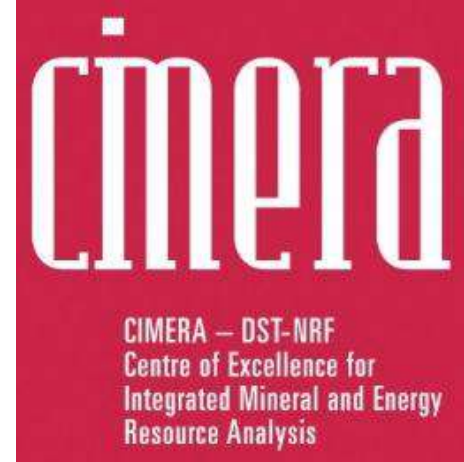
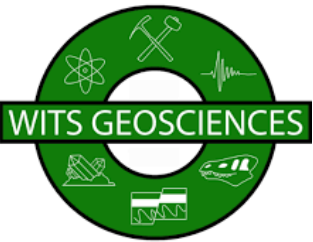




University of the  
Witwatersrand



## Pegmatites - questions and answers?

Judith A. Kinnaird

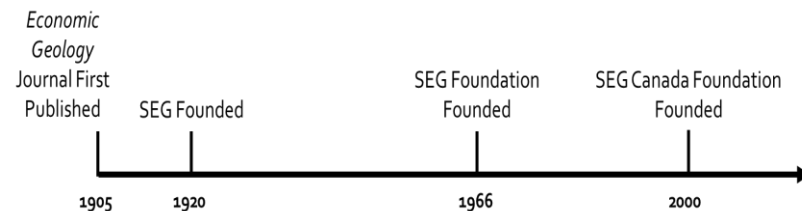
SEG Regional Vice President lecturer 2019

Paul Nex

# The Society



Devoted to advancing the science, discovery, and responsible development of mineral resources.



# 2019 At a Glance

**SEG  
founded  
1920**



**6,400  
members**



**From**



**countries**

**118 student  
chapters in  
33 countries**



**Provided  
US\$ 600K  
in financial  
support to  
students**

**Funded 88 field  
trips & courses  
(students &  
professionals)**



# We all know what pegmatites are:



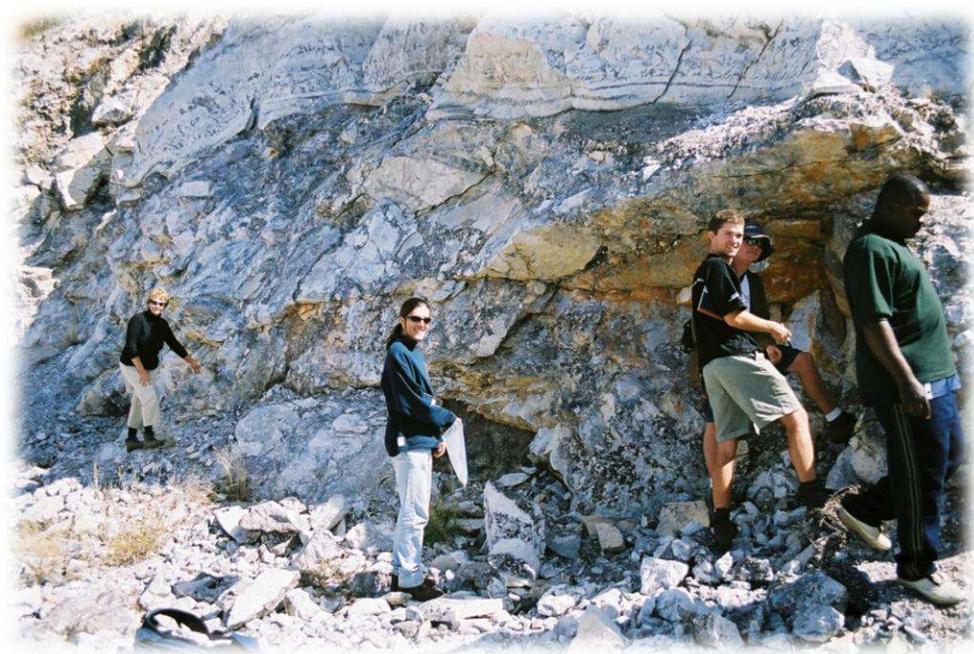
Helicon Li-rich pegmatite, Namibia

- An igneous rock mostly of granitic composition
- extremely coarse and systematically variable size of its crystals and/or
- an abundance of crystals with skeletal, graphic, or other strongly directional growth habits, and/or
- a prominent spatial zonation of mineral assemblages, including monomineralic zones (London, 2018).

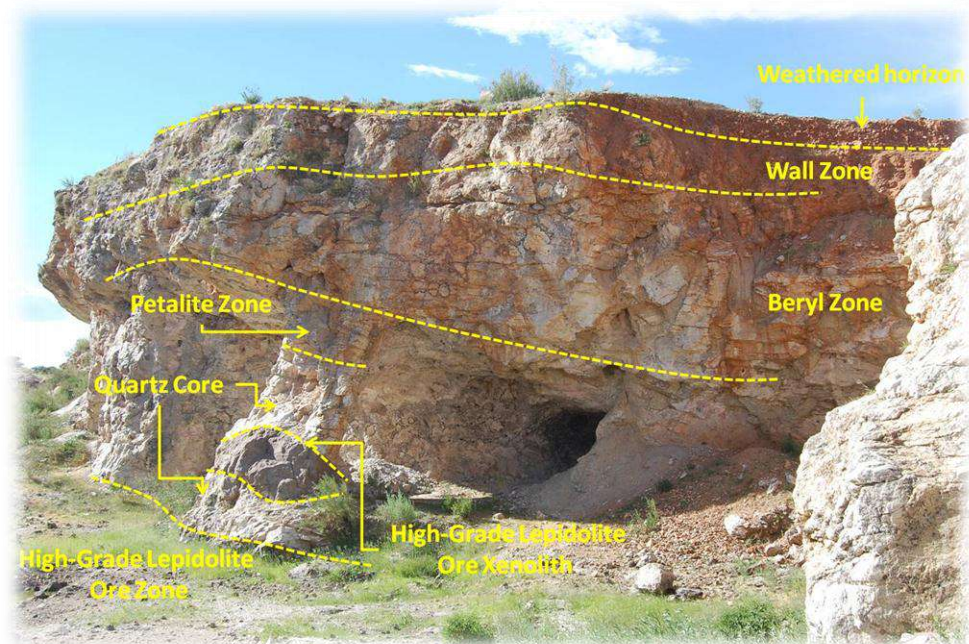
It's difficult to have a precise definition!!

- African pegmatites span ages from Archaean (Bikita) to Jurassic (Nigeria).
- Variable data on the mineralogy and structural setting of these pegmatites
- Few attempts at continent or orogen-wide regional syntheses since the work of Clifford and von Knorring.

Rubikon LCT 499.7 & 505.5 Ma (U-Pb columbite, Oberthur pers comm)

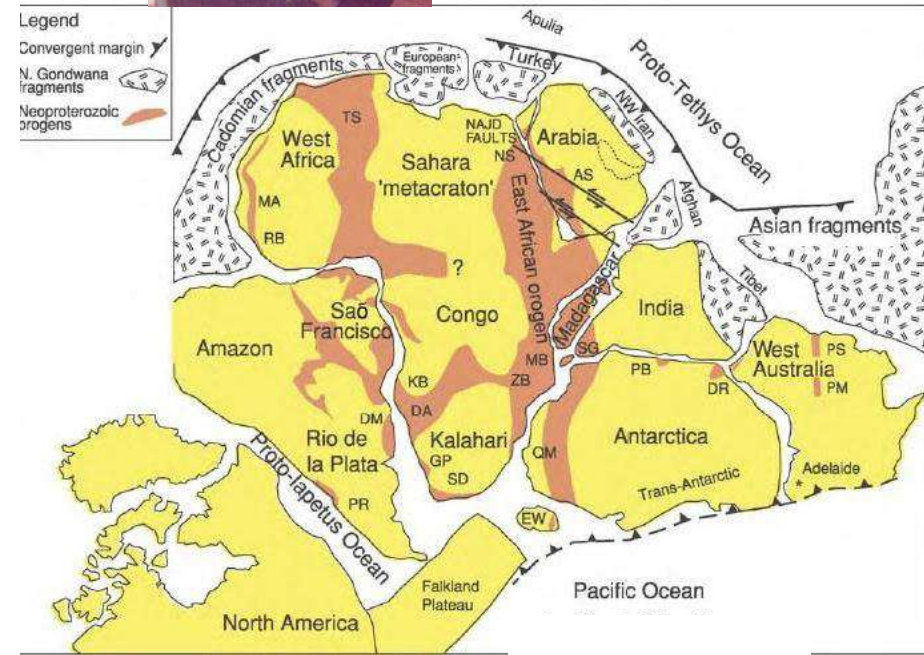
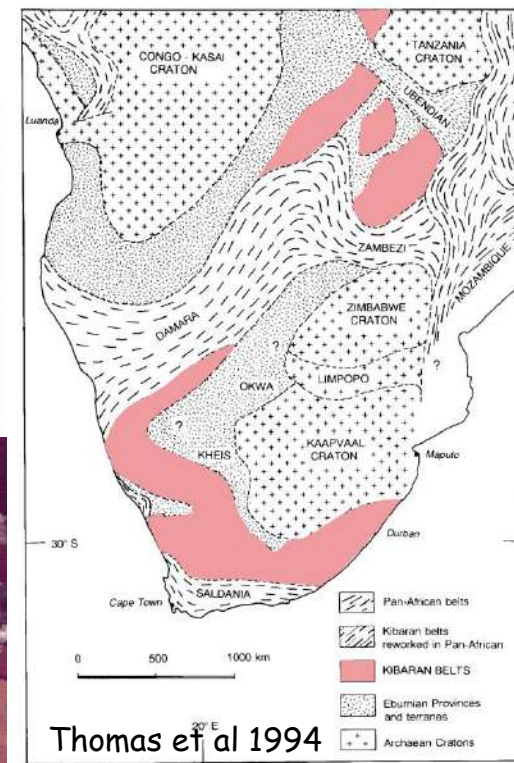


Bikita LCT 2.58 -2.65 Ga (Melcher et al., 2009)



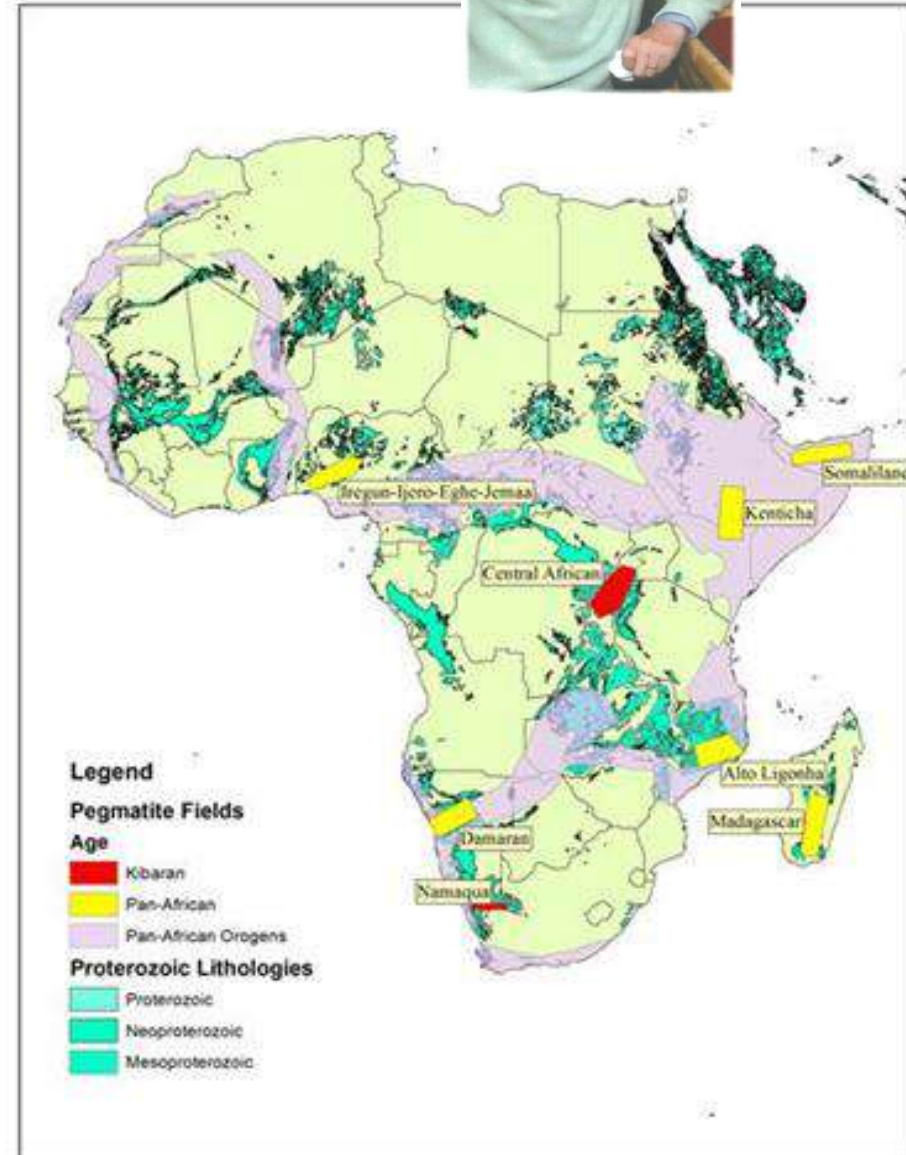
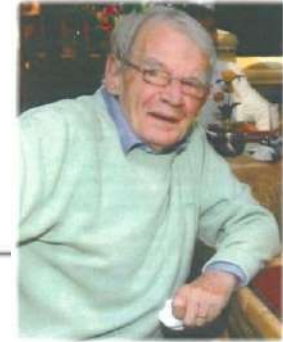
# African orogenic cycles

- Pegmatites form late in an orogenic cycle - there is a link between tectonism, magmatism and late pegmatites.
- von Knorring (1970) separated Kibaran - around 1100+/-200 with peak of magmatism ~1030Ma from those in Panafrican belts (550 ± 100 Ma).
- Panafrican of Kennedy (1964) - refers to orogenic areas surrounding cratons with collision from late Precambrian to Lower Palaeozoic. e.g. in Namibia: 550+/-100, magmatism 560-495, pegmatites 515-495



# Pegmatites in Africa

- studies on pegmatite districts limited until late 1960's-1970's
- **Kibaran pegmatites**
  - Rwanda, SW Uganda, eastern DR Congo, Namaqualand
- **Panafrican pegmatites**
  - West Africa, NE Africa and southern Africa.
- Clifford (1966) noted that certain elements such as Be, W and Sn were generally restricted to the younger pegmatites.



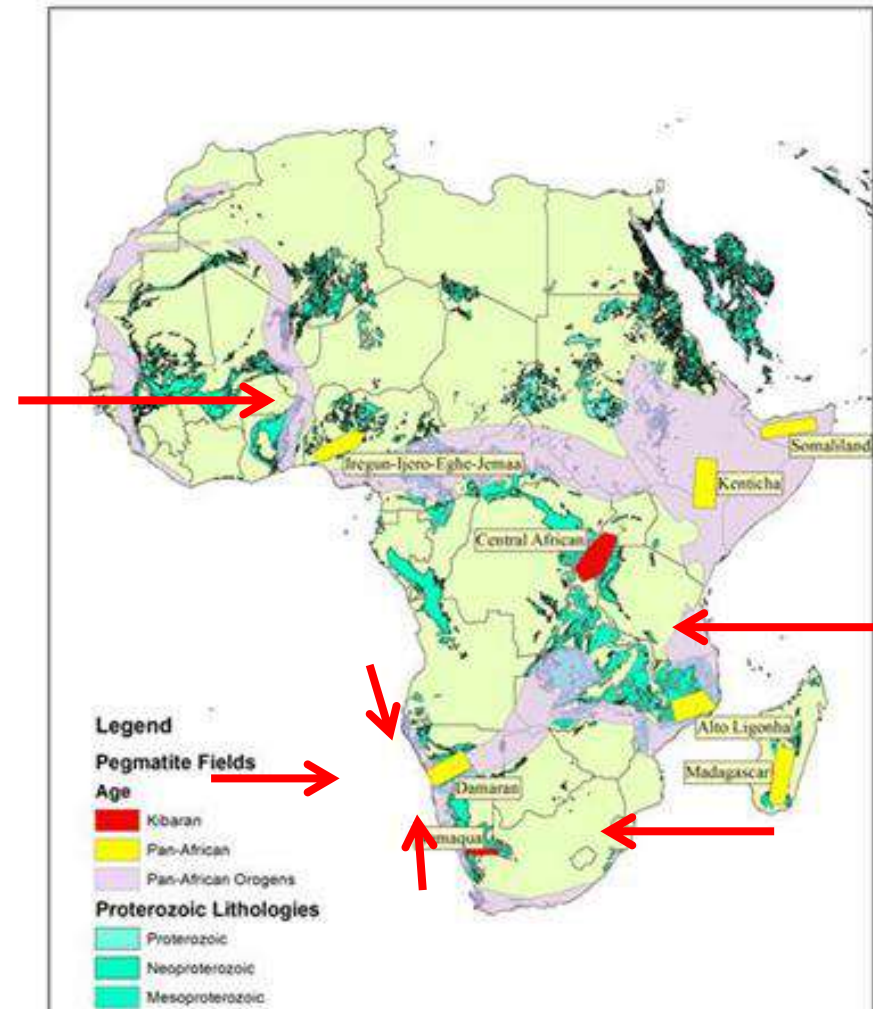
# Panafrican pegmatites

~500 Ma

# Late Neoproterozoic creation of Gondwana

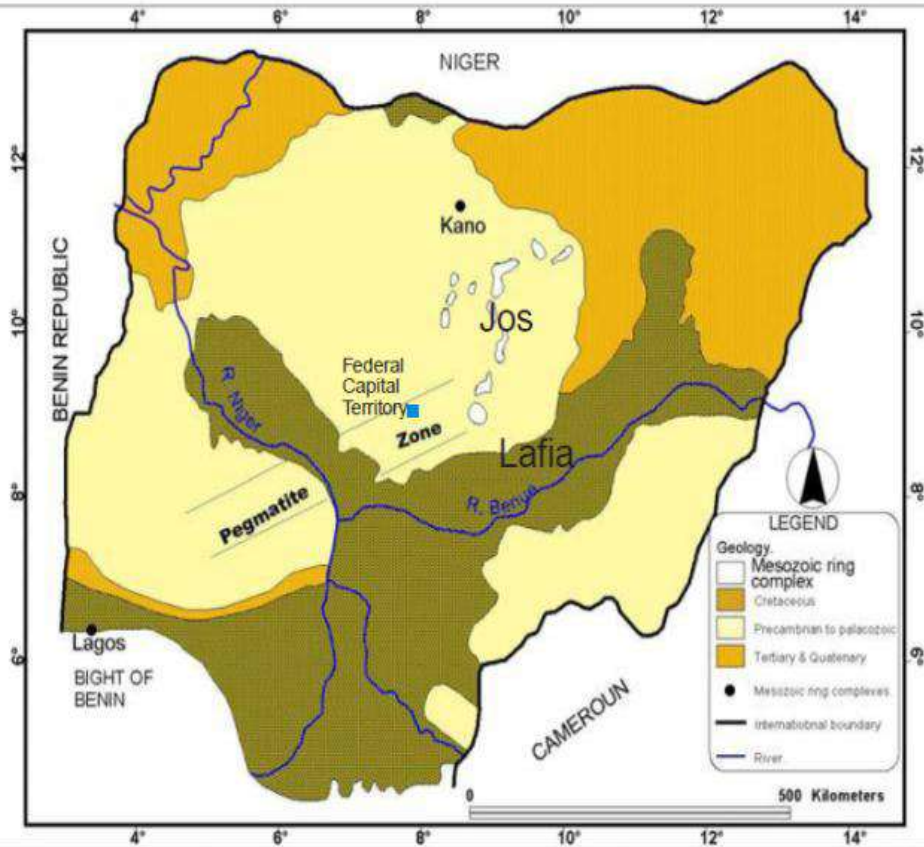
## 500 Ma Panafrican pegmatites

- Trans-Saharan belt - passive margin of the West African craton collided with the active continental margin of the East Saharan block. Ocean closure/peak plutonism in north central Nigeria  $\sim 597 \pm 20$  Ma (van Breemen *et al.* 1977). Numerous Hbl-Bt granites  $\sim 585$  Ma. Later undeformed post-tectonic intrusives and pegmatites at 550 Ma.
- Collision between E and W Gondwana  $\sim 600$ -550 Ma - late extension and plutonism in NE Mozambique at c. 520-515 Ma (Ueda *et al.*, 2012).
- Namibia - collision of cratons with lithosphere delamination, heating 560-540 Ma, then extension at 520 to 510 Ma (Longridge *et al.*, 2018) and pegmatites  $\sim 500$  Ma
- Pegmatites: locally important producers of cassiterite, mica, feldspar, columbite-tantalite, beryl, Li minerals and gemstones



Craton collision with late-tectonic extension and plutonism produced pegmatites in NE Mozambique, Nigeria and Namibia,

# Nigeria 3000 pegmatites



# Pan-African pegmatites in Nigeria

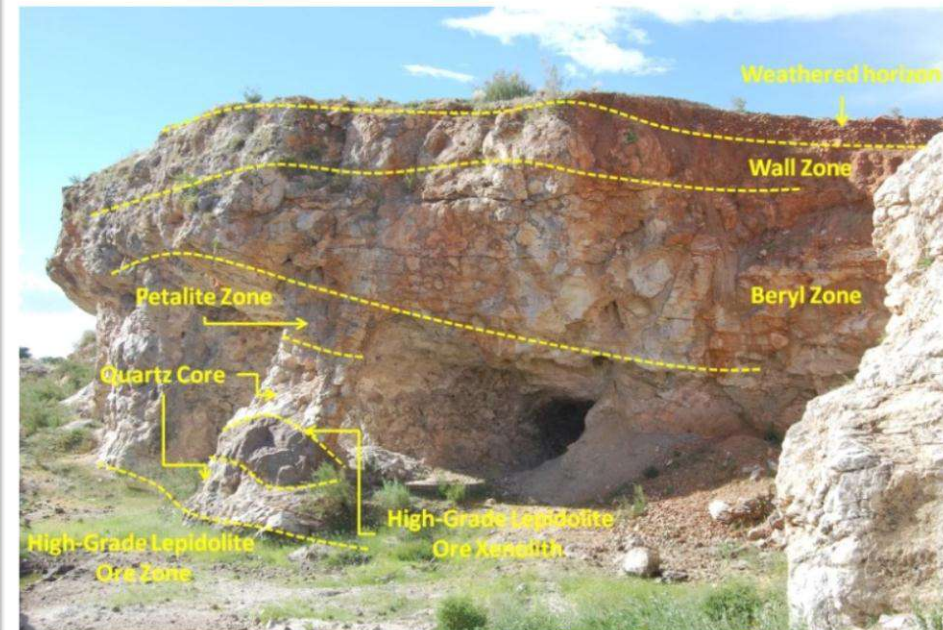
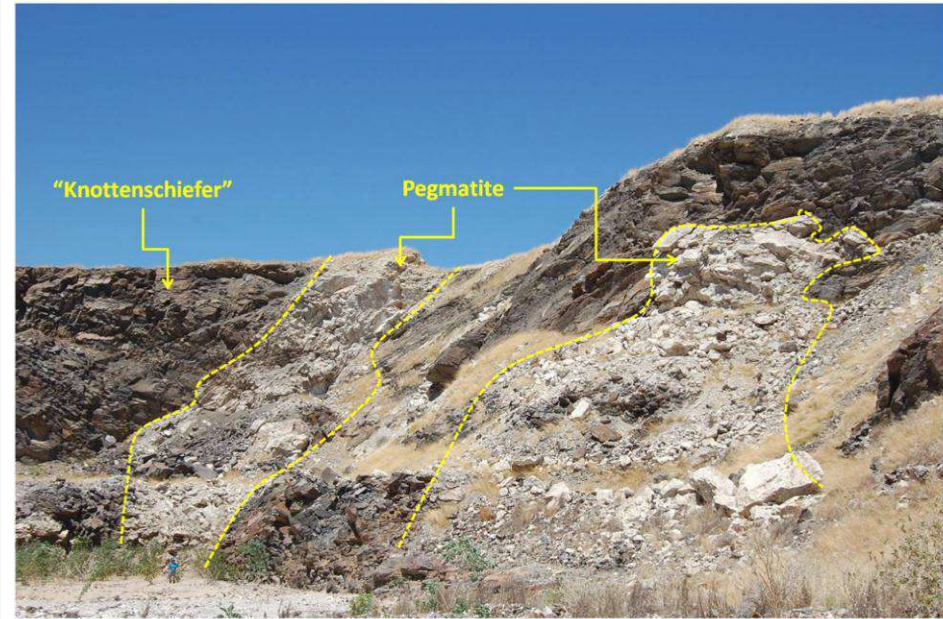
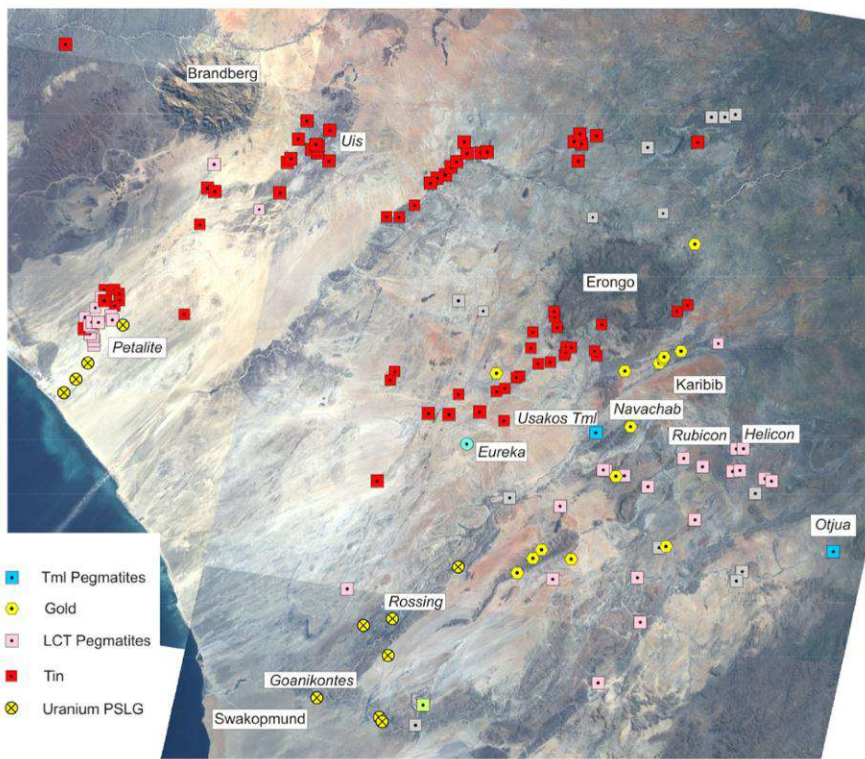
- Barren pegmatites are small and occur in and around early granodioritic plutons.
- Later mineralised Palaeozoic pegmatites not related to any apparent intrusions.



Gahnite, Kinnaird, 1987

- LCT and Sn-W types:-
- Nb-Ta: columbo-tantalite, microlite tapiolite,
- Sn: cassiterite and wodginite,
- W: scheelite
- Zn: nigerite or more commonly gahnite.
- tourmaline, lepidolite, almandine-spessartine, beryl, chrysoberyl, apatite, amblygonite, monazite, lithiophilite-tripphillite, pyrite, magnetite, pandaite, ilmeno-rutile, bismuthinite, bismutite,
- Mineralized pegmatites also enriched in Rb, Cs, Y,

# Namibia



# Gem tourmaline pegmatites

Omapyu I & II

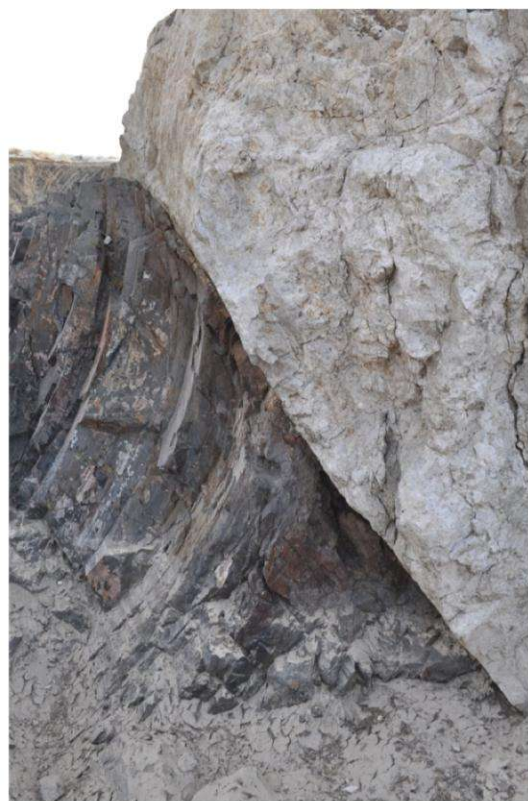


Usakos Tourmaline Mine

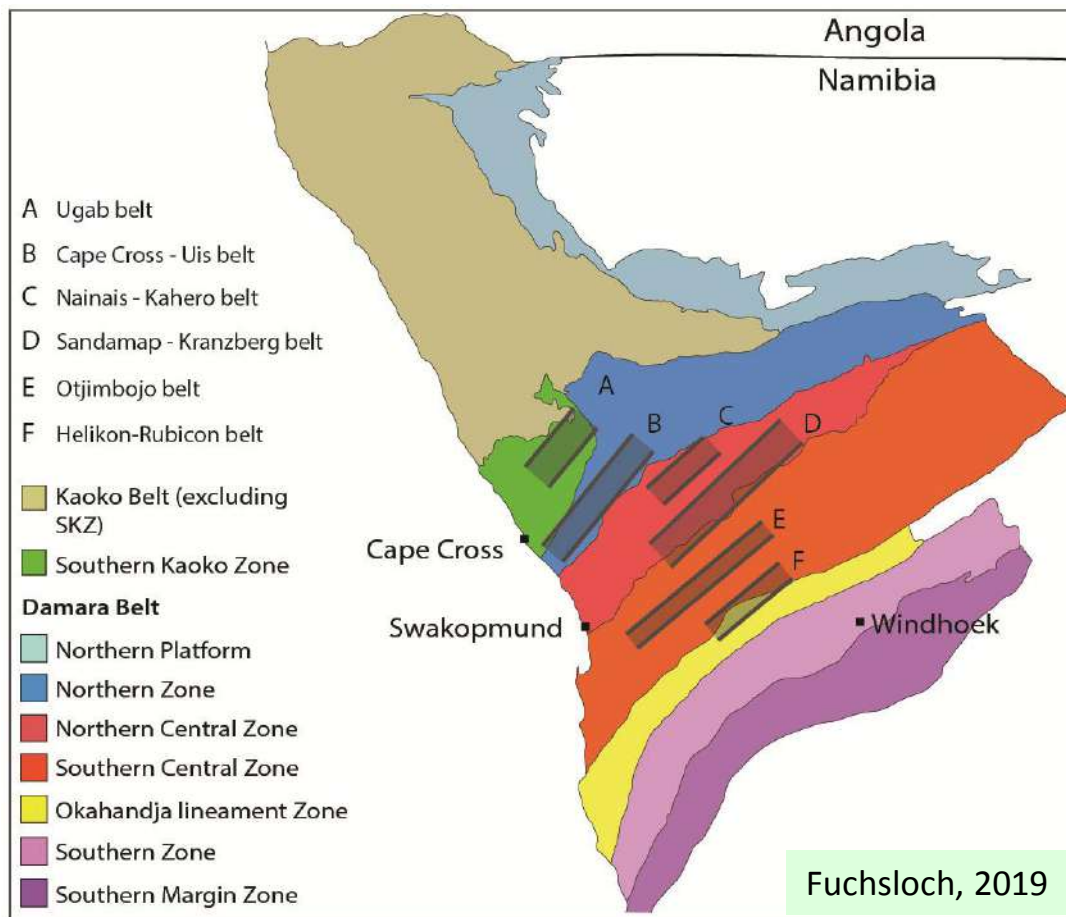


Becker's (Otjua) pegmatite



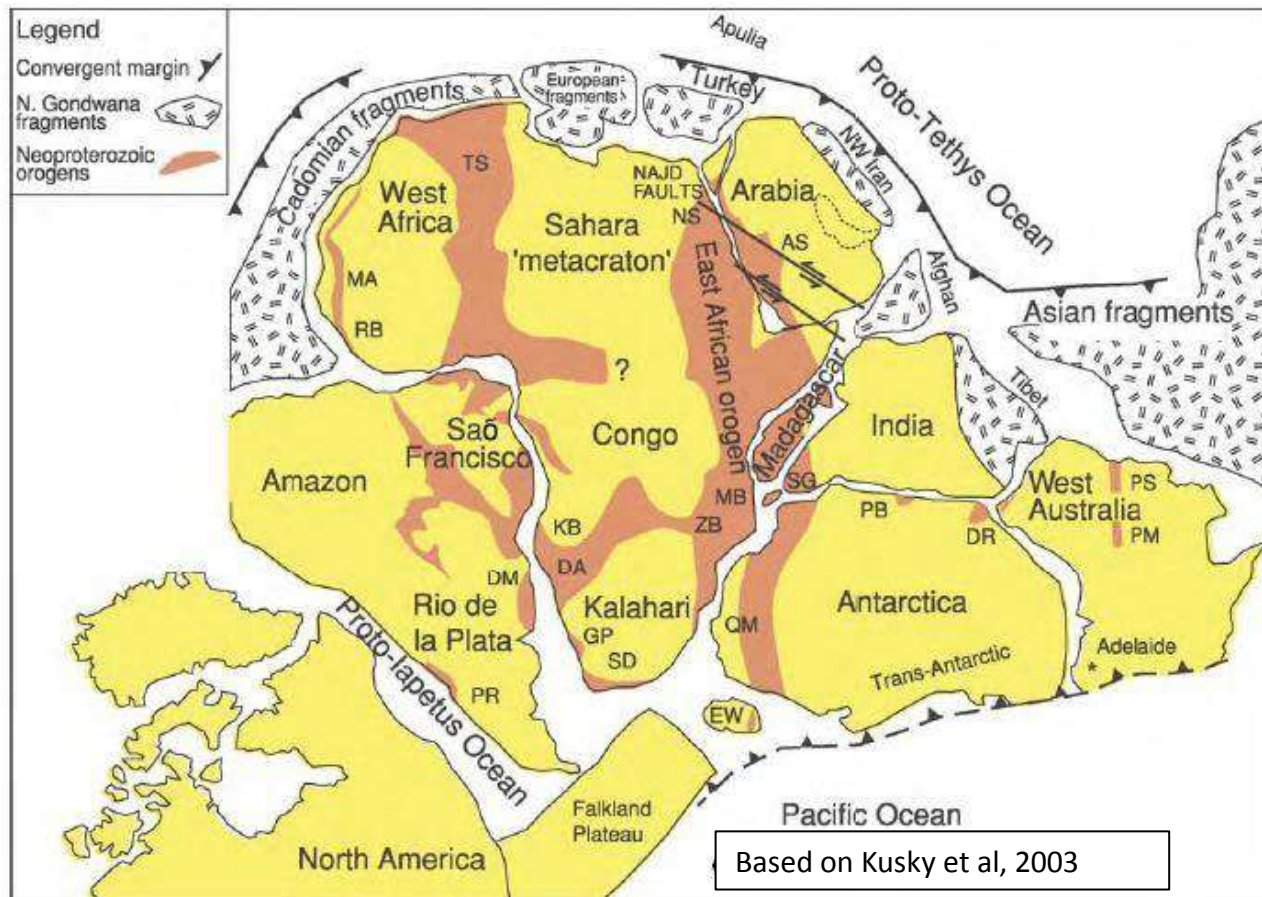


Pegmatites are  
post tectonic



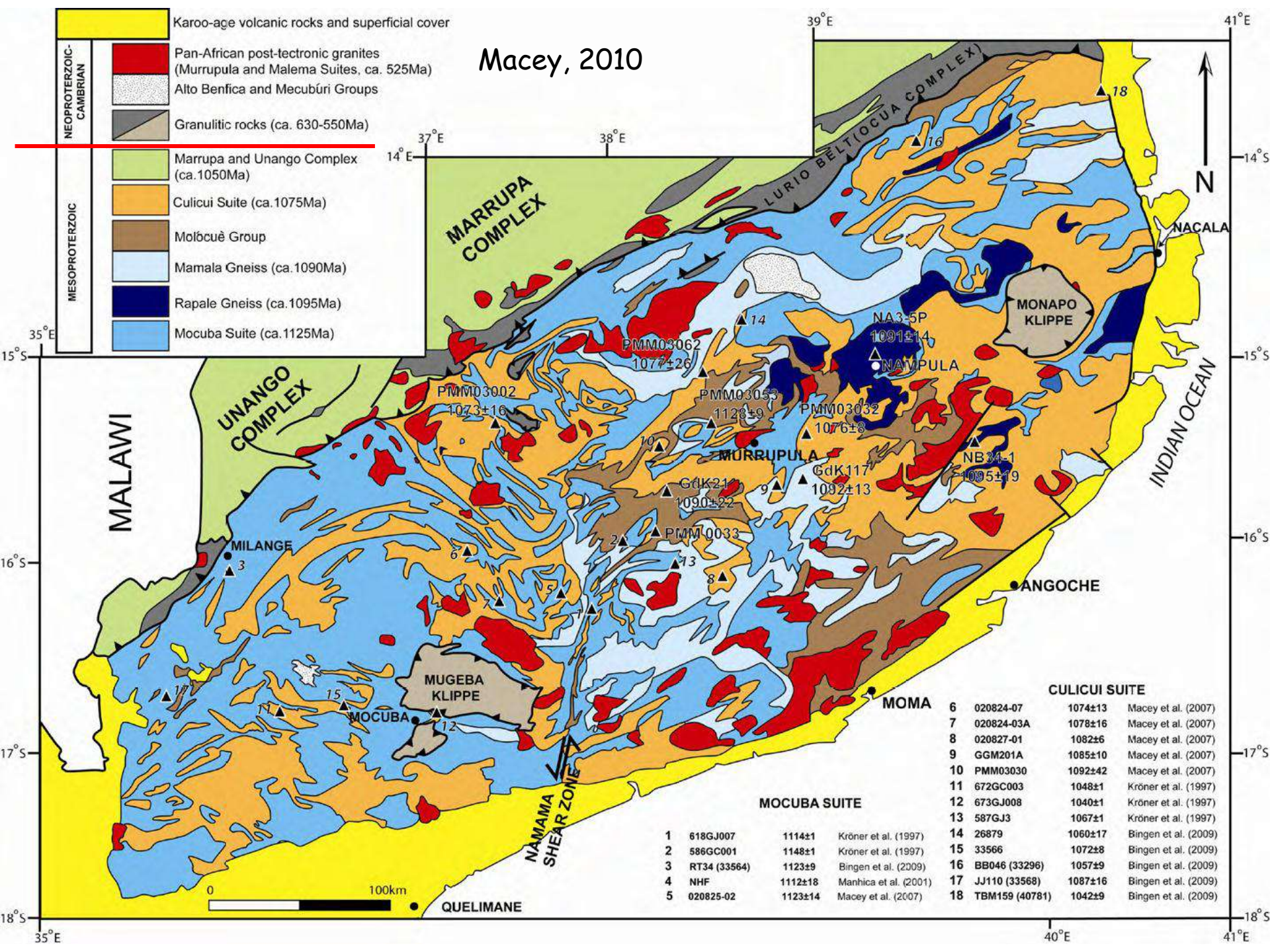
# Panafrican pegmatites in the Mozambique belt

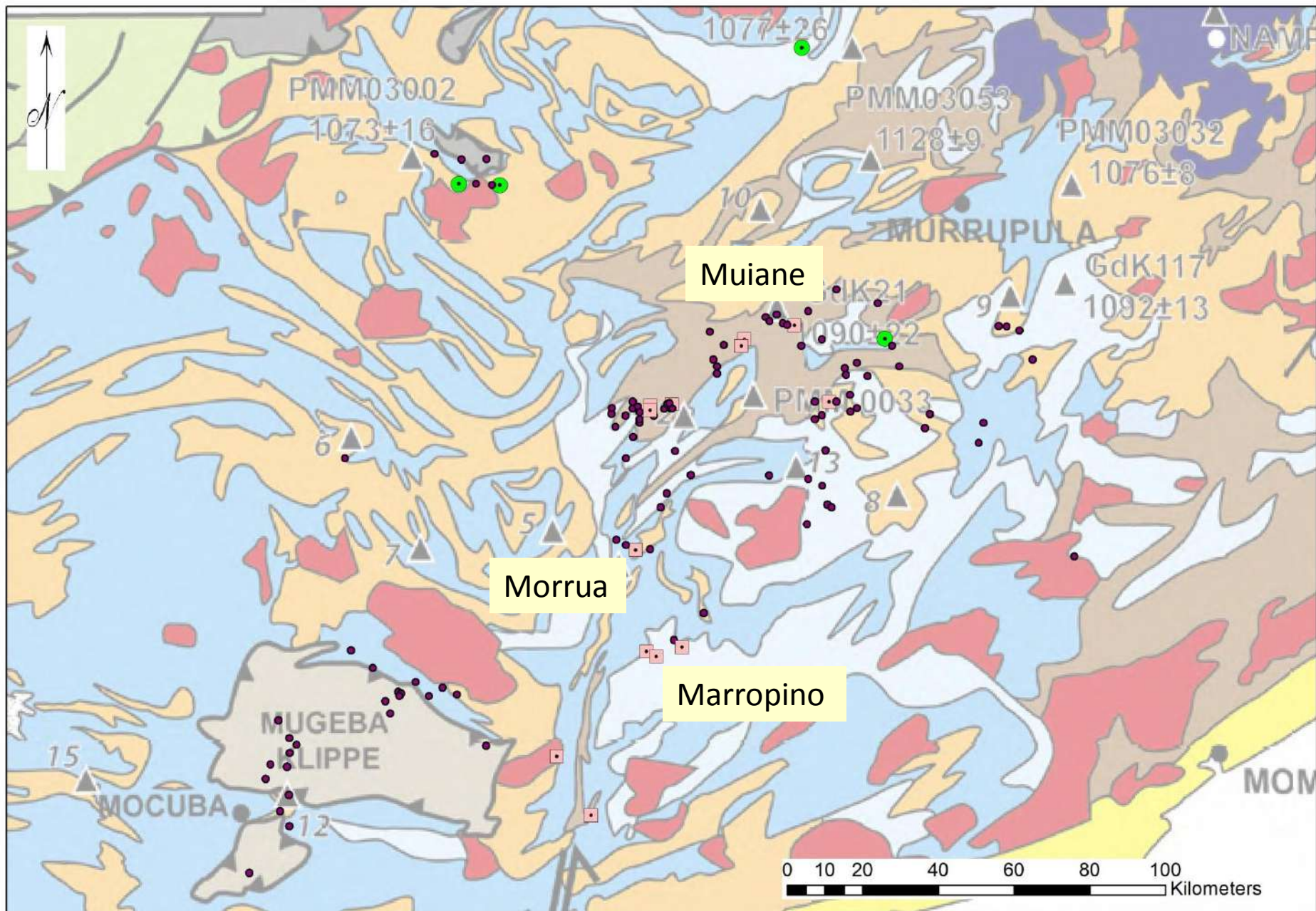
- Arabian-Nubian Shield rare-metal peralkaline granites (with Nb-Zr-REE-Ta) and peraluminous granites
- pegmatites (Ta-Li-Cs mineralisation) (Kuster, 2009).



**Figure 1** Map of Gondwana at the end of Neoproterozoic time (~540 Ma) showing the general arrangement of Pan African belts. AS,

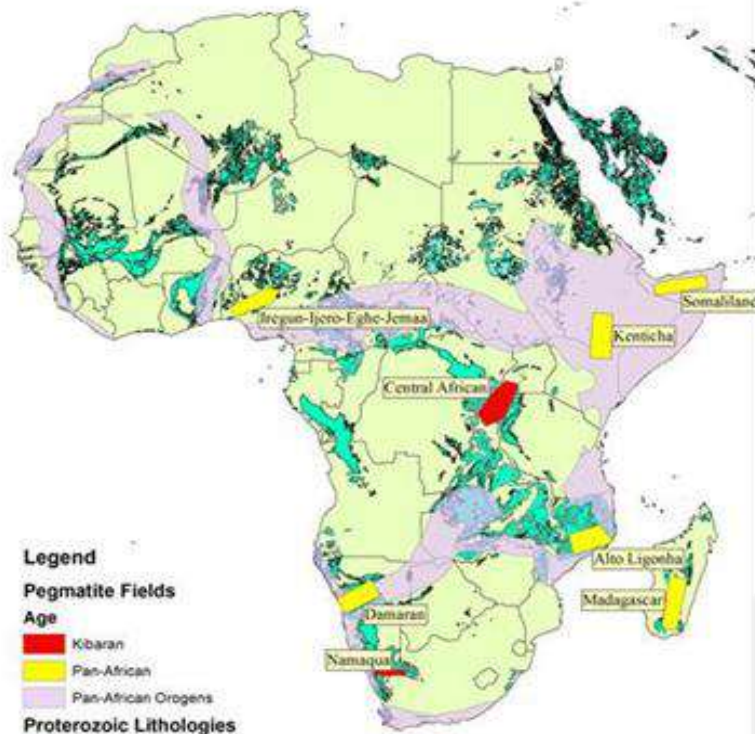
Macey, 2010



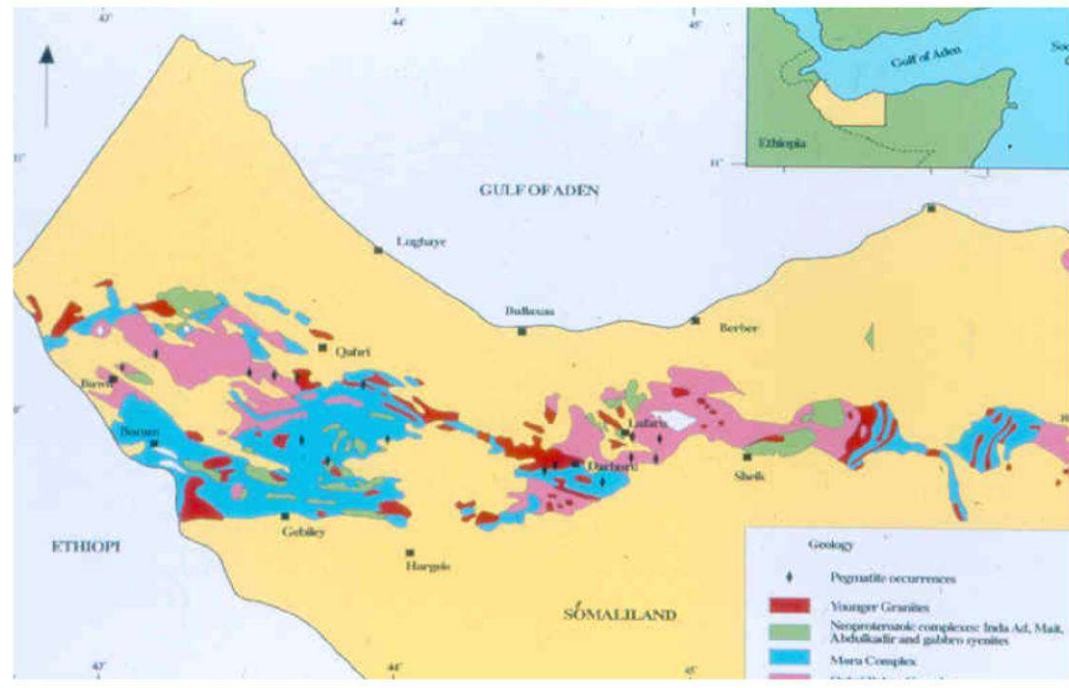


~450 Ma pegmatites (Cronwright, 2005)

Green circles- classic NYF not previously recognized. Pink squares - classic LCT: spod, Li, Ta



- Further north in the Mozambique belt, Ta-Nb mineralization in the Kenticha LCT field of Ethiopia, associated with post-orogenic granites.
- Kenticha pegmatite dated at ~530 Ma (Melcher *et al.*, 2009).
- In Somaliland, post-orogenic pegmatites, some are zoned, cross-cut an east-west oriented Proterozoic basement.
- Pegmatites variably host beryl, tourmaline, columbo-tantalite, monazite and samarskite and cassiterite locally.



# Pan-african pegmatites in Somaliland

Two types pegmatites:-

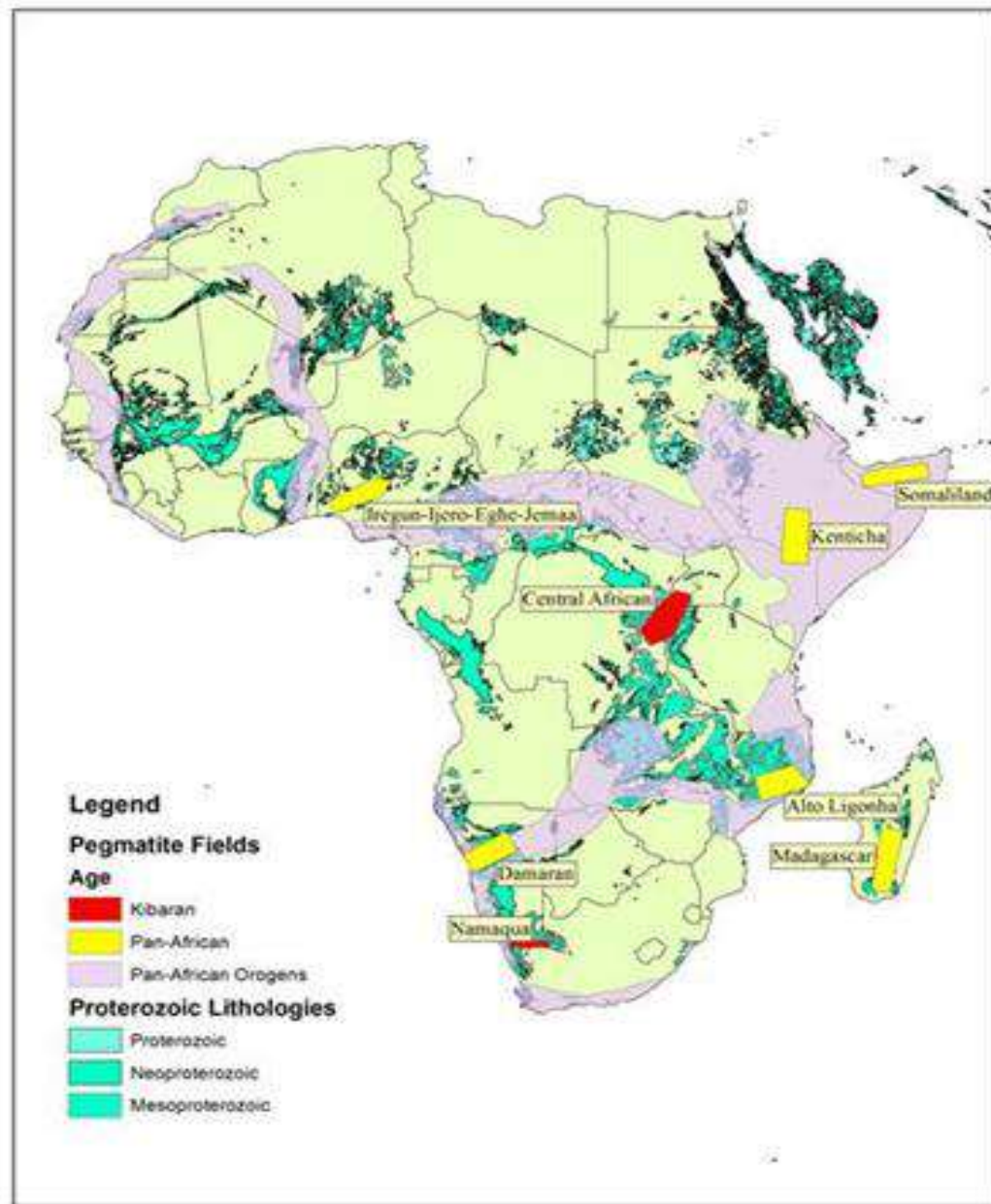
- (1) white, quartz-poor, saccharoidal feldspathic  $\pm$  emerald/ aquamarine
- (2) pink, coarser textured, quartz-rich  $\pm$  coarse zircon and garnet.

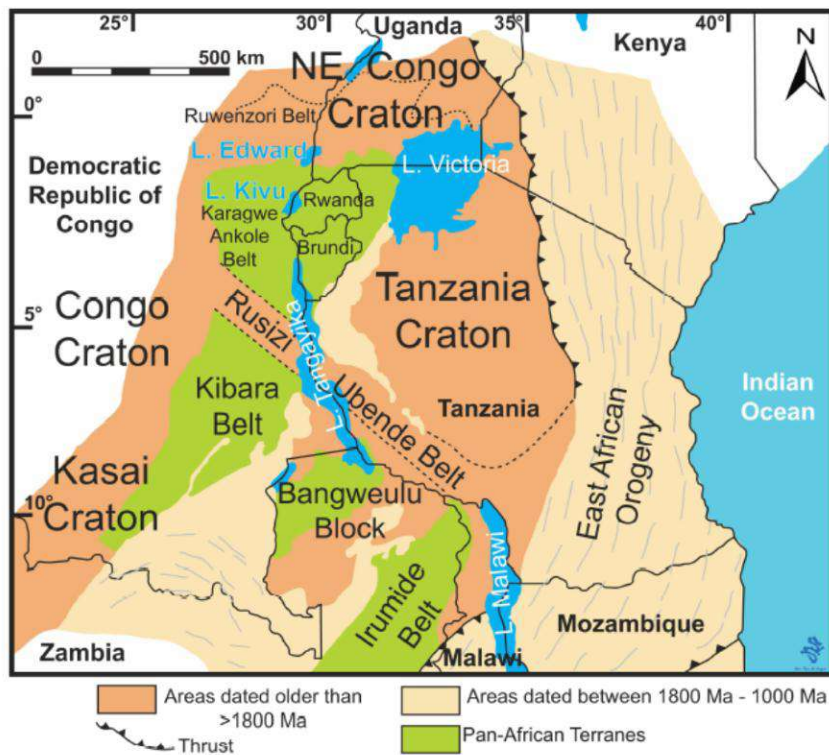
- Most simple: qu + microcline + minor muscovite.
- Some are more complex and zoned, only a few have cassiterite



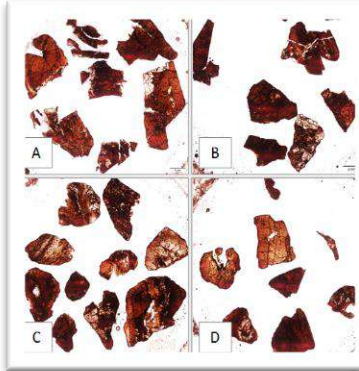
# Kibaran

~ 1000 Ma

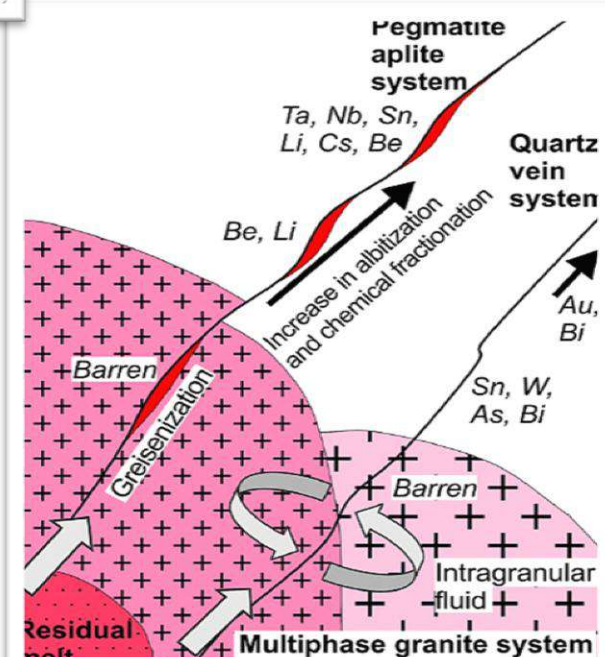




Dewaele et al, 2011

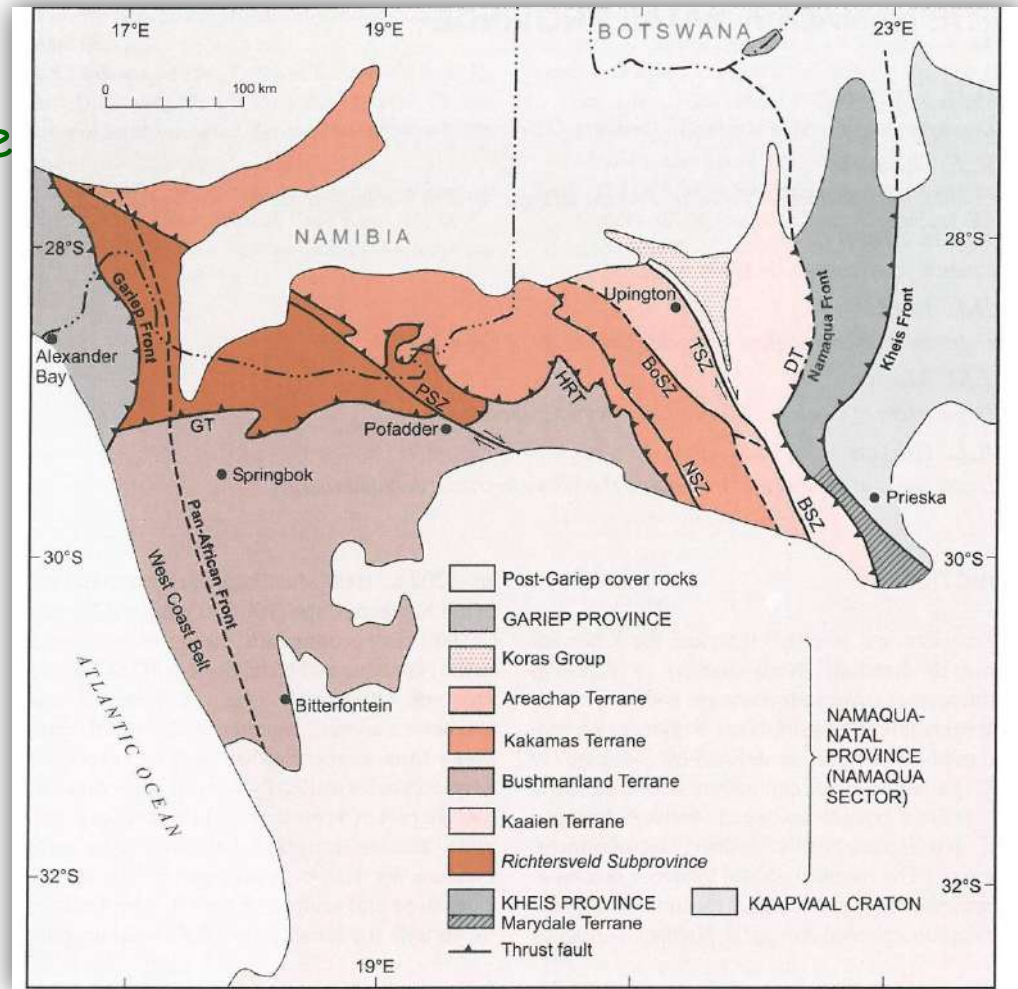
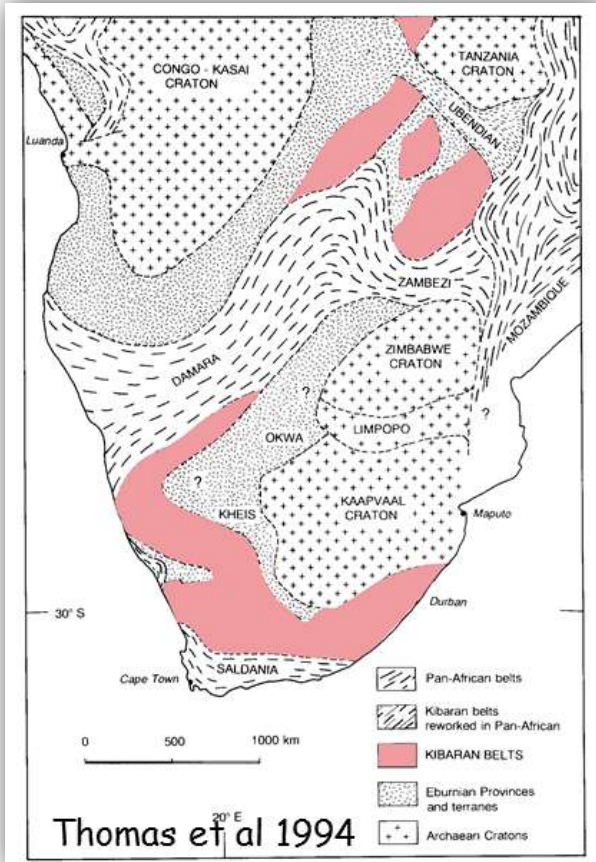


- Post-compressional G4 Kibaran "tin granites" intruded at  $986 \pm 10$  Ma (U-Pb SHRIMP zircon; Tack et al., 2010; Dewaele et al., 2010; Melcher et al., 2015).
- Tin granites are sub-alkaline, strongly peraluminous equigranular biotite-muscovite granites (Pohl and Gunther 1990).
- The Karagwe-Ankole belt hosts zoned clusters of barren and rare-metal pegmatites and Sn-W mineralised quartz veins, related to the G4 granites
- The most distal pegmatites underwent intense albitisation with growth of albite and white mica.



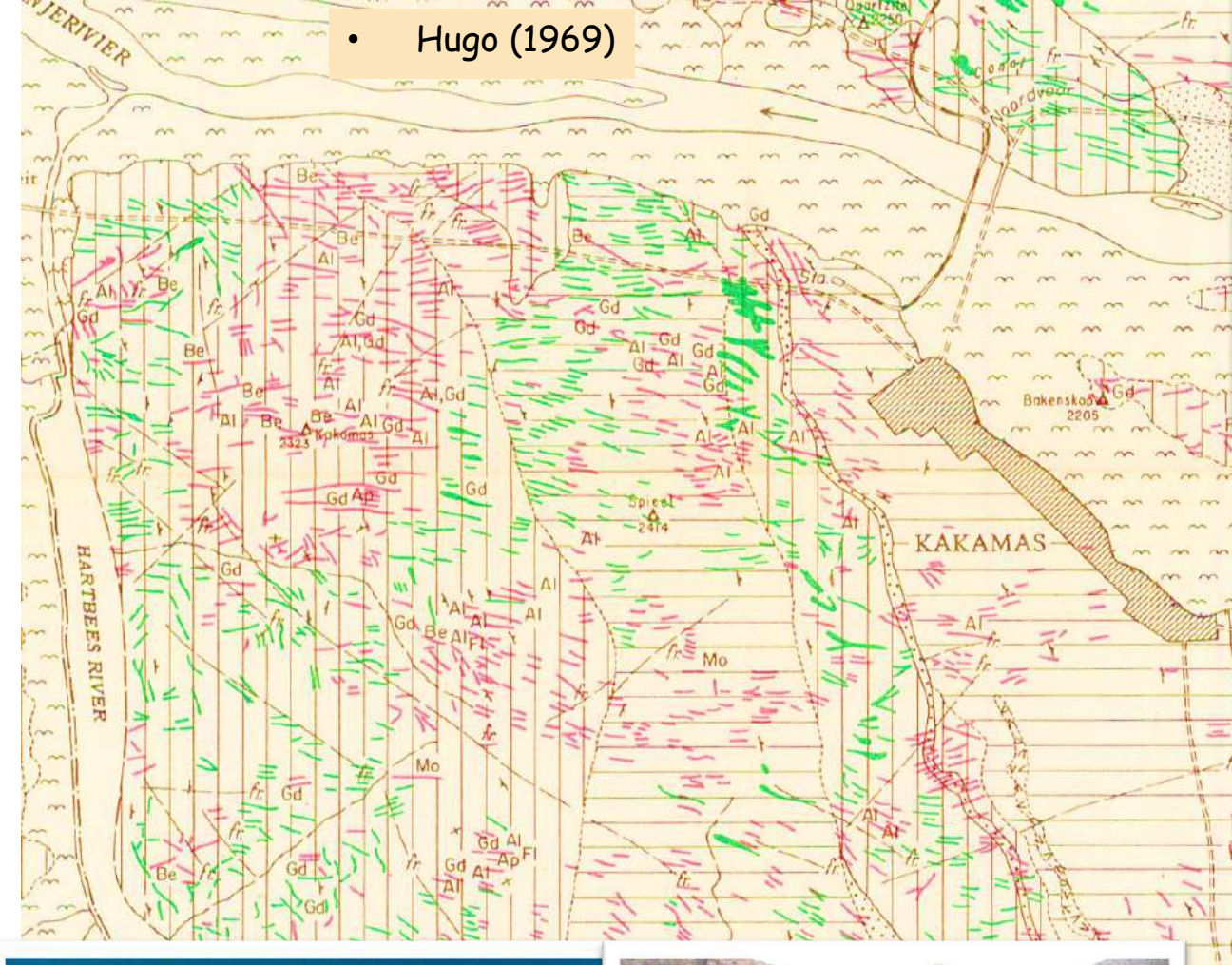
# Kibaran pegmatites in central Africa

- Namaqualand pegmatites are essentially the same age as pegmatites in Uganda, Rwanda and eastern DRC and related to the formation of Rodinia



- Several terranes accreted onto the western margin of the Archaean Kaapvaal craton
- Intense deformation and metamorphism and voluminous syn- and post- tectonic granitoids between 1200 Ma to 930 Ma (Cornell *et al.*, 2006).

- Hugo (1969)



*Mica books developed in the wall zone at Blesberg south of Vioolsdrif*



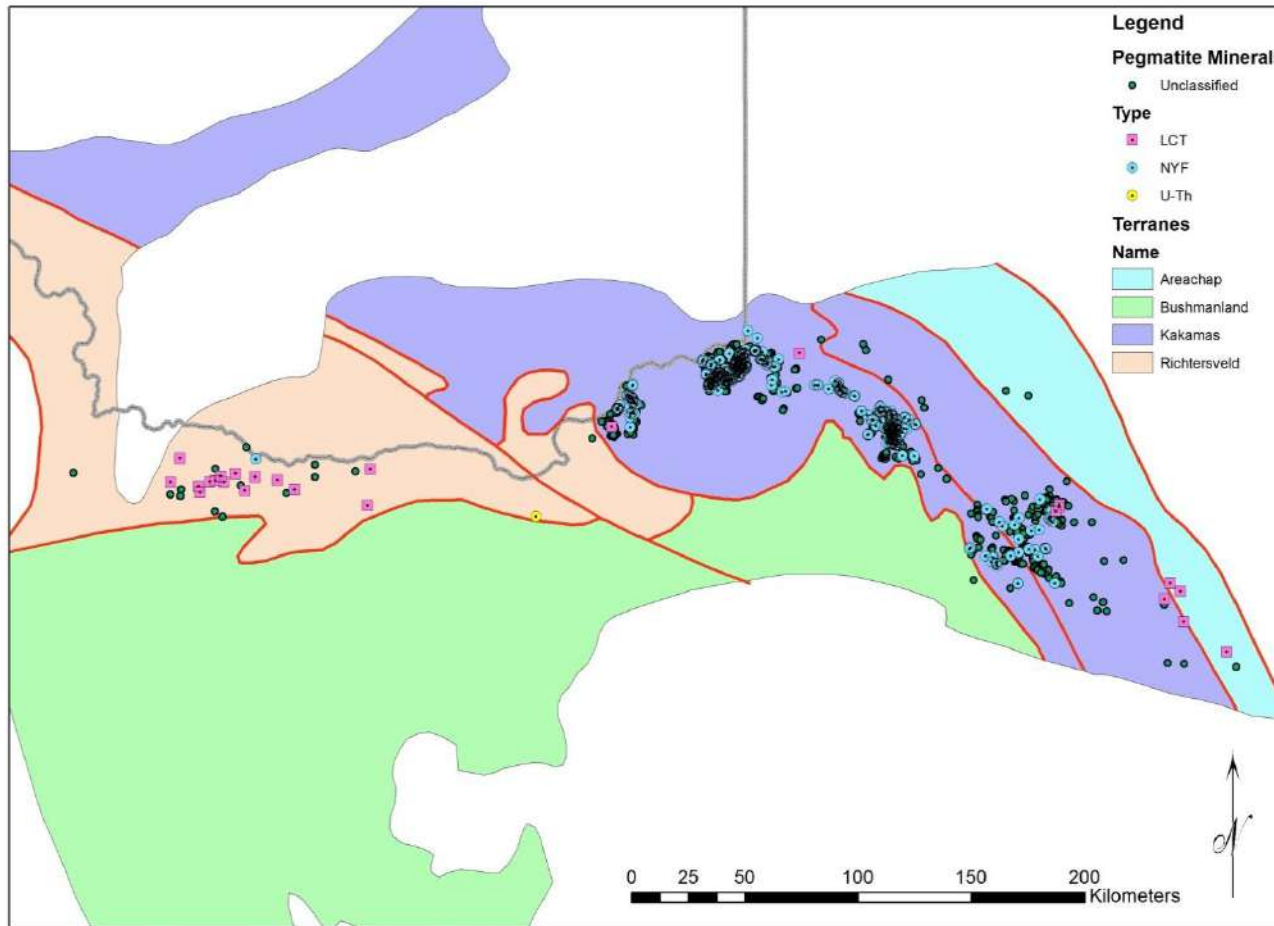
*Intergrown rose quartz and feldspar at Steyns Puts, Kenhardt district,*



*Mined-out tantalite-spodumene pocket at Blesberg, south of Vioolsdrif*

*photos Hendrik Minnaar*

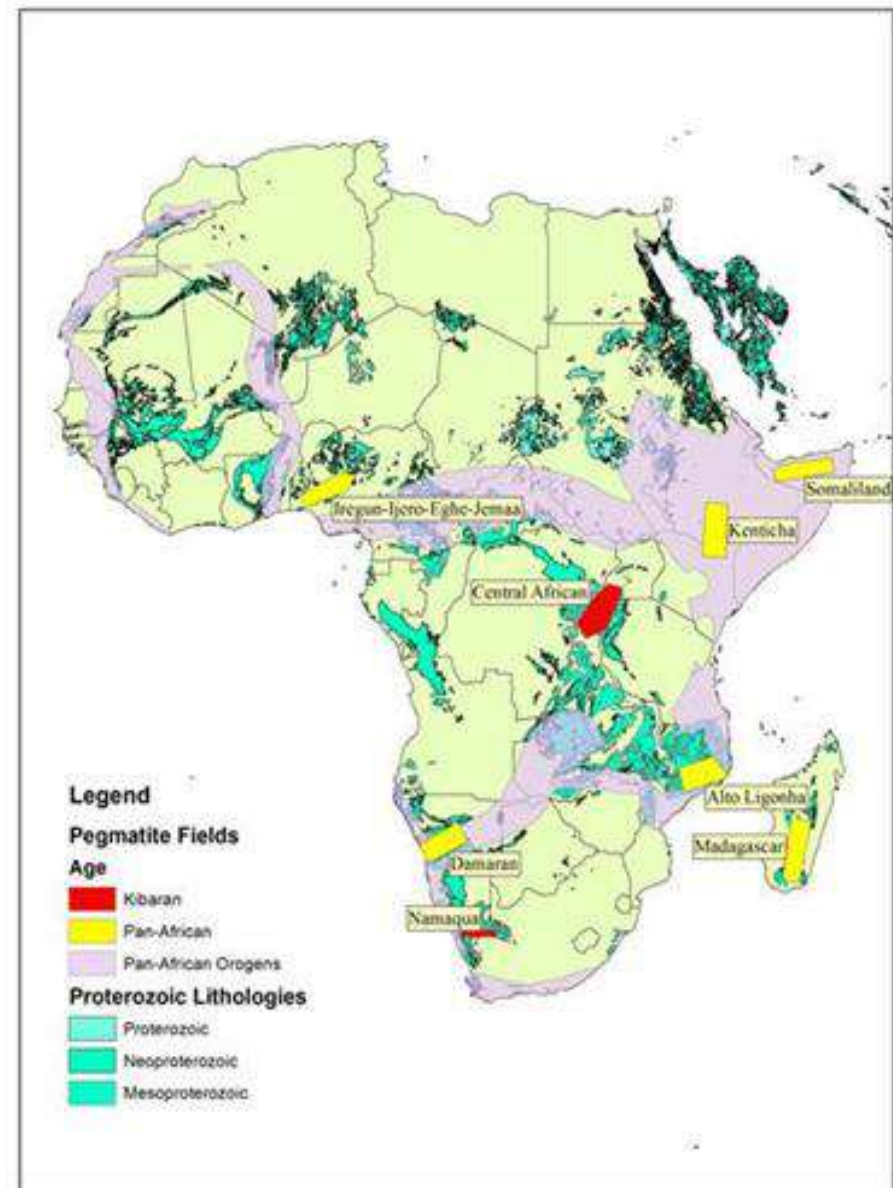
# Kibaran pegmatites in Namaqualand South Africa



- Post-orogenic pegmatites show LCT affinities in west and east
- Possible NYF or mixed NYF-LCT pegmatites in the centre.
- Produced feldspar and mica + watermelon tourmalines.
- Minor extraction of gadolinite, rose-quartz, cassiterite, and columbite-tantalite from the pegmatites (Hugo, 1969)

# Distribution of ore metals

- Across Africa the character of pegmatite fields varies
- Von Knorring (1970) noted that the pegmatites of the Damaran Belt in Namibia and the Kibaran Belt of central Africa are tin-enriched
- In pegmatites of the Mozambique Belt tin-enrichment notably absent.
- Pegmatites of the Mozambique Belt, including Madagascar, are enriched in REE compared to the Damaran and Kibaran Belts.
- West African Pan-African pegmatites, especially those in Nigeria, are similar to Damaran pegmatites of Namibia with both LCT pegmatites and a Sn-W association.



# Archaean

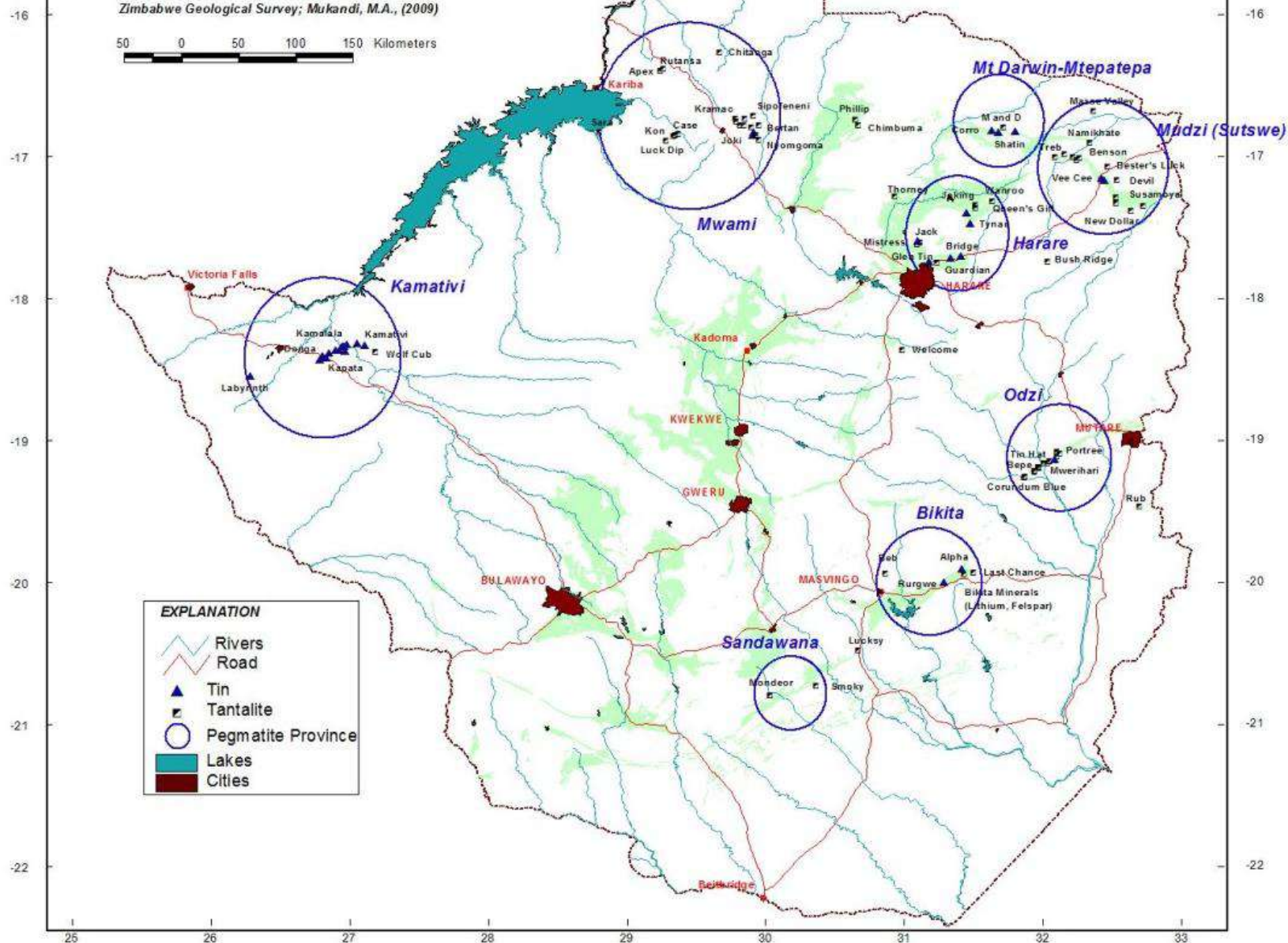
Archaean pegmatites all seem to be  
LCT

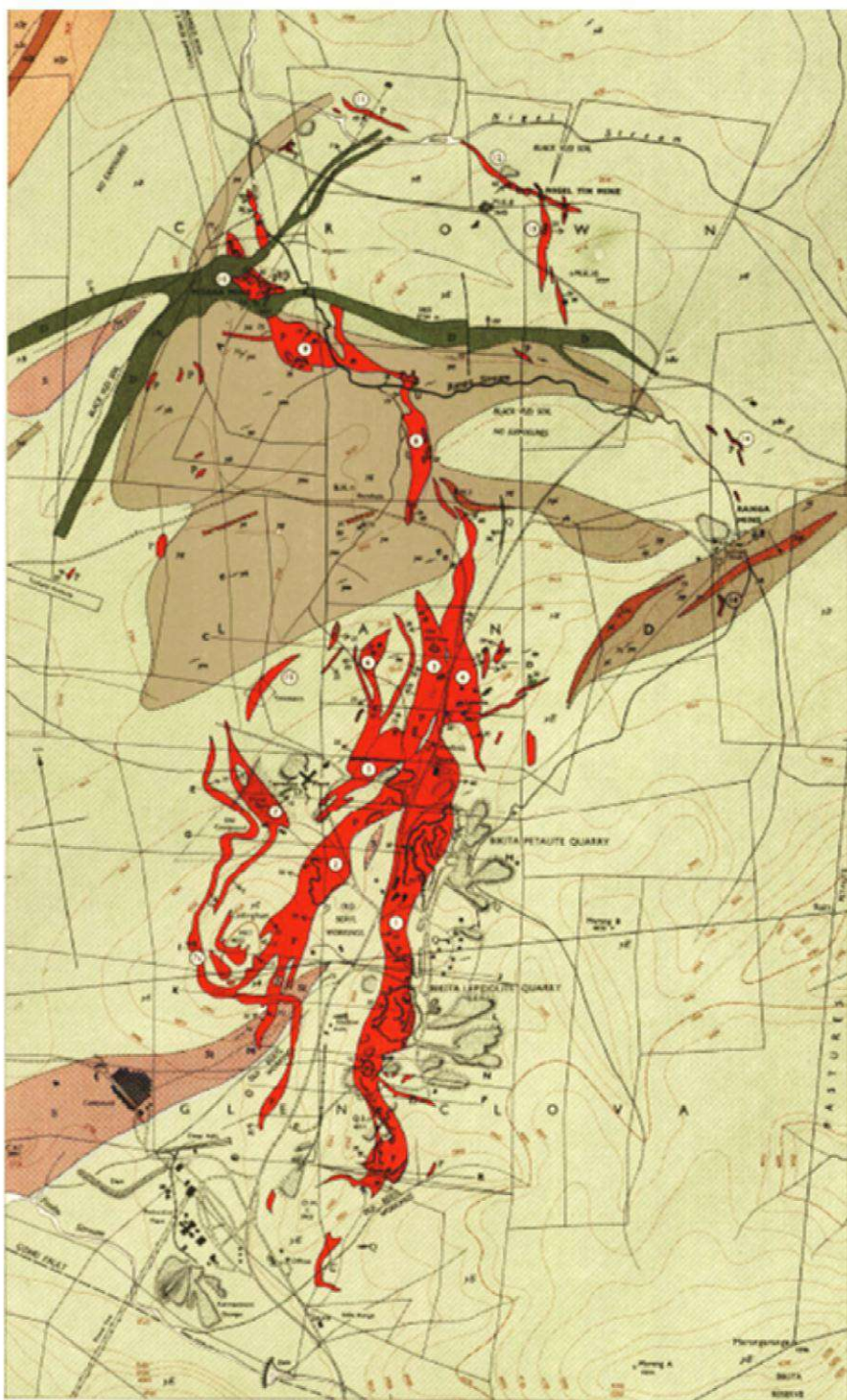


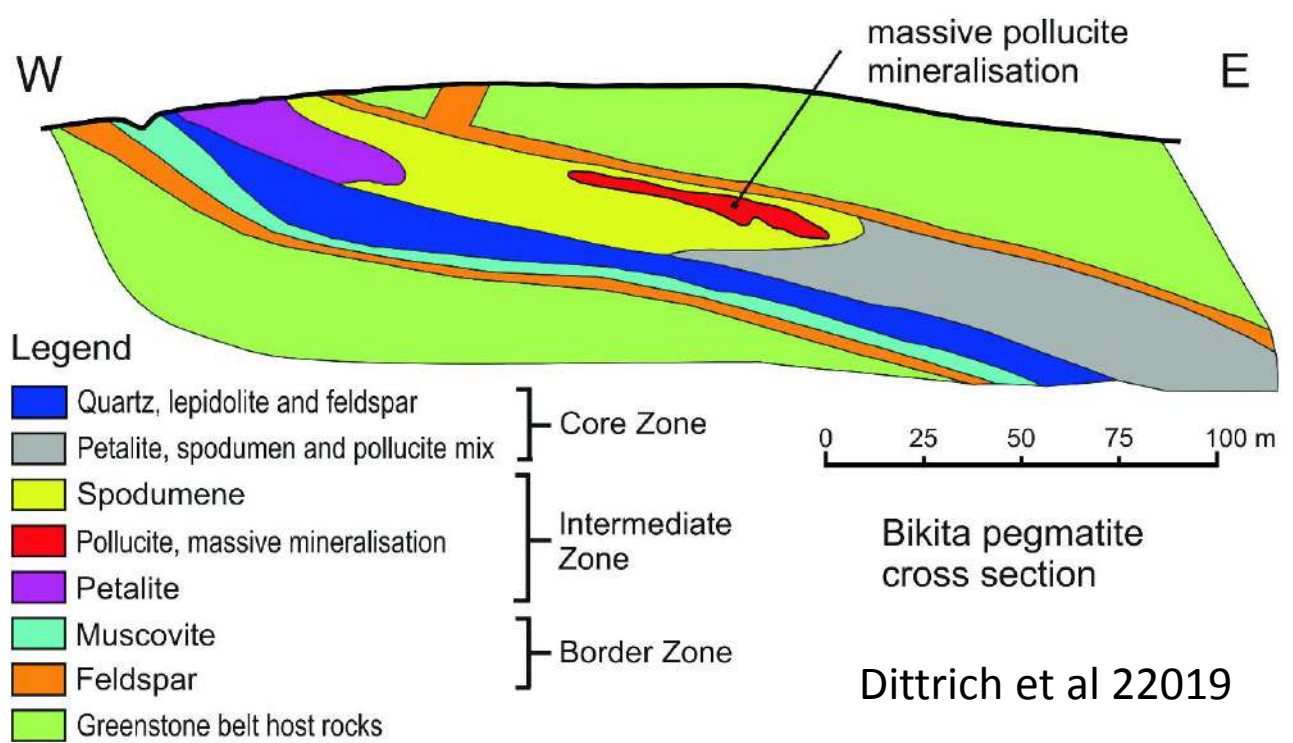
# Tin and Tantalite Deposits of Zimbabwe

Zimbabwe Geological Survey; Mukandi, M.A., (2009)

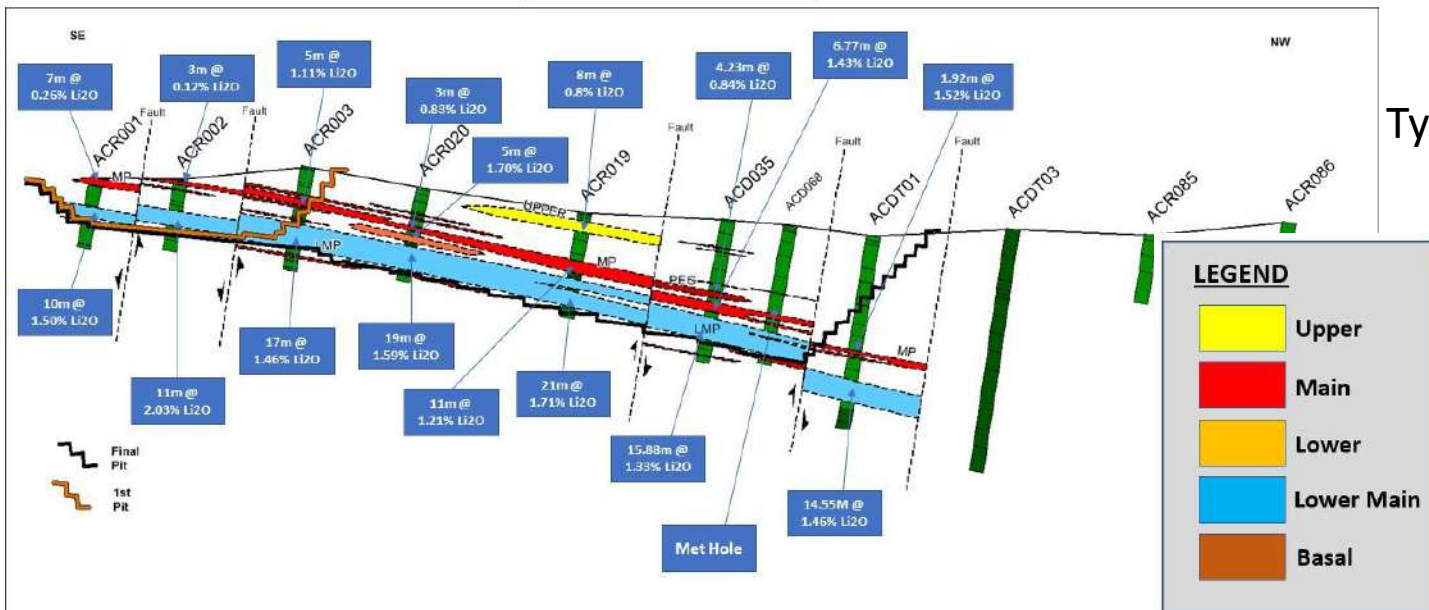
50 0 50 100 150 Kilometers







Cross Section Line 6 - Annotate

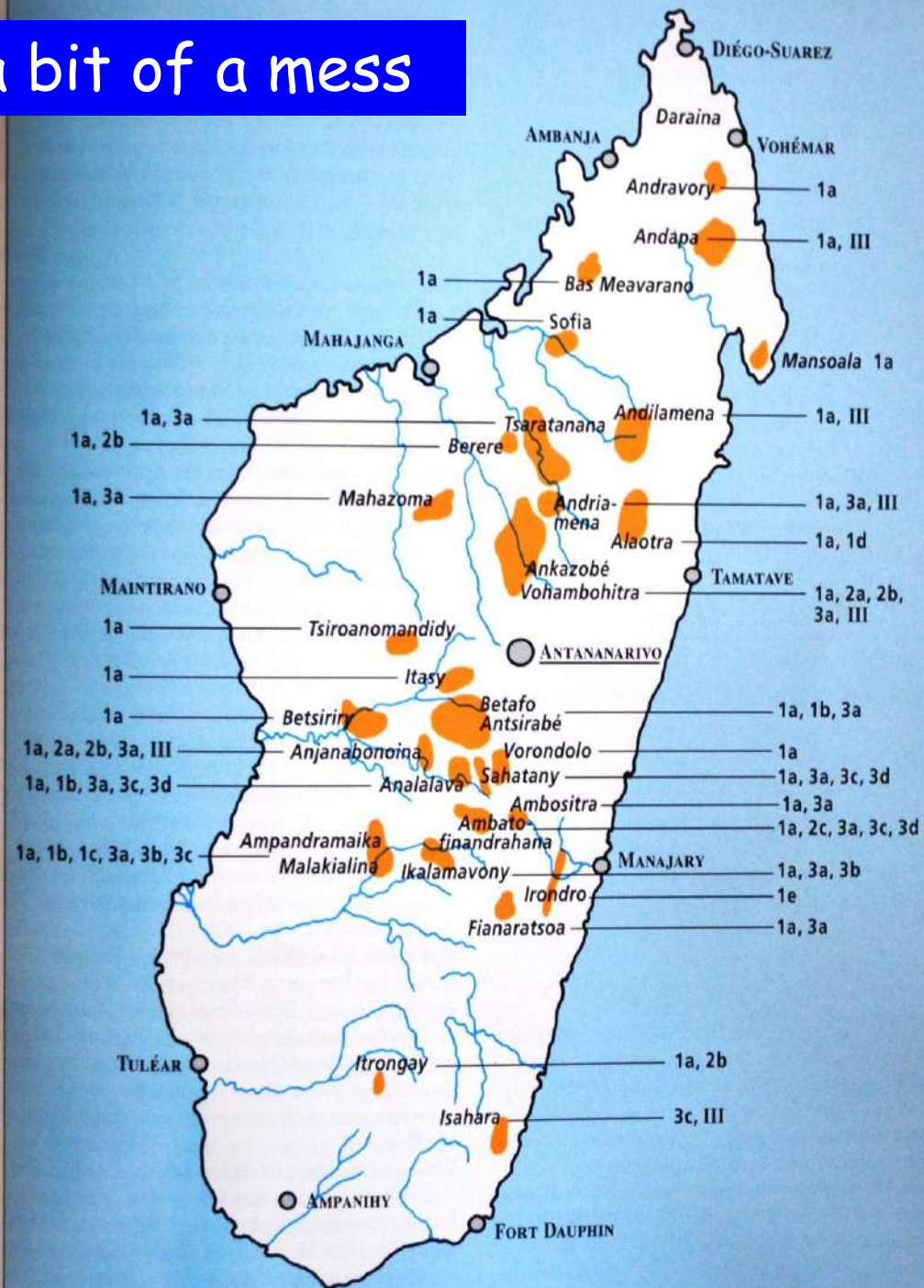


# Classification of pegmatites

# Pegmatite classification a bit of a mess

- **Abyssal class**
  - K feldspar
  - corundum
- **Rare earth LCT class**
  - beryl-columbite
  - beryl-columbite-U
  - beryl-columbite-P
  - chrysoberyl
  - emerald
- **Rare earth NYF**
  - allanite-monazite
  - monazite - Sc
  - bastnaesite
- **Complex LCT**
  - lepidolite
  - amblygonite
  - elbaite
  - danburite

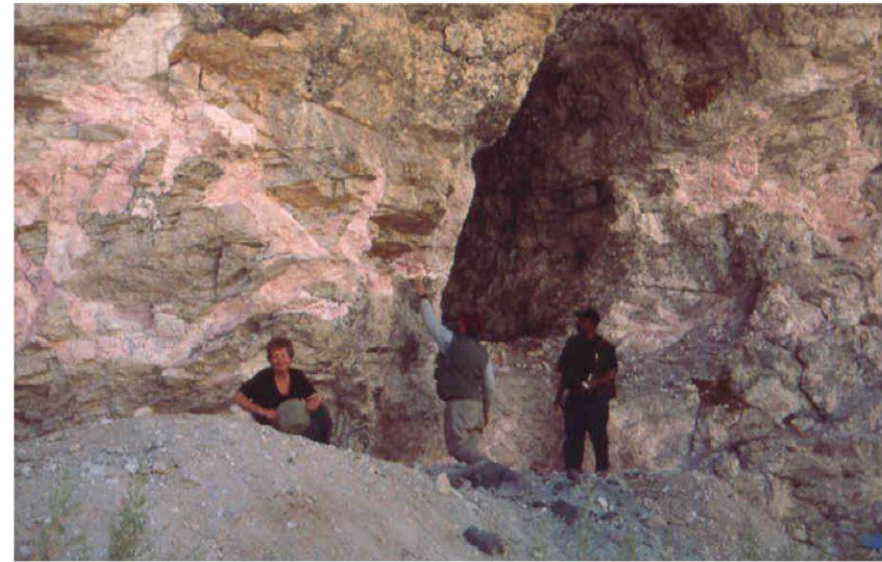
(Pezzotta, 1999)



# NYF-LCT pegmatites, 500 Ma - Namibia



Classic Rossing type with Nb>Ta, U, enriched HREE, fluorite 509 Ma



Classic LCT at Rubikon - 508 Ma

- The concept of NYF emplaced during extension and LCT emplaced during compression doesn't work in several parts of Africa.
- In Namibia both occur within the same time frame with the same structural setting at around 500 Ma. The classic Rubikon LCT is post-tectonic.



- If we look at the NYF subdivisions of Pezzotta there is a problem because beryl-columbite-uranium subtypes are classed as LCT type
- In Nigeria such a type is associated with A-type granites and elsewhere within the Nigerian A type there is the arfvedsonite-aegirine type of pegmatites of Wise 1999 classified as NYF.



# Parameters that affect pegmatite type implications for classification

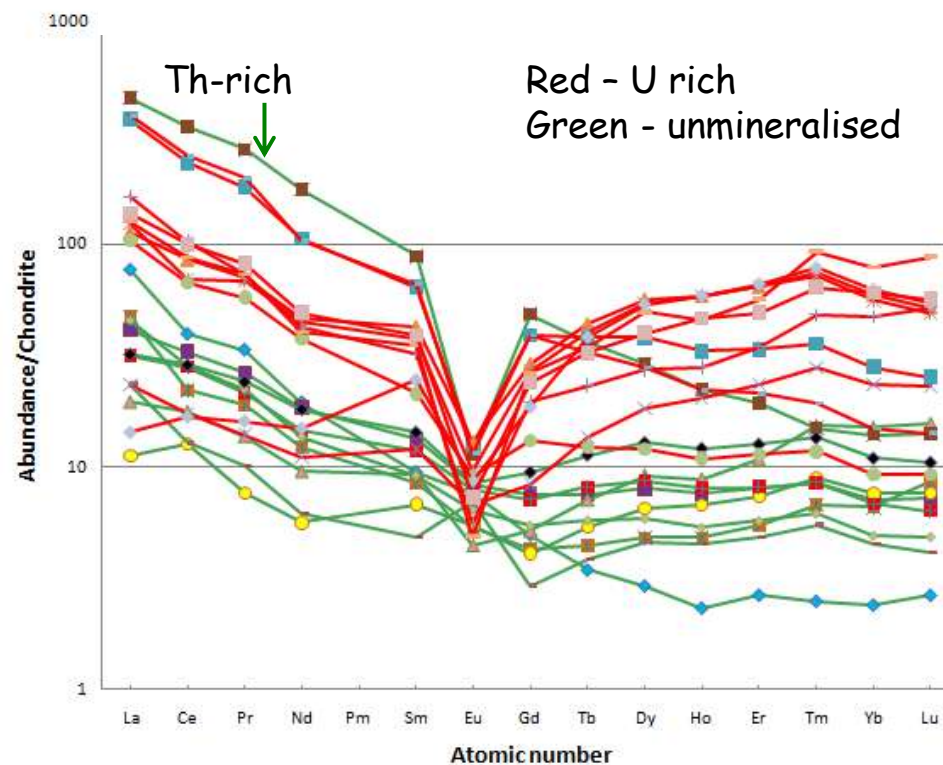
## Criteria to be considered

- Pegmatites may be younger than the country rock
- Mineralogy - recognition not always easy. Does a few grains of gadolinite make a pegmatite an NYF?
- Individual pegmatites may not be classified, rather a field is classified on the dominant type.
- Classification based on occurrence of a particular element may reflect province enrichment e.g. the REE enrichment in Mozambique and Madagascar
- The source regions - may change with time during orogenesis, crustal thickening, then thermal relaxation and extension.

# Source change with time

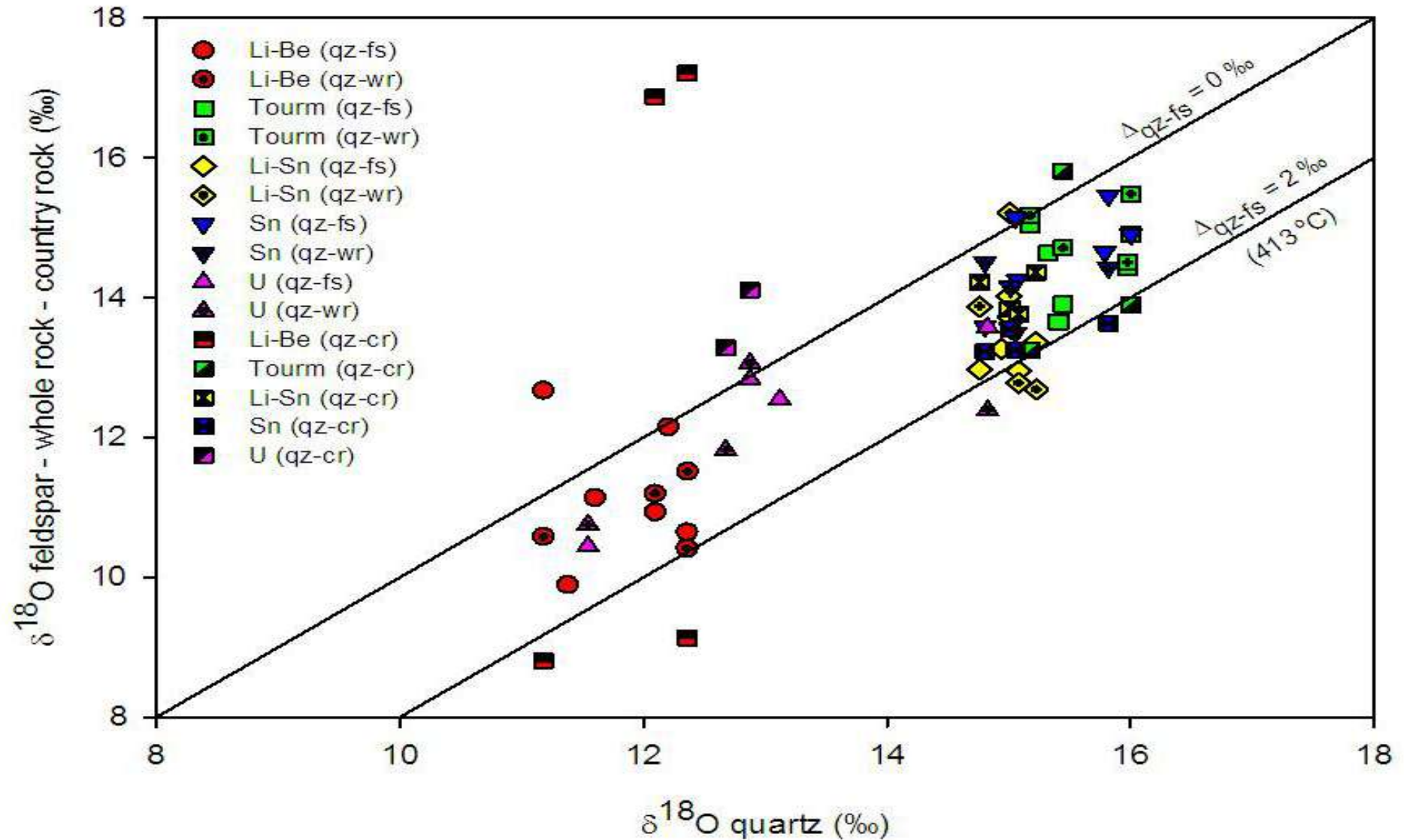


Pegmatitic sheets with (c) garnet (a) magnetite (b) tourmaline - no U mineralisation



U mineralised pegmatitic sheets - Holland's Dome

# Source and country rocks



Tourmaline- and tin-bearing pegmatites have a considerable crustal component  
Li pegmatites fall in two groups

# Parameters that affect pegmatite type implications for classification

## Other criteria to be considered

- The country rocks that the melt passes through
- Processes - variations in temperature and pressure, phase separation - Archaean pegmatites formed in a hotter Earth
- Melt structure modifier content such as  $\text{H}_2\text{O}$ ,  $\text{OH}^-$ ,  $\text{CO}_2$ ,  $\text{HCO}_3^-$ ,  $\text{CO}_3^{2-}$ ,  $\text{SO}_4^{2-}$ ,  $\text{PO}_4^{2-}$ ,  $\text{H}_3\text{BO}_3$ , F, Cl, Li, Na, K, Rb, Cs and Be
- The combination and amount of the different species (Thomas et al 2012)

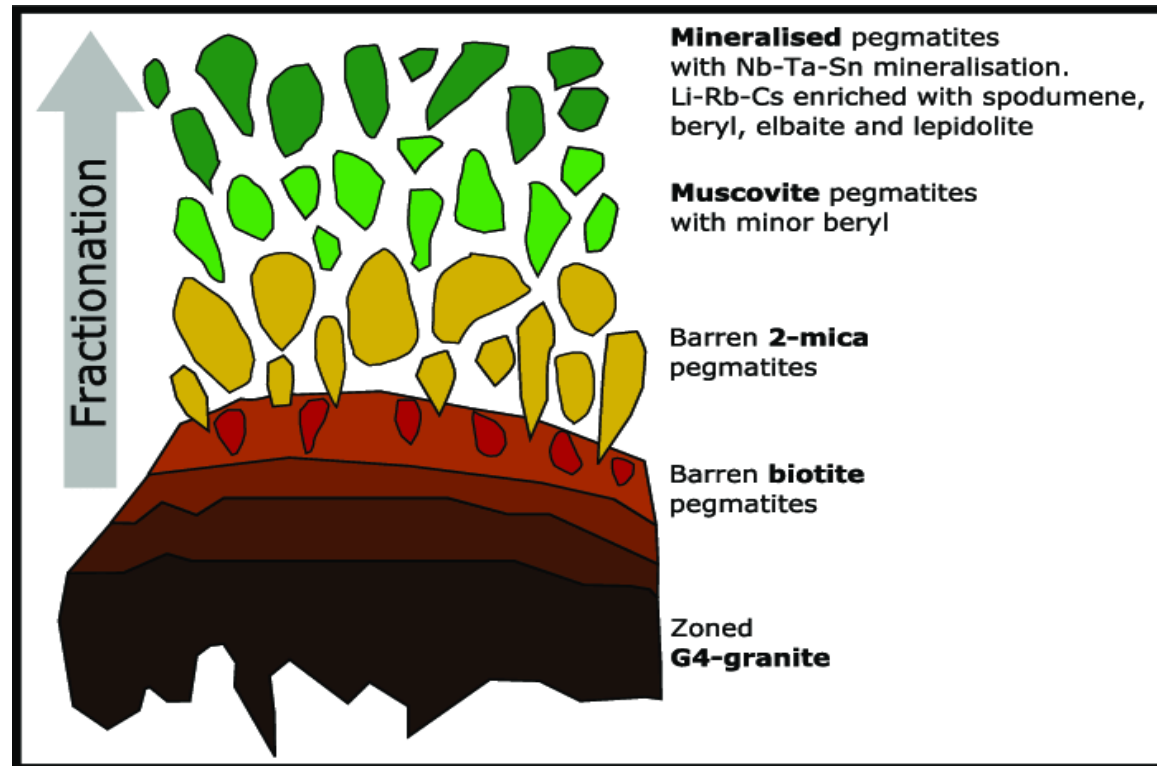
What is the source/genesis of  
pegmatites?

Do we know where they come  
from?

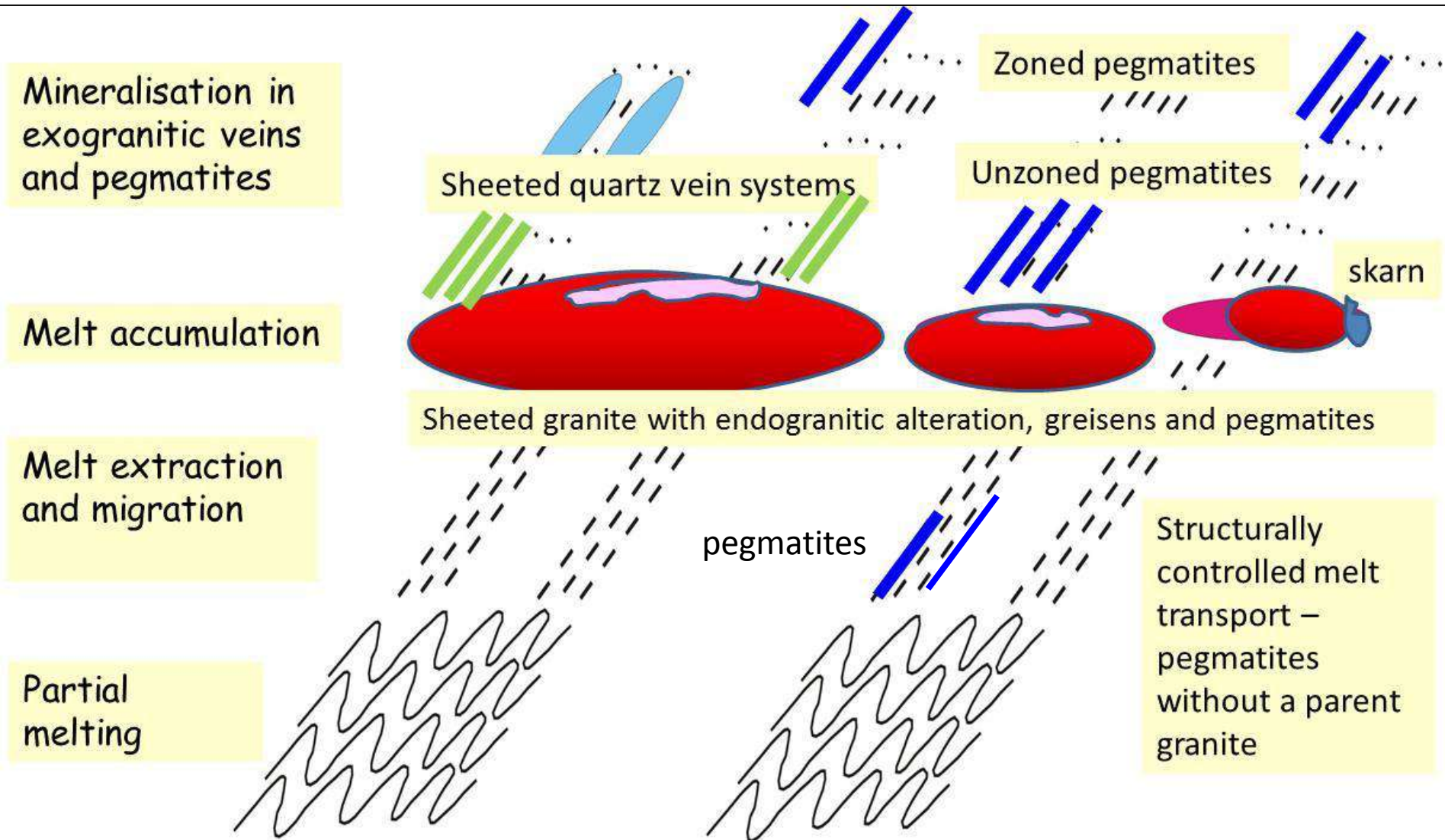
# Pegmatite Genesis by fractionation or "anatectic" (low volume partial melting)

London 2018 "The fundamental relationship in which granites spawn  
pegmatites is not in doubt" Ore Geol Rev.

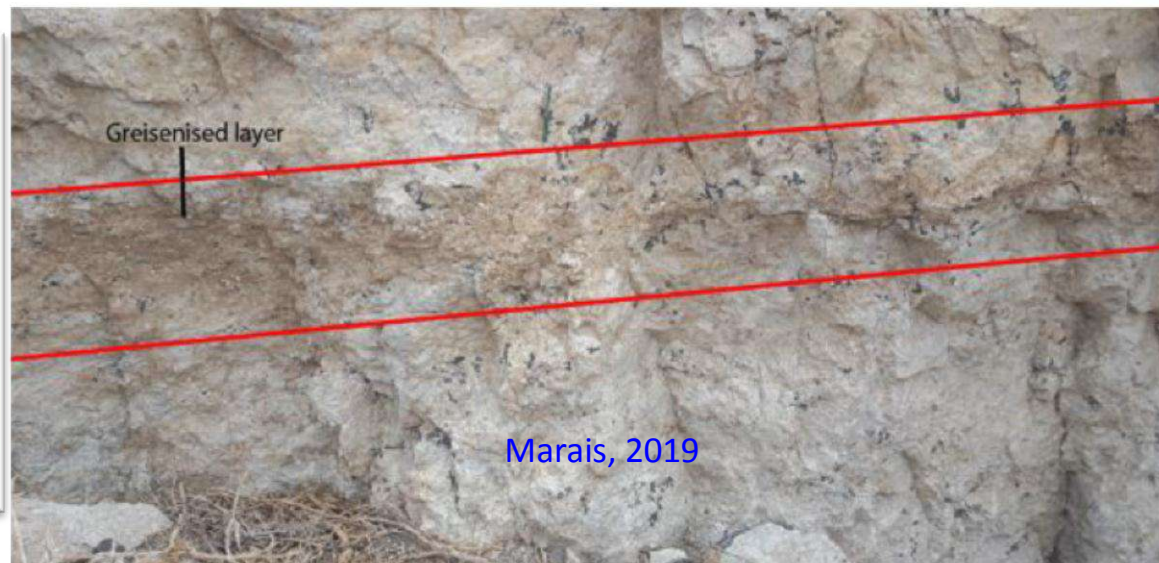
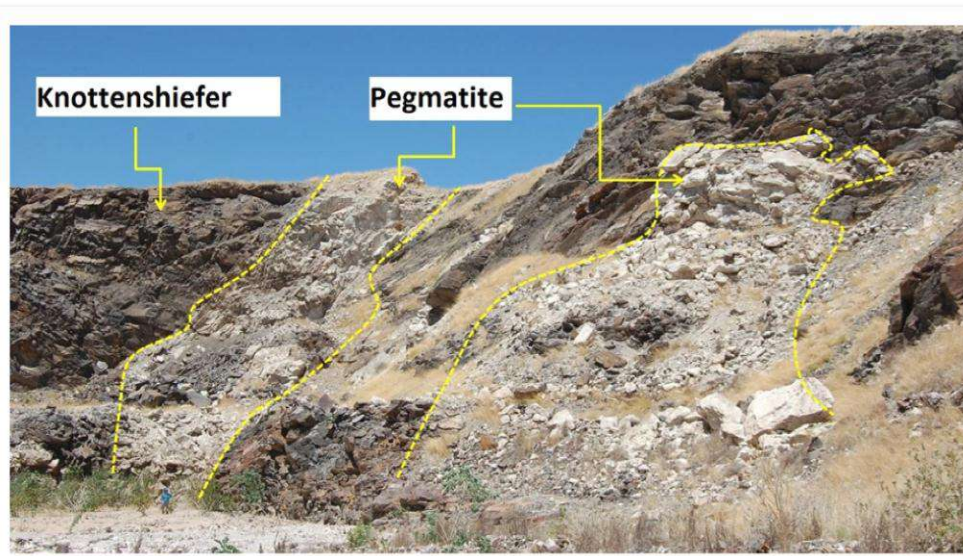
- Lack of supposed regional zonation of pegmatites.
- Age differences between pegmatites and local granites of ~15-35 Ma
- REE data suggesting that the spatially associated granites cannot produce the enrichment in incompatible elements seen in the pegmatites.



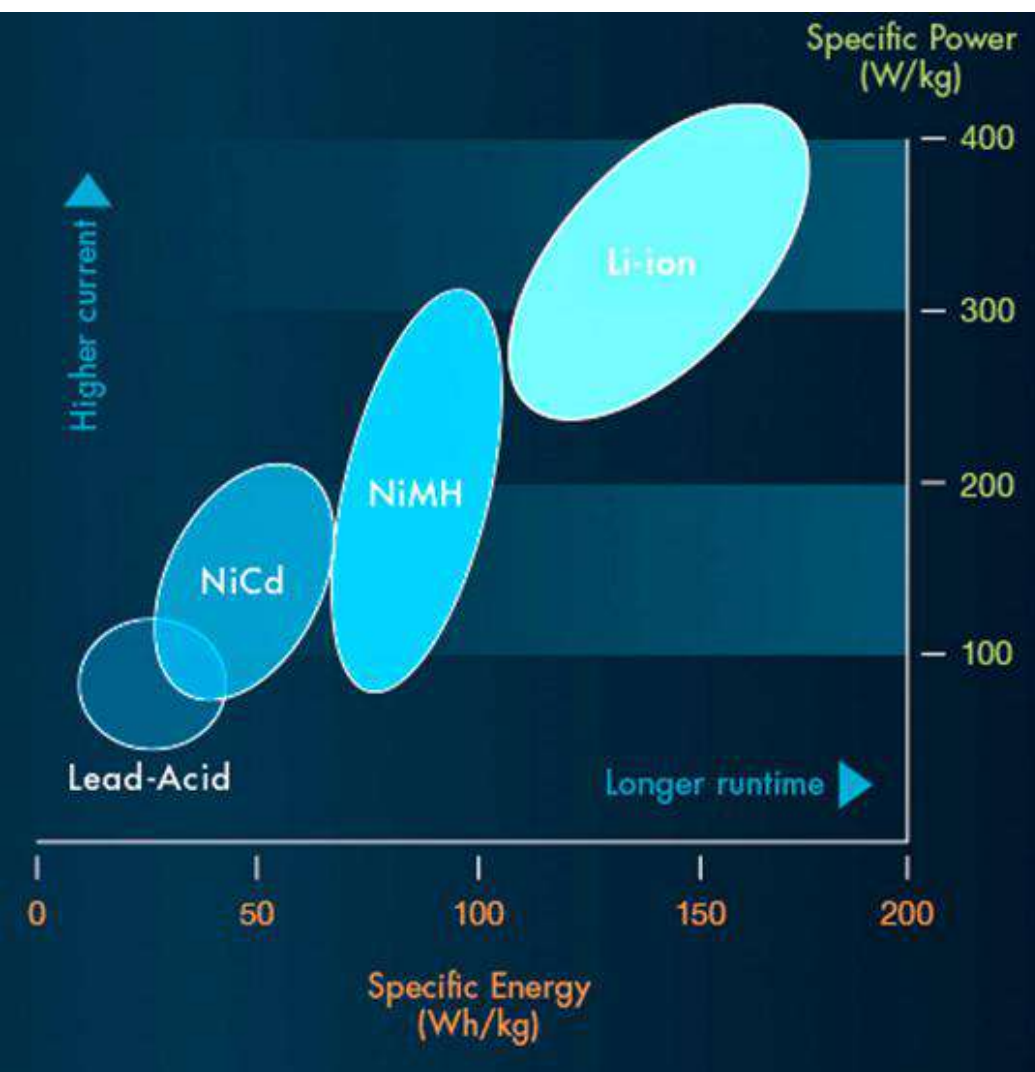
Cerny (1992)



# Is the mineralisation magmatic or hydrothermal?



Why pegmatites?



Relative efficiency of various battery types in terms of specific energy and specific power showing that lithium-ion batteries have a longer run time and higher current output than other available battery types

Fuel cell vehicles	
Toyota	Mirai
Honda	Clarity
Hyundai	Tucson FCEV
Electric vehicles	
Bolloré	Bluecar
BMW	i3
BTD	E6
Chery	QQ3 EV
Chevrolet	Bolt
Fiat	500e
Ford	Focus Electric
JAC	J3 EV
KD	5011
Kia	Soul EV
Lada	Ellada
Mitsubishi	I MiEV
Nissan	Leaf
Opel	Ampera-e
Renault	Zoe
Roewe	E50
Tesla	Models S, X and 3
VW	e-Up!, e-Golf
Whorpe	Whip LiFe

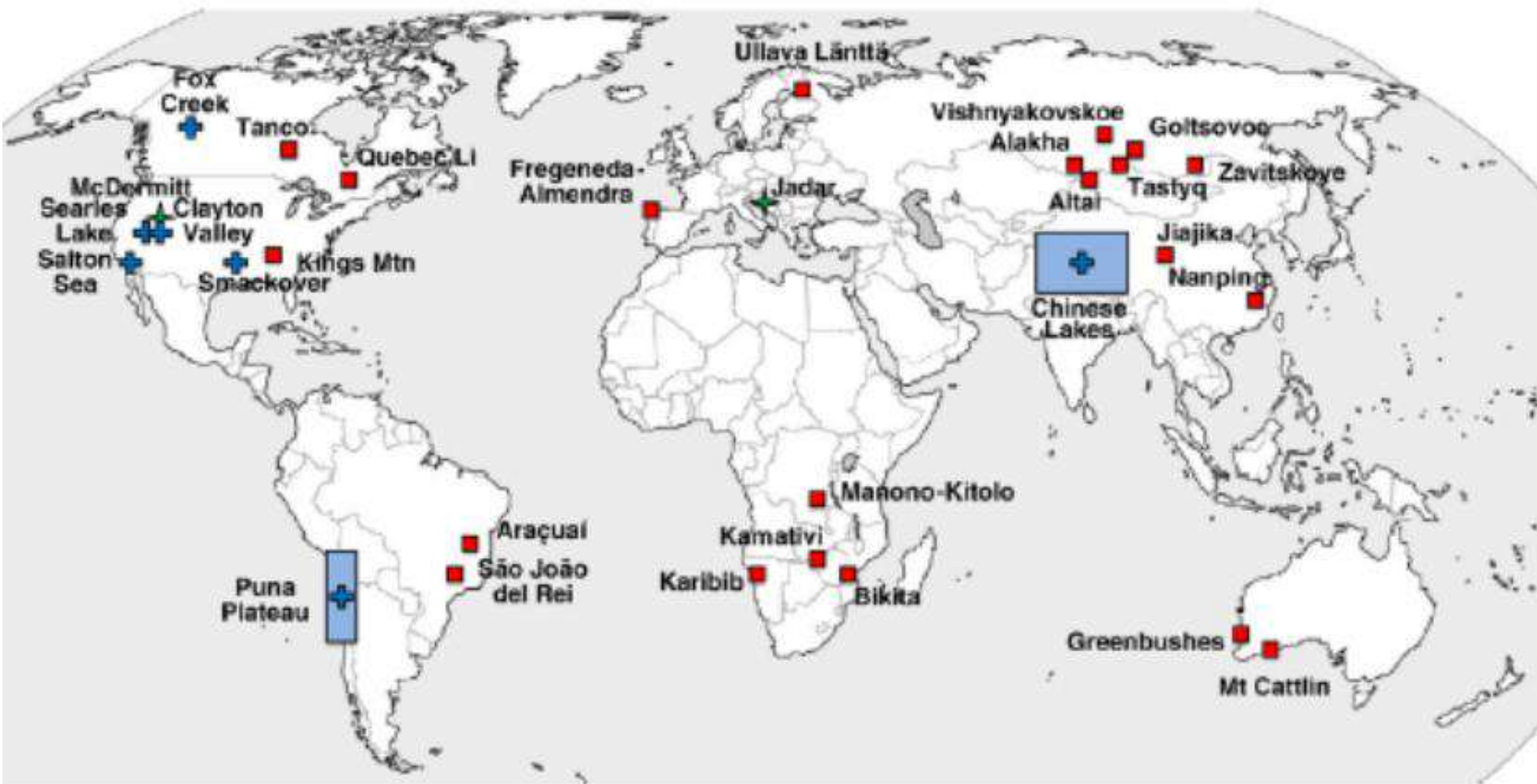
# Lithium Minerals



Mineral	Formula	Lithium (Li)	Li <sub>2</sub> O
Spodumene	$\text{LiAl}(\text{SiO}_3)_2$	3.73%	8.03%
Petalite	$\text{LiAlSi}_4\text{O}_{10}$	2.09%	4.50%
Amblygonite	$(\text{Li},\text{Na})\text{AlPO}_4(\text{F},\text{OH})$	3.44%	7.40%
Lepidolite	$\text{K}(\text{Li},\text{Al})_3(\text{Al},\text{Si},\text{Rb})_4\text{O}_{10}(\text{F},\text{OH})$	3.58%	7.70%
Eucryptite	$\text{LiAlSiO}_4$	5.51%	11.86%

	Project	Company		Ore	Grade (Li <sub>2</sub> O)	Contained LiO <sub>2</sub>
DRC	Manono-Kitololo		Historical	35 Mt	0.6%	
DRC	Manono	AVZ Minerals	2018 (JORC)	259.9 Mt	1.63%	4.236 Mt
Ghana	Egyasimanku	Iron Ridge Resources	Historical	1.48 Mt	1.66%	
Mali	Goulamina	Mali Lithium	2017 (JORC) 2018 (JORC)	32.9 Mt 103.2 Mt	1.37% 1.56%	1.380 Mt
Namibia	Helicon & Rubicon		Historical	1.1 Mt	1.4%	
Namibia	Helicon & Rubicon	Lepidico	(JORC)	8.8 Mt	0.56%	
Zimbabwe	Arcadia	Prospect Resources	2017 (SAMREC)	40.5 Mt	1.44%	0.583 Mt
Zimbabwe	Bikita	Bikita Minerals	Kesler, 1978 Clarke, 2011	10.8 Mt 10.8 Mt	1.4% 0.58%	
Zim	Kamativi Tailings	CAT Strategic Metals	2018 (NI43-101)	26.3 Mt	0.28%	0.073 Mt
Zim	Zulu	Premier African Minerals	2017 (SAMREC)	20.1 Mt	1.06%	0.213 Mt
		Total		449.8 Mt		6.412 Mt

The newly determined hard-rock resources in Africa equate to approximately 3 Mt of Li. (Global production of Li is in the region of 80,000 tpa)

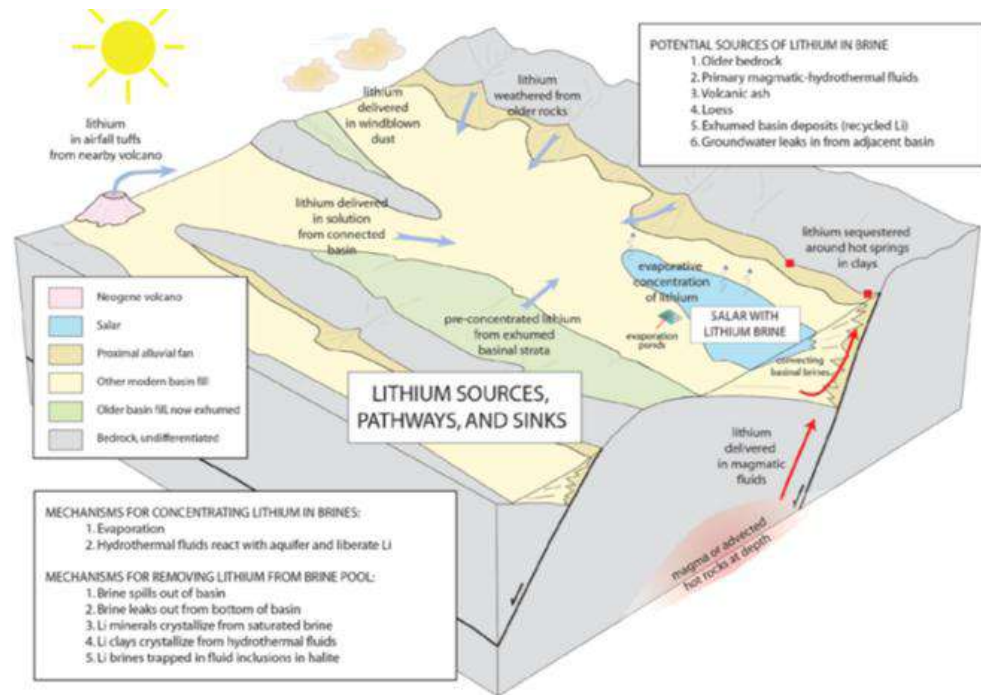


Location of major lithium deposits of the world. Pegmatite deposits are shown in squares, brine deposits are shown as shaded areas.



Economist.com

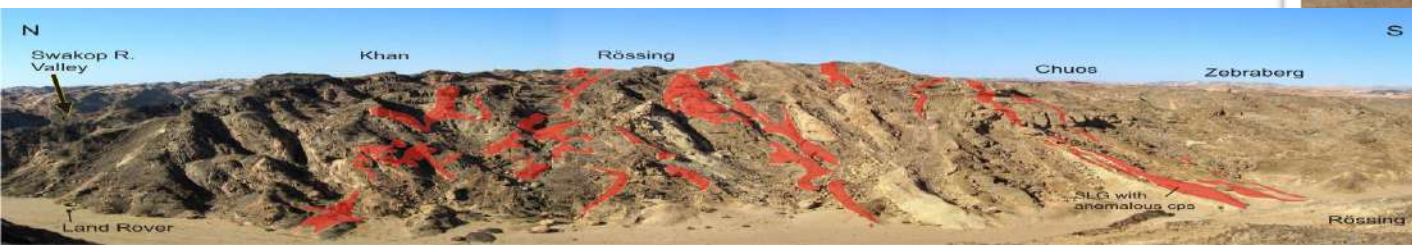
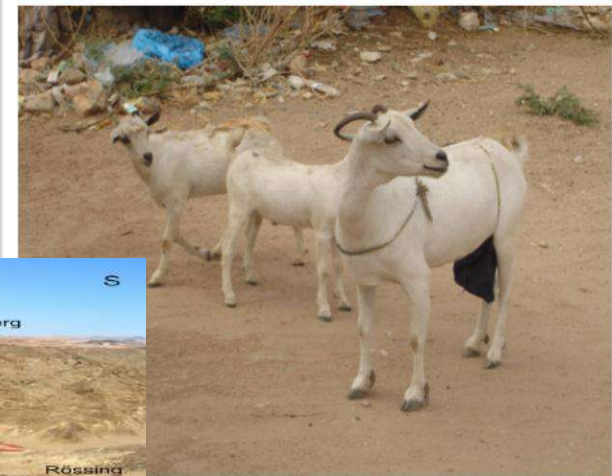
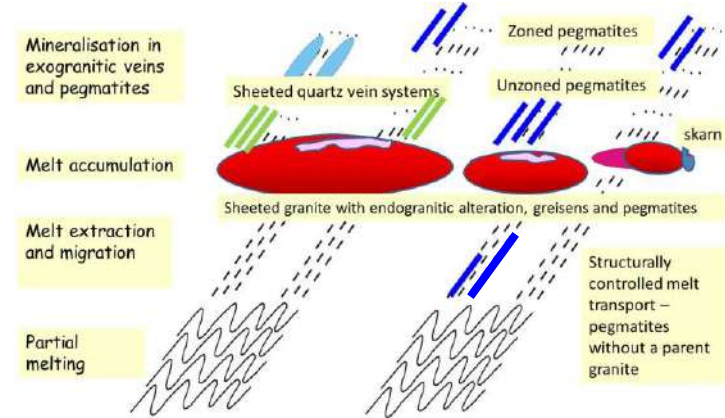
Li brines in South America and China.



- Li-brines derived from silicic volcanic rocks, pumped to surface into ponds. High altitudes and low rainfall promote evaporation. Cost effective.
- Economical brines - hundreds ppm Li to >7,000 ppm.
- Filtering removes unwanted elements (e.g. B or Mg) then sodium carbonate (soda ash) added to precipitate lithium carbonate.
- Li sourced from brines inferior to pegmatite
- Li is in low concentrations, <100 to 200 ppm in brines from many salt lakes including the 1-20 ppm Li in brines in Merouane Chott in Algeria (Haccini et al, 2008).

# Conclusions

- Archaean, Birrimian, Kibaran and PanAfrican
- Pegmatites are products of supercontinent assembly.
- Not all pegmatites have a parental granite
- Classifications are fraught with problems: Different types can occur across a range of terranes at the same time.
- We need to focus more on the tectonic setting, source material and geochemistry of major minerals.



# PEG 2021

- Every 2 years a meeting is held
  - 2019 San Diego
  - 2017 Oslo
  - 2015 Poland
  - (2014) Namibia
  - 2013 New Hampshire
  - 2011 Mendoza
- Peg people would like to come to Zimbabwe
  - Propose with your help to start at Vic Falls - hotel?
  - Day at Kamativi
  - End at Bikita



Thank you

