DISCOVERY

DISclosing the **C**ritical mineral potential resulting from pre- to post-**O**rogenic **V**ariscan g**E**ological histo**RY**

FRANCE 2030 — PROGRAMME DE RECHERCHE SOUS-SOL

29/01/2026

Authors

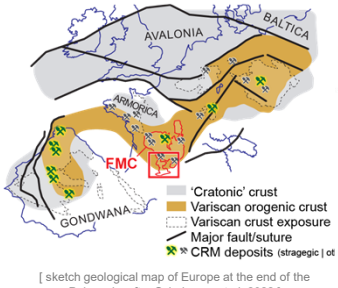
Oscar LAURENT, *CNRS-Géosciences Environnement Toulouse* / Laurent BECCALETTO, *BRGM Orléans* / Dominique CHARDON, *IRD-Géosciences Environnement Toulouse* / Caroline LOTOUT, *Université Clermont Auvergne* / Pierre BOUILHOL, *Université de Lorraine* / Matthieu HARLAUX, *BRGM Orléans* / Sophie LELEU, *INP Bordeaux* / Philippe BOULVAIS, *Université de Rennes* / Guillaume MARTELET, *BRGM Orléans* / Stéphane MARC, *BRGM Orléans*

DISCOVERY is an ambitious, community project addressing key scientific questions about the construction and destruction of the Variscan orogenic crust, in a region with high potential for several critical metals (Cu, W, Sb). It will provide key constraints on the genesis of these deposits and propose comprehensive mineral system models and targeting proxies for exploration.

CONTEXT and SCIENTIFIC STRATEGY

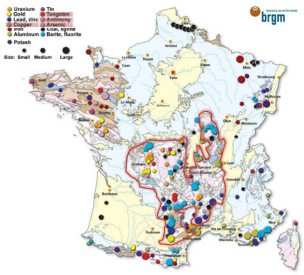
The European Critical Raw Materials Act aims to increase domestic extraction of strategic mineral resources. The Paleozoic (360–270 million years ago) **Variscan orogenic crust is a major source of these resources** in Europe. In France, the largest exposure of this crust is represented by the **Massif Central**, which also hosts the country's highest concentration of critical metal deposits.

The Variscan belt is increasingly recognized as a "hot" orogen, with a unique crustal structure, composition, and rheology shaped by its debated geological history (Franke, 2014; Vanderhaeghe et al., 2020; Schulmann et al., 2022; Faure, 2024). This history has **influenced all components of Variscan mineral systems** including the fertility and architecture of the lithosphere; tectonic settings favorable for fluid-/melt-assisted element transfer; and preservation of ore deposits (e.g. critical melts like Cu, W and Sb) (Romer and Kroner, 2022; Faure, 2024).

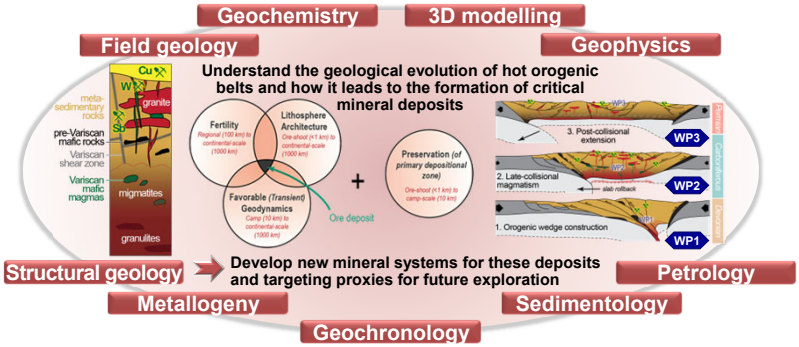


[sketch geological map of Europe at the end of the Paleozoic, after Schulmann et al. 2022]

[map showing the distribution of mineral resource deposits in France, BRGM]



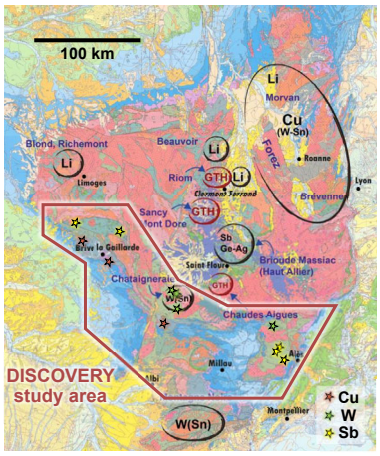
➡ DISCOVERY proposes a multidisciplinary and multi-scale approach to understanding the major stages of the Variscan orogenic history, which in turn will allow to build up comprehensive mineral system models and provide geophysical and geochemical tools for the future discovery of as yet unknown deposits.



[the DISCOVERY's rationale – from left to right: simplified structure of the Variscan orogenic crust (after Laurent et al. 2023); the mineral system concept (after McCuaig & Hronsky 2014); and the Variscan tectonic evolution (after Monnier et al. 2021)]

The project focuses on the **southern Massif Central & eastern Aquitaine basin** (s. Limousin - Châtaigneraie - Rouergue - Quercy - Cévennes). This area features key geological objects representative of the major stages of the Variscan history; Cu, W, and Sb deposits; and a comprehensive geophysical dataset (seismic reflection, EM, aero-magnetic…).

DISCOVERY complements PEPR's PC13 ("Massif Central" targeted project) by providing **a large spatial and temporal scale geological framework**, essential for studying the socio-environmental aspects of resource exploitation at the district level within PC13.



[extract from the geological map of France (1:1'000'000) showing the areas of interest for the PC13 project (black circles) and the DISCOVERY study area (red polygon) – the targeted critical metal occurrences/deposits are indicated by stars]

ORGANISATION and DELIVRABLES

★ = MSc (master 2) thesis

WP0 – Project coordination [resp. O. Laurent]

WP1 – Variscan tectonic-metamorphic evolution and related metallogenesis [resp. D. Chardon, C. Lotout]

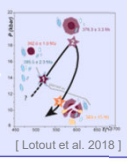
[J. Baraille, ongoing PhD thesis]

T1.1 – structural framework of 4D orogen-building processes

T1.2 – timing and conditions of the pre- to post-collisional metamorphic evolution ★

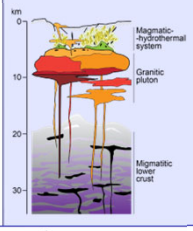
T1.3 – origin and fertility of pre-Variscan lithologies and metal behaviour during metamorphism ★ ★ ★

PhD



[Lotout et al. 2018]

WP2 – Granitic magmatic – hydrothermal systems [resp. P. Bouilhol, M. Harlaux]



T2.3 – link between magmatism and peri-granitic (W-Sb) mineralization ★ ★

T2.2 – geometry, construction and emplacement conditions of granitic plutons ★ ★

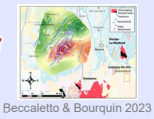
T2.1 – from source to granite: source and melt compositions and magma transfer processes ★ ★

PDoc

WP3 – Late-/post-orogenic basins and hosted base metal deposits [resp. L. Beccaletto, S. Leleu]

T3.1 – sedimentology, geometry and history of ★ basins

PhD



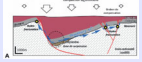
[Beccaletto & Bourquin 2023]

[Ortiz 2021]

PDoc

T3.2 – geochronology of source-to-sink processes

[Lopez et al. 2023]

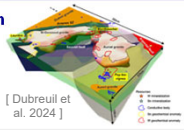


T3.3 – hydrothermalism, remobilisation of metals and associated deposits ★ ★

WP4 – Geophysical and geochemical integration towards exploration targeting [resp. P. Boulvais, G. Martelet]

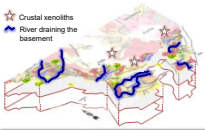
PDoc

T4.1 – geophysical imagery and 3D modelling of deposits in their geological framework

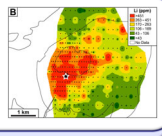


[Dubreuil et al. 2024]

T4.2a – integrated composition and fertility of crustal/lithospheric reservoirs



T4.2b – geochemical footprints of hidden deposits



[Harlaux et al. 2025]

Outreach – communication, scientific mediation, targeted actions in collaboration with local stakeholders

CONSORTIUM

The **consortium unites 32 experts** from diverse disciplines across **10 partner institutions**.

DISCOVERY aims to **build a multidisciplinary community** of French geologists focused on the Variscan Massif Central and **train a new generation of geoscientists** with cross-disciplinary expertise bridging academia and industry.

References

- Beccaletto L., and Bourquin S., 2023. The Brécy depocenter as part of a new northern Massif Central Carboniferous–Permian Basin (France), Comptes Rendus Géosciences 355, Special Issue 2, 163-190. https://doi.org/10.5802/crgeos.246
- Dubreuil, G., et al., 2024. Multimethod Geophysical Modelling for Granite-Related Tungsten Exploration: Example of the Puy-les-Vignes/ Saint-Goussaud District (Limousin, France). NSG 2024 5th Conference on Geophysics for Mineral Exploration and Mining, vol. 2024, 1-5. https://doi.org/10.3997/2214-4609.202420182
- Faure, M., 2024. Alpine, Variscan, eo-Variscan belts: comparison between hot and cold orogens from the examples of French segments. Comptes Rendus Geoscience 356(S2), 289-307. https://comptes-rendus.academie-sciences.fr/geoscience/articles/10.5802/crgeos.215/
- Franke, W., 2014. Topography of the Variscan orogen in Europe: failed–not collapsed. International Journal of Earth Sciences 103, 1471-1499. https://doi.org/10.1007/s00531-014-1014-9
- Harlaux, M., et al., 2025. Geochemical footprints of peraluminous rare-metal granites and pegmatites in the northern French Massif Central and implications for exploration targeting. Ore Geology Reviews, 106409. https://doi.org/10.1016/j.oregeorev.2024.106409
- Laurent, O., Couzinié, S., Doucet, L.S., 2023. Timescales of ultra-high temperature metamorphism and crustal differentiation: Zircon petrochronology from granulite xenoliths of the Variscan French Massif Central. Earth Planet Sci Lett 611, 118133. https://doi.org/10.1016/j.epsl.2023.118133
- Lopez, M., et al., 2023. Tour d'horizon du basin stéphano-permien de Graissessac-Lodève. Géochronique, 168, 56-67. https://insu.hal.science/insu-04341835/
- Lotout, C., et al., 2018. Timing and duration of Variscan high-pressure metamorphism in the French Massif Central: A multimethod geochronological study from the Najac Massif. Lithos 308-309, 381-394. https://doi.org/10.1016/j.lithos.2018.03.022
- McCuaig, T.C., Hronsky, J.M. (2014). The mineral system concept: the key to exploration targeting, Society of Economic Geologists Special Publication, 18, 153-175. https://doi.org/10.5382/SP.18.08
- Monnier, L., et al., 2021. Episodic Precipitation of Wolframite during An Orogen: The Echassières District, Variscan Belt of France. Minerals 11(9), 923. https://doi.org/10.3390/min11090923
- Romer, R.L. and Kroner, U., 2022. Provenance control on the distribution of endogenic Sn-W, Au, and U mineralization within the Gondwana-Laurussia plate boundary zone. In: Kuiper, Y.D., et al. (eds.), New Developments in the Appalachian-Caledonian-Variscan Orogen. GSA Special Papers 554. https://doi.org/10.1130/2021.2554(02)
- Schulmann, K., et al., 2022. Tectonic evolution and global crustal architecture of the European Variscan belt constrained by geophysical data. Earth-Science Reviews 234, 104195. https://doi.org/10.1016/j.earscirev.2022.104195
- Vanderhaeghe, O., Laurent, O., et al, 2020. Flow of partially molten crust controlling construction, growth and collapse of the Variscan orogenic belt: the geologic record of the French Massif Central. BSGF-Earth Sciences Bulletin 191(1), 25. https://doi.org/10.1051/bsgf/2020013

This work benefited from government funding managed by the ANR under the France 2030 program, with the reference ANR-25-EXSS-0002