HOT OROGENS: THE NEOPROTEROZOIC ARAÇUAÍ OROGEN CASE STUDY, SE BRAZIL

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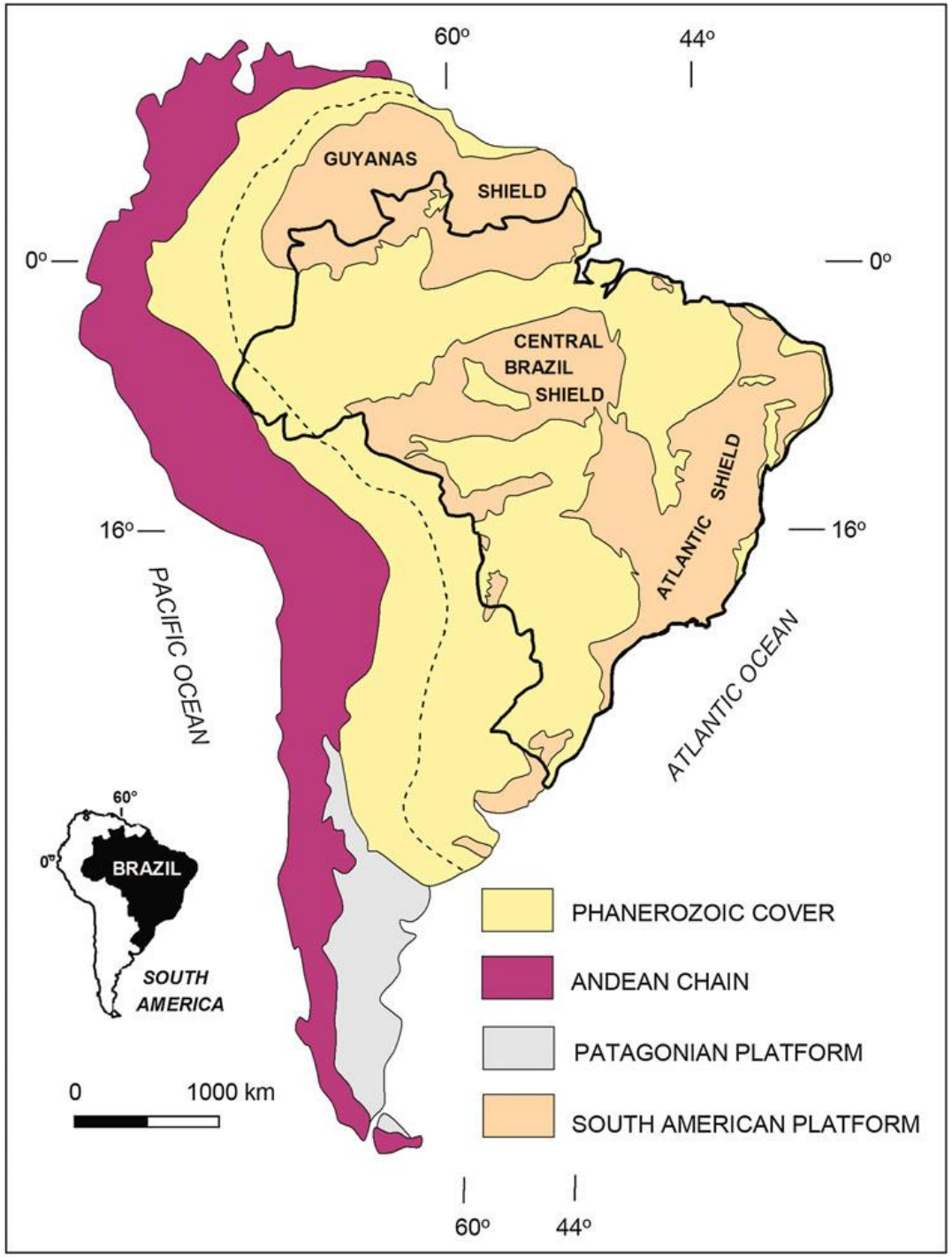
- **Undergrad at U. São Paulo, 2016**
- **Masters at U. Campinas**
  - 6-months scholarship in USA (WWU and WSU)
- **Adviser:** Prof. Vinícius Meira
  - Prof. Sean Mulcahy collaboration
- **Question**: What were the P-T-t paths and rates of the Neoproterozoic Araçuaí Orogen?
- **How are we tackling the problem?**
  - Field work
  - Petrography control
  - Geochronology – grt, zr, mon(?)
  - Metamorphic Modelling

Western Sierras Pampeanas Field Trip, Argentina. 2016

TECTONIC SETTING – THE SOUTH AMERICAN PLATFORM

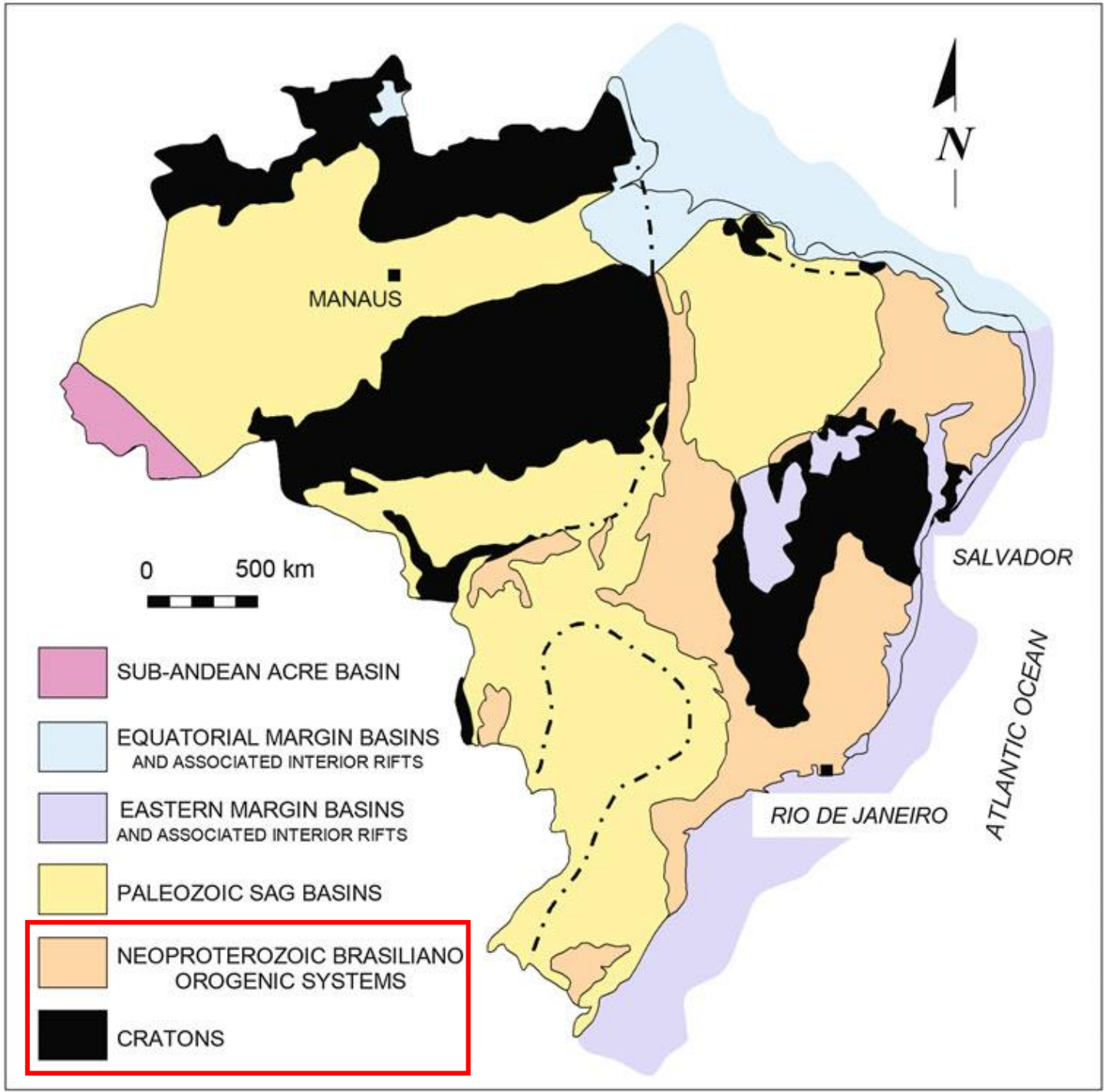
Alkmin, 2015



A BROAD DIVISION OF BR GEOLOGY

- As hard-rock geologists, we are mainly interested in the **Neoproterozoic Orogenic Systems and Cratons**!

Alkmin, 2015

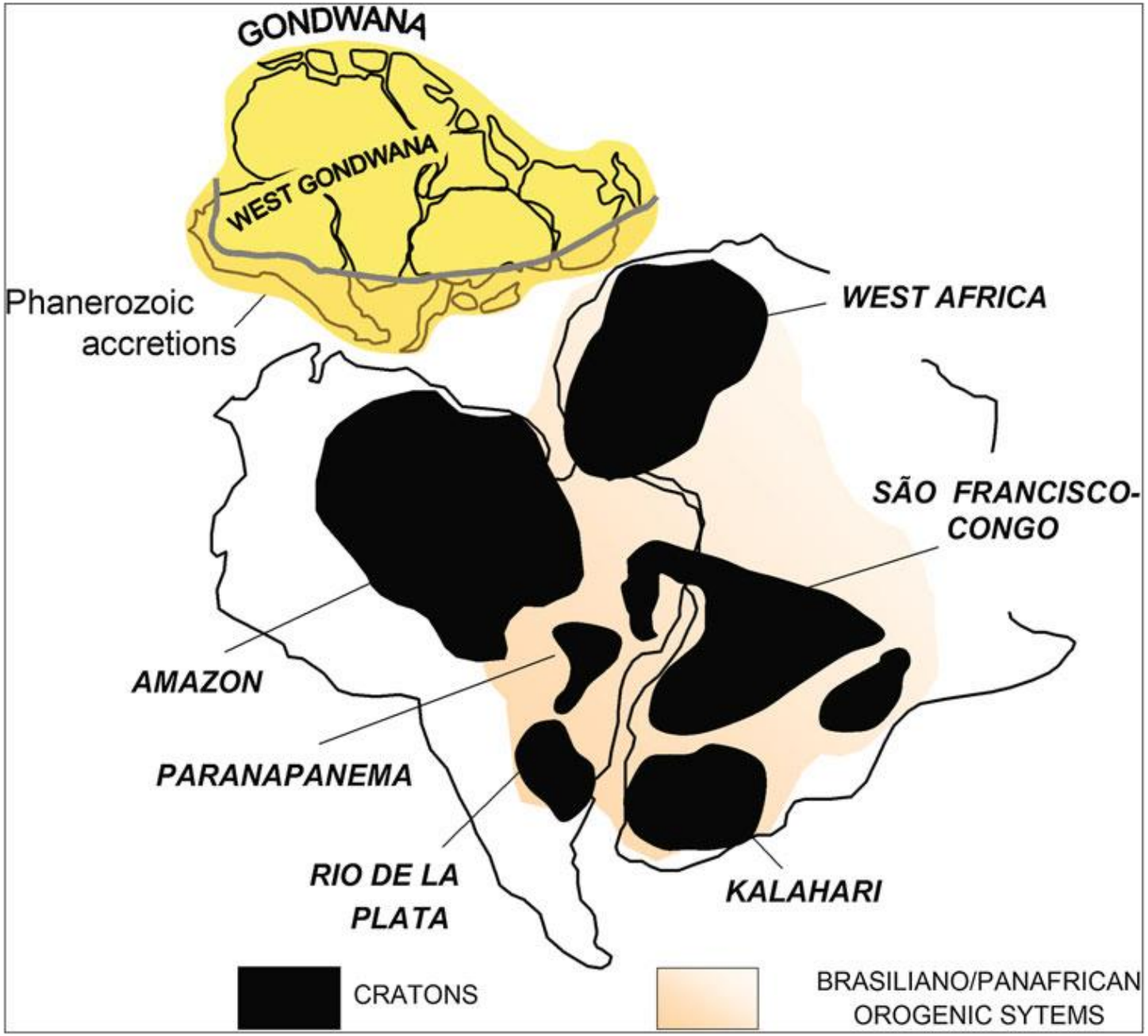


WEST-GONDWANA PALEOCONTINENT

- Cratons – **São Francisco-Congo**
  - Brasiliano/Pan-African

Neoproterozoic orogenic systems

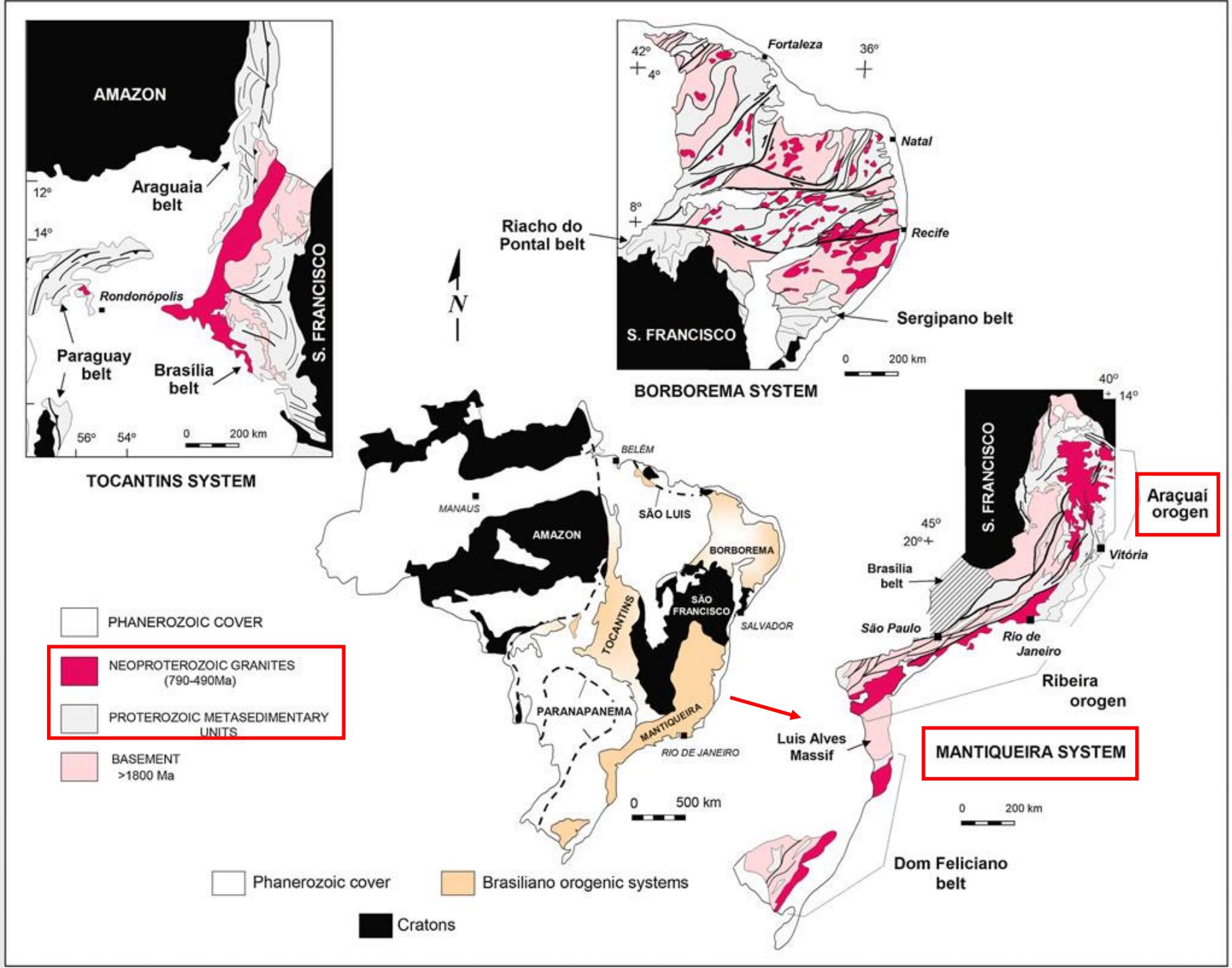
Alkmin, 2015



NEOPROTEROZOIC OROGENIC SYSTEMS

- Borborema
- Tocantins
- **Mantiqueira Province – SE**

Alkmin, 2015



THE MANTIQUEIRA PROVINCE

- Uruguay to Central Brazil
- **Long-lived orogenic evolution**
- **Complex terrane accretion processes** towards the south (Ribeira Belt)
- Araçuaí Orogen
  - **~650 km wide**
  - **High-T anatectic/magmatic hinterland**

Fossen et al., 2017

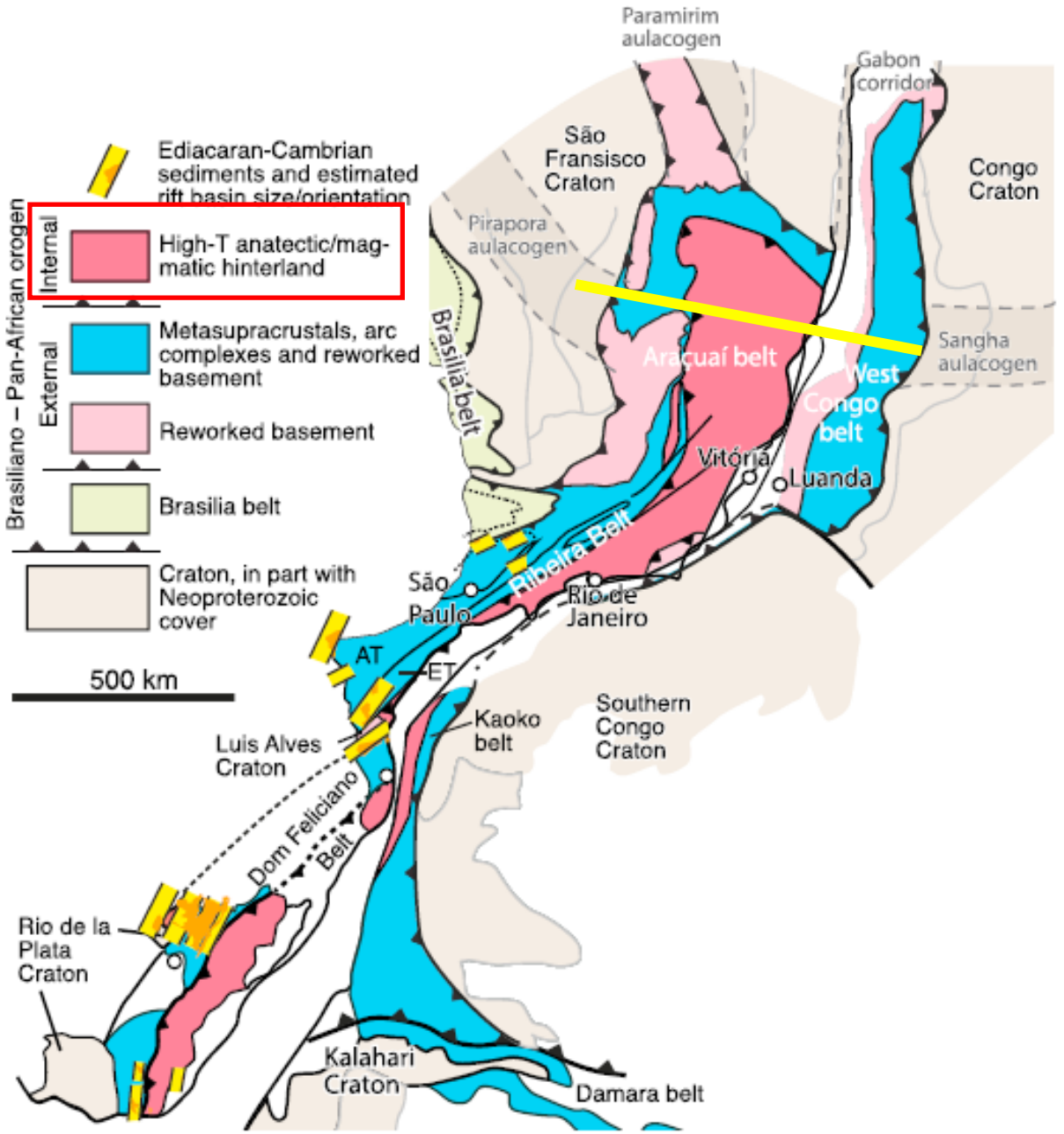


Figure 4. Tectonic map of the Mantiqueira (Araçuaí-Ribeira-Dom Feliciano) orogenic system. Based mainly on Heilbron et al. (2008), Tack et al. (2001), Pedrosa-Soares et al. (2008), and Almeida et al. (2012). AT = Andrelândia terrane; ET = Embu Terrane.

THE ARAÇUAÍ OROGEN AS AN EXAMPLE OF HOT OROGEN

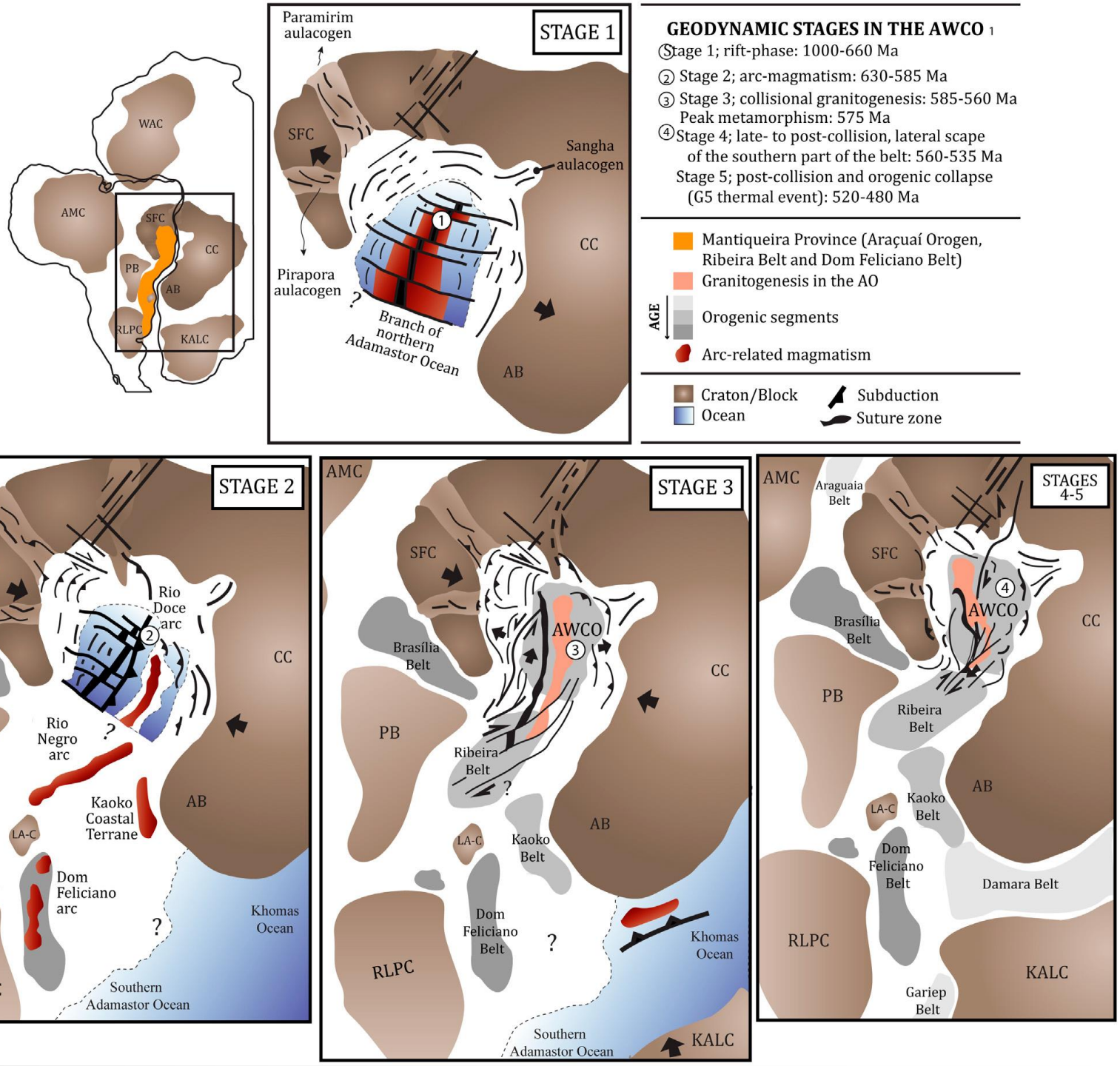
- 2 main lines of thought

1. SUBDUCTION RELATED - GEODYNAMICAL MODEL

- Subduction of a Mid-Ocean Ridge
- Magmatic stages
  - **PRE**collisional 630-585 My - **ARC**
  - **SYN**collisional 585-530 My
  - **POST**collsional 530-480 My
- "Nut-cracker Tectonics"

Cool, but...what about T and P?

Richter et al., 2017



THE HOT INTERNAL ZONE - TEMPERATURE

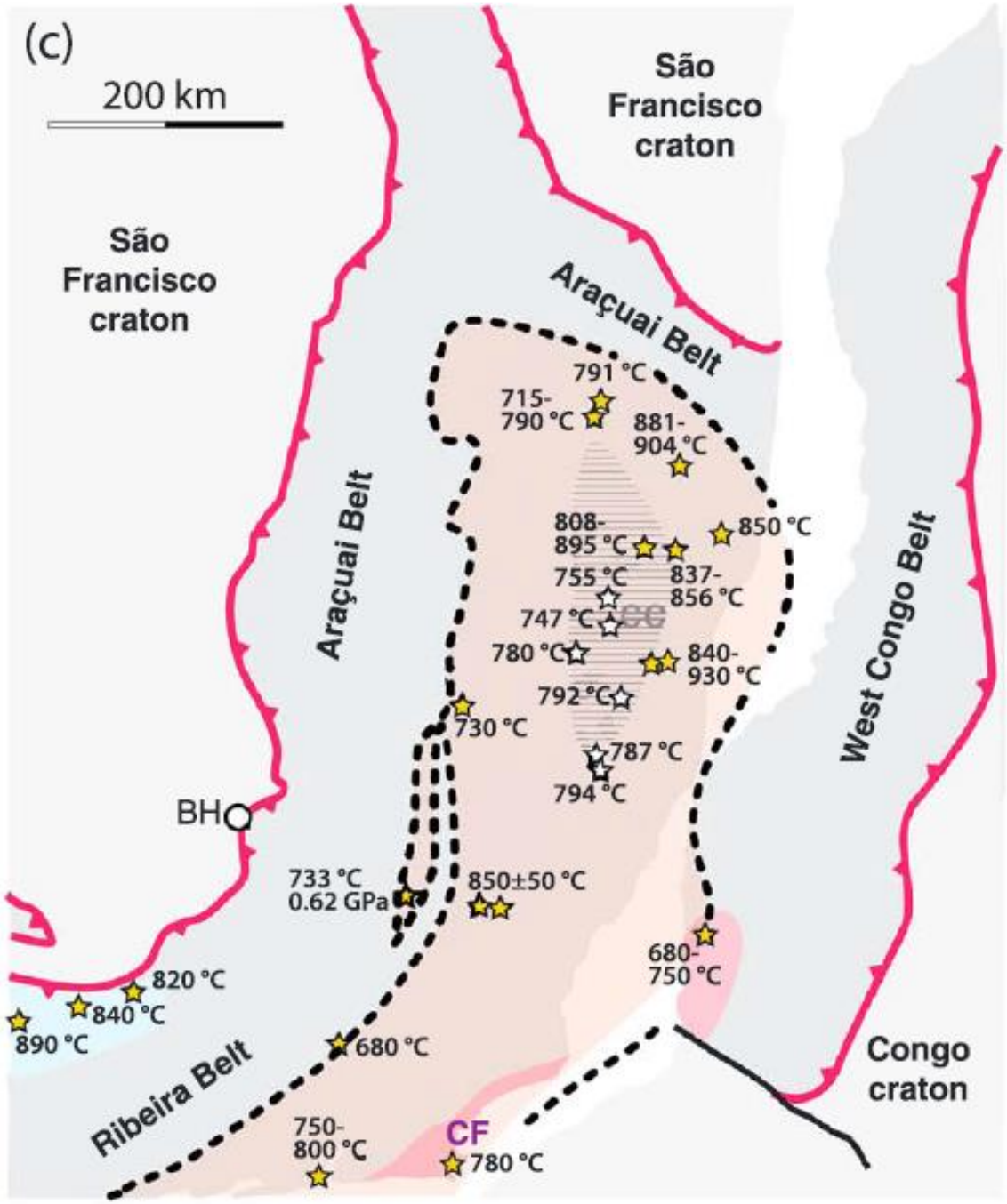
- Vast amount of magmatic and anatectic rocks:
  - Crystallization ages 630-480 Ma, **overlaping**

- **Peak T in excess of 750 °C**. Locally, up to **850 °C**, or even higher!

- ASM (magnetic fabrics) studies on anatectic bodies show complex structures…

- **Non-solid state deformation** with conditions of 750-800 °C and **high melt volume** (> 30%)

Fossen et al., 2017



Orogenic transport
Cabo Frio orogen
TitaniQ temperatures
Geobarothermometry localities

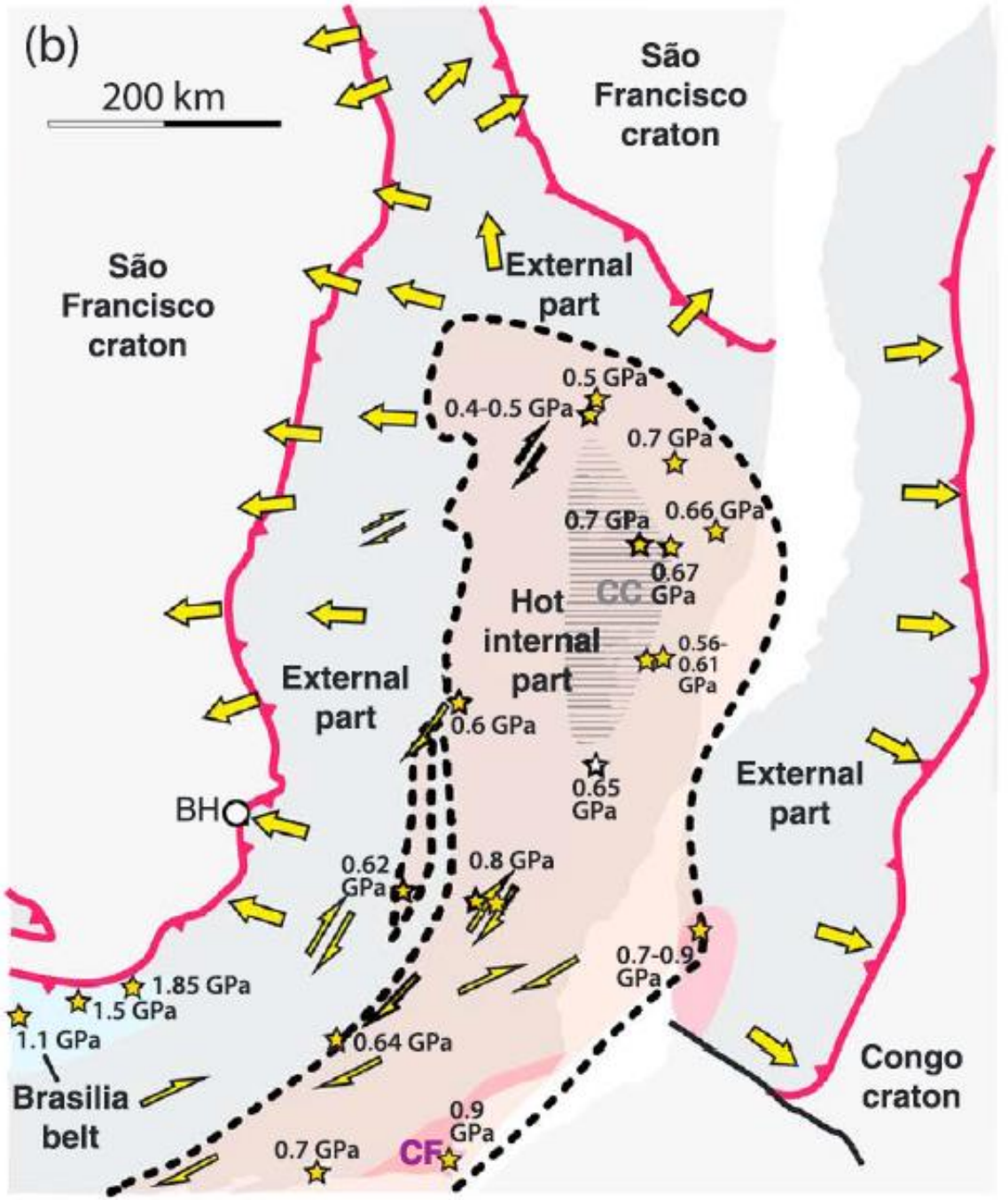
THE HOT INTERNAL ZONE - PRESSURE

- Paleopressures of 5-7 Kbar
  - 20-25 km depth (midcrustal levels)
  - Plus 40 km of the current depth
  - **60-65 km crustal thickness**

- **Putting T and P together…**
  - Very hot rocks at midcrustal levels…

- **HOT OROGEN?**

Fossen et al., 2017



2. EARLY THICKENING/PLATEAU

1. If Arc/Pre-collisional magmatism – 625 My…

- **45-50 my of subduction** and precollisional shortening of 1000 km, even for low rates, **is not likely considering orogen geometry**;

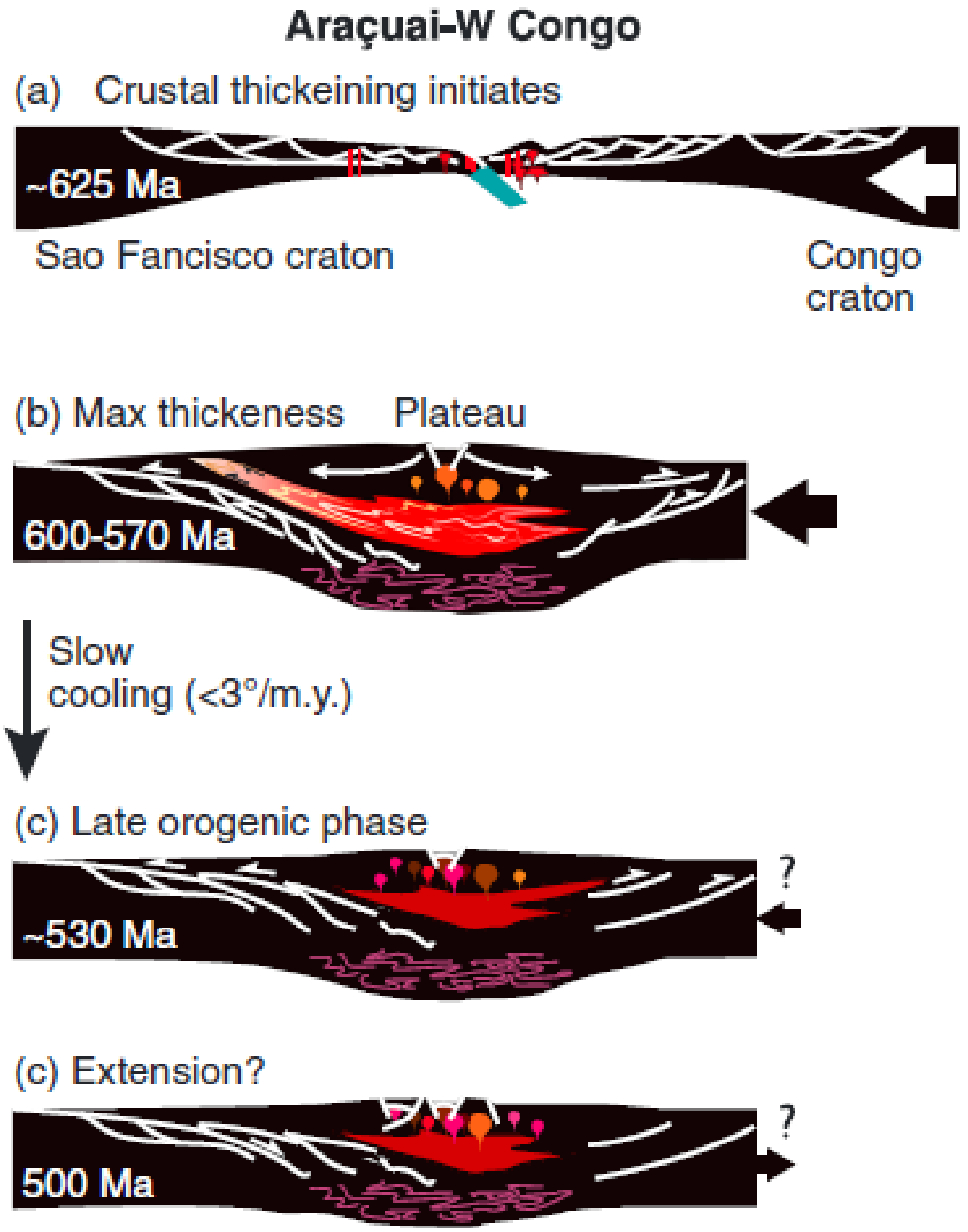
2. 500 km of shortening is necessary to the 65 km thickening (P estimates)…

- **Previous arc development is unlikely!**

3. Melting in 600 My but…if 20-25 My is necessary to establish a large hot middle-crustal anatectic domain…

- Crustal thickening started in 620-625 My
- **Mid-ocean ridge limited or not present!**

Fossen et al., 2017



WHY SO HOT?

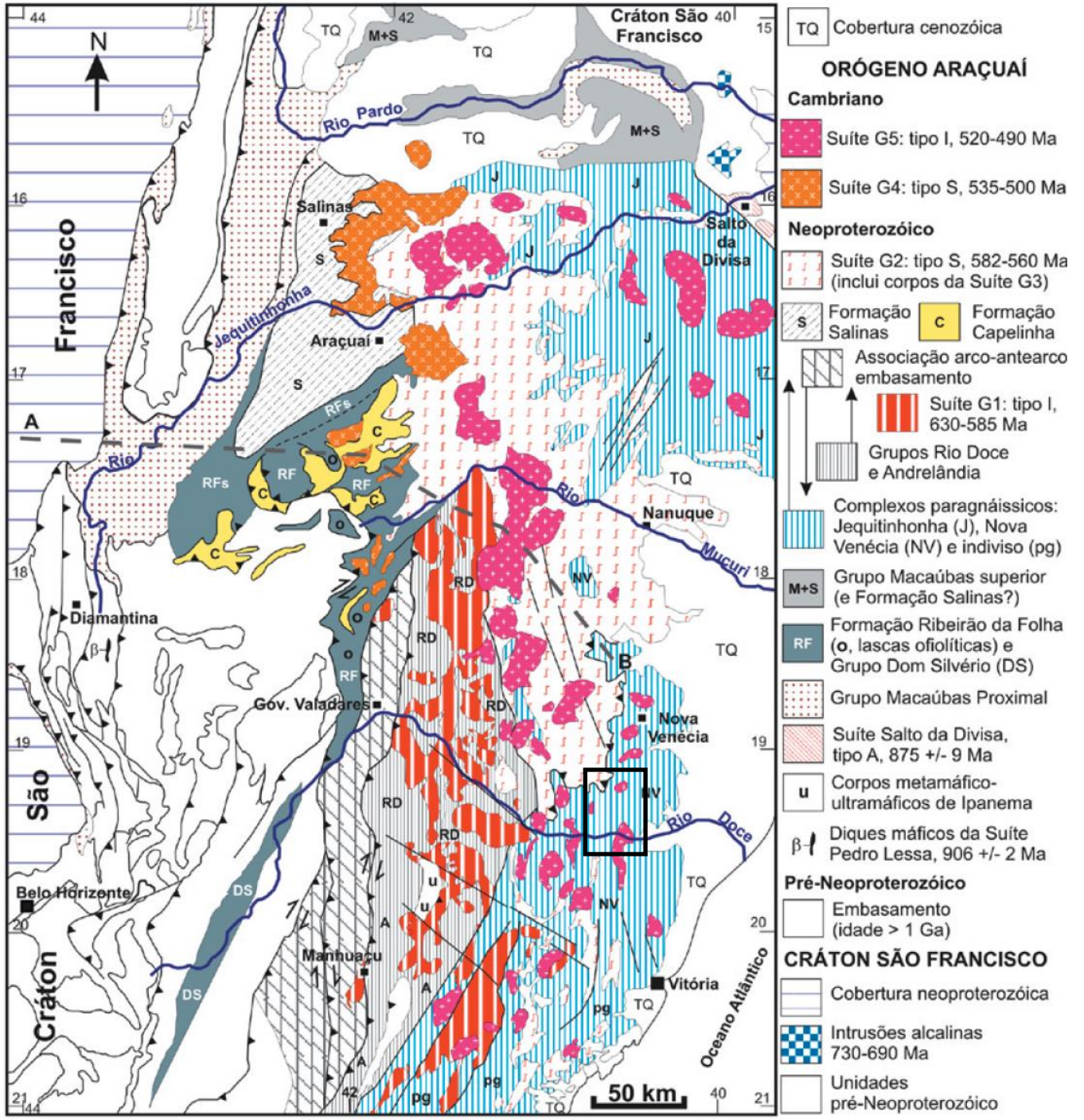
- Unsolved question but…
- **Main process (Fossen *et al*. 2017): crustal heat production from radioactive elements (U, Th, K)**
  - Metamorphism through tens of My
  - Source: large volume of pelitic sediments from previous big basin (600 km wide)
  - T > 700 °C after ~20 My, similar to Himalayan and Greenville orogens
- **Does magmatism plays a role?**

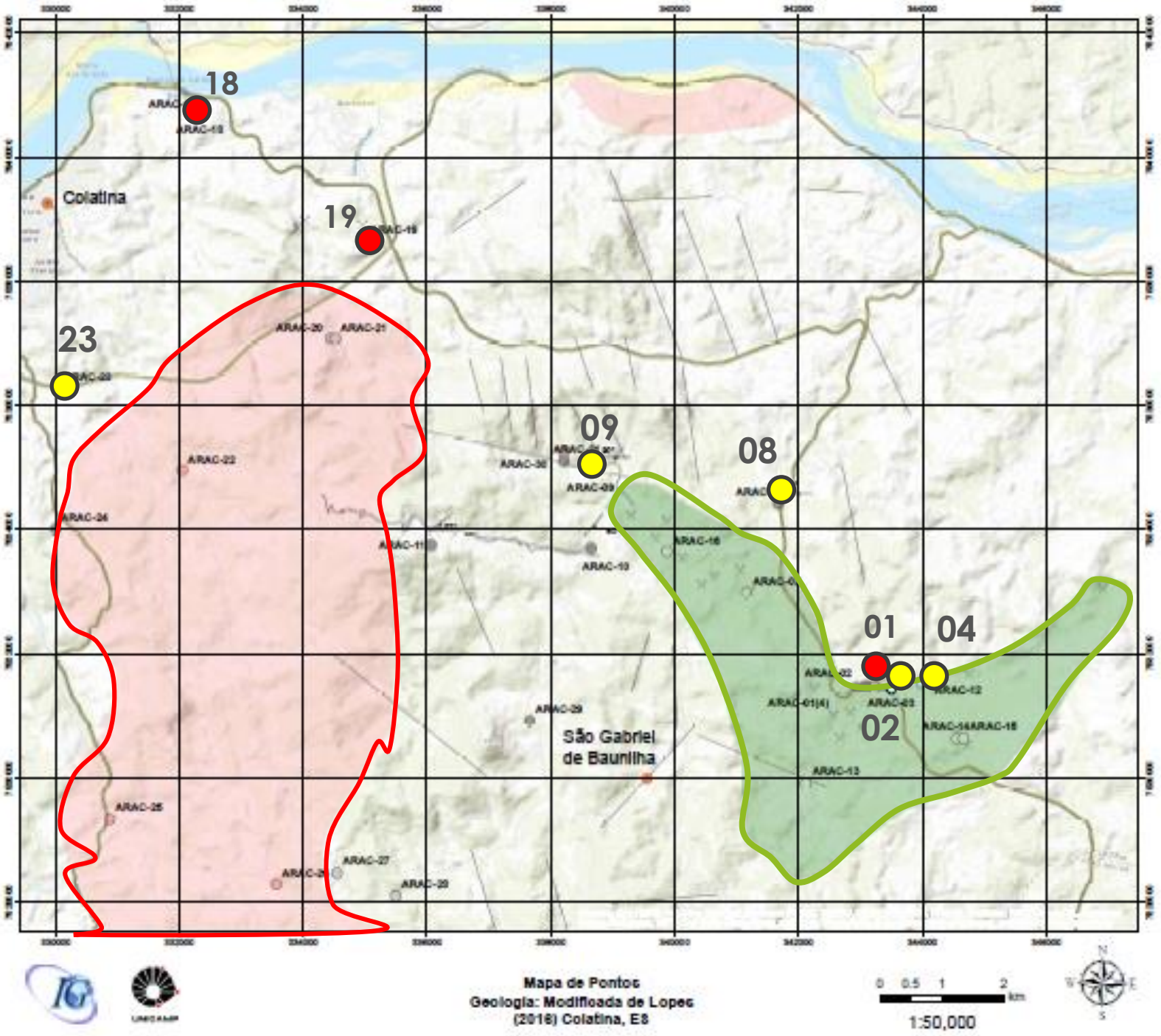
MY RESEARCH WITHIN THIS CONTEXT...

Colatina region, Espírito Santo State. SE Brazil

ARAÇUAÍ OROGEN

Pedrosa-Soares et al., 2007





1. **Metasediments**
   - *Nova Venécia Complex*
   - Al-rich migmatictic paragneisses
   - Calc-silicate lenses
   - Granulite facies

2. **Sin-colisional magmatism**
   - *Colatina Granitoid*
   - *Bt-Grt granite*

3. **Post-colisional magmatism**
   - São Gabriel Pluton
   - Isotropic, coarse, gabbro-norite

FIELD FEATURES

FIELD FEATURES – METASEDIMENTS

- Granulitic paragneisses with deformed **grt**, coarse-grained leucocratic granitic veins and fine isotropic gray calc-silicate rocks

- Stromatic metatexite with local vein structures; leucossome segregation

FIELD FEATURES – METASEDIMENTS

- Complex variations on outcrop scale, diffusive contacts, complex deformation

FIELD FEATURES – SIN-COLLISIONAL MAGMATISM

- Typical topographic response

- Medium-coarse isotropic **bt**-**grt** granite

FIELD FEATURES – COLATINA GRT-GRANITE

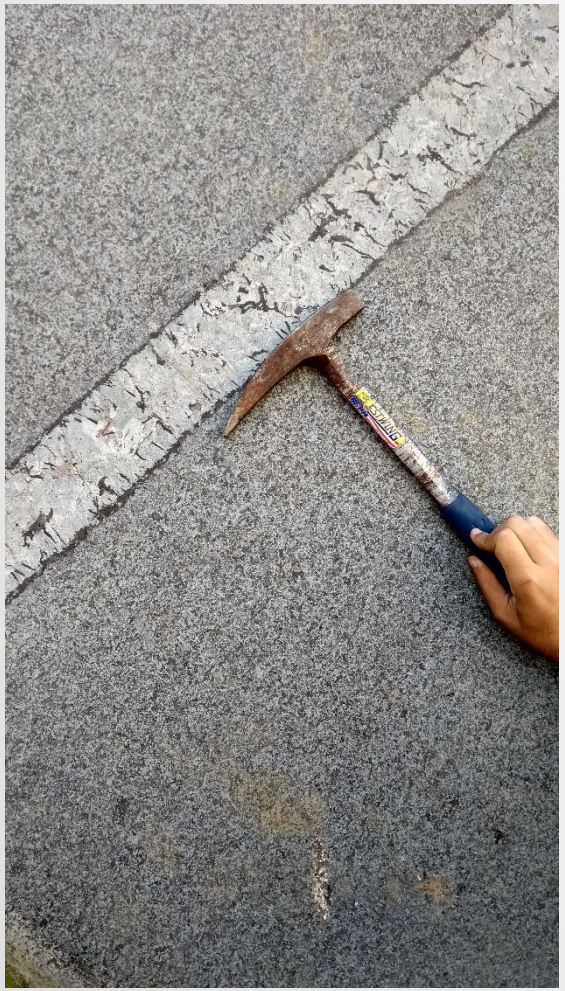
- Non-solid state deformation, **kfs** phenocrystals

- Isotropic fine-medium **bt**-**grt** granite

FIELD FEATURES – SÃO GABRIEL PLUTON

- Important ornamental stone (“Preto São Gabriel”)

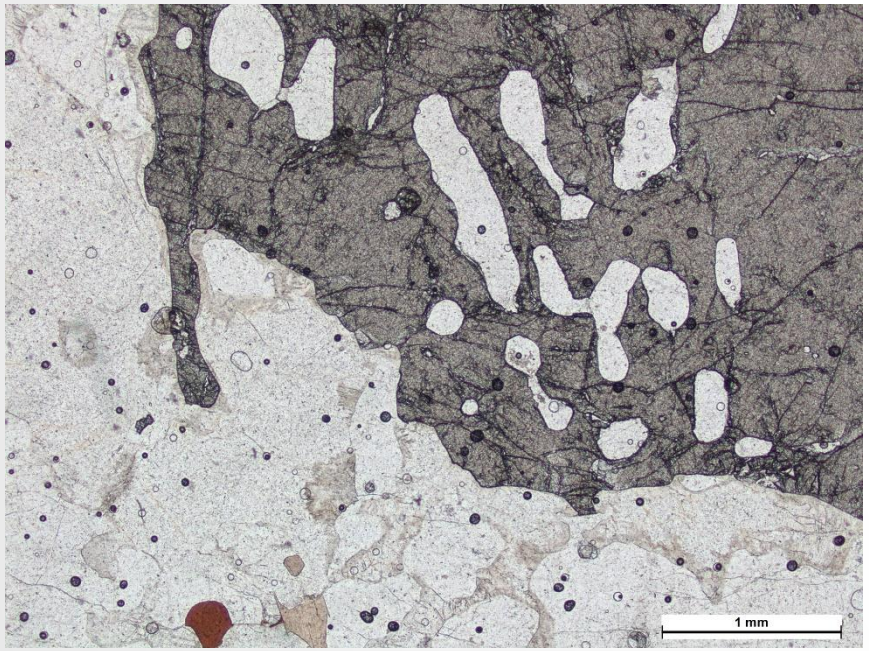
FIELD FEATURES – SÃO GABRIEL PLUTON



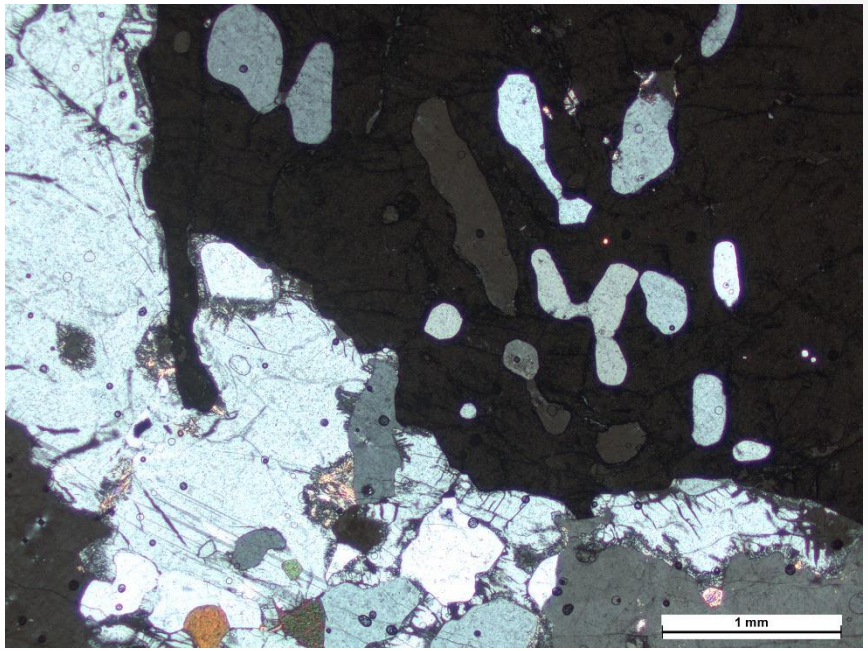
- Gray, isotropic, inequigranular, phaneritic medium-coarse gabbro-norite (**opx** + **pl**) with later regular cm granitic veins

FIELD FEATURES – DIFFUSIVE CONTACT

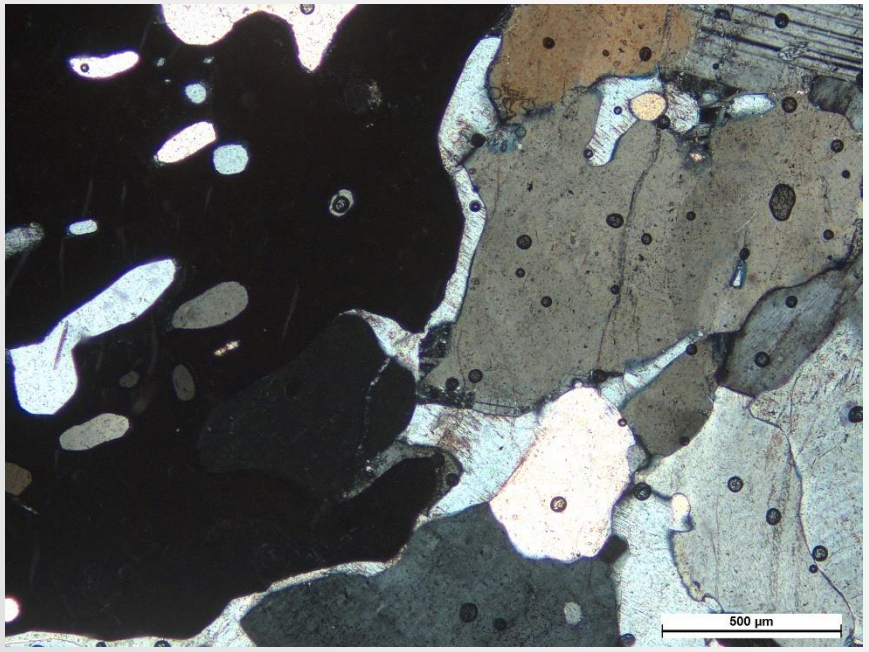
MINERAL TEXTURES



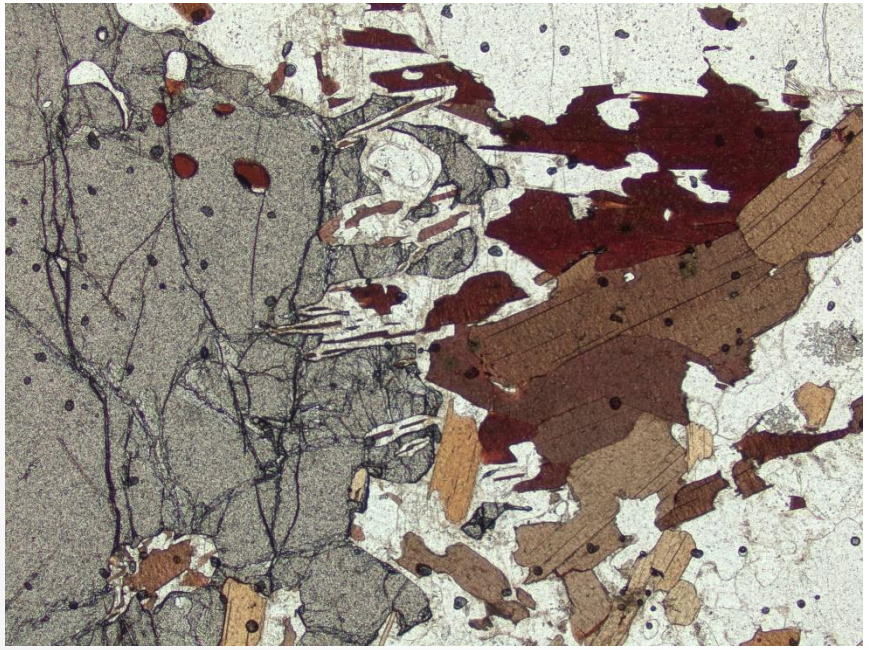
Poiquiloblastic grt + crd



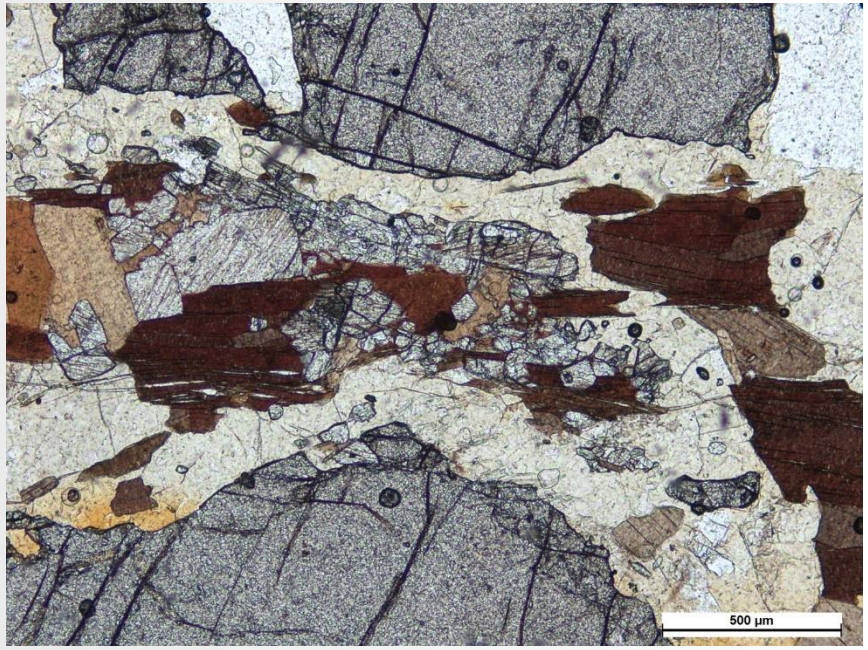
Poiquiloblastic grt + crd



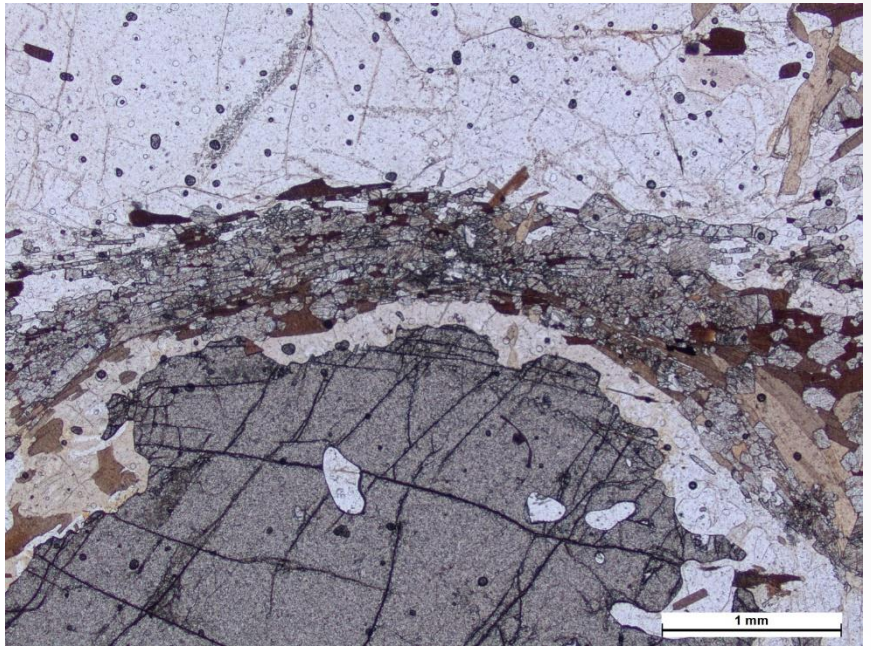
Pl rim/films – melt + grt



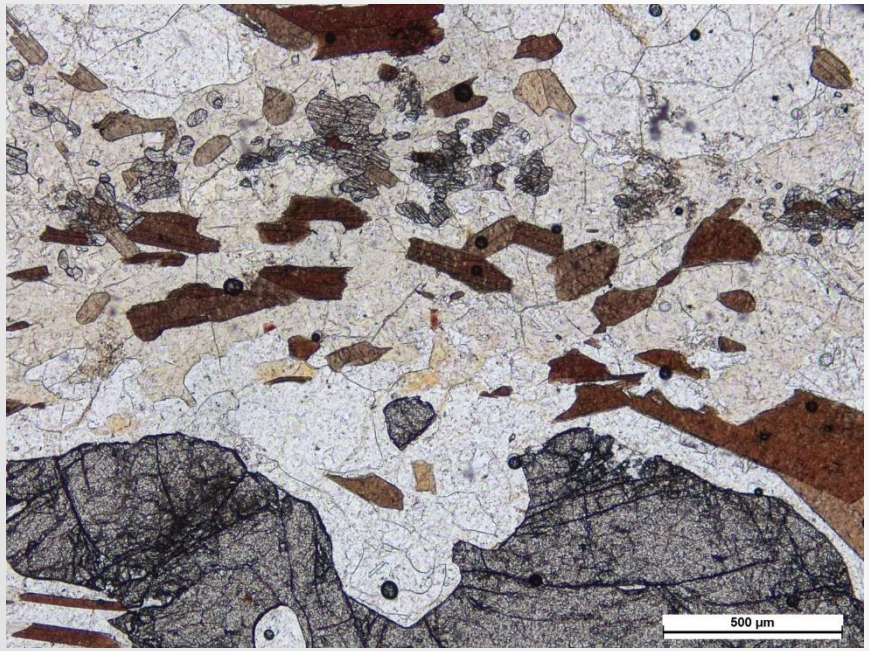
Retrograde intergrowth of (pl + bt) + grt



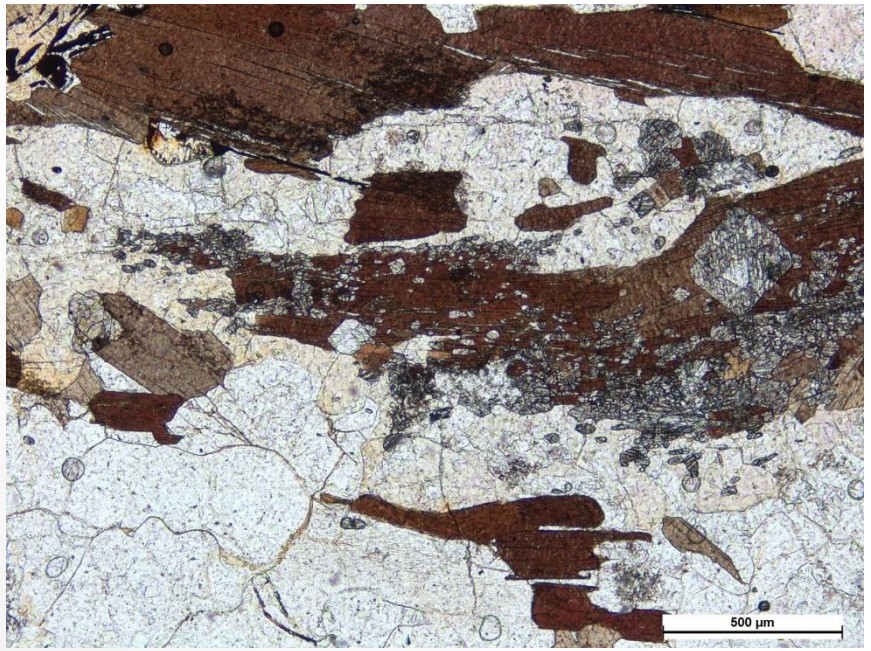
Crd rimming of grt + (bt + sill) within crd



Crd rimming of grt + (bt + sill) within crd



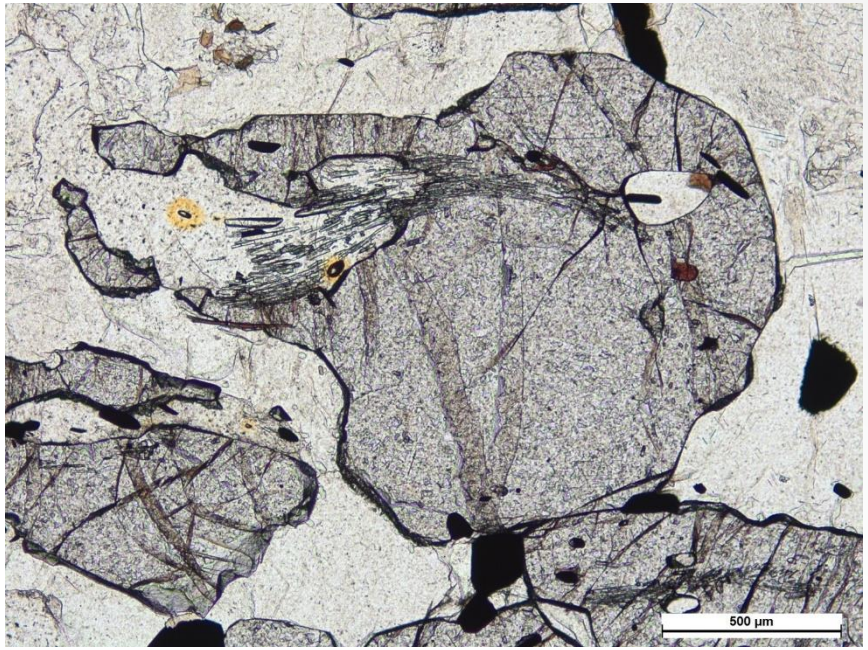
Grt being consumed



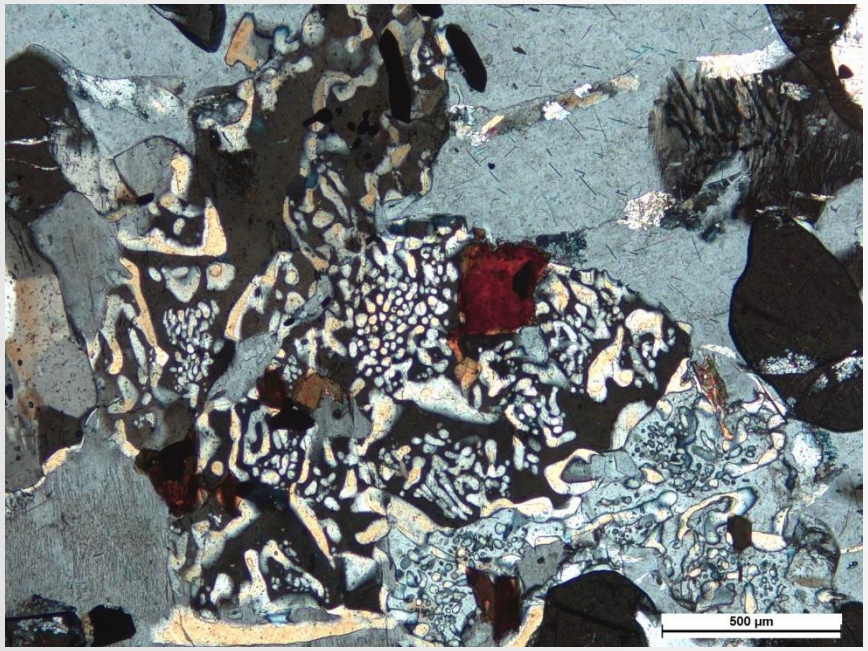
Sill growth after bt within crd

01b

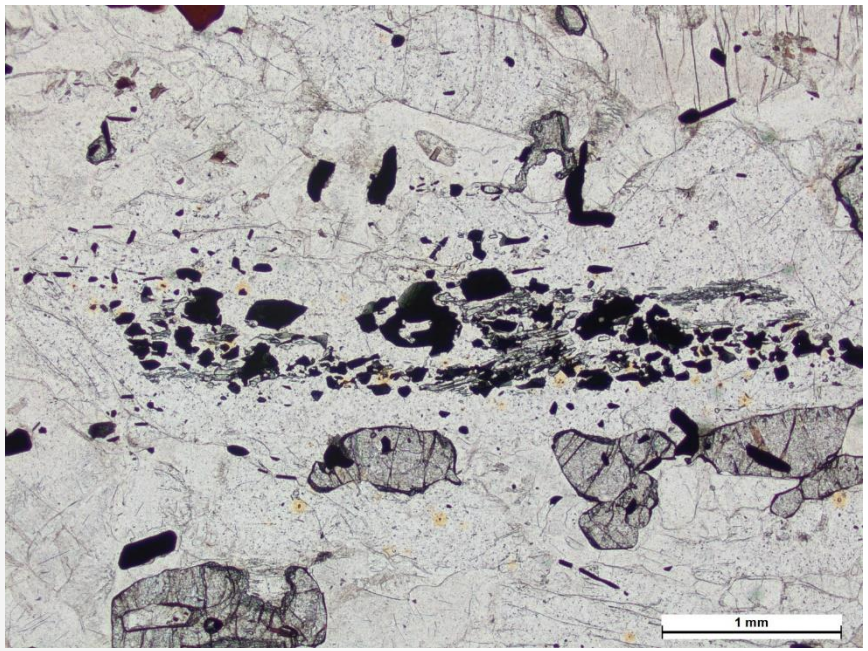
crd (halos) + spl



grt + sill + crd

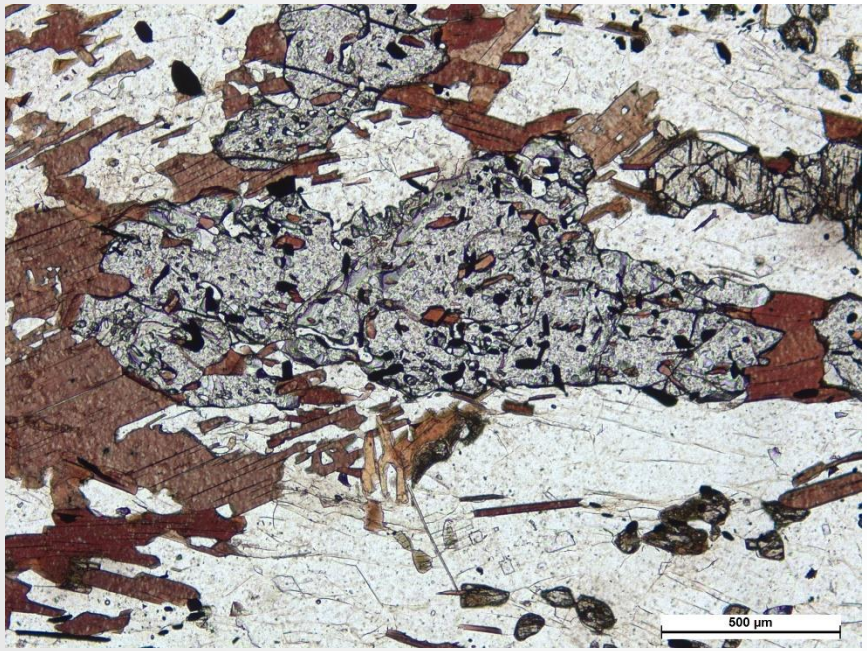


(crd + qz) symplectite within micropertitic kfs

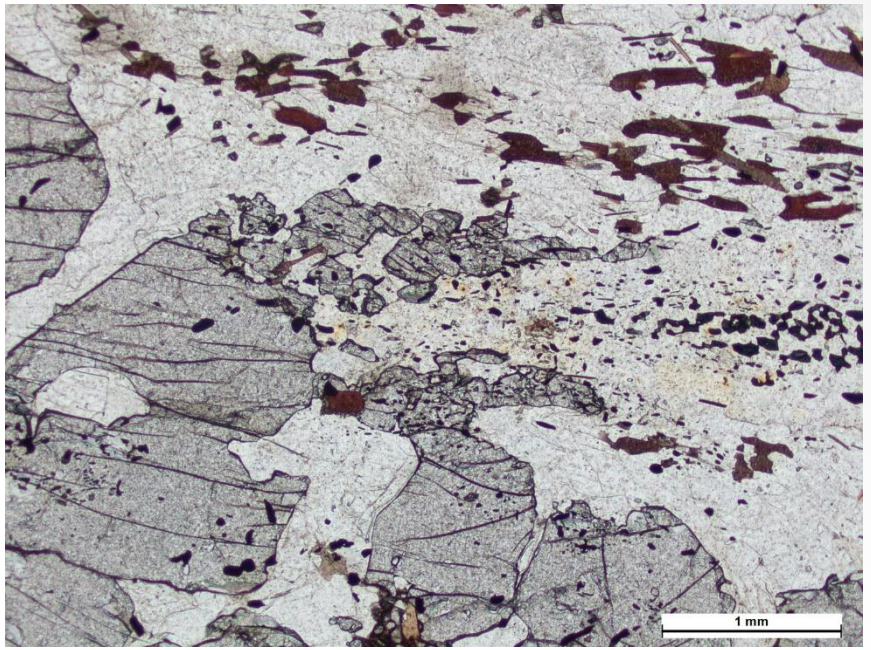


crd + sill + spl + ilm

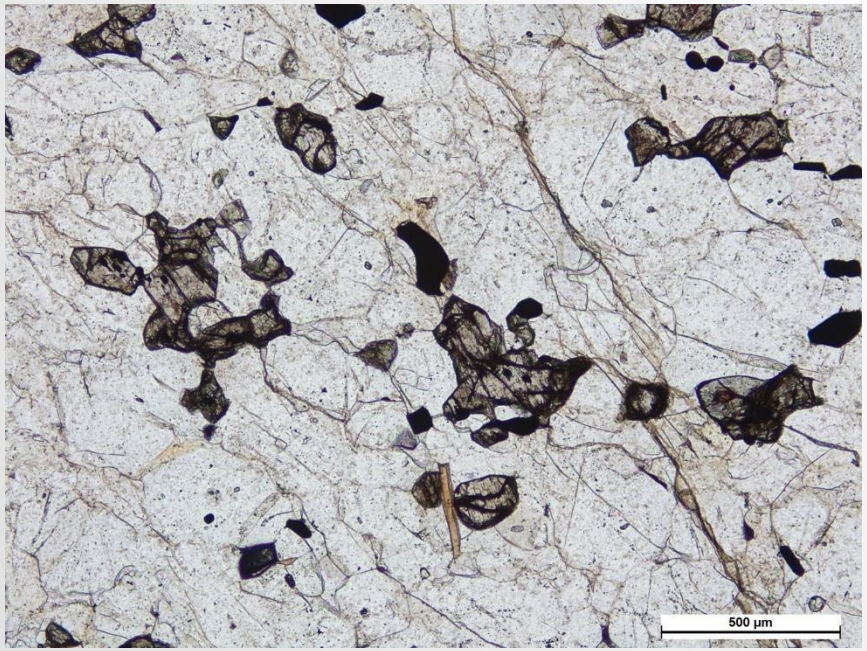
02



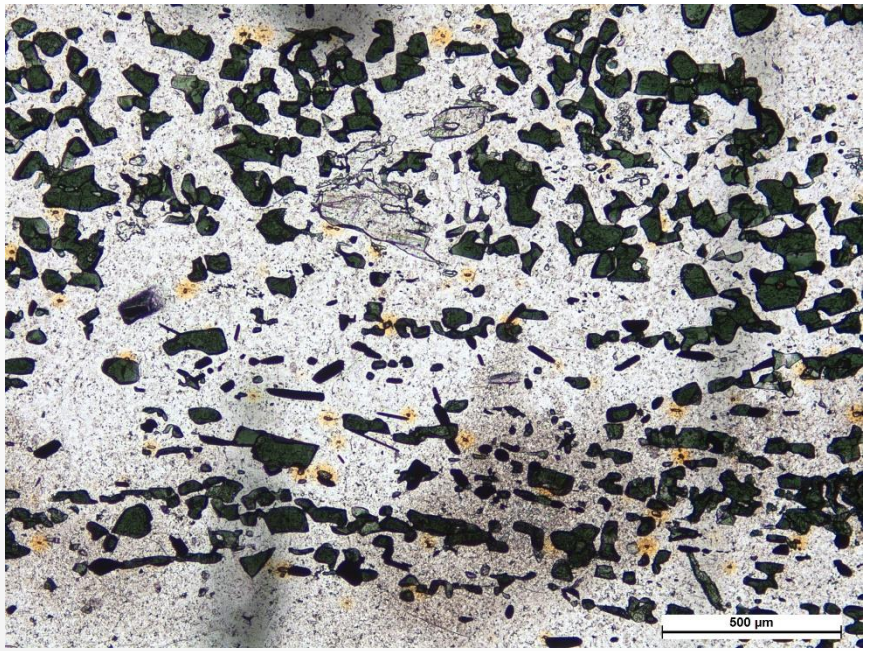
Poiquiloblastic anhedral grt



grt + sill = spl + crd

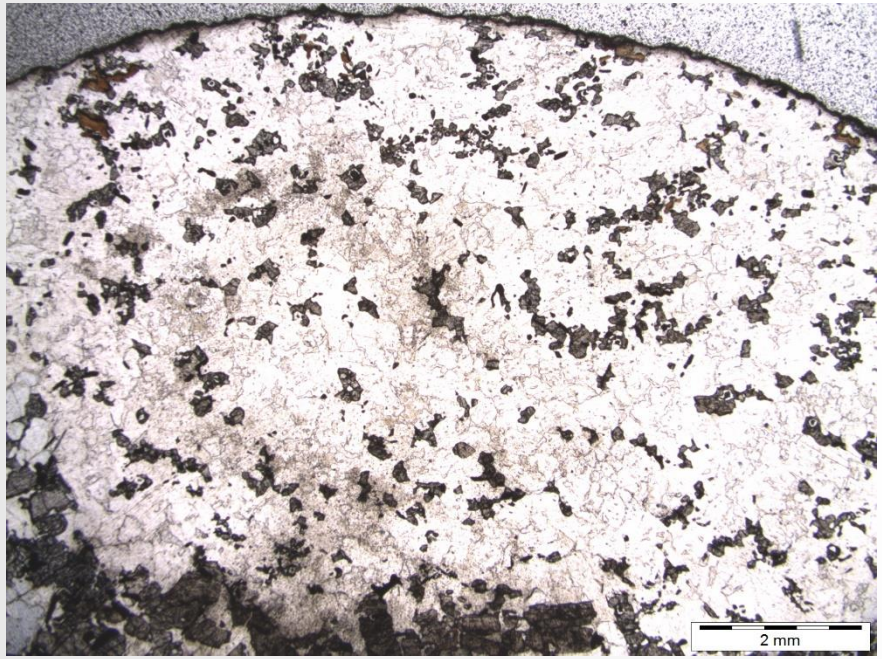


Interstitial fine opx within pl

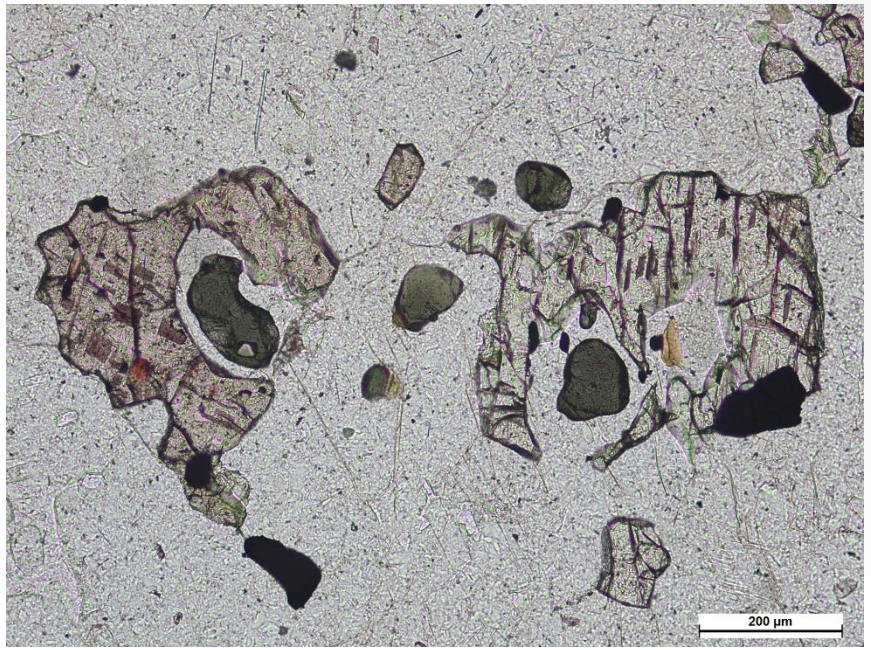


Coarse crd with spl + sill + ilm inclusions

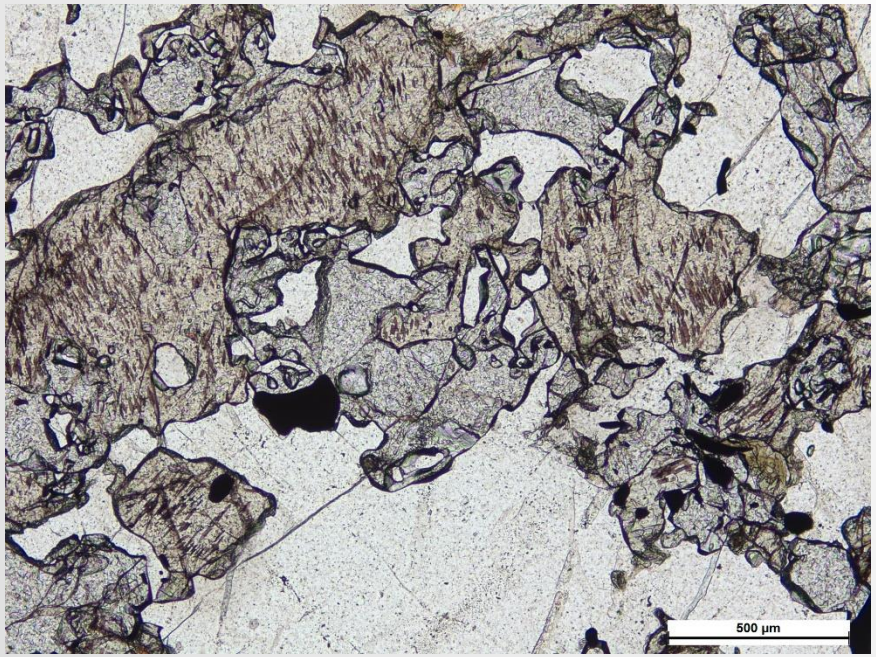
04R1



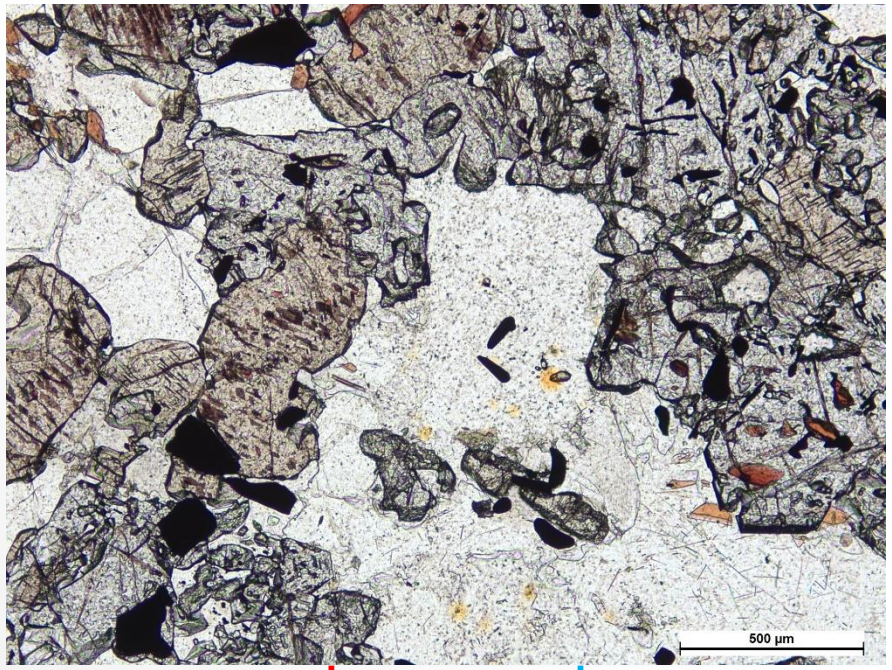
interstitial opx + spl with pl



“eye” texture- interstitial opx + spl with pl



grt + opx



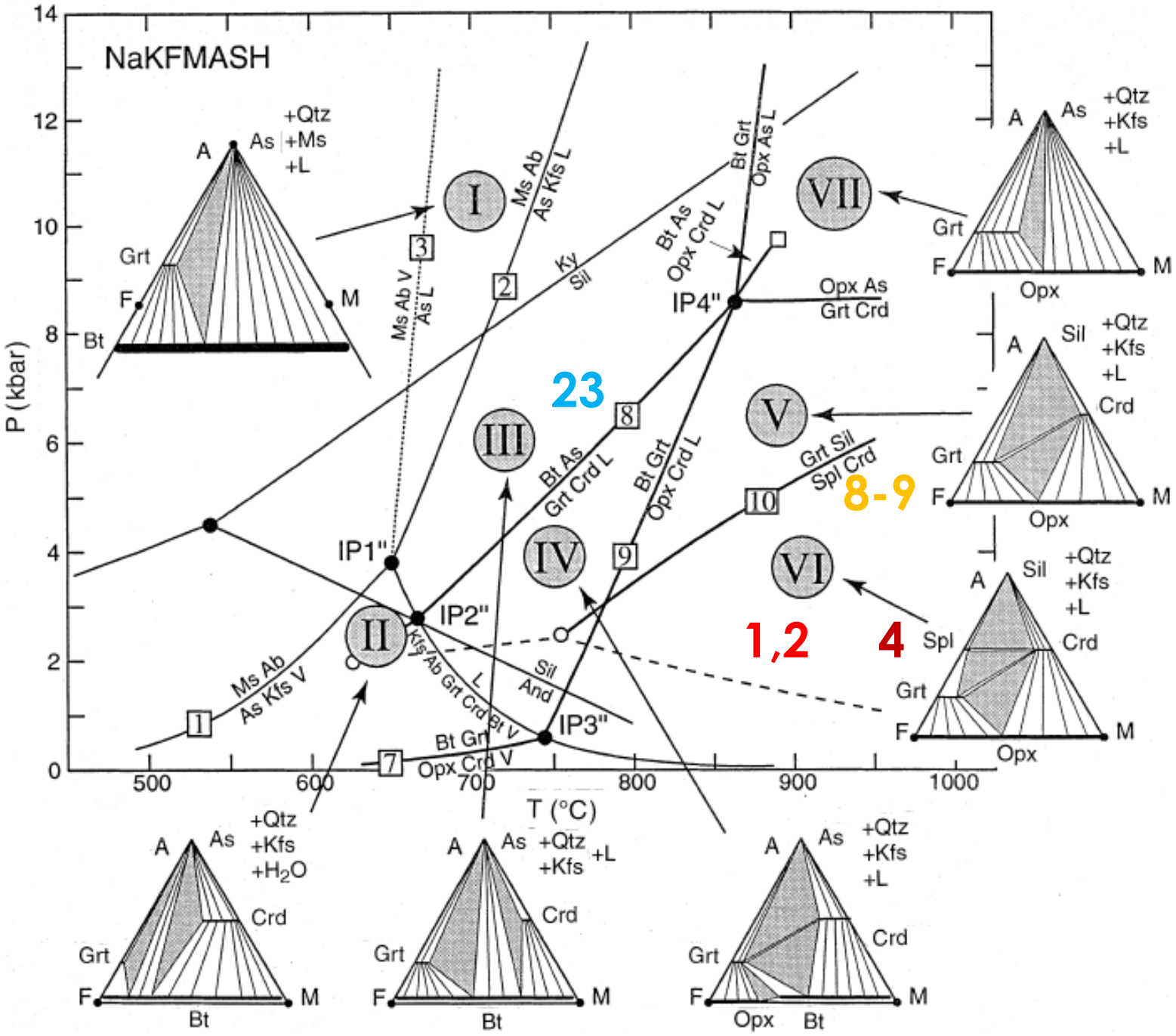
grt + opx + crd

METAMORPHIC MODELLING

REACTIONS AND AFM FIELDS

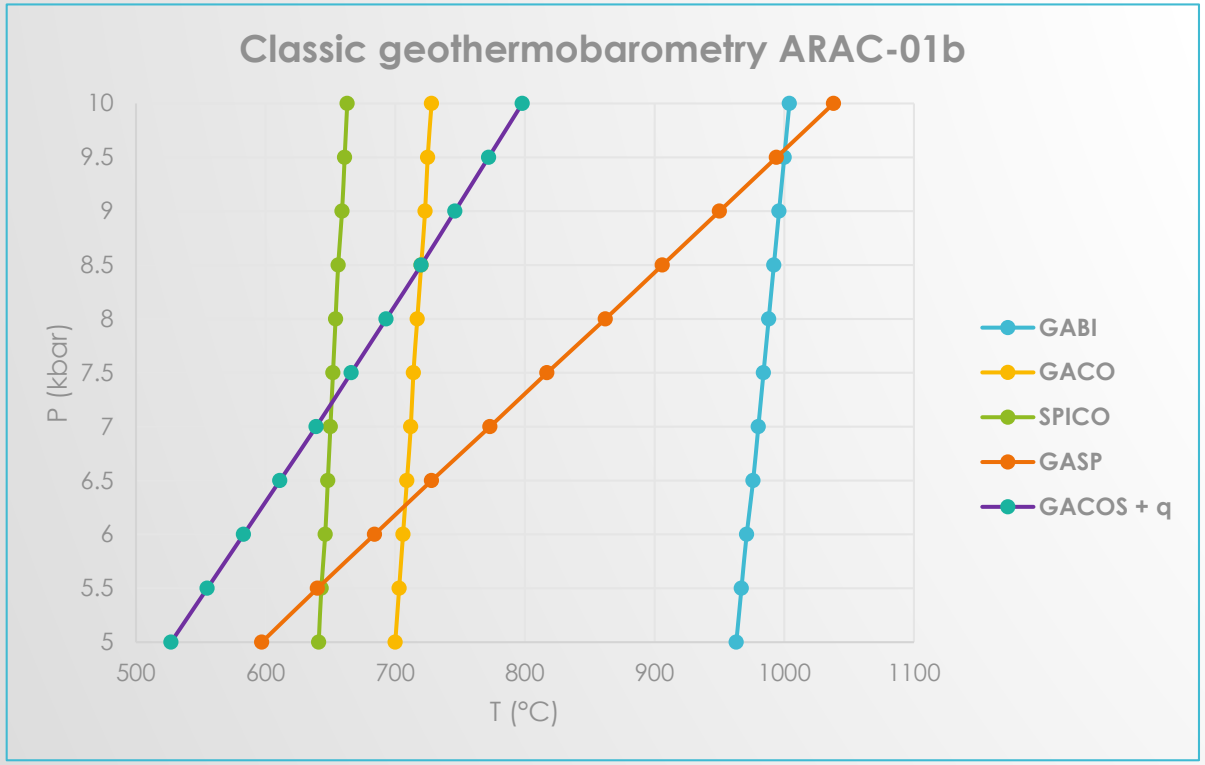
- **8**: Bt + As –> Grt + Crd + L
- **9**: Bt + Grt –>Opx + Grt + L
- **10**: Grt + Sil –> Spl + Crd

Spear et al., 1999



GABI + GASP

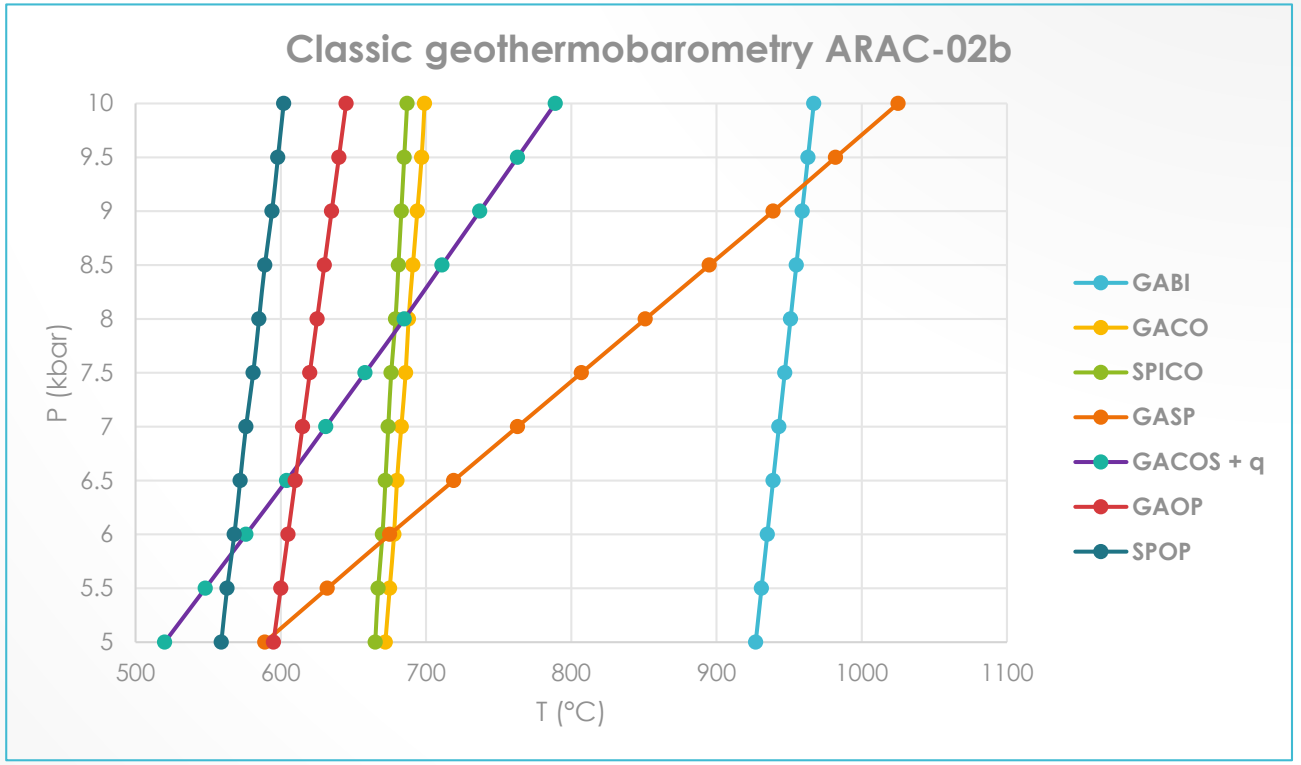
- T = Fe-Mg Exchange
- P = Net transfer reactions



T = 1000 °C
P = 10 kbar

Problems

- bt could be retro and not peak
- Thermometers (GACO and SPICO) use *fcrd* (low activity)



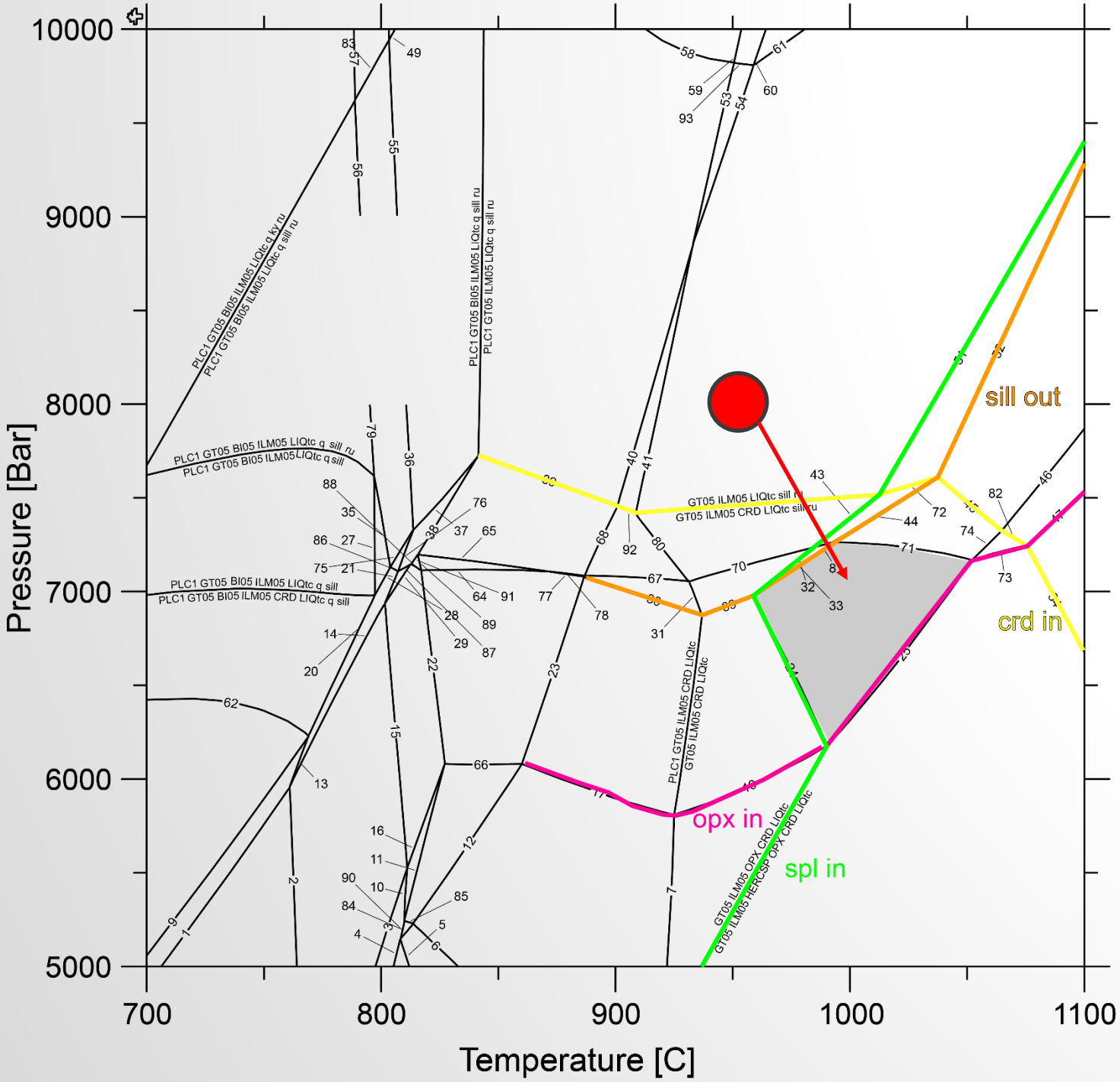
T = 960 °C
P = 9.2 kbar

avPT - THERMOCALC

- Powell & Holland (1994)
- Independent sets of reaction between end-members to calculate equilibrium lines
  - Uses an internally consistent dataset
- Combination of lines in PT space, with errors, are used to average an estimate

Sample	Calculation	Members	T	P	cor	sigfit
ARAC-01	avPT	bt crd kfs grt pl spl hem q H20 sill	**954 ± 69**	**8.1 ± 1**	0.732	1.49
ARAC-02	avPT	bt crd kfs grt spl fs q H2O sill	**1043 ± 64**	**8.2 ± 0.9**	0.772	1.23

ARAC-04R1 – avT ~1200 °C with very good fit



ARAC-01b

Isochemical Phase-Diagram

- *Bulk-composition (XRF data)*
- *Minimizes Gibbs Free Energy*
- T = ~950-1050 °C
- P = 6-7.2 kbar

- **Problem**: Isopleths not in peak field
  - Local bulk composition, Fe^{3+}, Mn..

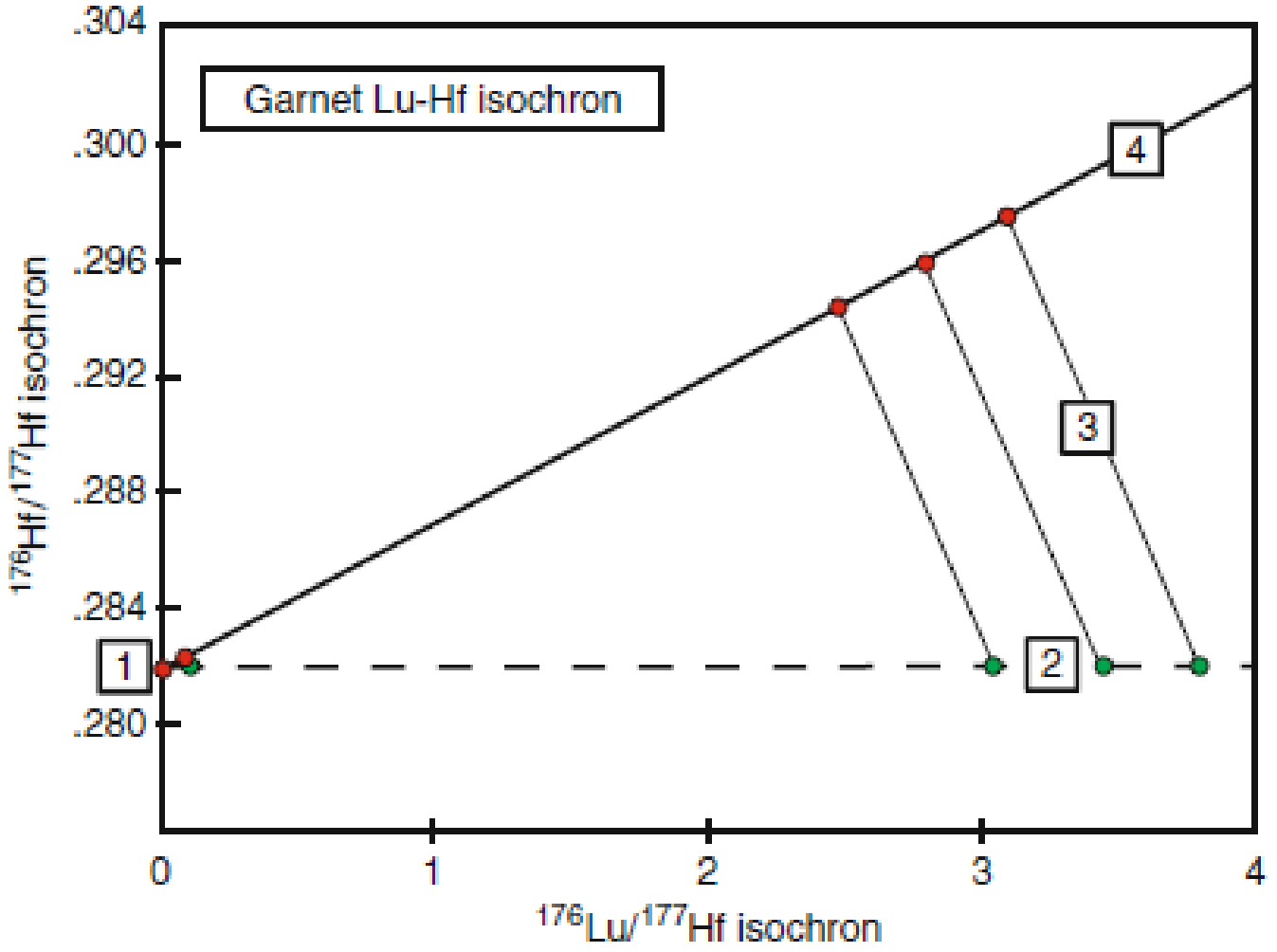
Lu-Hf GARNET GEOCHRONOLOGY

Lu-Hf System

- Variations in **^{176}Hf** resulting from the radioactive decay of **^{176}Lu** to **^{176}Hf** and variations in the Lu/Hf ratios in rocks and minerals

1. **t = 0**, before metamorphism or crystallization
2. **Initial Lu/Hf** ratio, high in grt
3. With time, **Hf/Hf will increase** as function of initial Lu/Hf
4. If **system is closed**…

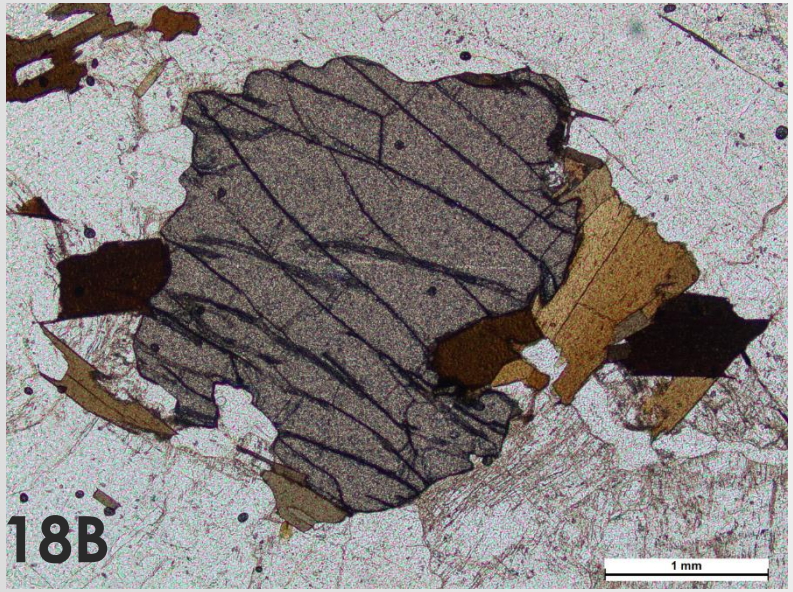
$$\text{Age} = \ln(\text{slope} + 1)/\lambda^{176}_{\text{Lu}}.$$

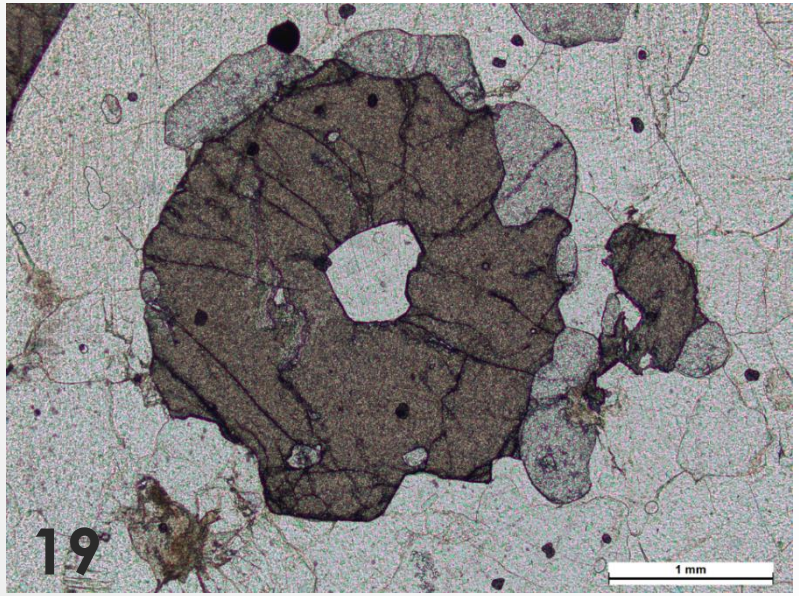


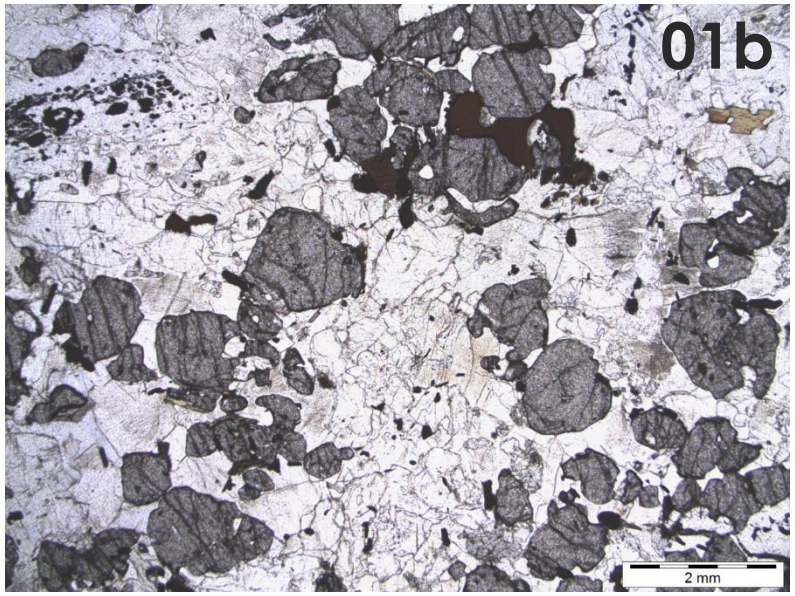

18B


19

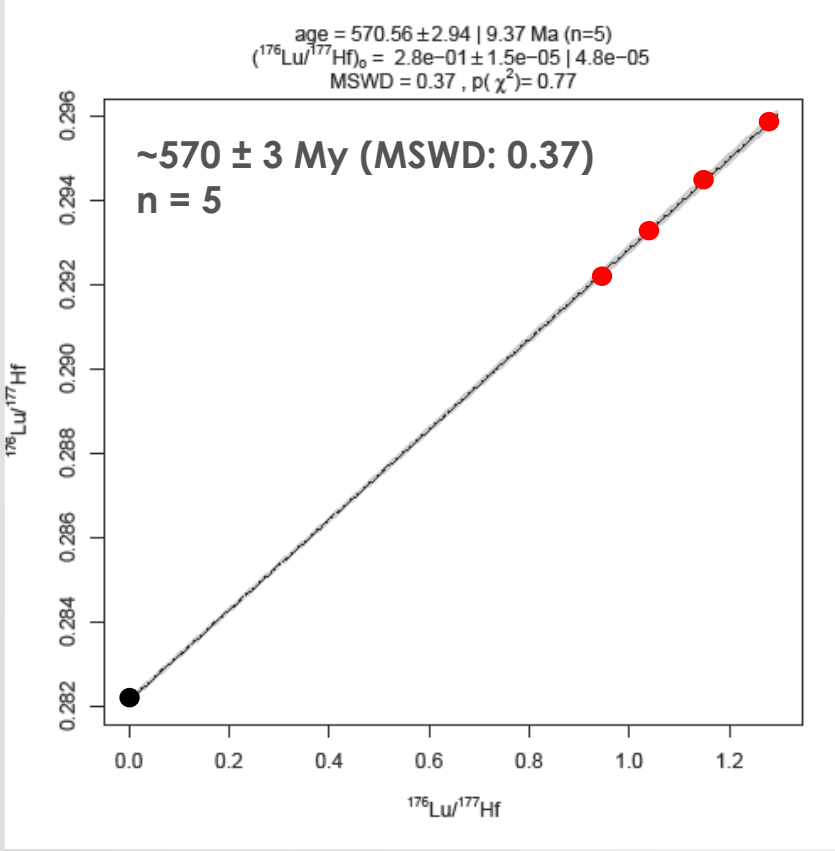

ARAC-01B


18B
1 mm


19
1 mm

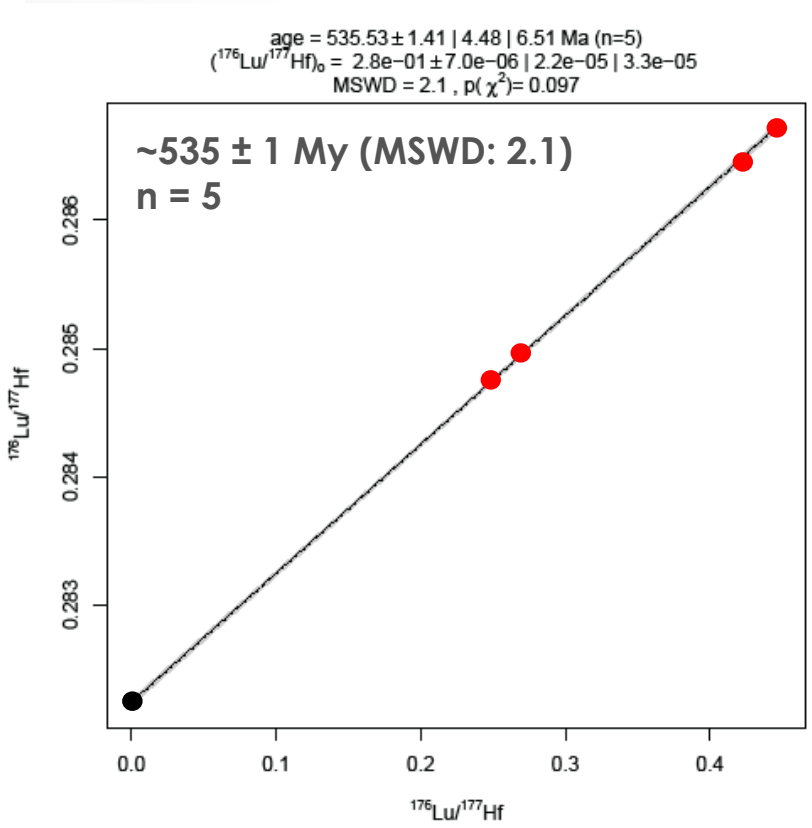

01b
2 mm

ARAC-18b



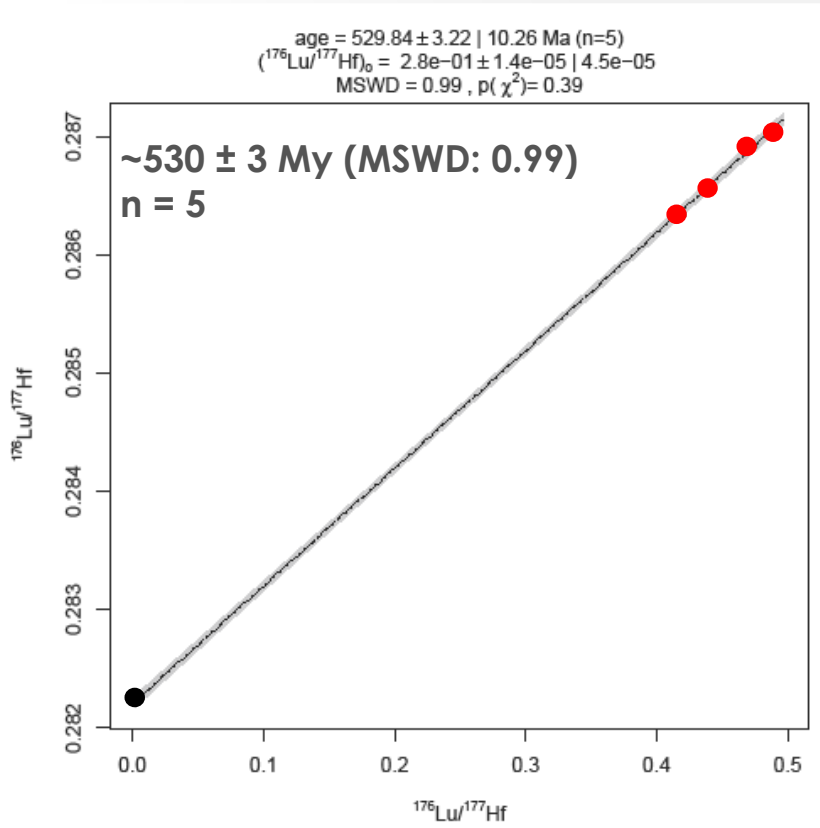
- Main anatectic event

ARAC-19



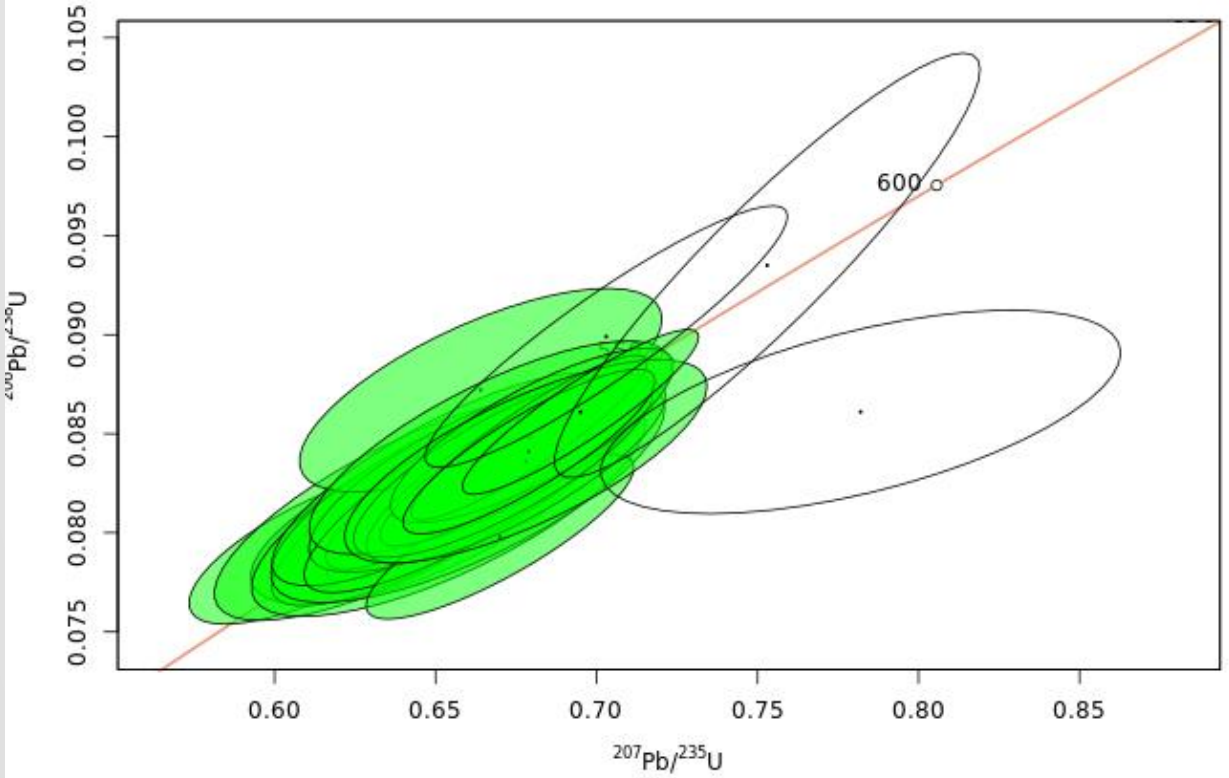
- Second regional metamorphic event

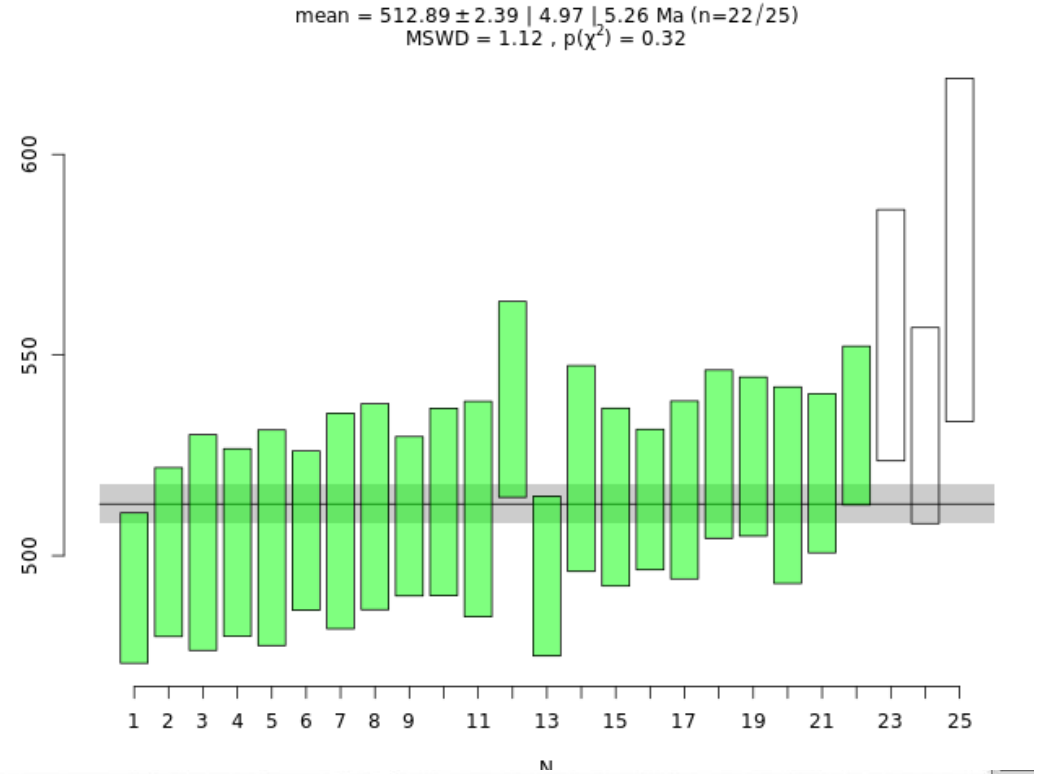
ARAC-01b



- Second regional metamorphic event

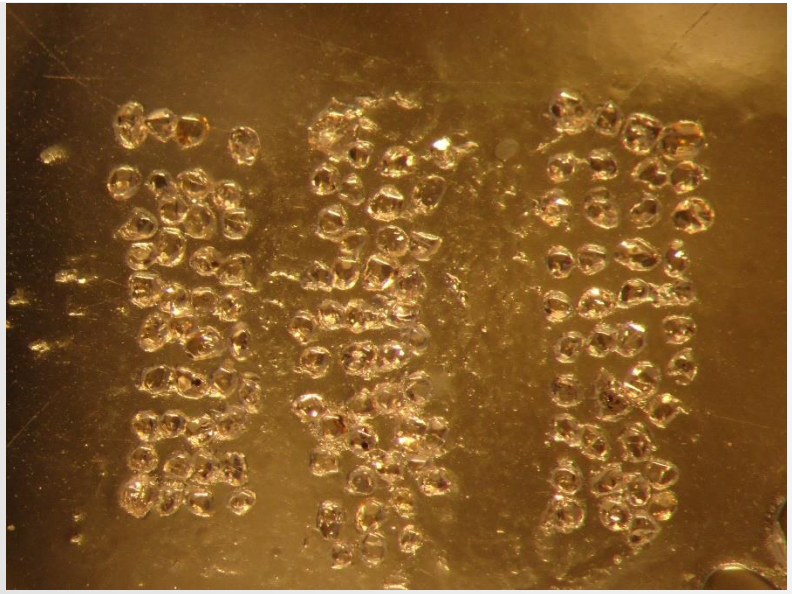
U-Pb ZIRCON GEOCHRONOLOGY

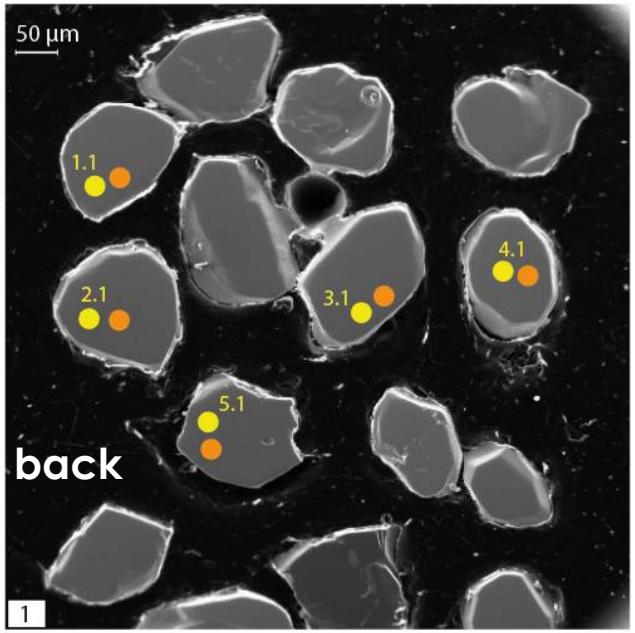


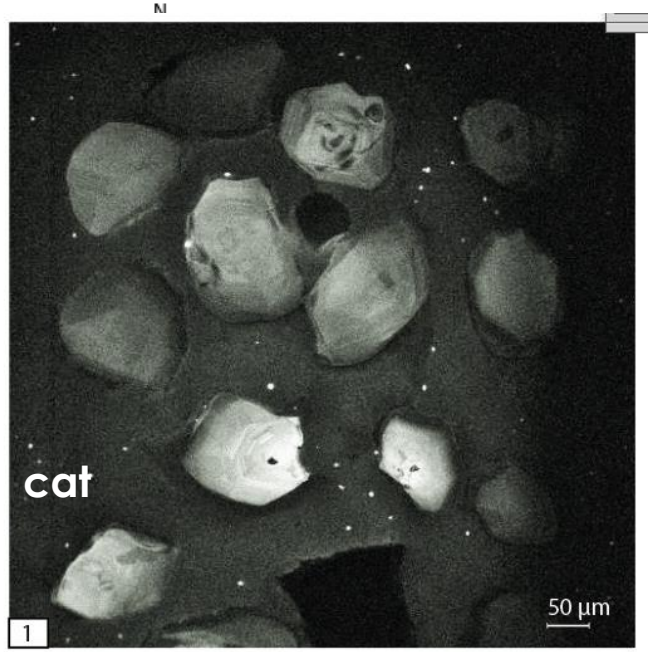


ARAC-01b

- Soccer-ball typology
- 513 ± 2.4 My
- MSWD = 1.12
- n = 22
- **Intrusion related!**

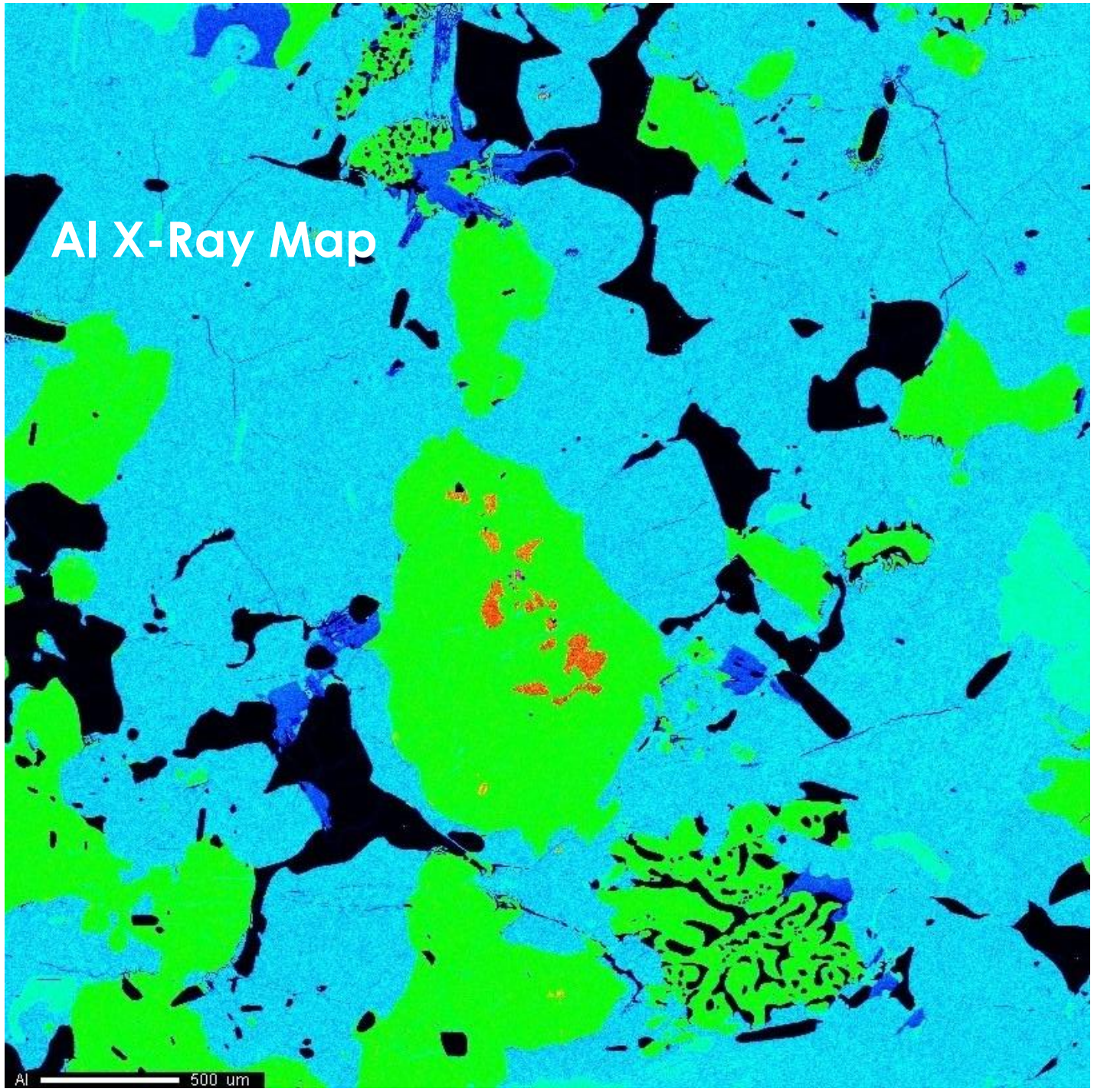






SOME THOUGHTS GOING FORWARD…

- We need more detail on mineral textures!
- **X-Ray Maps** to constrain local bulk!
  - 3 maps made
- New zircon data!
  - 1 sample ready for data reduction
  - 1 mount ready in Br
  - 4 new samples to be dated
- Can zircon trace elements help?
- Is it possible to model a P-T profile in the metamorphic aureole? **WWU SEM…**



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  - Dan, Gui, Fi, Biriba and "diretoria"
  - Peter, Katie, Andy, Wes, Andra, Harley, Rachael and Aidan

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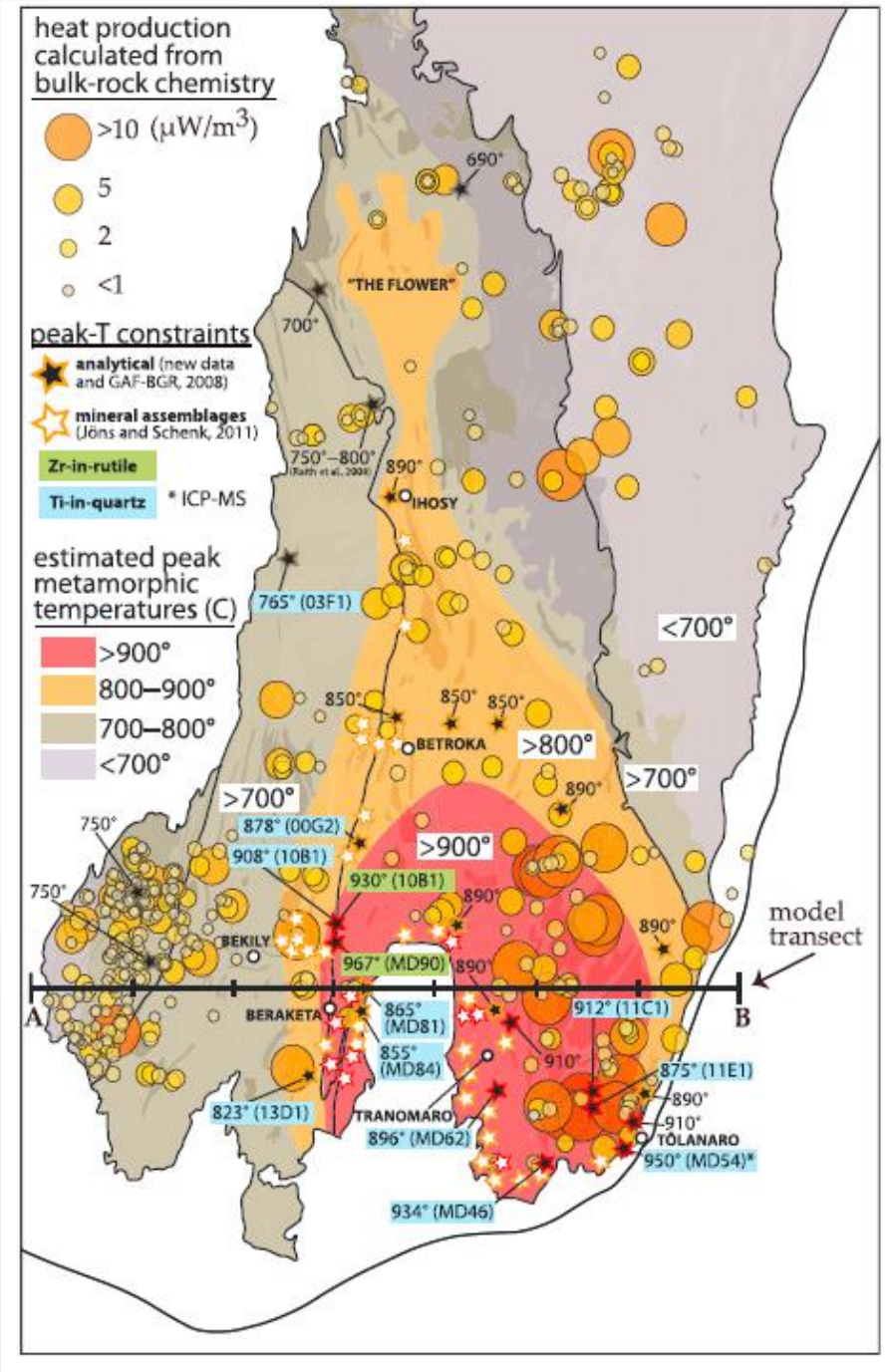
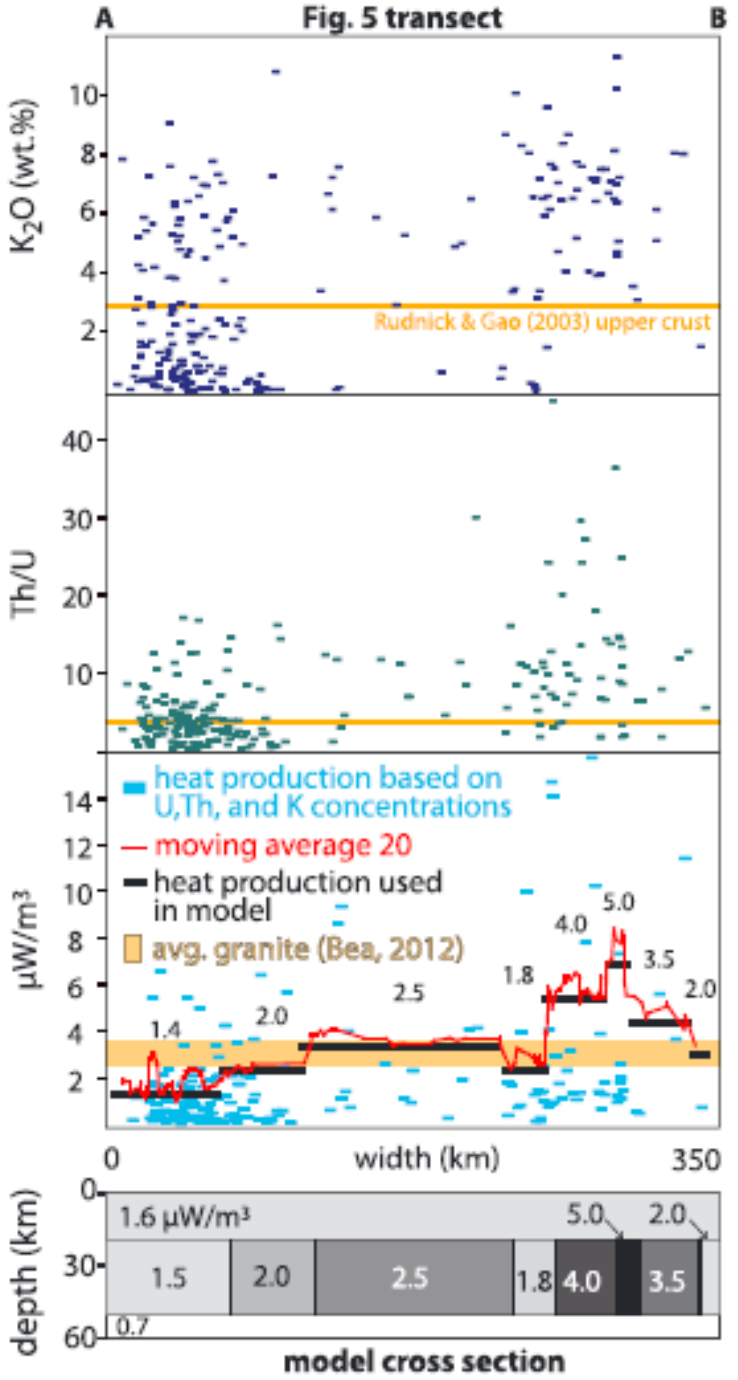
NEXT STEPS…

- P-T modelling, petrochronology (**time of processes**)
- Quantitative data for **heat production**
- **Numeric modelling**

Horton et al., 2016





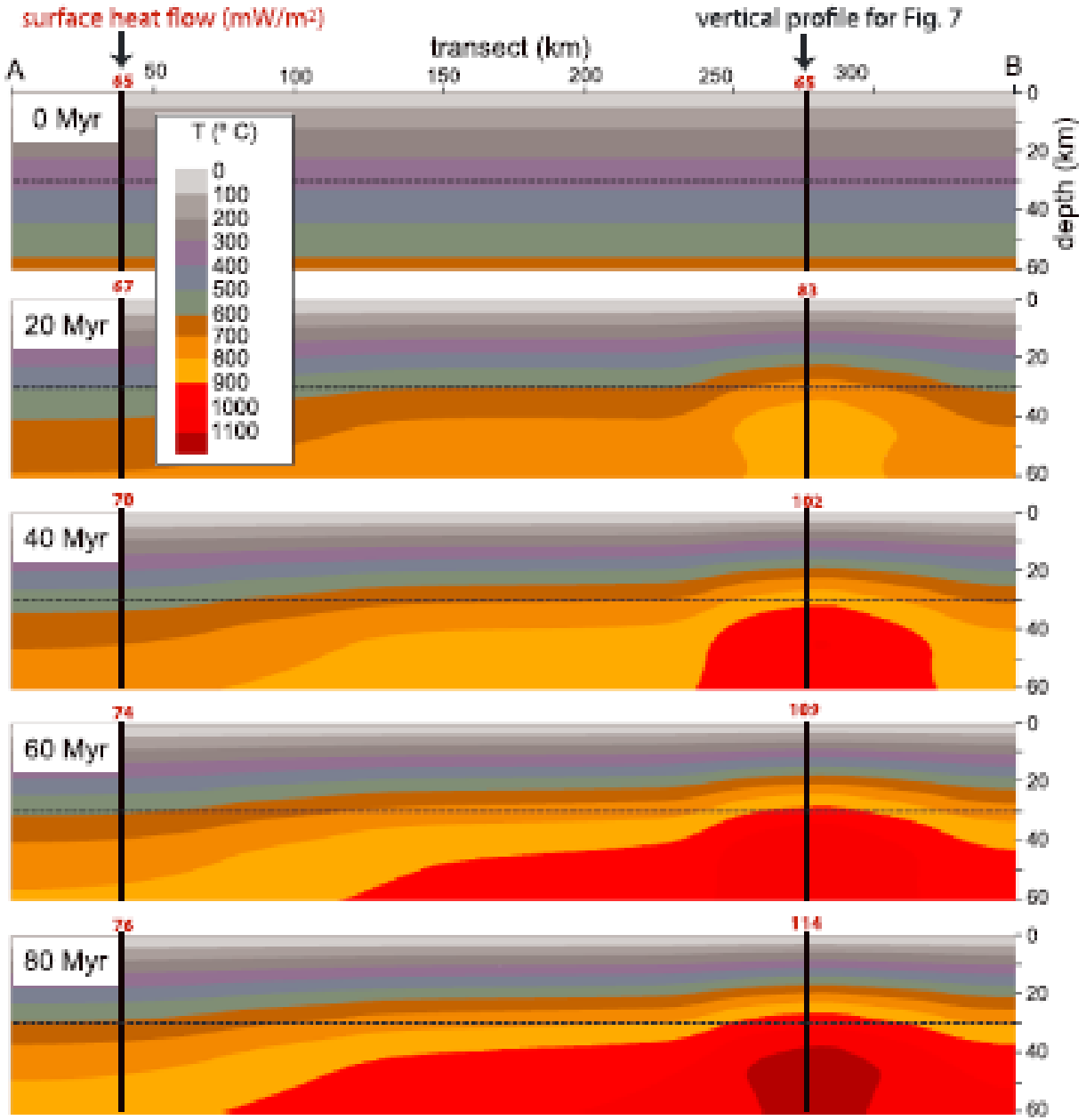


Figure 8. Time slices for the preferred parameterization of the model (see text for justification). Approximately 60 Myr is necessary to reproduce temperatures at 30 km depth that are representative of peak conditions across southern Madagascar.