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Harare, 26 November 2021



Detrital zircon geochronological data bearing on the reconstruction of the late Mesoproterozoic Umkondo-Ritscherflya foreland basin (Zimbabwe/Antarctica)

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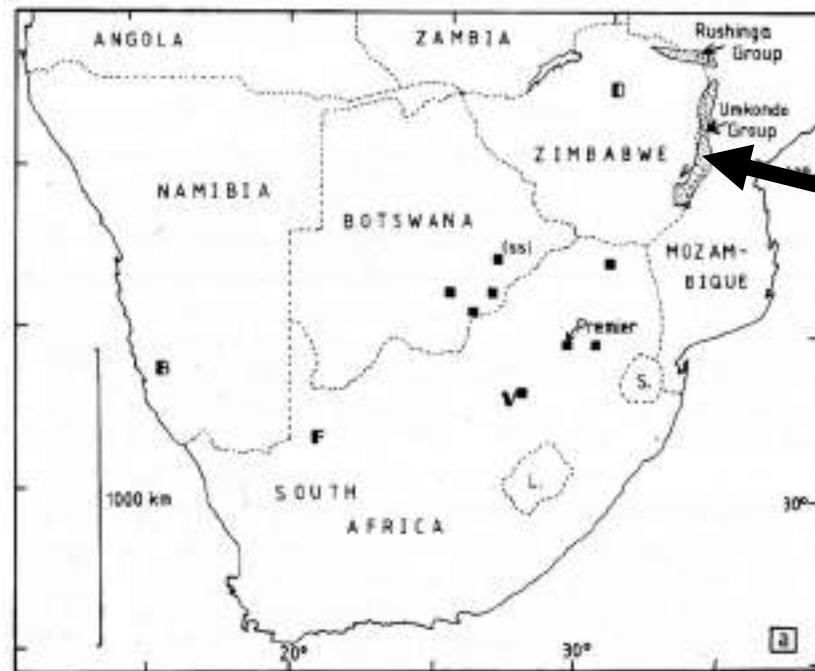


Figure 1 Sampling localities for igneous formations in southern Africa which have yielded Umkondo-type magnetization directions (a) and the corresponding pole positions (b). S: Swaziland, L: Lesotho. Some of the Umkondo dolerite and lava sampling sites are shown in Figure 2.

Umkondo Group

Jones & Kramers (1989)/ SAJG

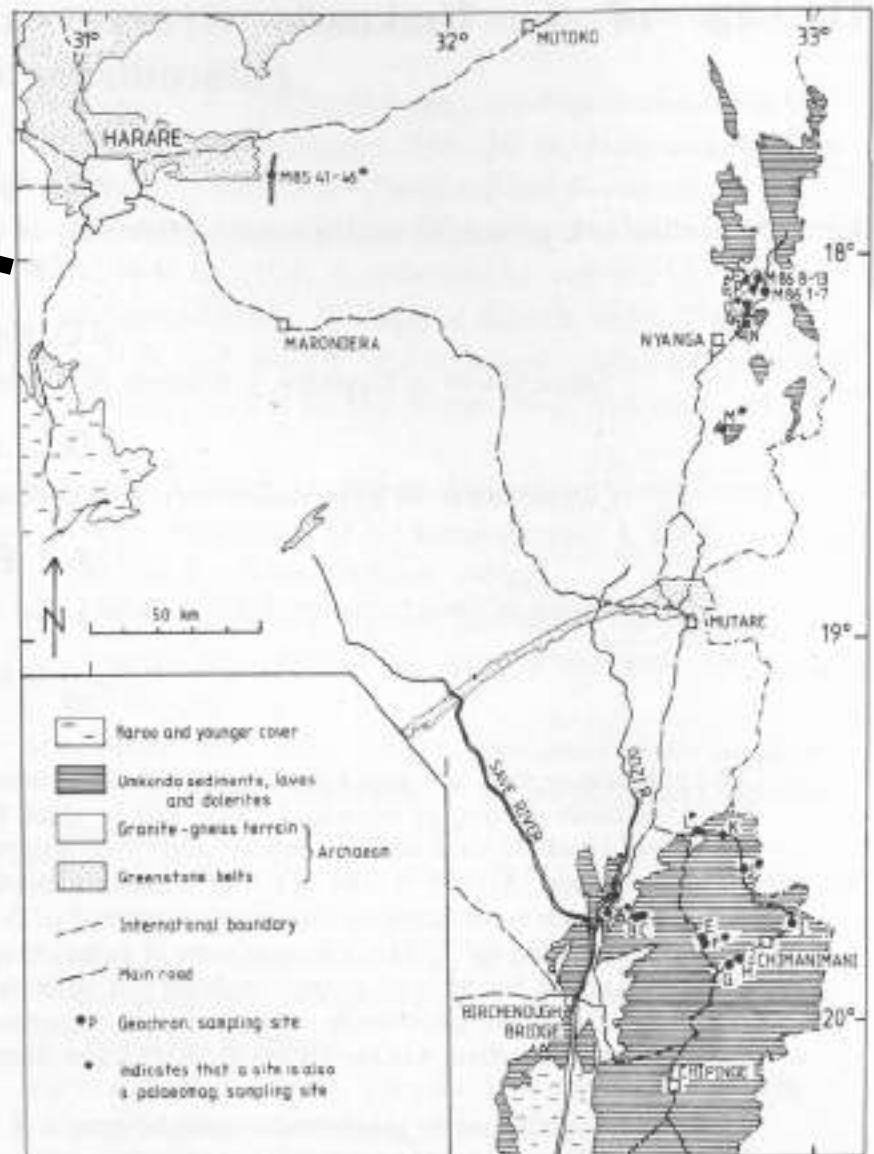
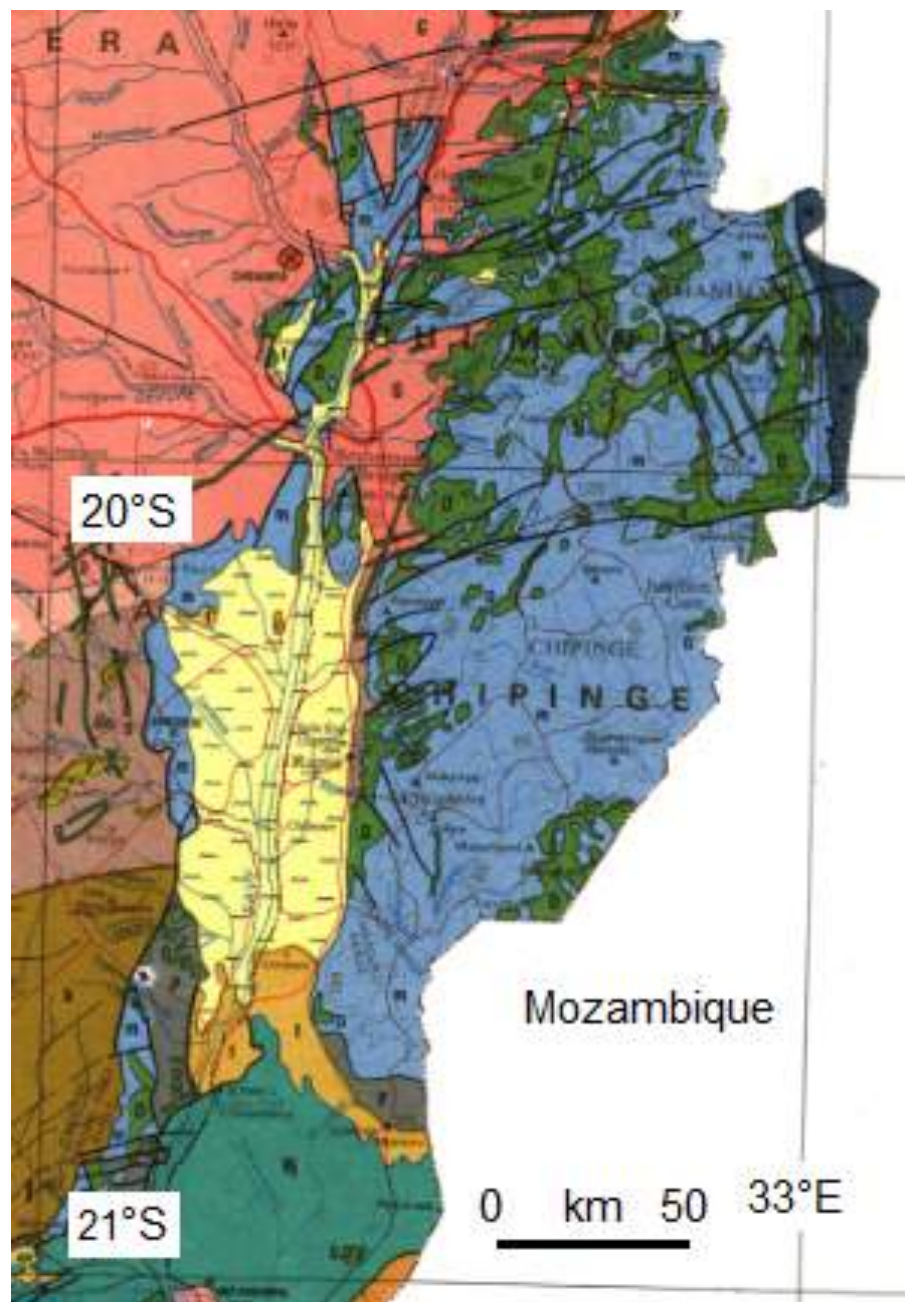


Figure 2 Map of eastern Zimbabwe showing the extent of outcrops of the Umkondo Group and sampling sites for this study.





University of Zimbabwe Expedition 30-31 March 1996

Hubert Munyanyiwa, Richard and Deanna Hanson, Sharad Master

Umkondo Group Stratigraphy

Button
(1977)

EGRU Inf.
Circular

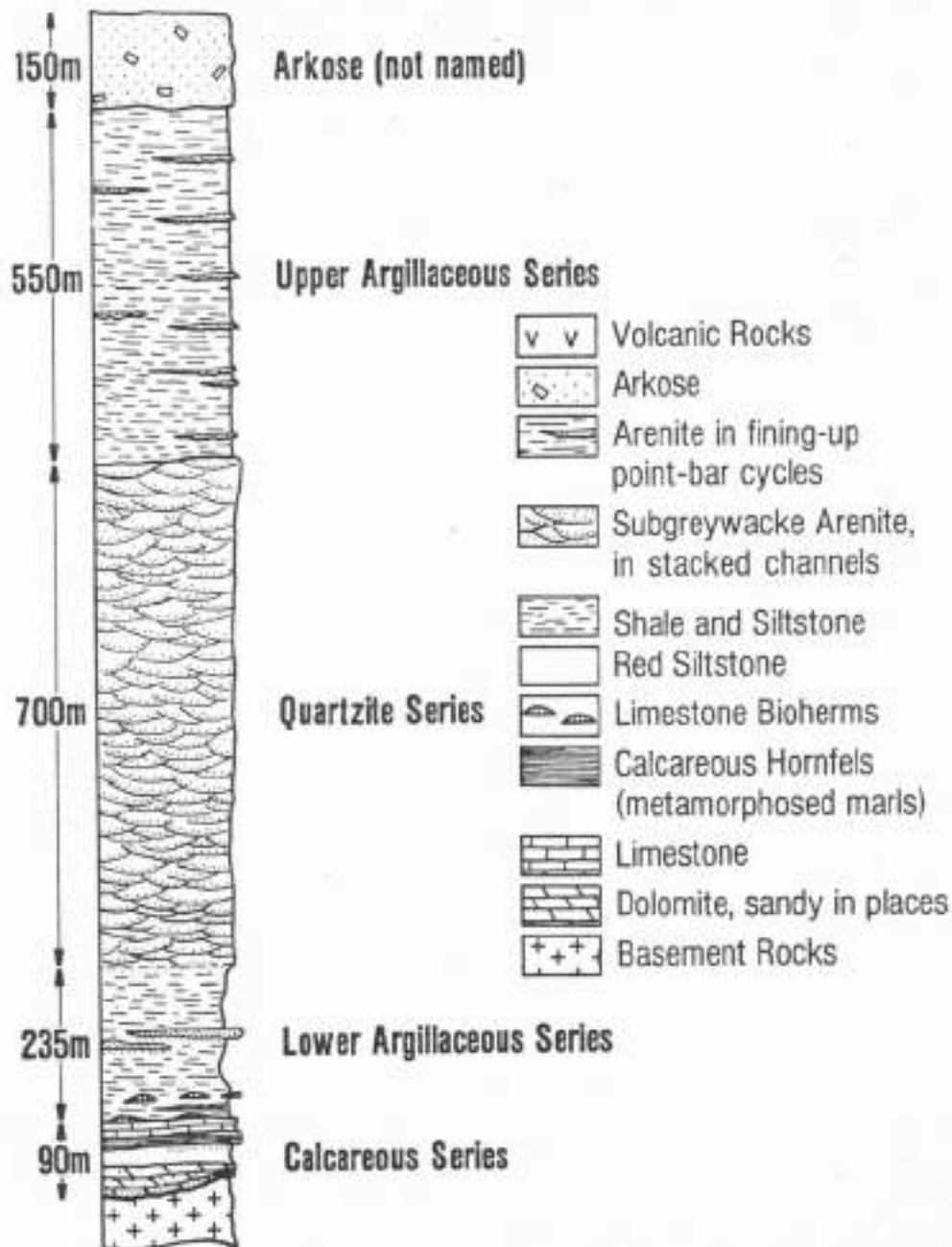
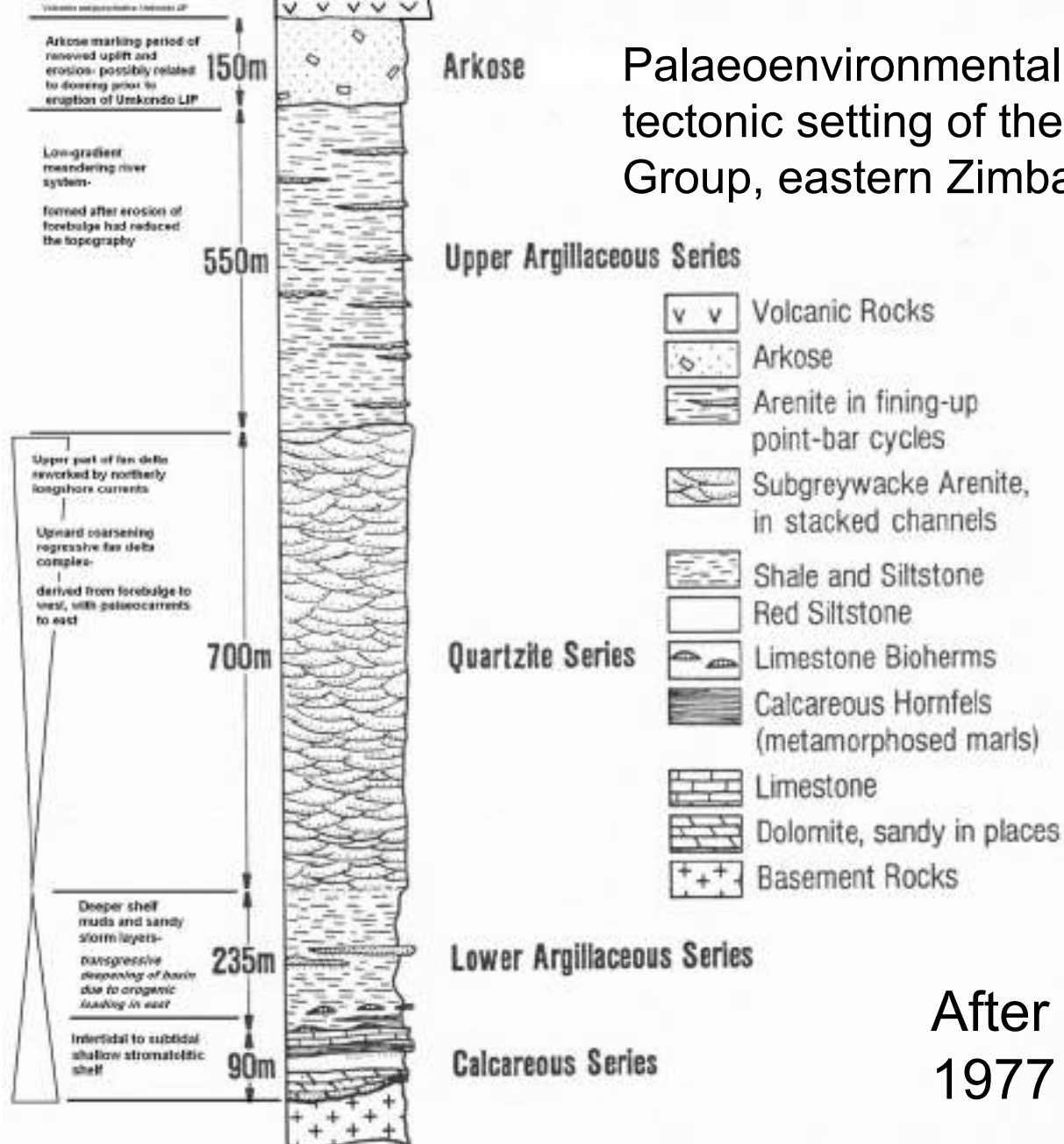


Figure 3 : Generalised stratigraphic column of the Umkondo System in the Chipinga area



Palaeoenvironmental and palaeotectonic setting of the Umkondo Group, eastern Zimbabwe

After Button,
1977

Generalised stratigraphic column of the Umkondo System in the Chipinga area

Umkondo Group

Palaeocurrent directions

NE to E off
Zimbabwe Craton

Button (1977)

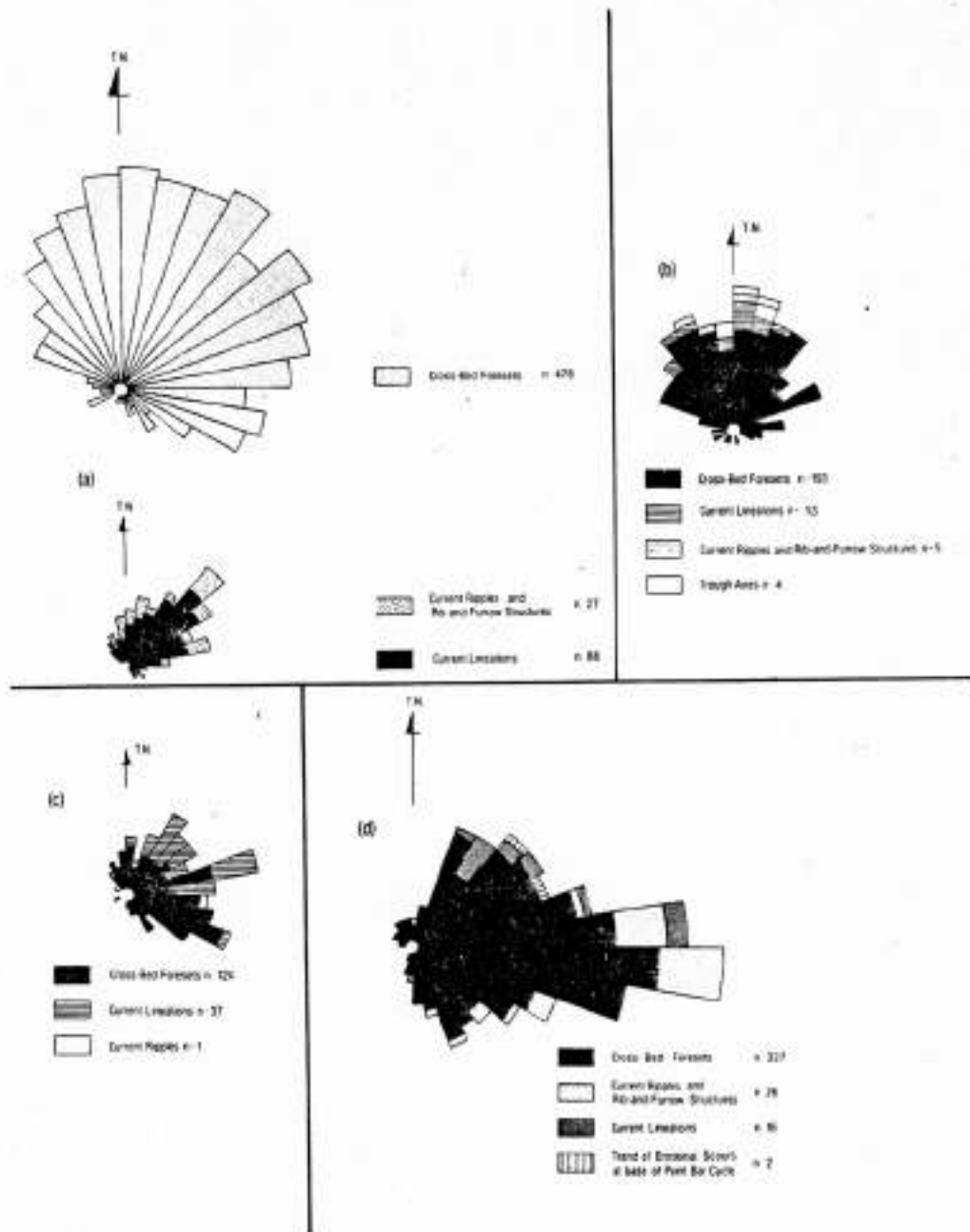


Figure 19 : Rose diagrams of palaeocurrent vectors in the Umkondo System. (a) Quartzite Series as a whole; (b) uppermost phase of Quartzite Series; (c) basal half of Quartzite Series and (d) Upper Argillaceous Series



Umkondo Group marble, Moosgwe Farm roadcut



Umkondo Group marble

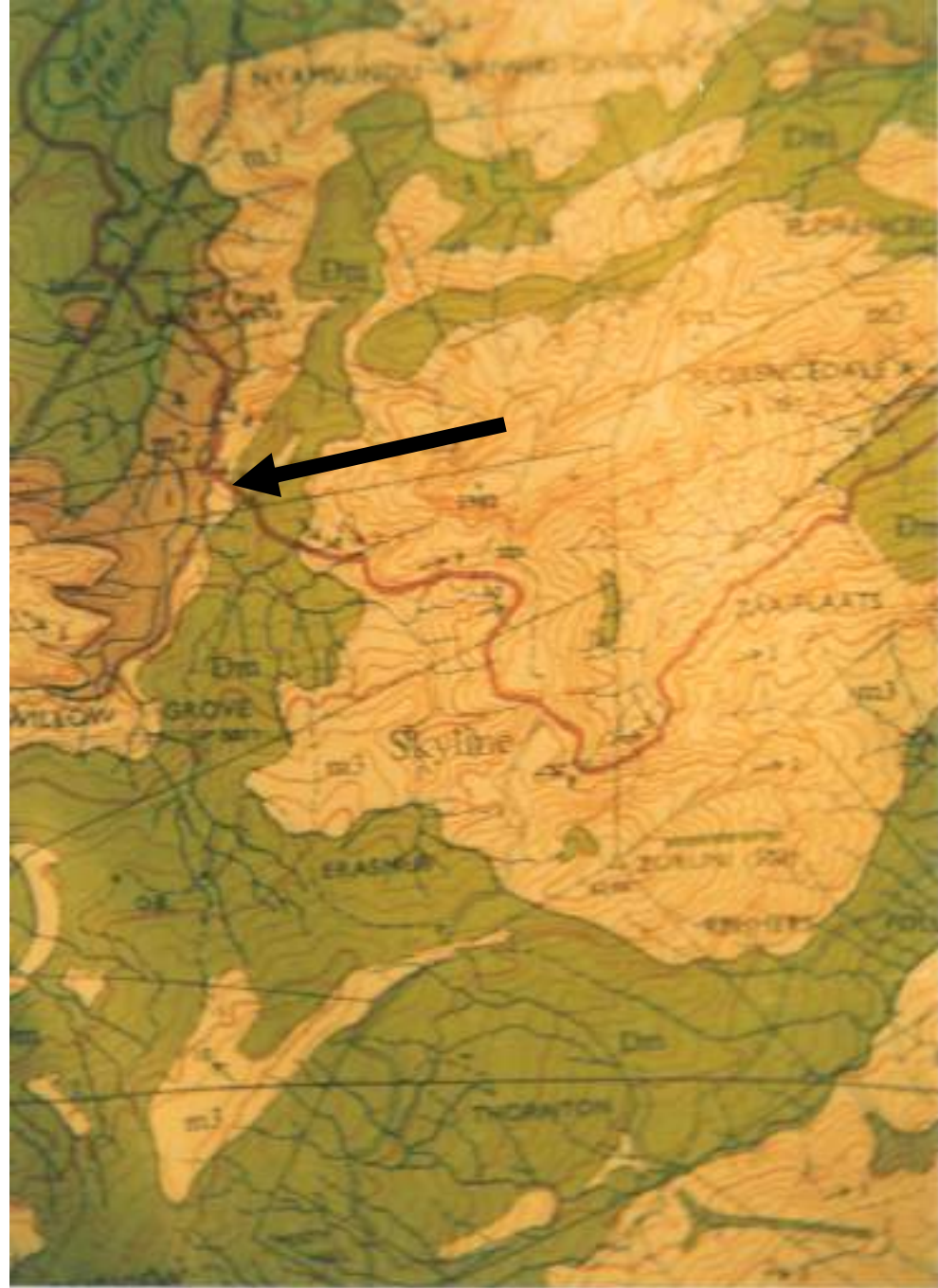


**Ripple-marked
quartzites**

Umkondo Group



Rippled quartzite, Umkondo Group





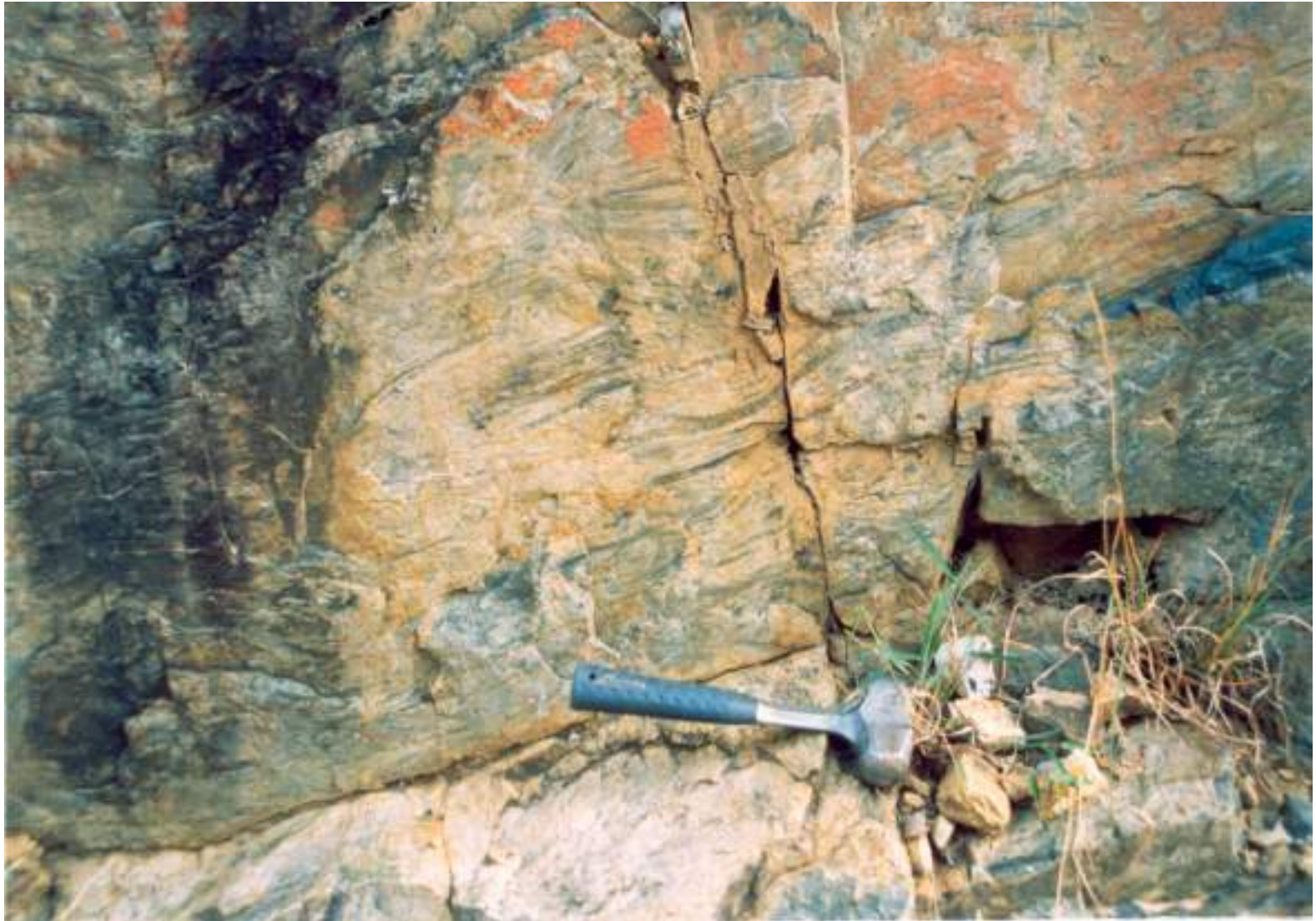
A photograph of a geological outcrop. The upper portion of the cliff is composed of reddish-brown, horizontally bedded sandstone layers. The lower portion is a darker, more irregularly bedded dolerite. A person wearing a hat and a backpack stands on a paved road at the base of the outcrop, providing a sense of scale. A black diagonal line separates the two rock units. The text 'Umkondo Group sandstones' is written in yellow above the line, and 'Umkondo dolerite' is written in green below the line.

Umkondo Group sandstones

Umkondo dolerite



Contact zone between Umkondo sedimentary rocks (top) and contaminated xenolithic Umkondo sill



Peperite consisting of xenoliths of hanging-wall semipelite country rock incorporated into dolerite sill.



Folded ductile soft-sediment xenolith which foundered from hanging-wall into dolerite sill



Close-up of chloritic semipelite xenolith in pink alkali-feldspar-rich contaminated dolerite, together with dark clots of tourmaline. Scale in mm and cm.

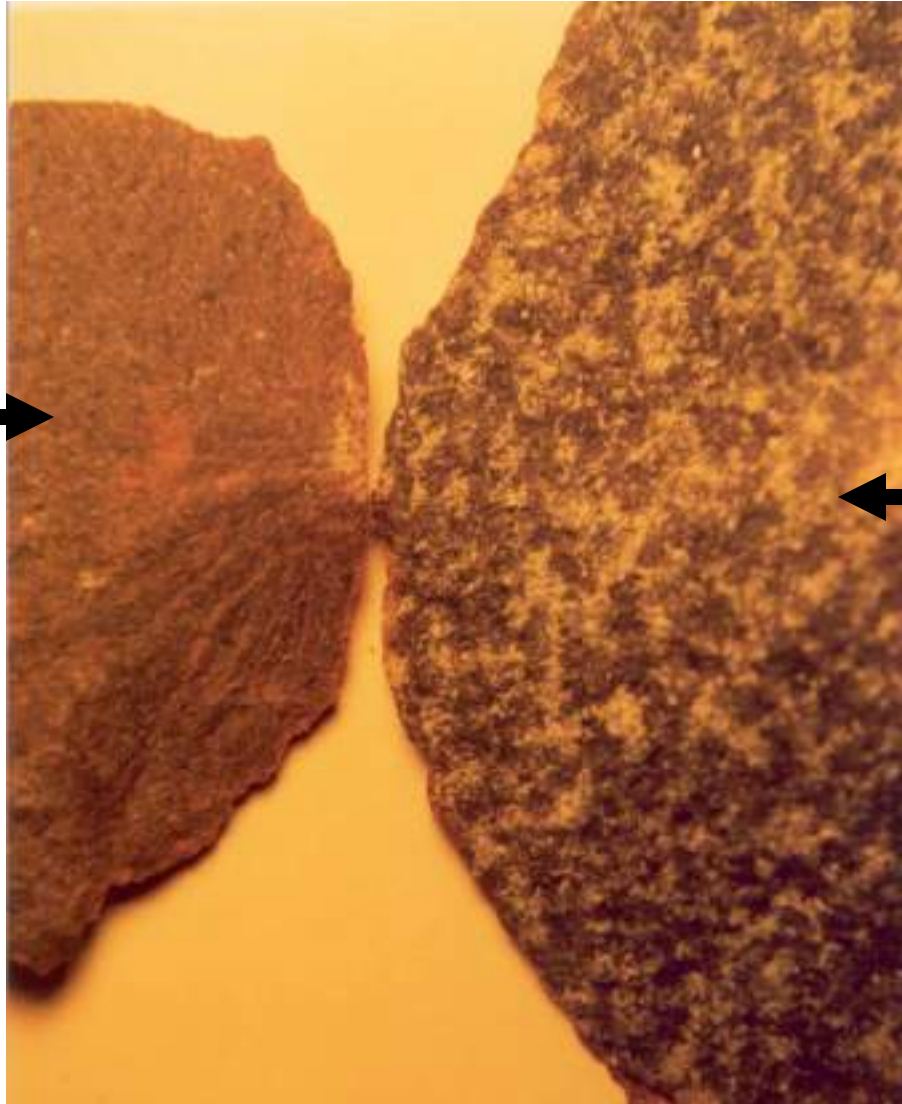


**Normal
Umkondo
dolerite sill**



**Contaminated Umkondo
sill with granophyric
texture**

**Fine-
grained
Umkondo
dolerite**



**Coarse-
grained
granophyric
Umkondo
dolerite**

Umkondo Group

New detrital zircon U-Pb geochronological results

(ICP-MS, at Stellenbosch and Wits Universities)

1. Basal Umkondo Conglomerate, Marange

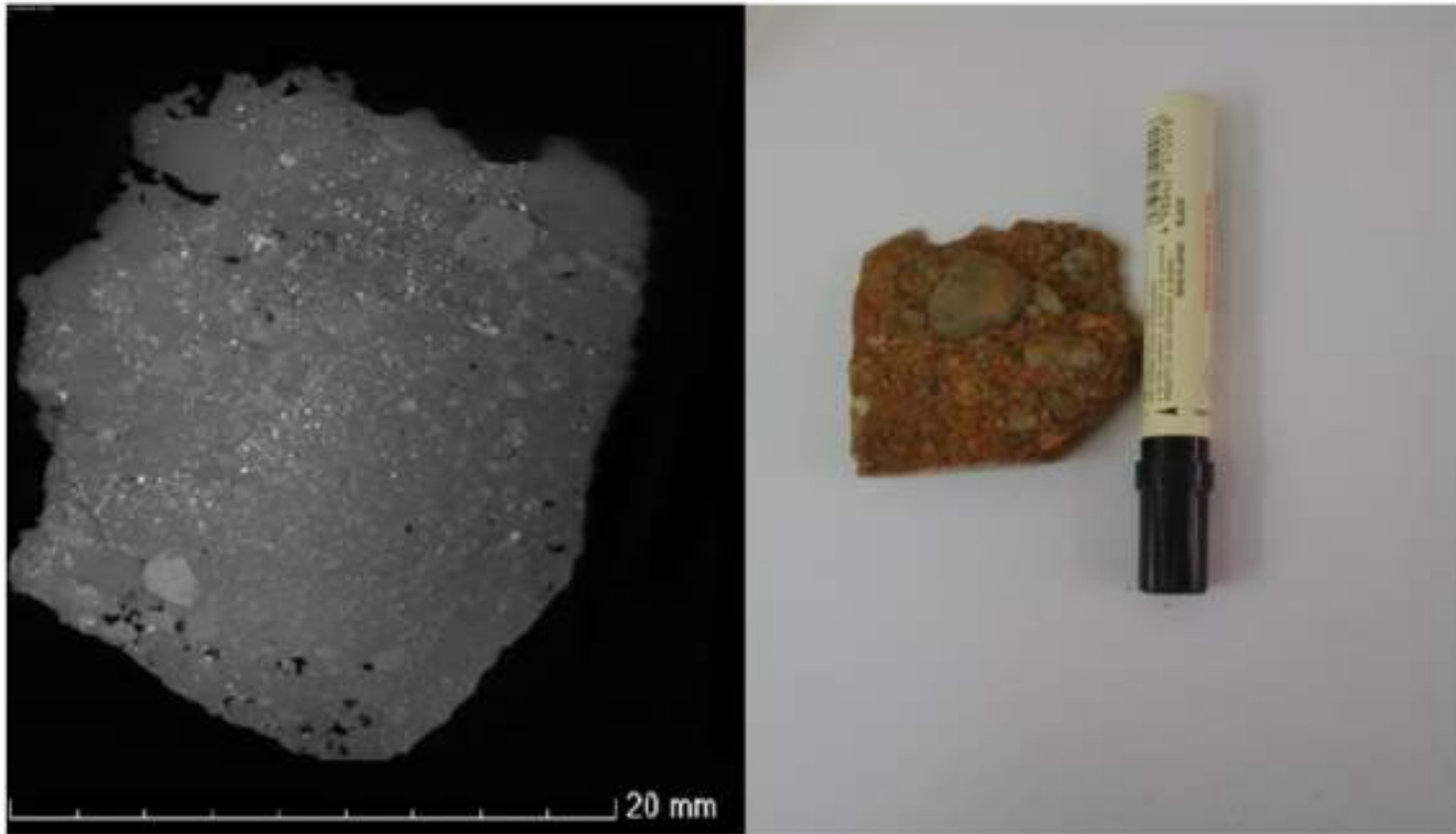
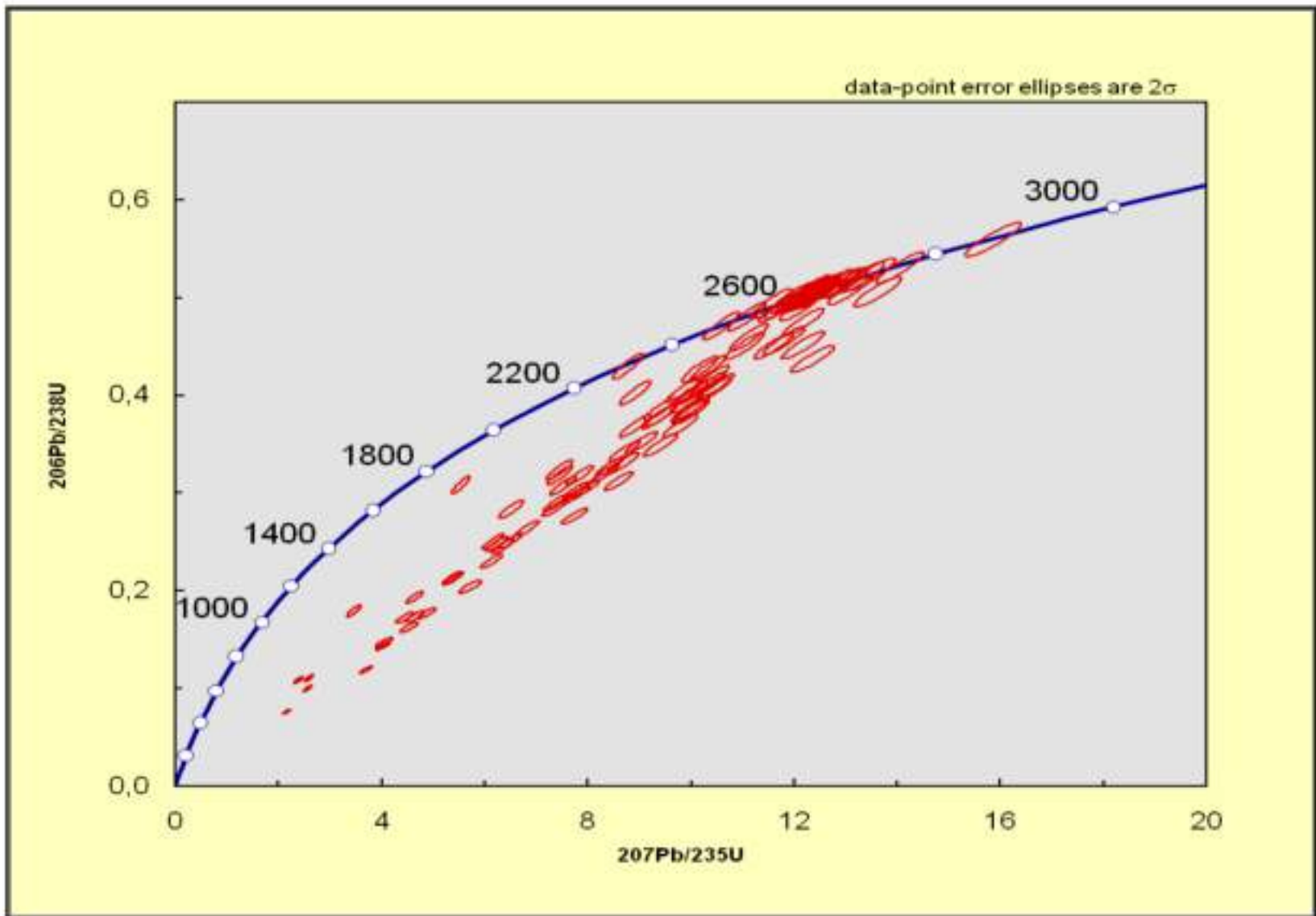


Figure 10 Left: X-ray tomographic scan of one side of the mineralised conglomerate. The white dots are all the heavy minerals. Right: The mineralised conglomerate used for the scan on the left. The sample has been crushed and used for the geochemical analyses. (Permanent marker for scale = 14.4cm).

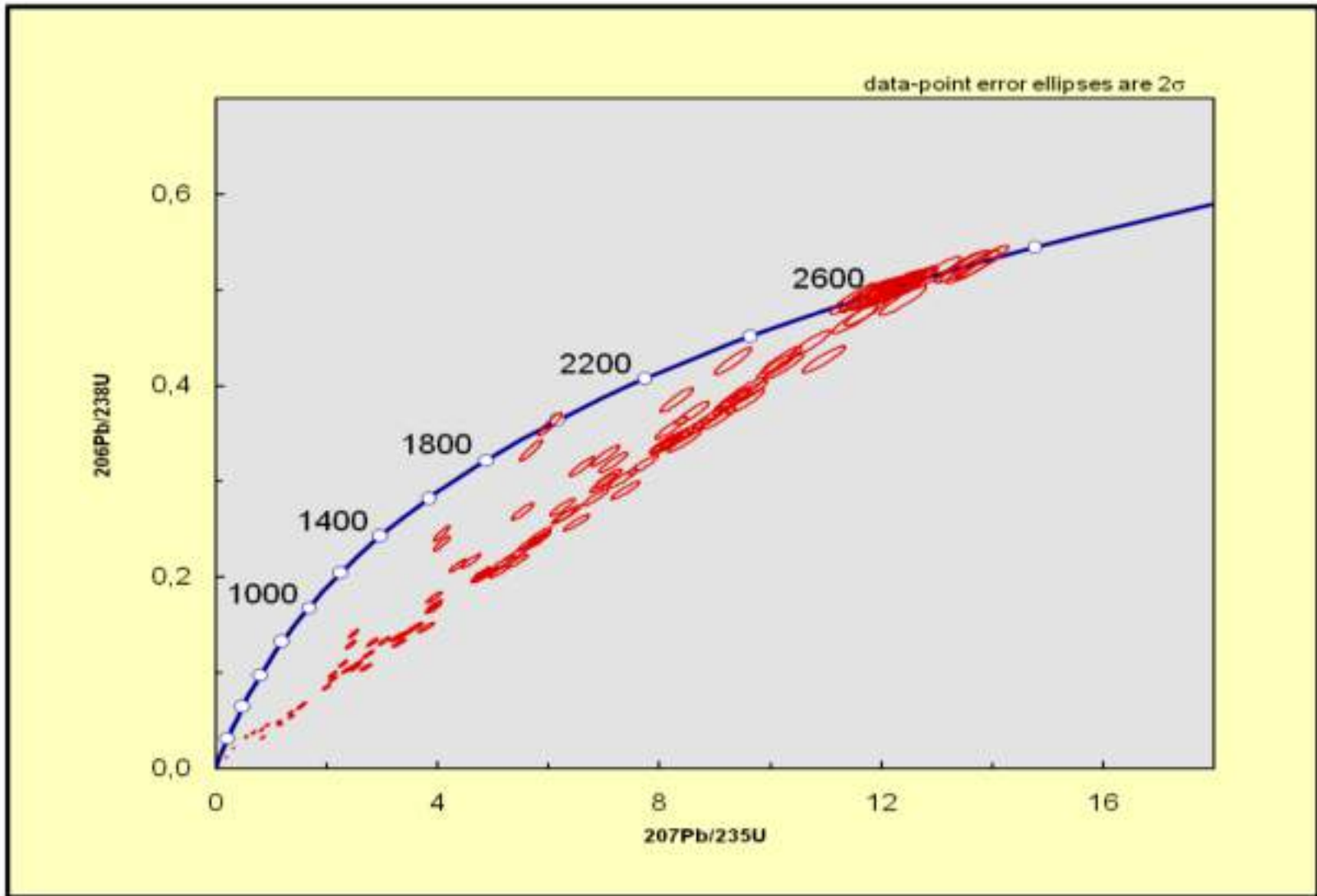


Wetherill Concordia Plot for zircons from basal Umkondo Marange Conglomerate



2. Basal Umkondo
conglomerate,
Birchenough
Bridge,
nonconformably
overlying massive
Neoarchaeane
granite of the c.
2.6 Ga Chilimanzi
Suite

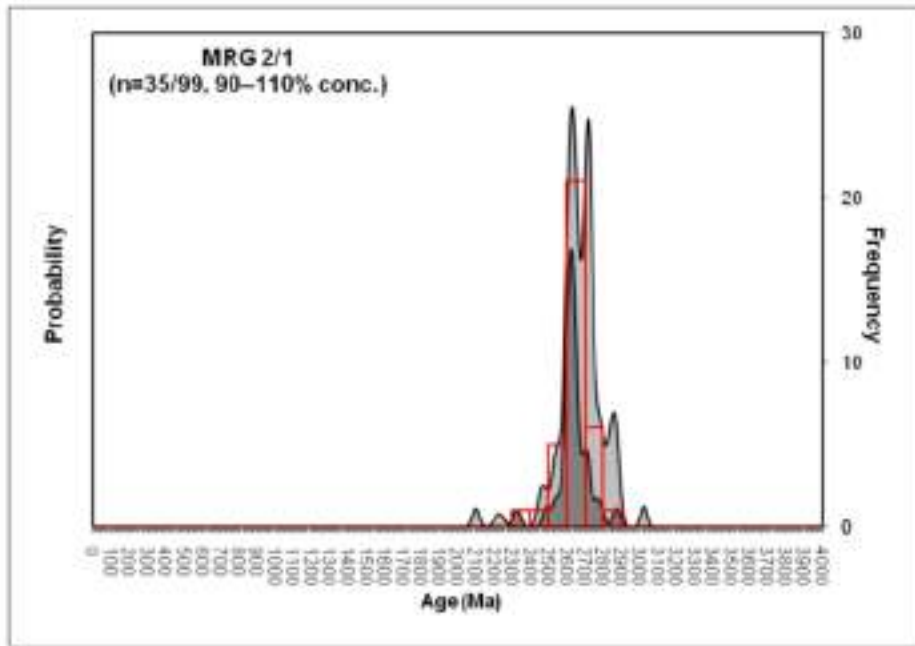
Figure 3 Outcrop where the Umkondo conglomerates are seen unconformably overlying the Archaean Basement Complex at Birchenough Bridge in the south eastern area of Zimbabwe.



Wetherill Concordia plot for zircons from the basal Umkondo conglomerate at Birchenough Bridge

1. Basal Umkondo conglomerate, Marange

Mainly 2.6 Ga Chilimanzi granite basement source;
a few c. 2 Ga zircons



2. Basal Umkondo conglomerate, Birchenough Bridge

Mainly 2.6 Ga Chilimanzi granite basement source;
a few c. 2 Ga zircons

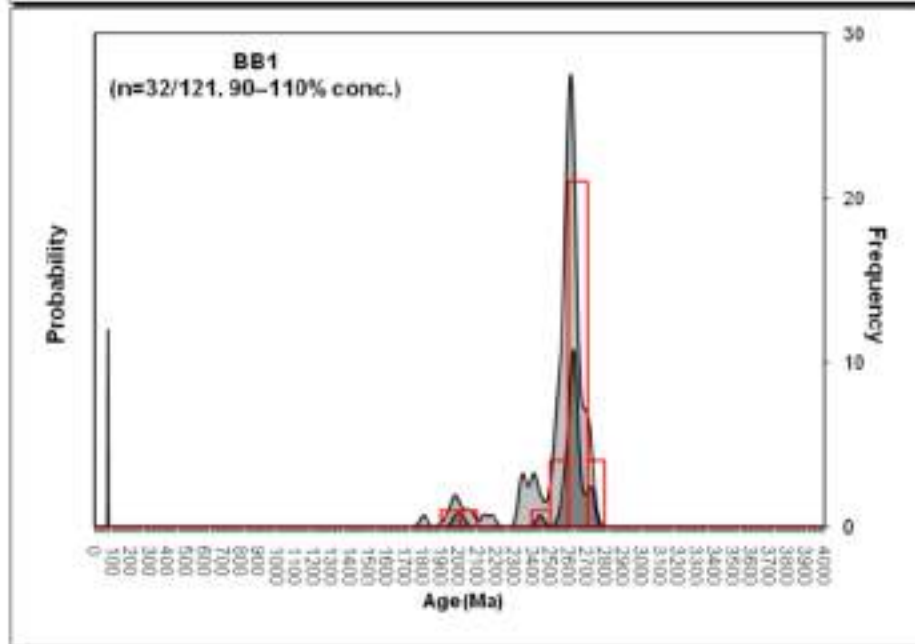


Figure 15 Density probability and zircon age frequency curves of the mineralised conglomerate (top) and the unmineralised conglomerate (bottom).

3. Granulestone (grit), basal Umkondo Beds near Birchenough Bridge

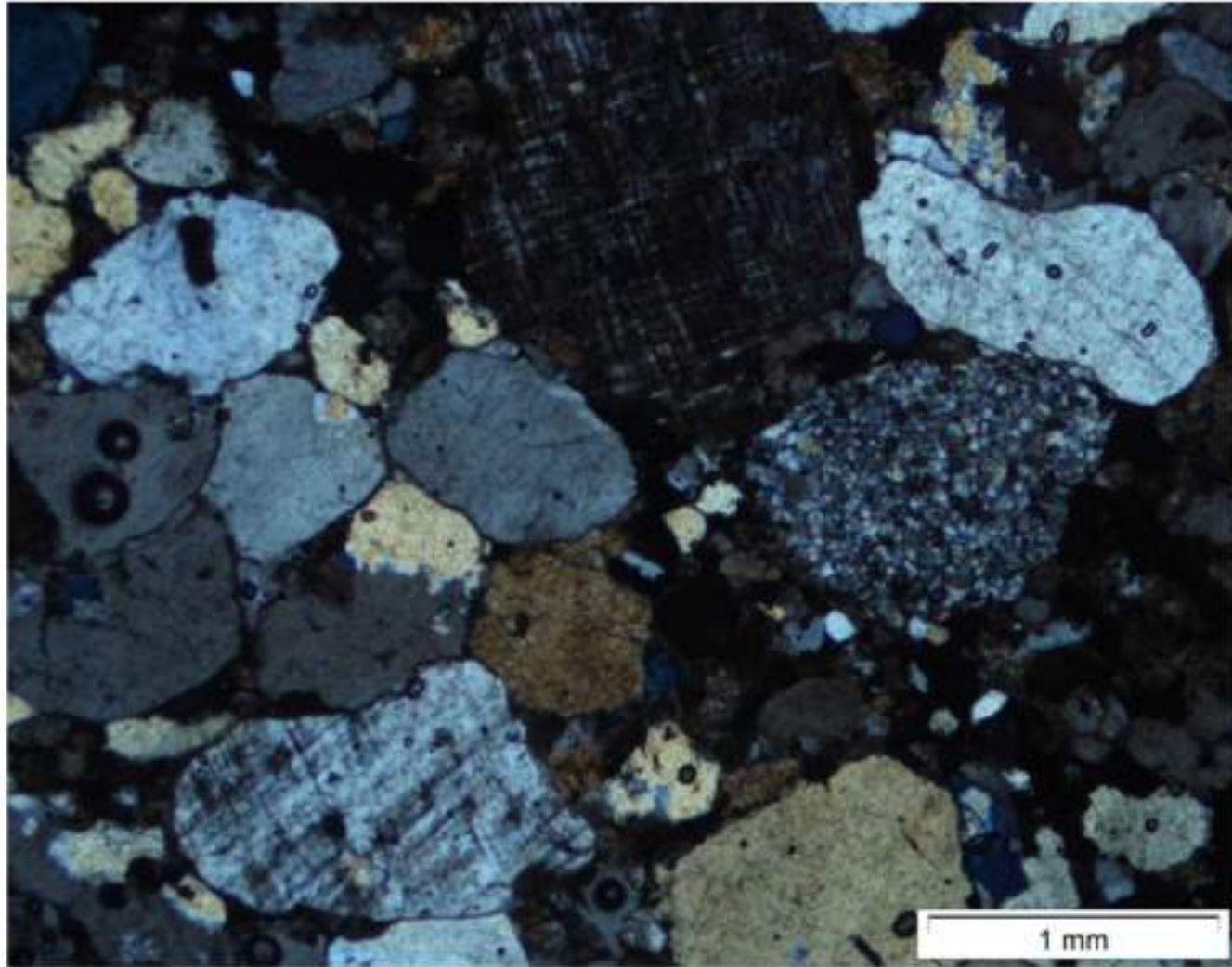


Figure 12 XPL thin section image of the grit showing microcline feldspar mineralisation associated with polycrystalline quartz mineralisation.

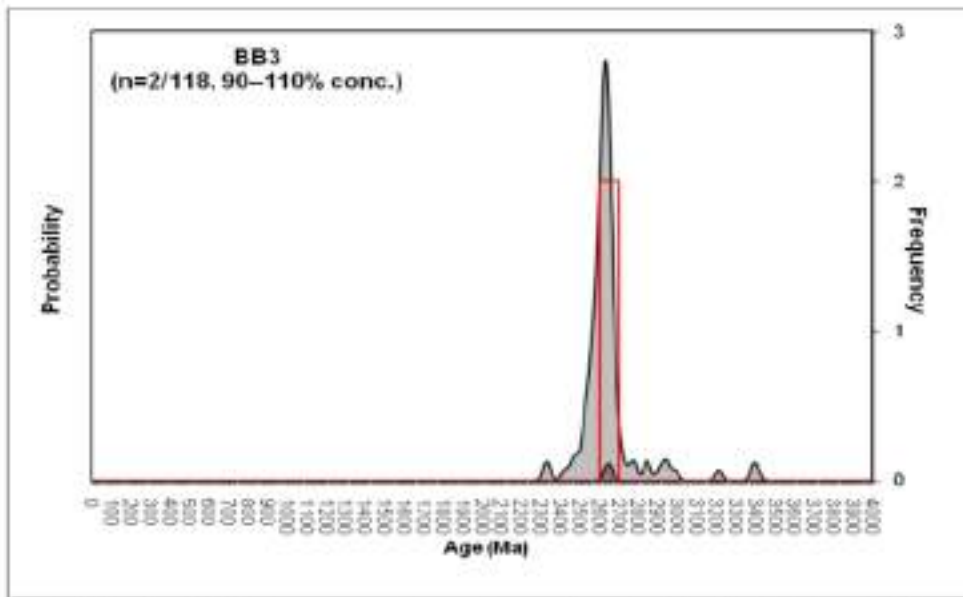


Figure 28 Density probability diagram and zircon age frequency diagram for the grit. Only 2 out of the 118 zircons that were picked are concordant

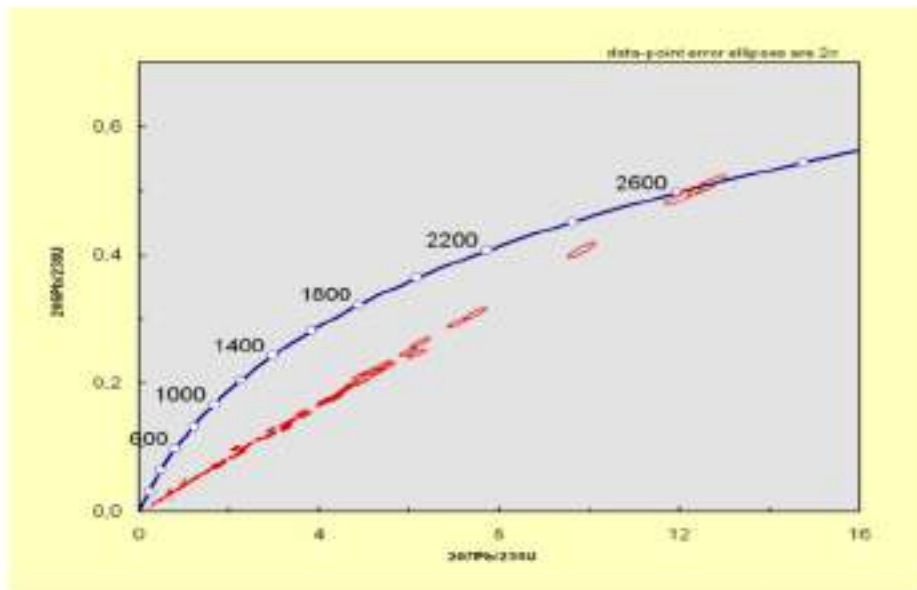


Figure 29 Wetherill concordia diagram for the grit. Only 2 ellipses plot on the line of concordance. Discordance trends directly through the origin which indicates recent Pb loss

3. Granulestone (grit),
from basal Umkondo
Beds, near
Birchenough Bridge

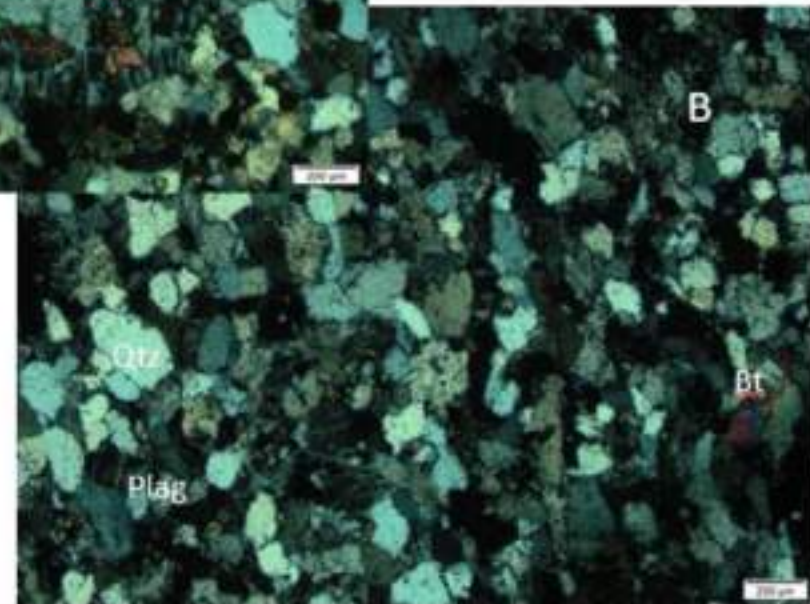
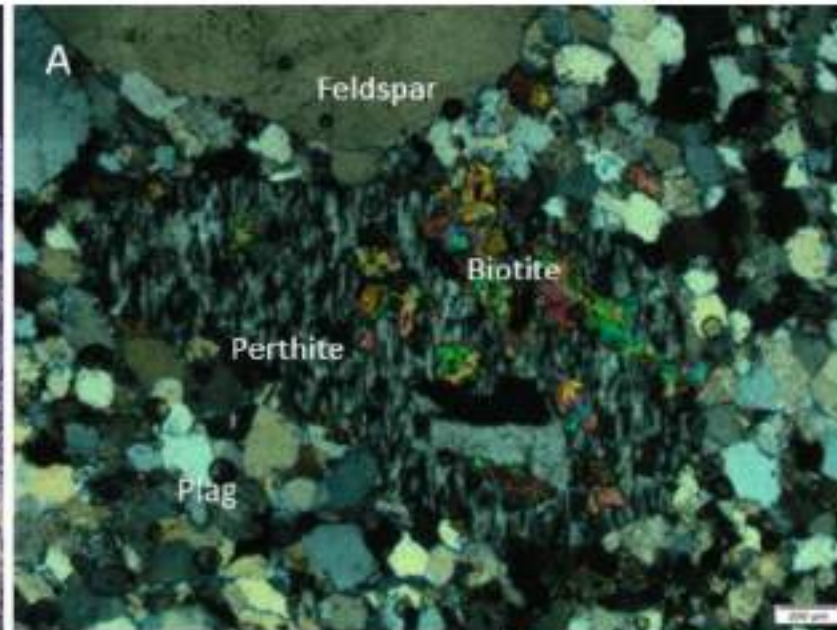
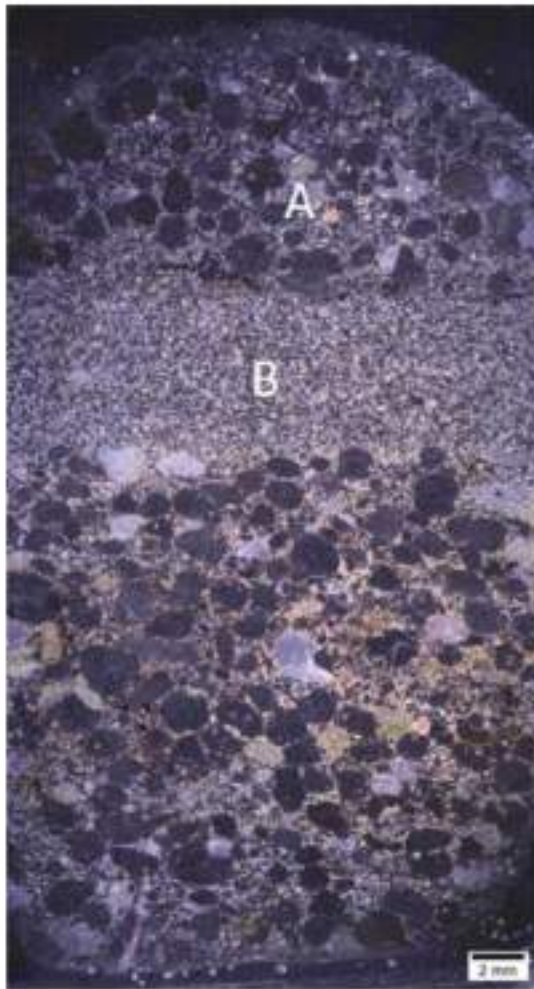
Mostly discordant zircons,
defining a Discordia line with
upper intercept age of c. 2.6
Ga (Chilimani Suite
basement granite age)



Watson (1969)

Sandstone MTS4
From Mutsago Hill

(“Calcareous Series”)



4. Umkondo sandstone MTS4, Mutsago Hill

Detrital zircon with metamorphic rim, MTS4 sandstone

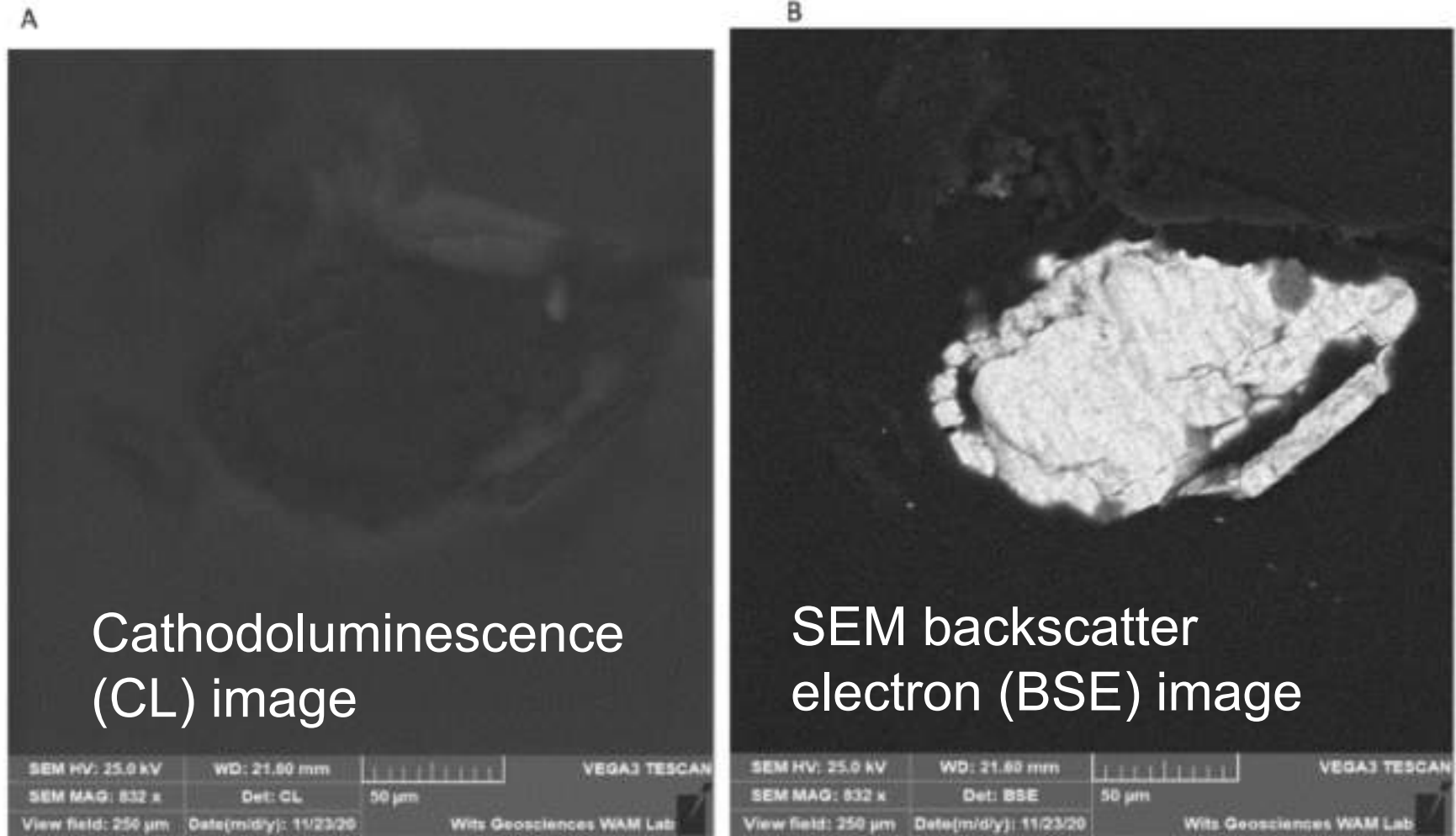
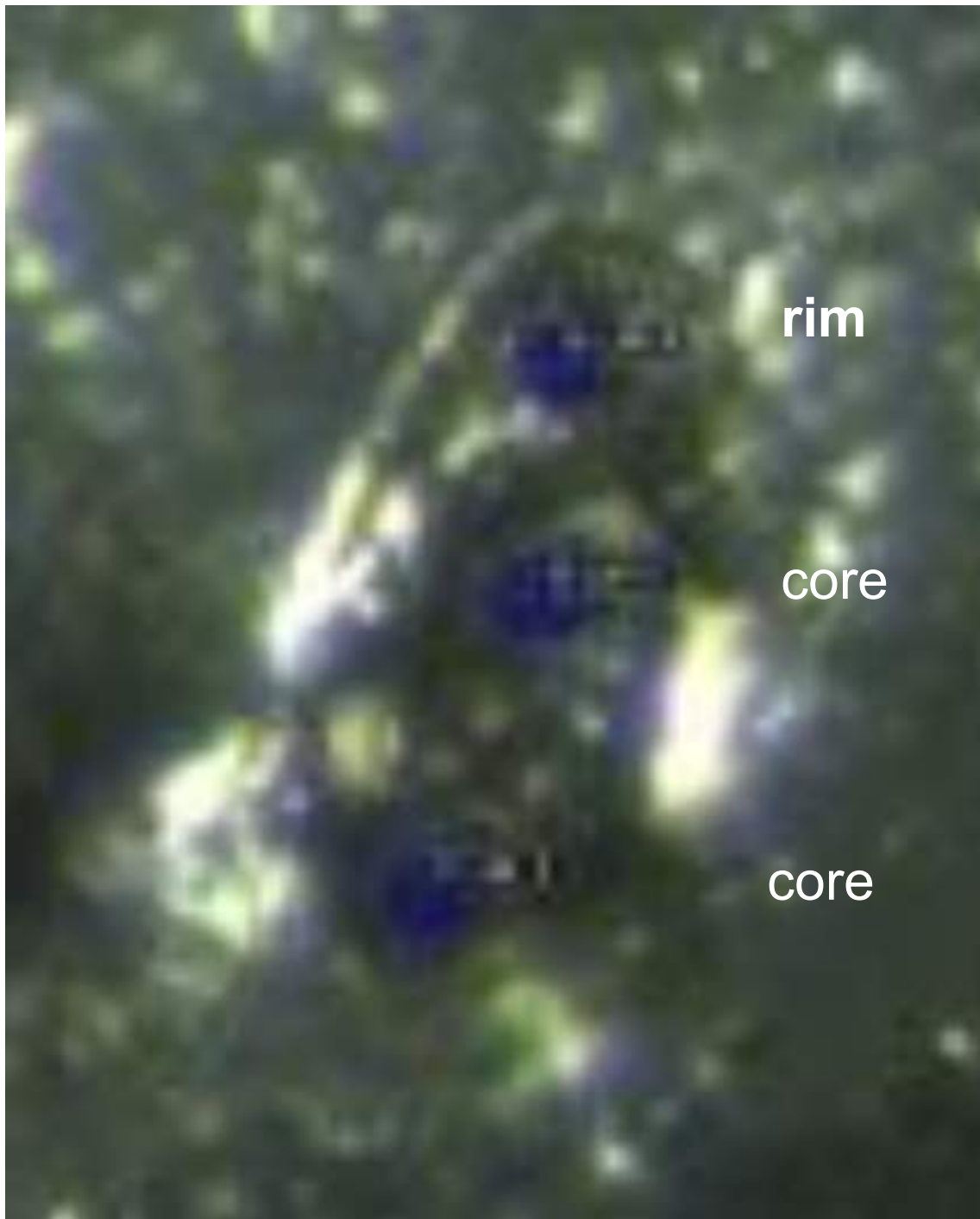


Figure 11: A representative the CL image of detrital zircons from sandstone (MTSS4), B represents the BSE image of the same zircon.



Laser ablation spots on a single zircon grain, two on older zircon core, one on younger zircon metamorphic overgrowth rim

Wetherill plot of zircons, Sandstone MTS4, Mutsago Hill

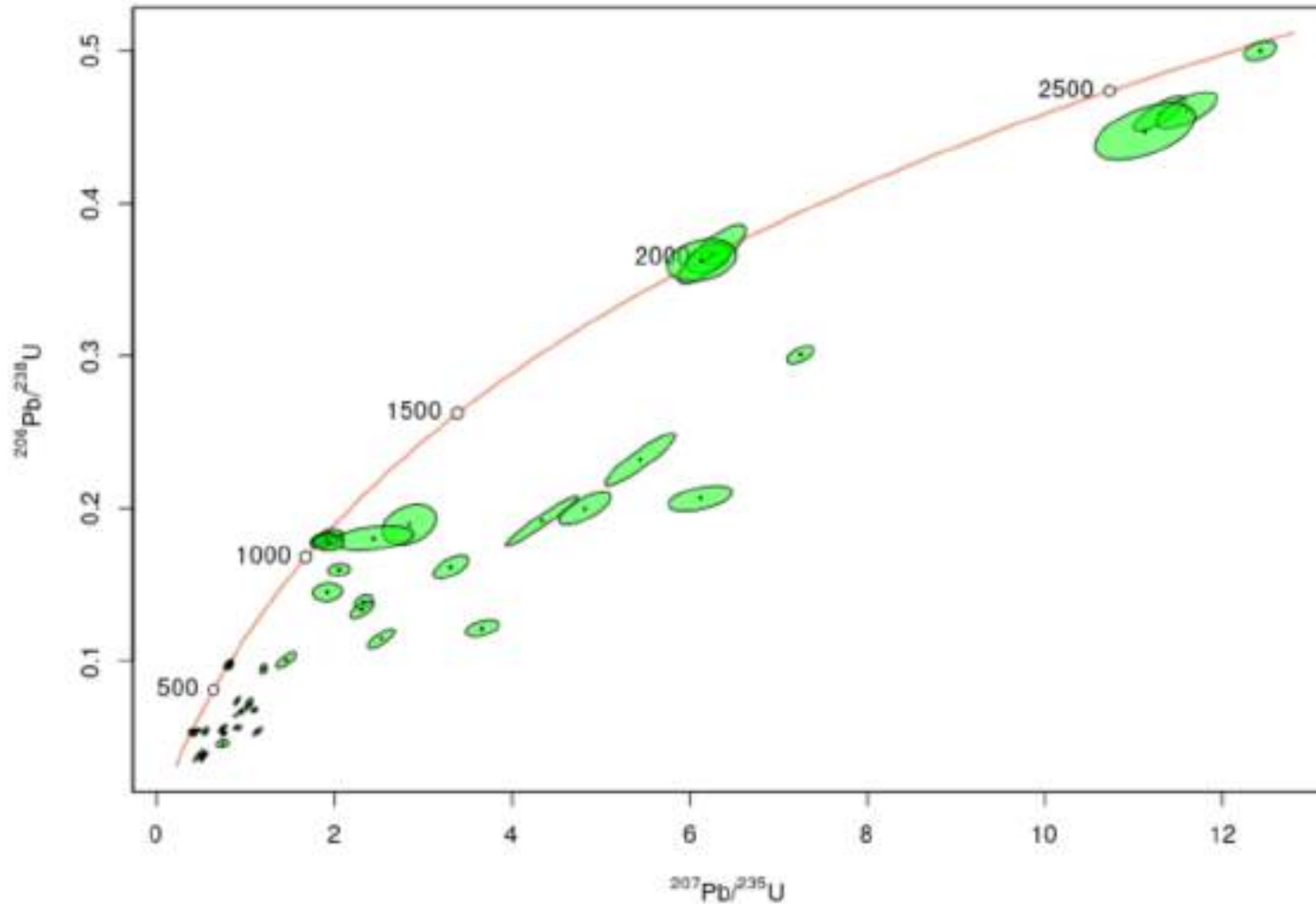


Figure 13 Wetherill concordia plot for the zircons extracted from the sandstone. Used internal uncertainties, $n=65$.

Sandstone MTS4 histogram of detrital zircon ages

n=65

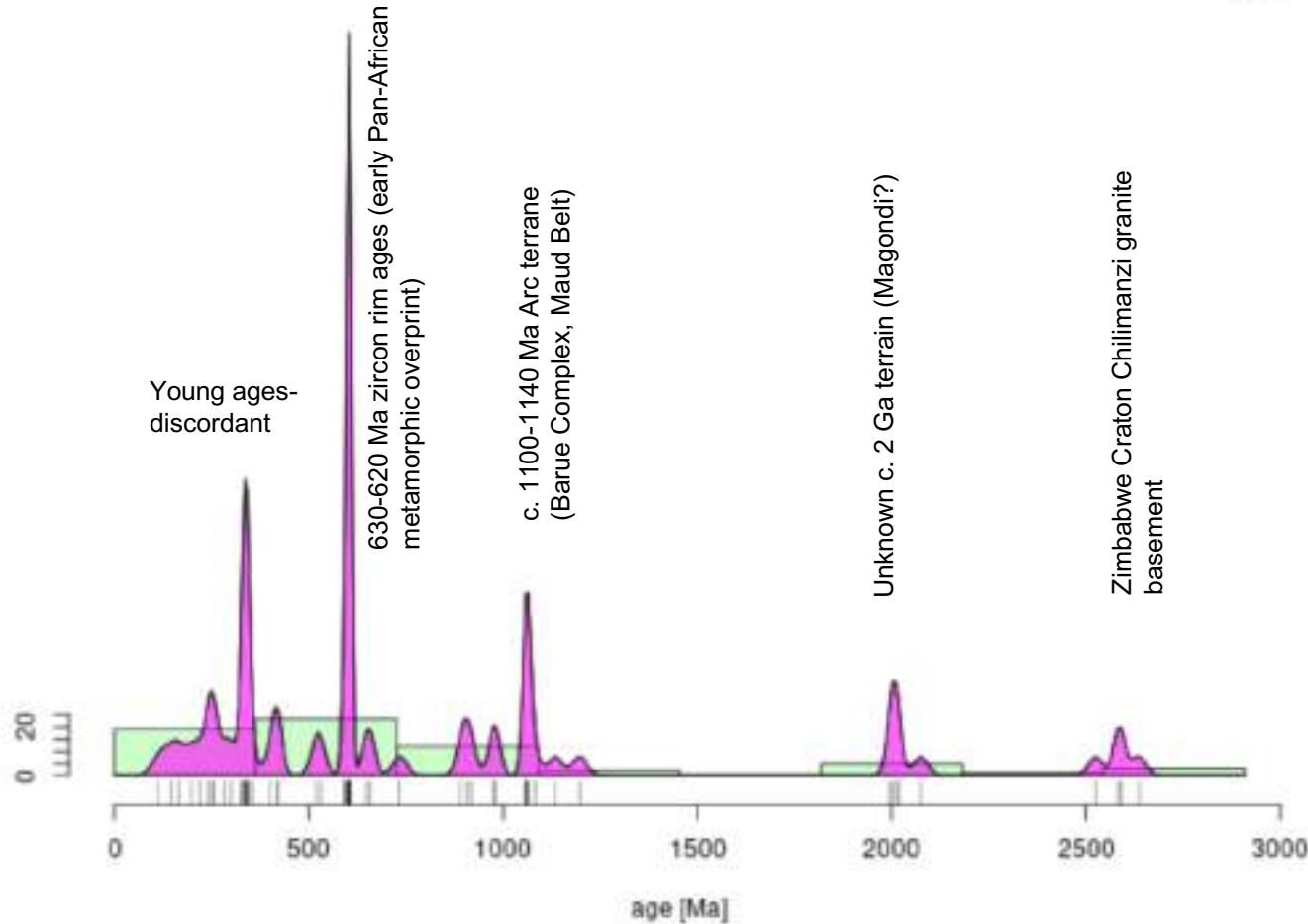


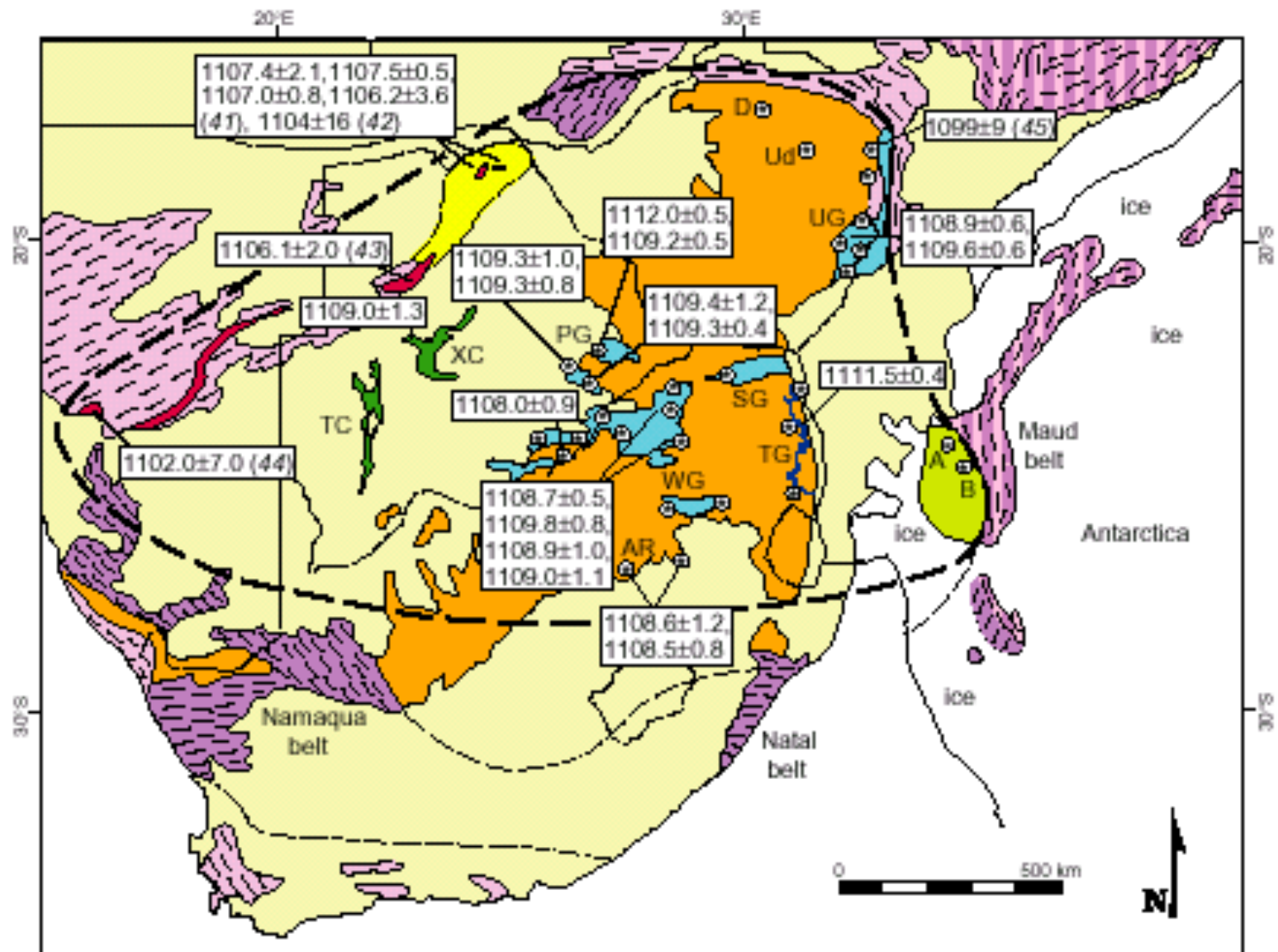
Figure 17 smooth data by applying a (Gaussian) kernel: $KDE(t) = \sum N(t | \mu=t_i, \sigma=h[t])$, where $N(\mu, \sigma)$ is the probability of observing a value t under a Normal distribution with mean μ and standard deviation σ . $h[t]$ is the smoothing parameter or 'bandwidth' of the kernel density estimate which may or may not depend on the age t .

Early Pan-African metamorphism

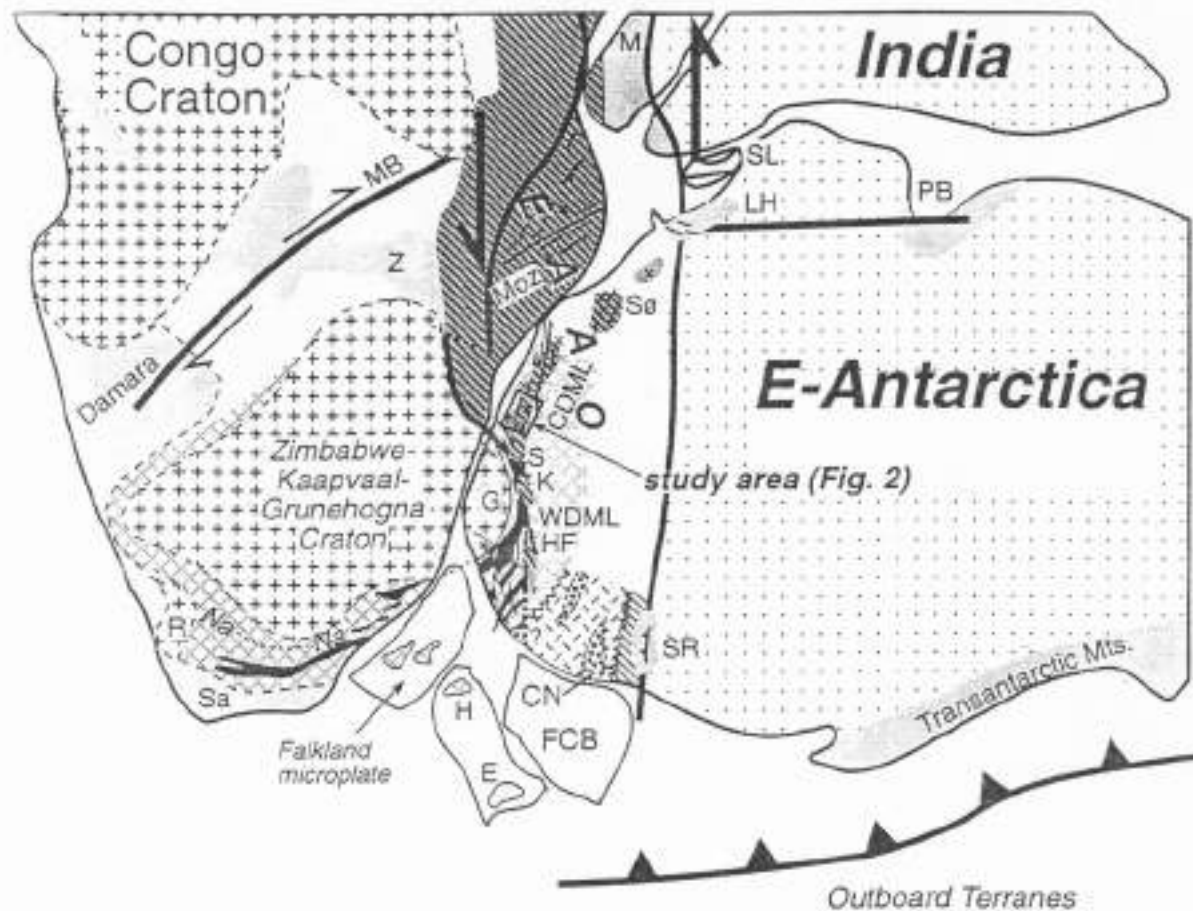
The metamorphic rims of zircons from MTS4 sandstone give an age of 630-620 Ma.

This is similar to a biotite K-Ar age of 615 ± 30 Ma recorded from gneiss at Nyapanani Hill, Nyanga (Snelling et al., 1964).

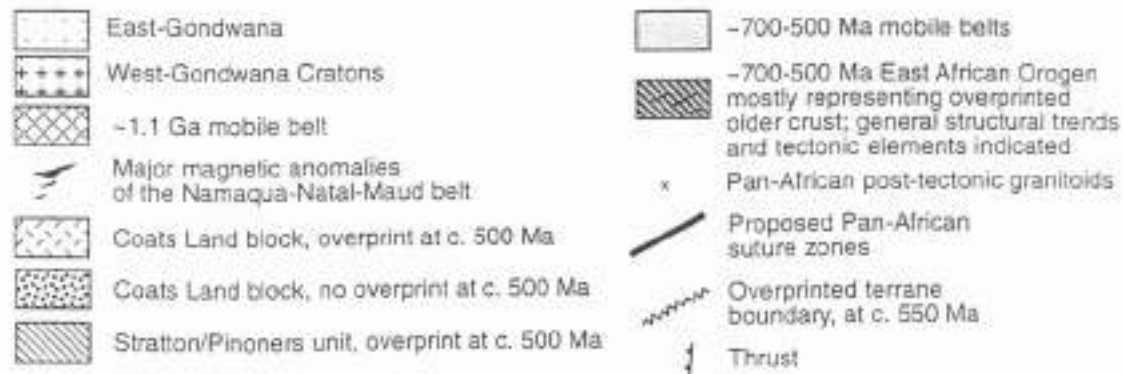
It is also similar to the >632 Ma ages of the youngest detrital zircons in the Sijarira Group of western Zimbabwe (Master et al., 2020).



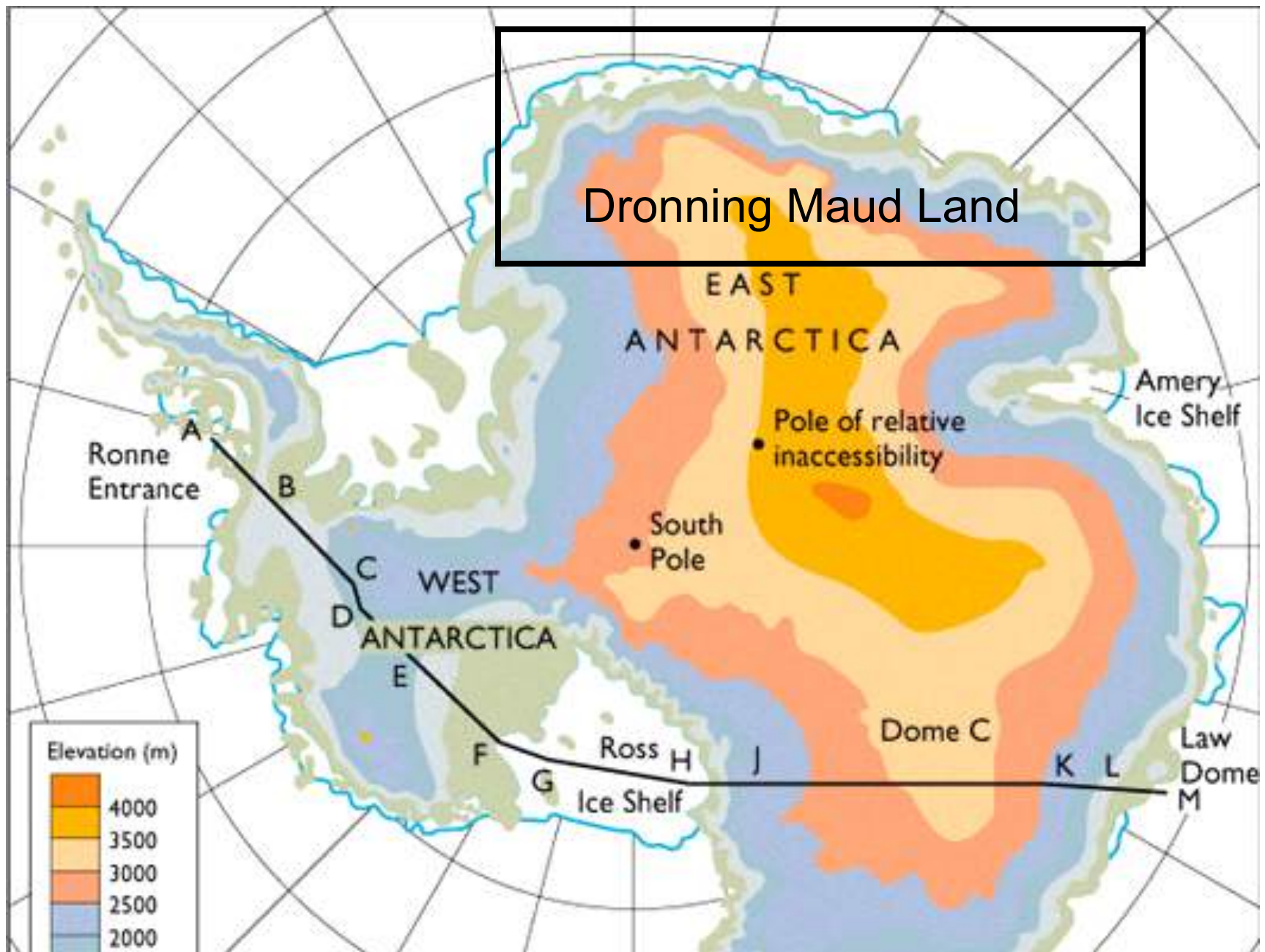
Umkondo Large Igneous Province, ca. 1108-1110 Ma
(after Hanson et al., 2004)



Jacobs et al.
(2003). Int. J.
Earth Sci.









Queen Maud of
Norway- 1869-1938

After whom
Dronning Maud
Land is named

West Dronning Maud Land (WDML), East Antarctica

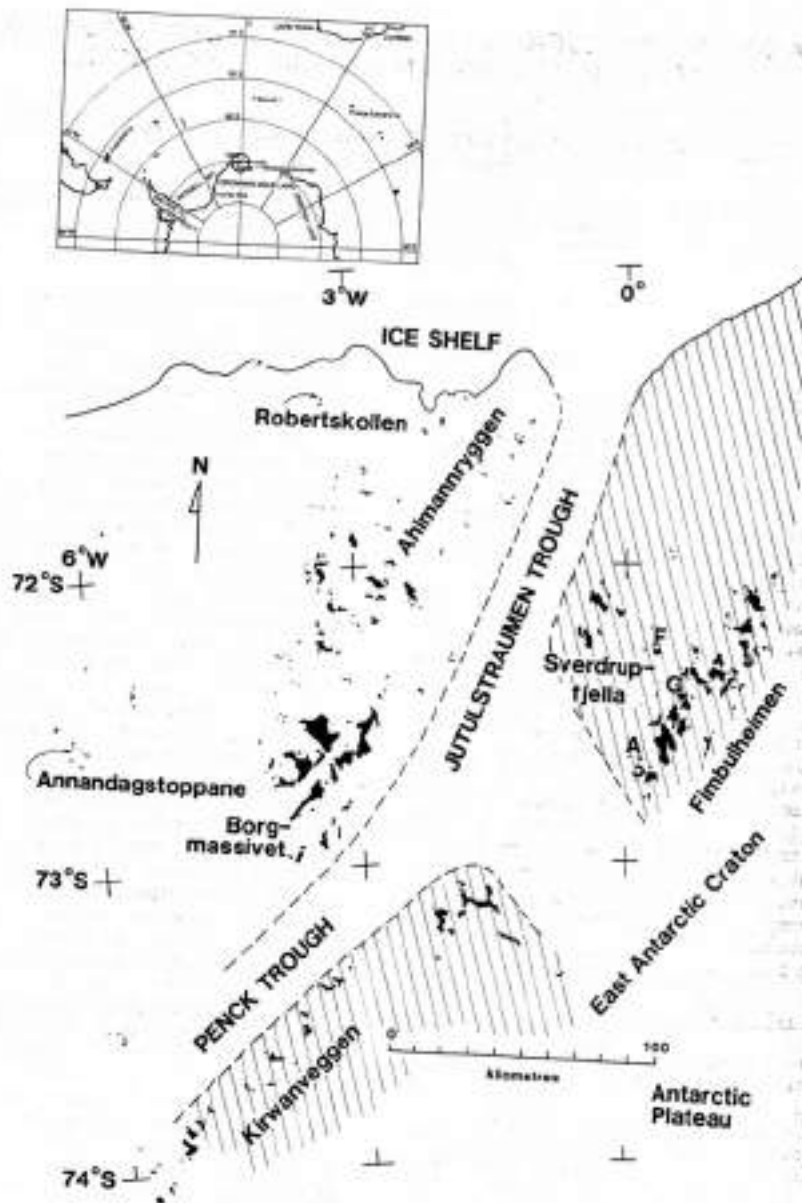


Figure 1. Outcrop map of Western Dronning Maud Land, Antarctica, showing the localities mentioned in the text. The shaded areas have a K_h-Sr biotite mineral age of about 430 Ma. (After Barton et al., 1986b, Fig. 1).





SANAE IV BASE-
Vesleskarvet, Antarctica

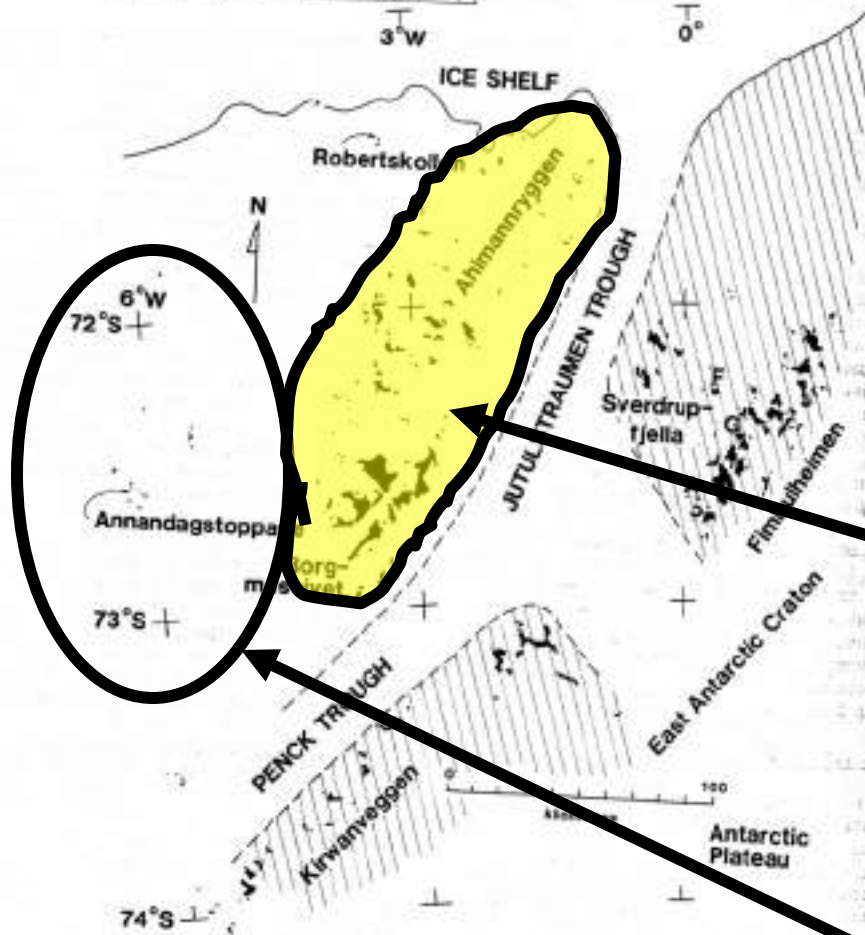




nunatak



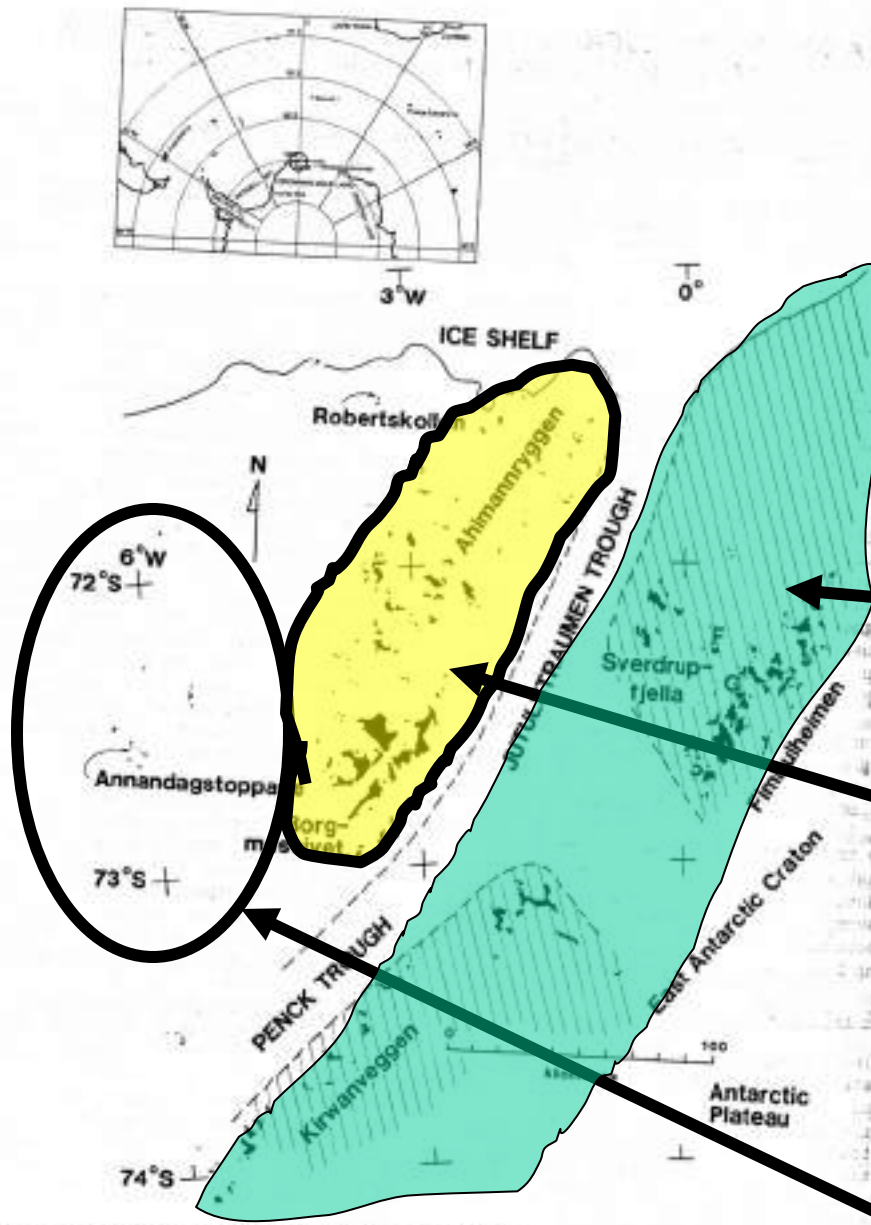
West Dronning Maud Land, West Antarctica



**Ahlmannryggen
Group (c. 1.13 Ga)**

**Grunehogna craton
(c. 3 Ga)**

Figure 1. Outcrop map of Western Dronning Maud Land, Antarctica, showing the localities mentioned in the text. The shaded areas have a K₂O-Sr biotite mineral age veil of about 430 Ma. (After Barton et al., 1986b, Fig. 1).



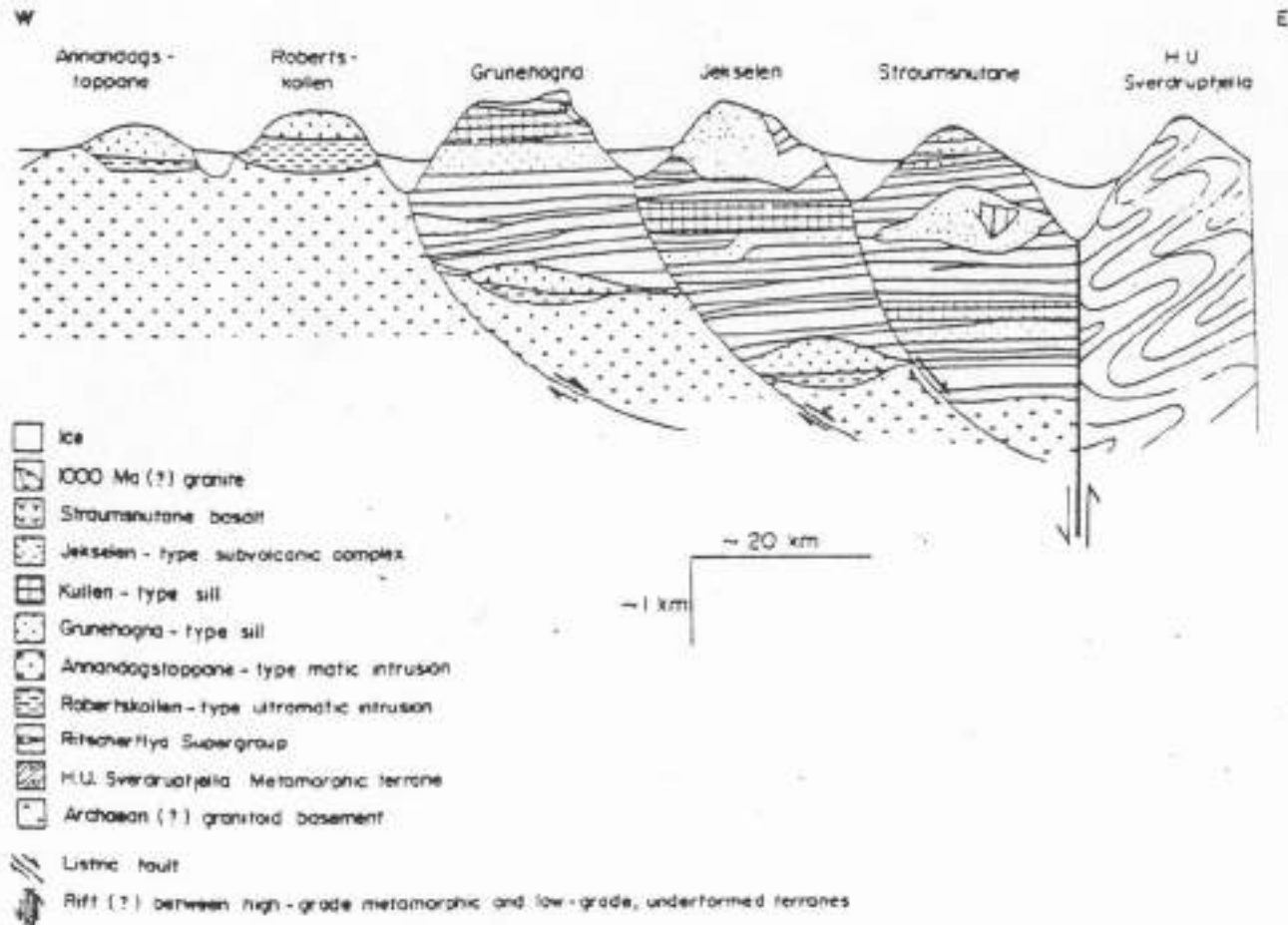
West Dronning Maud Land, West Antarctica

Maud Belt,
ca. 1.14 Ga

Ahlmannryggen
Group, Ritscherflya
Supergroup

Grunehogna craton,
ca. 3 Ga

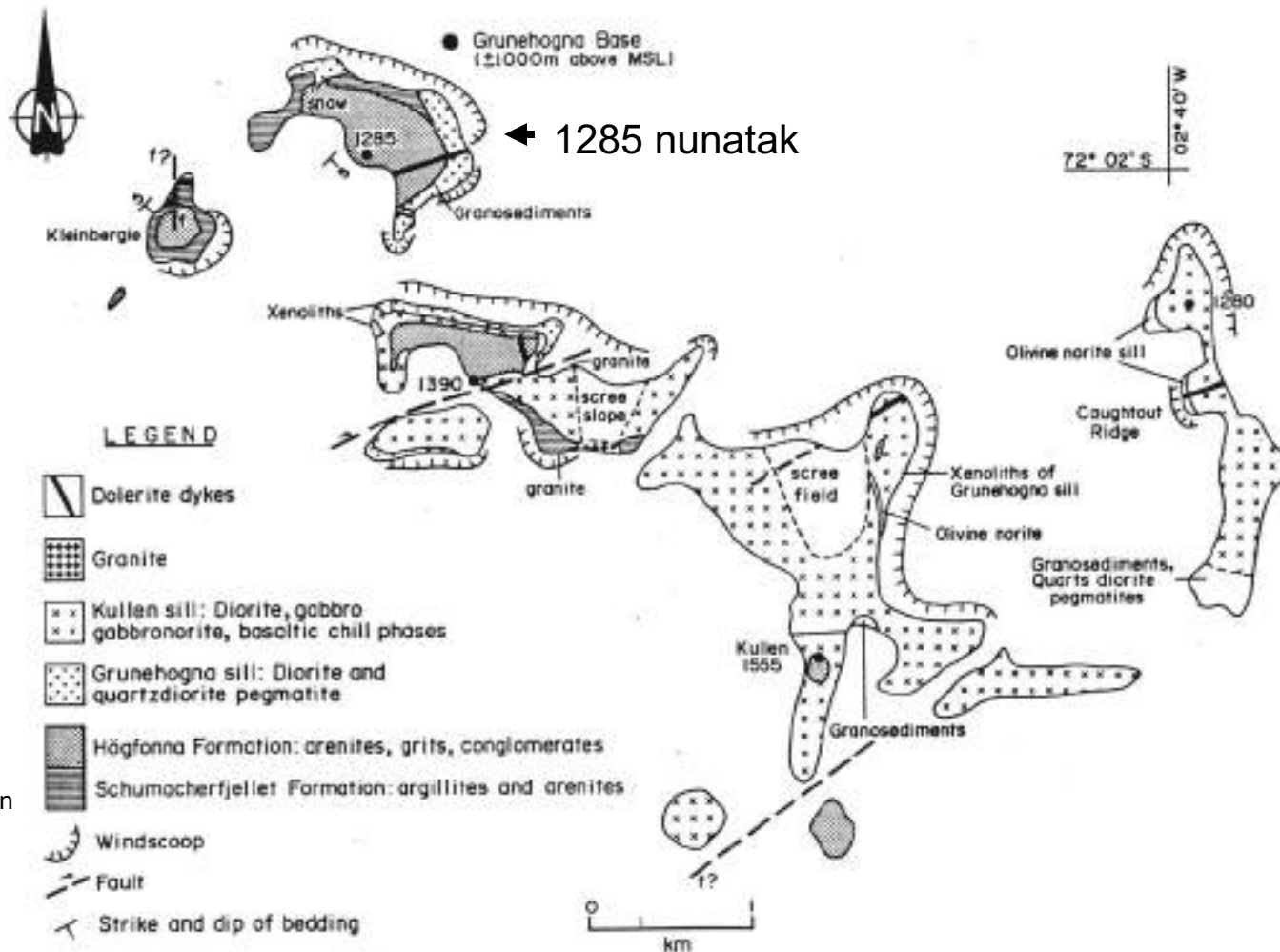
Figure 1. Outcrop map of Western Dronning Maud Land, Antarctica, showing the localities mentioned in the text. The shaded areas have a K₂O-Sr biotite mineral age veil of about 430 Ma. (After Barton et al., 1986b, Fig. 1).



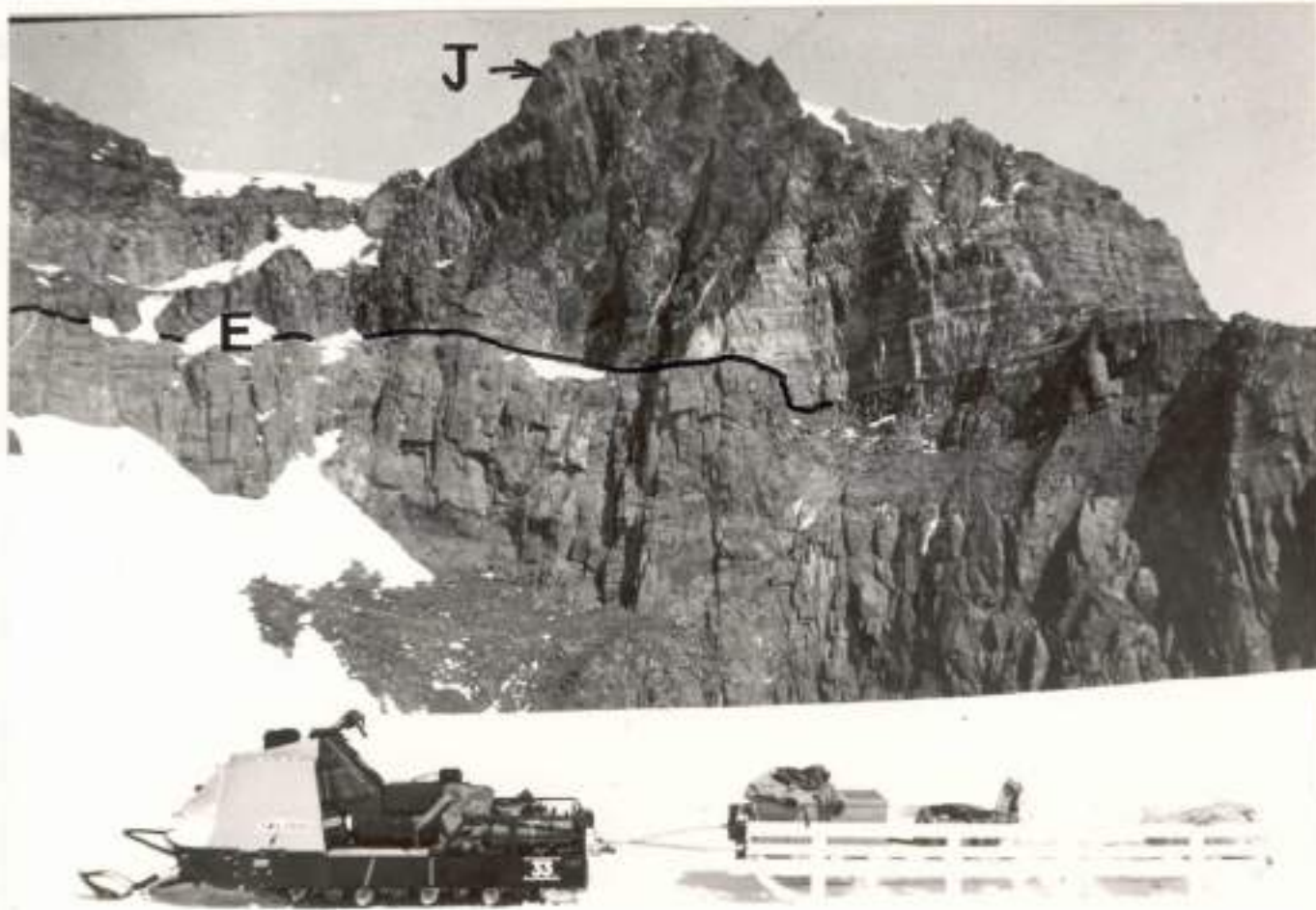
Schematic section of geology of WDML,
showing faulting From Krynaauw (1986), Ph.D. thesis, UNP

Geology of the Grunehogna and Kullen Areas, West Dronning Maud Land, Antarctica

From Krynauw (1986); modified after Aucamp (1972), Bredell (1976).

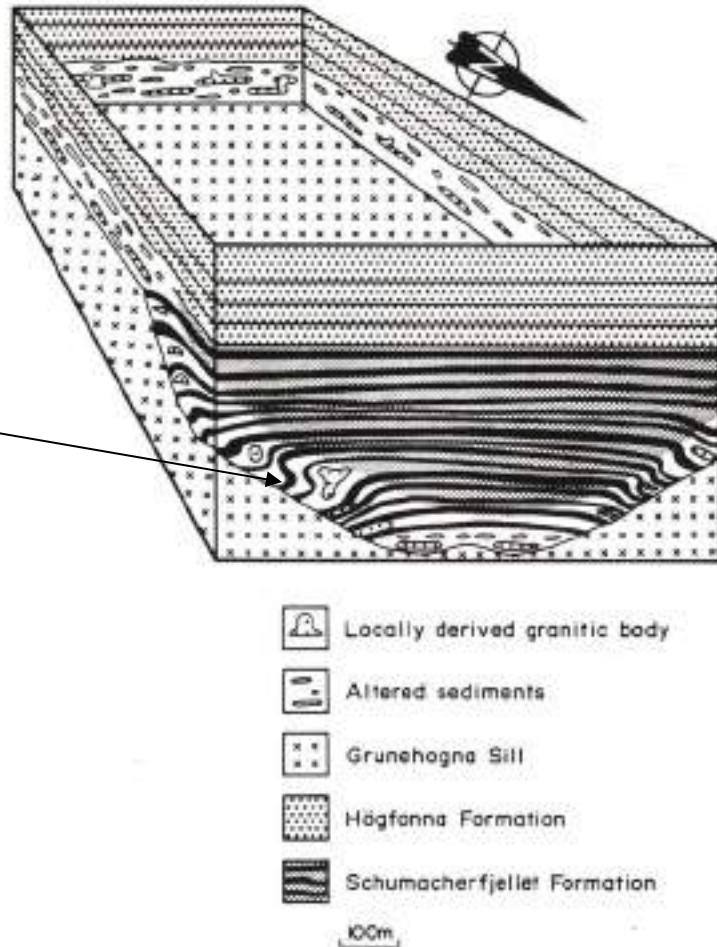


Ritscherflya
Supergroup,
Ahmannryggen
Group

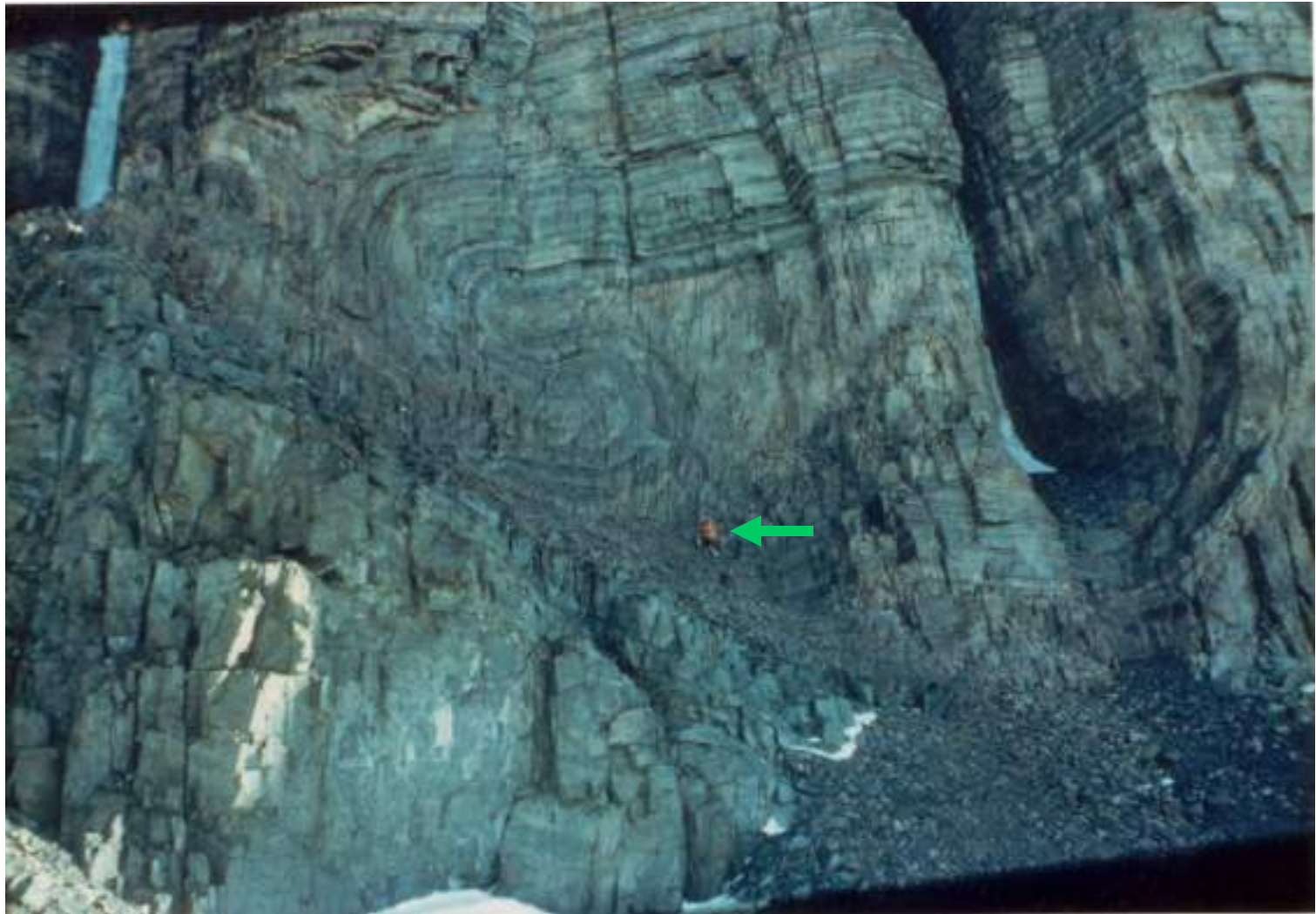


Dyke (J) transgressed by Kullen Sill along plane E, near nunatak 1390, Kullen area, WDML, Antarctica.

From Krynauw (1986), Ph.D. thesis, UNP



Schematic block diagram of Grunehogna sill-sediment relationships in the 1285 nunatak, Grunehogna area, WDML, Antarctica. From Krynauw (1986), Ph.D. thesis, UNP



S-fold in Schumacherfjellet Formation along contact with Grunehogna sill, 1285 north face. Note person for scale (arrow). From Krynauw (1986), Ph.D. thesis, UNP



Contorted laminations in **sedimentary xenolith** from the Grunehogna Sill, 1285 nunatak, SE windscoop, WDML, Antarctica. From Krynauw (1986), Ph.D. thesis, UNP



Wispy laminations in **granosediment**, 1285 SE face, Grunehogna area, WDML, Antarctica

From Krynauw (1986), Ph.D. thesis, UNP



Grunehogna **pegmatitic granophyre**, 1390 N face,
Grunehogna area, WDML, Antarctica.

The dark mineral is hornblende, white laths are albite, and brick-red areas consist of granophyric intergrowths of quartz and K-feldspar. From Krynauw (1986), Ph.D. thesis, UNP



Ahlmannryggen Gp, Ritscherflya Supergroup, WDML, Antarctica

From Krynauw (1986), Ph.D. thesis, UNP

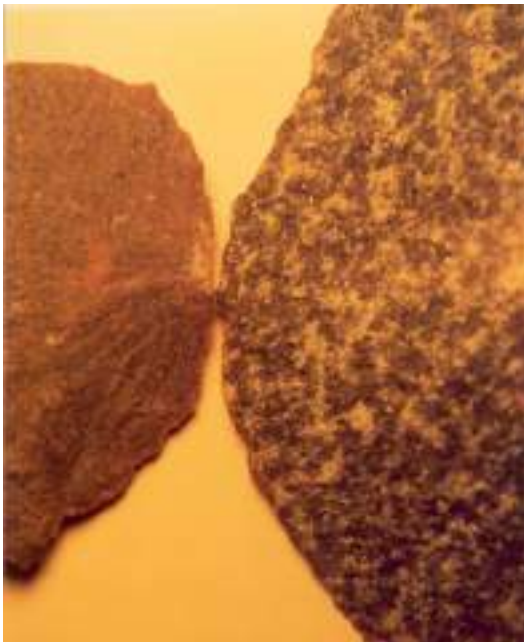
Umkondo Group, Zimbabwe





Granophyre, Borgmassivet Intrusions, WDML, Antarctica

From Krynauw (1986), Ph.D. thesis, UNP

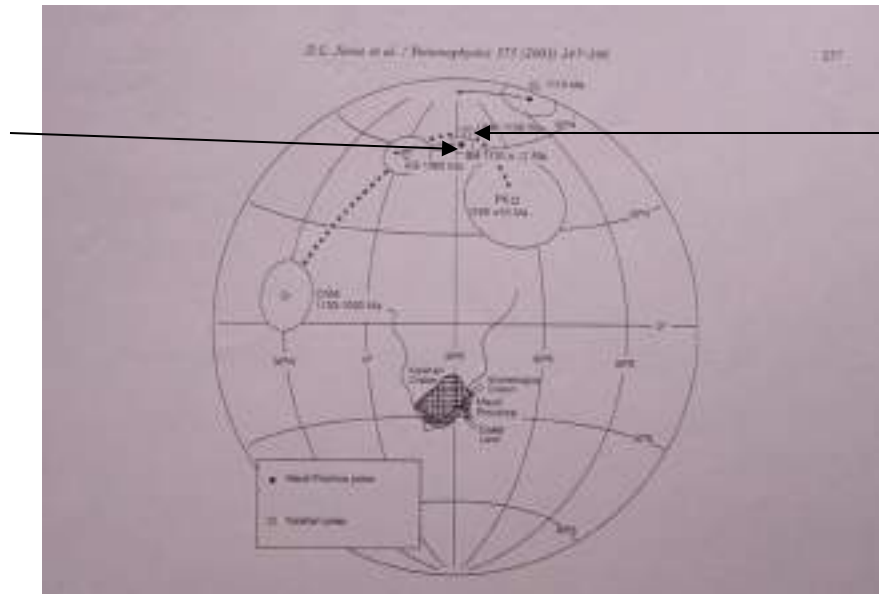


Granophyre, Umkondo Sills, Zimbabwe

Comparisons of Ritscherflya Supergroup (Antarctica) and Umkondo Group (Zimbabwe).

Palaeomagnetism of Intrusions

**Borgmassivet
Intrusions,
Ahlmannryggen
Group**



**Umkondo sills
and lavas**

Jones et al. (2003), Tectonophysics, 375, 247-260.

- Mafic sills in the Umkondo and Ahlmannryggen Groups show remarkable similarities in terms of age, composition, palaeomagnetism. This study demonstrates that they also share a common field characteristic, i.e., evidence for intrusion into unconsolidated wet sediments, with the formation of peperitic breccias, contaminated and metasomatised “granosediments”, and coarse-grained granophyres.

- This field and petrographic evidence indicates that during the intrusion of Umkondo LIP, sediments in both the Umkondo Gp and Ritscherflya Sgp were still unconsolidated- ***hence their ages are similar and they may have been part of the same foreland basin system***

Högfonna Formation
Ahlmannryggen Group
Ritscherflya Supergroup
West Dronning Maud Land
Antarctica

New detrital zircon U-Pb geochronological results

(ICP-MS, Wits University)

Sandstone, Högfonna Formation, Antarctica

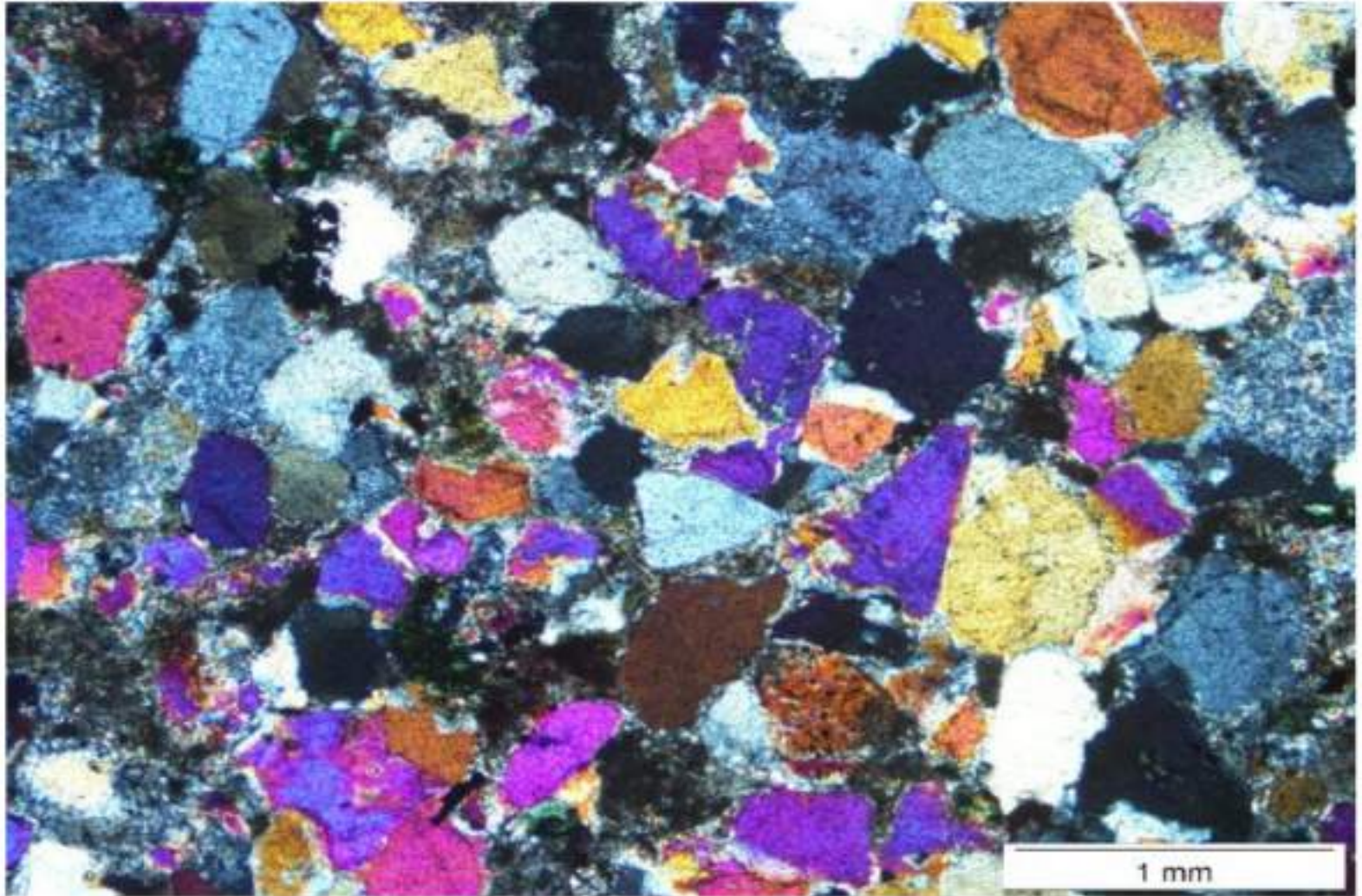
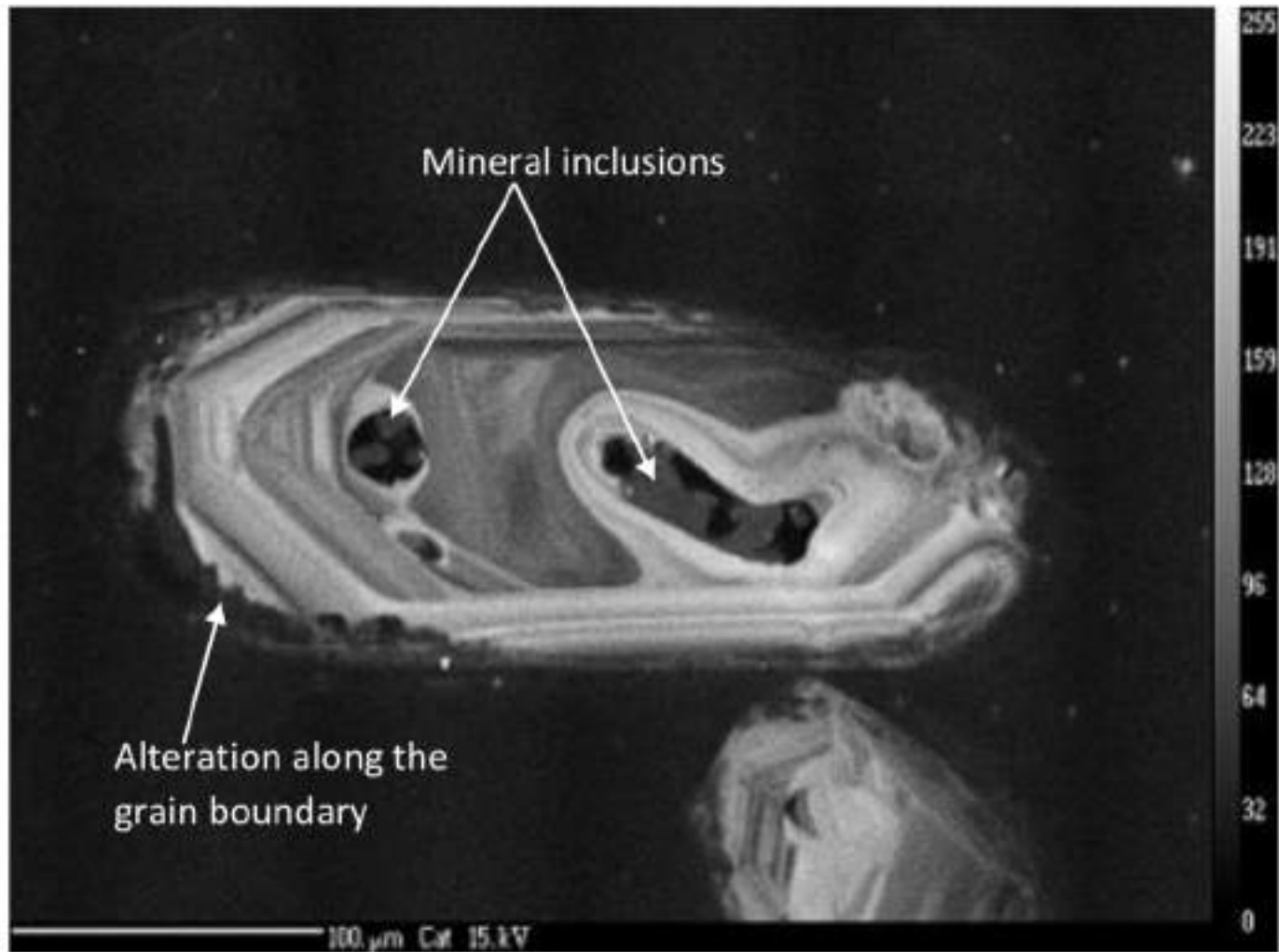
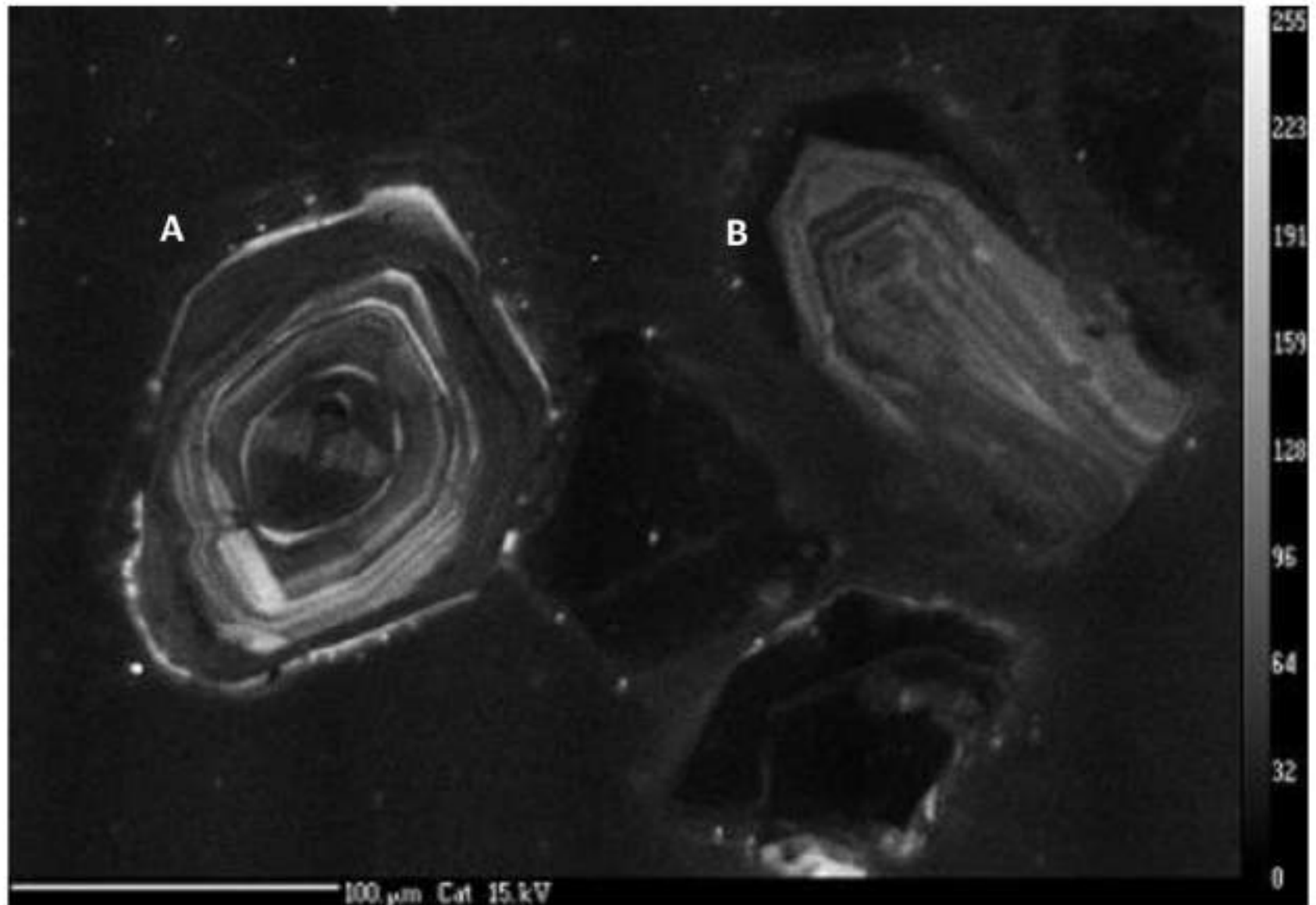


Figure 4 (xpl): Quartz clasts in a matrix of biotite, chlorite, epidote, sericite, fine-grained quartz and calcite cement.

Magmatic zircons with inclusions, Högfonna Formation, Antarctica



Oscillatory zoning in magmatic zircons from Högfonna Fm, Antarctica



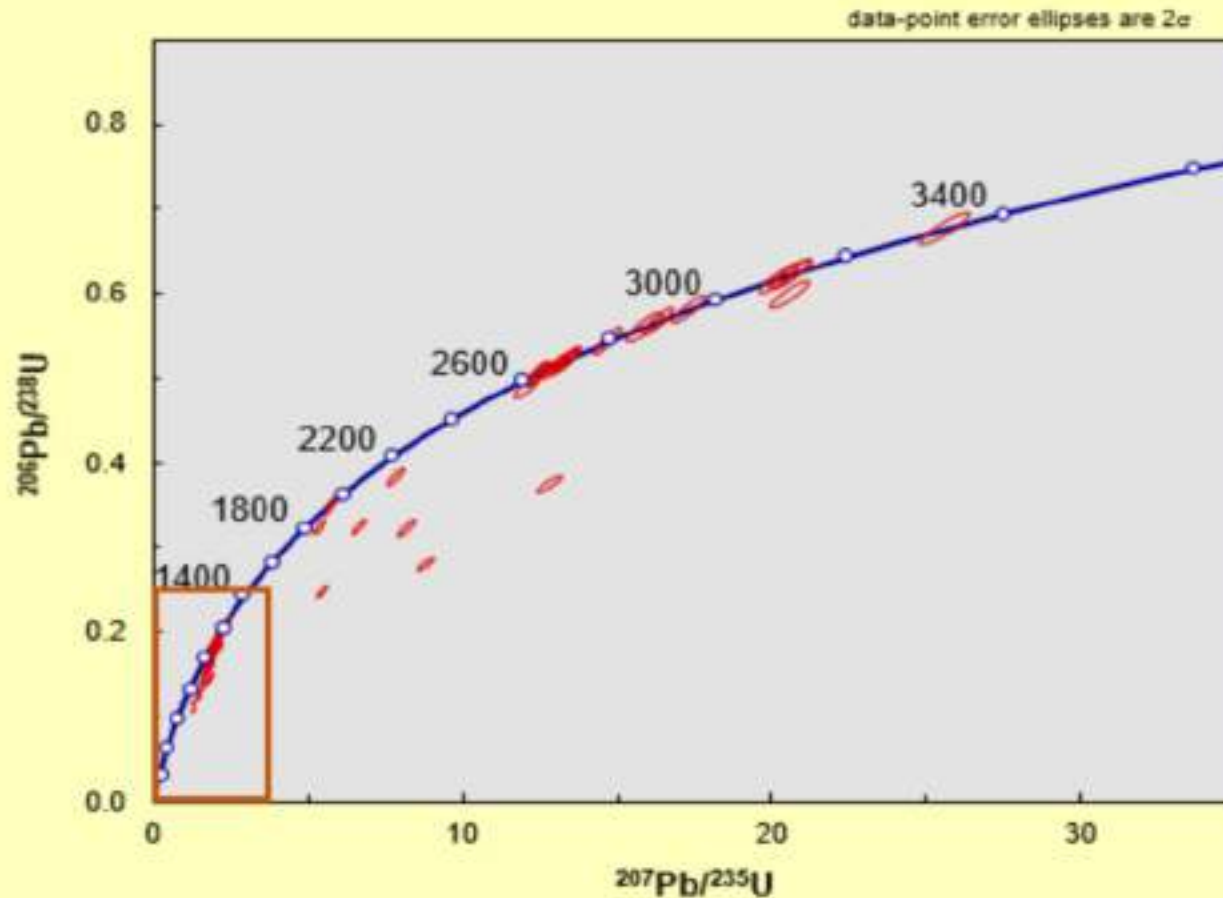


Figure 7: $^{207}\text{Pb}/^{235}\text{U}$ vs $^{206}\text{Pb}/^{238}\text{U}$ concordia diagram of ages of detrital zircon grains from the Hogfonna Formation of the Ahlmannryggen Group in the Ritscherflya Supergroup, Antarctica. Zircons were recovered from sample RB4 and the ages are reported in Ma. The **boxed** area is enlarged in figure 8.

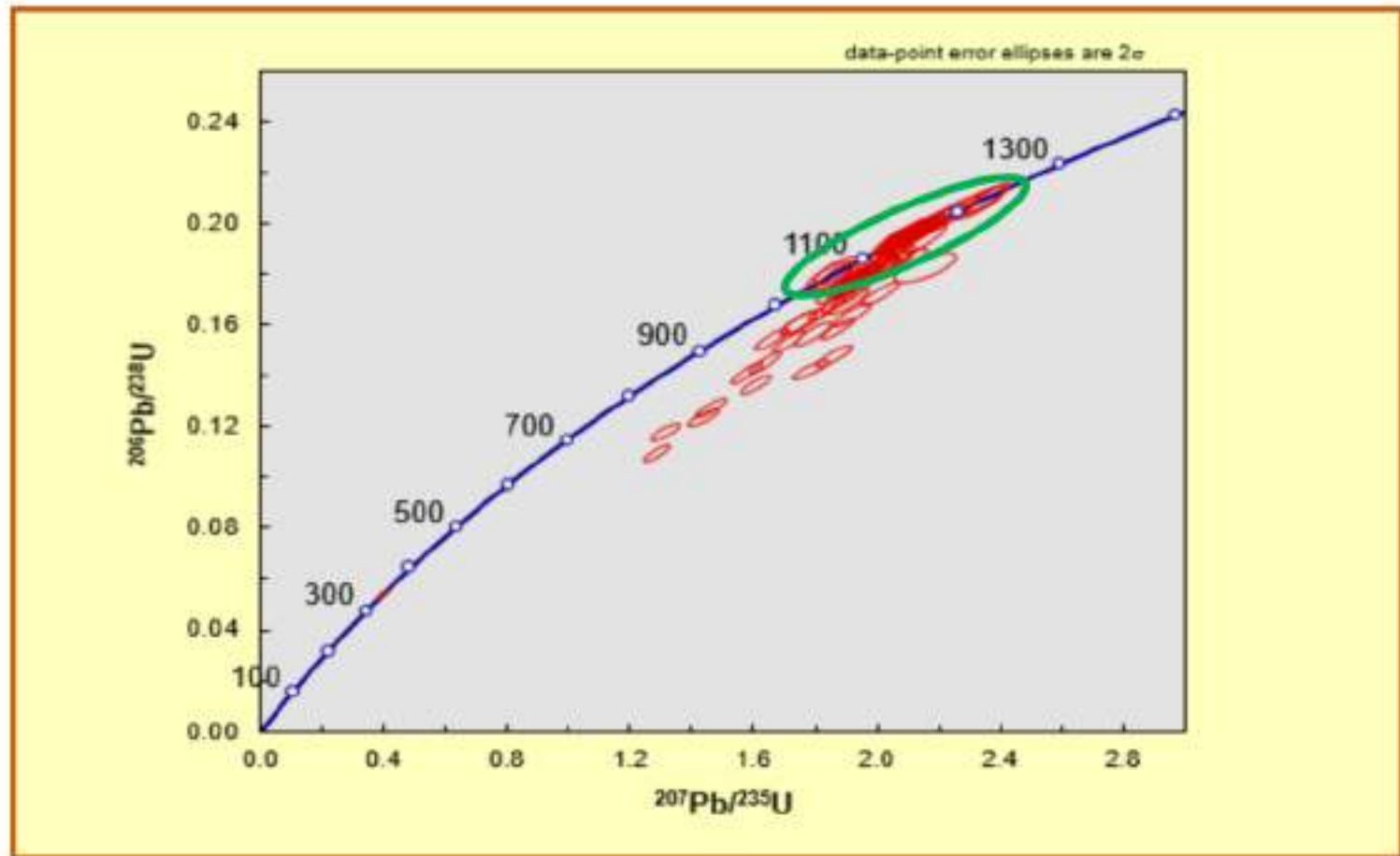


Figure 8: enlarges the **boxed** area in figure 7 to show a **cluster** of late Mesoproterozoic ages. Approximately 68% of the ages are late Mesoproterozoic. Ages with more than 10% discordance are not included in the discussion.

Högfonna Fm, Antarctica

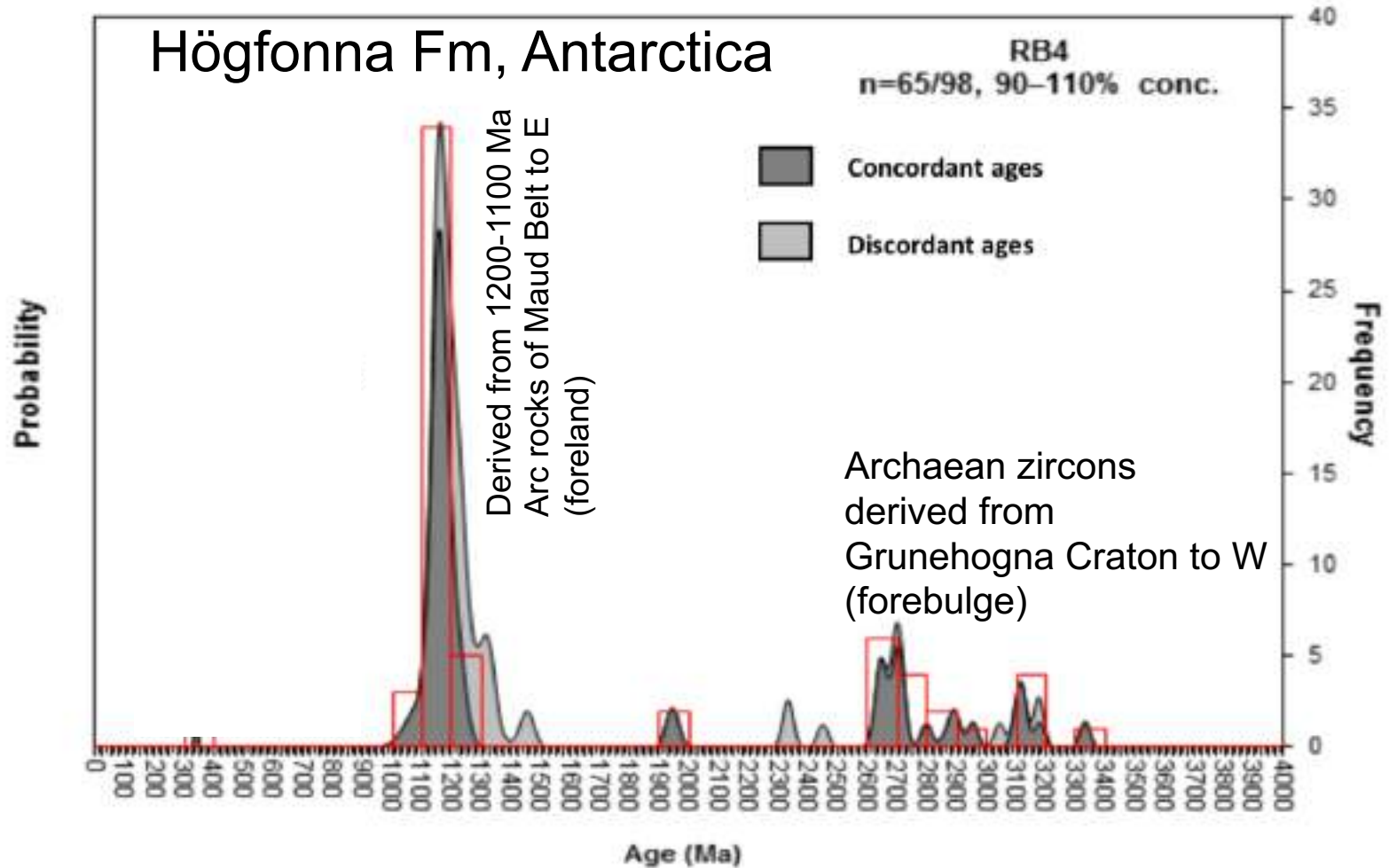
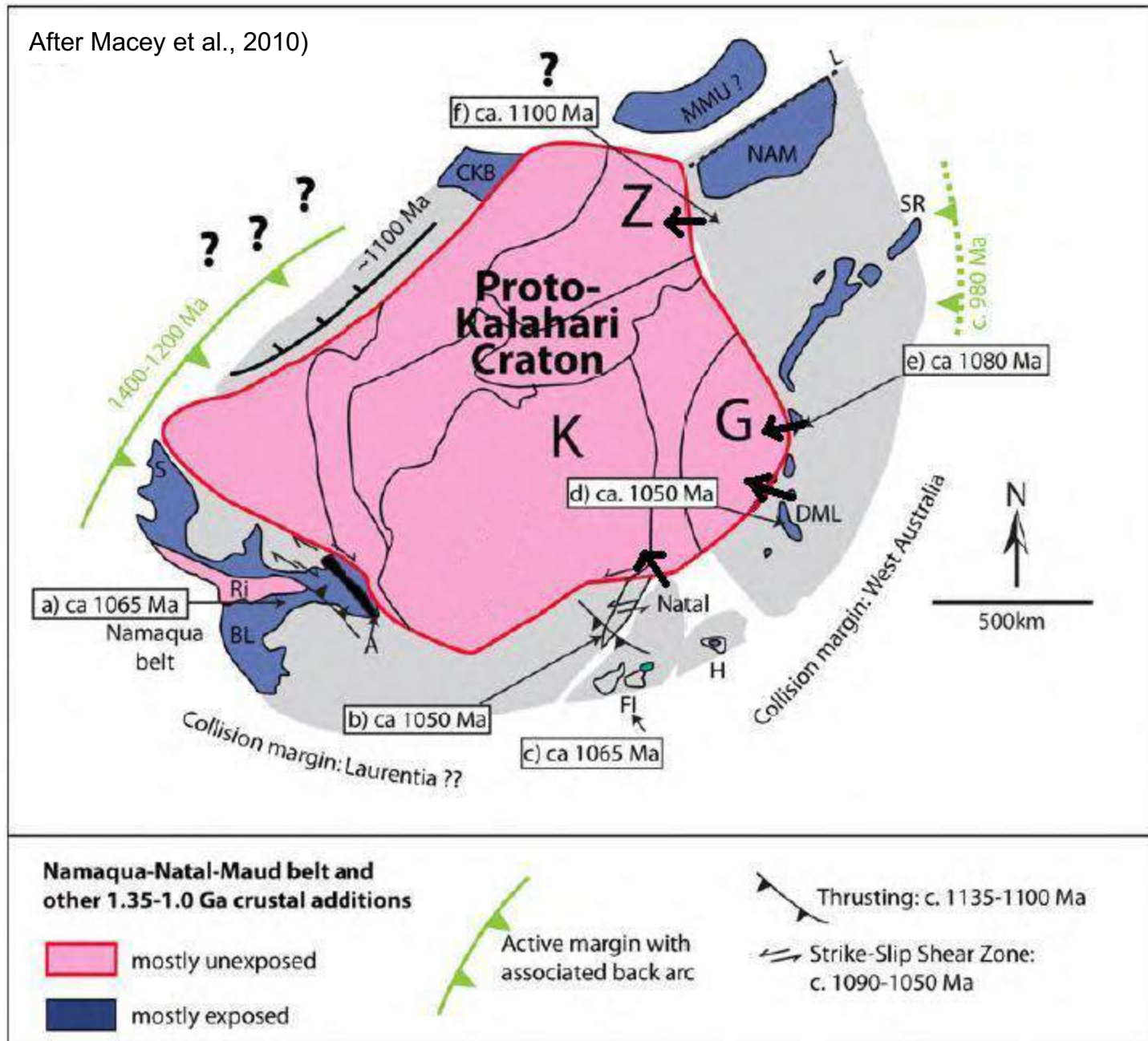
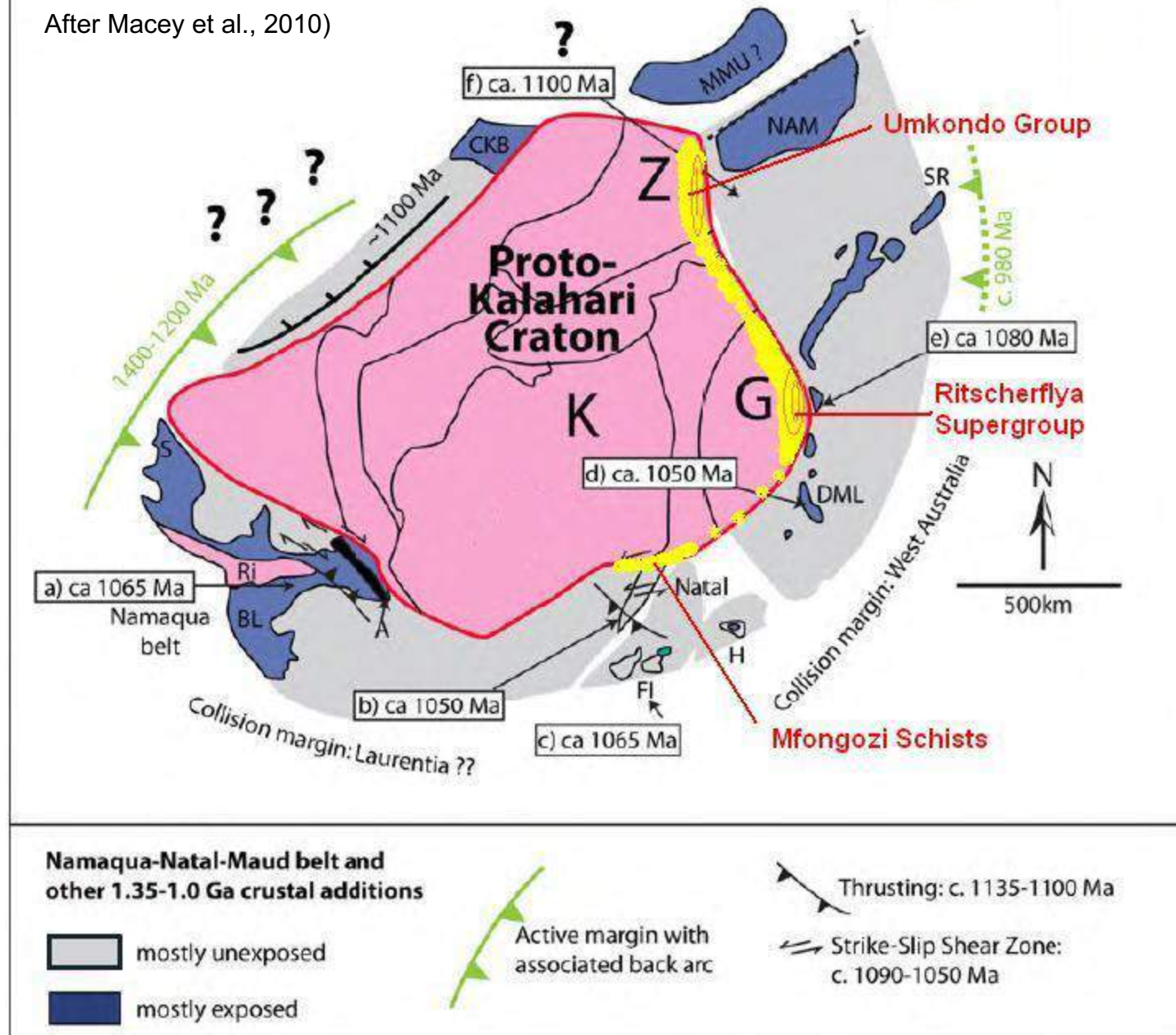


Figure 9: A plot showing the distribution $^{207}\text{Pb}/^{206}\text{Pb}$ zircon ages for sample RB4. The plot combines a probability density diagram which plots ages in Ma against probability, with a histogram which plots ages in Ma against frequency. n is the number of zircons analysed. 65 of 98 analyses are concordant.

After Macey et al., 2010)



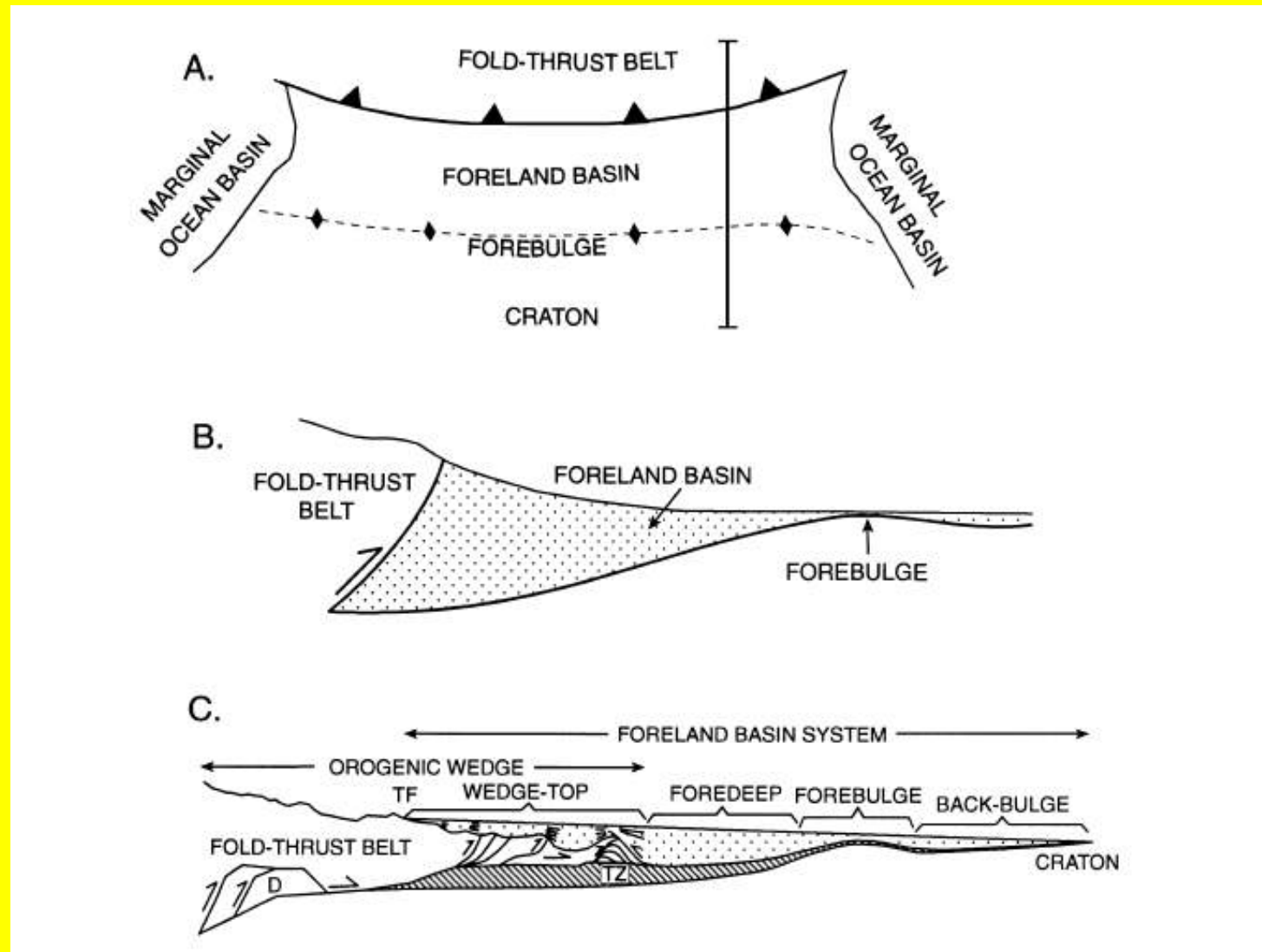
After Macey et al., 2010)



A foreland basin system is defined as

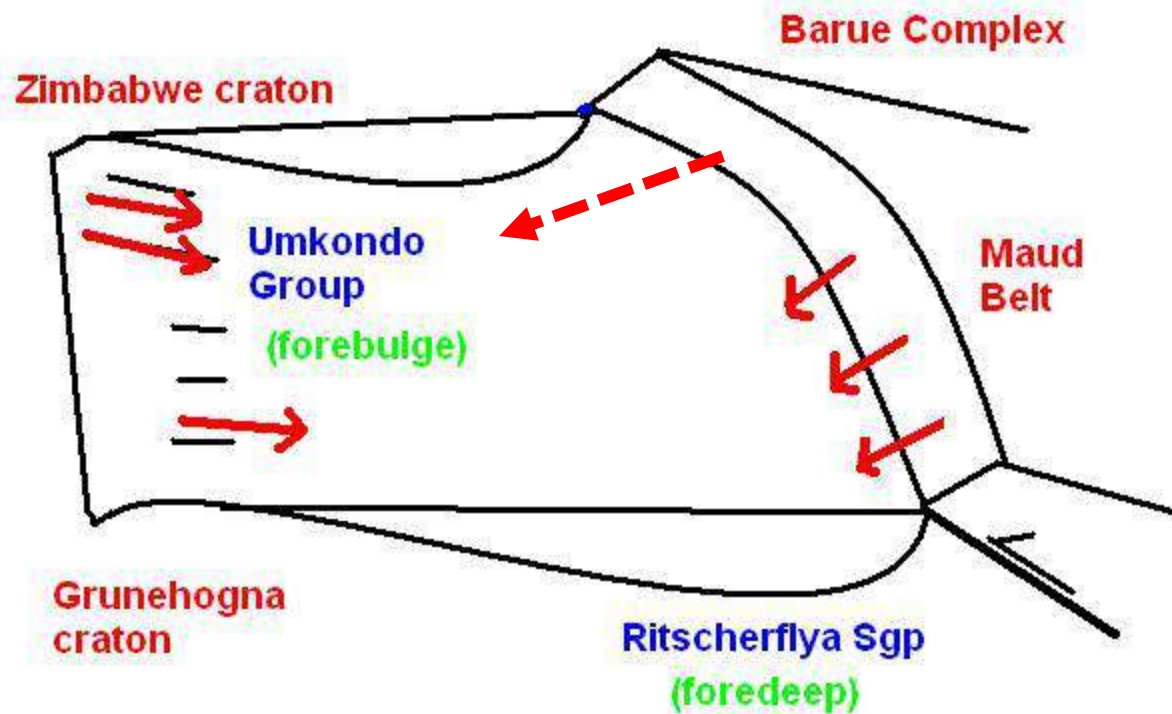
“an elongate region of potential sediment accommodation that forms on continental crust between a **contractional orogenic belt and the adjacent craton**, mainly in response to geodynamic processes related to subduction and the resulting peripheral or retroarc fold-thrust belt” (DeCelles and Giles, 1996).

Foreland Basins

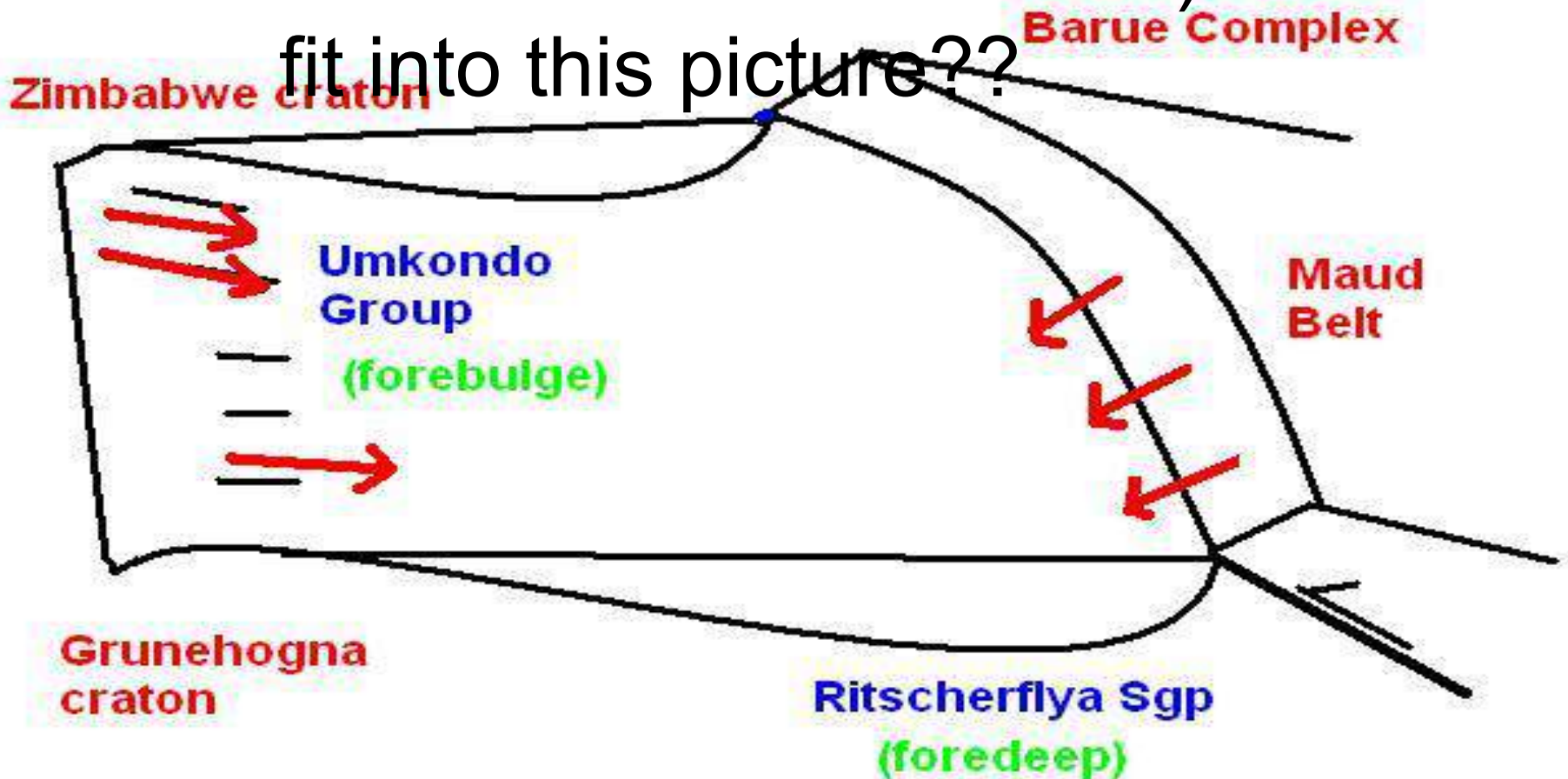


De Celles & Giles 1996

Schematic relationship between the Umkondo Group and Ritscherflya Supergroup



So where does the Frontier
Group (including the
Chimanimani Mountains)
fit into this picture??



Chimanimani (Frontier Gp) quartzite, with Hm => age <2.3 Ga

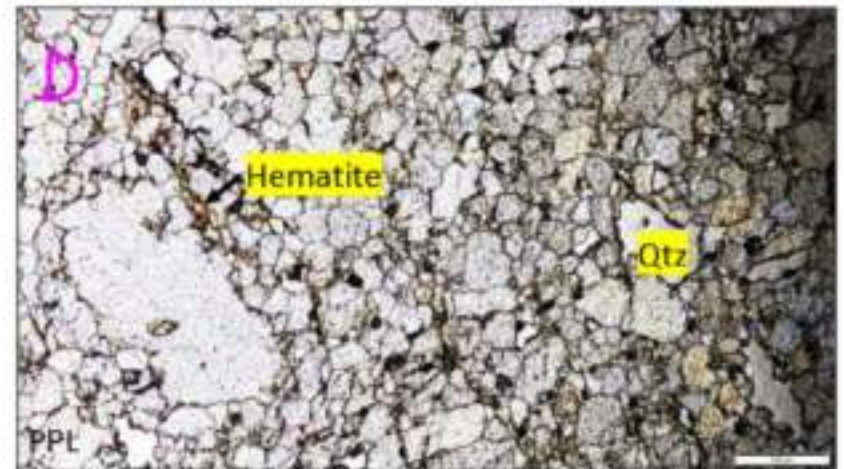
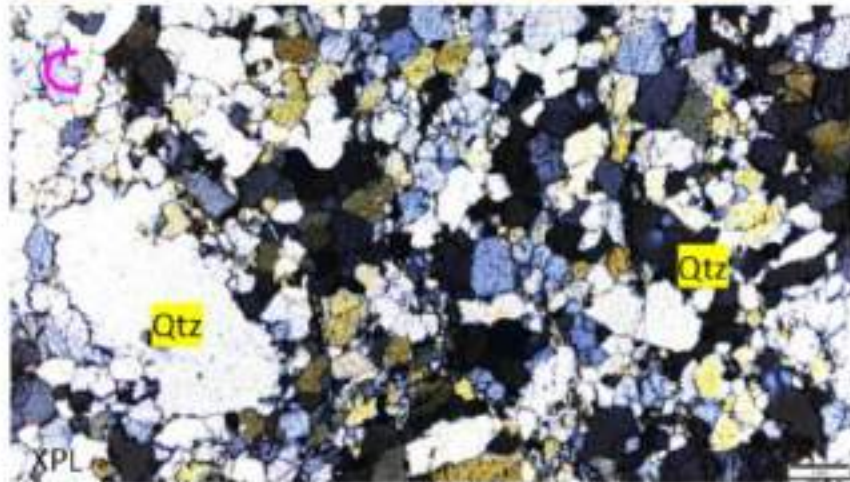
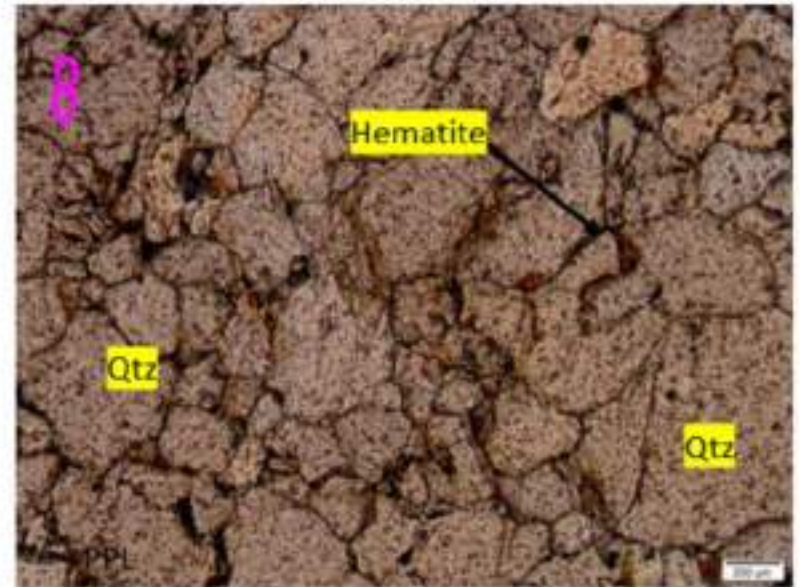
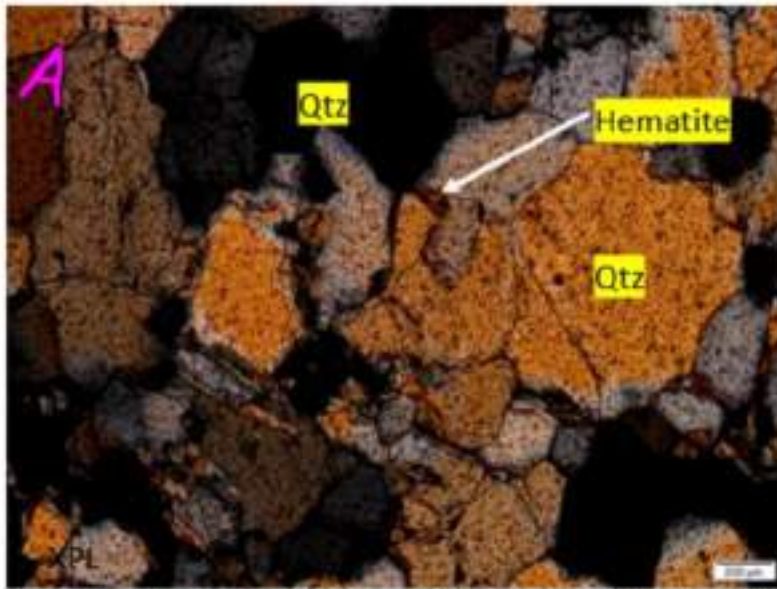


Figure 5: A and B shows a thin section of quartzite both in XPL and PPL at scale of 200µm whereas C and D is at a scale of 1mm.

Gairezi Schist, Frontier Group

Quartz-rich microlithon in muscovite-biotite schist

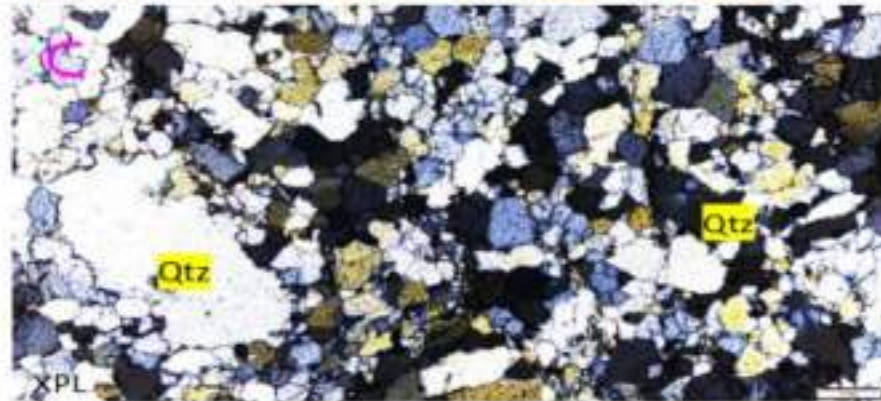
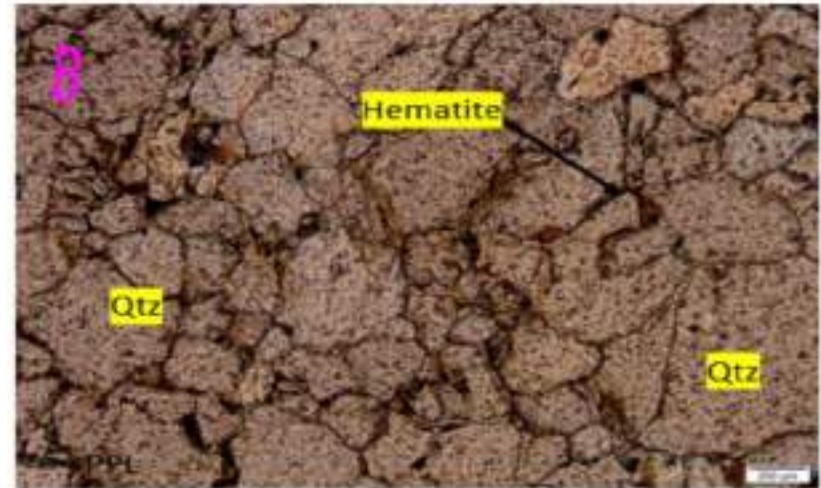
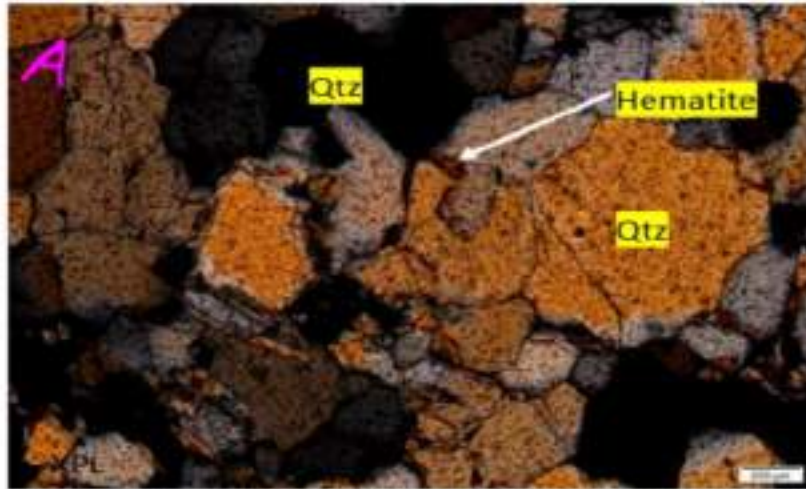


Figure 5: A and B shows a thin section of quartzite both in XPL and PPL at scale of 200µm whereas C and D is at a scale of 1mm.

Superposition of foreland basin on a former passive margin

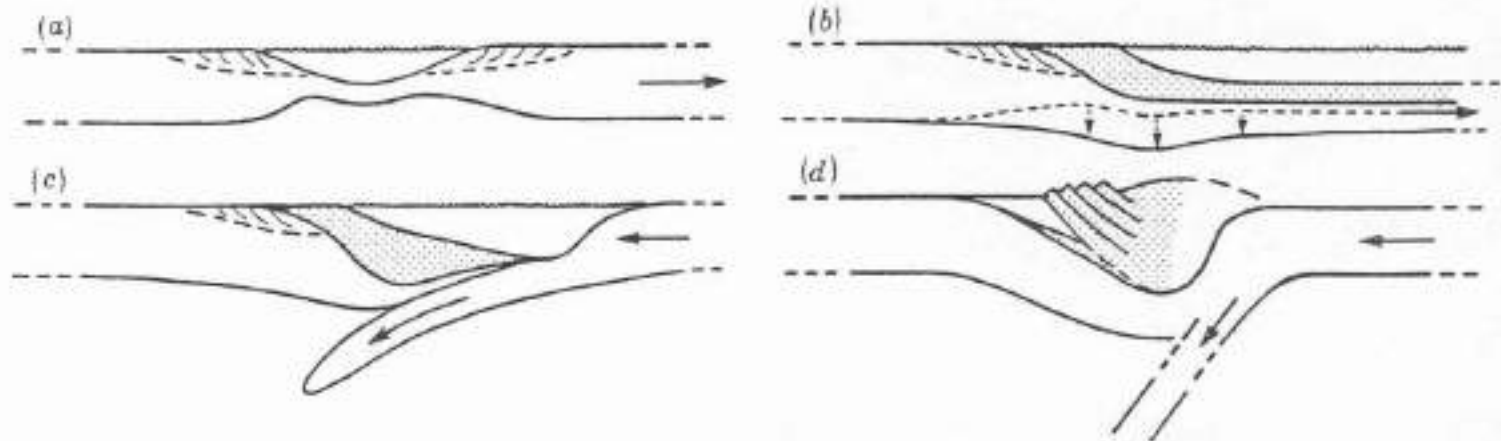


FIGURE 12. Diagrams illustrating the way in which a foreland basin can be superimposed on a rifted margin basin as a result of ocean closure. (a) Phase 1: rifting and initial subsidence. (b) Phase 2: drifting and thermal subsidence. (c) Phase 3: closure and stabilized margin. (d) Phase 4: collision and flexural subsidence.

(Beaumont, Keel & Boutilier, 1982)

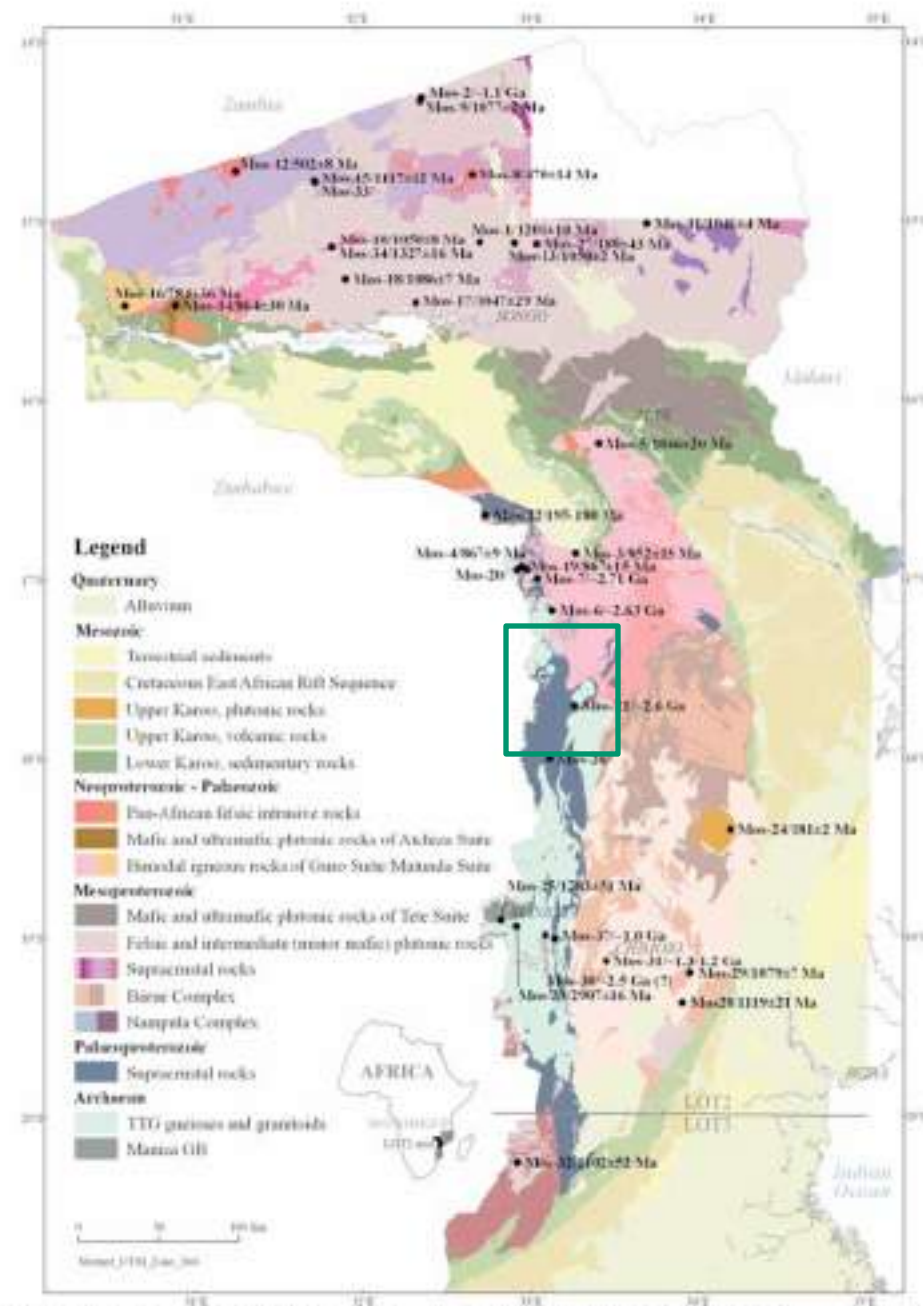


Fig. 1. Simplified geological map of the LUT 2 area, NW Mozambique (simplified and modified after the work by the GTK Consortium). Sample numbers and time of the dated rock samples are marked on map. See Table 1 for further sample information.

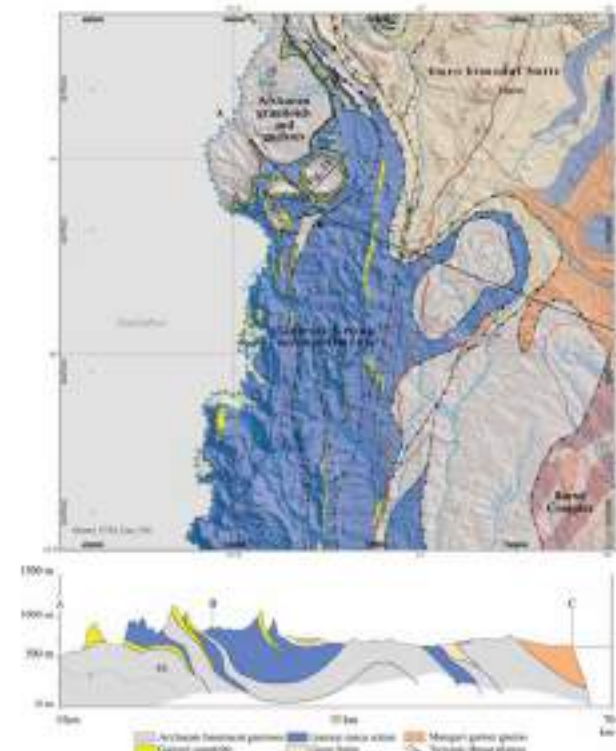
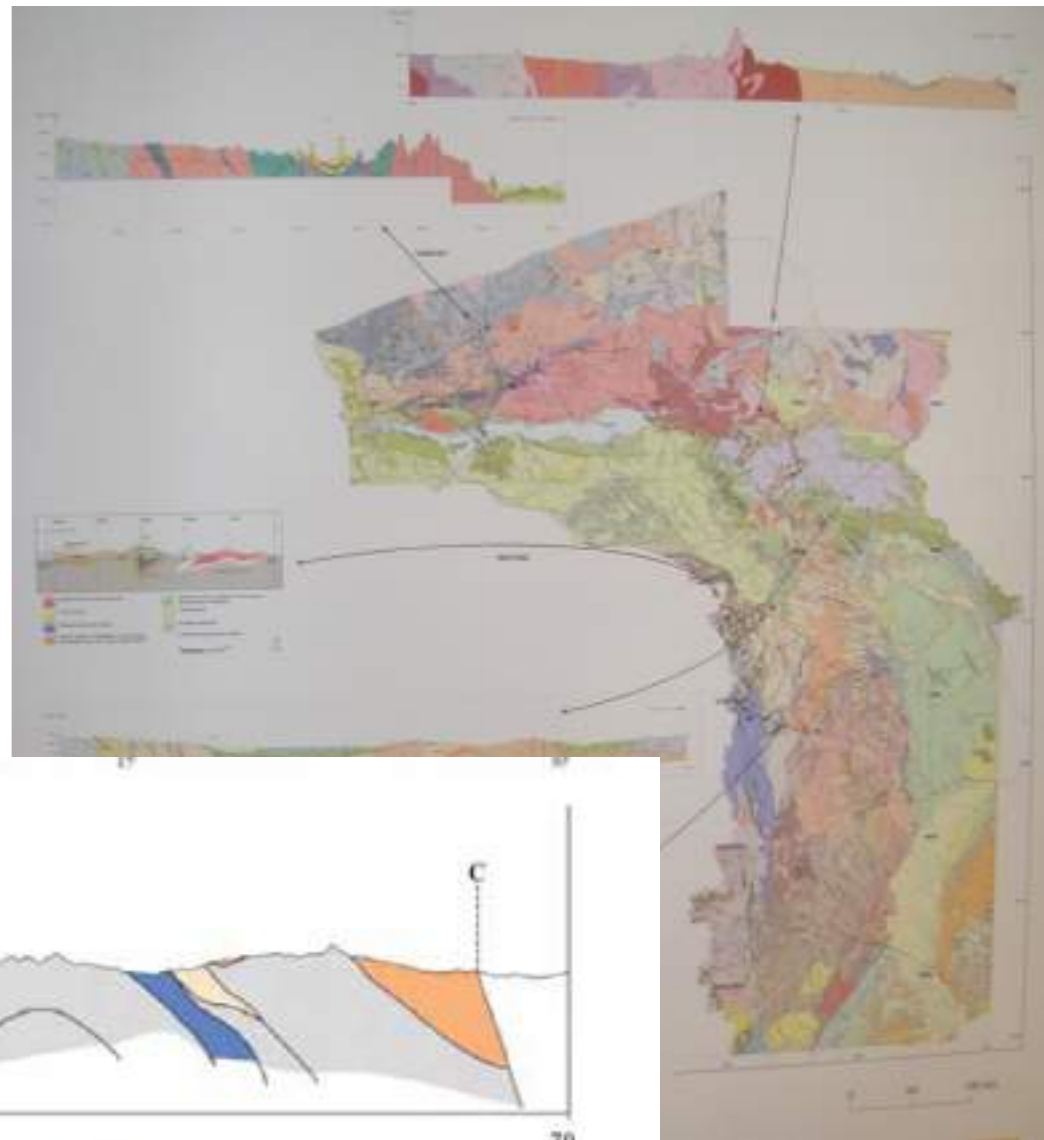
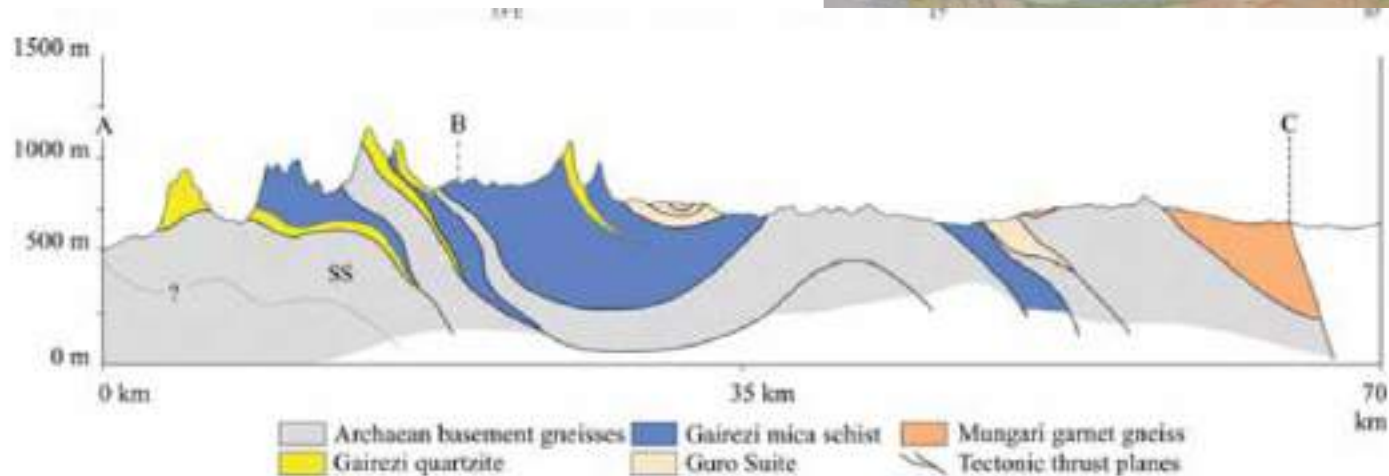
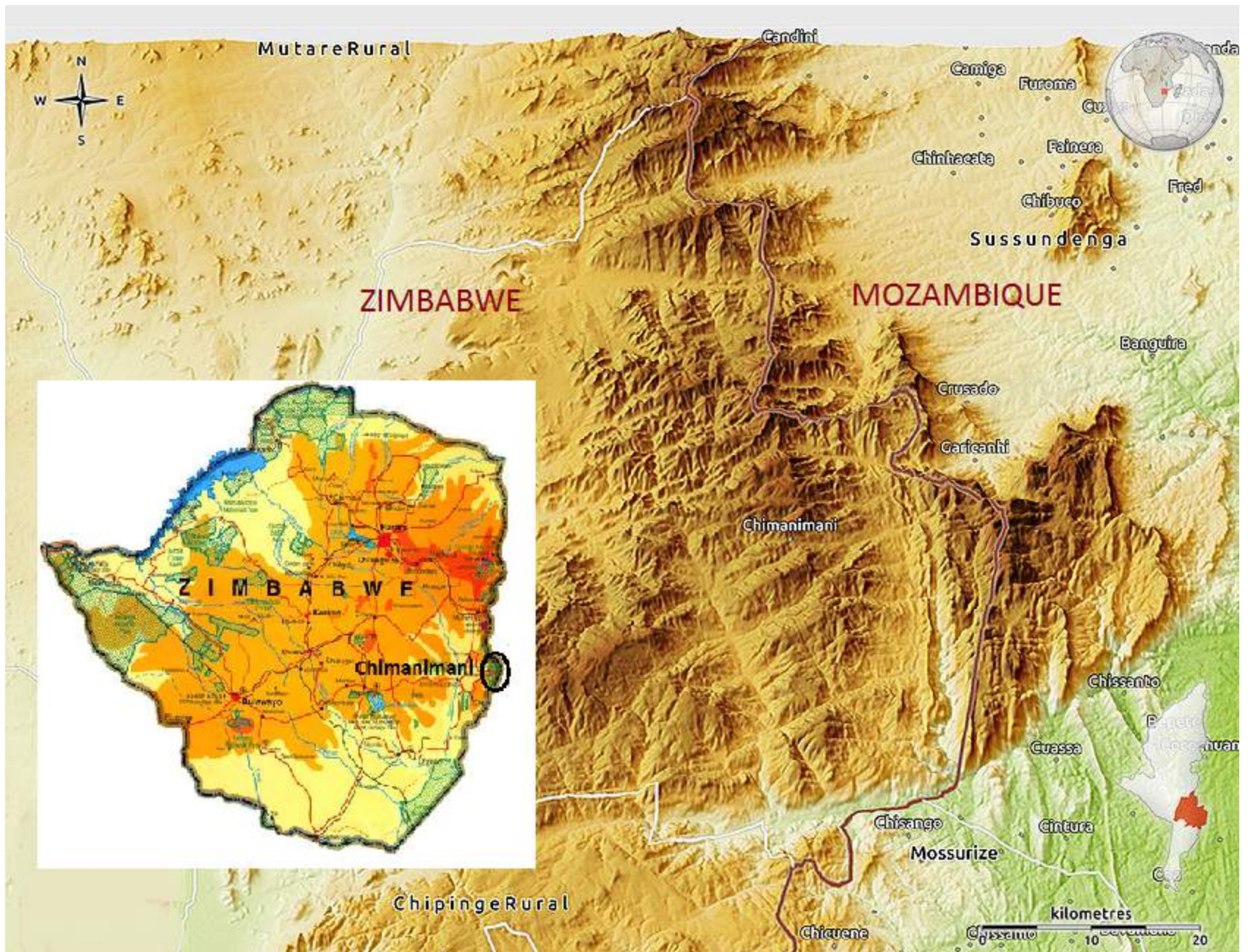


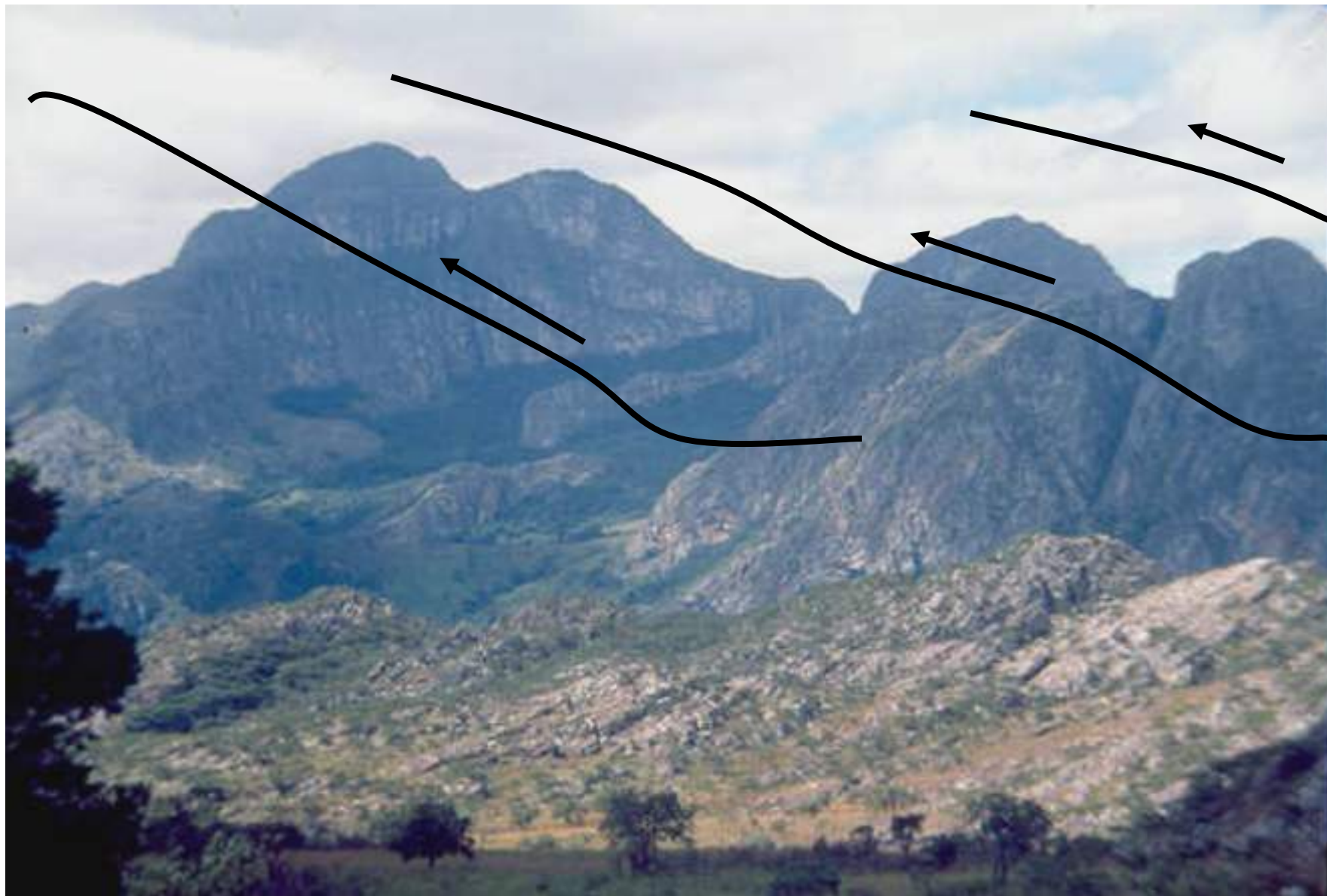
Fig. 2. Middle part of the cross-section. The top profile A-B-C shows part of the figure illustrating an interpretation of the structural information structure, using stratigraphy. Note the right group marked by a pair of letters D-E within in the profile A-B-C. And below the profile the group has given to time the large fragments of Fig. 11. East of C is shown in the profile the Indian Ocean, belonging to the Bimic Complex.

The Frontier Group (former passive margin) was thrust onto the Umkondo foreland basin during the Pan-African orogeny, which affected Dronning Maud Land.



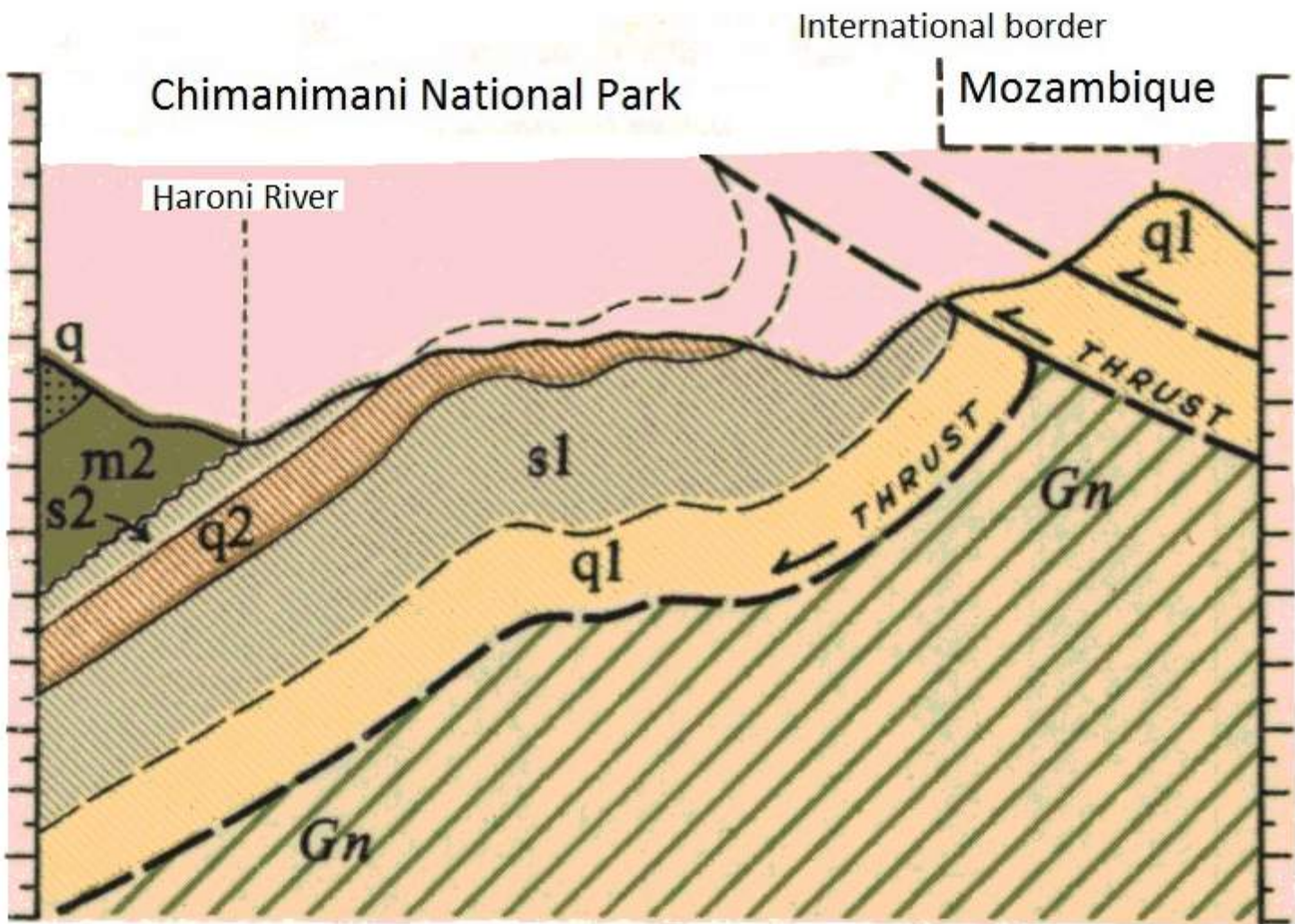








Cross sections through the Umkondo Group and Chimanimani Mts

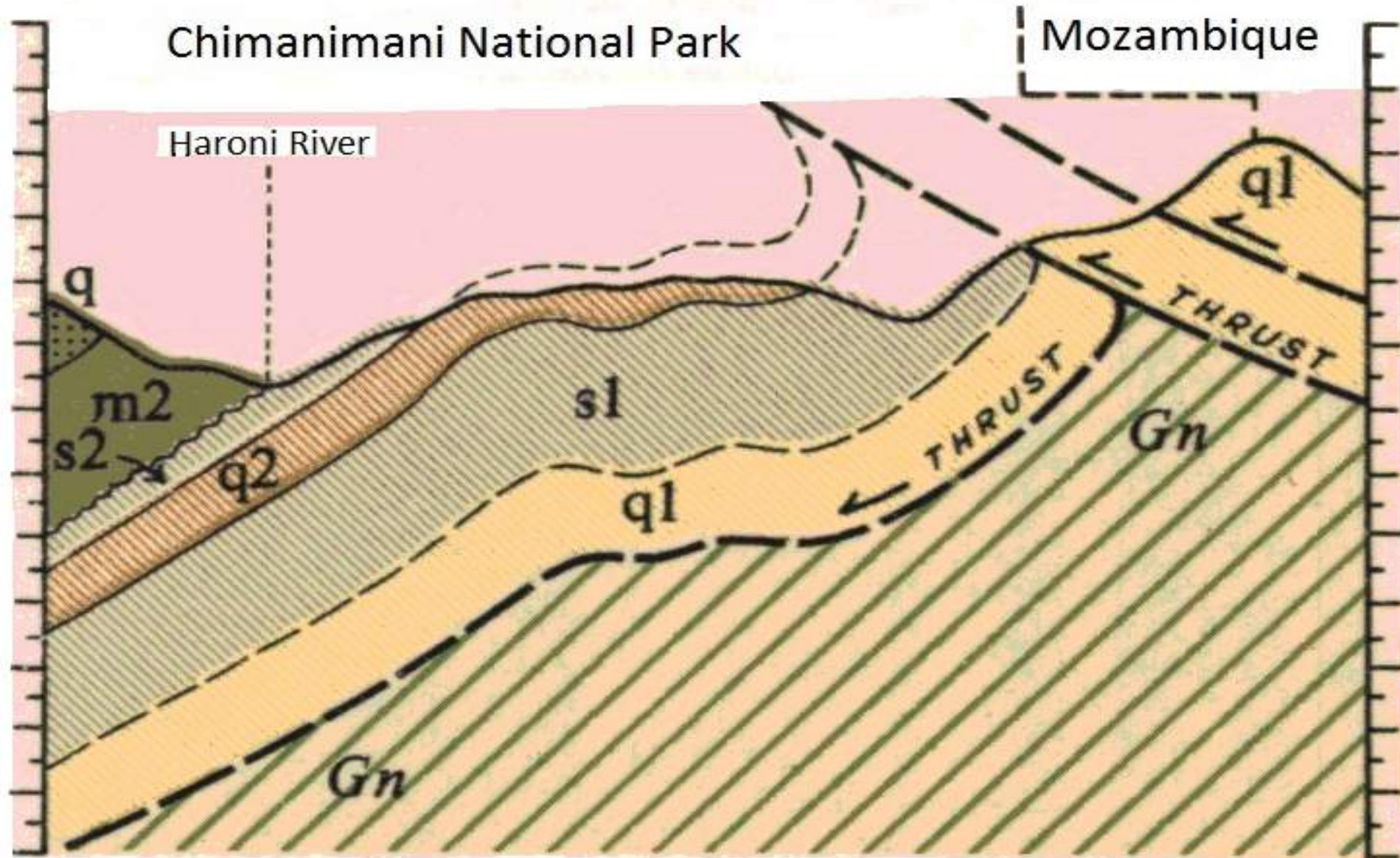


Chimanimani National Park

International border

Mozambique

Haroni River



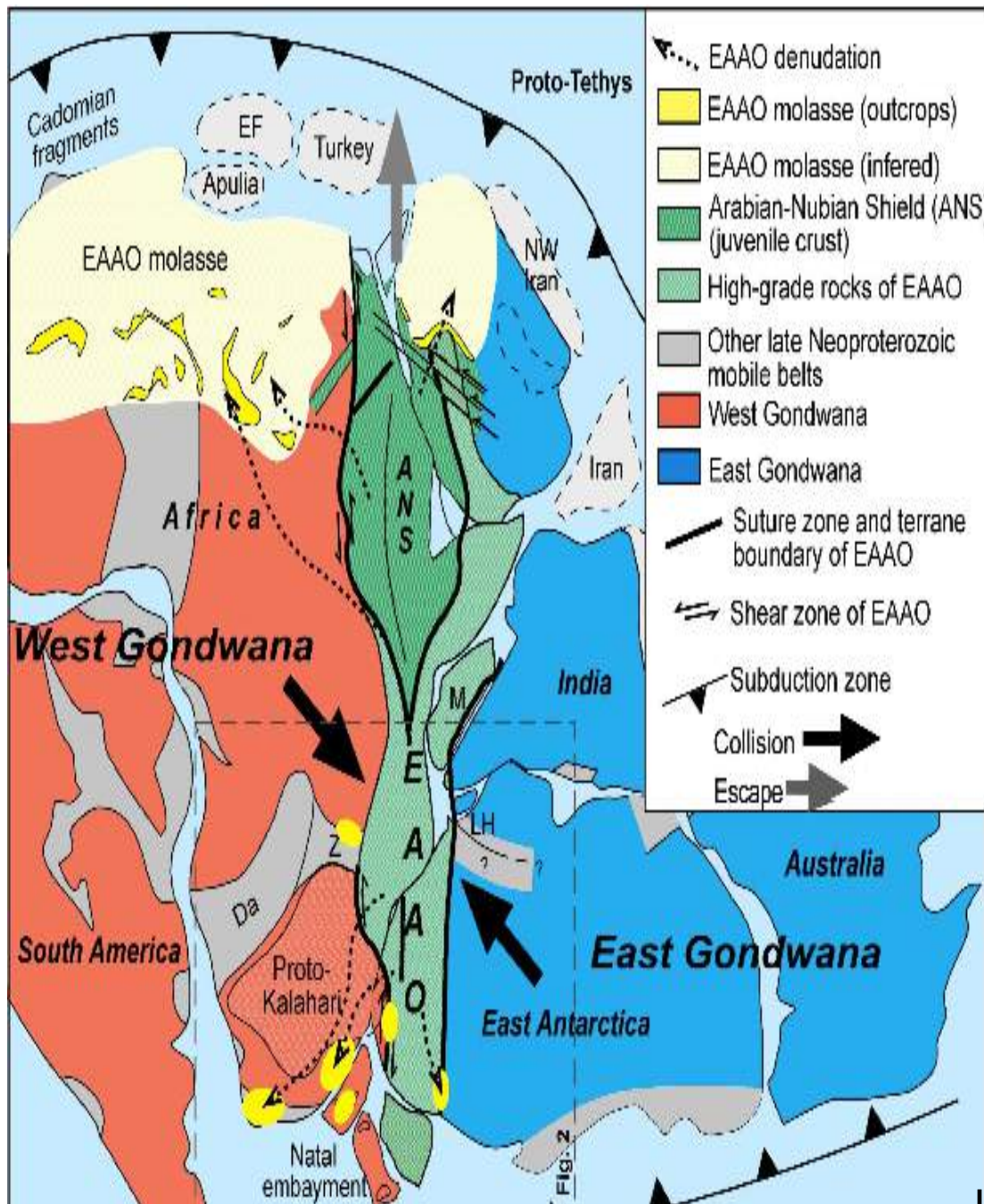


Late Pan-African thrusting, Chimanimani, c. 550 Ma (Snelling et al., 1964)

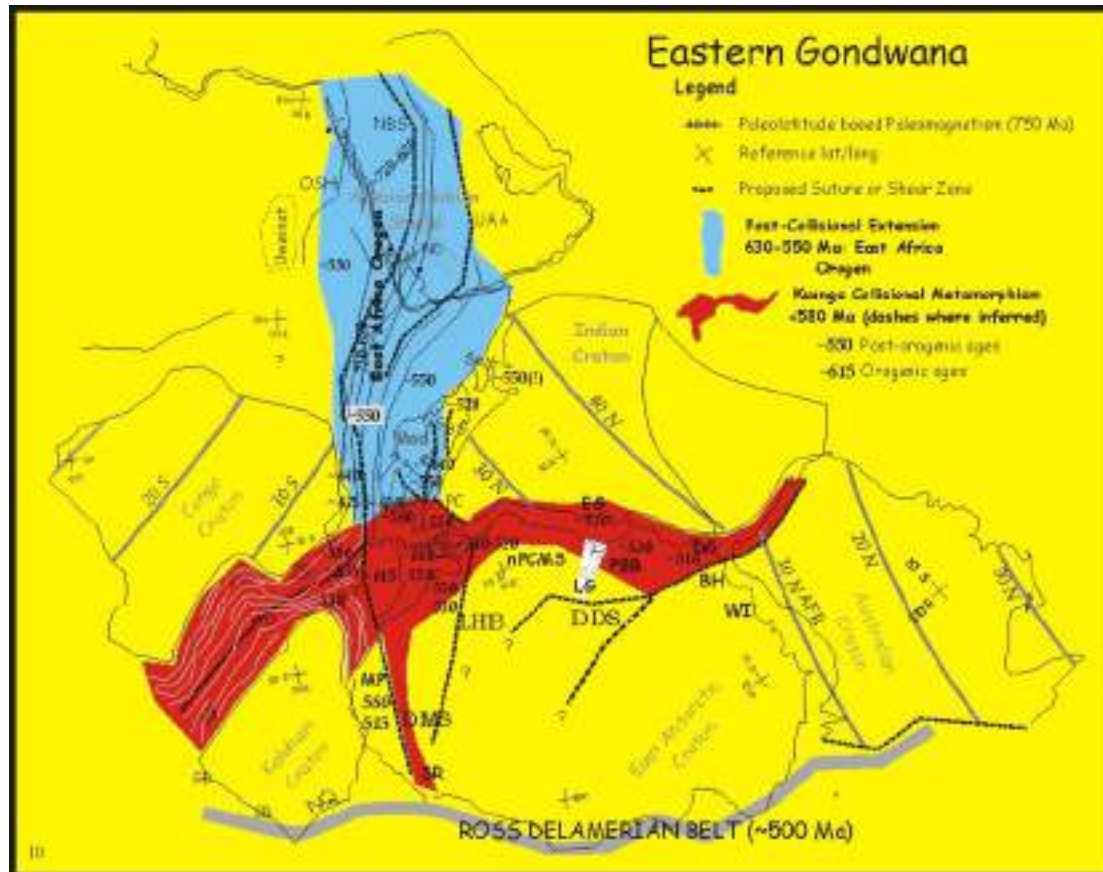
Pan-African deformation in Chimanimani is part of the East Africa-Antarctic Orogen



Jacobs, J. & Thomas, R.J. (2004)



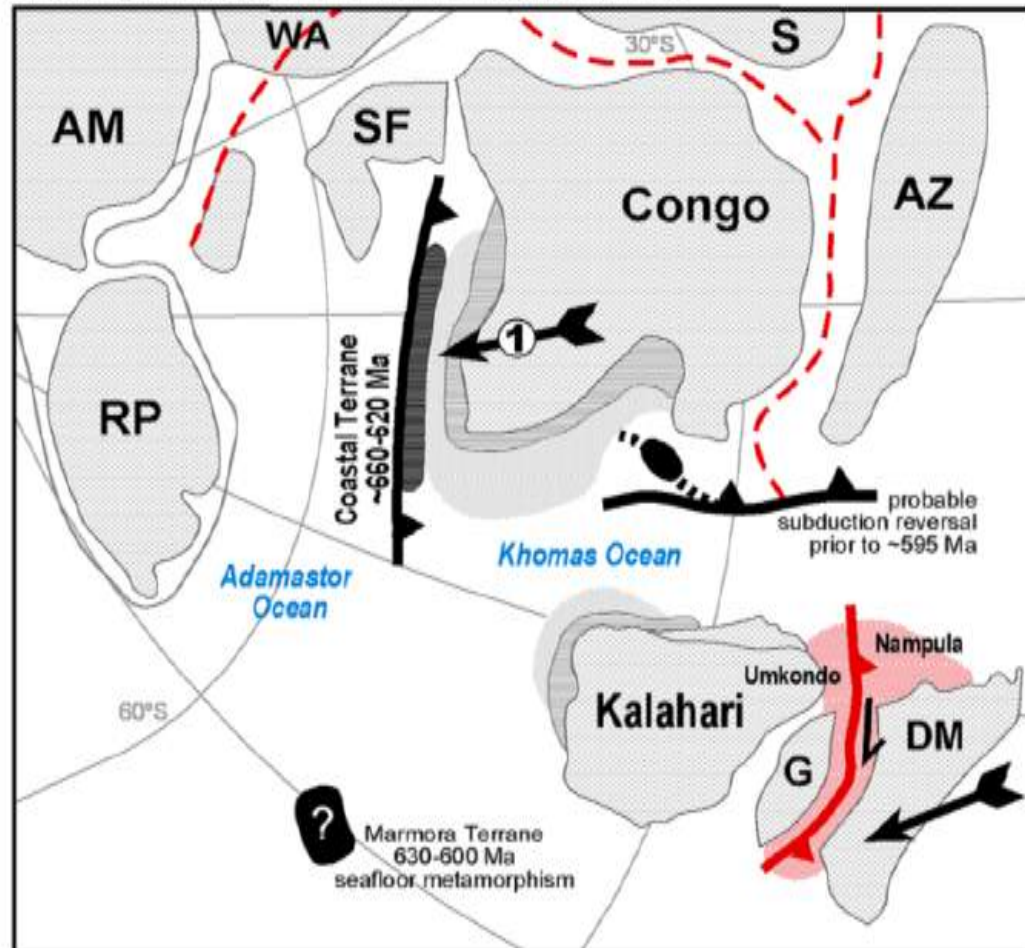
East Africa Antarctic Orogen in Southern Mozambique Belt, and in WDML, Antarctica, due to Pan-African collision of East Antarctica with Proto-Kalahari Craton (including Grunehogna Block), resulting in reactivation of structures in Maud Belt, and thrusting of the Frontier Group (Mozambique/Zimbabwe border region) onto Umkondo basin.



“Kuunga Orogen”

(c) 640-610 Ma Umkondo Phase

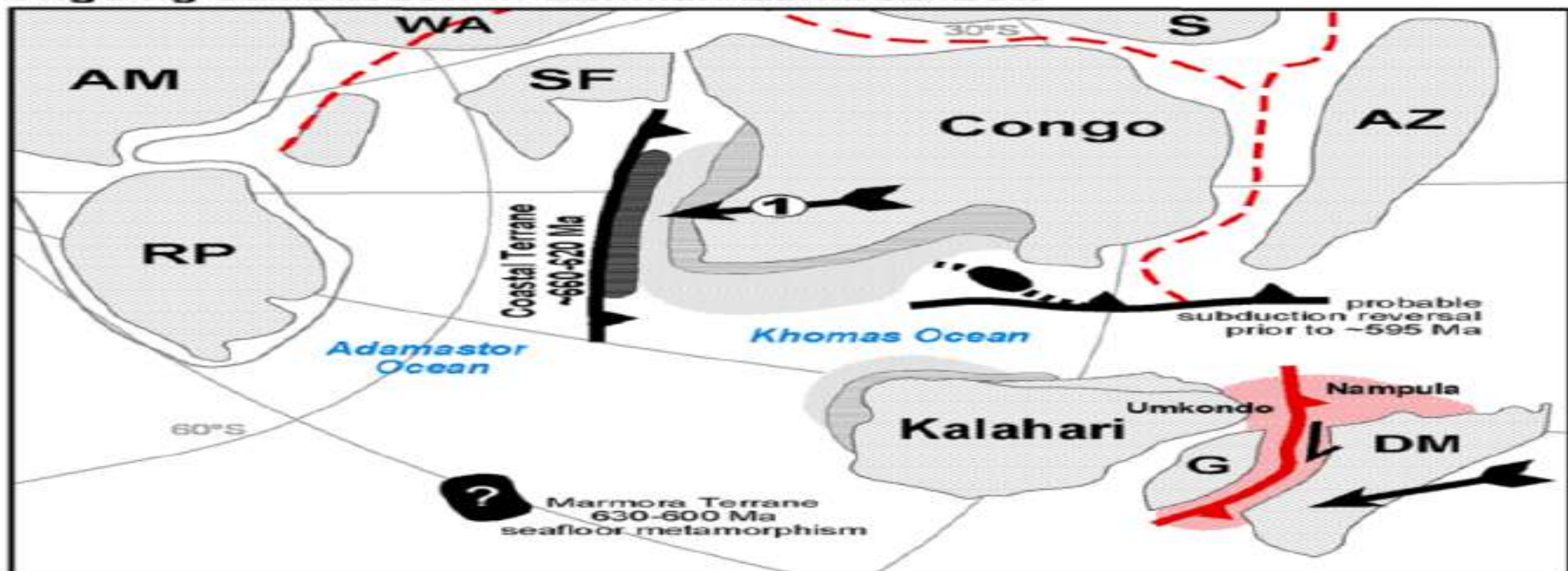
Collision of Antarctic elements with Kalahari craton in Umkondo Belt
Ongoing subduction in Lufillian-Zambezi Belt



Goscombe et al. (2019)
Gondwana Research

(c) 640-610 Ma Umkondo Phase

Collision of Antarctic elements with Kalahari craton in Umkondo Belt
Ongoing subduction in Lufillian-Zambezi Belt



- Active shear zone / thrust: inactive (thin line)
- Active collisional suture: palaeo-suture (dashed)
- Active subduction zone: triangles indicate direction of subduction
- Shortening & tectonic transport direction of upper-plate: see caption
- Core complex of exhumed high-T/low-P metamorphics
- Zone of active main phase deformation & metamorphism

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We thank **Brian Mapingere** and **Lingululani Mukwevho** for help with sampling and preparation of sample MTS4. We are grateful to the **Geological Survey of Zimbabwe** for supplying some of the samples. **Andy du Toit** is thanked for his generous assistance during the 2012 GSZ Marange excursion when some of the samples were collected.

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