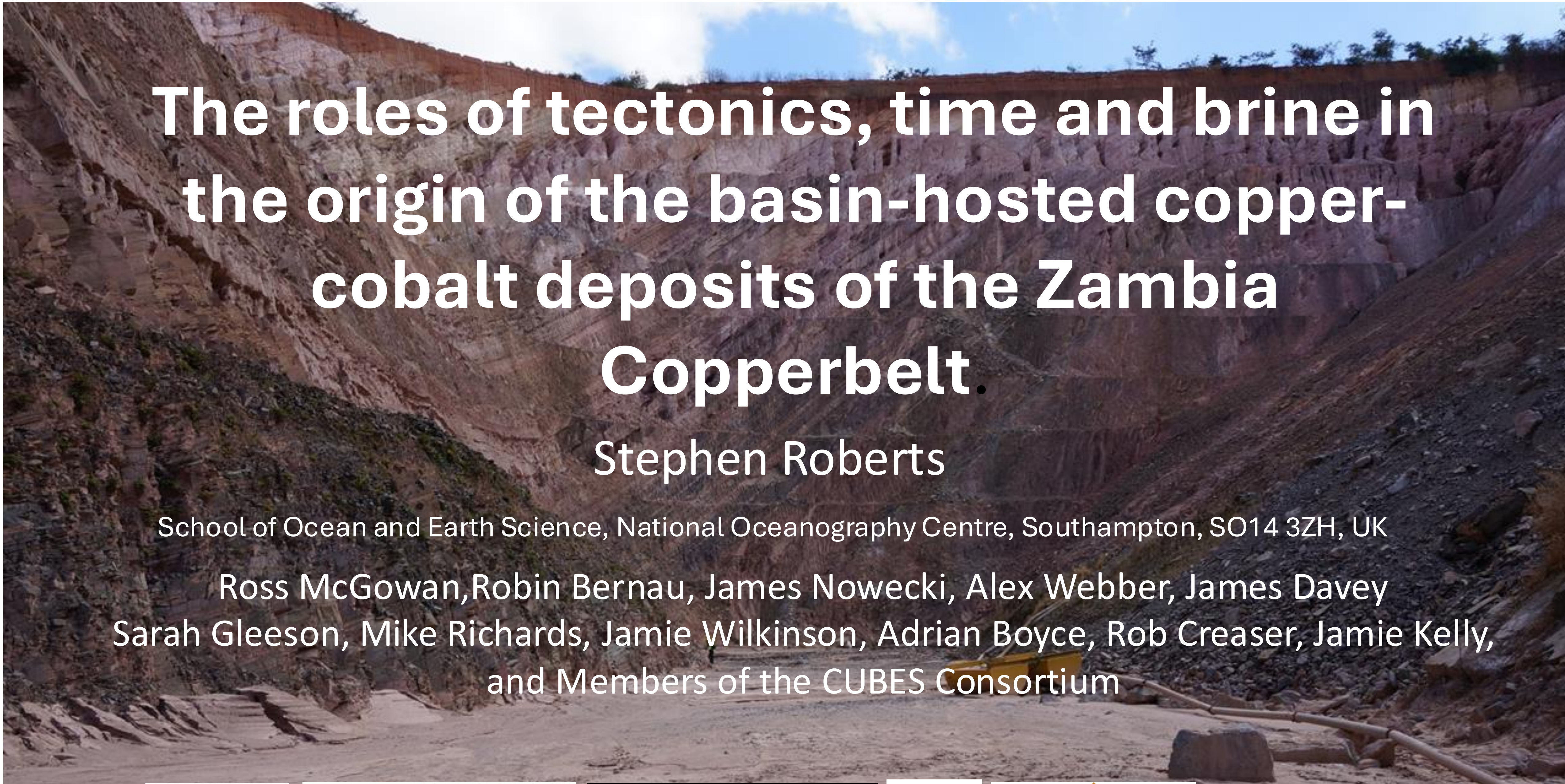


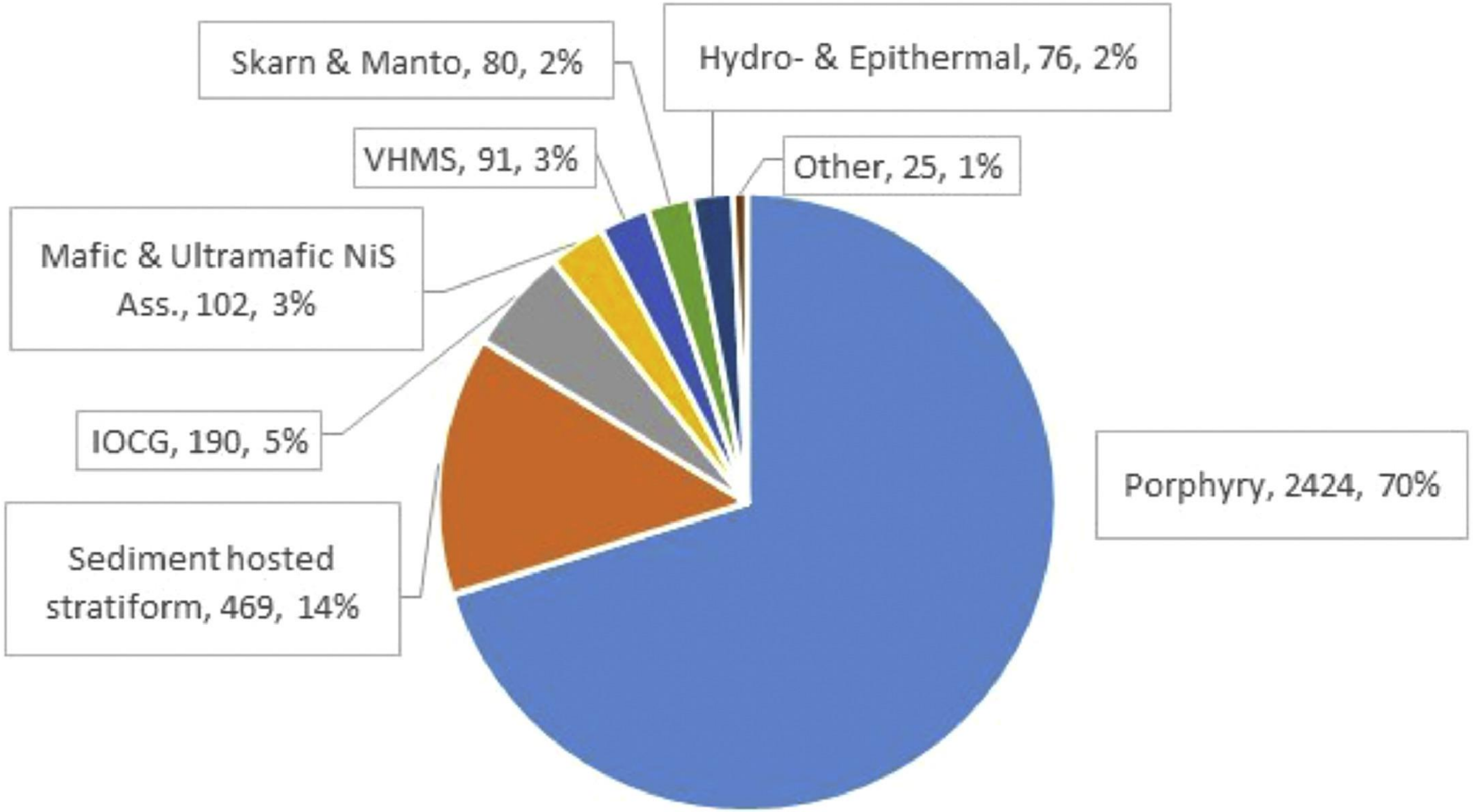
The roles of tectonics, time and brine in the origin of the basin-hosted copper-cobalt deposits of the Zambia Copperbelt.

Stephen Roberts

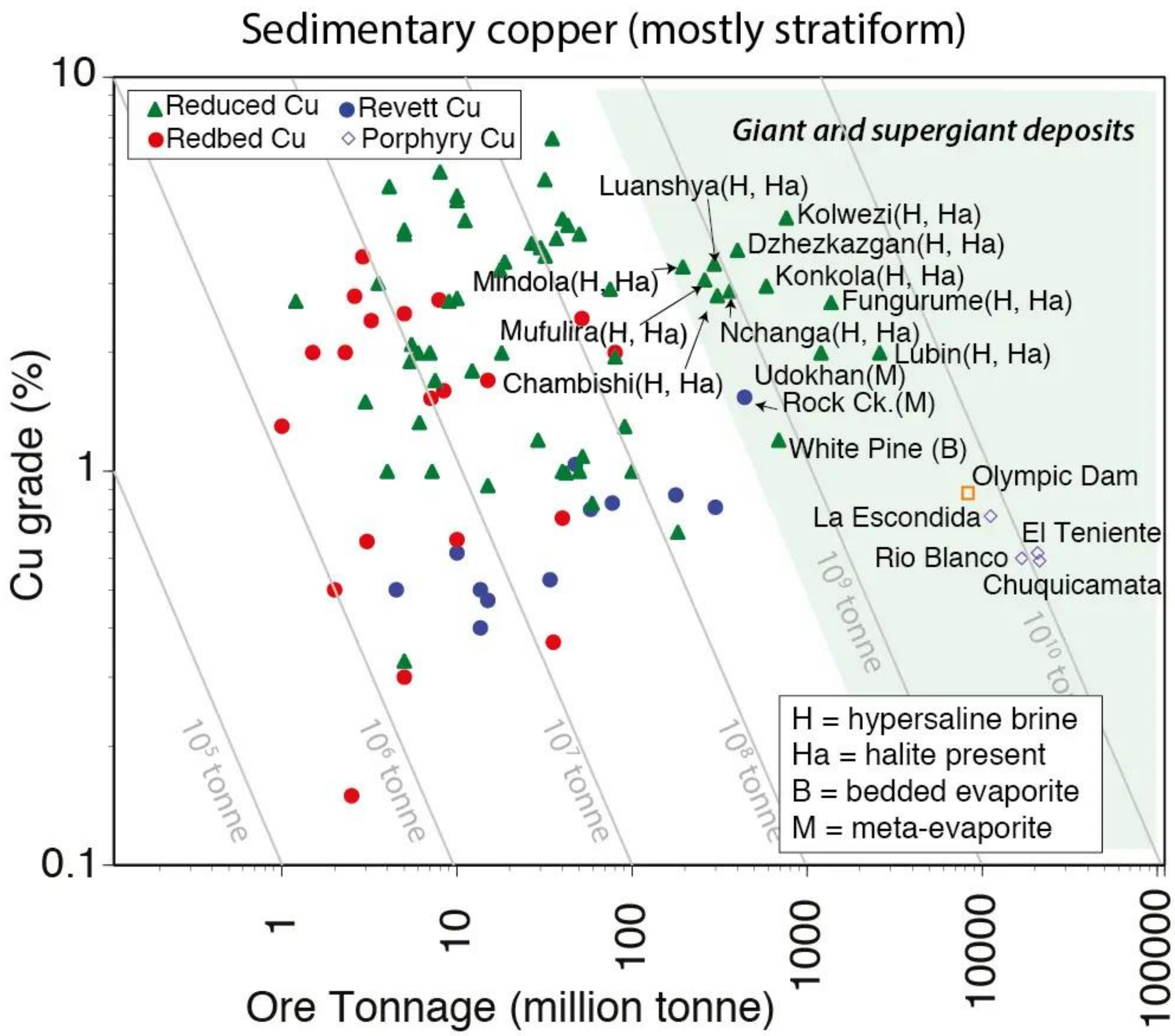
School of Ocean and Earth Science, National Oceanography Centre, Southampton, SO14 3ZH, UK

Ross McGowan,Robin Bernau, James Nowecki, Alex Webber, James Davey
Sarah Gleeson, Mike Richards, Jamie Wilkinson, Adrian Boyce, Rob Creaser, Jamie Kelly,
and Members of the CUBES Consortium

Resource Importance of Copper Deposit Types: Mt and %



Pietro Guj and Richard Schodde 2025 https://doi.org/10.1016/j.geogeo.2024.100320



Grade Tonnage Plot Sedimentary Copper

https://www.saltworkconsultants.com/metals/

Introduction:

- Resurgence in exploration activity and scientific investigations over the past 25 years
- Generating a wealth of geological observation and geochemical analyses

However ,despite the richness of data, as a scientific community we find many controversies which have arisen from the interpretation of these new data.

For example: The timing of mineralization in a basin that evolved over >300+ Ma during the Neoproterozoic is increasingly disputed.

Miner Deposita (2017) 52:1245 1268
DOI 10.1007/s00126-017-0726-8

CrossMark

ARTICLE

Age of the Zambian Copperbelt

Richard H. Sillitoe[1] · José Perelló[2] · Robert A. Creaser[3] · John Wilton[4] · Alan J. Wilson[5] · Toby Dawborn[6]

Miner Deposita (2017) 52:1273–1275
DOI 10.1007/s00126-017-0767-z

CrossMa

DISCUSSION

Discussion: "Age of the Zambian Copperbelt" by Sillitoe et al. (2017) *Mineralium Deposita*

M. W. Hitzman[1] · D. W. Broughton[2]

Lumwana Deposit Cu-Co Deposit- Zambia

UNIVERSITY OF Southampton

The stratigraphic location of the deposits is often disputed. In the last 5 years the Lumwana Deposits have been described as a basement shear zone deposit or metamorphosed lower Roan.

Miner Deposita (2013) 48:137 153
DOI 10.1007/s00126-012-0424-5

ARTICLE

The geology and geochemistry of the Lumwana Cu (± Co ± U) deposits, NW Zambia

Robin Bernau · Stephen Roberts · Mike Richards · Bruce Nisbet · Adrian Boyce · James Nowecki

Ore Geology Reviews 75 (2016) 52–75

Contents lists available at ScienceDirect

Ore Geology Reviews

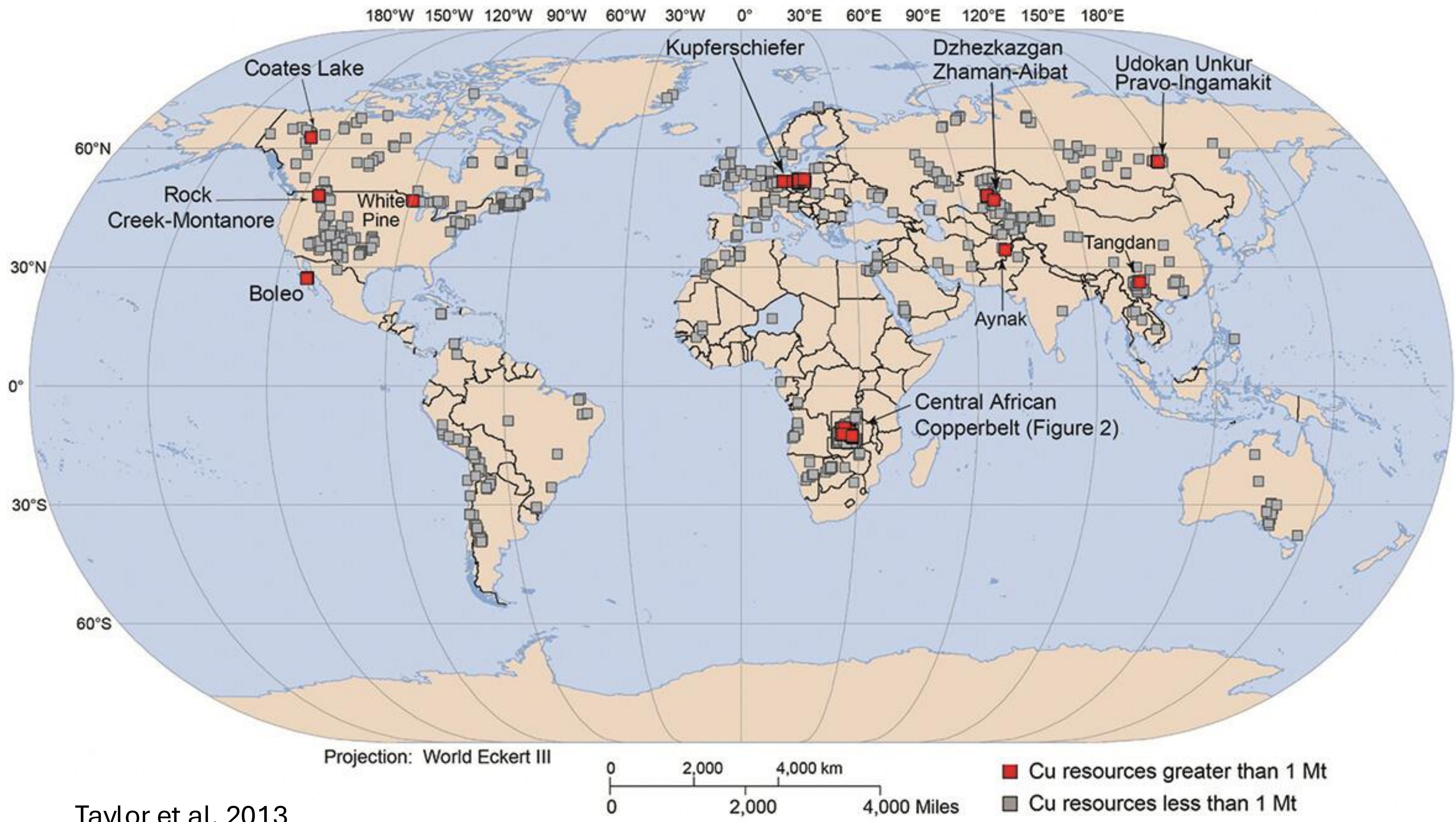
journal homepage: www.elsevier.com/locate/oregeorev

ELSEVIER

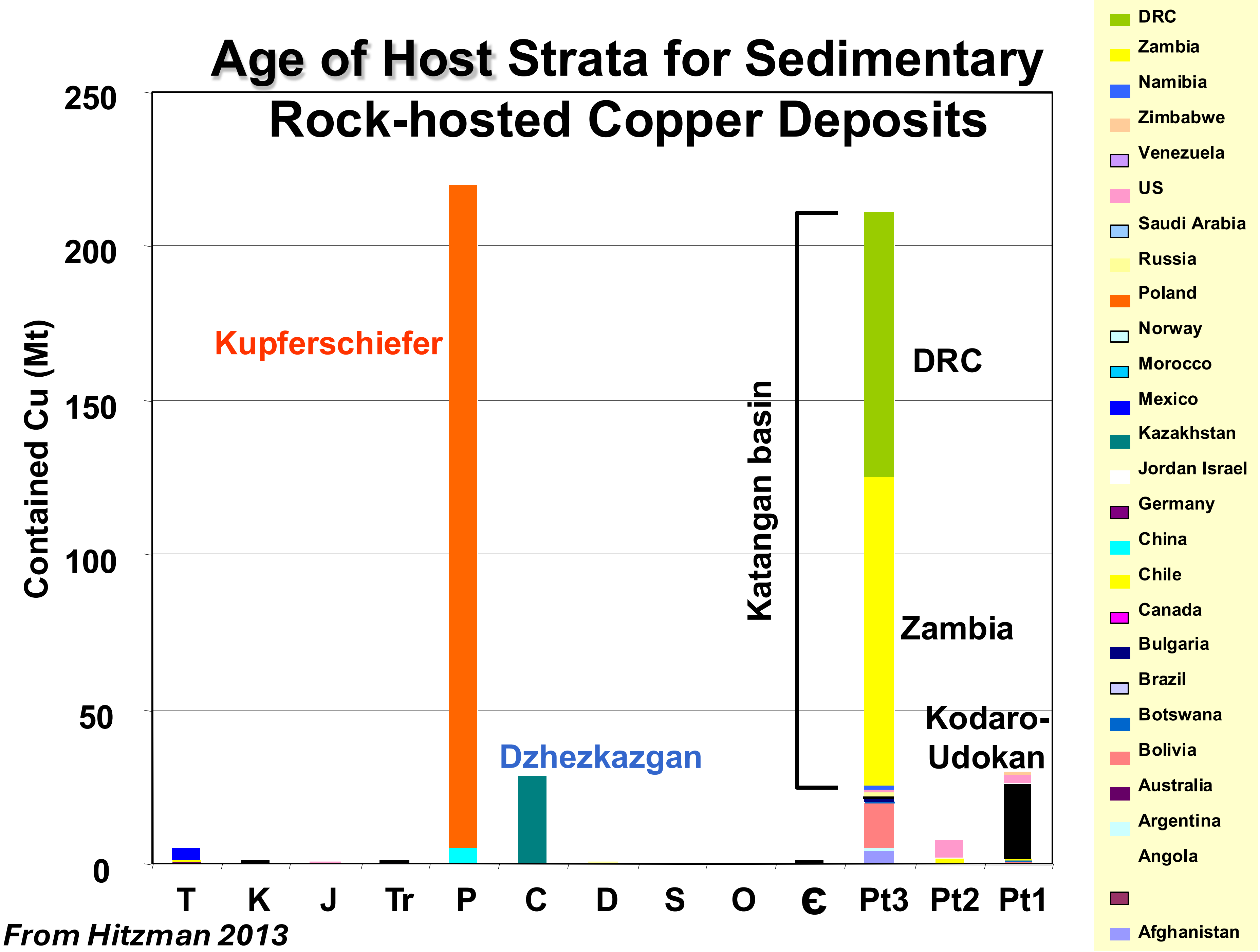
Synmetamorphic Cu remobilization during the Pan-African orogeny: Microstructural, petrological and geochronological data on the kyanite-micaschists hosting the Cu(–U) Lumwana deposit in the Western Zambian Copperbelt of the Lufilian belt

François Turlin [a,*], Aurélien Eglinger [a,1], Olivier Vanderhaeghe [a,2], Anne-Sylvie André-Mayer [a], Marc Poujol [b], Julien Mercadier [a], Ryan Bartlett [c]

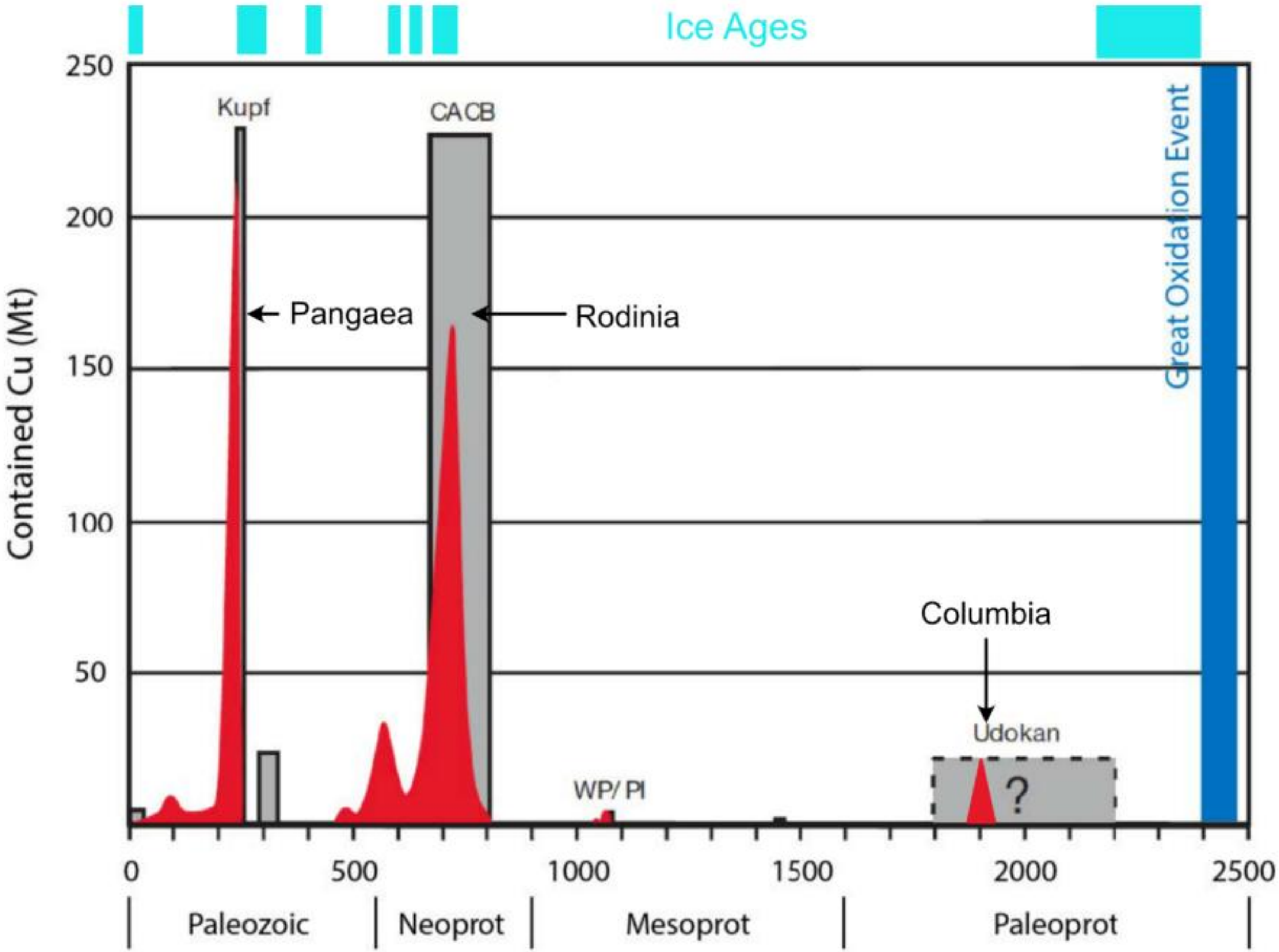
[a] GeoRessources Lab., Université de Lorraine, CNRS, CREGU, Campus Aiguillettes, Faculté des Sciences et Technologies, rue Jacques Callot, Vandoeuvre-lès-Nancy, F-54506, France
[b] Géosciences Rennes, UMR 6118, Université de Rennes 1, 35042 Rennes Cedex, France
[c] Barrick Limited, Lumwana, Zambia



Taylor et al. 2013

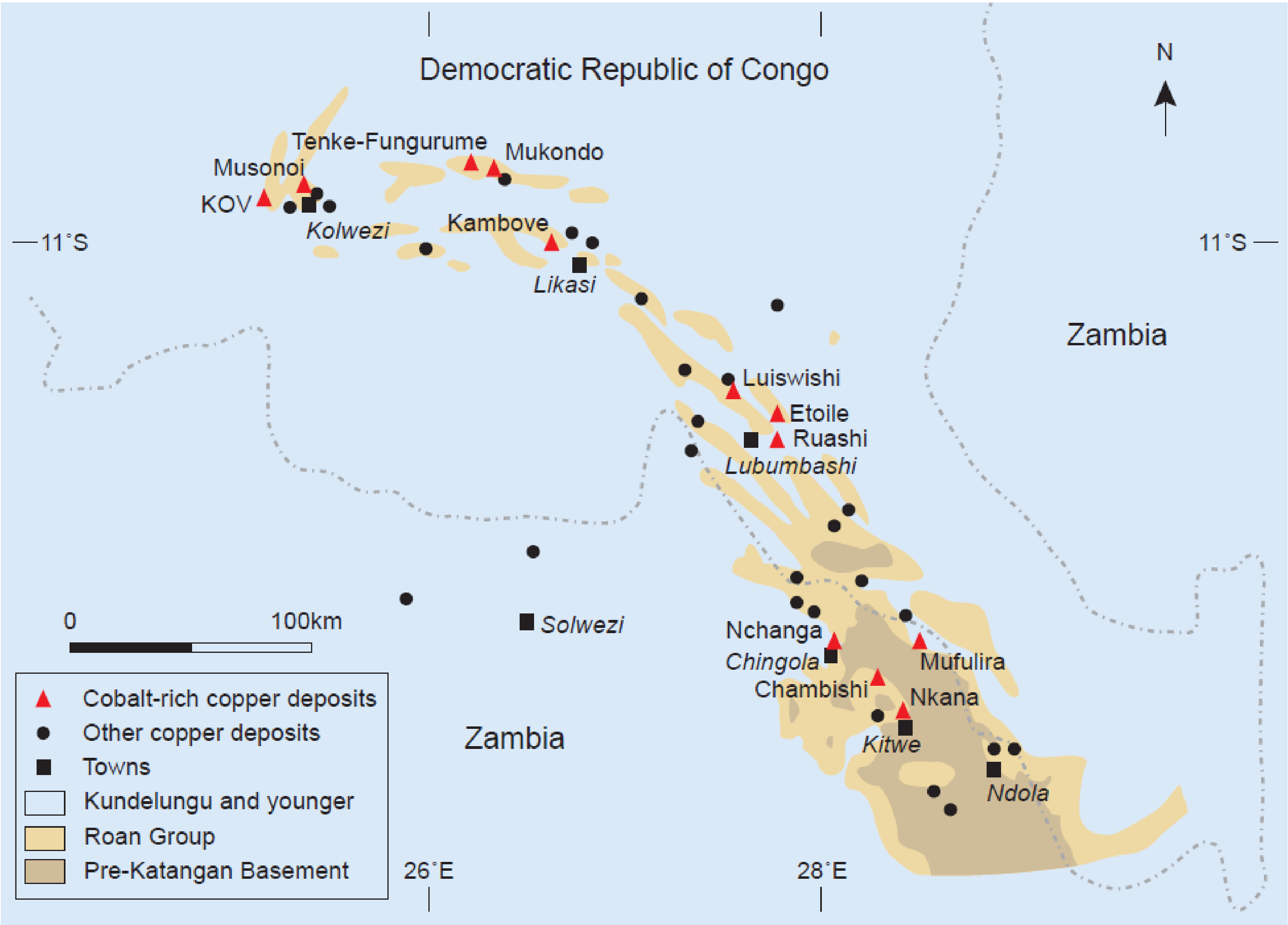


From Hitzman 2013



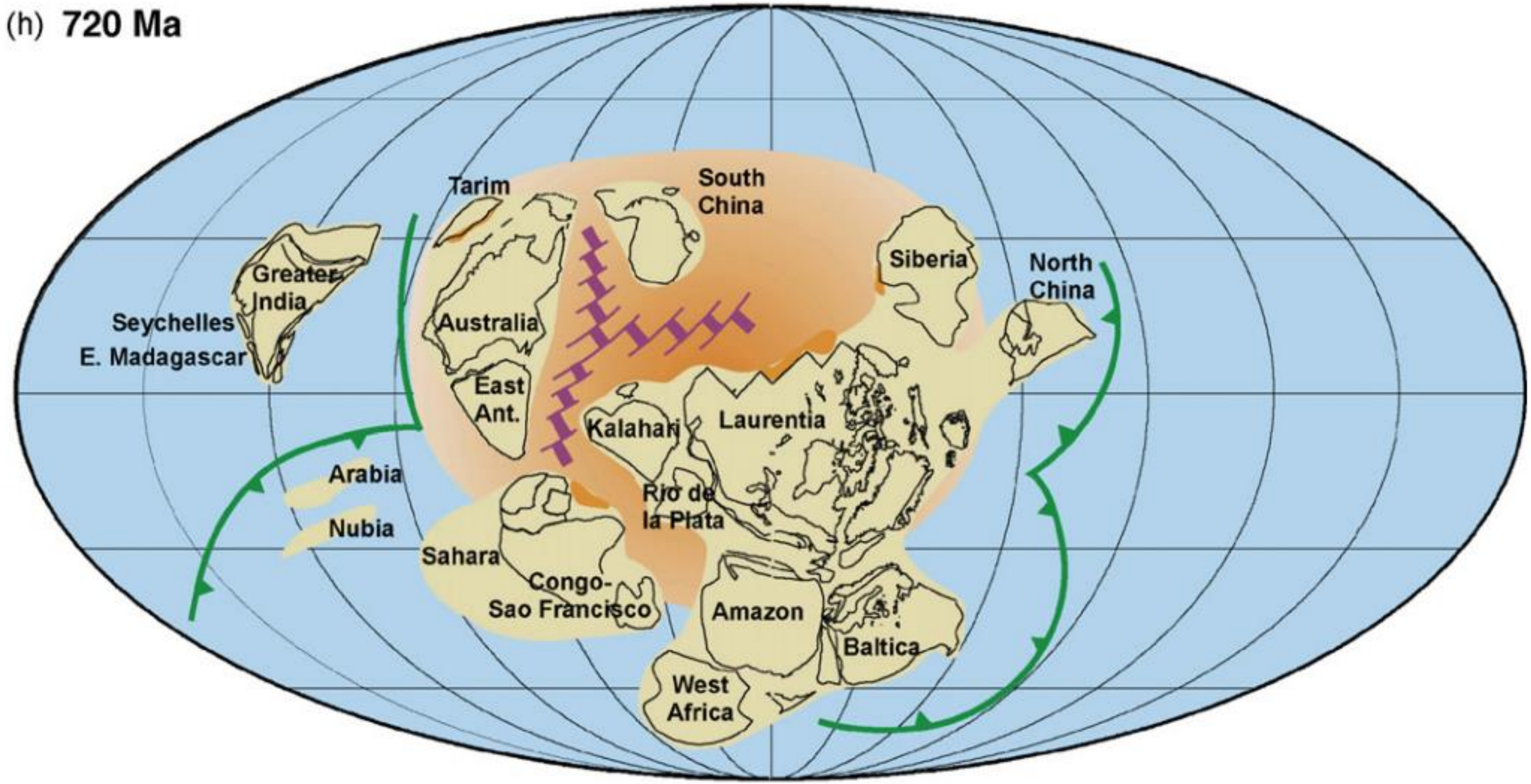
Ice Ages
Great Oxidation Event
Contained Cu (Mt)
250
200
150
100
50
Kupf
CACB
Pangaea
Rodinia
Columbia
Udokan
WP/ PI
?
0
500
1000
1500
2000
2500
Paleozoic
Neoprot
Mesoprot
Paleoprot

Basic Location Map – Zambian Copperbelt



Note deposits with and without Cobalt credits

Pan African Tectonics and formation of Katangan Basin



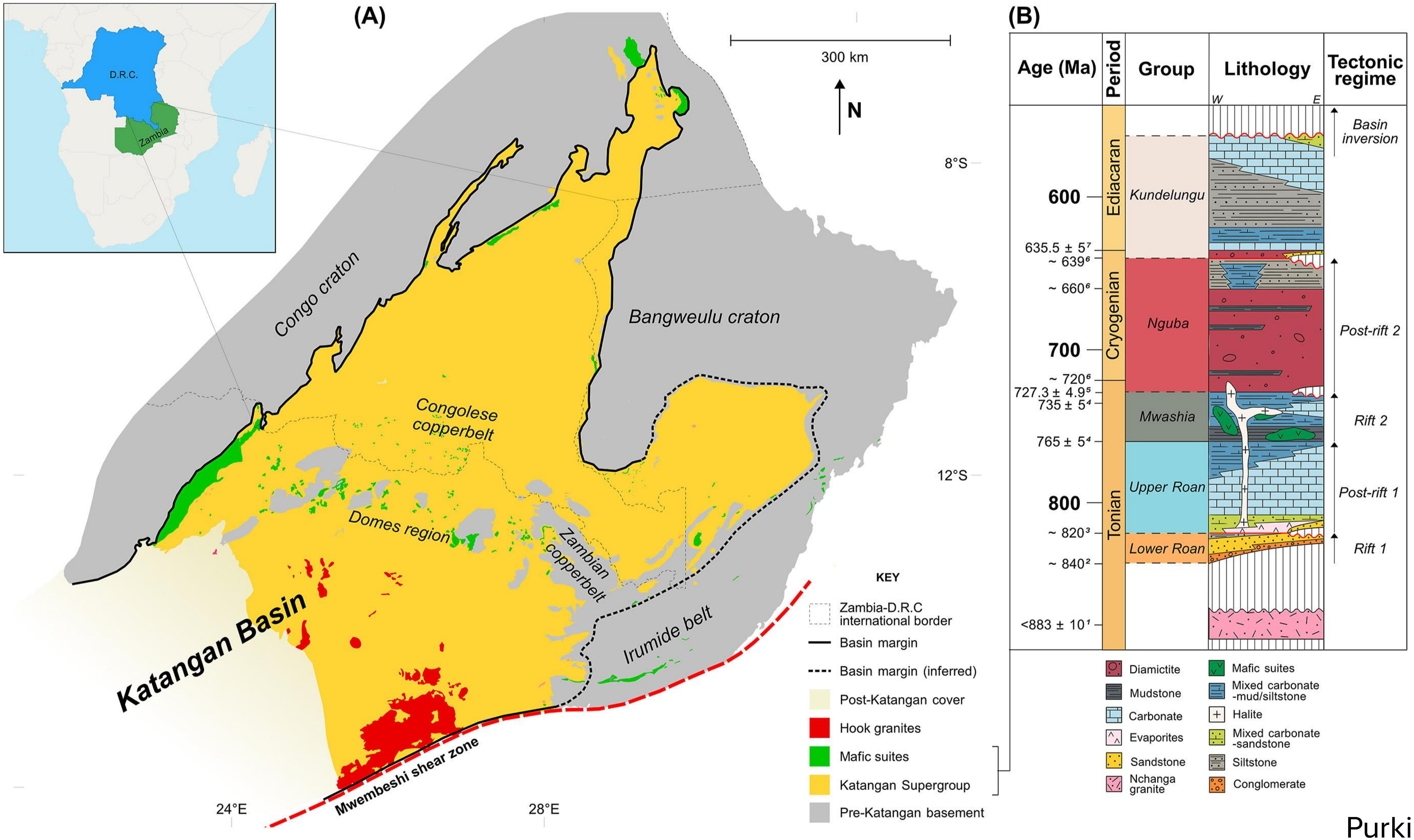
Katanga Basin within 20 degrees of the equator.

Li et al. (2008)

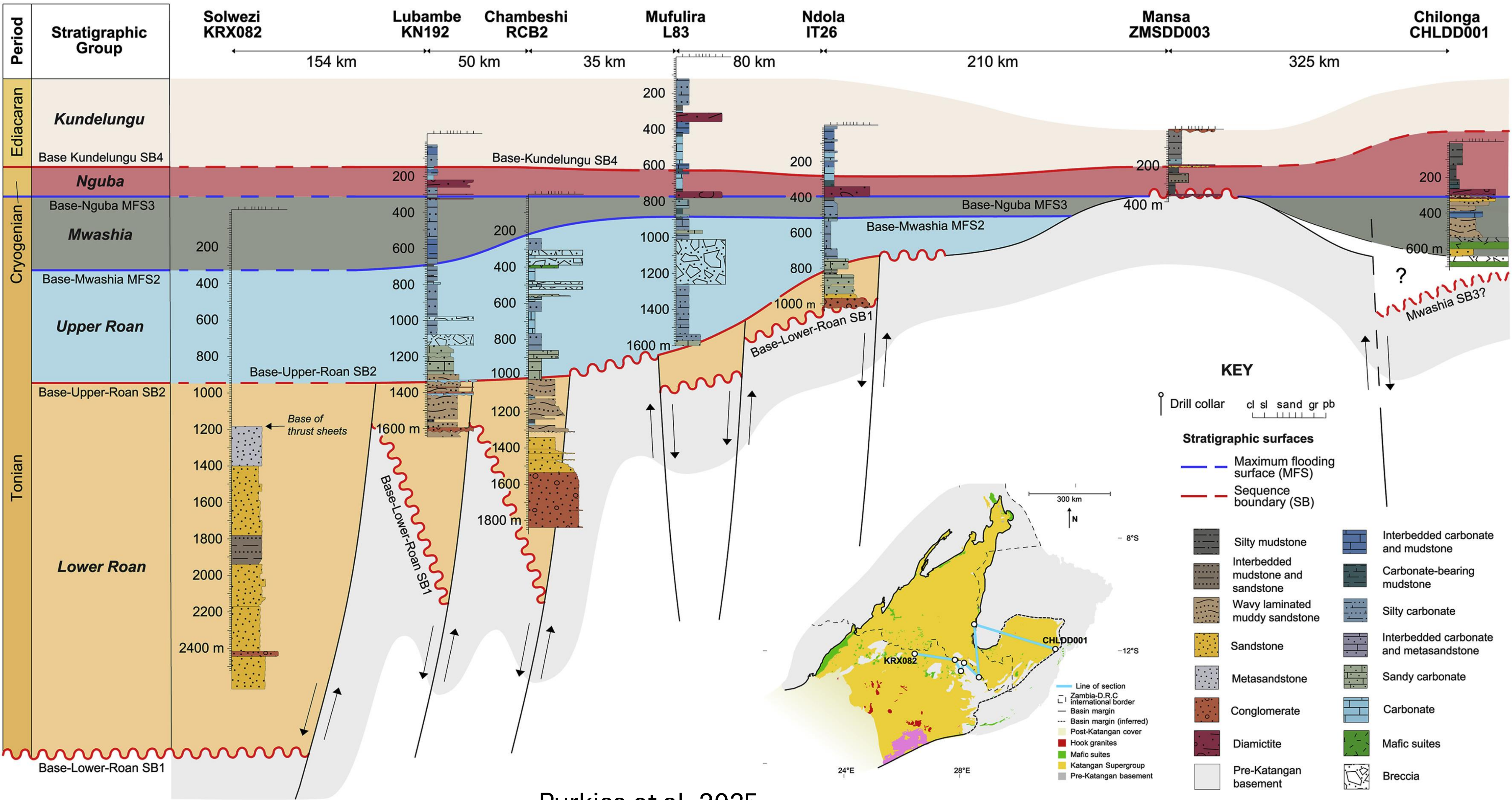
Pan African Tectonics – the perfect environment for sedimentary-hosted copper?

~530 Ma

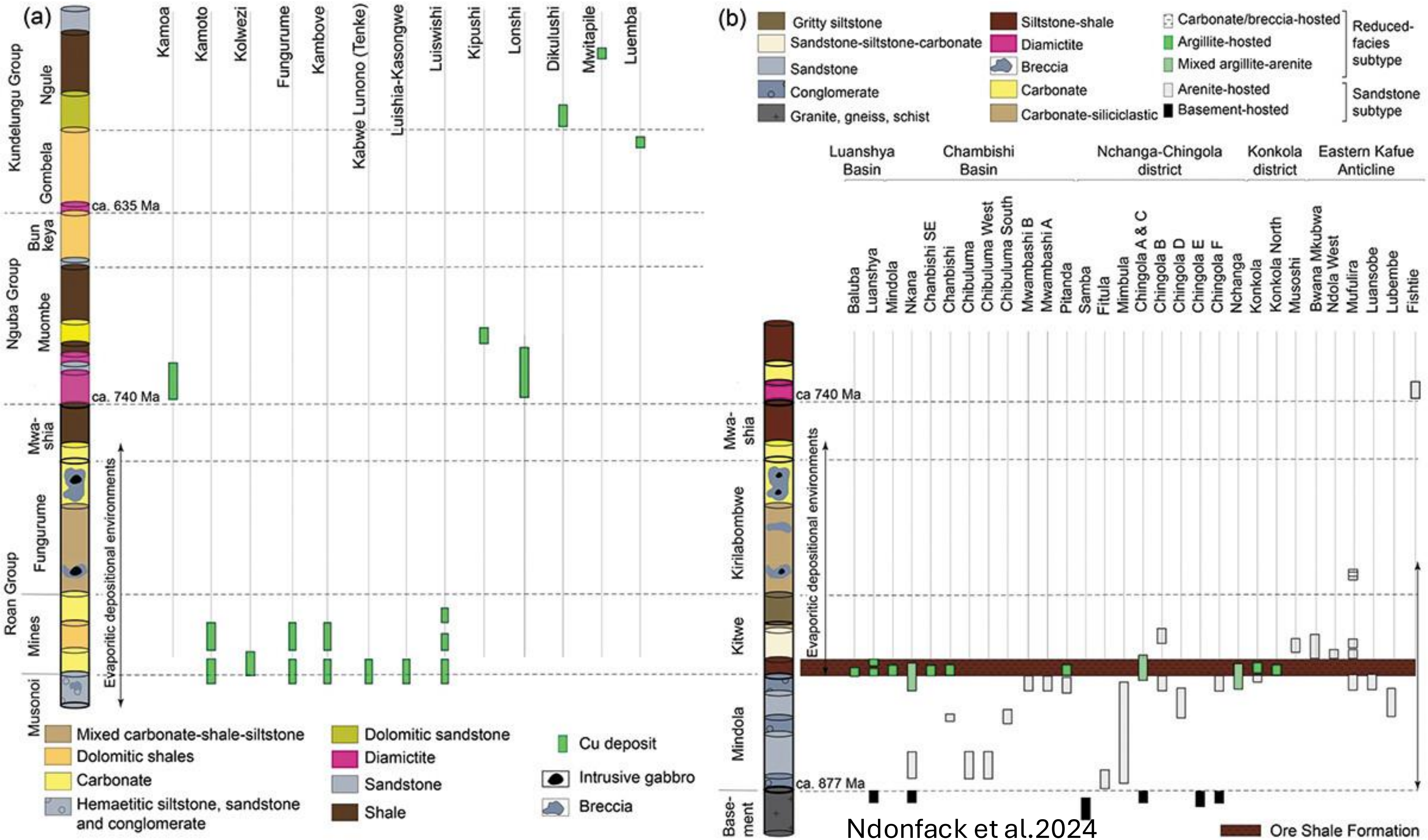
Katangan Basin



Purkiss et al. 2025

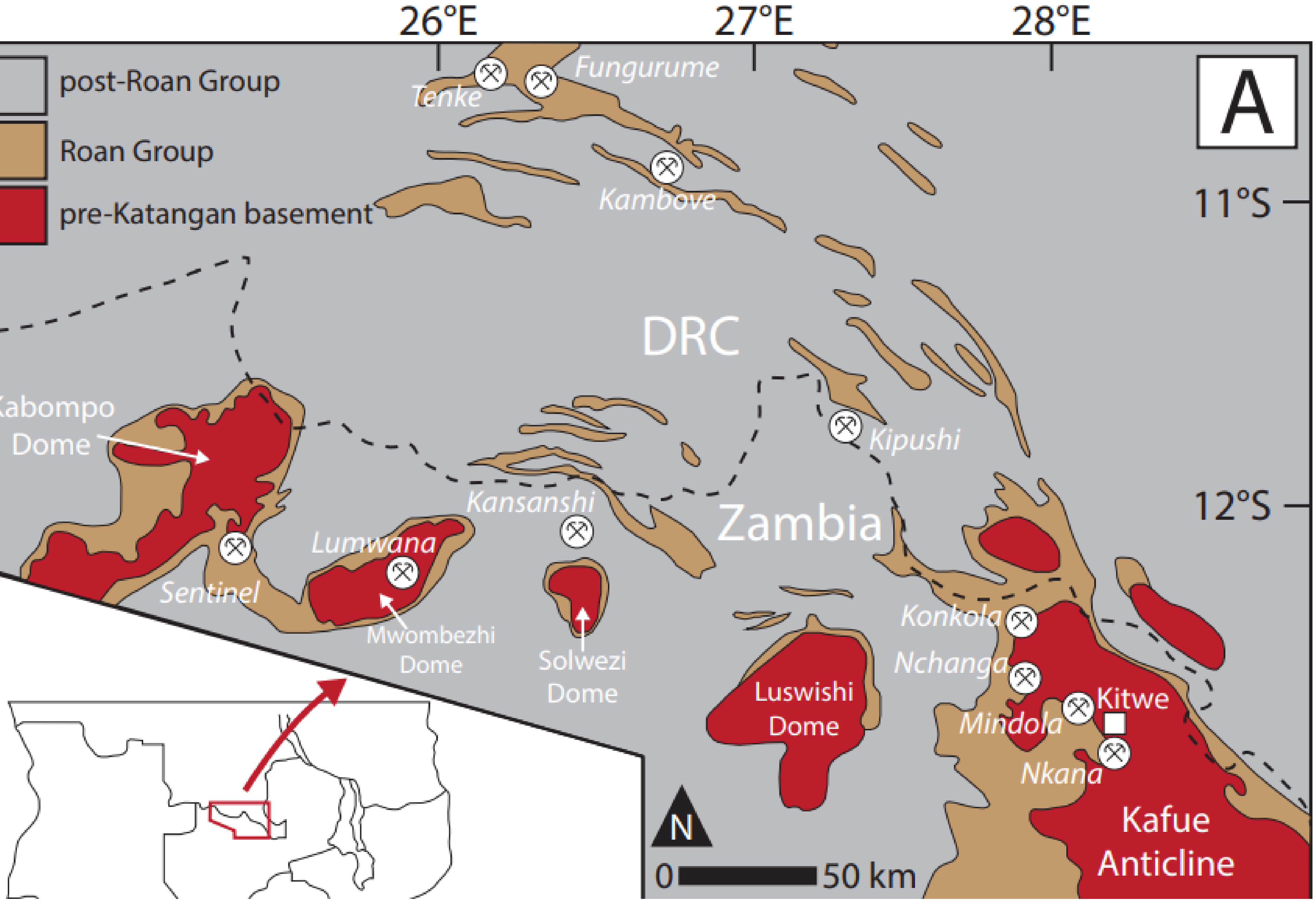


Purkiss et al. 2025



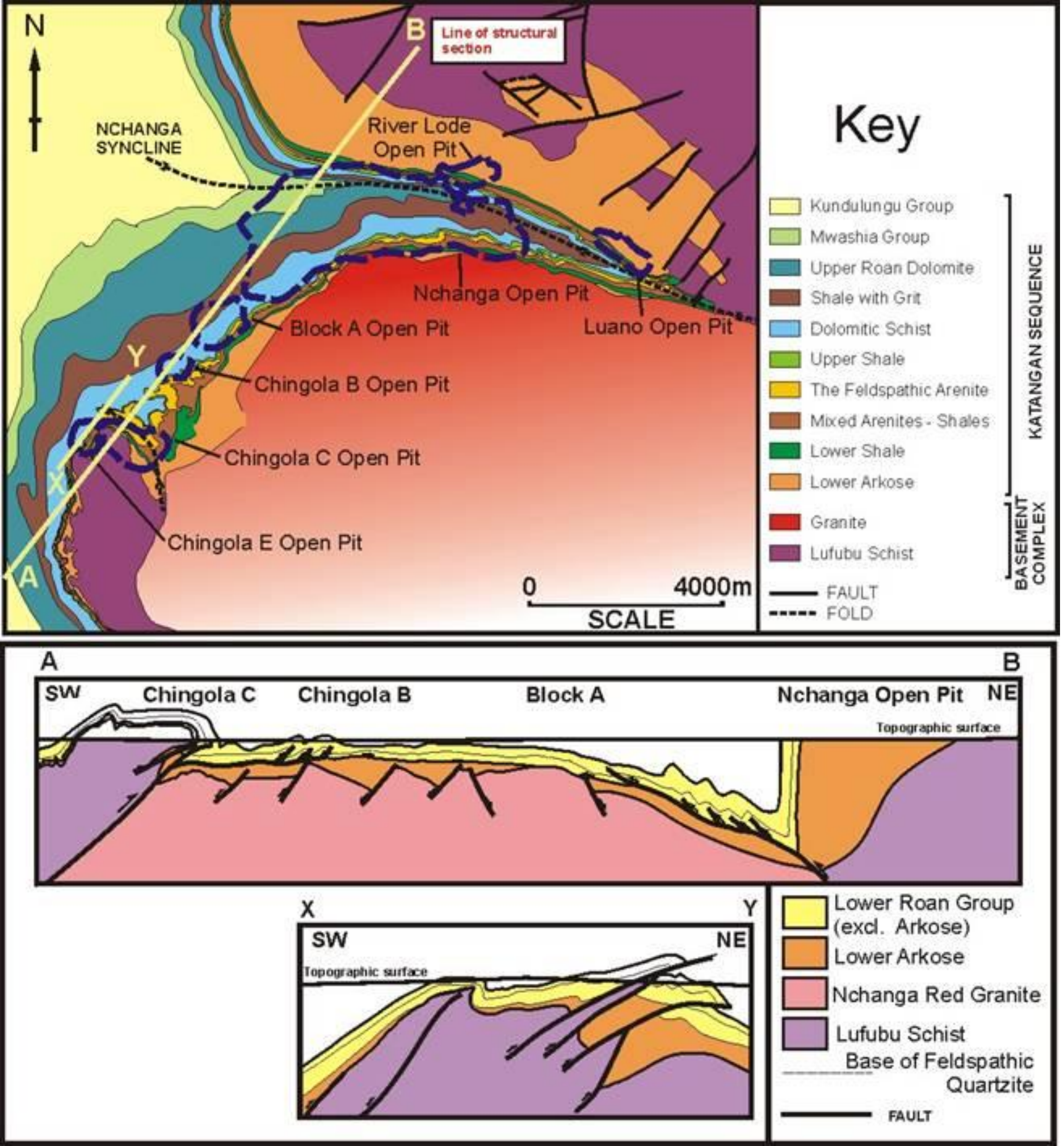
Ndonfack et al.2024

Mine Geology

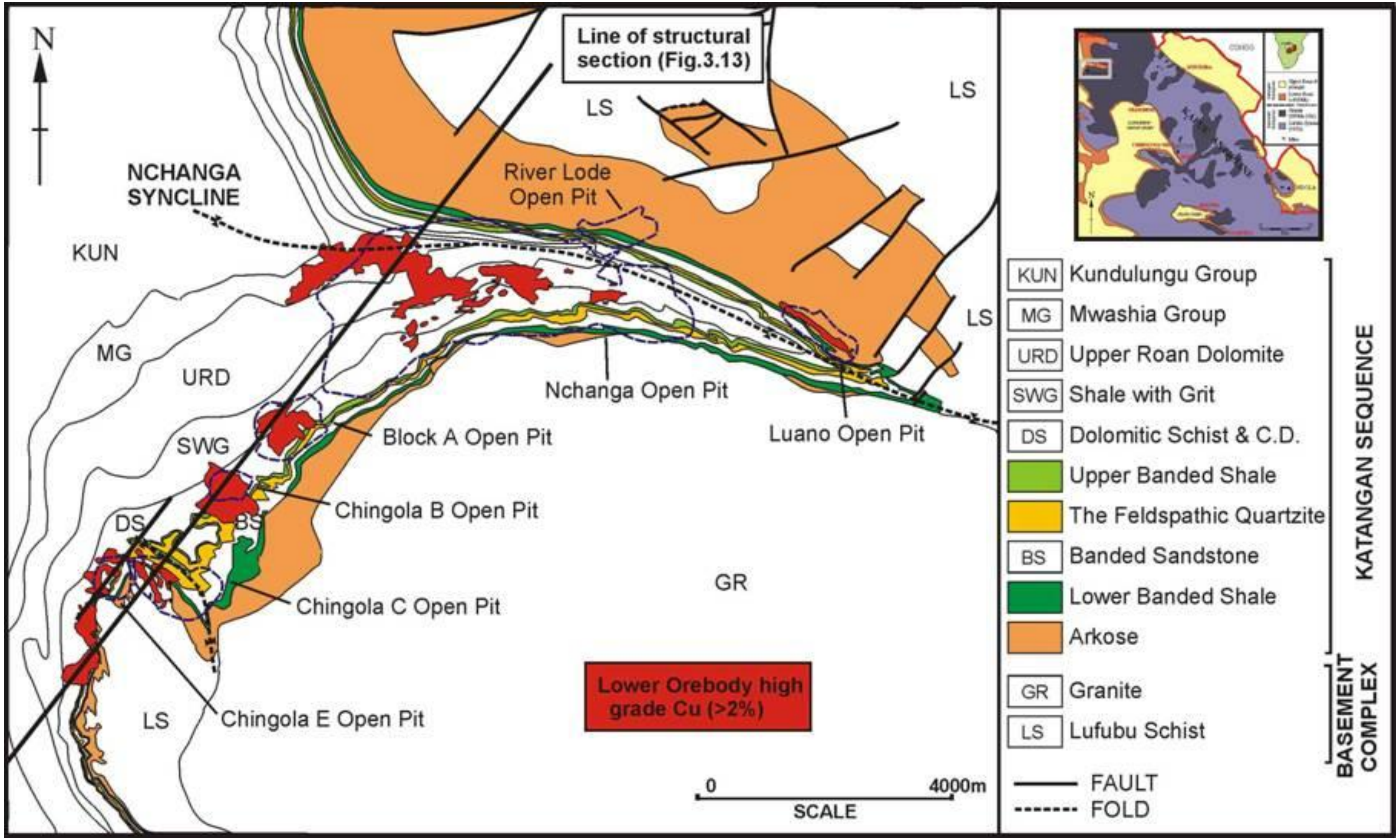


Nchanga
Kansanshi
Lumwana
Kamoa

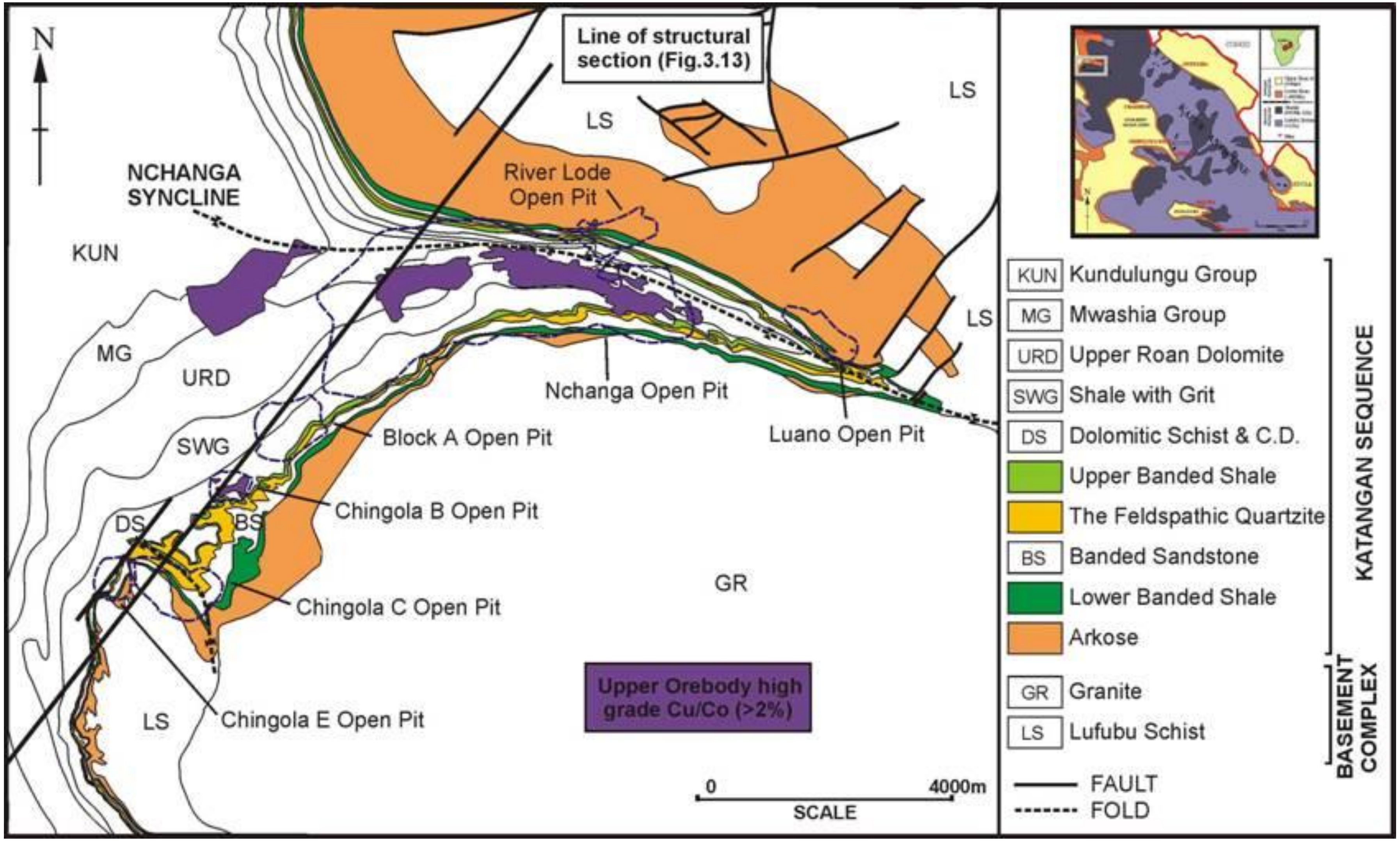
Location Map Deposits Investigated



Geology of Nchanga Mine



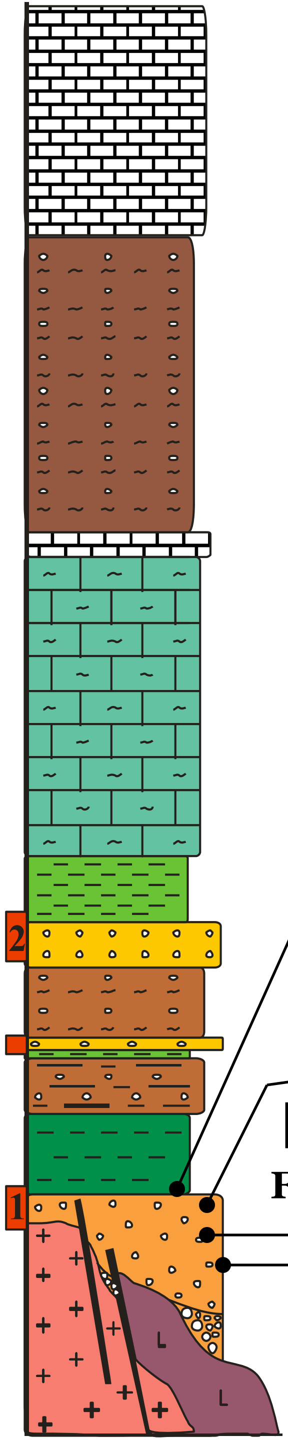
High-grade Lower Orebody mineralization Nchanga area projected to surface

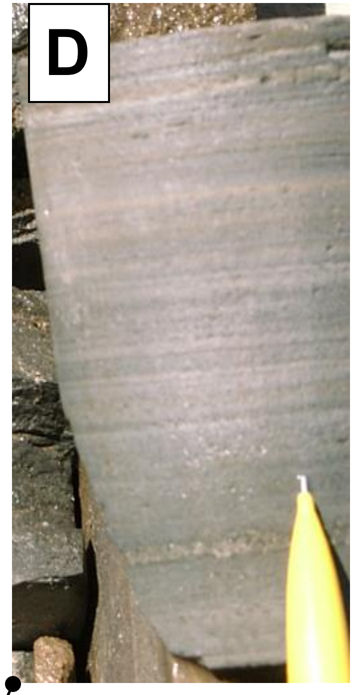


High-grade Upper Orebody mineralization in the Nchanga area projected to surface

Nchanga Stratigraphy

UNIVERSITY OF Southampton



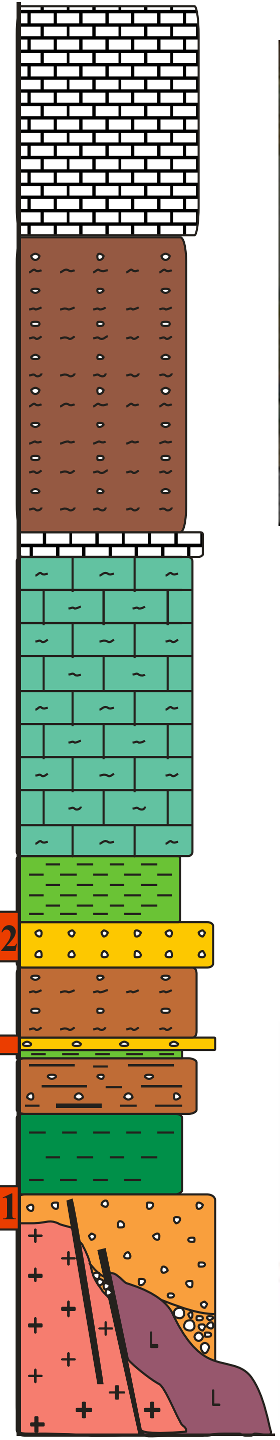


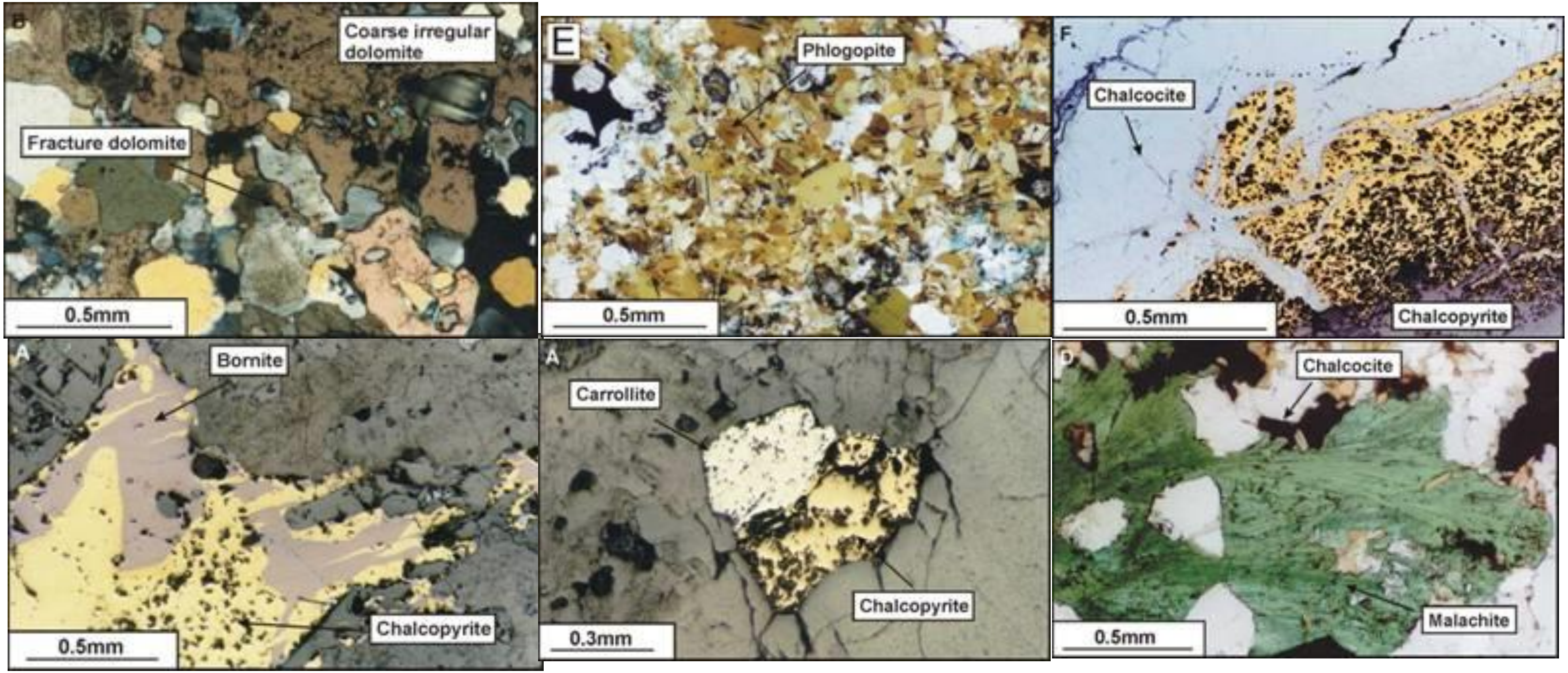
D. Shale overlying lower orebody

C. Sample of lower ore-body

B. Lower arkose in vicinity of mineralization, Fe-oxide staining and development of malachite

A. Lower arkose, coarse feldspars with shear zones evident within samples.

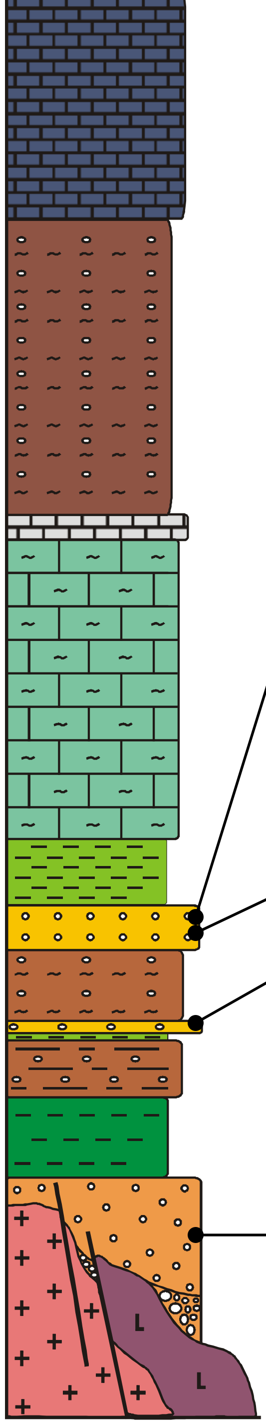




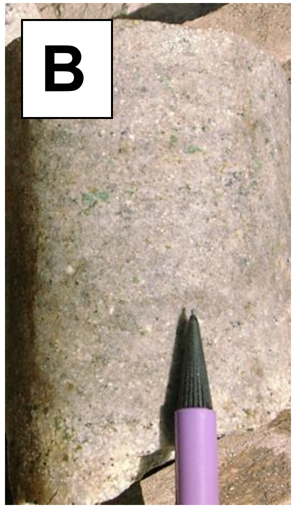
Nchanga Mine

UNIVERSITY OF Southampton

Nchanga Mine



D. **Sericite quartz alteration of Upper Orebody in NE511**

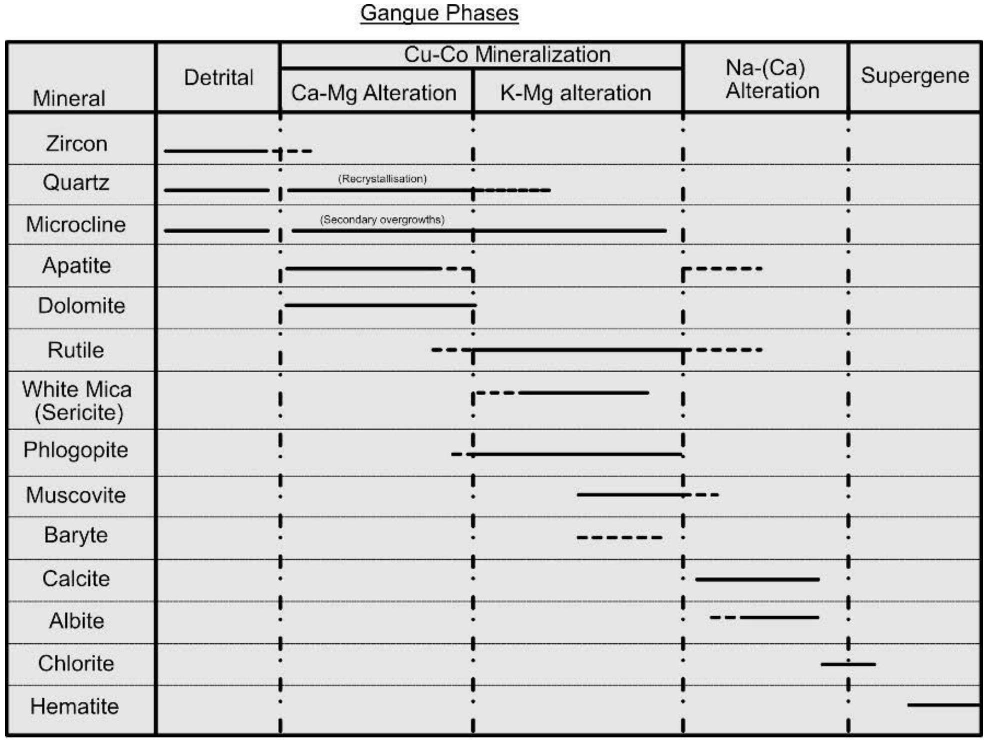


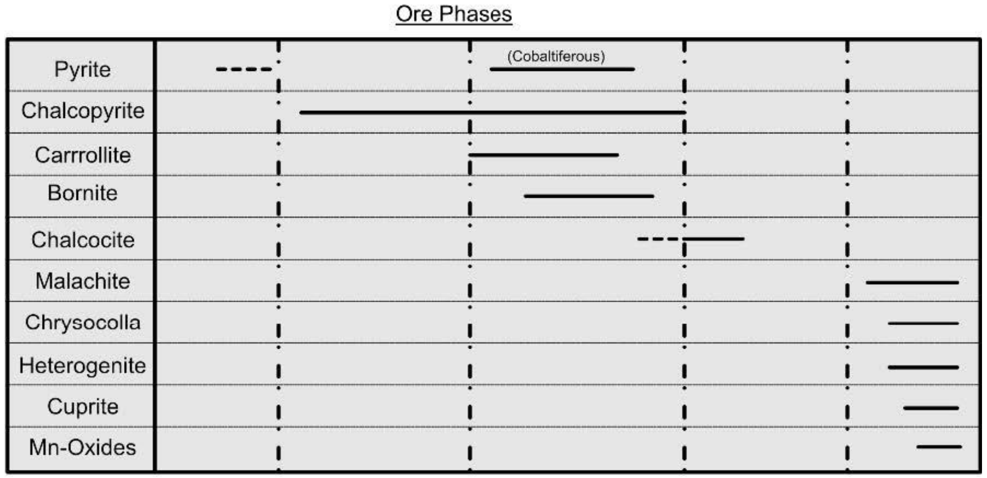
C. **Carrollite bearing upper arkose with variable amounts of dolomite**

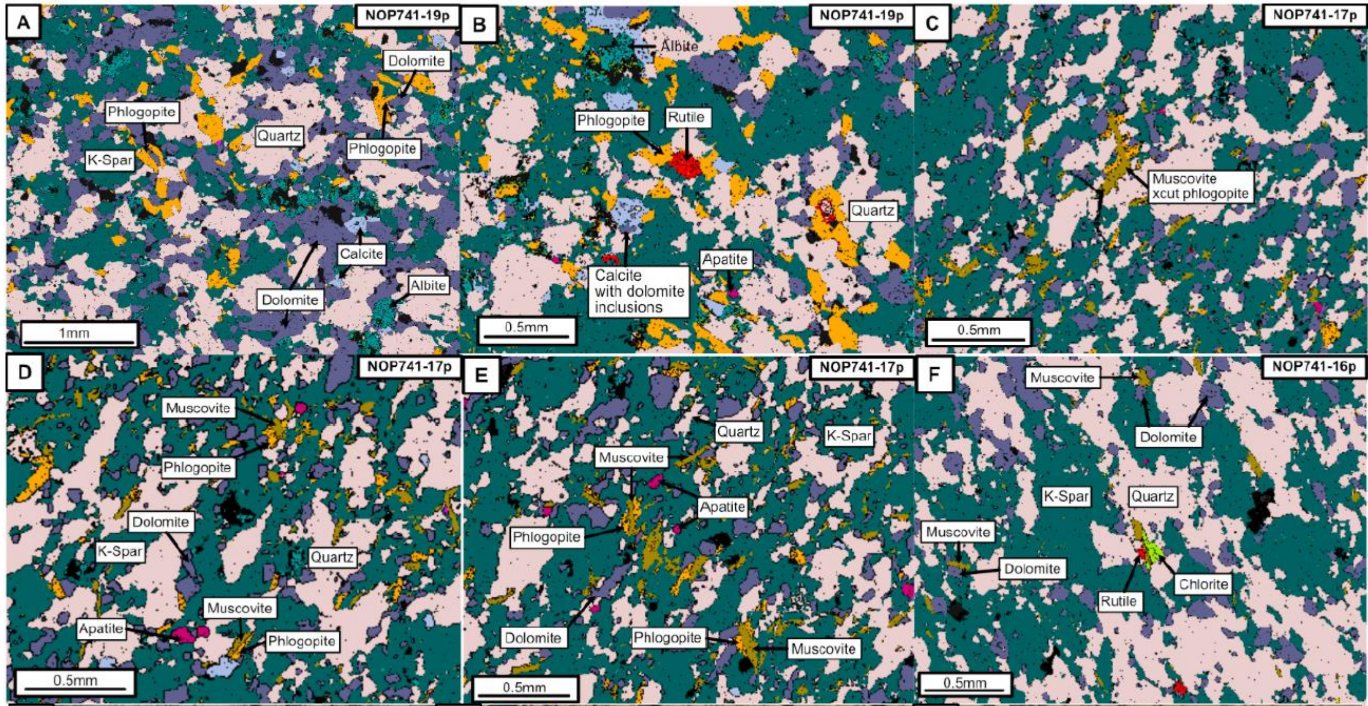
B. **Sample of weakly mineralised Pink Arkose.**

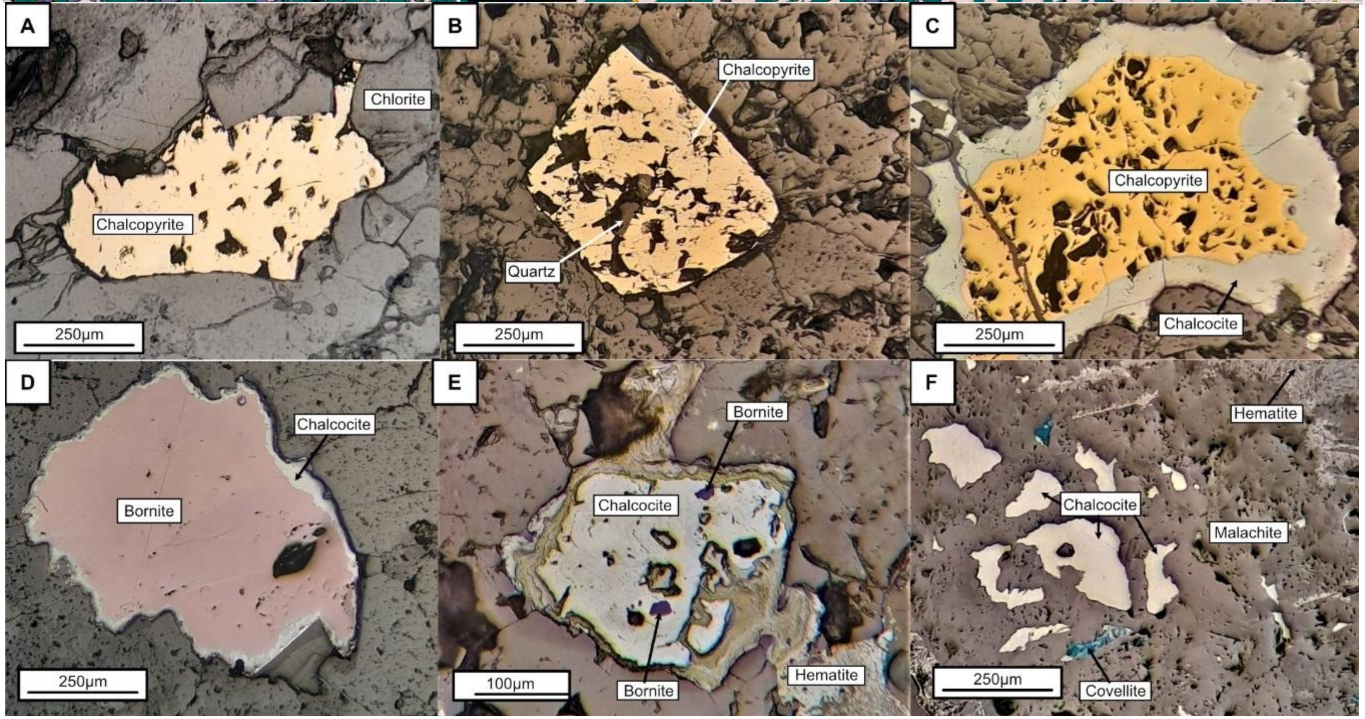
A. **Biotite/phlogopite alteration front preserved within arkose in lower section of NE511 Borehole**

Upper Orebody - Nchanga

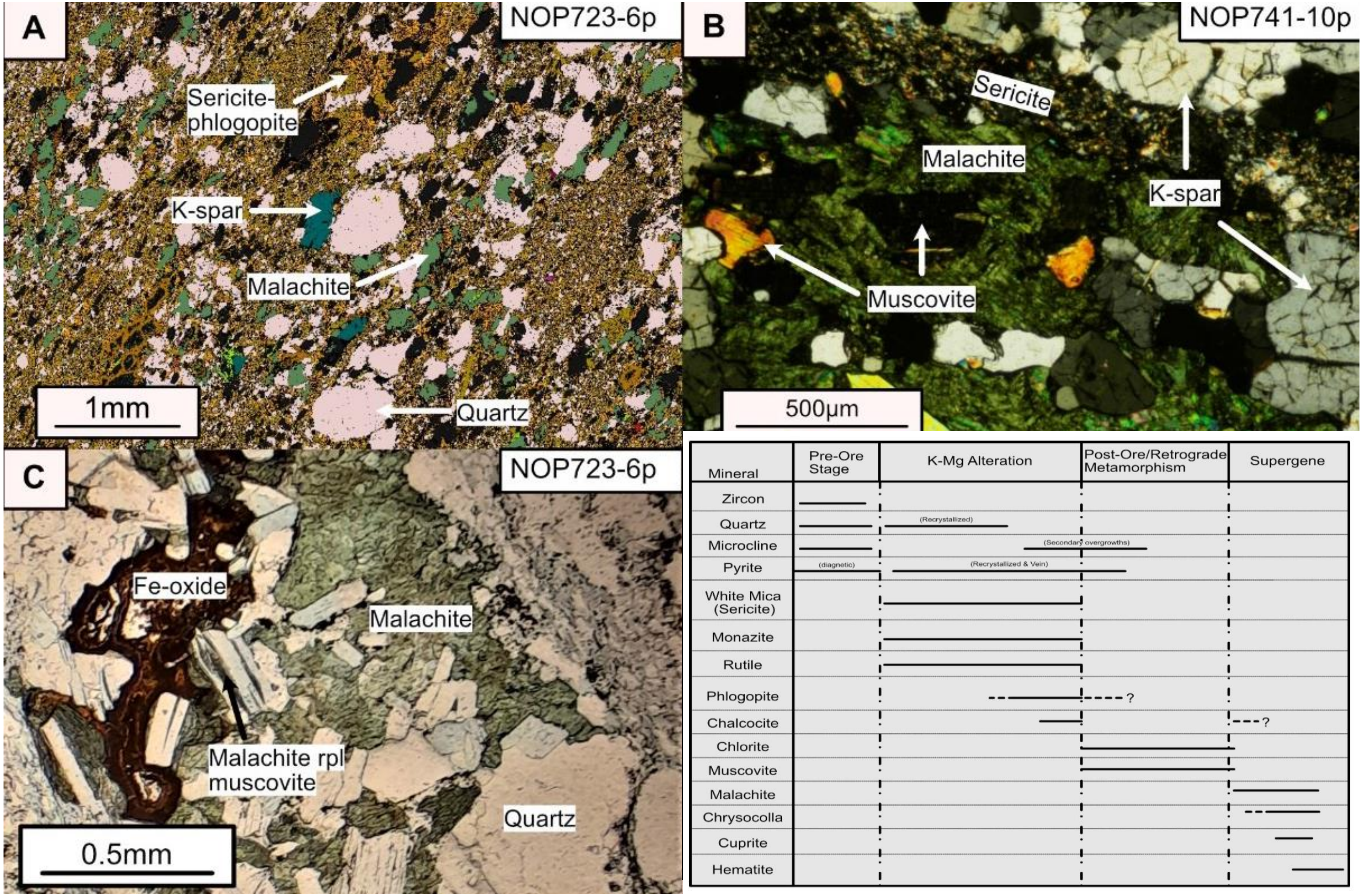




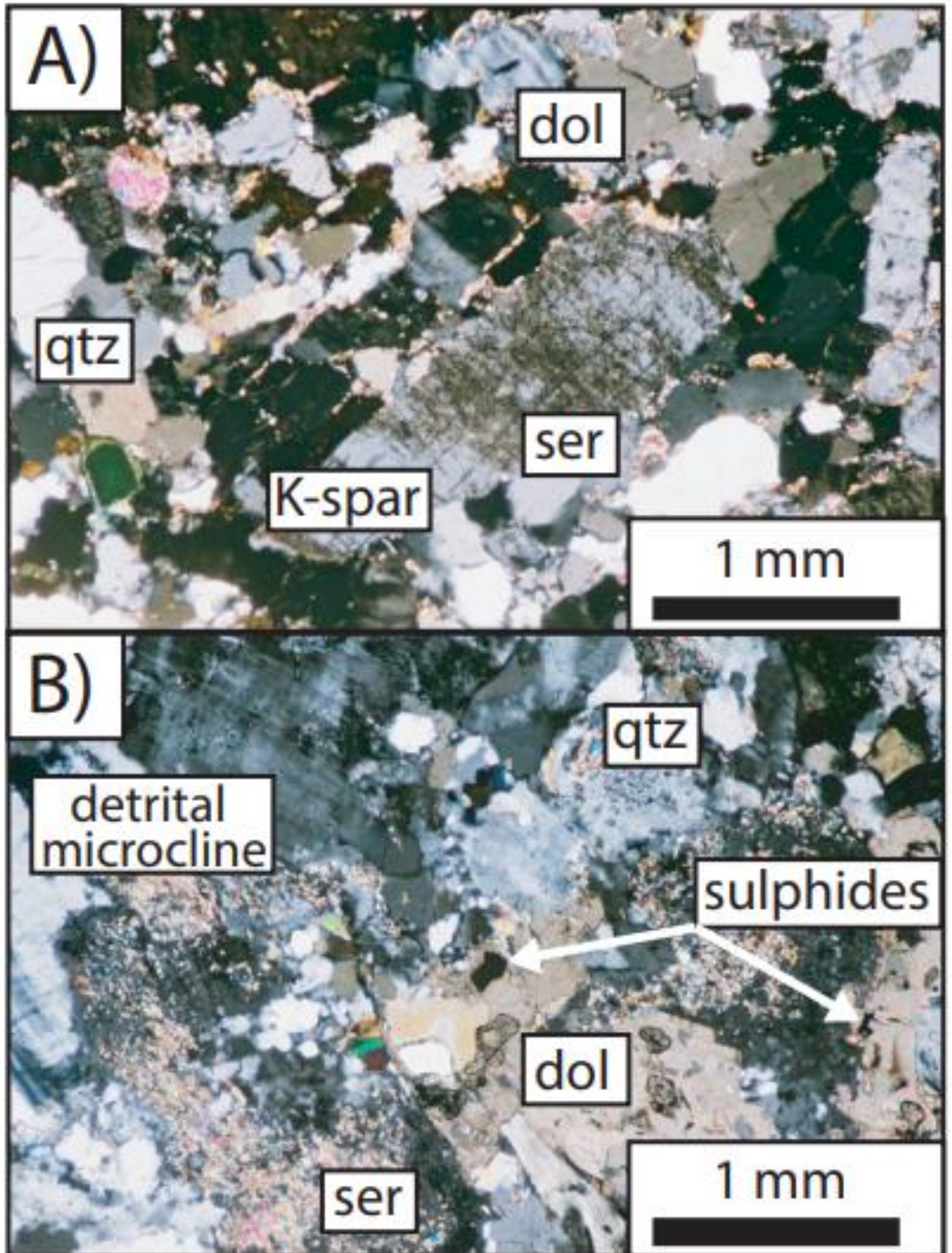


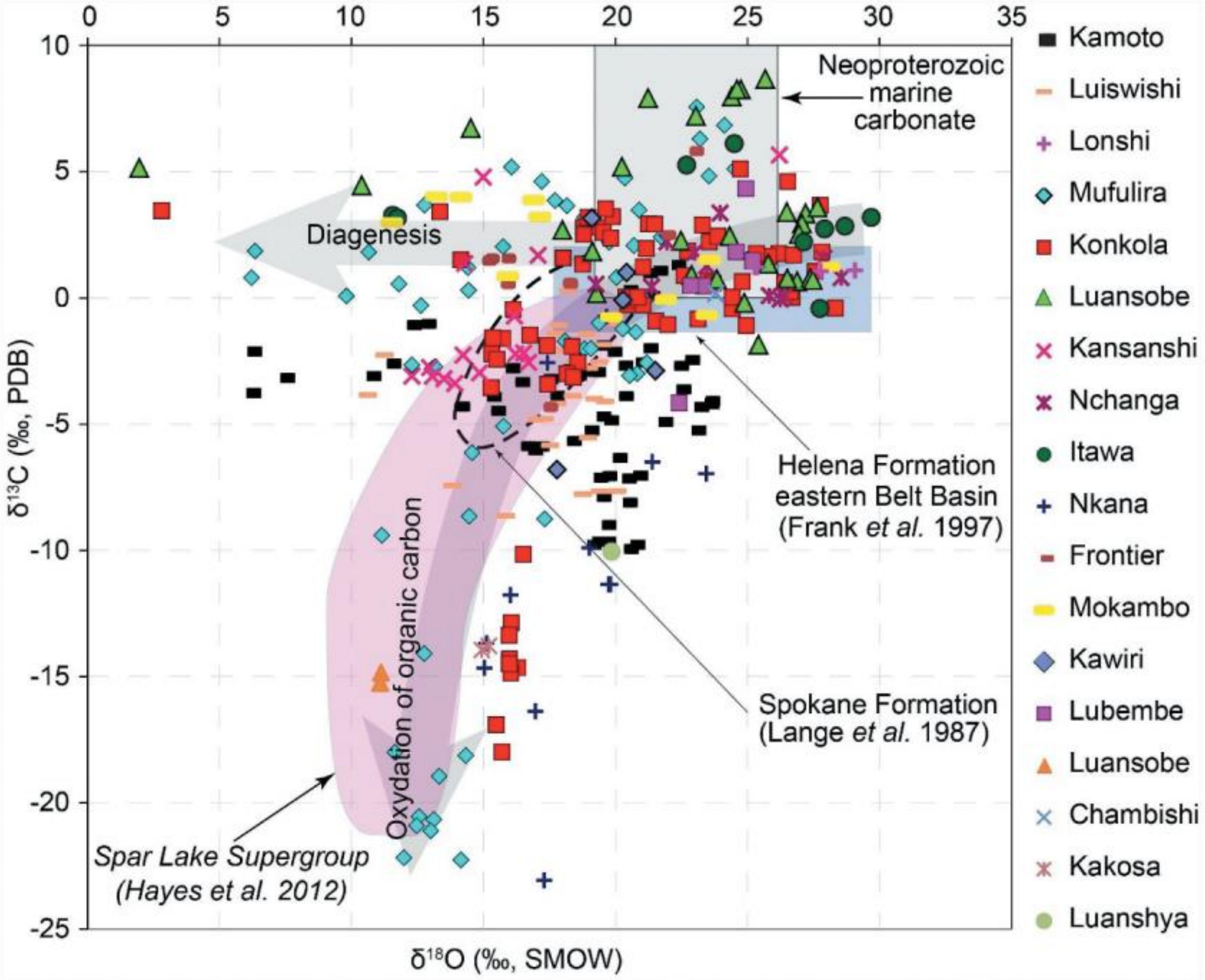


Lower Orebody Nchanga



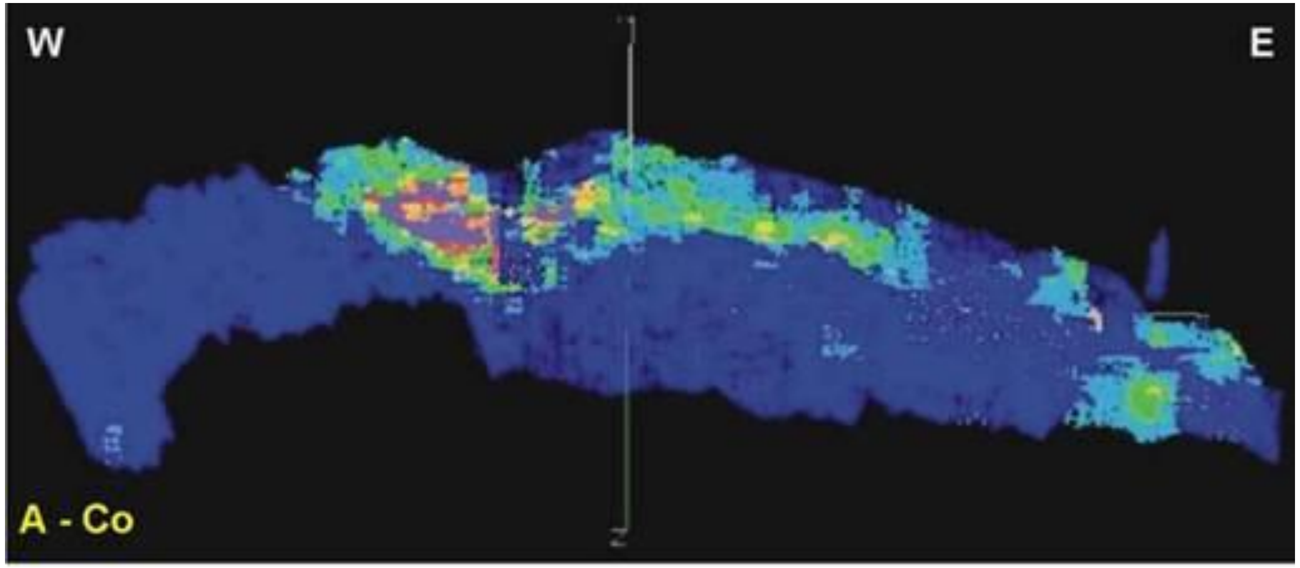
$\Delta^{18}O$ v Δ^{13C}

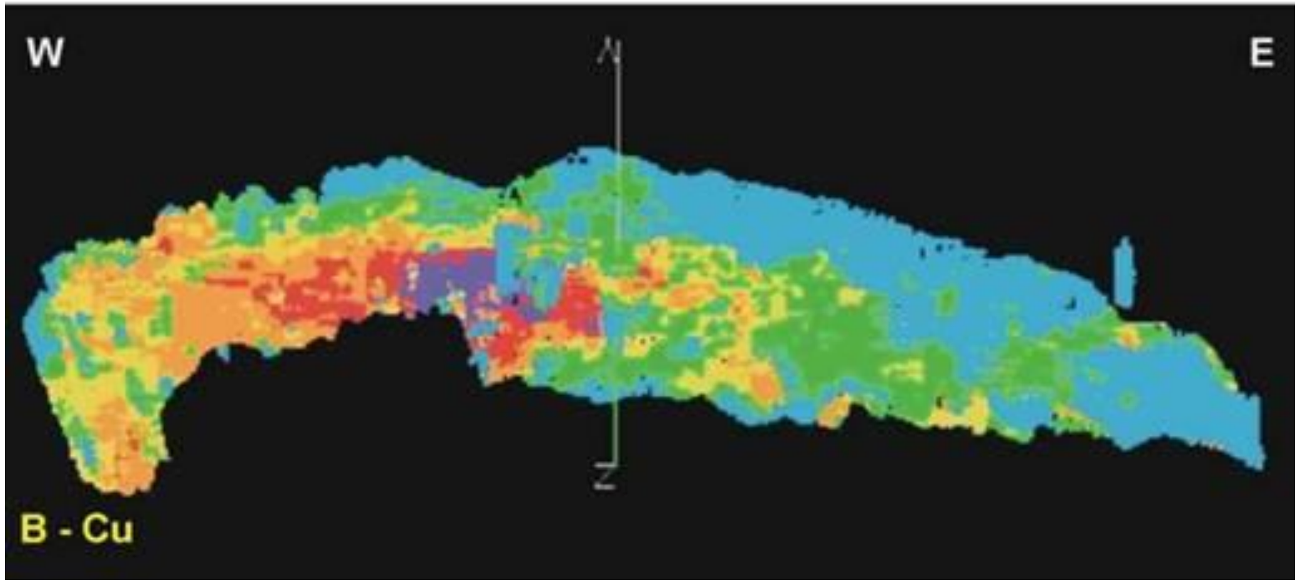




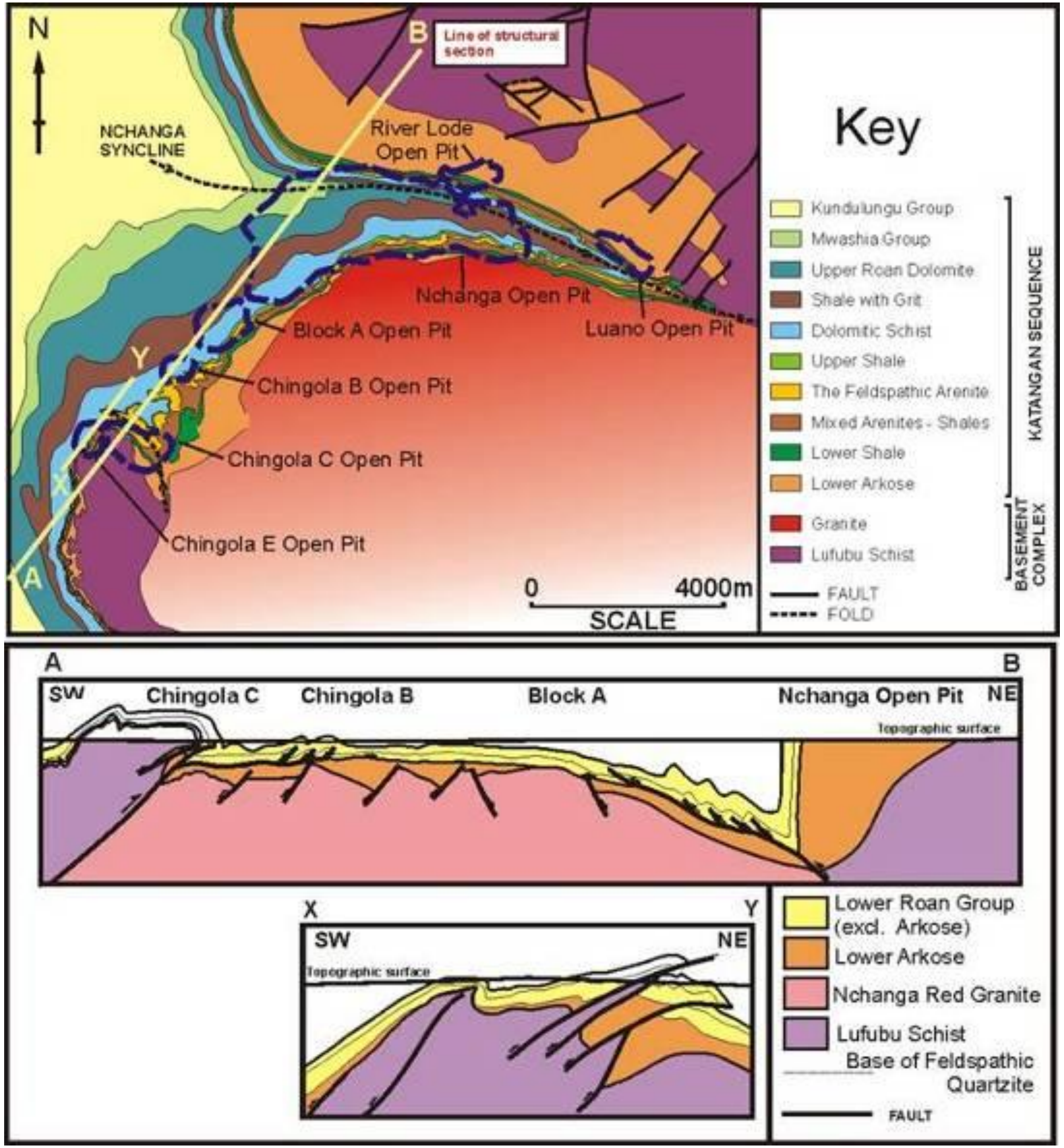
Ndonfack et. Al. 2024

Cu and Co Distributions

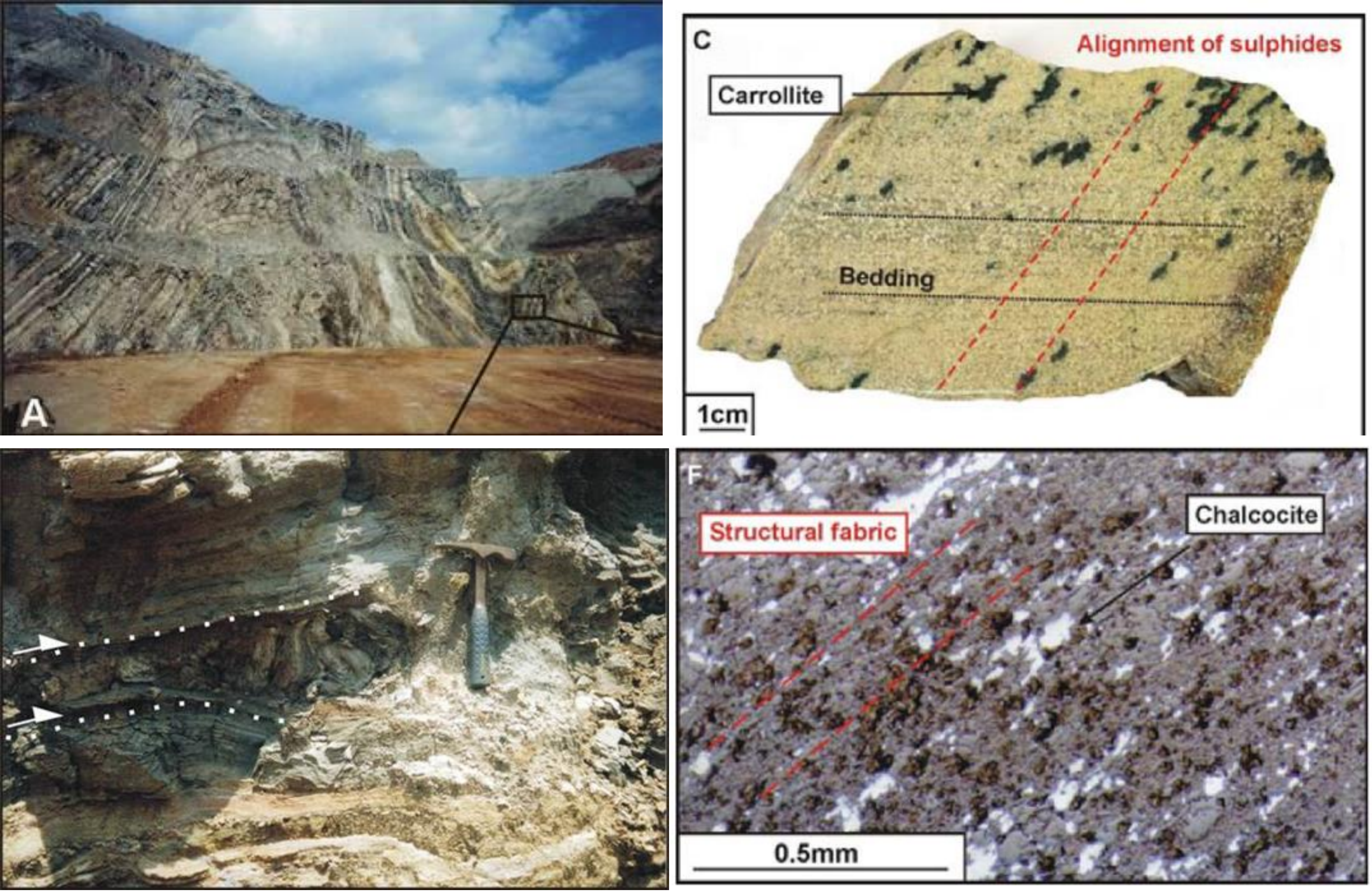




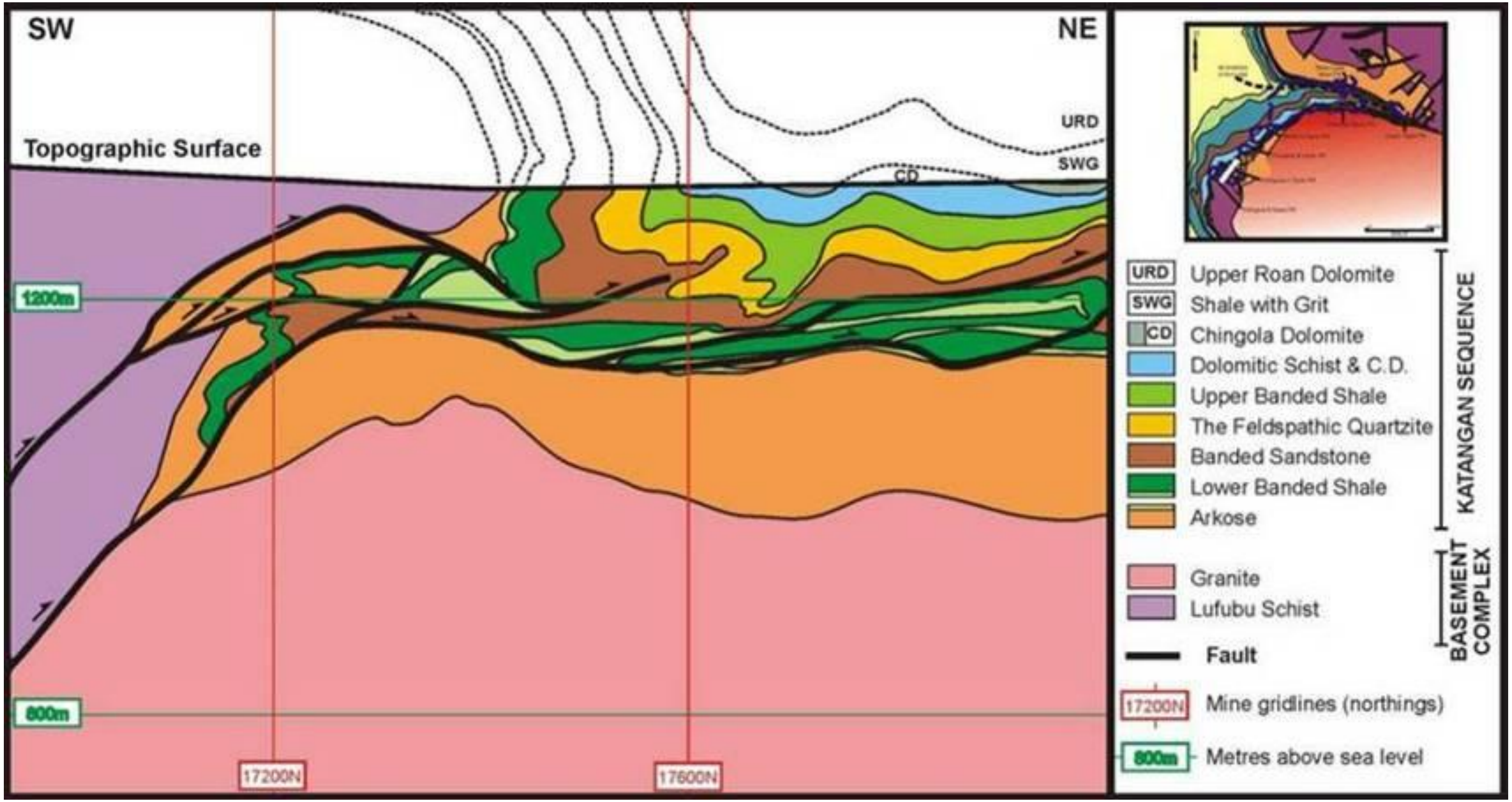
Plan view datamine image from Nchanga Open Pit Upper Orebody showing location of high-grade (A) cobalt and (B) copper, and the inverse relationship between the two (***Nchanga Mine Geology Department***).



Tectonic Setting


A
C
Alignment of sulphides
Carrollite
Bedding
1cm
F
Structural fabric
Chalcocite
0.5mm

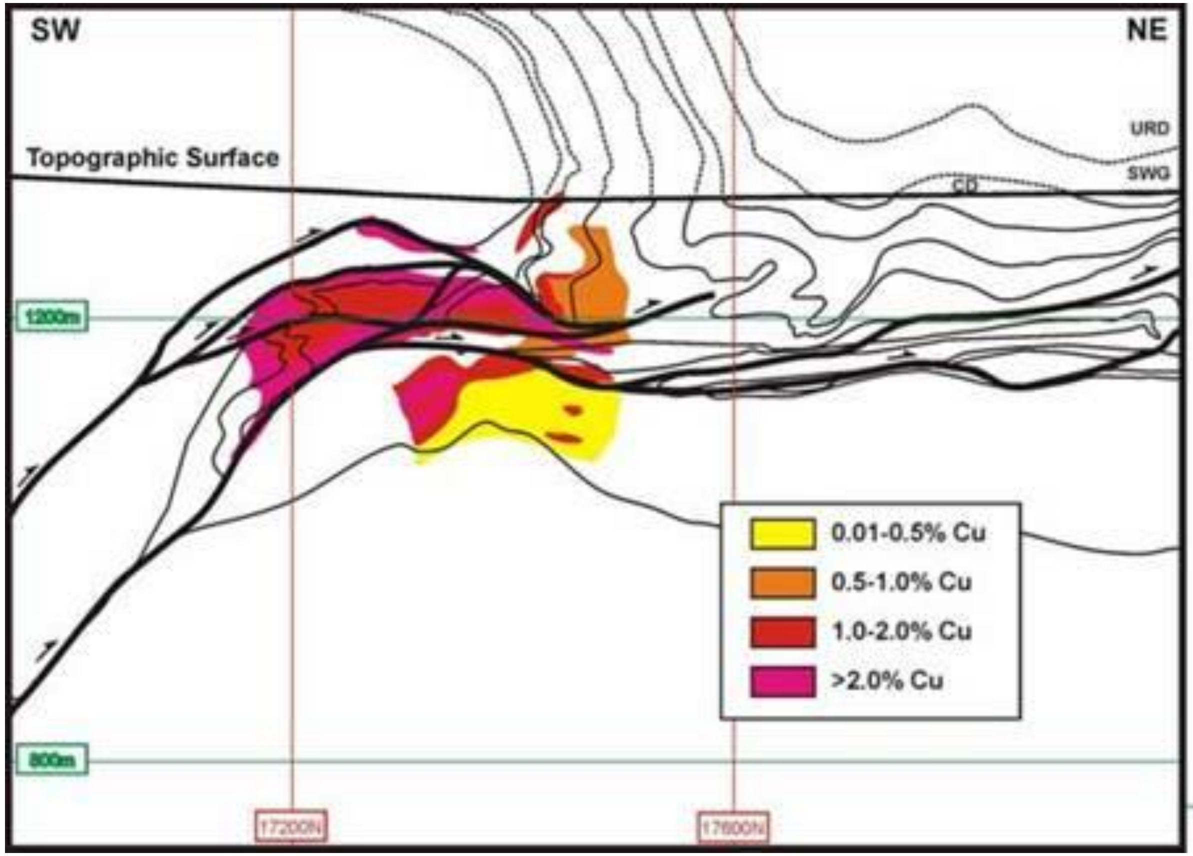
Geology – Chingola C



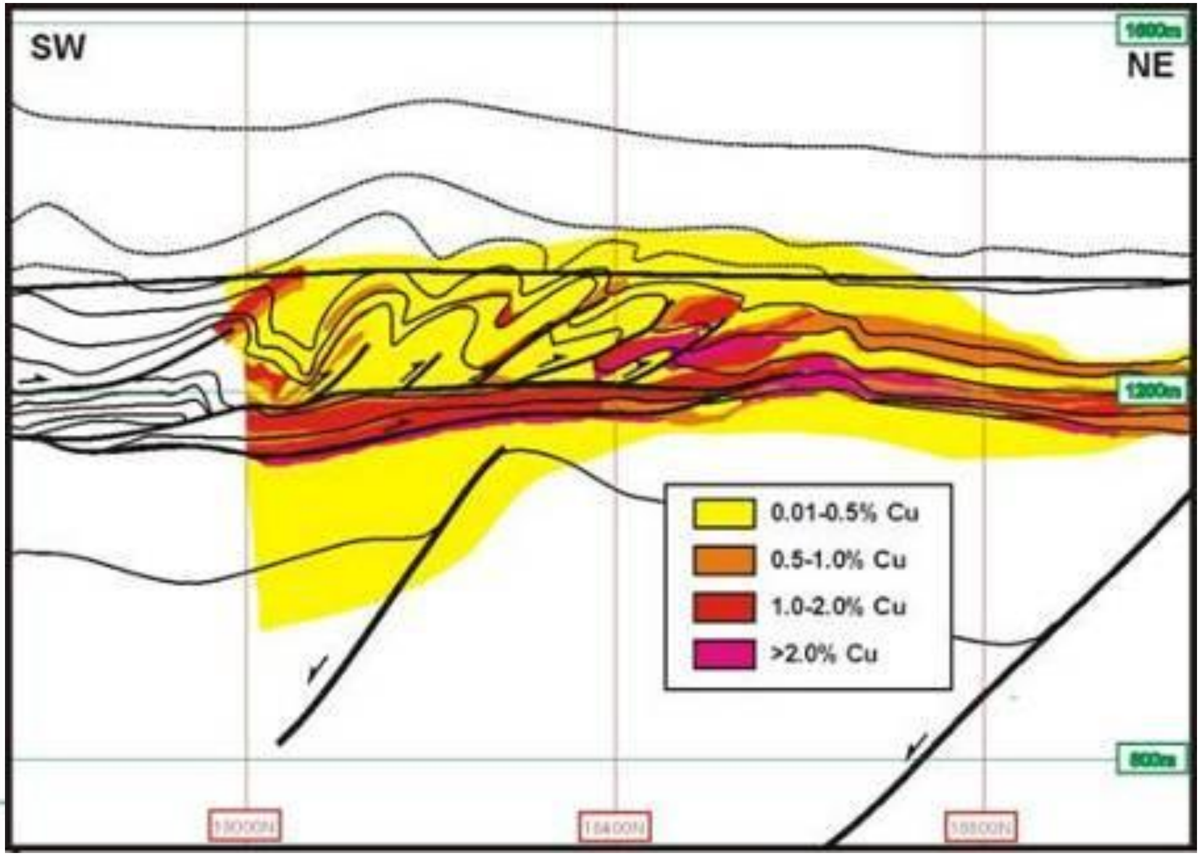
Geology of the Chingola C deposit where a NE-verging recumbent anticline structure has developed where basement schists are thrust over Lower Roan stratigraphy

Distribution of mineralization at Chingola B & C

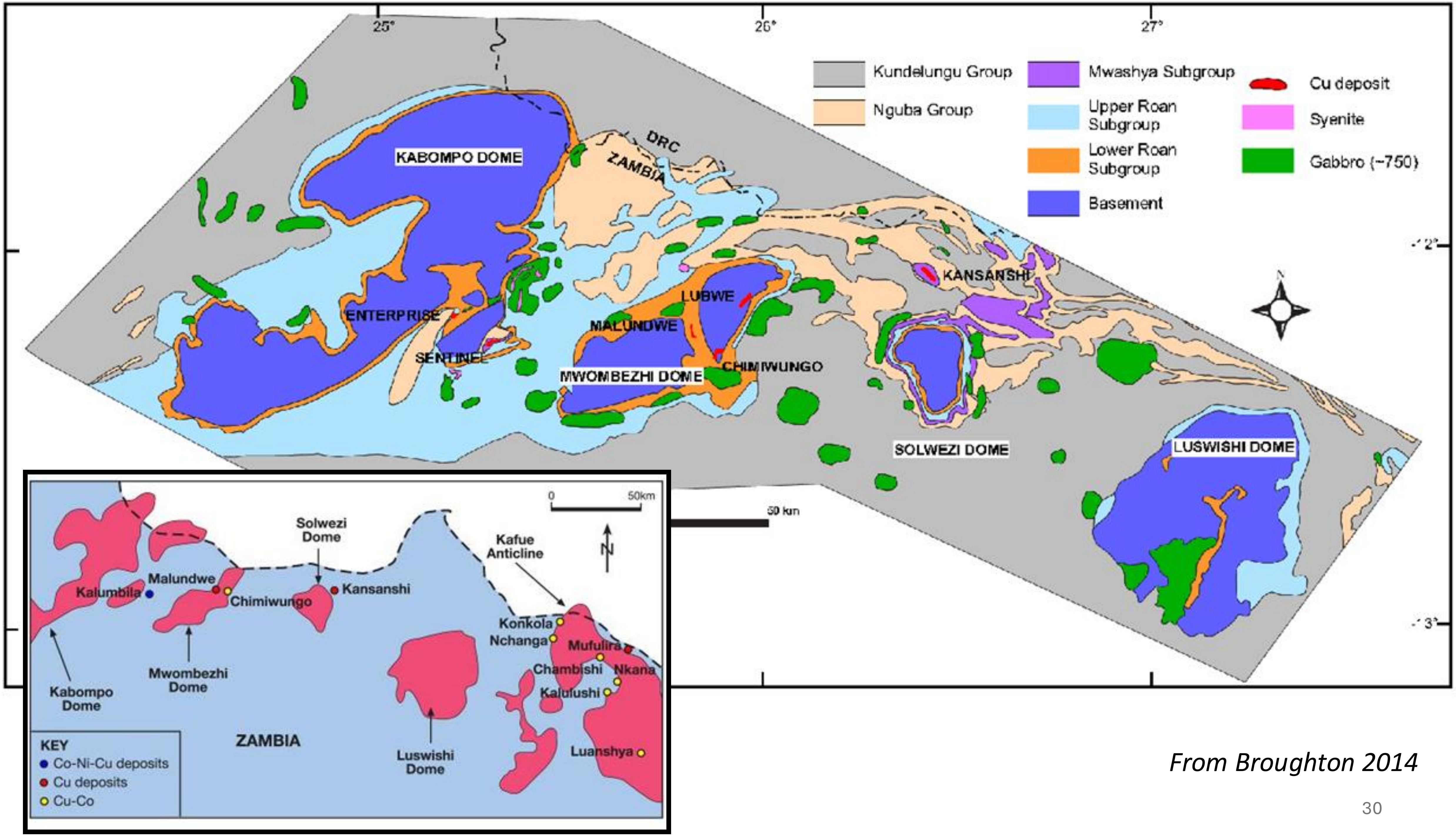
UNIVERSITY OF Southampton



The distribution of mineralization at Chingola C (based on copper grade boundaries) plotted on to the section geology. High-grade mineralization is strongly related to thrust structures.

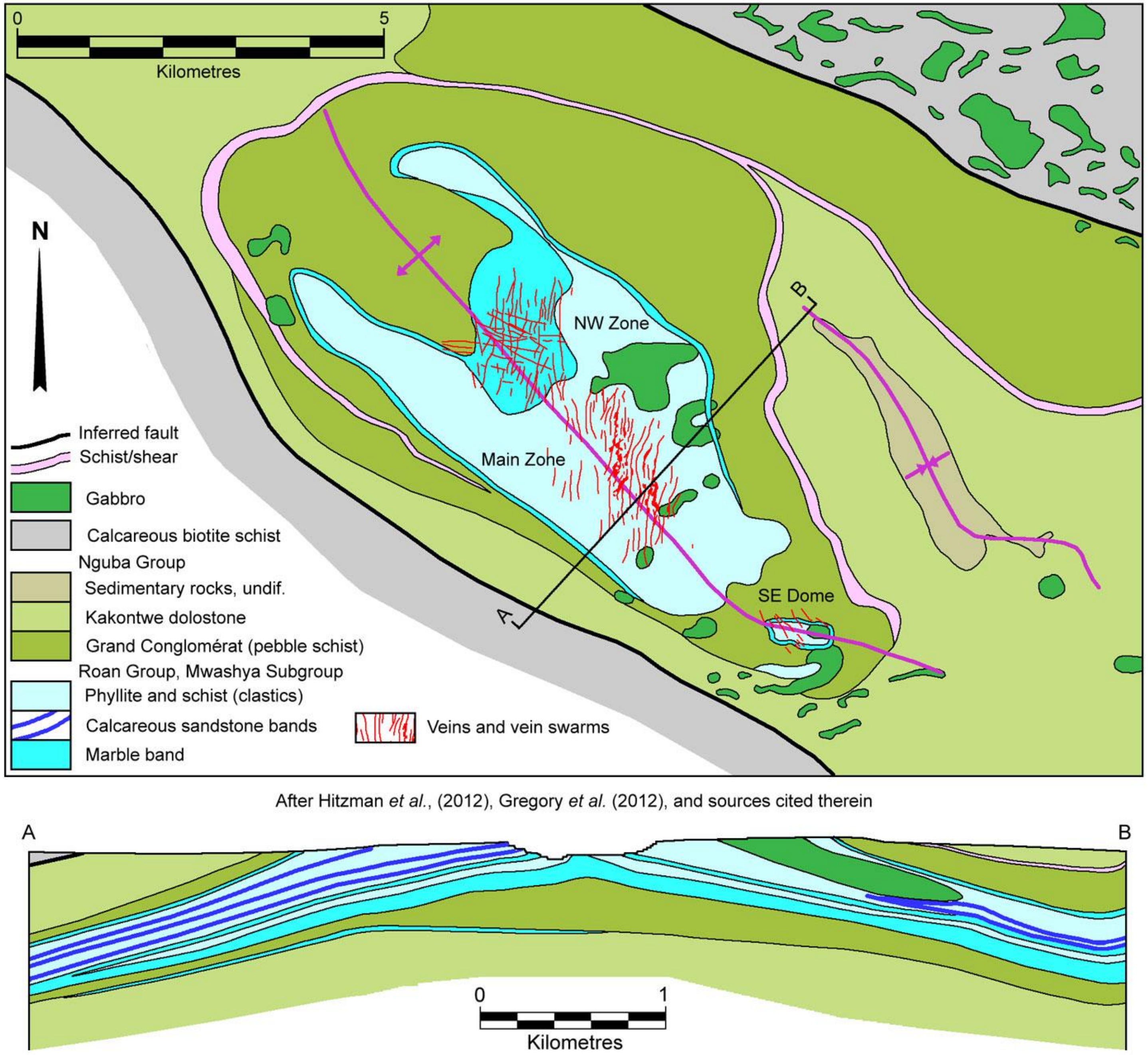


The distribution of mineralization at Chingola B (based on copper grade boundaries) plotted on to the section geology. Mineralization is strongly related to the fault-propagation folds and controlling thrusts, as well as basal detachments.



From Broughton 2014

Geology Kansanshi



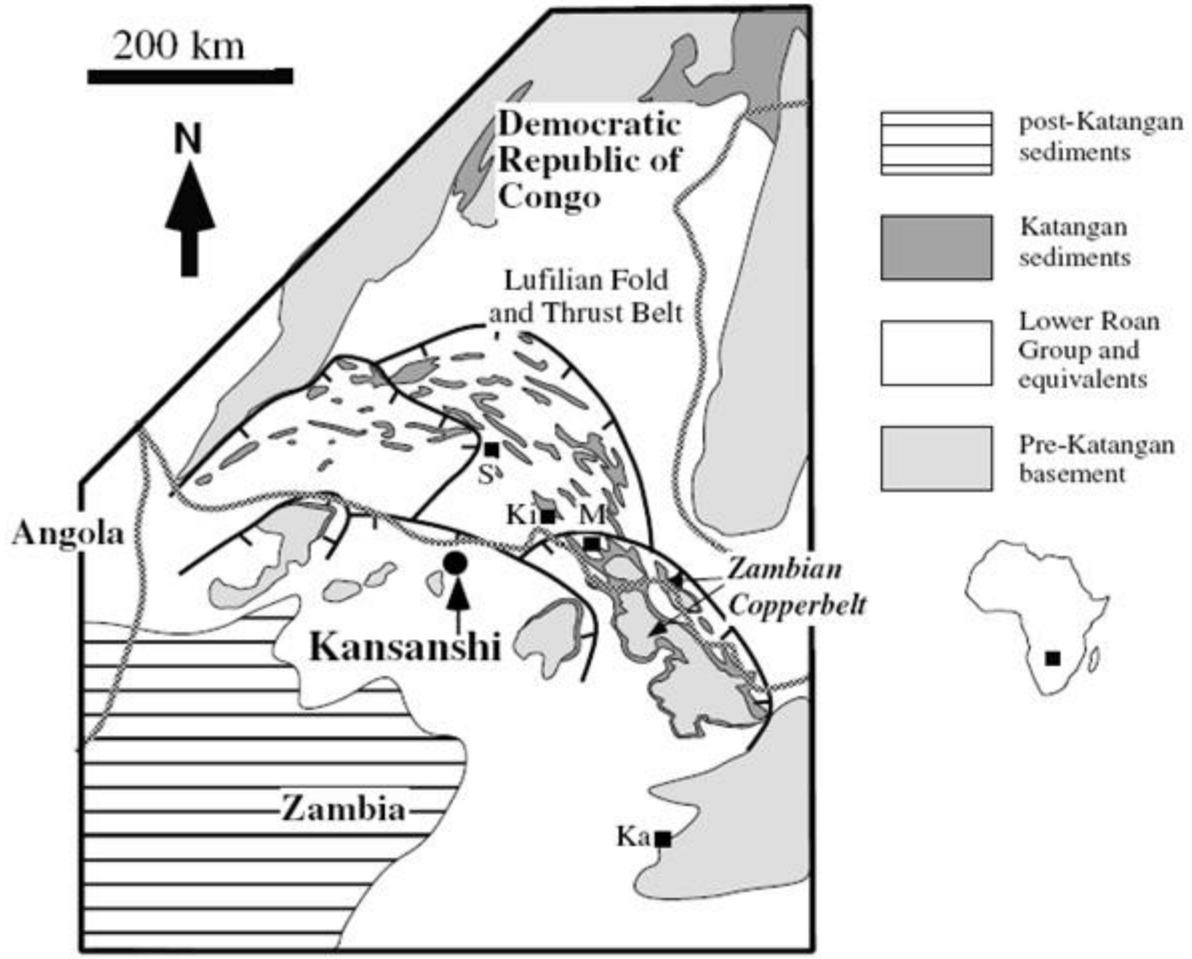
Geology and Mineralisation of the Kansanshi Deposit, Northwest Province, Zambia

After Hitzman et al, 2012

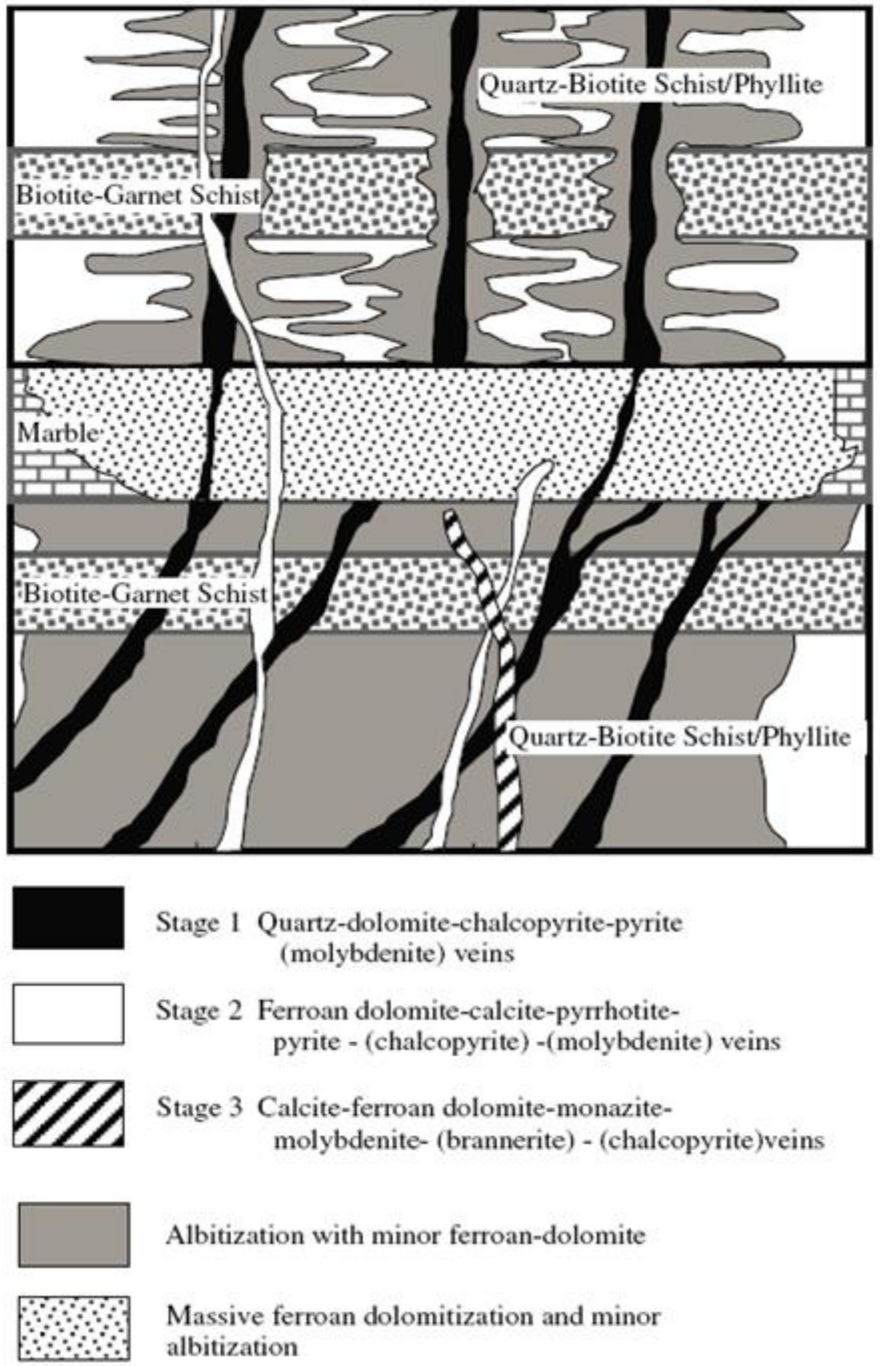
Kansanshi Post Kinematic Veins

Kansanshi Post Kinematic Veins

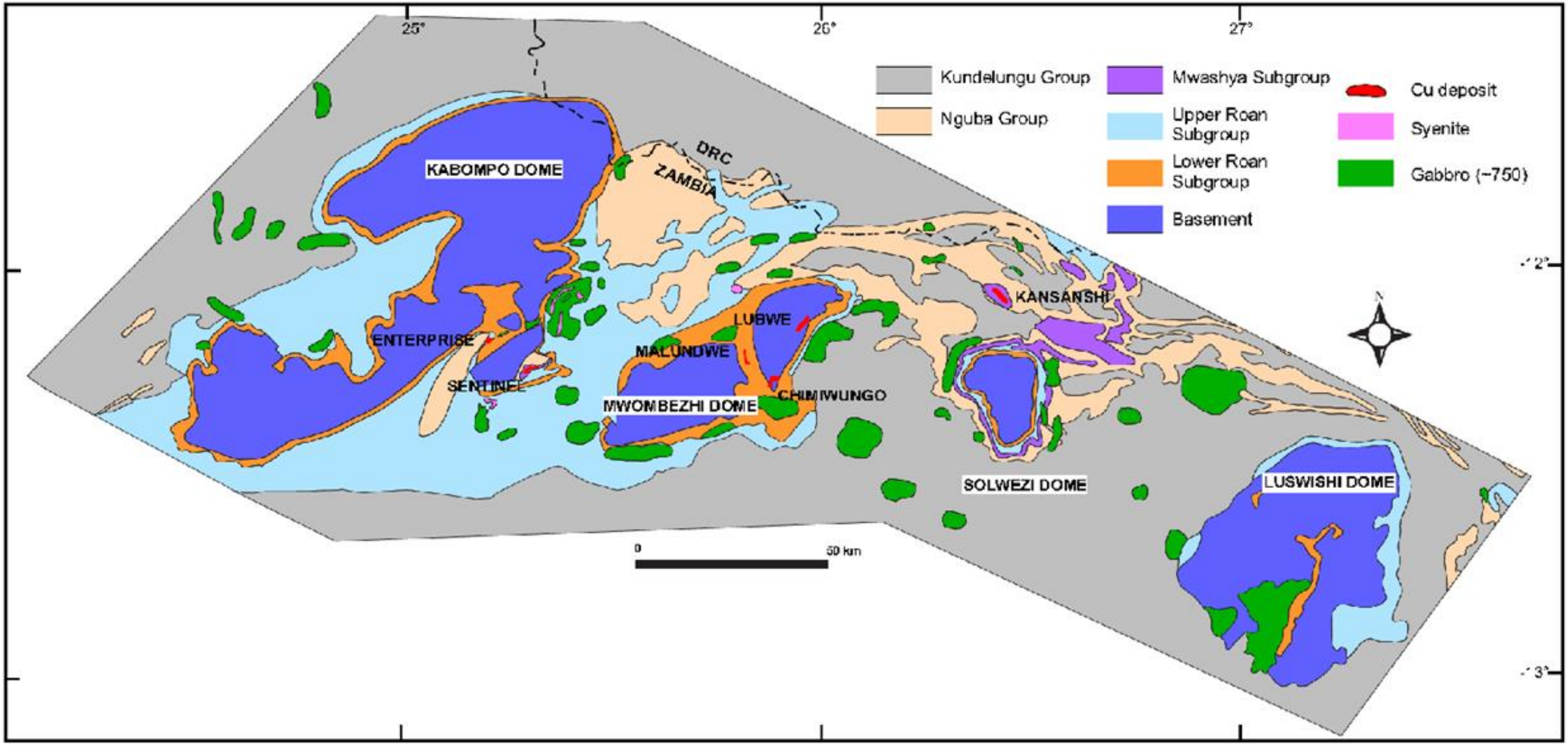
Kansanshi Mine



Molybdenite within chalcopyrite Veins
Re-Os 511 +/- 1.7Ma

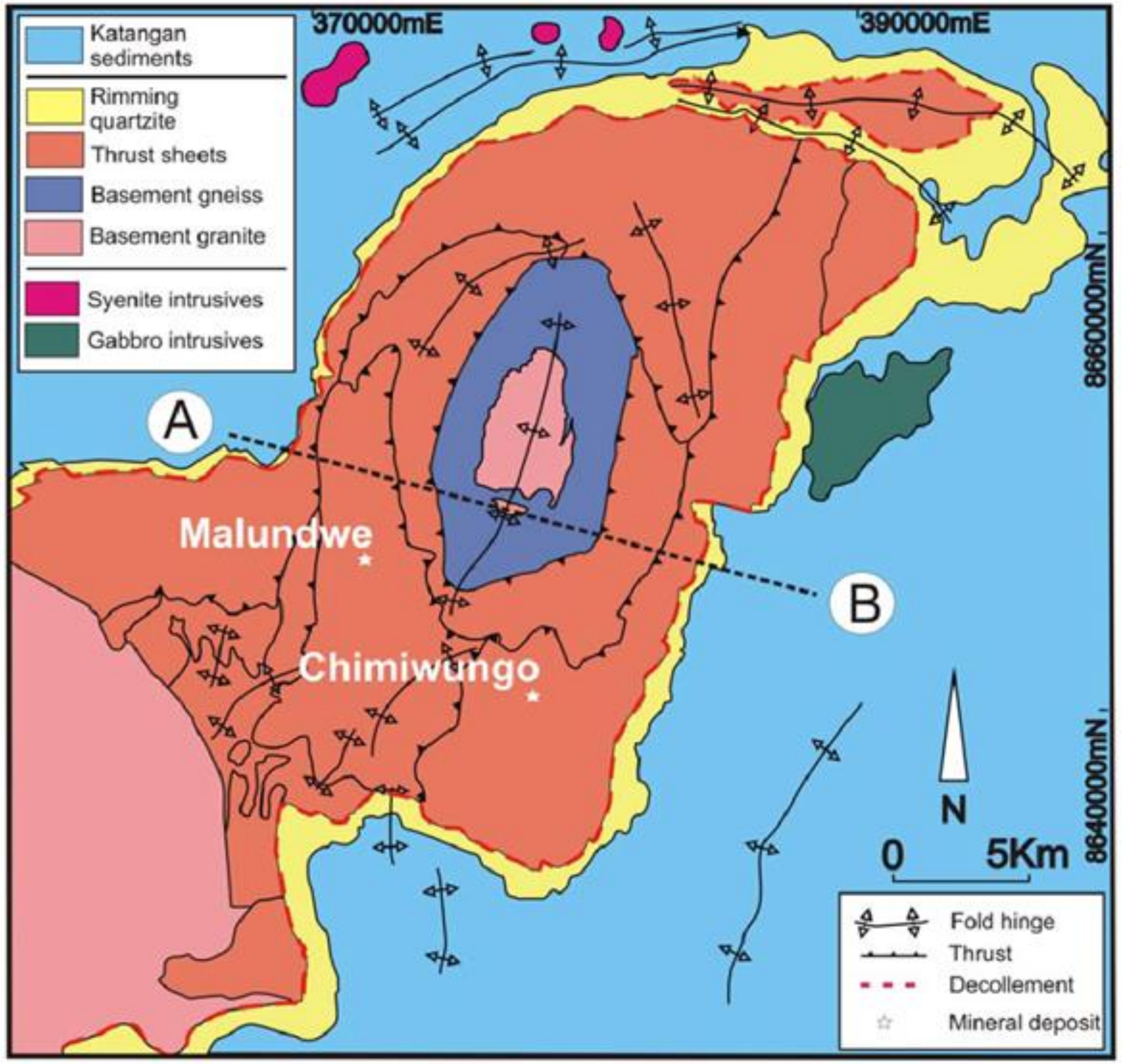


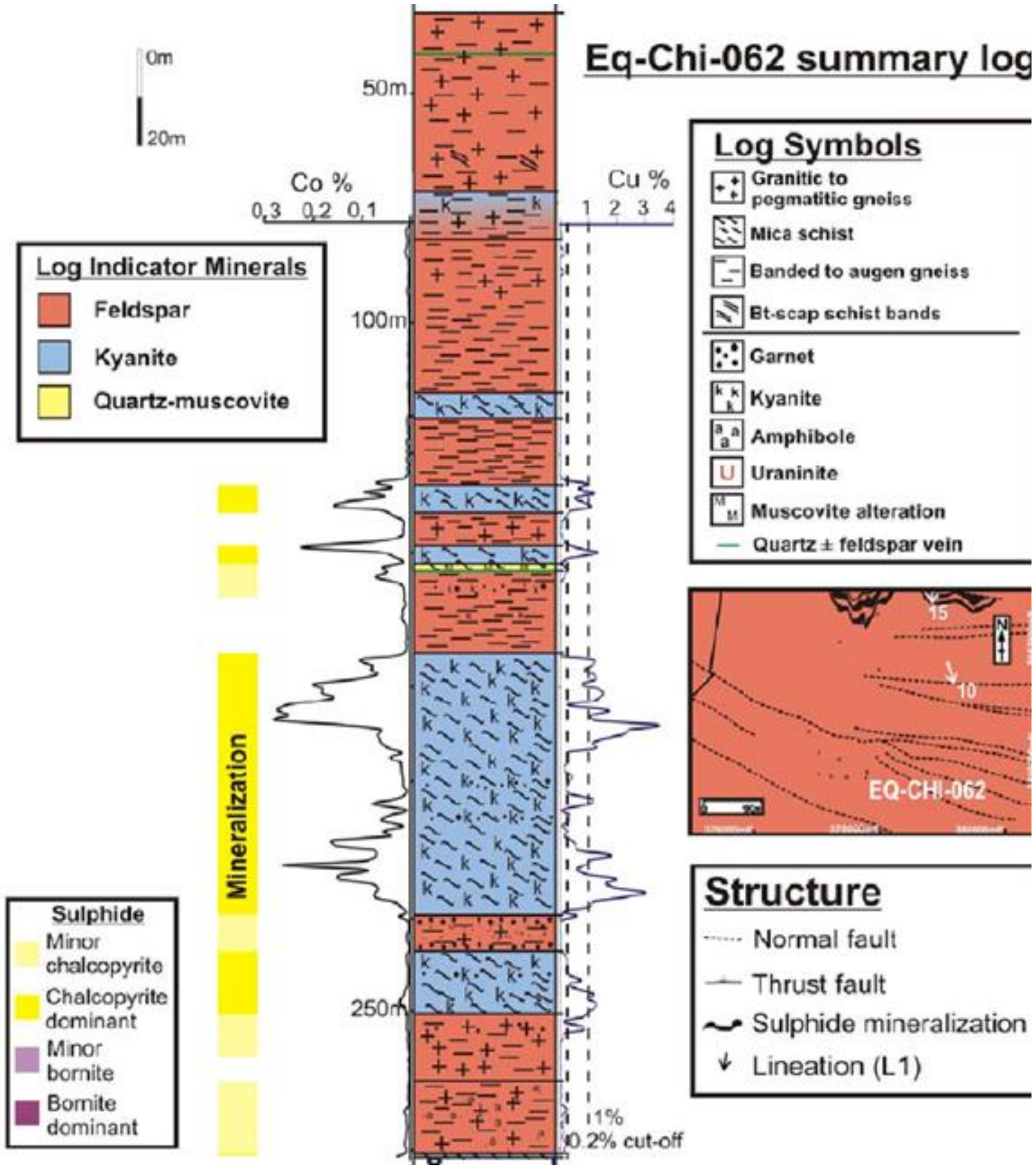
Diagrams from Torrealday - 2000



From Broughton 2014

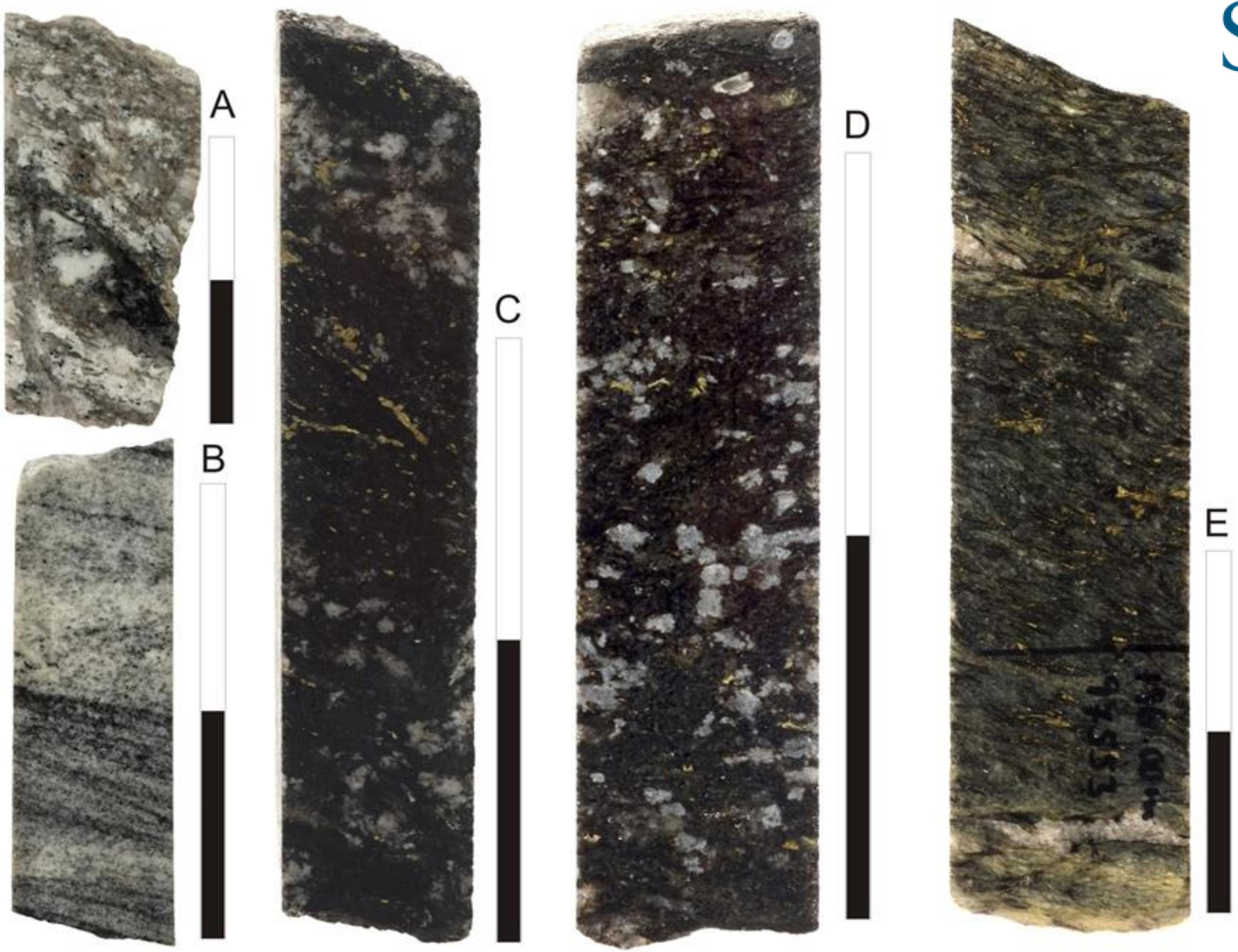
Lumwana Mineralization



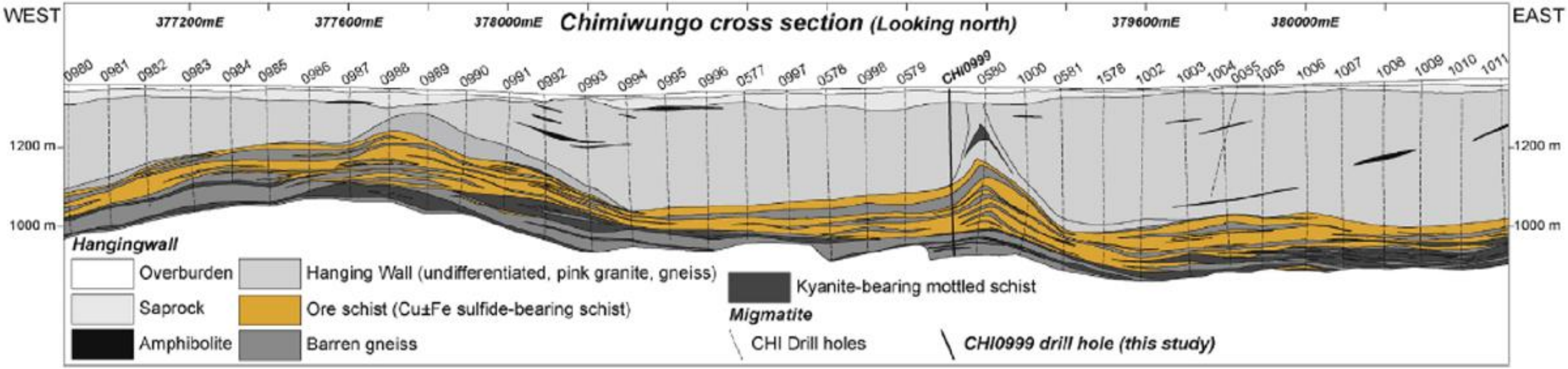

Eq-Chi-062 summary log
0m
20m
50m
100m
250m
Co %
0,3 0,2 0,1
Cu %
1 2 3 4
Log Indicator Minerals
Feldspar
Kyanite
Quartz-muscovite
Mineralization
Sulphide
Minor chalcopyrite
Chalcopyrite dominant
Minor bornite
Bornite dominant
1%
0.2% cut-off
Log Symbols
Granitic to pegmatitic gneiss
Mica schist
Banded to augen gneiss
Bt-scap schist bands
Garnet
Kyanite
Amphibole
Uraninite
Muscovite alteration
Quartz ± feldspar vein
15
10
EQ-CHI-062
Structure
Normal fault
Thrust fault
Sulphide mineralization
Lineation (L1)

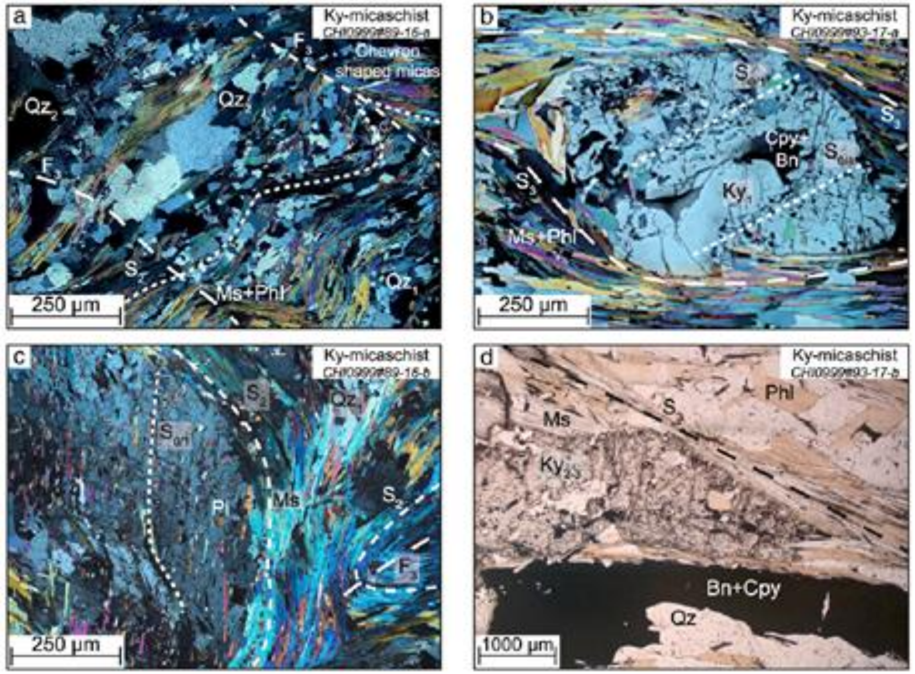

95.00
96.00


154.50
HW
OS
137.50


A
B
C
D
E

Lumwana Deposits – Domes Region

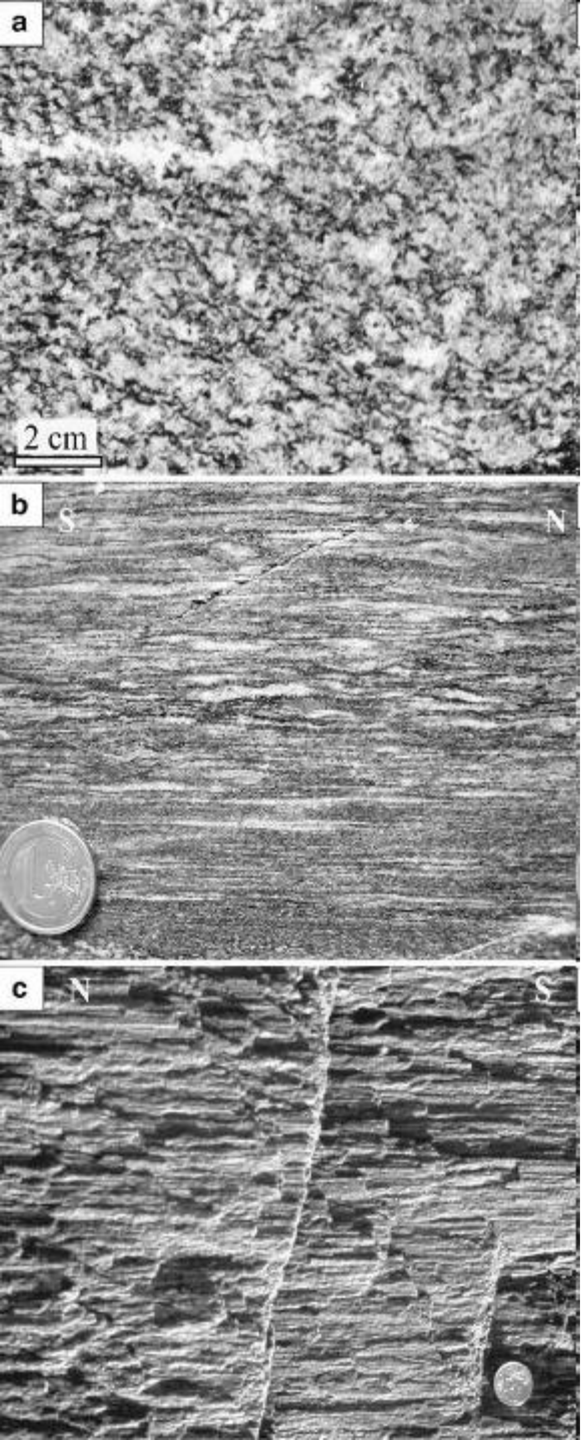


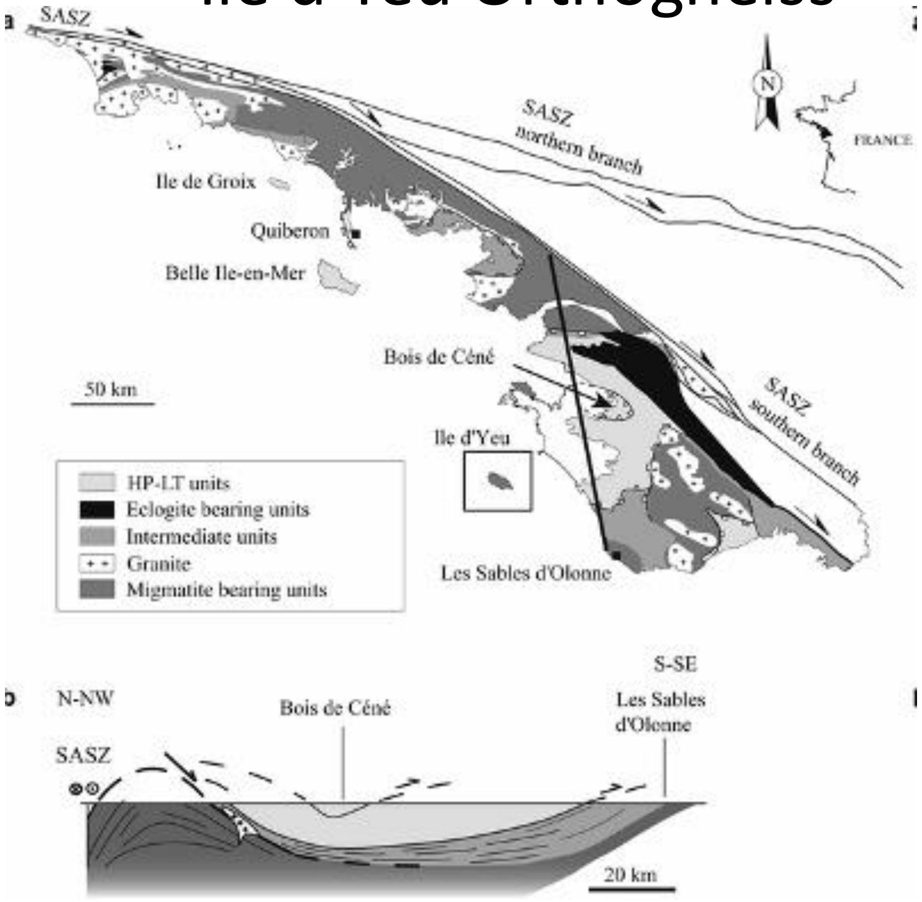


Sedimentary Protolith. Metamorphism of a pre-existing copper-stock.

From: Turlin et al. 2016

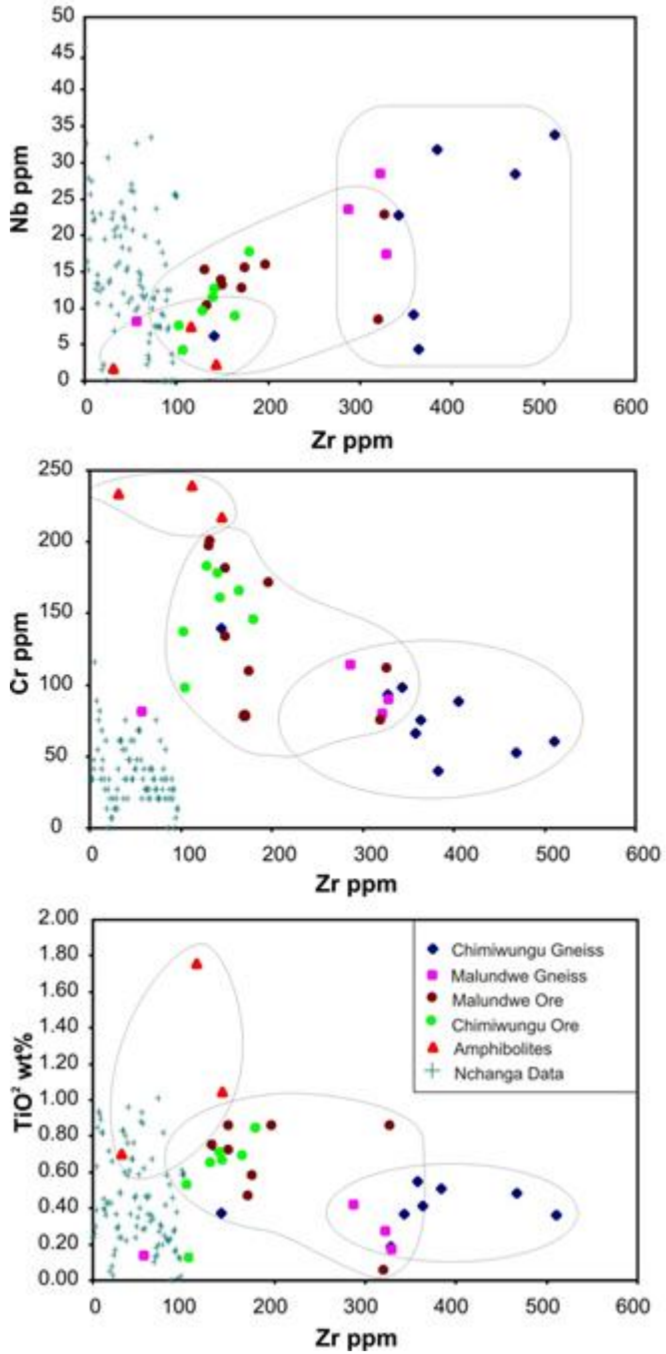
Ile d'Yeu Orthogneiss



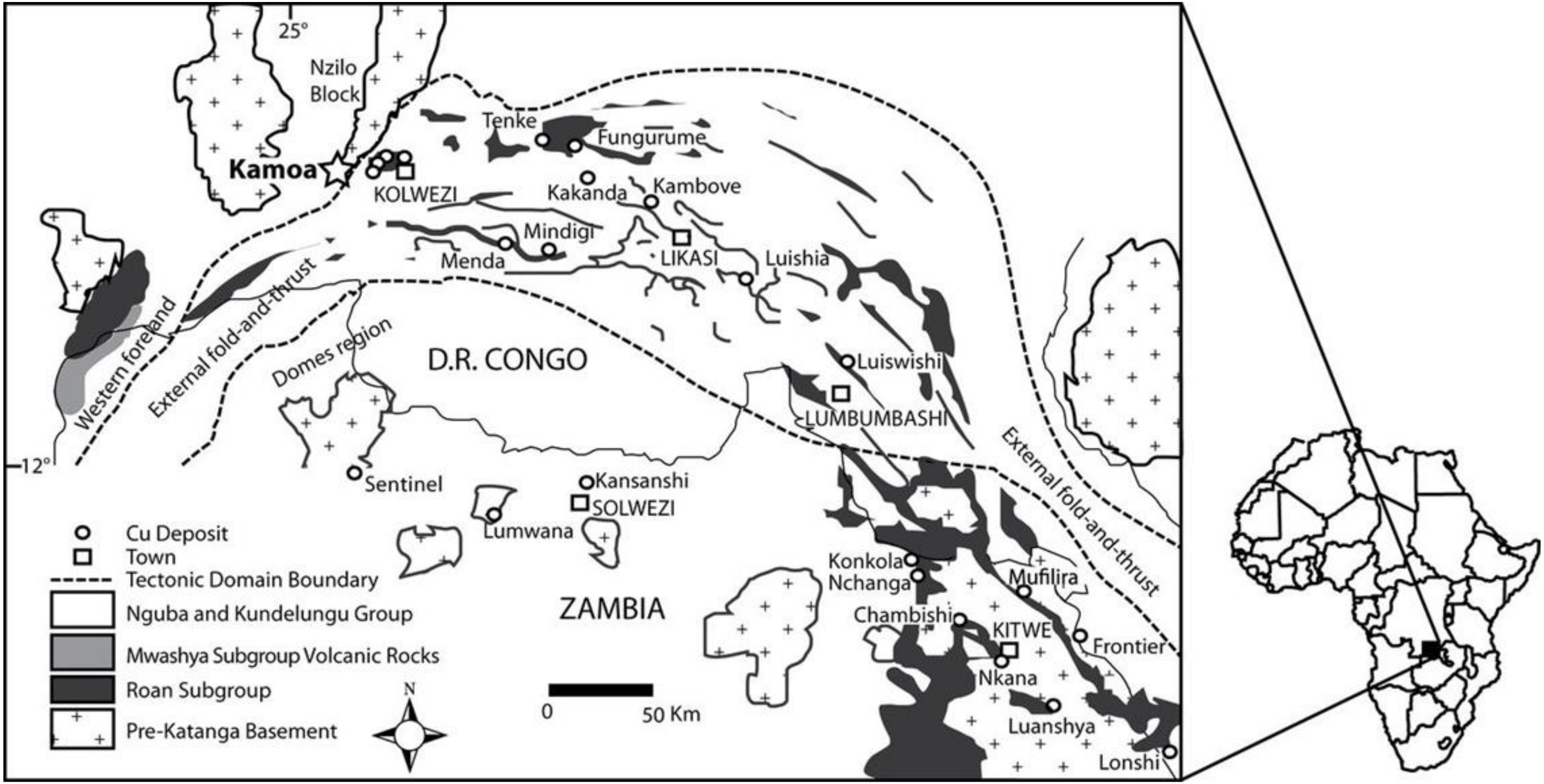


During shearing, extensive fluid channelling led to a change from a Qtz+Pl+Kfs+Bt±Ms mineralogy to more aluminous micaschist assemblages made of Bt+Ms+Qtz±Ky. Mass transfers record gains in H2O, K, Mg, P, Rb, W, Sn, and losses in Ca, Na, Sr and Pb.

From Sassier et al. 2006

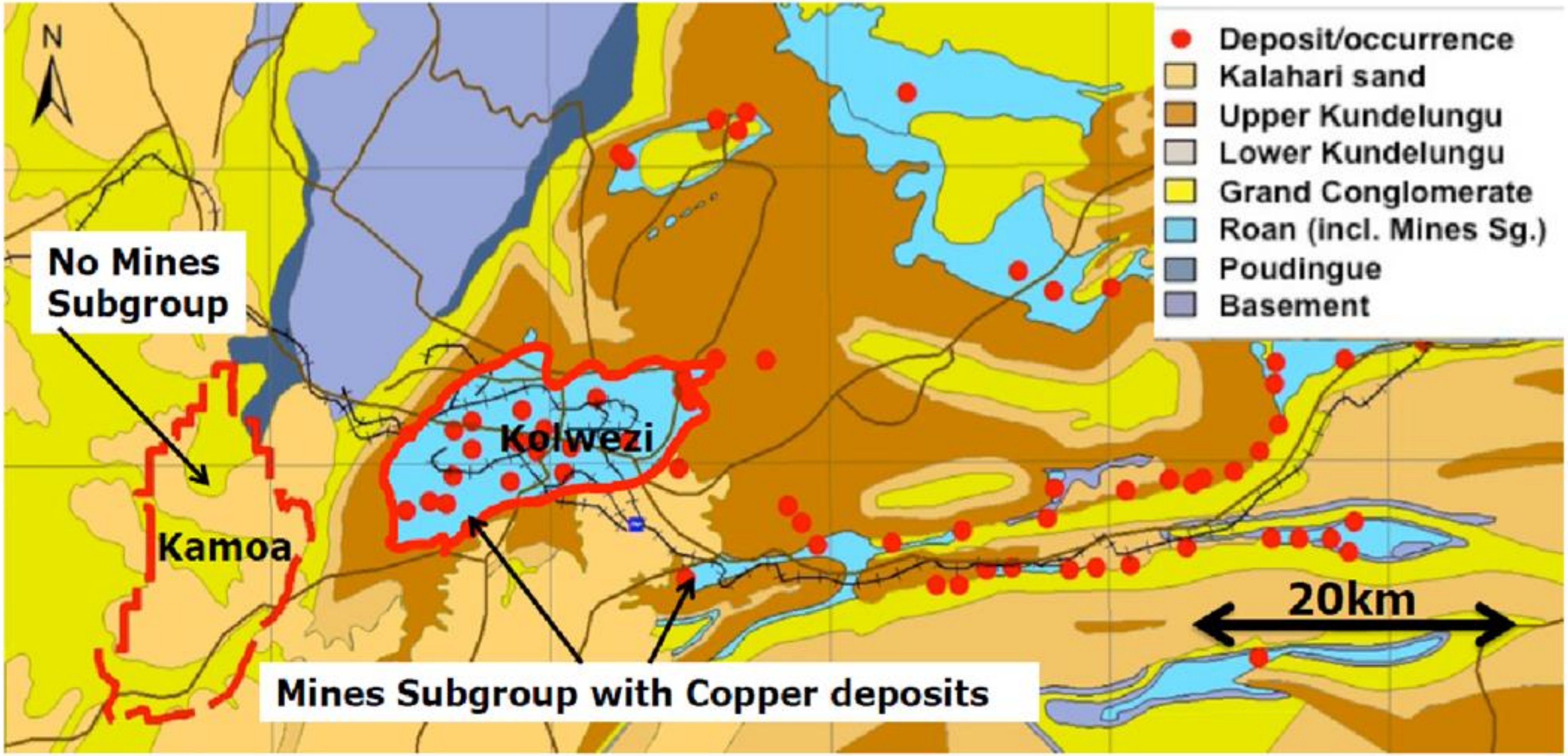


Kamoa – Democratic Republic of Congo



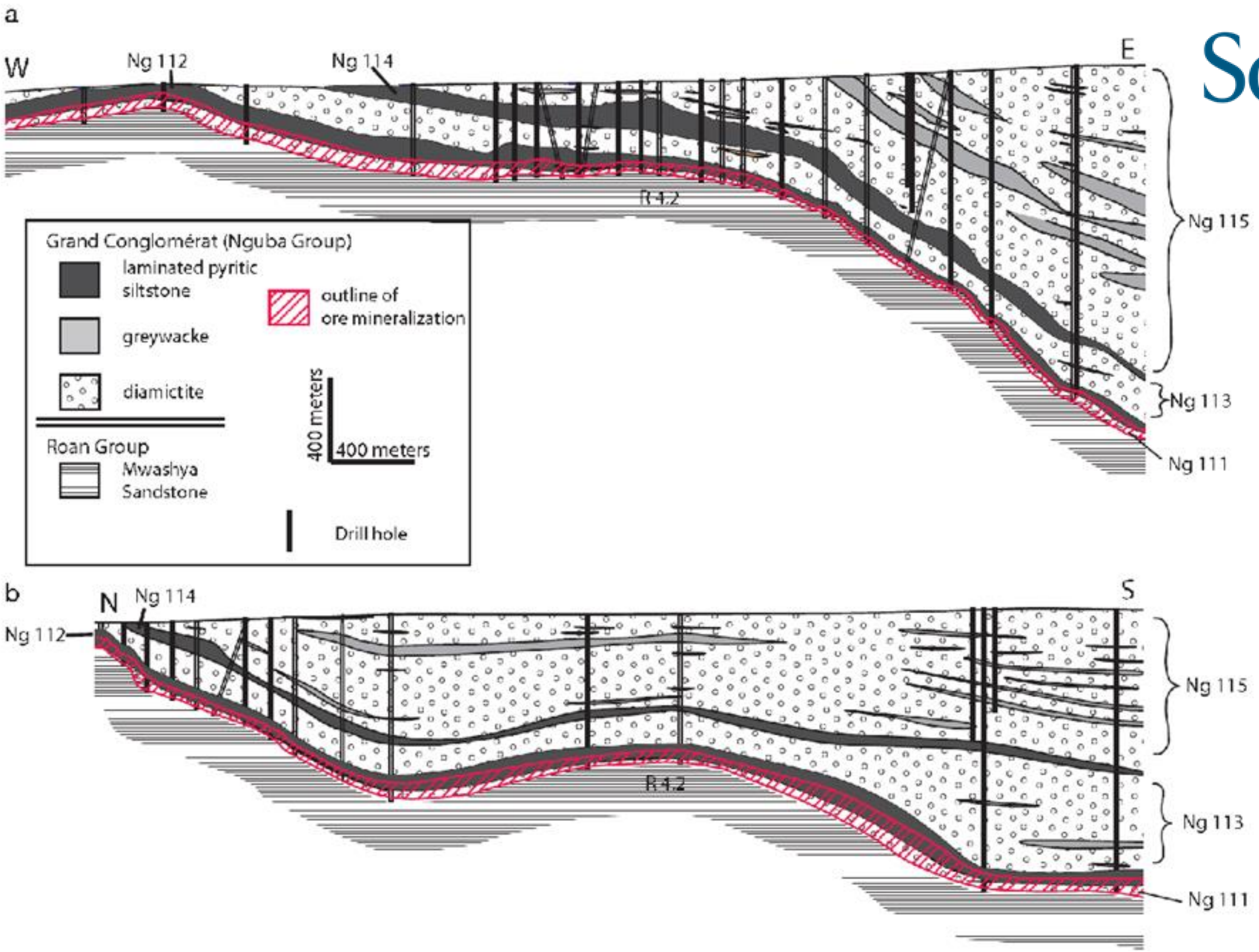
From Schmandt et al. 2013

Kamoa – Democratic Republic of Congo

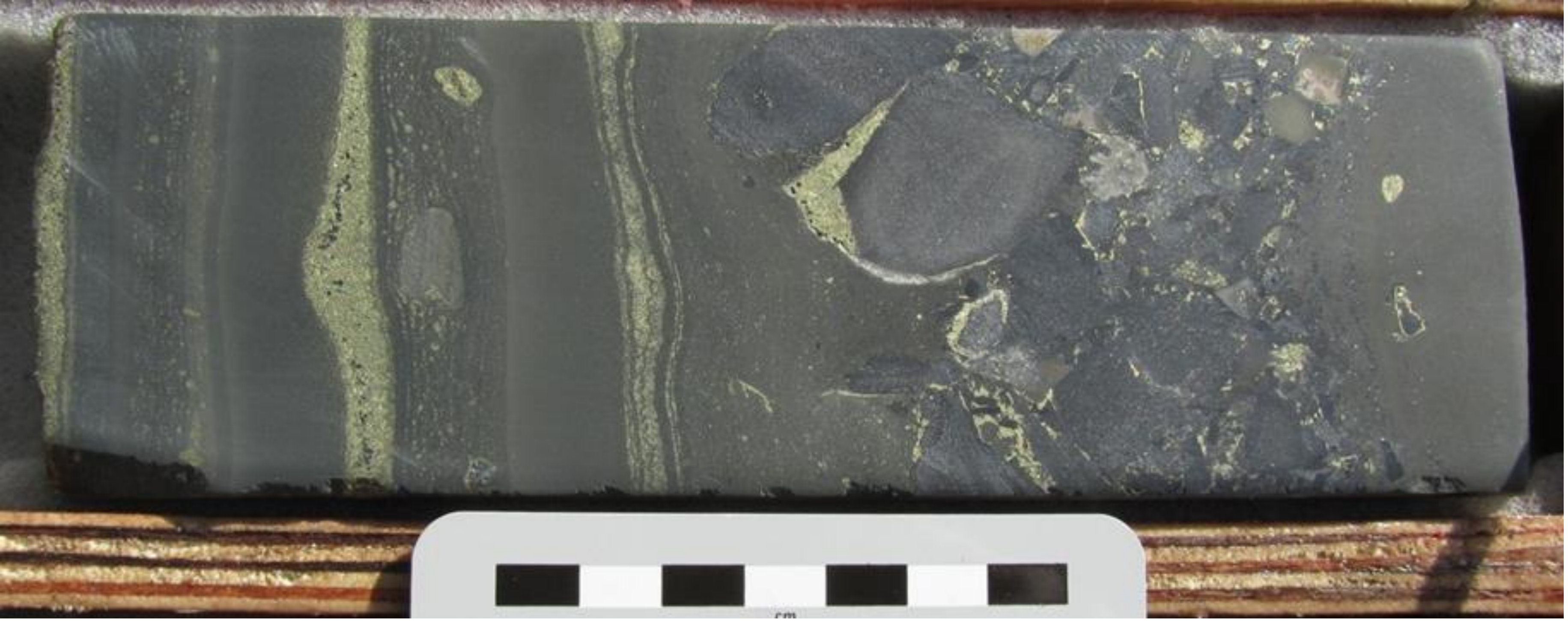


Kamoa area explored since early 1900s, but lacked “typical” Copperbelt indicators.

From Broughton 2013



From Schmandt et al. 2013



Kamoa
Mineralised
Diamictite

Timing of Mineralization

Two competing hypotheses for Zambian Copperbelt mineralisation:

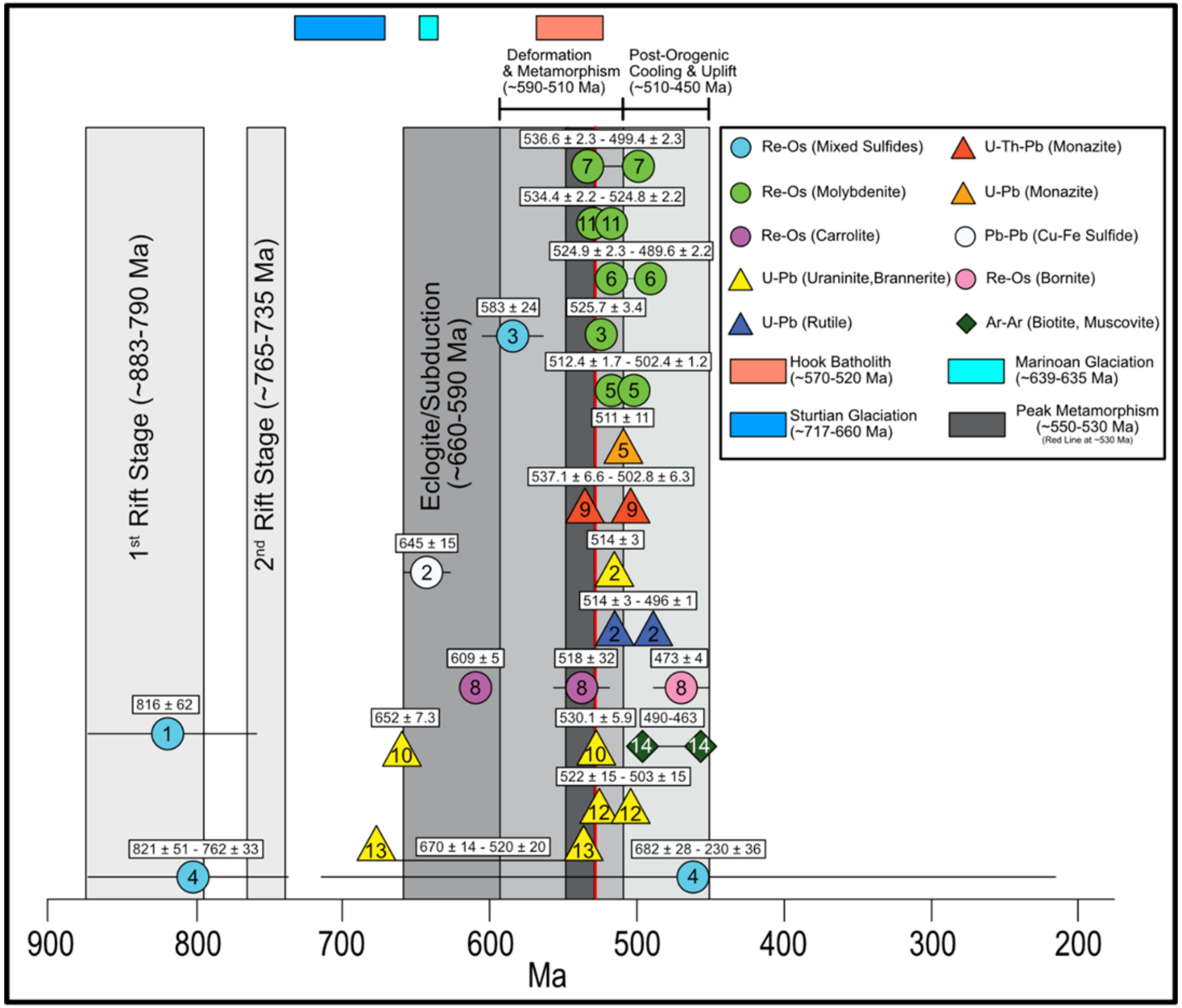
1. Multiphase, >300 Ma mineralisation from syndiagenesis-post-orogenesis
2. Restricted syn-post orogenic mineralisation related to the Lufilian Orogeny

- Re-Os mixed sulphide ages are older (816-790 Ma), considered to date diagenetic mineralization but are very high in error

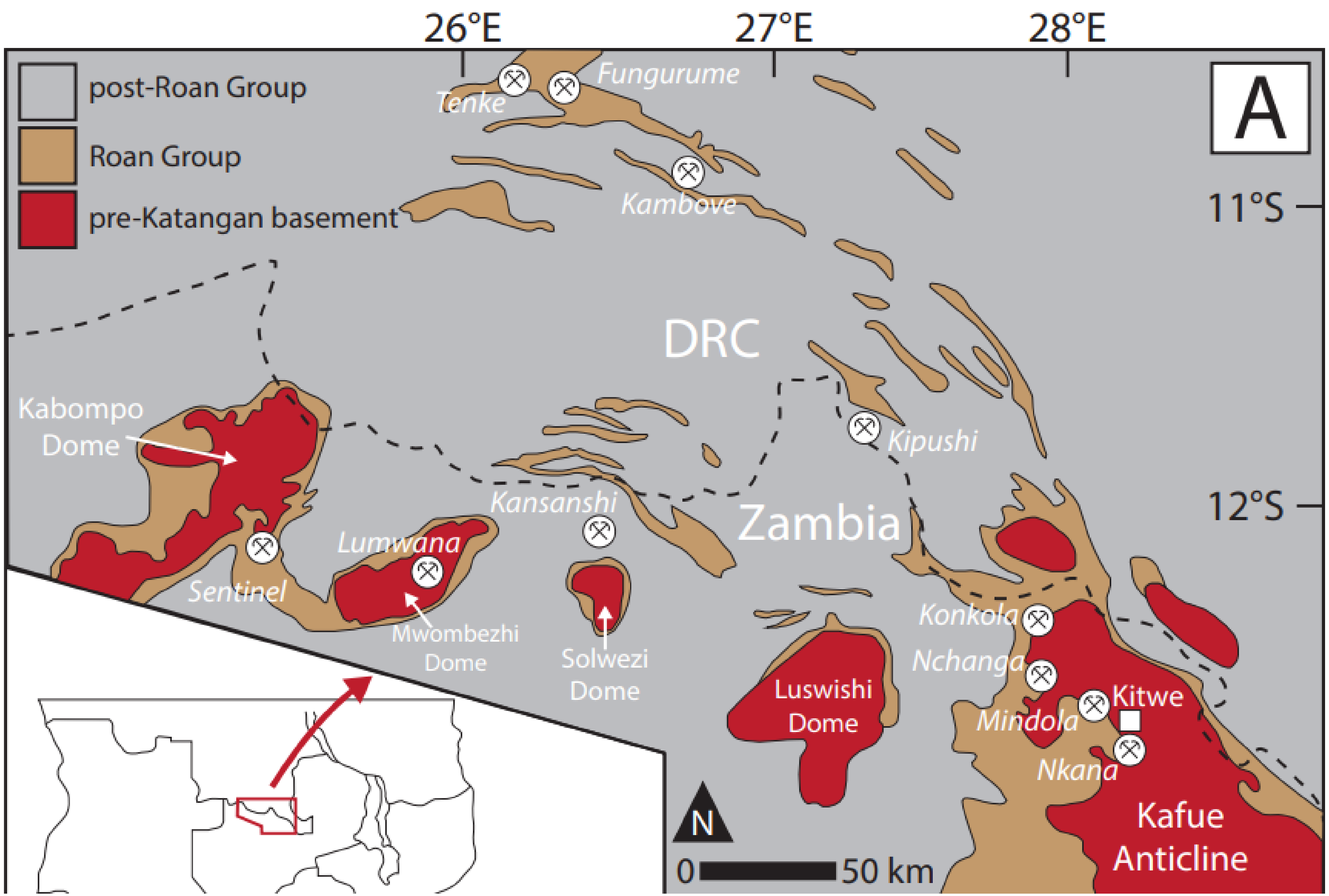
Molybdenite Re-Os ages fall in a cluster from 540-490 Ma. Considered syn-orogenic to post-orogenic timing.

- Uranium mineralization occurs at approximately 650 Ma, prior to the Lufilian Orogeny and potentially 1st Cu mineralization. Remobilisation occurs at ~530 Ma – Peak Metamorphism
- Carrollite Re-Os date at 609 ± 4 Ma suggests some Cu-Co mineralization predates the main Lufilian stage
- One rutile age dates late stage, 514 Ma post-orogenic mineralization in veins at Musoshi. No apatite or carbonate ages

Geochronology



Modified from Sillitoe et al. 2017

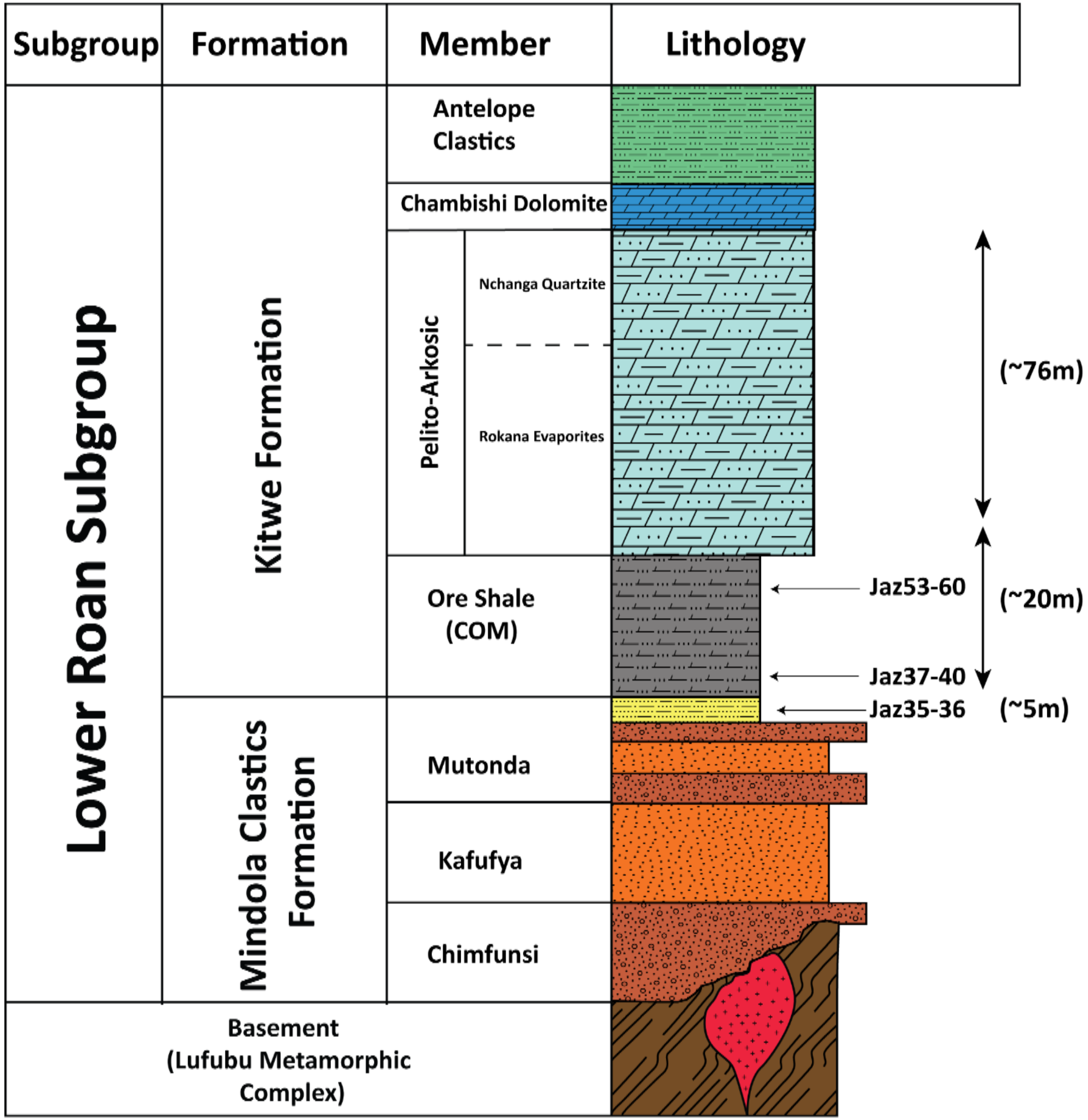


Mine Geology Locations

Nchanga
Kansanshi
Lumwana
Kamoa

Mindola

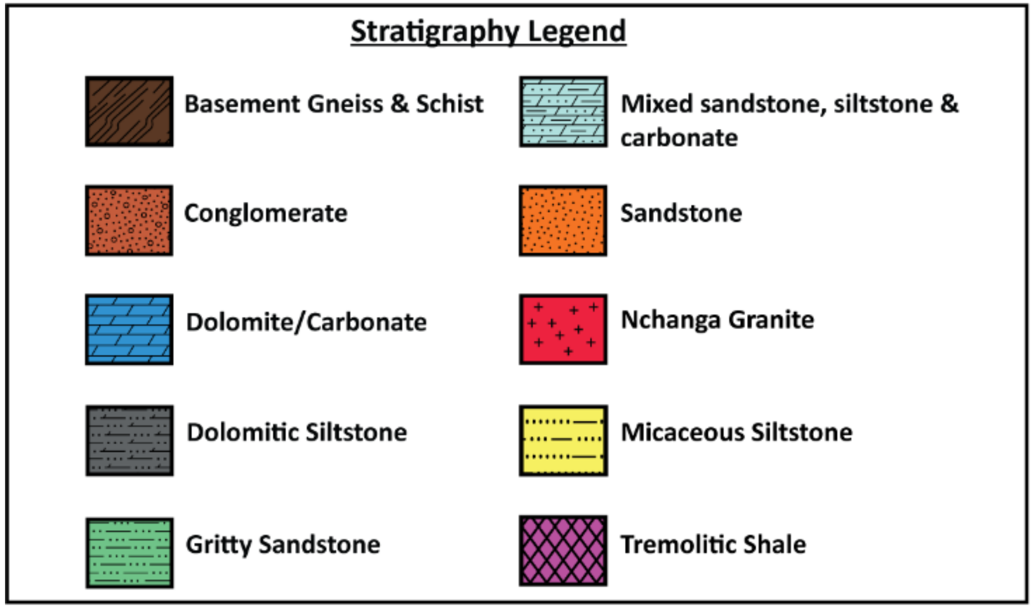
Location Map Deposits Investigated



Modified from Selley et al. 2005

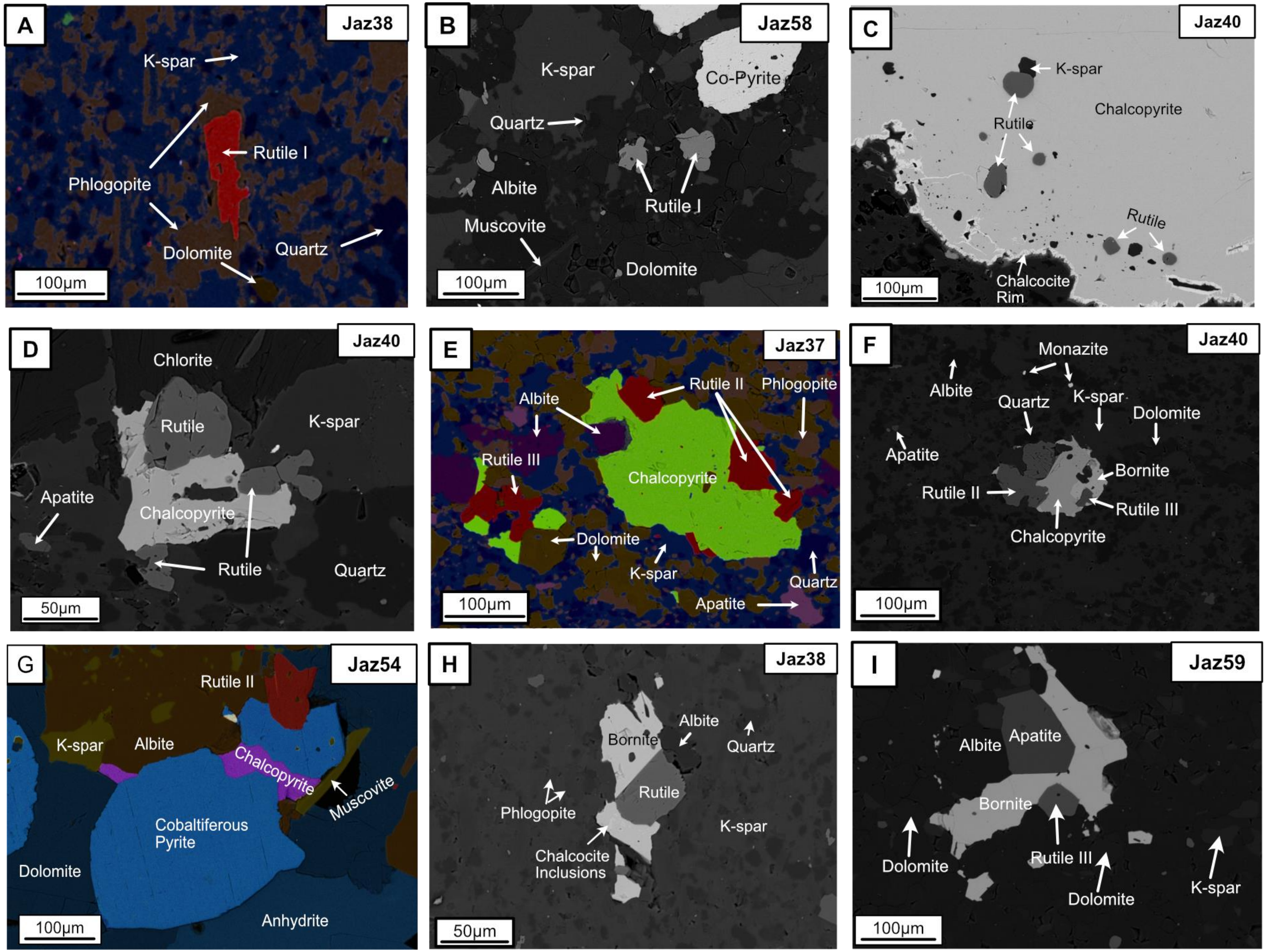
Mindola North Stratigraphy

- 12 Samples selected from mineralized Kitwe Formation metasediments
- Jaz35-36 = Micaceous Siltstones
- Jaz37-40 = Dolomitic Siltstones
- Jaz53-59 = Impure Dolomites
- Jaz55 & 56 = Quartz-Carbonate vein samples in impure dolomites
- Jaz60 – Anhydrite Conglomerate



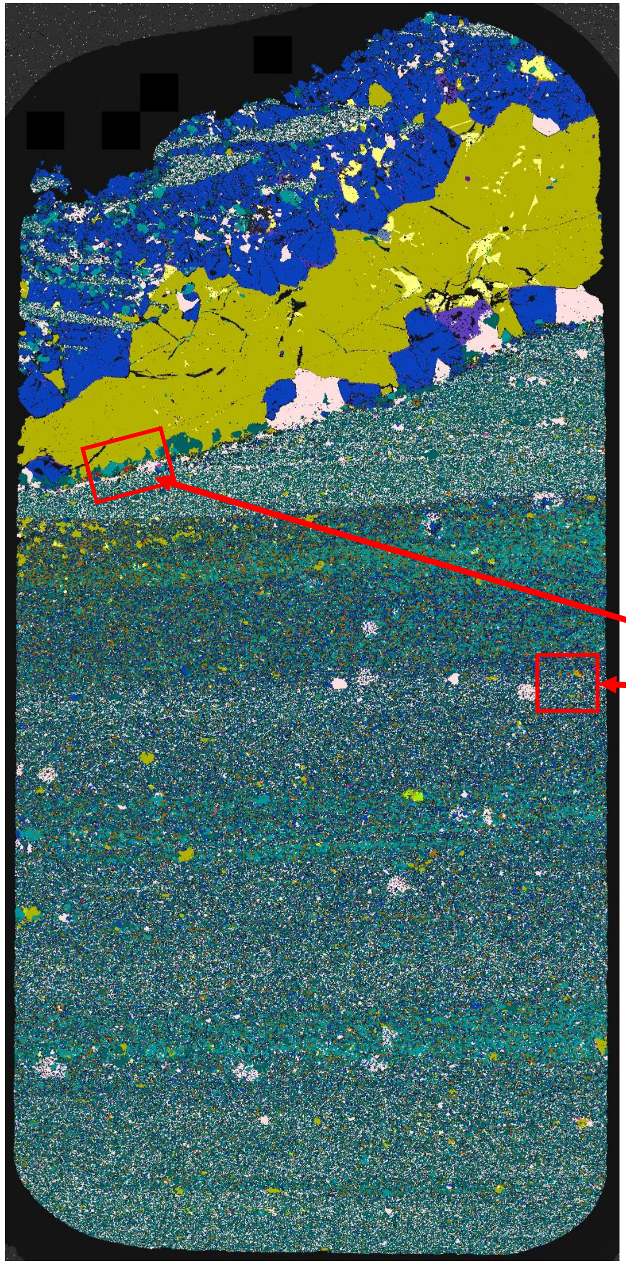
Rutile Textures

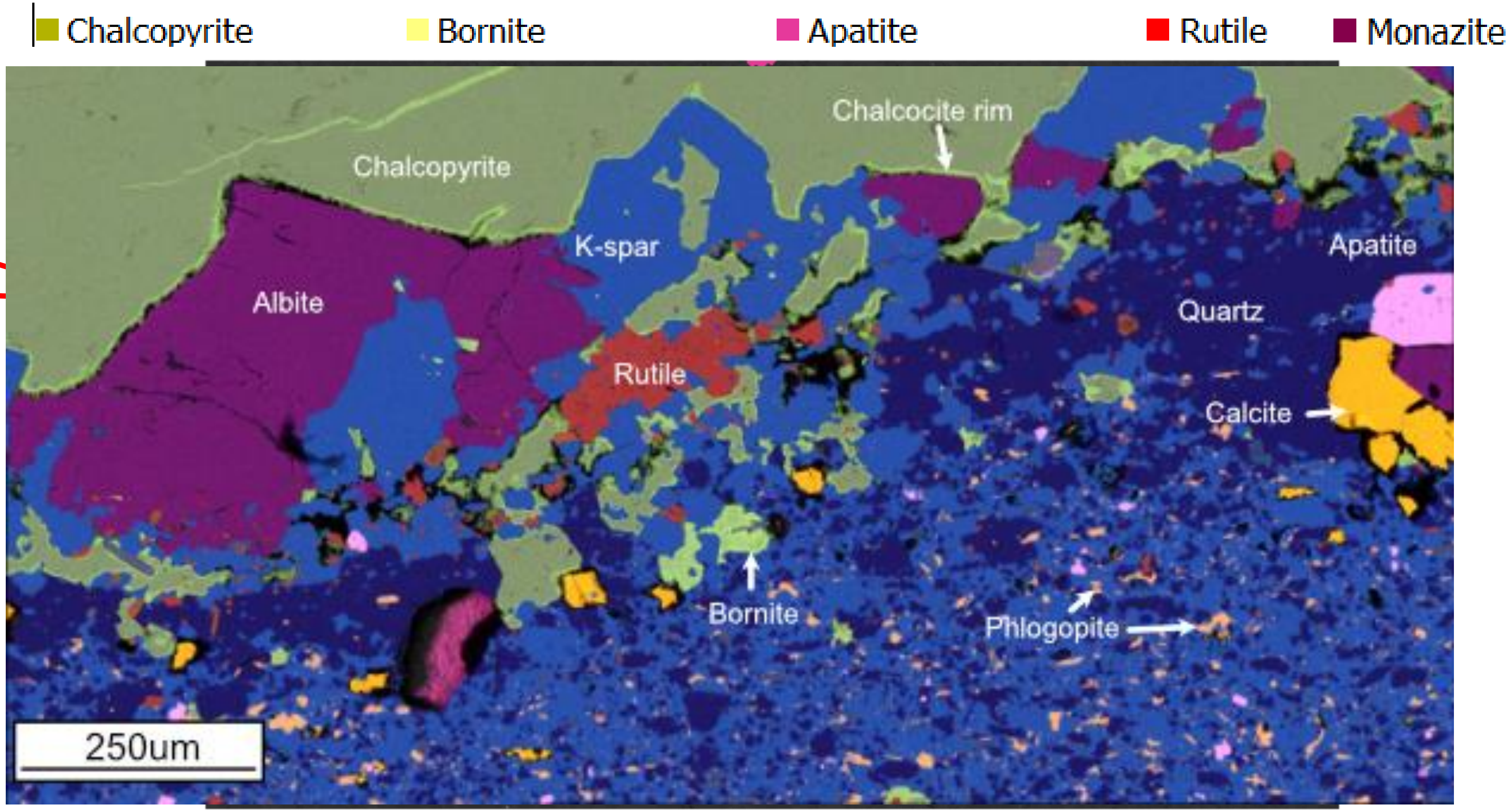
- Rutile 1 (A-B) = Isolated grains of rutile in the matrix
- Vein Rutile (C-D) = Rutile occurring at the margins and within pre-syn kinematic veins
- Rutile 2 (E-G) = Rutile forming mutual growth textures with sulphide
- Rutile 3 (H-I) = Rutile associated with bornite



TIMA Images – Jaz37a

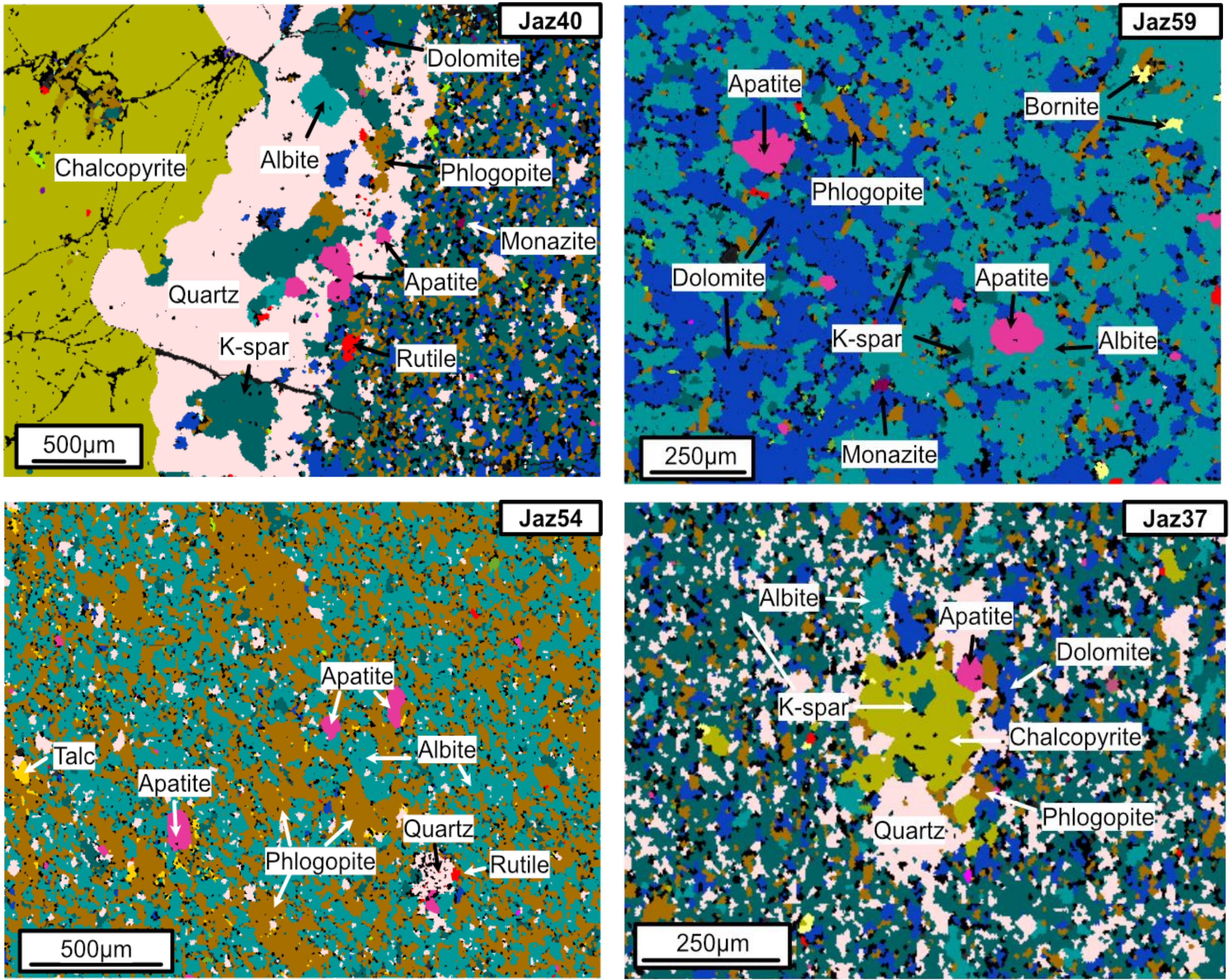
- **Rutile concentrated around pre-syn kinematic quartz-dolomite-feldspar veins**
- **Rutile intergrown with sulphides in the matrix**





Apatite Textures

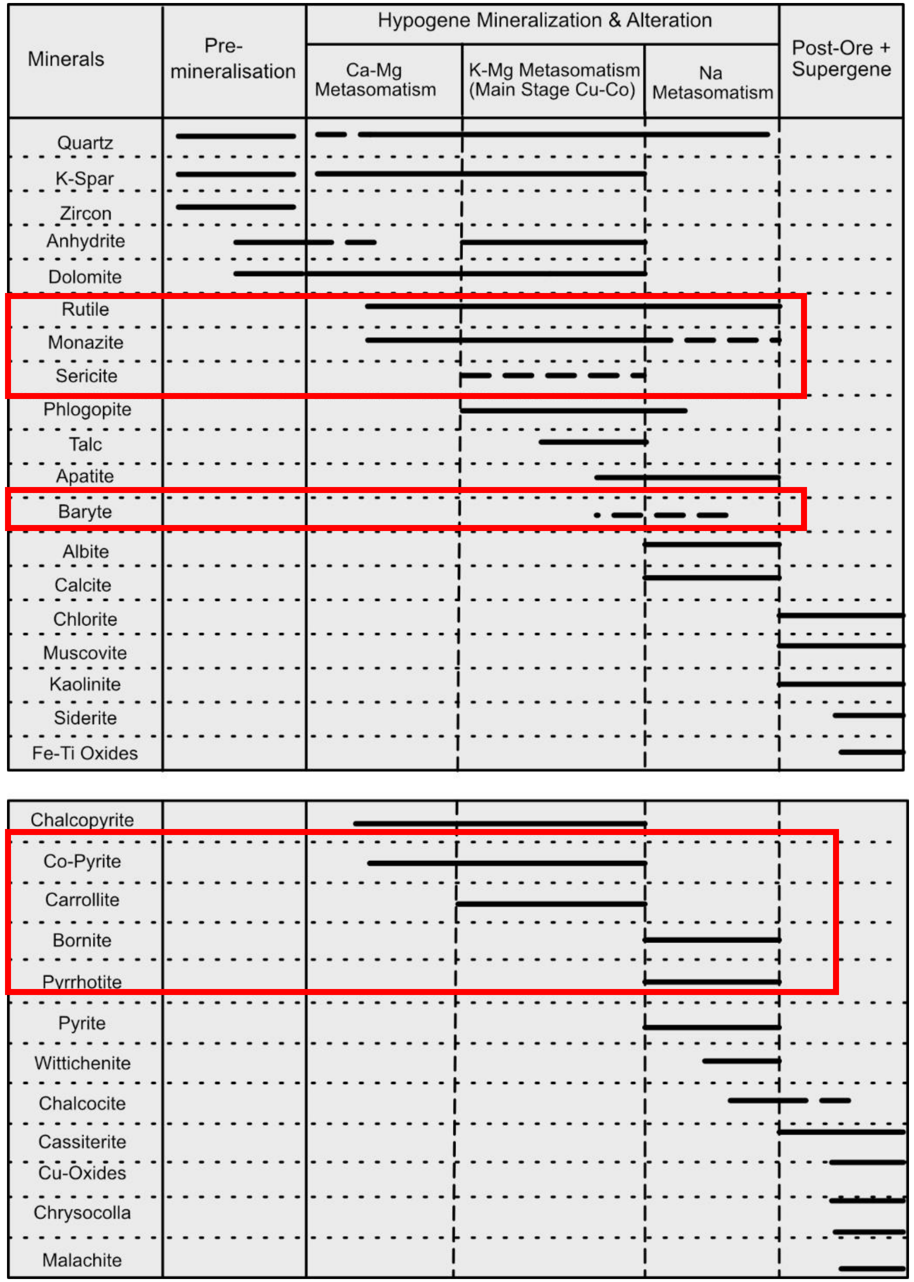
- Apatite found within vein margins
- Matrix apatite commonly associated with albite
- Rare apatite-chalcopyrite associations



Paragenesis

<u>Key Takeaways:</u>

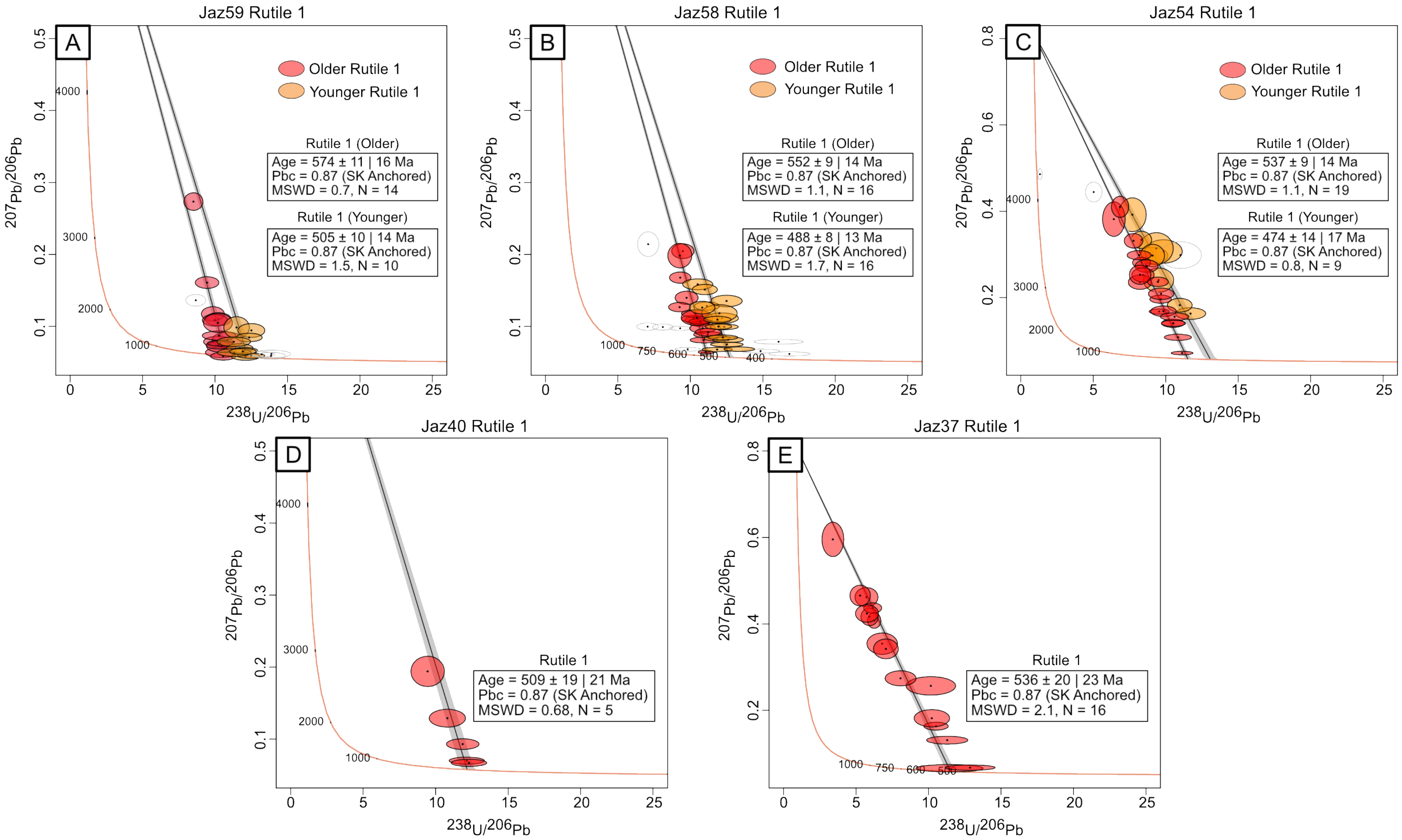
- Chalcopyrite-Pyrite-Carrollite-Chalcocite-Bornite sulphide paragenesis
- Rutile found intimately associated with sulphides in the matrix and in veins
- Apatite found in mineralized quartz-carbonate veins and increases in abundance in impure dolostones
- Extensive phlogopite in the matrix that forms around chalcopyrite
- Albite significantly increases in abundance moving up the stratigraphy at the expense of potassic phases
- Chalcopyrite found nucleating around monazites

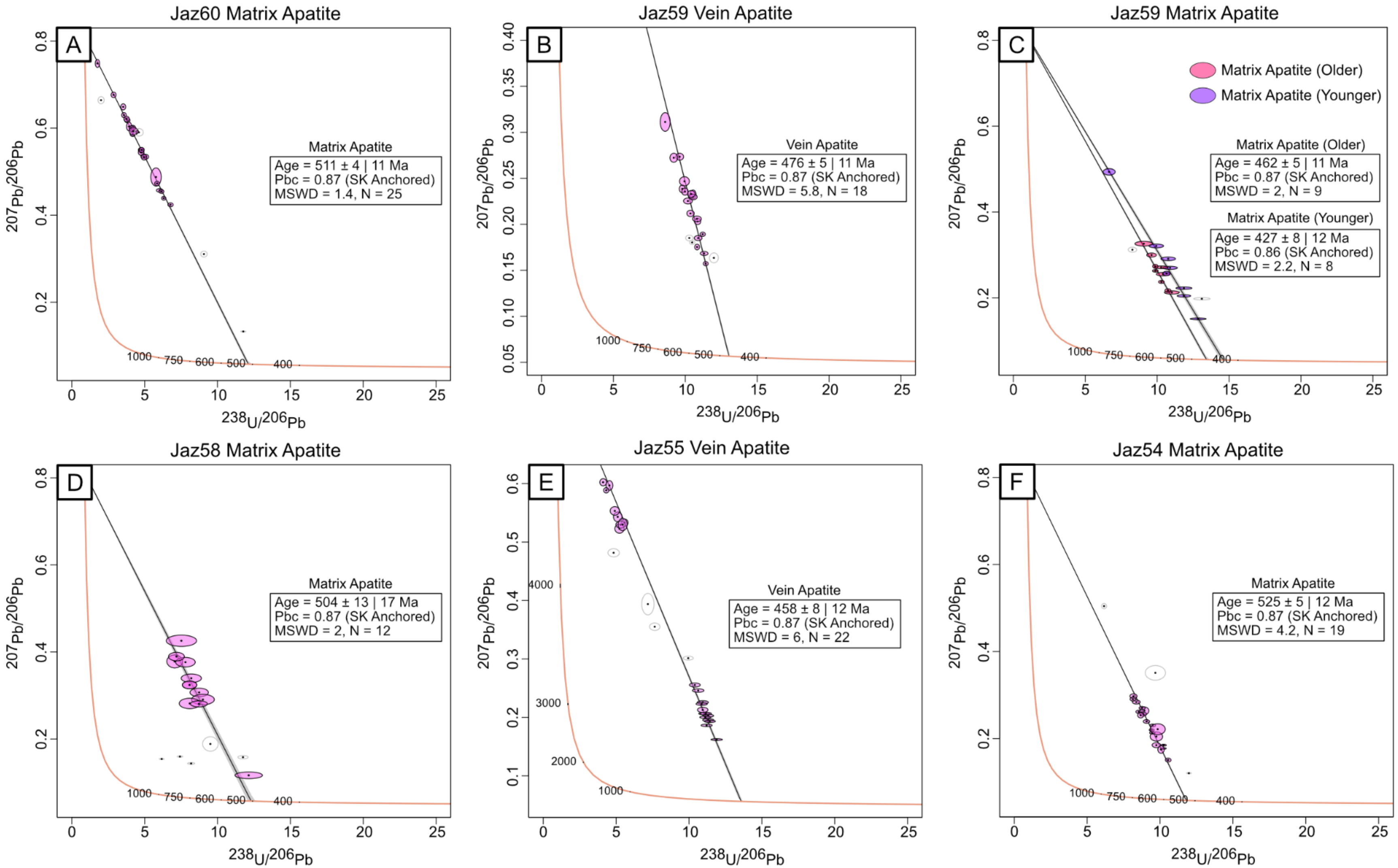


Rutile Isochrons

Rutile displays 3 data populations:

- Older trajectories:
  - 574 ± 11 Ma
  - 552 ± 9 Ma
- Middle trajectory:
  - 537 ± 9 Ma
  - 536 ± 20 Ma
- Younger trajectories:
  - 509 ± 19 Ma
  - 505 ± 10 Ma
  - 488 ± 8 Ma
  - 474 ± 14 Ma
- Older trajectory results align with pre-peak to peak metamorphism
- Middle trajectory aligns with peak metamorphism
- Younger trajectories align with post-orogenic cooling





Apatite Geochronology

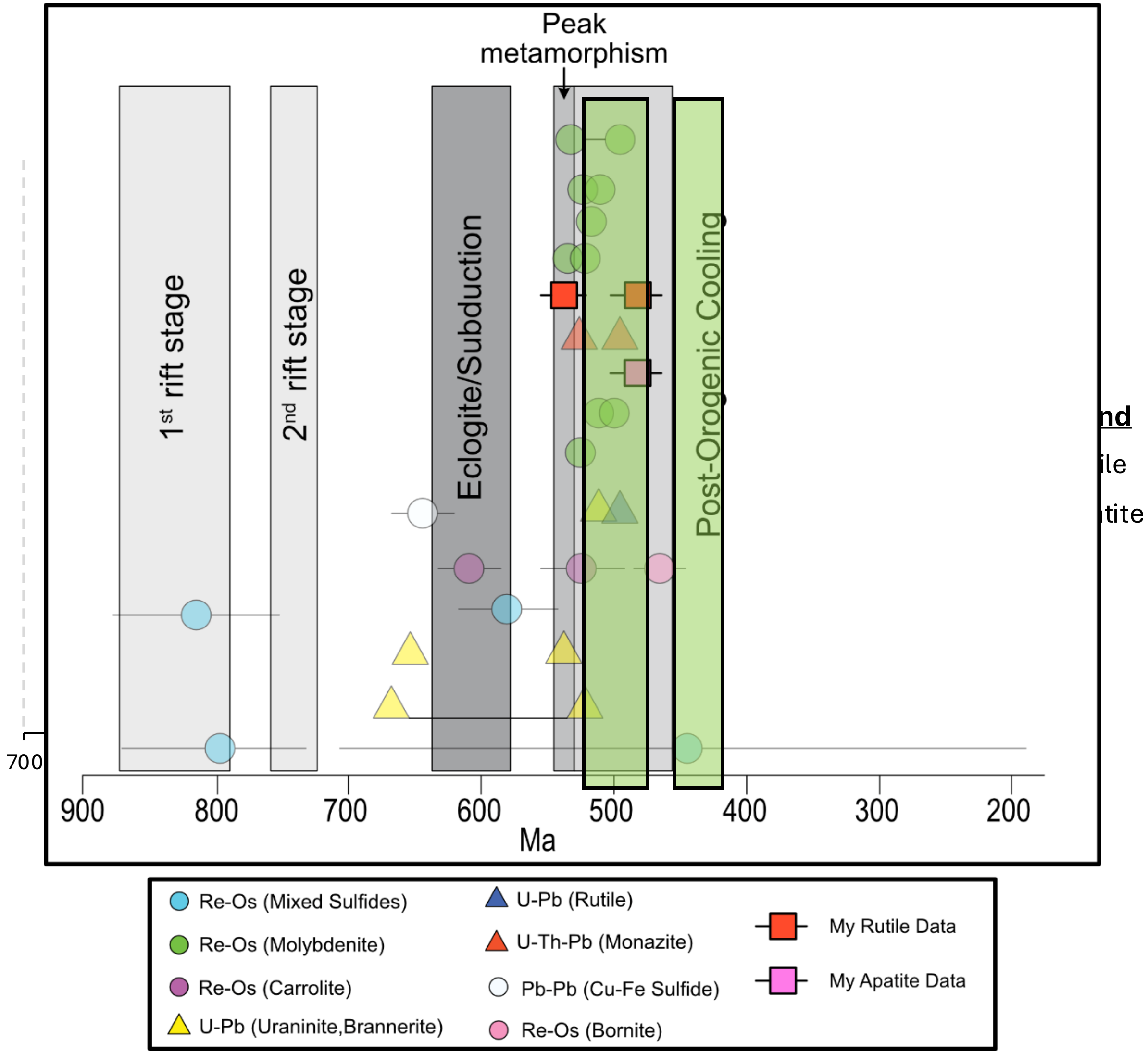
- Matrix Apatite isochrons range between ~525-460 Ma
- Vein-hosted apatite produces isochrons between ~460-480 Ma with 5-10 Ma uncertainties
- Dates confirm younger trajectories observed in rutile

Geochronology Summary

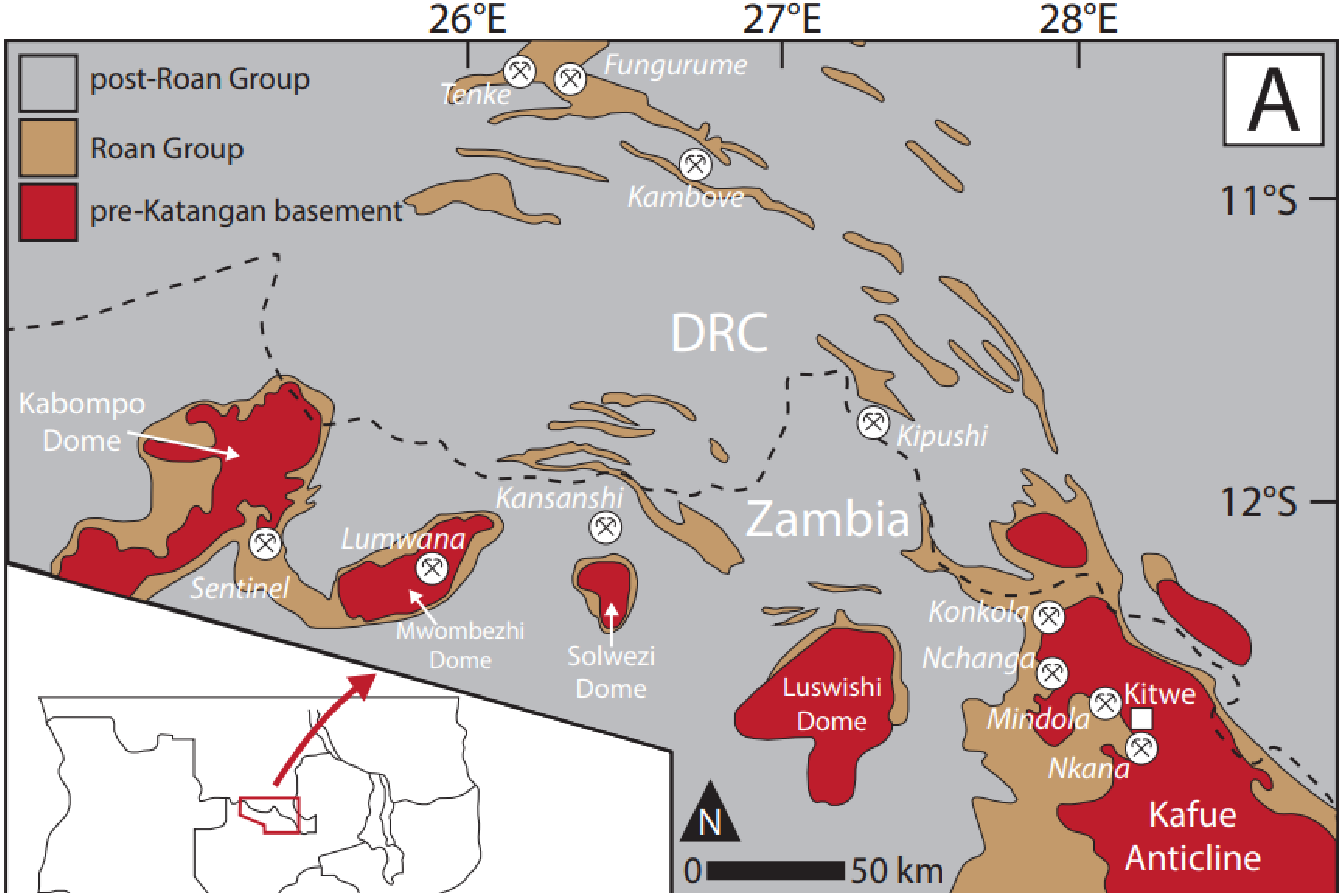
Two main data clusters

1. A ~520-570 Ma trend
2. Younger 460-490 Ma trend

- Rutile & K-Mg alteration likely begins prior to peak metamorphism
- 520-570 Ma trend supports previous geochronology by Re-Os molybdenite, overlaps with peak metamorphism in the ZCB and hook batholith emplacement
- Younger 470-490 Ma trend overlaps with post-orogenic uplift and previous Re-Os bornite
- Syn-orogenic and post-orogenic events spanning ~ 100 Ma
- No syndiagenetic or reliable >600 Ma ages obtained

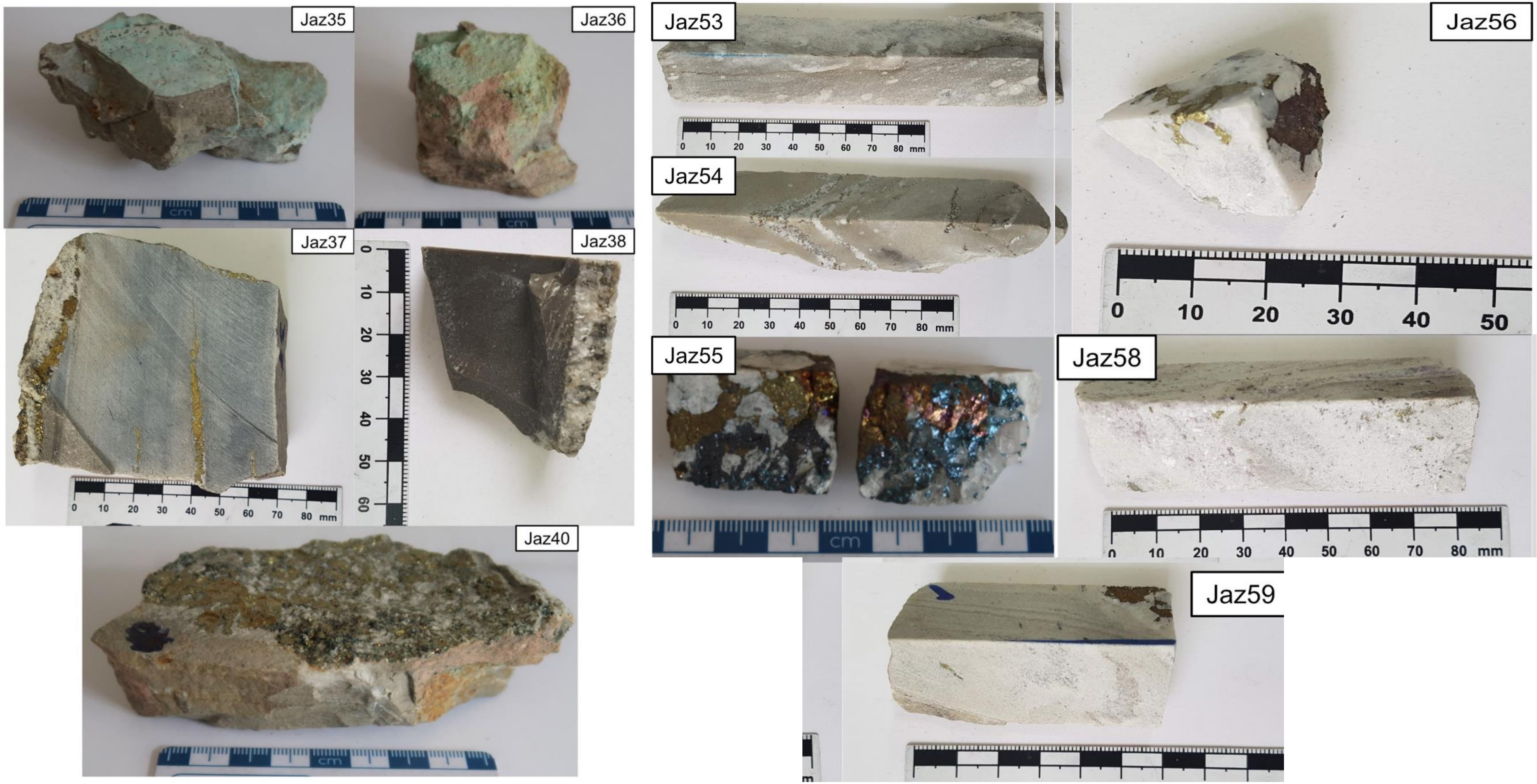


Characterisation of Basinal Brines

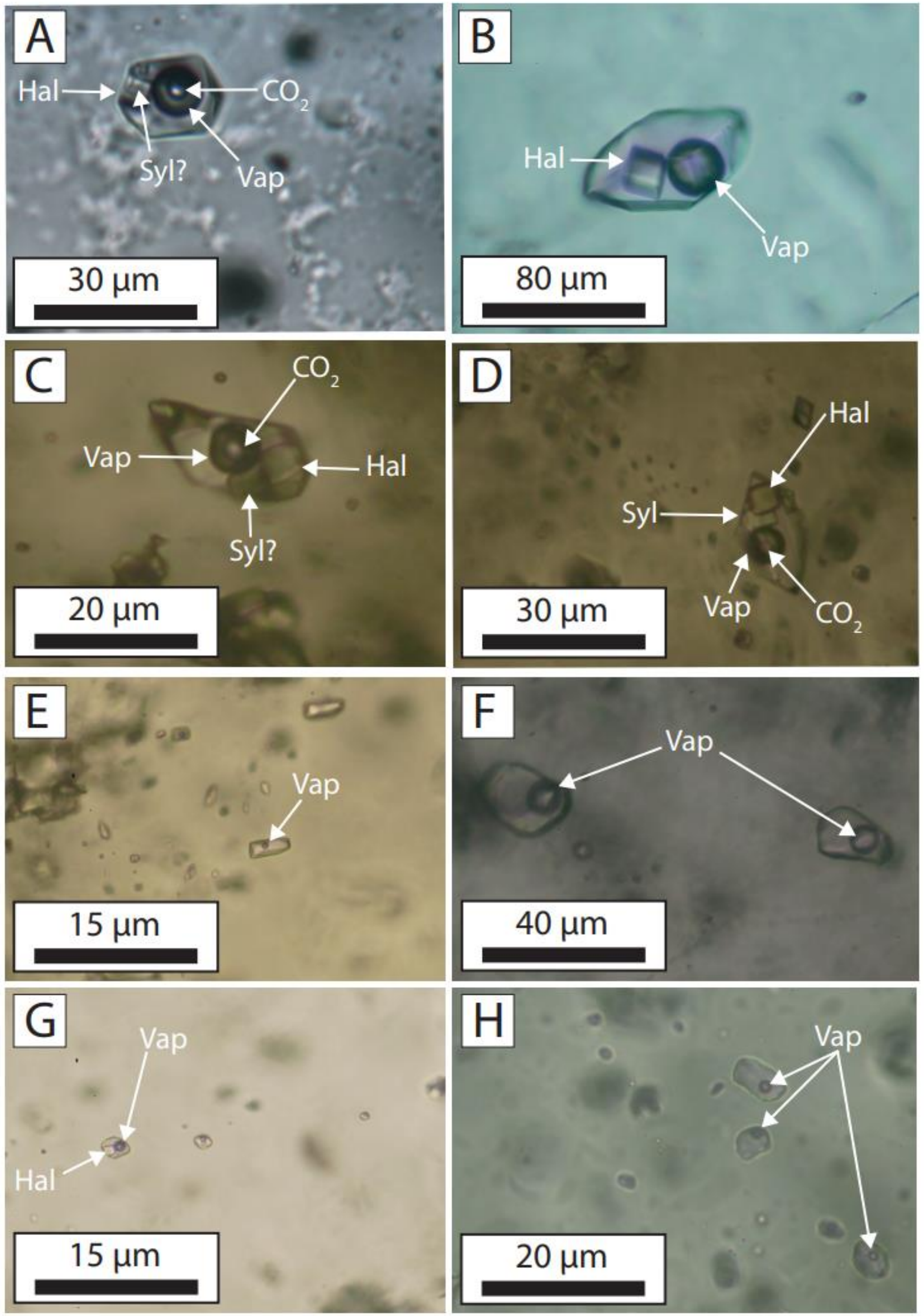


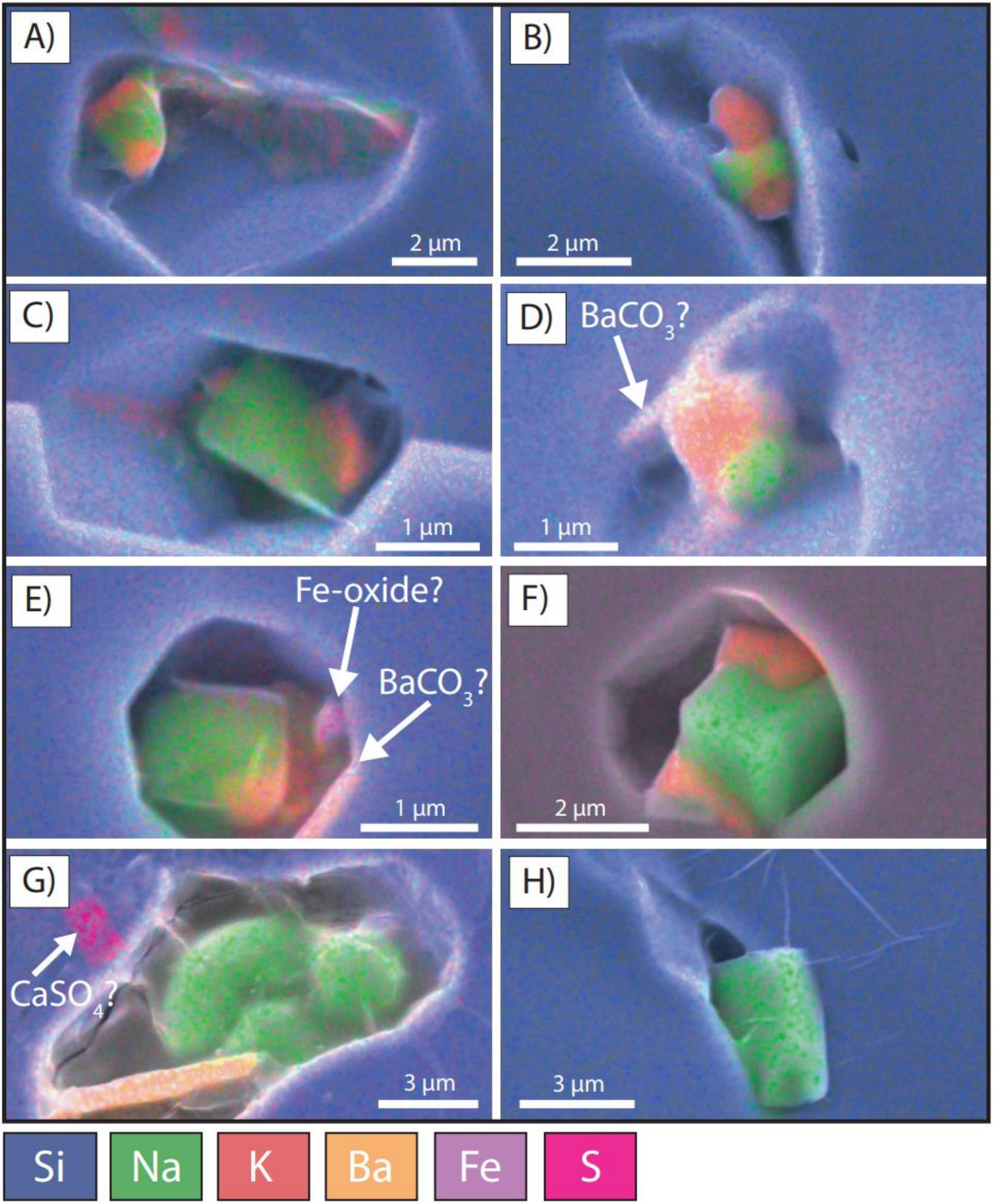
Nkana-Mindola
Nchanga
Lumwana

Location Map Deposits Investigated


Jaz35
Jaz36
Jaz37
Jaz38
Jaz40
Jaz53
Jaz54
Jaz55
Jaz56
Jaz58
Jaz59


A)
6 cm
B)
20 cm
C)
80 cm
D)
80 cm
E)
5 cm
F)
6 cm


A
Hal
CO_2
Syl?
Vap
30 µm
B
Hal
Vap
80 µm
C
CO_2
Vap
Hal
Syl?
20 µm
D
Hal
Syl
Vap
CO_2
30 µm
E
Vap
15 µm
F
Vap
40 µm
G
Vap
Hal
15 µm
H
Vap
20 µm



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SEM Images of complex multi-phase daughter phases within fluid inclusions.

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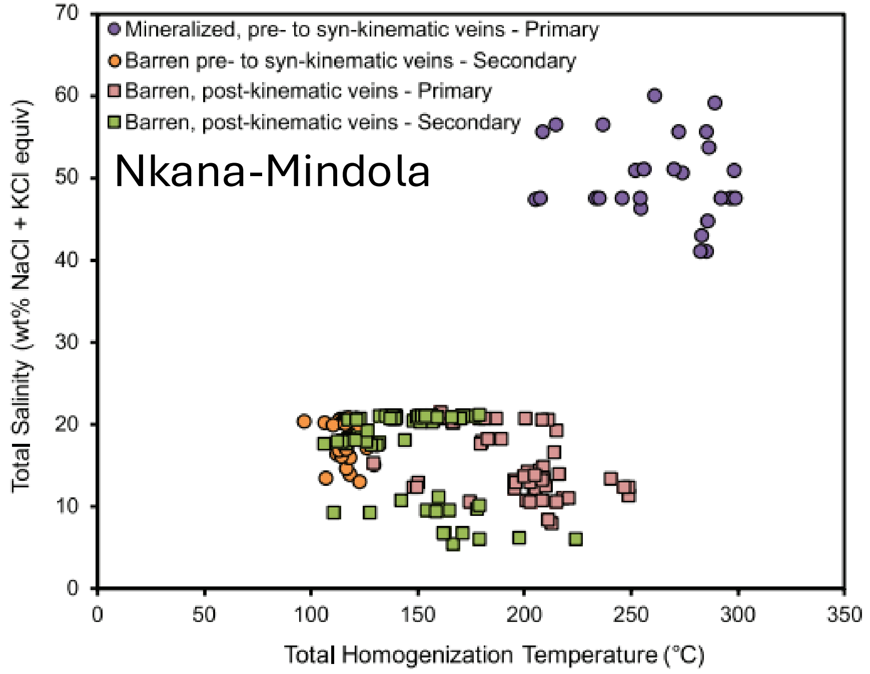
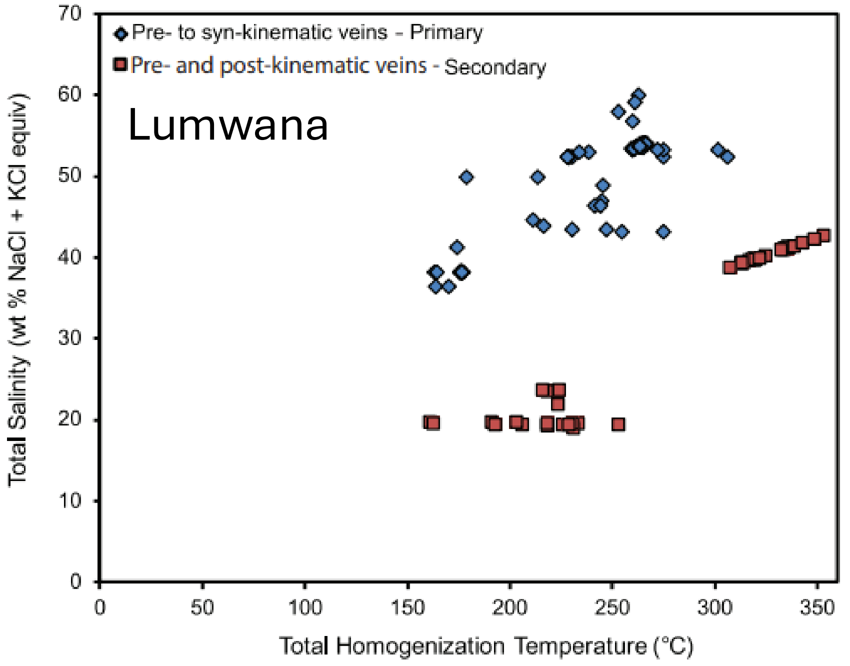
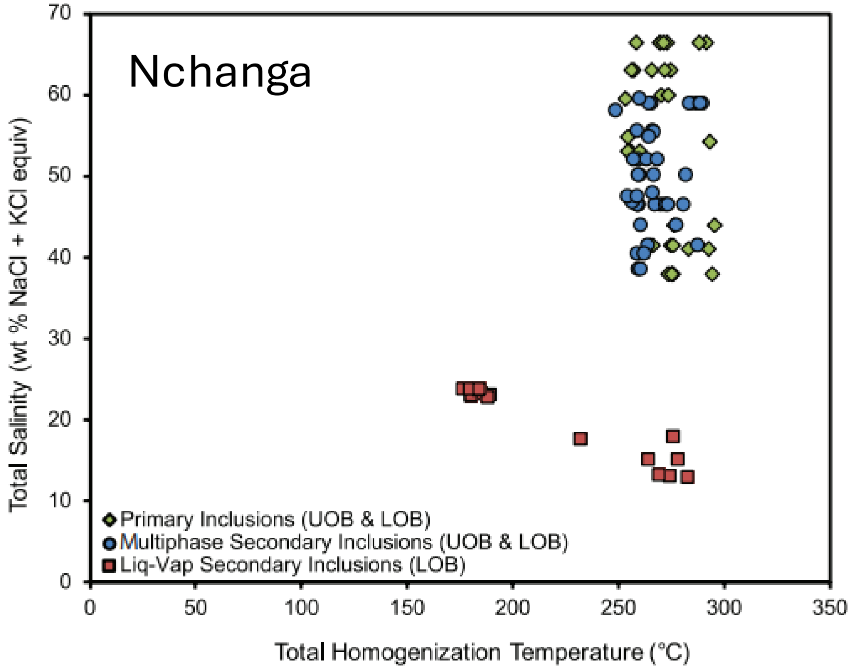
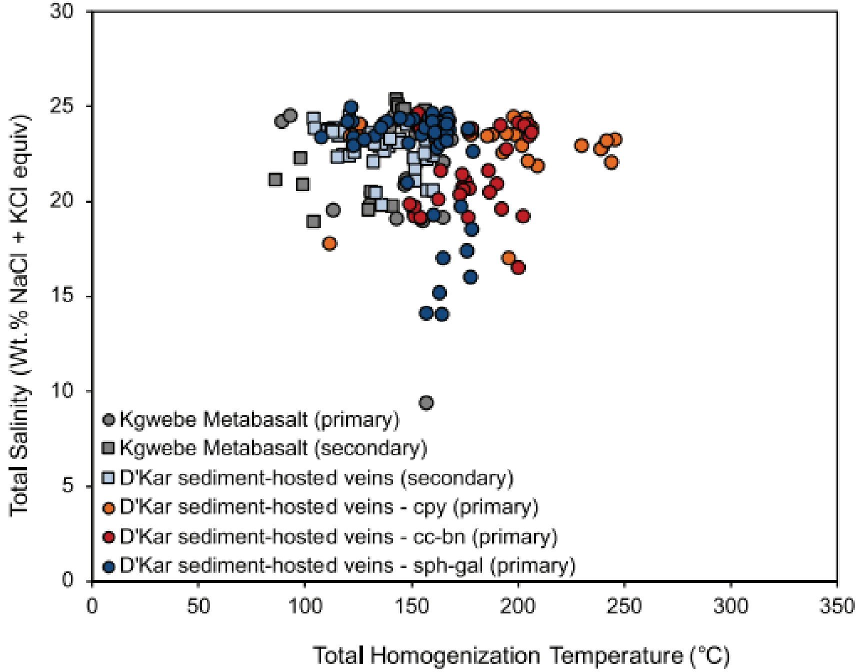


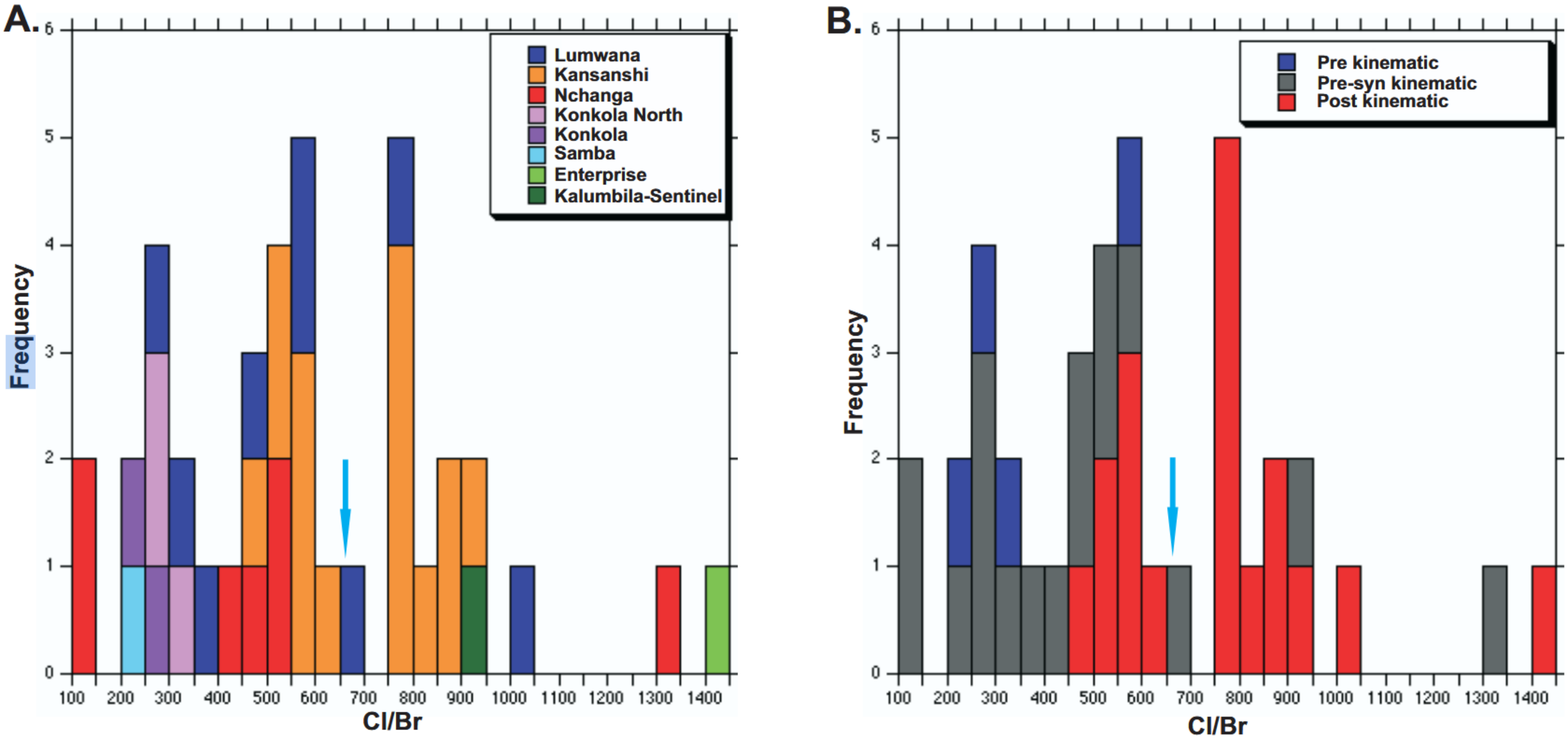


Microthermometric Data





Cl/Br Ratios Crush-Leach Fluid Inclusion - Data Zambia Copperbelt



Seawater Evaporation v Halite Dissolution

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Laser Ablation Fluid Inclusion Analyses I

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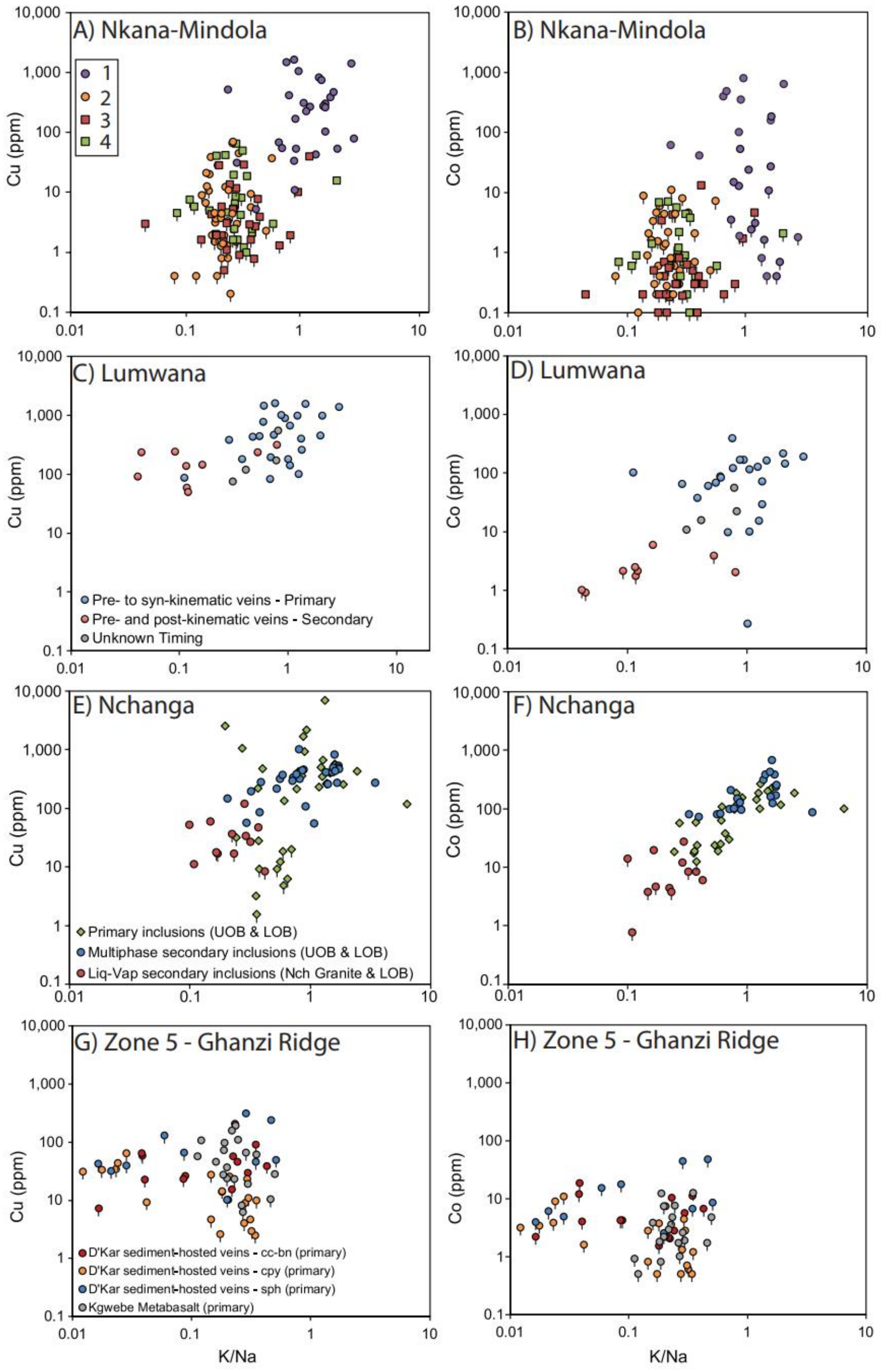
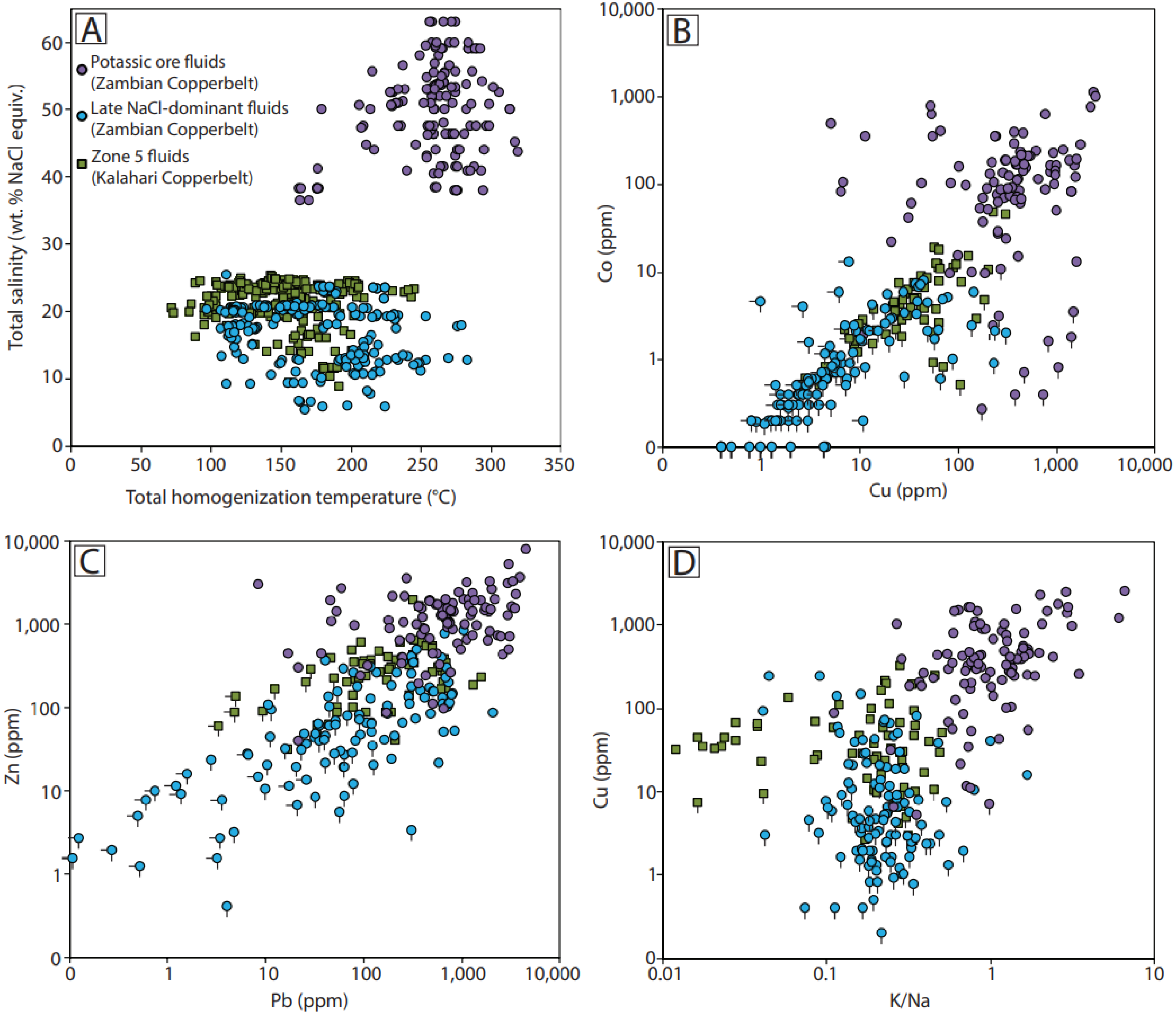
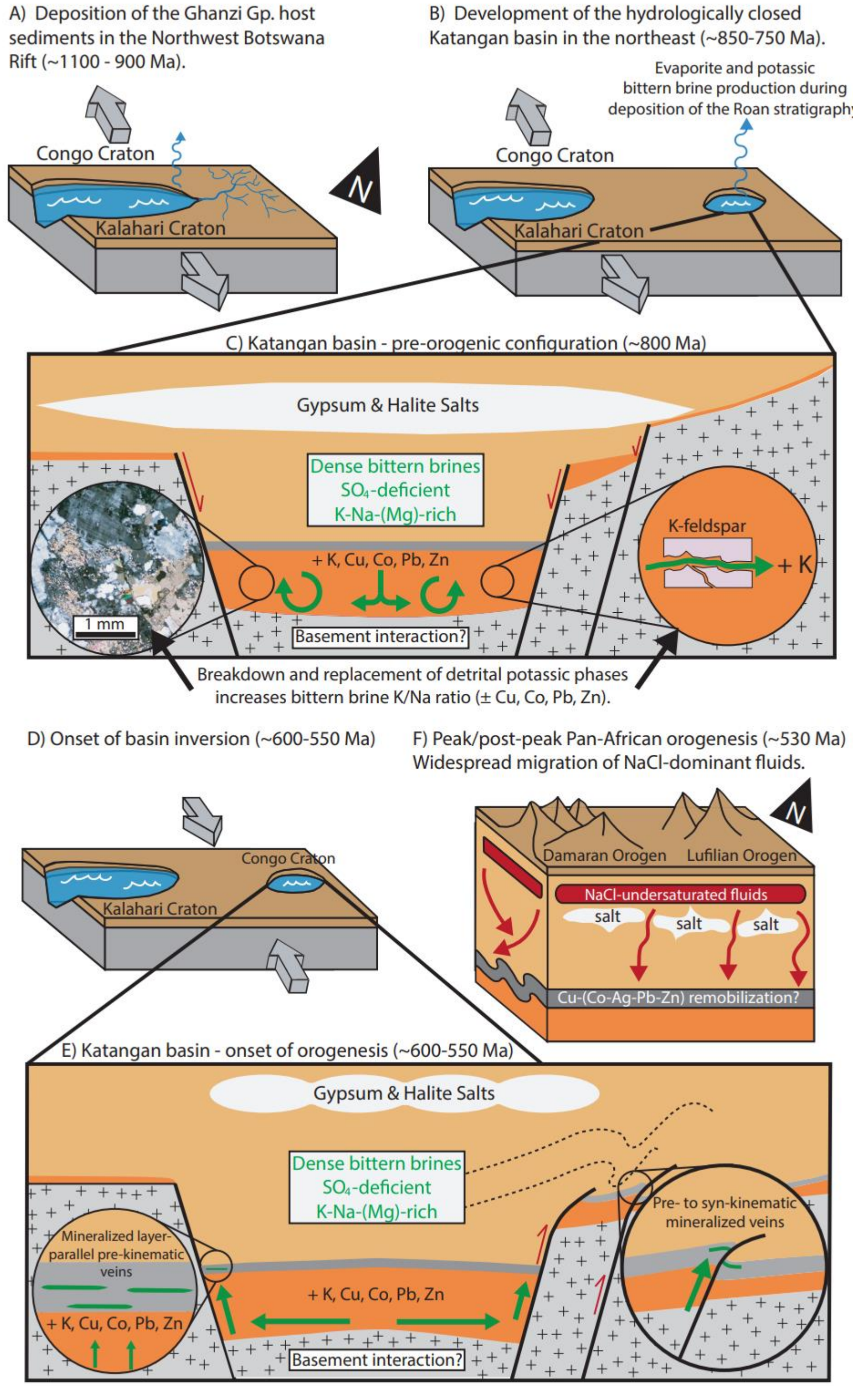
London Centre for Ore Deposits and Exploration



K/Na v Cu – Co ppm

Laser Ablation Fluid Inclusion Analyses II





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Time Tectonics and Brine

Time: 300 Ma Basin, with inversion well characterized by various geochronometers

Tectonics: Inversion structures to basement shear zones to late faulting all contribute to variable ore deposit characteristics

Brine: Early pre-syn orogenic vein formation characterized by hot-high salinity brines,