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Unraveling the Thermochemical State of the Whole Lithosphere in Space and Time: New Methods and Their Predictive Power for Exploration

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It is now widely accepted that the interaction of different processes and systems at lithospheric scale are responsible for the formation of many types of ore deposits. In this context, the thermochemical structure of the whole continental lithosphere holds key information on its origin and evolution that can be used to inform exploration strategies. As such, unravelling the nature of the continental lithosphere, its thermochemical modification through time, and its interactions with the sublithospheric mantle and shallow fluid systems constitutes one of the main goals of modern geoscience. Despite its fundamental importance, imaging the fine-scale thermochemical structure of the lithosphere using indirect (remote) data has been plagued with difficulties.

In recent years, however, "simulation-based" inverse methods that i) integrate multiple geophysical, geodynamic, and geochemical data sets within an internally and thermodynamically consistent platform and ii) utilize state-of-the-art AI and numerical techniques to solve the inverse problem in a fully probabilistic manner have opened new and promising ways to address this "grand challenge." The result of such inversions is a complete thermo-chemical-dynamical model of the subsurface, including the whole lithosphere and sublithospheric upper mantle. These images unravel fertility zones, metasomatized mantle domains, melting regimes, fluid pathways, and thermochemical signatures directly linked to mineral systems. With this information, full thermo-chemical-mechanical inversions of metallogenic processes can be run to aid in the understanding of specific mineral systems and their potential. In this presentation, I will review i) some recent progress, case studies, and future directions on the mapping of the thermochemical structure of the continental lithosphere, ii) their connection with fully dynamic inversion techniques for studying the evolution of specific mineral systems, and iii) their predictive power for the critical minerals and energy sectors.