CAPES 2010

Les grands processus dans les chaînes de Montagne

Exemples des Alpes, de l'Himalaya et de la chaîne Varisque

Stéphane Guillot

CNRS – ISTerre

Observatoire de Grenoble
Université de Grenoble

CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE

INSU

UNIVERSITE JOSEPH FOURIER SCIENCES, TECHNOLOGIE, MEDECINE

Plan

Introduction

Les grandes étapes du cycle orogénique

- L’accrétion océanique
- La subduction océanique
- L’obduction
- La subduction continentale
- La collision
- Le retour à l’équilibre

Application aux Alpes, l’Himalaya, la Chaîne Varisque

Conclusion

Qu'est ce qu'une chaîne de montagnes ?

Une zone d ’anomalie topographique positive

Une zone d ’épaississement de la croûte continentale

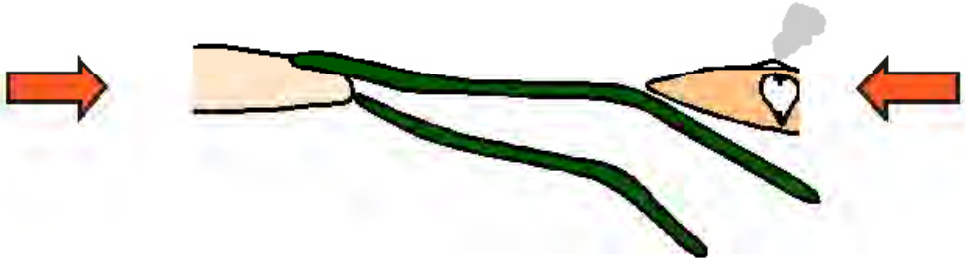
Quels sont les grands types de chaînes de montagnes ?

Collision

Alpes

Himalaya

Varisque



Obduction

Oman

Papouasie

Nlle Calédonie

Subduction

Cord. N américaine

Cord. Andes

Les grandes étapes du cycle orogénique

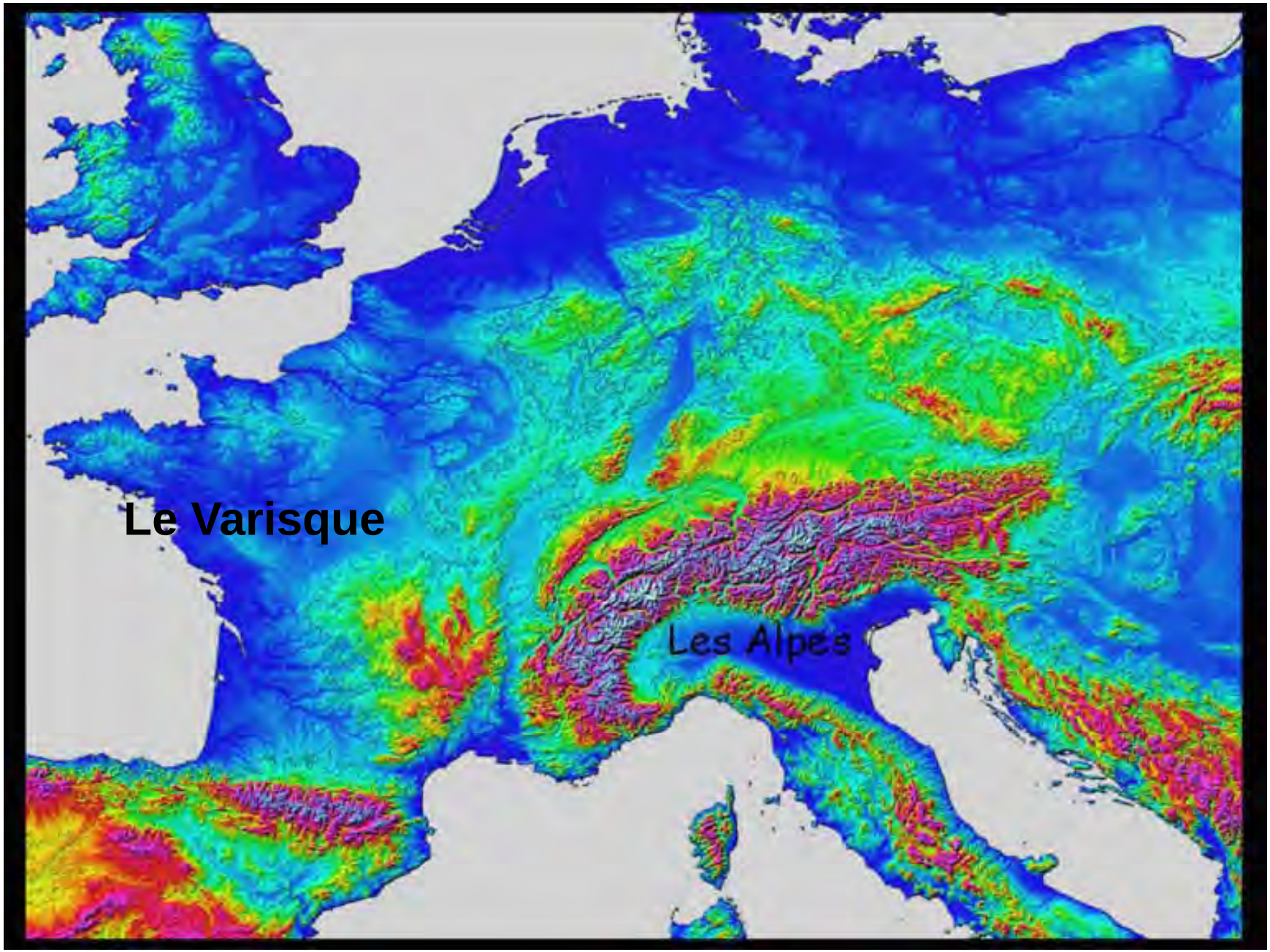
- Le Rifting

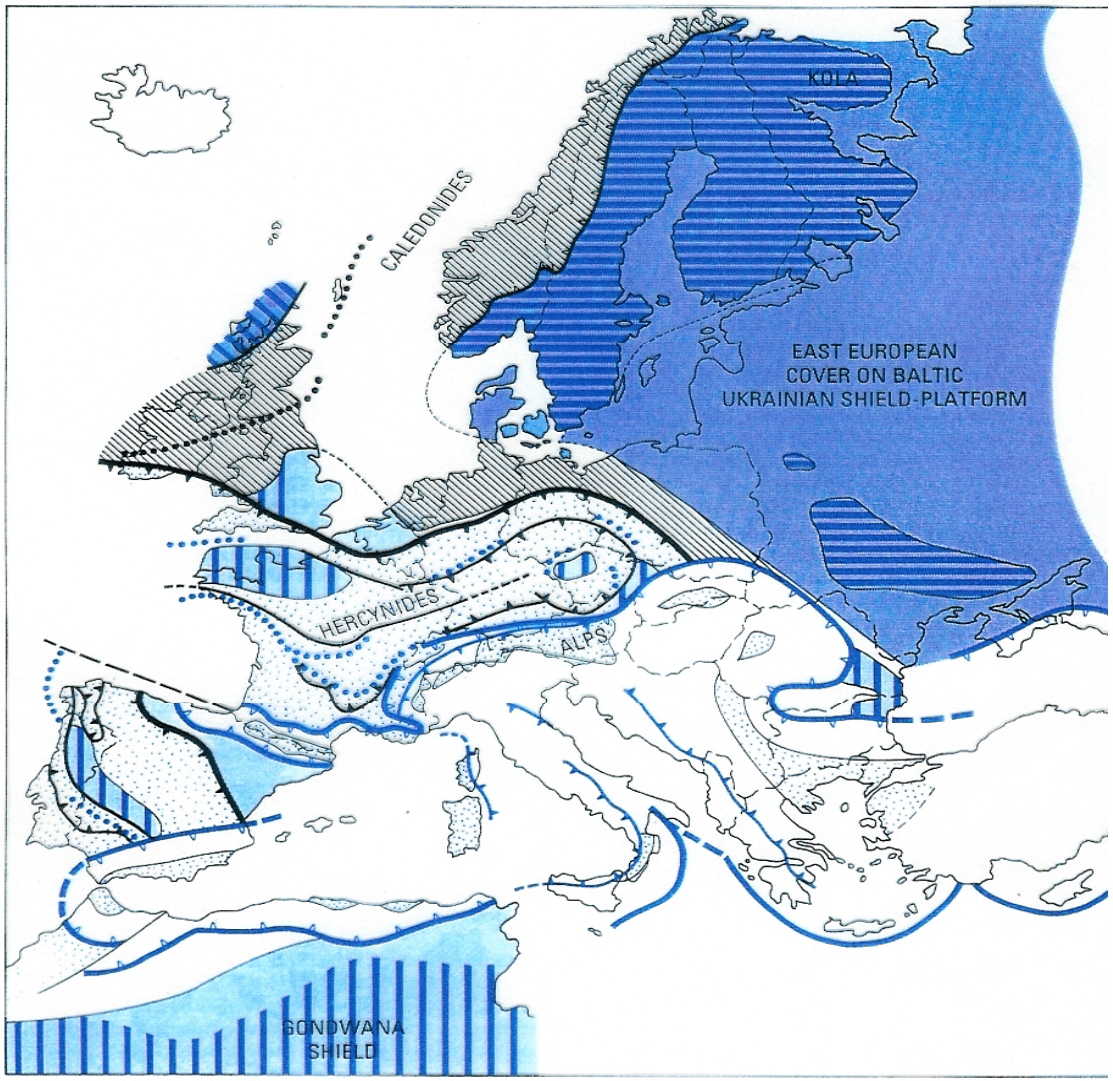
– La subduction océanique

– La subduction continental

– La collision

– Le retour à l’équilibre


Le Varisque
Les Alpes



PRECAMBRIAN SHIELDS 3500 to 600 Ma

Fennoscandian
Ukrainian

Laurentian

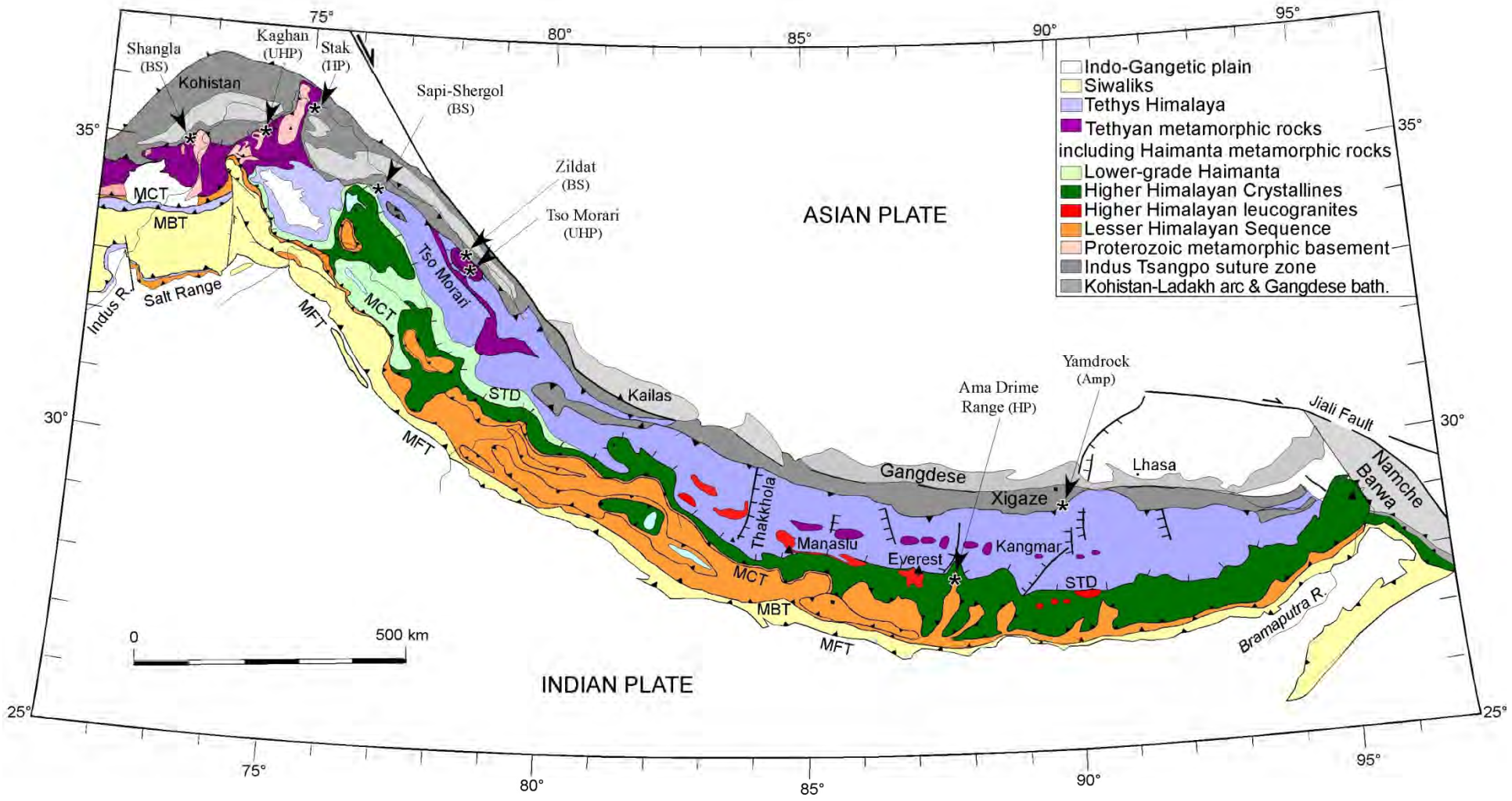
Gondwanian
(Cadomian p.p.)

Alpine belt
(100 to present)

a Hercynian belt
(400 to 260 Ma)

a Caledonian belt
(550 to 400 Ma)

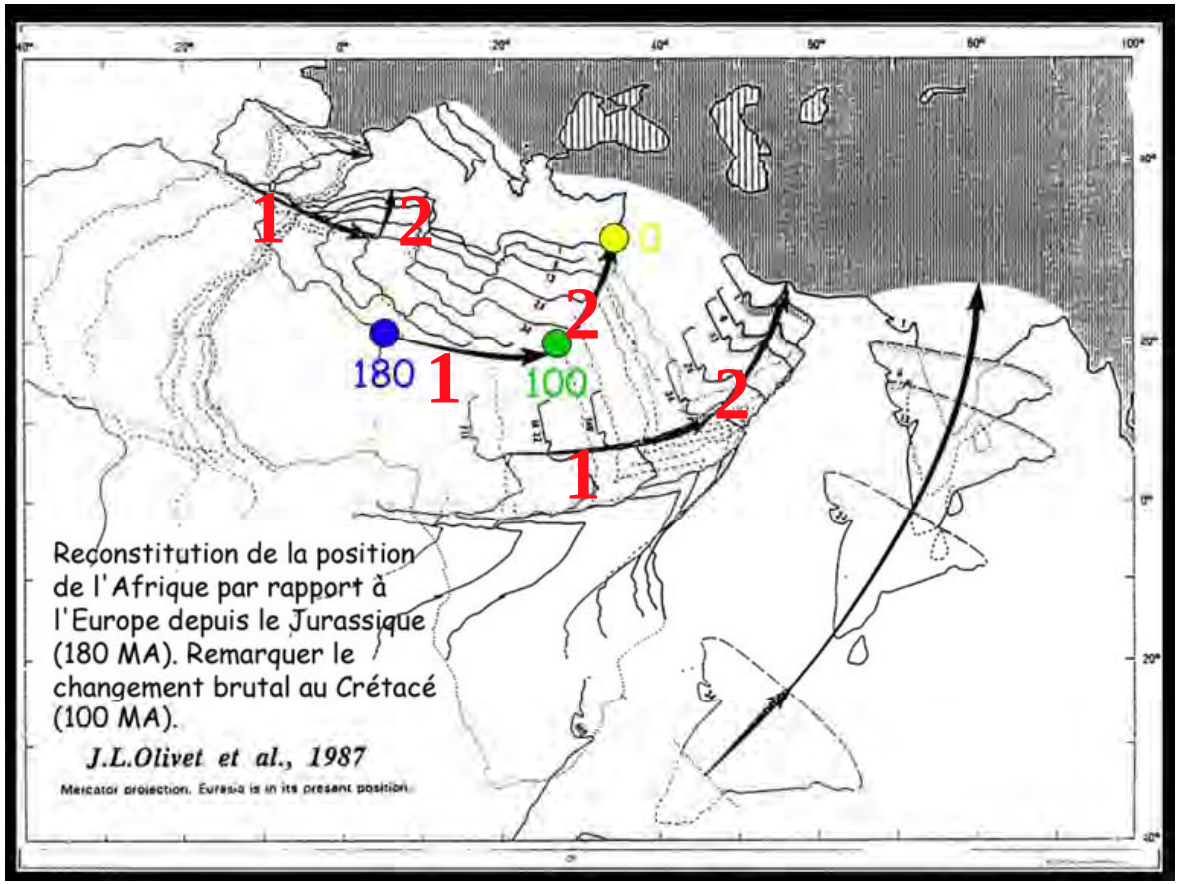
a - Suture zone : remnants of closed oceanic areas



Guillot et al., 2008

Mvt - relatif Afrique - Eurasie

1) **Mouvement divergent (déformations en extension)**
2) **Convergence subduction puis collision (déformations en racourcissement)**

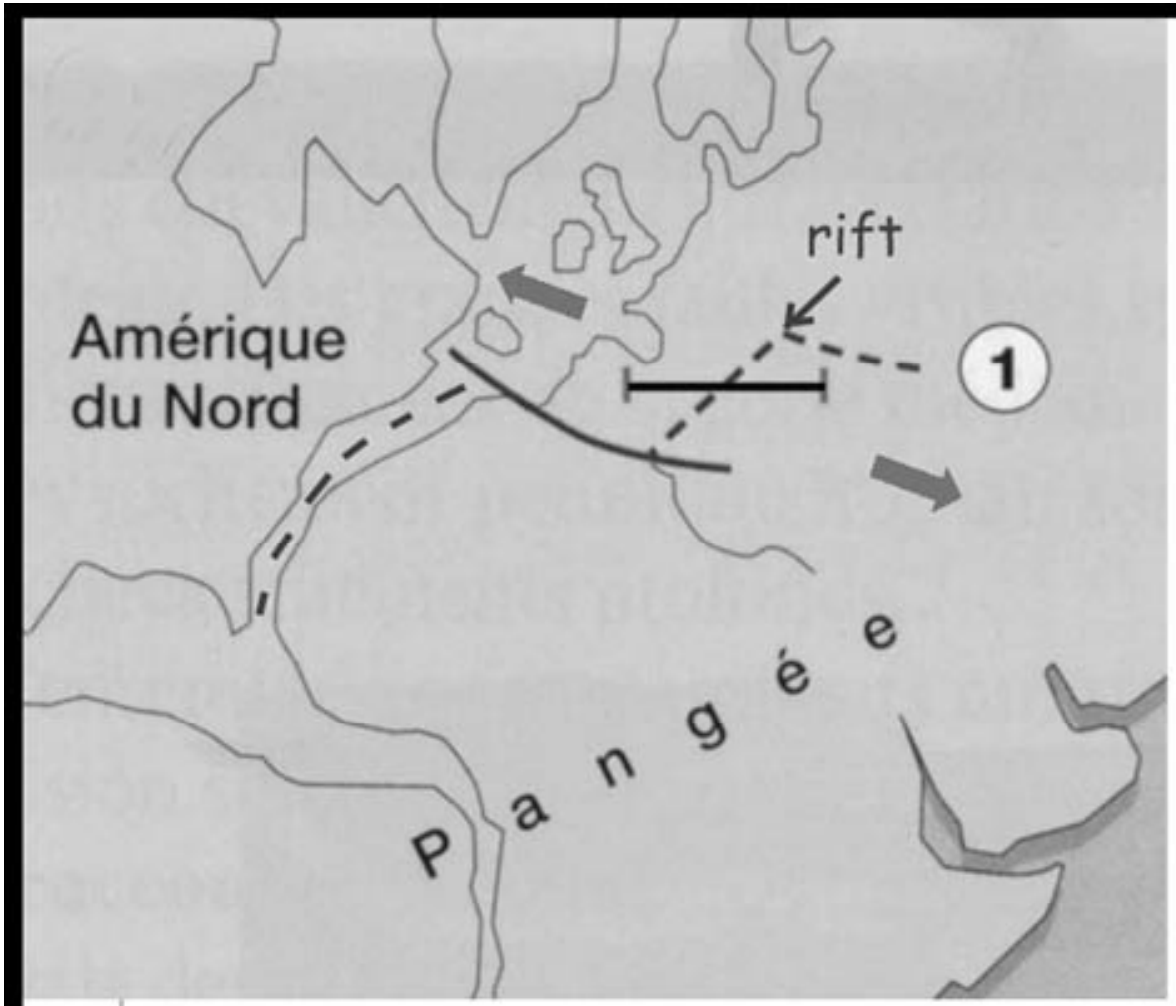


Les marqueurs du rifting océanique

- Extension de la marge: bien preservée dans les alpes

- Des témoins de la lithosphère océanique:

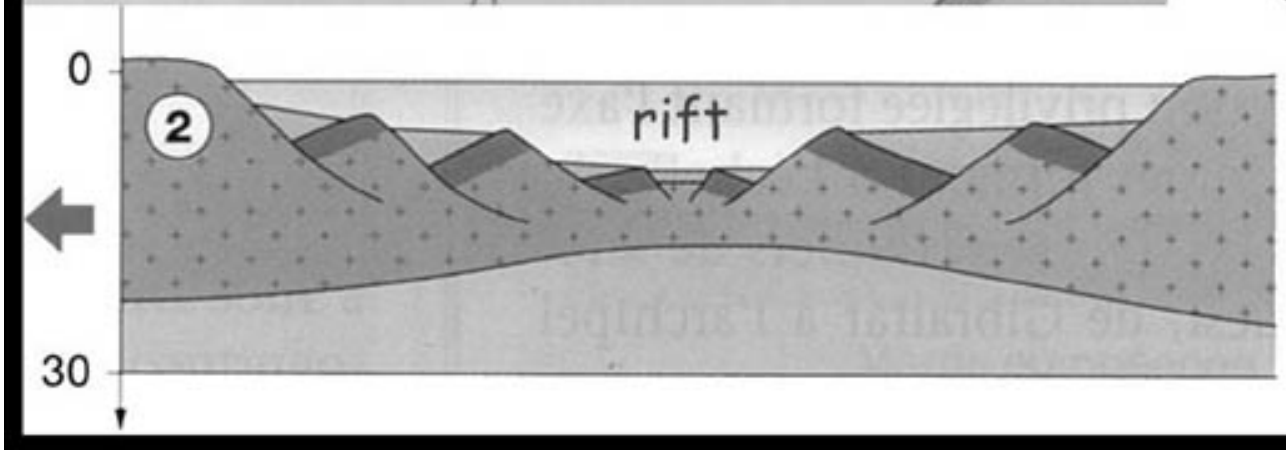
des ophiolites dans les 3 chaînes



A la fin du cycle Hercynien, les Continents sont regroupés (« pangée »).

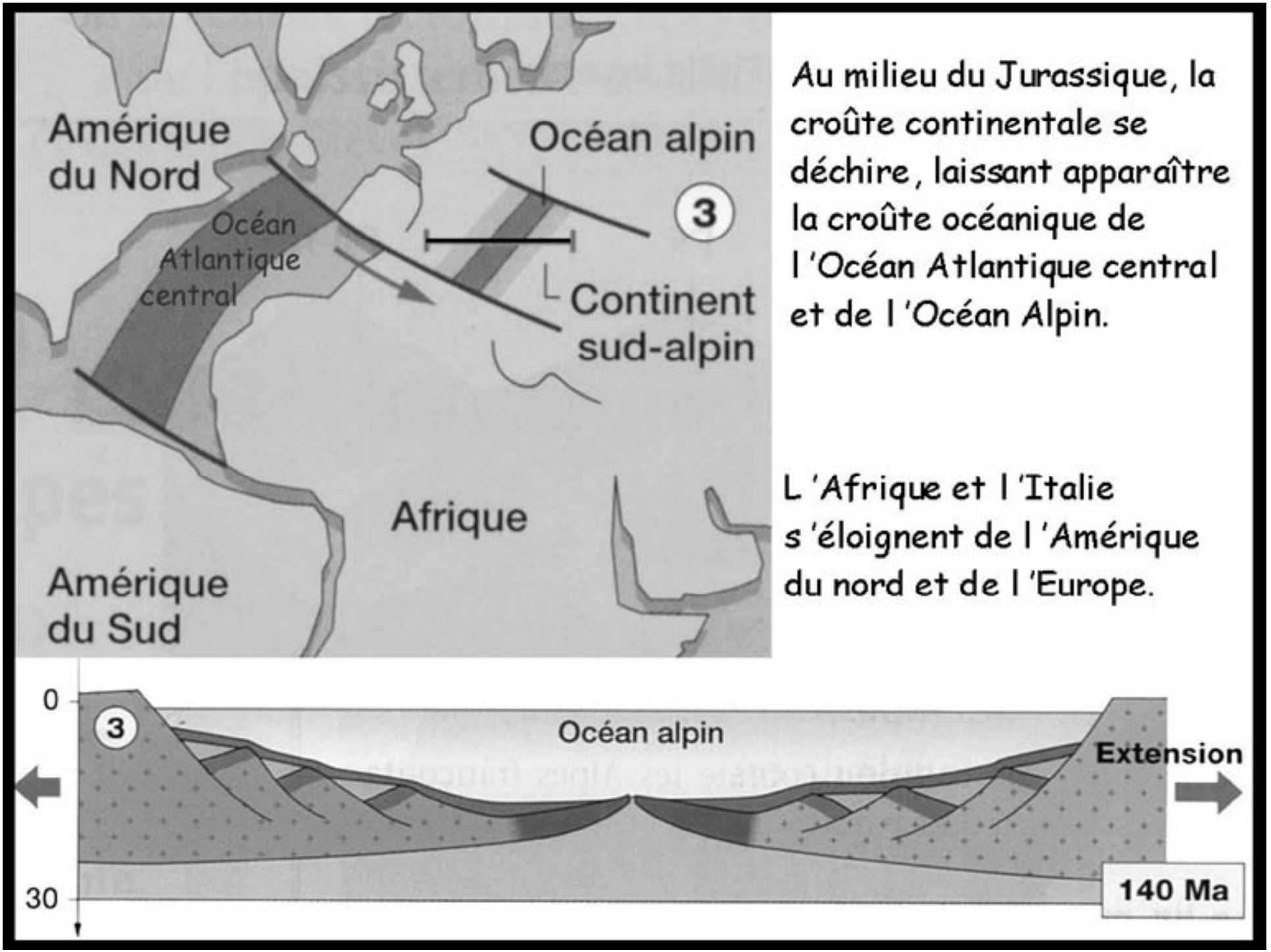
L 'Océan Atlantique n 'existe pas encore.

Mais au tout début du Jurassique, la croûte continentale commence à être étirée et amincie au niveau des « rifts ».



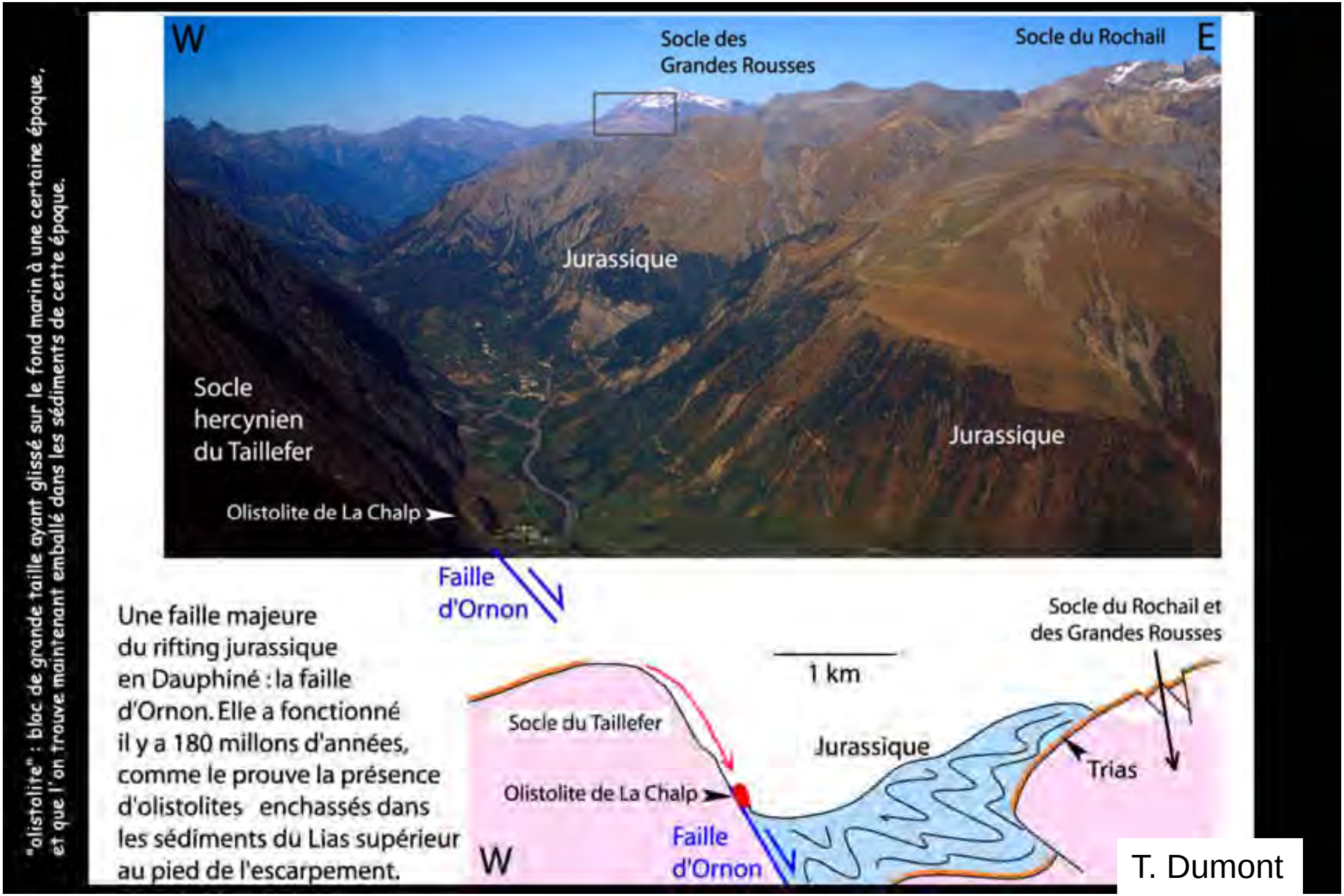
Extension

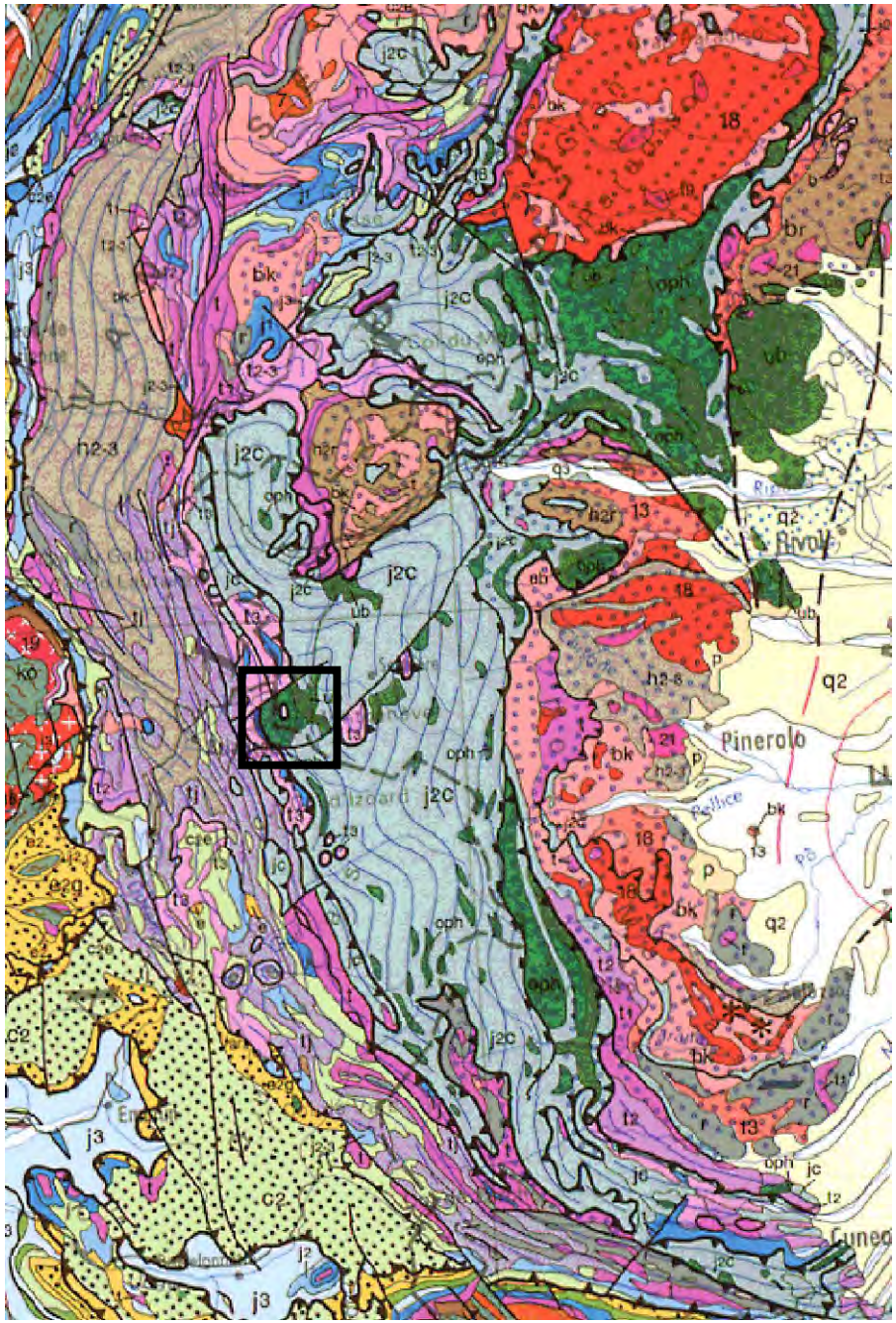
180 Ma

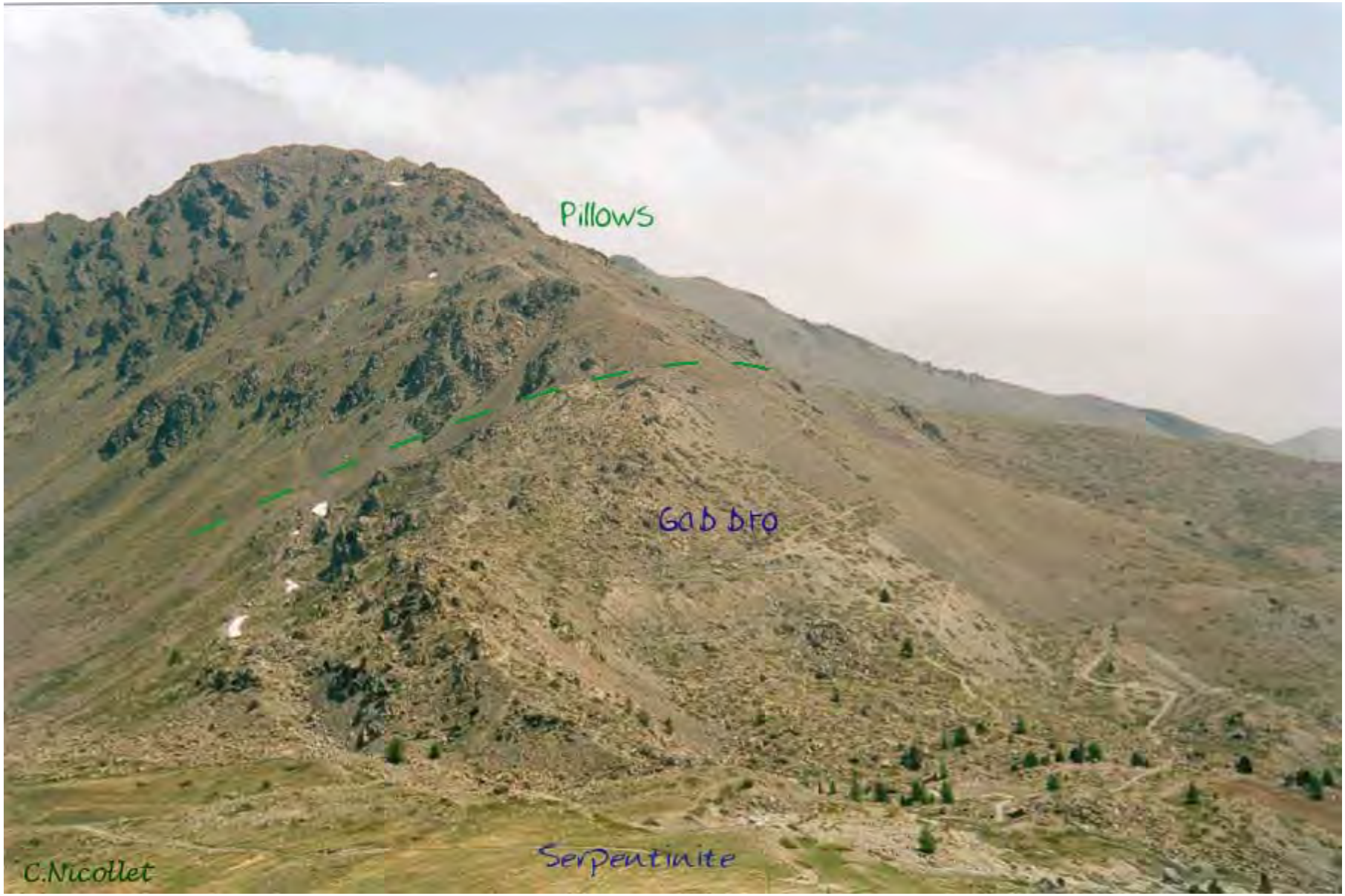

Amérique du Nord
Océan alpin
3
Océan Atlantique central
Continent sud-alpin
Afrique
Amérique du Sud
Au milieu du Jurassique, la croûte continentale se déchire, laissant apparaître la croûte océanique de l'Océan Atlantique central et de l'Océan Alpin.
L'Afrique et l'Italie s'éloignent de l'Amérique du nord et de l'Europe.
0
3
Océan alpin
Extension
30
140 Ma

Evidences des anciennes failles normales

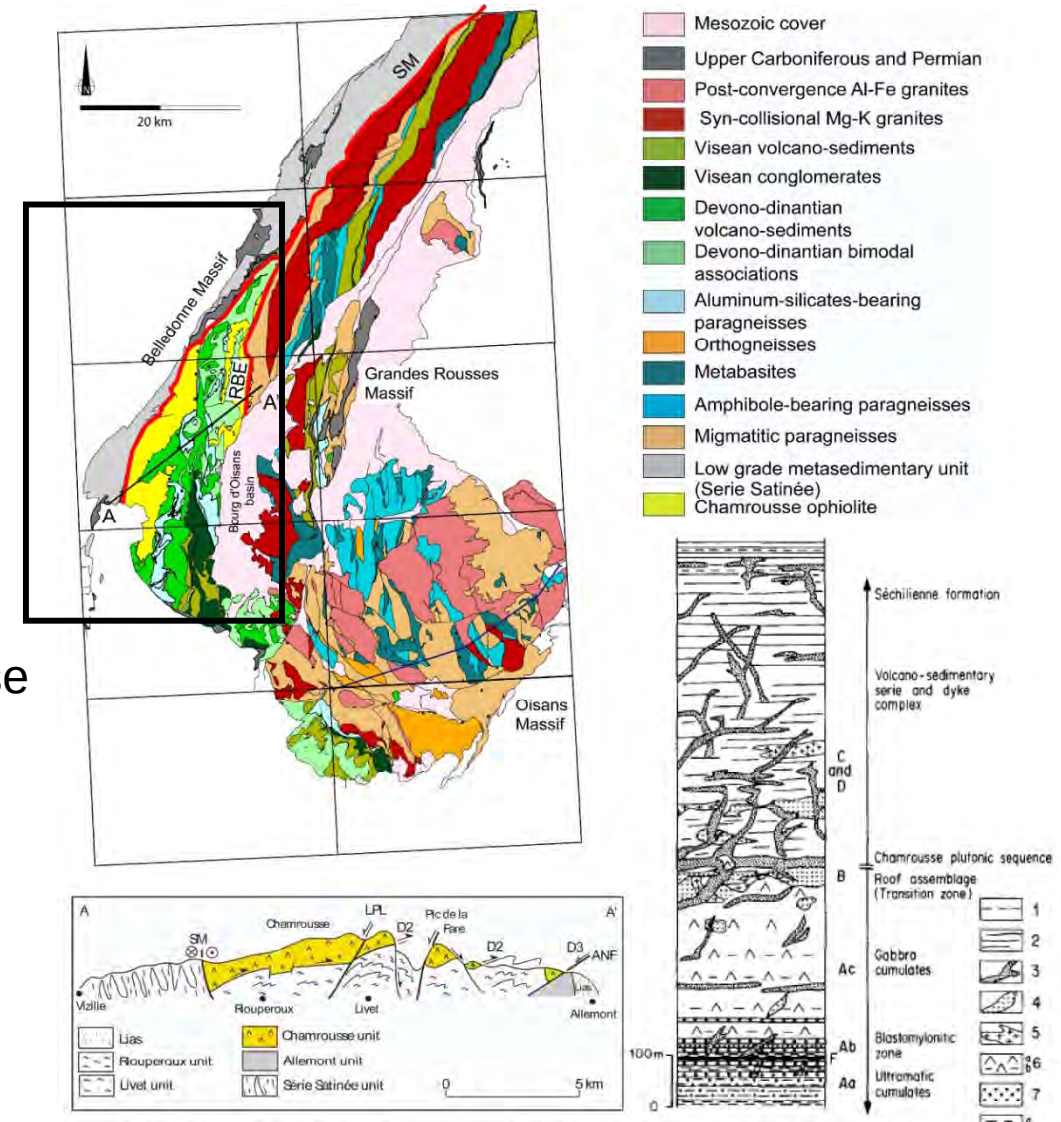
Evidences des anciennes failles normales




Pinerolo
Rivoli
Cuneo
j2c
j3
h2-3
h2-8
q2
oph
bk
18
13
21
p
t2
t3
c2
j2


Pillows
Gabbro
Serpentinite
C.Nicollet

Chamrousse
500 Ma

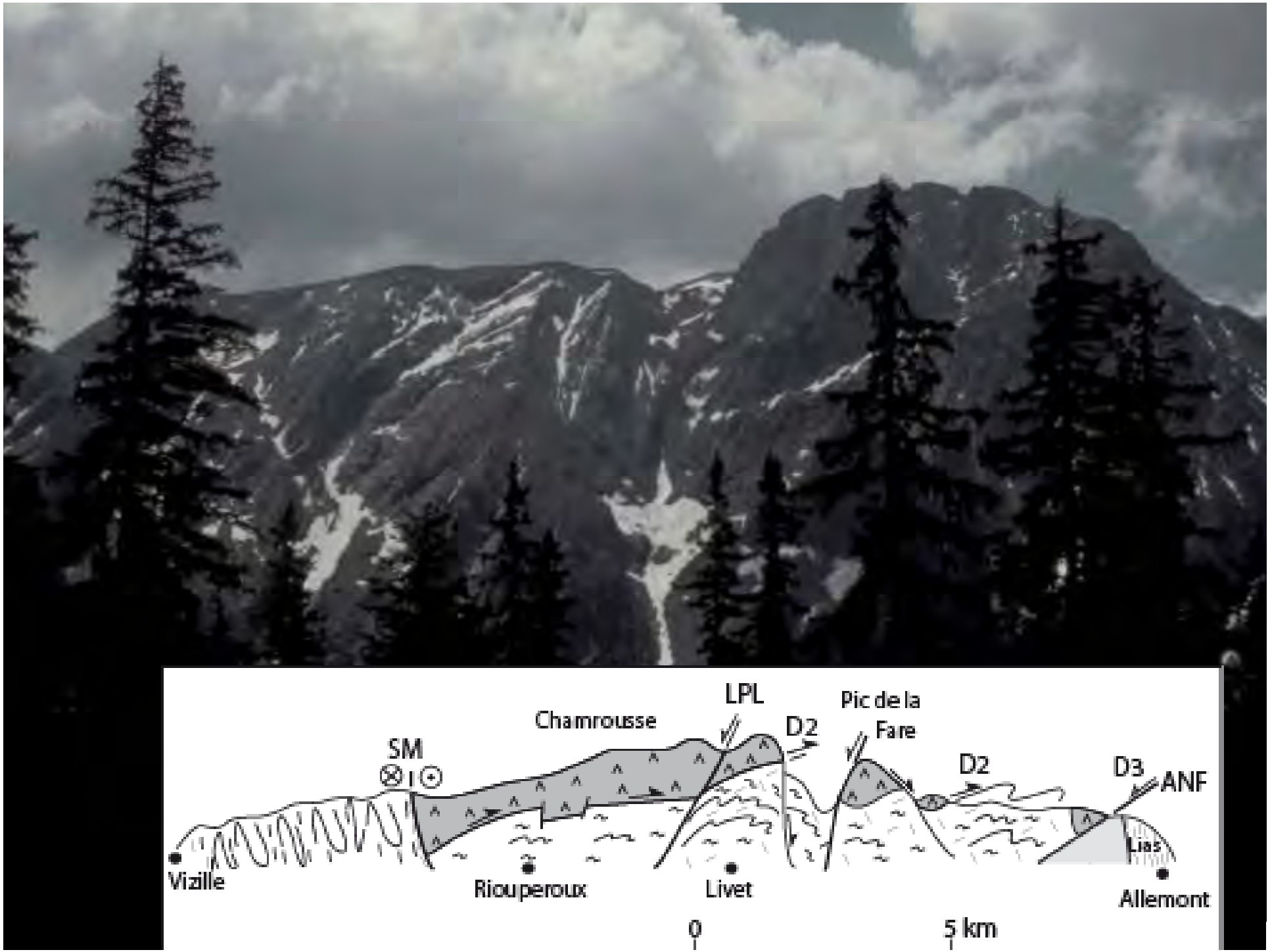


Coupe du massif de Belledonne au niveau de la vallée de la Romanche

D'après Ménot, 1988
Fernandez et al., 2002
di Paola et al., in press

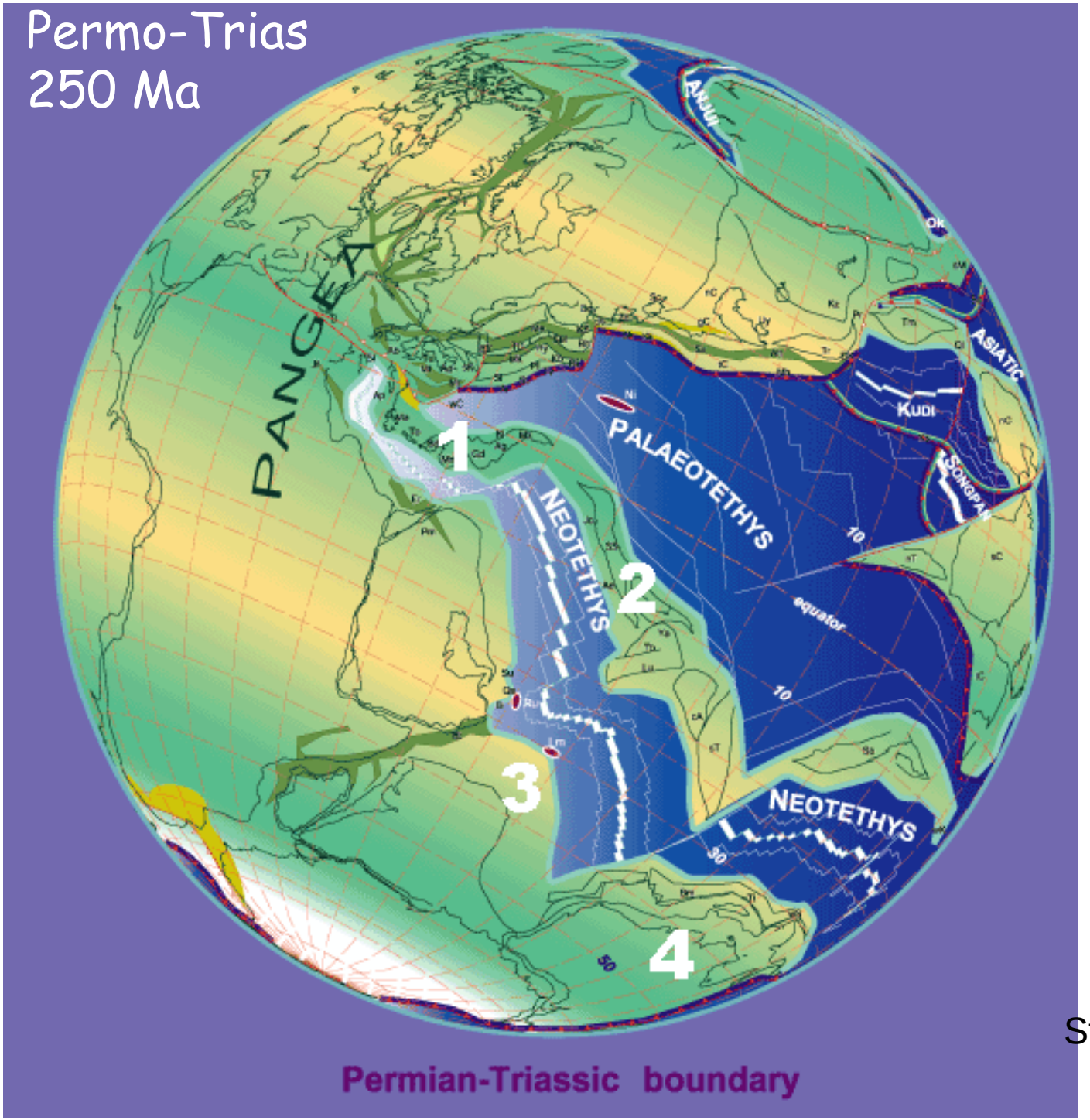
Fig. 2. Schematic reconstruction of the Chamrousse ophiolite with the primitive lithostratigraphic polarity (actually overturned). *1* = metapelites; *2* = amphibolites and leptynites of igneous (Na-granites and keratophyres) and of sedimentary (arenites) origin; *3* = metabasalts and metadolerites; *4* = isotropic metagabbros (fine-grained and pegmatoid); *5* = metaplagiogranites and related rocks; *6* = metacumulates (*a*: massive; *b*: layered); *7* = metapyroxenites, dykelets and cumulates. *8* = serpentinites (*a*) with Ca pyroxenes (*b*), or with spinels (*c*). *A* = plutonic sequence (*Aa*: ultramafites, *Ab*: blastomylonitic zone, *Ac*: gabbroic cumulates); *B* = transition zone or roof assemblage; *C* = volcano-sedimentary series (Séchilienne Formation); *D* = dyke complex (no scale for the dykes).

Guillot, 2007

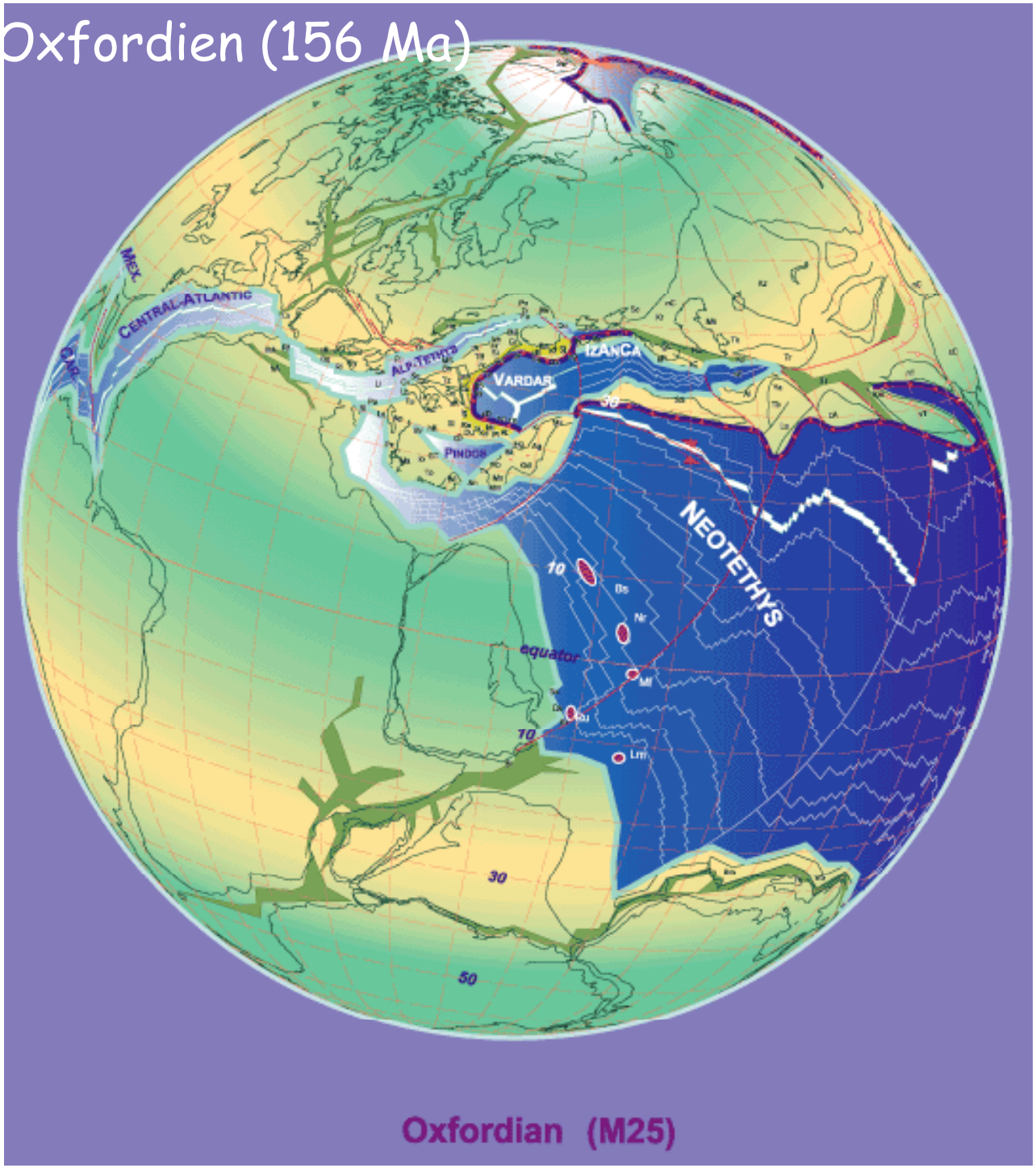

LPL
Pic de la
Fare
Chamrousse
D2
SM
D2
D3
ANF
Lias
Vizille
Riouperoux
Livet
Allemont
0
5 km

Canon
S. Guillot

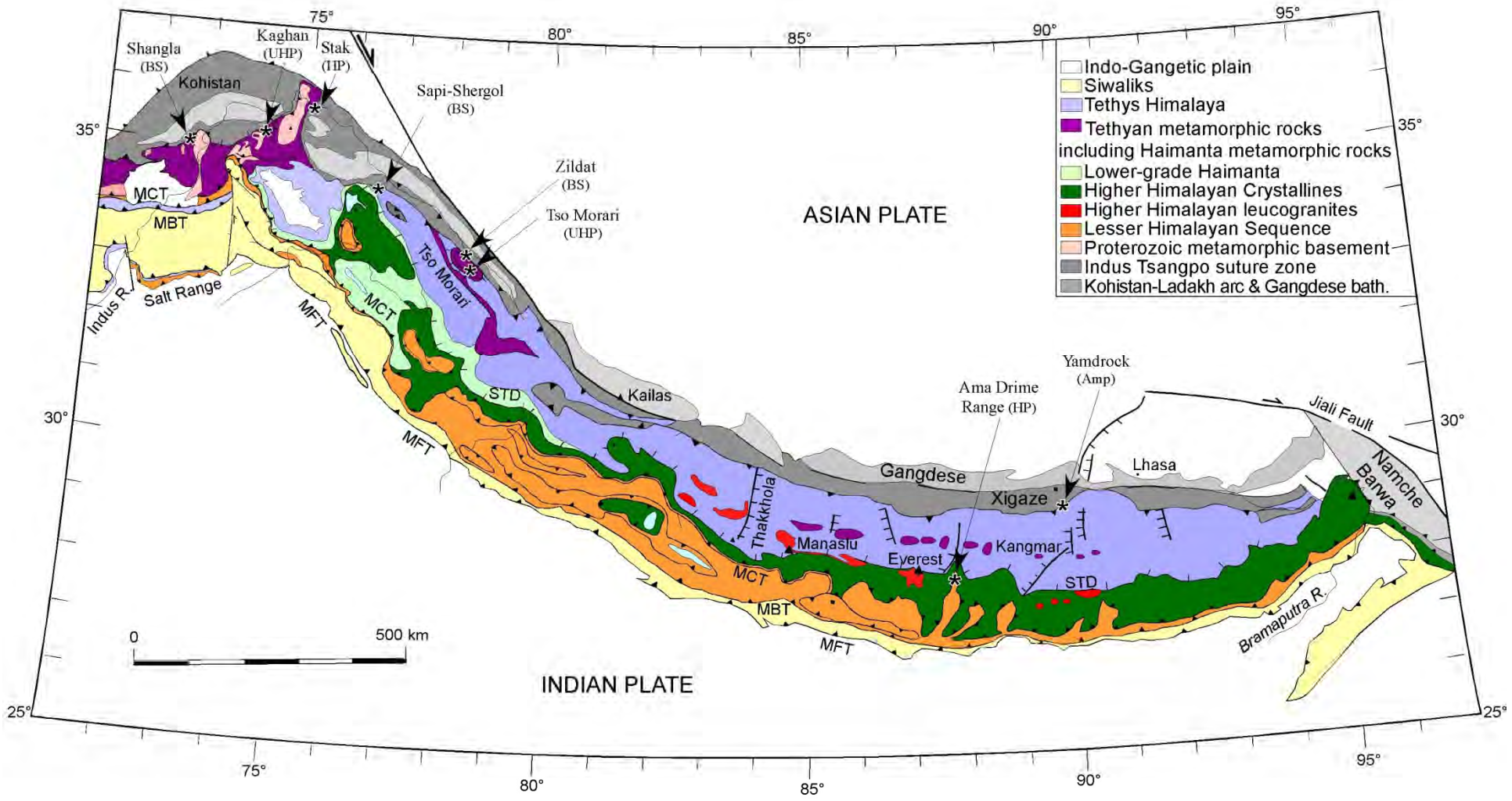
S. Guillot



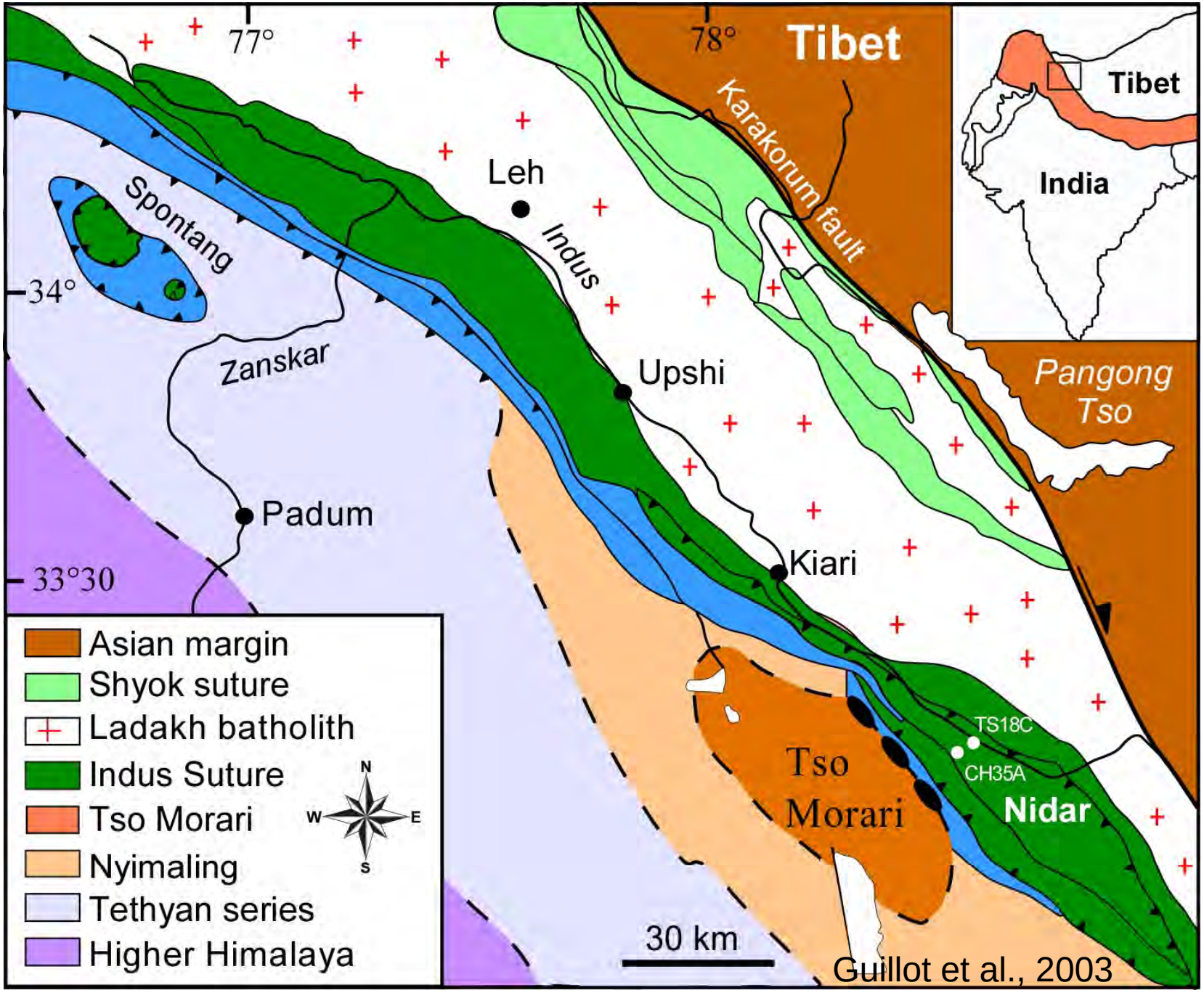
Stampfli, 2005



Stampfli, 2005



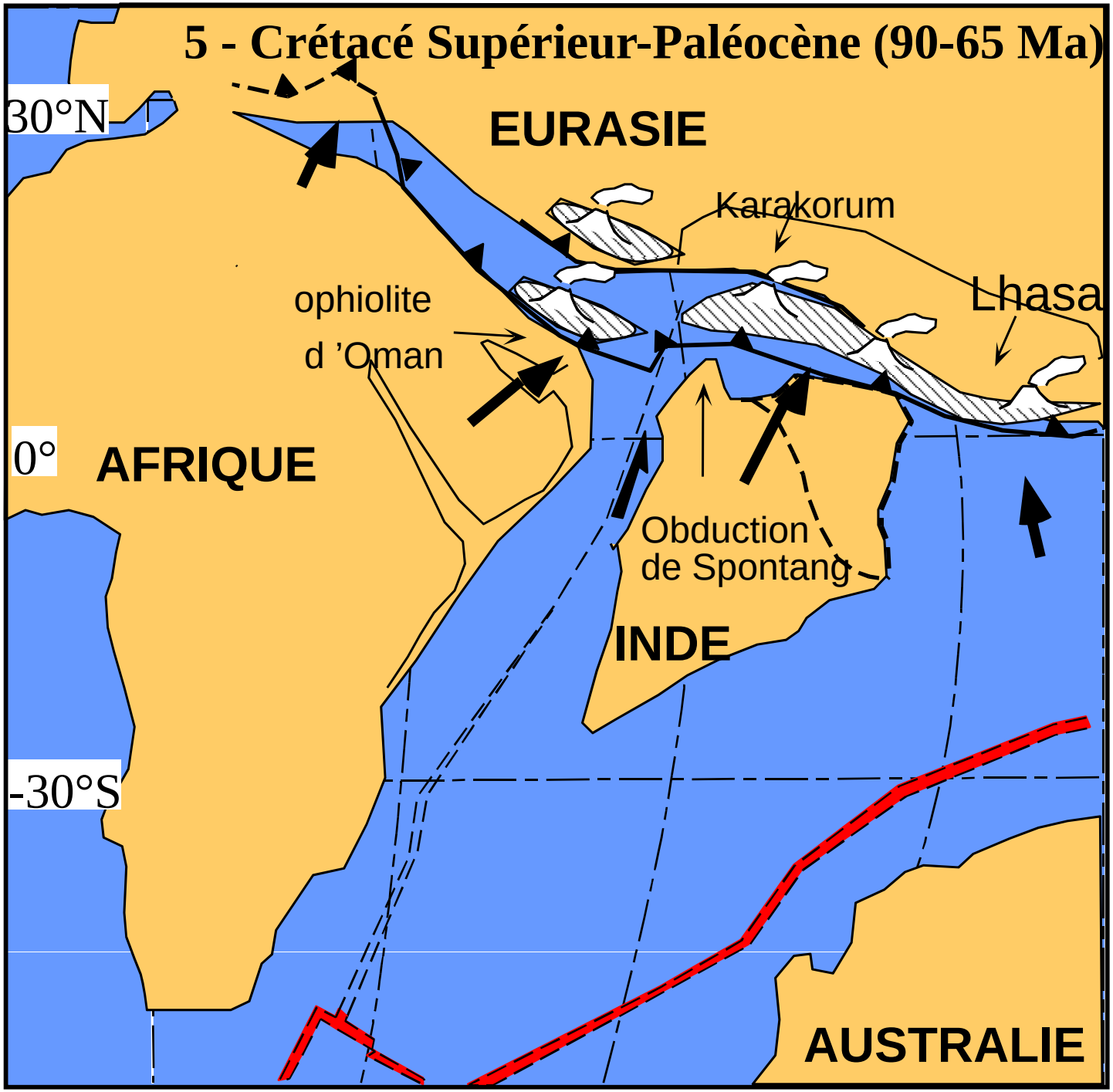
Guillot et al., 2008


77°
78°
Tibet
Karakorum fault
Leh
Indus
Spontang
34°
Zanskar
Upshi
Pangong Tso
Padum
33°30
Kiari
TS18C
CH35A
Tso Morari
Nidar
Tibet
India
Asian margin
Shyok suture
Ladakh batholith
Indus Suture
Tso Morari
Nyimaling
Tethyan series
Higher Himalaya
N
W
E
S
30 km
Guillot et al., 2003

S. Guillot

Les marqueurs de la subduction océanique

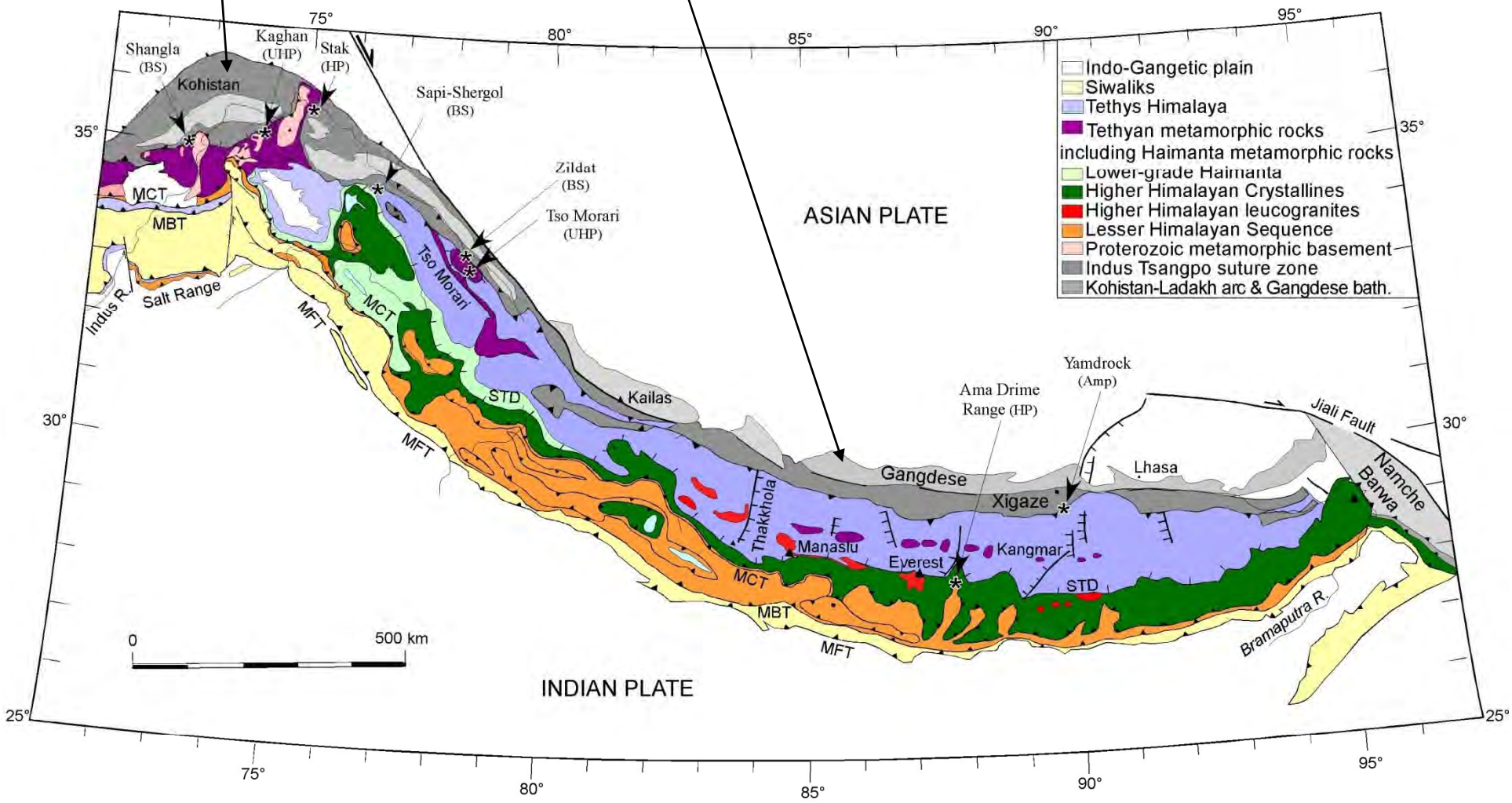
- du magmatisme d’arc ou d’arrière-Arc :
  - Bien préservé en Himalaya
  - Repris dans la collision dans le Varisque
  - Absent dans les alpes



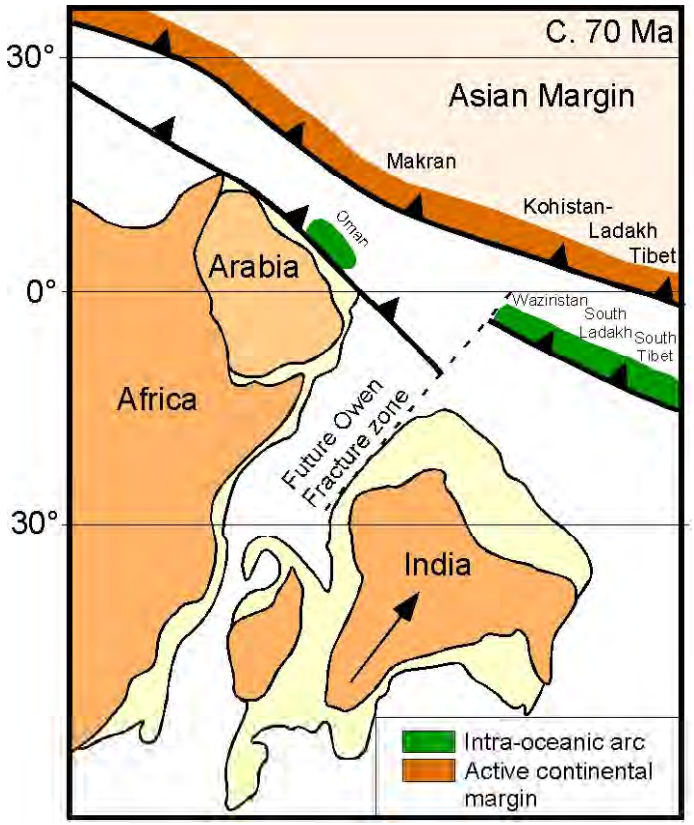
Rolland, 2002

Arc volcanique

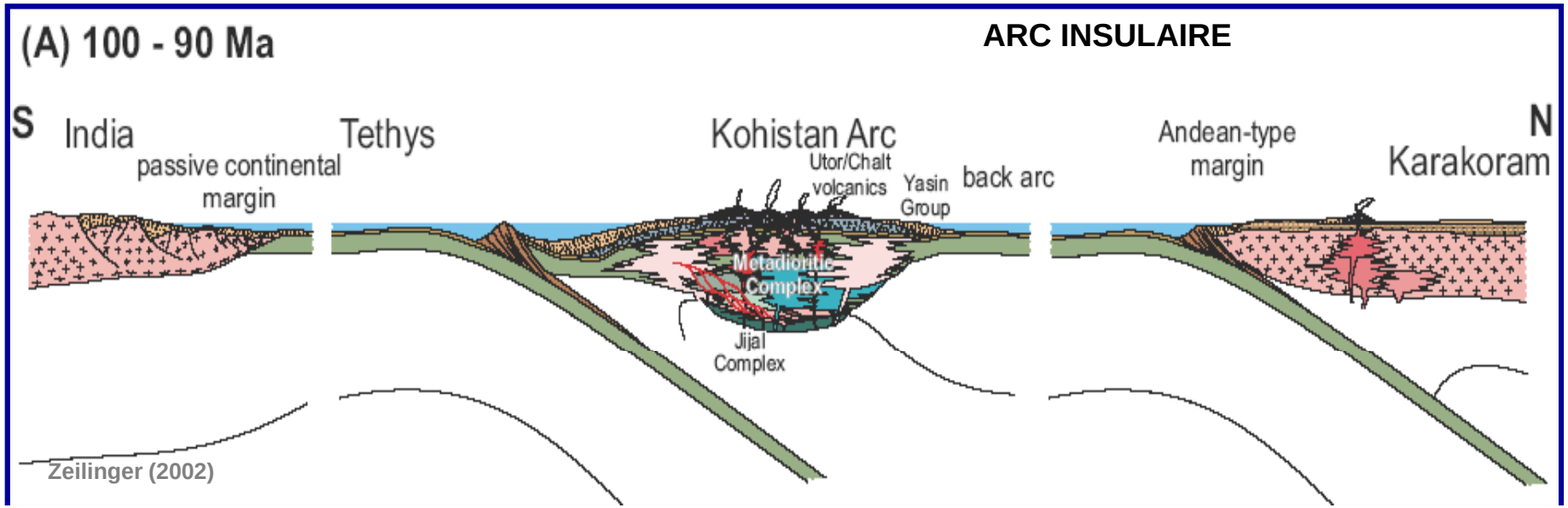
Magmatisme calco-alcalin



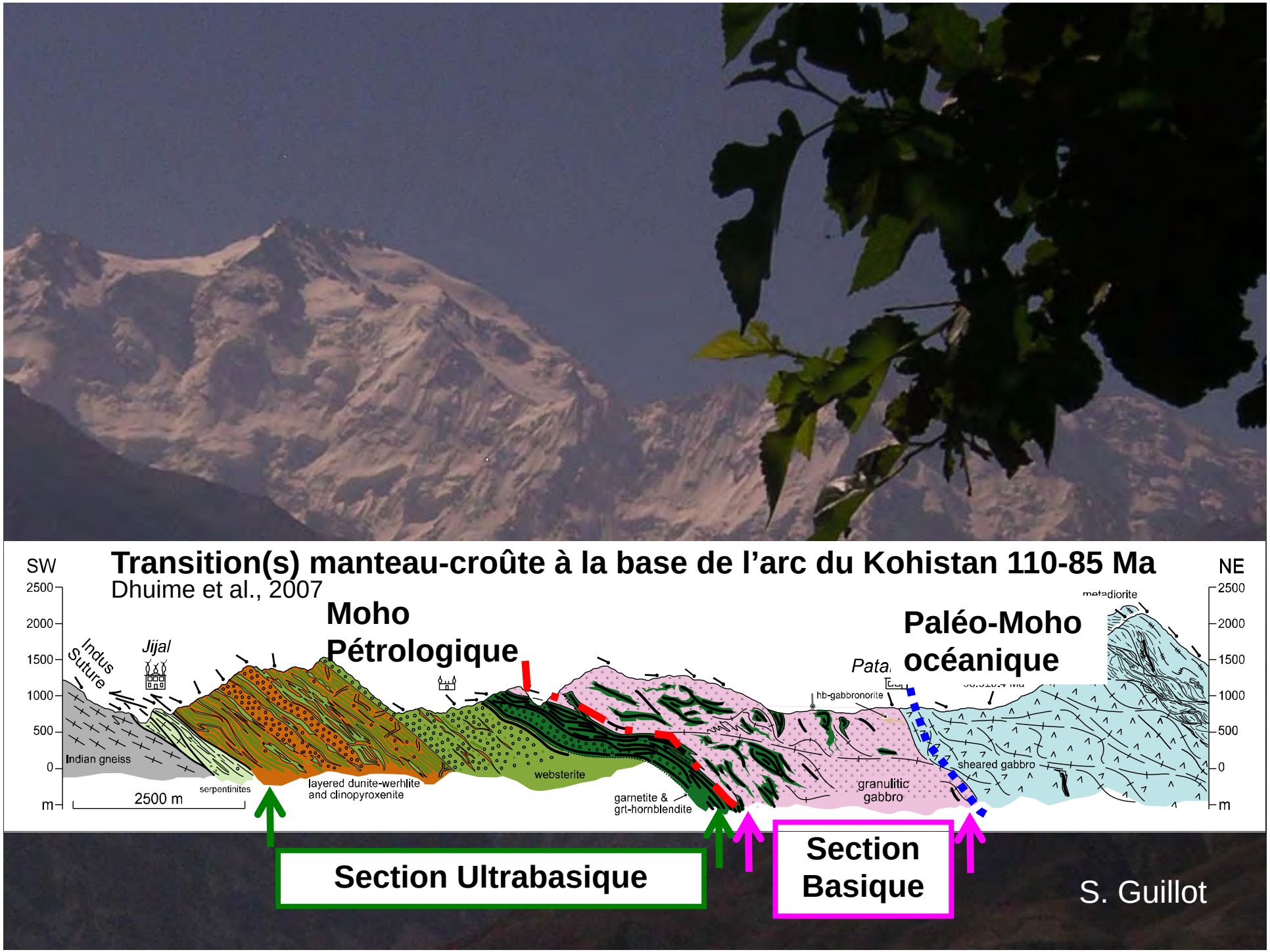
Guillot et al., 2008

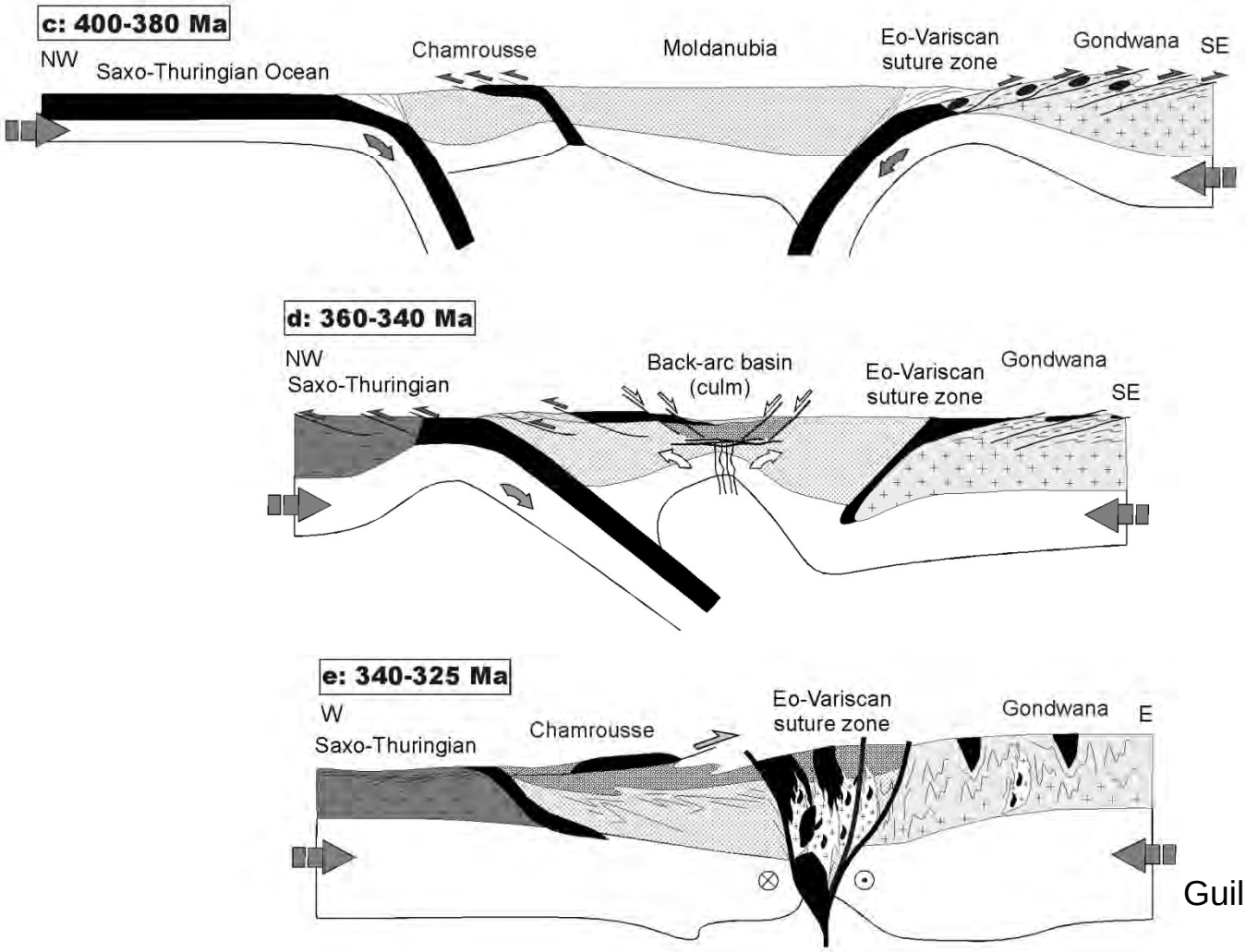


Guillot et al. 2003

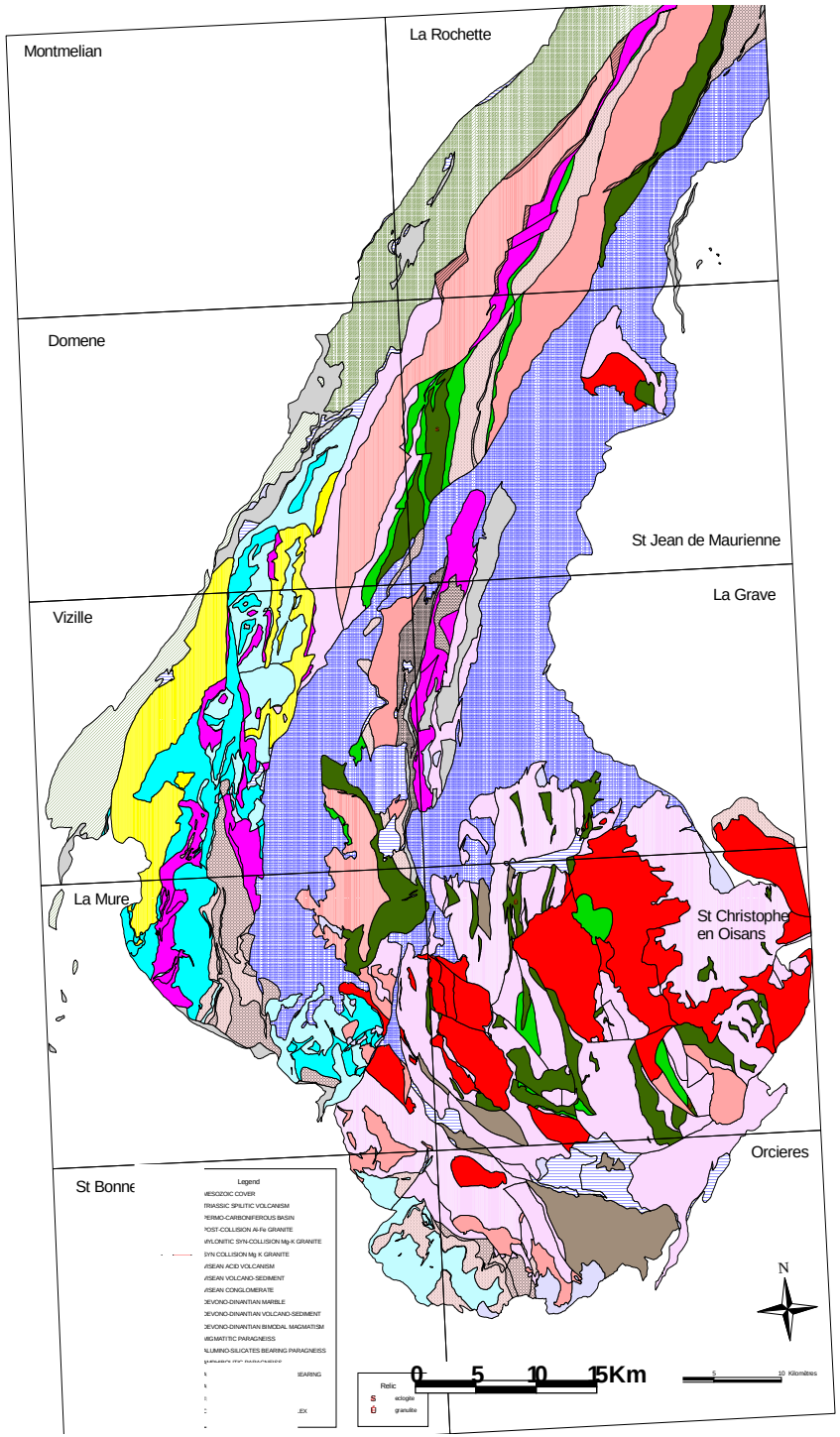


S. Guillot


Transition(s) manteau-croûte à la base de l'arc du Kohistan 110-85 Ma
Dhuime et al., 2007
SW
NE
Moho
Pétrologique
Paléo-Moho
océanique
Indus
Suture
Jijal
Indian gneiss
serpentinites
2500 m
layered dunite-werhlite
and clinopyroxenite
websterite
garnetite &
grt-hornblendite
hb-gabbronorite
granulitic
gabbro
sheared gabbro
metadiorite
2500
2000
1500
1000
500
0
m
Section Ultrabasique
Section
Basique
S. Guillot



Guillot et Ménot, 2008

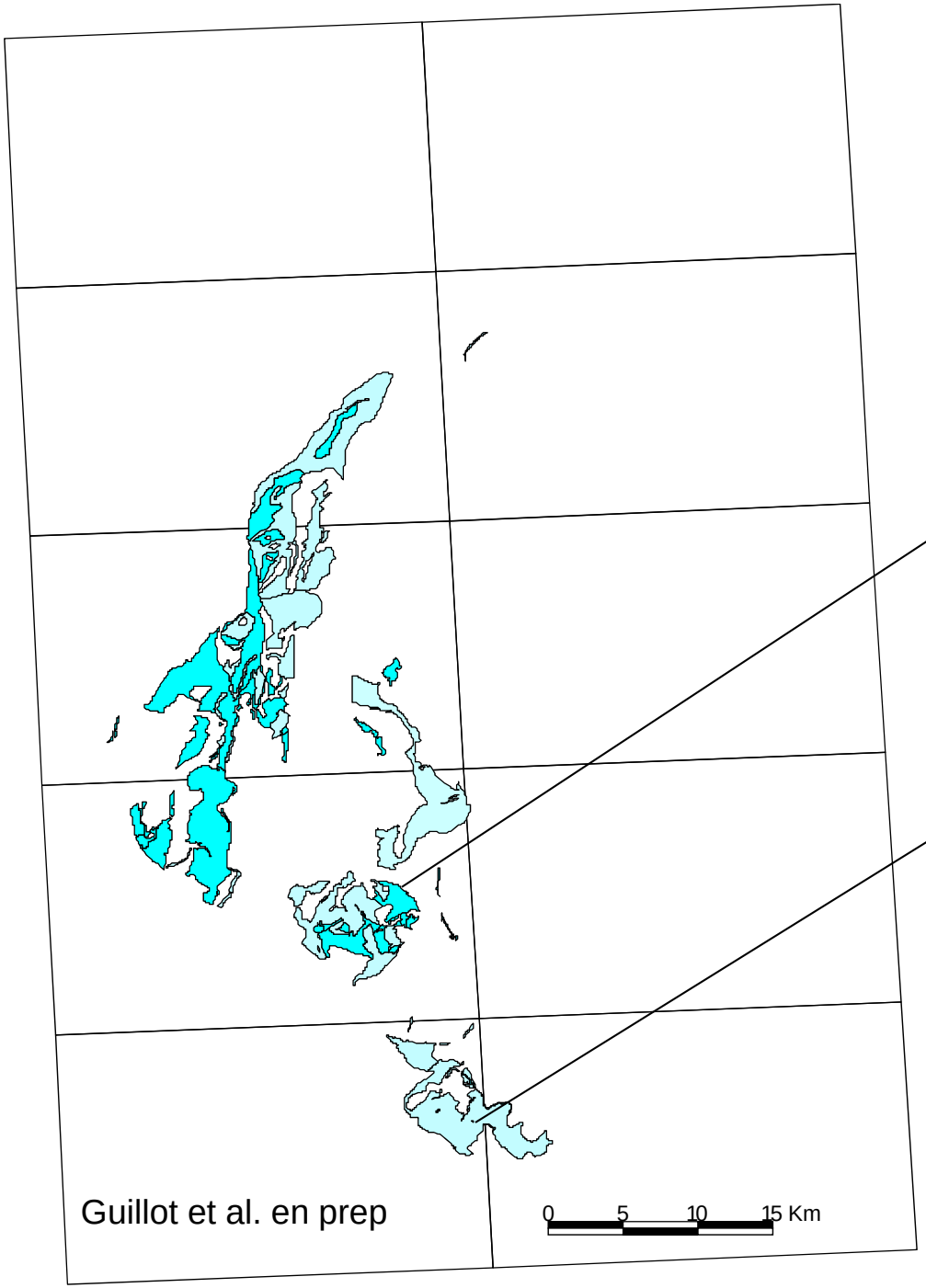


Digitalized regional
Geological maps
And correlated local
Geological formations

Guillot et al. en prep.

DEVONO-DINANTIAN BACK-ARC

Bimodal volcanism developed on thin continental crust during a global convergence context

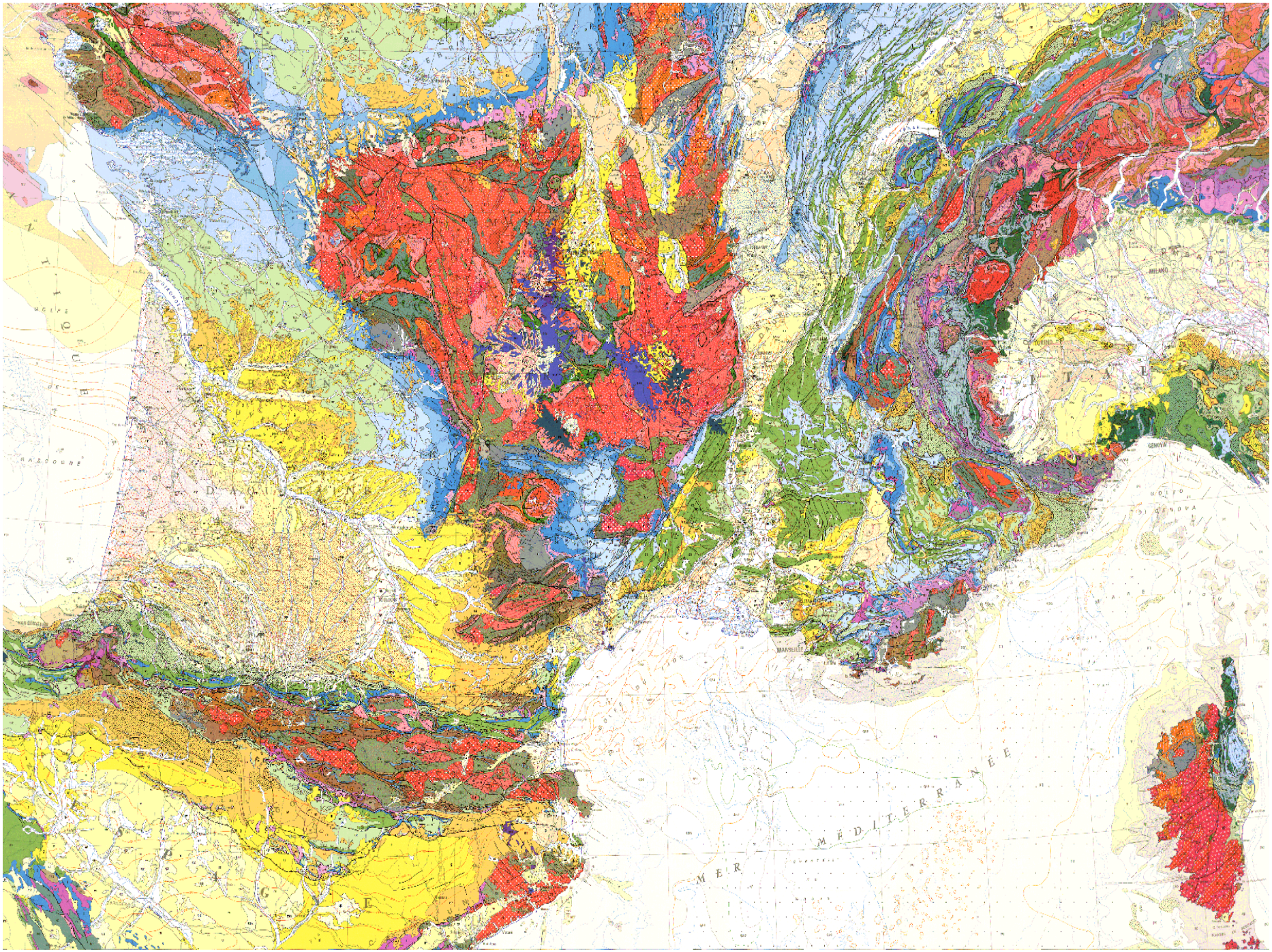


N S

MARBLE

VOLCANO-SEDIMENT

GRANITE-DIORITE

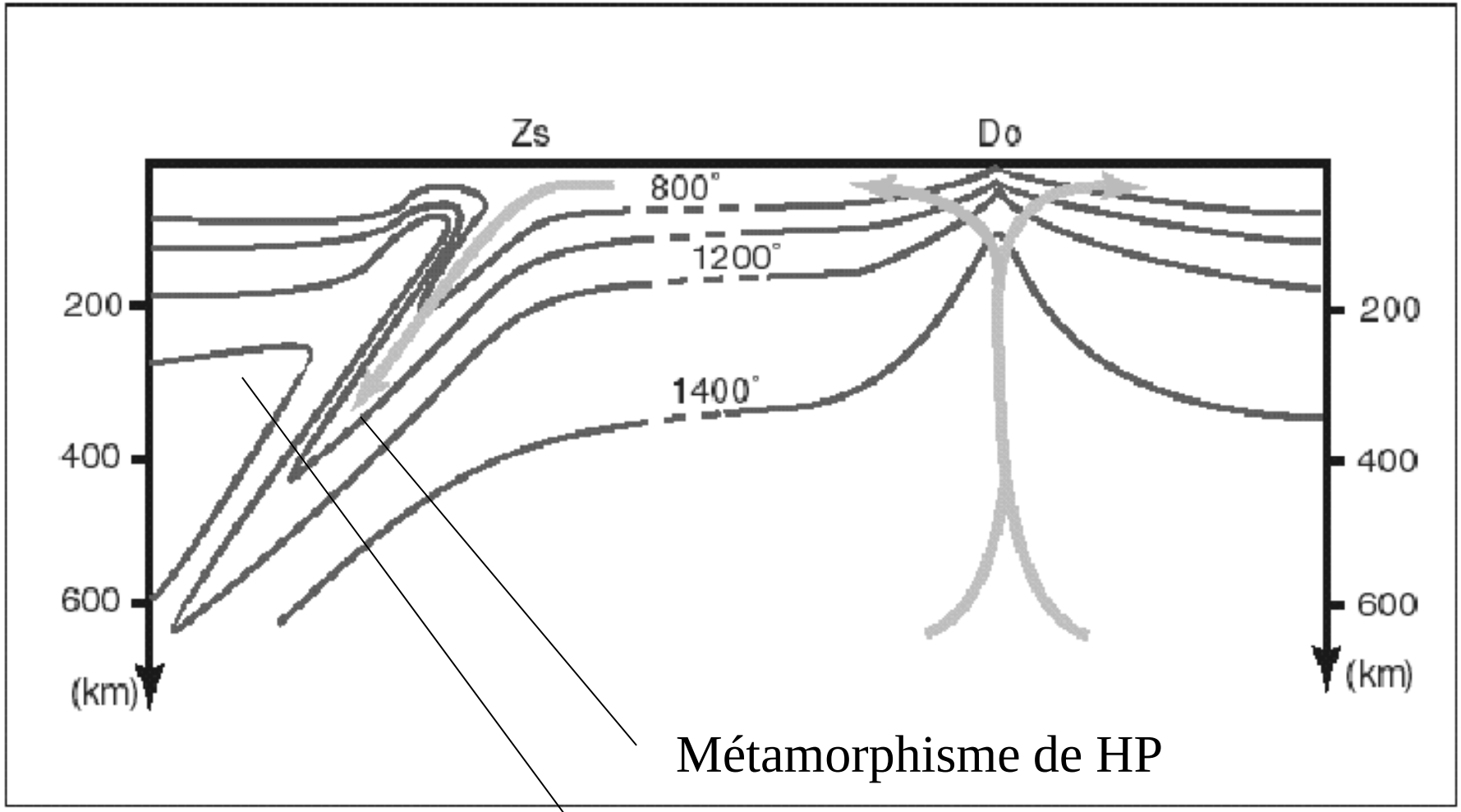

MER MÉDITERRANÉE
MARSEILLE
GENOVA
MILANO
TORINO

Les marqueurs de la subduction océanique

Du métamorphisme de HP-BT: Schistes bleus

Présent dans les 3 chaînes mais surtout dans les Alpes

Témoins métamorphiques
de la subduction océanique : les Schistes Bleus

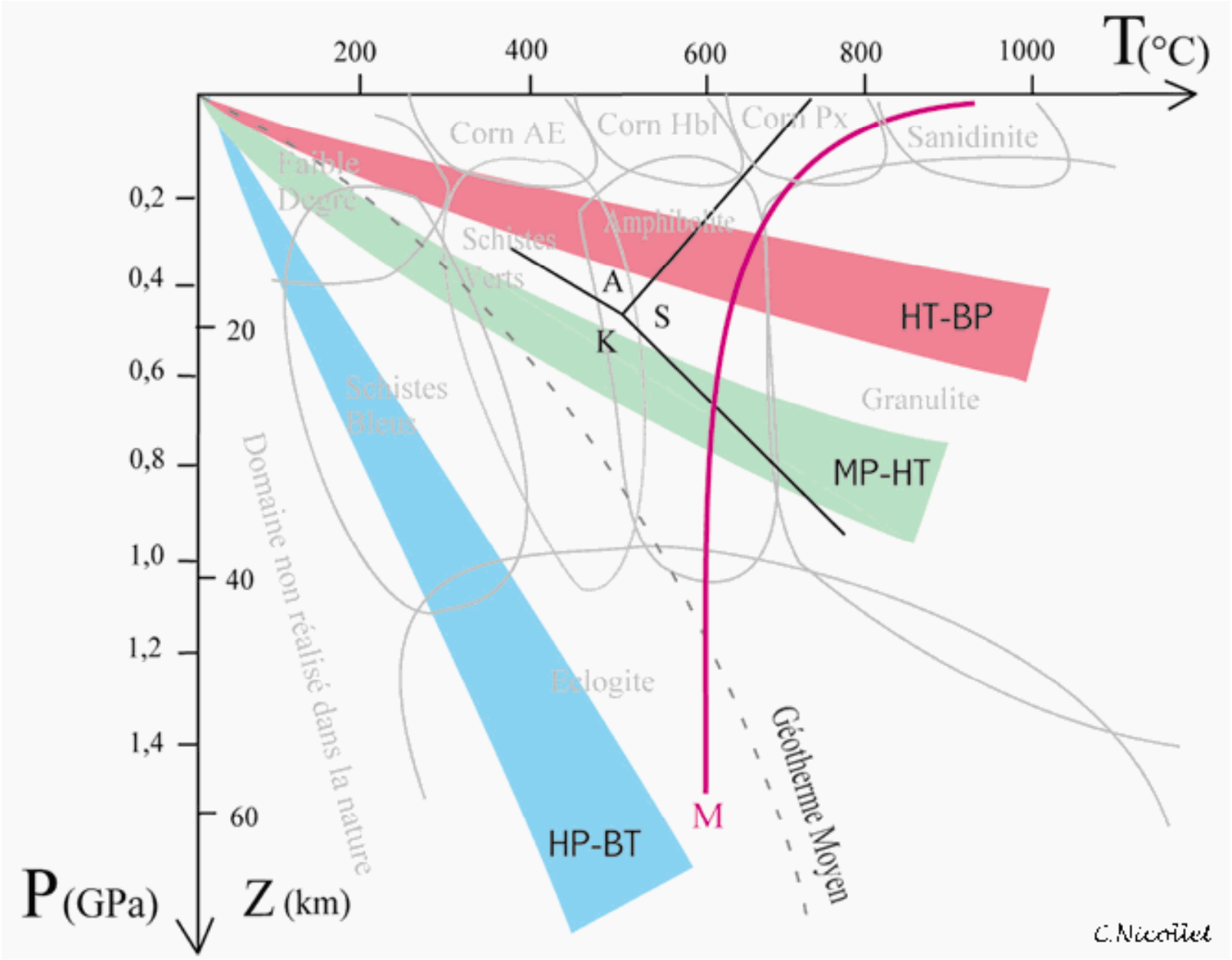


Métamorphisme de HP

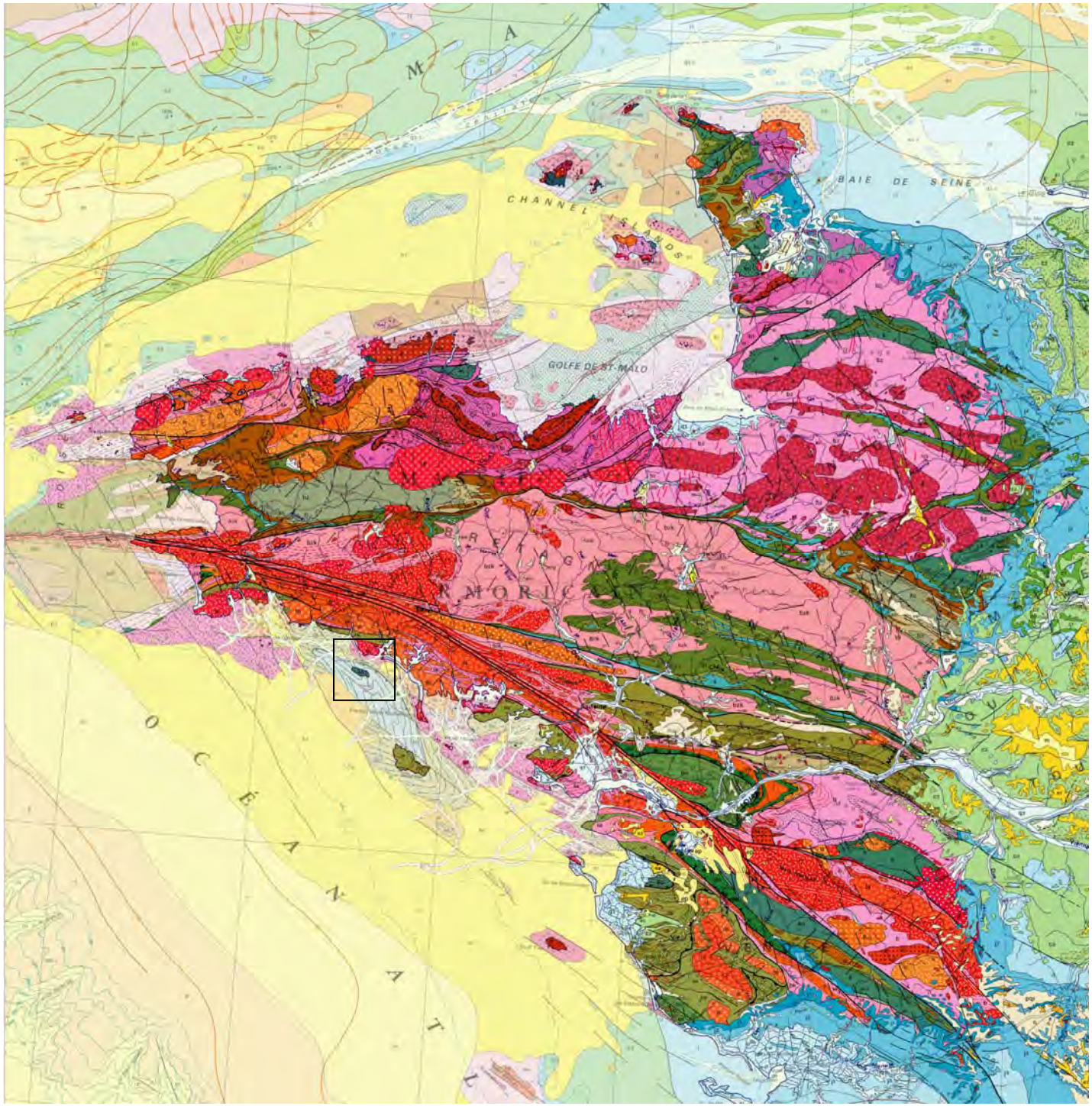
-> déshydratation de la plaque plongeante

-> hydratation du manteau sus-jacent,

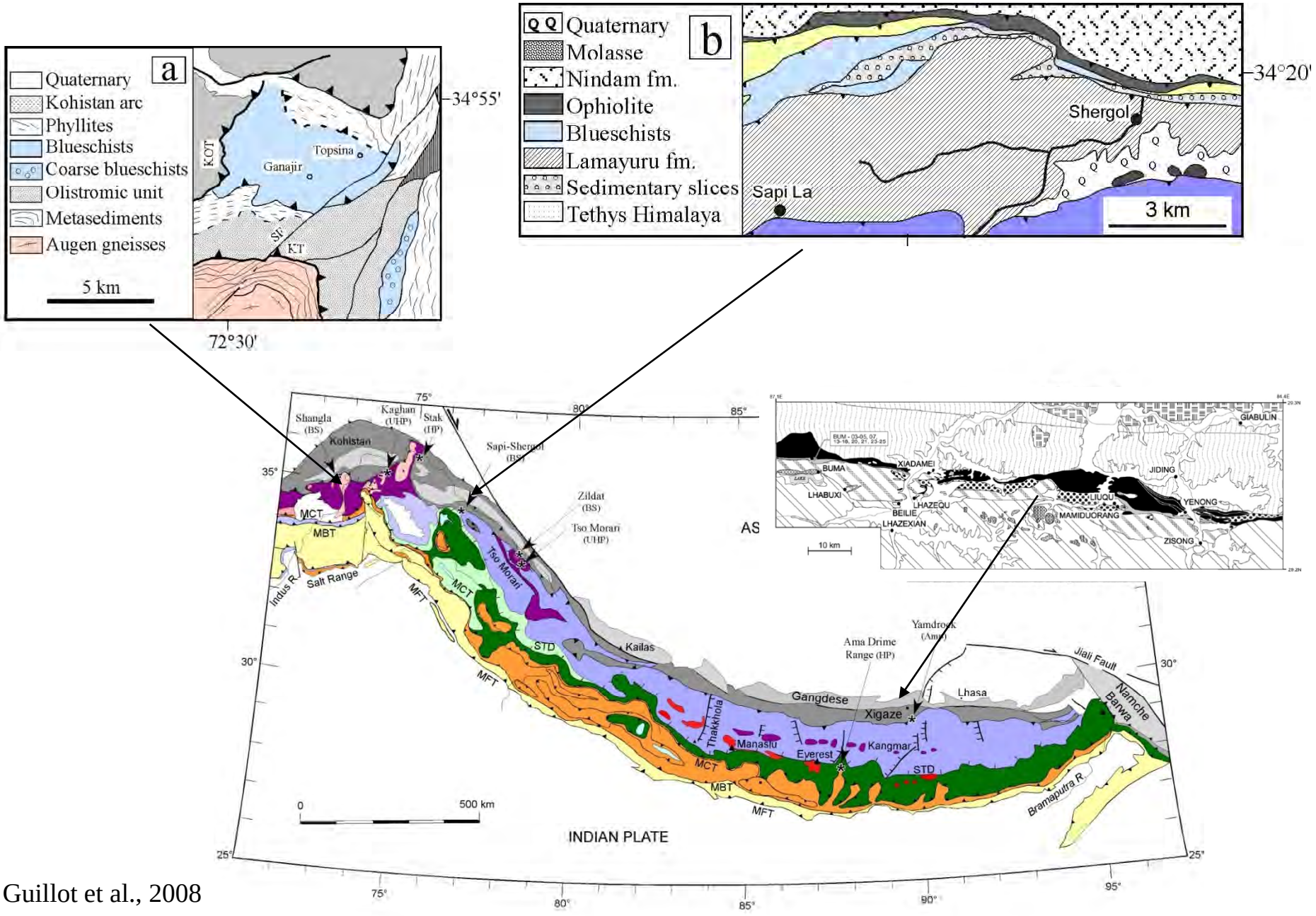
-> FP et volcanisme d'arc



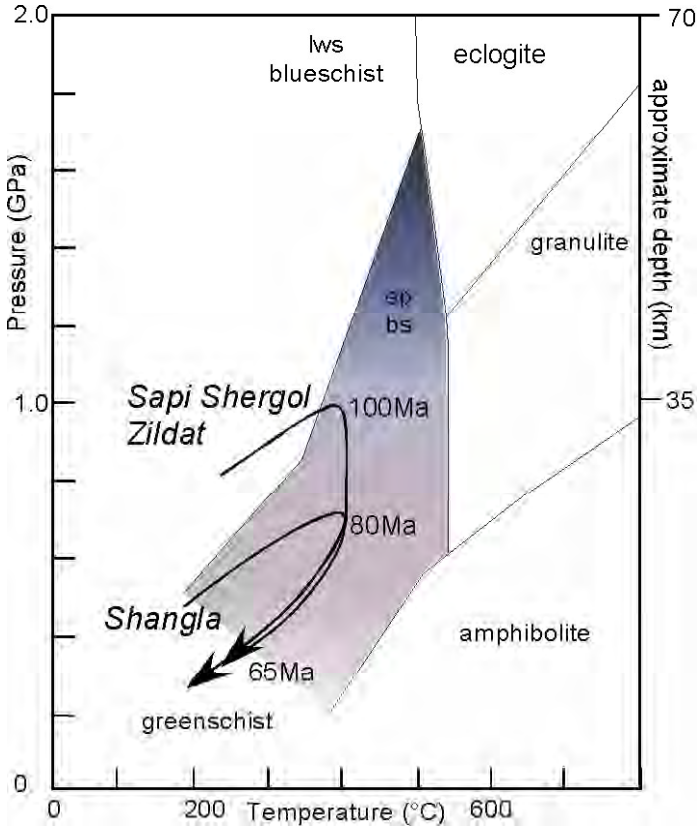
Notion de gradient métamorphique

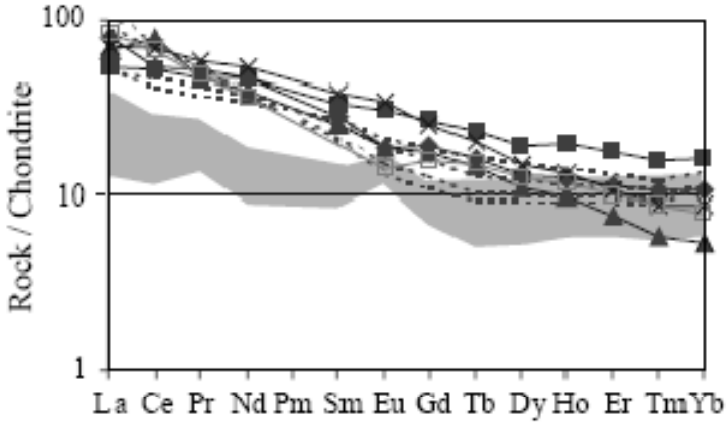

M A
CHANNEL ISLANDS
BAIE DE SEINE
GOLFE DE ST-MALO
BRETAGNE
ARMORICAIN
OCÉAN ATLANTIQUE

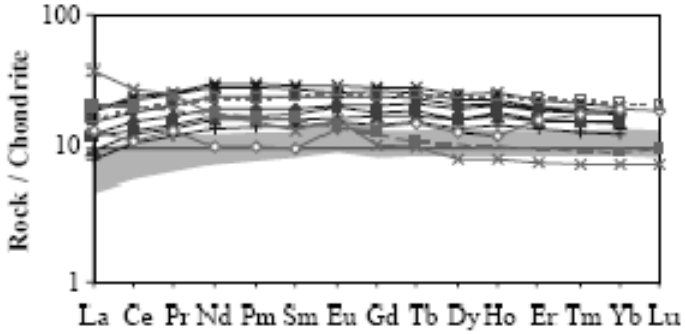
Photographie : Valérie Bosse



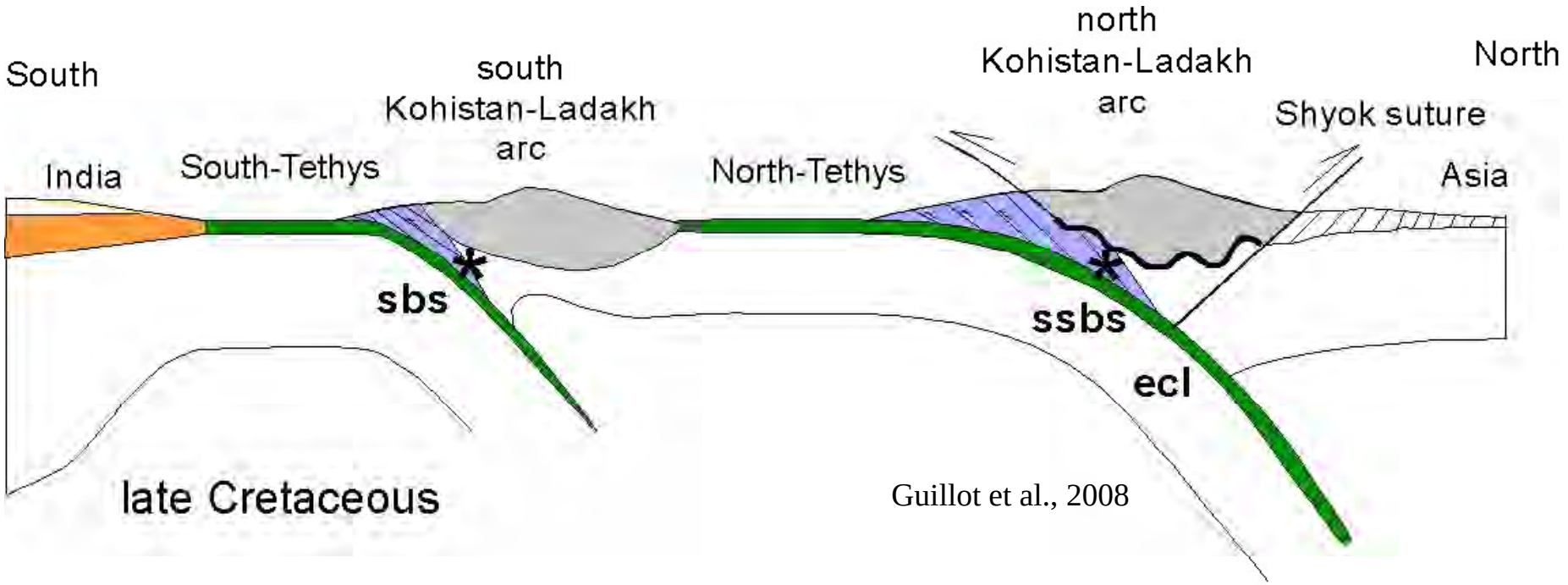
Guillot et al., 2008



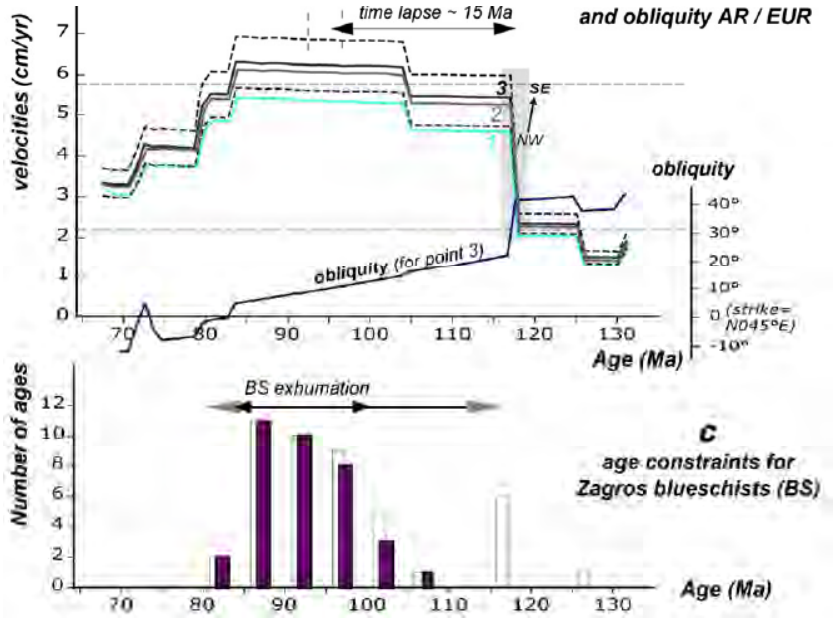




Mahéo et al., 2005



Guillot et al., 2008

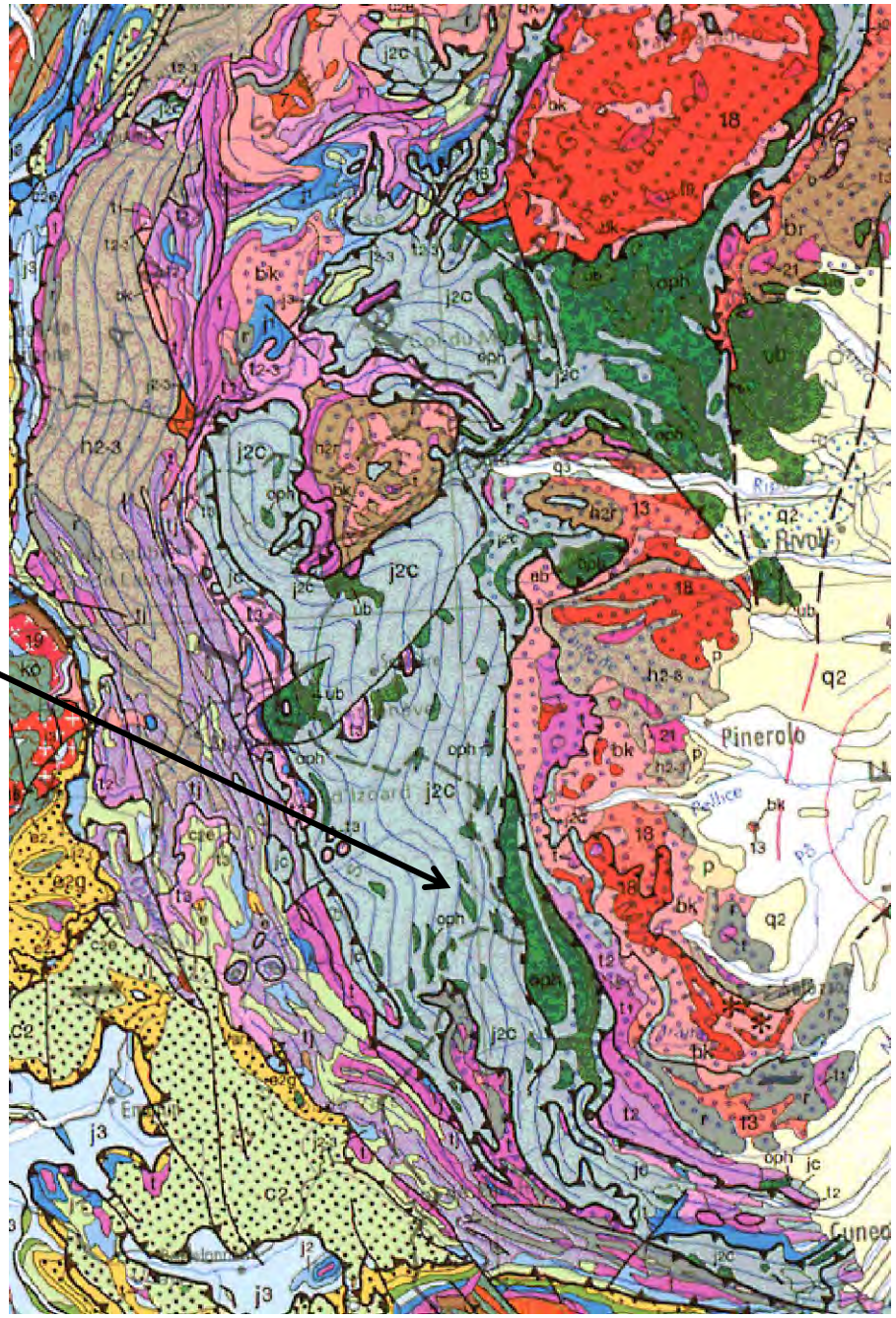


Discontinuous exhumation
of oceanic materials is related to
Increase in the subduction velocity
(Zagros and Himalayan cases)

Agard et al., 2007

Conditions métamorphiques

Assemblage **minéralogique** dans un métagabbro



Réactions:

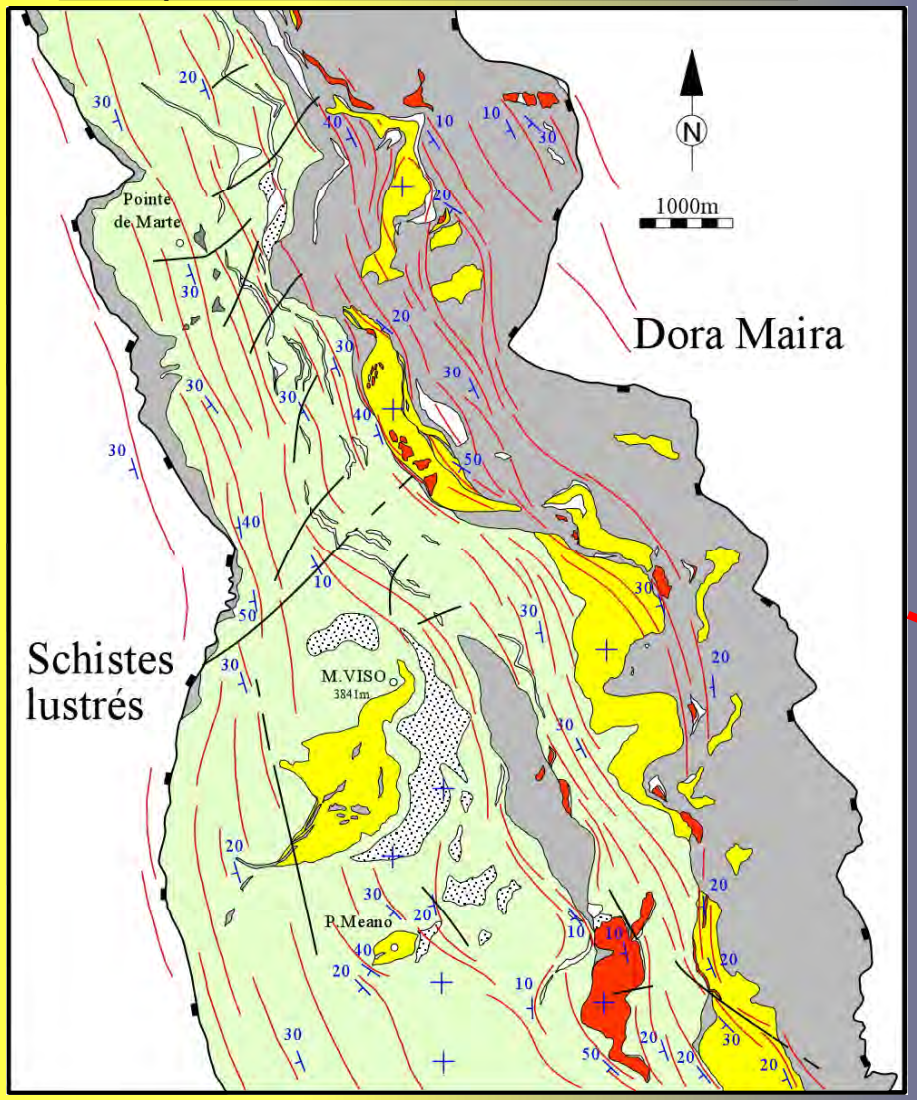
1- cpx+pl+eau = glaucophane

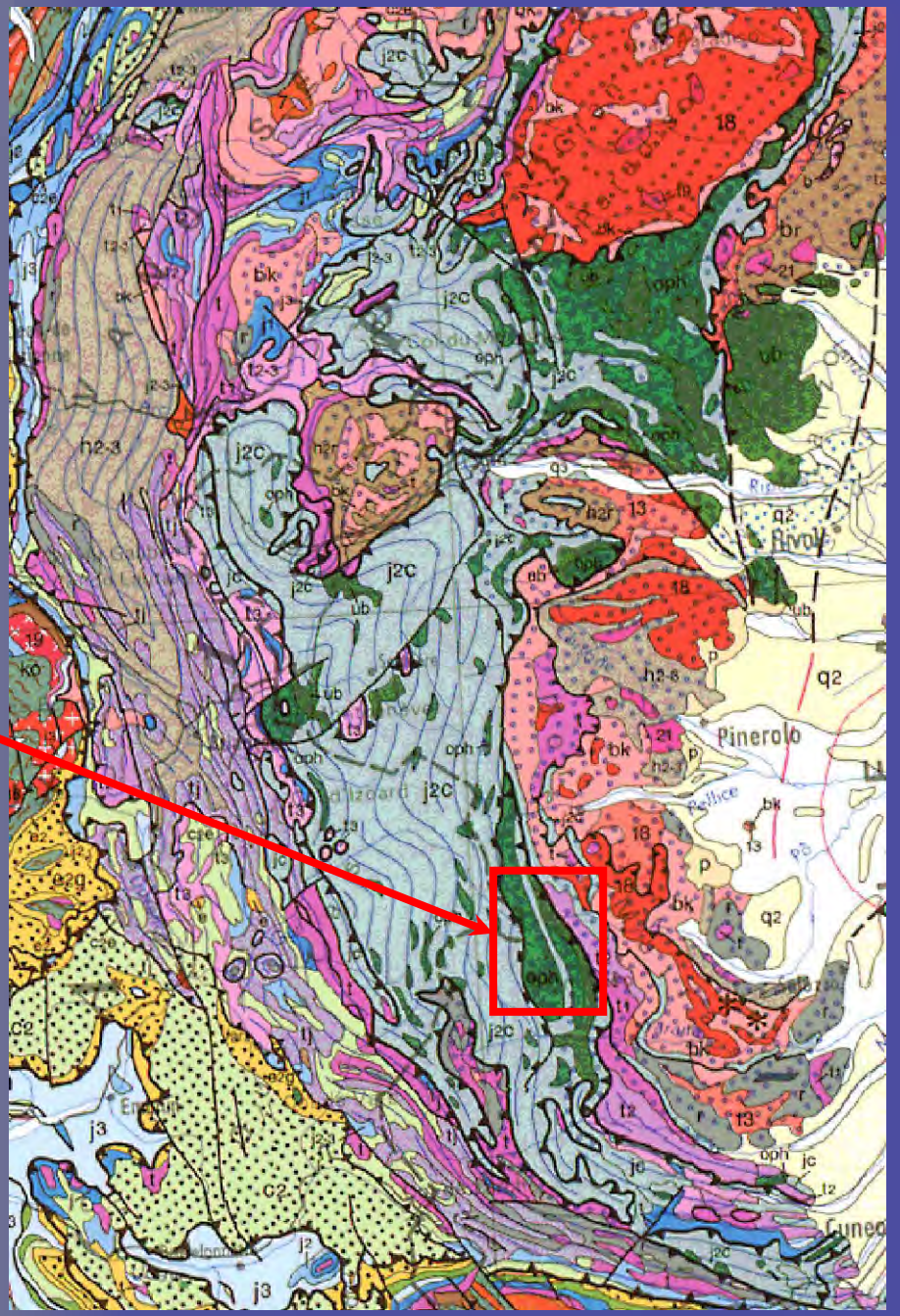
2- pl+eau+ox = lawsonite+albite

PARAGENESE à gl+lws+al

Schwartz, 2000.

Carte géologique de la partie centrale du VISO



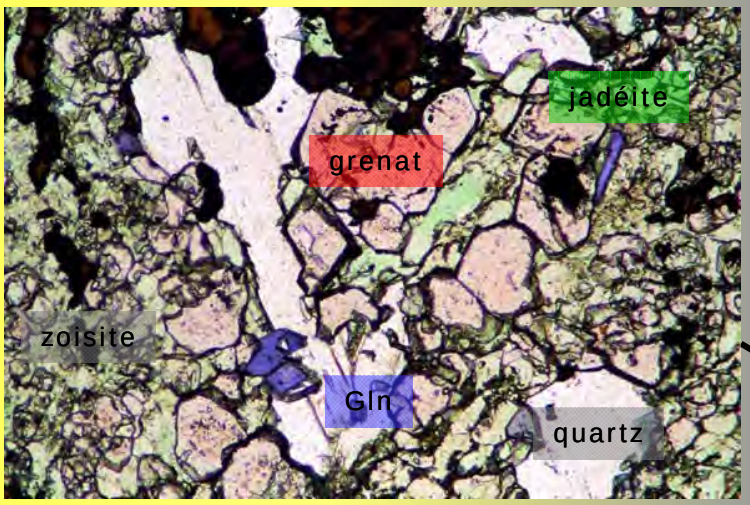


Peu de méta-sédiments par rapport aux méta-ophiolites

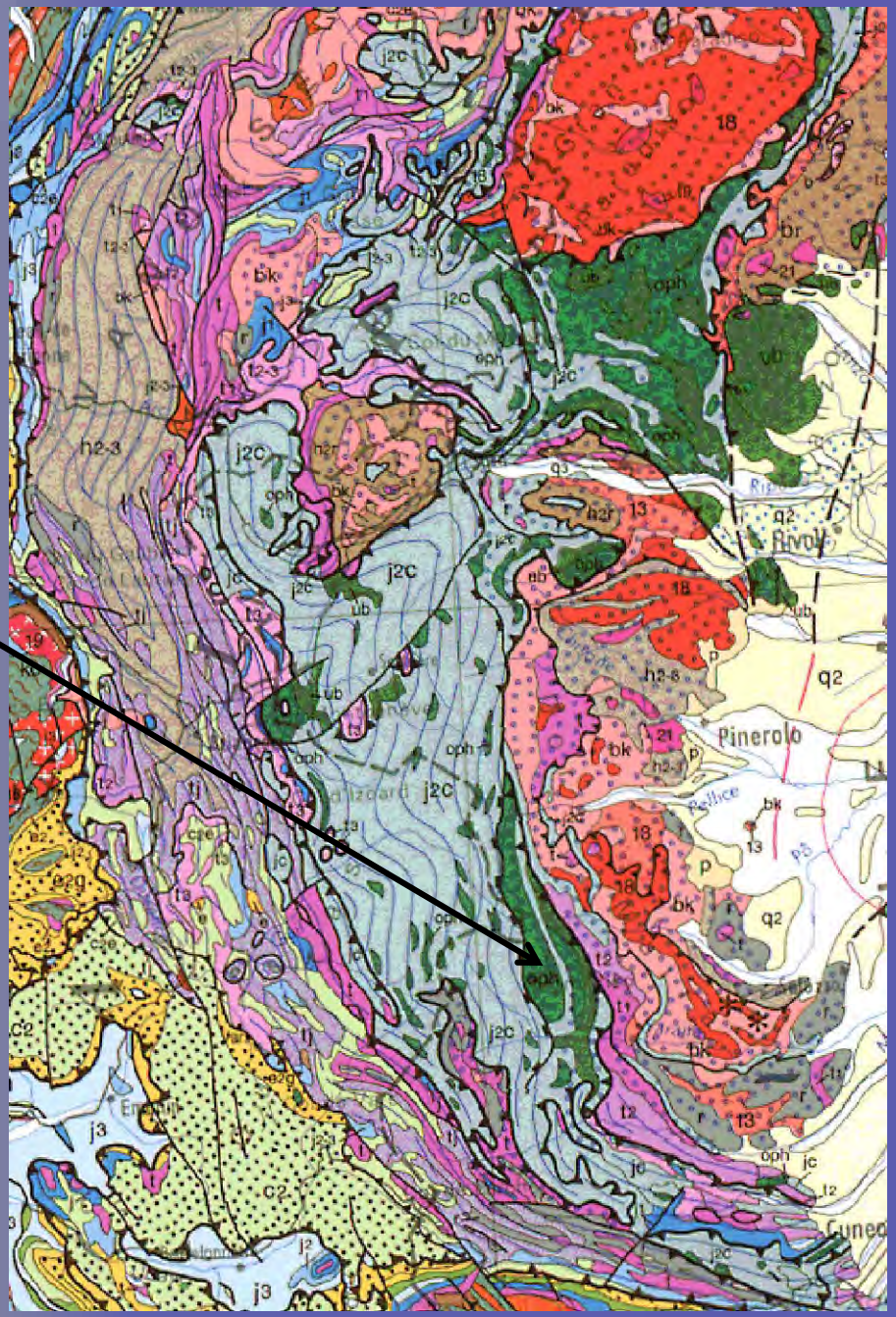
Schwartz, 2000

Conditions métamorphiques

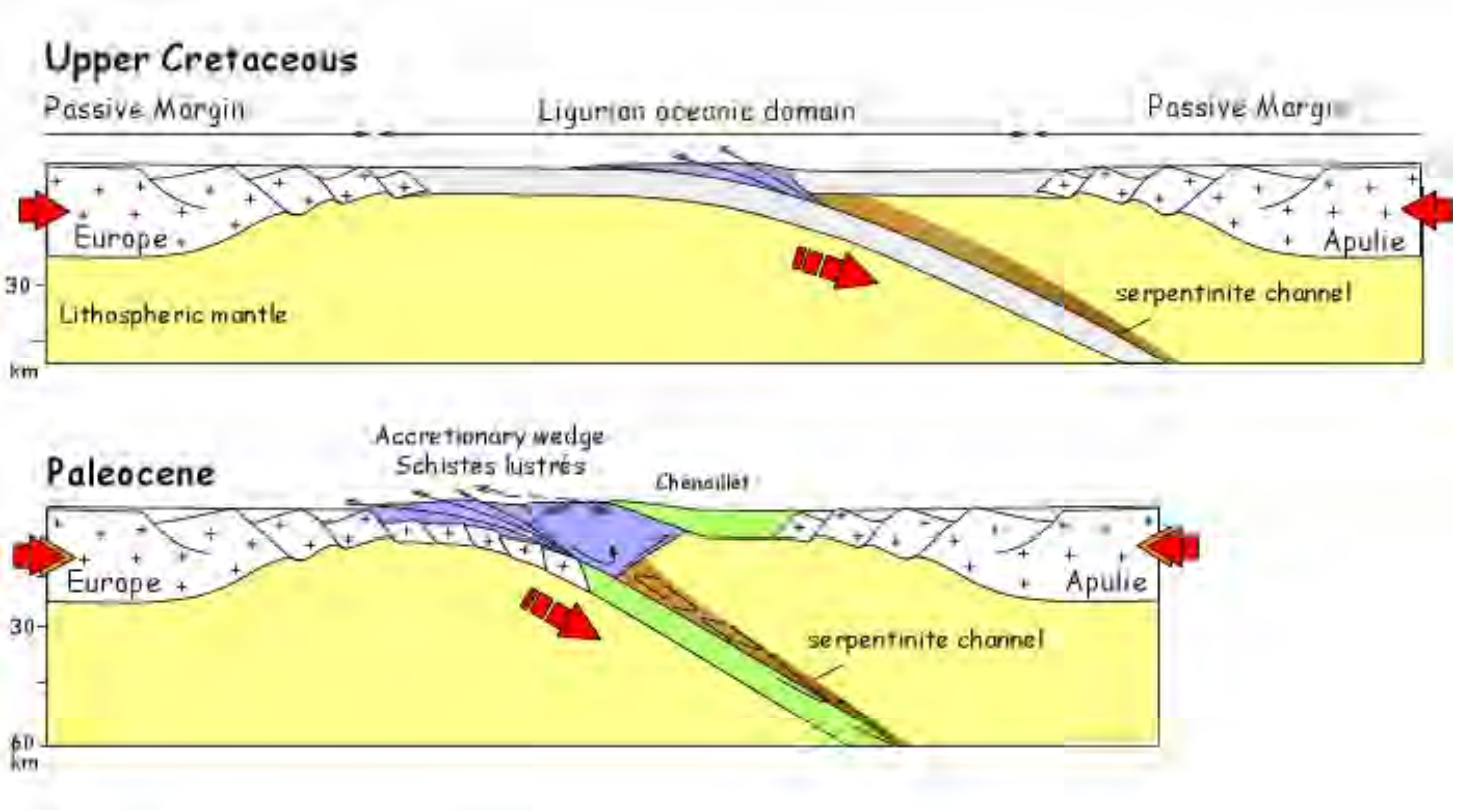
Assemblage minéralogique
dans un métagabbro



PARAGENESE à
glaucophane
+
grenat
+
quartz
+
jadéite
+
zoisite



Schwartz, 2000.

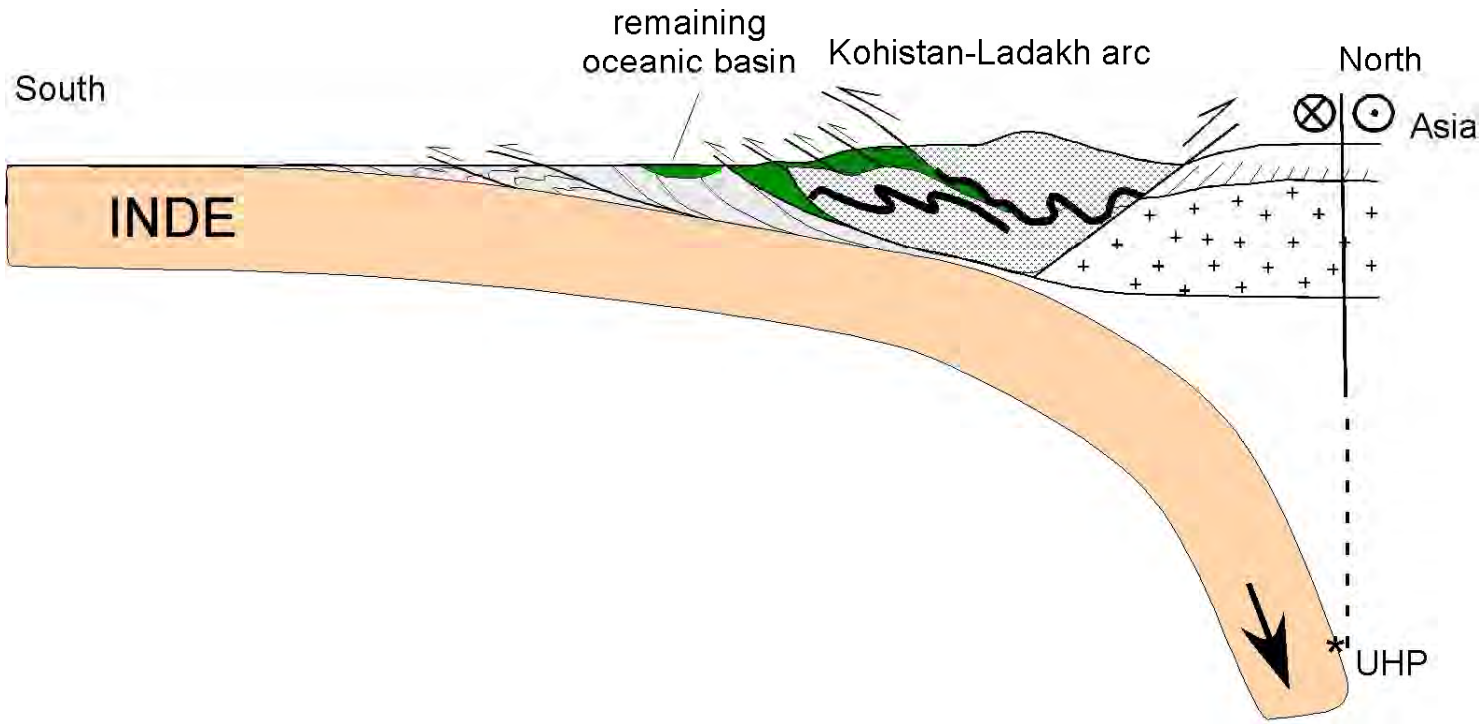


Schwartz, 2000.

Les marqueurs de la subduction continentale

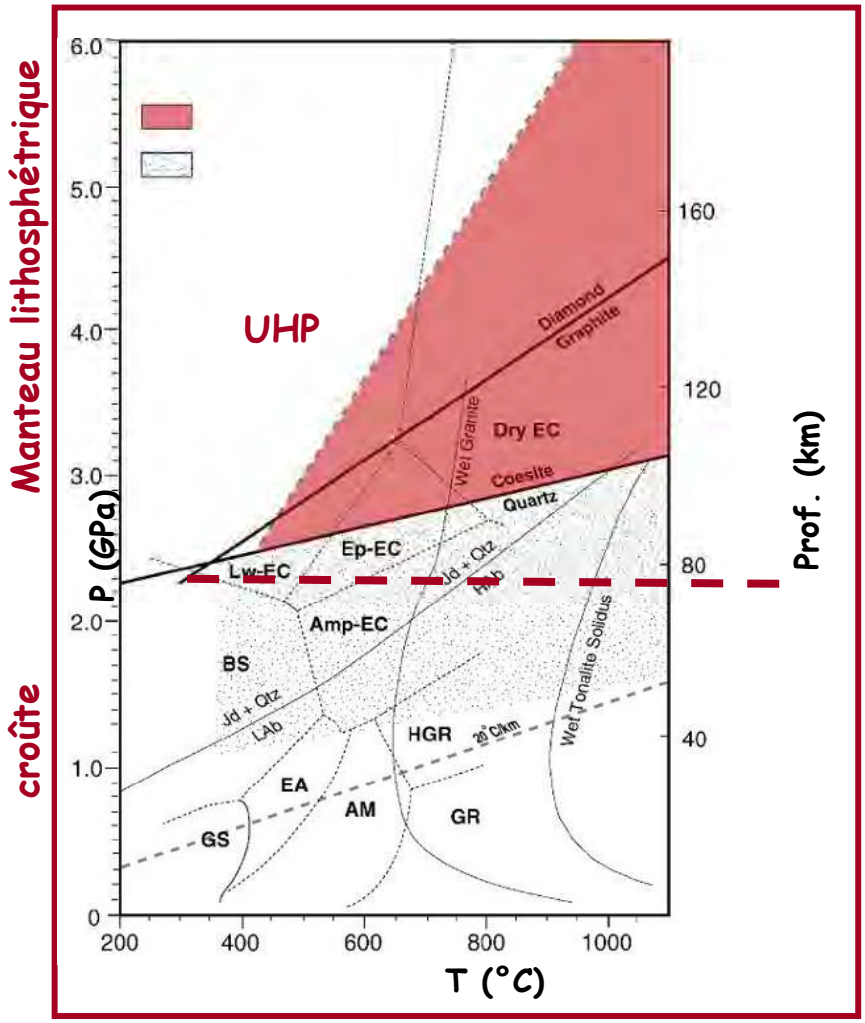
- Un métamorphisme de UHP dans des roches d’origine continentales

55 Ma

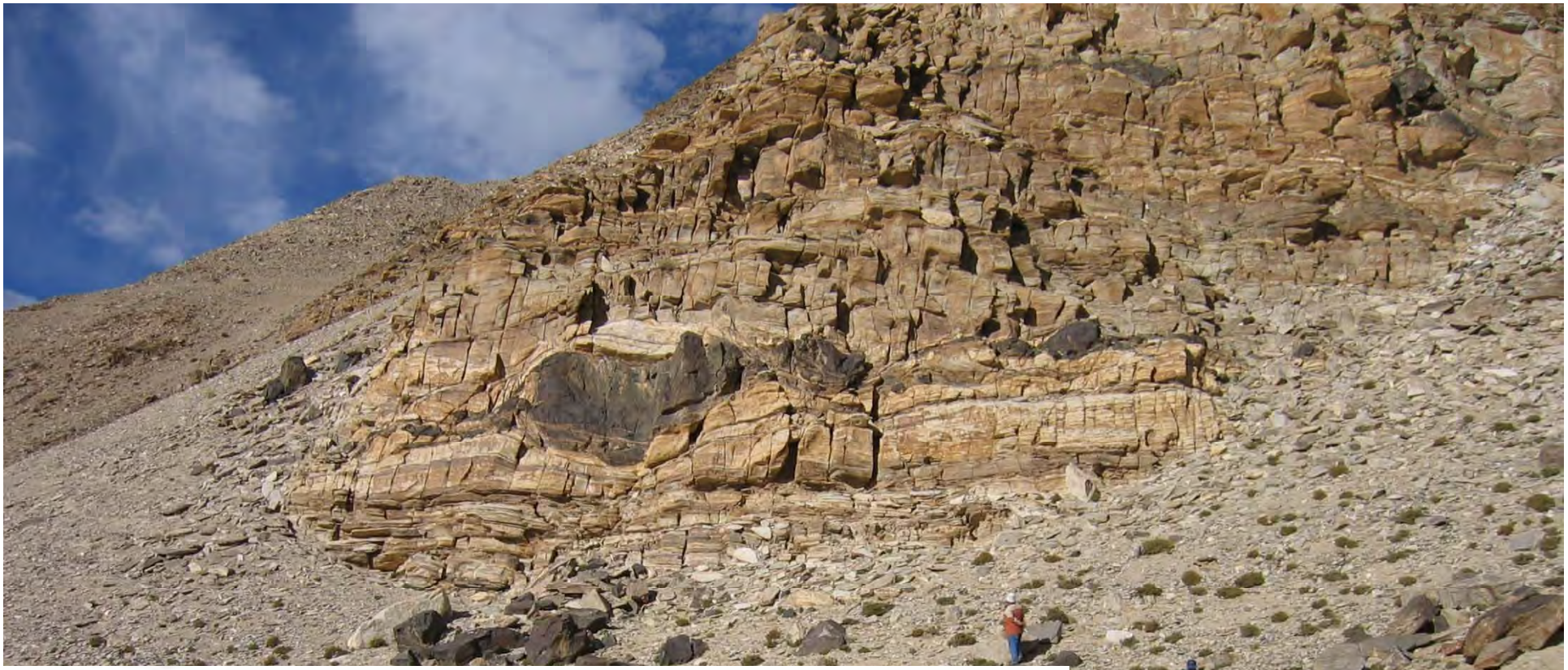


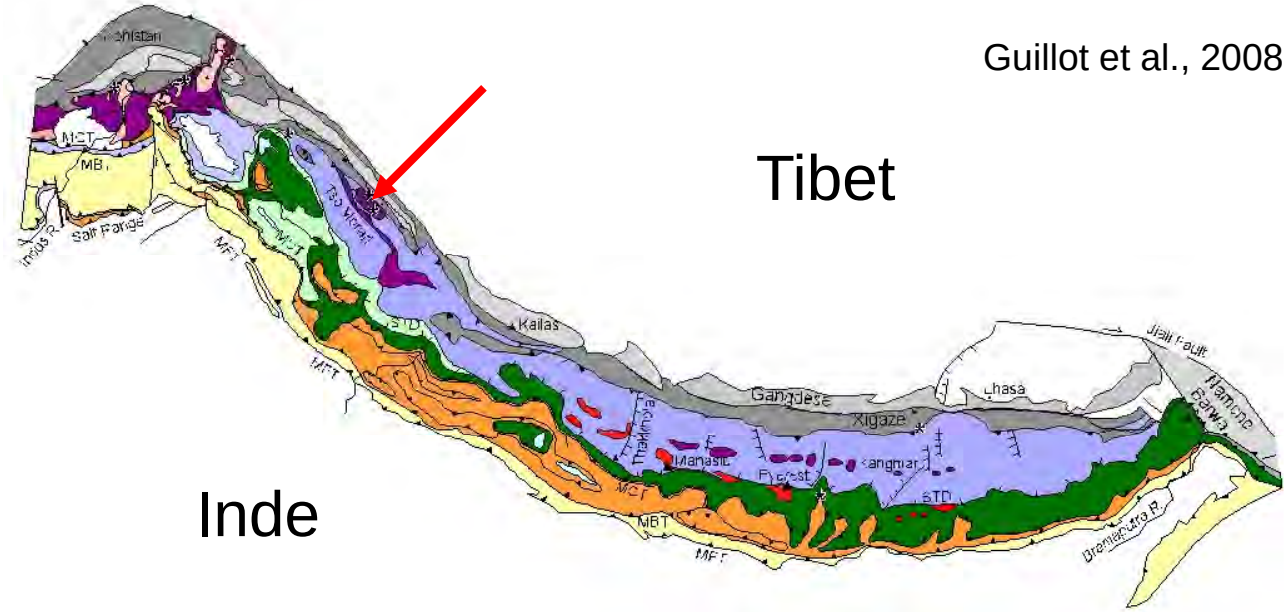
Guillot et al., 2007

Le métamorphisme de UHP



Chopin, 2003





Guillot et al., 2008

Tibet

Inde

Les roches profondes exhumés dans les chaînes de montagne

Eclogite basique

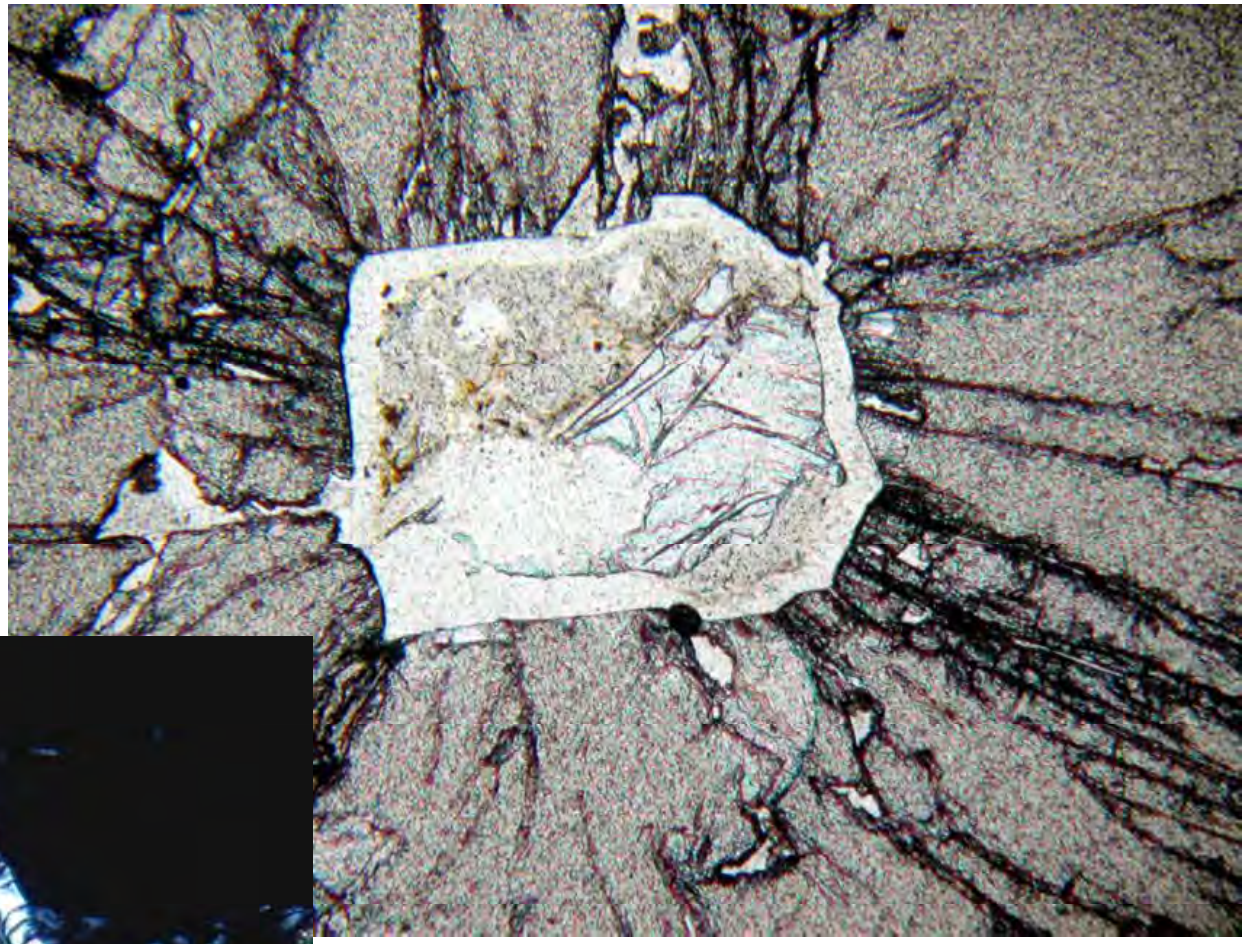
Métasédiment éclogitique

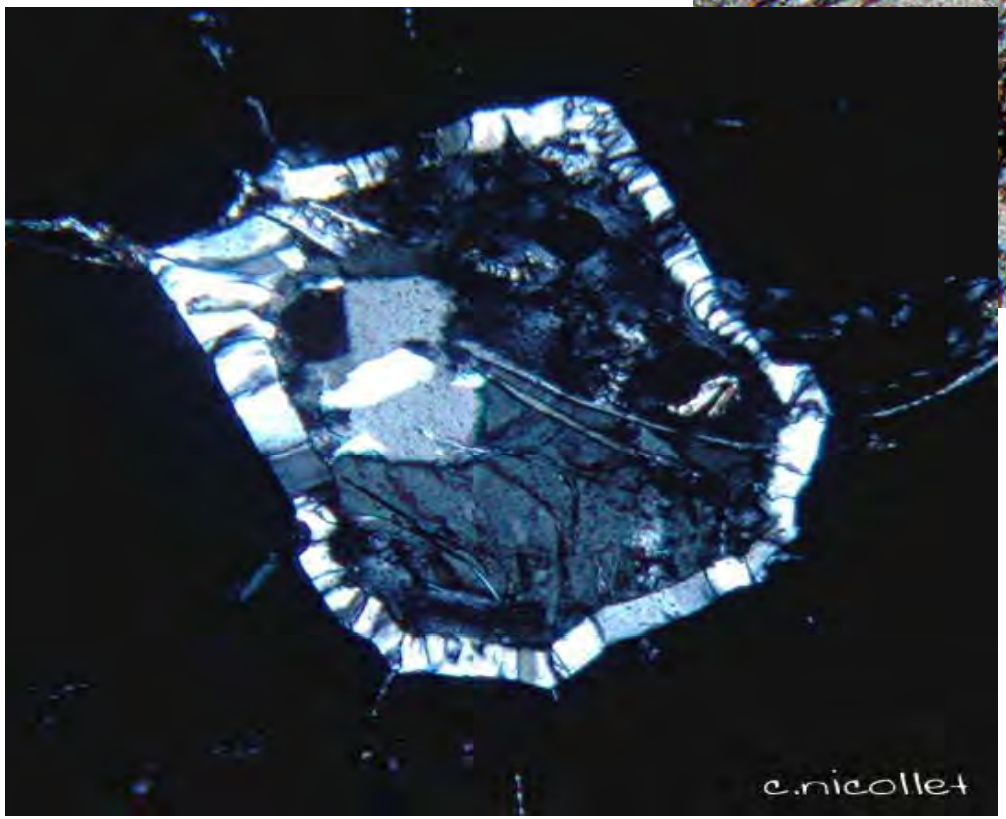
Coesite

polymorphe de UHP du Quartz

C. Chopin: Alpes
D.Smith: Norvège

300 μm.

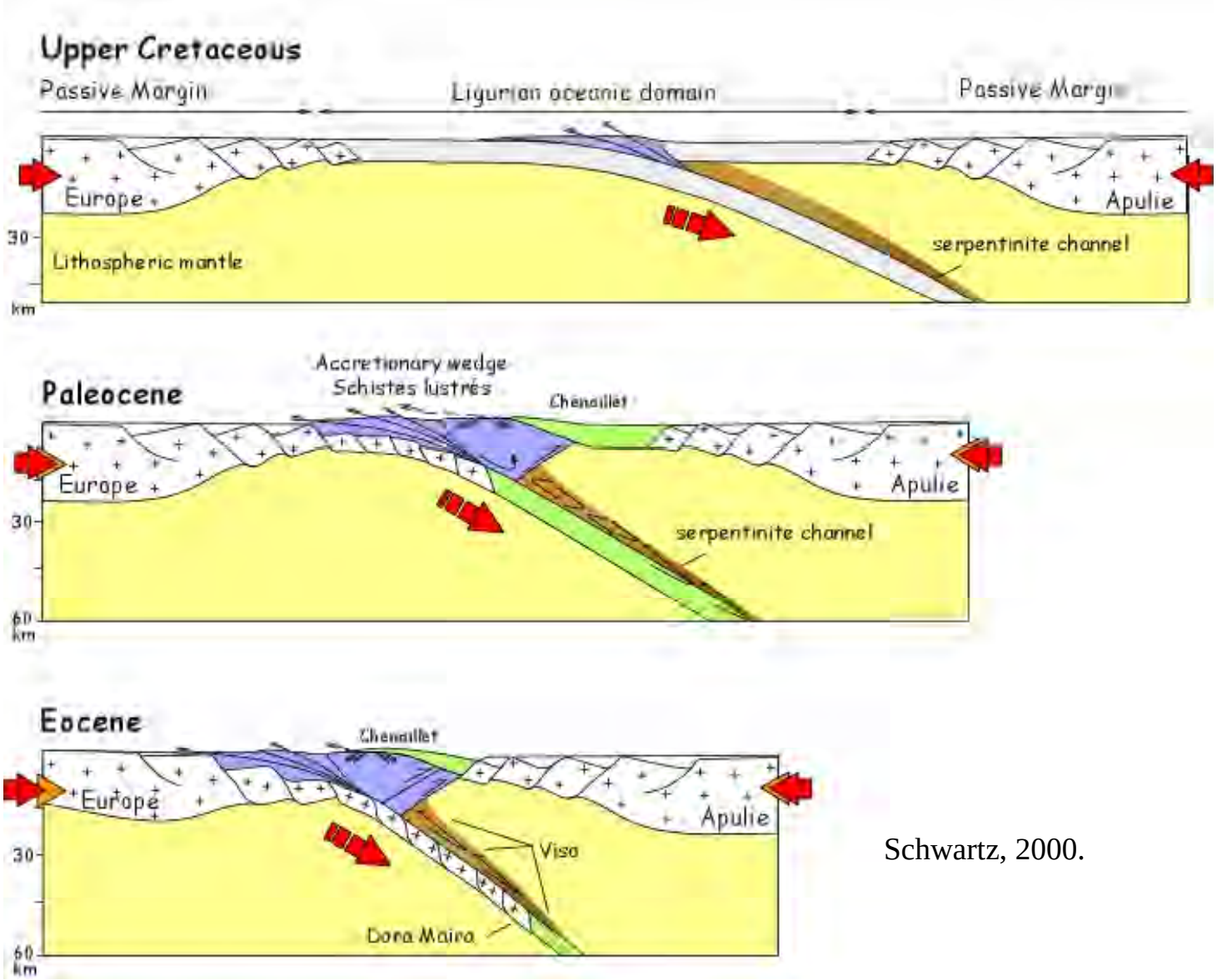




⇒1984 : Enfouissement et exhumation

de la croûte continentale

à plus de 100 km de profondeur

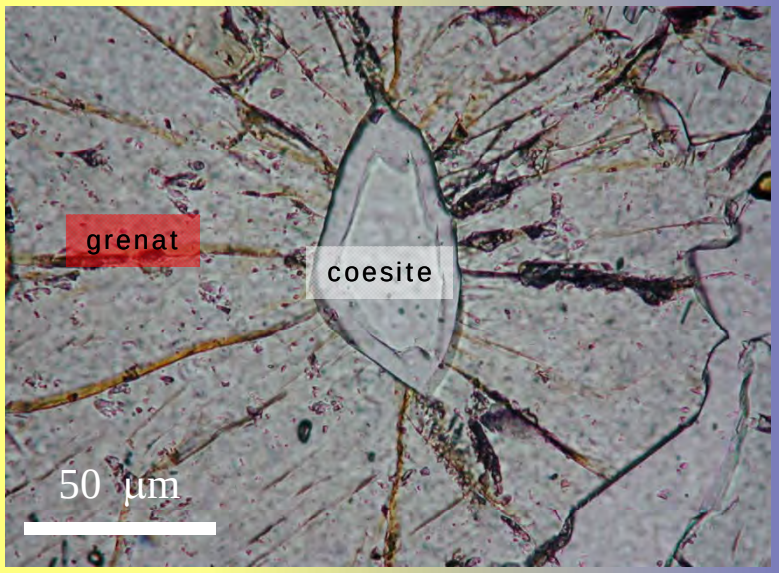


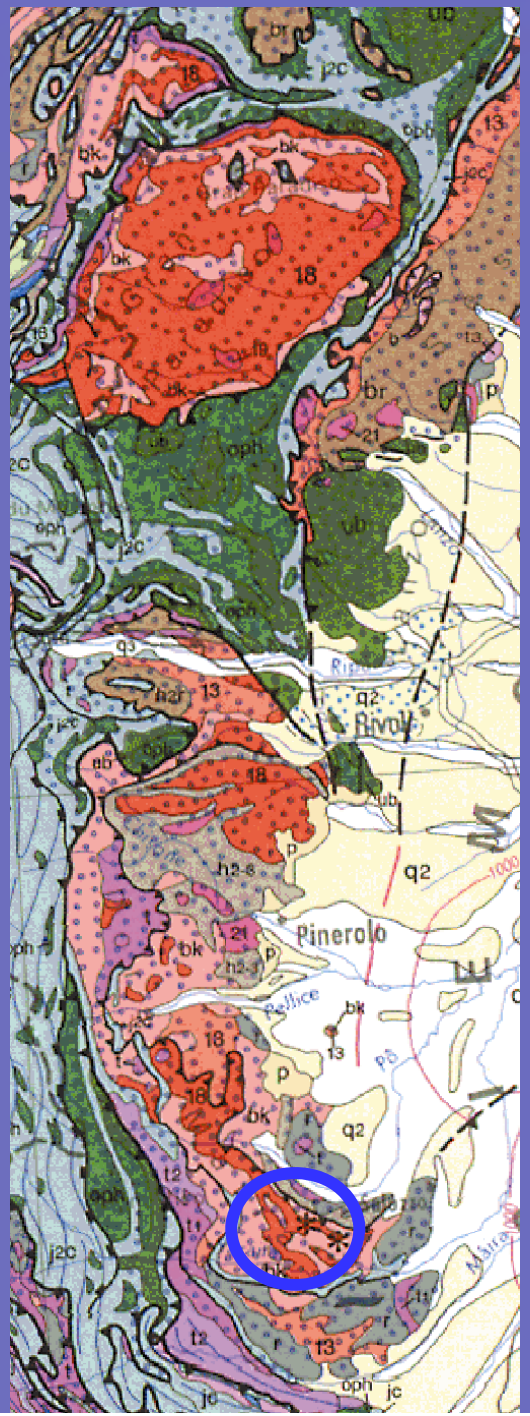
Schwartz, 2000.

1-Croûte continentale

2-Structure en dome

3-Présence de COESITE





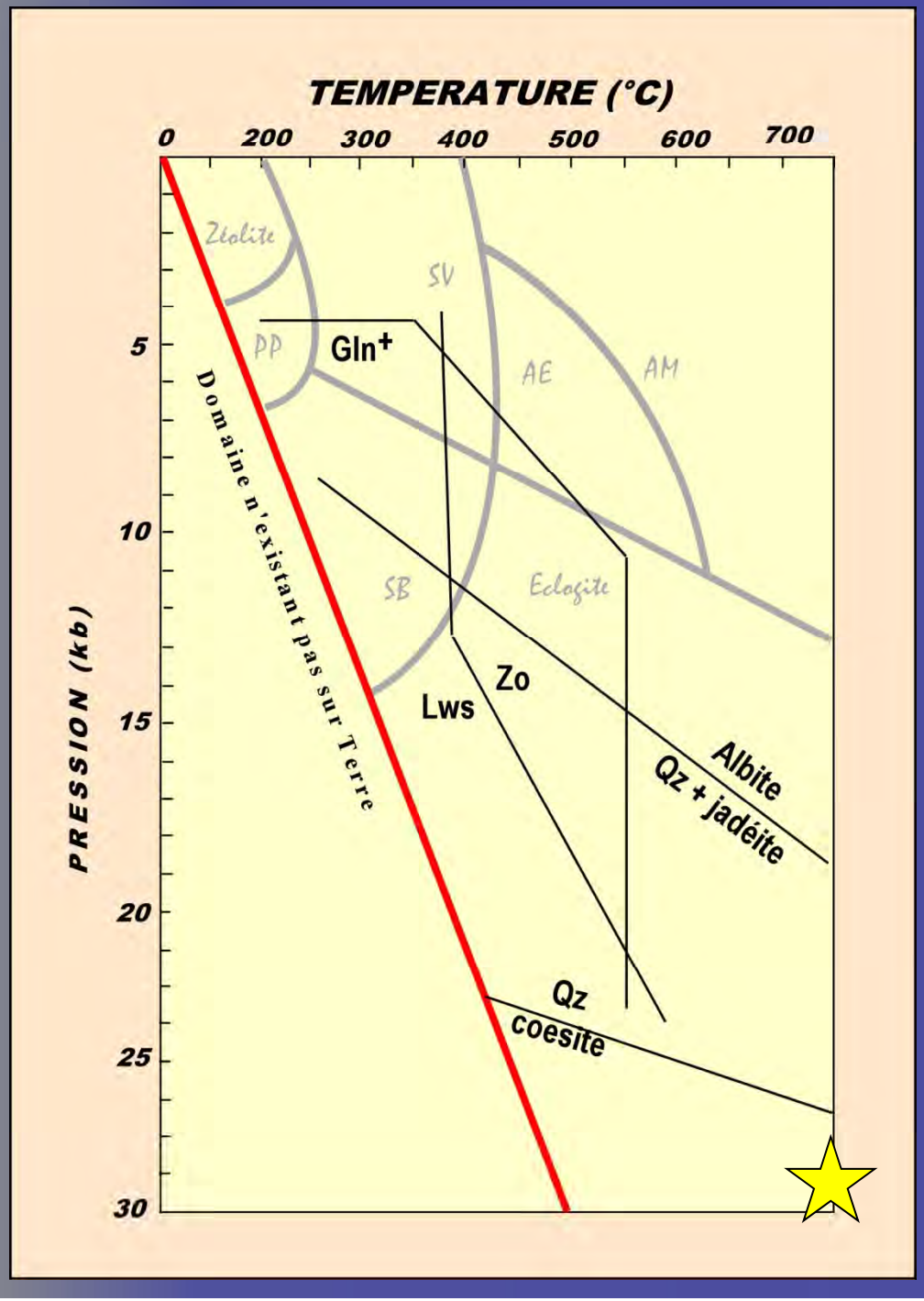
Schwartz, 2000.

Estimation des conditions
Pression - Température

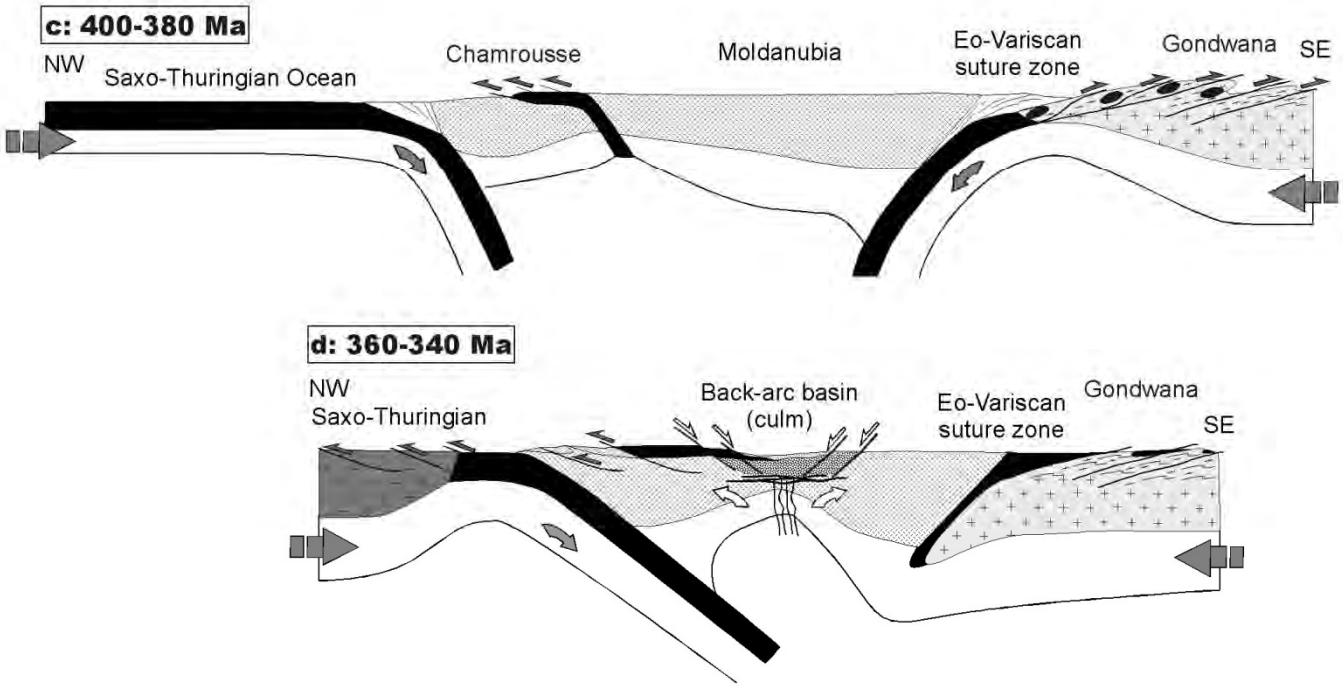
PARAGENESE à
grt+coesite

faciès des
ECLOGITES de UHP
P > 30 kbars
T > 700°C

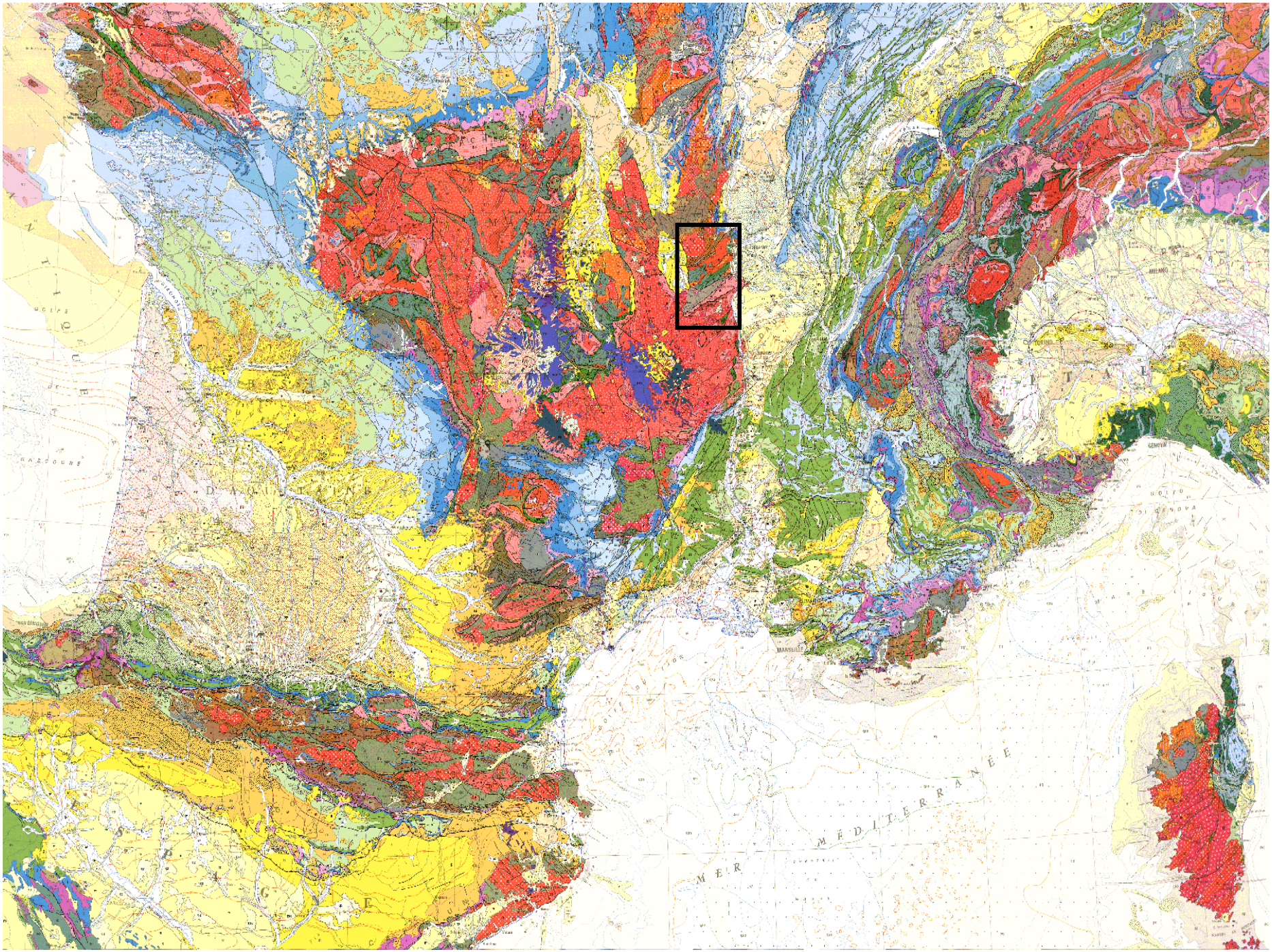
Caractérise les conditions P-T des massifs cristallins internes

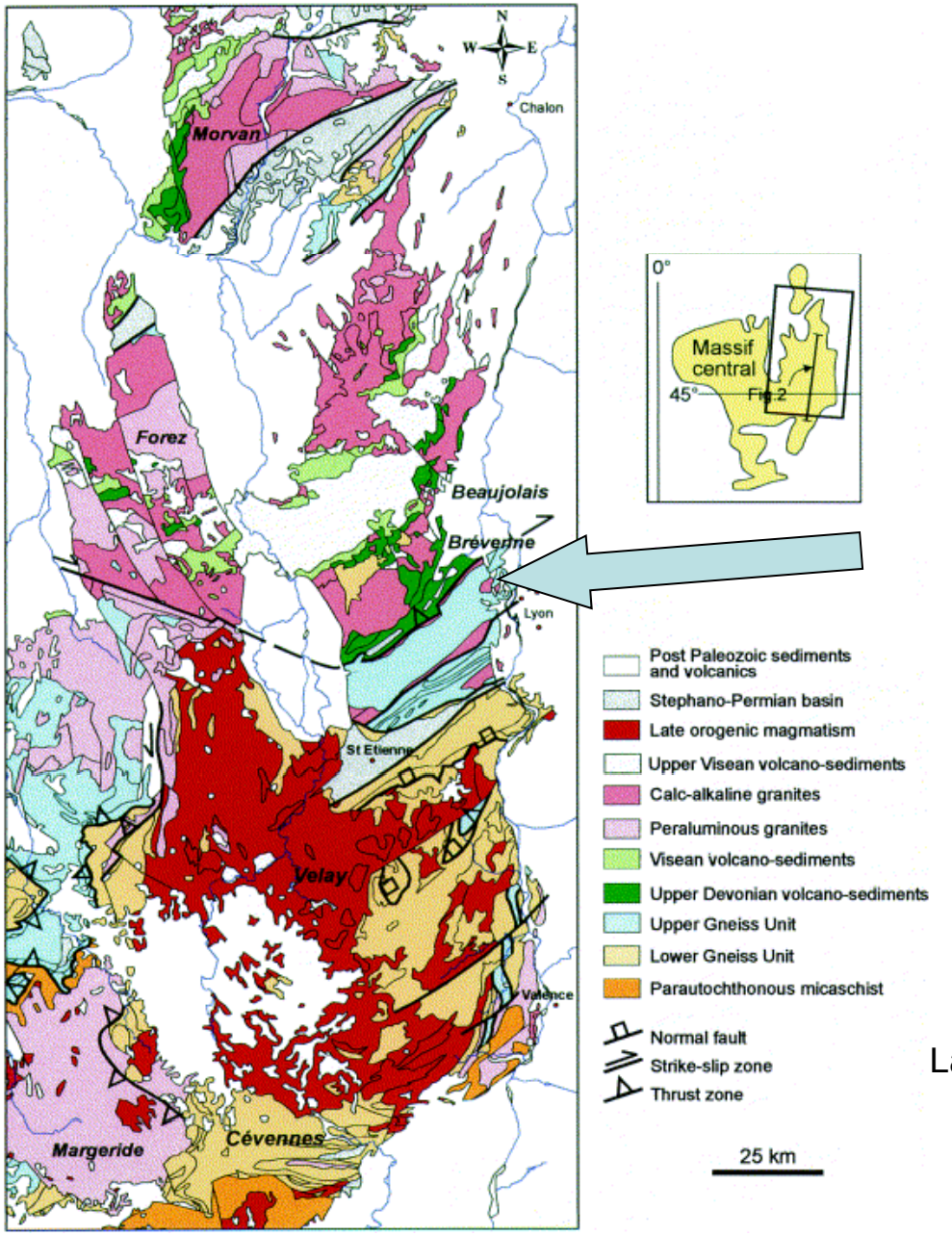


Schwartz, 2000.

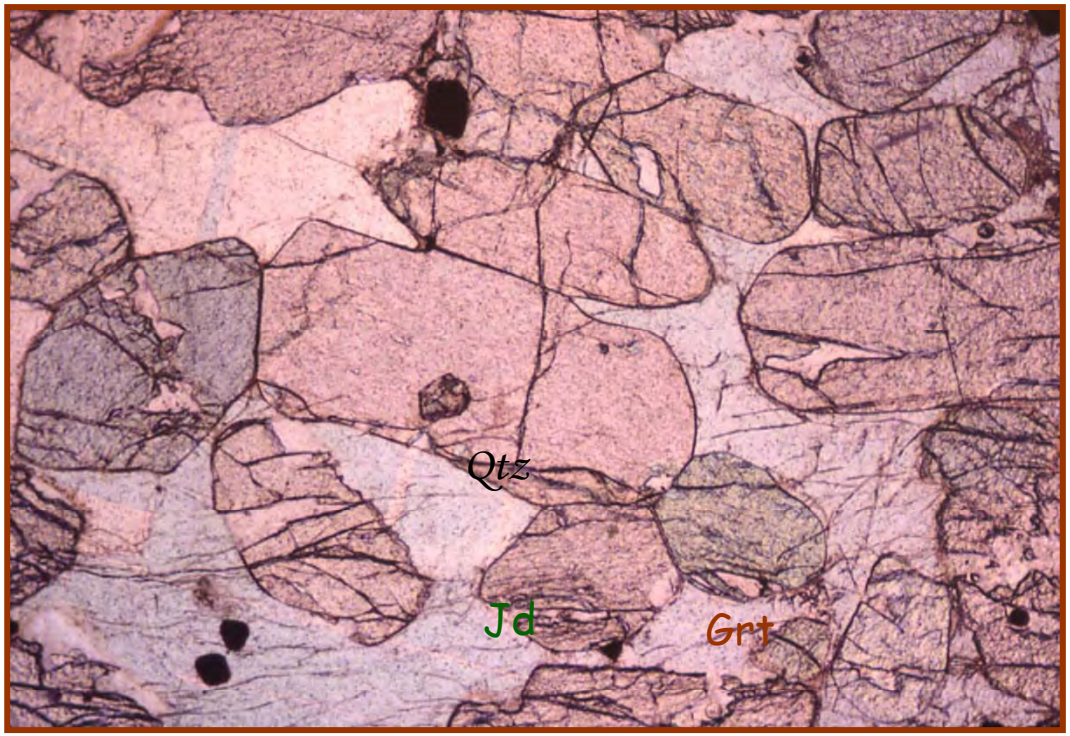


Guillot et Ménot, 2008

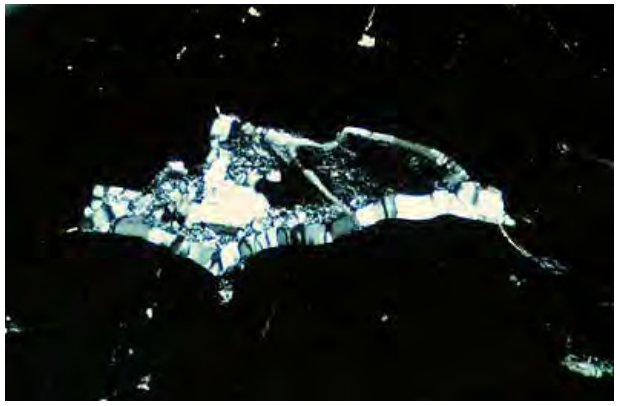

MER MÉDITERRANÉE
MARSEILLE
GENOVA
MILANO
TORINO



Lardeaux et al., 1997



coesite

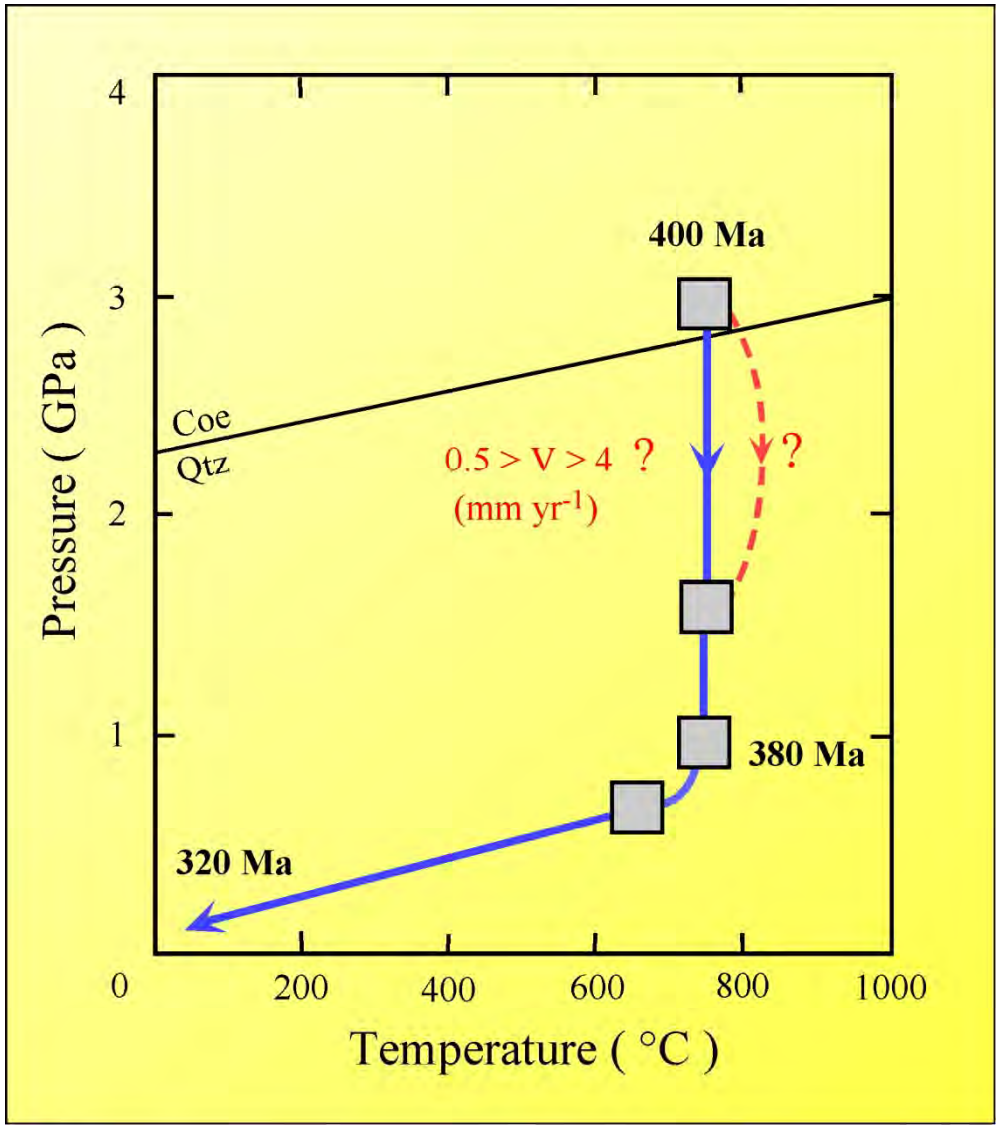


Métamorphisme de UHP
vers 400 Ma exclusivement
dans le Lyonnais (unité sup)

Lardeaux et al., 1997

Evolution P-T-t des Monts du Lyonnais

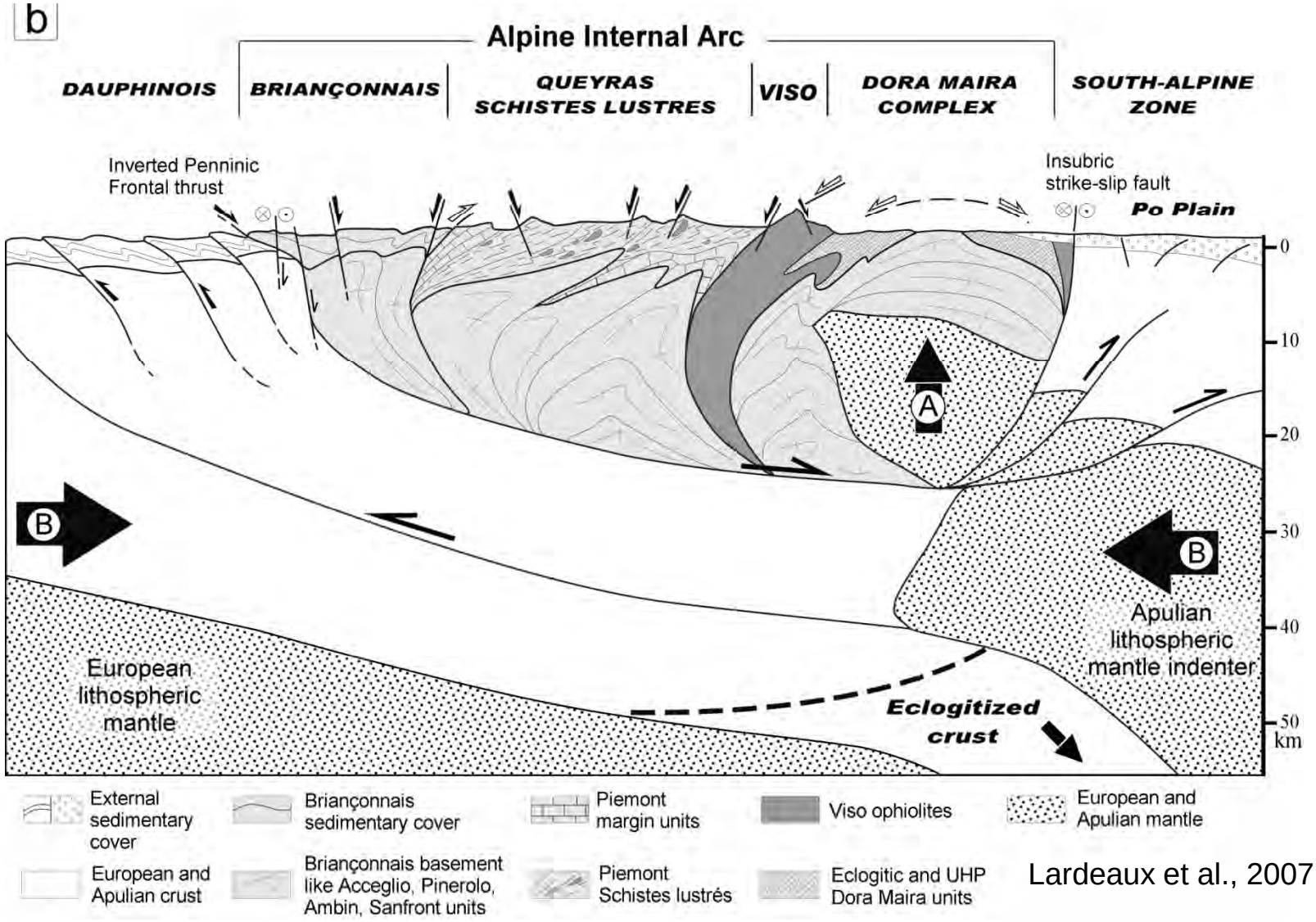
420 Ma



Lardeaux et al., 1997

Les marqueurs de la collision continentale

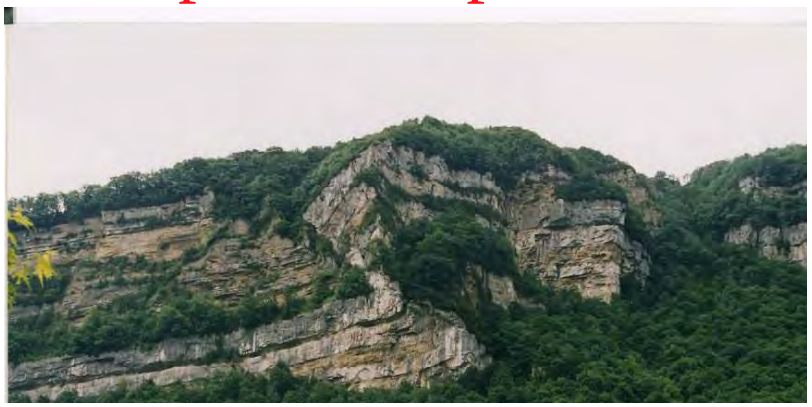
- De la tectonique compressive (nappes et chevauchements) dans les 3 chaînes
- Du métamorphisme Barrovien (MP-MT) : bien représenté en Himalaya et dans le Varisque, plus faible en zone externe dans les Alpes
- De l'anatéxie crustale: bien représenté en Himalaya et dans le Varisque, peu représenté dans les Alpes internes Suisse
- Des bassins Molassique dans les 3 chaînes

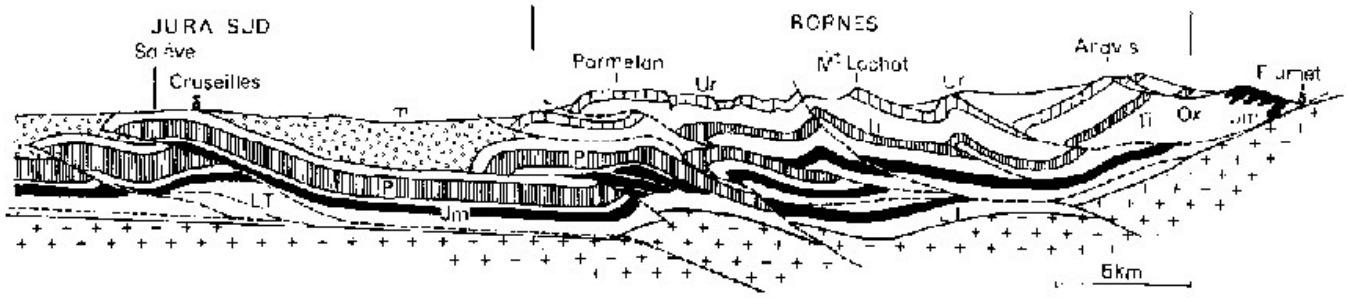


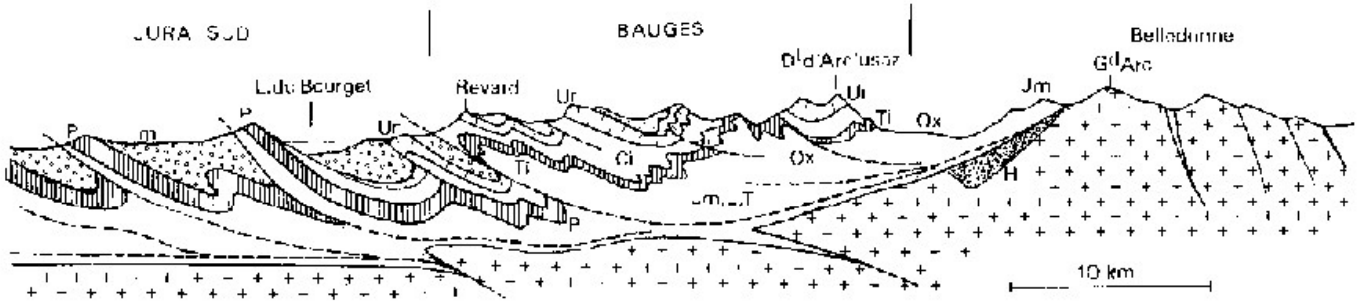
Lardeaux et al., 2007

Evidences de compression
structures en compression: plis et chevauchements

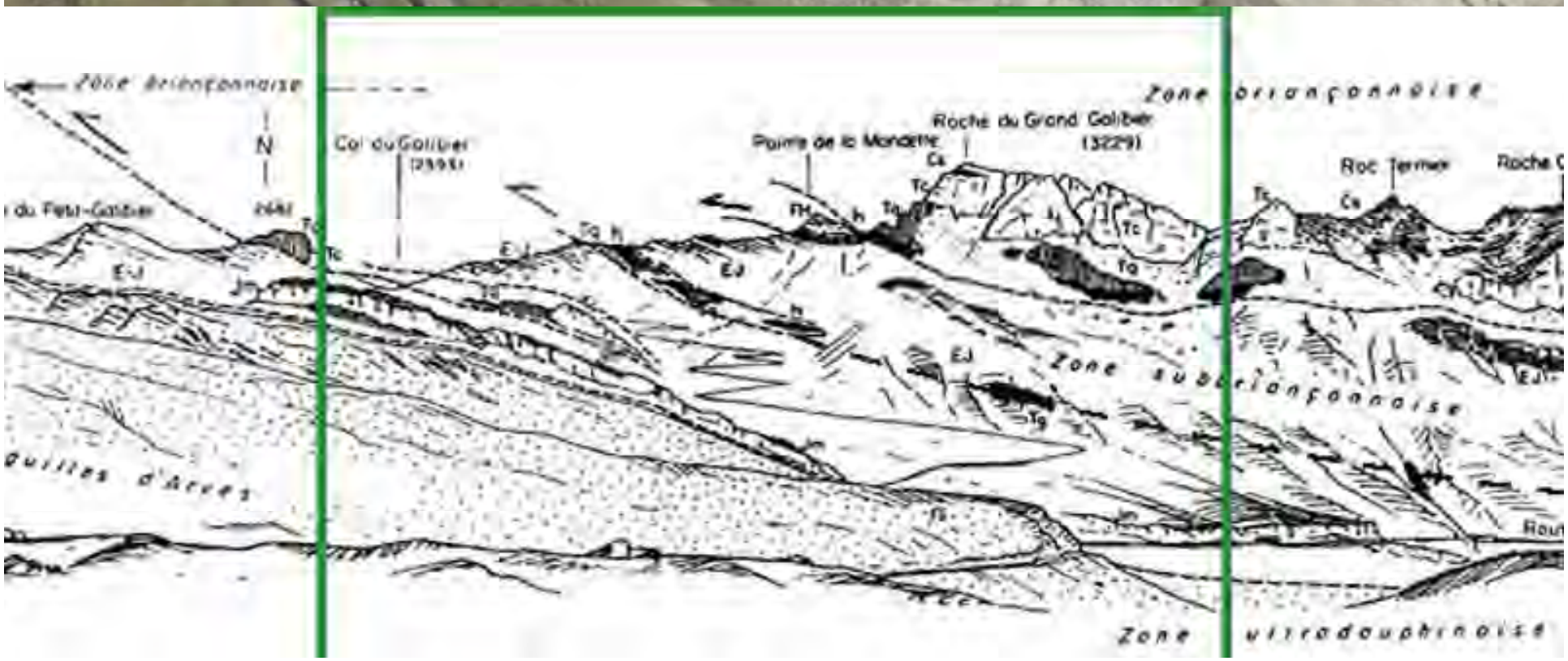
Les Alpes externes (ou dauphinoises): le Jure et les chaînons sub alpins







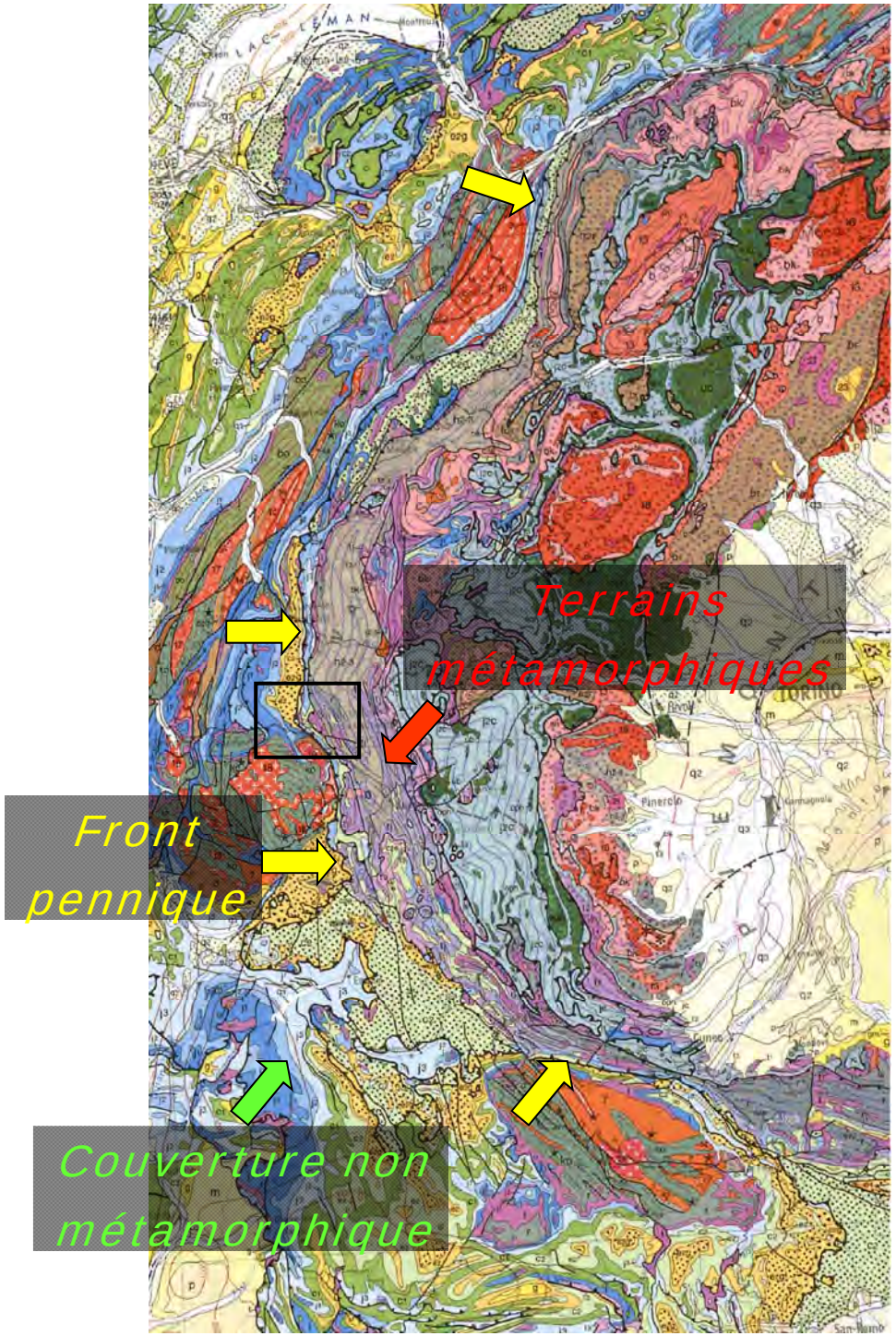
Debelmas & Mascle, *Les grandes structures géologiques*

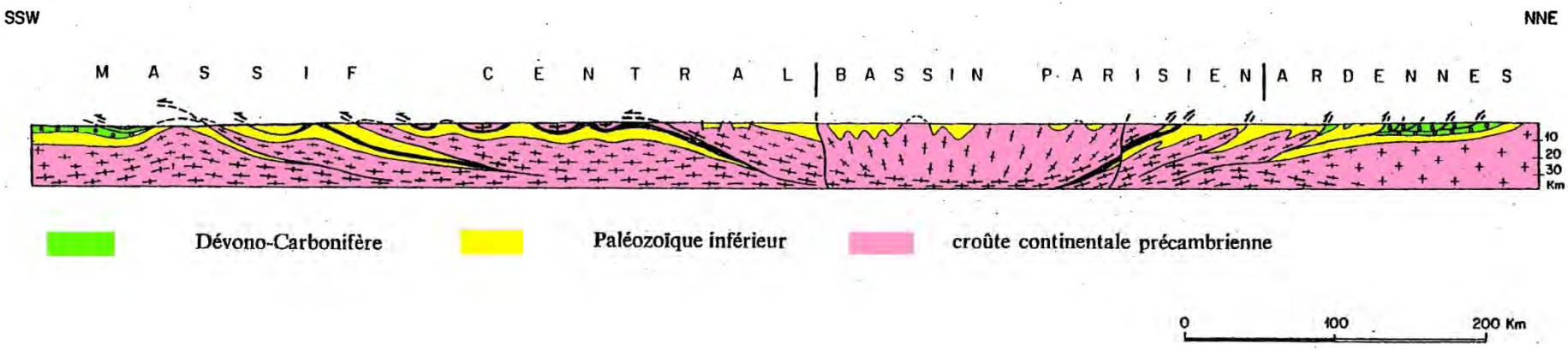

Zone briançonnaise
Zone briançonnaise
N
Col du Galibier
Pointe de la Mandette
Roche du Grand Galibier
(3229)
Roc Termier
Roche
du Petit-Galibier
Zone subbriançonnaise
Zone ultradauphinoise

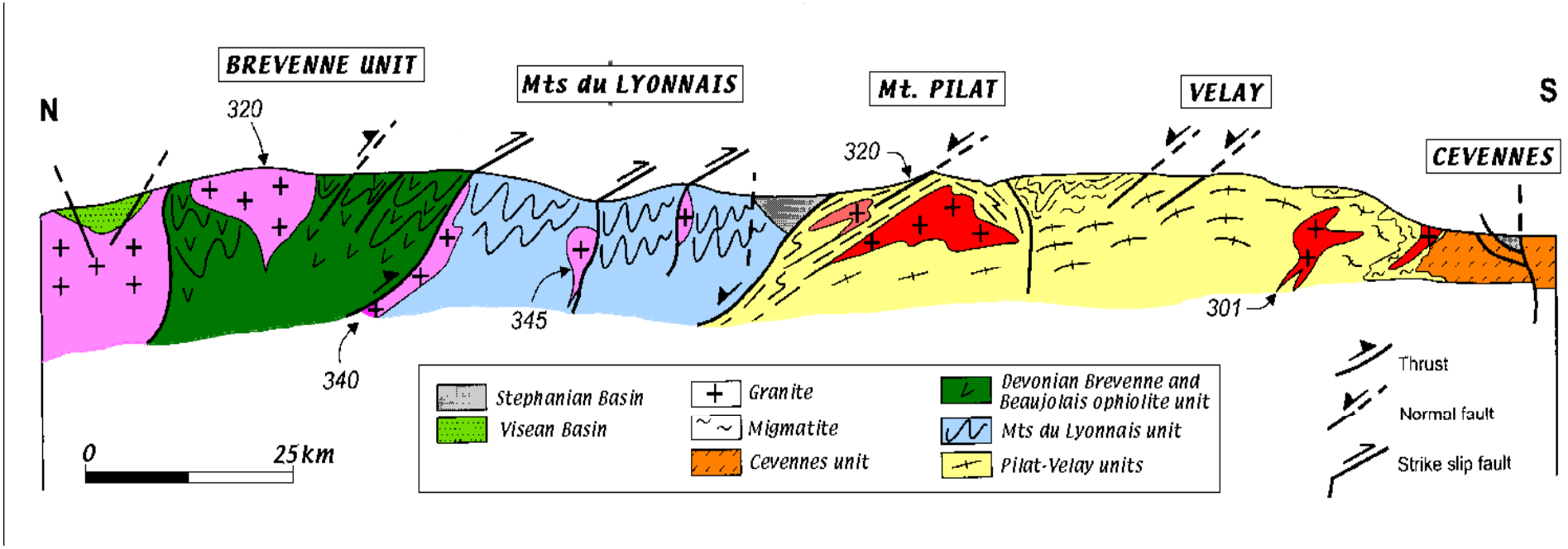
Front pennique
Structure majeure
à l ’échelle de l ’arc alpin

Limite tectonique:
chevauchement des zones métamorphiques sur l’avant-pays européen

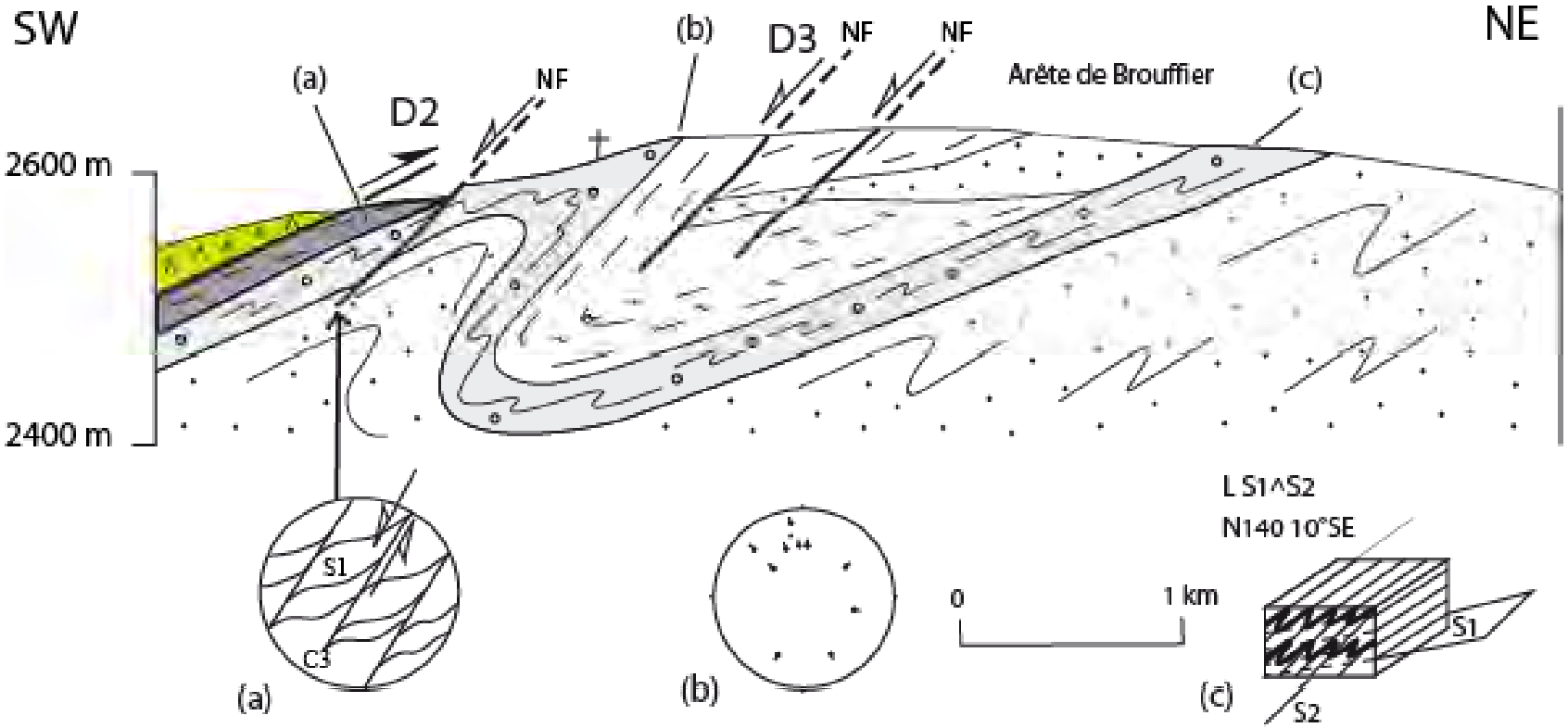
Schwartz, 2000.




SSW
NNE
M A S S I F C E N T R A L
B A S S I N P A R I S I E N
A R D E N N E S
10
20
30
Km
Dévono-Carbonifère
Paléozoïque inférieur
croûte continentale précambrienne
0
100
200 Km



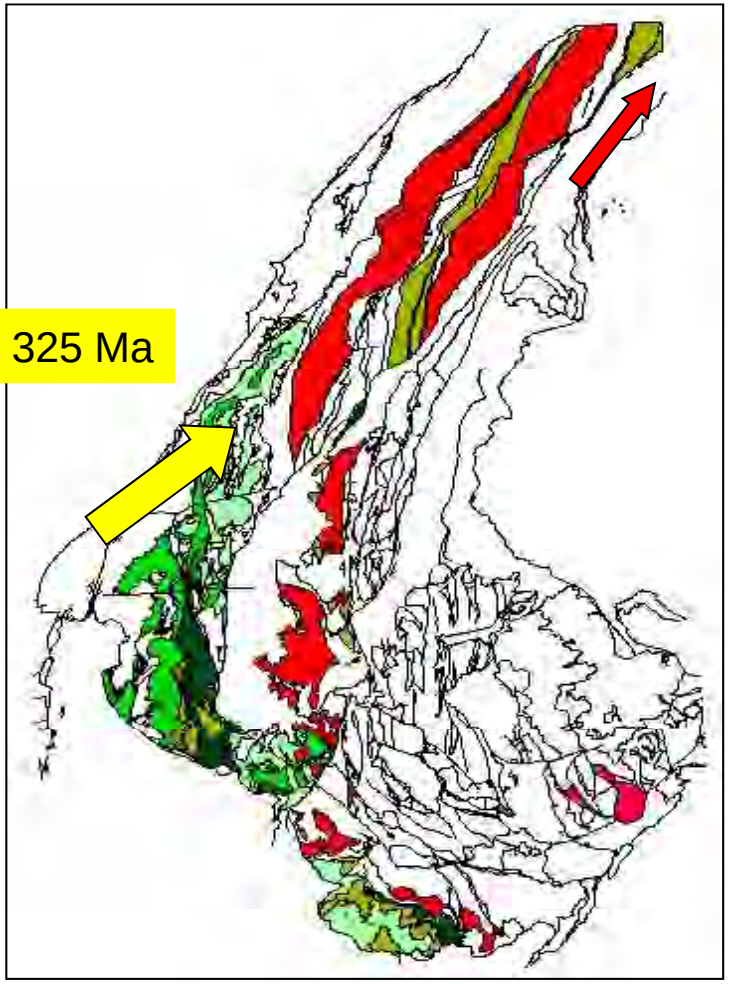
Lardeaux et al., 1997



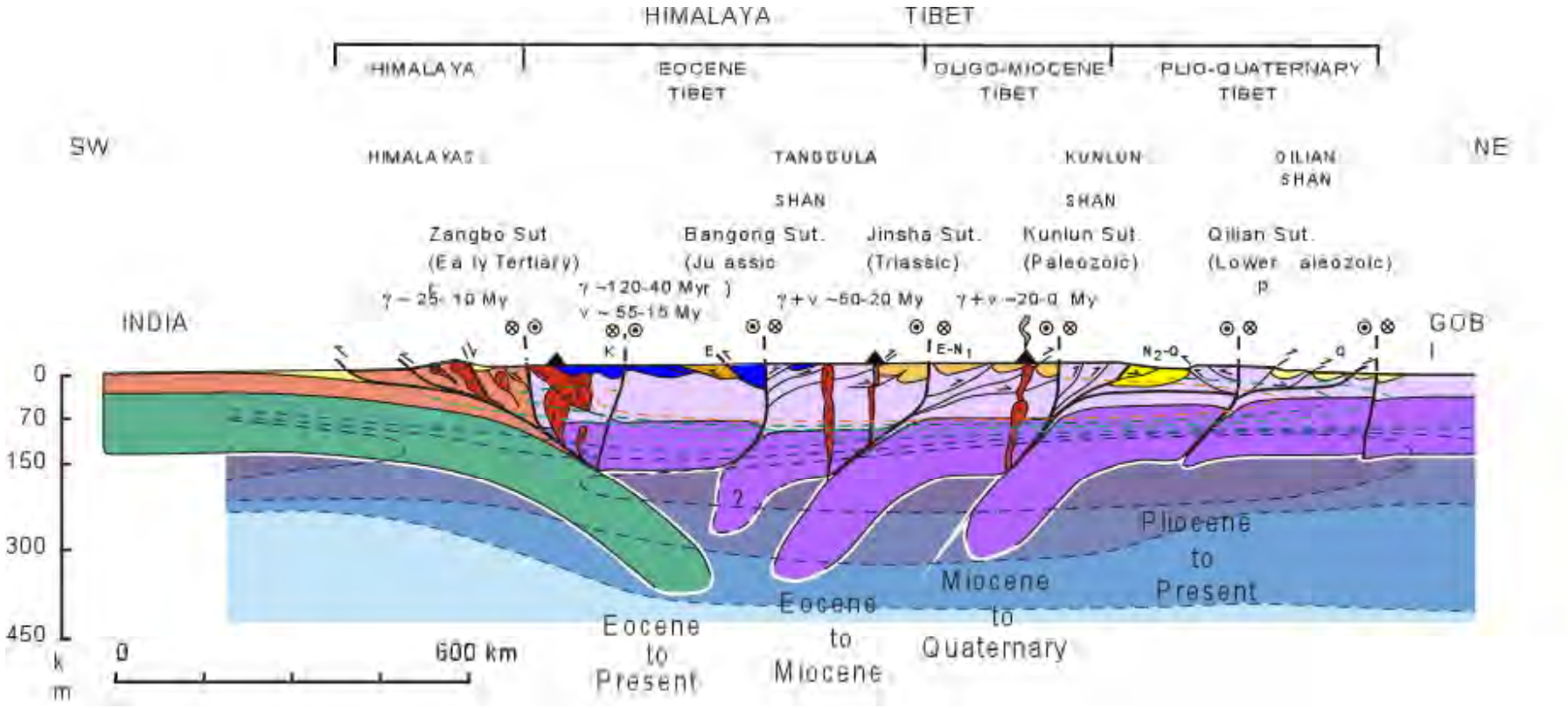
Fernandez et al., 2002

Dated at 324 +/- 12 Ma (Ménot et al., 1987)

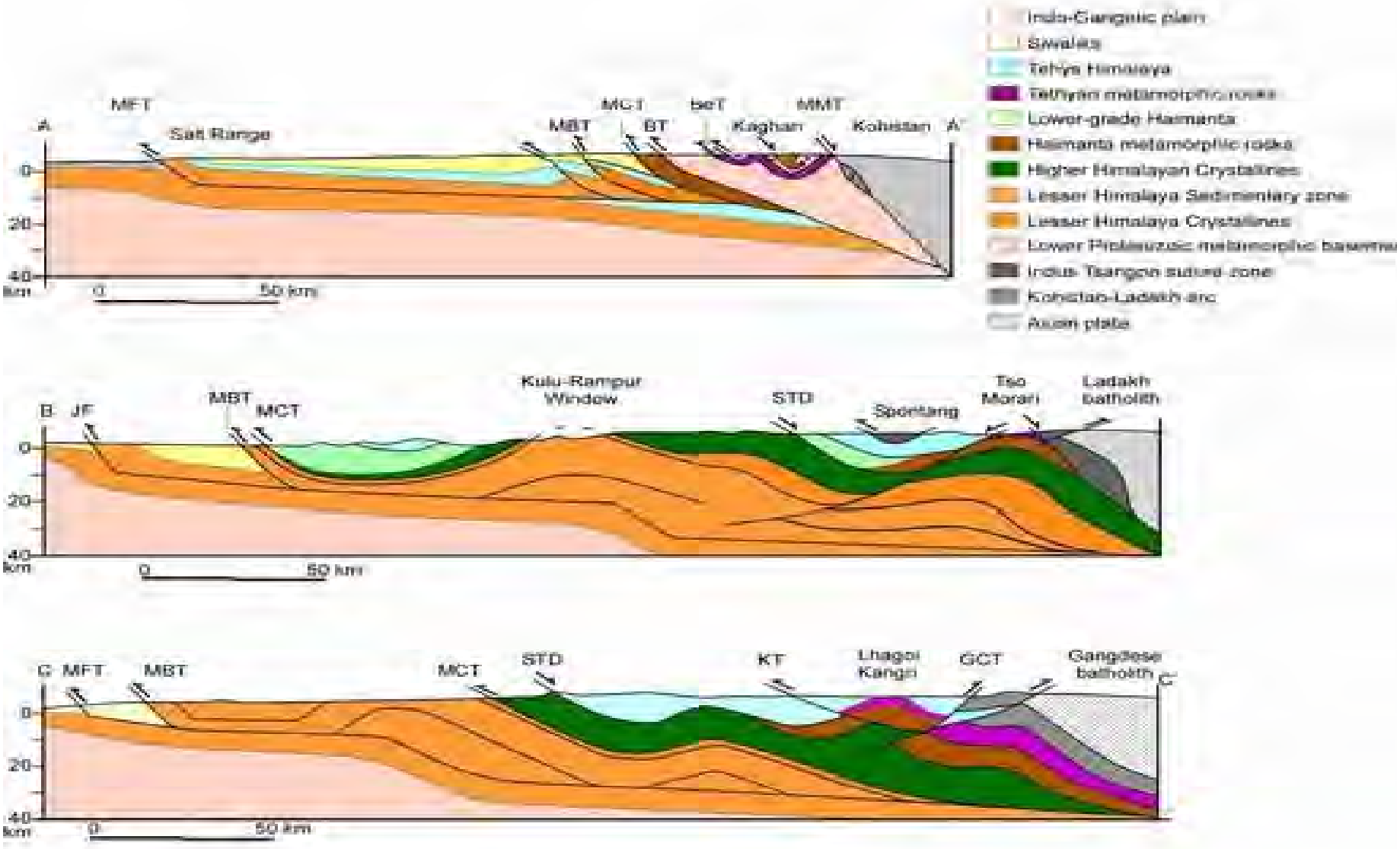
Visean Collision



Guillot et al., en prep.



Tapponnier et al., 2001

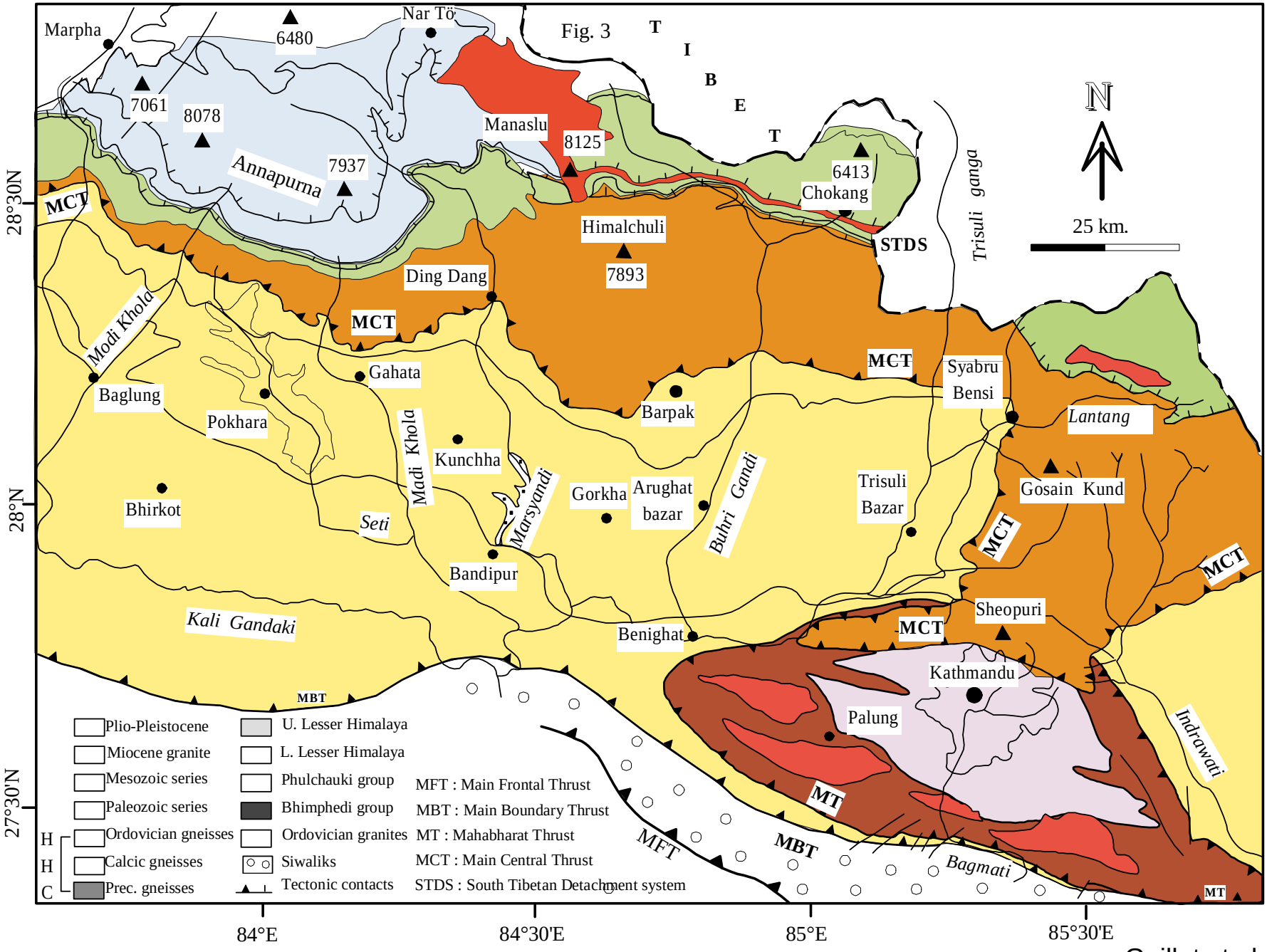


Guillot et al. 2003

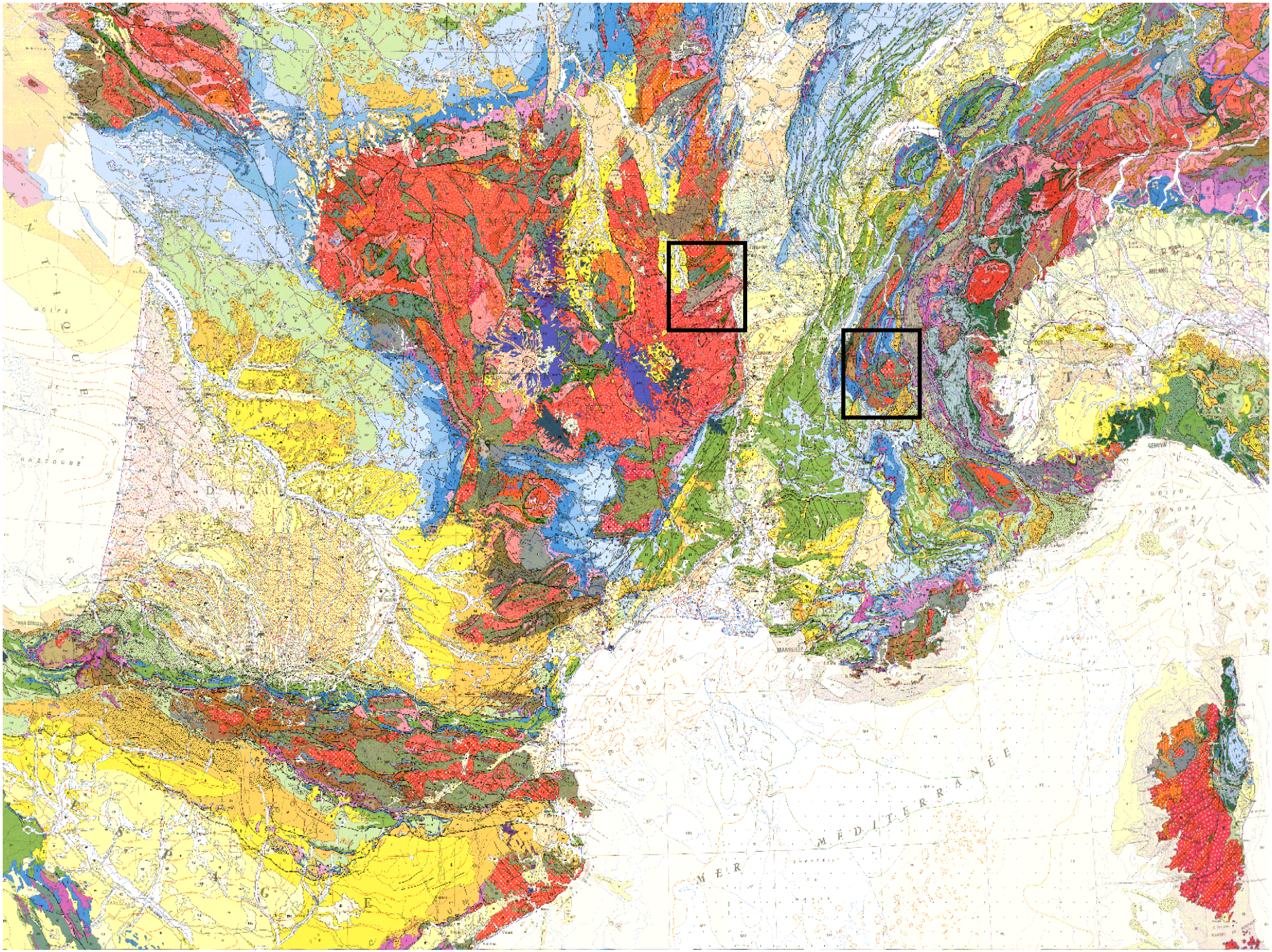
Fig. 3

Les marqueurs de la collision continentale

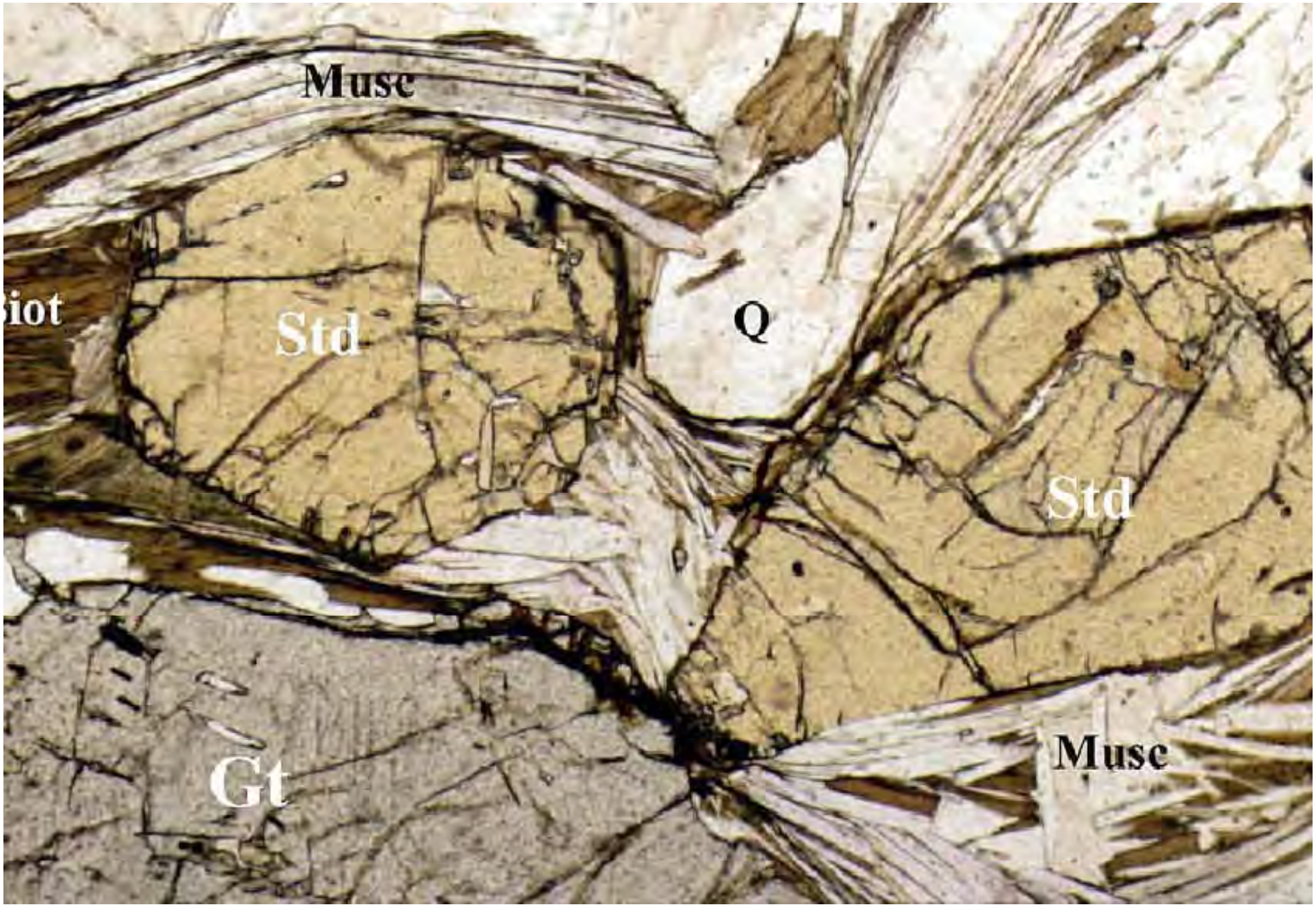
- Du métamorphisme Barrovien (MP-MT) : bien représenté en Himalaya et dans le Varisque, plus faible en zone externe dans les Alpes



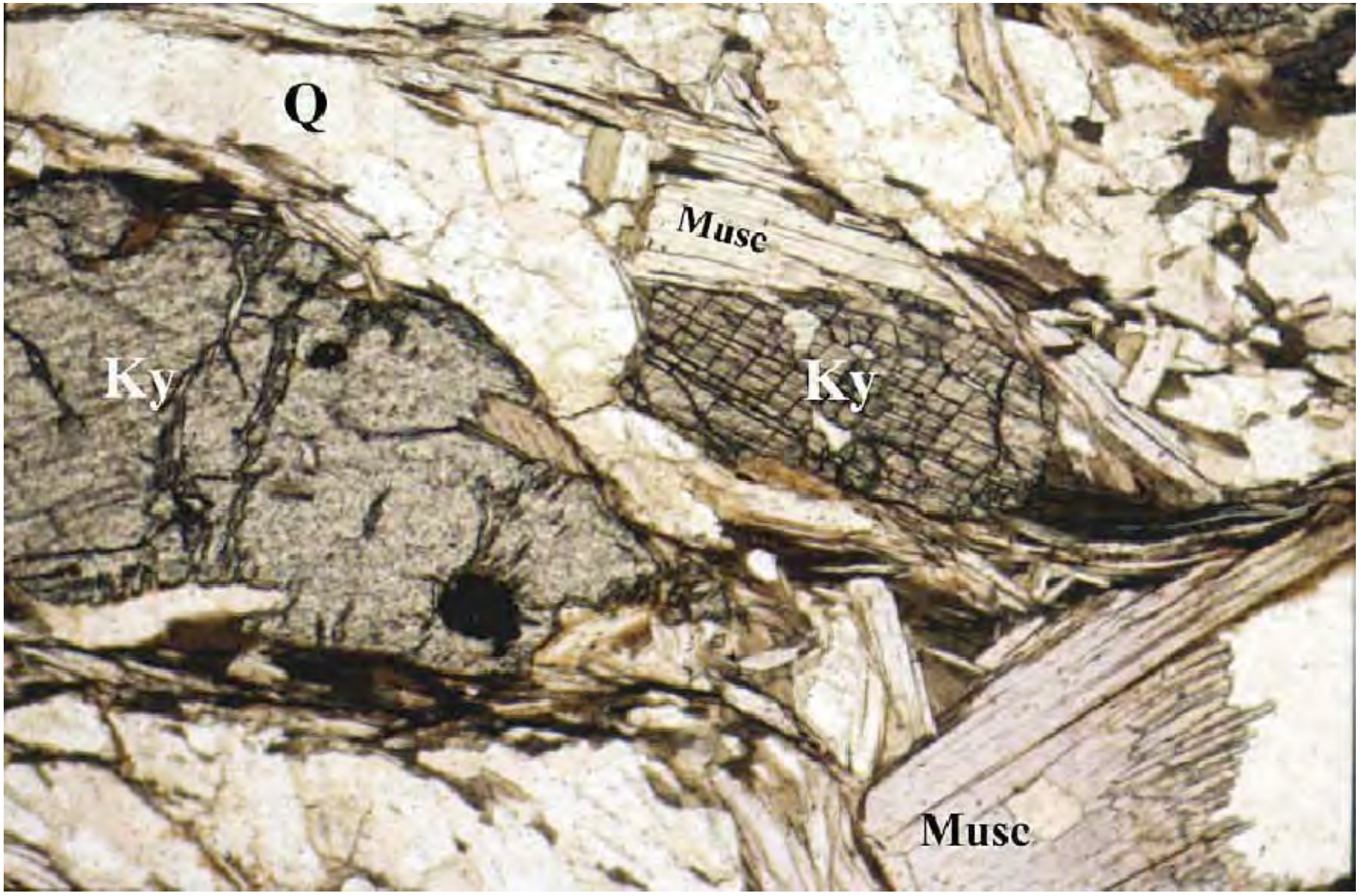
Guillot et al. 1998


MER MÉDITERRANÉE
MARSEILLE
GENOVA
MILANO
TORINO

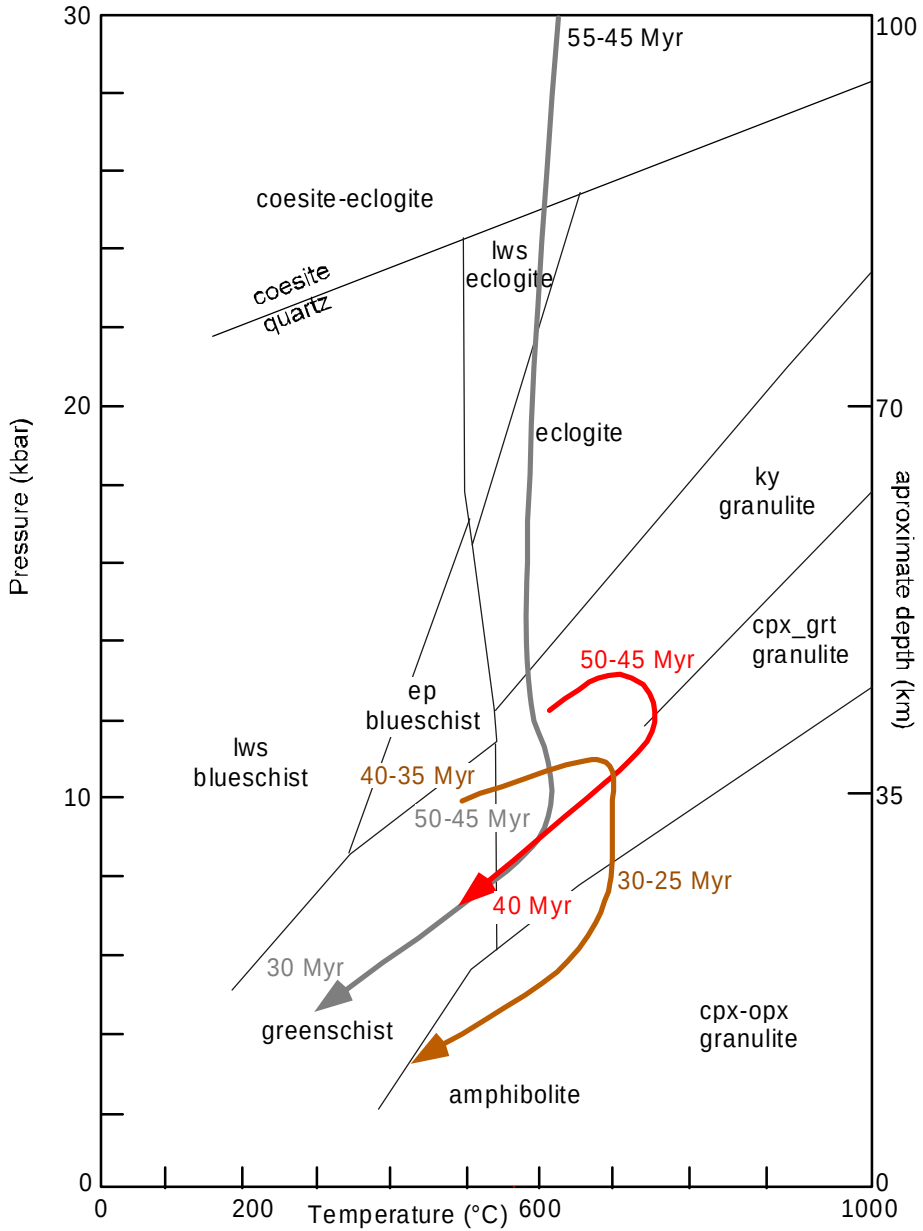
S. Guillot



Métapélite à grenat - Staurotide

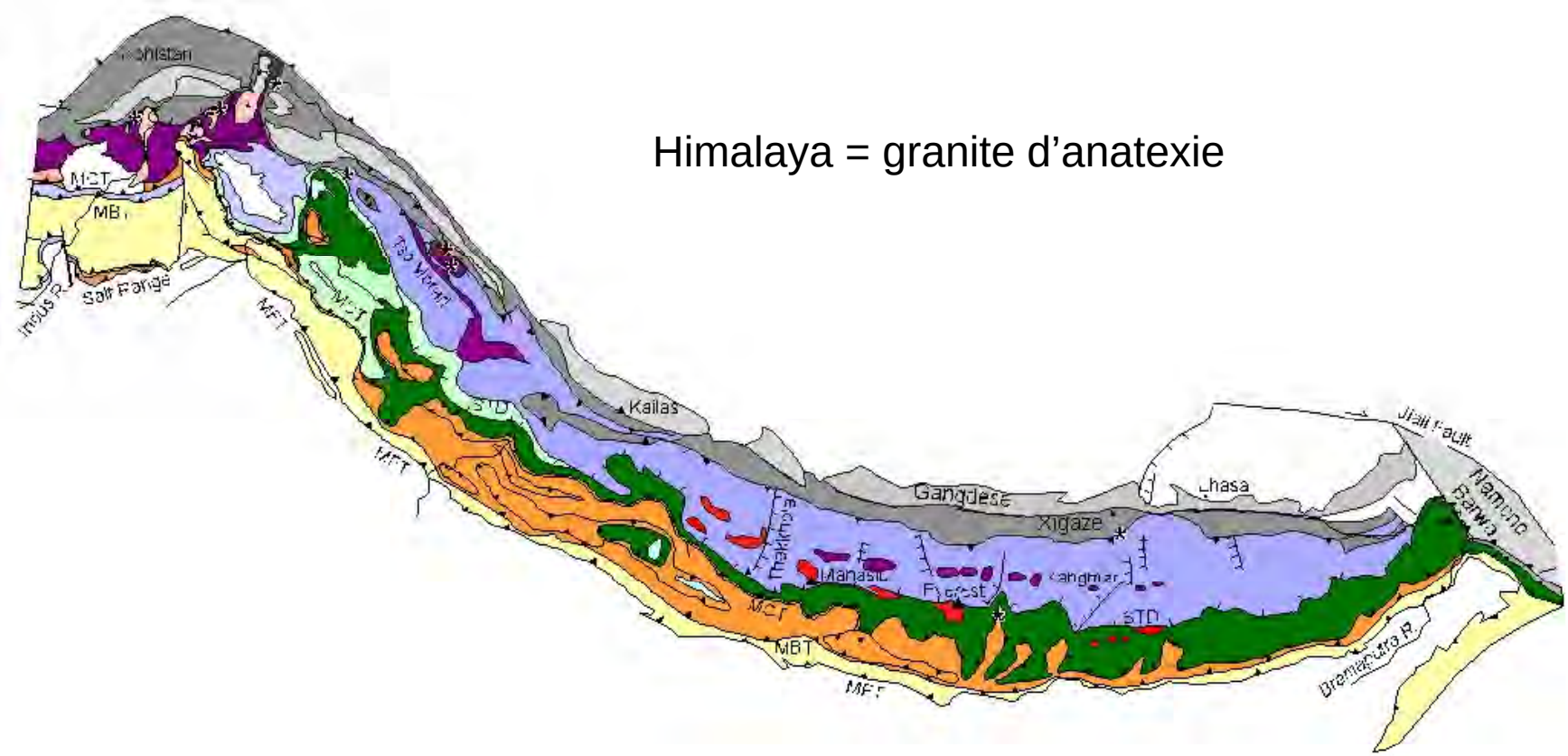


Métapélites à disthène (Ky)

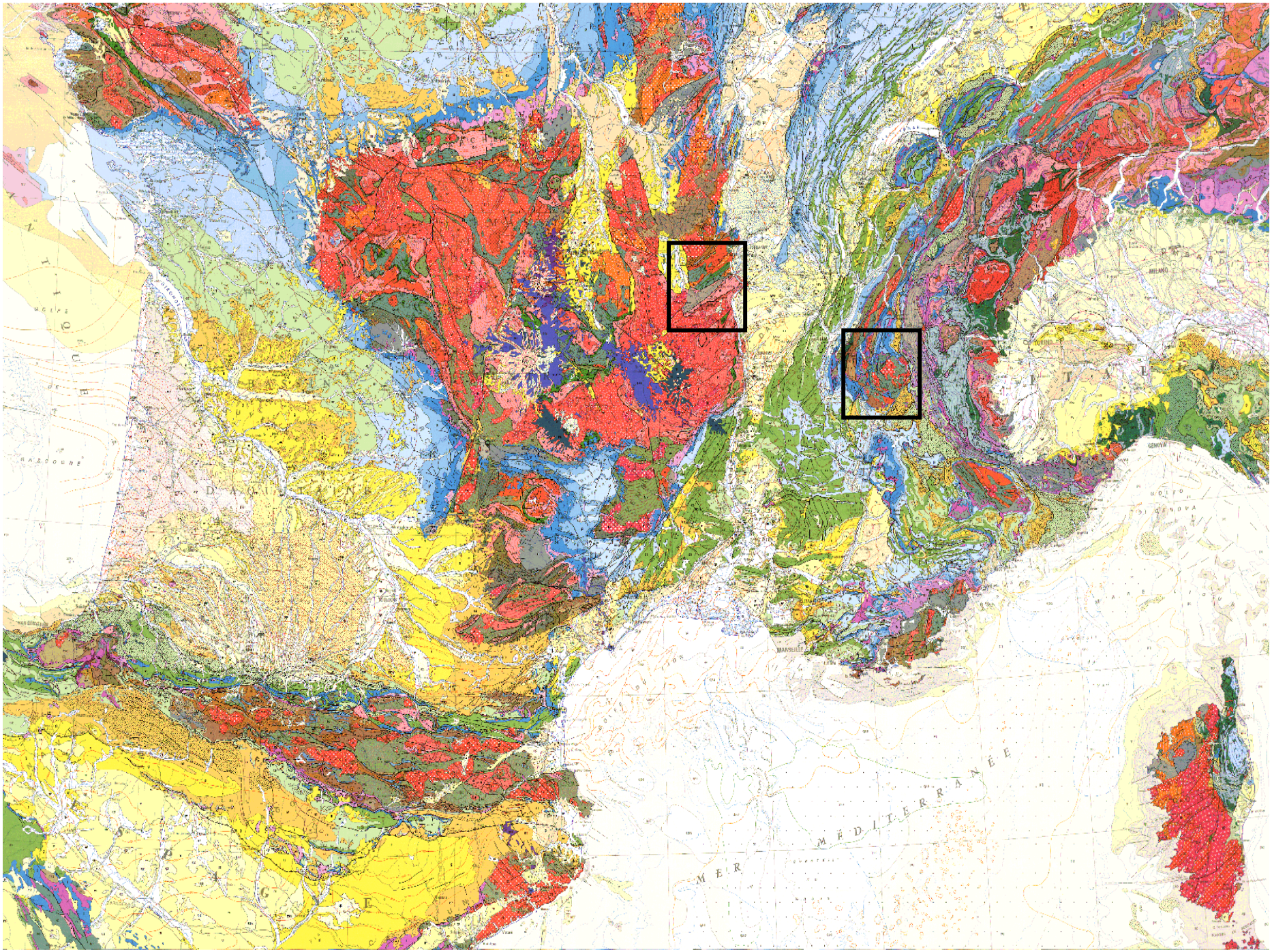


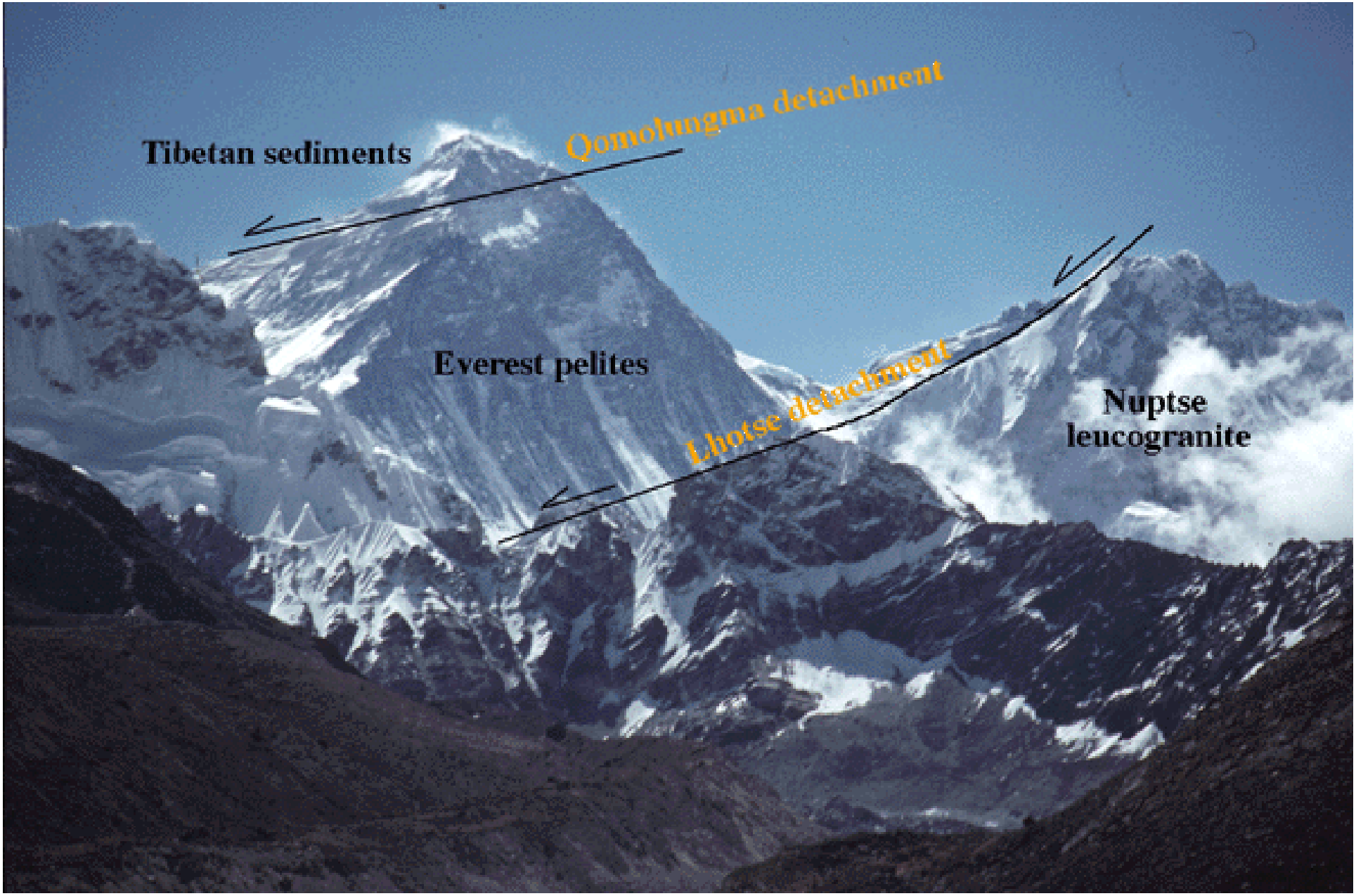
Guillot et al., 2003

Himalaya = granite d’anatexie



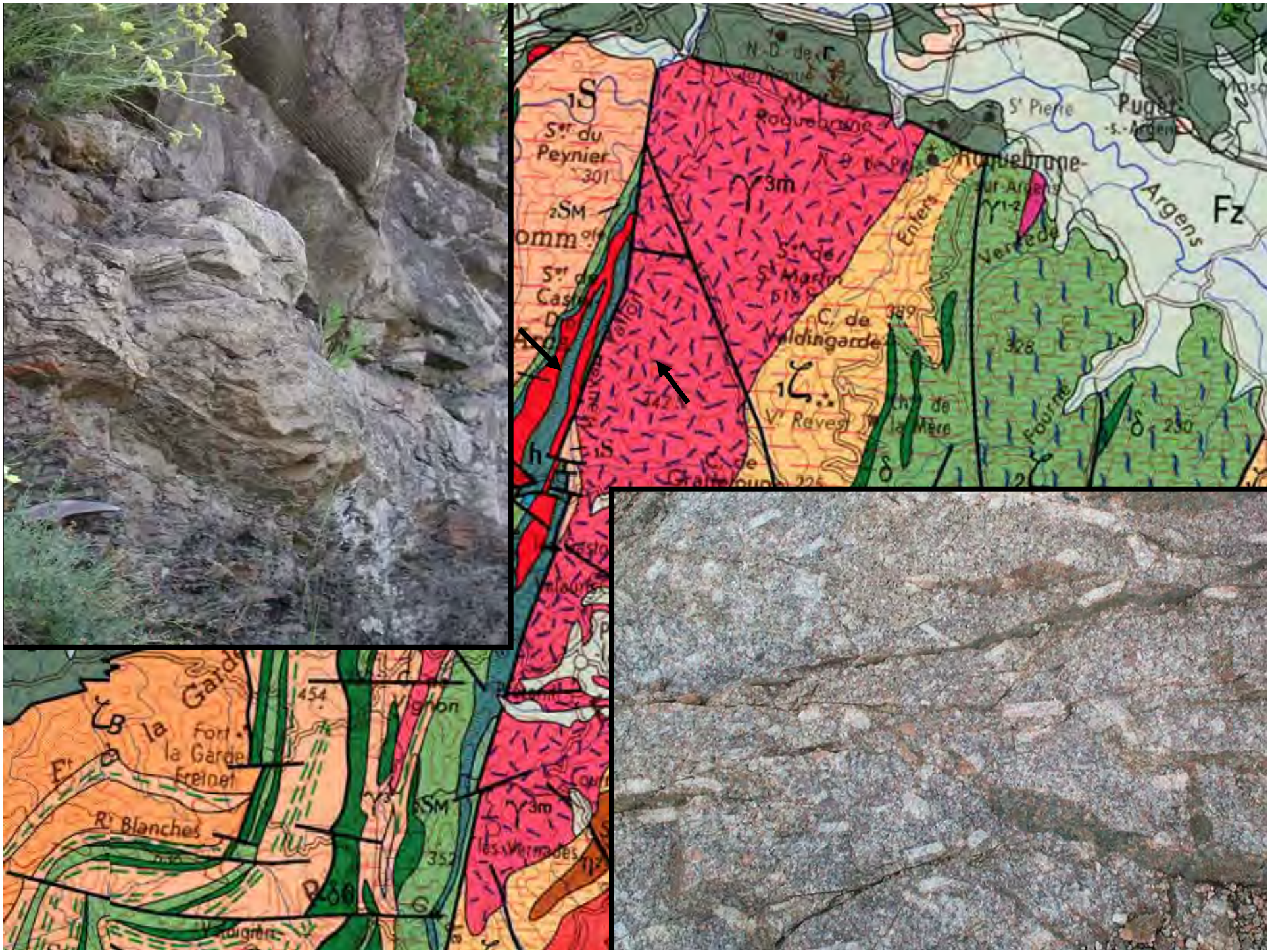
Guillot et al., 2008


MER MÉDITERRANÉE
MARSEILLE
GENOVA
MILANO
TORINO



Searle et al., 2003

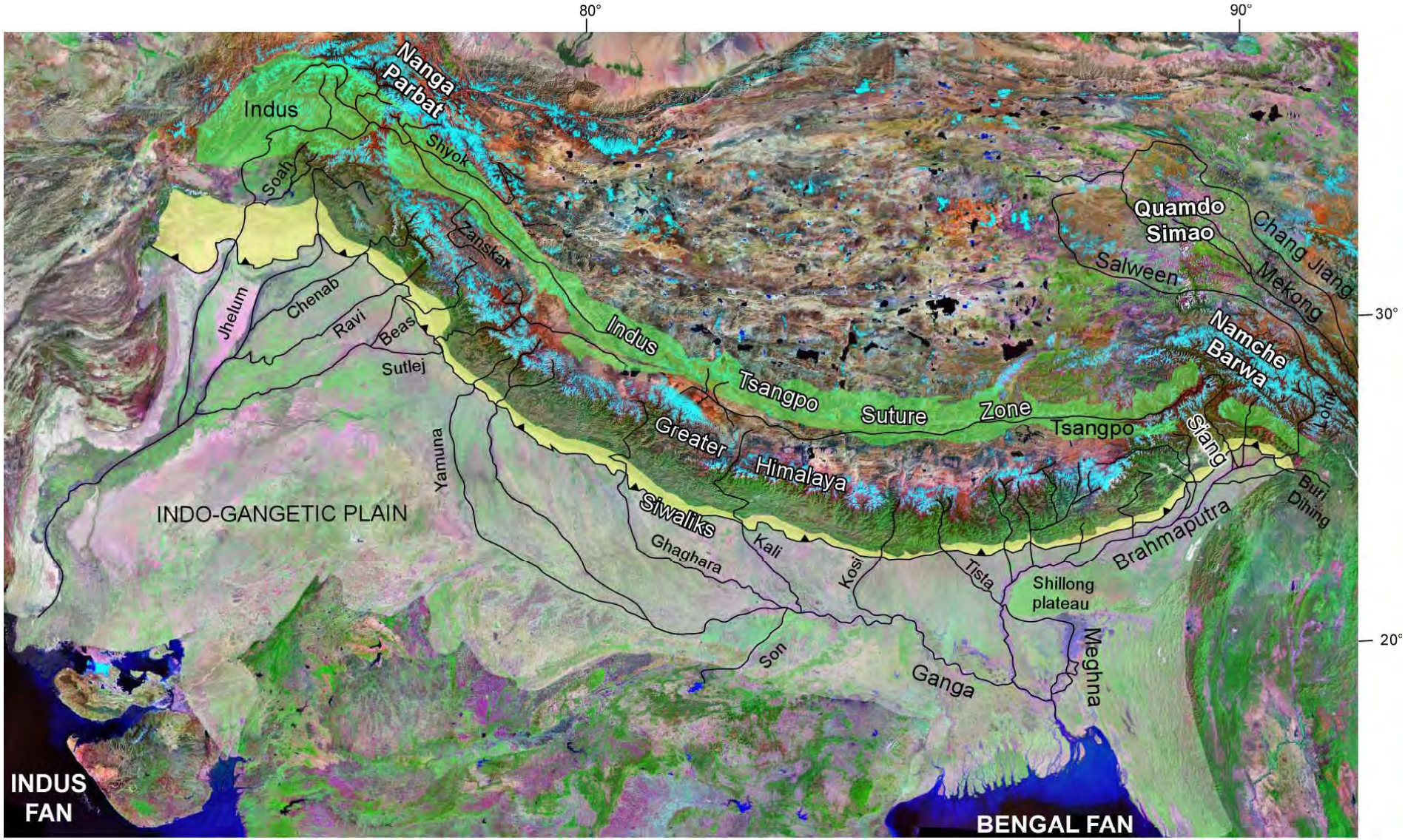
S. Guillot



Peynier
Roquebrune
Argens
Fz
Fort la Garde
Freinet
Blanches

Les marqueurs de la collision continentale

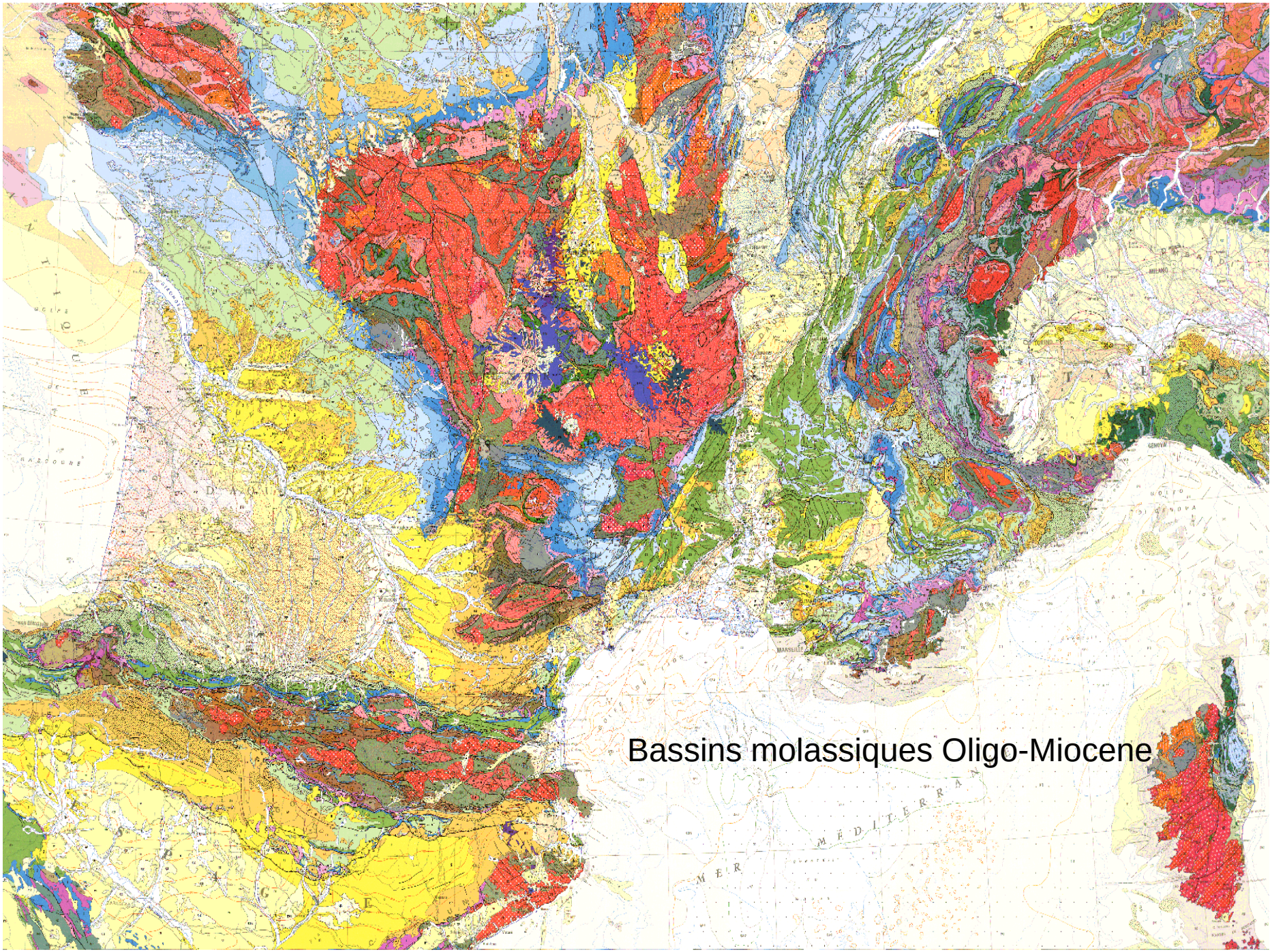
- Des bassins Molassique dans les 3 chaînes



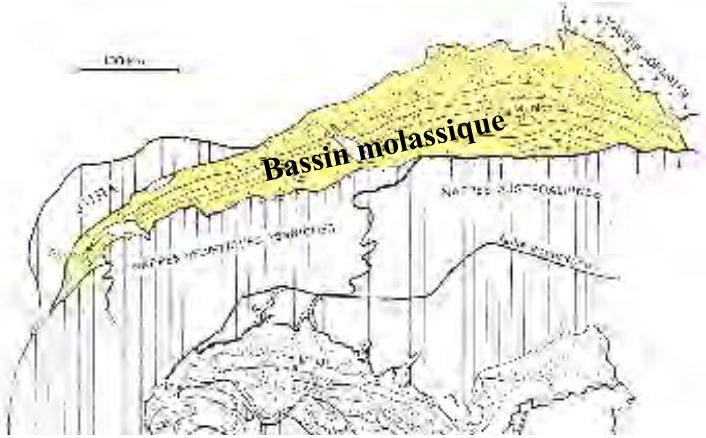
Les bassins Molassiques

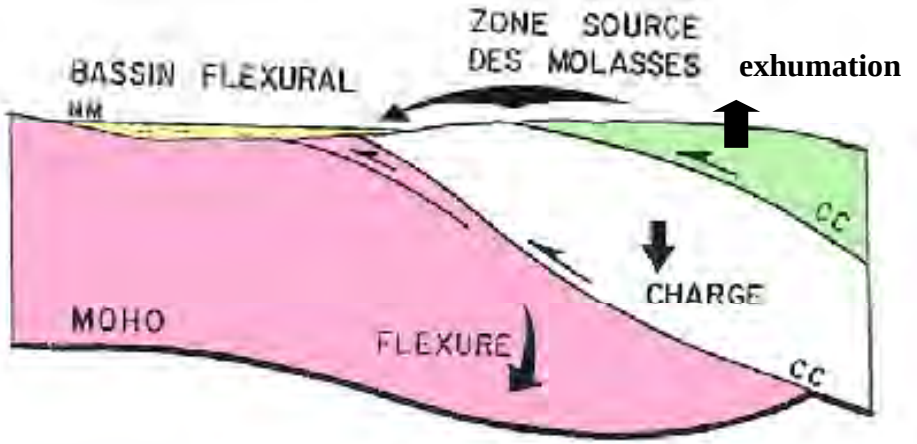
Guillot et Charlet, 2007

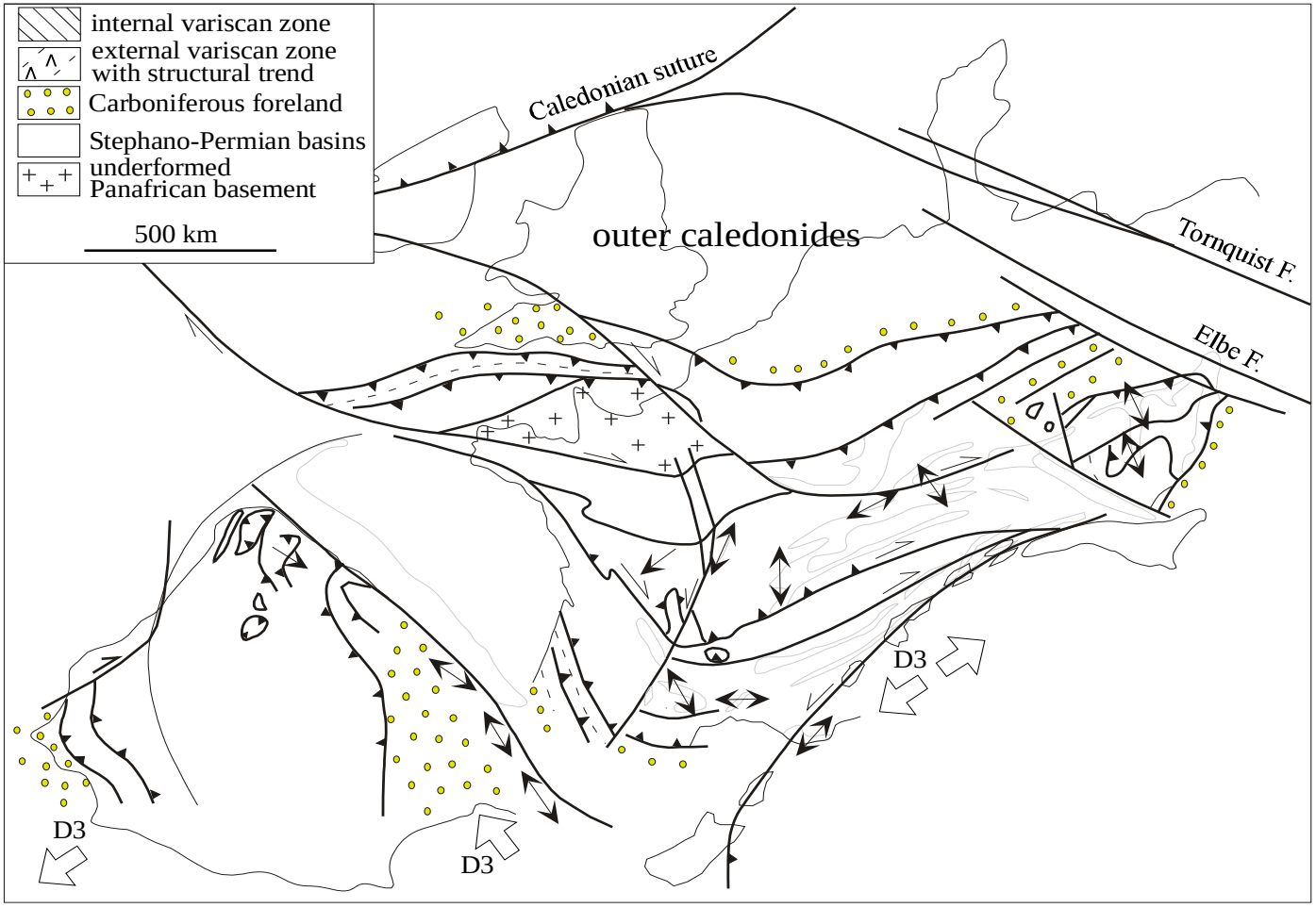
Karakoram
Hindu Kush
Tibetan Plateau
Afganistan
Pakistan
Indus River
Himalayas
Ganges River
Bramputra R.
Arabia
India
Bay of Bengal
Indus Fan
Arabian Sea
Bengal Fan
2500 km


Bassins molassiques Oligo-Miocene

Evidence indirecte d'augmentation du relief:
Sédiments détritiques (molasses) dans les bassins flexuraux:





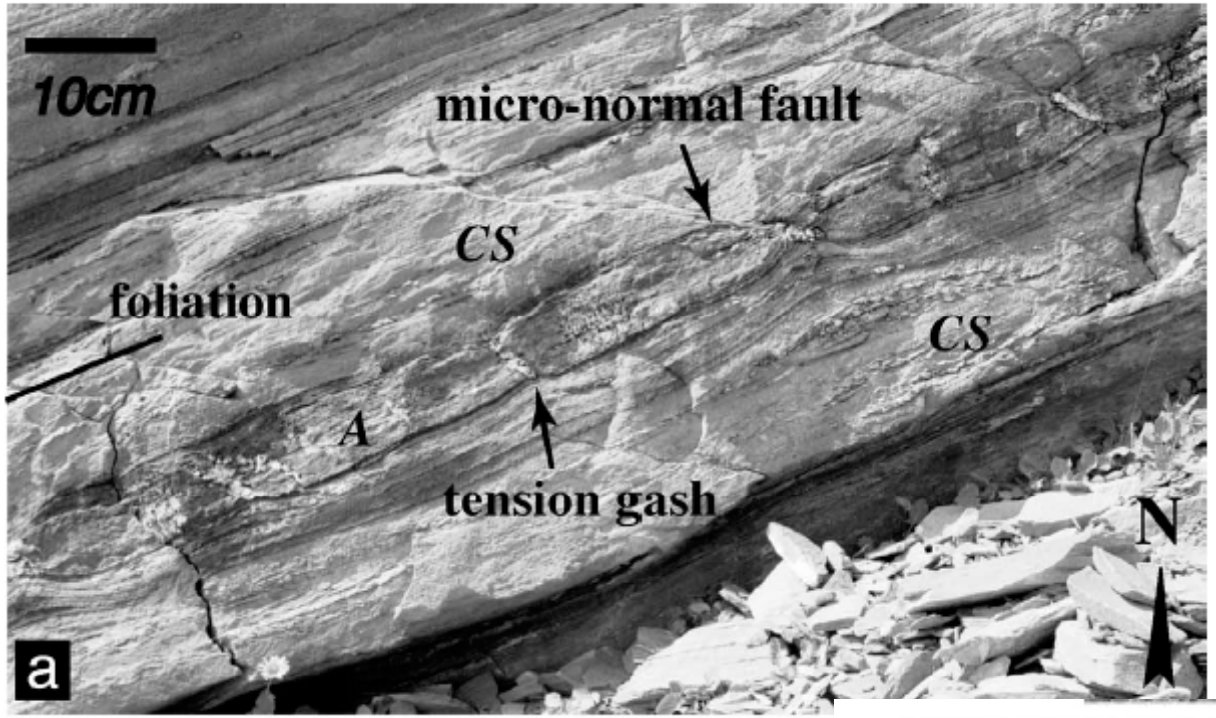

internal variscan zone
external variscan zone with structural trend
Carboniferous foreland
Stephano-Permian basins underformed
Panafrican basement
500 km
Caledonian suture
outer caledonides
Tornquist F.
Elbe F.
D3
D3
D3

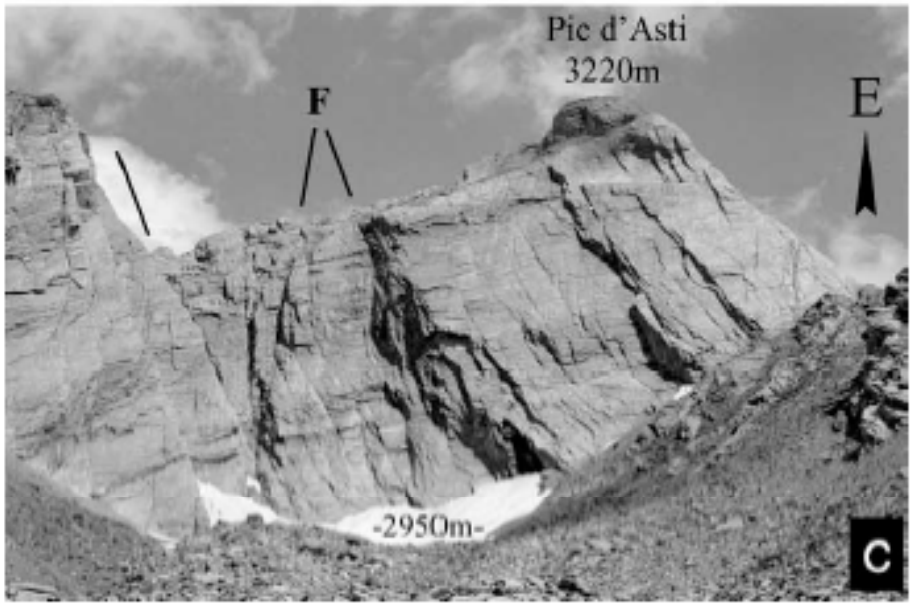
330-320 Ma

Le retour à l'équilibre de la Chaîne

Le devenir d'une chaîne de montagne : devenir une plaine !!

- Arrêt de la convergence
- Tectonique extensive
- Métamorphisme de BP-HT
- Bassin sédimentaire tardif
- Très abouti dans la Chaîne Varisque, fin de vie pour les Alpes, en cours en Himalaya ?





Schwartz et al., 2008

Figure 34 **: photo du Mont Viso, vue du Agnel.**

NW **SE**

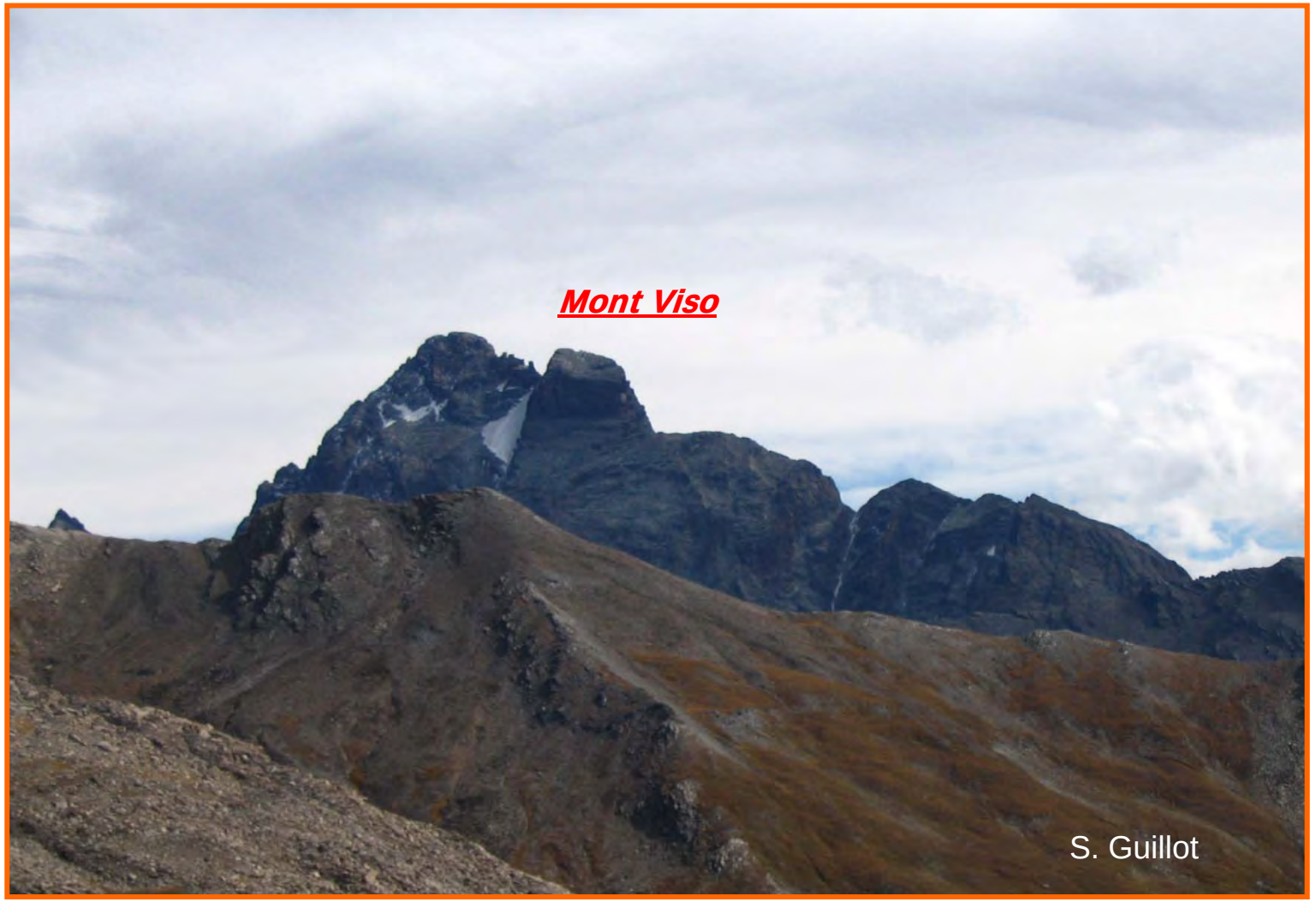
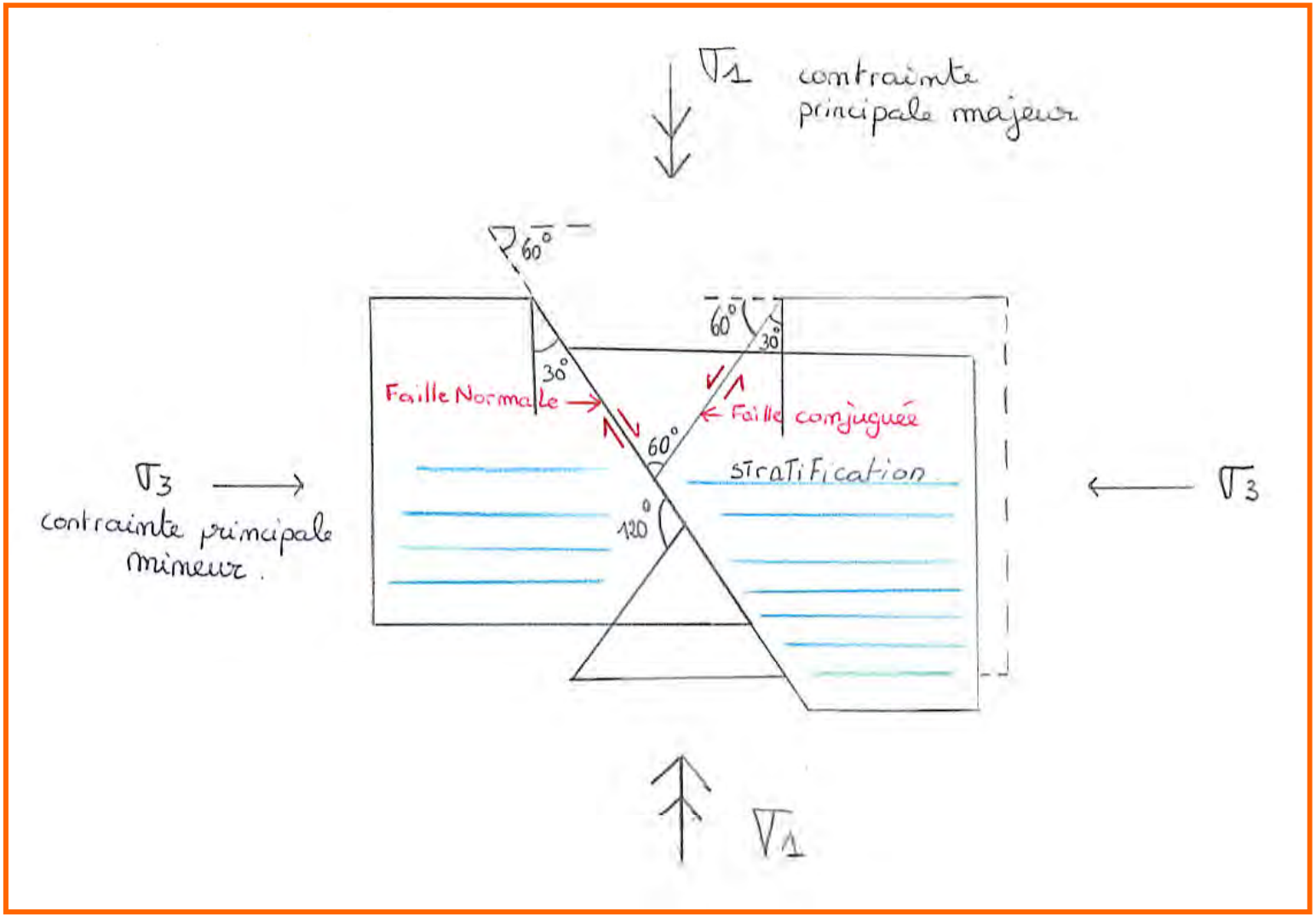
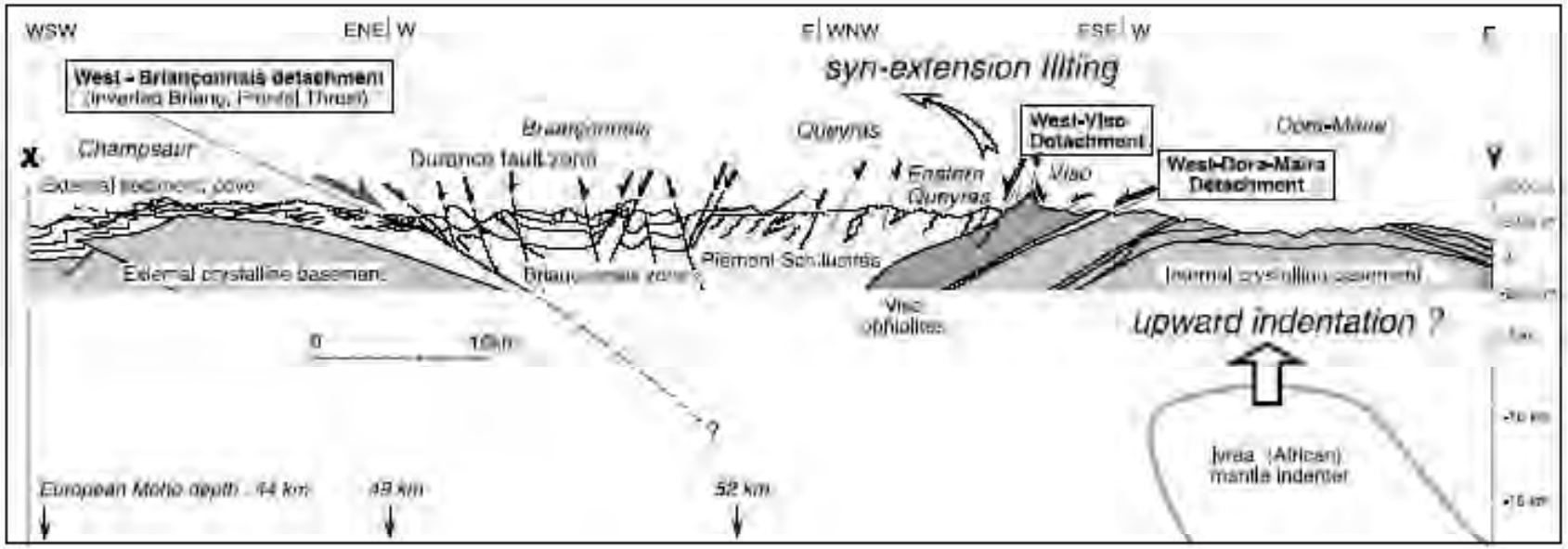
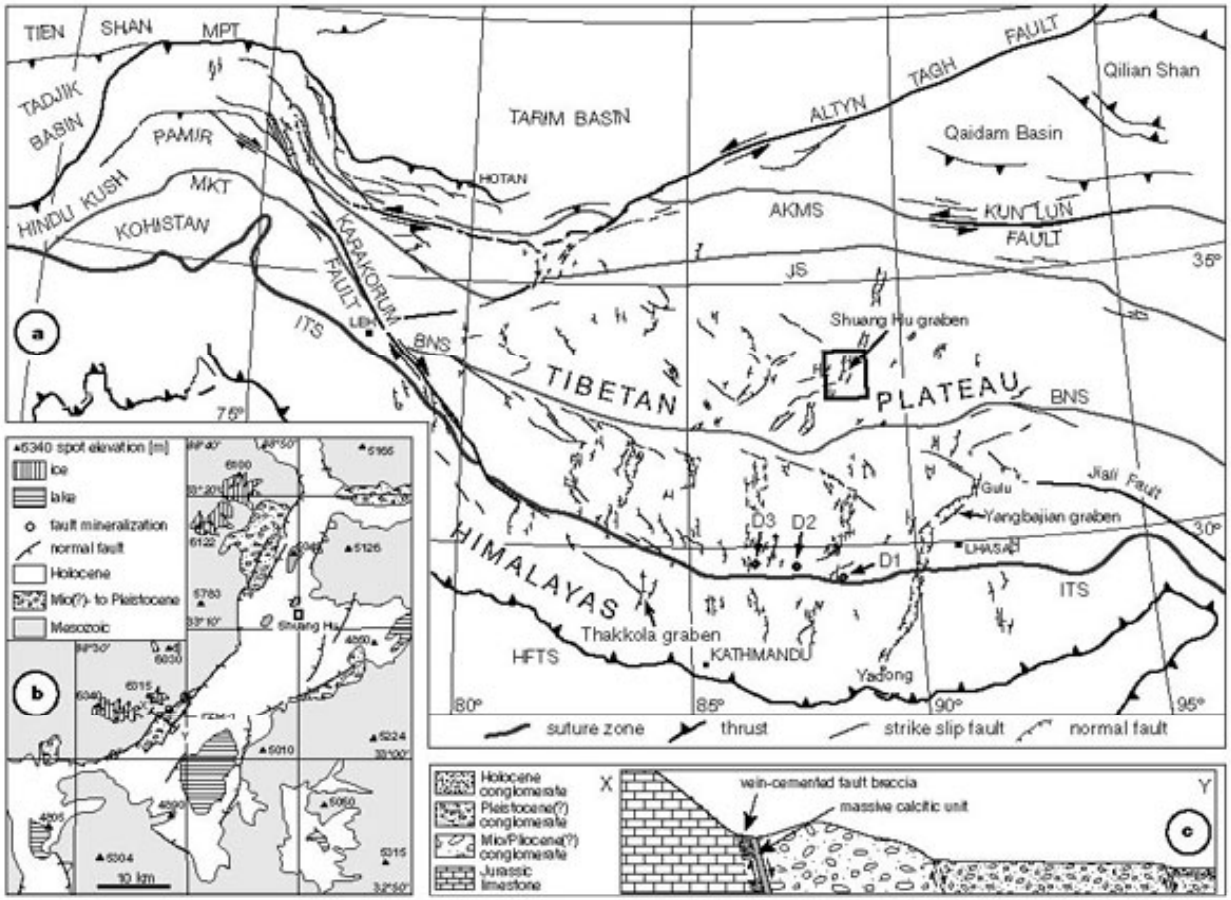


Figure 36 **: schéma expliquant les failles conjuguées.**

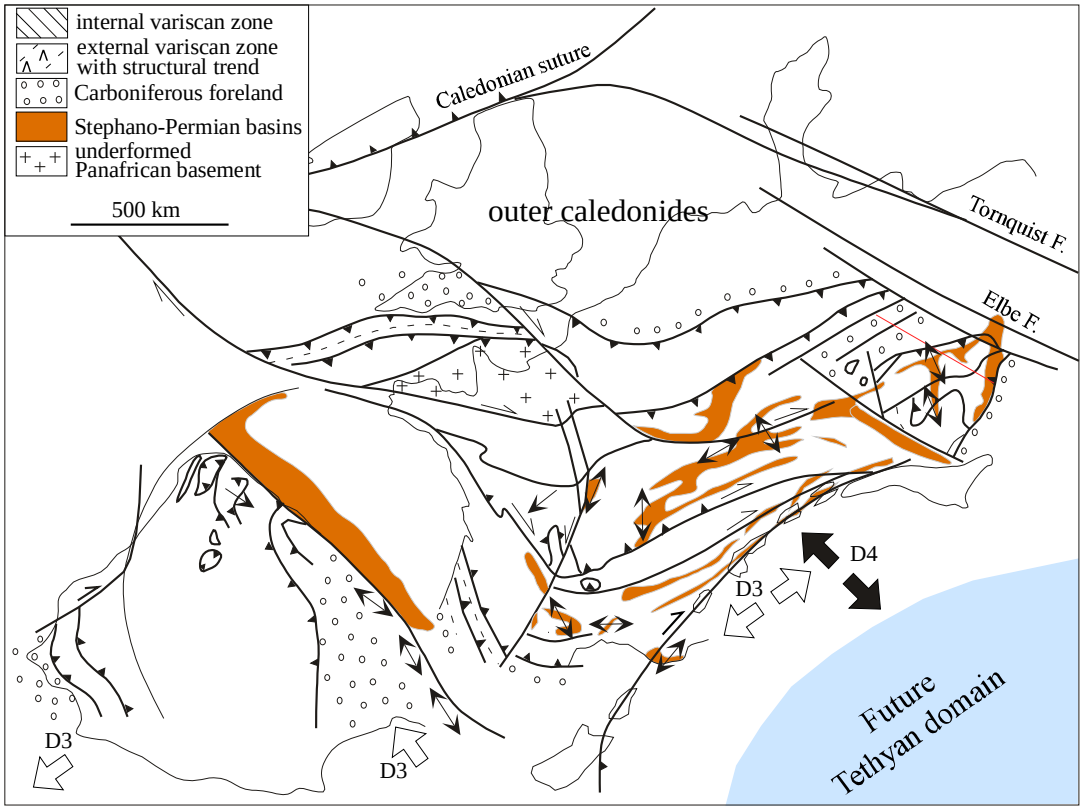




Tricart et al., 2004


TIEN SHAN
MPT
TADJIK BASIN
PAMIR
HINDU KUSH
MKT
KOHISTAN
KARAKORUM FAULT
ITS
BNS
TARIM BASIN
HOTAN
ALTYN TAGH FAULT
Qilian Shan
Qaidam Basin
AKMS
KUN LUN FAULT
JS
Shuang Hu graben
TIBETAN PLATEAU
Gulu
Jiali Fault
Yangbajian graben
LHASA
D3
D2
D1
HIMALAYAS
Thakkola graben
KATHMANDU
HFTS
Yadong
ITS
80°
85°
90°
95°
35°
30°
75°
suture zone
thrust
strike slip fault
normal fault
a
b
c
6340 spot elevation [m]
ice
lake
fault mineralization
normal fault
Holocene
Mio(?)- to Pleistocene
Mesozoic
Shuang Hu
10 km
Holocene conglomerate
Pleistocene(?) conglomerate
Mio/Pliocene(?) conglomerate
Jurassic limestone
X
Y
vein-cemented fault breccia
massive calcitic unit

Carbonifèrous extension : 320-300 Ma
And Permian wrenching



Guillot et al., en prep.

Evidence of Carboniferous ductile/brittle extension in the Belledonne massif

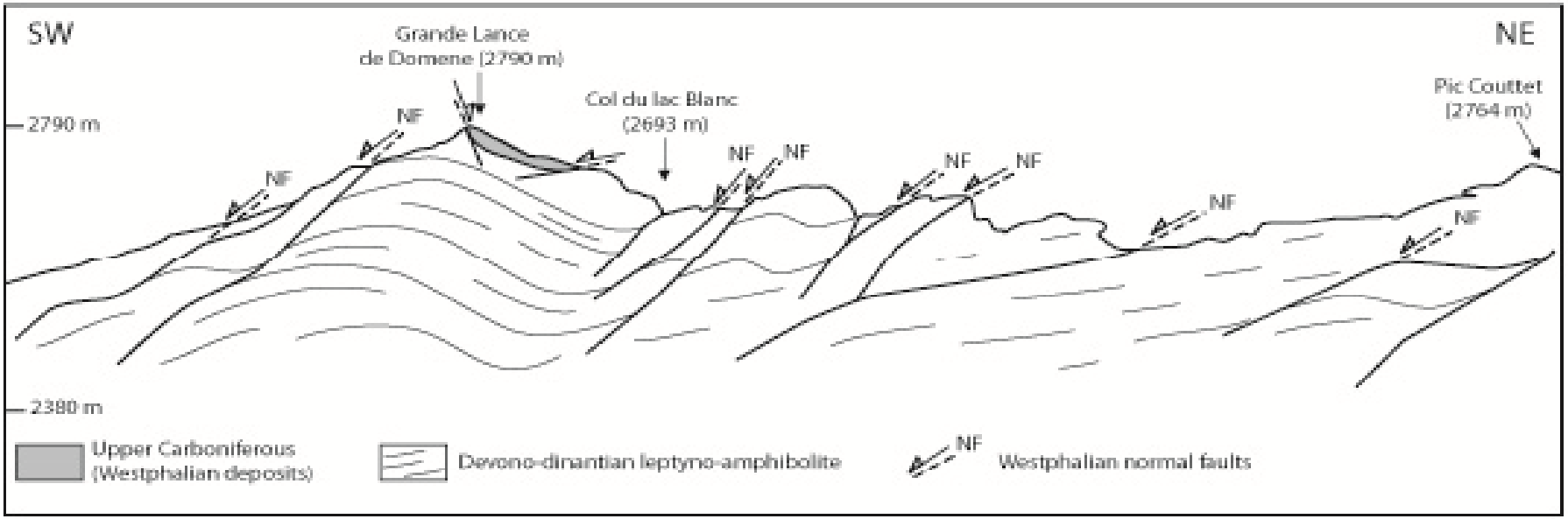
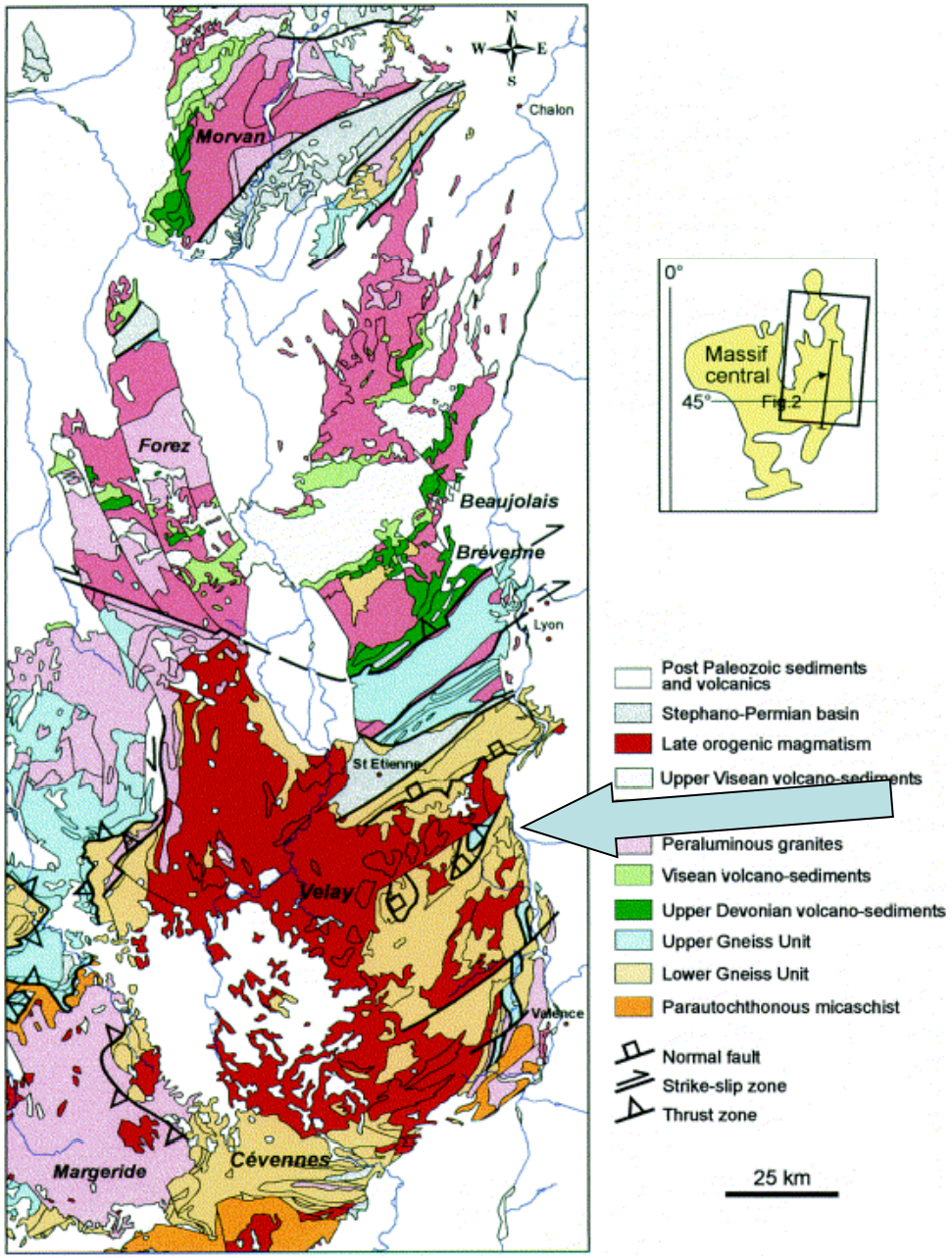
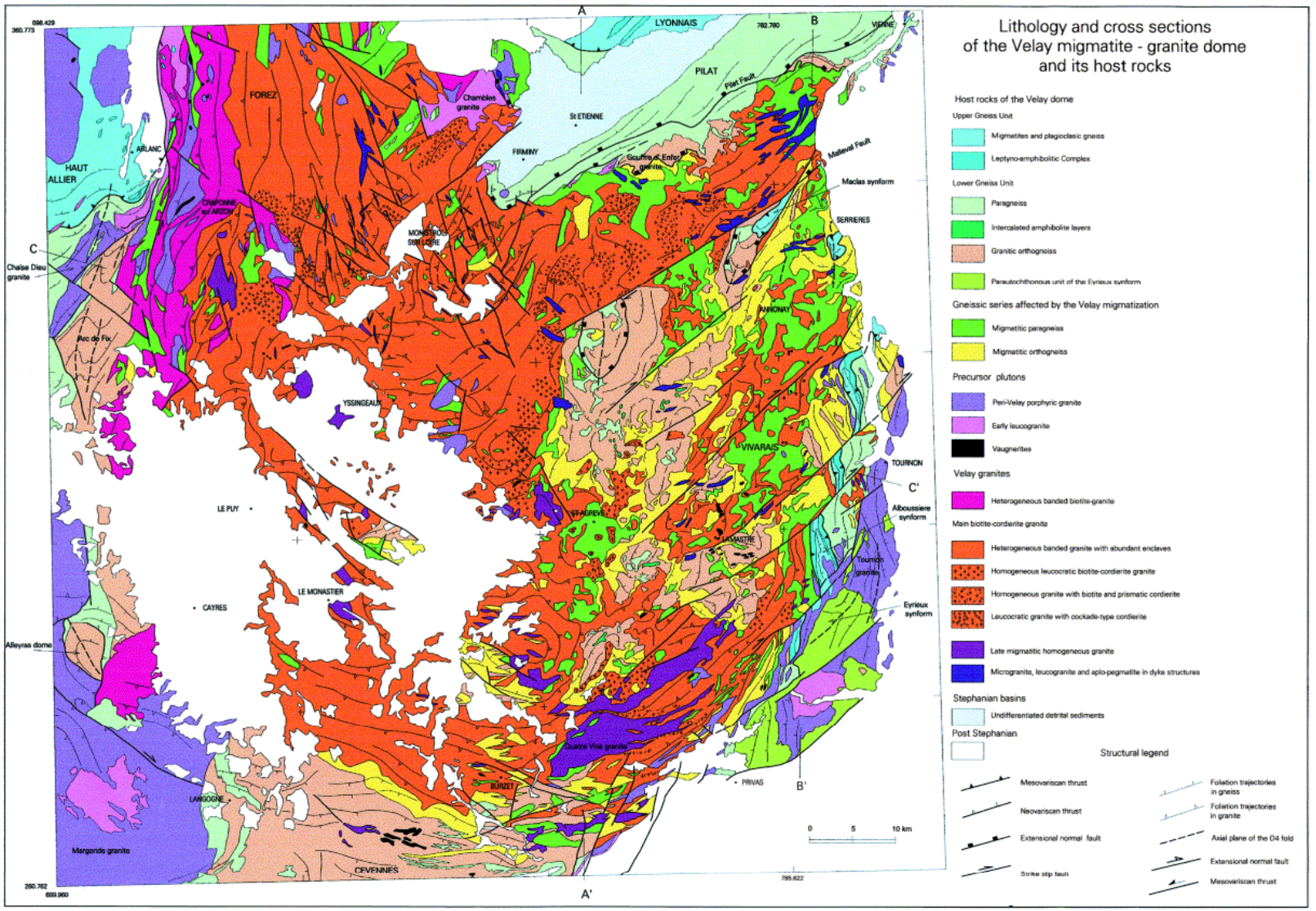


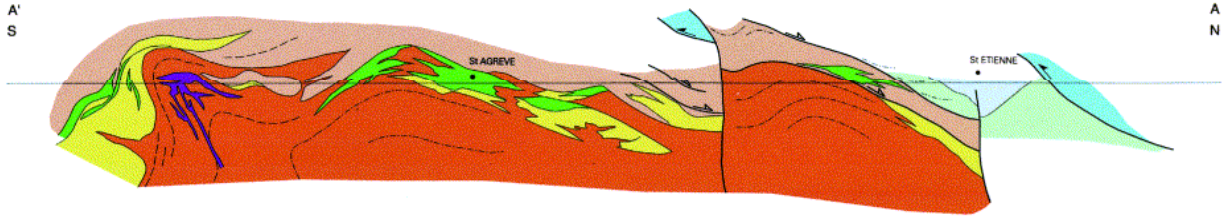
Fig.12.-

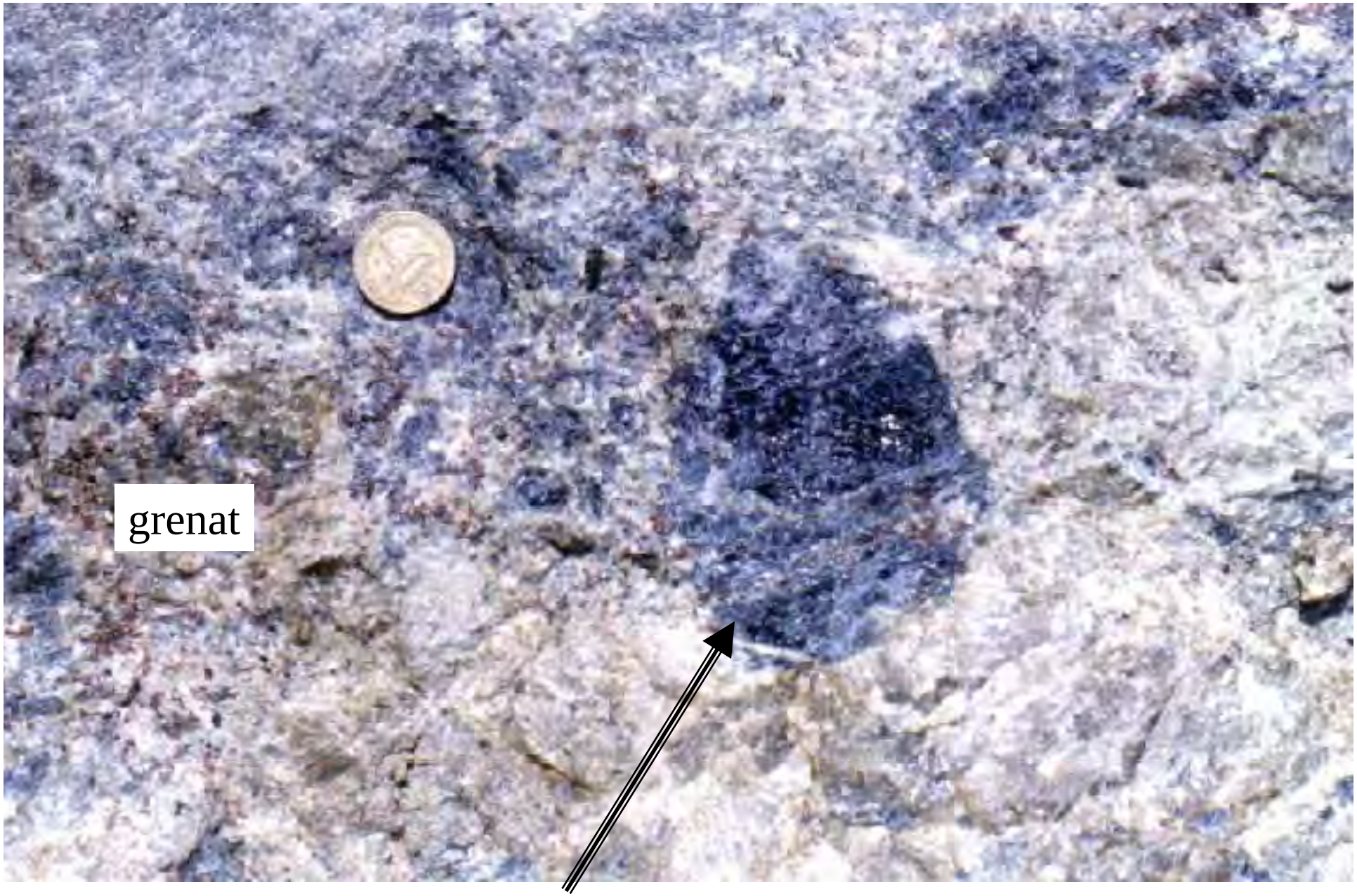
Guillot et Ménot, 1999



Lardeaux et al., 1997

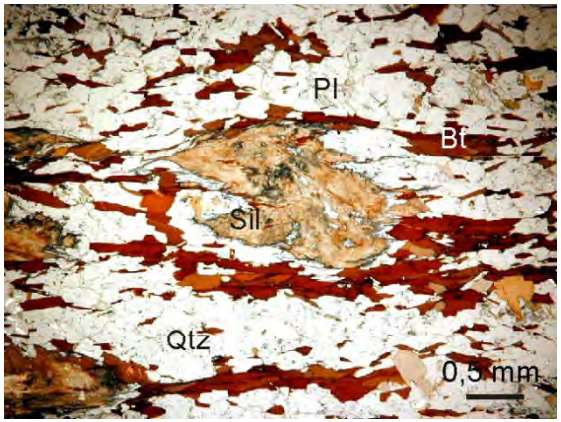

Lithology and cross sections
of the Velay migmatite - granite dome
and its host rocks
Host rocks of the Velay dome
Upper Gneiss Unit
Migmatites and plagioclasic gneiss
Leptyno-amphibolitic Complex
Lower Gneiss Unit
Paragneiss
Intercalated amphibolite layers
Granitic orthogneiss
Parautochthonous unit of the Eyrieux synform
Gneissic series affected by the Velay migmatization
Migmatitic paragneiss
Migmatitic orthogneiss
Precursor plutons
Peri-Velay porphyric granite
Early leucogranite
Vaugnerites
Velay granites
Heterogeneous banded biotite-granite
Main biotite-cordierite granite
Heterogeneous banded granite with abundant enclaves
Homogeneous leucocratic biotite-cordierite granite
Homogeneous granite with biotite and prismatic cordierite
Leucocratic granite with cockade-type cordierite
Late migmatitic homogeneous granite
Microgranite, leucogranite and aplo-pegmatite in dyke structures
Stephanian basins
Undifferentiated detrital sediments
Post Stephanian
Structural legend
Mesovariscan thrust
Neovariscan thrust
Extensional normal fault
Strike slip fault
Foliation trajectories in gneiss
Foliation trajectories in granite
Axial plane of the D4 fold
Extensional normal fault
Mesovariscan thrust
LYONNAIS
PILAT
VIENNE
FOREZ
HAUT ALLIER
ARLANC
CHAPTONNE sur ARZON
Chambles granite
St ETIENNE
FIRMINY
Pilat Fault
Malleval Fault
Maclas synform
SERRIERES
ANNONAY
Chaise Dieu granite
Pic de Fix
YSSINGEAUX
VIVARAIS
TOURNON
Alboussiere synform
LE PUY
ST AGREVE
LARGENTIERE
Tournon granite
Eyrieux synform
CAYRES
LE MONASTIER
Alleyras dome
Quatre Vios granite
BURZET
PRIVAS
LANGOGNE
Margeride granite
CEVENNES
0 5 10 km
A
A'
B
B'
C
C'

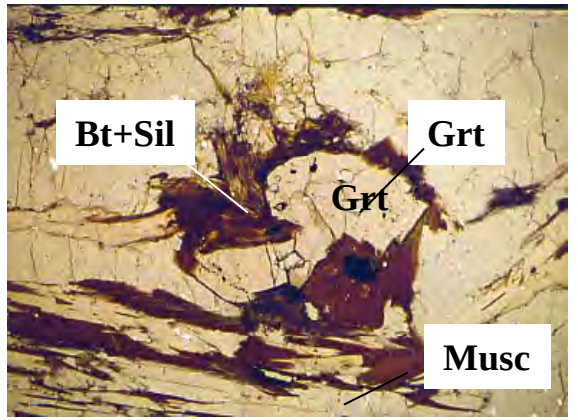

A'
S
St AGREVE
St ETIENNE
A
N



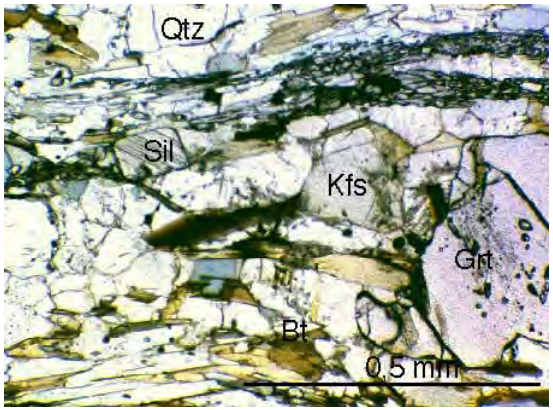
Cordiérite (à l ’affleurement)

A. Caractéristiques Pression-Température des granulites du Velay



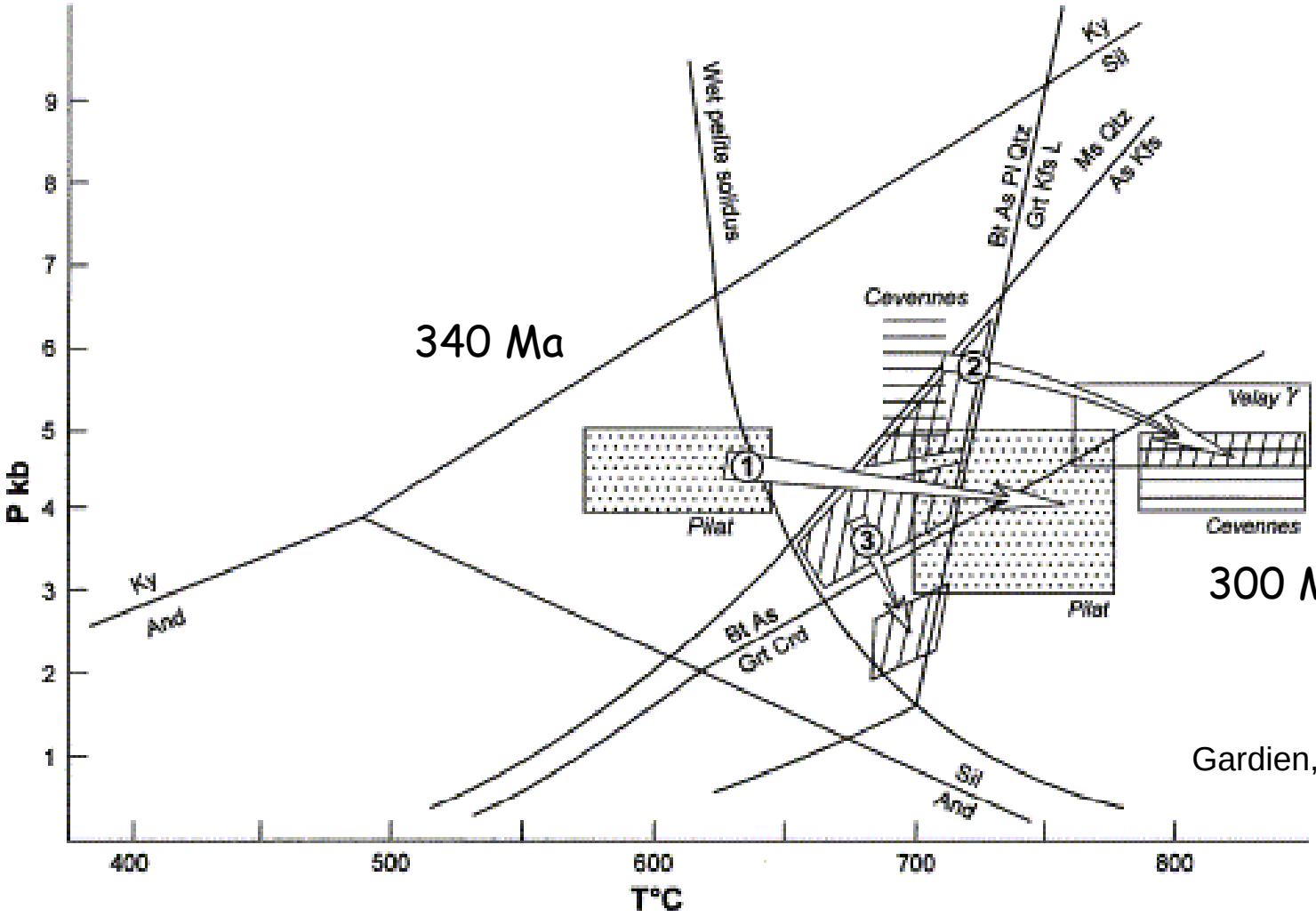


Grenat + Muscovite => Biotite + Sillimanite + eau
0.65 GPa 650-700°C



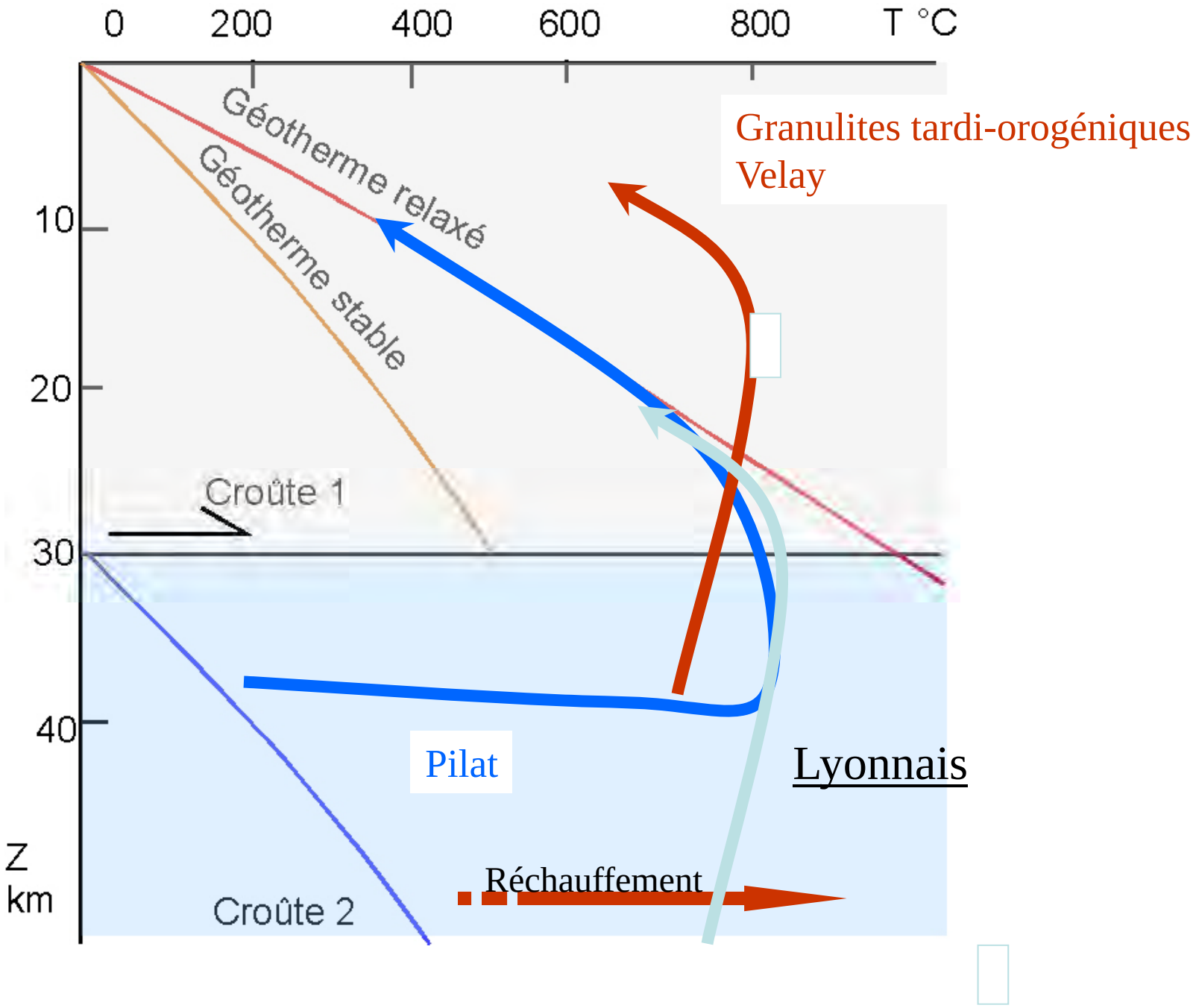
Biotite + Sillimanite =>
Grenat + feldspath potassique + fusion
750°C

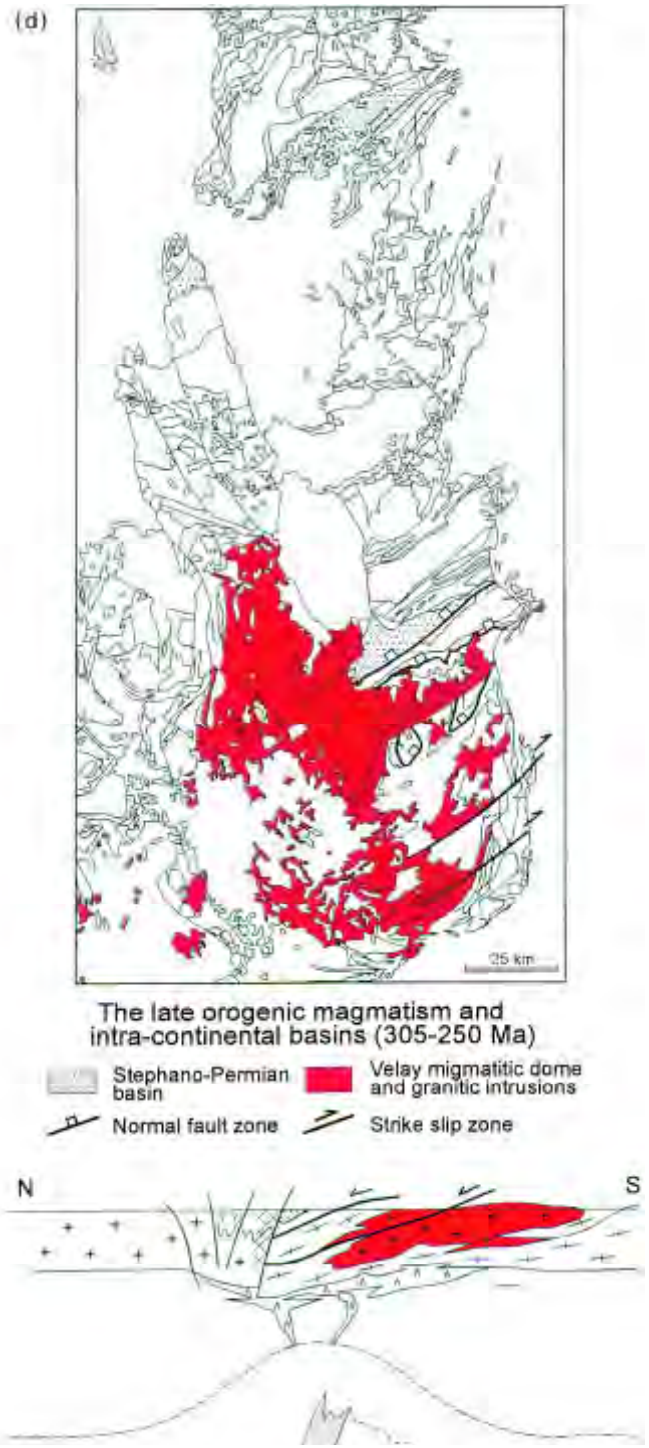
Rolland et al., 2002



Gardien, 1990

Origine de la granulitisation dans les zones de convergence





Lardeaux et al., 1997

Conclusion

L’évolution des chaînes de Montagne obéit à des lois thermo-mécaniques universelles

=> L évolution des 3 chaînes est très similaire mais chaque stade, de l’accrétion océanique au retour à l’équilibre, est soit plus ou moins bien marqué, soit plus ou moins bien préservé, soit plus ou moins abouti.