

The GREENPEG project toolset to explore for buried pegmatites hosting lithium, high purity quartz, and other critical raw materials



Axel Müller and the GREENPEG consortium

GREENPEG challenges pegmatites

GREENPEG project factsheet

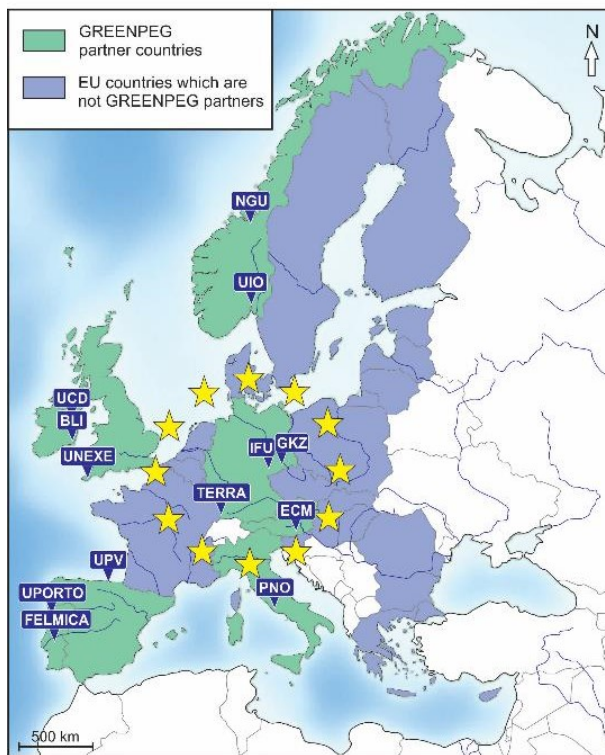


Title: GREENPEG: New exploration tools for European pegmatite green-tech resources

EU program frame: Horizon 2020 Climate action, environment, resource efficiency and raw materials

Duration: May 2020 to October 2024

Total costs: 9,248,355 EUR



- 1 University of Oslo
- 2 University of Dublin
- 3 Terratec Geophysical Services GmbH
- 4 GeoKompetenzZentrum Freiberg e.V.
- 5 Blackstairs Lithium Ltd.
- 6 Geological Survey of Norway
- 7 Institut für Umweltanalysen GmbH
- 8 University of the Basque Country
- 9 University of Exeter
- 10 European Lithium AT
- 11 University of Porto
- 12 Felmica Minerai Industriais
- 13 Ciaotech - PNO Innovation BV



Website:

<https://www.greenpeg.eu>



TARGET of the developed exploration toolset

Critical Raw Materials (**Li, Si**, REE, Be, Ta) for the green energy shift enriched in **pegmatite type deposits**.

Pegmatites are small (<5 million m³) but occur in large numbers and clusters in Europe, allowing exploitation with little investment. But they are hard to discover if buried.

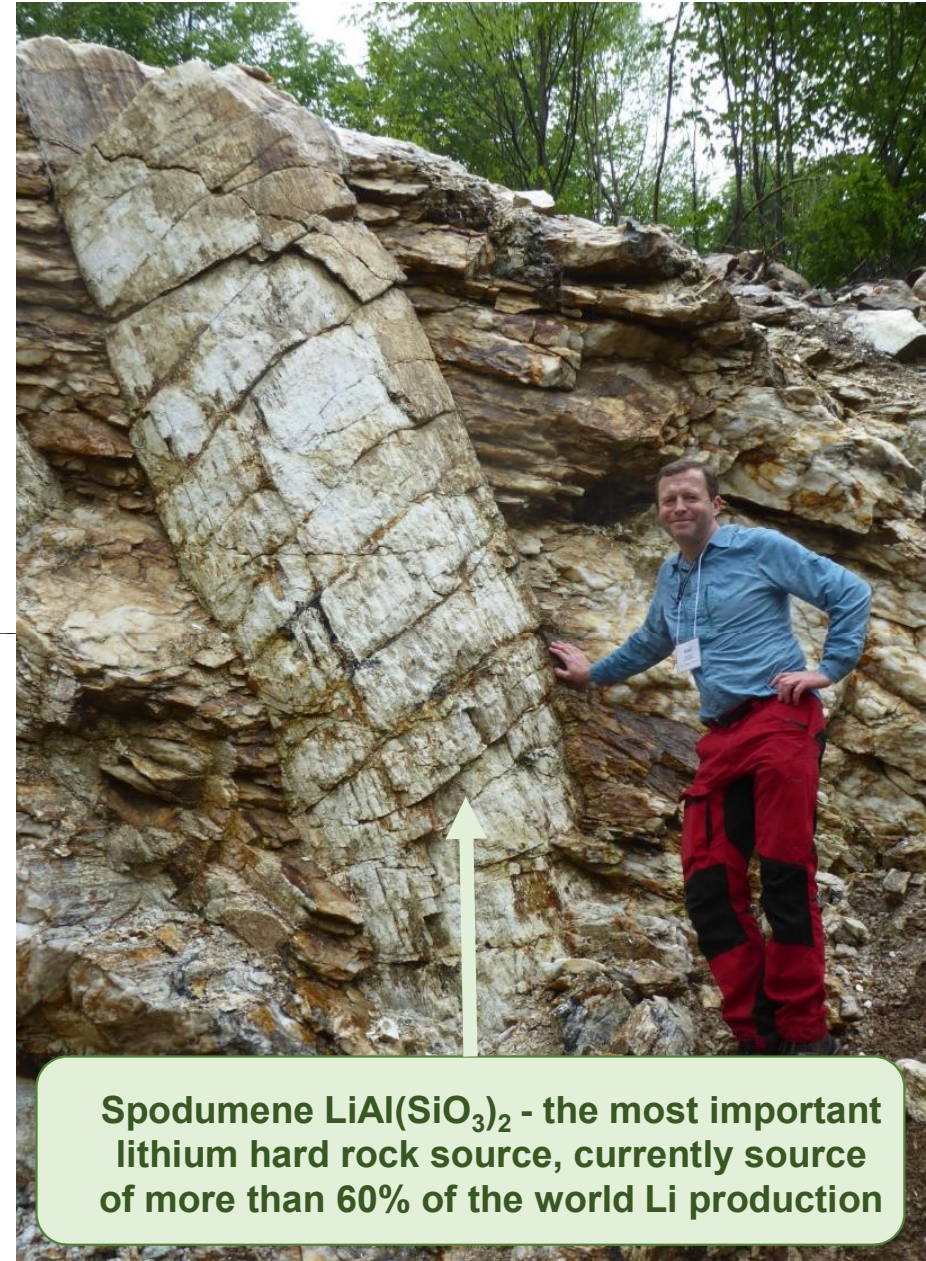
OBJECTIVES Exploration 'made in Europe'

GREENPEG projects developed an exploration approach for the identification of buried pegmatite ores in the form of a

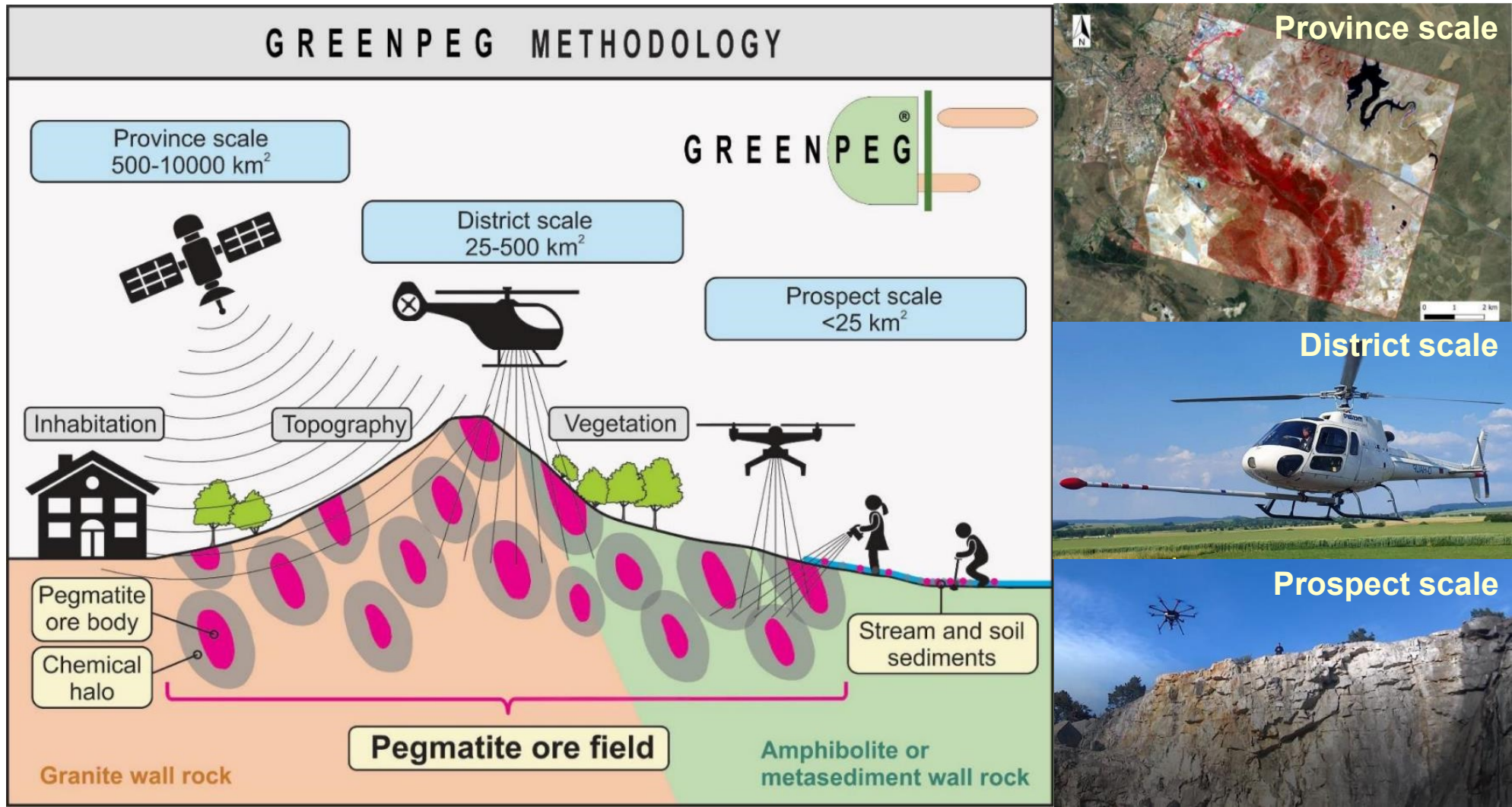
multi-method and environmental-economically viable TOOLSET

including:

- **three new instrumental exploration devices**
- **two new exploration datasets and workflows**



GREENPEG multi-scale approach of method testing and verification



GREENPEG demonstration sites



Different European conditions (topography, vegetation, soil cover, climate, inhabitation) for verification of the toolsets



Tysfjord, Norway

25 NYF pegmatites with 25 wt% HP quartz



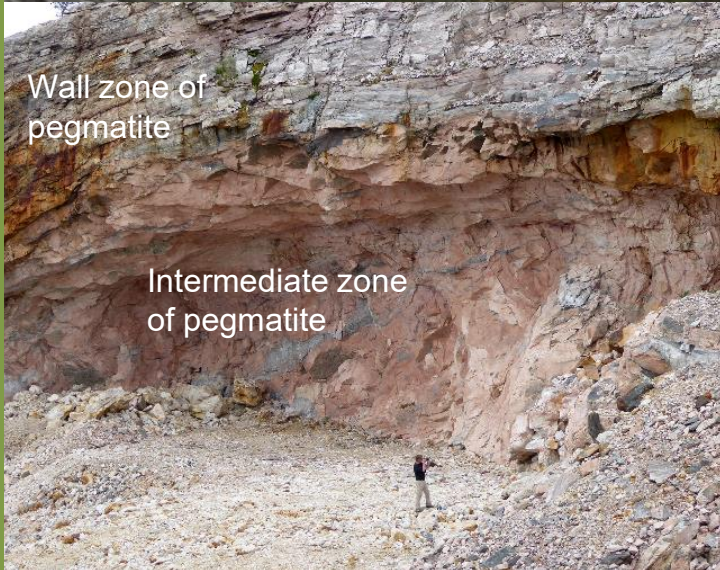
Leinster, Ireland

22 LCT pegmatites @ 1 wt% Li₂O



Wolfsberg, Austria

12 LCT pegmatites 13 Mt @ 1.5 wt%Li₂O



Wall zone of pegmatite

Intermediate zone of pegmatite



GREENPEG's new instrumental exploration devices



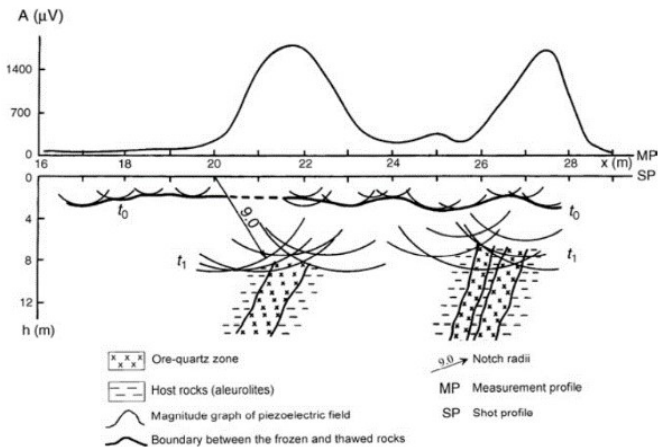
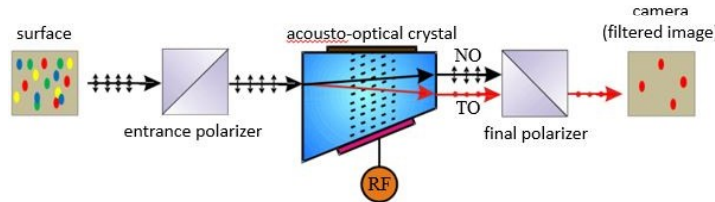
Piezoelectric seismograph
Geological Survey of Norway

Drone-borne hyperspectral imaging system (acousto-optical monochromator)
IFU Institut für Umwelttechnik GmbH

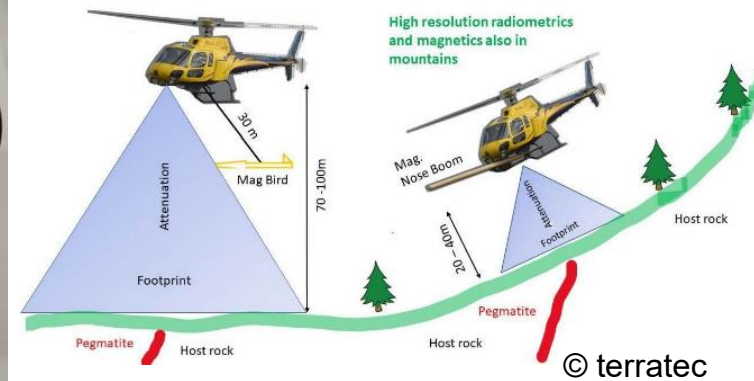
EASA-certified, helicopter-compatible nose stinger magnetometer/radiometer
terratec Geophysical Services GmbH



PE unit, v2.0



© IFU Institut für Umwelttechnik GmbH

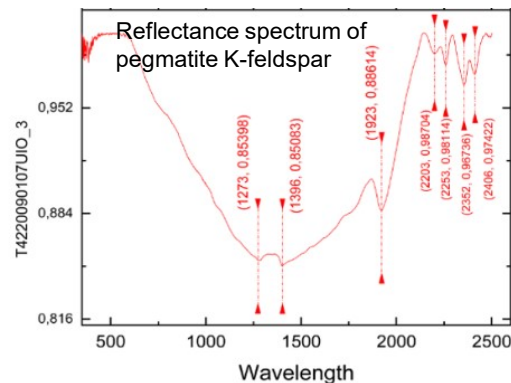


GREENPEG-established petrophysical database of European pegmatites and their host rocks



Spectral library of European pegmatites, pegmatite minerals and pegmatite host rocks

The database comprises laboratory- and field-obtained reflectance spectral data of European pegmatite ores and their wall rocks for satellite image processing.



Cardoso-Fernandes et al. (2022)
<https://doi.org/10.5281/zenodo.6518319>



Petrophysical database EuroPeg of European pegmatites and their host rocks

The database compiles petrophysical parameters of European pegmatite ores and their wall rocks to supplement geophysical surveys and deposit modeling which is crucial for the right choice of methods and, thus, saving time and money.



Database: Haase et al. (2022)
<https://zenodo.org/records/7347371>



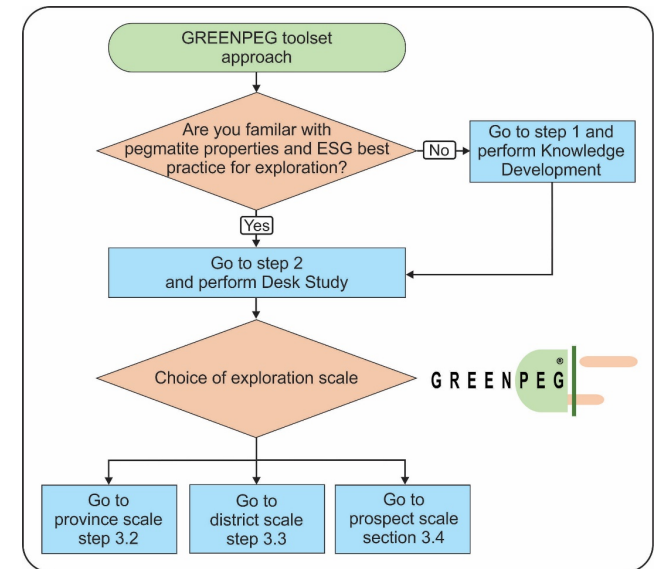
Publication: Haase and Pohl (2022)
<https://www.mdpi.com/2075-163X/12/12/1498>

The structure of the GREENPEG toolset



Knowledge development	State-of-the-art in pegmatite definition and genetic models, and ESG best practice in exploration		
Desk study	<p><i>Geological environment:</i></p> <ul style="list-style-type: none"> • Understanding of the geological and geographical setting • Analysis of available datasets • Application of the mineral systems approach <p><i>Exploration environment:</i></p> <ul style="list-style-type: none"> • Analyse the logistical, political, environmental and social environments and requirements • Develop a community relations strategy • Combine mappable desk study information using GIS <p><i>Financial environment:</i></p> <ul style="list-style-type: none"> • Evaluate financial limitations on which methods can be applied 		
Choice of exploration scale	Province scale	District scale	Prospect scale
Choice of exploration methods at respective scale	<ul style="list-style-type: none"> • Choose method/method combinations • Quantify number and duration of activities for each method • Assess ESG impacts of the methods and perform regularly review of community strategy • Order of exploration activities • Performance of methods 		
Implementation and data integration	<ul style="list-style-type: none"> • As results are obtained, review and revise forthcoming methods • Integration of desk study and exploration results • Review ESG requirements 		

Müller et al. (2024 in review)



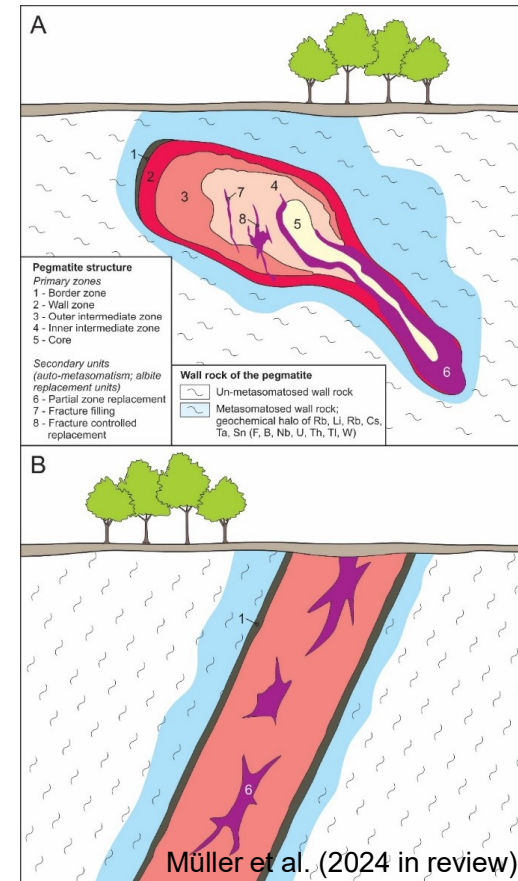
1. Knowledge development - Examples



Ore definition – genetic types and occurrences of pegmatites in Europe



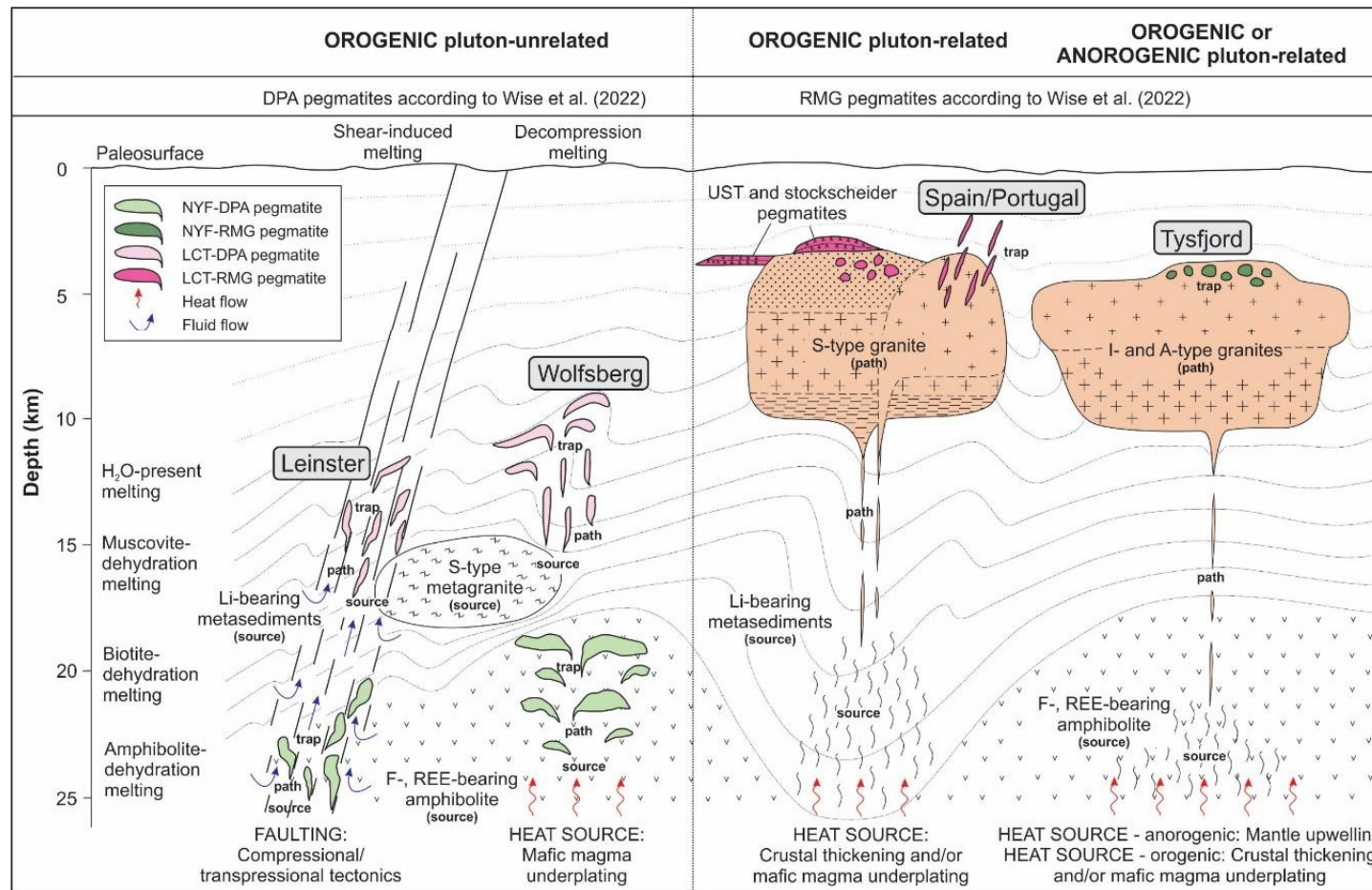
Ore definition – shape and zoning of pegmatites and geochemical halos



Müller et al. (2024 in review)

2. Desk study – Geological environment

Mineral systems approach applied to pegmatite deposit formation



Trap
(Modification)

Pathway

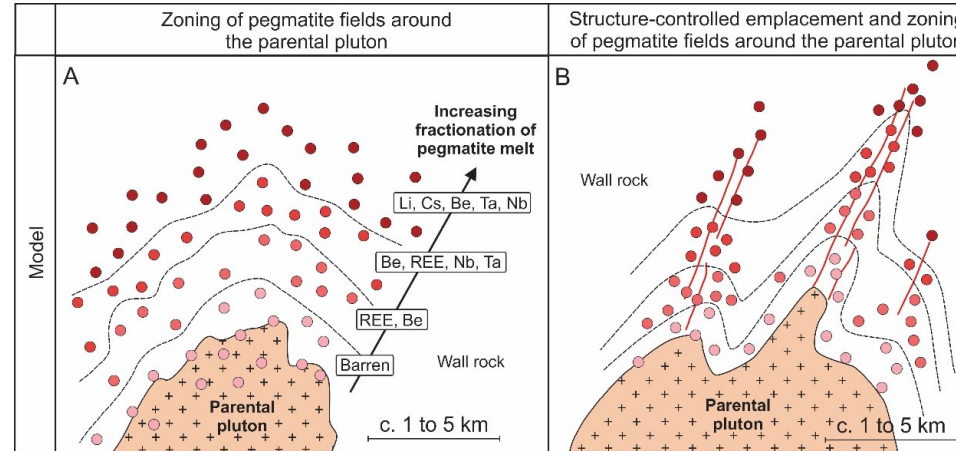
Source

Müller et al. (2022)

2. Desk study – Geological environment

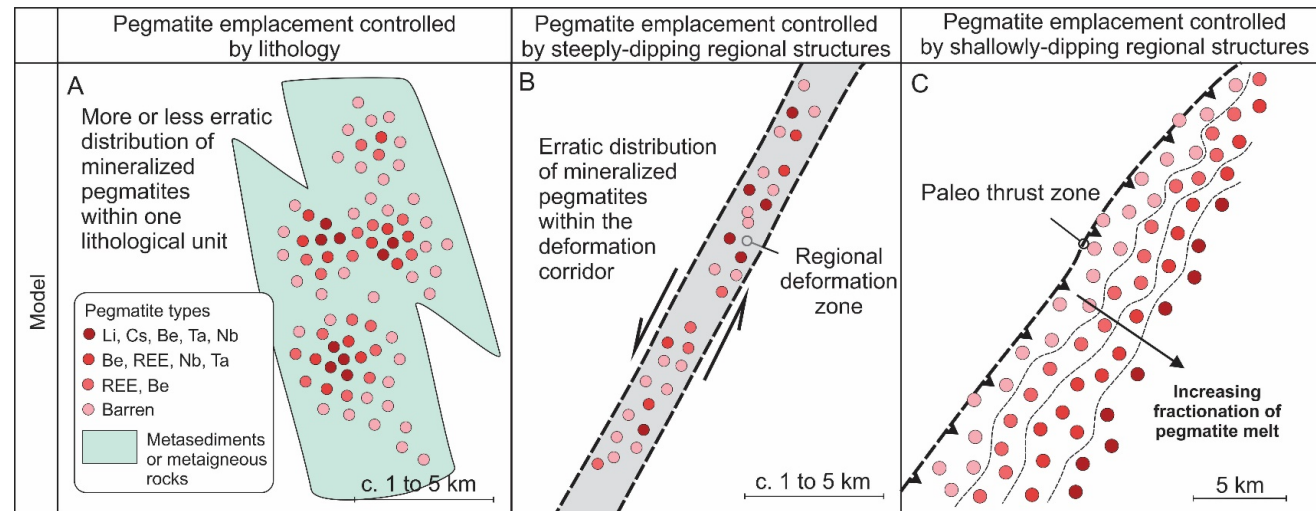
Geological environment and mineral systems approach

Regional zoning of pluton-related pegmatite fields (RMG)



Černý et al. (1991)

Regional zoning of pluton-unrelated pegmatite fields (DPA)

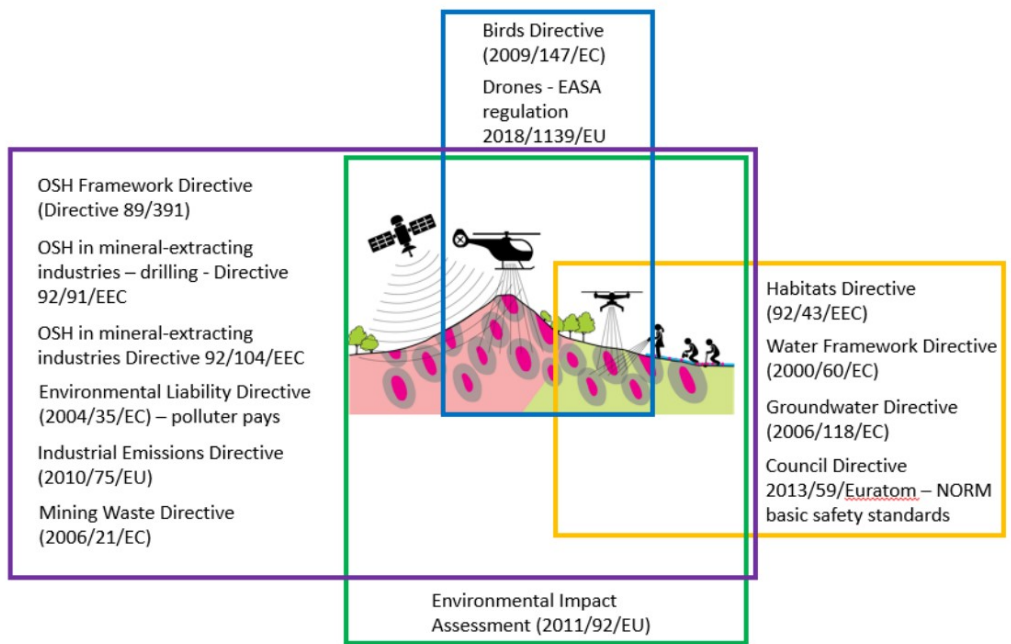


Müller et al. (in review)

2. Desk study – Exploration environment

Analysis of the logistical, political, environmental and social environments and development of community relations strategy

EU legislations and directives applicable to exploration activities – environmental and social impacts



Application of standards for responsible exploration



PROSPECTORS &
e3 Plus: A Framework for Responsible Exploration

Environmental Stewardship	Health & Safety	Social Responsibility
The Excellence in Environmental Stewardship (EES) e-toolkit promotes environmental awareness and the resulting responsibility in the exploration phase.	The Excellence in Health & Safety (EHS) e-toolkit addresses general safety principles, emergency response, survival, weather & environmental risks and much more.	The Excellence in Social Responsibility (ESR) e-toolkit helps to promote governance, project due diligence, community engagement, community development, ethical conduct, boundaries of responsibility and human rights.

Modified from Keith-Roach et al. (2016)

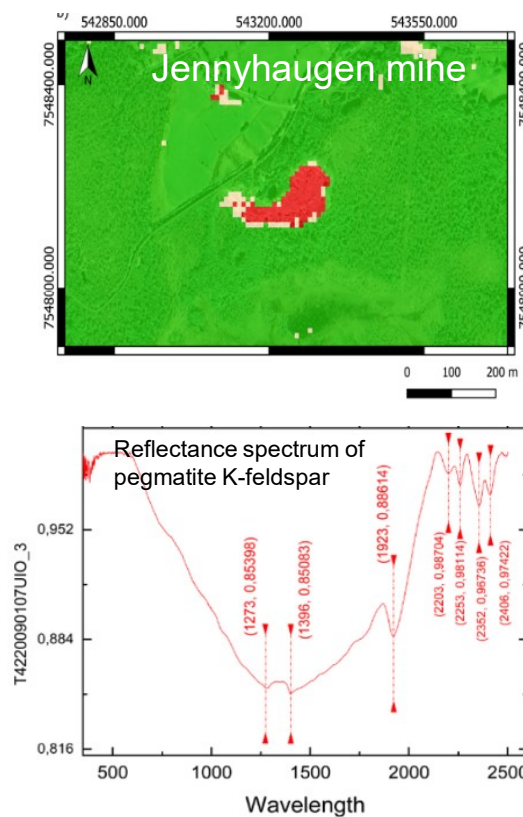
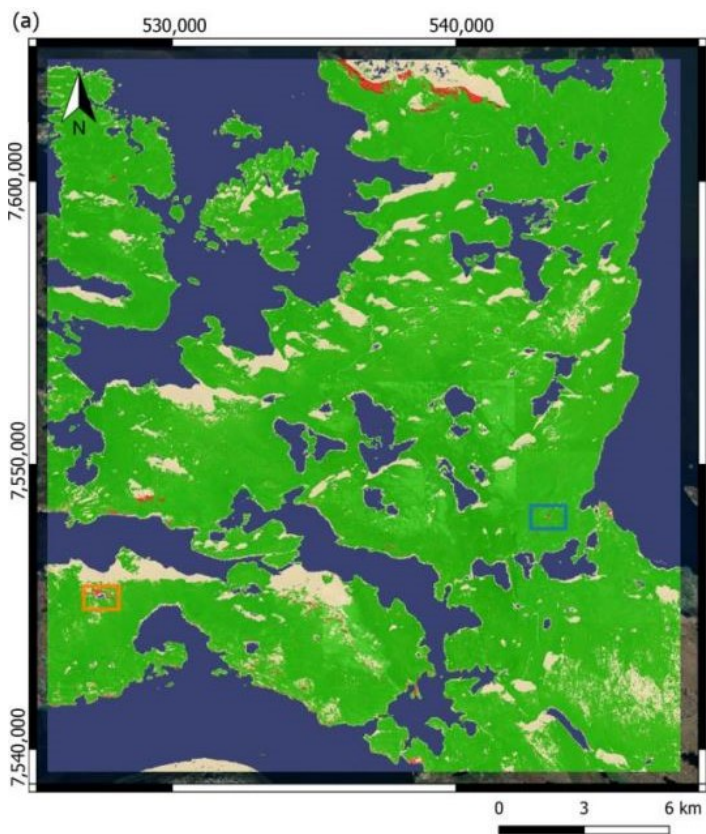
3. Choice of exploration methods (GREENPEG Expert Group)

Exploration services and expertise of toolset application will be offered by the GREENPEG expert group through <https://www.greenpeg.eu> adjusted by end October 2024.

Scale	Exploration method validated	Service contact/provider
Province scale (500 - 10,000 km ²)	Spectral identification of outcropping pegmatites	University of Porto, c/o Ana Teodoro
	Morphological identification of pegmatites using LIBS	University of Porto, c/o Alexandre Lima
	Remote-sensing-supported analysis of regional structures	University of Porto, c/o Ana Teodoro
	Spectral library of pegmatite ores and their wall rocks	Online: https://doi.org/10.5281/zenodo.6518319
District scale (25 - 500 km ²)	Airborne high-resolution magnetics with nose stinger	terratec Geophysical Services GmbH & Co. KG
	Airborne high-resolution radiometry with nose stinger	terratec Geophysical Services GmbH & Co. KG
	Airborne high-resolution electromagnetics	No service provided by GREENPEG
Prospect scale (<25 km ²)	Drone-borne radiometry	IFU GmbH Privates Institut für Umweltanalysen
	Drone-borne hyperspectrometry	IFU GmbH Privates Institut für Umweltanalysen
	Electric Resistivity Tomography: Resistivity and Induced Polarization	Terratec Geophysical Services GmbH & Co. KG
	Ground magnetics	terratec Geophysical Services GmbH & Co. KG
	Ground spectral radiometry	IFU GmbH Privates Institut für Umweltanalysen
	Ground penetrating radar	Geological Survey of Norway, c/o Marco Brønner
	Ground gravimetry	terratec Geophysical Services GmbH & Co. KG
	Piezoelectric seismograph	Geological Survey of Norway, c/o Marco Brønner
	Geological mapping	No service provided by GREENPEG
	Prospect scale structural analysis	Geological Survey of Norway, c/o Kerstin Saalman
	Whole rock geochemical mapping	No service provided by GREENPEG
	LIBS halo mapping	University of Porto, c/o Alexandre Lima
	Wall rock halo mapping using whole rock chemistry	No service provided by GREENPEG
	Trace-element-in-quartz mapping	University of Oslo, c/o Axel Müller
	Stream sediment geochemical mapping	University of Exeter, c/o Ben Williamson
	Soil A- and C-horizon geochemical mapping	University College of Dublin, c/o Julian Menuge
Borehole logging	terratec Geophysical Services GmbH & Co. KG	
Petrophysical database of European pegmatite ores and wall rocks	Online: https://doi.org/10.5281/zenodo.7347371	
All scales	Environmental, social and governance best practice in exploration	University of Exeter, c/o Kate Smith

3. Choice of exploration methods - Province scale (500-10,000 km²) Remote sensing – Spectral identification of outcropping pegmatites

Spectral identification of outcropping pegmatites through spectral band selection from Sentinel 2 satellite images treated by Random Forest and other tree-based ensemble algorithms



GREENPEG-established open-access database: Spectral library of European pegmatites, pegmatite minerals and pegmatite host rocks:



Cardoso-Fernandes et al. (2022)
<https://doi.org/10.5281/zenodo.6518319>

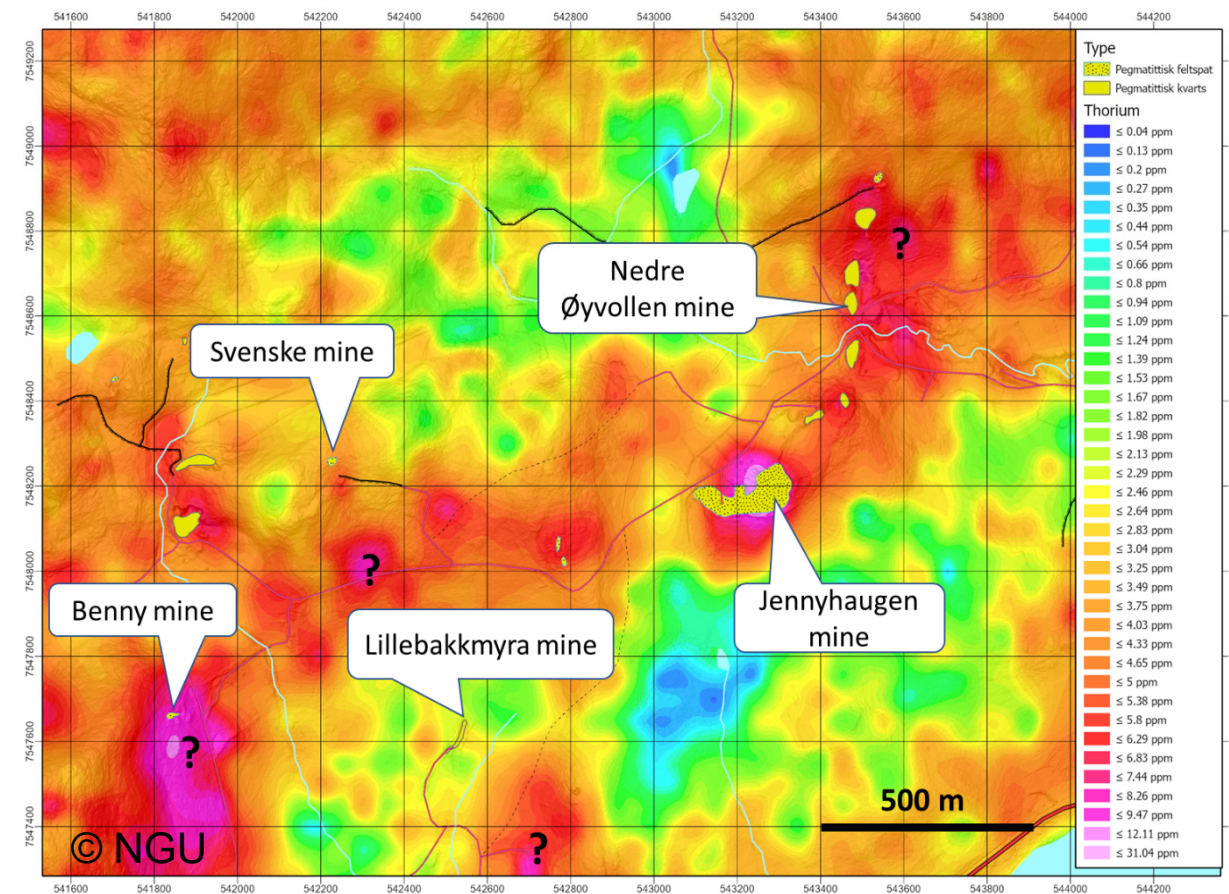
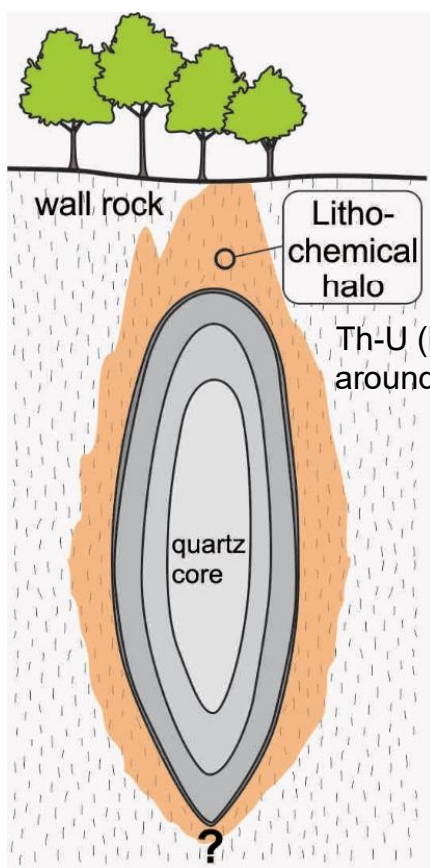
Santos et al. (2022, 2024 – in review)

3. Choice of exploration methods - District scale (25-500 km²)

Airborne radiometry



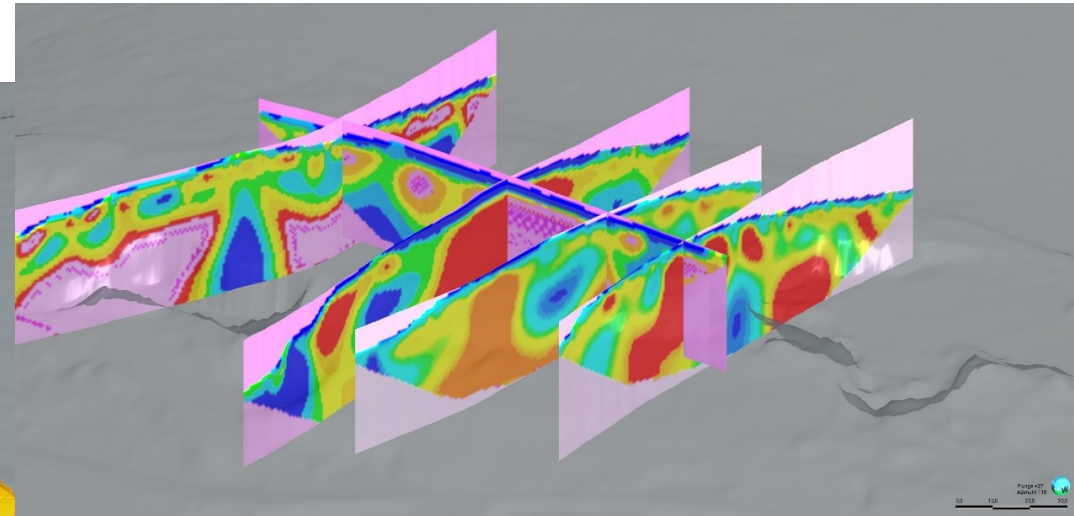
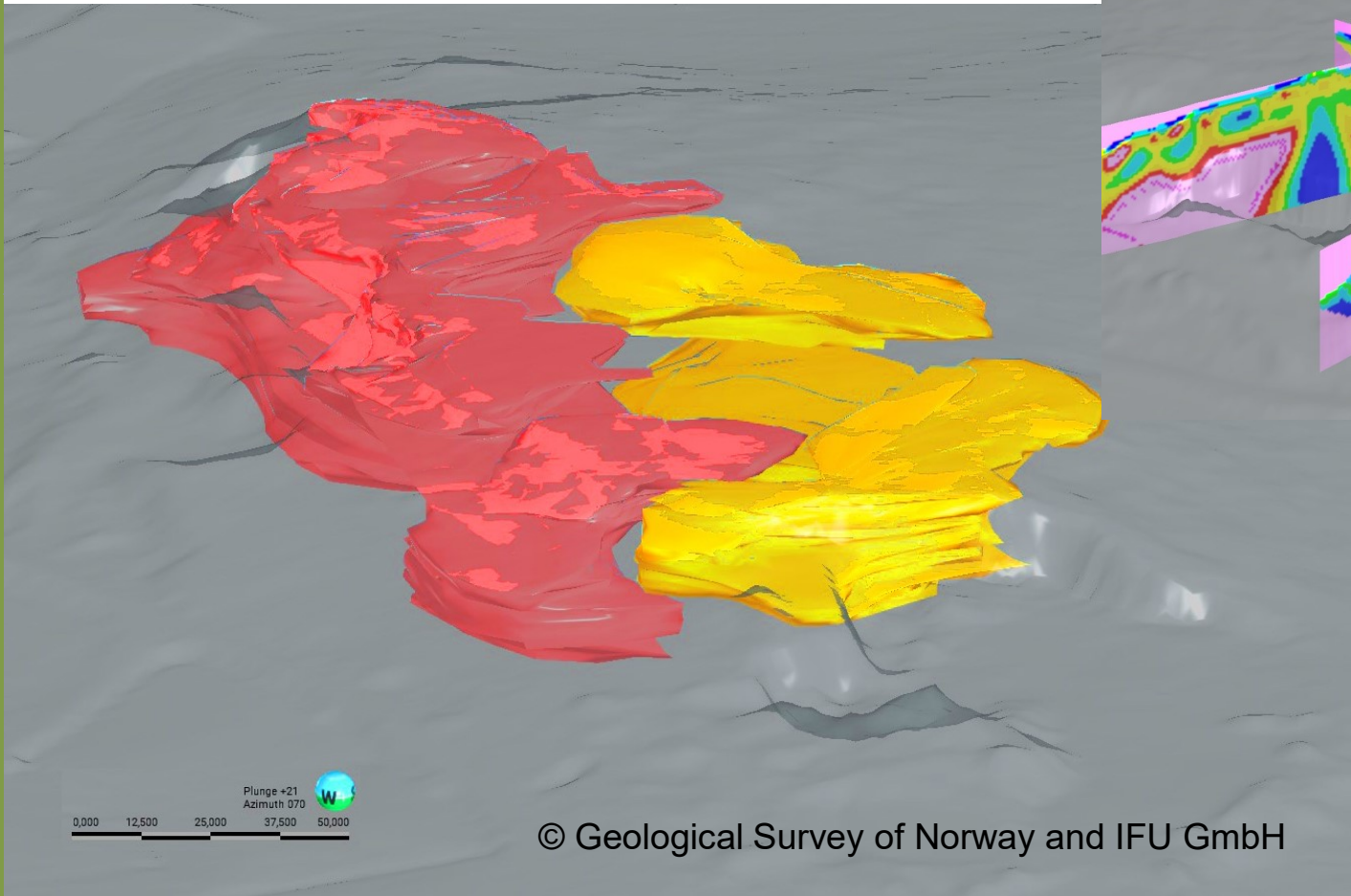
Airborne thorium signal map. **Flight line spacing 50 m** and flight altitude ~60 m using five crystals 16+4 liter RSX-5 gamma spectrometer mounted underneath the helicopter to map potassium, thorium and uranium.



3. Choice of exploration methods - Prospect scale (<25 km²) Electric resistivity tomography (ERT)



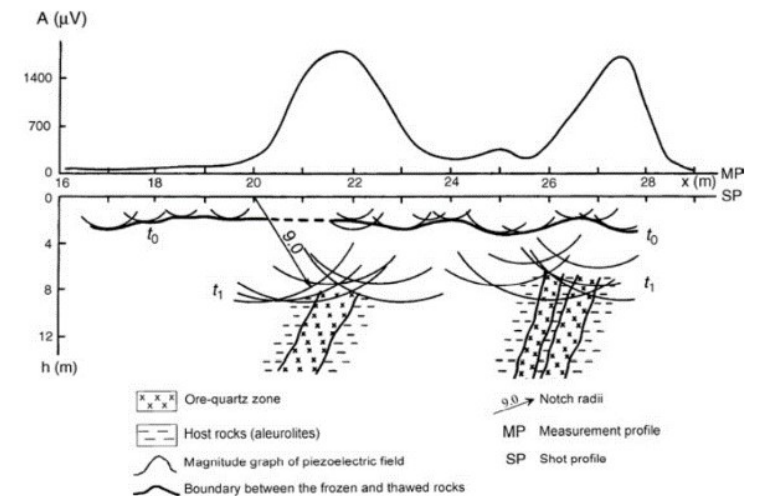
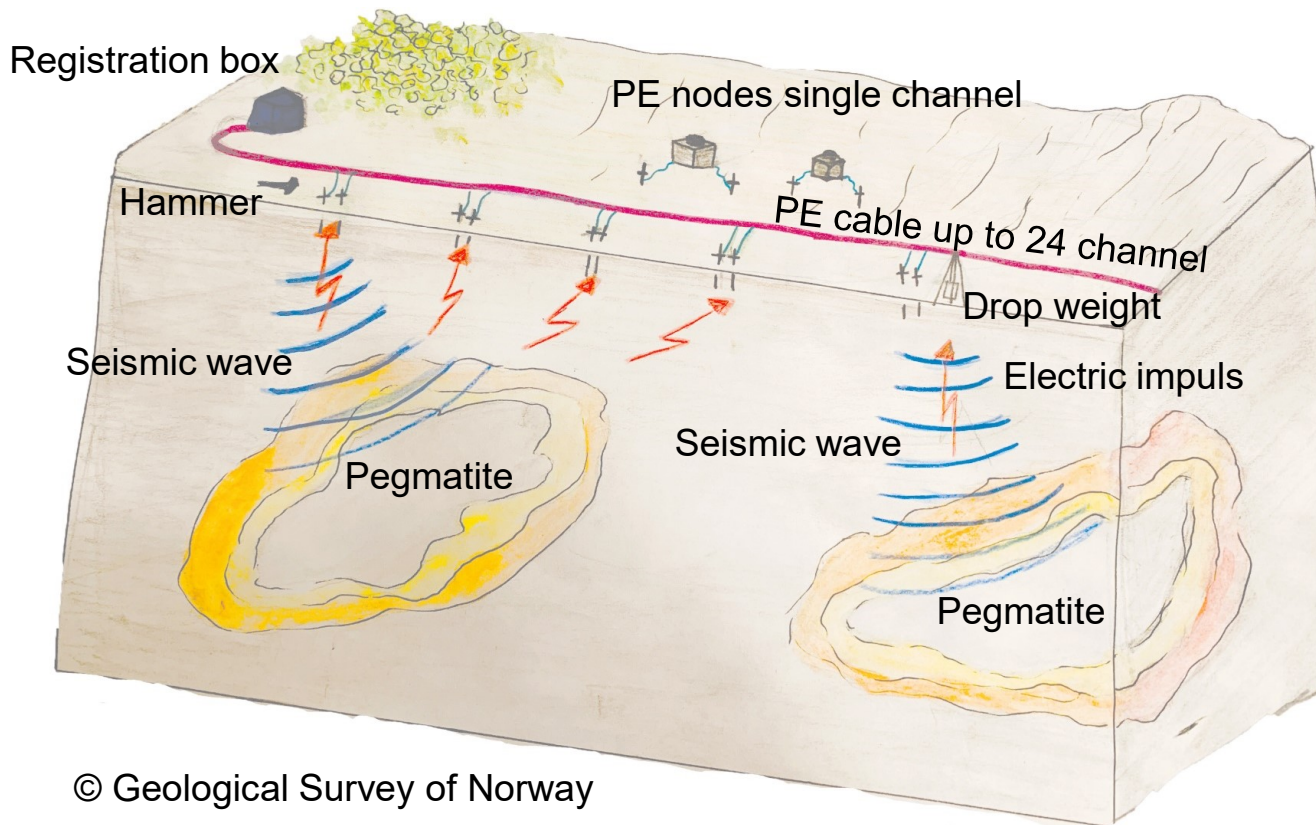
3D electric resistivity modeling Jennyhaugen hill
(with Leapfrog Geo)



3. Choice of exploration methods - Prospect scale (<25 km²) Piezoelectric seismograph



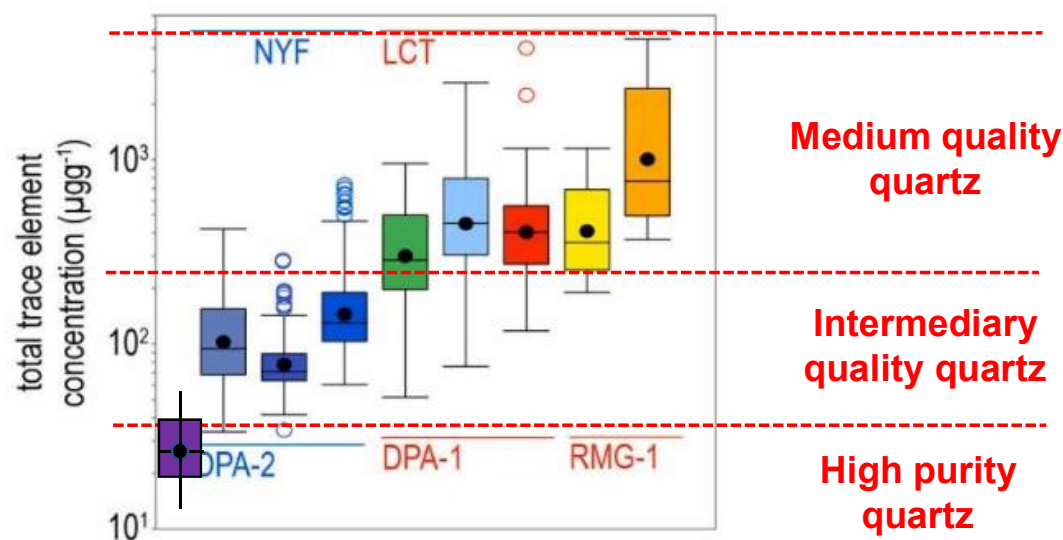
Source- receiver configuration: the seismic source should be close to at least one receiver



Neishtadt et al. (2006)

3. Choice of exploration methods – Province to prospect scale Trace-element-in-quartz mapping

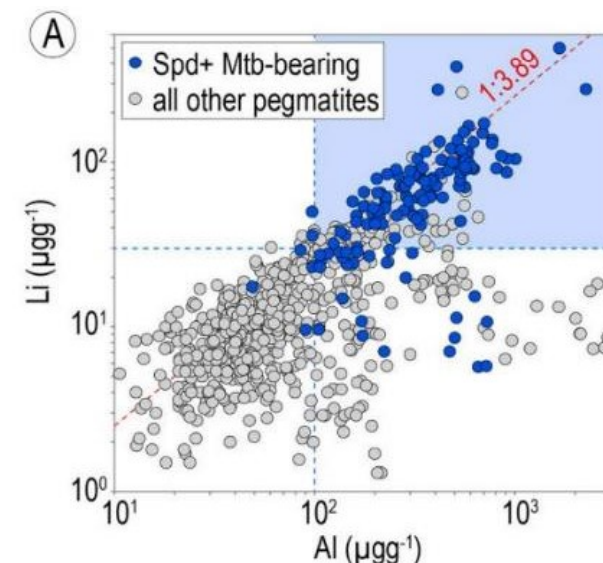
Chemical quality of quartz



- Locality
- Evje-Iveland, NYF/DPA-2
 - Borborema, LCT/DPA-1
 - Tres Arroyos, LCT/RMG-1
 - Froland, NYF/DPA-2
 - San Luis, LCT/DPA-1
 - Hagedorf-Pleystein, LCT/RMG-1
 - Tørdal, NYF/DPA-2
 - Oxford County, LCT/DPA-1
 - Tysfjord

Lithium exploration using quartz

>30 ppm Li in and >100 ppm Al in quartz indicates high potential of spodumene mineralization

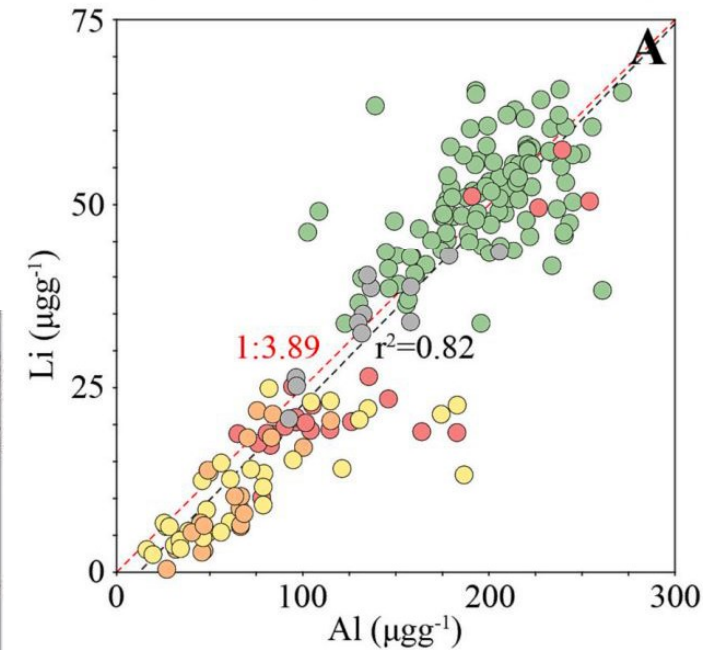
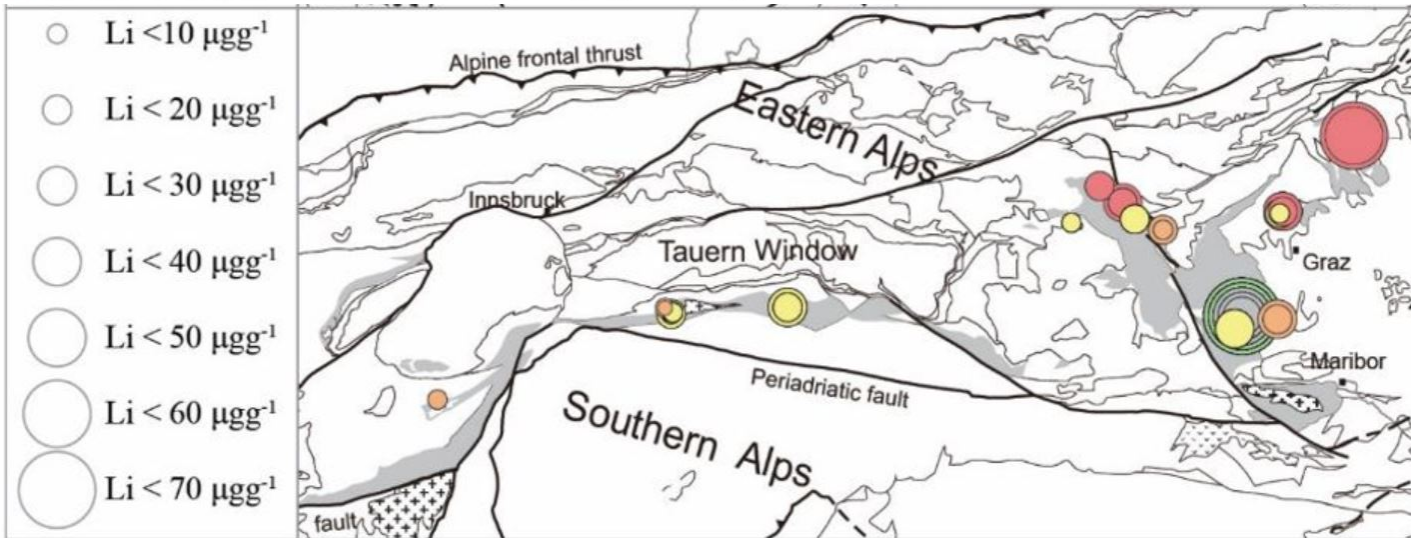
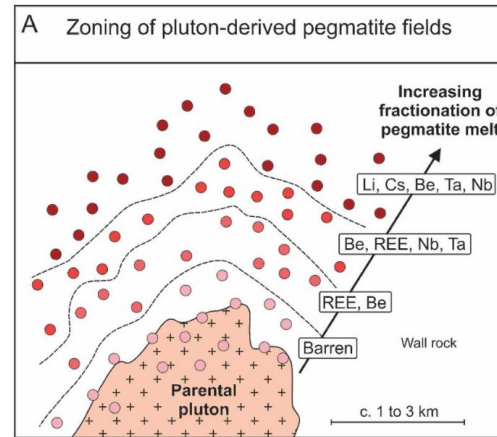


Müller et al. (2021)

3. Choice of exploration methods – Province to prospect scale Trace-element-in-quartz mapping

Quartz from Wolfsberg spodumene pegmatites contains >30 ppm Li + >100 ppm Al, indicative of significant Li mineralization; less the case for spodumene pegmatites elsewhere in Eastern Alps.

- simple pegmatite
- leucogranite
- mica schist host (Wolfsberg)
- spodumene pegmatite
- spodumene pegmatite (Wolfsberg)



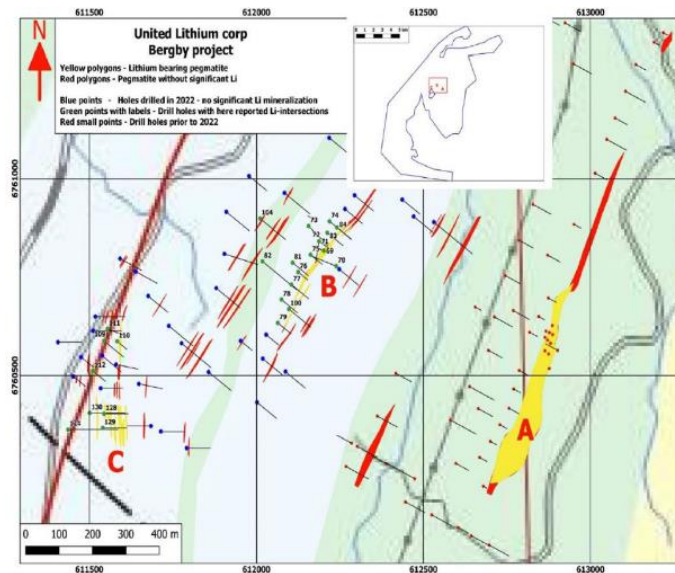
Keyser et al. (2023, 2024 in review)

New pegmatite discoveries in Europe through methodological support by GREENPEG



United Lithium Discovers Three New Spodumene Pegmatites – Drilling Returns 1.92% Li_2O over 26.8 m and 1.54% Li_2O over 28 m at Bergby, Sweden

Management to Host Webinar November 29th, 2023



Venue: Tranøy Lighthouse



GREENPEG Student Summer School Tysfjord, 19-30 June 2023



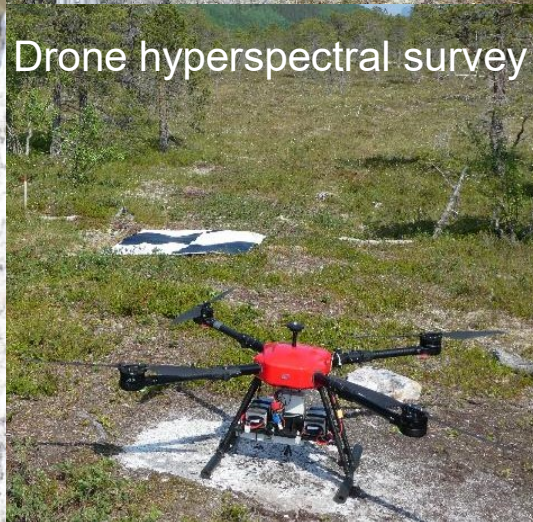
Handheld XRF measurements



GPR measurements



Drone hyperspectral survey





GREENPEG project published

(all publications are found on <https://www.greenpeg.eu>)

GREENPEG Project description:

„GREENPEG – exploration for pegmatite minerals to feed the energy transition: first steps towards the Green Stone Age“

GREENPEG Toolset description:

The GREENPEG toolset will be published by the end of 2024 in the thematic issue of *Economic Geology* “Lithium deposits and exploration” edited by Benson, T., Jowitt, S., Simon, A.

Open access:

<https://www.lyellcollection.org/doi/10.1144/SP526-2021-189>

