ST.171
Geologic and Tectonic Setting of Uranium Mineralisation in the Damara Orogen

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The southern Central Zone of the Damara Orogen, situated in the Erongo region of Namibia, is a well-known uraniferous province. In addition to the Rössing and Husab uranium mines, exploration for primary granite-hosted uranium mineralisation is actively ongoing beneath the desert plains. Understanding the tectonic setting of a mineral system is integral to understanding the processes that focused mineralisation into economic concentrations. This understanding forms a key component of modern approaches to exploration.

Primary uranium mineralisation is hosted by leucogranite sheets, which intruded into the mid-crust of the Damara Orogen during NW-SE collision between the Congo and Kalahari cratons at ~550-500 Ma. At the regional scale, pressure-temperature-time (P-T-t) paths show that uraniferous leucogranites intruded into the Damara Orogen at a relatively late stage, ~20-30 m.y. after the onset of crustal thickening. Their intrusion overlapped with peak metamorphic conditions of ~800°C/4-5 kbar, which was associated with in situ partial melting and the formation of migmatites. While the exact source of this late-stage high-T metamorphism is equivocal, the absence of a clear mantle signature in any Damaran granites, combined with elevated concentrations of radioactive elements in Damaran metasediments, a near-isobaric heating path, and an appropriate timescale for radioactive heating (~20-30 m.y.), suggests that internal crustal heat production may have been significant. Leucogranites have a predominantly S-type to slightly I-type chemistry, consistent with partial melting of metasedimentary to metaigneous crustal sources.

Geologic mapping shows that several domes in the lower Swakop and Khan rivers are cored by (1) overwhelming volumes of Damaran-aged granites and migmatites, which (2) crosscut rafts and/or locally continuous horizons of Damaran metasediments. Granite migration was structurally controlled; at deeper levels in the cores of domes, melt intruded pervasively along foliation planes and as crosscutting dikes, forming hectometre-scale granite-injection complexes. In the overlying metasediments, granite transport is restricted to crosscutting dikes, which intruded either as ductile fractures or as self-propagating hydrofractures. Paradoxically, many dikes exposed along the Swakop River strike consistently NE-SW, seemingly parallel to the sigma-3 principal stretching direction; this contrasts with theoretical models predicting dikes should be oriented normal to sigma-3.

Granite-hosted uranium mineralisation at the deposit scale is closely associated with a redox boundary at the Khan-Rössing Formation contact. However, an explanation for why uraniferous leucogranites are so localised to this contact, when barren leucogranites are regionally widespread throughout the cores of domes, is the most significant outstanding question. Distinct shear zones, which might act to localise the intrusion of uraniferous leucogranites, are not consistently developed. This likely reflects the high-temperature conditions at the time of granite intrusion, which led to widespread rheological weakening of the mid-crust and acted to prevent strain localisation. Similarly, post-Damaran deformation is relatively limited and there is little evidence for major fault zones, which might have caused postdepositional modification of the deposits.