Research Interests

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MISSION

Build open tools that turn scarce geological data into reliable discoveries to secure and power humanity's future.

BACKGROUND

My research began with subduction-zone petrology and geodynamics. I sampled high-pressure rocks in the U.S. Cordillera, Western Alps, Himalaya, and Greek Cyclades to learn how microscopic textures record metamorphic histories at convergent margins[1–4]. My work translated these petrological insights into numerical simulation of subduction, focusing on where plates couple[5], how rocks detach and return from depth[6], and how geodynamic interpretations based on surface heat flow can be misleading[7]. These studies compared numerical models with large emperical datasets to challenge long-standing views about how rocks are recovered from such extreme environments.

The same data-driven approach motivates my current research. I was involved in the OneGeochemistry community initiative to promote interoperable geochemical data standards[8]. At Montpellier I built RocMLMs[9], a suite of physics-informed AI models that reproduce thermodynamic calculations of rock properties 100–1,000 times faster than direct methods, now used by researchers at several institutions. At Liverpool I implemented a reaction kinetics framework into the community software project ASPECT for mantle convection[10,11]. These open software tools gained invitations to speak at the EGU General Assembly 2026 and to contribute an AI-focused chapter in *Methods in Tectonics* for the Geological Society of London[12]. I have other ongoing software projects spanning both research and teaching tools, all released with permissive licenses[13,14].

VISION

My future vision focuses on integrating geoscience with AI to secure and power humanity's future. Geoscience is fundamental to producing energy and critical materials society needs, and leading governments have recognized the increasing gap between rising resource demand and declining discovery rates[15–18]. Yet long and expensive data collection makes large labeled datasets inaccessible and AI integration fails. Generating the data AI needs requires removing bottlenecks in slow geoscience workflows. I classify these bottlenecks into three types: conceptual, emperical, technological. Where understanding of a critical process is limiting, improving models through basic research is key. Where data are scarce, producing labeled examples through data flywheels is key. Where community tools are missing, building software through open-source projects is key.

The projects below are a mix of basic research, bottleneck targeting, and AI integration. My default philosophy is to build pre-competitive, FAIR tools released openly for community use. All projects are intended to support one or more student researchers.

PENDING PROJECTS

→ **AI for characterizing microscope images for ore minerals** [**Full proposal; pending funding**]**.** Train AI to spot copper and gold minerals and textures in electron microscope images, with humans checking only uncertain cases, to turn thousands of images into usable records across four major deposit types. Study how researchers decide to trust or correct the AI, to build guidance on skills that remain essential (AI metascience).

→ **Fast AI for fluid and rock chemistry** [**Full proposal; pending funding**]**.** Train AI on large chemical databases to predict which minerals form and where metals go, hundreds to thousands of times faster than direct calculation, so fluid chemistry can work inside larger simulations of ore systems.

→ **Simulations that map where ores form** [**Full proposal; pending funding**]**.** Embed fast fluid-rock reactions in simulations of crustal evolution that test which geology, fluid pathways, and fluid-rock chemistry create rich deposits, checked against well studied mineral districts.

→ **Fast AI for deep mantle flow** [**Unfunded proposal; revise and resubmit**]**.** Train AI on rock chemistry to make density and fluid weakening evolve naturally as mantle rock flows. Use it to map how 410 and 660 km boundary topography, small local circulation, and water storage there change over time and compare to observed variations.

→ **Where subduction shear zones localize** [**Unfunded proposal; revise and resubmit**]**.** Test whether influx of external water spreads deformation into wide mixed zones versus narrow coherent slices along the plate interface. Sample oceanic rocks across shear contacts in exhumed terranes, and compare chemical fingerprints of external water with the amount of recrystallization that records strain.

→ **Data flywheel for nickel in ultramafic rocks** [**Concept**]**.** Portable instruments can identify minerals in seconds, but current databases are small and unbalanced[19]. Build a feedback loop where measurements of nickel-rich ultramafic rocks improve the classifier, lower cost for exploration, and support student work from field to lab[20].

→ **Sharper chemical maps from faster scans** [**Concept**]**.** Microscopic chemical maps reveal how rocks melt, deform, and concentrate metals, but high quality scans are slow and costly. Build AI that restores high resolution maps from fast low resolution scans to cut time and cost and widen access for student research[21,22].

→ **Fast AI for carbon cycling in subduction zones** [**Concept**]**.** Train AI on rock chemistry to predict how much subducted carbon returns through volcanoes versus stays in Earth's mantle Embed it in simulations of plate convergence to refine inputs to climate projections[6,23].

- → **Place-based geology with community partners** [**Concept**]. Design field and lab projects around local rocks, resources, or hazards in partnership with surveys or community groups, adaptable across regions and built to support undergraduate field work, sampling, and open data.

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