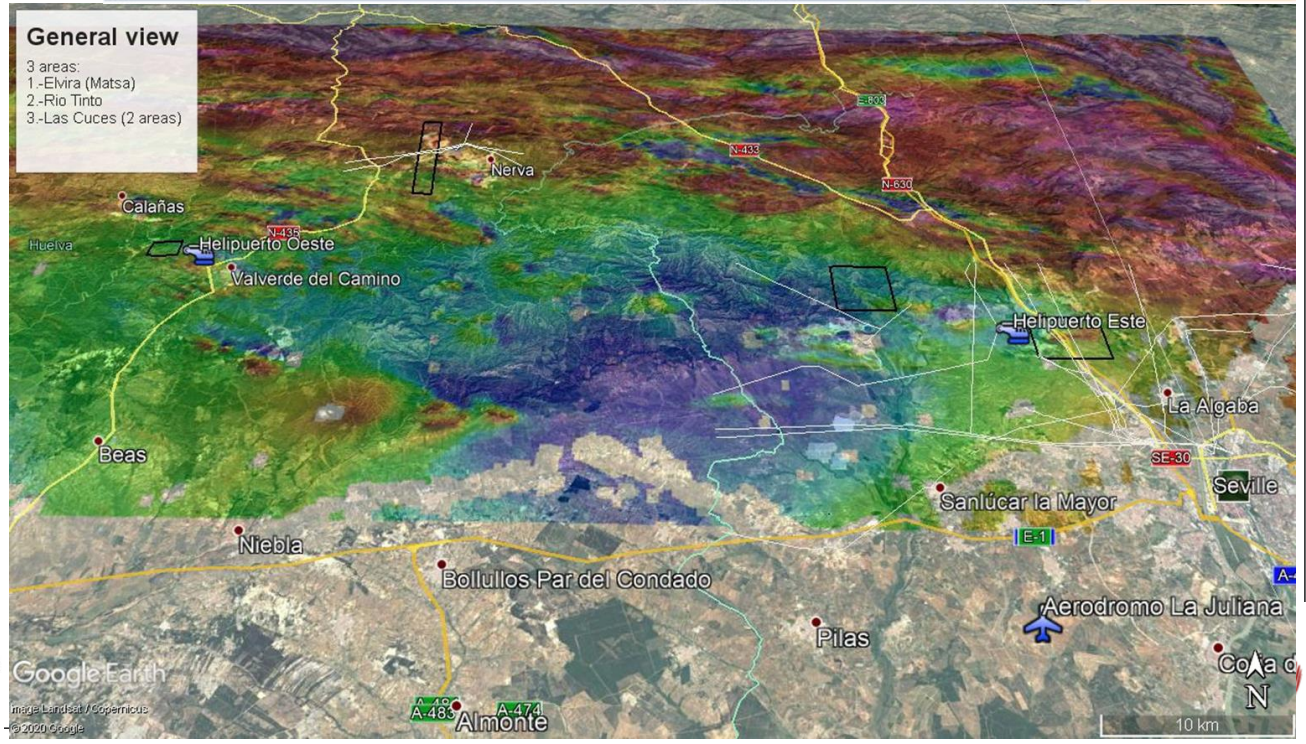
Demonstrations: Spanish pyrite belt

Test sites:

- **Rio Tinto** (one INFACT reference area; Supracon was project partner and has all details),
- **Las Cruces** area (also INFACT area),
- **Elvira** (Salgadinho): westernmost area in belt, investigated in several European projects.





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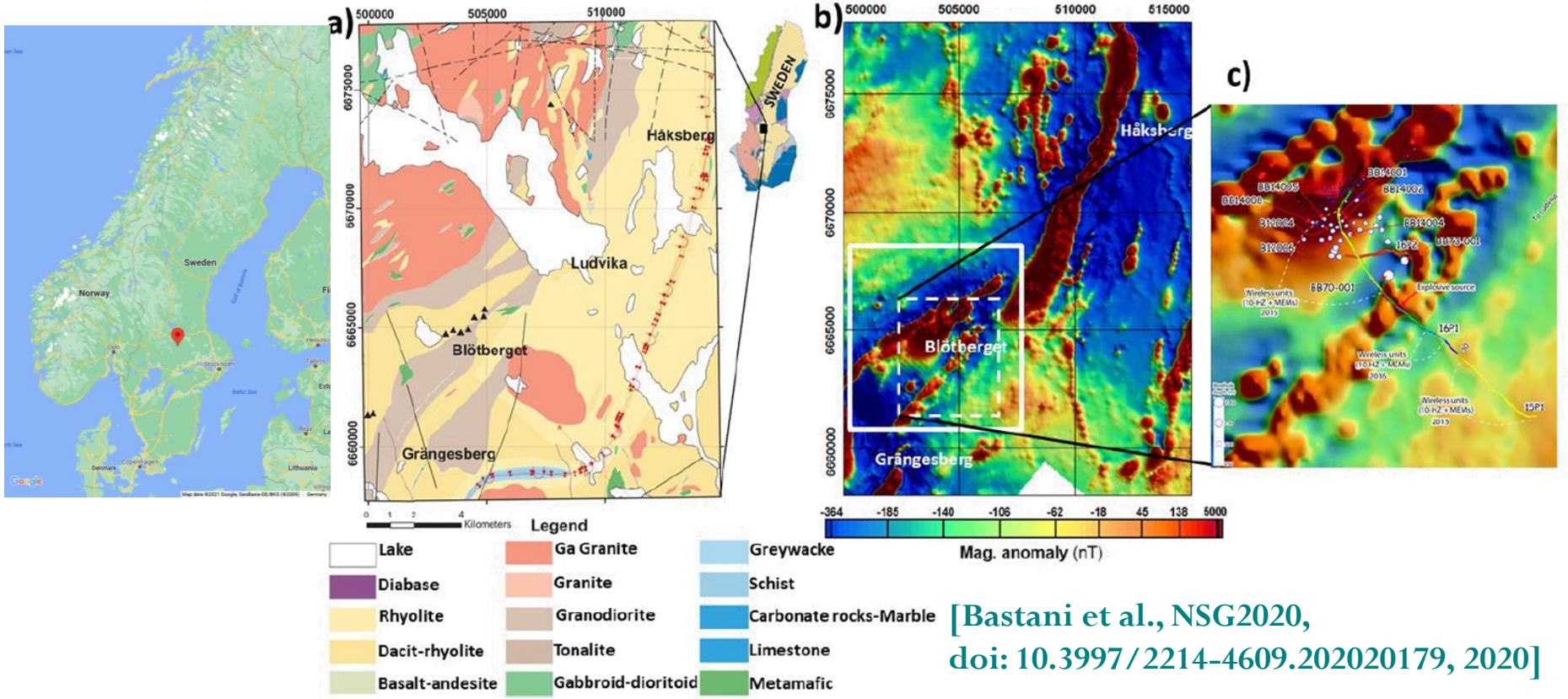
Demonstrations: Blötberget (Sweden)



[Bastani et al., NSG2020, doi: 10.3997/2214-4609.202020179, 2020]

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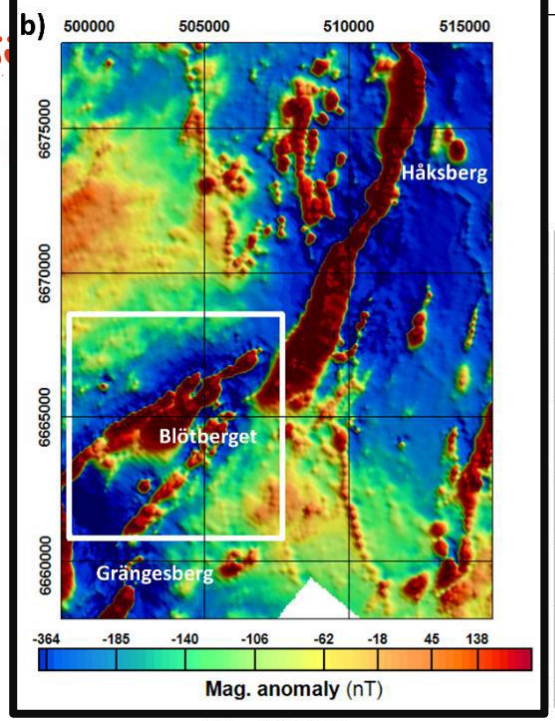
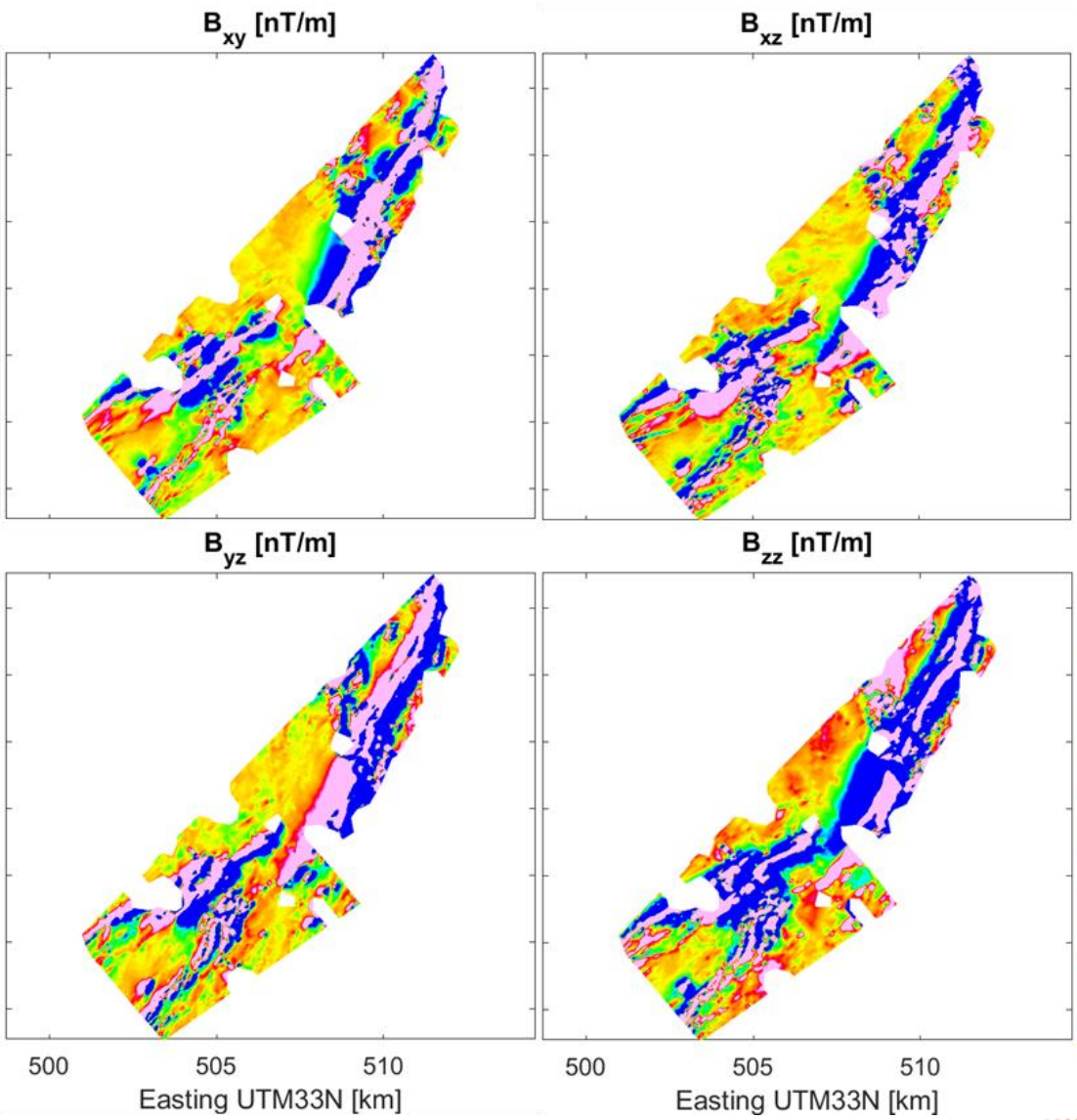
Demonstrations: Blötberget (III)

[Bastani et al., SAGA2019, 2019]





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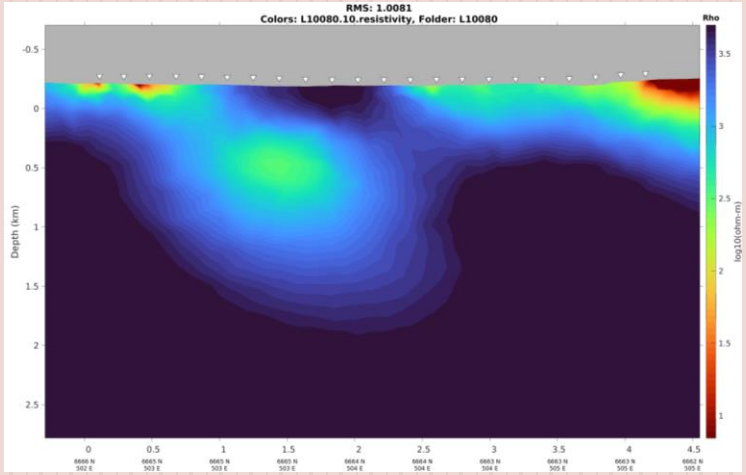
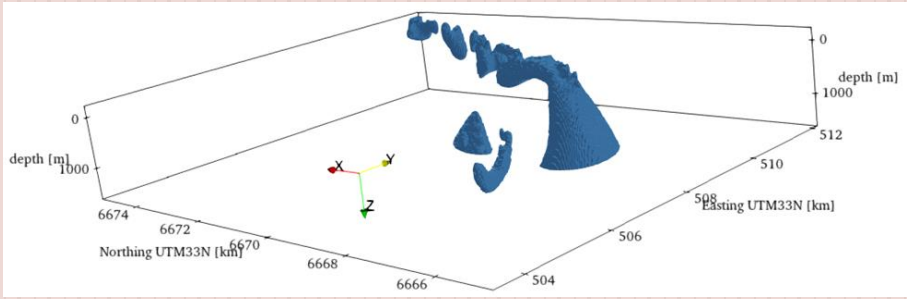
Demonstrations: Blötberget (III)

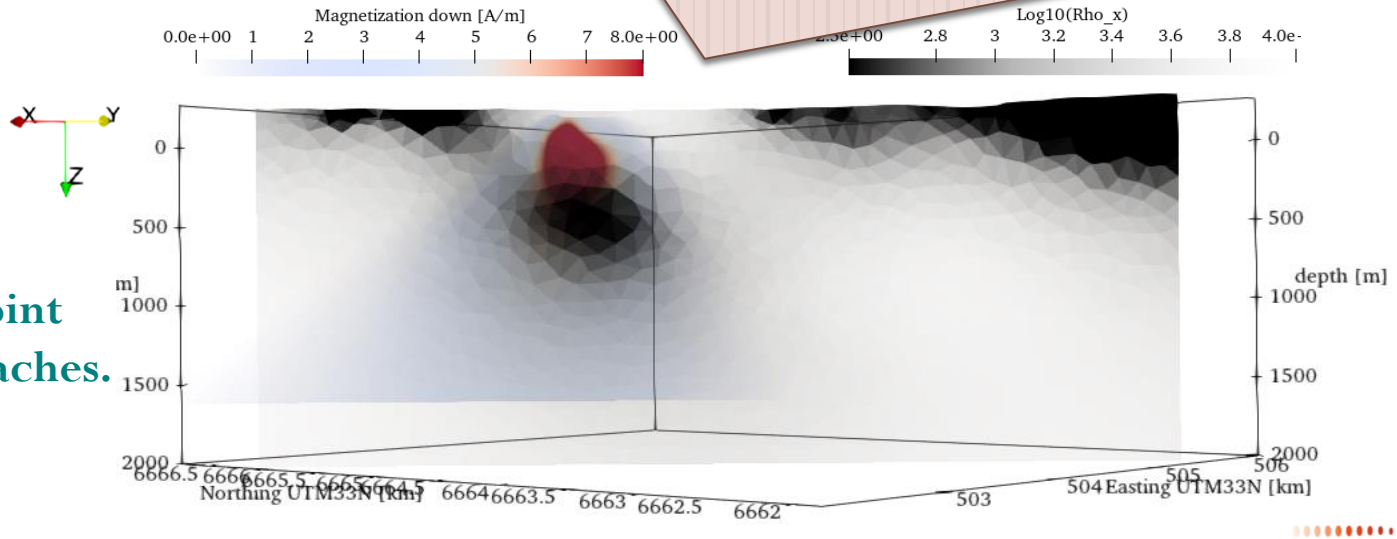


AFMAG: conductivity model (SQUID magn.).



FTMG (SQUID grad.) + TMI (later OPM) model of magnetic susceptibility (isocurves $M_{down} = 10$ A/m).

Homogeneous starting models without a priori information.



Joint model

- will resume in joint inversion approaches.

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Final Results

- all R&D topics towards a new multi-modal exploration tool (sensors, electronics, platform, IMU, data processing and interpretation, navigation tools) successfully performed,
- in accordance with funding agencies, the project goals were adapted due to pandemic situation
  - **no change of impact expected**
- Demonstration of the new AMTEG tool over real target at depth in Sweden,
- Outputs:
  - conferences with number of invited talks e.g. to ISS2019, ISEC2019, Cryogenic detector Workshop 2020,
  - publication: R. Stolz et al. (2020) Superconductor Science and Technology 33(5), DOI: 10.1088/1361-6668/ab78ba,
    R. Stolz et al. (2021) Superconductor Science and Technology 34(3), DOI: 10.1088/1361-6668/abd7ce,
- Communication and dissemination activities: presentations at PDAC2019, 2020, Raw Materials Week 2019 and SEG2021 as well as meetings with future customers (e.g. BGR, Southern Geoscience Consultant, Valé, etc.).

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Impact

- Lessons learned from the project period:
  - European cooperation works properly,
  - collaboration smoothly running until project end in October 2021,
  - deviations from project planning mainly caused by Corona pandemic,
  - as usual work left to be done within the phase of product development,
- New method discussed with scientific community especially AFMAG results and will be implemented in supracon's portfolio (industry) as well as the AMTEG system.

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