Tracing the mineralogical source of Tellus geochemical anomalies in the Mourne Mountains, to investigate processes that concentrate critical metals

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The raw materials for emerging technologies that come from a small number of mines in just a few geographical locations and are at high risk of supply disruption are termed the critical metals[1]. The Mourne Mountains provides a natural laboratory to investigate how economic concentrations of these critical metals can develop. For more than 30 years, the Mourne Mountains has been periodically explored for uranium, gold, base metals, tin, tantalum and niobium, many of which can be associated with REE enrichment; the Mournes Granites have compositions that suggest that they have the potential to be enriched in REE.

The overall objective of this project was to utilise and enhance the Tellus data set for the Mourne Mountains so that the potential for polymetallic critical metal mineralisation could be investigated. An understanding of the processes that concentrate critical metals will enhance our ability to predict where new sources may be located so that continued supply can be ensured.

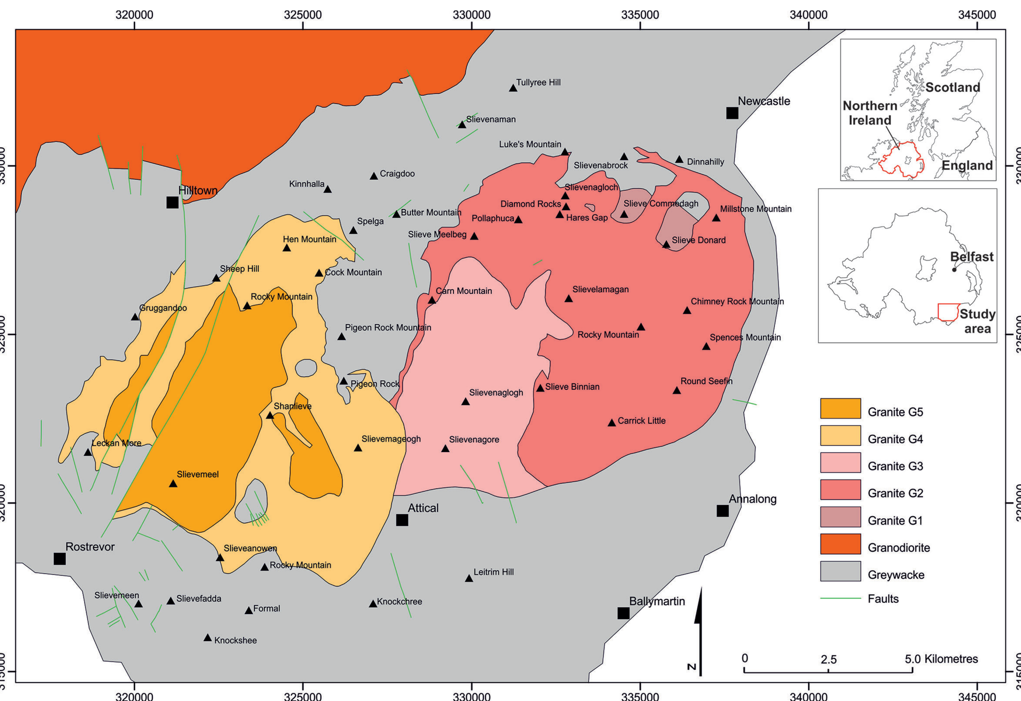


Figure 1. Geological map of the Mourne Mountains granite complex, from G1 (oldest to G5 (youngest). Inset maps showing location of Northern Ireland and the study area. Geological linework based upon Hood (1981). © Crown copyright and database right (2013).

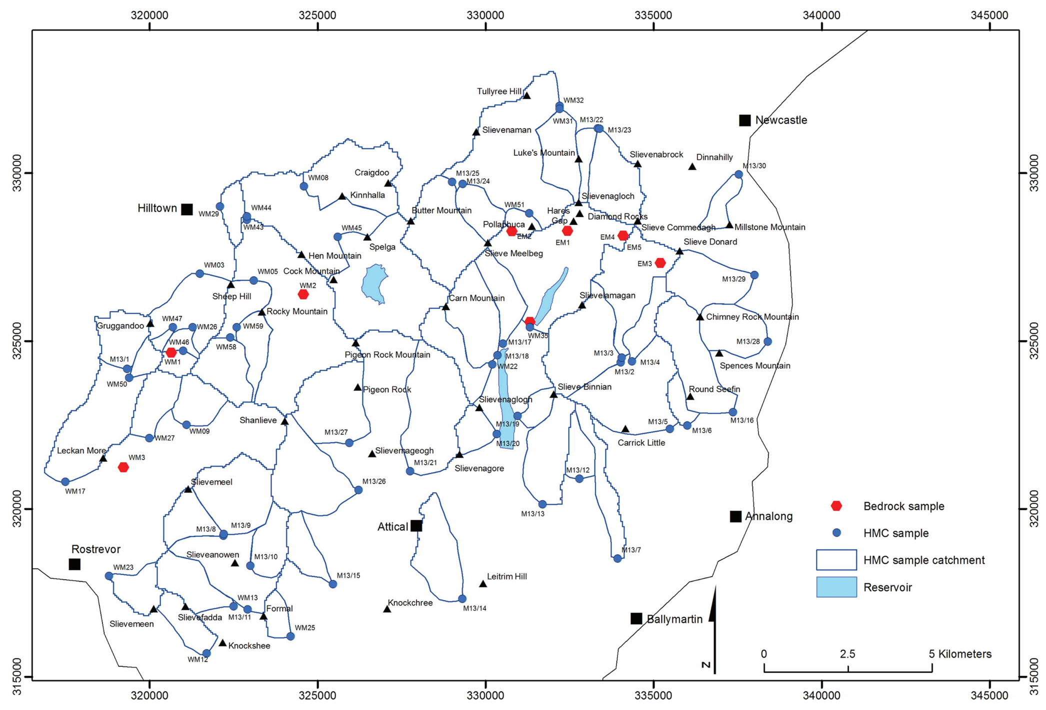


Figure 2. Map of mineral sample locations. The bue circles are locations were stream sediments from which the heavy mineral fraction was concentred (heavy mineral concentrates, HMCs). The HMCs represent drainage catchment areas denoted by blue polygons, inside which the bedrock sample sites (red dots) are located.

The project utilised the Tellus geochemical data over the area of the Mournes granites (Figure 1). New mineralogical data was gathered from 55 stream sediment samples and 8 bedrock locations (Figure 2) to identify the source of positive critical metal anomalies in the Tellus data. Four major patterns of chemical anomaly were identified:

1. Thorium, rare earth element and niobium enrichment associated with G1 and G2 granites.
2. Arsenic, tin, rare earth element and yttrium enrichment associated with hydrothermal processes.
3. Enigmatic isolated and scattered manganese and cerium (rare earth element) enrichments.
4. Rare earth element and variable additional enrichments associated with tectonic lineaments.

Anomaly type 1: eastern Mournes

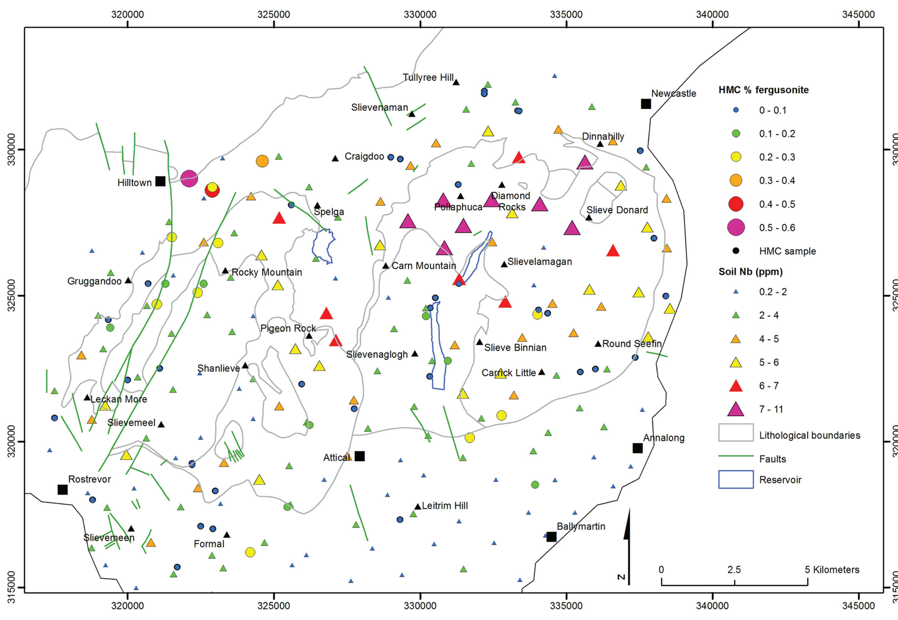


Figure 3. Map showing that the biggest niobium, Nb, anomalies (ppm) in Tellus deep soil Multi-Acid (near Total ICP data, triangles) are located in the eastern Mournes and do not coincide with the greatest abundance of fergusonite $Y(Nb,Ta)O_4$ in HMC (circles).

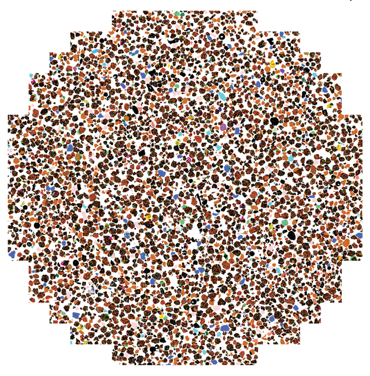


Figure 4. QEMSCAN® image of 30 mm wide grain mount of HMC sample WM35 showing dominance of magnetite, Ti-magnetite and ilmenite (black and brown) grains.

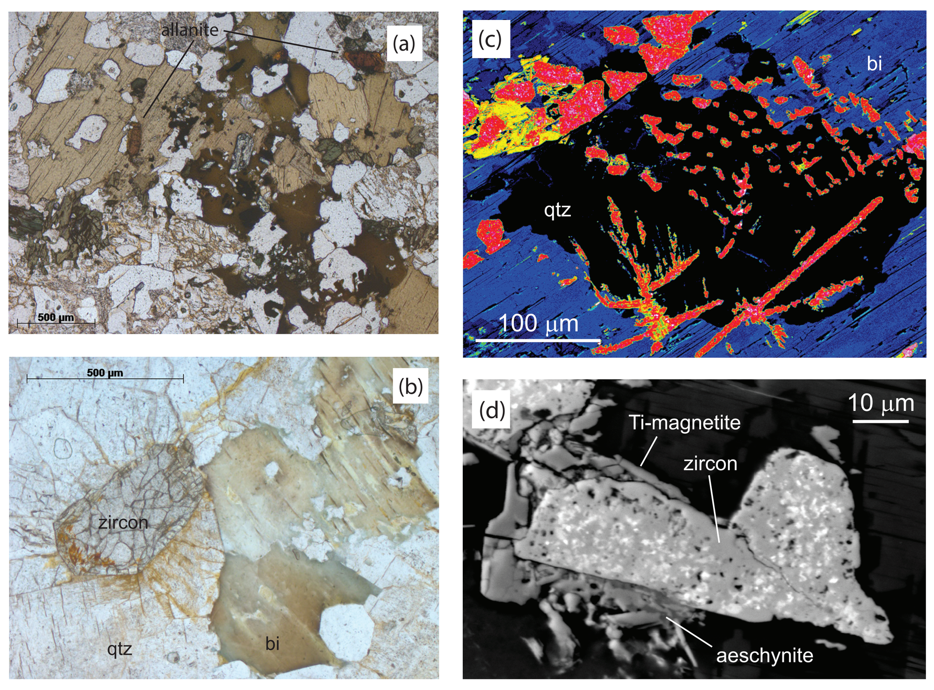


Figure 5. Rock and mineral textures in granites of the Eastern Mournes. (a) Photomicrograph of phaneritic texture in the least fractionated G1 allanite-biotite-(amphibole) granite, locality EM5. (b) Photomicrograph of a network of Th-rich veinlets emanating from a zircon crystal with a U, TH, Hf rich core, locality EM4. (c) False colour element map of micrographic texture in G2 granite, locality EM1, where an assemblage of zircon containing thorite, xenotime and other inclusions (red and pink), mantled by magnetite with aeschynite inclusions (yellow), is in intergrowth with biotite (blue) and quartz (black). (d) Detail of inclusions in zircon and magnetite. Allanite $(Ce,Ca,Y)_2(Al, Fe)_3(SiO4)_3(OH)$; thorite $(Th,U)SiO_4$; xenotime $(Y,REE)PO_4$; aeschynite $(Y,Ca,Fe,Th)(Ti,Nb)_2(O,OH)_6$

Critical metals concentrated during eutectic crystallisation in the roof zone of a granite intrusion.

Anomaly type 2: eastern Mournes

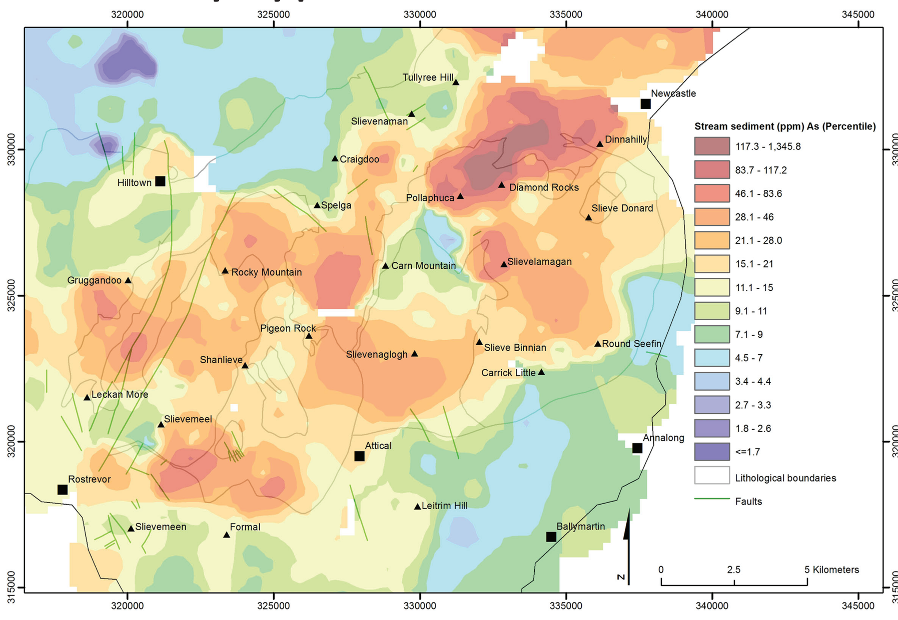


Figure 6. Map of gridded arsenic As concentration (ppm) in Tellus stream sediment Multi-Acid near Total ICP data. A large As plume emanates from sample location EM2 (Pollaphuca) and correlates with a very high volume of cassiterite in HMC samples (Fig. 7).

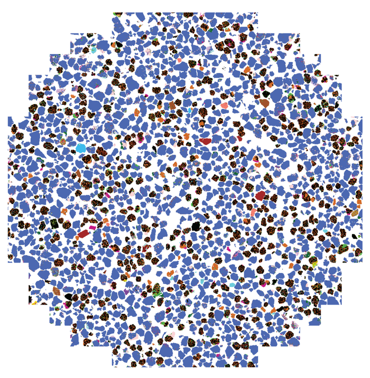


Figure 7. QEMSCAN® image of 30 mm wide grain mount of HMC sample WM51 showing dominance of cassiterite (blue) grains, 65.1 vol % of HMC.

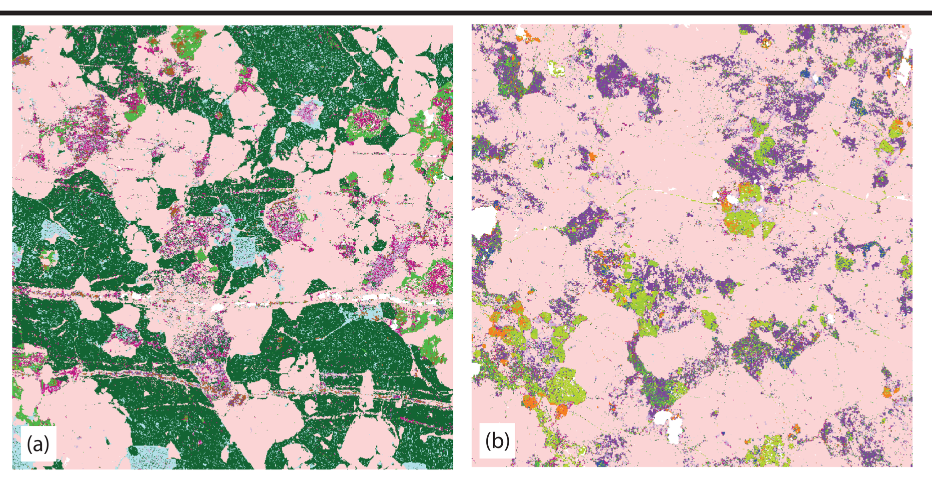


Figure 8. QEMSCAN® image of 20 mm wide sections from the margin (a) and core (b) of a mineralised vein at locality EM2. Plagioclase (pale blue) and k-feldspar (green) in G2 granite are progressively replaced with polymorphs of quartz (pink), which contain indium and tin in the core of mineralisation (b). Cassiterite occurs in microveins and replacement textures, accompanied by monazite, in the margins of mineralisation (a).

The arsenic-rich fluids preferentially replace mafic silicate minerals (Figure 8b). Intially, amphibole and biotite dissolve and are replaced at grain boundaries. Subsequently, voids are filled with botryoidal/choloform highly porous infill of minerals with extensive solid solution between end members of the crandallite group (purple) of minerals - arsenogoyazite $SrAl_3(AsO_4)_2(OH)_5.H_2O$, arsenowaylandite $BiAl_3(AsO_4)_2(OH)_6$, arsenocrandallite $CaAl_3(AsO_4)_2(OH)_5.H_2O$ and arsenoflorencite-(La): $(La,Ce,Nd)(Al,Fe)_3(PO_4,AsO_4)_2(OH)_6$. Later, this is replaced with an intergrowth of arseniosiderite $Ca_2Fe_3(AsO_4)_3O_2.3H_2O$ (orange) and scorodite $FeAsO_4.2H_2O$ (lime green), and pharmacosiderite $KFe_4(AsO_4)_3(OH)_4.6\text{-}7H_2O$ (blue), arsenopyrite FeAsS (khaki) and chernovite $(Ce,Y)AsO_4$ (darker green).

Critical metals were concentrated in minerals by the reaction of arsenic-rich fluids with granite rock.

Anomaly type 3: western Mournes

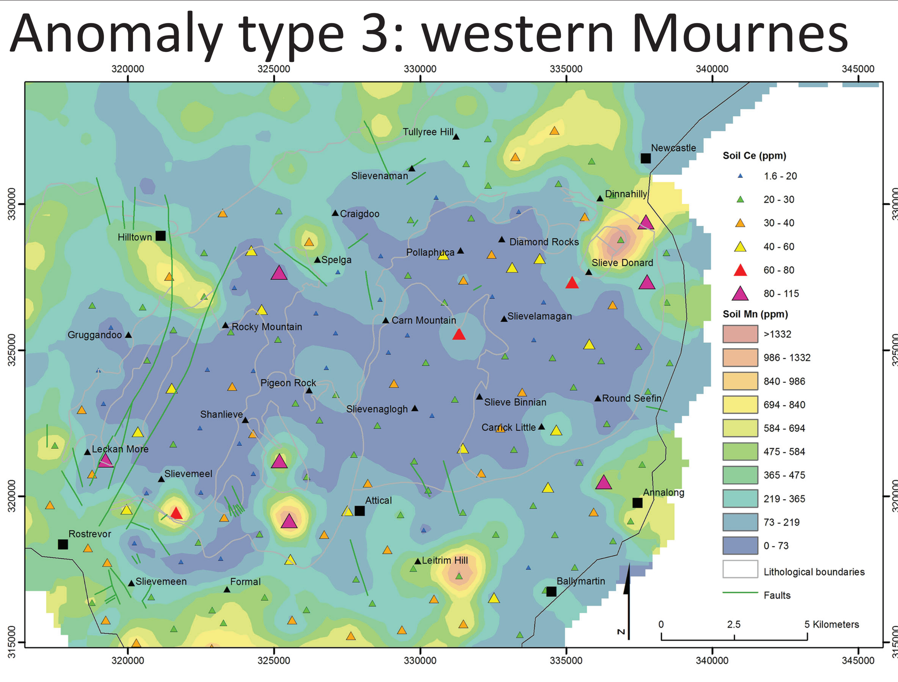


Figure 9. Three notable anomalies west of Attical and south of Shanlieve and Slievemeel have a coincidence between point Ce (ppm) and gridded Mn concentration (ppm), Tellus deep soil Multi-Acid near Total ICP data, similar to that observed in the sample from WM2.

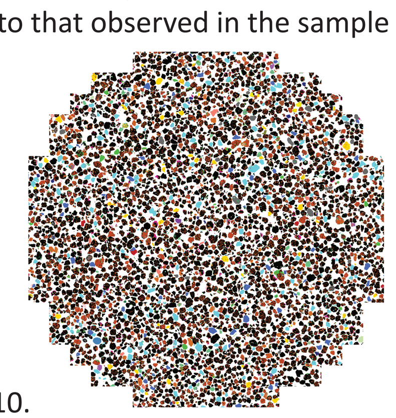


Figure 10. QEMSCAN® image of 30 mm wide grain mount of HMC sample WM05 showing that small Mn anomalies do not significantly affect the HMC samples.

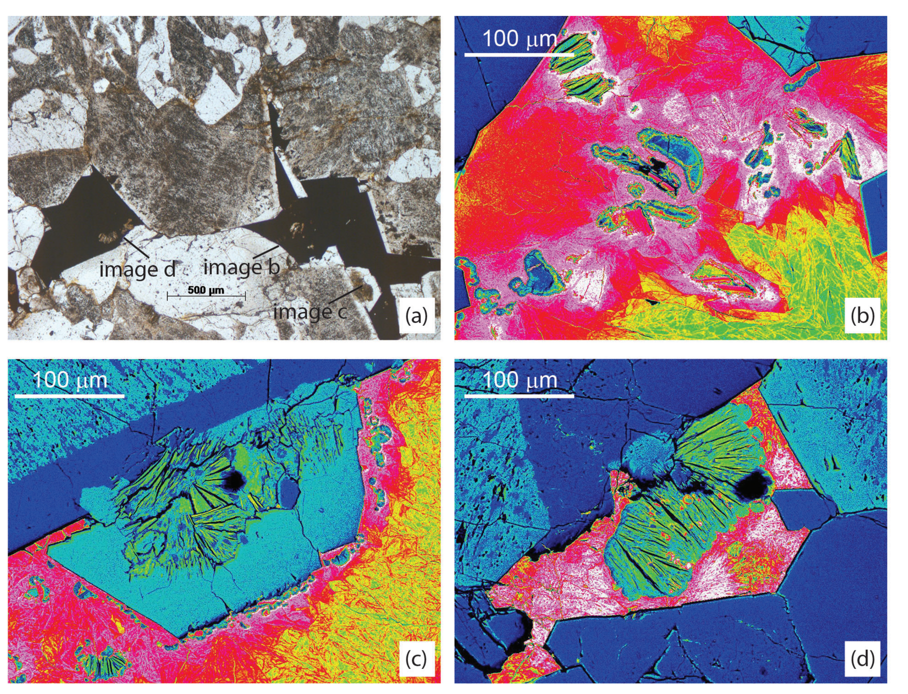


Figure 11. Photomicrograph (a) and false colour element maps (b-d) of infill of drusy cavity in G4 granite, locality WM2. Silicate minerals of the enclosing granitic assemblage are dark blue (quartz) and light blue (albite). Smaller biotite/chlorite crystal are included in the late-stage mineral assemblage infilling the cavity (green/blue). The secondary assemblage has the texture of a porous network and varies from manganese-rich (bright green) to cerium-rich (white-pink). Its composition is consistently dominated by manganese hydroxide and cerium Ce concentration is highly variable from 0 to >20 wt% Ce2O3.It also contains up to 5 wt% PbO_2, 2-4 wt% Al_2O_3, 1-2 wt% BaO; mean values of 1 wt% , 0.5 wt% and 0.5 wt% for CaO, K2O and MgO, respectively. Traces of arsenic, sulphur, and chlorine are common.

Critical metals were precipitated in small cavities in granite from post-magmatic fluids that percolated through the rock.

Anomaly type 4: western Mournes

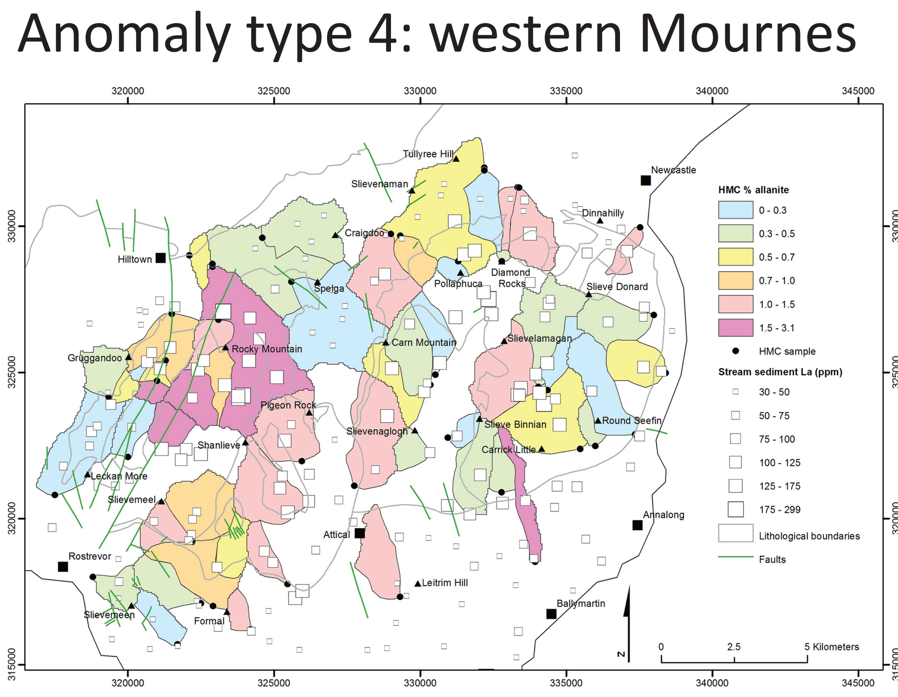


Figure 12. Map showing abundance of lanthanum La in Tellus stream sediment samples shown as proportional symbols overlain on a gridded map of allanite abundance in HMC sample catchments.

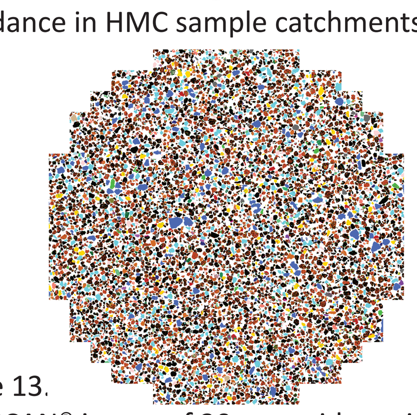
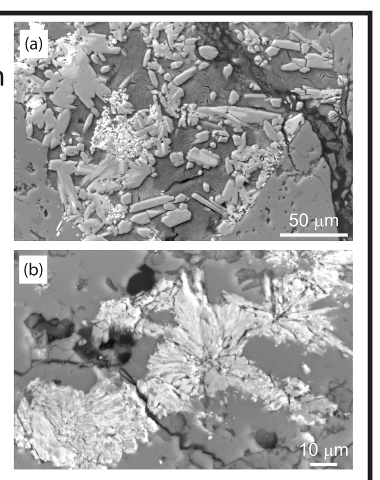


Figure 13. QEMSCAN® image of 30 mm wide grain mount of HMC sample WM43 showing great diversity: 9.4 vol % zircon (light blue), 5.8 vol % cassiterite (royal blue), 2.8 vol % allanite (yellow), 1.3 vol % monazite (coral), 0.5 vol % thorite (bright green).

Figure 14. BSE images showing secondary allanite: small Ti and Mn zoned epidote occur in chlorite-dominated pockets along grain boundaries (a) with tiny radiating acicular aggregates of allanite (b).



The higest concentrations of allanite in HMC samples occur in multiple stream catchments along major fault lineaments (Fig. 12). The same pattern of enrichment is observed for zircon, thorite & fergusonite, reflecting the diversity of minerals in Figure 13.

Critical metals were concentrated along post-intrusion faults, by episodic migration of fluids.

NOTE. QEMSCAN® is the Quantitative Evaluation of Minerals (QEM) using a Zeiss EVO® 50 scanning electron microscope (SEM), with four light element X-ray EDS (Energy Dispersive Spectrometers) detectors and an electron backscatter detector. It was used to rapidly obtain compositional information on a large number of mineral grains (for the heavy mineral concentrates) and to produce complete false colour mineral maps of whole rock sections. For either type of sample, QEMSCAN analysis generates a statistical analysis of grain-size, mineral abundance and mineral associations.

REFERENCES.

[1]Moss, R.L., Tzimas, E., Kara, H., Willis, P., Kooroshy, J., 2011. Critical Metals in Strategic Energy Technologies: Assessing rare metals as supply-chain bottlenecks in low-carbon energy technologies. JRC Scientific and Technical Report EUR 24884 EN – 2011 http://setis.ec.europa.eu/newsroom-items-folder/jrc-report-on-criticalmetals-in-strategic-energy-technologies

[2]Hood, D.N. 1981. Geochemical, petrological and structural studies on the Tertiary granites and associated rocks of the Eastern Mourne Mountains, Co. Down, Northern Ireland. PhD thesis, Queens University Belfast.

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