Rare earth element mineral systems of significance to the NT

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The renewable energy transition will require an unprecedented supply of rare earth elements (REE) for high-powered magnets for electric motors and turbines. The largest quantity of metals needed will be for the light REE (LREE), neodymium (Nd) and praseodymium (Pr), which are – and will continue to be – sourced primarily from carbonatite-related deposits such as Bayan Obo (China), Mountain Pass (California) and Mount Weld (Western Australia), and from monazite-rich mineral sands. Heavy REE (HREE), such as dysprosium (Dy) and terbium (Tb), are also crucial magnet metals but have relatively low concentrations in carbonatites. Ionic clay deposits of southern China have historically been a major source of the world's HREE, but this supply has diminished significantly in recent years as environmental concerns have led to restrictions on mining.

Australia's highly prospective geology and established mineral exploration and extractives industry mean that it is well placed to expand its role as a global supplier of REE. The Northern Territory (NT) not only has a world-class REE ore deposit at Nolans Bore (Huston *et al* 2016, Anenburg *et al* 2020) but also has enormous potential for further REE discoveries, including for highly sought-after HREE deposits. Herein, we outline the geological setting and ore genesis models for the most prospective REE deposit types for the NT.

A favourable exploration aspect for the NT is that a significant portion of the geology is of mid-Proterozoic age (ie 1 to 2 Ga), an age range recognised to be particularly prospective for the formation of REE deposits (Spandler *et al* 2020). Chandler (in prep) recognised that REE prospective carbonatites and carbonatite-related rocks fall into discrete belts within the continent, with one such belt running broadly east–west through the Aileron Province in central NT. This belt includes Nolans Bore (now regarded to be carbonatite-derived; Anenburg *et al* 2020), Mud Tank, and the Mordor Complex; however, the belt may ultimately be shown to extend further westward pending follow-up exploration on a new mineralised carbonatite discovery in the West Arunta (WA1 Resources 2022), just over the border in Western Australia (WA).

Furthermore, perhaps of greatest potential for REE in the NT are two emerging types of basin-hosted REE deposits: (1) phosphorite-hosted REE mineralisation, and (2) unconformity-related REE mineralisation.

Phosphorite-hosted REE mineralisation

Emsbo *et al* (2016) highlighted that sedimentary phosphate deposits (or phosphorites) that are currently targeted for phosphate production may also host significant REE contents. However, these authors concluded that REE 'fertility' of phosphorite is primarily controlled by global seawater REE contents, which vary through geological time. On this basis, they concluded that Cambrian phosphorites should have low prospectively for REE. Nevertheless, recent work by Valetich *et al* (2022) demonstrates that phosphorites of the Cambrian Beetle Creek Formation of the Georgina Basin, western Queensland, have amongst the highest REE contents known from any phosphorite deposit globally. Importantly, these rocks have relatively high contents of HREE. Ongoing petrographic, geochemical and isotopic work on these deposits shows that the REE contained in these rocks is seawater derived, but can be upgraded depending on conditions of sedimentation, hydrothermal alteration, and weathering.

Phosphatic deposits of the Georgina Basin in the NT represents an untested target for economic REE mineralisation, particularly if REE extraction can achieved as a by-product of phosphate mining. Our preliminary data suggest that elevated REE contents are favoured in pelletal-style phosphorite, as well as in phosphorite that is subject to surficial weathering and interaction with aluminous sediments allowing formation of plumbogummite mineral species such as crandalite and florencite.

Unconformity-related REE mineralisation

Recently defined unconformity-related HREE mineralisation (Nazari-Dehkordi *et al* 2018) consists of quartz plus xenotime mineralisation in veins and fault breccias near and along regional unconformities between Archean to Paleoproterozoic metasedimentary basement rocks and in overlying Mesoproterozoic sedimentary sequences. Although most occurrences have been recognised from the Browns Range Dome in the northern Tanami of WA, the mineralisation style has been identified across a broad area straddling the NT–WA border, including Killi Kill Hills (WA), Boulder Ridge (NT), and John Galt (east Kimberley region, WA). The mineralisation is purely hydrothermal in origin (>300ºC) and is proposed to have formed in response to mixing between REE-bearing, basement-derived saline fluids and low pH, phosphate-bearing fluids from the overlying basinal rocks (Nazari-Dehkordi *et al* 2018).

Our recent research (Walsh and Spandler in review) demonstrates that the source of REE in the Browns Range deposits is metamict detrital zircon from the hosting metasedimentary rocks. These radiation-damaged zircons absorbed REE (plus Th, U, P, Fe, Al, etc) during weathering and sediment deposition in the late Archean, followed by REE remobilisation via saline fluids during ore formation at ca 1.64 to 1.60 Ga. A key condition enabling REE leaching from zircon is a lack of zircon structural recovery via annealing, meaning that these rocks largely remained below 300ºC for most of their history.

The Proterozoic to Palaeozoic basinal systems of the NT hold enormous potential for unconformity-related REE deposits. Preliminary assessment of the xenotime rich Skyfall/Stromberg prospects in the Daly Basin, and the Arthur Pope's prospect in the eastern Arunta (Whelan *et al* 2023), suggest that these are unconformity-related REE

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mineral systems. Archean and Palaeoproterozoic basement rocks (eg Pine Creek, Aileron, Tanami, Murphy, and Warramunga) may represent suitable REE sources; overlying unconformity surfaces or fault zones may represent suitable metal traps for ore formation. Similarities of the geological setting and geological processes of formation between unconformity uranium and unconformity REE systems mean the Pine Creek Orogen would be particularly prospective.

References:

Anenburg M, Mavrogenes JA and Bennett VC, 2020. The fluorapatite P–REE–Th vein deposit at Nolans Bore: genesis by carbonatite metasomatism. *Journal of Petrology* 61(1), egaa003. https://doi.org/10.1093/petrology/egaa003

Emsbo P, McLaughlin PI, du Bray EA, Anderson ED, Vandenbroucke TR and Zielinski RA, 2016. Rare earth elements in sedimentary phosphorite deposits: A global assessment: in Verplanck PL and Hitzman MW (editors). '*Rare earths and critical elements in ore deposits*'. *Reviews in Economic Geology* 18. https://doi.org/10.5382/Rev.18.05

Chandler R and González-Álvarez I, in prep. Insights into the geological characteristics of the carbonatites and carbonatite-related rocks of Australia with a focus on associated rare earth element and niobium mineralization.

Huston DL, Maas R, Cross A, Hussey KJ, Mernagh TP, Fraser G and Champion DC, 2016. The Nolans Bore rare-earth element-phosphorus-uranium mineral system: geology, origin and post-depositional modifications. *Mineralium Deposita* 51, 797–822. https://doi.org/10.1007/s00126-015-0631-y

Nazari-Dehkordi T, Spandler C, Oliver NH and Wilson R, 2018. Unconformity-related rare earth element deposits: a regional-scale hydrothermal mineralization type of Northern Australia. *Economic Geology* 113, 1297–1305. https://doi.org/10.5382/econgeo.2018.4592

Spandler C, Slezak P and Nazari-Dehkordi T, 2020. Tectonic significance of Australian rare earth element deposits. *Earth-Science Reviews* 207, 103219. https://doi.org/10.1016/j.earscirev.2020.103219

Valetich M, Zivak D, Spandler C, Degeling H and Grigorescu M, 2022. REE enrichment of phosphorites: An example of the Cambrian Georgina Basin of Australia. *Chemical Geology* 588, 120654. https://doi.org/10.1016/j.chemgeo.2021.120654

Walsh JMJ and Spandler C, in review. The role of zircon in hydrothermal heavy REE mineralisation: The case for unconformity-related ore deposits of north-west Australia. *Chemical Geology.*

WA1 Resources Ltd, 2022. *West Arunta Project - Discovery of niobium-REE mineralised carbonatite system.* Australian Stock Exchange announcement: WA1, 26 October 2022.

Whelan JA, McGloin M, Close D, Mass R, Walsh J and Spandler C, 2023. Demystifying the Arthur Pope's prospect: REE, Y and Cu bearing carbonate–quartz veins in the Casey Inlier, central Australia: in '*Annual Geoscience Exploration Seminar (AGES) Proceedings, Alice Springs, Northern Territory 18–19 April 2023*'. Northern Territory Geological Survey, Darwin (this volume).