The Koperberg Suite of the Okiep Copper District –

an overlooked target for magmatic nickel sulphides in a convergent margin system

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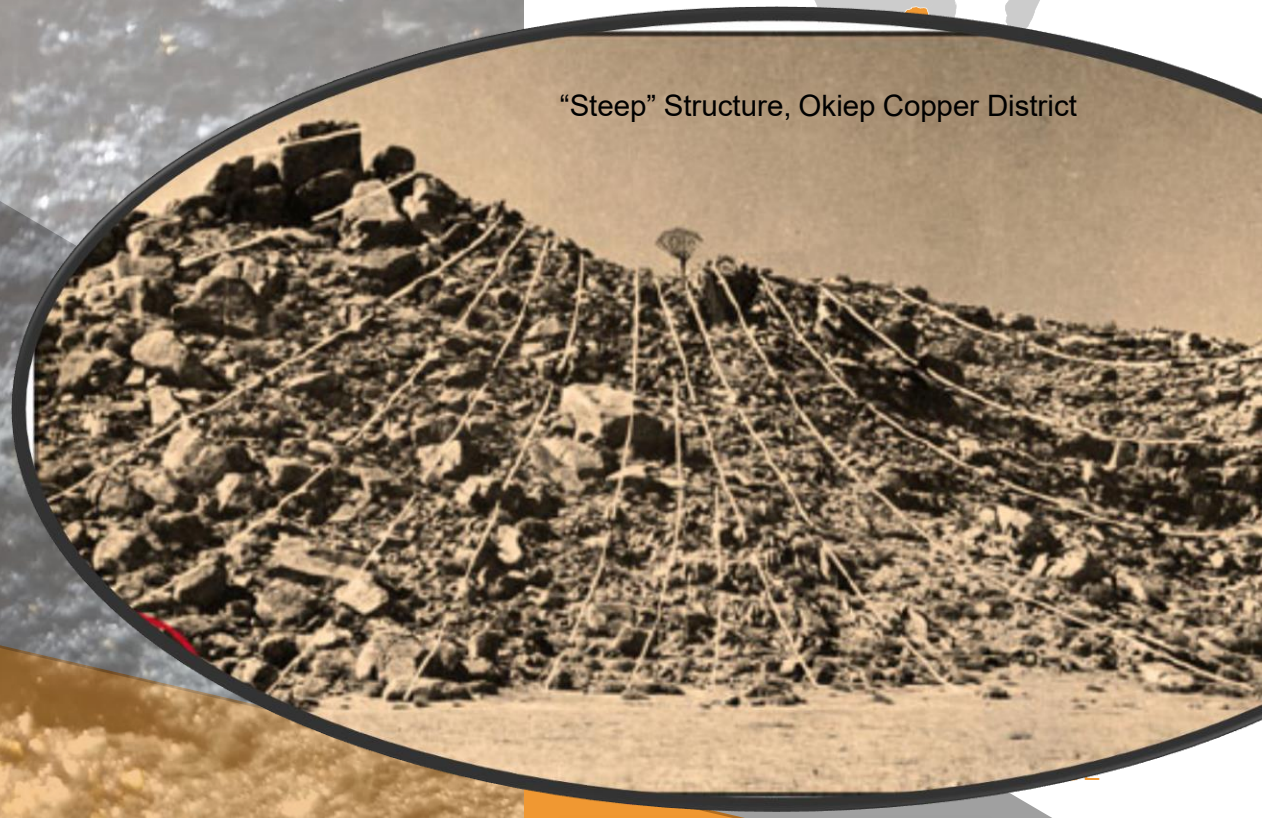
Hunt J.P., van Schalkwyk L., Smart E. and Benhura C.

Minerals



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The Koperberg Suite of the Okiep Copper District – an overlooked target for magmatic nickel sulphides in a convergent margin system

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Contents

HISTORY – OKIEP COPPER DISTRICT (OCD)

- First prospected 1680s by Gov Simon vd Stel
- First formal mine in 1852
- >2Mt Cu metal produced over 150-year period ending 2003
- 1852-1931 production reported 2.2 Mt >14% Cu largely hand-sorted ore
- Inability to recover grades <5% Cu
- 1937 O'okiep Copper Company founded
- First fully mechanised UG operations in RSA

O'okiep Mine – 284,000 tonnes of Cu (Dillon Marsh, 2024)

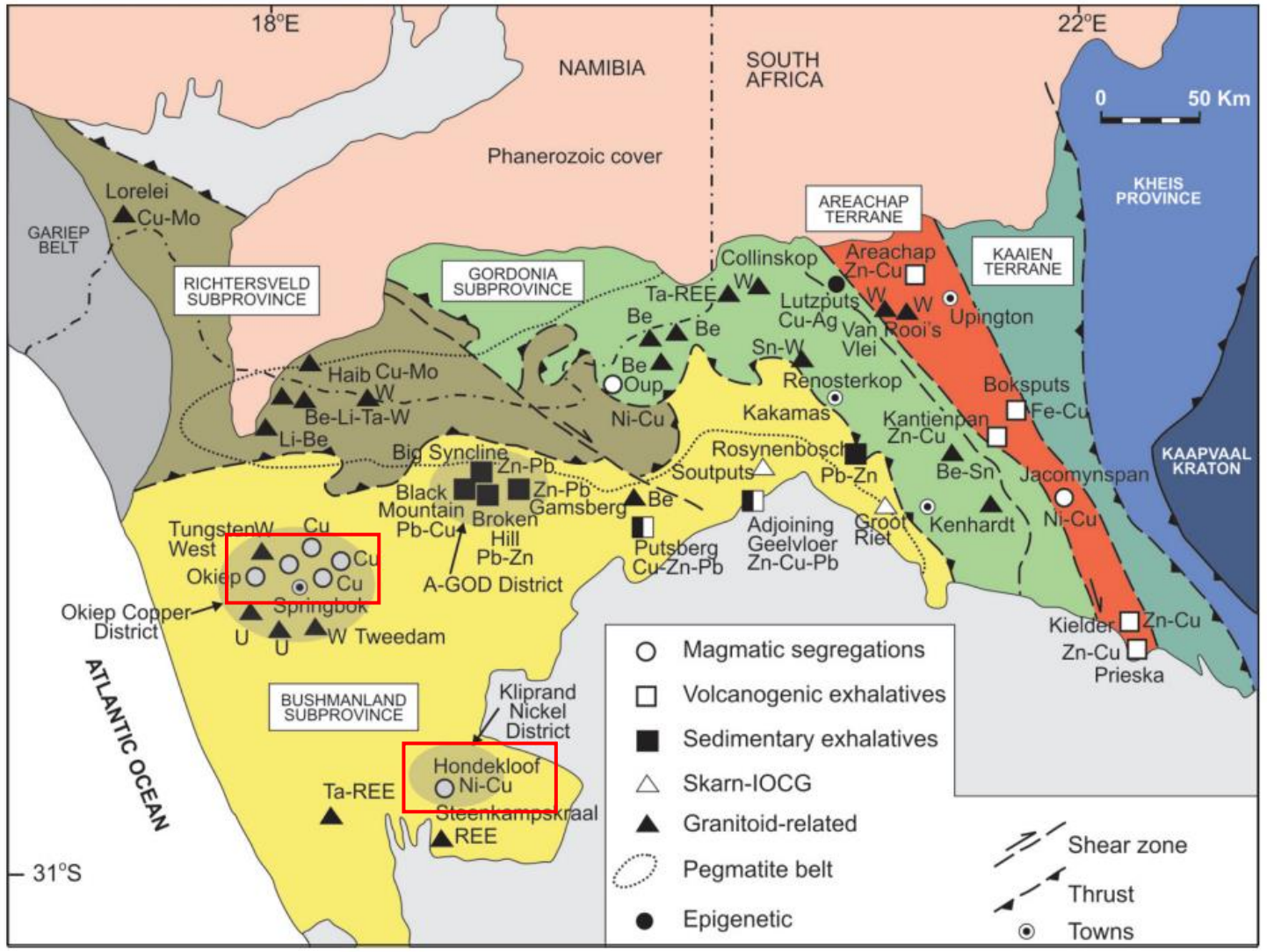
Nababeep Mine – 302,500 tonnes of Cu (Dillon Marsh, 2024)

Miners going on shift at Okiep – 1900

- **1,700** individual mapped mafic bodies
- **800** classified geophysical targets
- **220** targets drilled
- Individual orebodies size **25kt - 38,000kt** (Carolusberg)
- 27 larger mines within a 25km radius produced a total of 105.6Mt at 1.71% Cu 1940 -1998 (Newmont, Goldfields)
- 1940 and 1985, company paid out R180.3 million to its shareholders on initial investment of R3.2 million (>5600% return).
- **Smelter preference for low sulphur Bn ores, high sulphur ores (Cp-Po-Py) bypassed or neglected**

NAMAQUALAND METALLOGENIC PROVINCE

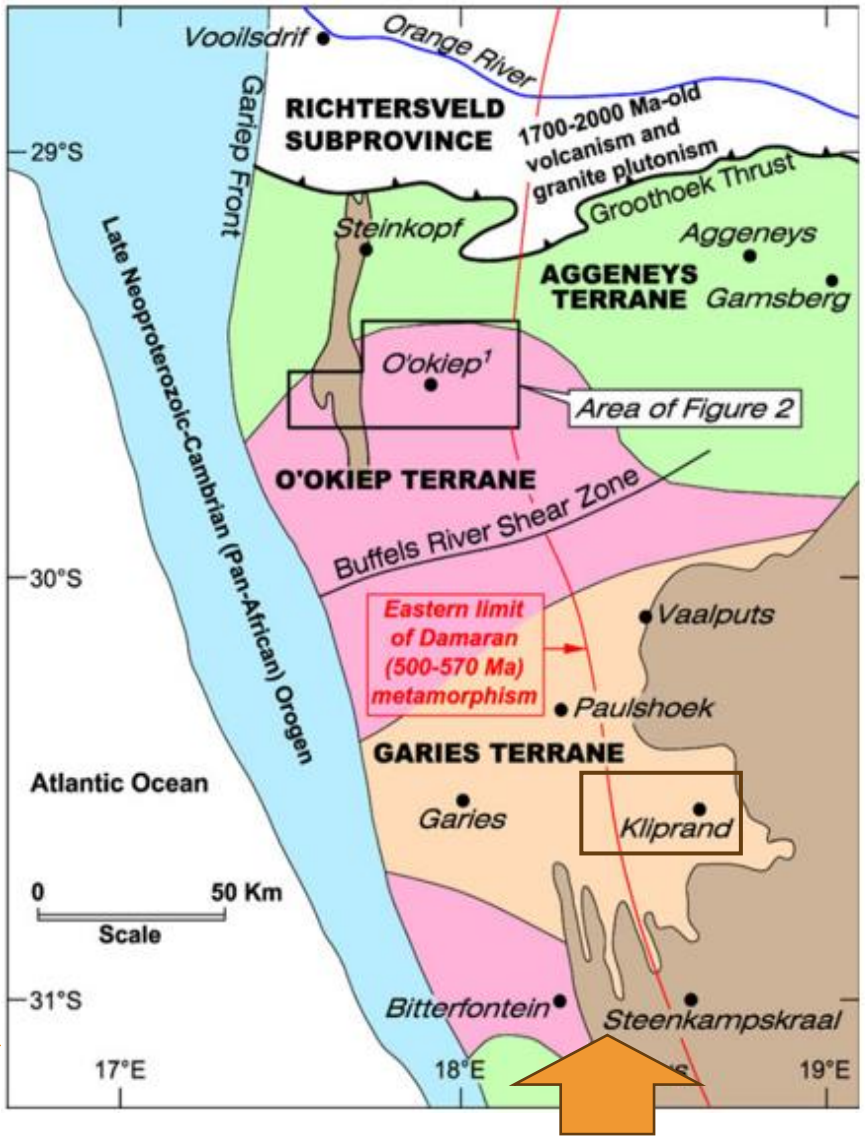
- Okiep classified as orogenic-type Cu
- Curaçá Valley Cu Province, Brazil closest analogue
- hosted in polyphase **Koperberg Suite** mafic intrusive bodies
  - Anorthosite (An_{40}) ★
  - diorite & biotite diorite ★ ★ ★
  - norite & leuconorite ★ ★
  - hypersthenite ★ ★
  - glimmerite ★
  - magnetitite and sulphides ★ ★ ★
- Intruded into otherwise **low-S** granite-gneiss basement
- Plugs dykes & sills along contacts or in “steep” structures
- Most productive orebodies occur stratigraphically above the Khurisberg metasediments
- Suggests contamination trigger for sulphides, but S isotopes do not support this (not enough work done)

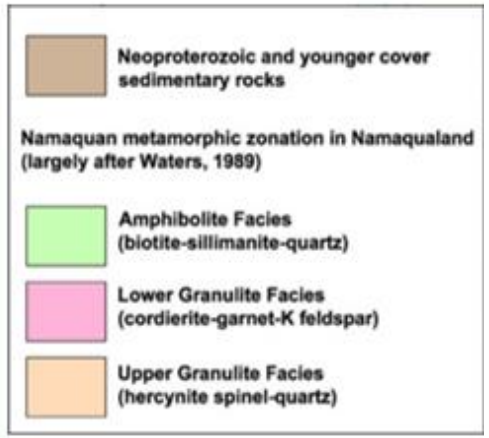


REGIONAL GEOLOGICAL SETTING

- Namaqua-Natal Metamorphic Province ("NNMP") Grenville-Kibaran aged
- Suturing Kalaghadi-Kaapvaal craton to Congo & Rio de la Plata cratons in amalgamation of Rodinia
- Collision to south may have been to Laurentia (Li et al, 2008)
- Structural terranes of varying metamorphic grade from granulite in the south to amphibolite in the north

- NNMP was affected by **two periods of orogenesis**:
  - the **Okiepian Episode** (D_2 1180-1210 Ma) a phase of crustal shortening and thickening, and voluminous granitic sheets, and
  - the **Klondikean Episode** (D_3 1020-1040 Ma), a phase of mafic underplating, ultra-high-temperature metamorphism, granitic sheets, dextral transtension, constrictional fabrics, and crustal thinning (Dewey et al., 2006)





After Clifford & Barton (2012)

MINERALISATION ASSEMBLAGES

- 3 styles of mineralisation
  1. **Carolusberg-type ore**: characterised by atypical bn-mgt (± cp) assemblage,
  2. **Narrap-type ore**: characterised by a typical *iss* assemblage: cp + po (± pn),
  3. **Hoits-type ore**: intermediate characterised by a bn-cp assemblage
- Carolusberg-type interpreted as being oxidation & S devolatilisation of primary Narrap-type during granulite facies metamorphism (Cawthorn & Meyer, 1993; Boer et al, 1994; van Zweiten et al, 1996)

$$5\ CuFeS_2 + 5\ FeS + [8\ O_2] = Cu_5FeS_4 + 3\ Fe_3O_4 + 6\ H_2S + 5\ SO_2$$

cpy po bn mgt

- paucity of replacement textures of mgt over cpy
  - more examples of cpy rims on mgt,
  - grain shapes consistent with trapped liquid during/after crystallisation of mgt

After Clifford & Barton (2012)

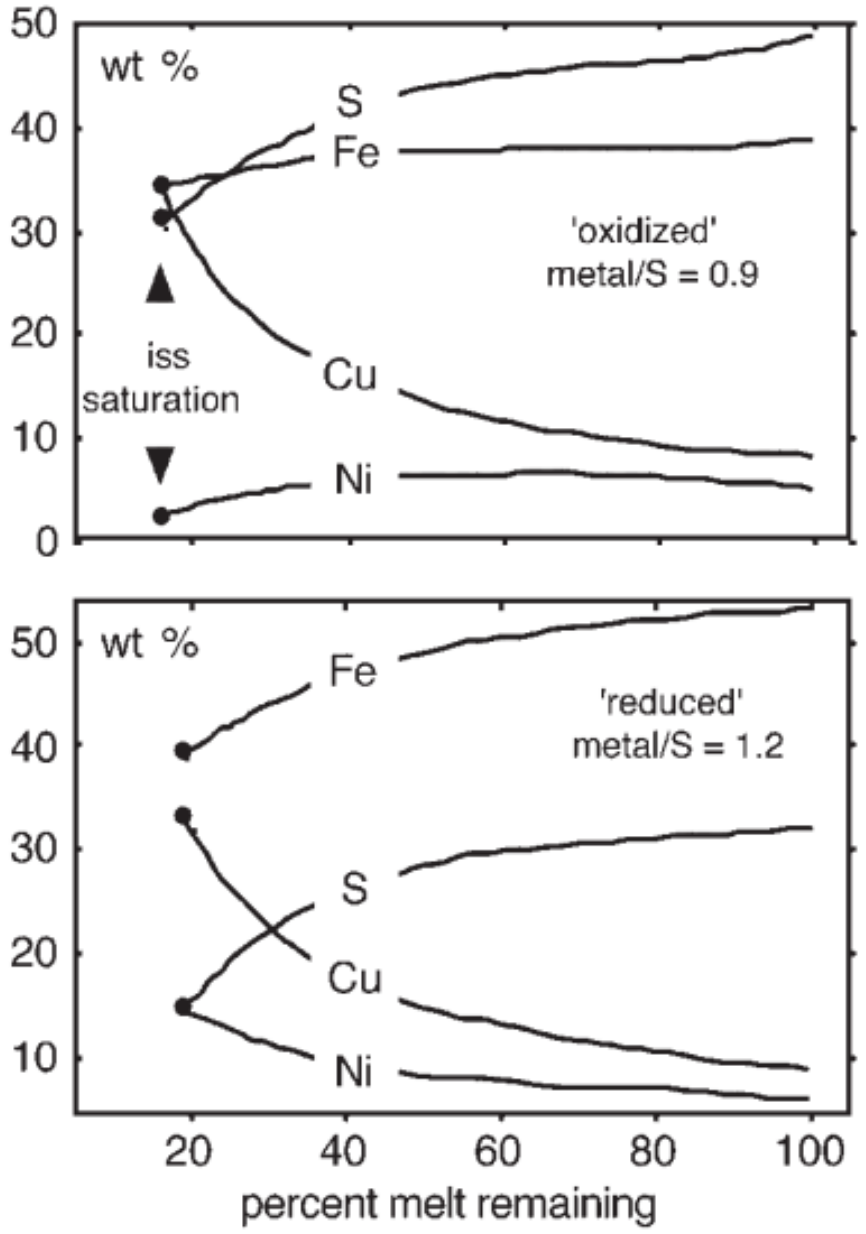
MINERALISATION ASSEMBLAGES

Alternative view (Hamman et al, 1996; Marima, 2021):

- Oxidation of the sulphide melt occurred during fractional crystallisation of the silicates and the *mss*
- As Fe^{2+}-rich phases crystallise (bt, px, po, pn) the Fe^{3+} ratio increases
- *$Fe^{3+}/\sum Fe$ ratio provides proxy for oxygen fugacity* (Sossi et al, 2012)
- As these phases crystallise the residual melt and sulphide liquid become increasingly more oxidised

- metal/S ratio ≤1 will crystallise in the iss stability field
- oxidation of this melt will form S-poor melts with metal/S ratios ≥1

- ∴ observed assemblages are syn-magmatic



Ballhaus et al (2001)

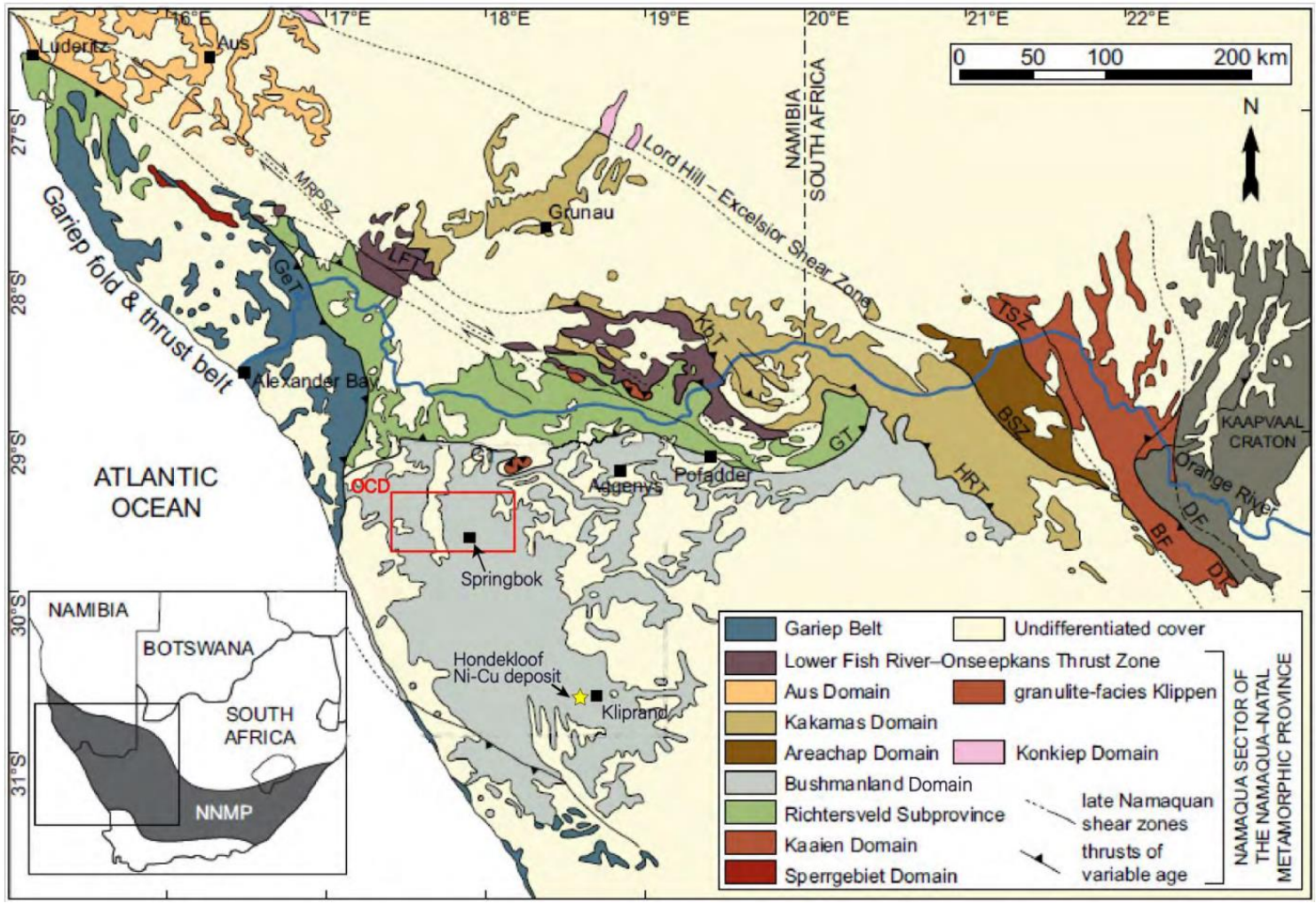
SIGNIFICANCE OF THE KLIPRAND NI DISTRICT

- Hondekloof Ni-Cu deposit located 140 km SE of Okiep in southern Bushmanland
- Gabbronorite-hosted
- Displays *in situ* segregations of anorthosite, diorite and glimmerite, juxtaposed to unmineralized norite

- Basal msv sul: po(-pn-cp-py)

- 2 largest msv sul bodies comb *in situ* ore: **2mt @ 0.88% Ni 0.20% Cu, 410ppm Co trPGE**

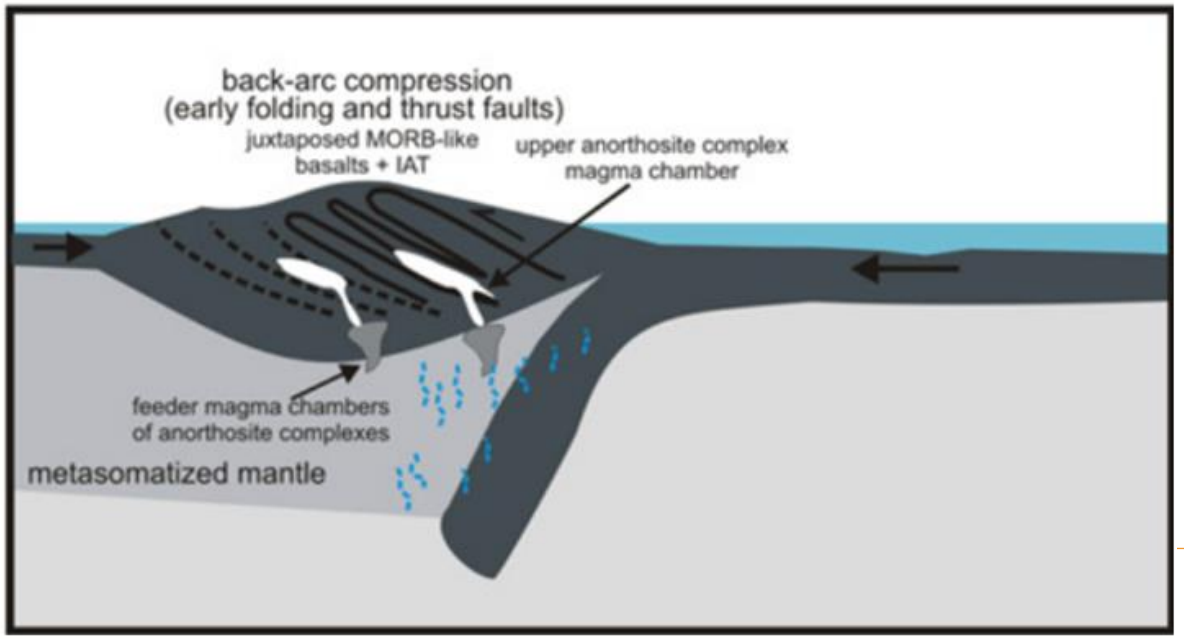
- Hamman etal (1996) correlated the gabbronorite host with a pre-Koperberg Suite “two pyroxene granulite” of the OCD



(Marima, 2022, after Macey et al., 2018; Schorn et al., 2020)

TWO-STAGE MODEL

- Hamman et al (1996) demonstrated that Hondekloof gabbronorites and OCD 2px-granulites mineralogically and geochemically similar
- 2px-granulites represent earlier pulse of the mainly anorthosite Koperberg Suite
  i.e. pre- to syntectonic orthomagmatic msv sulphide preceding the mainly disseminated low-S OCD Cu deposits



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1. an early nickeliferous mss sulphide liquid was extracted from the magma chamber associated with common mantle-derived pre- to syn-tectonic gabbronorites **Okiepian Episode** (D_2 1180-1210 Ma)
2. renewed tectonism and compression of magma chamber **Klondikean Episode** (D_3 1020-1040 Ma) resulted in the extraction of
   i. first an anorthositic suite,
   ii. followed by increasingly more mafic assemblages and
   iii. ultimately the most hypermelanic phases and the low-S, high-mgt, cupriferous residual iss sulphide liquid

- Narrap-type ores tend to occur where increased spatial association with 2px-granulites (Hamman et al, 1996)

EXPLORATION IMPLICATIONS

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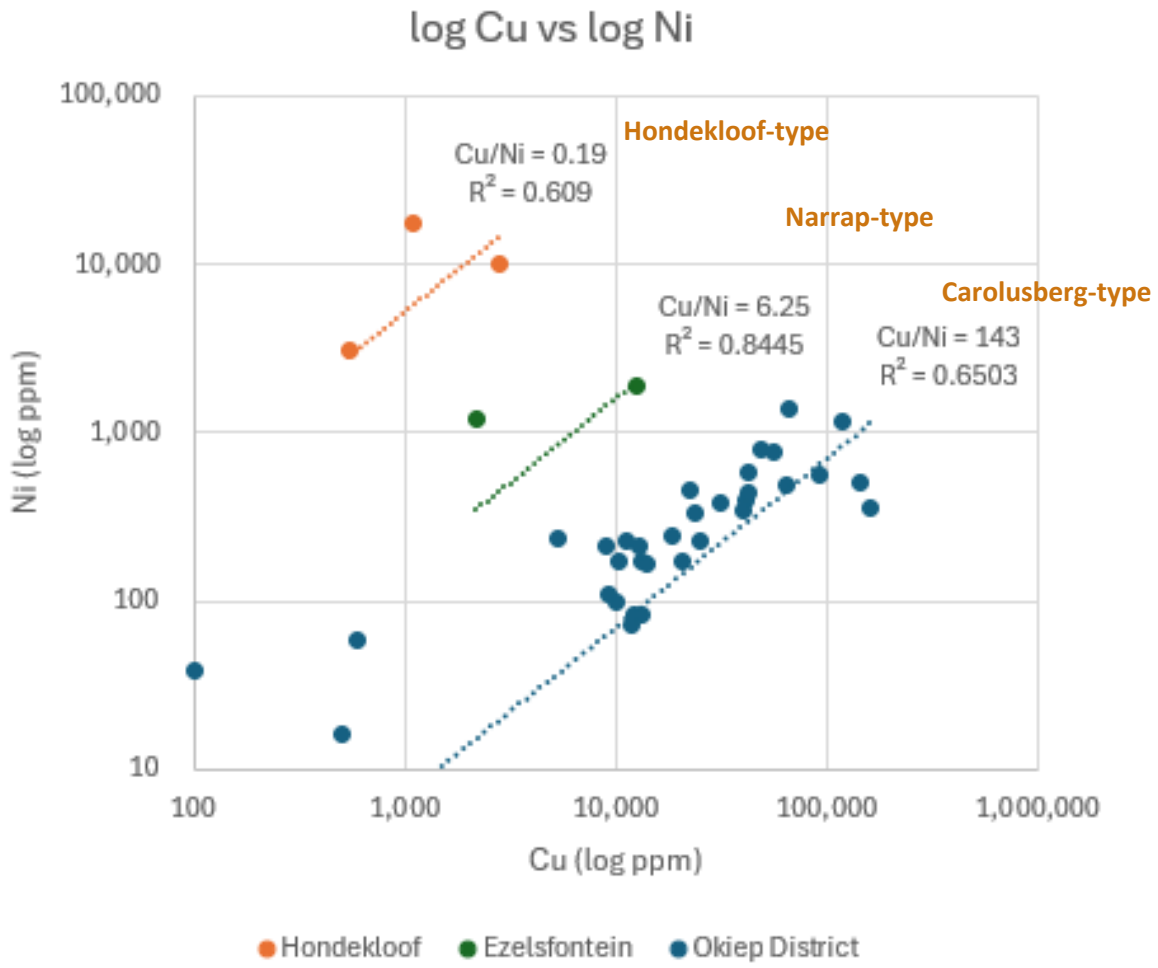
- Maier et al (2012) illustrated the differences between Cu/Ni ratio from Hondekloof and OCD sulphides, suggesting that the Ezelsfontein sulphides (Narrap-type) being intermediate between OCD and HKF
- viewed the Hondekloof sulphides as *mss* precipitated at depth
- OCD deposited shallower from highly fractionated sulphide liquids enriched in *iss*
- Alternately: fractionation taking place in magma chamber and injected during two stages of compressional deformation



Binary log-log plot of Cu vs Ni from the Okiep district and Hondekloof highlighting the variation in Cu/Ni ratio (Maier et al., 2012).

EXPLORATION IMPLICATIONS

Exploration Implications:

1. Small, low-grade, conformable and discordant sulphide deposits

    - Known operating mines in rocks of tholeitic character, e.g. Tati Nickel

      Phoenix: Measured + Indicated Mineral Resources (2010) - 208.9 Mt @ 0.21% Ni, 0.19% Cu,

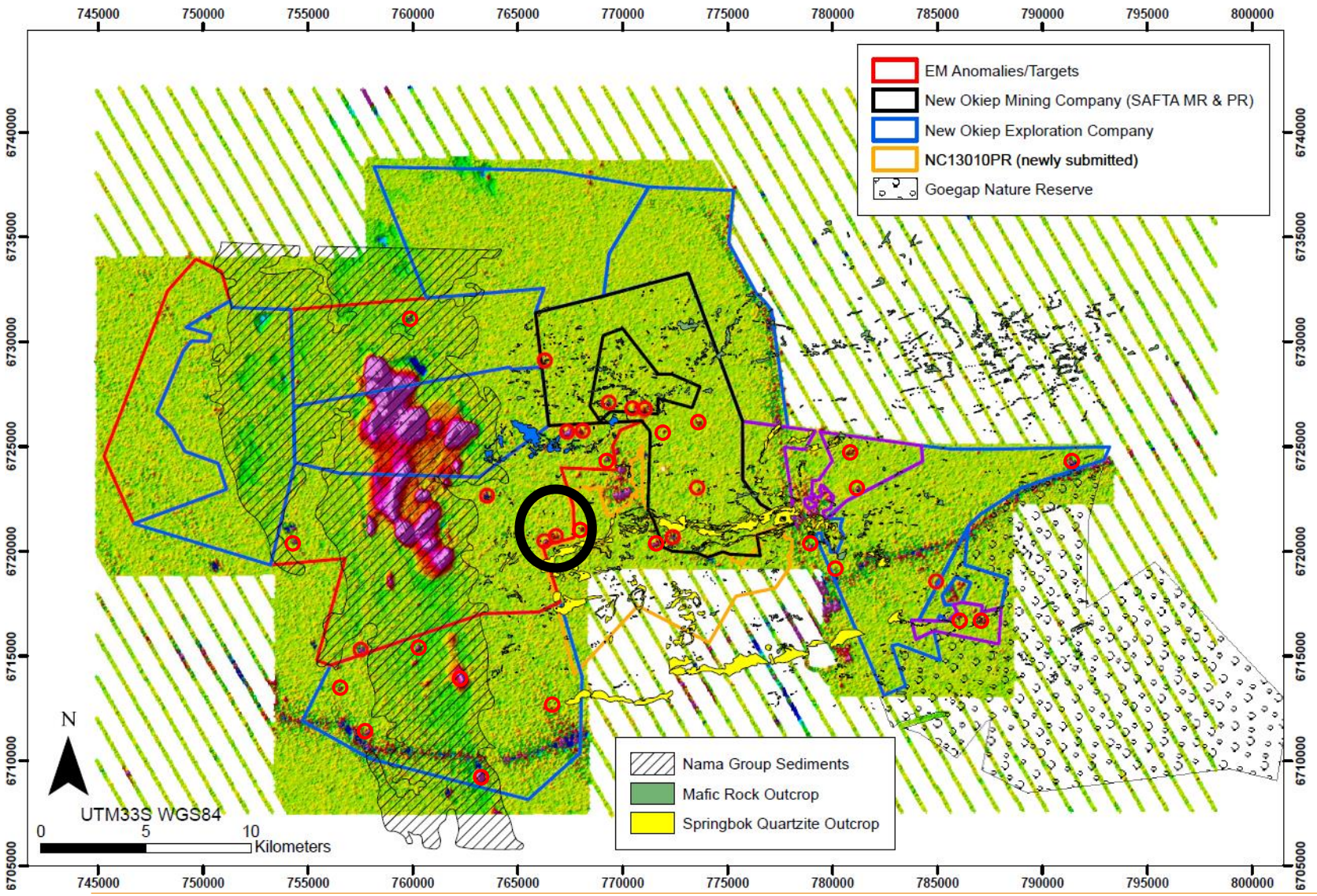
      Selkirk: 2Mt @ 2.6% Ni, 1.6% Cu

2. But other large unexplored gabbronorite bodies with less deformation and could offer exploration potential

The possibility of Ni-Cu msv sul associated with the 2 pyroxenite granulites has never been looked at.

- Analysed in many cores, but only for Cu and not with with a comprehension of the potential based on the current model

AIRBORNE EM



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- Numerous SkyTEM EM targets identified (>35) within an overall low- to non-conductive region
- Narrap-type
- Ezelsfontein East and Narrap are notable inclusions

OCD NICKEL PROSPECTS

- Nous mineralisation po-cpy-py
  - Net-textured and vein
  - Presence of Ni-bearing sulphides distinct from most OCD
  - Up to 0.40% Ni assayed
  - 4 DHs completed, with additional untested anomalies

- Deposits with Narrap-type ores are noted to have a higher spatial association to 2-px granulites, suggesting repeated use of pre-existing intrusive pathways
- Ni min may be co-located with Cu min or completely distinct

Selected assay results

Deposit	Ni%	Cu%
Carolusberg	0.08	4.88
East Okiep	0.02	1.33
Hoits	0.02	2.50
Nous*	**0.15**	**0.82**
Ezelsfontein E	0.19	1.27
Hondekloof	1.00	0.28

*unpublished intersection

SUMMARY

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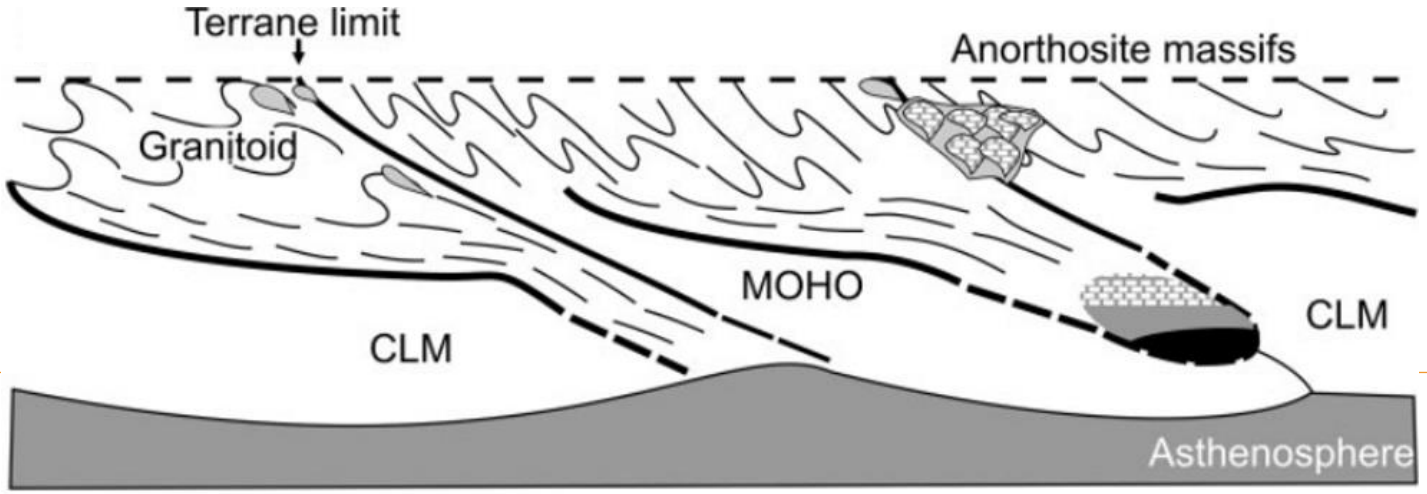
- Okiep Copper District formed in the extensional backarc of a continental margin subduction
- Two episodes of magma injection
  - Early magmas: mss-bearing gabbronorites at various levels within lower crust
  - 20myr hiatus undisturbed magma chamber, fractionates and increasingly more oxidised
  - Second episode of deformation injected oxidised iss using previously formed structural architecture and localised in contemporaneous steep structures
- Ni sulphide potential largely unrecognised, but may be found in proximity or dislocated from Cu min



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For further information, contact:

Orion Minerals Limited
Level 21, 55 Collins Street
Melbourne Vic 3000
Australia
Phone: +61 (0)3 8080 7170
Email: info@orionminerals.com.au
Website: www.orionminerals.com.au

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