RÖSSING URANIUM MINE, NAMIBIA: INSIGHTS INTO ITS GENESIS FROM STRUCTURAL MAPPING AND ORE BODY MODELING

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SYNOPSIS

Late-tectonic (D_4) rotation and southward impingement of the competent Etusis Formation core of the Rössing Dome into the surrounding relatively incompetent Rössing and Khan formations approximates a large-scale “porphyroblast : matrix” configuration, essentially the surface expression of block rotation caused by left-lateral shearing along NNE-trending (Welwitschia trend) D_4 shears. D_3/F_3 domes were formed in a metamorphic core complex, initiated by a N-S transpressional regime, synchronous with peak deformation due to oblique collision of the Kalahari and Congo cratons. A protracted period of transtension, generating abundant granites and alkali-leucogranites, followed. Strain variation in D_4 served to localize and enhance the intrusion of late-tectonic U-enriched granites, particularly within the Rössing and Khan Formations at the southern tip of the relatively competent core of the Rössing Dome. Dome core movement and consequent mobilization of granites indicates a *c.* 510-468 Ma (peak granite intrusion to end of prolonged cooling) rejuvenation of the stresses that caused the earlier *c.* 600-550 Ma transpressional event.

INTRODUCTION

Intrusive granite-hosted uranium deposits comprise only 2.2%, of global uranium deposits catalogued by the IAEA (Tauchid and Underhill, 1997). Granite-hosted uranium deposits occur primarily in Proterozoic and Archean (9 examples) and Palaeozoic host rocks (3 examples), with only one in the Mesozoic. The Palaeozoic Rössing deposit occurs in the medium- to high-grade (high-T, low-P) Central Zone (CZ) of the NE-trending Intracontinental Branch of the Damara Orogen, situated between the Kalahari and Congo Cratons. Late- to post-tectonic granite-hosted uranium mineralization is related to NNE-trending mantled D_3/F_3 domes between the Omaruru and Okahandja lineaments of the CZ (Berning, 1986; Bowden and Tack, 1995; Bowden *et al.*, 1995), and potentially the NNE-trending Welwitschia Lineament (Corner, 1983).

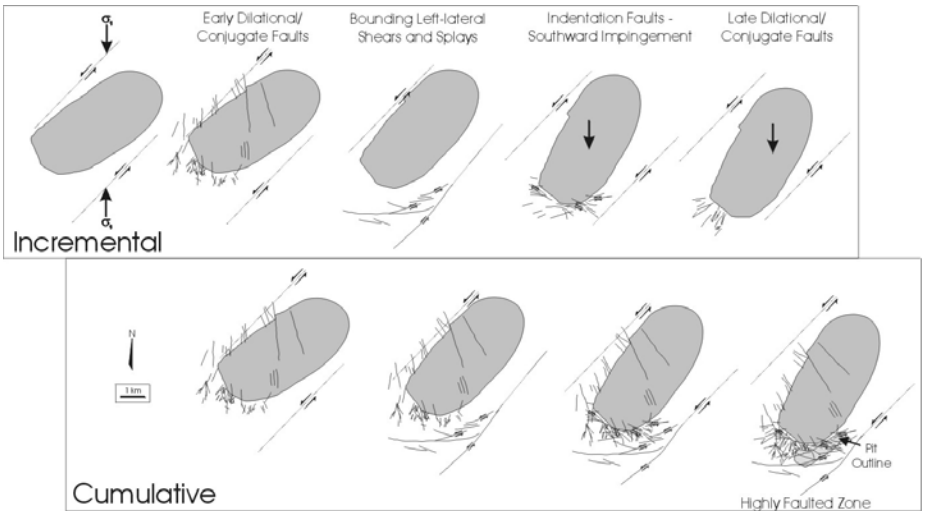
STRUCTURAL EVOLUTION AND LITHOSTRATIGRAPHY

Martin (1983) and Coward (1983), amongst others, detail CZ deformational events. D_1 and D_2 effects were largely obliterated by D_3. Rare S_1 and S_2 migmatitic banding occur in the Khan and Etusis formations, and as laminar foliations in Rössing Formation metapelites. D_3 produced highly ductile flow folding in Rössing Formation marbles. The Etusis Formation exhibits brittle-ductile deformation of rare S_1 and S_2 migmatitic banding. D_4 is expressed as rare, small isolated folds with axial planar foliations. The Etusis Formation (Nosib Group):Abbabis Complex contact is often indistinct due to anatexis of the Etusis Formation within D_3/F_3 dome cores. The Etusis Formation in the core of the Rössing Dome comprises migmatized psammites and pelites intruded by late- to post-kinematic granites. Khan Formation gneisses gradationally overly the Etusis Formation. The heterogeneous Rössing Formation paraconformably and disconformably overlies the Khan Formation. The Rössing Dome therefore demonstrates the effects of a relatively competent Etusis metaquartzite core, rimmed by relatively incompetent Khan and Rössing formations. A transpressional tectonic environment (*c.* 600-550 Ma, incorporating D_3), is pivotal in most models of dome formation e.g. interference folding and diapiric rise of granitic basement into overlying D_3-folded metasediments (Kröner, 1984), shear-induced sheath folding (Coward, 1983), doming over metamorphic core complexes (e.g. Crittenden *et al.*, 1980) and cusping by horizontal constriction due to a basement:cover competency contrast (Oliver, 1995). Granites form where transpression or continental collision thickens the crust and lithospheric mantle mechanical boundary layer, following which the latter enters hot asthenosphere, upwelling of which causes delamination of lithospheric mantle, fusion of the lower crust and extension/transtension, protracted upwelling and crustal assimilation (e.g. Bowden *et al.*, 1995). Subsequent tensional or transtensional sheared environments cause magma boiling while local post-extensional (D_4) structural catalysts caused repeated magma mobilization and localization, particularly at Rössing and nearby Goanikontes. CZ granite complexes yield intrusion, syn-metamorphic, tectonic or anatexis ages from 563±4 Ma to 505±4 Ma (Table 1). Peak transpressional movement due to N-S oblique collision of the Kalahari and Congo cratons occurred from *c.* 600 to 550 Ma (Bowden *et al.*, 1999), culminating in F_3 dome formation, followed by transtensional tectonism and metamorphism from *c.* 542 to 526 Ma. Bowden *et al*. (1995) suggest that granite intrusion peaked at 510±3 Ma. Late- to post-tectonic uranium-enriched granites are dated at 508±2 Ma (Briqueu *et al.*, 1980) and *c.* 510 Ma (Kröner, 1982), to 468±8 Ma (e.g. Von Backström & Jacob, 1978).

REVISED INTERPRETATION

The competent Rössing Dome core has been rotated approximately 27° anticlockwise, from an initial NE F_3 dome trend (Figure 1; Corner, 1983), during D_4. Relatively incompetent Khan and Rössing formation layers ("matrix") were offset left-laterally by NNE-trending (Welwitschia trend) bounding shears, comprising a large-scale "porphyroblast-matrix" system. Pre-D_3 and Post-D_3 granite intrusion (*c.f.* Nex *et al.*, in press) are resolvable. Rotation and southward impingement of the dome core produced a dense fault network at the Rössing deposit (Figure 1). D_4 (*c.* 510 to 468 Ma) therefore comprised a transpressional regime with a N-S maximum principal stress orientation almost identical to that of the *c.* 600-550 transpressional event (q.v. Bowden *et al.*, 1999). A revised ore body model shows that enhanced uranium mineralization trends at an acute angle (approximately 048°) to the 060°-trending $S_{3/4}$ banding in Khan and Rössing formations. Economic mineralization is concentrically distributed along the amphibole schist, due to granite intrusion and uranium mineralization in the high strain zone, resulting from cyclical pure shear (southward dome core indentation) and lateral (dome core rotation) mineralization redistribution.

Figure 1: *Incremental* and *Cumulative* brittle-ductile D_4 fault evolution of the Rössing Dome area.



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.Lithology/Locality	Dating Method/Mineral	Event Description from Reference	Age (Ma)	Reference	**Interpretation** (Bowden *et al.*, 1995, 1999; Jacob *et al.*, 2000)	**Interpretation** (Nex *et al.*, in press, *q.v.* Goanikontes area)
Kibaran granitoid-gneiss, Khan River (Abbabis)	U-Pb SHRIMP - zircon cores	Basement granite-gneiss	1038±58	Kröner *et al.* (1991)	Min. age of polycyclic pre-Damara basement	-- Orogenesis, continental collision & crustal thickening **Type A** granite Peak Damaran Met.
	U-Pb SHRIMP - zircon rims	Damaran met. overprint	571±64	Kröner *et al.* (1991)	*c.* 600-550 Ma – Peak transpressional tectonism & met. – Oblique N-S collision of Kalahari & Congo Cratons	
Mon Repos diorite, Navachab	U-Pb SHRIMP - zircon	Intrusion	563±4 to 546±6	Jacob *et al.* (2000)		Syn-met. red granite
Rotekuppe monzogranite, Navachab	U-Pb SHRIMP - zircon	Intrusion	543±5 to 539±6	Jacob *et al.* (2000)		
Granitoids, Ida Dome	U-Pb SHRIMP - zircon	Early post-collisional	*c.* 542-526	Bowden *et al.* (1999)	*c.* 542-526 Ma – Transtensional tectonism & metamorphism	
Red Granite, Goanikontes	U-Pb single ziron	Syn-met. anatexis	534±7	Briqueu *et al.* (1980)		
White-grey granite, Goanikontes	U-Pb - monazite	Syn-met. anatexis	517±7	Briqueu *et al.* (1980)	*c.* 510 Ma - Peak of granite plutonism	Decompression, D$_3$ deformation & dome formation, continued red & grey granite intrusion **Types B & C** granites Constrictional deformation in high strain zones Post-decompression isobaric annealing & crystallization
Okongava diorite	U-Pb – zircon evaporation	Early-tectonic	516±6	de Kock & Walraven (1994)		
Salem granite, Goas	U-Pb – zircon	Syn-met. intrusion	512±40	Allsopp *et al.* (1983)		
Khan Formation gneisses Goanikontes	U-Pb - monazite	Syn-met. growth	510±3	Briqueu *et al.* (1980)		
Alkali leucogranite, Goanikontes	U-Pb - **uraninite**	Intrusion/post-tectonic doming	**508±2**	Briqueu *et al.* (1980)	*This c.* 505-478 Ma (extended to *c.* 429 Ma?) – late/post-tectonic intrusion, cooling & closure *This study: reactivation of N-S compression, causing left-lateral movement along NNE-trending shears*	**Type D** granite & main **U mineralization**
Alkali leucogranite, Goanikontes	U-Pb - **monazite**	Intrusion/post-tectonic doming	**509±1**	Briqueu *et al.* (1980)		
Donkerhuk granite, Otjimbingwe	U-Pb - zircon	Intrusion/late-tectonic	505±4	Kukla *et al.* (1991)		**Types E & F** granites
Meta-lamprophyre sill, Navachab	U-Pb – SHRIMP, titanite met. overgrowths	Mineralization/cooling below closure	496±12	Jacob *et al.* (2000)		
Mineralized quartz veins, Navachab	U-Pb – SHRIMP, titanite	Mineralization/cooling below closure	494±8 to 500±10	Jacob *et al.* (2000)		
Diorite, Otjozondjou	^{40}Ar/^{39}Ar - hornblende	Cooling below 500°C	478±4	Hawkesworth *et al.* (1983)		Donkerhoek Granites (*q.v.* de Kock & Walraven, 1995 Cooling & localized resetting of Rb-Sr ages
U-enriched alkali leucogranite, Rössing	Rb-Sr biotite (possibly spurious)	Late- to post-tectonic intrusion	**468±8**	Von Backström & Jacob (1978)		

Table 1: Intrusion-related anatexis, metamorphic & tectonic events of the Central Zone