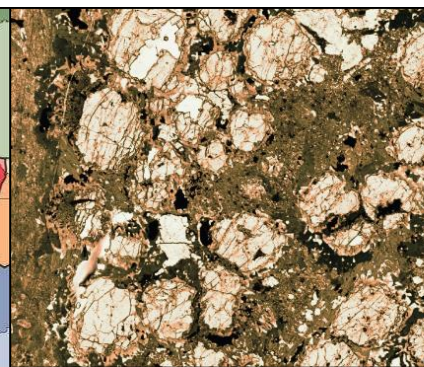
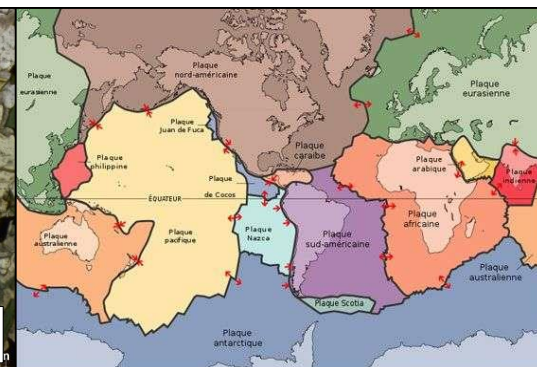
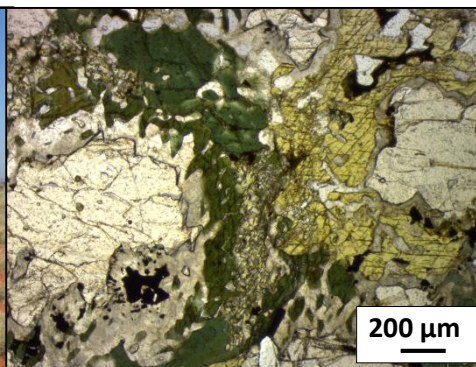


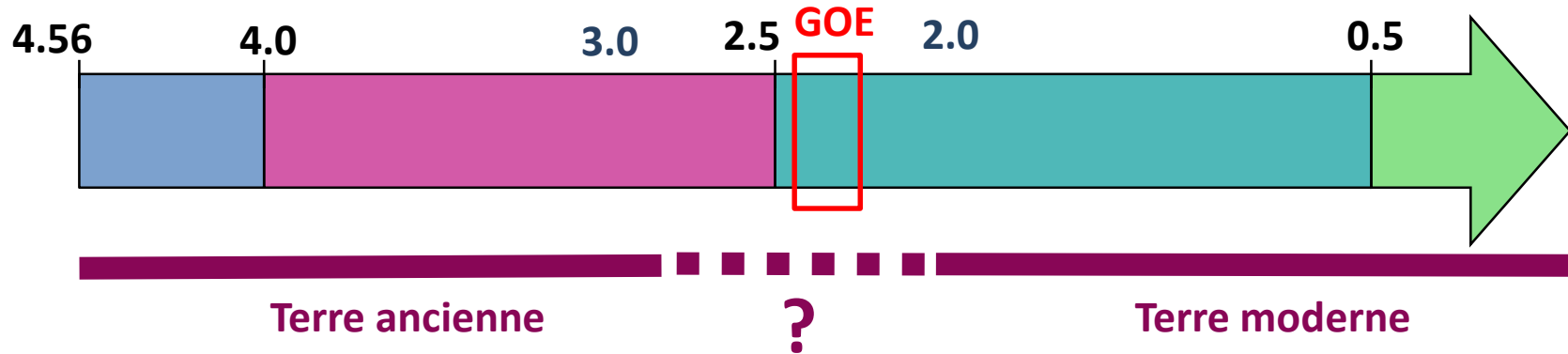
# Découverte des plus vieilles éclogites de subduction et implications pour le début de la tectonique des plaques

*Camille FRANÇOIS*

*Paris, 16 Mars 2019*



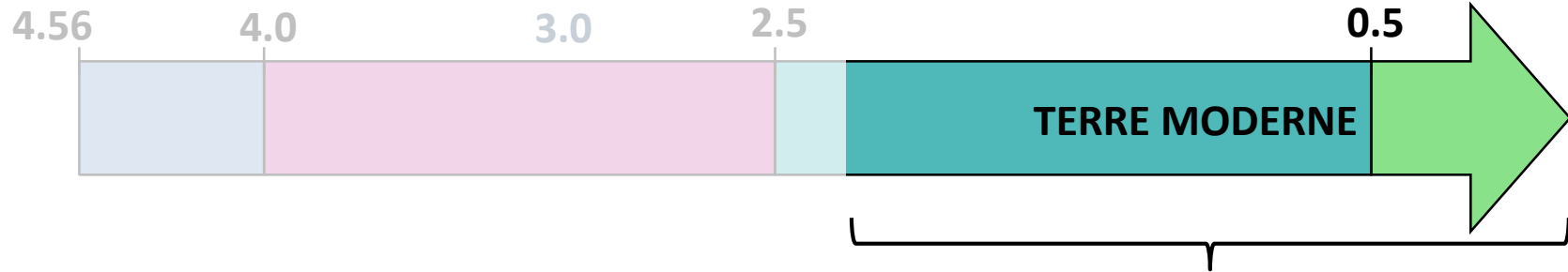
# Terre ancienne & début de la tectonique des plaques



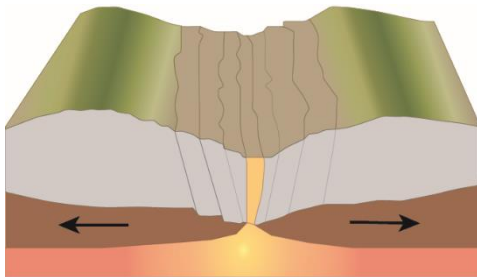
- Quels processus géodynamiques existaient sur la Terre ancienne ?
- Comment caractériser ces différents processus ?
- La tectonique des plaques était-elle présente ? (subduction, collision, ...)
- Était-elle similaire à aujourd'hui ?
- Quand la tectonique des plaques moderne est-elle apparue sur Terre ?



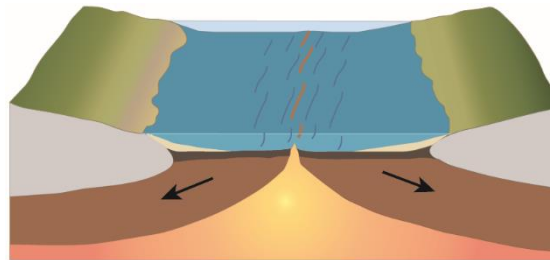
# Terre Moderne = Tectonique des plaques



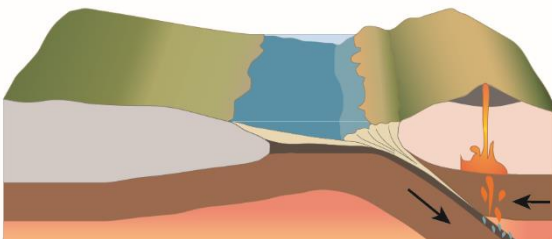
## Rupture Continentale



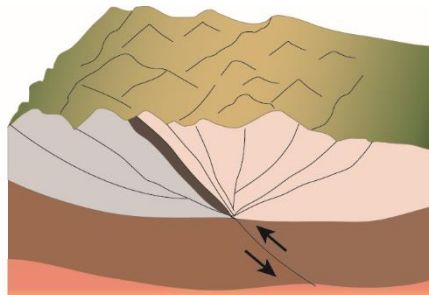
## Ouverture océanique



## SUBDUCTION

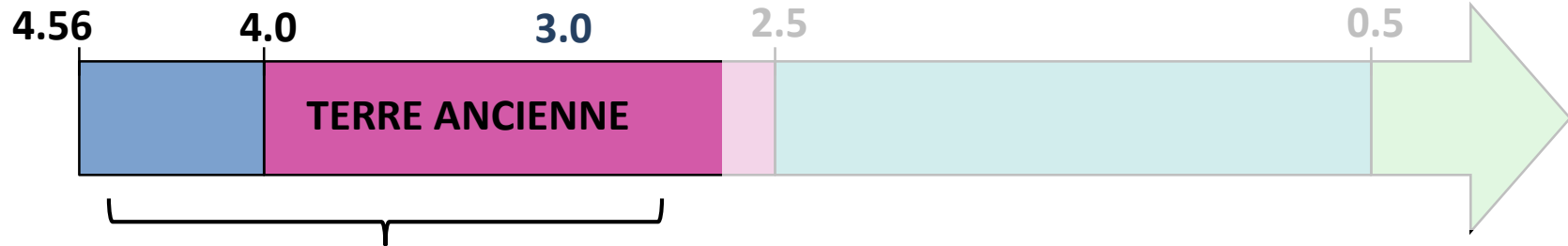


## COLLISION

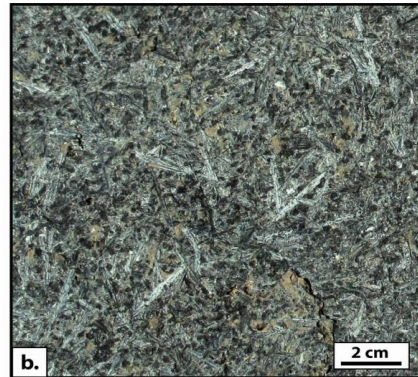


- Contribue au refroidissement de la Terre
- Volcanisme, dégazage dans l'atmosphère
- Responsable de la formation de la croûte continentale et de la croûte océanique
- Formation des orogènes
- Erosion, apport de nutriments

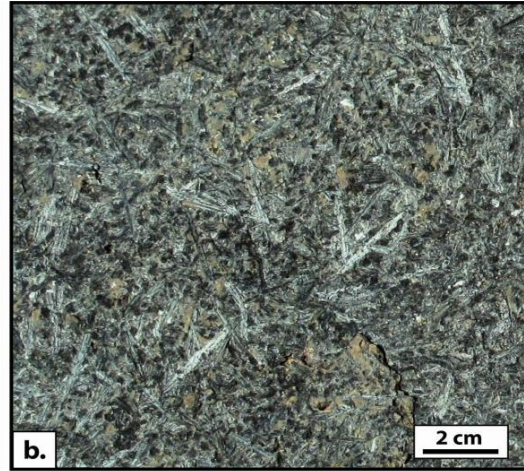
# TERRE ANCIENNE



- Flux de chaleur mantellique plus élevé
- Croute plus chaude et plus faible rhéologiquement (TTG)
- Volcanisme très intense (roche dense et épaisse: greenstones)



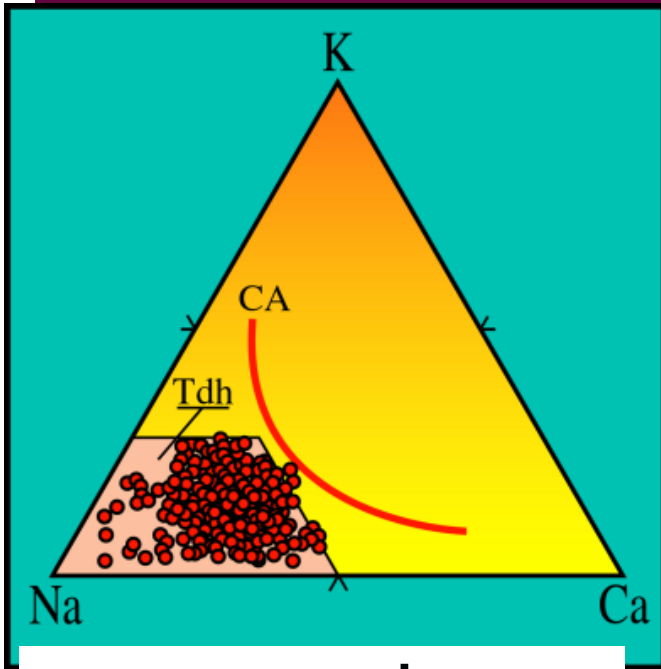
# Roches archéennes



Greenstones:  
komatiites, amphibolites...

TTG: Tonalite-Trondhjemite-  
Granodiorite = granitoïdes

# Les TTG

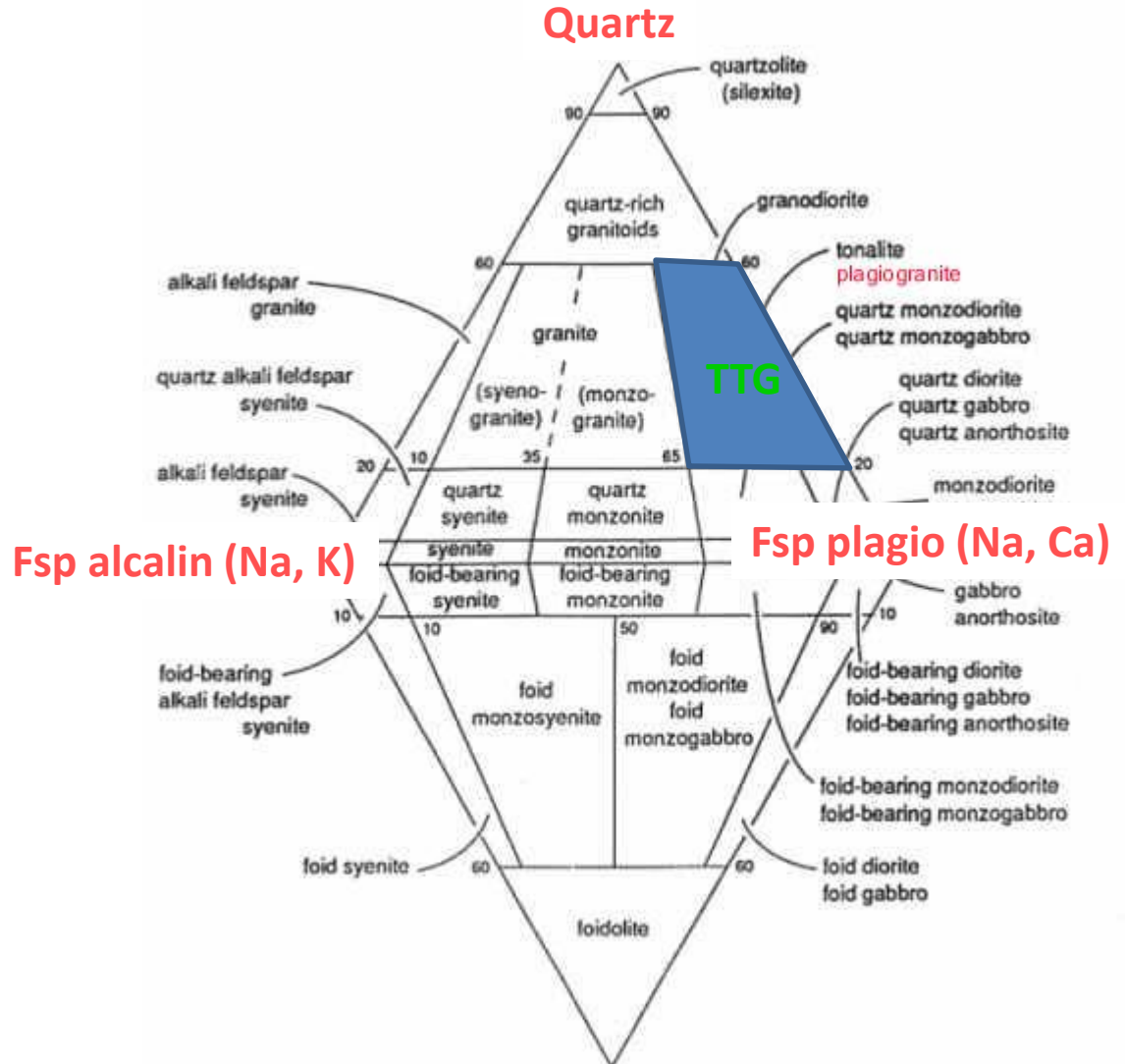


Tdh = Trondhjemite

To = Tonalite

Gd = Granodiorite

= TTG



Fsp alcalin (Na, K)

Fsp plagio (Na, Ca)

From H. Martin

Feldspathoïde

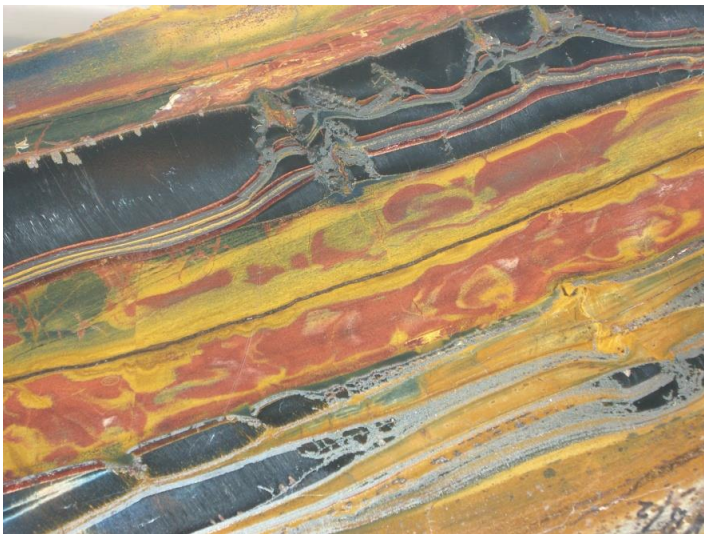
# Les Greenstones

**-Komatiites: laves ultramafiques, point de fusion élevé (1600°C), taux de fusion partielle élevé (50%)  
Très denses**



**+ Amphibolite et roches métamorphiques (voir suite cours)**

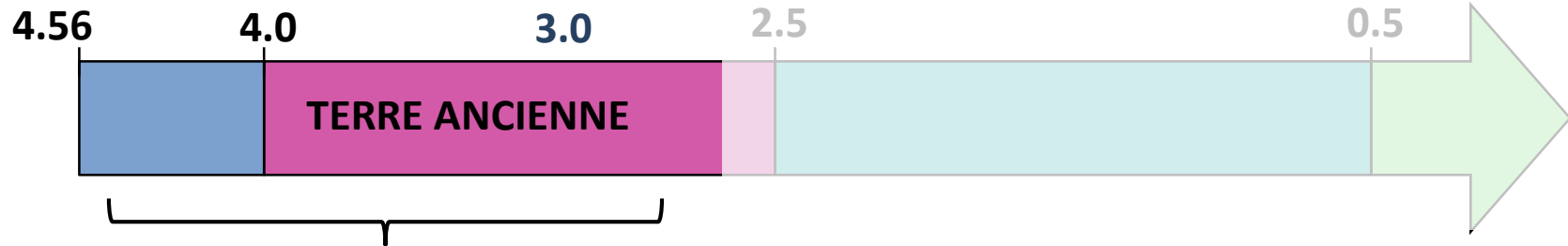
# Les BIF



+ Cherts, shales, + barites, pyrites...

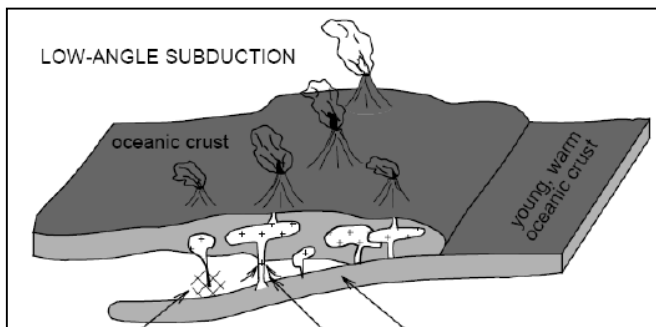


# TERRE ANCIENNE



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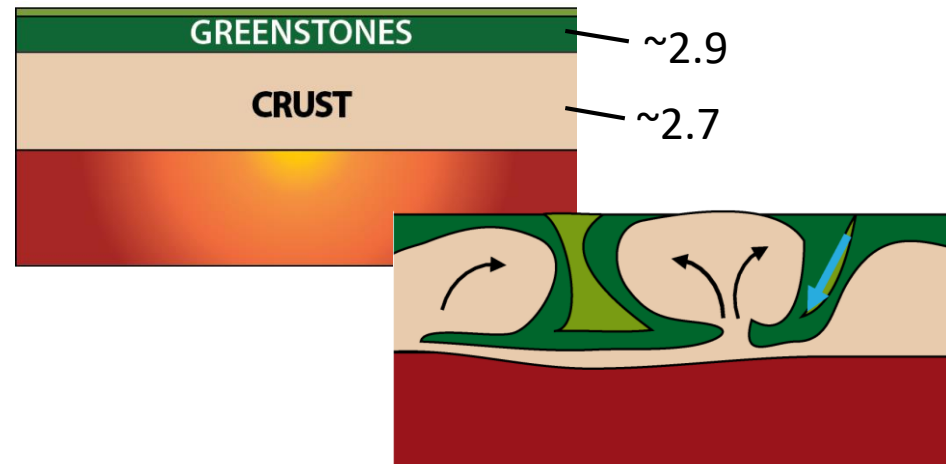
## SUBDUCTION (PLATE) (= mobile lid)



*Smithies et al., 03*

➡ **TECTO DES PLAQUES**

## SAGDUCTION (= stagnant lid)



➡ **PAS (nécessairement) de la TECTO DES PLAQUES**

# SAGDUCTION

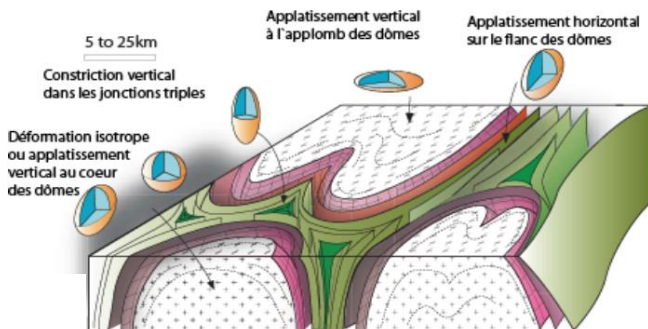
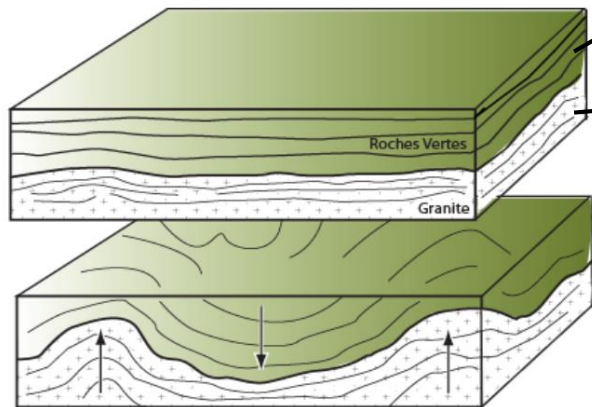
Inversement gravitaire par contraste de densité et convection crustale

**Greenstones**

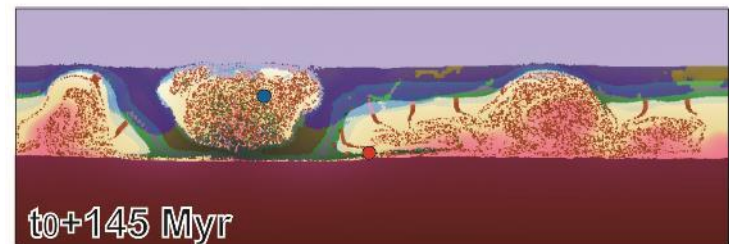
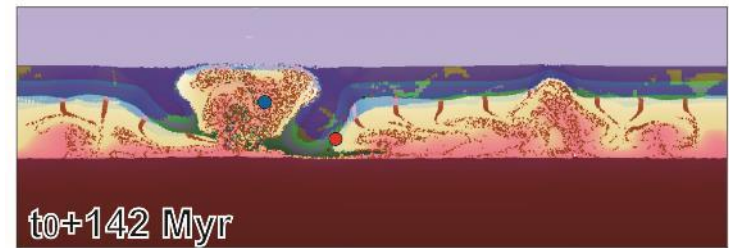
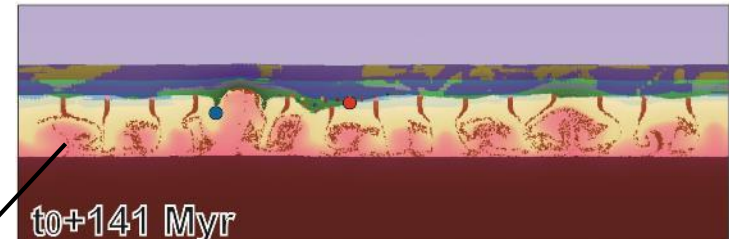
Densité élevée (~2.9)

**TTG**

Densité plus faible (~2.7)



*Rey et al., 2003*

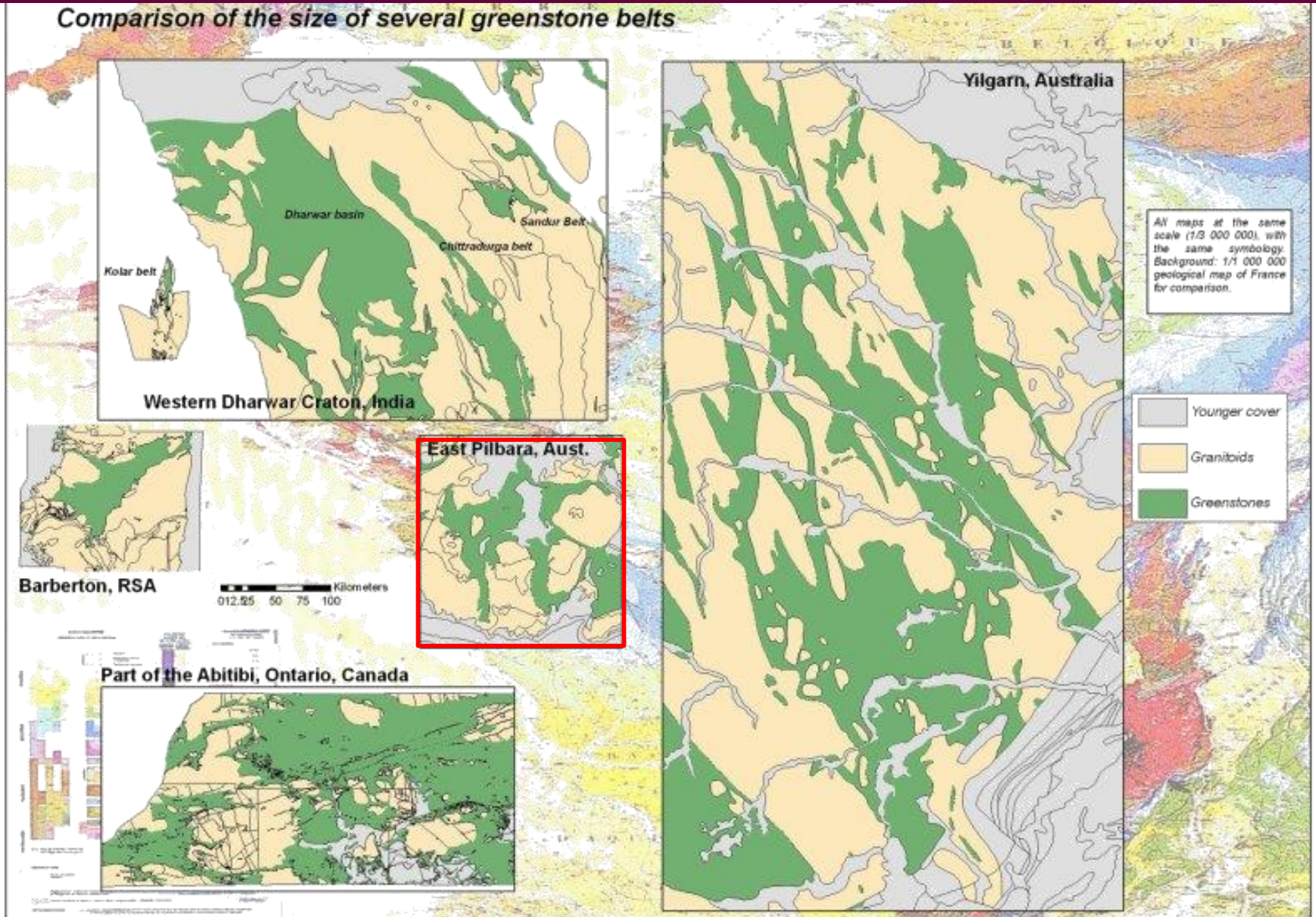


**Fusion partielle en base de croute**

*François et al., 2014*

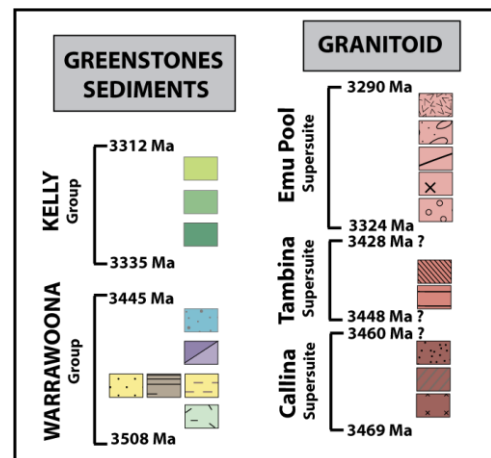
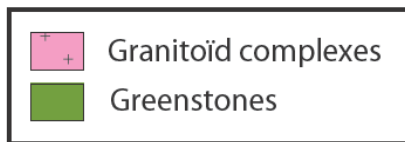
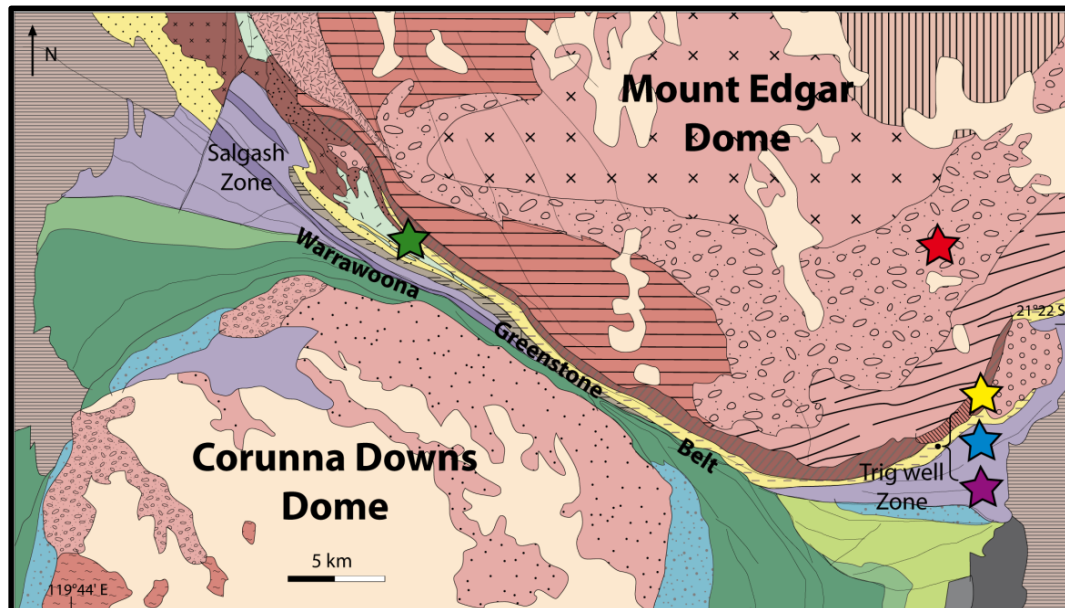
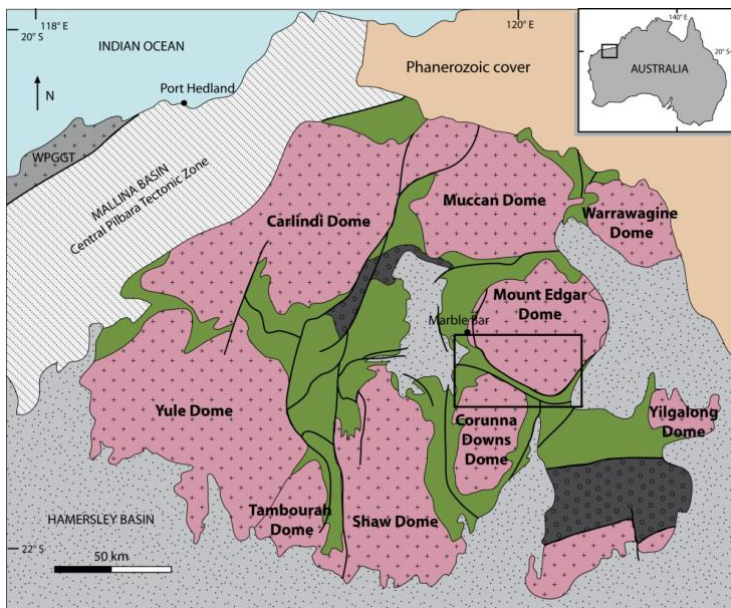
# STRUCTURE en DOMES & BASSINS

Comparison of the size of several greenstone belts



# Caractérisation des processus géodynamiques: Application à la sagduction archéenne (3.5-3.2 Ga)

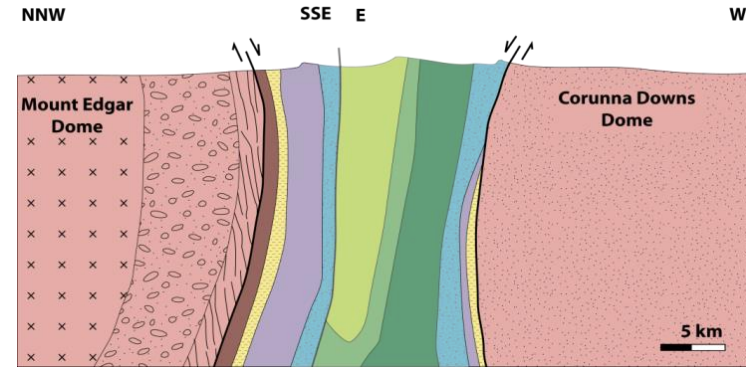
(Pilbara craton, Australia)



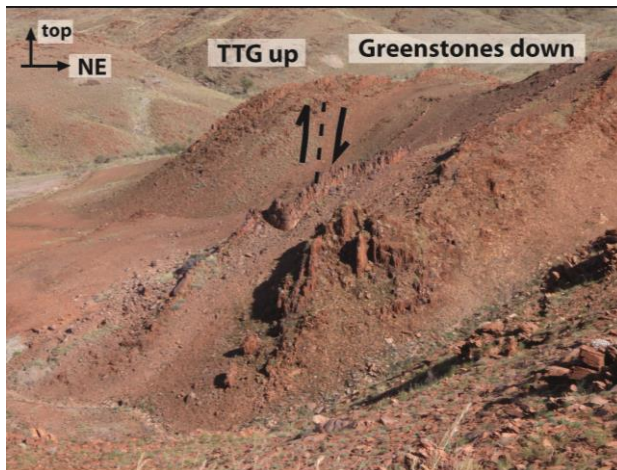
François et al., 2014, EPSL

# East Pilbara Granite-Greenstone Terrane

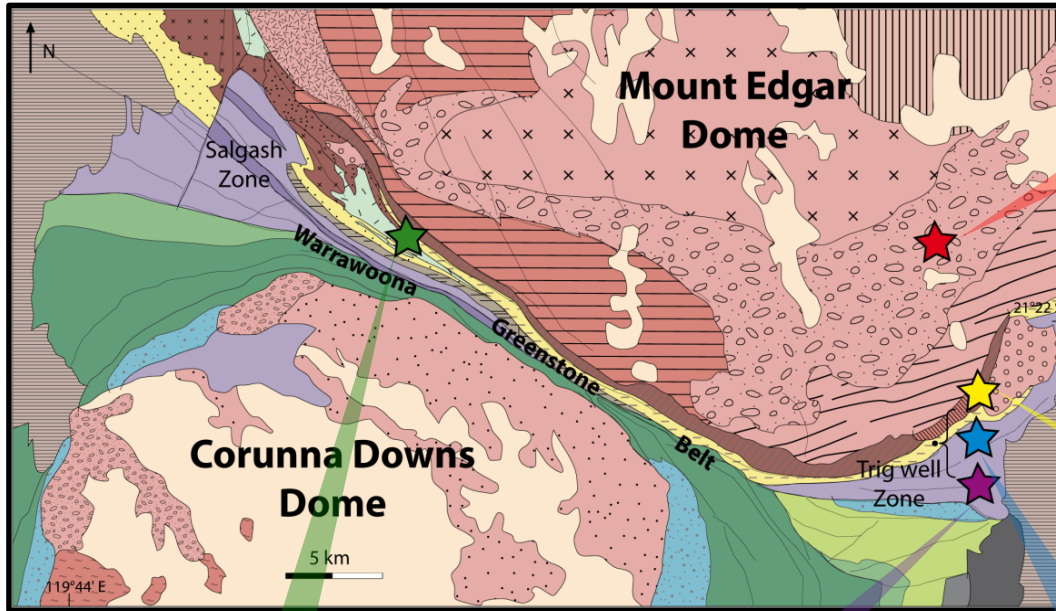
(3.6-3.2Ga) Western Australia



Warrawoona Greenstone Belt



# Echantillons Métamorphiques

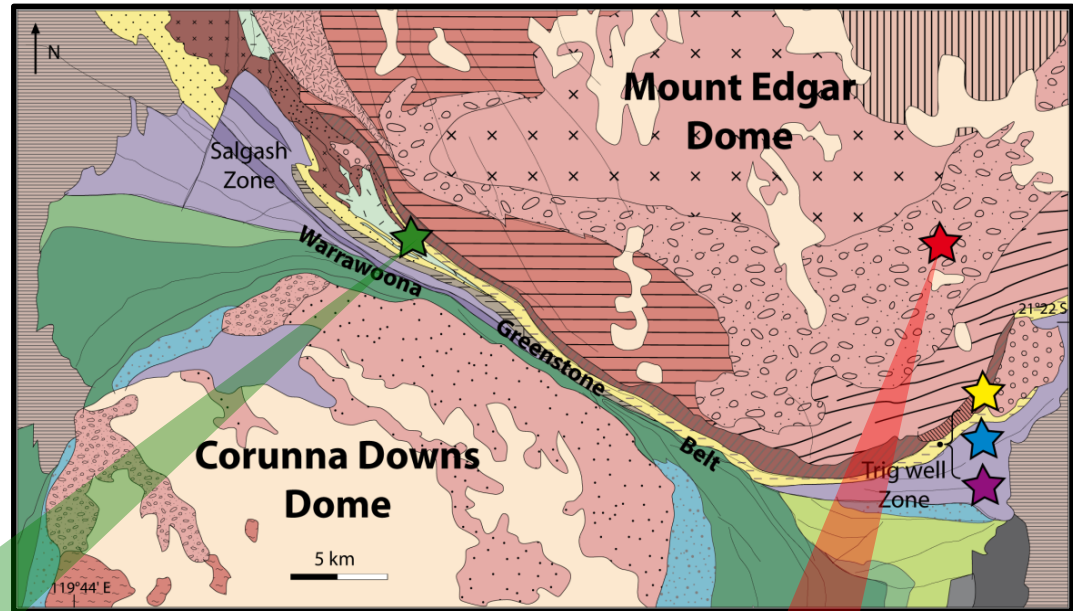


Coeur

Bordure  
De dôme

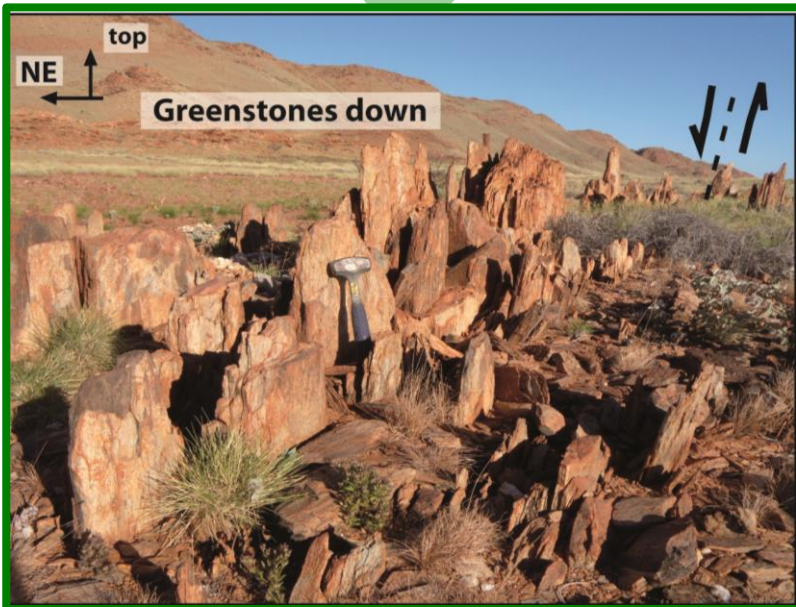


# Echantillons Métamorphiques

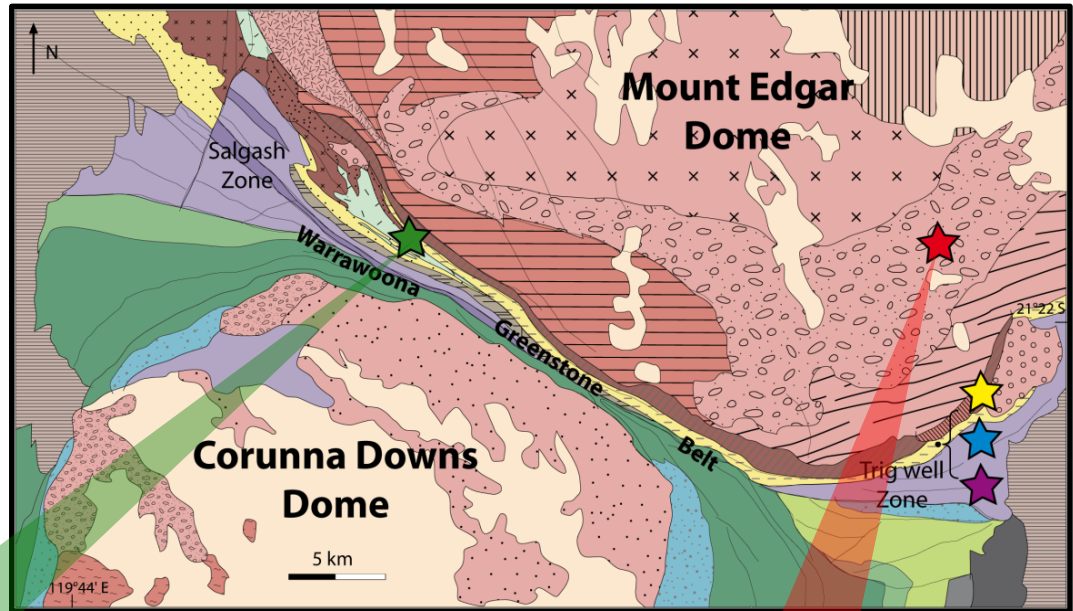


★ Bordure  
De dôme

Coeur  
★

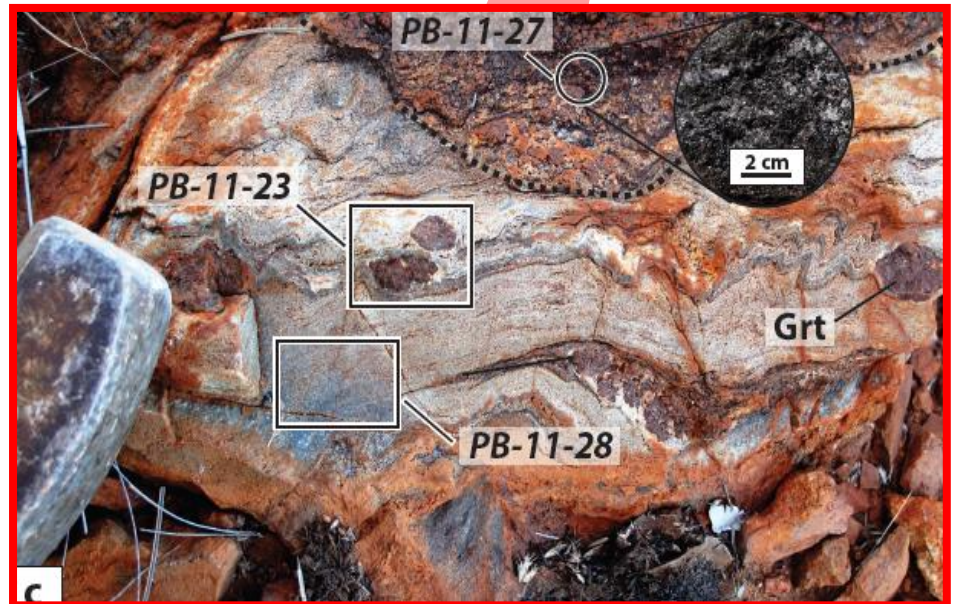
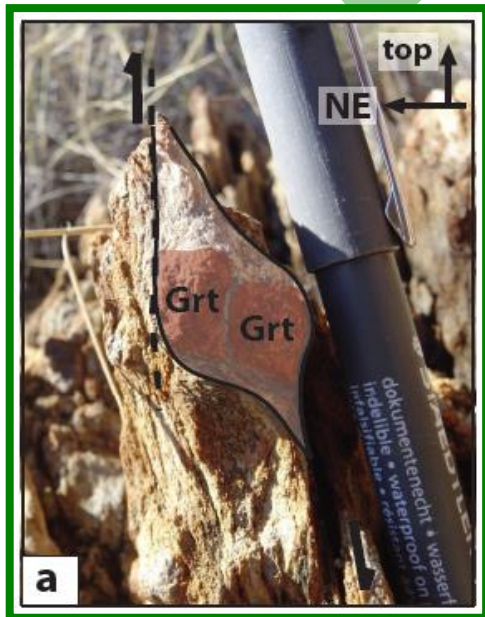


# Echantillons Métamorphiques



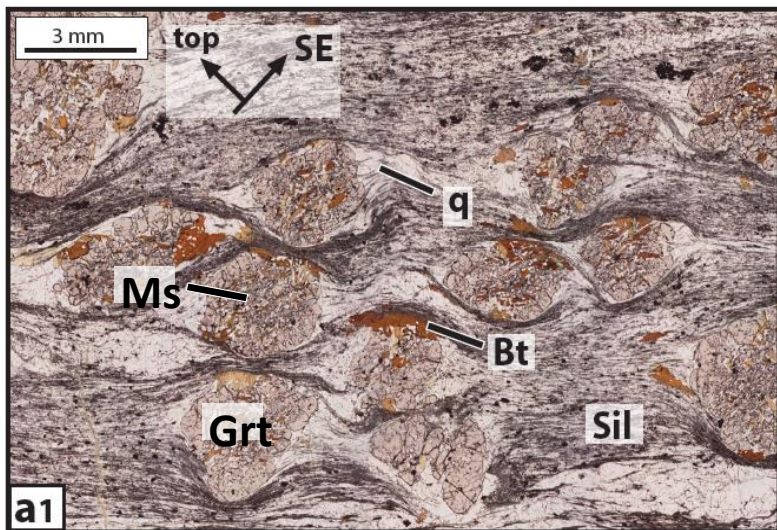
★ Bordure  
De dôme

Coeur  
★

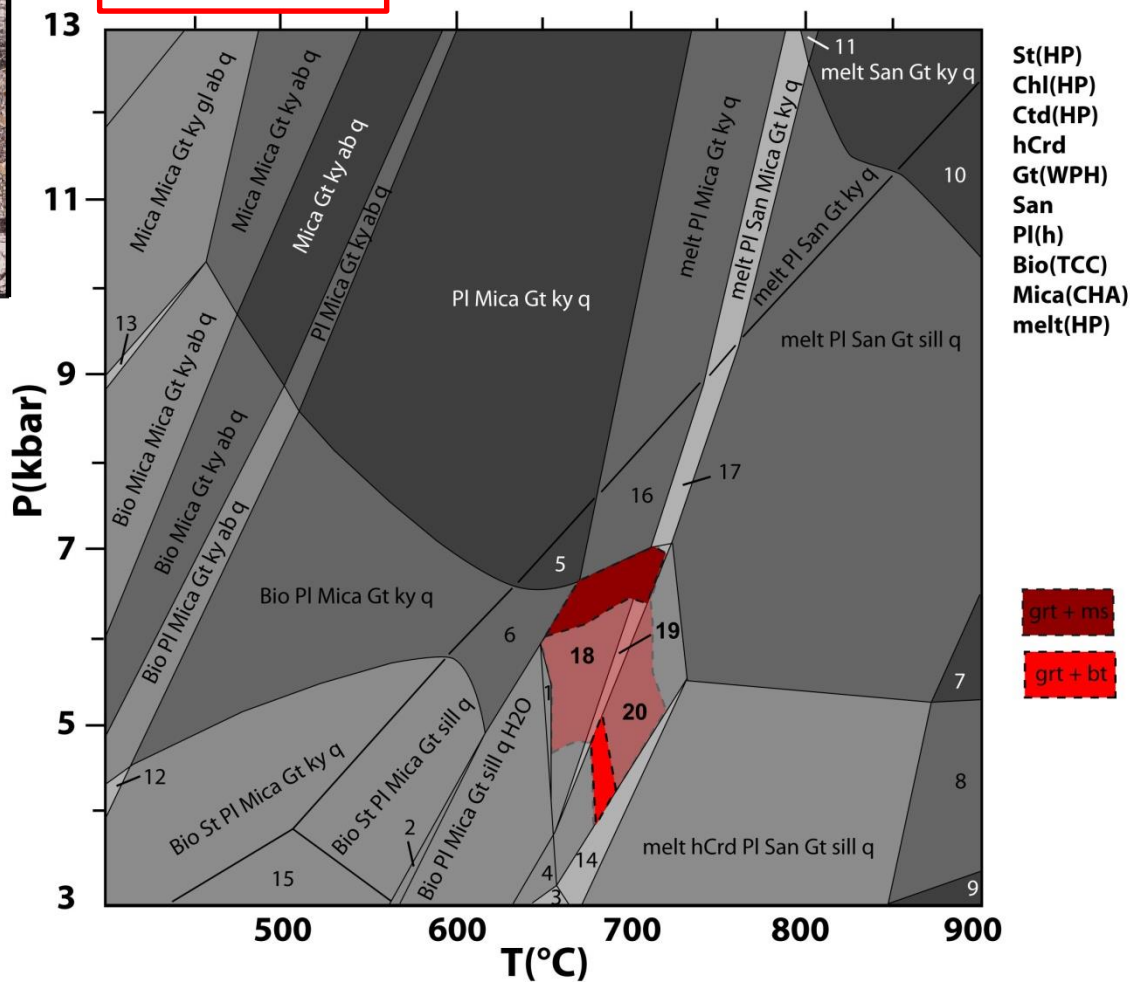




# Pétrologie / Thermobarométrie



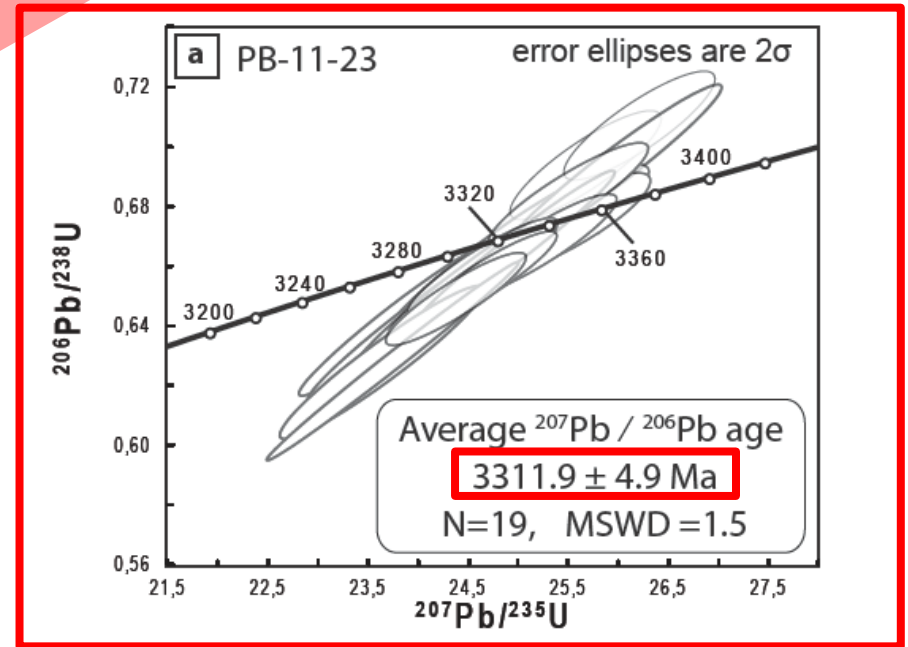
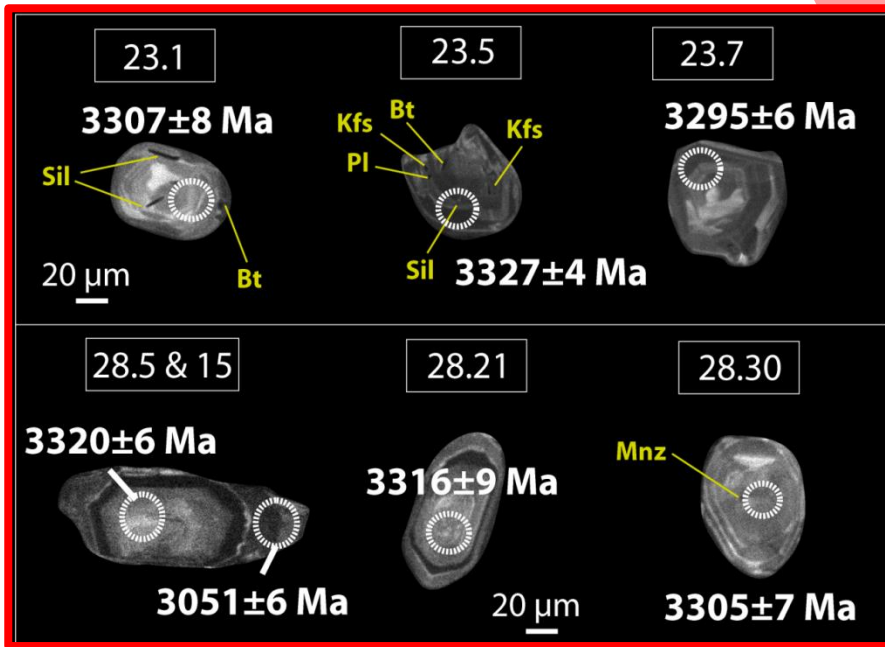
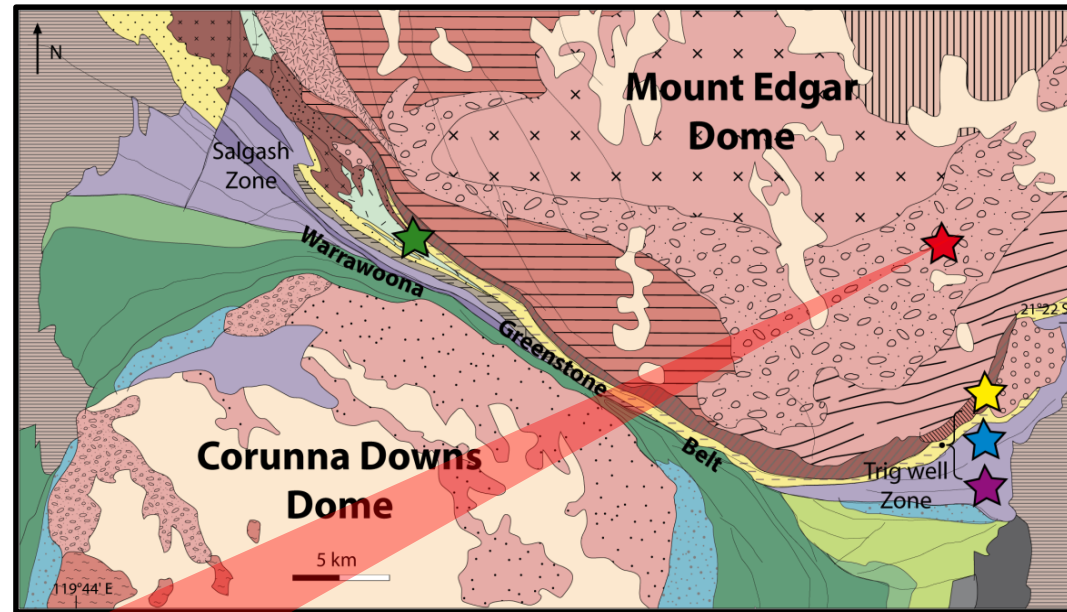
SiO <sub>2</sub>	Al <sub>2</sub> O <sub>3</sub>	FeO	MnO	MgO	CaO	Na <sub>2</sub> O	K <sub>2</sub> O	TiO <sub>2</sub>	H <sub>2</sub> O
68,64	20,97	5,16	0,16	0,77	0,46	0,30	0,91	1,47	2,70



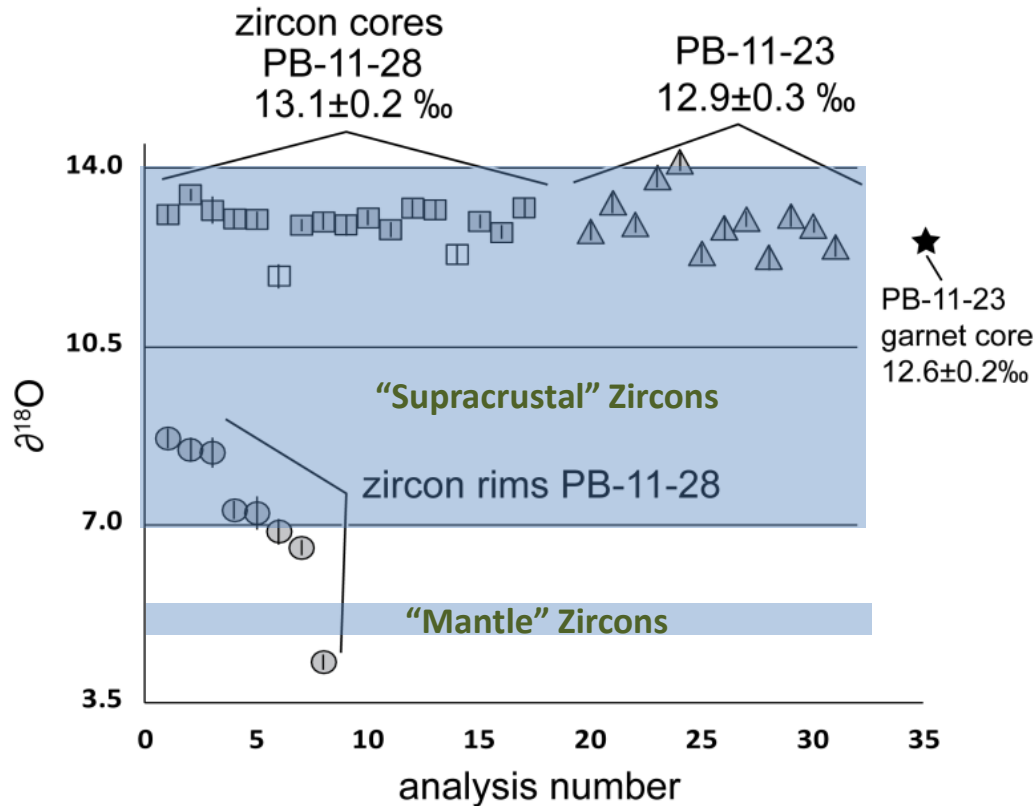
 **Composition felsique**  
 **Faciès Amphibolite à Granulite**

# Géochronologie

U/Pb sur ZIRCONS



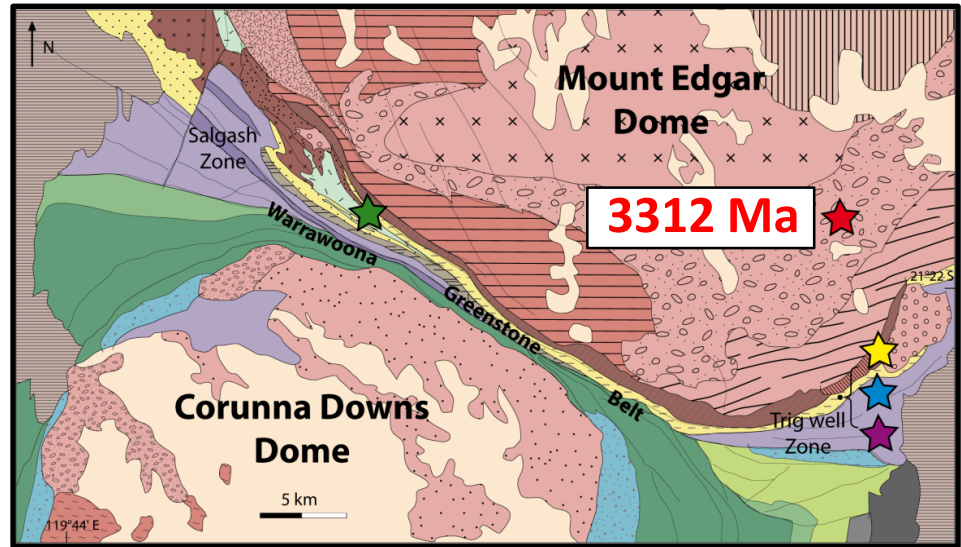
# Isotopes de l'Oxygène



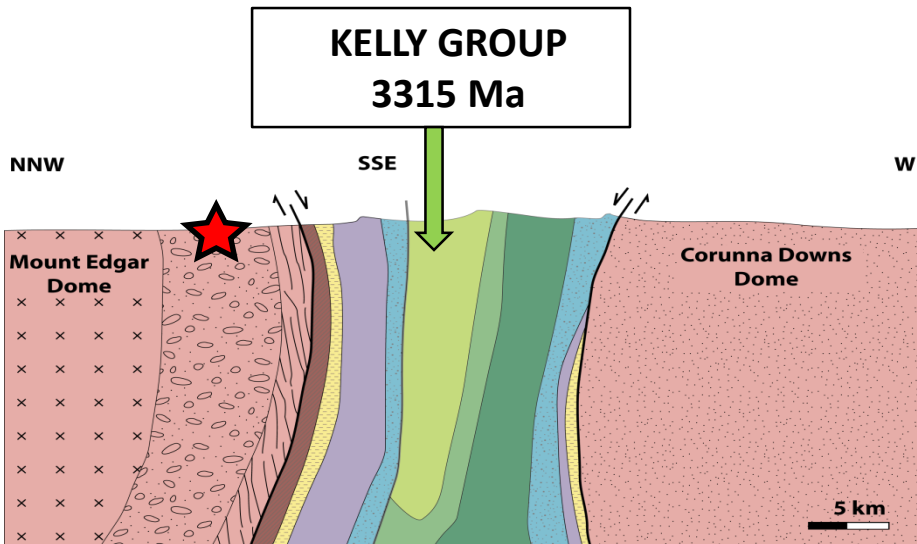
$\delta^{18}\text{O} \sim +13 \text{ ‰}$  (élevé)

➔ Origine Sédimentaire

- ➔ Composition Felsique
- ➔ Conditions PT = Granulite
- ➔ Zircons métamorphiques

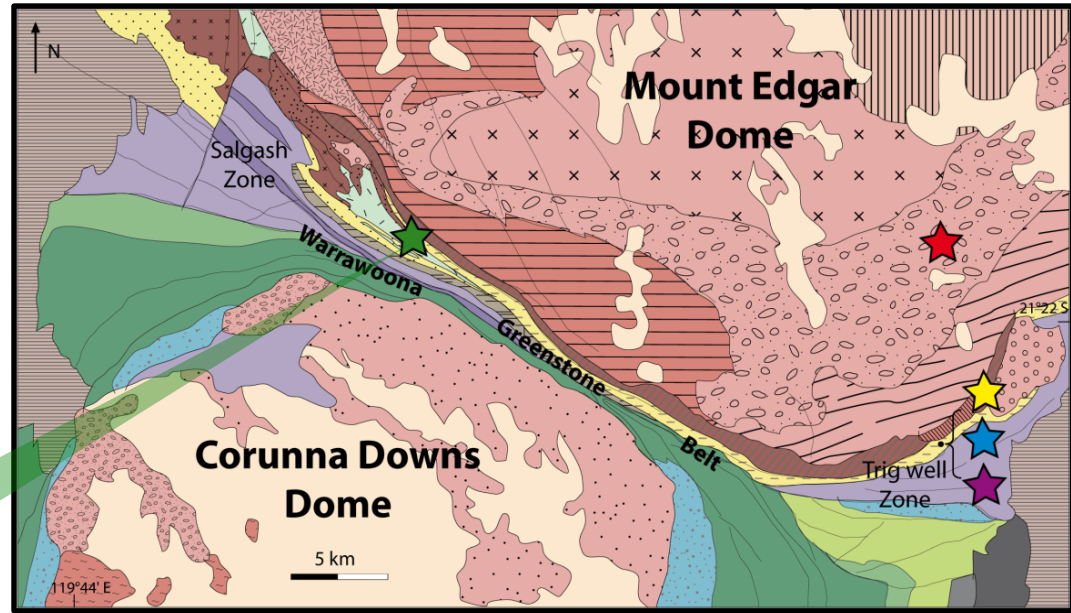


Cette enclave **métasédimentaire** suggère **enfouissement + exhumation** durant un cycle unique de "sagduction de roches de surface" et "exhumation à l'intérieur des domes par convection"



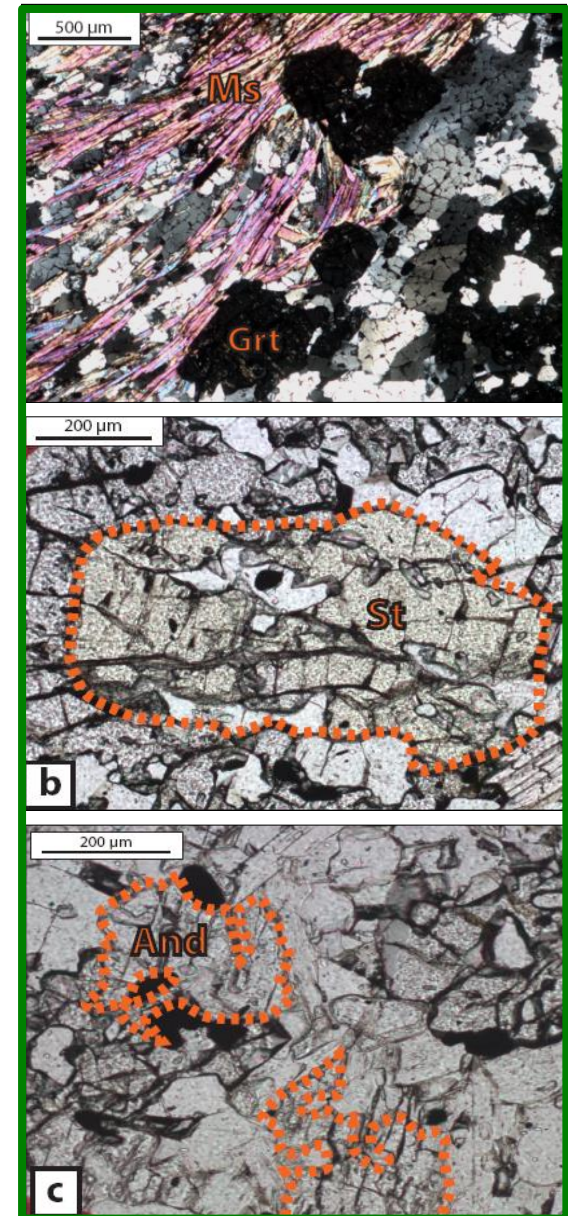
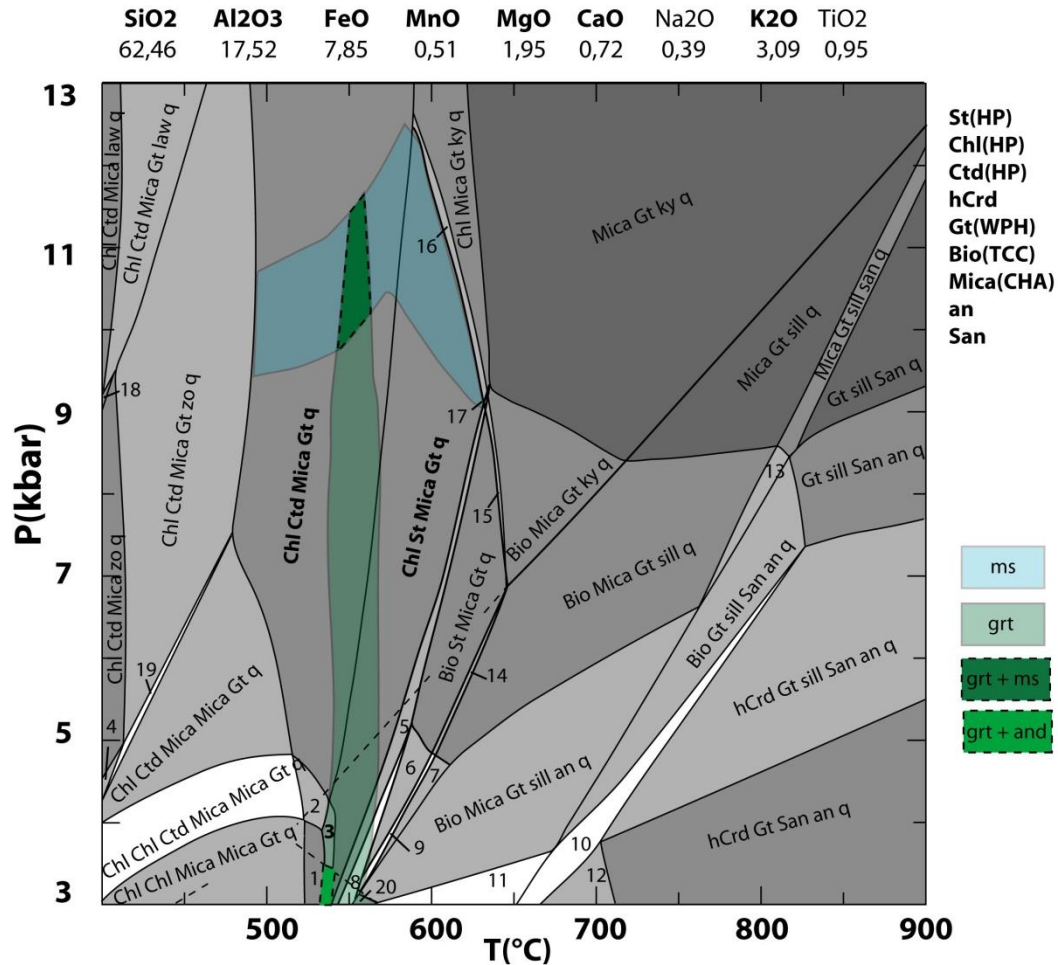
➔ **RAPIDE "CRUSTAL LOOP"**

# Echantillons



## Bordures

# Thermobarométrie



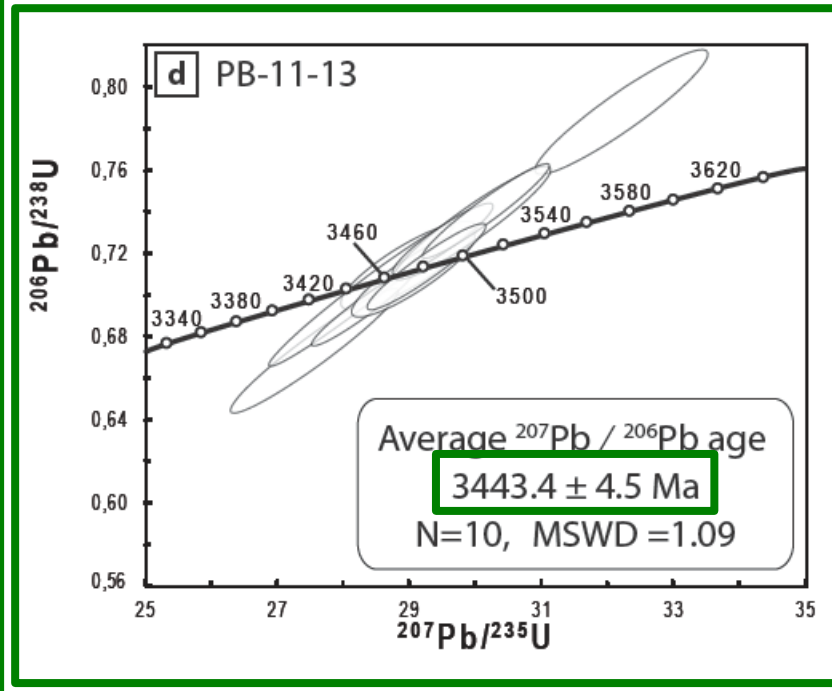
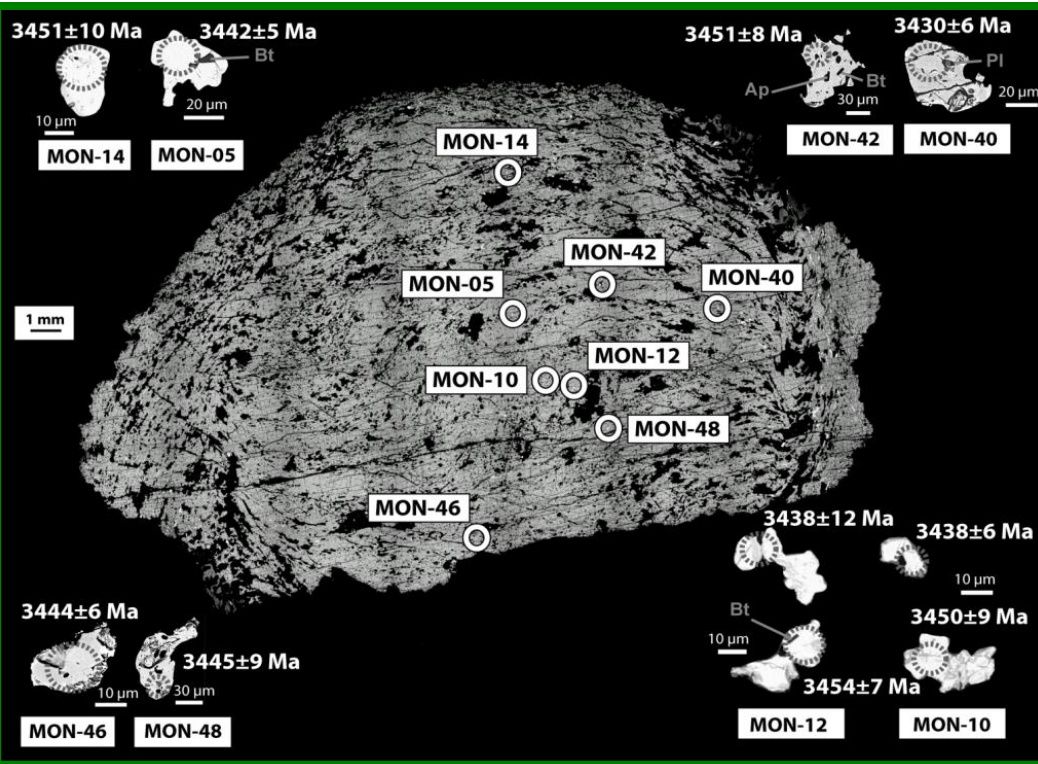
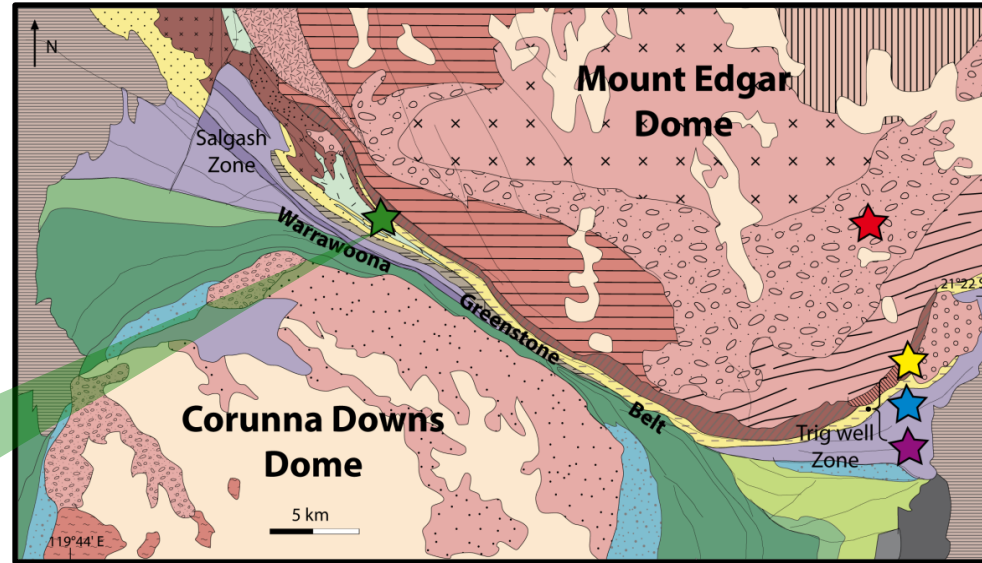
# Géochronologie

François et al., 2014, EPSL

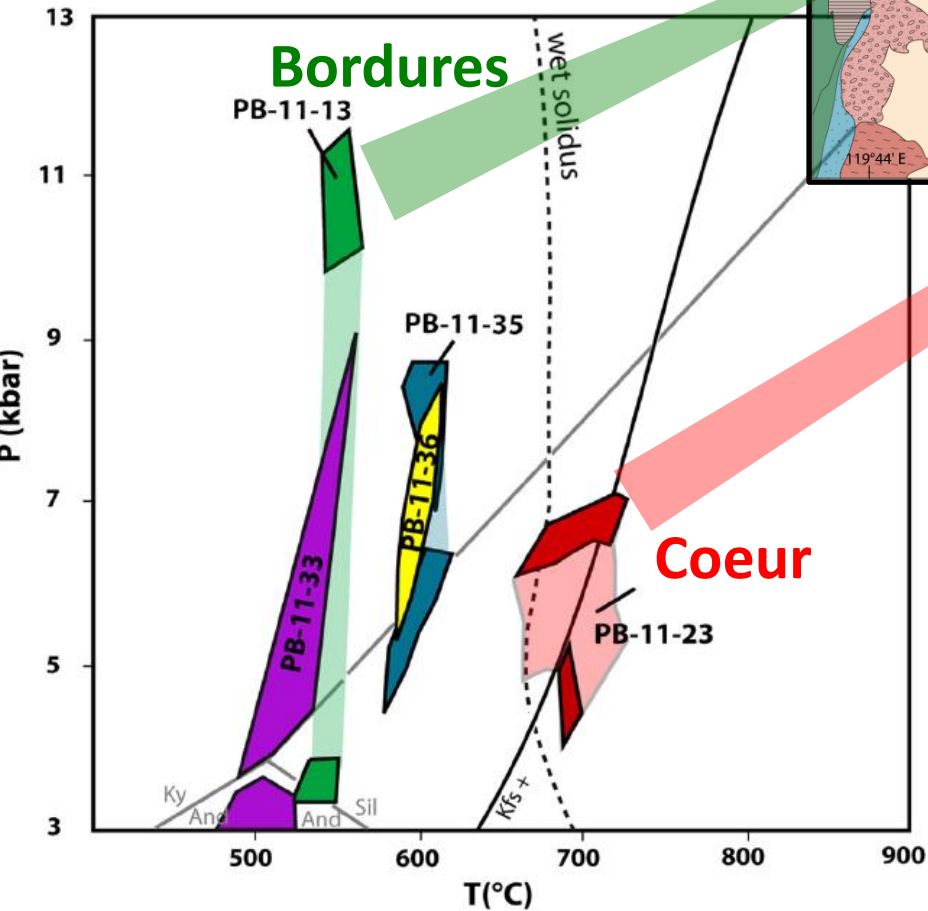
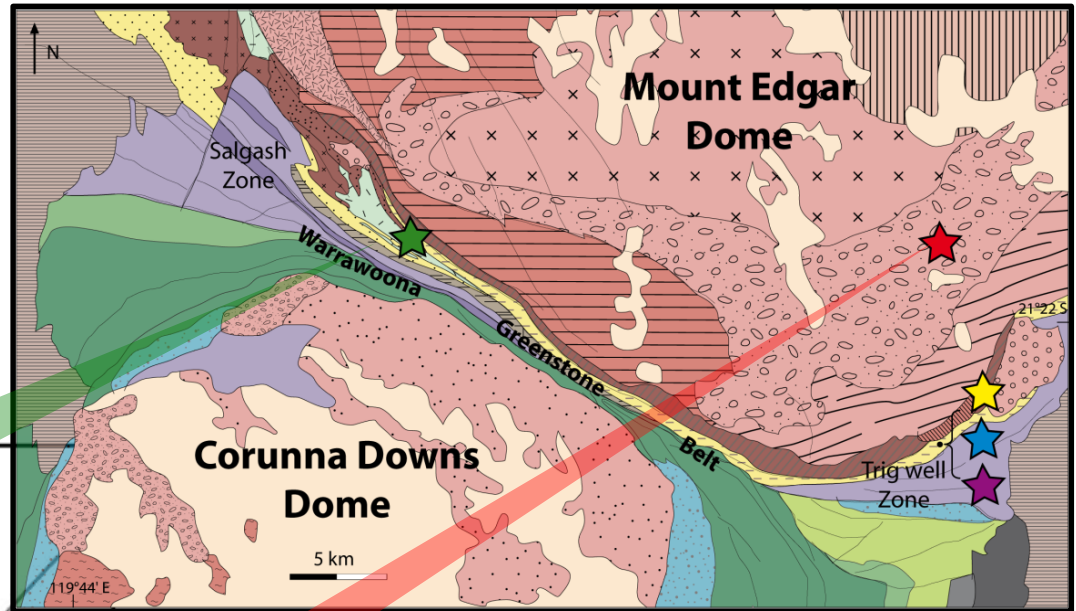
SHRIMP II, ANU, Canberra

U-Th-Pb sur MONAZITES

Bordures



# Résumé Thermobarométrie



- ➡ **P<sub>max</sub> : 7-12 kbar**
- ➡ **T gamme: 500-750°C**
- ➡ **Progressive augm de la Temp des bordures au coeur**

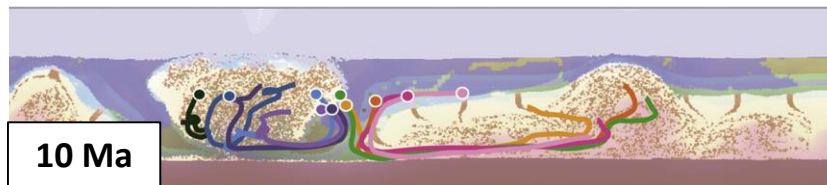
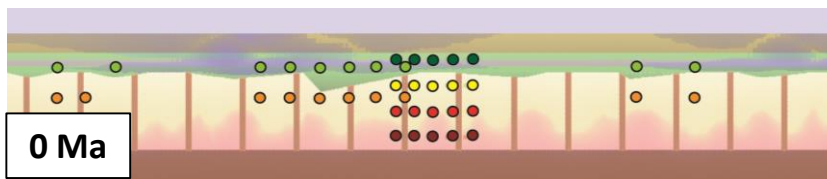
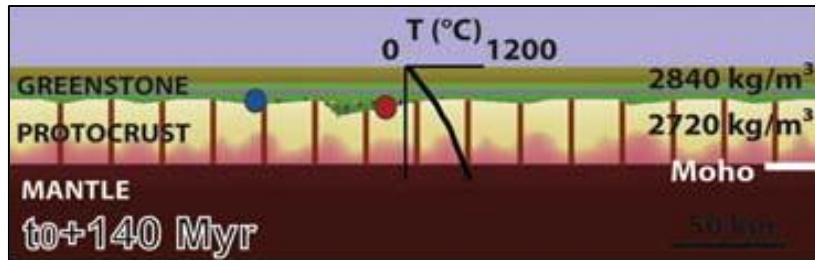


# Caractérisation des processus géodynamiques: Application à la sagduction archéenne (3.5-3.2 Ga)

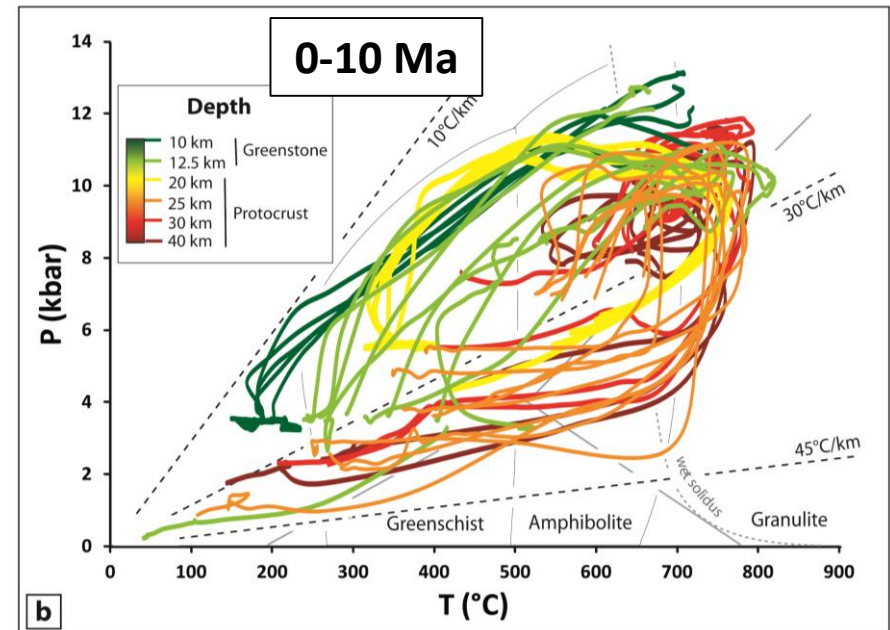
(Pilbara craton, *Australia*)



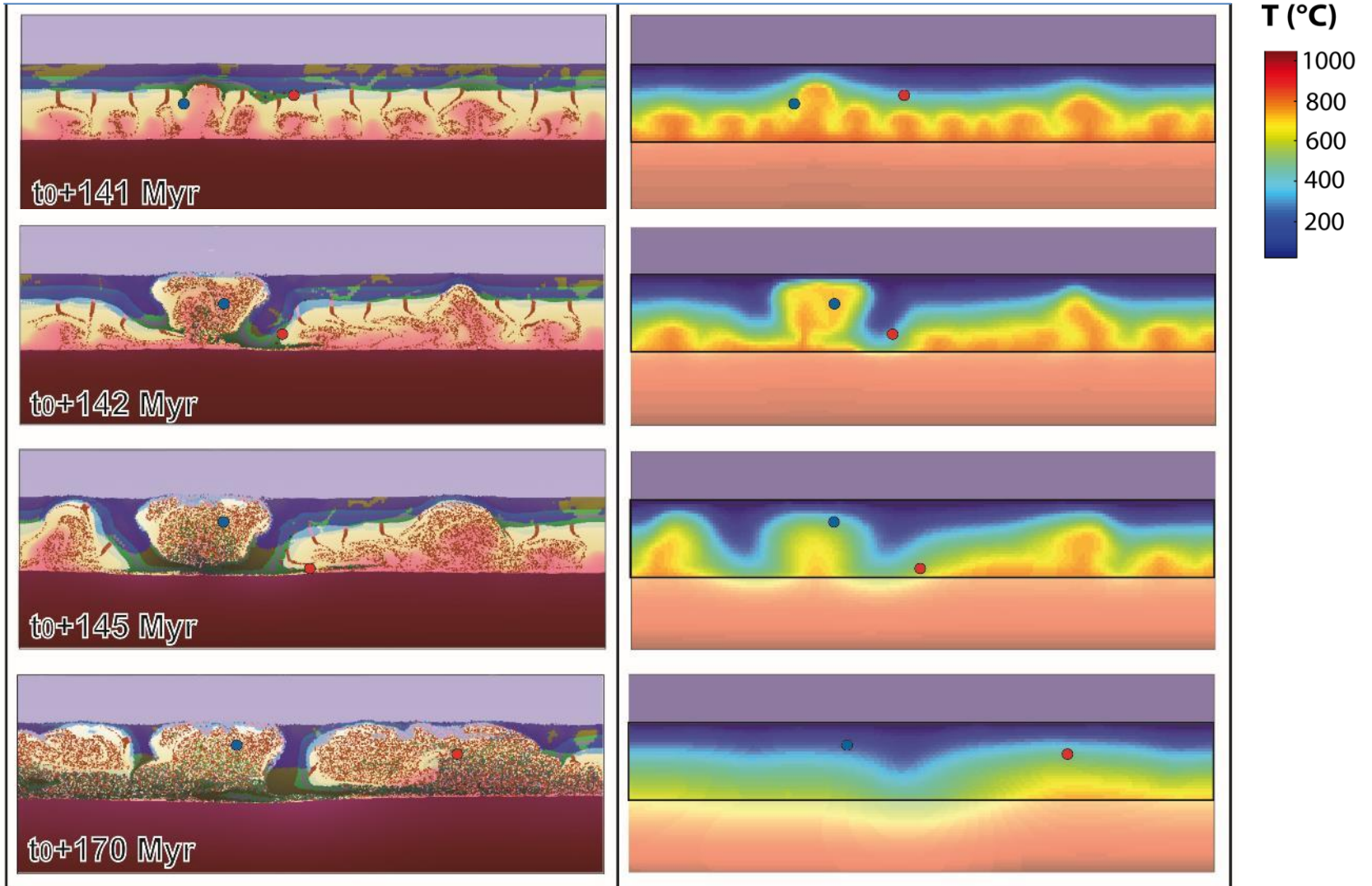
## ■ Modélisation numérique



## CRUSTAL LOOP



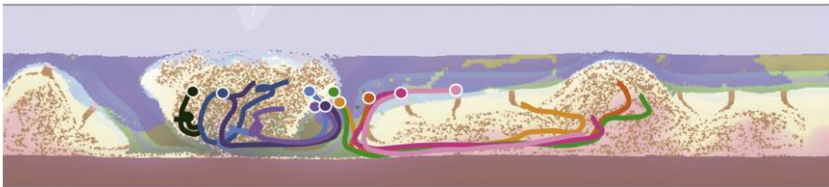
# Histoire Thermique



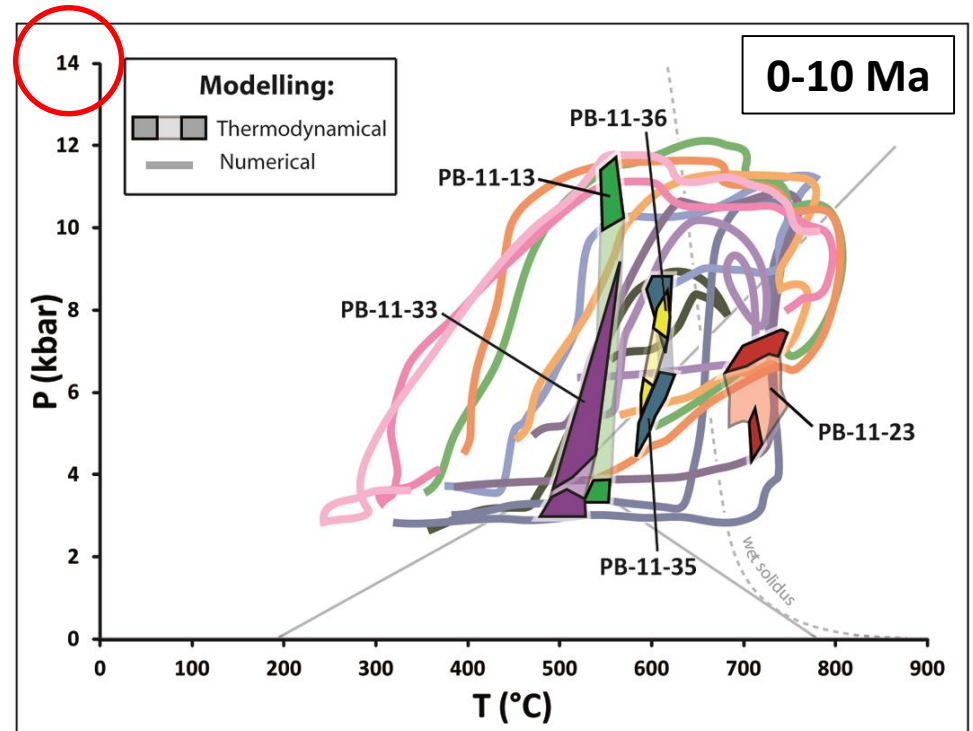
# Caractérisation des processus géodynamiques: Application à la sagduction archéenne (3.5-3.2 Ga)

(Pilbara craton, *Australia*)

Recyclage crustal rapide (<10 Ma)

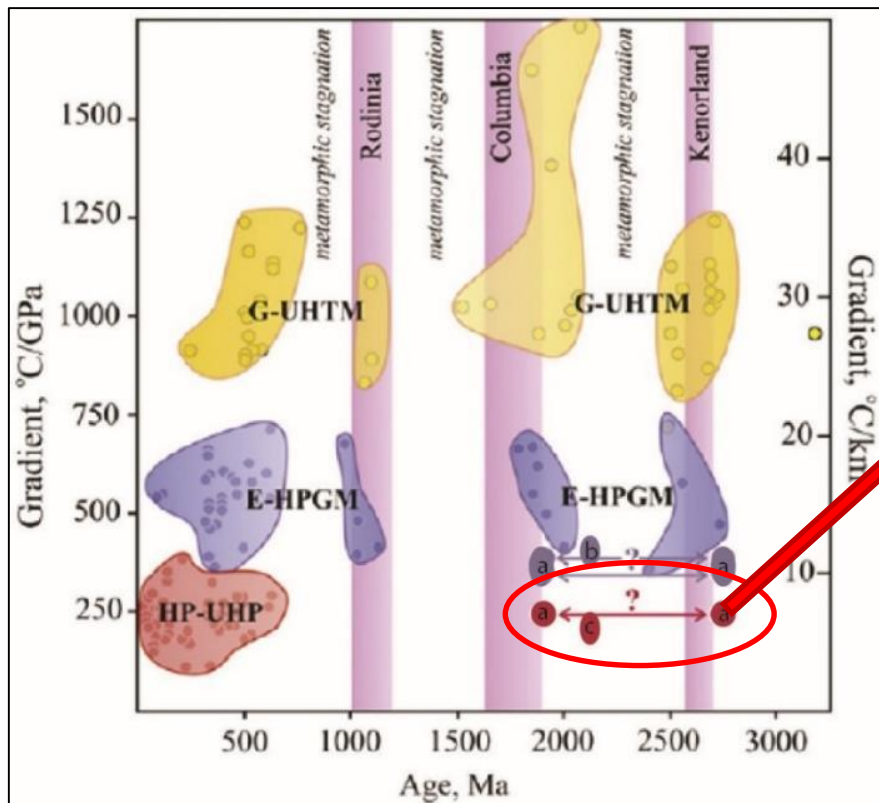


➔ Pas de roches metam UHP



# Enregistrement métamorphique

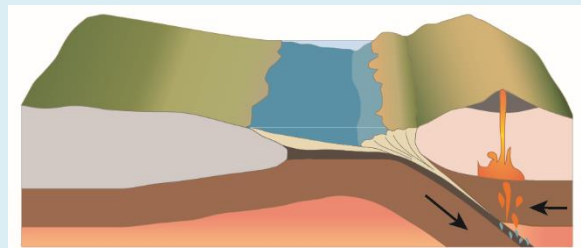
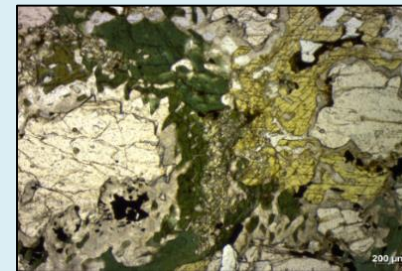
- A partir de quand les conditions mantelliques permettent-elles le processus de subduction (roches de metam HP & UHP) ?



HT & UHT  
MT & MP  
HP-UHP & BT

Brown, 2006

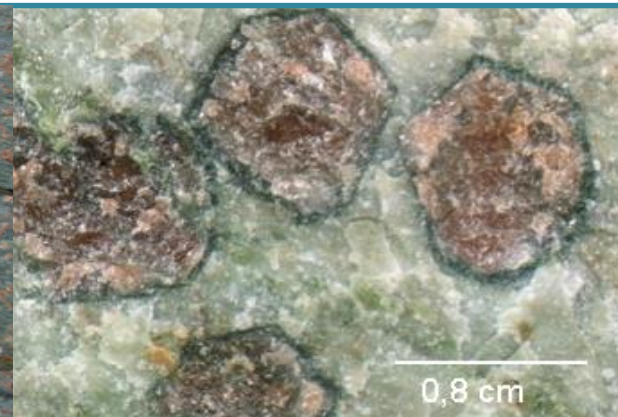
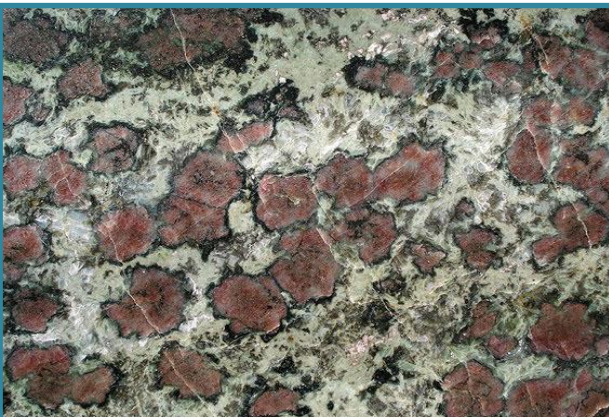
➤ Eclogites et roches de HP-UHP :  
témoins de processus de subduction  
anciens



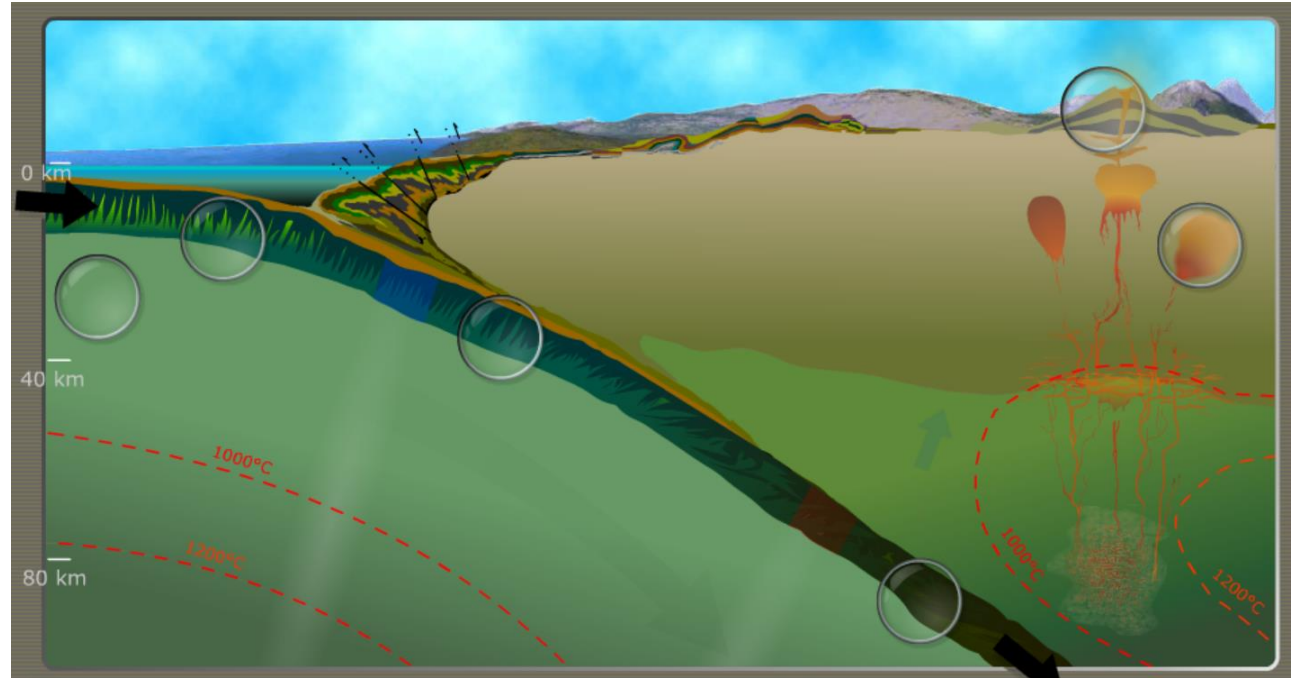
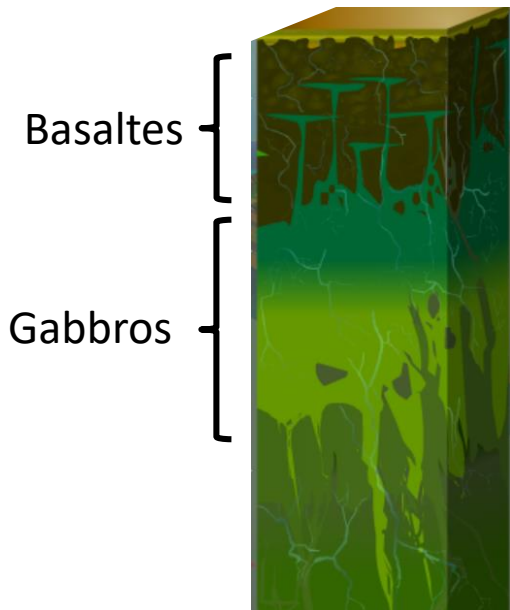
# Les roches (U)HP pour mettre en évidence le processus de subduction

## ECLOGITES:

- ❑ (Ultra) Haute Pression / Basse Température
- ❑ Composées de grenat et clinopyroxène  $\pm$  amphibole
- ❑ Protolithe basaltique
- ❑ Formées par subduction profonde (> 40 km)



# Formation des éclogites dans les zones de subduction



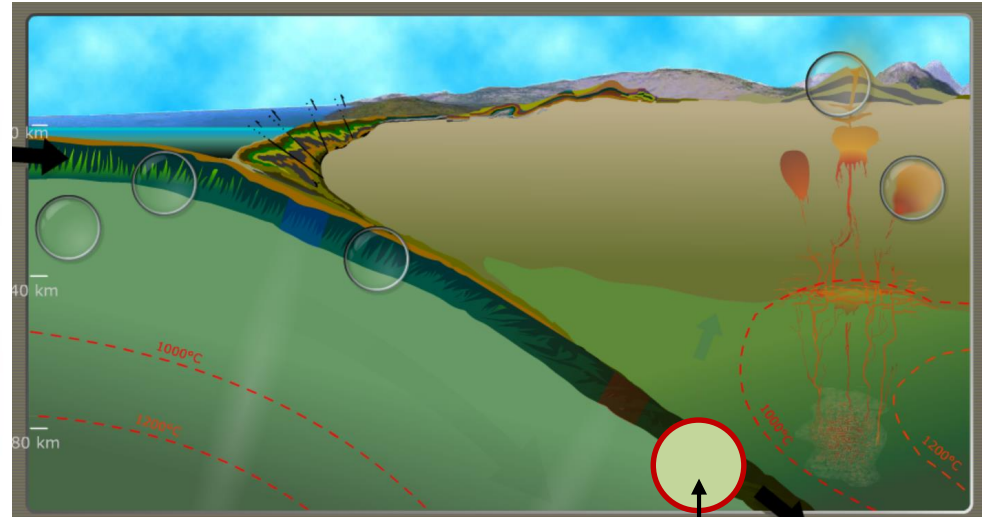
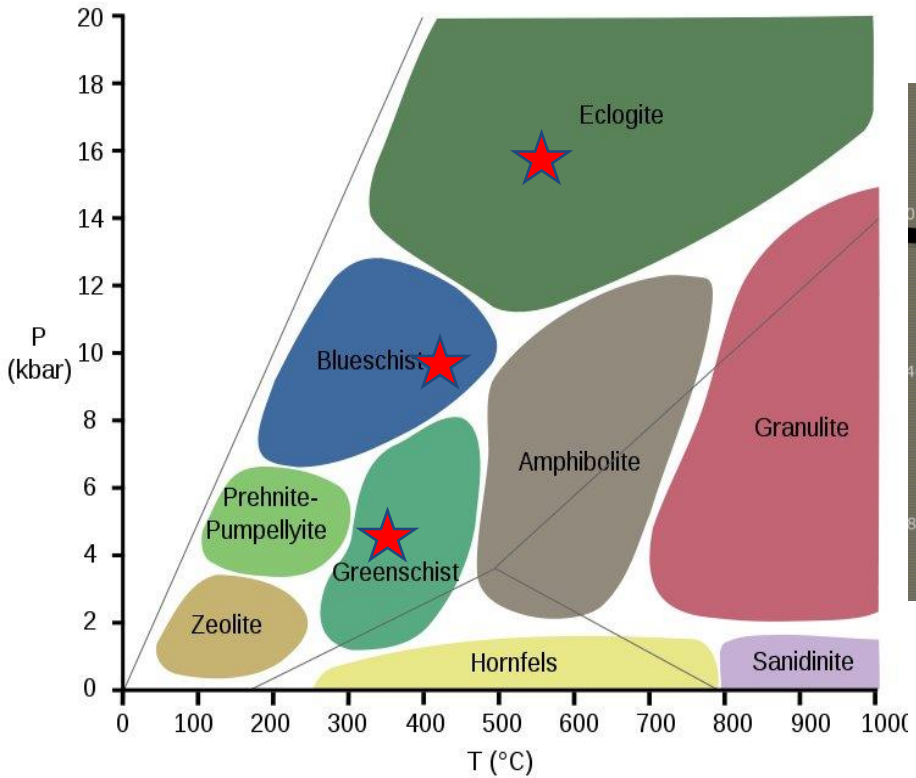
## CROUTE OCEANIQUE

fine, dense, **froide** & hydratée

Logiciel Subduction et magmatisme:  
<http://www.labosvt.com/download-file-17.html>

composition de gabbro/basalte (protolithe)

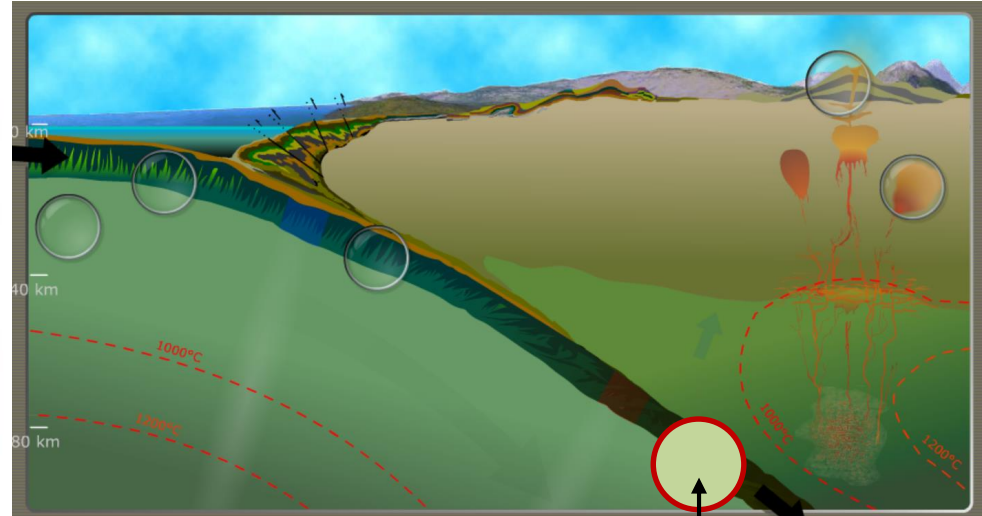
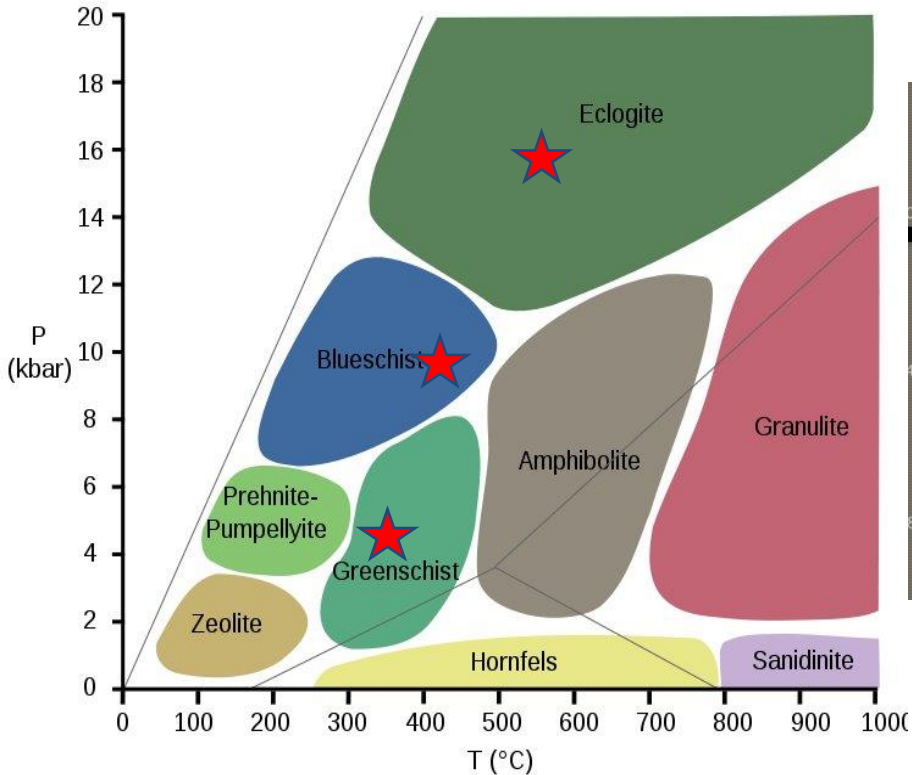
# Formation des éclogites dans les zones de subduction



Eclogite

☐ Schiste vert / Schiste bleu / Eclogite

# Formation des éclogites dans les zones de subduction



Eclogite

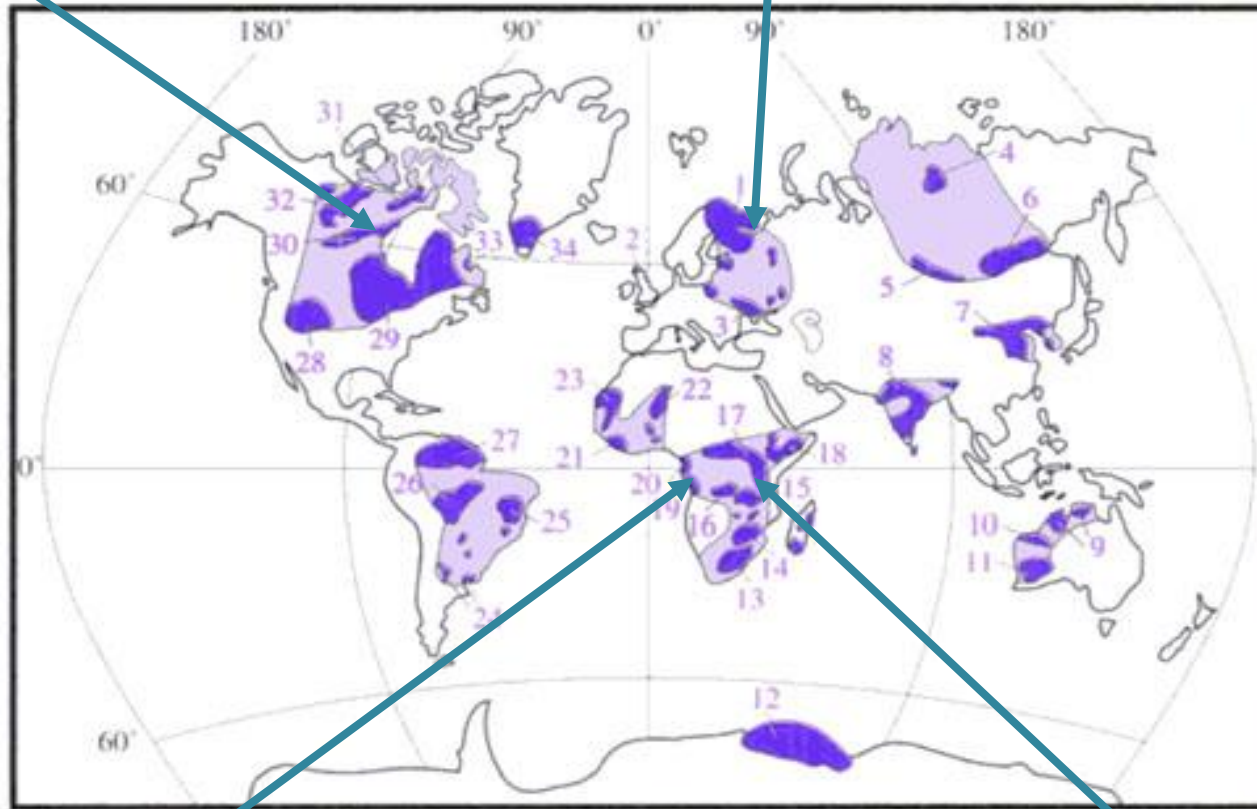
- Les conditions PT enregistrées par les éclogites sont typiques des zones de subduction
- Les éclogites sont représentatives du processus de subduction et donc de la tectonique des plaques dans l'enregistrement géologique.



# Eclogites archéennes à paléoprotérozoïques

Snowbird zone, Canadian Shield (1.9 Ga)

Belomorian Belt, the Baltic Shield, Russia (1.9-2.8 Ga)



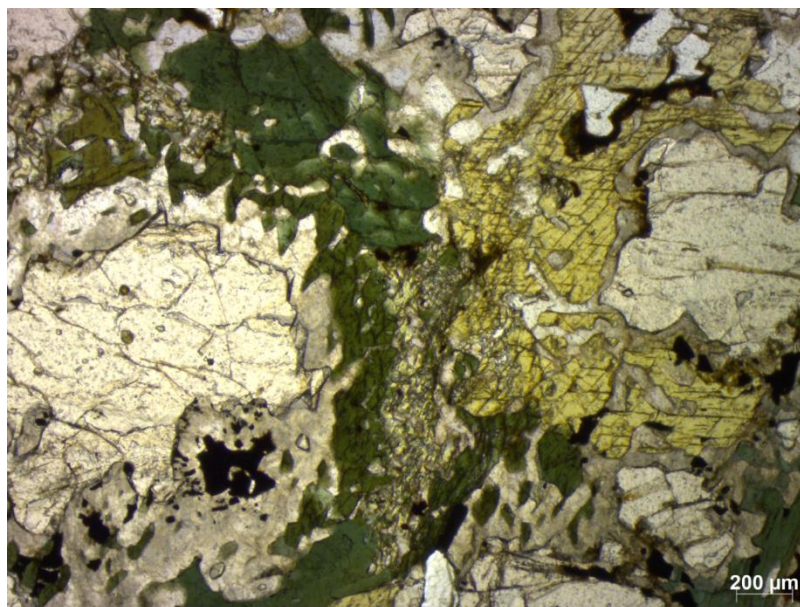
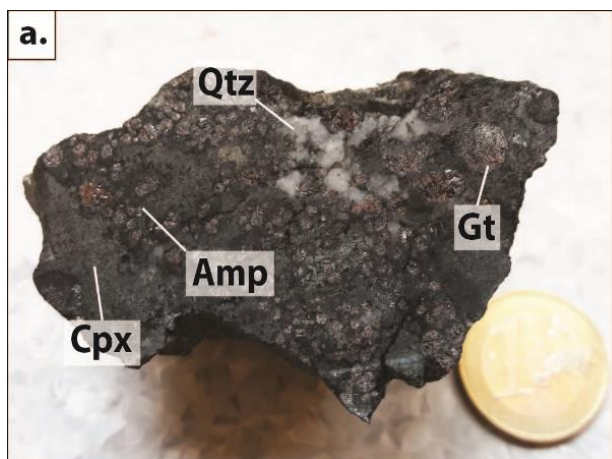
Nyong Complex, Congo craton, Cameroon (2.09 Ga)

*From H. Martin*

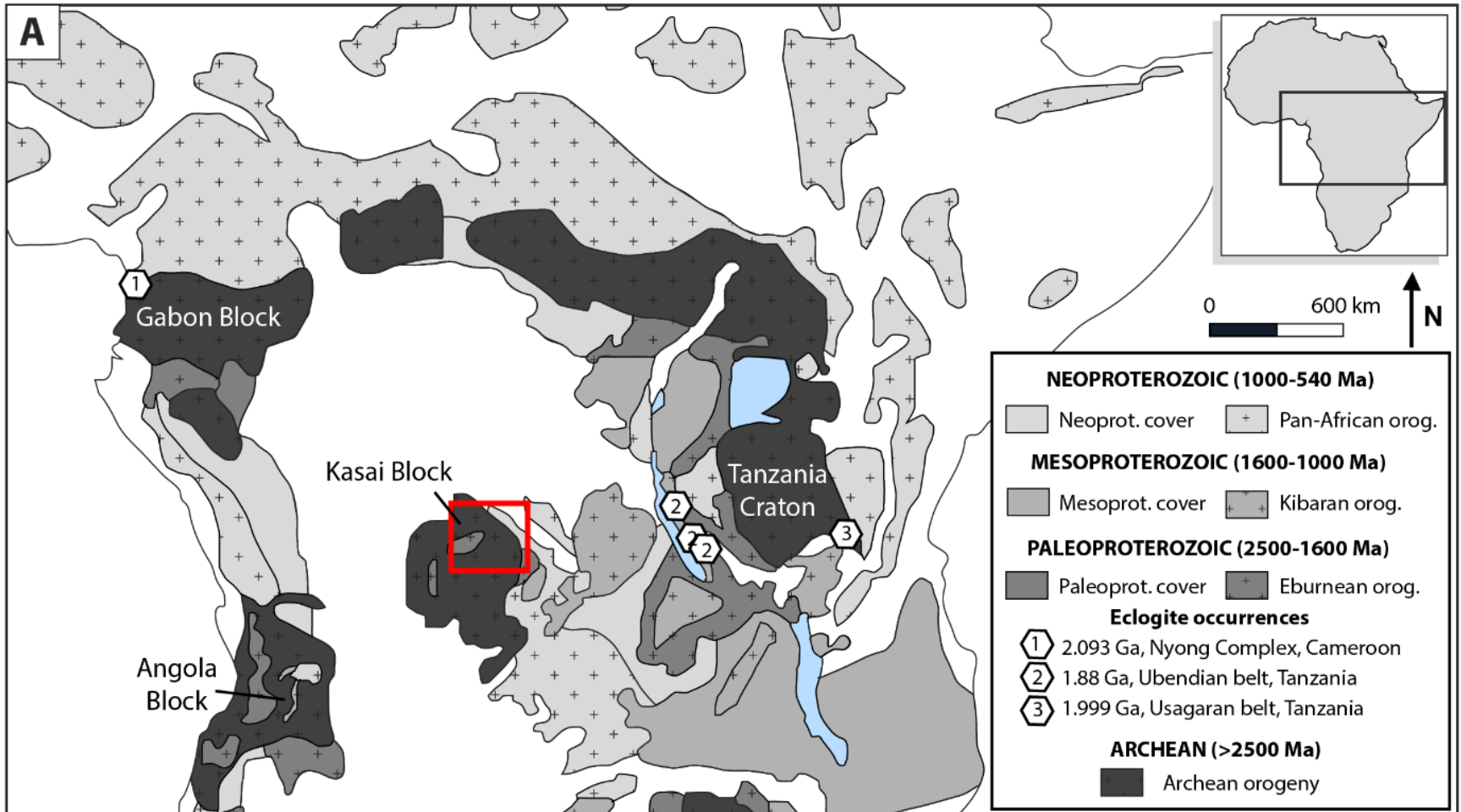
Ubendian-USagaran Belts, Tanzania craton (1.9-2.0 Ga)

# The earliest evidence for modern style plate tectonics recorded by HP–LT metamorphism in the Paleoproterozoic of the DR Congo

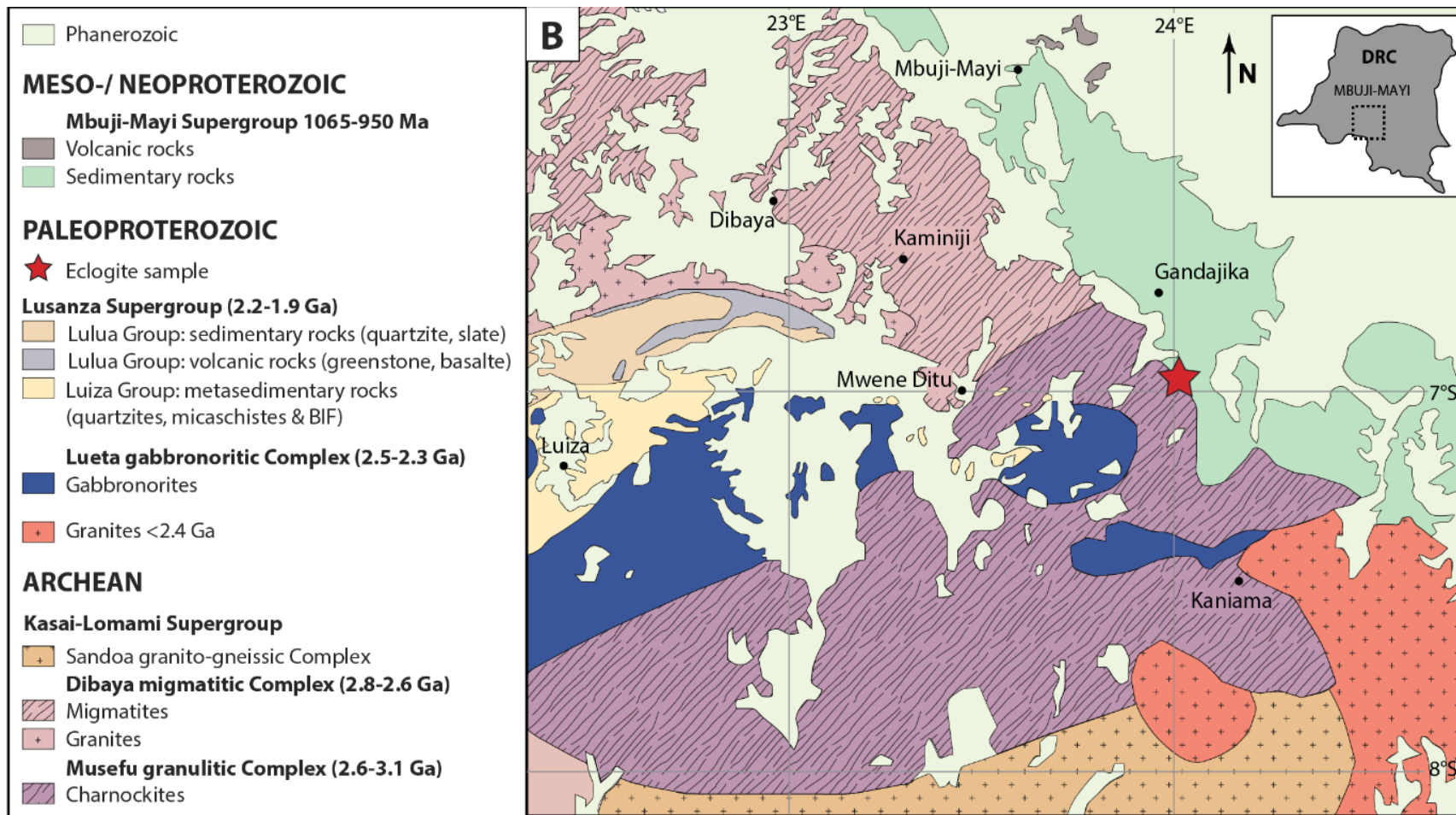
*C.François, V.Debaille, J-L.Paquette, D.Baudet & EJ.Javaux, Scientific Reports, 2018*



# Contexte géologique

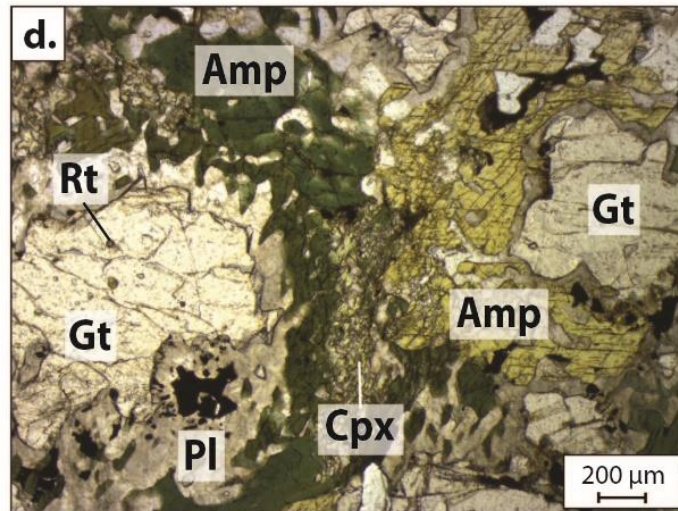
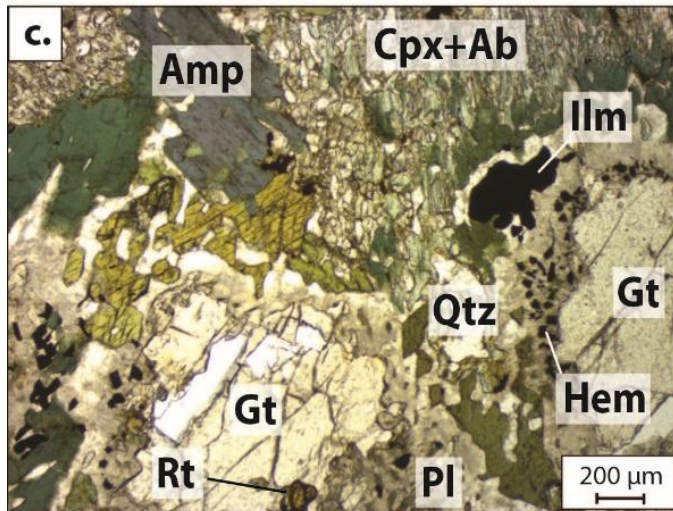
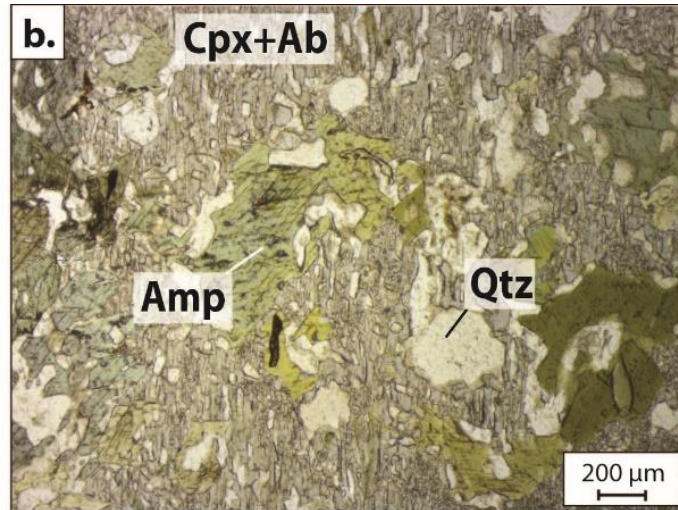
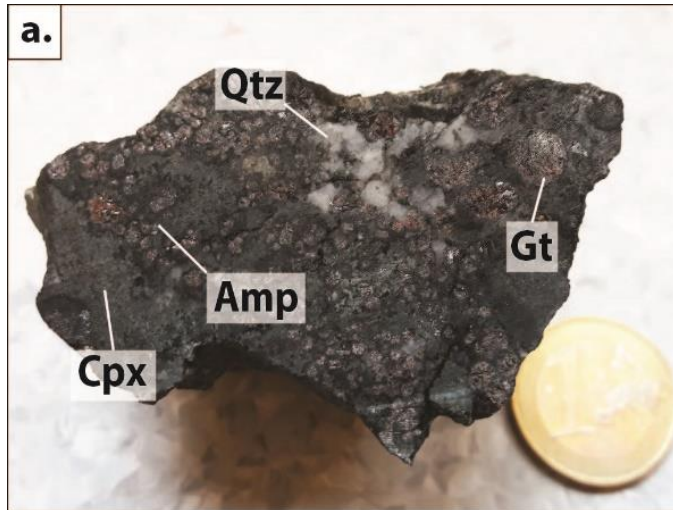


# Contexte géologique



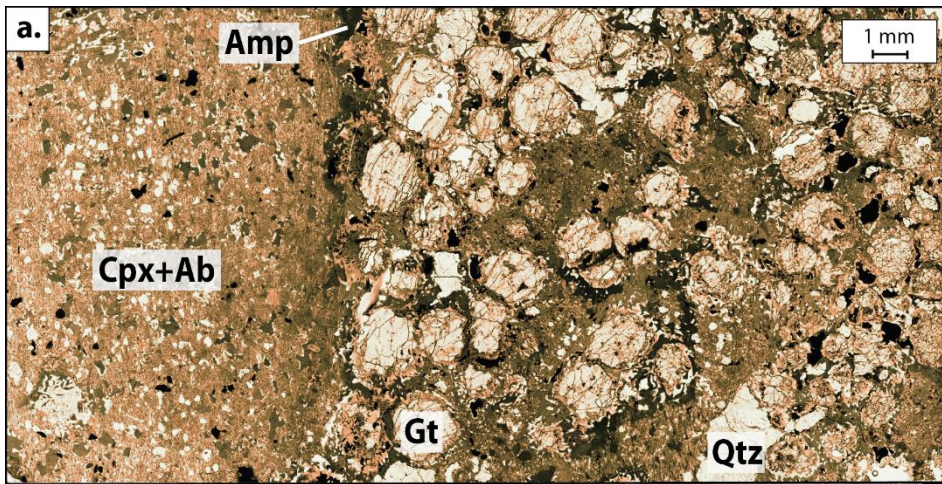
Le Bloc du Kasai a été marqué par l'orogénèse **Eburnéenne–Transamazonienne (2.2-1.98 Ga)** qui résulte de l'accrétion du Craton du Congo et du Craton Brésilien de São Francisco.

# Echantillon et Pétrologie

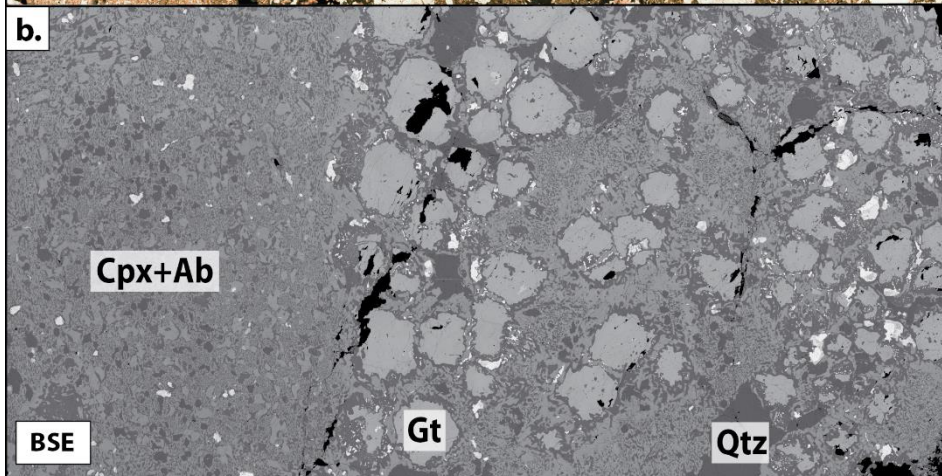


□ Paragenèse 1:  
Gt-Cpx-Amp-Qtz-Rt

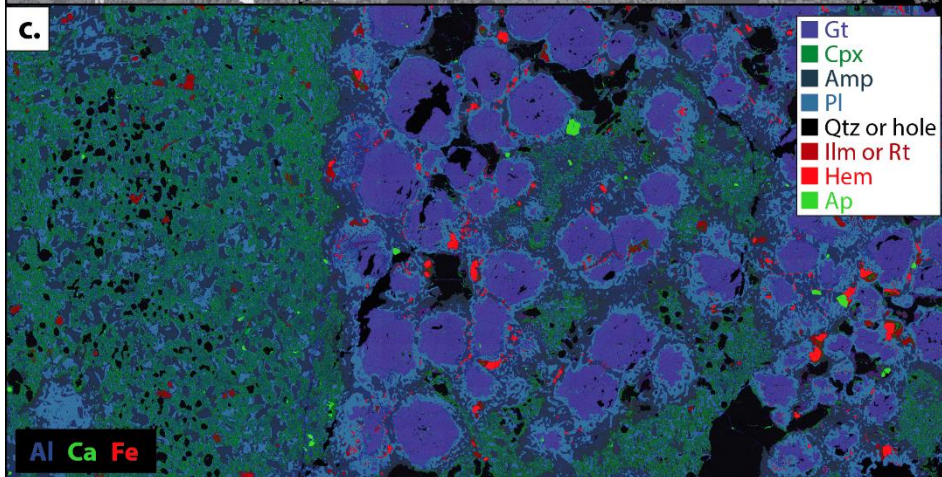
□ Paragenèse 2:  
Gt-Cpx-Amp-Qtz-Pl-Ilm±Hem



Microscope optique

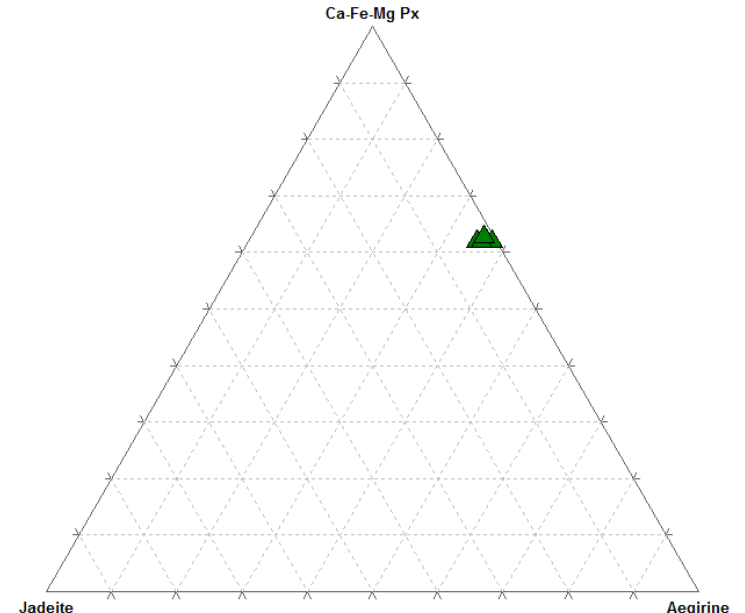
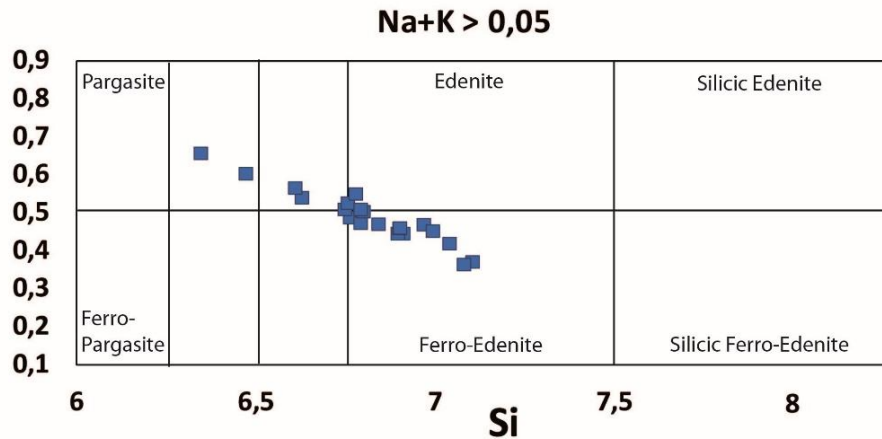
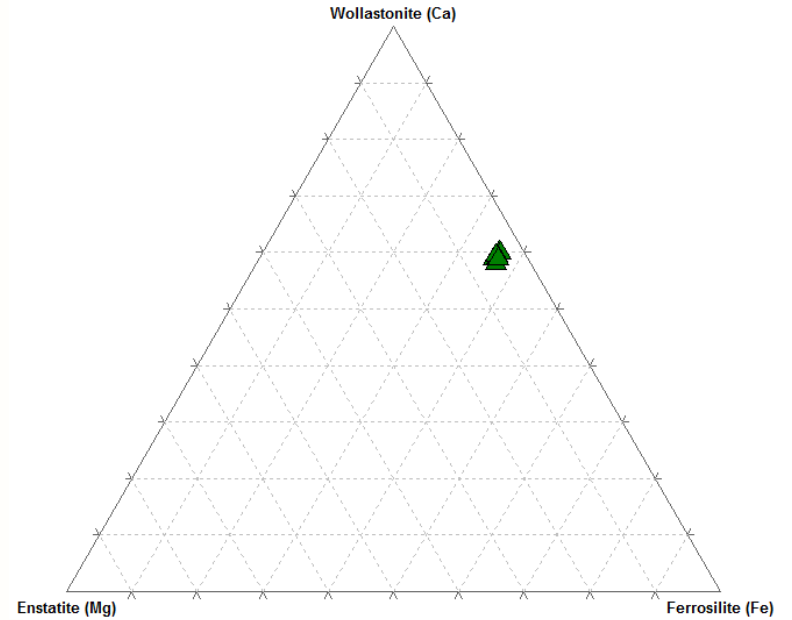
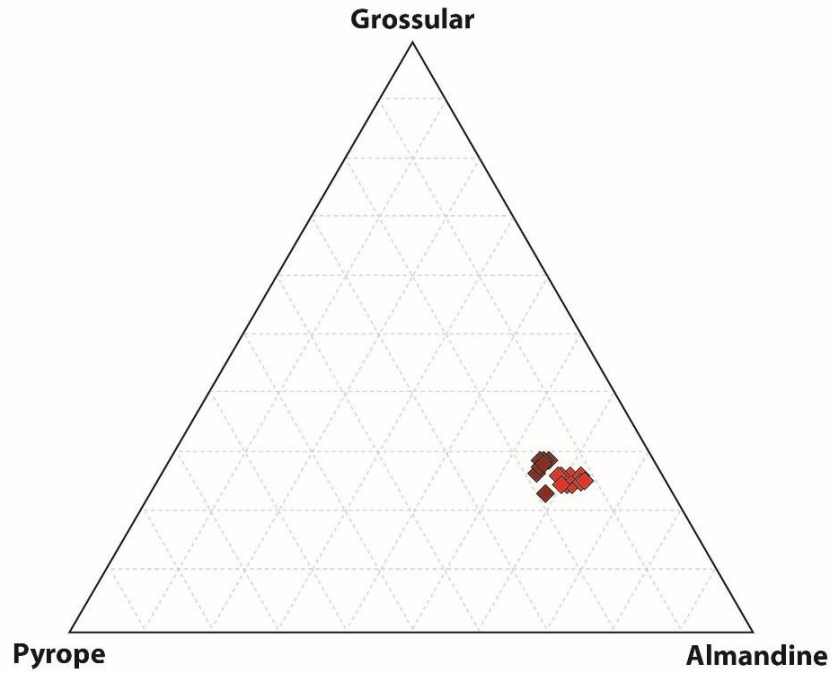


Microscope électronique à balayage (MEB)

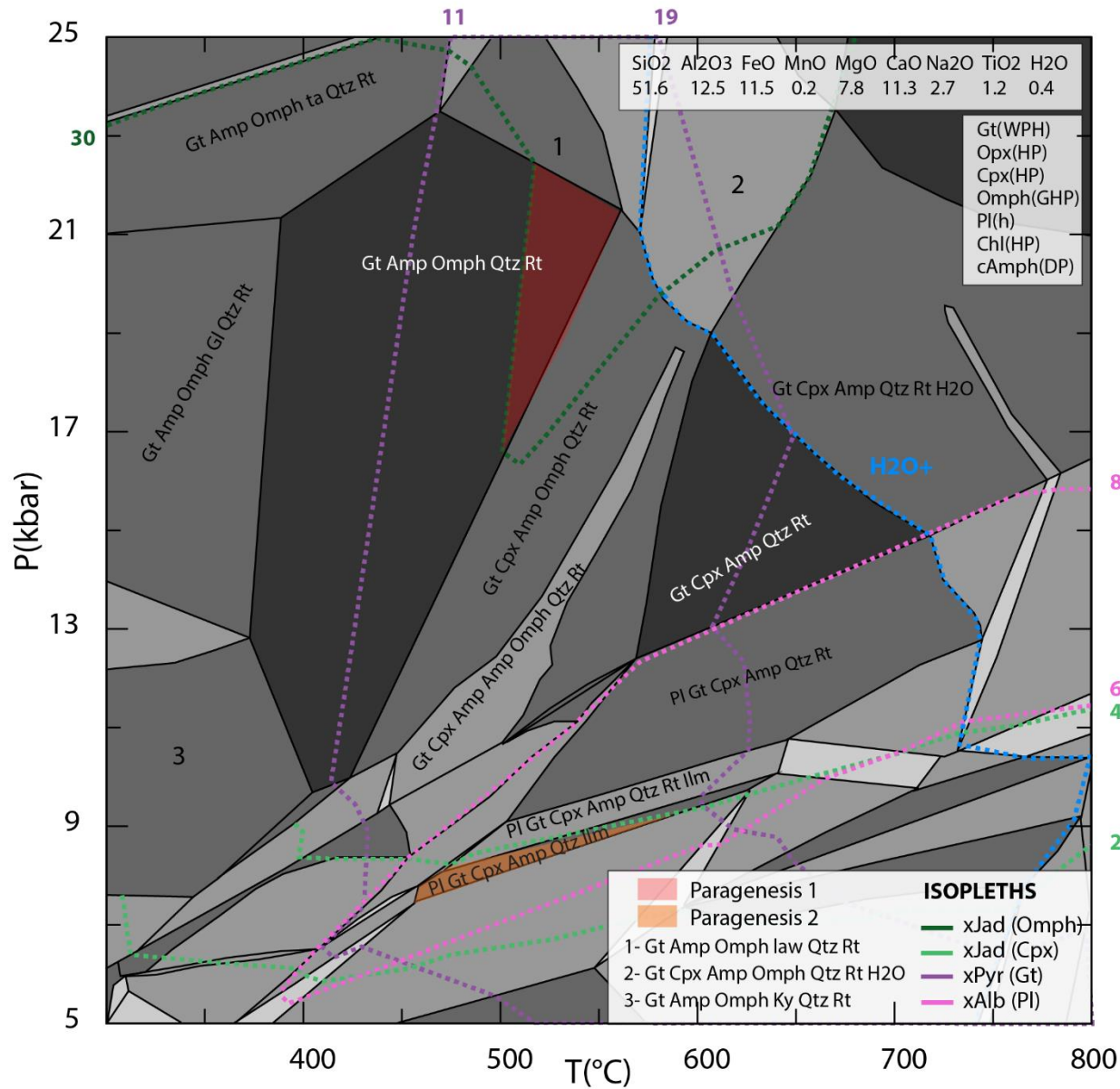


Cartographies chimiques Al, Ca, Fe (MEB)

# Pétrologie



# Thermobarométrie

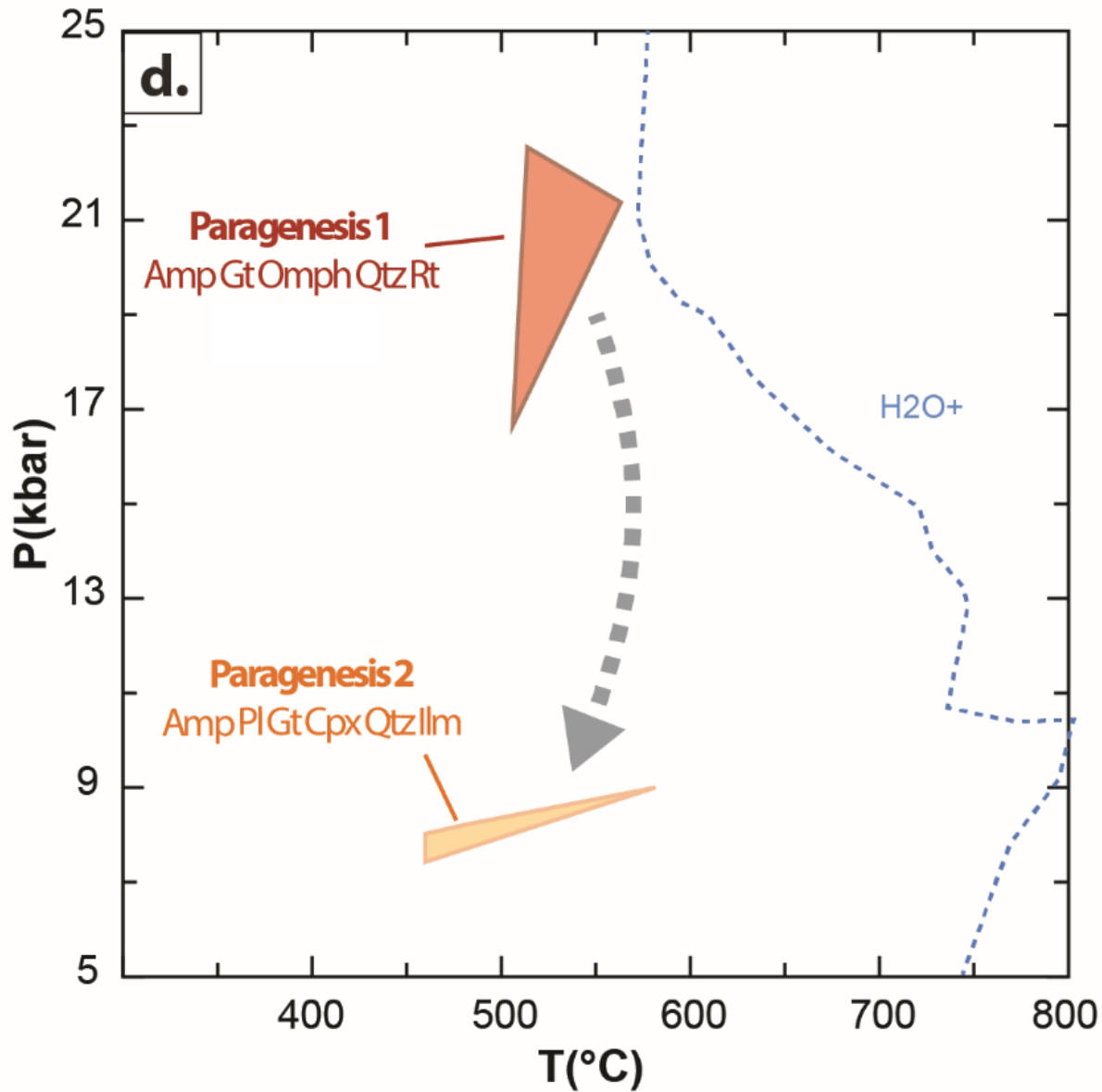


Sample	Wt %
Al <sub>2</sub> O <sub>3</sub>	12,5
TiO <sub>2</sub>	1,2
Fe <sub>2</sub> O <sub>3</sub>	12,7
MnO	0,2
MgO	7,8
CaO	11,3
Na <sub>2</sub> O	2,7
K <sub>2</sub> O	0,5
SiO <sub>2</sub>	51,6
Total	101
LOI	0,4

H<sub>2</sub>O = 0,4%



# Thermobarométrie



## Paragenèse 1:

- HP: 17-23 kbar
- BT: 530-580°C
- > 65 km de profondeur

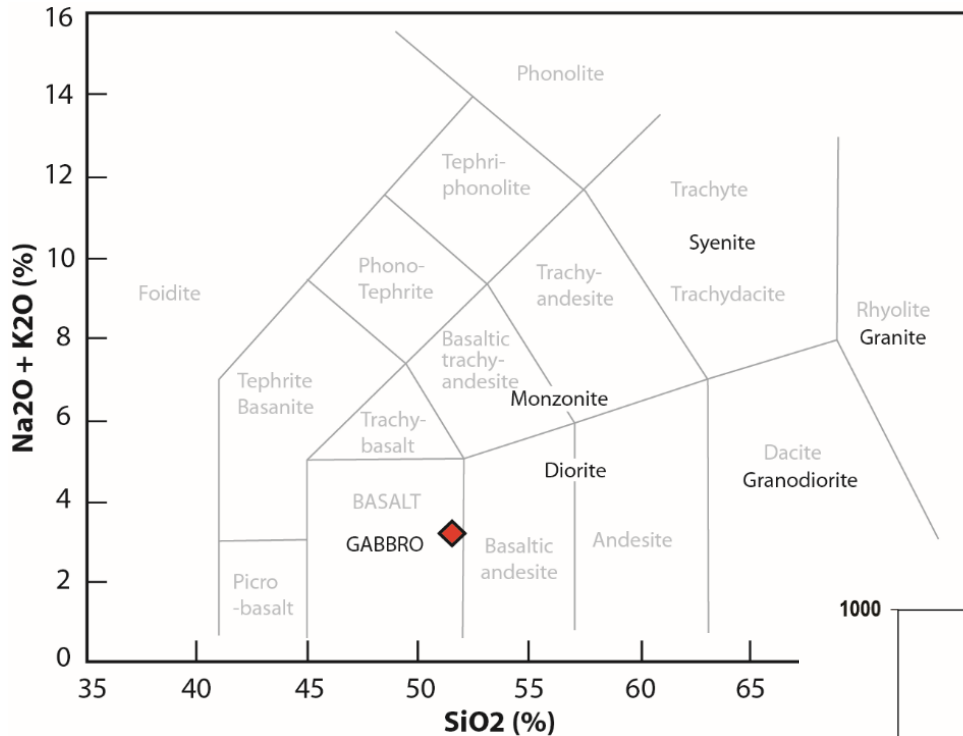
## Paragenèse 2:

- 7-9 kbar
- 450-600°C
- Synchronique de l'exhumation

# Géochimie

## Composition de basalte/gabbro

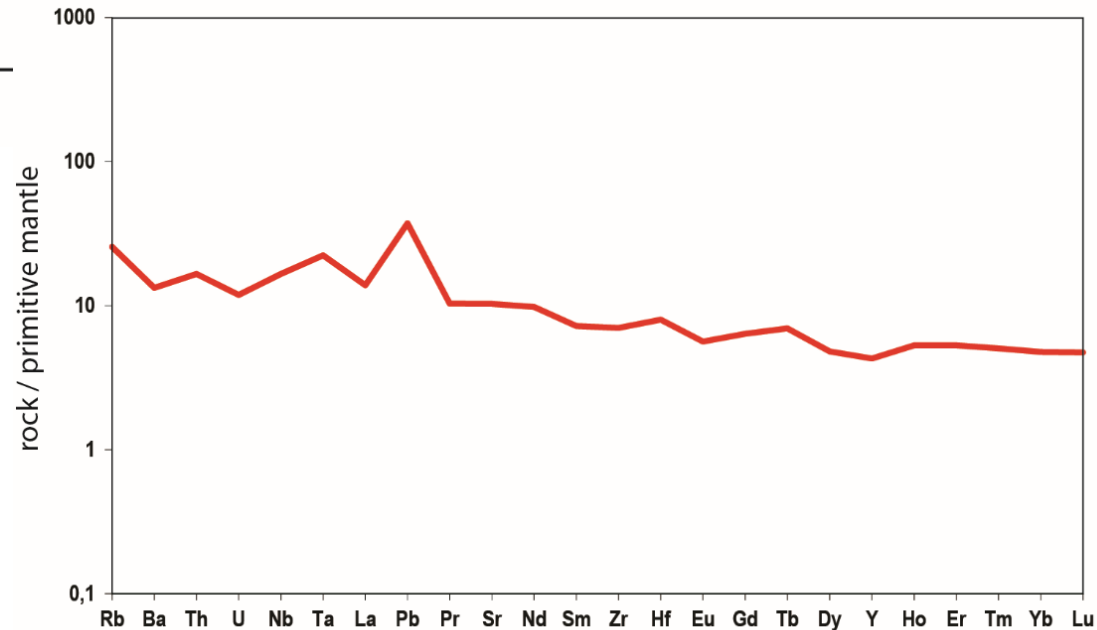
*François et al., 2018*



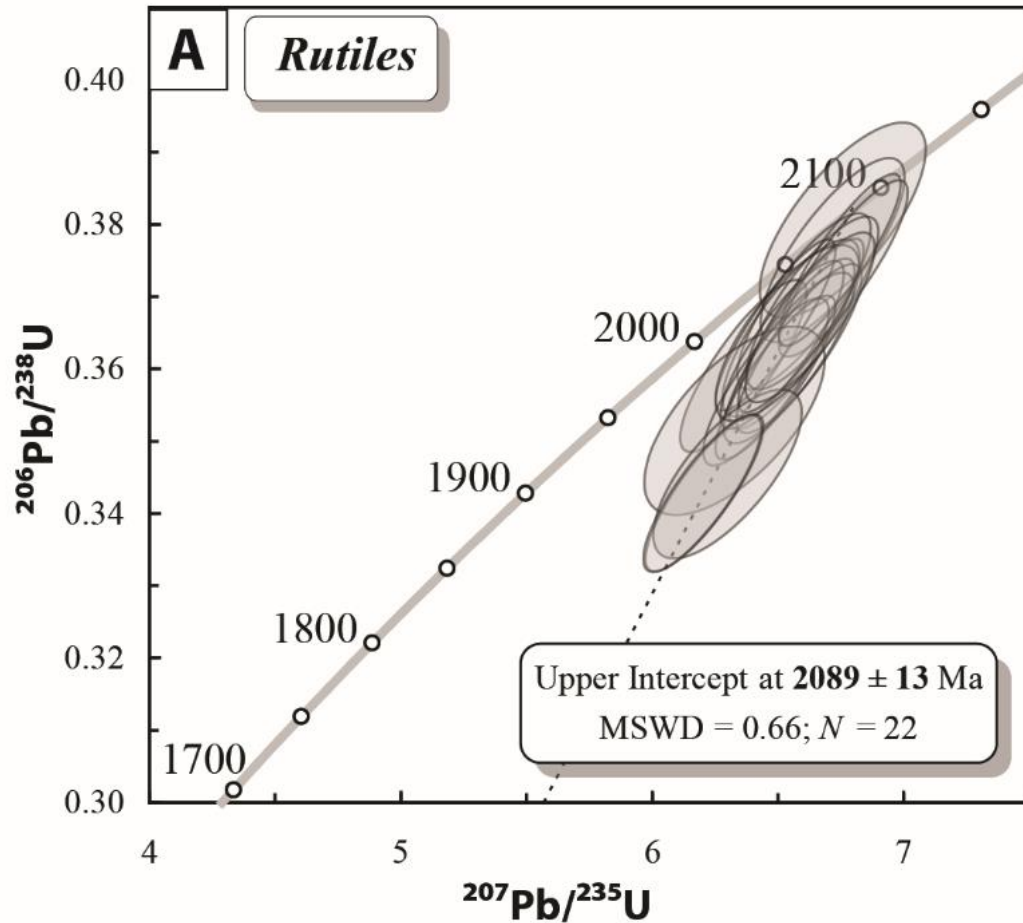
## Signature de T(transitional)-MORB :

Léger enrichissement en éléments incompatibles + immobile (Zr, Nb et Y)

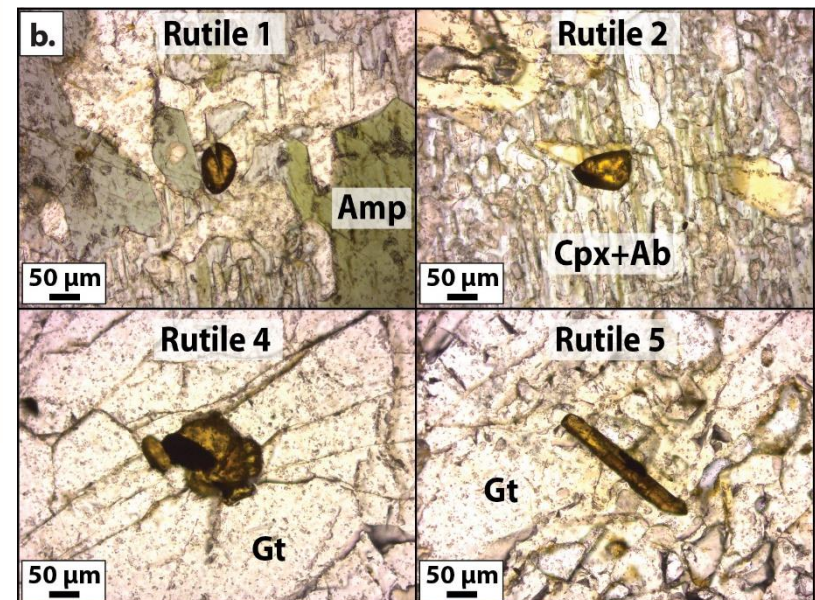
- Contamination crustale
- **Contexte géodynamique de transition entre rifting et dorsale**



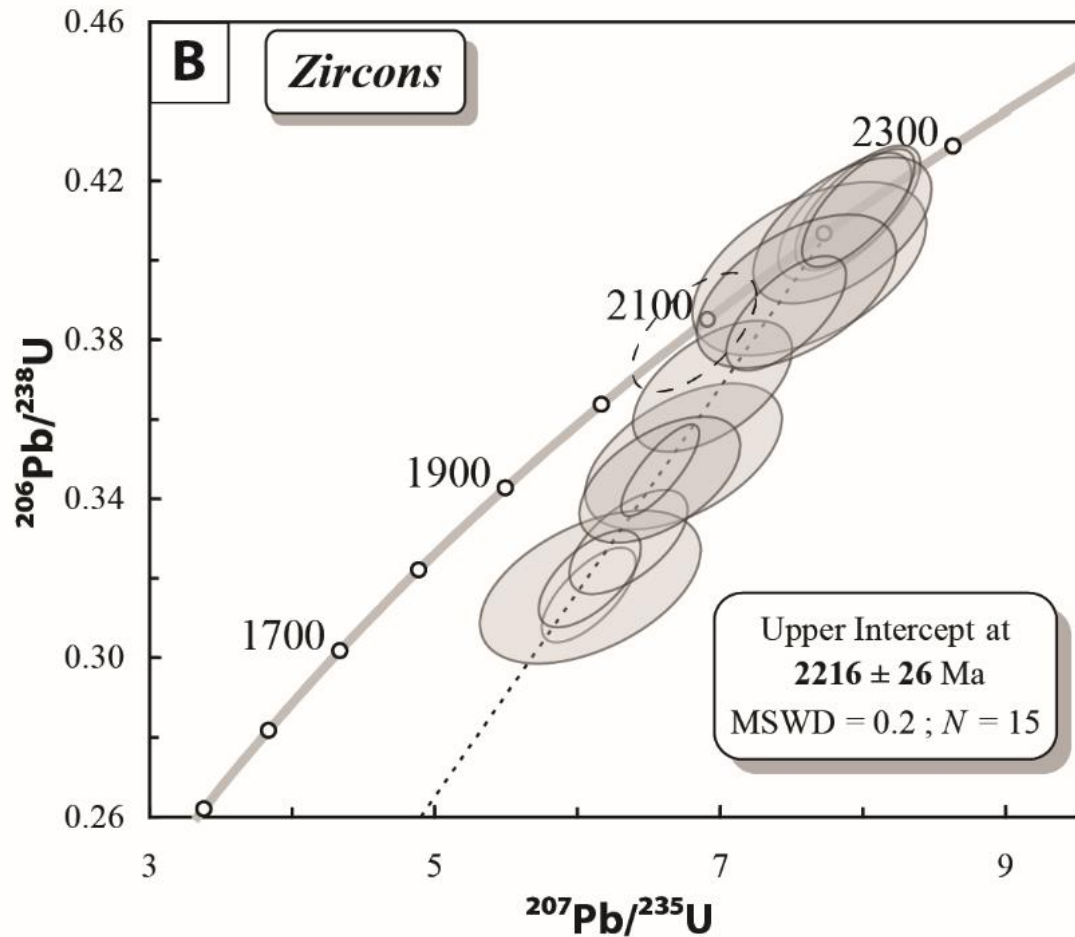
# Datations U-Pb



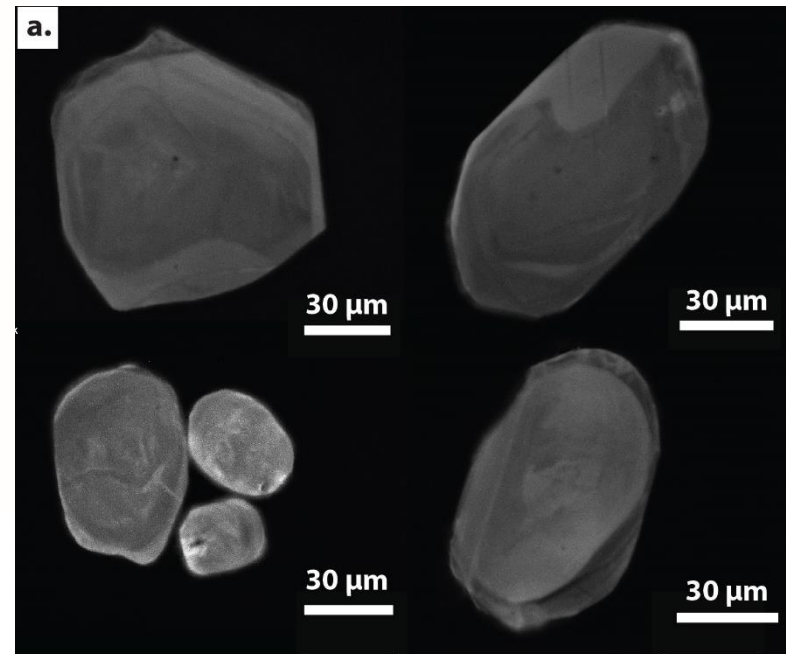
□ Rutiles métamorphiques:  
 **$2089 \pm 13$  Ma (âge des éclogites)**



# Datations U-Pb



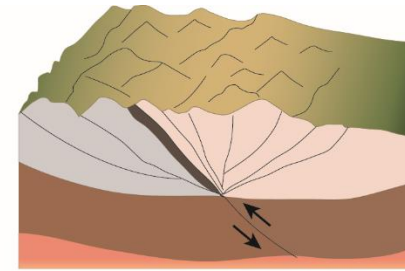
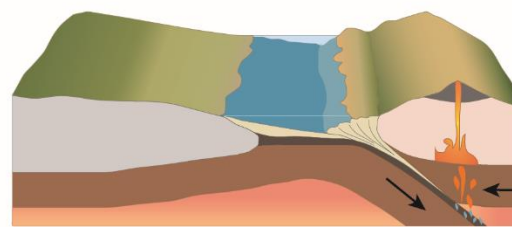
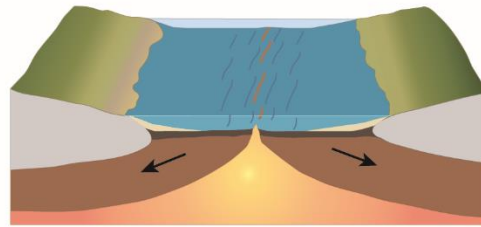
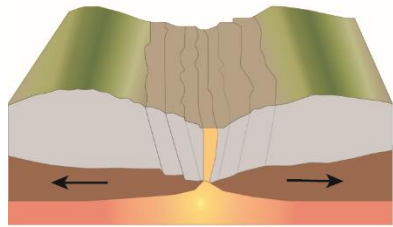
- Zircons hérités provenant du protolithe (gabbro):  
 **$2216 \pm 26$  Ma**



# Un cycle de Wilson Paléoprotérozoïque

RIFTING

SUBDUCTION



2216 Ma

2089 Ma



GABBRO

~130 Ma

HP-BT ECLOGITE

- Cette éclogite derive d'un **protolithe gabbroïque** avec une signature de T-MORB, formé à **2216 Ma** dans un bassin **intra-cratonique** dans le craton du Congo, puis a été enfoui à **HP-BT** durant **la subduction et exhumée** le tout dans un **cycle > 130 Ma**.

# Implications pour les processus géodynamiques anciens

- 1ère évidence d'un **cycle de Wilson au Paléoproterozoïque** comprenant une subduction de HP-BT
- Cela met en évidence que la **tectonique des plaques moderne était fonctionnelle depuis au moins le Paleoproterozoïque (ca. 2.2-2.1 Ga)** comme mis en évidences par cette subduction froide et profonde (> 65 km)



# Remerciements:



<https://ccgm.org/fr/16-tous-nos-produits>

