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Reading Minerals: Rare Element Enrichment, the Magmatic-Hydrothermal Transition, and Geochemical Exploration of Lithium Pegmatites in Ireland

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The battery market for electric vehicles and renewable energy storage is dominated by rechargeable lithium-ion batteries, making lithium supply essential to climate action through decarbonization. In 2019, more than half of the world's lithium was sourced from lithium pegmatites of the Li-Cs-Ta (LCT) family, predominantly from Australia. Current global lithium supply involves long diesel-fueled maritime transport routes, which counteracts lithium's role in climate action. Responsible consumption and production require shorter supply chains from deposit to battery.

Reading the mineralogical record of LCT pegmatite deposits can help address the challenge of reducing the climate impact of lithium production, by informing deposit models, mineral exploration, and geometallurgy, therefore promoting local supply. Our research focuses on a belt of LCT pegmatites, which is located along the eastern margin of the late-Caledonian S-type Leinster Batholith, southeast Ireland. The LCT pegmatites are hosted by a major regional shear zone and are part of a tin-lithium province that stretches subparallel to the Iapetus suture from Europe through Nova Scotia to North and South Carolina.

We investigated crystal chemical zoning in muscovite, cassiterite, and columbite-tantalite using petrography, scanning electron microscopy, and LA-ICP-MS chemical mapping. The zoning patterns record that pegmatite rare element mineralization resulted from an interplay of magmatic crystallization, metasomatism, and hydrothermal processes. Late-stage metasomatic alteration led to partial resorption of early minerals including the lithium ore-mineral spodumene, followed by dispersion of lithium and other rare elements into country rocks, mostly within dark mica. Dispersion led to formation of geochemical halos around the LCT pegmatites with the potential to use country-rock lithogeochemistry and mica composition as geochemical vectoring tools.

Geochemistry of mica in the granite host analyzed by handheld LIBS has been found to exhibit coherent spatial patterns occurring adjacent to and above LCT pegmatites known at depth from drilling. These channels of mineral-specific geochemical information are distinct from soil geochemical patterns and are not influenced by the same secondary, surface processes such as dilution.

As outcrop is virtually absent in the study area, regional stream sediment geochemistry data (Geological Survey Ireland) was assessed as an LCT pegmatite exploration tool. After correcting for geologic background using a linear regression approach, catchments containing LCT pegmatites show high residuals for concentrations of both tantalum and tin. The mineralogy of stream sediment samples from a subsample of these catchments was subsequently analyzed to characterize the host minerals of tin and tantalum. Cassiterite and columbite-tantalite were identified, and both show geochemical and textural signatures that correspond to the zoning patterns mentioned above, which indicates that these minerals were derived from the local LCT pegmatites.

These results suggest that, when regional geology and tectonic setting are prospective, lithium pegmatite prospectivity can be further assessed for tin-tantalum associations in (often publicly available) regional stream sediment data. Following geospatial analysis, stream sediment samples could be obtained from individual prospective catchments and their mineralogy analyzed. Local-scale geochemical surveys could follow where stream sediments of prospective catchments contain tin and tantalum oxides with chemistries and textures indicative of a lithium pegmatite source.