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Mineral chemistry of Rare Earth Element (REE) mineralization, Browns Ranges, Western Australia

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ABSTRACT

'Green energy futures' are driving unprecedented demand for Rare Earth Elements (REE), underpinning significant exploration activity worldwide. Understanding how economic REE concentrations form is critical for development of exploration models. REE mineralisation in the Browns Ranges, Gordon Downs Region, Western Australia, comprises xenotime-dominant mineralisation hosted within Archaean to Palaeoproterozoic metasedimentary units (Browns Range Metamorphics). Mineralogical, petrographic and mineral–chemical investigation, including trace element analysis by Laser-Ablation Inductively-Coupled Plasma Mass Spectroscopy, gives insights into the mineralogical distribution and partitioning of REE, and also provides evidence for the genetic evolution of the Browns Range REE mineralisation via a succession of hydrothermal processes.

Two main REE-bearing minerals are identified: xenotime [$(Y,REE)PO_4$], which is HREE selective; and subordinate florencite [$(REEAl_3(PO_4)_2(OH)_6$] which is LREE selective. Two morphological generations of xenotime are recognised; compositions are however consistent. Xenotime contains Dy (up to 6.5 wt.%), Er (up to 4.35 wt.%), Gd (up to 7.56 wt.%), Yb (up to 4.65 wt.%) and Y (up to 43.3 wt.%). Laser Ablation ICP–MS element mapping revealed a subtle compositional zoning in some xenotime grains. LREE appear concentrated in the grain cores or closest to the initial point of growth whereas HREE, particularly Tm, Yb and Lu, are highest at the outer margins of the grains. The HREE enrichment at the outer margins is mimicked by As, Sc, V, Sr, U, Th and radiogenic Pb. Florencite is commonly zoned and contains Ce (up to 11.54 wt.%), Nd (up to 10.05 wt.%) and La (up to 5.40 wt.%) and is also notably enriched in Sr (up to 11.63 wt.%) and Ca. Zircon (which is not a significant contributor of REEs overall due to its low abundance in the rocks) is also enriched in REE (up to 13 wt.% ΣREE) and is the principal host of Sc (up to 0.8 wt.%).

Early, coarse euhedral xenotime has undergone fracturing, partial breakdown and replacement by florencite. Second generation xenotime occurs as abundant small blades commonly associated with acicular hematite. Mineralization is attributed to percolation of a volatile-rich, acidic fluid, possibly granite-derived, through porous arkose units. Late hematite may suggest mixing with meteoric water and subsequent oxidation. Field observations suggest that faults acted as fluid conduits and that brecciation, possibly associated with release of volatiles from the fluid, occurred along these faults.

The data provide valuable constraints on chemical compositional trends in xenotime and coexisting minerals. Given the current surge in exploration for REE, this information will assist in the development of exploration models for comparable terranes.

1. Introduction

Rare Earth Elements (REE) have multiple uses (Hoatson et al., 2011; Long et al., 2010) and are critical for the sustained development of new 'green' technologies. The current drive towards green energy is part of the reason for the dramatic increase in demand for REE in the past 2–3 years. Demand for REEs is expected to grow further over the next 5–10 years. China currently accounts for 95% of global REE production and no less than 99.8% of global Heavy Rare Earth Element (HREE) production (Hoatson et al., 2011; Long et al., 2010). Recent reductions in Chinese export quotas have caused anxiety about supply shortages and a dramatic rise in market prices for all REE. Australia is one country actively pursuing a 'green energy' future and its share of global REE demand is expected to increase, generating interest in establishing domestic production that will reduce dependence on China.

There is a marked gap in current knowledge with respect to the formation of hydrothermal REE deposits and the controls on economic

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concentration of REE-minerals (particularly those which carry HREE), as well as the partitioning behaviour of elements of interest among coexisting phases. REE-host minerals such as xenotime, florencite, goyazite and zircon all have complex chemistries with substitution and replacement mechanisms often incompletely constrained. Careful petrographic and mineralogical observation is a critical requirement for characterisation of REE deposits, for development of exploration models and for processing of mineralogically complex ores. Understanding the mineralogy and textural relationship among REE-minerals thus carries both economic and exploration significance. Factors such as pressure, temperature, fluid chemistry, the distinct generations of fluid that passed through the system, age and source of REE can all be potentially constrained by mineralogical and petrological observation and associated microanalysis.

An exploration project at Browns Ranges, Gordon Downs Region, Northeastern Western Australia, is one of a number of new projects generating attention during the current upsurge in the search for exploitable REE resources. The present focus in the exploration tenement areas are elevated HREE/Light Rare Earth Element (LREE) ratios in a number of previously-known and newly-discovered xenotime-dominant prospects. The pronounced HREE/LREE enrichment is unusual and of potential major economic significance. The restricted information on the geology of the area and the limited analogues elsewhere in the World for this style of REE-mineralisation have hampered development of an exploration model.

The present contribution characterises potential REE-ore from currently defined prospects. Goals include identification of the mineral hosts for REE and other elements of economic interest or significance, the paragenetic, chemical and textural characteristics of the REE deposit, relationships between ore and host rocks. We also provide components for a preliminary genetic model to account for the observations at various scales.

2. Geological setting

The Browns Range Dome is located within the Gordon Downs (Western Australia) and adjacent Tanami (Northern Territory) regions of north-central Australia. The prospects under consideration here are located solely within the Western Australia segment, approx. 150 km southeast of Halls Creek (Fig. 1a). Regional geology is complex with multiple deformation events affecting the package of Late Archaean to Palaeoproterozoic rocks. Bedrock geology of the Browns Range area is dominated by metamorphosed Archaean metasediments and Lower Proterozoic arkoses (Blake et al., 1979; Cross and Crispe, 2007; Hendrickx et al., 2000; Page et al., 1995; Tunks and Cooke, 2007). Hendrickx et al. (2000) discuss geophysical evidence for the dome being a large (buried) granite pluton and correlated this with "The Granites" suite to the southeast. Although rarely exposed, the basement rocks are known to be gneisses of igneous origin and meta-sedimentary rocks that have undergone regional metamorphism at conditions up to amphibolite facies. The basement rocks outcropping within the Browns Range Dome are known as the Browns Range Metamorphics (Blake et al., 1979, 2000; Hendrickx et al., 2000). Granite gneisses within the Browns Range Dome were initially dated at 2510–2500 Ma (Page et al., 1995) and were considered (e.g., Hendrickx et al., 2000) to have undergone high-grade metamorphism at ~1970 or ~1880 Ma. The latter metamorphic event was refuted by new evidence given by Cross and Crispe (2007). Reassessment of zircons in the sample analysed by Page et al. (1995) by Cross and Crispe (2007) revealed three distinct clusters of $^{207}Pb/^{206}Pb$ ages (~3.15 to 3.04 Ga, ~2.67 to 2.44 Ga and ~ 1.99 to 1.87 Ga). The latter, Palaeoproterozoic ages, in zircons that did not show characteristics typical of metamorphism or recrystallization clearly demonstrates that the Browns Range Dome granite complex includes rocks of both Archaean and Palaeoproterozoic age, thus contradicting Page et al. (1995) who considered the complex to be essentially all Archaean.

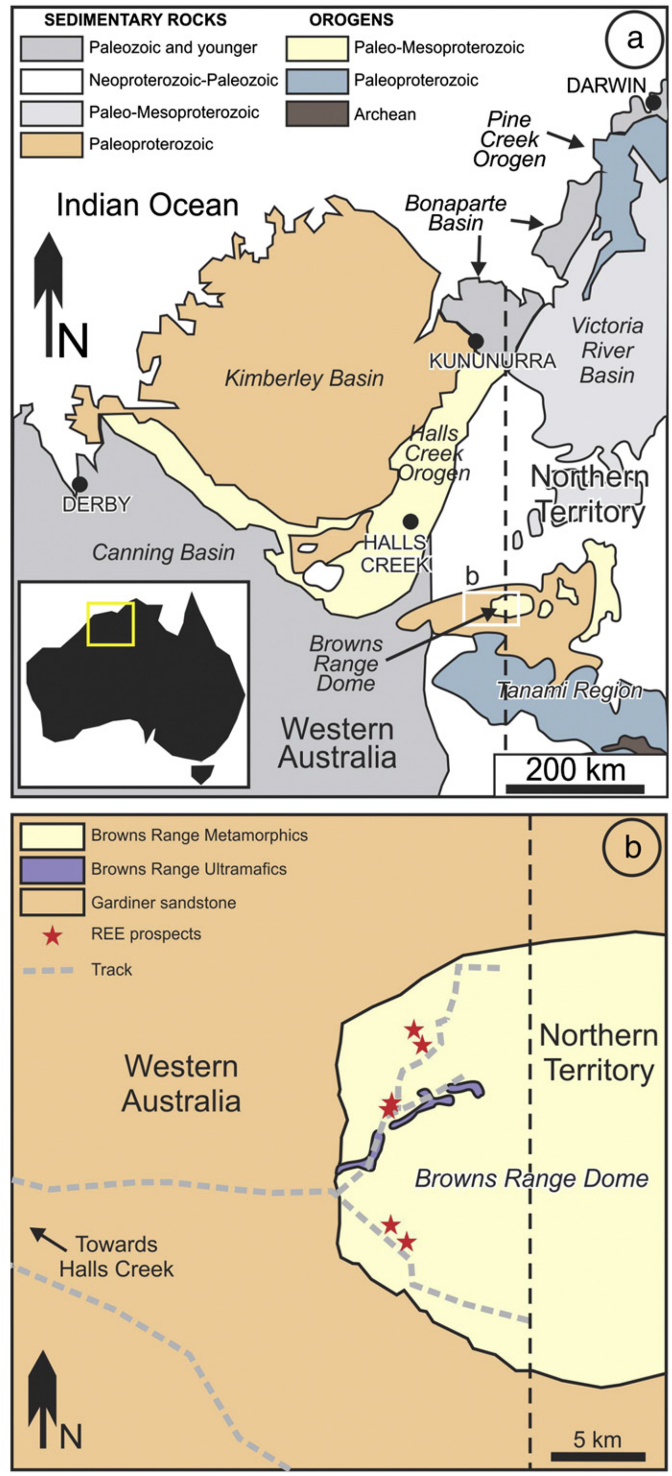

Fig. 1. (a) Schematic geological map of the Browns Range area after Hendrickx et al. (2000). Rectangle indicates the location of the prospects described here. Inset shows location within Australia. (b) Geological sketch map of the eastern part of the Browns Range Dome with identified REE prospects located by red stars.

Tanami Group sedimentary sequences unconformably overlie the Archaean rocks and are dated at 1880–1830 Ma (Bagas et al., 2009; Cross and Crispe, 2007). The lower unit within the Tanami Group, the deepwater siltstone Dead Bullock Formation, is an important gold host within the area (Crispe et al., 2007). Overlying this is the turbiditic Killi Killi Formation. Deposition was terminated by the Tanami event