Fusion partielle, granites et migmatites

la dynamique des croûtes chaudes archéennes

Jean-François Moyen

Avec des idées empruntées à

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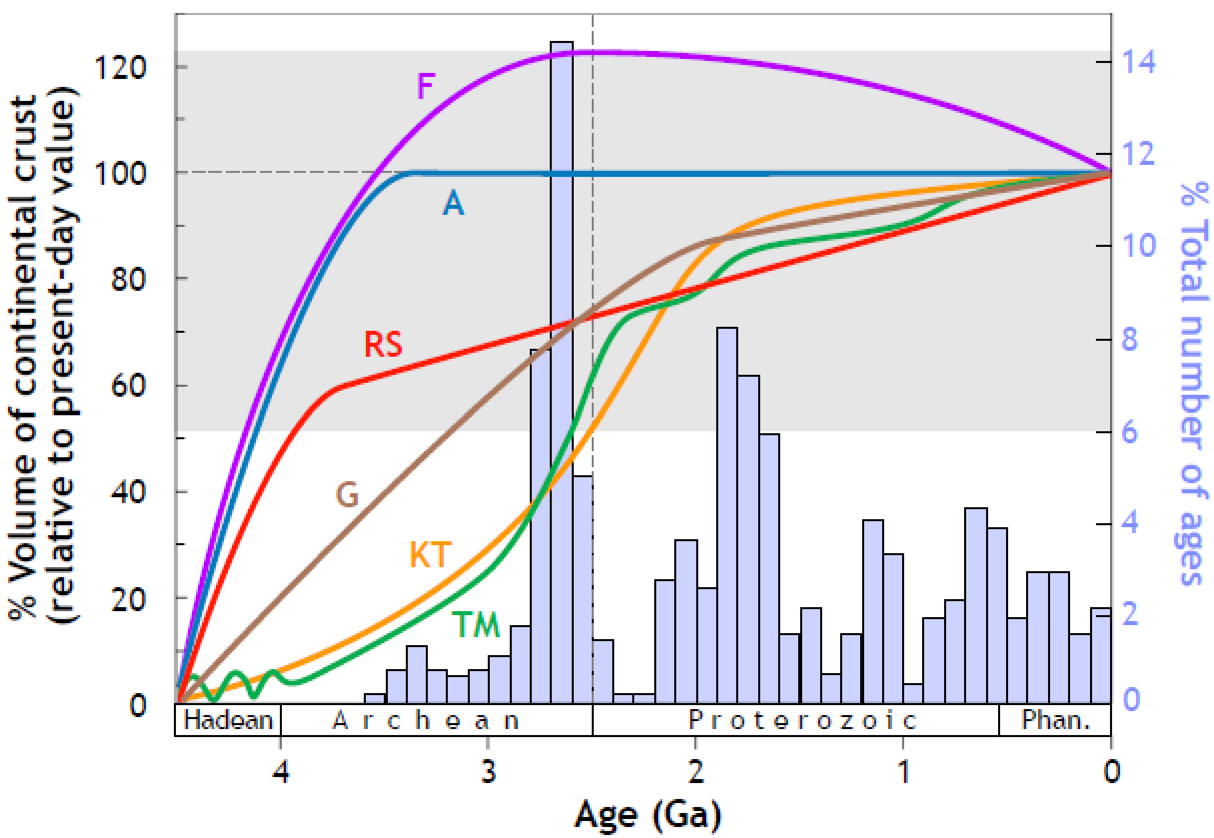
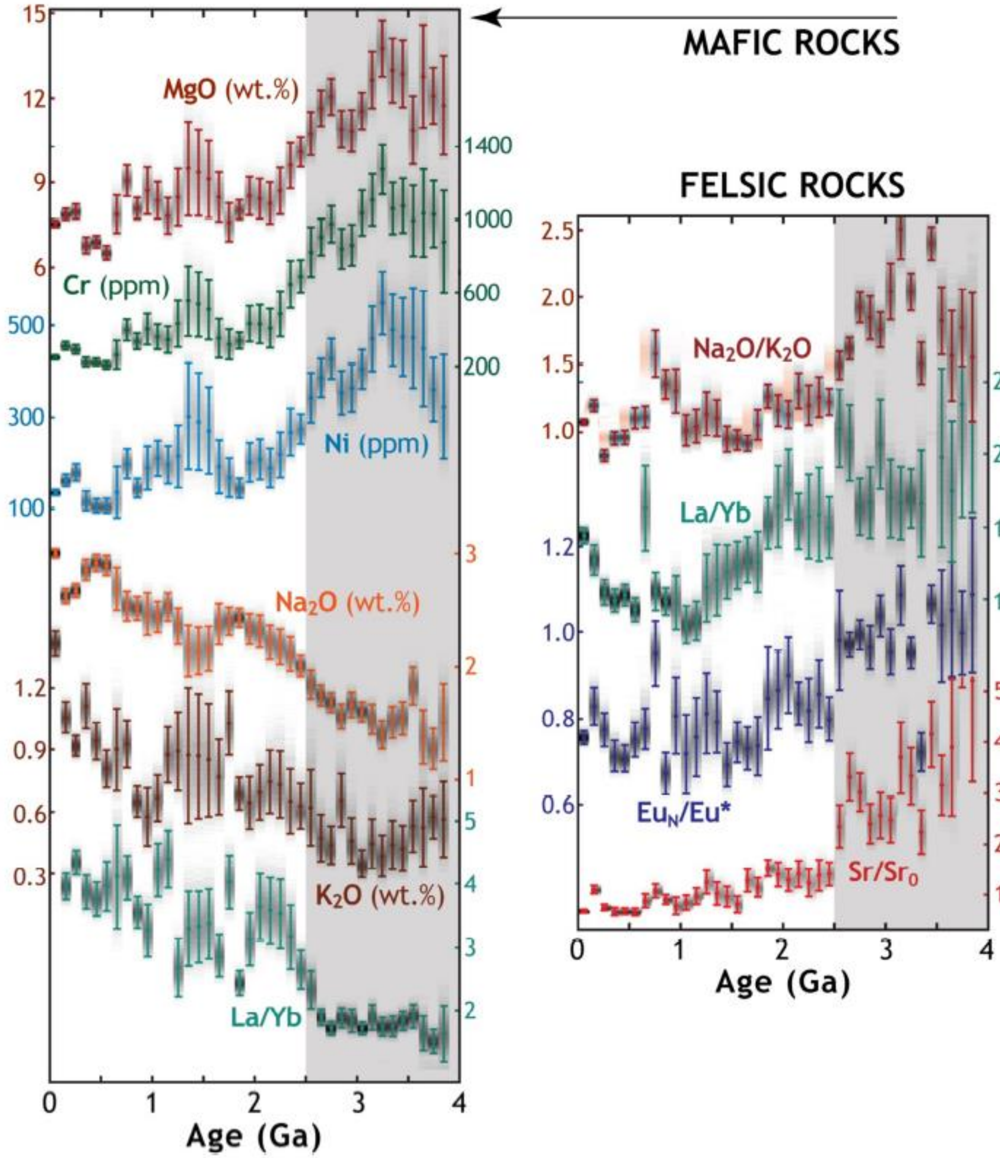
De quoi ça parle?

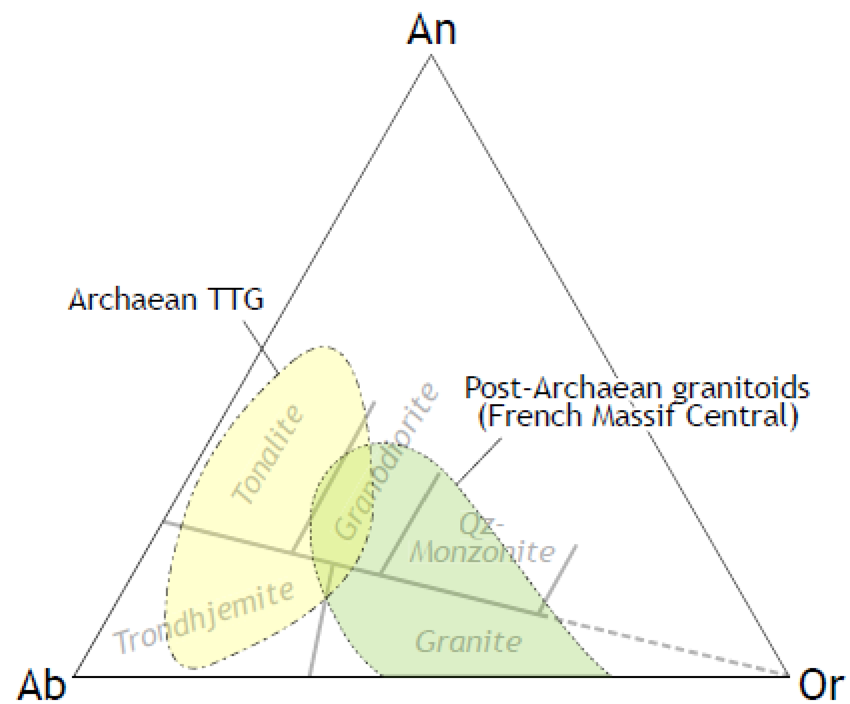
- Les granitoïdes et la construction de la croûte archéenne
- Que nous dit la géochimie des granitoïdes?
- Les granitoïdes comme marqueurs de la dynamique de la croûte
- Un peu de géodynamique

La croûte continentale est surtout Archéenne

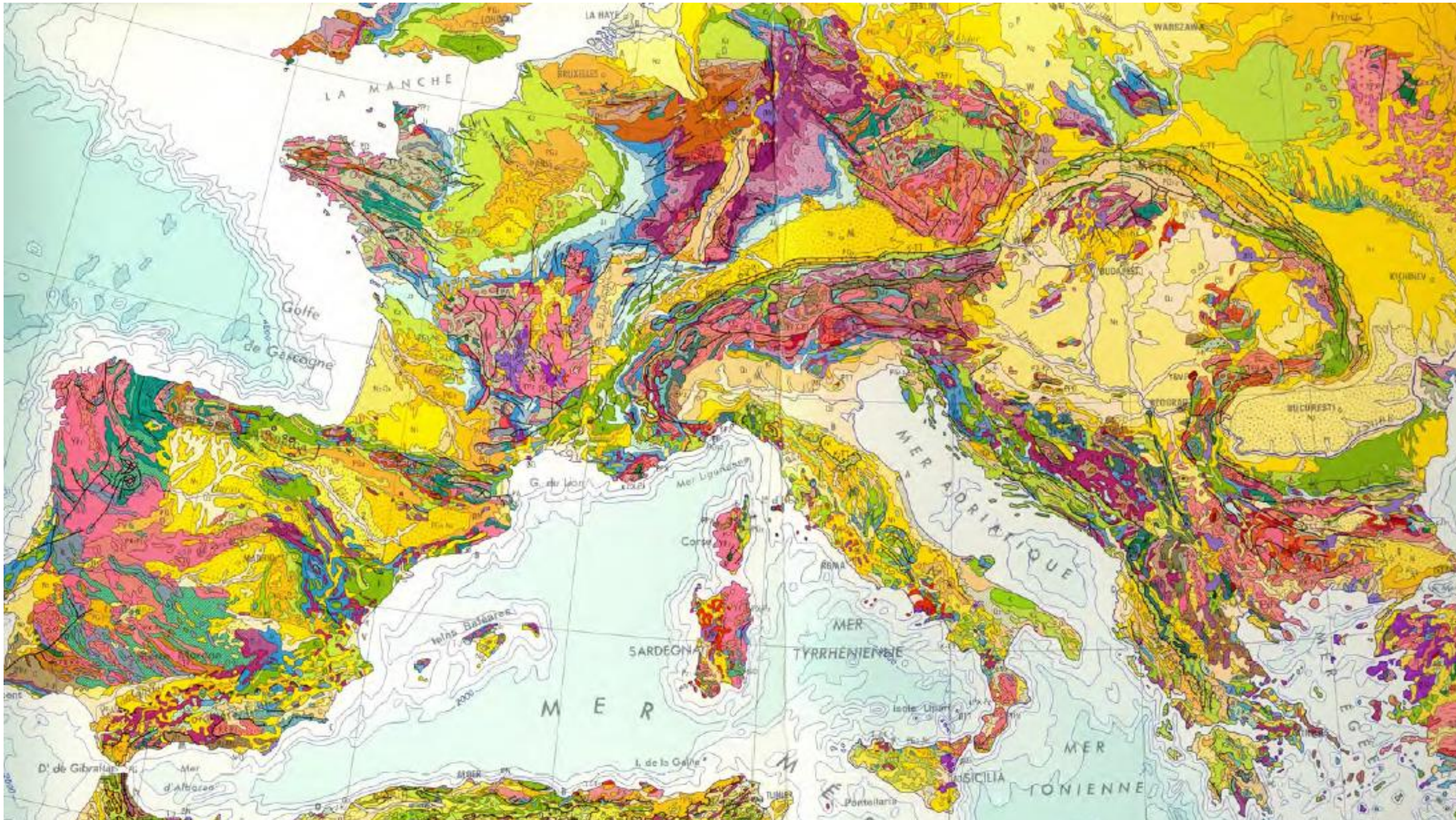


La CC archéenne est différente de la CC moderne

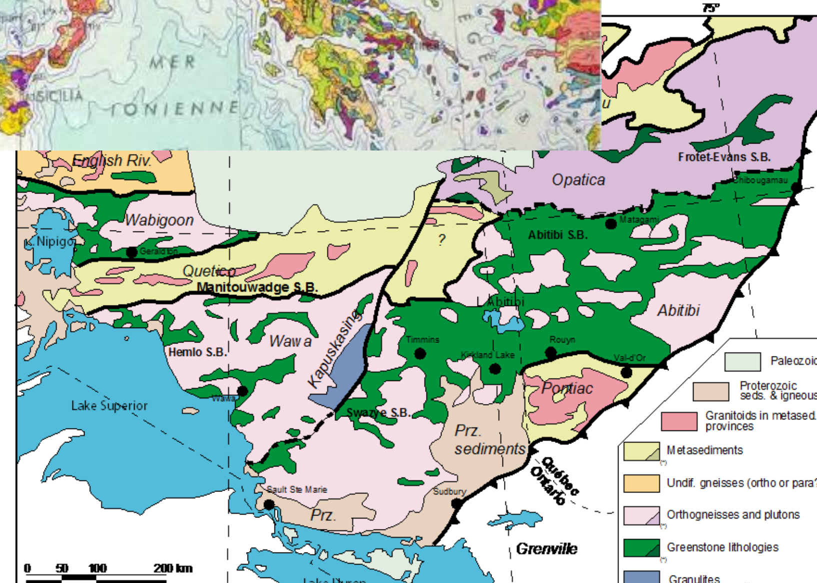




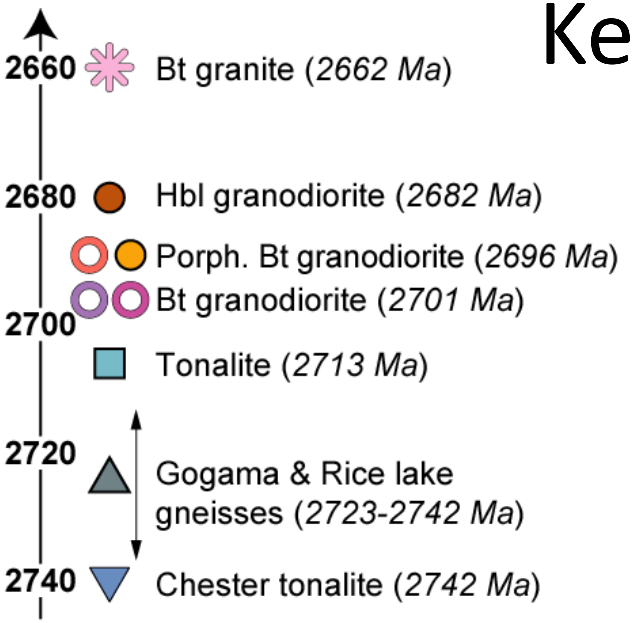
... et les granites aussi !

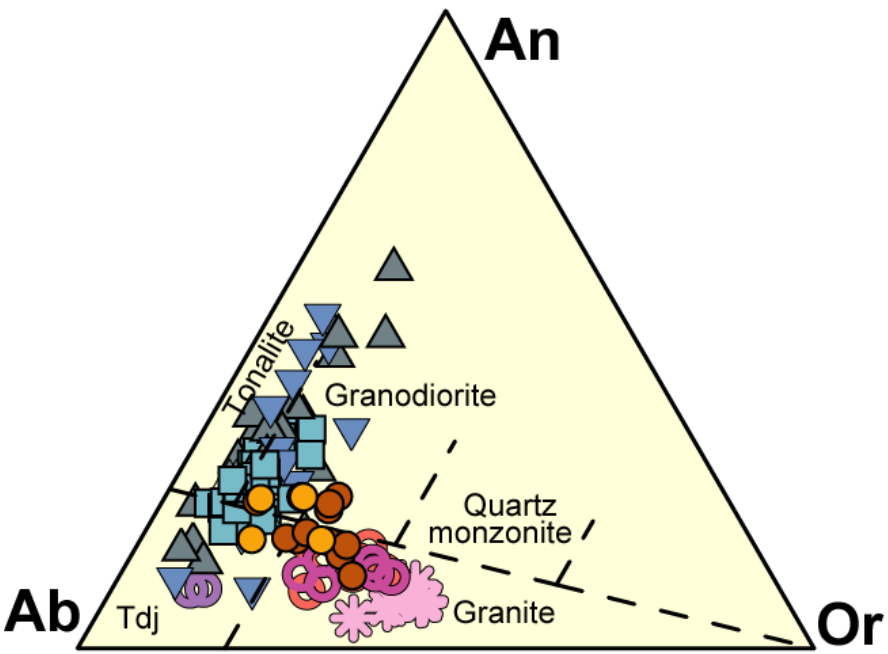


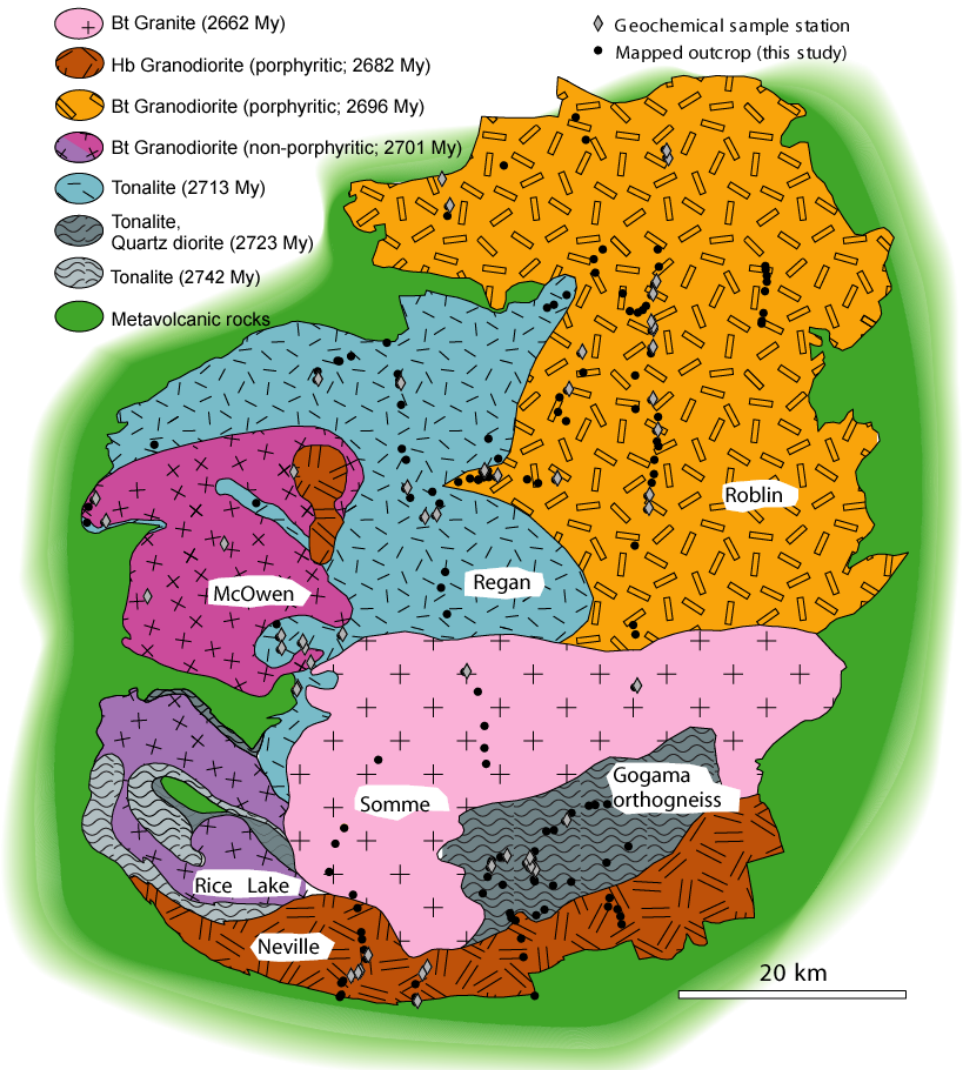
Proto-croûte
Vs.
Croûte felsique évoluée



Evolution progressive de la crt : Kenogamissi complex







Benn & Moyen 2008 (GSA Spec.Pub. 440 in press)

Archaean geology: the basic question

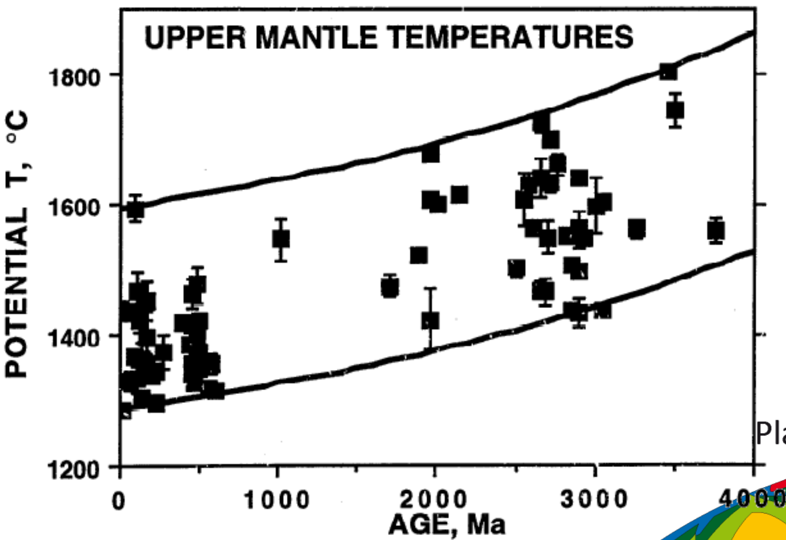
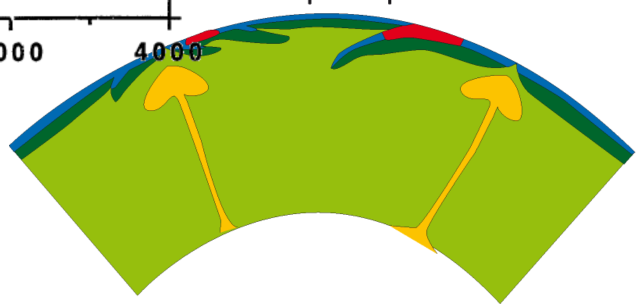


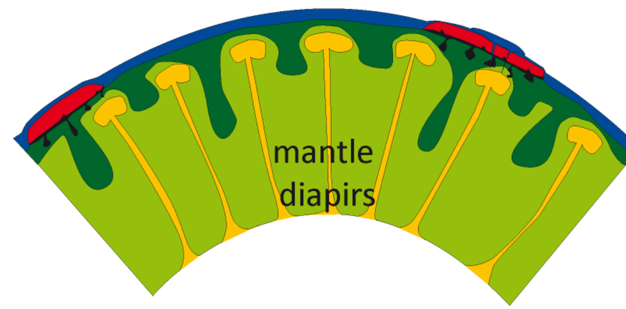
Plate tectonics or not in the hotter Archaean mantle ?

Archaean Geodynamics

Platelets-protoplates

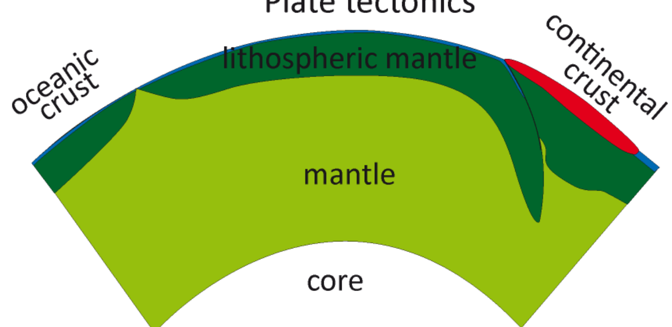


Stagnant lithospheric lid

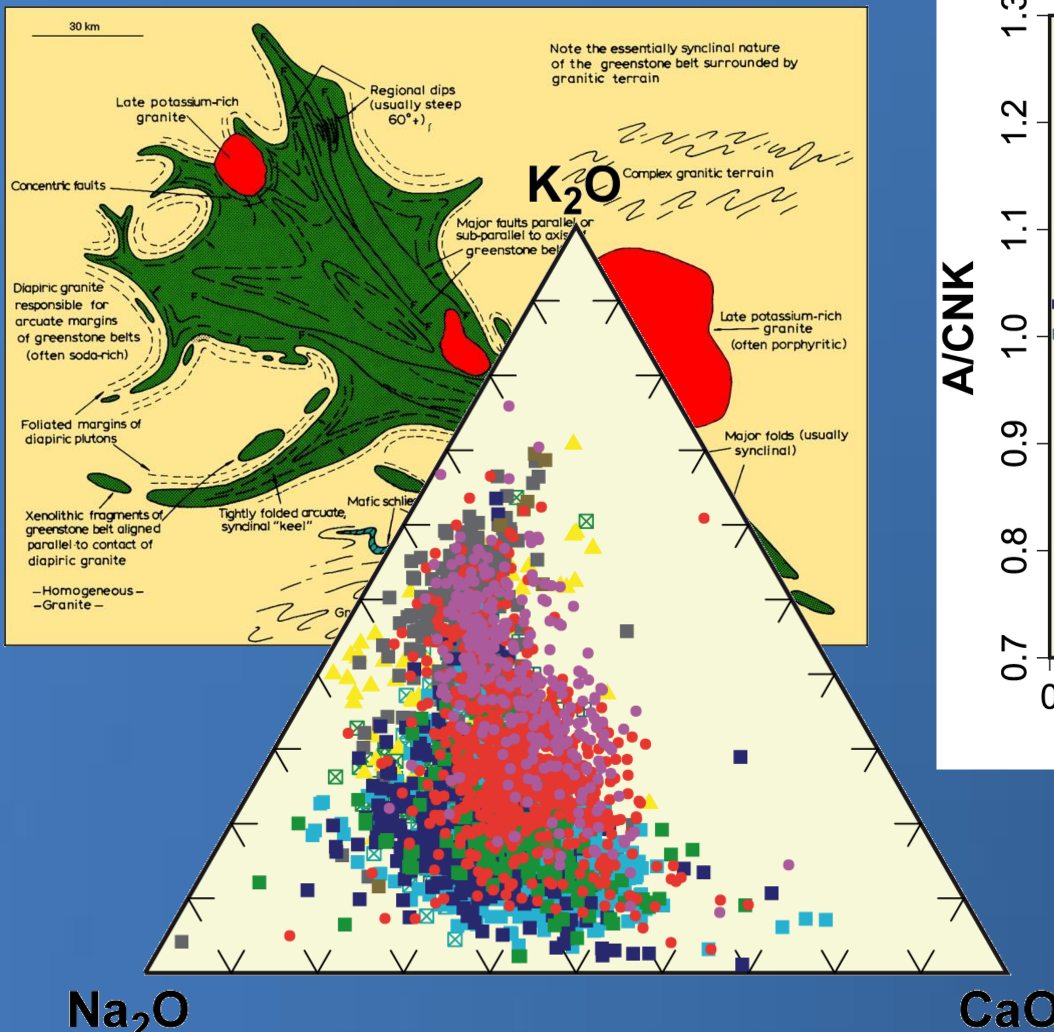


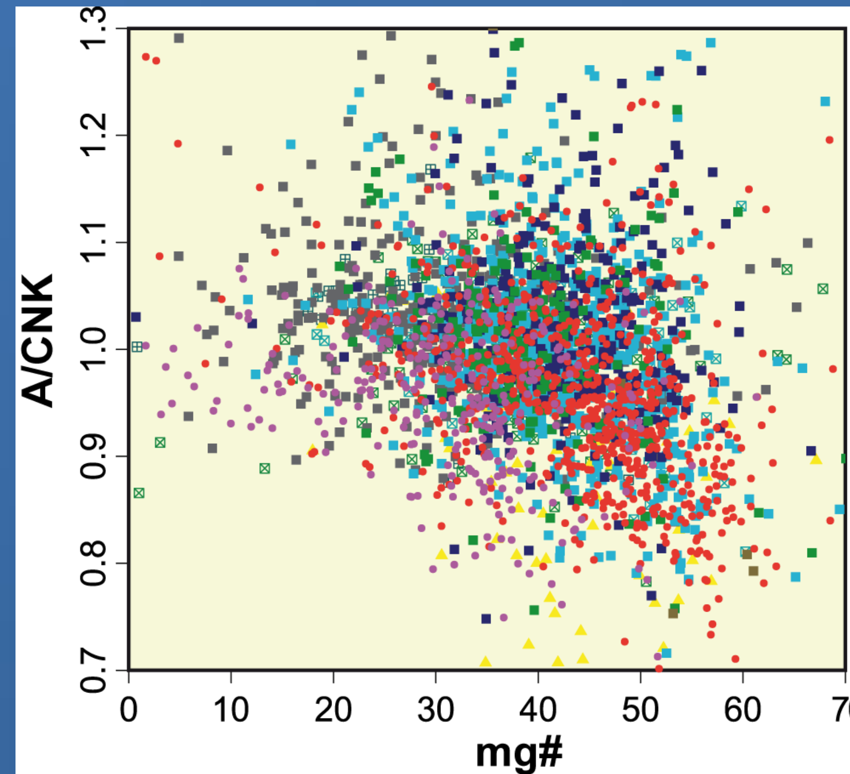
Phanerozoic Geodynamics

Plate tectonics



Géochimie des granites Archéens

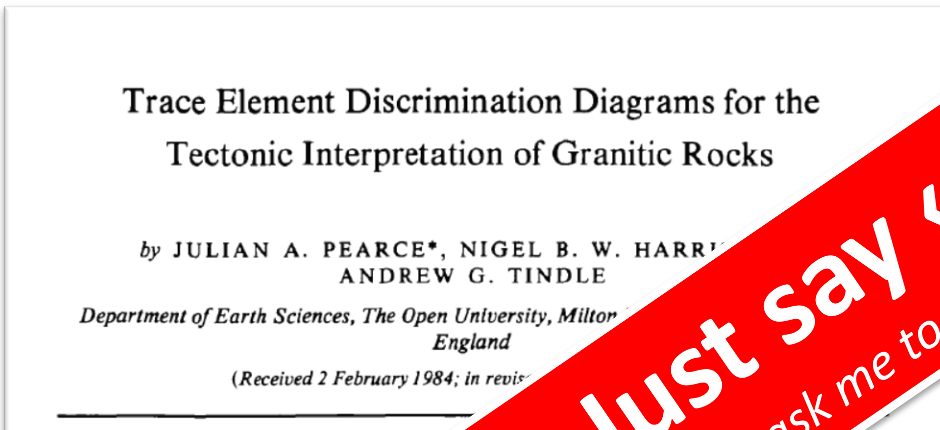




$SiO_2 > 60\%$

N ≈ 3000

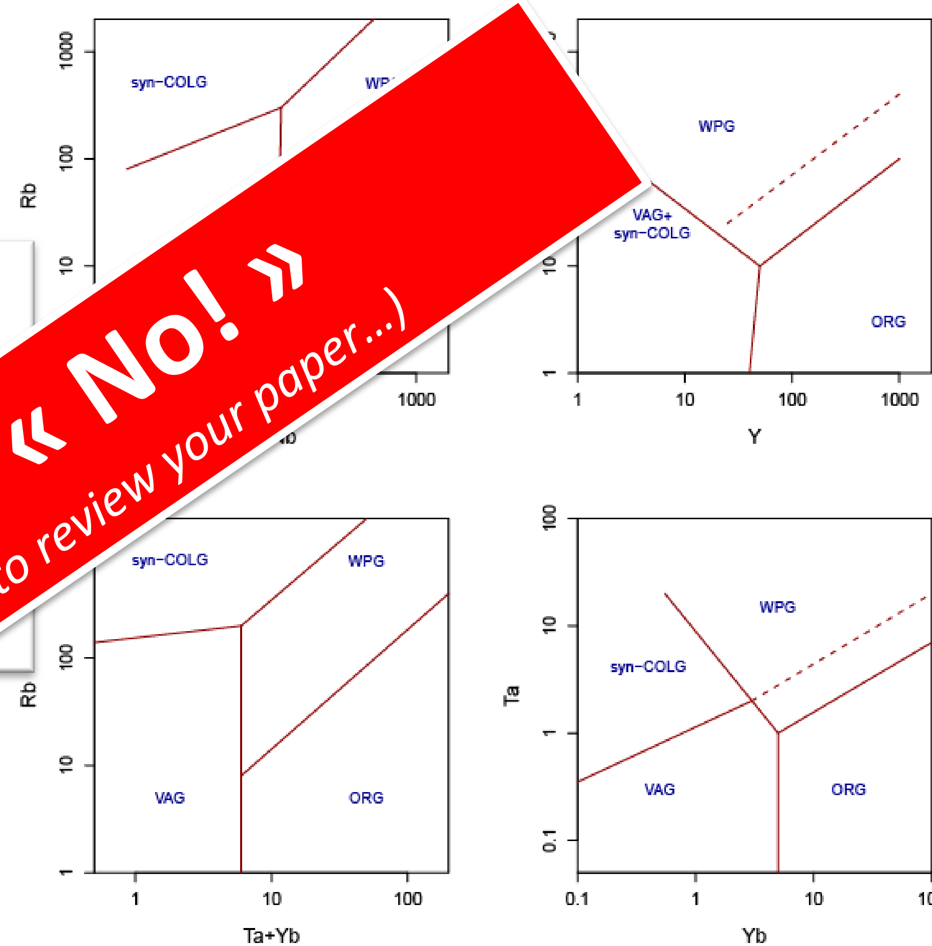
A common approach:
« tectonic discrimination »


Trace Element Discrimination Diagrams for the Tectonic Interpretation of Granitic Rocks

by JULIAN A. PEARCE*, NIGEL B. W. HARR
ANDREW G. TINDLE

Department of Earth Sciences, The Open University, Milton
England

(*Received 2 February 1984; in revis*



Just say « No! »

(or don't ask me to review your paper...)

What's wrong with geotectonic (« discriminant ») diagrams for (Archaean) granites?

1. They assume a finite, well-defined set of possible tectonic sites (e.g. no post-orogenic setting ?!)
2. They assume we know possible Archaean tectonic sites (!)
3. They do not tell anything you don't know before…
4. They do not work anyway (at least for complex settings)

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(*Received 2 February 1984; in revised form 19 April 1984*)

Post-collision granites

This group represents a major problem in all tectonic-geochemical classifications of granites. The probable reason is that, unlike granites from other settings, post-collision granites cannot be explained in terms of a single, well-defined mantle or crustal source. It has

Thus, at present, geological criteria and the zonation of intrusions are the best indicators of a post-orogenic setting. However, if the setting can be defined as 'post-collision' on *a priori*

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Age

Since the diagrams are based on analyses of Phanerozoic rocks they cannot automatically be applied to rocks of Precambrian age. In detail, the main differences between magma genesis in the Archaean and at the present day are likely to be:

(i) The mantle evolution line in Fig. 5*a* will be displaced to higher Rb values, and very slightly higher (Y + Nb) values.
(ii) The degree of partial melting *may* be greater.
(iii) The mantle may be less fractionated than at the present-day so that generation of magmas from very enriched and very depleted sources would be less common.
(iv) Crustal melting *may* be more important in magma genesis in all environments.

The net effect on the diagrams should be to blur the syn-COLG/VAG discrimination and displace the (VAG + syn-COLG)/(WPG + ORG) boundary to lower values of Y, Yb, (Y + Nb) and (Yb + Ta). However, the precise effect cannot be known until further studies have been made on granites of varying ages.

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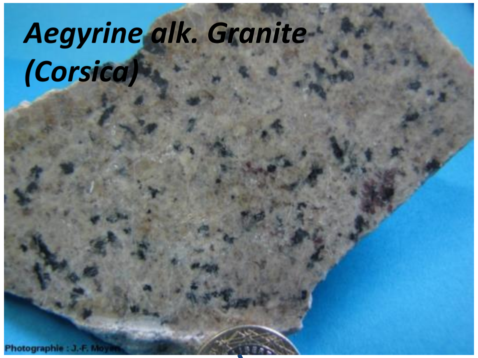

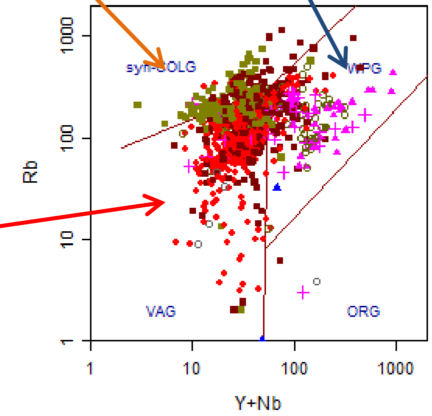

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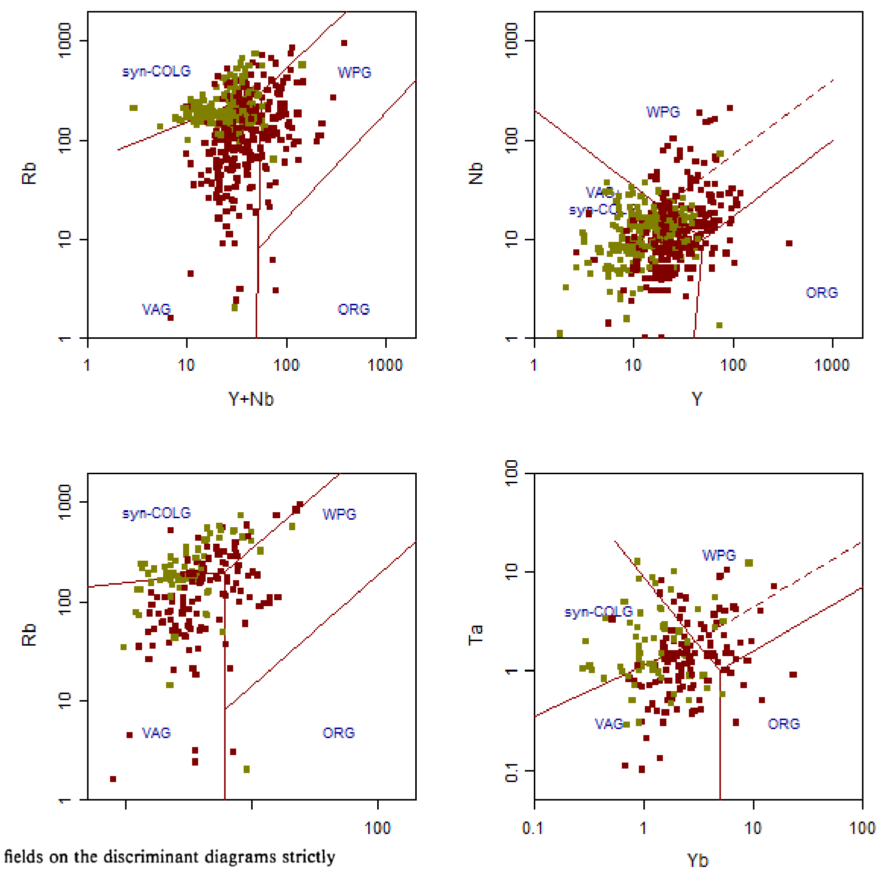
Granite tectonic discrimination – Pearce et al. (1984)



Complex tectonic regimes

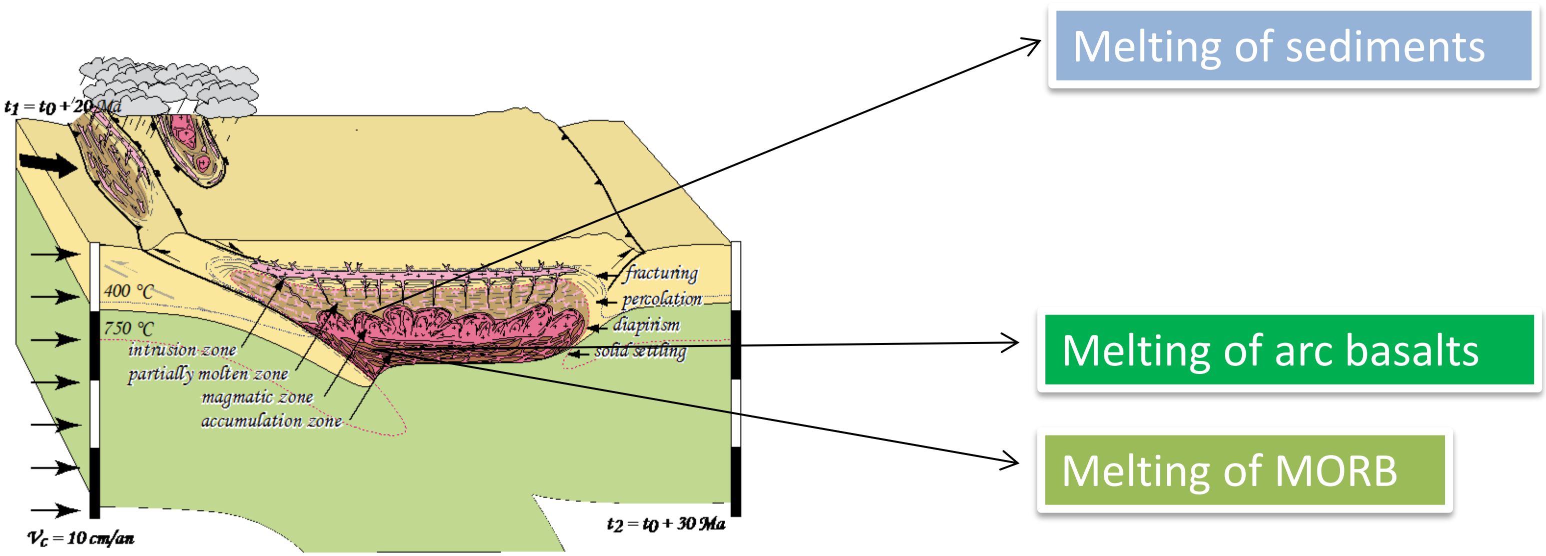
As we emphasized in the previous section, the fields on the discriminant diagrams strictly reflect source regions (and melting and crystallization histories) rather than tectonic regimes. For syn-COL, VA, 'normal' OR and WP granites source regions and tectonic regimes show a clear correlation. However, post-COL granites can plot in the syn-COLG, VAG or WPG fields and OR granites can plot in the VAG or ORG fields according to their precise setting. Thus, the discrimination is not perfect between *all* groups and interpretations must be made with this caveat in mind.

A further cause for caution concerns the complex nature, not only of collision settings, but of many apparently simple tectonic regimes. We have already pointed out, for example, that

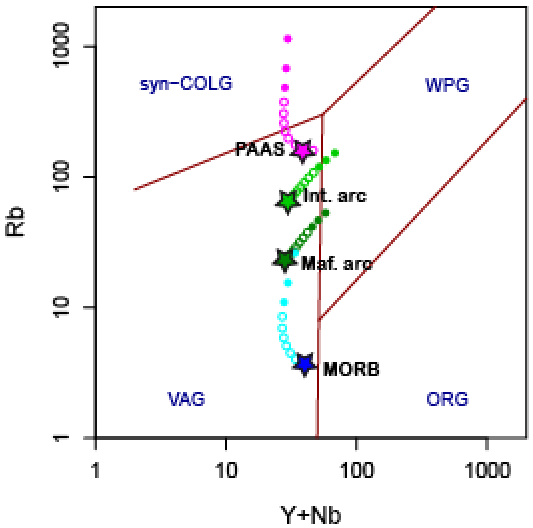
So, what can we do ?

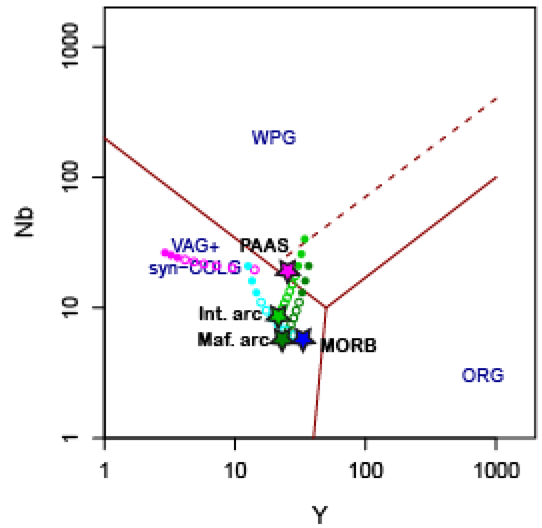
- Remember that

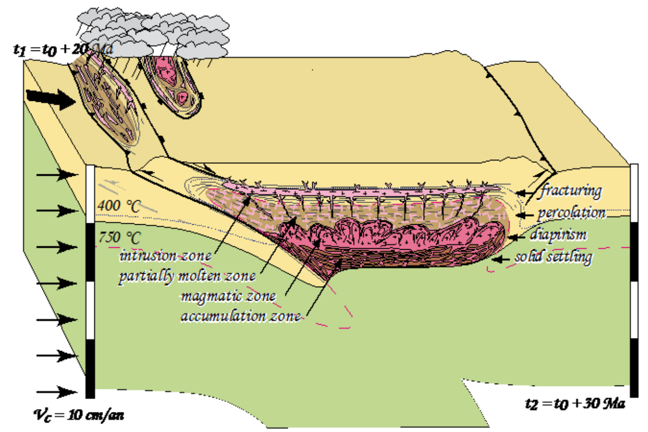
$$C_l = \frac{C_0}{F + D\,(1 - F)}$$

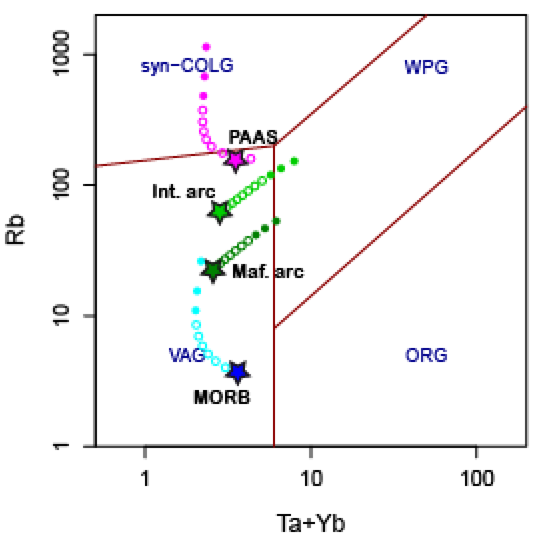


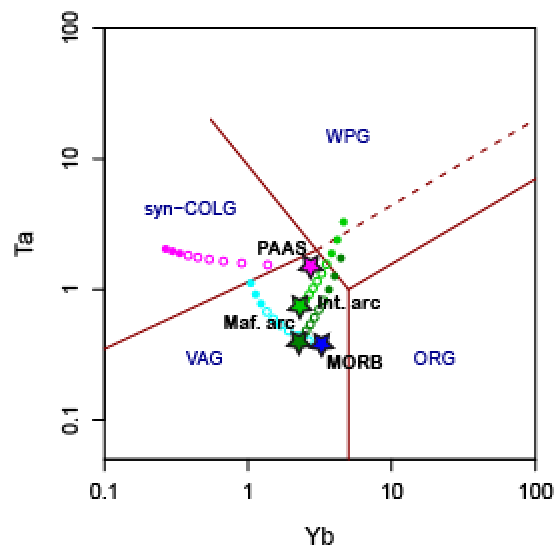
Apparently different tectonic sites!





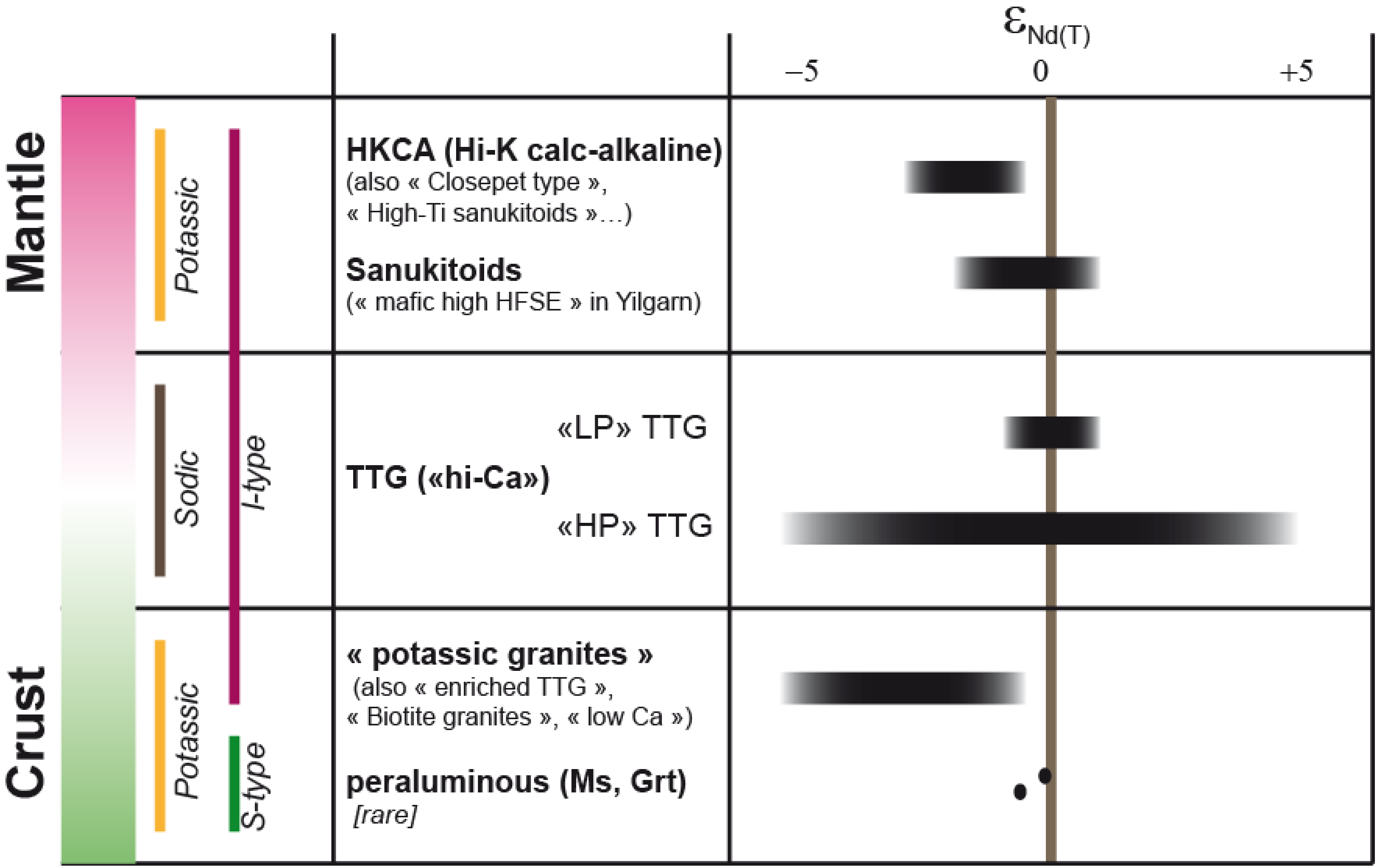




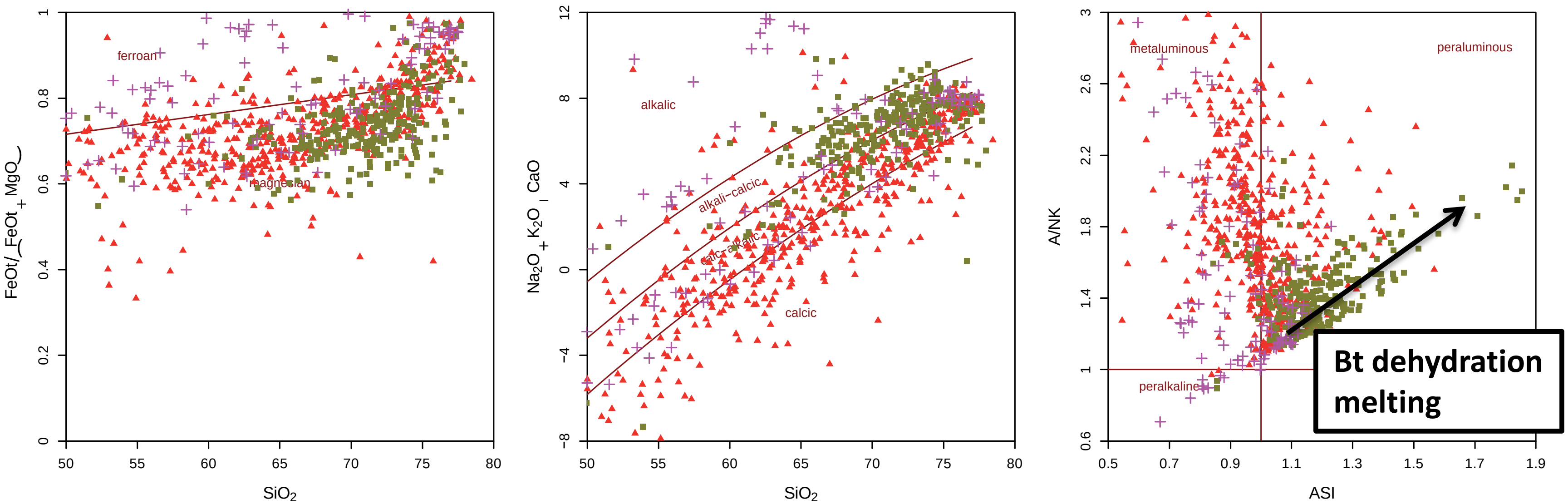


But, of course, everything happens in the same place (= same setting…)

Types of Archaean granites



Modern (phanerozoic) granites



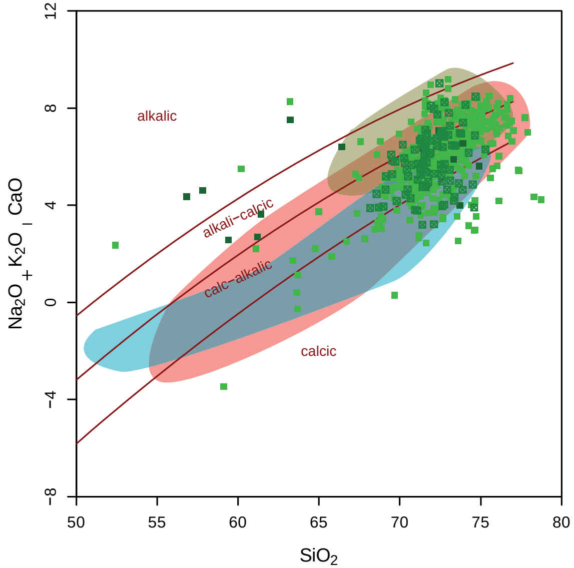
Frost et al 2001 (J. Pet)

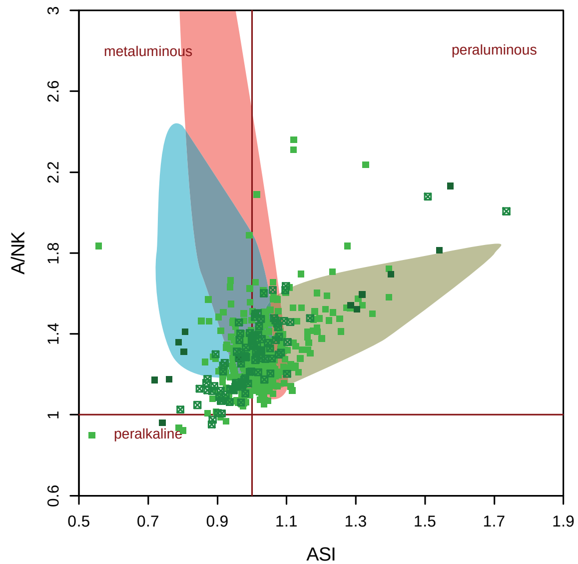
ASI = A/CNK
Molar Al_2O_3/ $CaO + Na_2O + K_2O$
A/NK
Molar Al_2O_3/ $Na_2O + K_2O$
(Fsp stoechiometry)

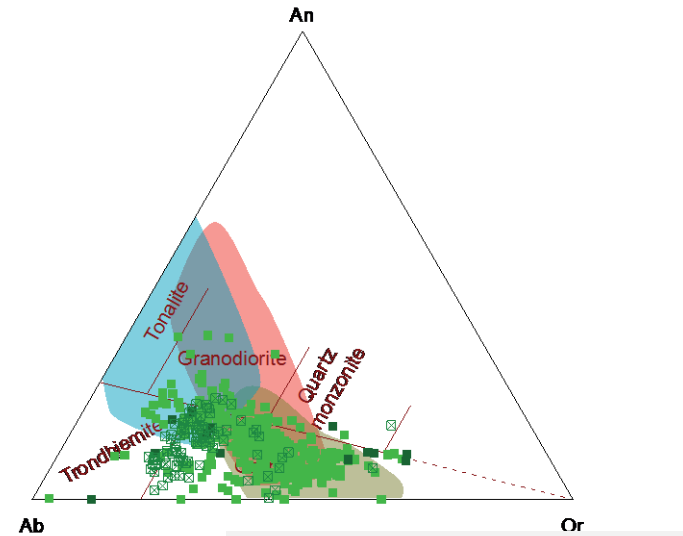
- « Crustal » (collision) granites show short trends (no intermediate/mafic rocks associated)
- Very distinctive behaviour in A/CNK vs. A/NK (cst Ca)

→ Fundamental difference in petro. behaviour between both types!

Some Archaean granites are comparable to modern

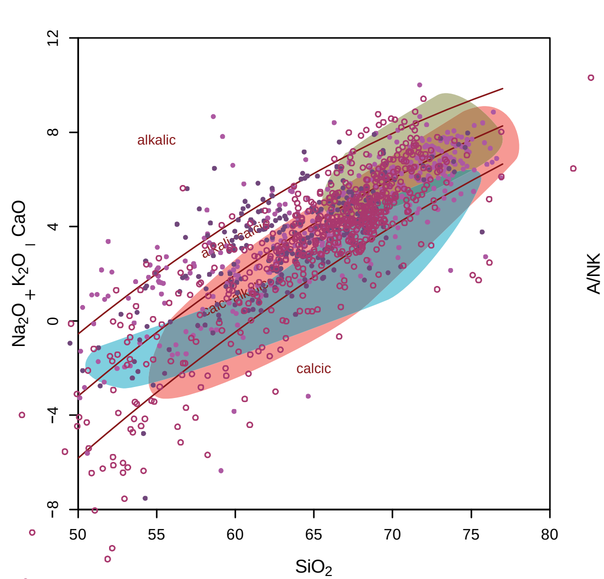


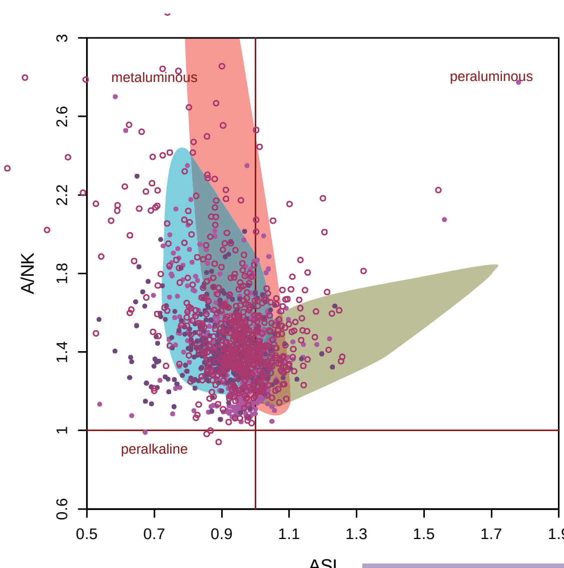


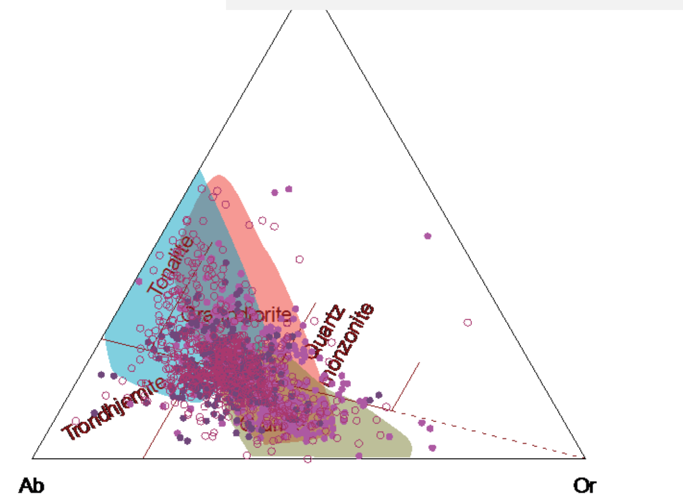


Crustal granites and collisions

Fields:
Brown- collision
Red- Active margin/post coll
Blue- Oceanic plateau/ridge

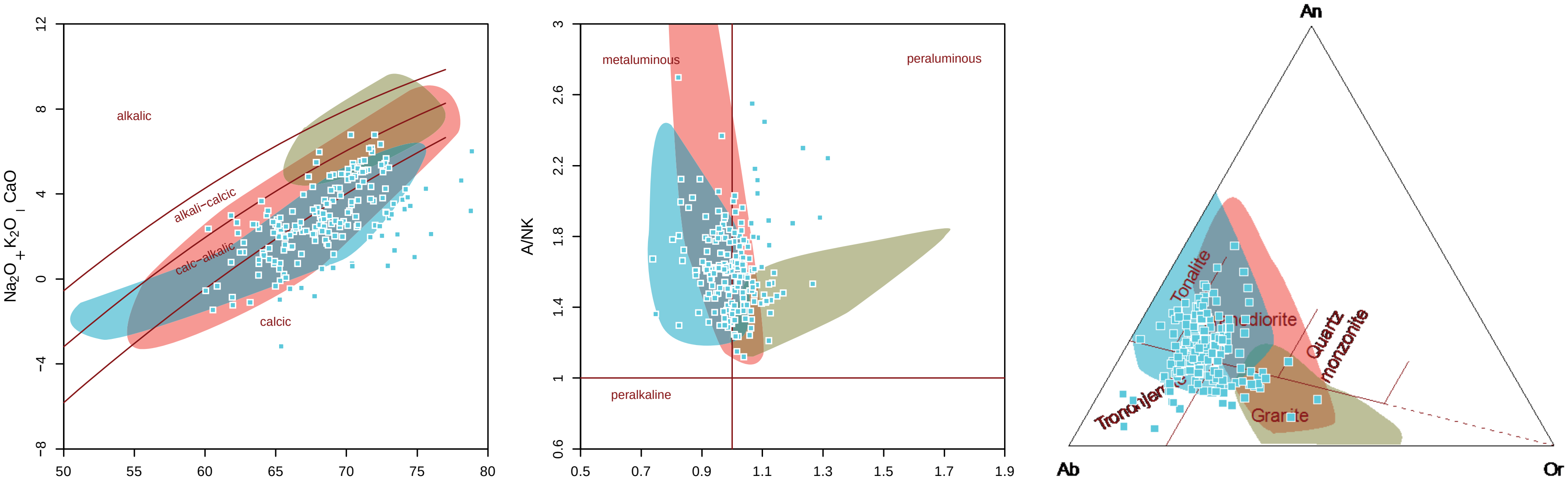






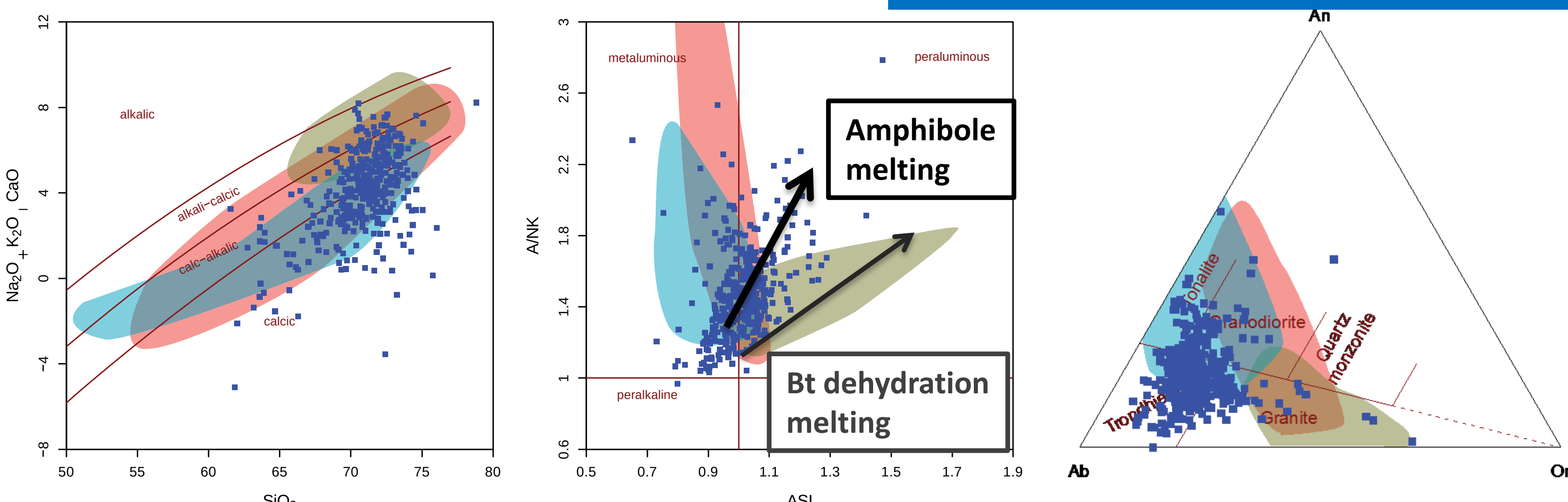
Mantle (HKCA, sanukitoids) and post-collision

No real equivalent for TTGs



« low pressure » (ca. 10 kbar evolution) TTGs and oceanic plateaus/ridges

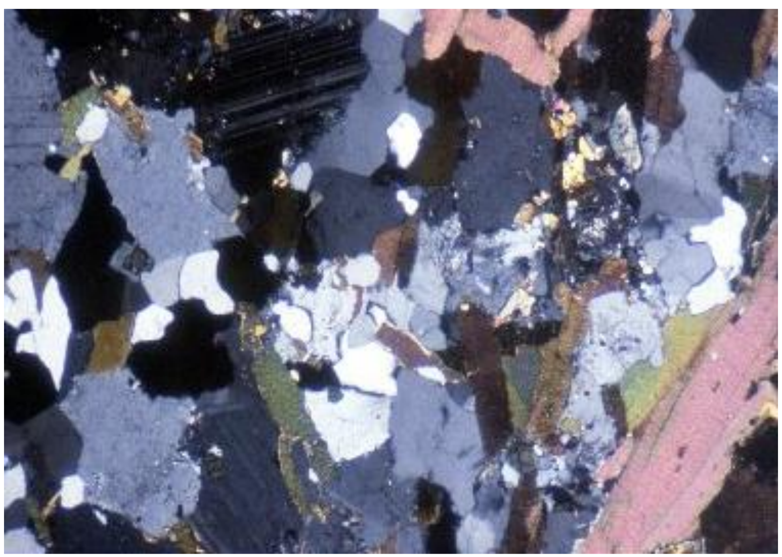
« high pressure » TTGs (20 kbar) and ???

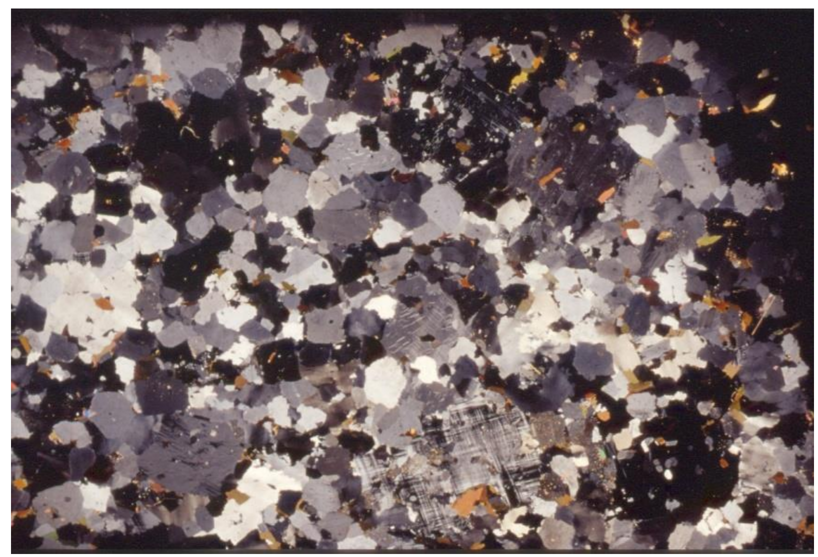


« Crust » vs. « Mantle » granites

Mantle origin	Crust origin
Comagmatic microgranular mafic enclaves (MME) ubiquitous	MME rare
Generally Hornblende bearing	Hornblende rare
Generally potassic	Potassic or sodic
Often K-feldspar porphyritic	Variable, more frequently equigranular
Syn to post tectonic	Variable from pre to post tectonic
Little zircon inheritance	Significant zircon inheritance (old cores etc.)
Relatively low A/CNK negative slope in Shand diagram	Relatively high A/CNK positive slope in Shand diagram
Relatively high mg#	Relatively low mg#

Archaean C-type granites

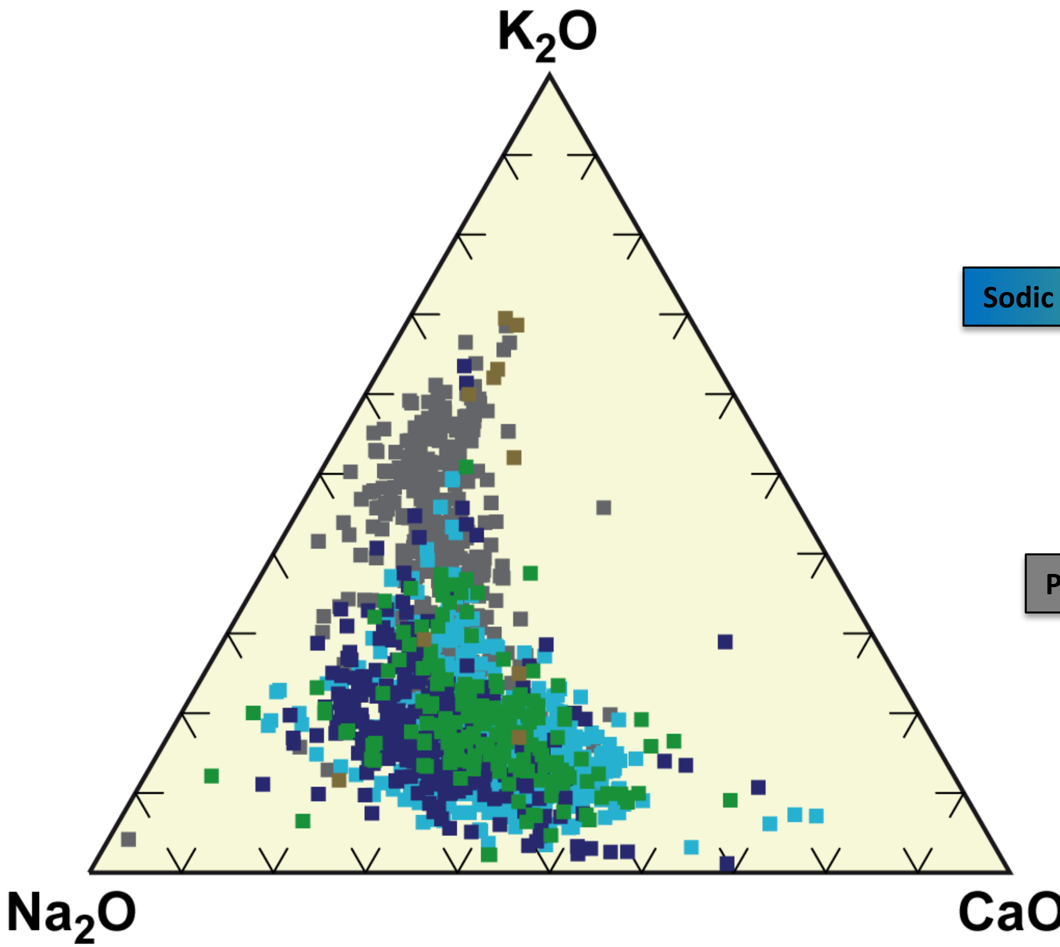




Pg + Qz + Bt (± amp, Ep)

Pg + Qz + Bt + KSp

C-types compositions



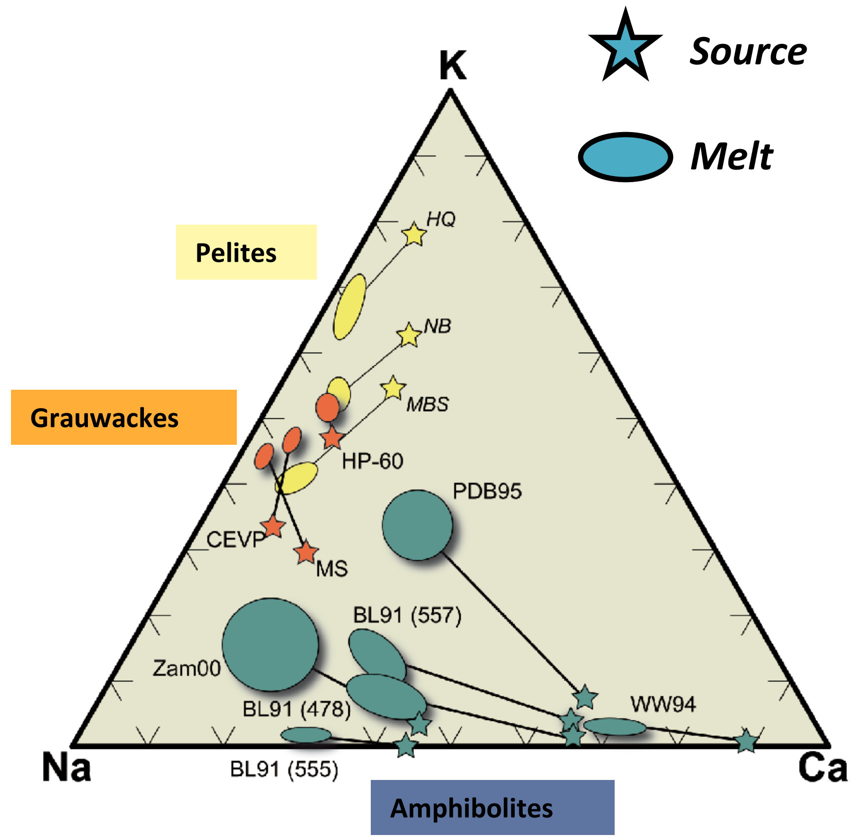
Sodic C-type (TTGs)

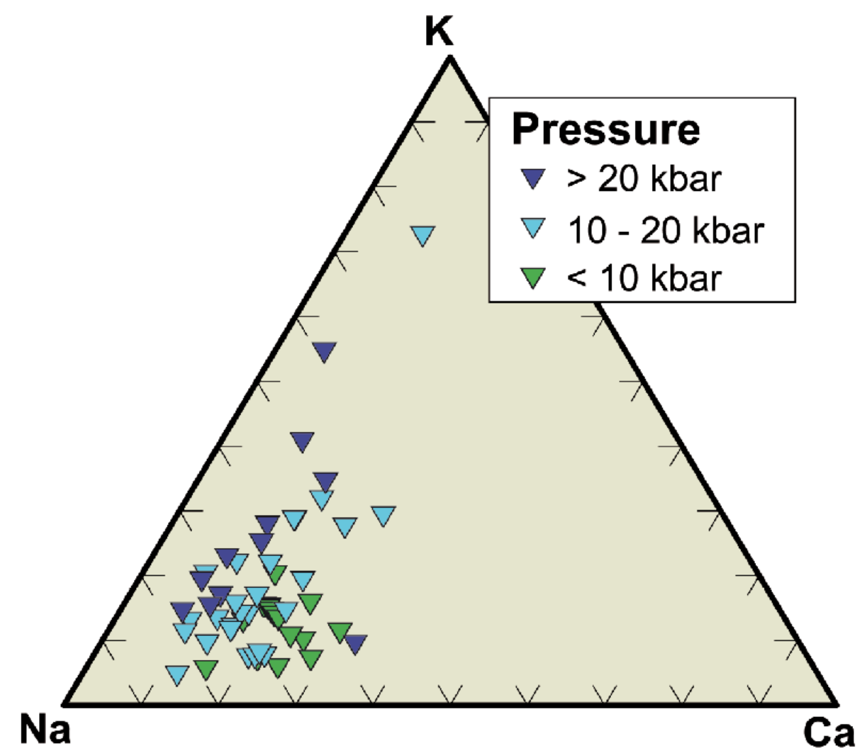
End-members of a continuum?

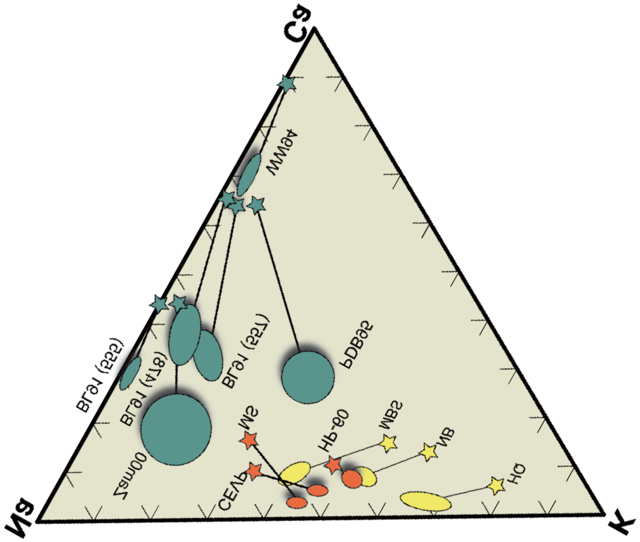
Potassic C-types

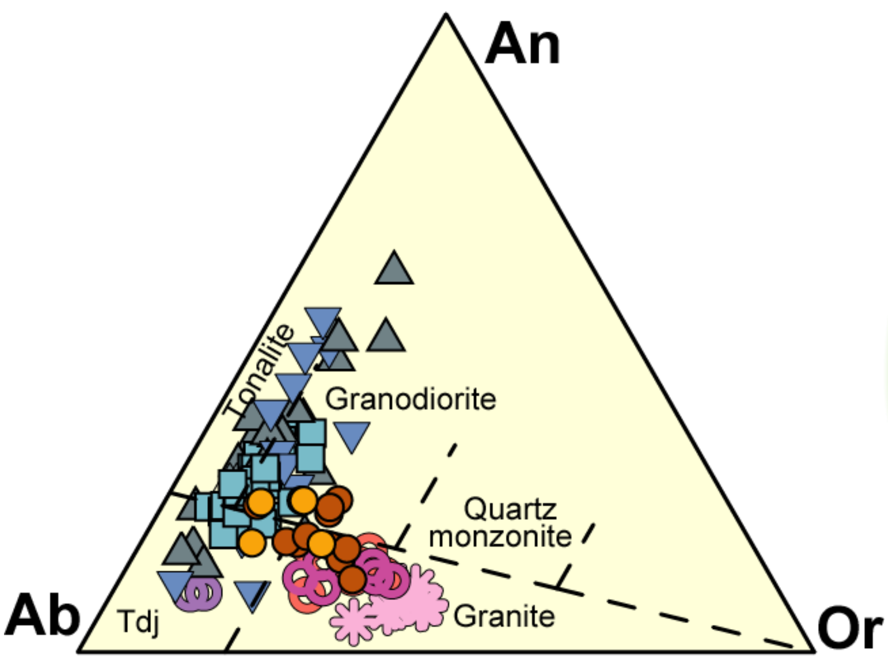
Experimental melts and C-type granites

- Effect of different sources
- Effect of pressure (same source: Zamora, 2000)

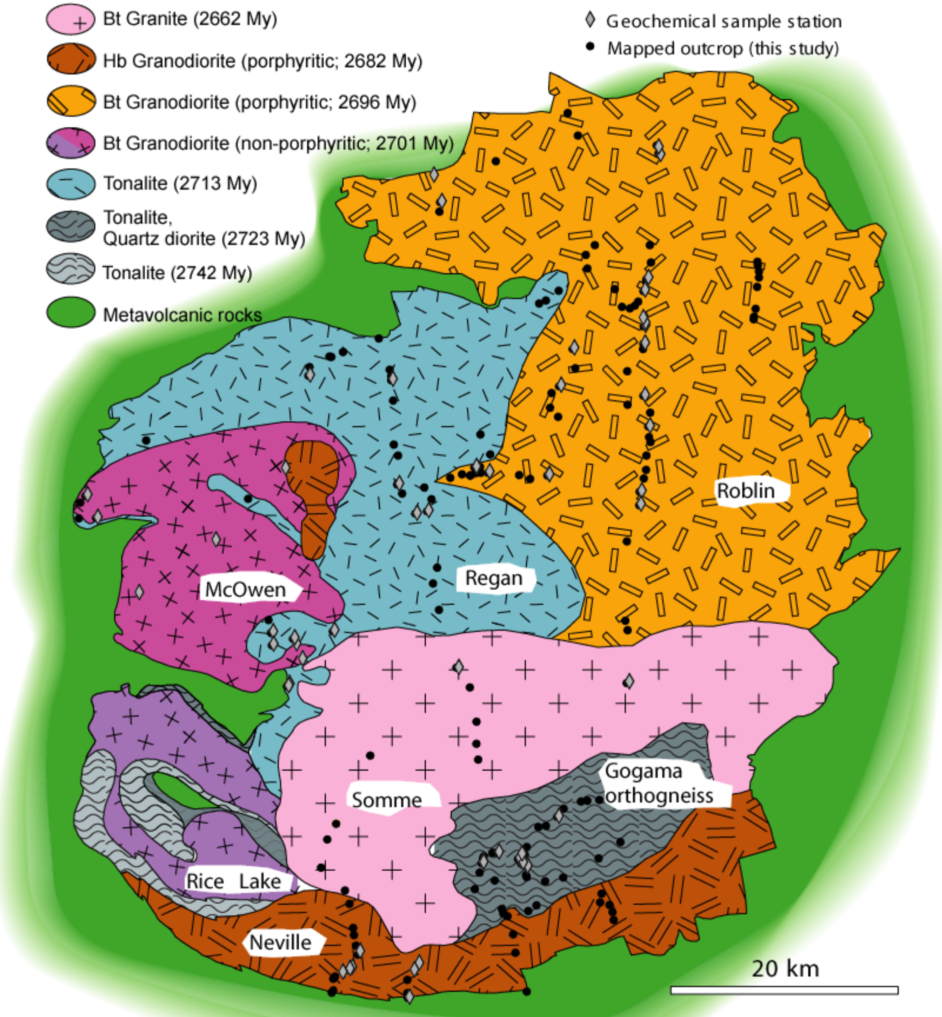






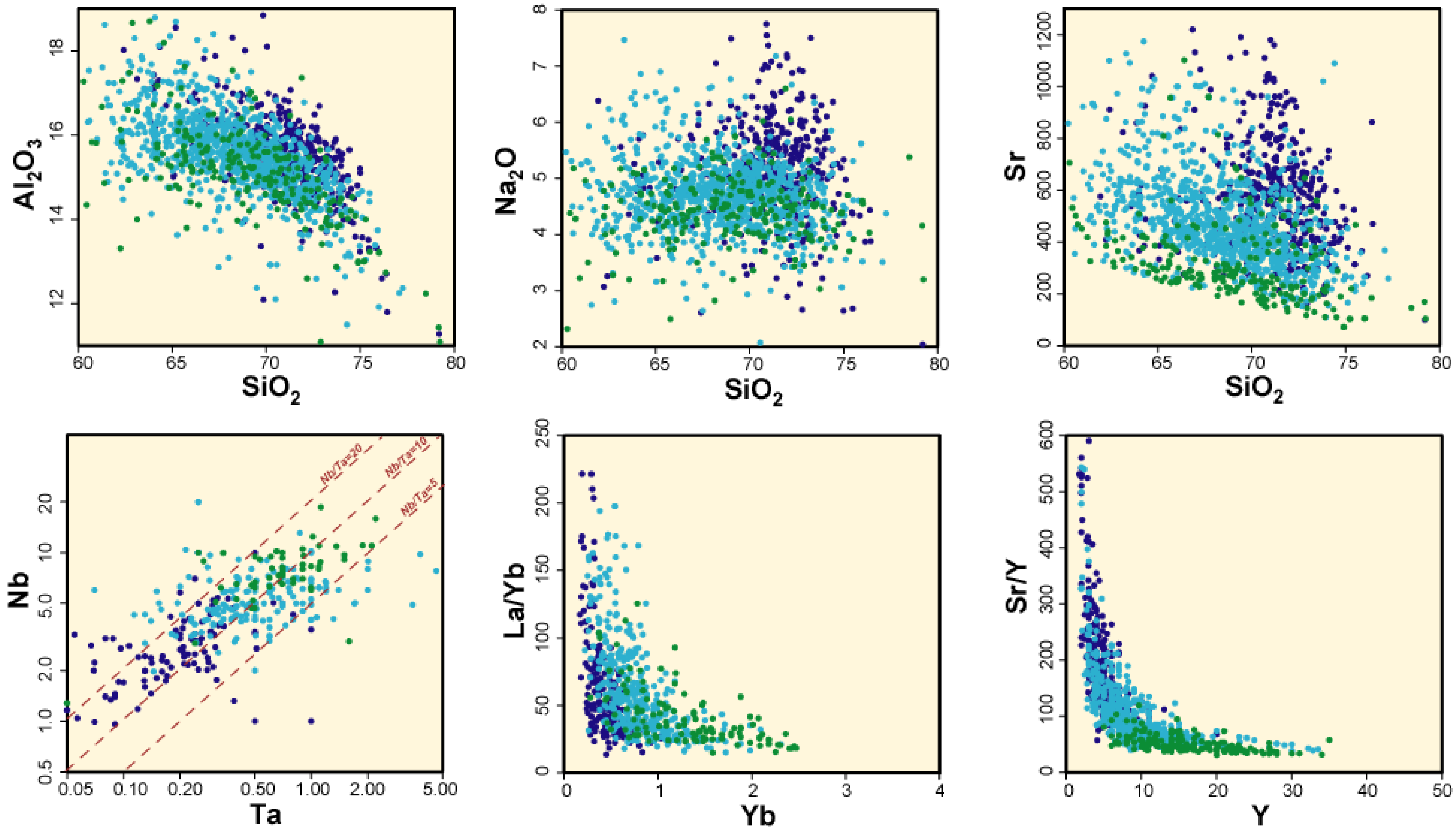


An
Ab
Or
Tonalite
Granodiorite
Quartz
monzonite
Granite
Tdj

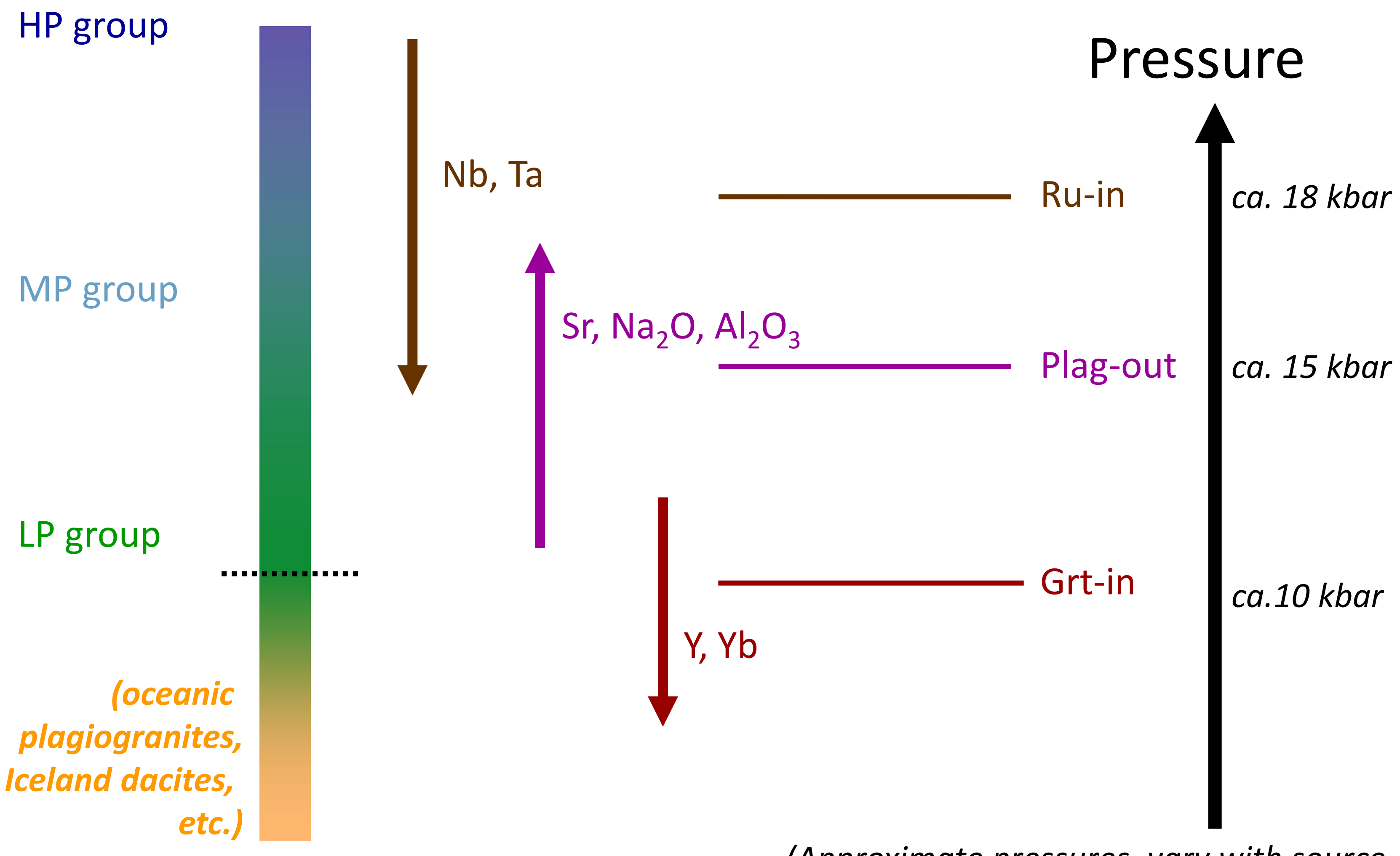


Bt Granite (2662 My)
Hb Granodiorite (porphyritic; 2682 My)
Bt Granodiorite (porphyritic; 2696 My)
Bt Granodiorite (non-porphyritic; 2701 My)
Tonalite (2713 My)
Tonalite,
Quartz diorite (2723 My)
Tonalite (2742 My)
Metavolcanic rocks
Geochemical sample station
Mapped outcrop (this study)
Roblin
Regan
McOwen
Somme
Gogama
orthogneiss
Rice Lake
Neville
20 km

TTG (sub)types – worldwide

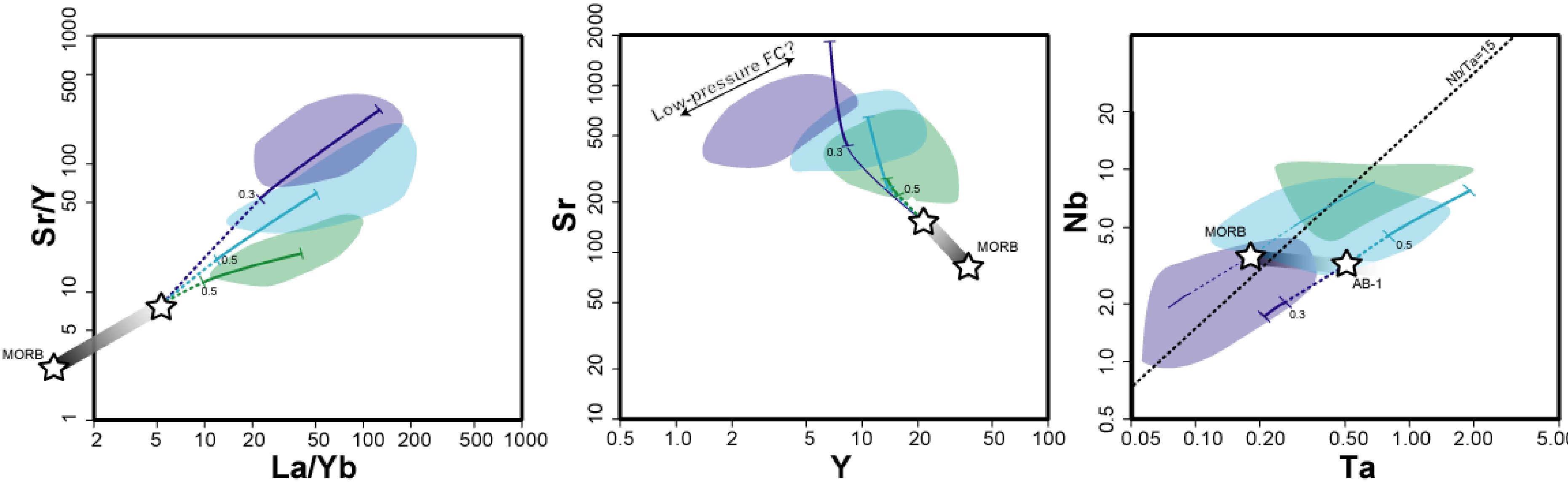


TTG subtypes: different pressures of melting



(Approximate pressures, vary with source composition and water availability)

Evidence for different melting depths in the TTG record



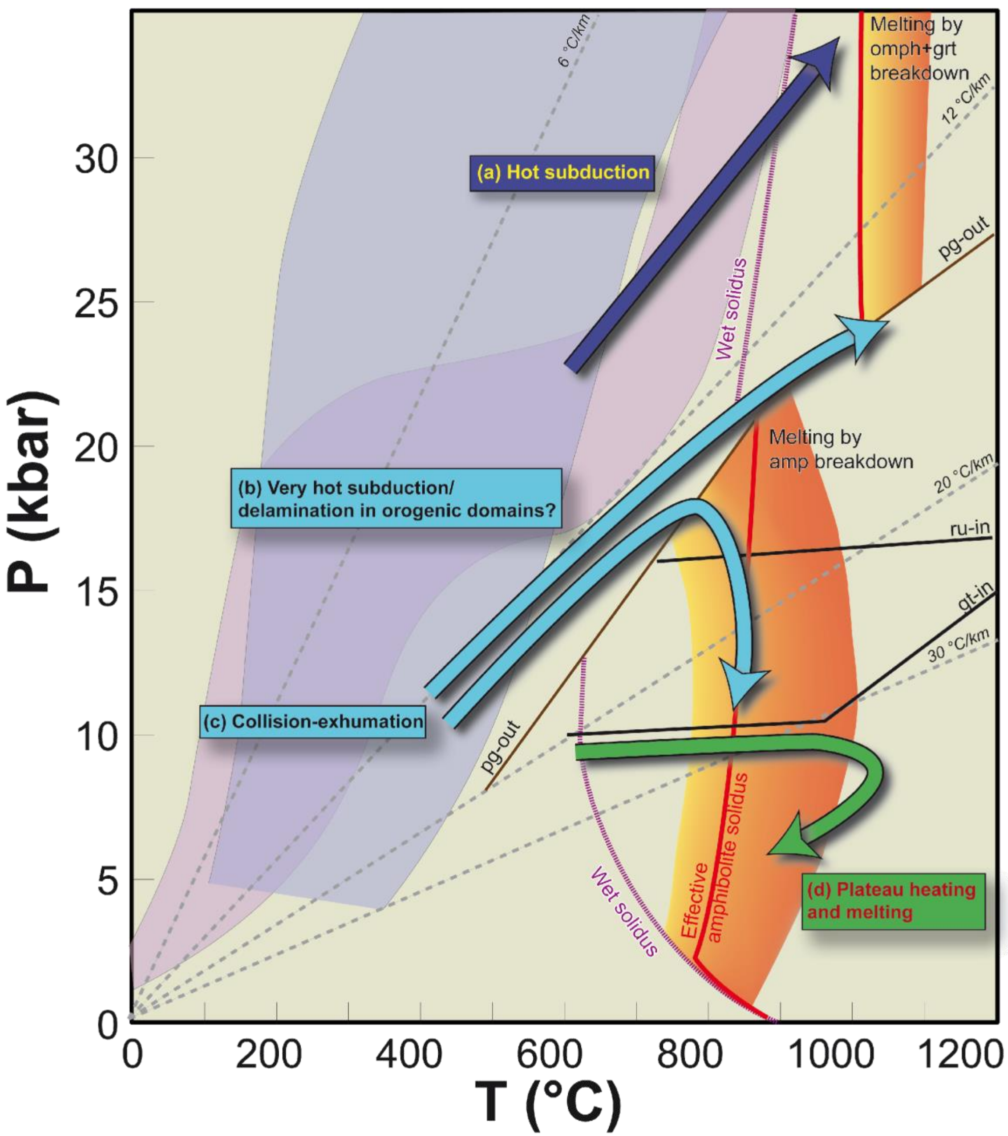
1. 20 Cpx 50 Amp 20 Pg 10 Grt → **ca. 10-12 kbar**
2. 25 Cpx 60 Amp 15 Grt → **ca. 12-18 kbar**
3. 60 Cpx 40 Grt 1 Rt → **ca. 20+ kbar**

Willbold, today 14.50

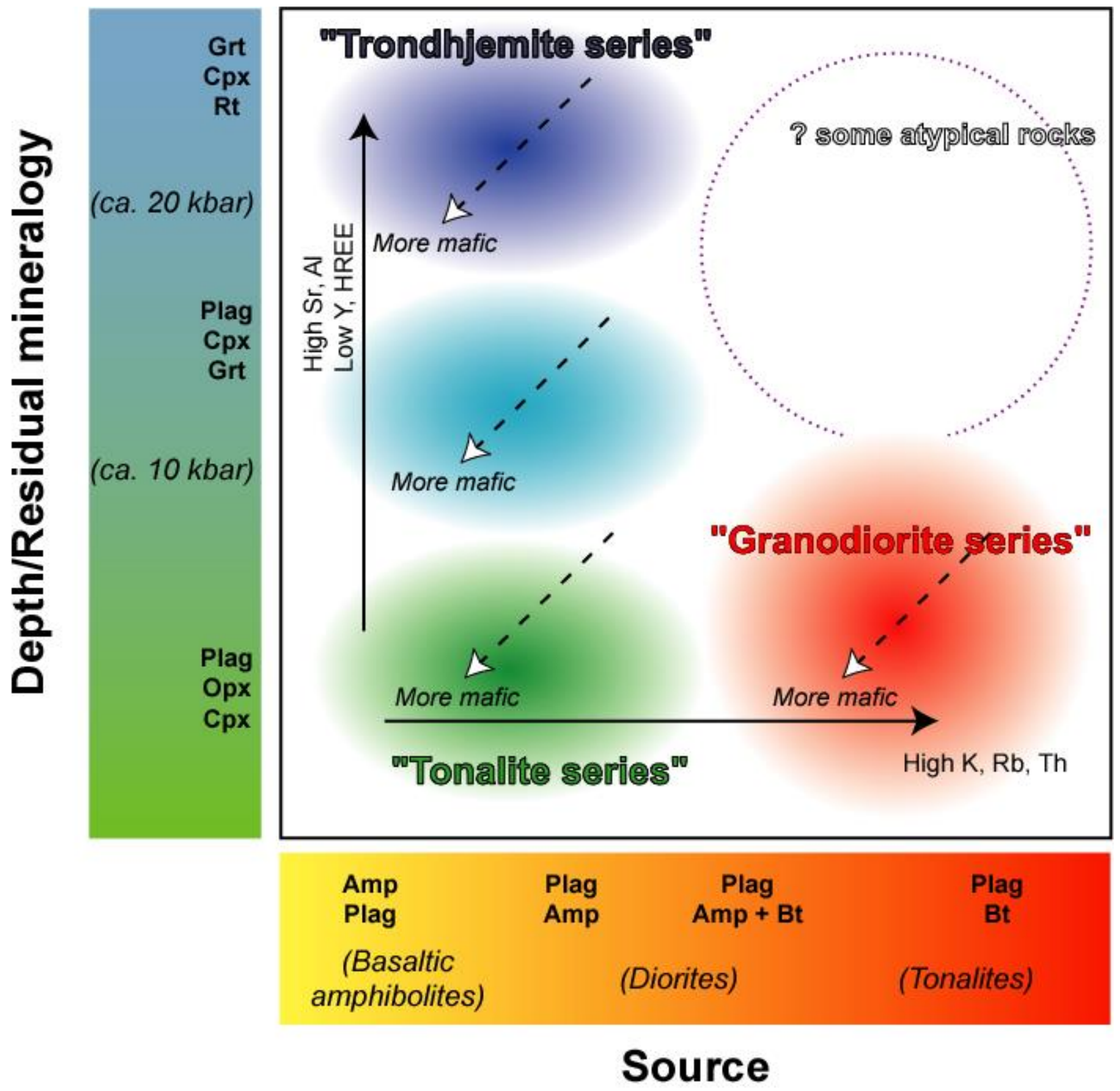
Laurie, today 15.10

(Approximate pressures, vary with source composition and water availability)

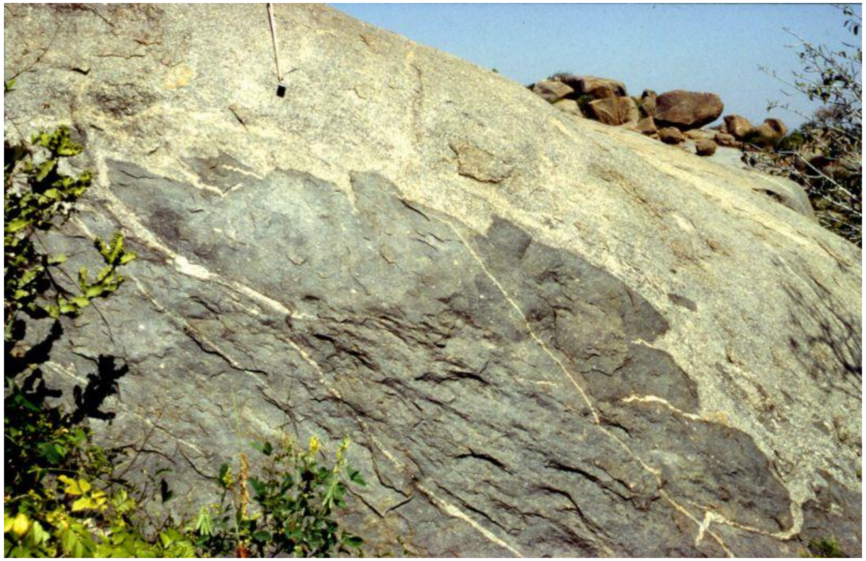
PT conditions for different TTG types



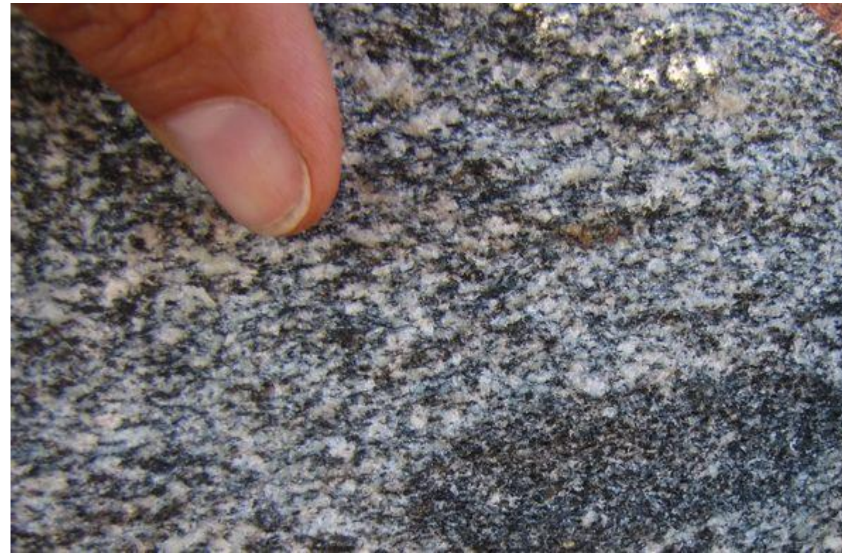
Source and melting pressure of Archaean C-type granitoids



Archaean M-type granites (and associated intermediate diorites etc.)

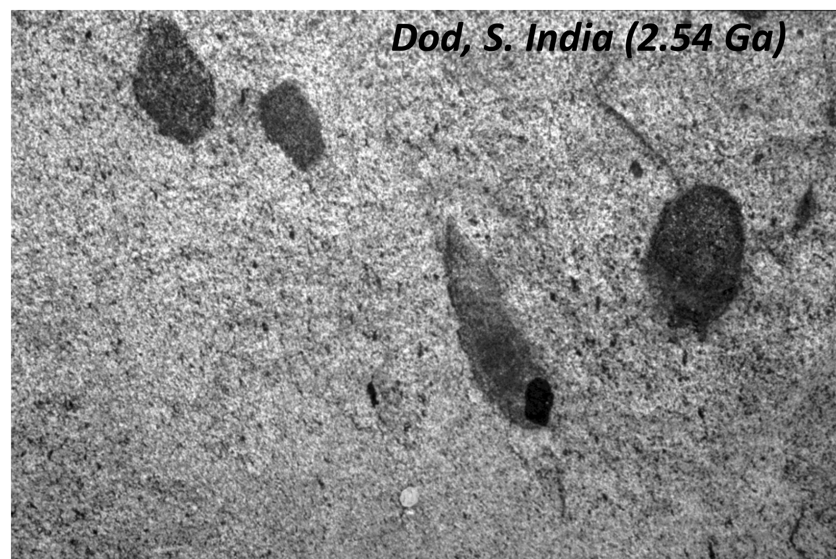


Closepet, S. India (2.52 Ga)



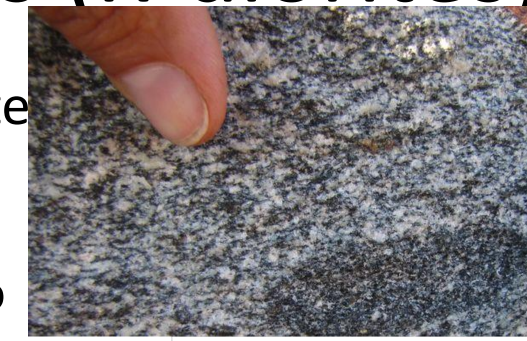
Peewah, WA (2.95 Ga)

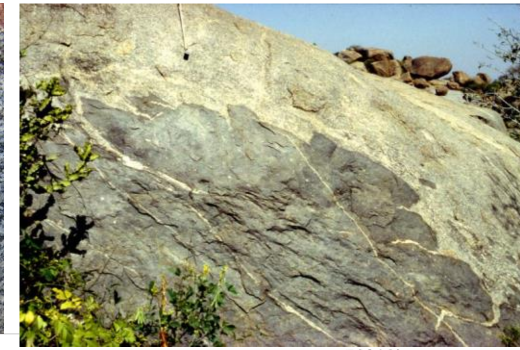
Matok, S. Africa (2.67 Ga)



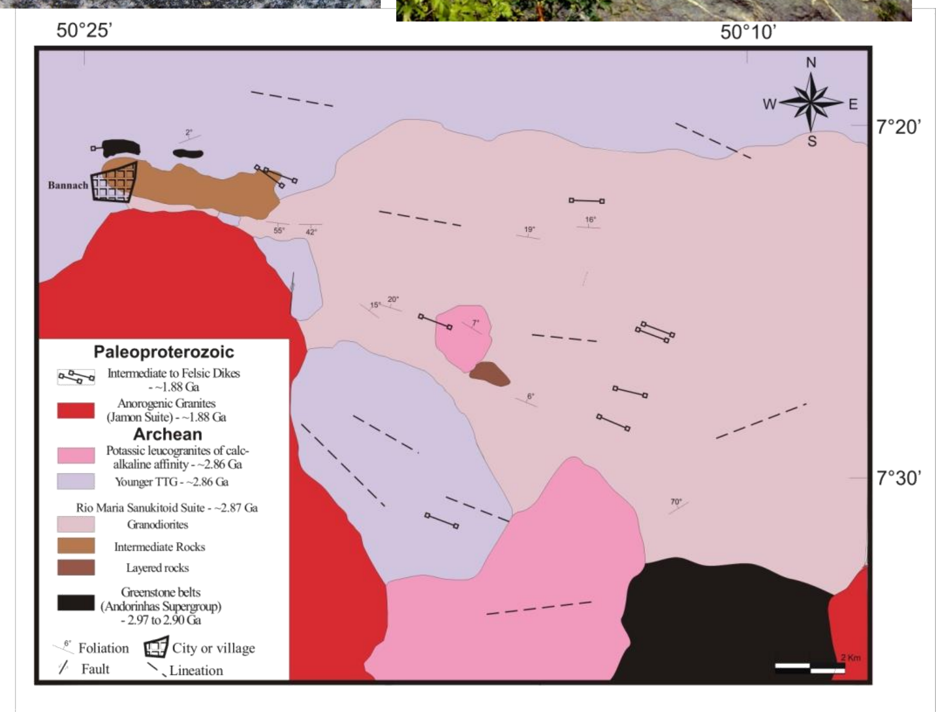
Dod, S. India (2.54 Ga)

M-type granitoids: link with intermediate rocks (K-diorites)





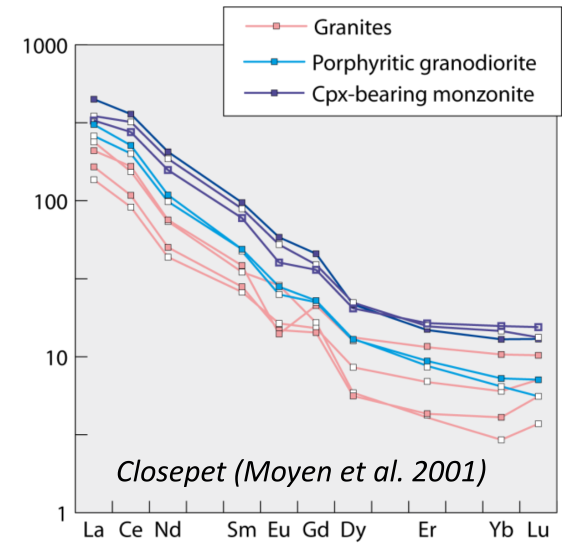
- M-types are always associate with intermediate rocks
  - Evidenced by MME
  - But also larger stocks up to ≈ 1 km
- K-diorites
- 2 petrological questions:
  - Relations between diorites and granodiorites/granites
    - Fractionnal crystallization?
    - Remelting of mafic precursor?
    - In-situ mixing with local country rocks or crustal melts?
  - Origin of the diorites

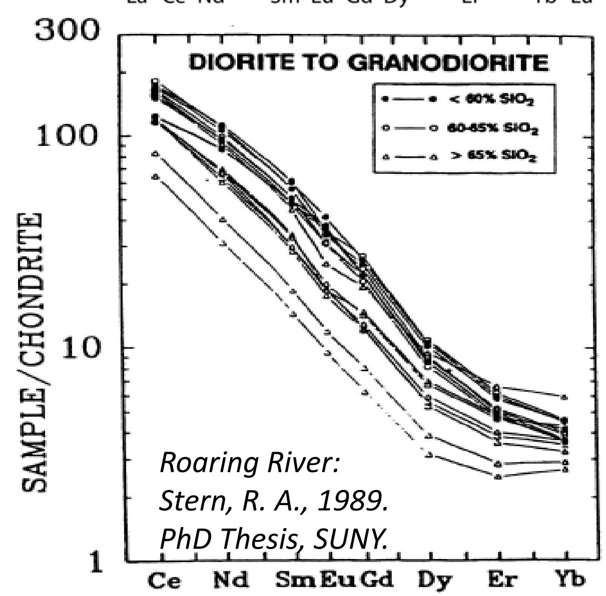


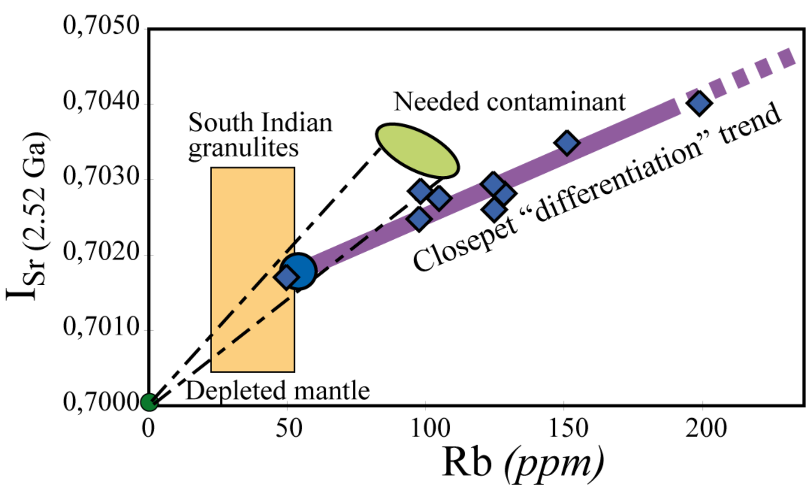
Rio Maria GGT, Oliveira et al.

M-type granitoids: origin of the K-diorites

- The most enriched components in the suite are the diorites
- They typically have higher LILE & LREE than surrounding crust
  - Crustal contamination unlikely
  - Enriched mantle source







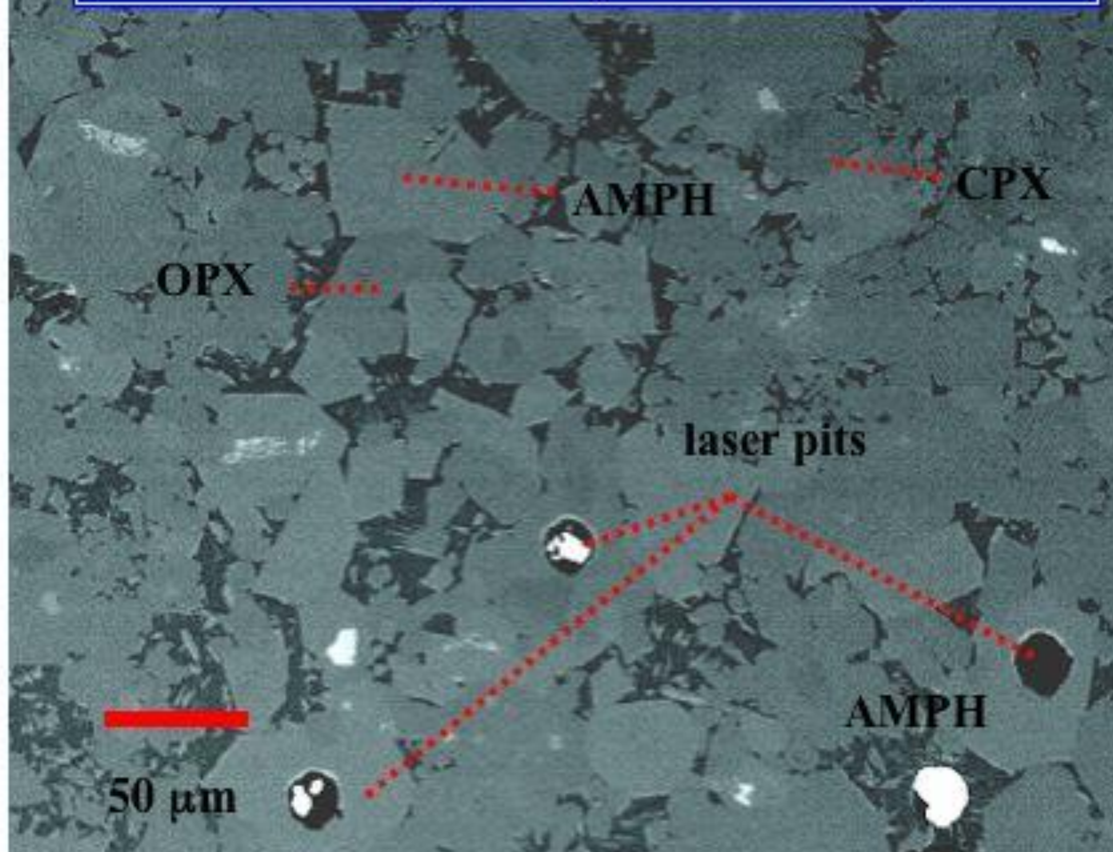
sanukitoid origins

Melting of TTG-metasomatized mantle III: dehydration of amphibole, w/out garnet signature

(Amphibole + OPX ± CPX)

P (GPa)	1.6
Temp (°C)	1100
Melt/Rock	1:2
SiO_2	54.35
TiO_2	0.38
Al_2O_3	18.60
FeO	3.43
MnO	0.05
MgO	2.59
CaO	3.63
Na_2O	6.05
K_2O	2.23
TOTAL	91.64%
Mg#	0.57

Hydrous adakite SV-4 + peridotite 8710P
1.6 GPa, 1100°C (melt:rock = 1:2)



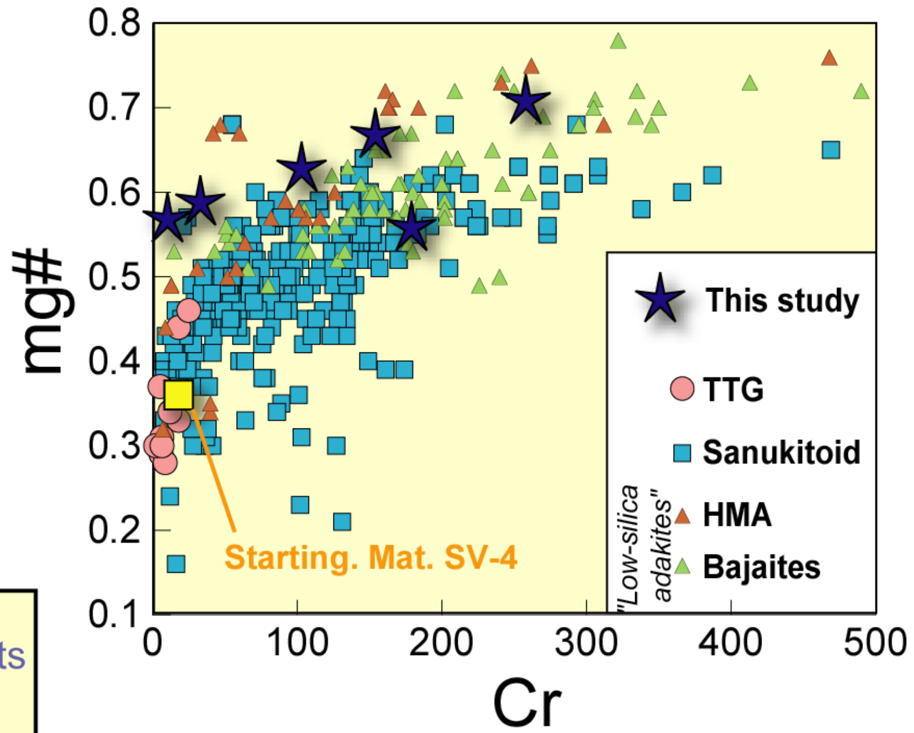
P = 1.6 GPa

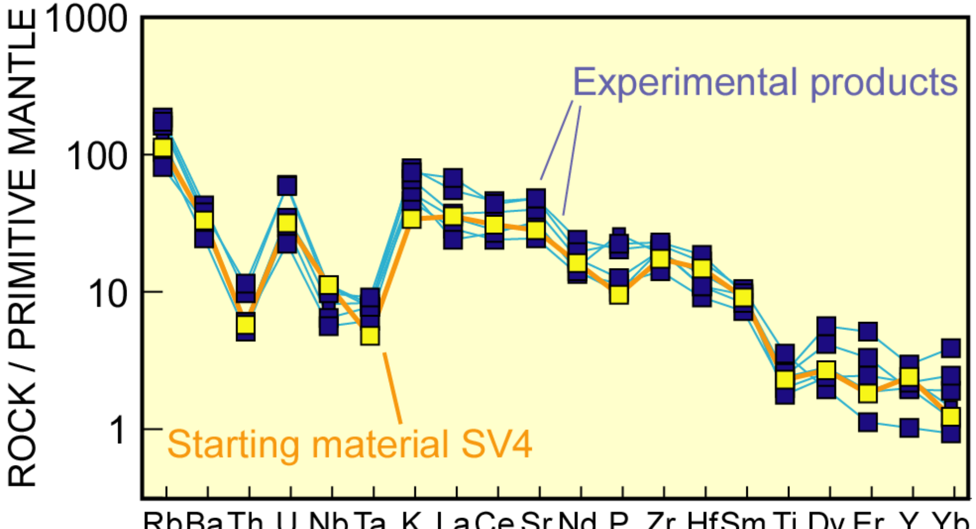
amphibole signature, OPX signature

R. Rapp (Hutton 2007 poster)

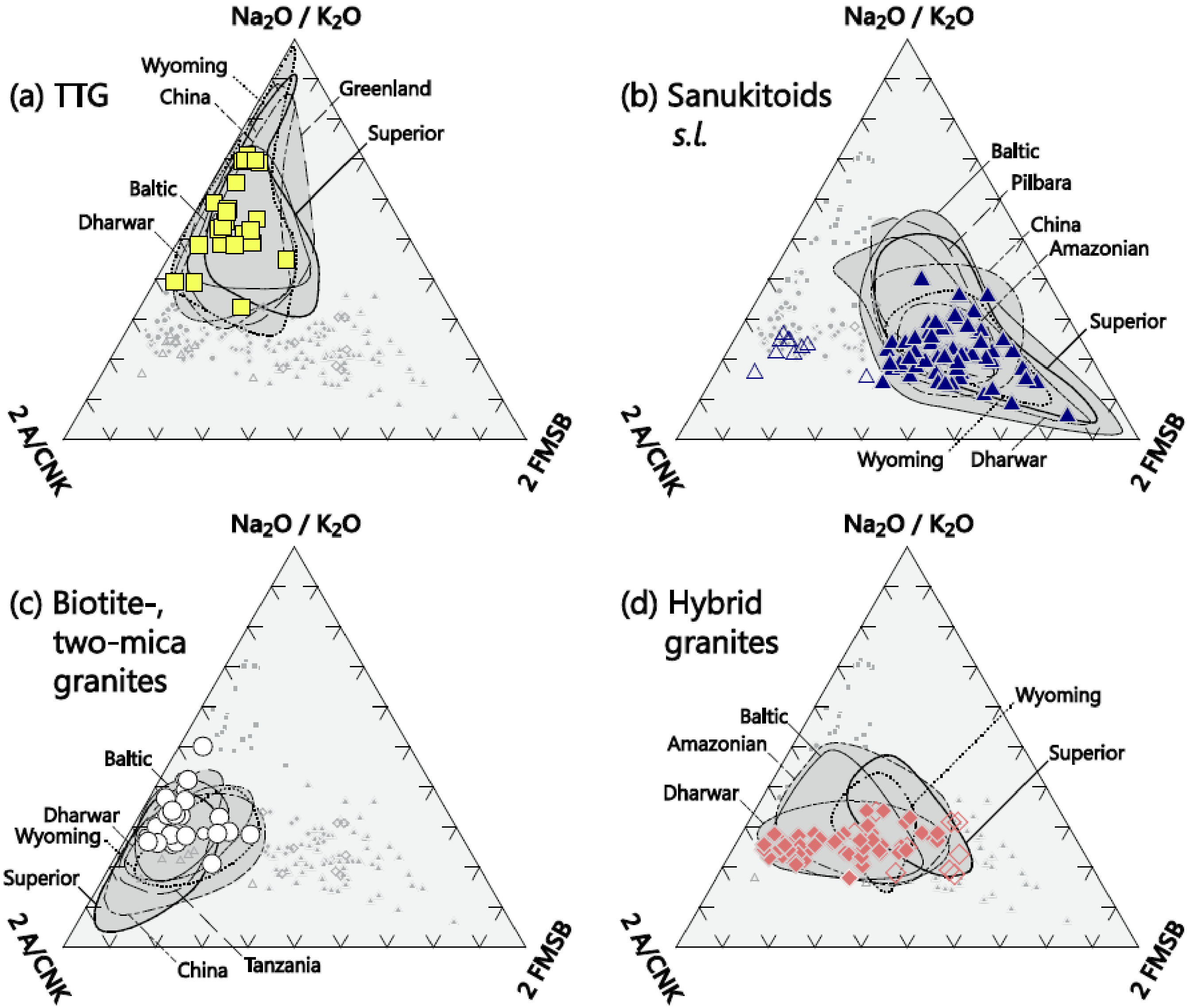
Experimental results

As expected, experimental melts have high mg# and Cr, and TTG-like trace elements patters are preserved.





Hybrid granites



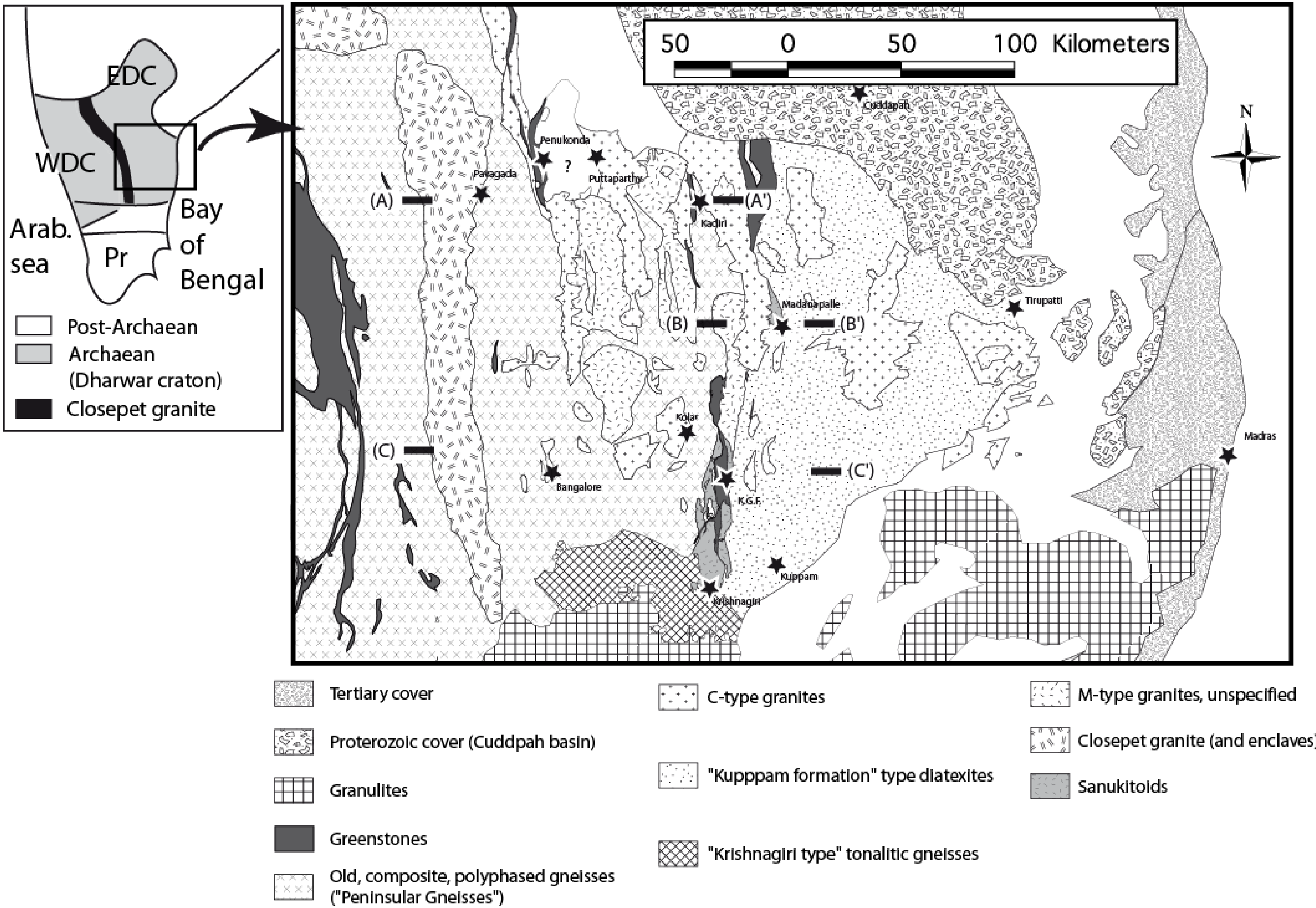
Laurent et al. In press

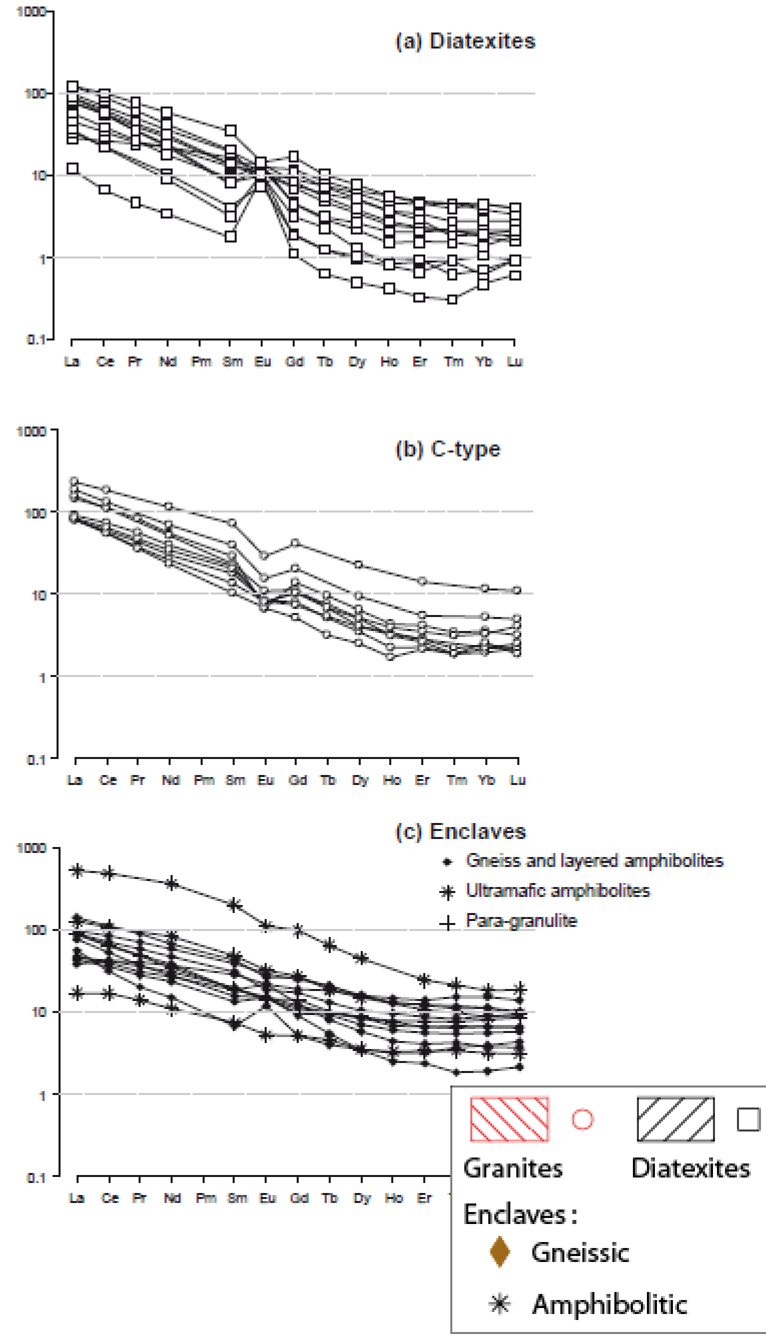
Granites, gneiss et migmatites

Sand River Gneisses (3.1 Ga), Limpopo, South Africa

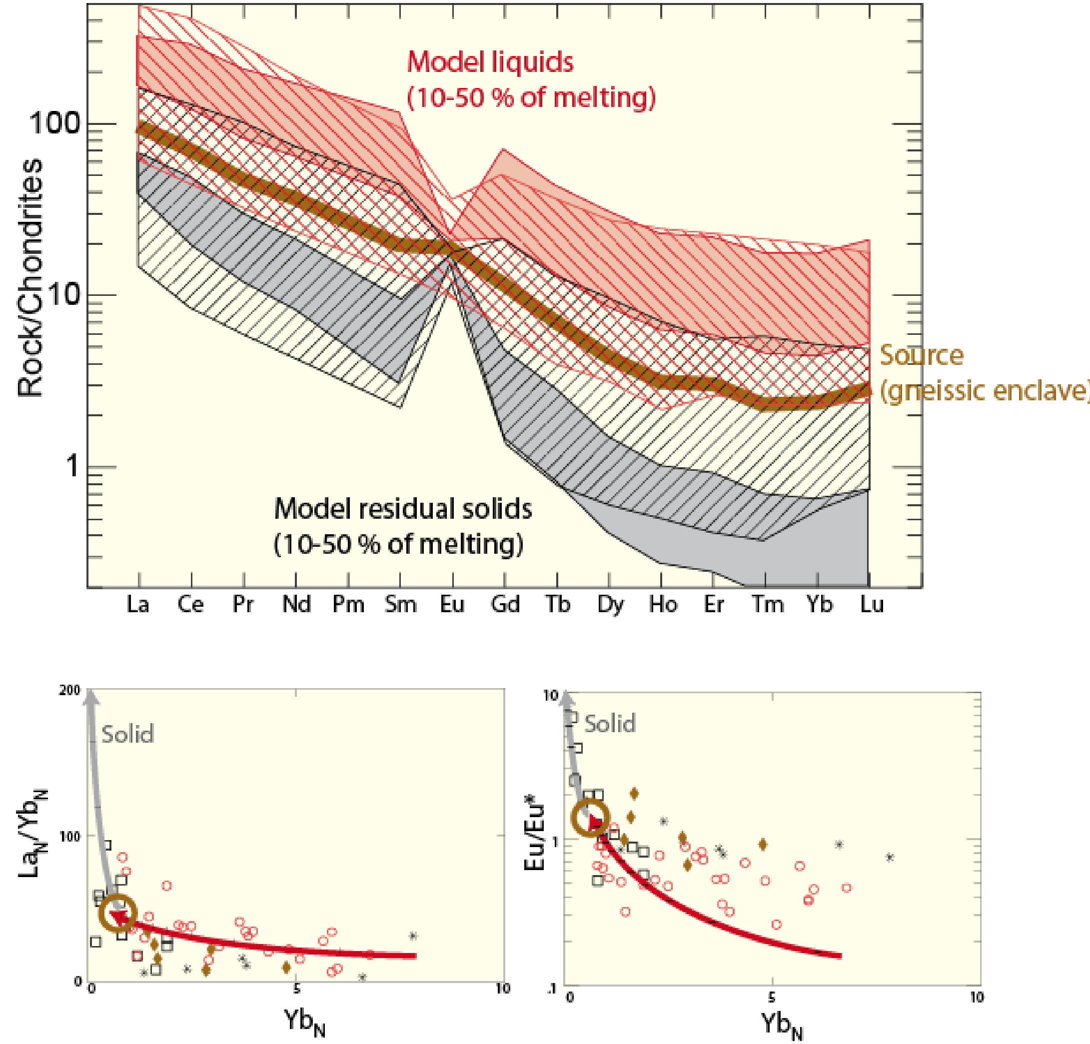
- **Grey gneisses** = « background » lithology of Archaean terranes. May form up to 80% of Archaean C.C.
- **TTG** = Tonalite-Trondhjemite-Granodiorite. Sodic granitoids, high Sr/Y and La/Yb, form by melting of metamafics. Supposedly protolith of grey gneisses (!)

Grey Gneisses and TTG


EDC
WDC
Arab. sea
Pr
Bay of Bengal
Post-Archaean
Archaean (Dharwar craton)
Closepet granite
50 0 50 100 Kilometers
N
Cuddapah
Penukonda
Puttaparthy
Paragada
(A)
(A')
Kadiri
Madanapalle
(B)
(B')
Tirupatti
Kolar
(C)
(C')
Bangalore
K.G.F.
Kuppam
Krishnagiri
Madras
Tertiary cover
Proterozoic cover (Cuddpah basin)
Granulites
Greenstones
Old, composite, polyphased gneisses ("Peninsular Gneisses")
C-type granites
"Kupppam formation" type diatexites
"Krishnagiri type" tonalitic gneisses
M-type granites, unspecified
Closepet granite (and enclaves)
Sanukitoids

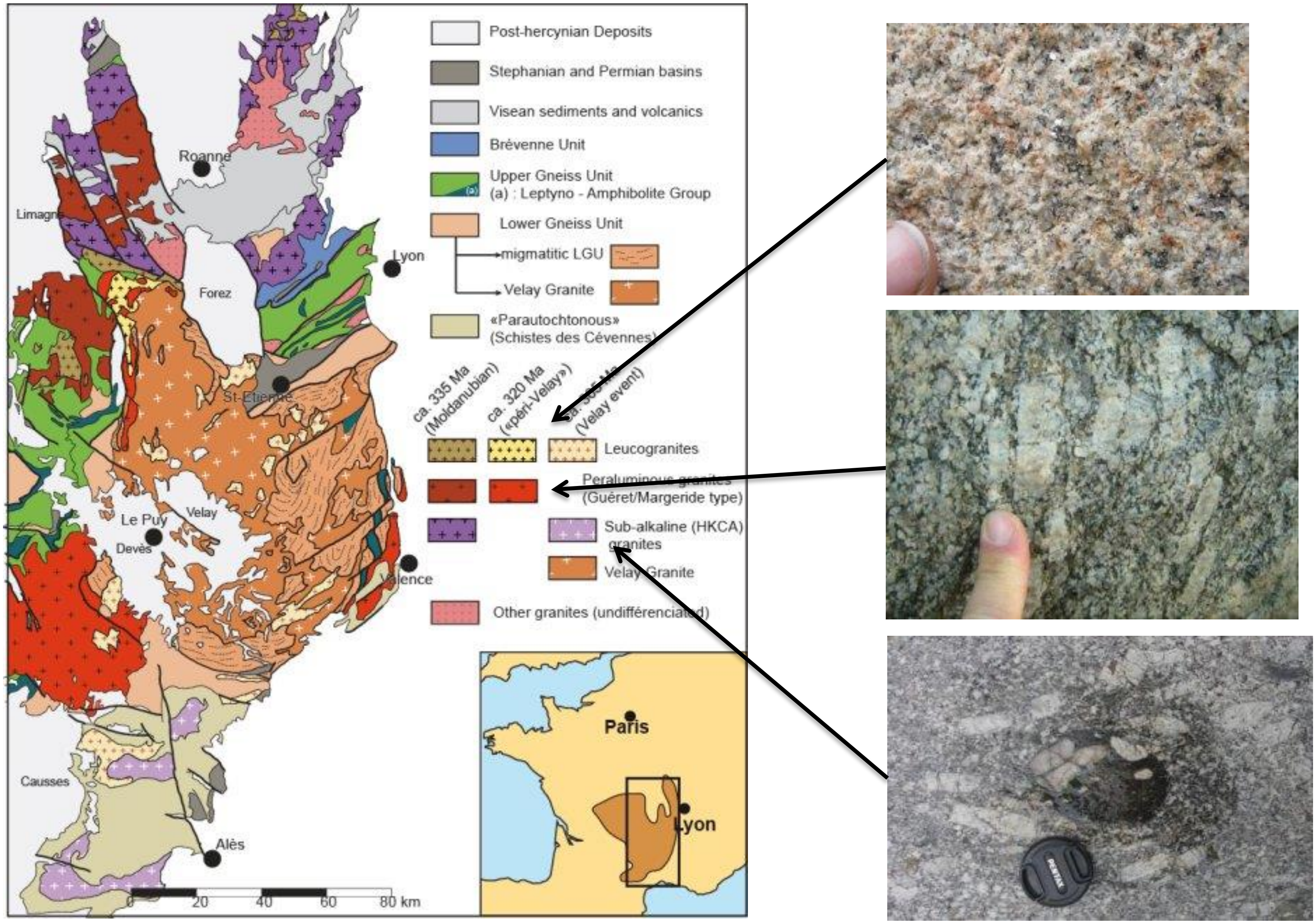


(a) Diatexites
1000
100
10
1
0.1
La Ce Pr Nd Pm Sm Eu Gd Tb Dy Ho Er Tm Yb Lu
(b) C-type
1000
100
10
1
0.1
La Ce Pr Nd Pm Sm Eu Gd Tb Dy Ho Er Tm Yb Lu
(c) Enclaves
Gneiss and layered amphibolites
Ultramafic amphibolites
Para-granulite
1000
100
10
1
0.1
La Ce Pr Nd Pm Sm Eu Gd Tb Dy Ho Er
Granites
Diatexites
Enclaves :
Gneissic
Amphibolitic



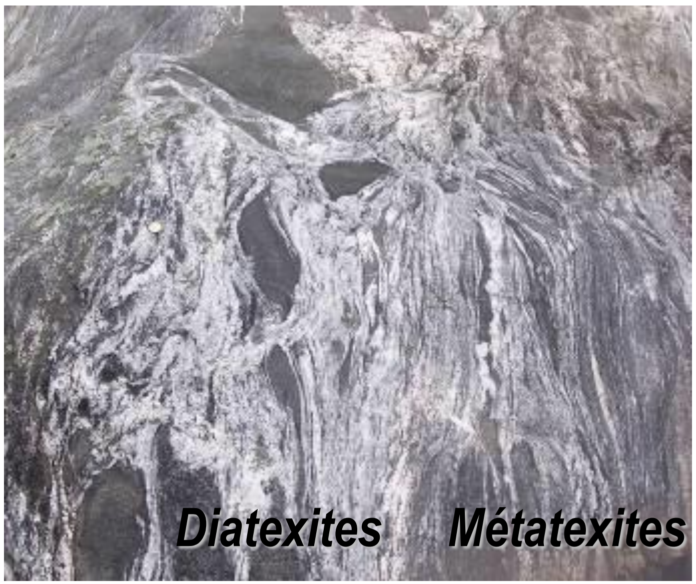
Model liquids
(10-50 % of melting)
Source
(gneissic enclave)
Model residual solids
(10-50 % of melting)
Rock/Chondrites
100
10
1
La Ce Pr Nd Pm Sm Eu Gd Tb Dy Ho Er Tm Yb Lu
Solid
La_N/Yb_N
200
100
0
5
10
Yb_N
Solid
Eu/Eu*
10
1
.1
0
5
10
Yb_N

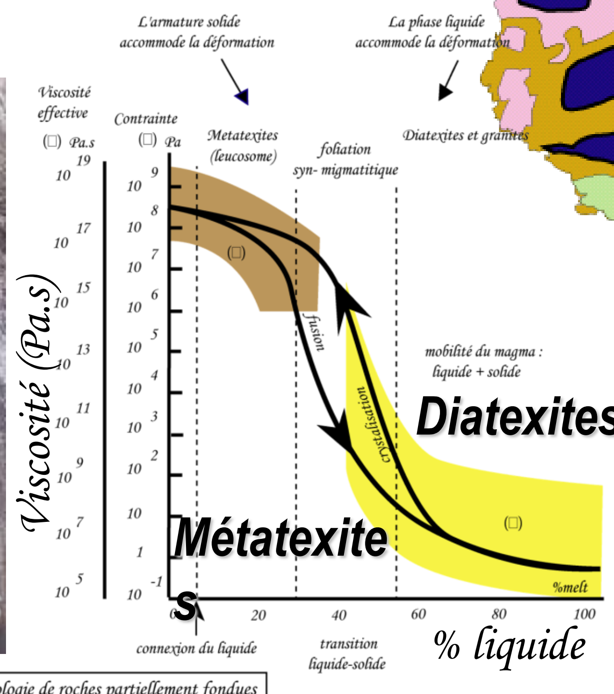
Le Massif Central Français: granites

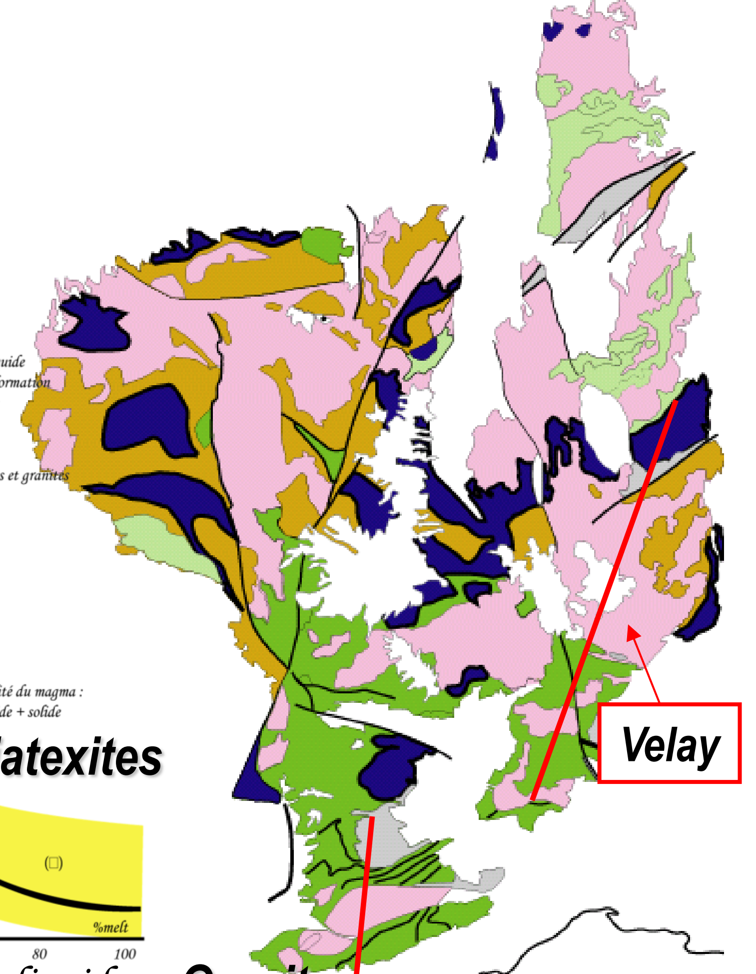


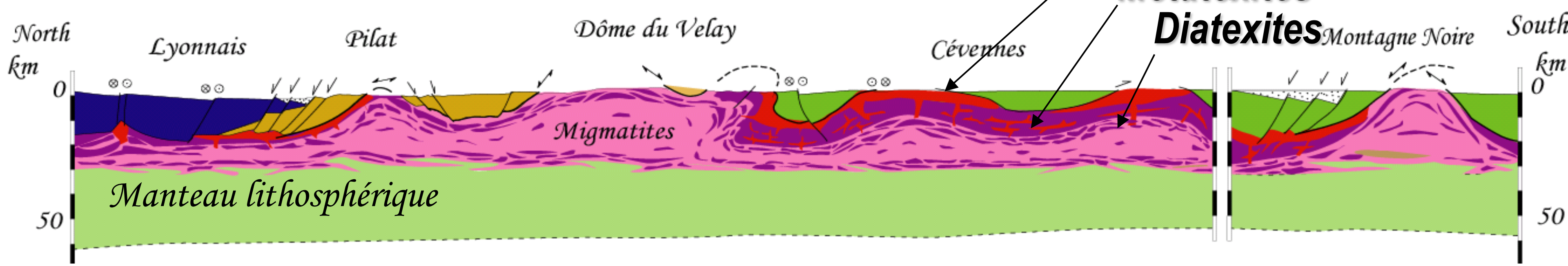
Diapo O. Vanderhaeghe

..et migmatites



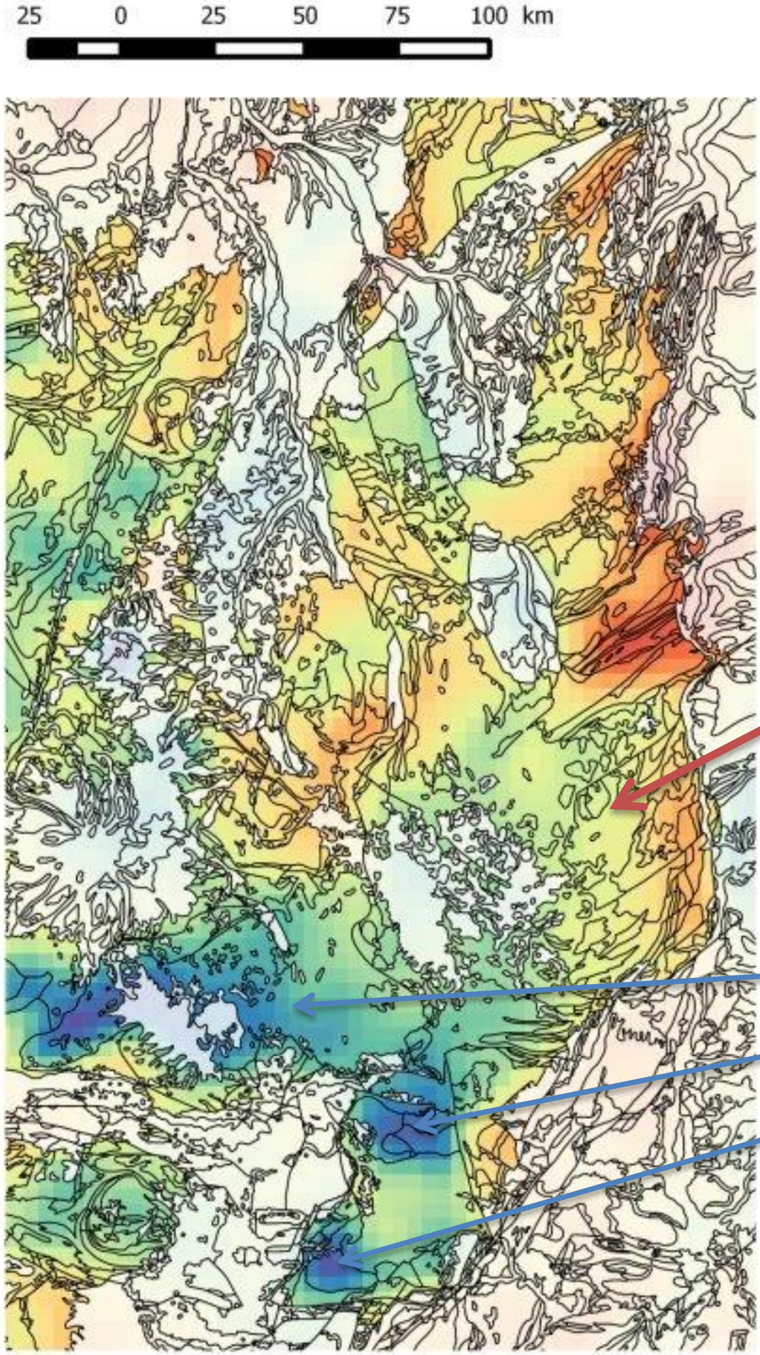






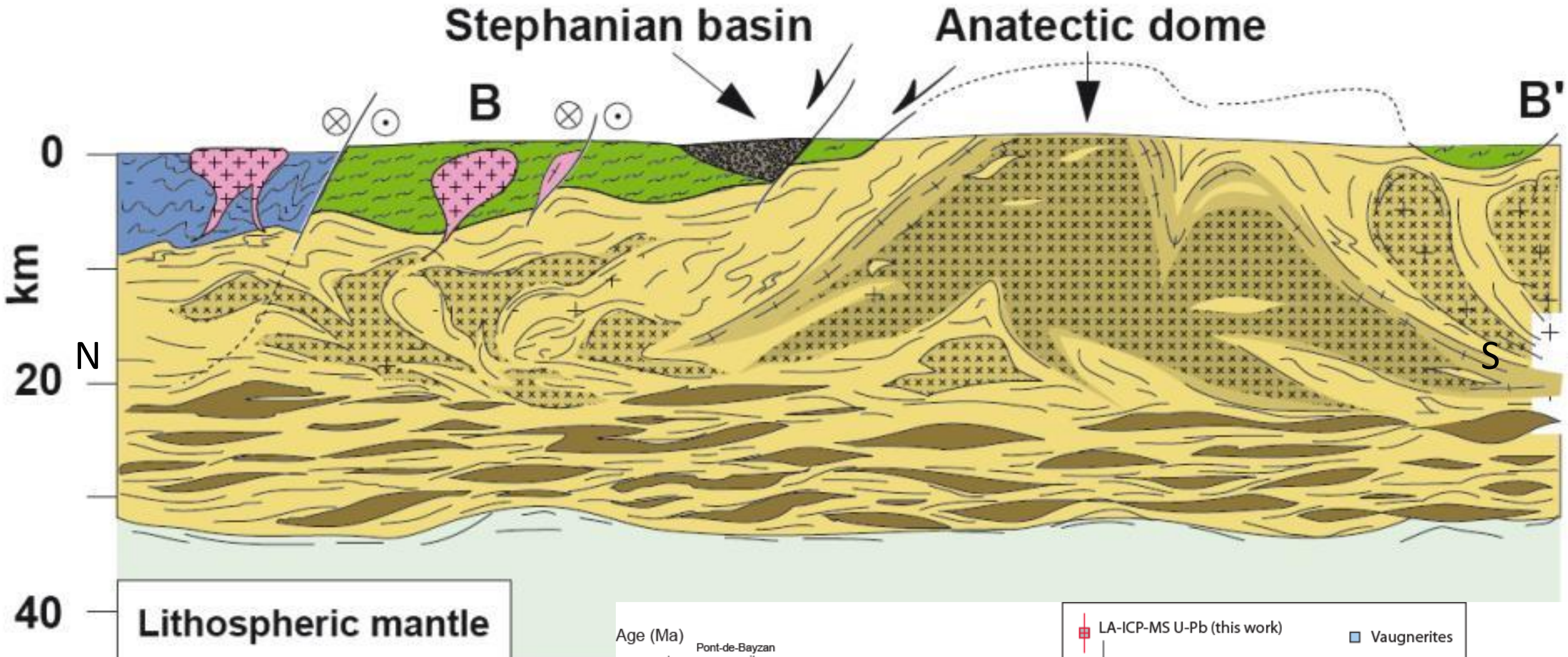
(Burg & Vanderhaeghe, 93; Vanderhaeghe et al., 99; Ledru et al.; 01)

Bouguer anomaly

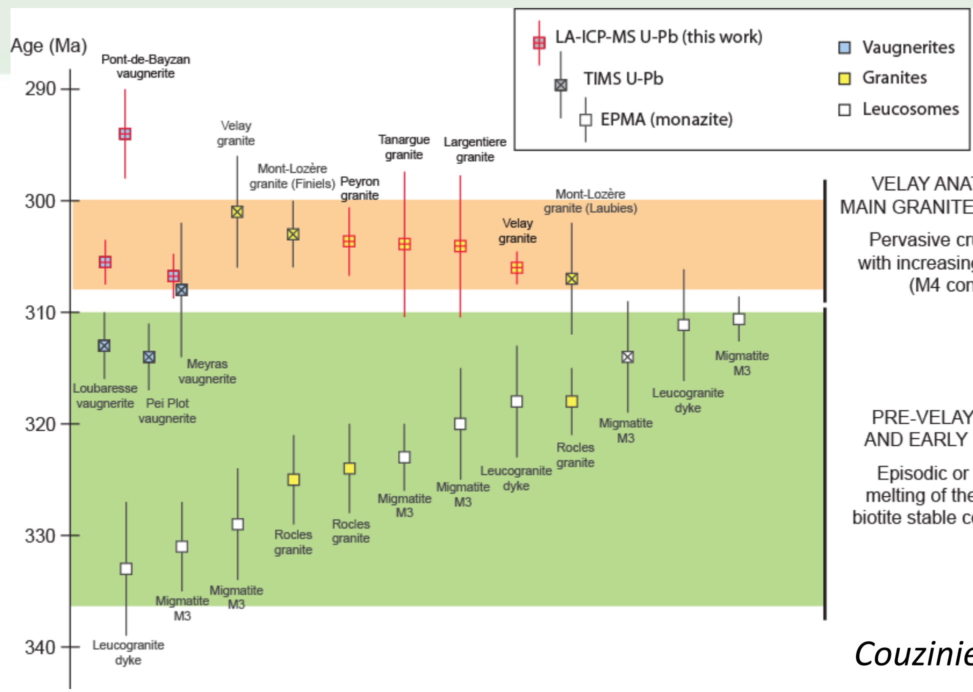


Velay complex = no melt extracted
Source layer outcrops
No Bouguer anomaly

Granites = melt extracted
from source layer
Negative Bouguer anomaly

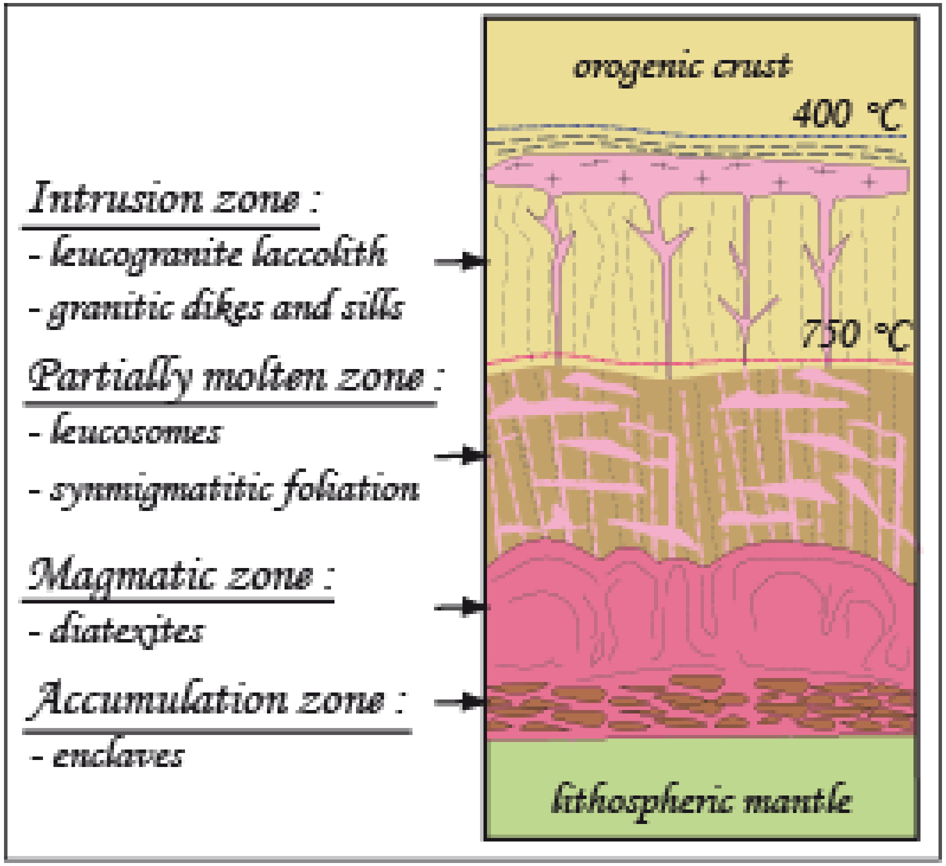


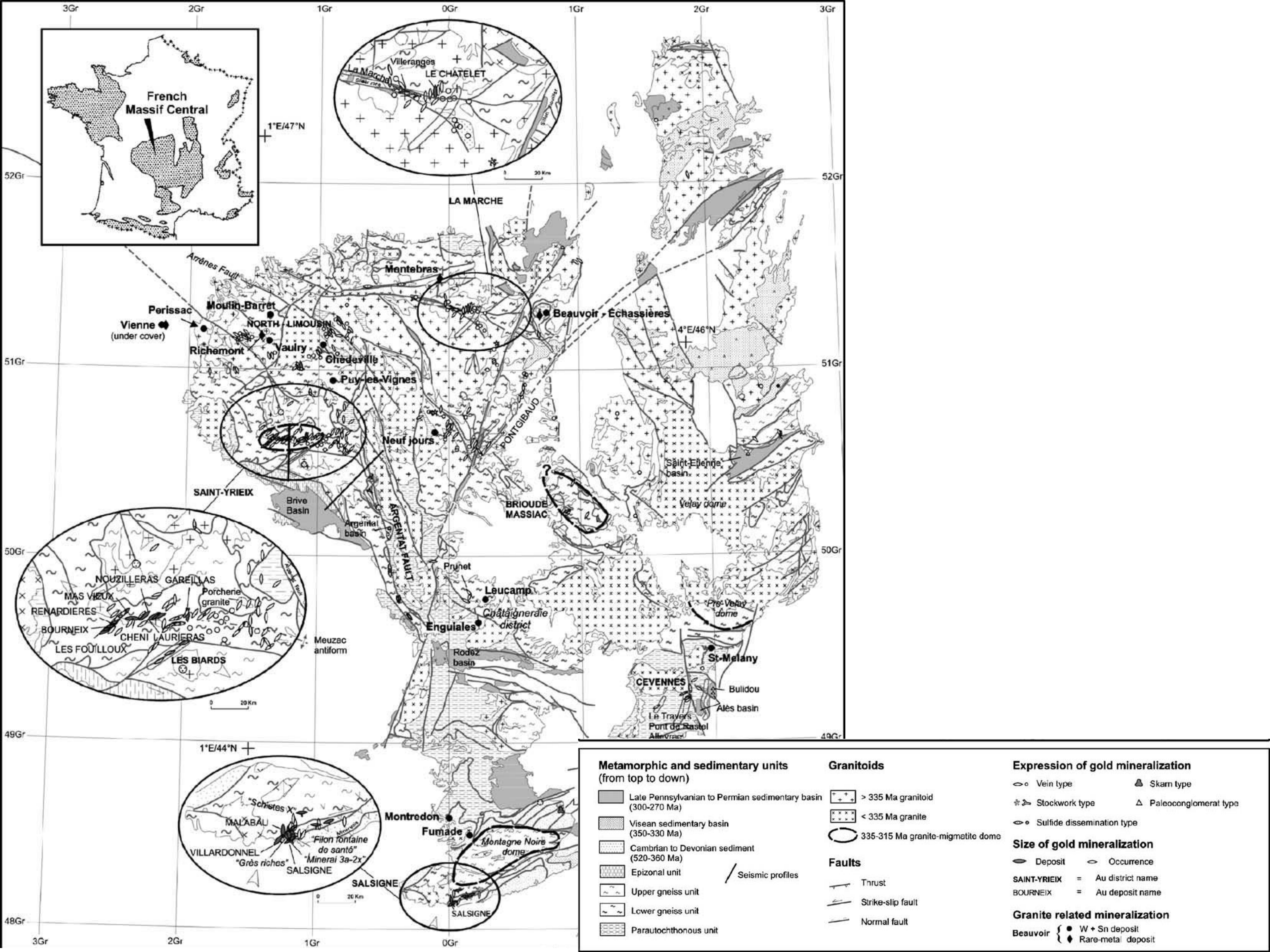
- Crt fondue sur le long terme
- Extraction ponctuelle



Couzinié et al. 2014

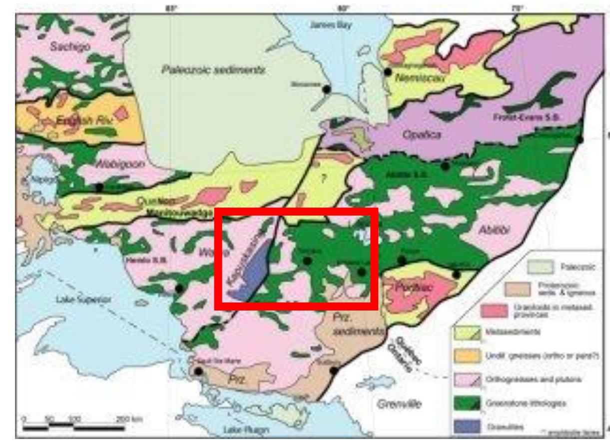
Structure de la croûte anatectique

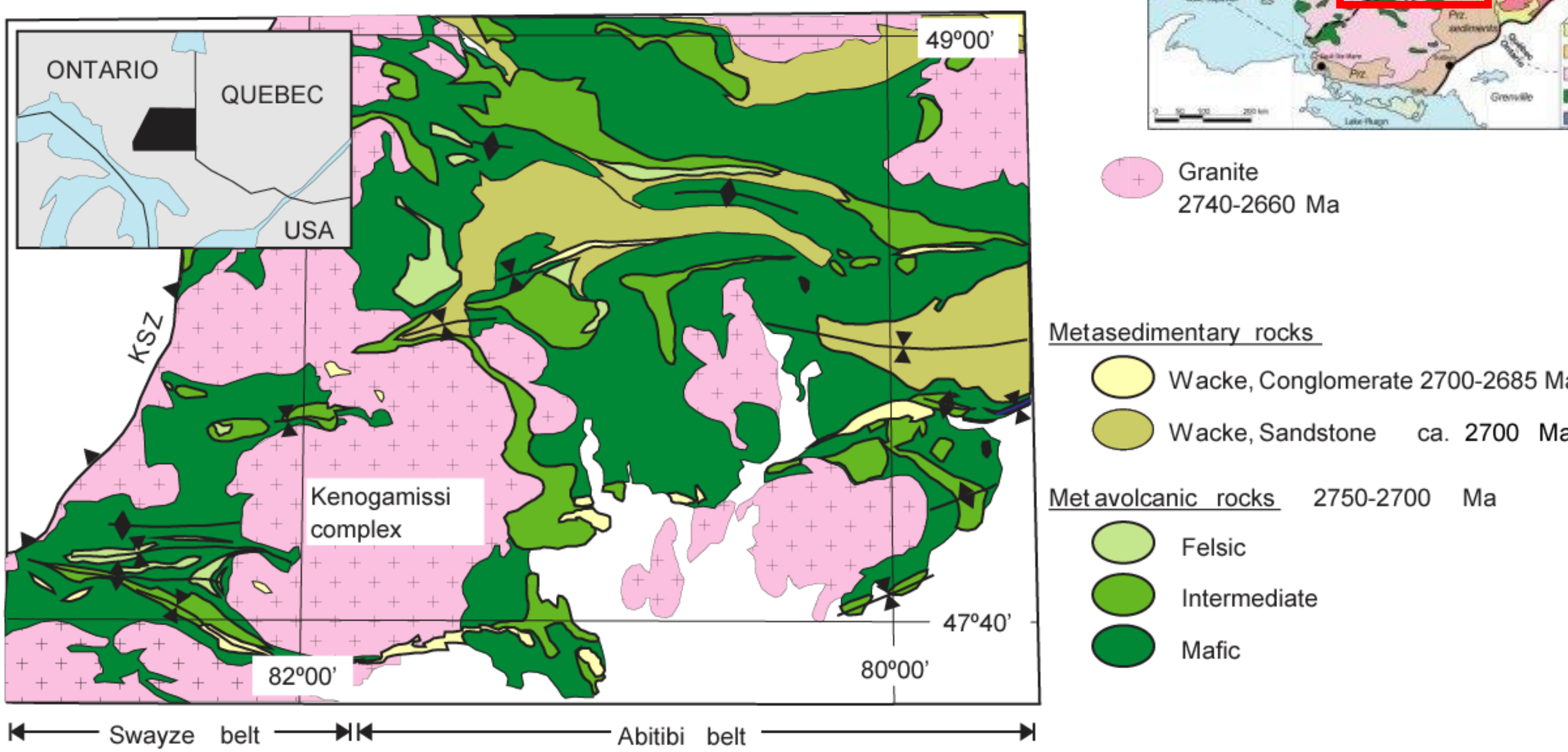




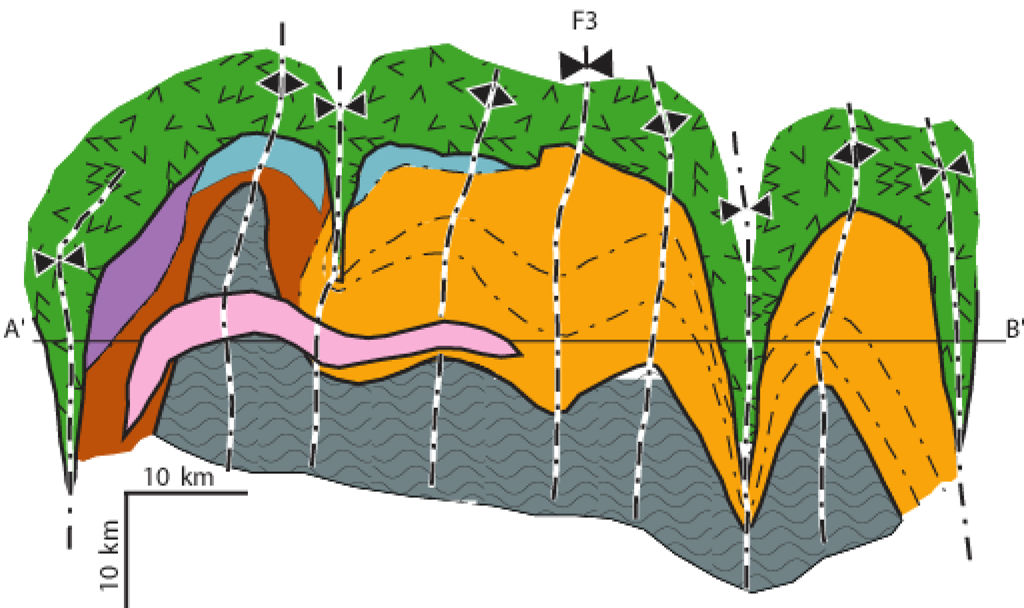
French Massif Central
1°E/47°N
1°E/44°N
4°E/46°N
3Gr
2Gr
1Gr
0Gr
52Gr
51Gr
50Gr
49Gr
48Gr
Villeranges
LE CHATELET
La Marche
LA MARCHE
Arrènes Fault
Montebras
Moulin-Barret
Perissac
Vienne
(under cover)
NORTH - LIMOUSIN
Vaulry
Richemont
Chèdeville
Puy-les-Vignes
Beauvoir - Échassières
Neuf jours
PONTGIBAUD
SAINT-YRIEIX
Brive Basin
Argentat basin
ARGENTAT FAULT
BRIOUDE MASSIAC
Saint-Etienne basin
Velay dome
NOUZILLERAS
GAREILLAS
MAS VIEUX
RENARDIERES
Porcherie granite
BOURNEIX
CHENI
LAURIERAS
LES FOUILLOUX
LES BIARDS
Meuzac antiform
Prunet
Leucamp
Châtaigneraie district
Engulales
Rodez basin
Pré-Velay dome
St-Mélany
CEVENNES
Bulidou
Alès basin
Le Travers
Pont de Rastel
Allevrac
"Schistes X"
MALABAU
VILLARDONNEL
"Grès riches"
"Filon fontaine de santé"
"Minerai 3a-2x"
SALSIGNE
Montredon
Fumade
Montagne Noire dome
0 20 Km
Metamorphic and sedimentary units (from top to down)
Late Pennsylvanian to Permian sedimentary basin (300-270 Ma)
Visean sedimentary basin (350-330 Ma)
Cambrian to Devonian sediment (520-360 Ma)
Epizonal unit
Upper gneiss unit
Lower gneiss unit
Parautochthonous unit
Seismic profiles
Granitoids
> 335 Ma granitoid
< 335 Ma granite
335-315 Ma granite-migmatite dome
Faults
Thrust
Strike-slip fault
Normal fault
Expression of gold mineralization
Vein type
Skarn type
Stockwork type
Paleoconglomerat type
Sulfide dissemination type
Size of gold mineralization
Deposit
Occurrence
SAINT-YRIEIX = Au district name
BOURNEIX = Au deposit name
Granite related mineralization
Beauvoir
W + Sn deposit
Rare-metal deposit

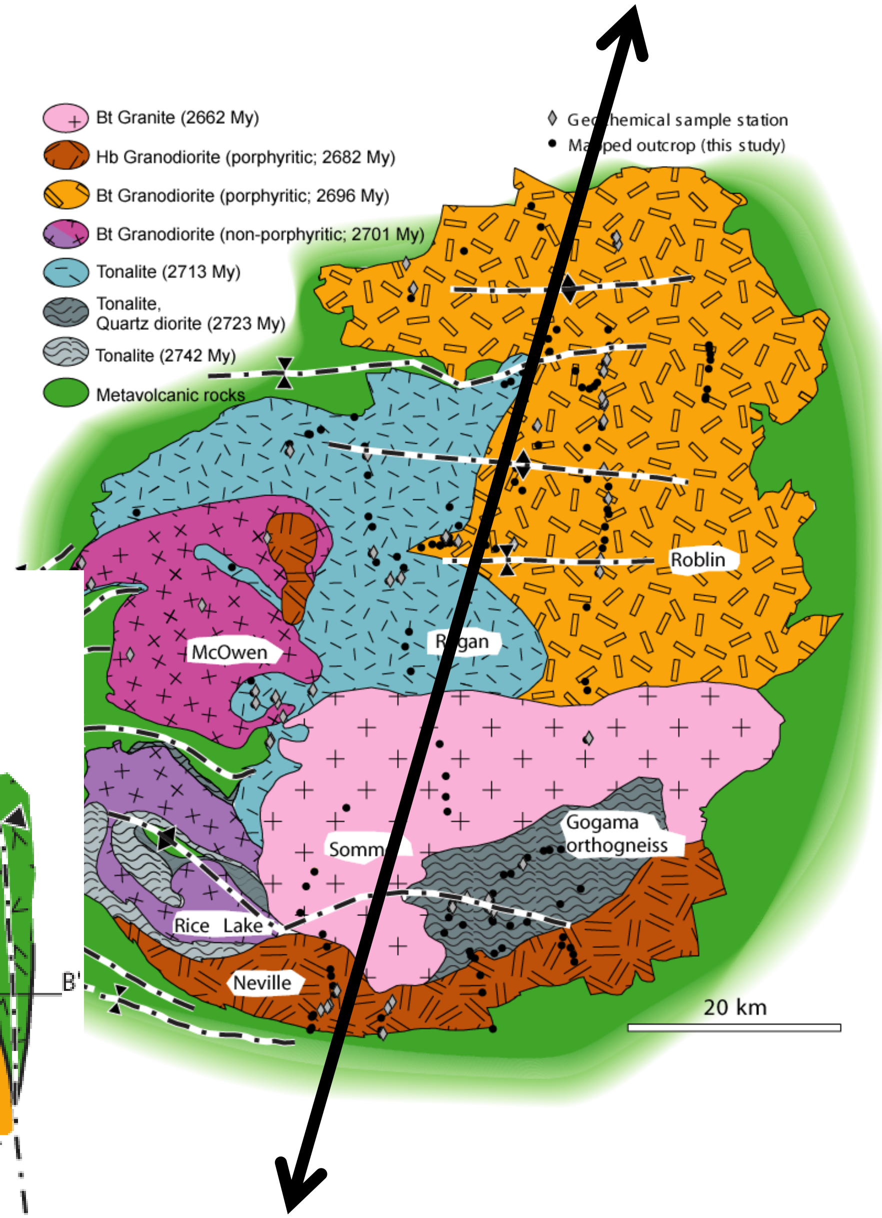
Abitibi: zone des plutons?



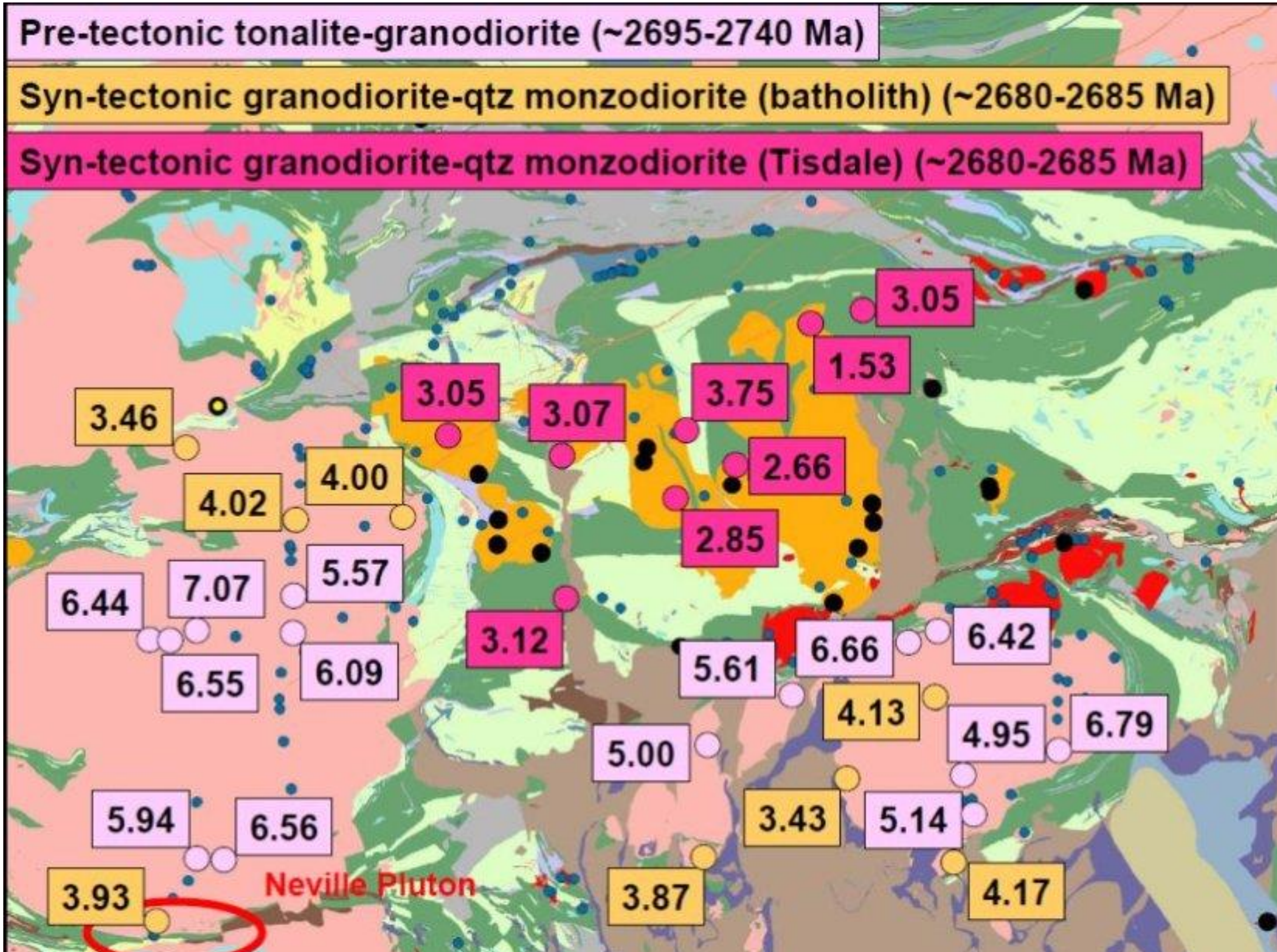


Kenogamissi complex: structure



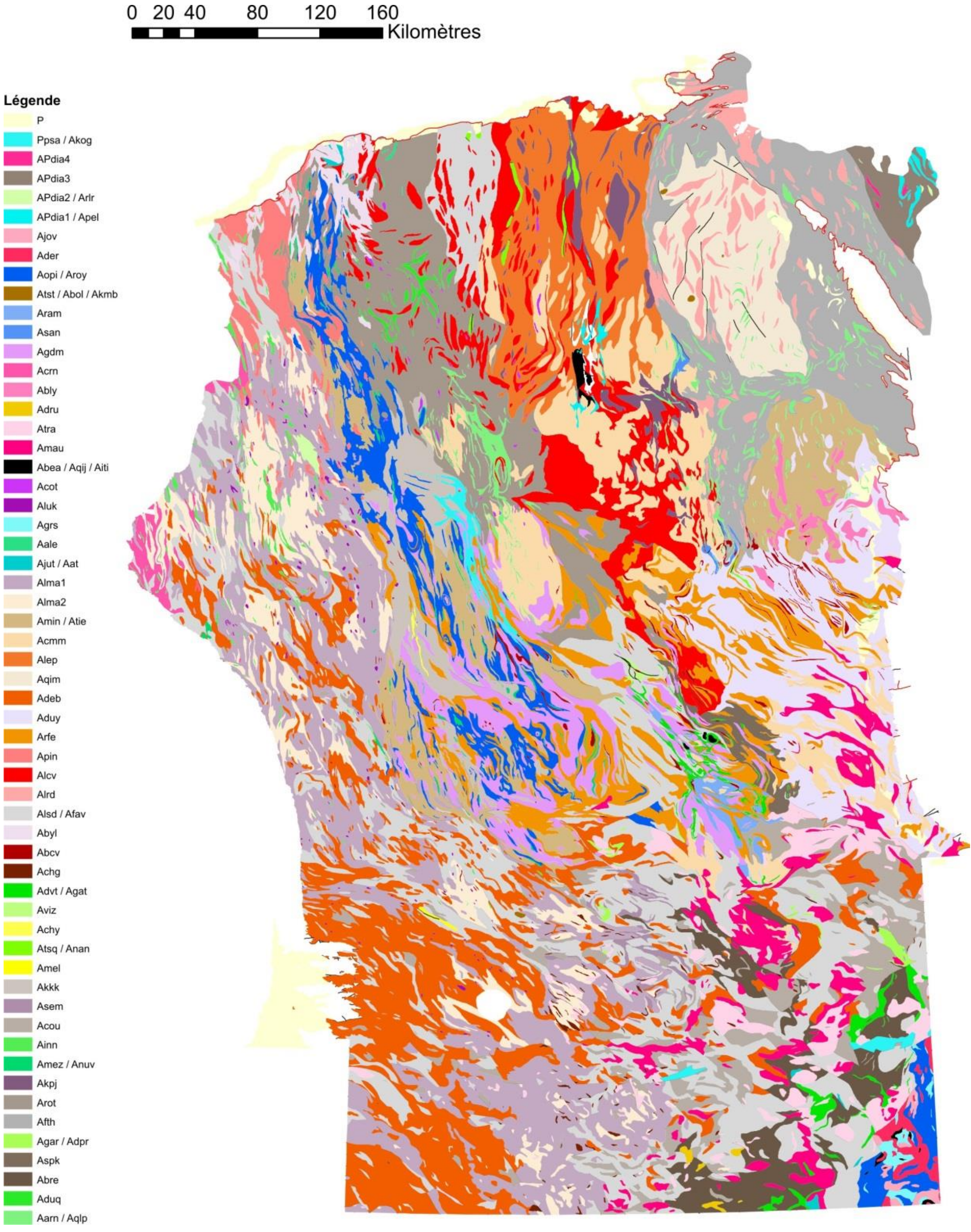


Map patterns and crustal level

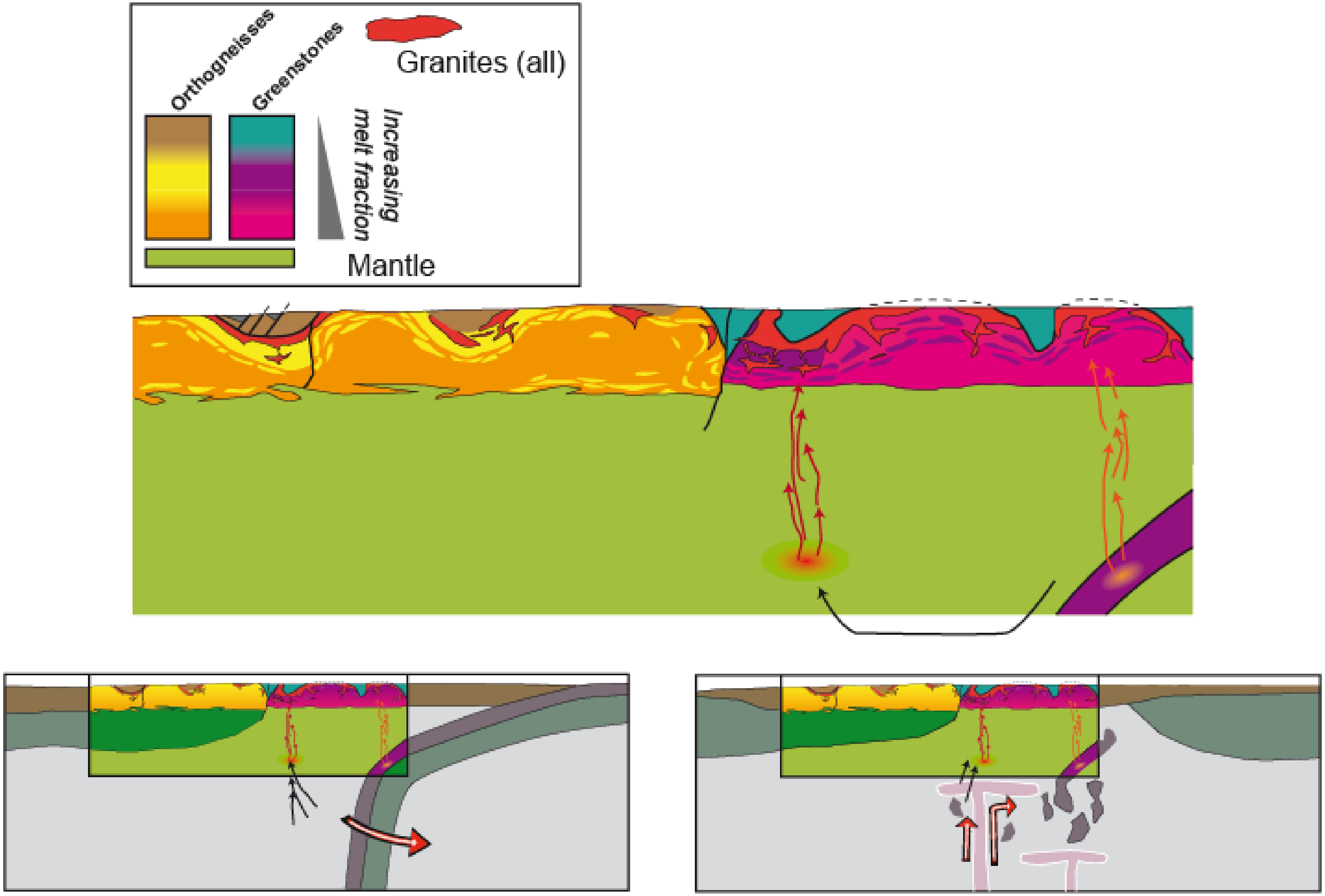


Gary Beakhouse OGS

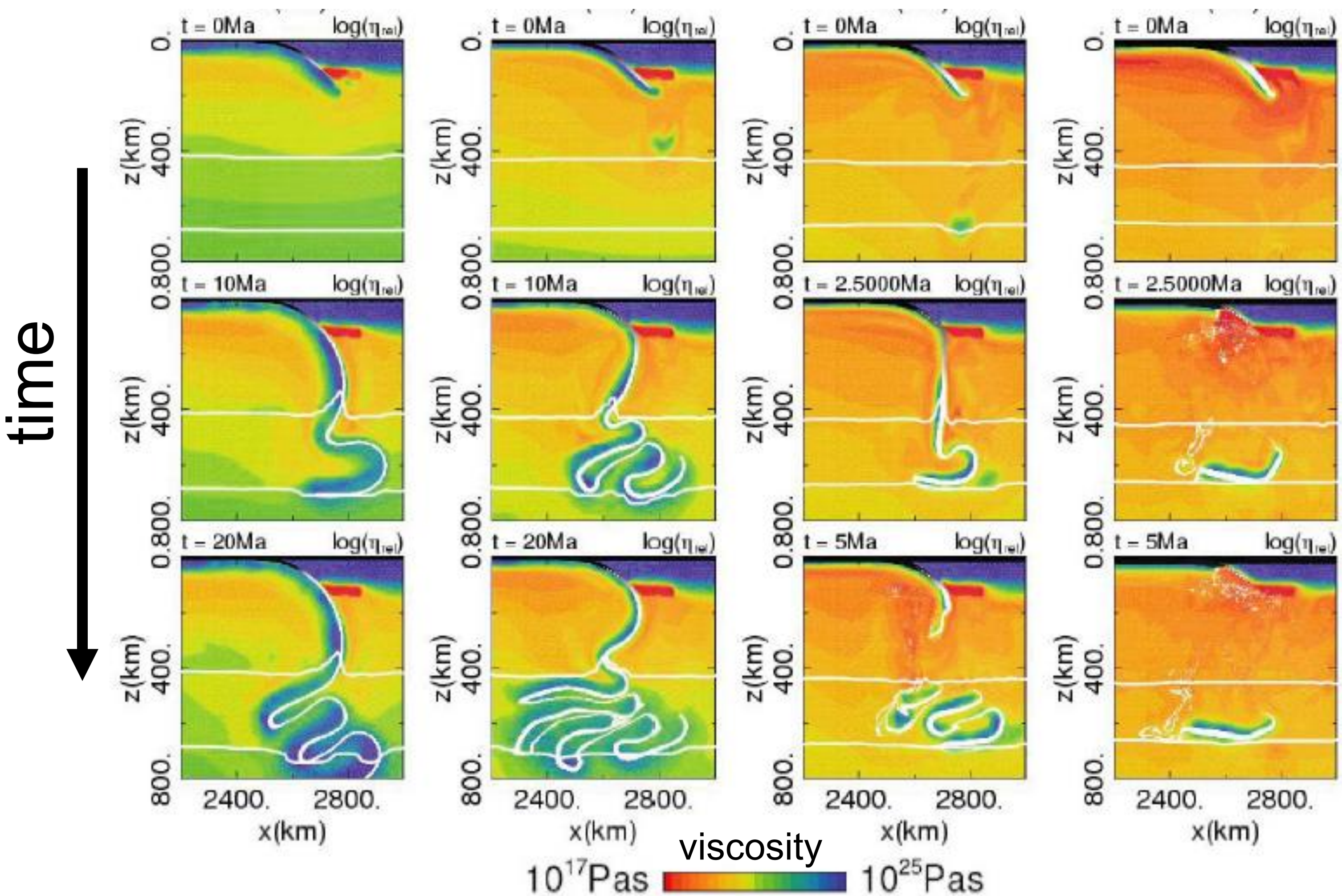
NEPS:
zone fondue



Considérations géodynamiques



Subduction ?



colors = viscosity

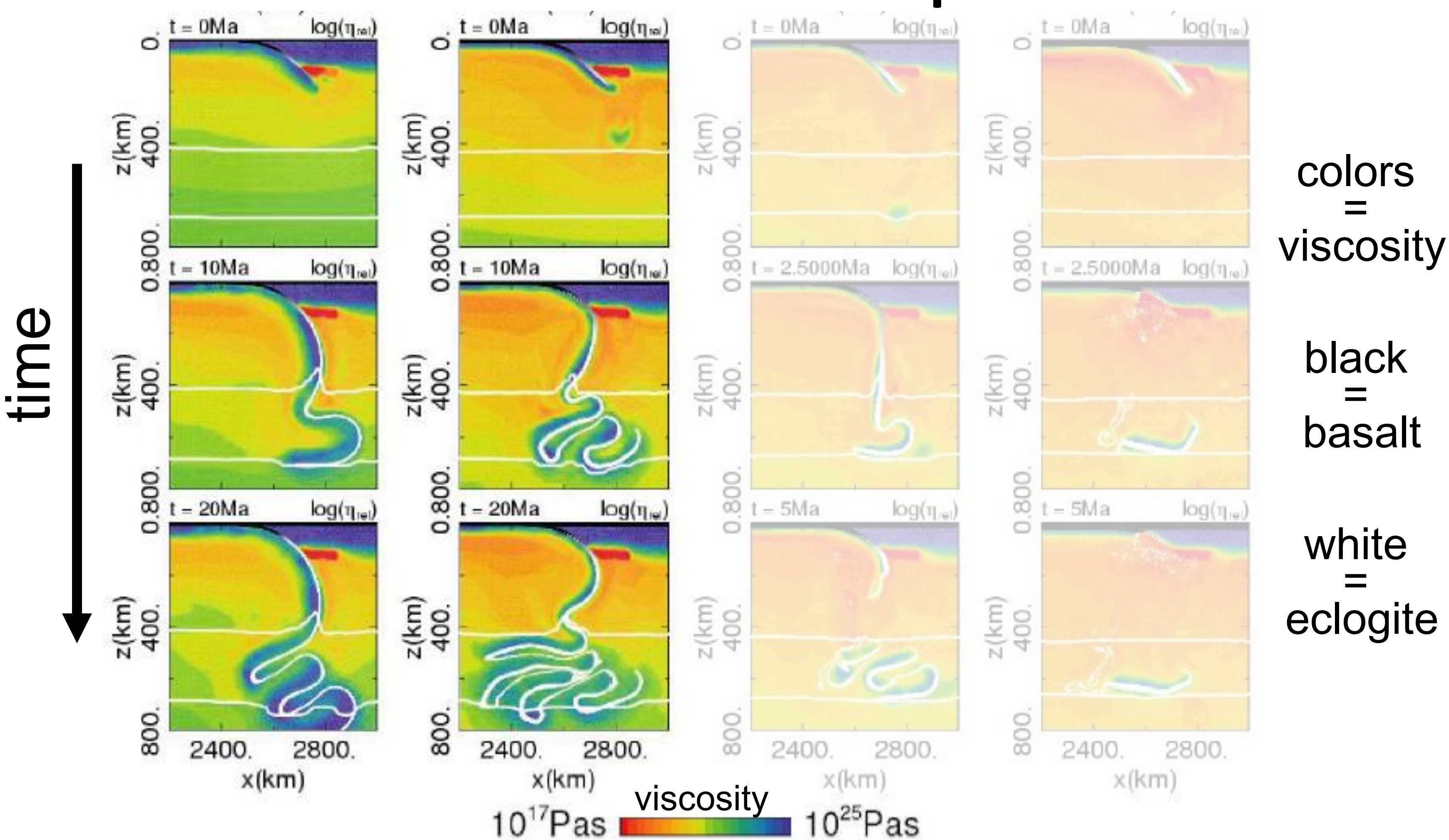
black = basalt

white = eclogite

ΔT_{mantle} = 0°C 100°C 200°C 300°C

(van Hunen & van den Berg, 2008)

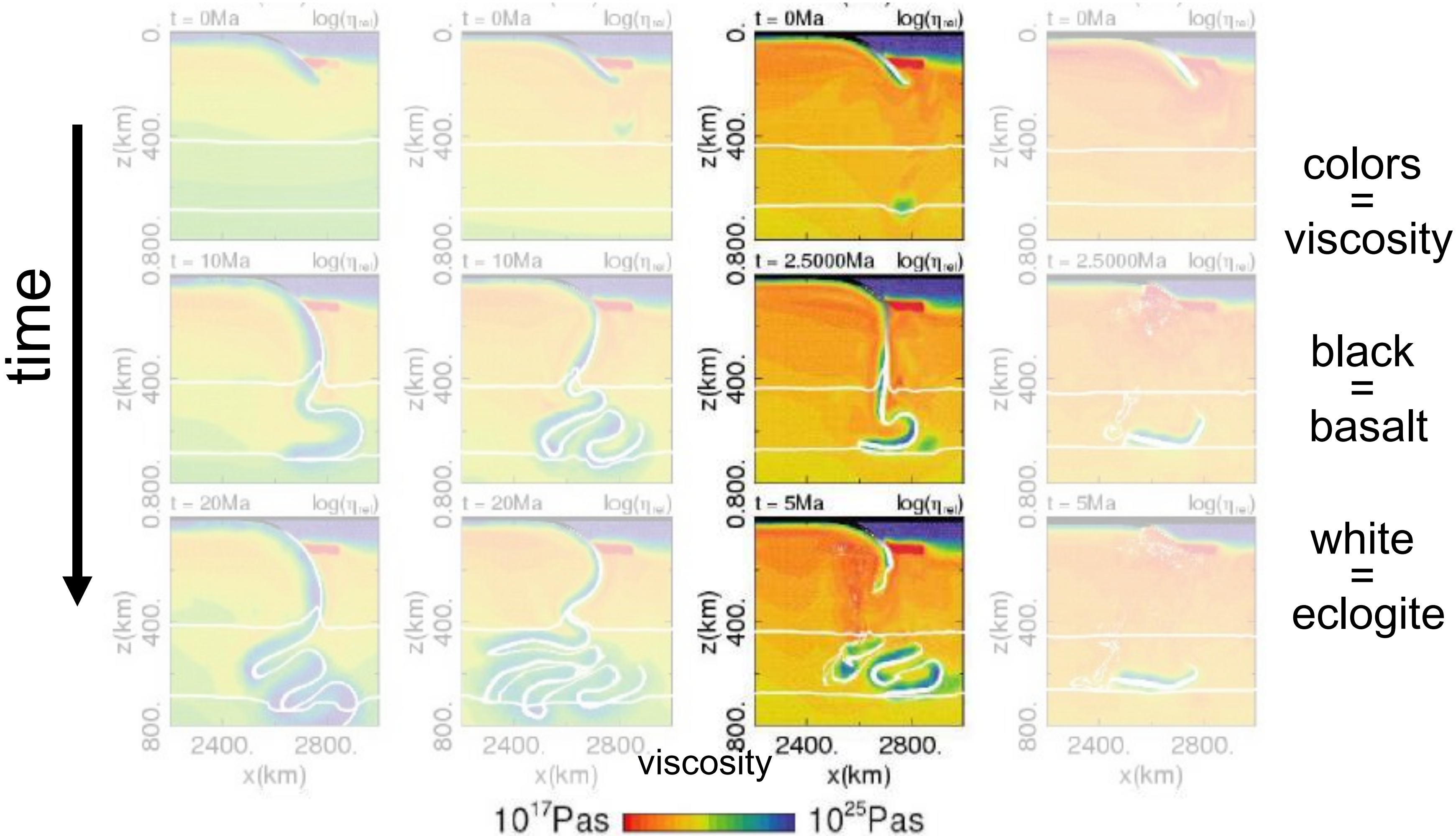
Weaker Archaean plates?



- For low T_{mantle} subduction looks like today's

(van Hunen & van den Berg, 2008)

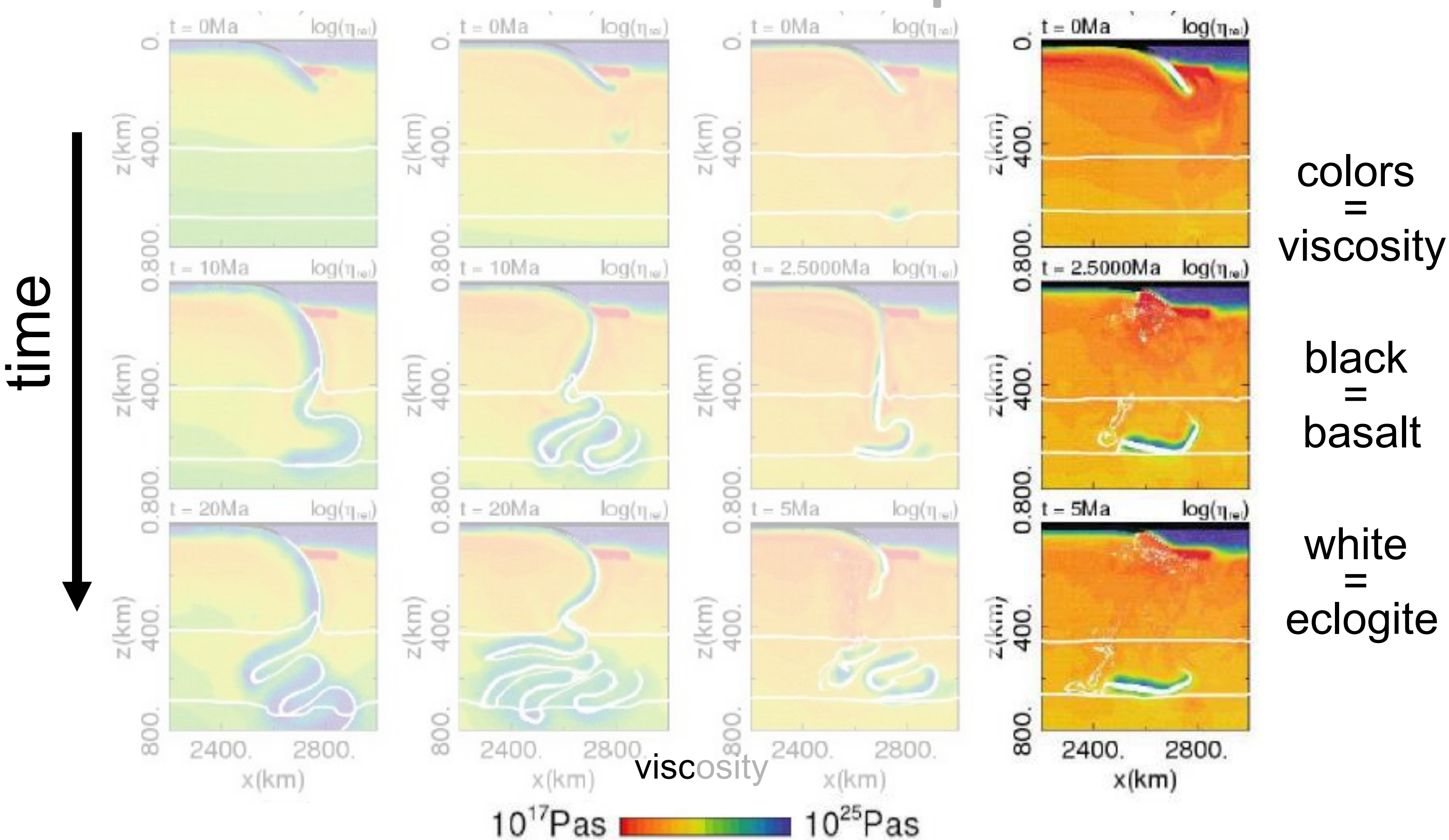
Weaker Archaean plates?



- For higher T_{mantle} frequent slab break-off occurs …

(van Hunen & van den Berg, 2008)

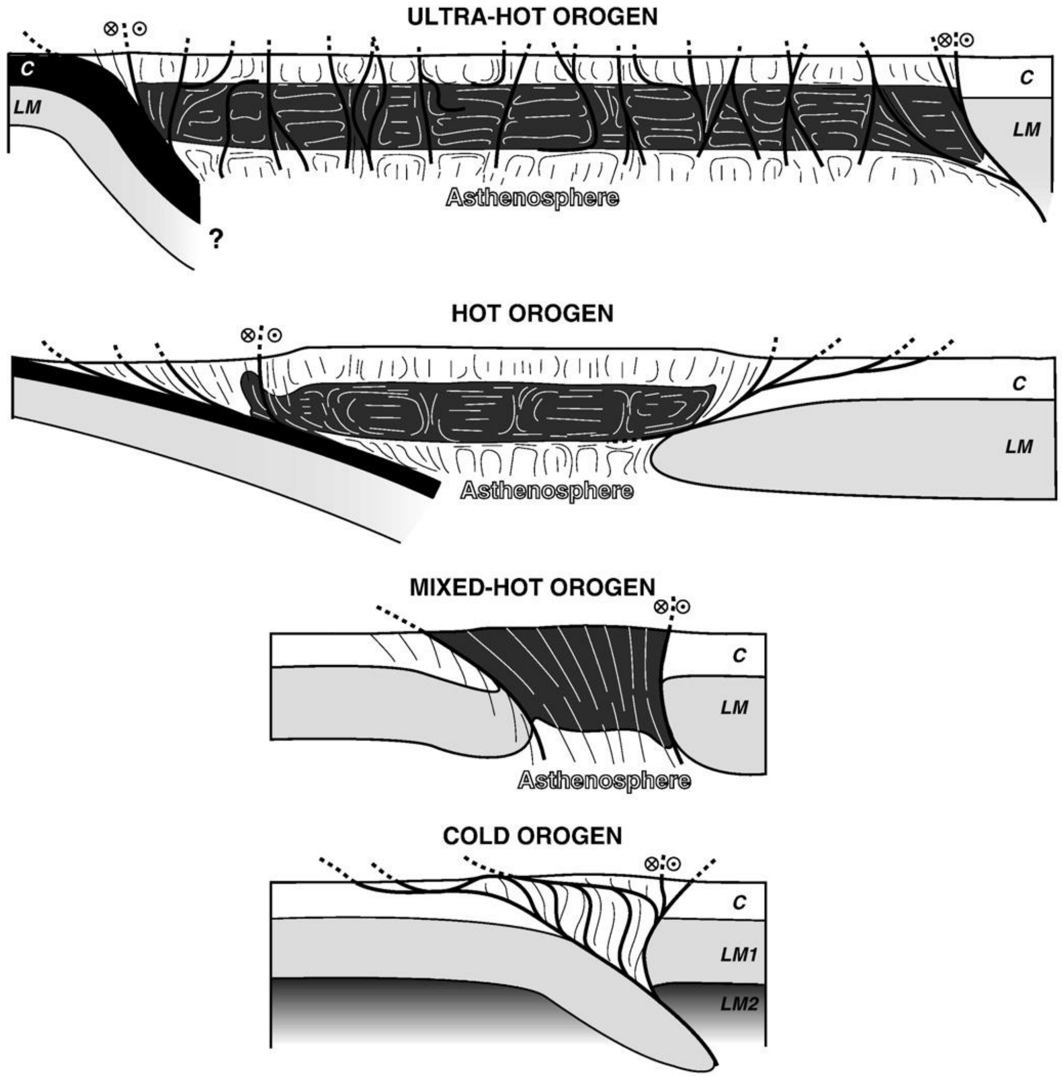
Weaker Archaean plates?



- … or subduction completely stops.

(van Hunen & van den Berg, 2008)

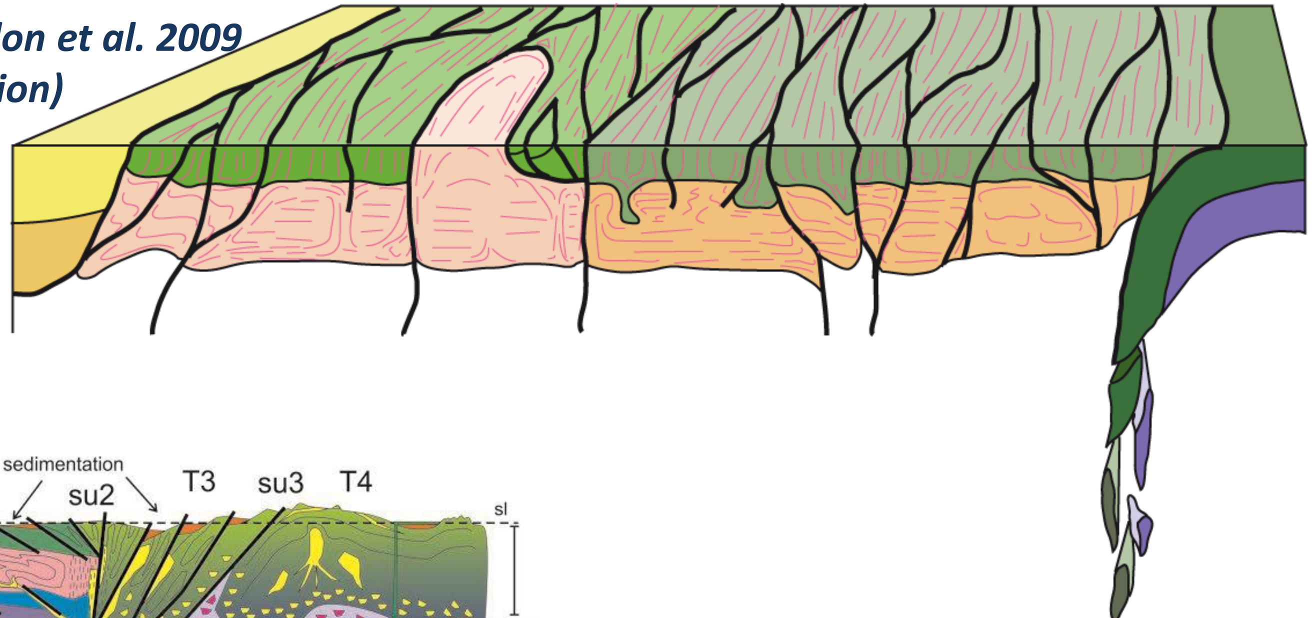
Collision ?

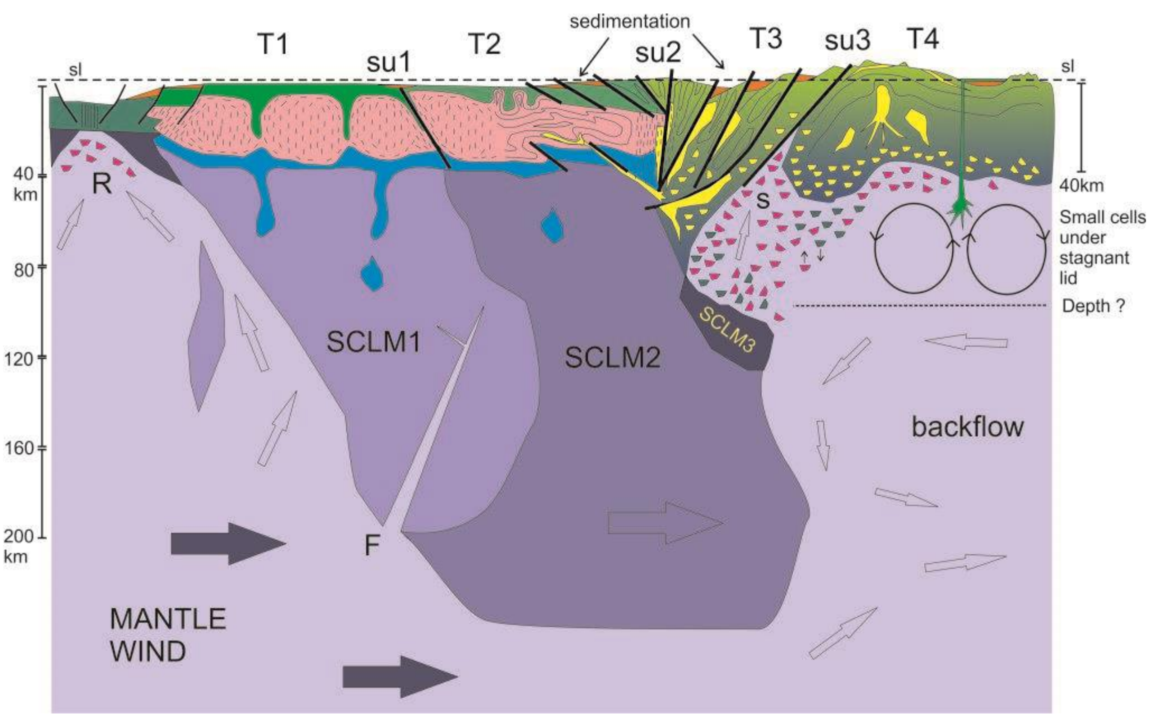


Chardon et al. 2009

Subduction and collision – they may not look like what we expect

Hot orogens, inspired by Chardon et al. 2009 (adding discontinuous subduction)





J. Bédard's « snarc-ish » Earth (2012)

Le message…

- Les granites reflètent la construction, la différentiation et la stabilisation de la croûte continentale
- Origine crustale (surtout) mais il y a aussi des composants mantelliques
- Les granites crustaux reflètent surtout leur source, un peu les conditions de fusion: différentiation progressive de la croûte
- Les plutons de la croûte supérieure sont les traces de l’extraction de liquide de la croûte inférieure fondue


Merci !
Barberton (R.S.A.)
Syénites et granites « tardifs » (3.1 Ga) intrudant les gneiss TTG à 3.45 Ga