Multi-disciplinary characterisation of the Callista clay-hosted REE prospect

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The clay-hosted Rare Earth Elements (REE) Supply Chain project is a collaboration between the Commonwealth Scientific and Industrial Research Organisation (CSIRO), Geoscience Australia, and the Australian Nuclear Science and Technology Organisation (ANSTO). The CSIRO examined five sites across Australia to improve understanding of the country's varied low-grade REE resources and identify common features that may guide exploration. The Callista prospect study applied multiple analytical techniques to distinguish primary REE minerals from their weathered secondary products and to map mineralogical changes through the regolith profile. Collectively these techniques enabled the rapid building of detailed insights into REE distribution, alteration pathways, and the development of secondary REE phosphates and carbonates at the Callista REE prospect case study area held by GSW Resources (GSWR).

Geological setting and source rocks

The Callista prospect lies within the western part of the Aileron Province of the Arunta Region in the Northern Territory, Australia, which forms the southern part of the North Australian Craton (**Figure 1**). The 1570–1530 Ma Southwark Suite, which hosts the Callista prospect, comprises biotite and muscovite–biotite granite, commonly with K-feldspar megacrysts and locally with rapakivi feldspars (Scrimgeour 2013) (**Figure 2a**). The Southwark Suite is defined as elevated in SiO_2, K, Th and U and as a high-heat-producing granite suite.

The source granite at the site comprises megacrystic to finer grained phases (**Figure 2**) with similar total rare earth oxide (TREO) concentrations (~750–800 ppm) but contrasting primary REE mineralogy. Allanite dominates megacrystic phases, whereas monazite prevails in finer grained phases.

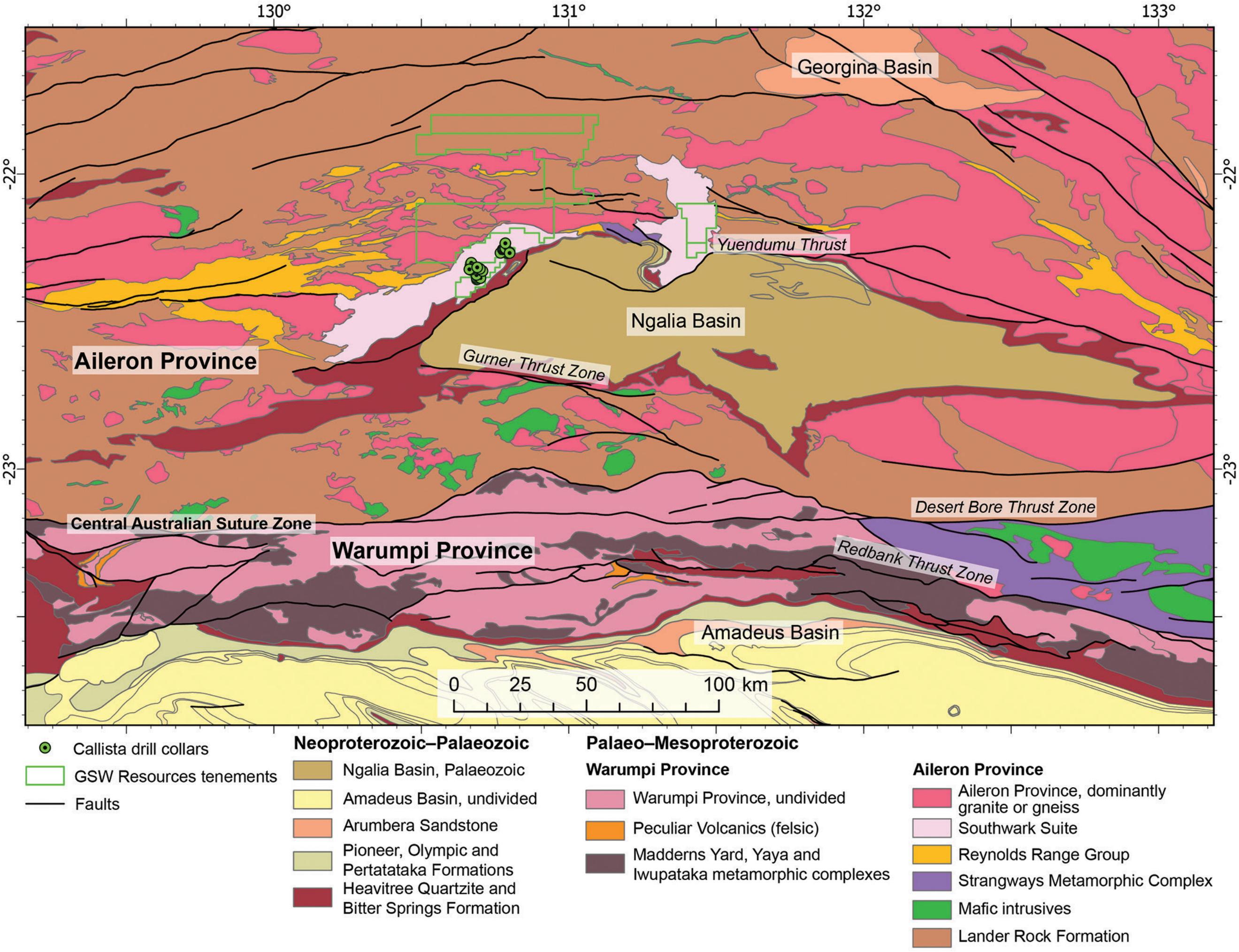

Figure 1. Annotated regional geology map extracted from the NTGS 1:250 000-scale solid geology map layers, showing the Callista drill sites and GSW Resources tenements as at June 2025.

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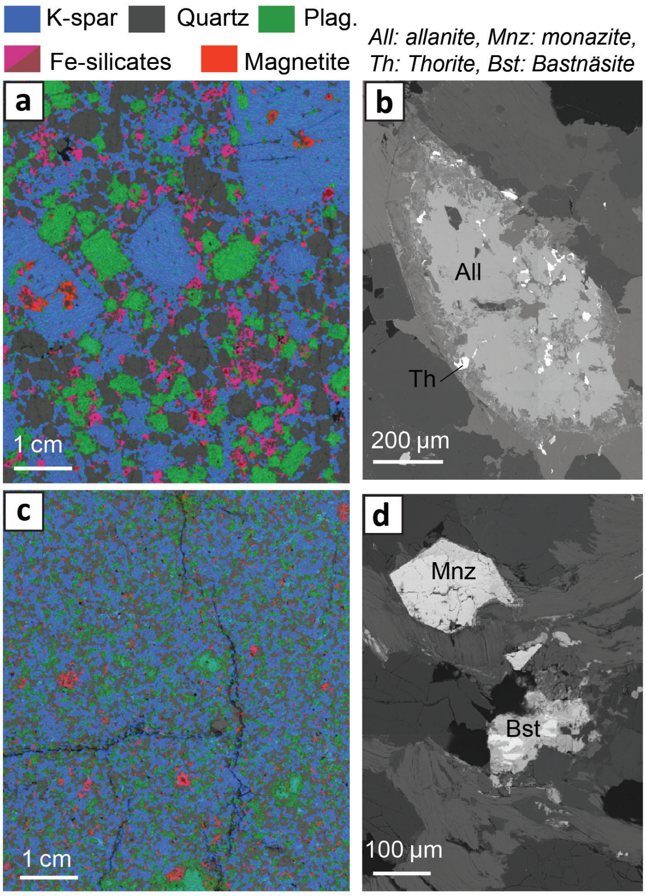

Figure 2. Micro-XRF and backscattered electron (BSE) images of unweathered megacrystic granite (**a**, **b**) and microgranite (**c**, **d**).

Geomorphology

The project area is situated within an erosional landscape adjacent to the modern drainage networks of Waite Creek and close to the tributaries of the Ethel Creek to the north. Surface regolith materials include silcrete, residual quartz gravel and clay, dissected gravel fans, granitic sand and outcropping granitic saprolite. Quaternary cover comprises alluvial and colluvial deposits dominated by sand, silt, and quartz-rich gravel sheetwash, with localised aeolian silt and sand.

A north–south-oriented ferricrete rise in the area represents inverted topography and the remnants of a palaeodrainage system. This feature, dated as Miocene (13.9 Ma) by this study, sits next to scattered, low, isolated silcrete hills approximately 100–200 m apart.

Surface exploration

Twenty-nine soil samples were collected along a NNW–SSE and an E–W transect to capture regolith variability relevant to REE exploration. Multi-acid and borate-fusion digestions produced highly comparable REE results. Samples span residual, sheet-flow, colluvial, alluvial, loess and aeolian materials derived from granitic saprolite, floodplain processes and wind reworking. Residual and thin sheet-flow soils over saprolite are the most REE-enriched (TREO ≈ 900 ppm, up to 1535 ppm), with REE most strongly correlated with P, Ga, Al and kaolinite, reflecting hosting by phosphates, Al-rich clays and resistate minerals. Transported units (colluvial, alluvial, sheet-flow on depositional plains, loess and aeolian sands) show progressively lower REE concentrations due to dilution by quartz, though finer overbank horizons retain moderate enrichment.

In general, downhole weathering profiles are shallower in areas with higher soil REE concentrations, probably because the relatively higher-grade portions of the profile have been exposed by erosion in these areas.

Profile characterisation and REE mineralogy

Weathering profiles were characterised using geochemical and mineralogical techniques, with the latter incorporating mineral indices based on hyperspectral analysis (**Figure 3**). Two different profile types were identified, exhibiting broadly similar major mineral assemblages dominated by quartz and kaolinite within in-situ saprolite and saprock. However, notable variations are observed in the relative proportions of K-feldspar**,** titanium oxides and iron oxides/hydroxides, as well as in the composition and abundance of REE-bearing carbonate minerals.

Scanning electron microscope mineral mapping (using the Tescan integrated mineral analyser – TIMA) and the geochemistry of drillhole CA37 best represents the profiles containing both phosphate and carbonate-bearing minerals. The analysis reveals three mineralogically distinct zones (**Figure 4**) within the weathering profile:

1. upper saprolite (0–7 m), dominated by carbonates (mainly calcite with minor dolomite), kaolinite, quartz, and fine-grained intergrown kaolinite and carbonate
2. lower saprolite (7–25 m), characterised by abundant kaolinite with quartz and minor K-feldspar
3. saprock (25–33 m), composed predominantly of kaolinite with a higher proportion of iron hydroxides.

Downhole concentrations of TREOY (total rare earth oxides and yttrium) reach up to 6000 ppm but generally range between 1000 and 3000 ppm. Accessory minerals are primarily refractory phases such as rutile, ilmenite and zircon, with minor barite/gypsum associated with the sulphate-rich upper zone. The abundance of iron oxides and hydroxides (predominantly goethite with minor hematite and magnetite) increases substantially towards the base of the profile.

The characterisation of the weathering profiles indicates that REE phosphates are present across the deposit, but REE carbonates are locally present and more abundant in the lower portions of the weathering profile (**Figure 4**). REE phosphates (probably rhabdophane and/or monazite) can occur in some profiles as coarse-grained, massive crystals that locally alter to fine-grained, porous secondary phosphates with a distinctive needle-like morphology (**Figure 5a**). These phases have also been found as fine-grained (>20 µm) secondary minerals within kaolinite lamellae, as fine aggregates retaining pseudomorphic crystal shapes or, less commonly, as coarse, massive, rounded grains hosted within partially weathered biotite. REE carbonates form as alteration products of REE phosphates, often precipitating directly along their boundaries (**Figure 5b**), or as isolated crystals occasionally displaying colloform textures (**Figure 5c**).

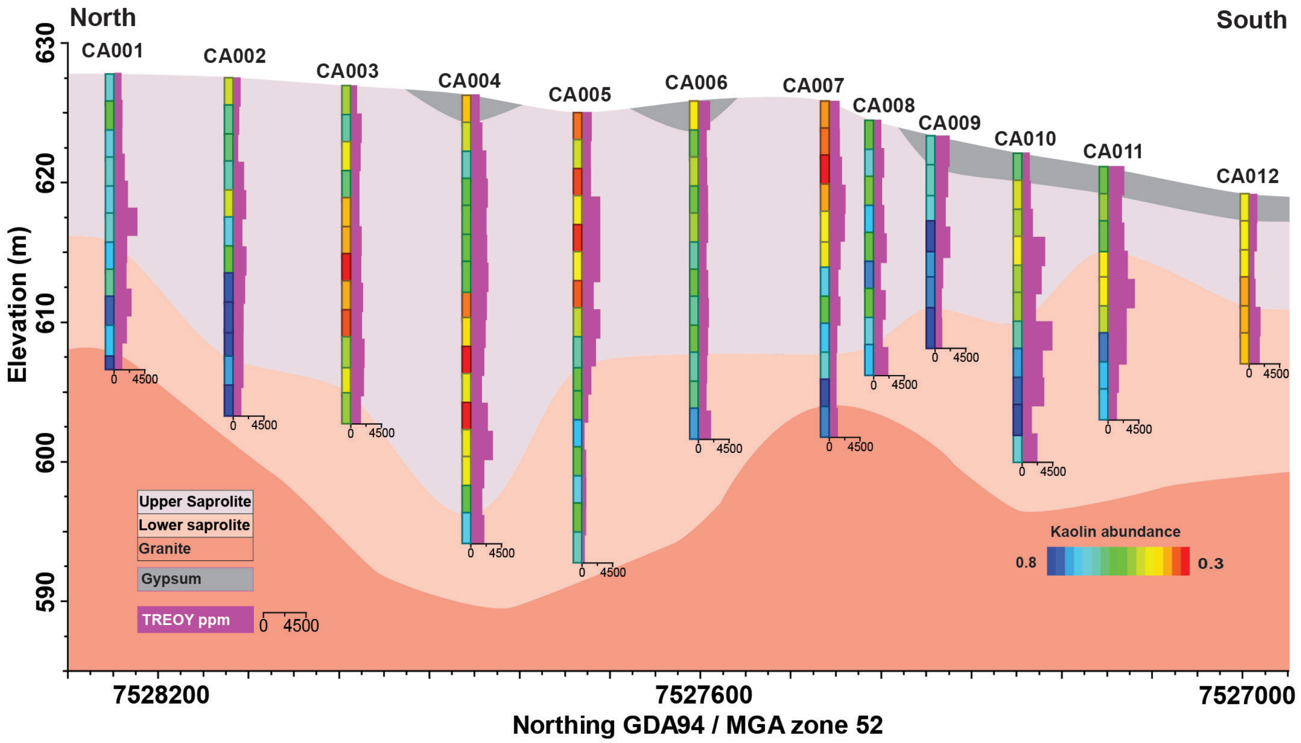

Figure 3. Cross-section of the Callista prospect showing TREOY distribution and hyperspectral kaolin abundance indices along downhole profiles.

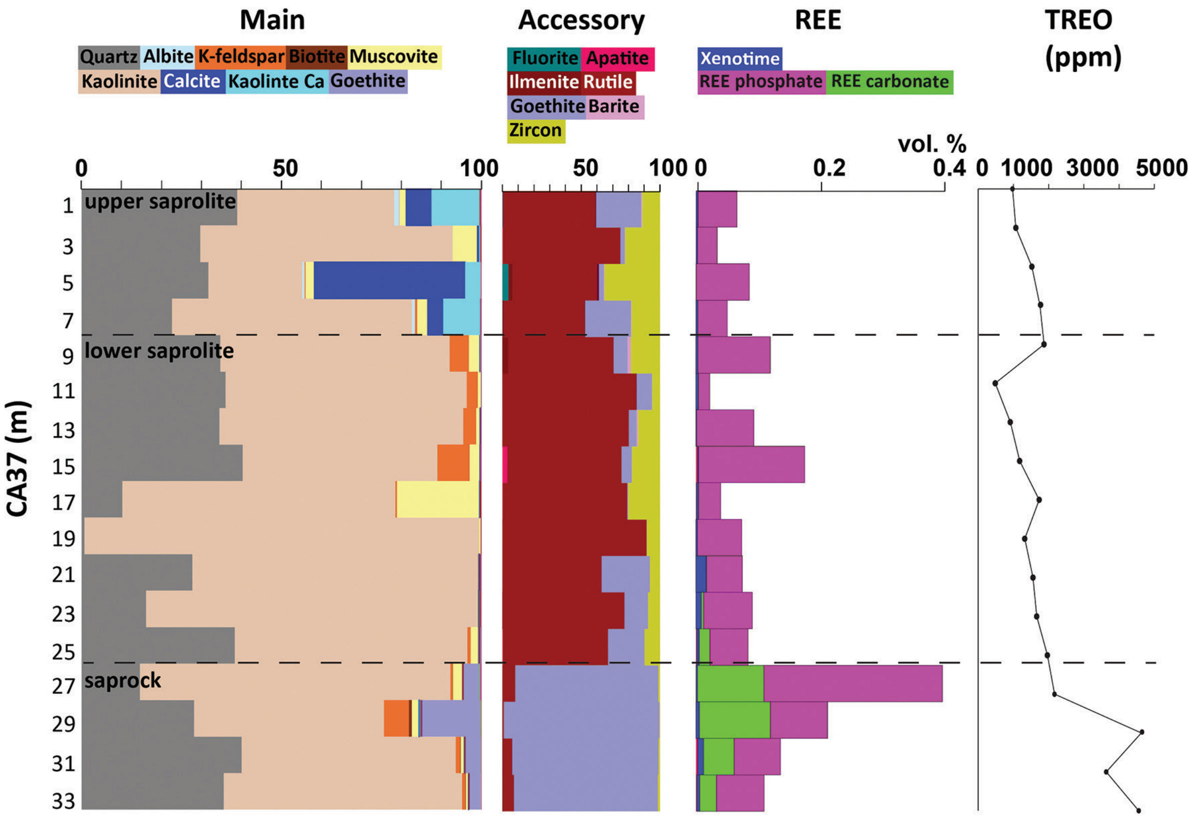

Figure 4. Downhole TIMA mineralogy for main, accessory and REE minerals with associated total rare earth oxides (ppm) from bulk rock.

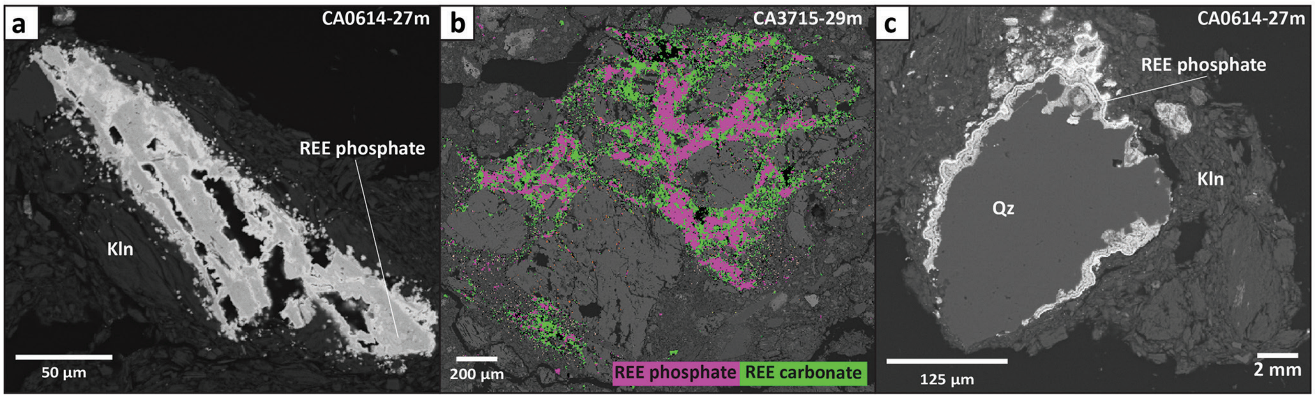

Figure 5. TIMA mineral maps and BSE images of REE minerals from drillhole CA37 (Qtz = quartz, Kln = kaolinite): (**a**) primary REE phosphate showing altered edges with brighter BSE (secondary phosphate precipitation); (**b**) weathered REE phosphate with associated fine-grained carbonates within a fractured K-feldspar crystal; (**c**) colloform REE carbonate precipitated at the boundary of a quartz crystal.

Discussion

The Miocene ferricrete-related palaeodrainage represents the last major phase of intensive weathering preserved in the region. The silcrete probably formed during the same broad time period as the ferricrete, in topographic lows before landscape inversion and differential erosion that led to the hill formation. Comparable silcrete development is known from central Australia, where significant groundwater-related silcrete formed at the base of palaeovalley and lake systems during the Eocene to mid-Miocene under subtropical monsoonal climatic conditions (Alley *et al* 1999). The duricrusts that have developed in the region would have provided protection from erosion to the underlying REE-bearing saprolite, aiding preservation.

Initially, weathering of the Southwark Suite granite before and during the Miocene would have led to REE remobilisation preferentially from allanite-dominated material compared to monazite-dominated material. However, primary mineralogy does not exert first-order control on secondary REE phases, as REE remobilisation coupled with apatite weathering can produce secondary REE phosphates (eg rhabdophane). These secondary phosphates contain the bulk of the REE found at Callista. In areas with more intensive weathering related to drainage and fluid flow, carbonates are found replacing phosphates towards the base of the weathering profiles.

Comparisons with other prospects in this study show distinct similarities and differences with the Callista prospect. In Western Australia, the Balladonia and Splinter Rock prospects (Reid *et al* 2025) possess similar secondary REE phosphate mineralogy in the upper saprolite, preserved in transported material deposited in palaeochannel systems. This landscape position and mineralogy suggest similar formation mechanisms. In South Australia, the Boland site, hosted within a palaeochannel in the Gawler Craton, presents REE enrichment in the transported materials, with no surface expression of the REEs.

Conclusions

Overall, the Callista case study demonstrates how integrated geological, mineralogical and geochemical investigations can reveal the complex pathways controlling REE enrichment in weathered granite terrains. Despite contrasting primary REE hosts within the Southwark Suite, secondary processes – particularly the formation of REE phosphates and, under stronger weathering conditions, REE carbonates – are the dominant controls on REE distribution in the regolith. The geomorphic context, especially Miocene palaeodrainage development and subsequent erosion, strongly influences profile preservation and surface expression of REE enrichment. This work provides a framework for exploring clay-hosted REE systems in Australia by linking REE behaviour to regolith architecture, weathering intensity and landscape evolution. Comparisons with similar prospects in Western Australia and South Australia further highlight the importance of secondary REE phosphate formation and the role of transported regolith in preserving REE signatures, underscoring the broader applicability of these findings to critical mineral exploration across Australia.

Acknowledgements

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