Isotopically fingerprinting the source to Orange River rare metal pegmatites

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Collaborators: Dr Leo Vonopartis, Dr Scott Maclennan, Dr Paul Nex, University of the Witwatersrand.

Project Highlights:

- Orange River pegmatites constitute both LCT and NYF types
- Magmatic sources to these deposits are poorly constrained
- Aim to apply geochemical and isotopic techniques to build petrogenetic models

Overview:

LCT pegmatites are small granitic intrusions which also carry rare metals such as lithium, tantalum and tin. The converging consensus is that many economic LCT pegmatites result from low-degree partial melting of a source pre-enriched in Li (Müller et al., 2017; Webber et al., 2019). Therefore, a key question is what this melt source is, and how it becomes pre-enriched in rare metals. The canonical view is that akin to S-type granites, LCT pegmatites are formed via the partial melting of a metasedimentary protolith, and that to attain the high levels of Li and other metals this material is pre-enriched via weathering processes. However, other models to elevate initial Li contents have been proposed, including multi-stage magmatic processing (Koopmans et al. 2024, Stirling et al. 2026).

This PhD will use innovative isotopic and geochemical tools to tackle the issue of the crustal source(s) to mineralised LCT-type pegmatites of the Orange River Pegmatite Belt. The 450km-long Orange River Pegmatite Belt lies in the Northern Cape of South Africa, and is hosted by the ca. 1.3–1.0 Ga Namaqua-Natal Metamorphic Province (Ballouard et al., 2020) (Fig. 1). The extremities of the Belt host lithium-caesium-tantalum (LCT)-type pegmatites, with many mineralised in lithium and tin (Minnaar and Theart, 2006). Despite recent studies, a robust chronology for the pegmatites is yet to be fully established, and their relationship to surrounding host rocks (e.g. Thomas et al. 2026) properly constrained – the focus of this study.

The candidate will develop and deploy non-traditional mineral-based isotopic tools such as Sr isotopes in apatite and Pb-Sr isotopes in feldspar coupled with geochronometers e.g. U-Pb or Lu-Hf in apatite. They will compare both selected mineralised and barren examples to surrounding continental crust including regional magmatic rocks and metasedimentary protoliths.

The project builds on recent work by the supervisory team and the establishment of new analytical techniques at the University of St Andrews. The project is in partnership with the University of the Witwatersrand, Johannesburg, with whom the candidate will collaborate.

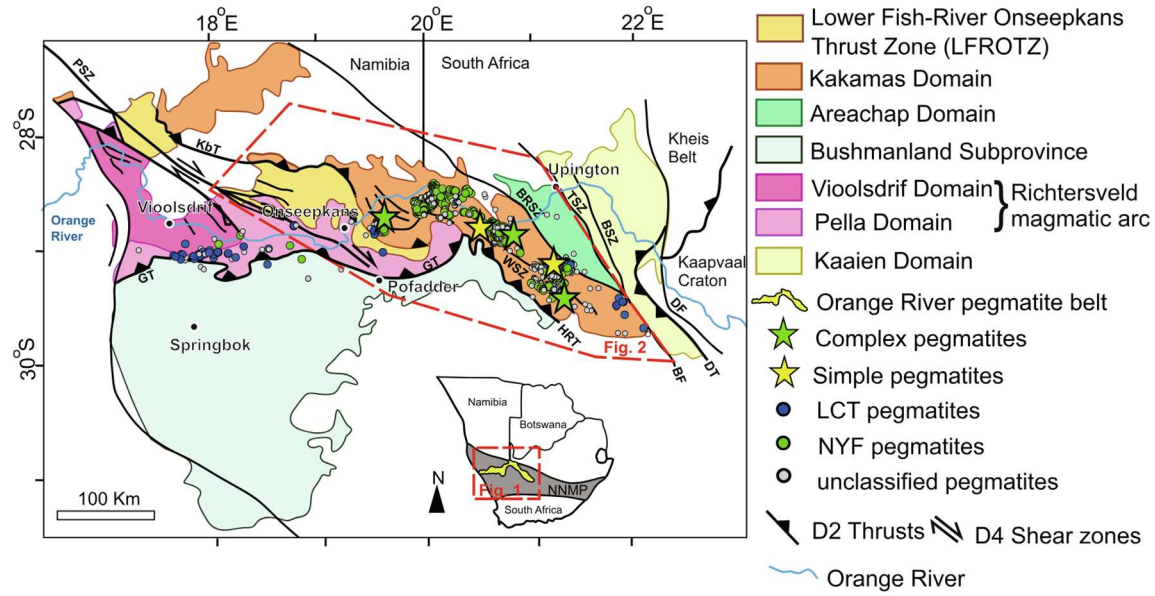

Figure 1: A geological map of the Orange River Pegmatite Belt, from Maphumulo et al. 2025

Alt text: A geological map of the Western a

Key research questions:

This project aims to answer the following key research questions:

1) Can we further develop a chronology for the LCT pegmatites in the Orange River Pegmatite Belt?

2) What is the genetic relationship of mineralised pegmatites to the surrounding host rocks?

4) How do mineralised and unmineralized pegmatites differ, and does this hint at a distinct origin?

5) Can we develop enhanced rare metal pegmatite formation models, and how might this inform mineralisation?

Methodology:

The student will:

(i) Sample appropriate mineralised and unmineralized pegmatite, and country rocks in South Africa;

(ii) Deploy mineral-based chronometers via LA-ICPMS to further develop a chronological framework;

(iii) Apply mineral-based isotopic tracers of source to both mineralised and barren examples to probe their genetic origins.

Possible Timeline

Year 1: Fieldwork, initial sample collection and training

Year 2: Geochronology and isotope analysis; possible 2nd field season

Year 3: Data interpretation, presentation at conferences and paper writing.

Training and skills:

TARGET researchers will participate in a minimum of 40 days training over the 3.5 years of study composed of:

- an annual one-week workshop dedicated to their year group, and tailored to that cohort's needs in terms of skills development – *for the first three years of their study*;
- an annual all-TARGET workshop with cross-year interactions, advanced training and opportunities to specialise in particular areas – *all years of study*;
- a number of one-day workshops;
- additional online events and in-person workshops attached to relevant conferences.

The student will trained in isotope geochemistry and geochronology analysis via LA-ICPMS, data reduction and interpretation at the St Andrews Geochronology Laboratory (StAGE) and at the Isotope and Tracing Facility, British Geological Survey. They will become part of a vibrant research culture in the School of Earth and Environmental Sciences, with MSc, PhD and postdocs working on a range of research projects in the PALS (Pegmatites and Laser) and PaStA (Petrology at St Andrews) research groups. It is anticipated a number of publications will arise from this study, and training in scientific manuscript preparation and presentation will be given.

Partners and collaboration (including CASE):

This project is in partnership with the British Geological Survey and the University of the Witwatersrand. At least one visit to the BGS in Keyworth is expected, where the student will perform some of the analytical work. Additionally, at least one trip to South Africa is expected for fieldwork and sample collection, and for collaboration with Wits.

Further reading:

Ballouard, C., Elburg, M.A., Tappe, S., Reinke, C., Ueckermann, H., Doggart, S., 2020. Magmatic-hydrothermal evolution of rare metal pegmatites from the Mesoproterozoic Orange River pegmatite belt (Namaqualand, South Africa). Ore Geology Reviews 116, 103252. https://doi.org/10.1016/j.oregeorev.2019.103252

Koopmans L, Martins T, Linnen R, Gardiner NJ, Breasley C, Palin R, Groat L, Silva D, Robb L. 2024. The formation of lithium-rich pegmatites through multi-stage melting. Geology 52(1) 7-11

Maphumulo, M.S., Ballouard, C., Elburg, M.A., 2025. Age and origin of NYF pegmatites from the Mesoproterozoic Orange River pegmatite belt (Namaqualand, South Africa): insights from monazite and titanite U-Pb geochronology and Nd isotope systematics. Lithos 510–511, 108110. https://doi.org/10.1016/j.lithos.2025.108110

Minnaar, H., Theart, H.F.J., 2006. The exploitability of pegmatite deposits in the lower Orange River area (Vioolsdrif – Henkries – Steinkopf). South African Journal of Geology 109, 341–352.

Müller, A., Romer, R.L., Pedersen, R.-B., 2017. The Sveconorwegian Pegmatite Province – Thousands of Pegmatites Without Parental Granites. The Canadian Mineralogist 55, 283–315. https://doi.org/10.3749/canmin.1600075

Stirling, J.E., Kemp, A.I.S., Fisher, C.M., Bevan, D., Hagemann, S.G., Gill, C.E., Kong, E., 2026. Geochronological evidence for multi-stage melting in lithium-rich pegmatite formation. Geology. https://doi.org/10.1130/G54140.1

Thomas, R.J., Cornell, D.H., Macey, P.H. 2026. The Namaqua-Natal Province. South African Journal of Geology 129(1)

Webber, K.L., Simmons, W.B., Falster, A.U., Hanson, S.L., 2019. Anatectic pegmatites of the Oxford County pegmatite field, Maine, USA. The Canadian Mineralogist 57, 811–815.

Further details:

Please visit https://target.le.ac.uk/ for additional details on how to apply. Informal enquiries regarding this project may be addressed to Nick Gardiner (nick.gardiner@st-andrews.ac.uk).

https://www.st-andrews.ac.uk/earth-sciences/people/njg7