



Tsavorite deposits

Giuliani Gaston
GET/IRD and CRPG/CNRS



GARNET mineral group

Groupe des grenats alumineux

PYRope (X = Mg)



© J. Scovil

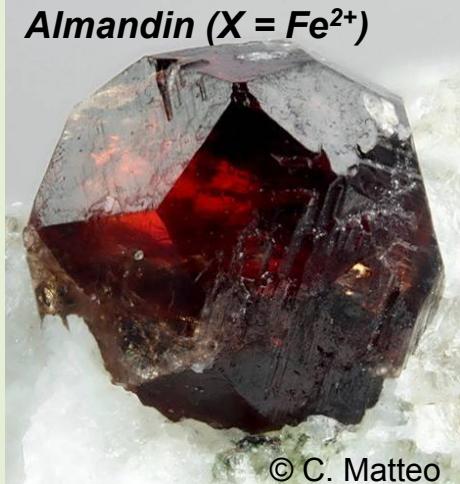
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Spessartine
(X = Mn)

PYRALSPITE
 $X_3\text{Al}_2(\text{SiO}_4)_3$

Almandin (X = Fe²⁺)



© C. Matteo

Uvarovite (X = Cr)



© T. Peterson

UGRANDITE
 $\text{Ca}_3\text{X}_2(\text{SiO}_4)_3$

ANDradite (X = Fe³⁺)



© J. Scovil

© J. Scovil



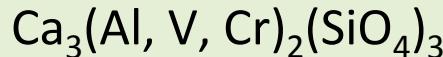
Grossulaire (X = Al)

Groupe des grenats calciques

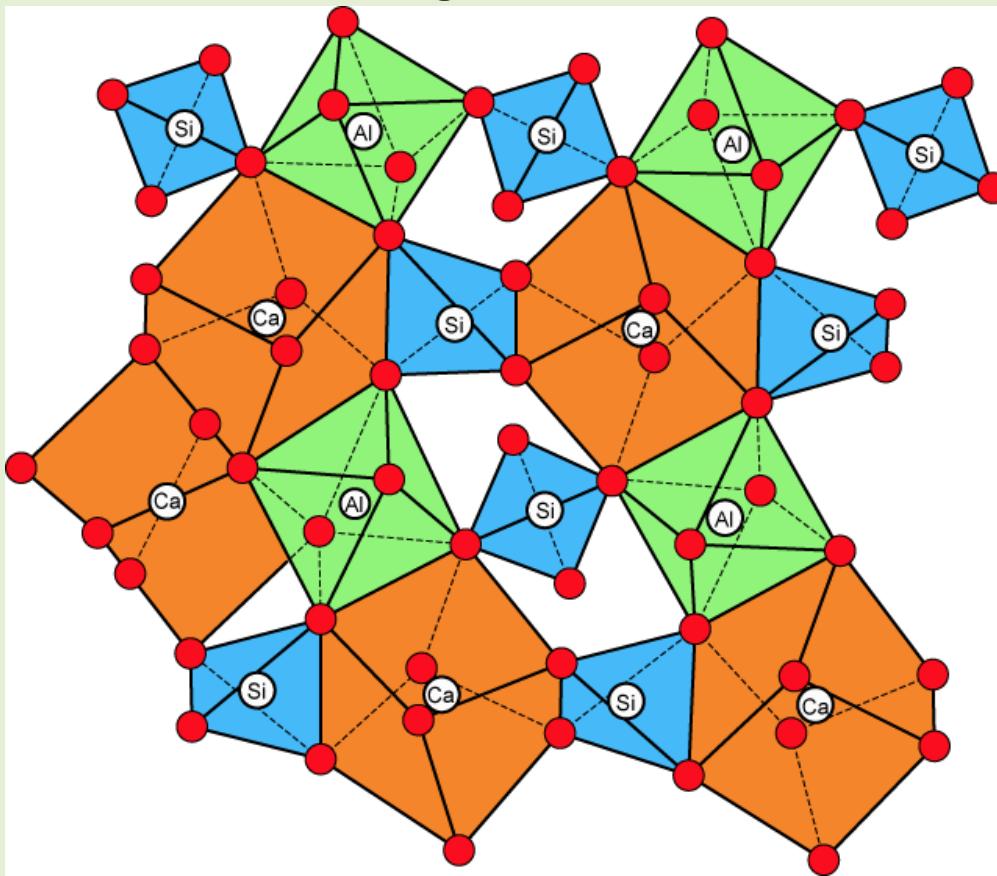


TSAVORITE

Structural formula



→ Vanadium-bearing grossular garnet



Tsavorite rough
925 carats (185 g)



© Gemshare

© Gemshare

Tsavorite cut
325 carats (65 g)



4,2 x 3,6 cm

Colour

→ green (yellow green)

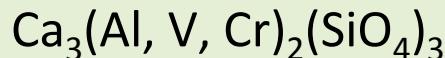
Economic interest

→ Jewellery

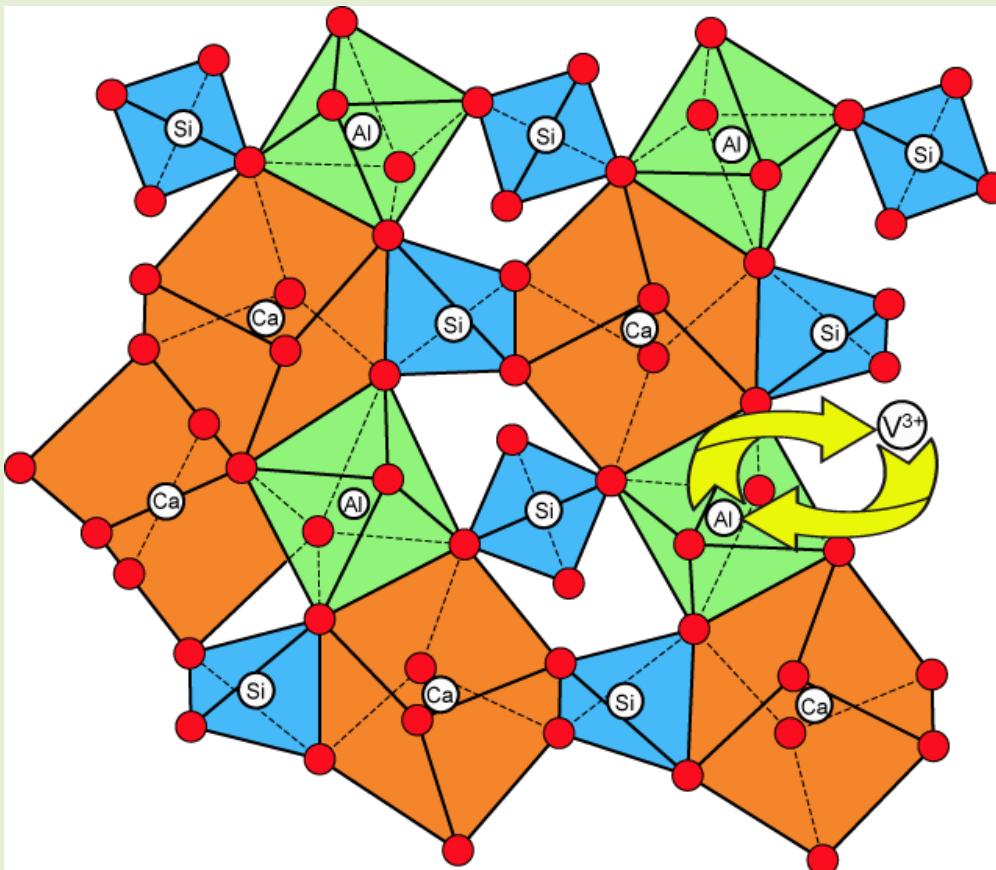


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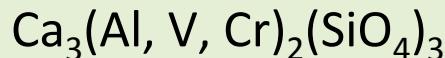
Colour
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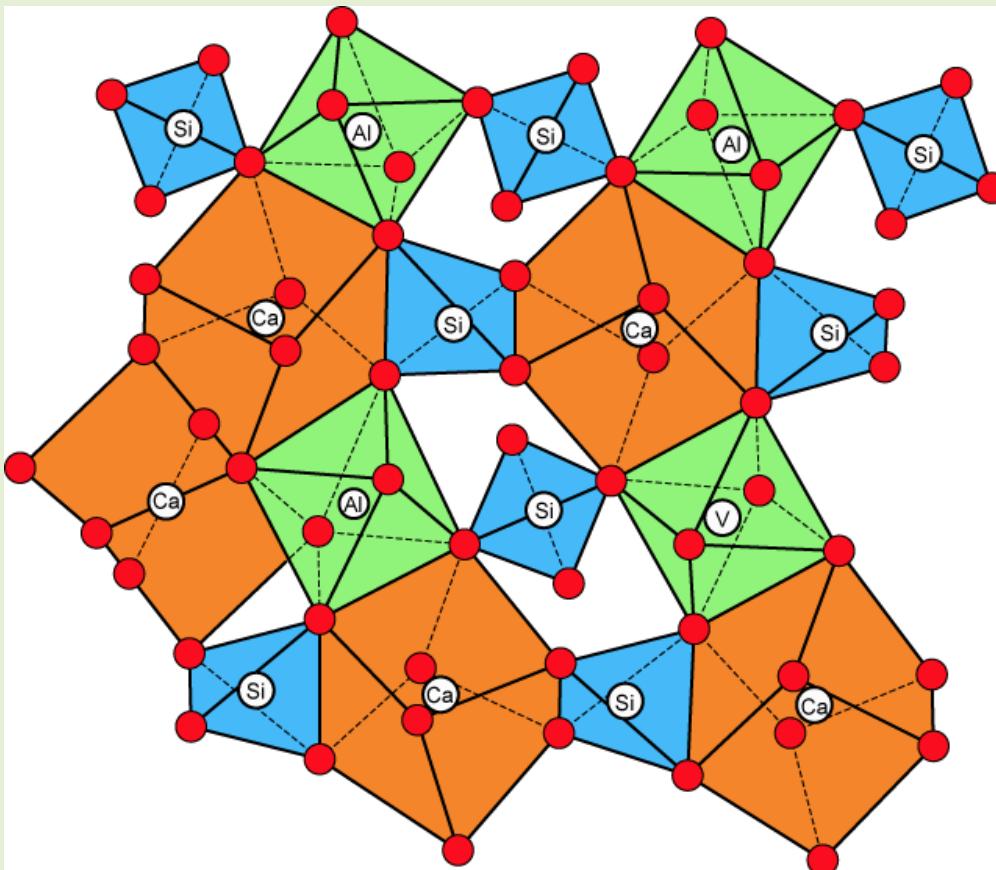


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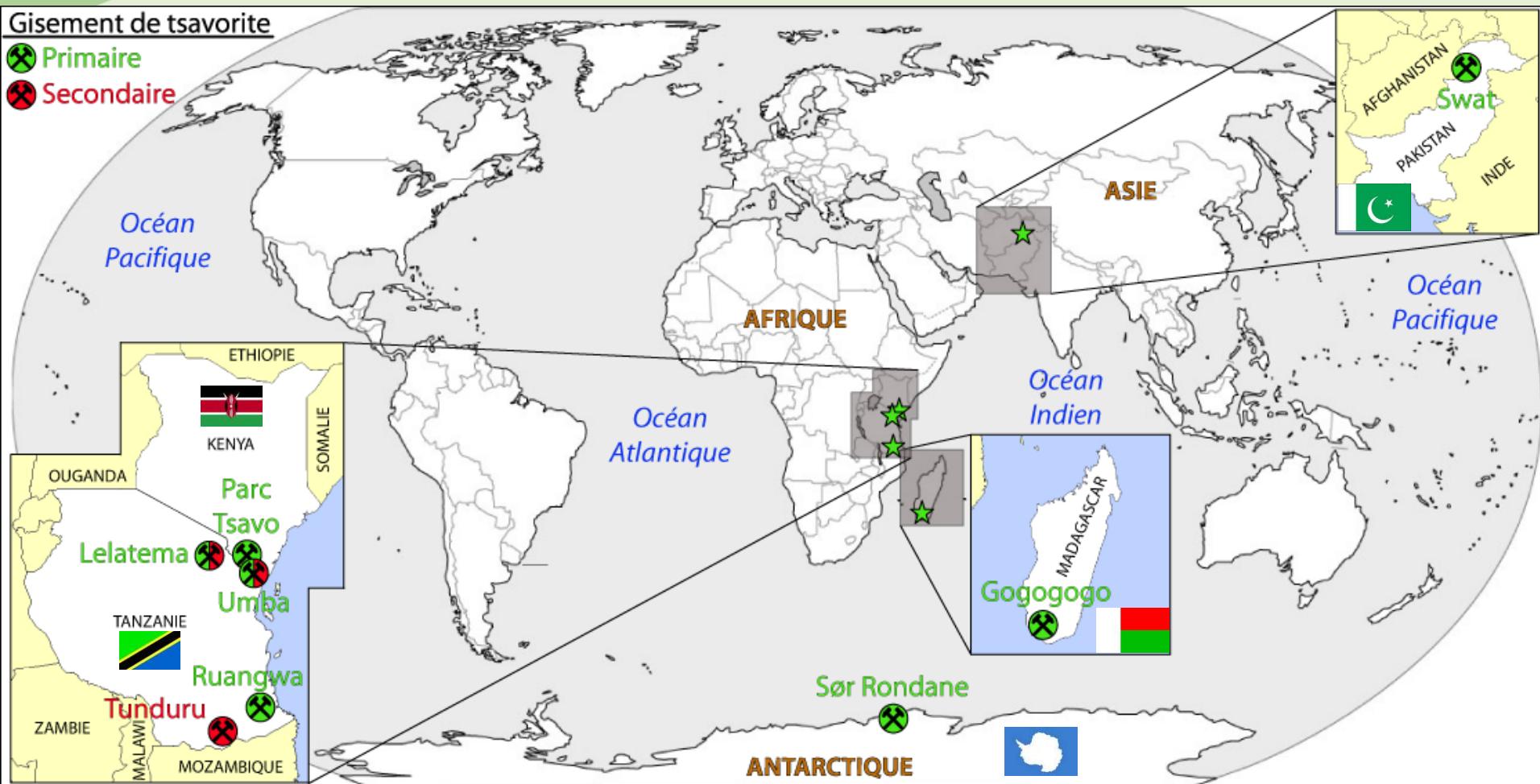
4,2 x 3,6 cm

Colour
→ green (yellow green)

Economic interest
→ Jewellery



The deposits of tsavorite



KENYA : Bridges, 1974; Pohl et Niedermayr, 1978; Suwa et al., 1996

TANZANIE : Bridges, 1974; Malisa, 1987; McClure, 1999; Pardieu et Hughes, 2008; Feneyrol et al., 2010a,b

MADAGASCAR : Mercier et al., 1997

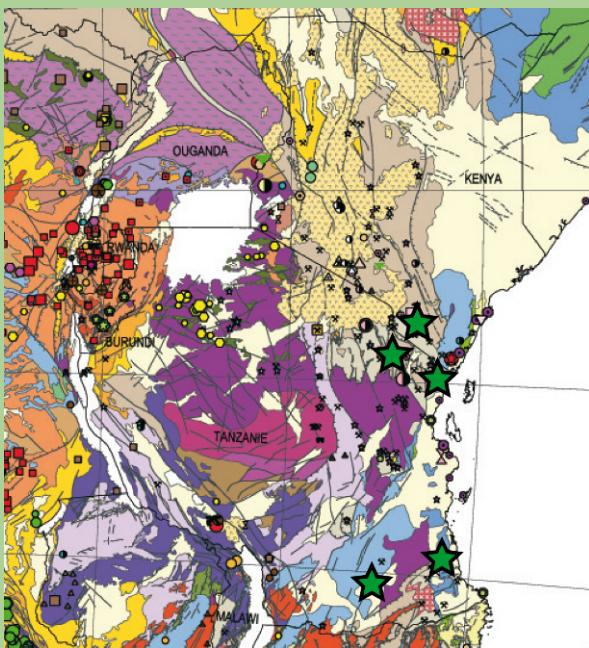
PAKISTAN : Jackson, 1992; Hussain, 2005

ANTARCTIQUE : Osanai et al., 1990



OUTLINE

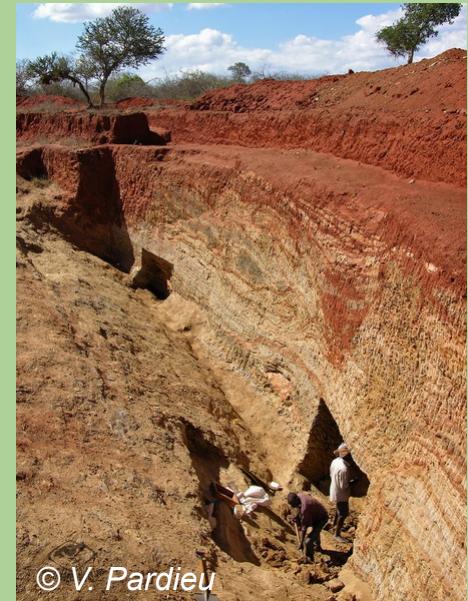
1. Geological context
2. Geological study of the Lemshuku and Namalulu deposits
3. The deposits of Kenya
4. Geochronological study: dating the events
5. Chemistry of tsavorites
6. Metallogenetic model



1. THE GEOLOGICAL CONTEXT



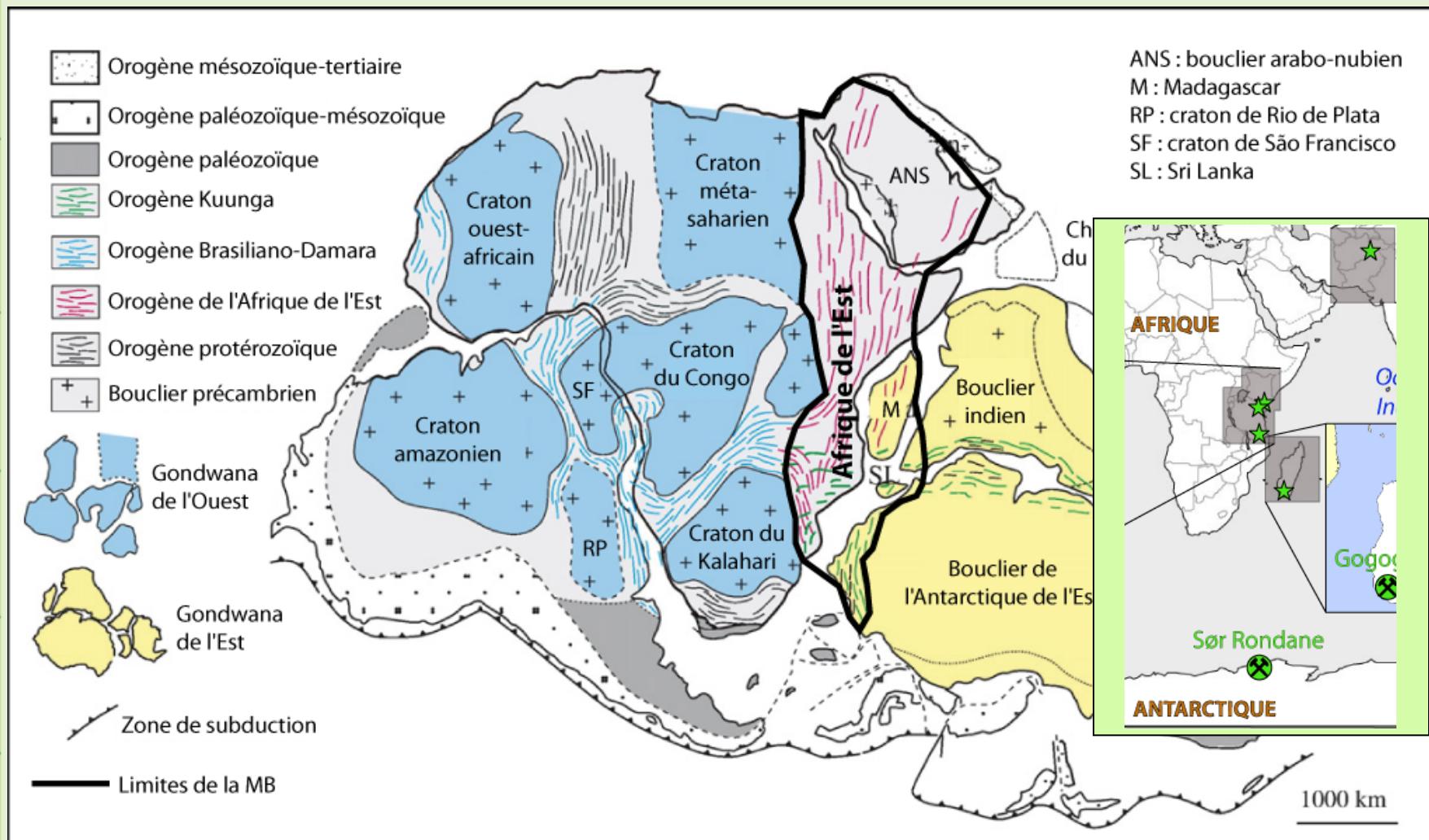
© V. Pardieu



© V. Pardieu



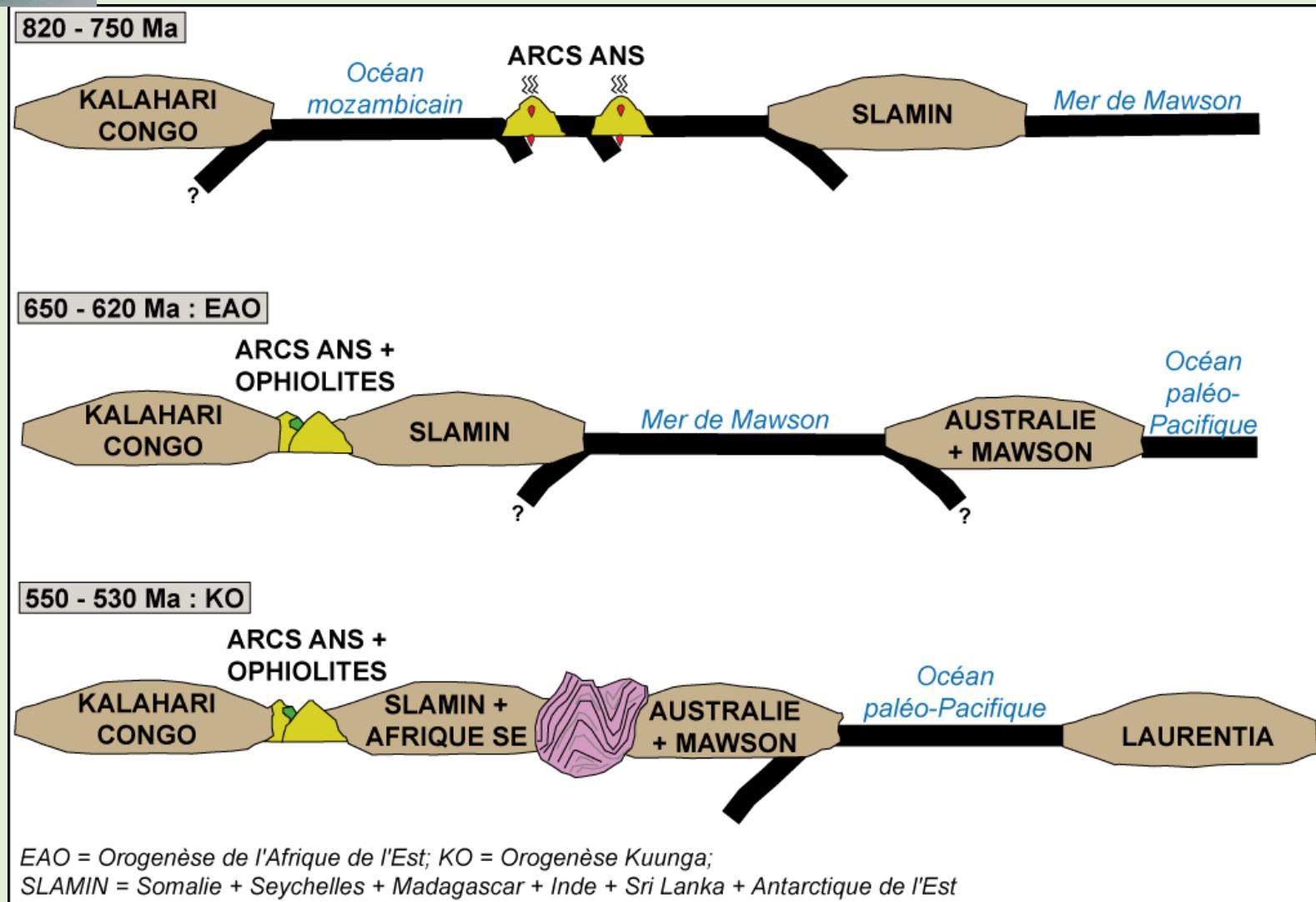
THE NEOPROTEROZOIC METAMORPHIC MOZAMBIQUE BELT (NMMB)



Gray et al. (2007)

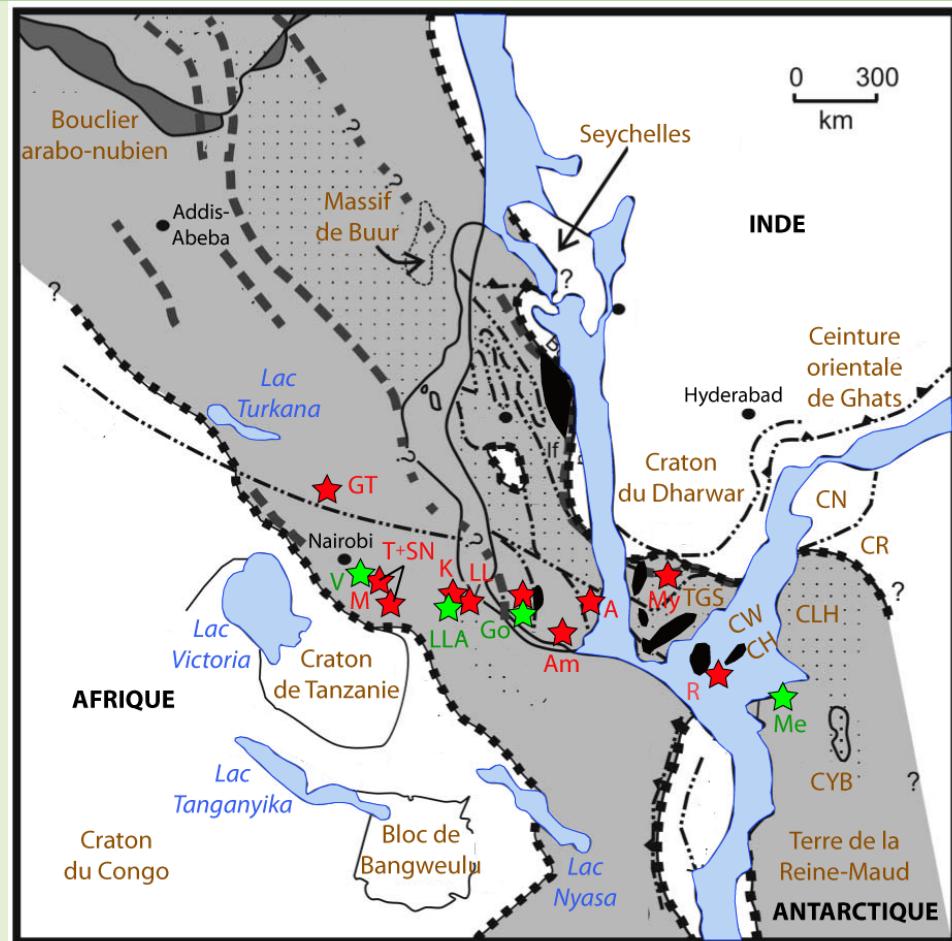
THE NEOPROTEROZOIC METAMORPHIC MOZAMBIQUE BELT (NMMB)

The assemblage of the eastern Gondwana (Meert, 2003)





A GEM BELT



Ceinture Métamorphique Néoprotérozoïque Mozambicaine (affectée par du métamorphisme de faciès amphibolite supérieur à granulite entre 750 et 500 Ma)

Zone de suture néoprotérozoïque

Zone de cisaillement/chevauchement

Limite de la CMNM

Gisement de corindon

Gisement de tsavorite

Dépôt de graphite majeur dans la partie est du Gondwana

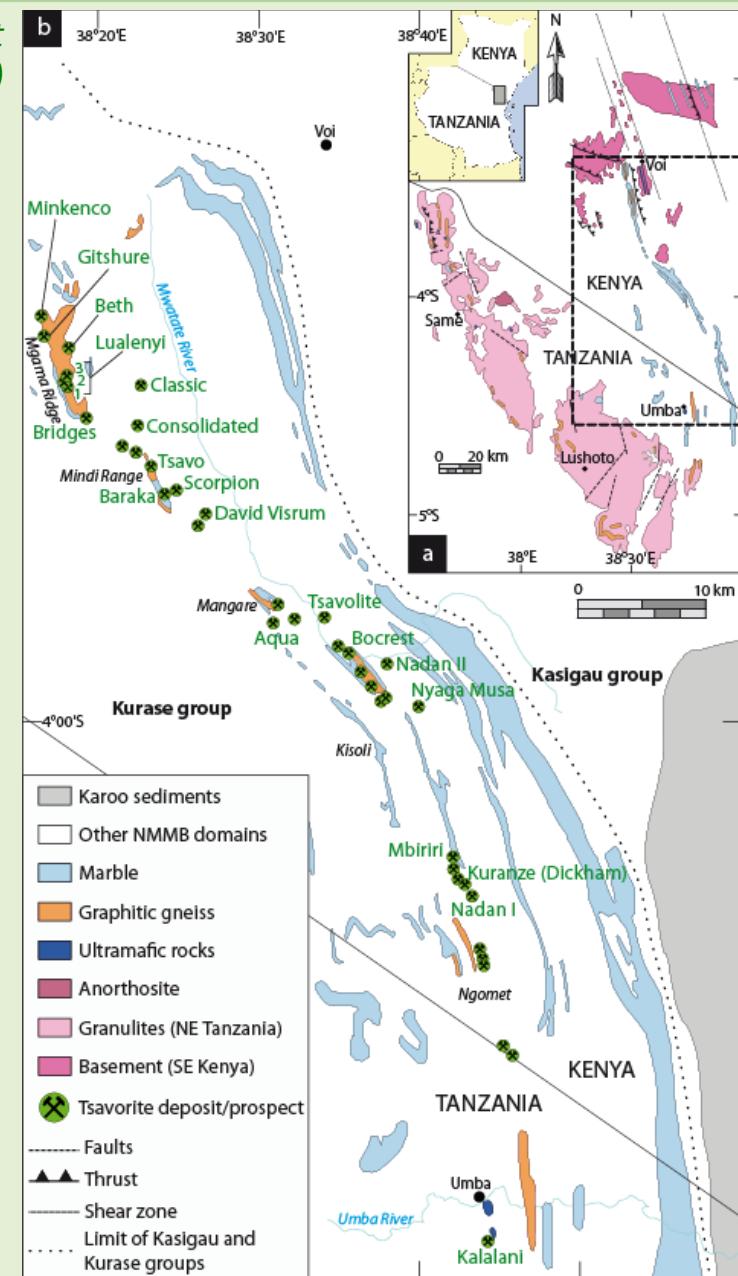
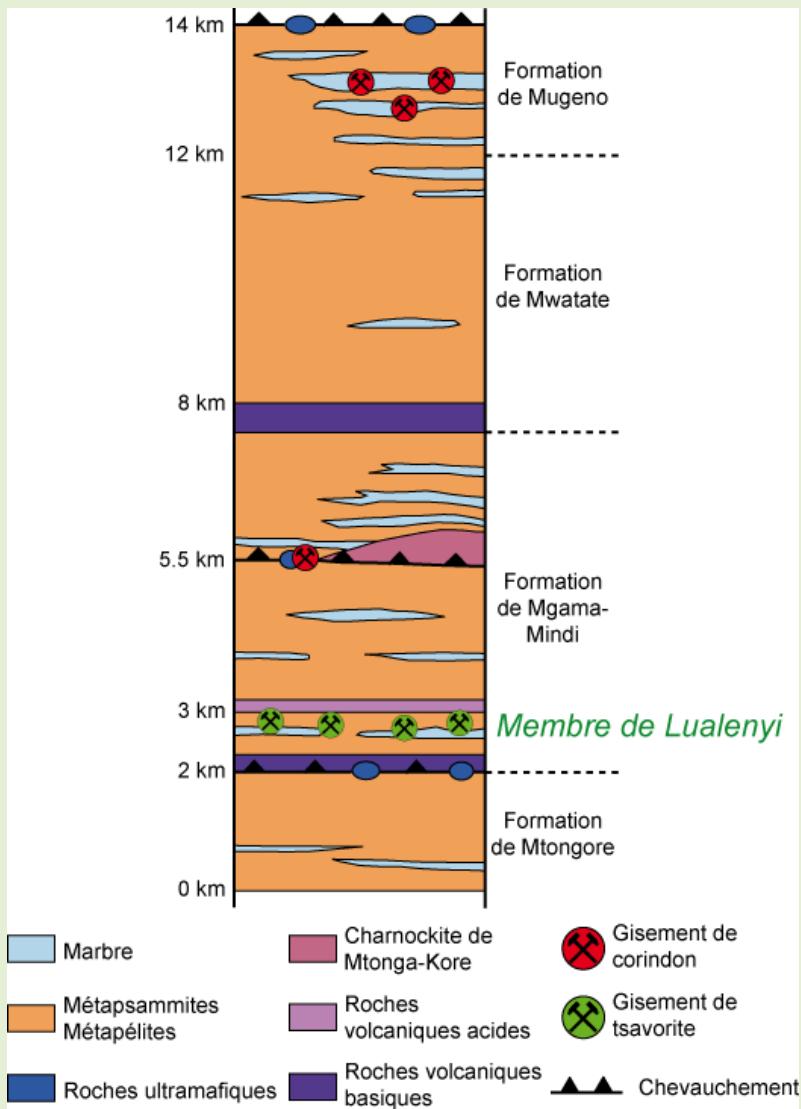
Croûte antérieure à 1500 Ma et comprise dans la CMNM

Mer ou lac actuel



THE METASEDIMENTARY FORMATIONS

Modified from Simonet (2000) et Bauernhofer et al. (2008)





TYPES OF MINERALISATION

Nodules

*All the deposits excepted
Ruangwa (Tanzania)
Jambil (Pakistan)*



© V. Pardieu



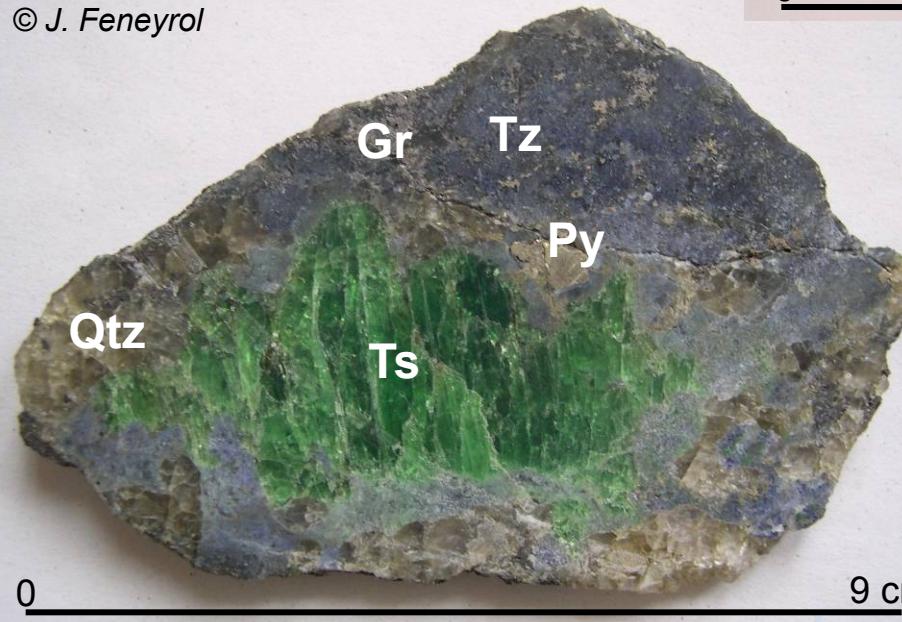
TYPES OF MINERALISATION

Quartz veins

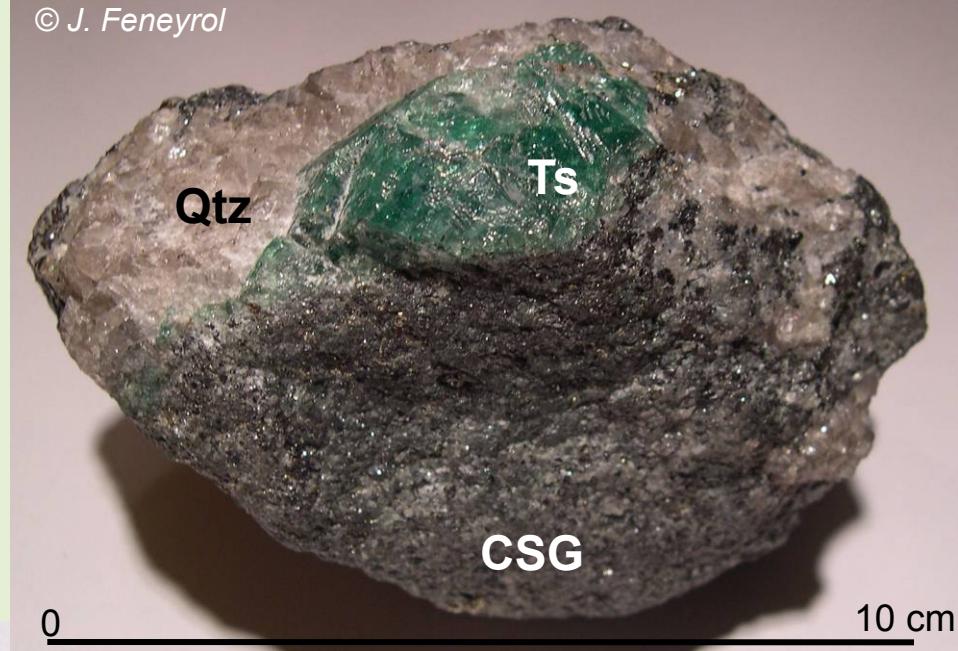
*Lemshuku, Namalulu, Merelani
and Ruangwa (Tanzania)
Jambil (Pakistan)*

CSG = calc-silicates with graphite;
Py = pyrite; Qtz = quartz;
Ts = tsavorite; Tz = tanzanite

© J. Feneyrol



© J. Feneyrol



9 cm

© J. Feneyrol





TYPES OF MINERALISATION

Pebbles of tsavorite in placers

Lemshuku, Tunduru and Umbo (Tanzania)



Production of
60 ct/day

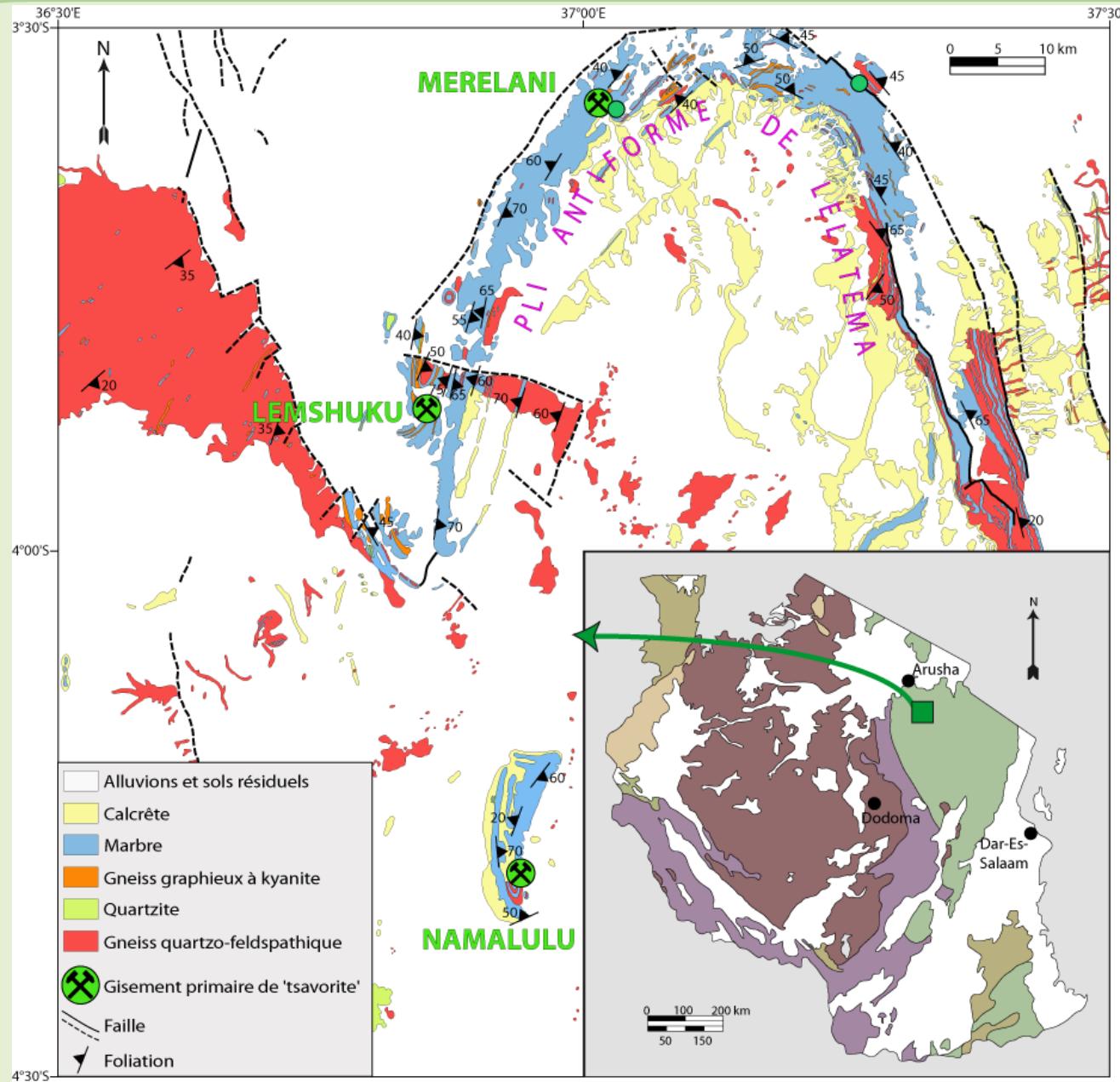


2. The deposits of Lemshuku and Namalulu (tANZANIA)





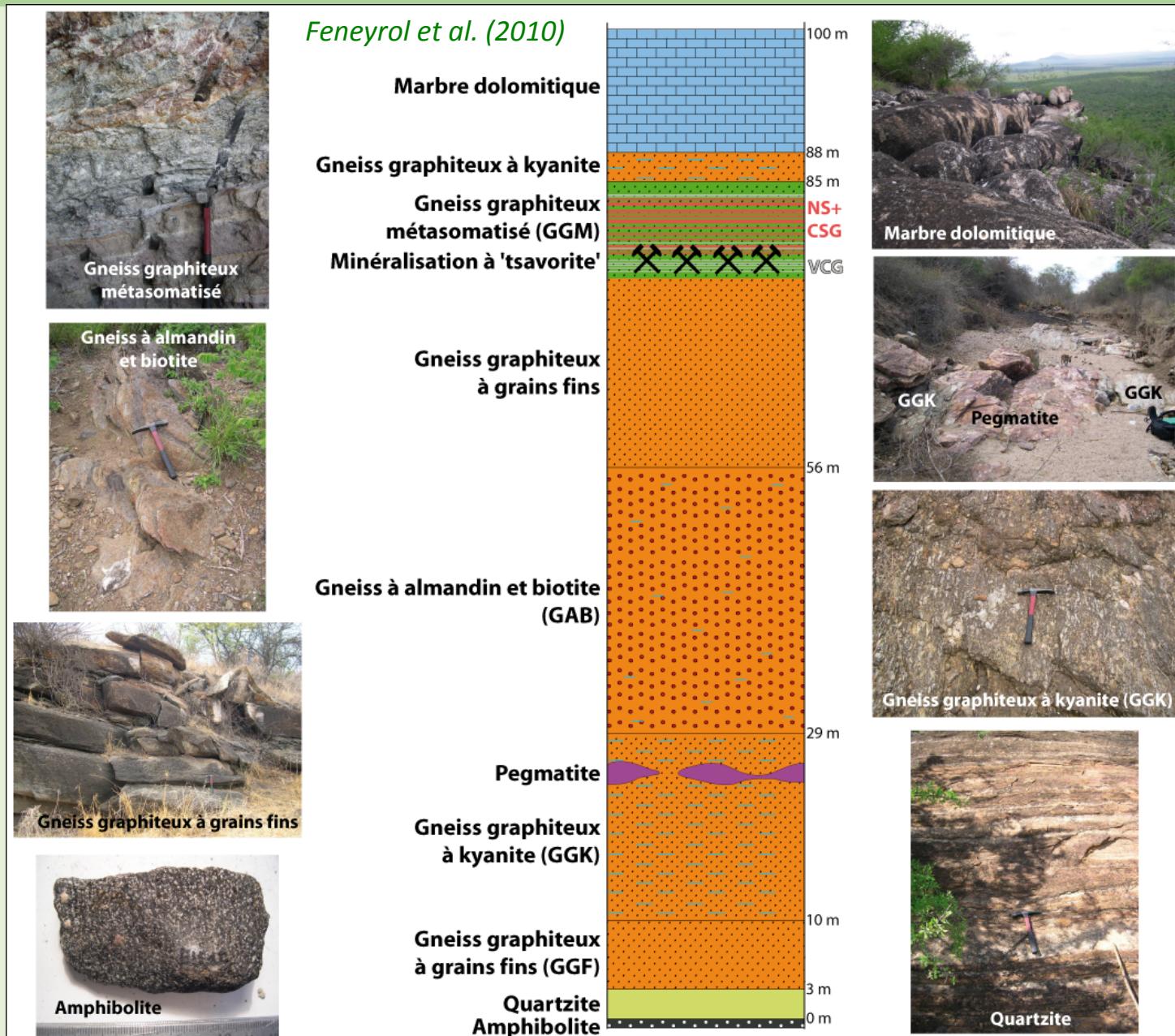
Location of the deposits



Modified from
Grainger (1964),
Macfarlane (1965) &
QDS n°87 Naberera

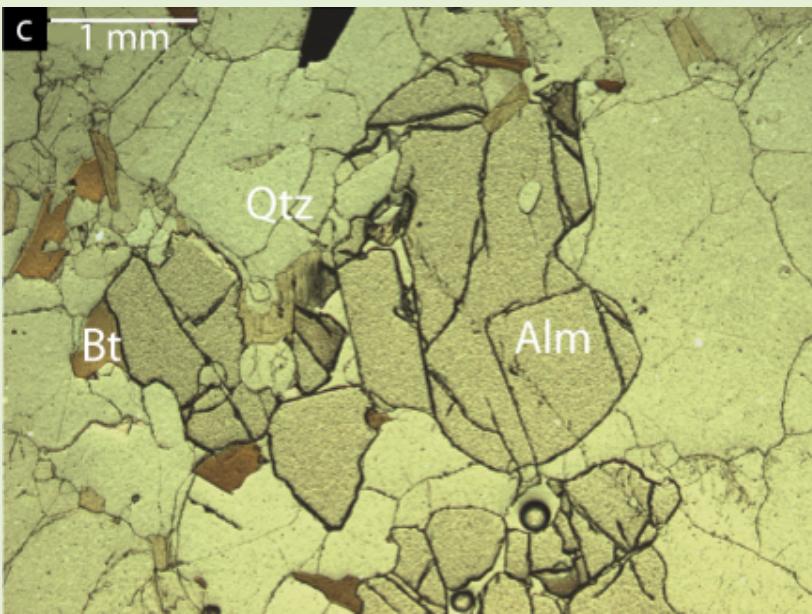
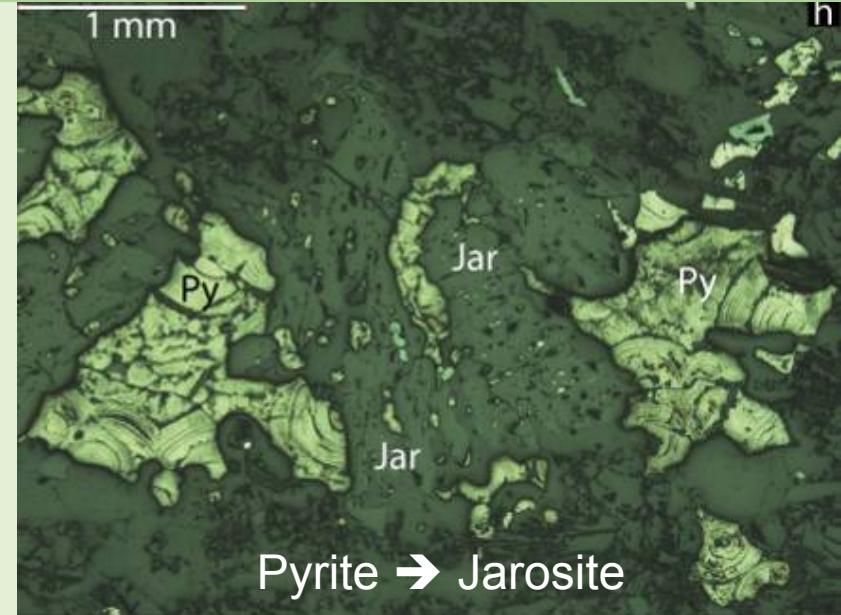


THE LITHOSTRATIGRAPHIC COLUMN



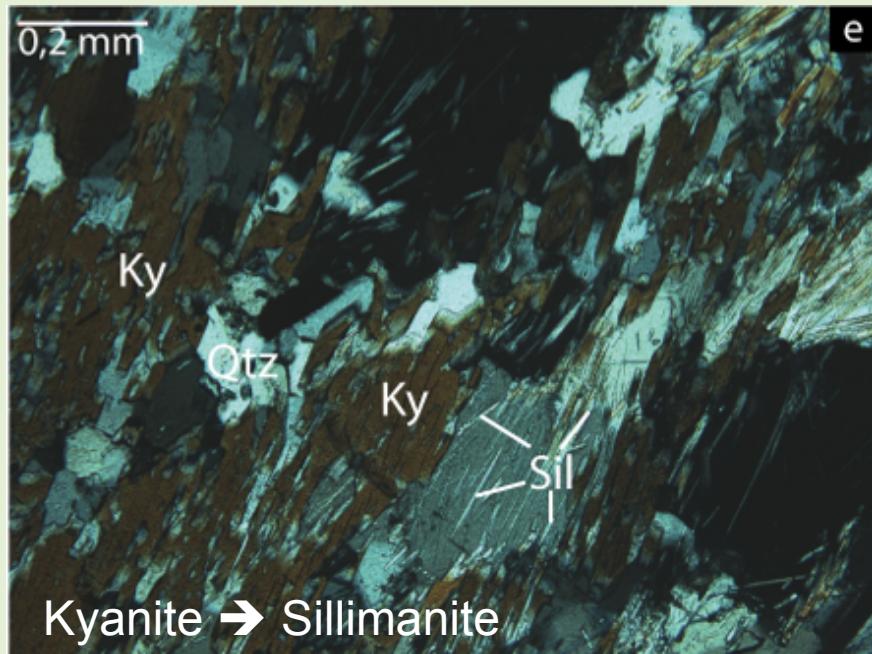
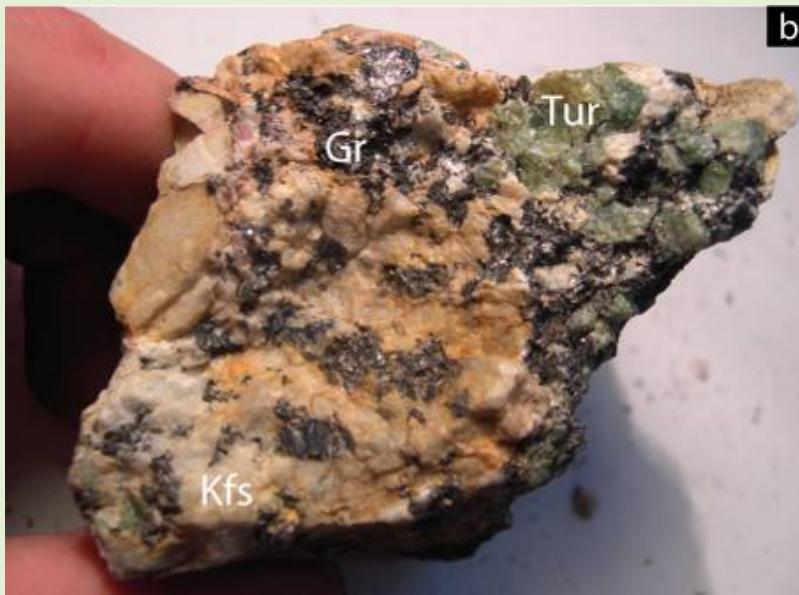
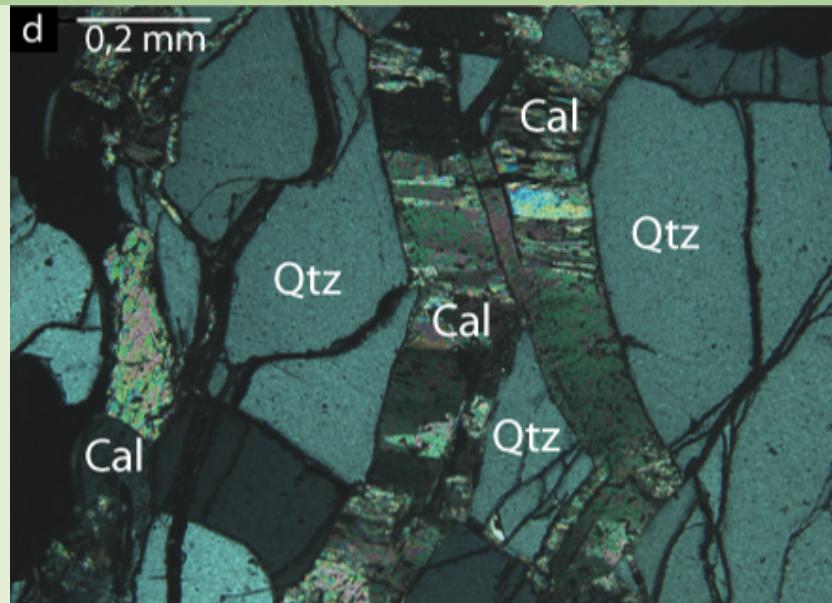


The gneisses





The metasomatized graphitic gneisses





The calc-silicates

CSGB_{II}



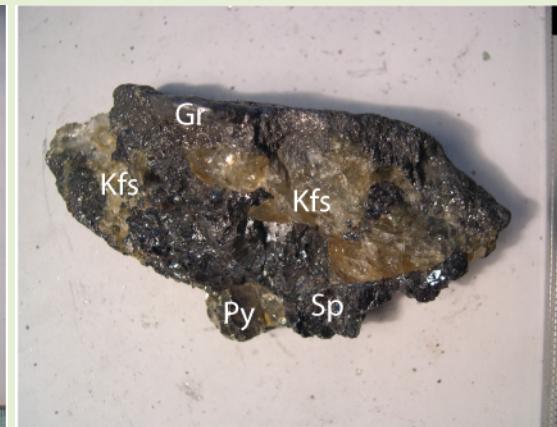
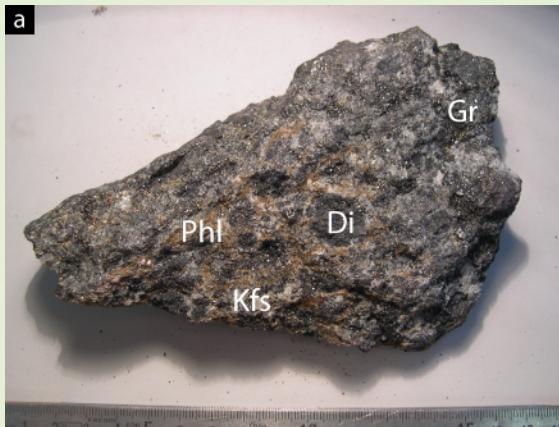
CSG = graphitic calc-silicate

CSGB = breccia of CSG

CSGB_{III}

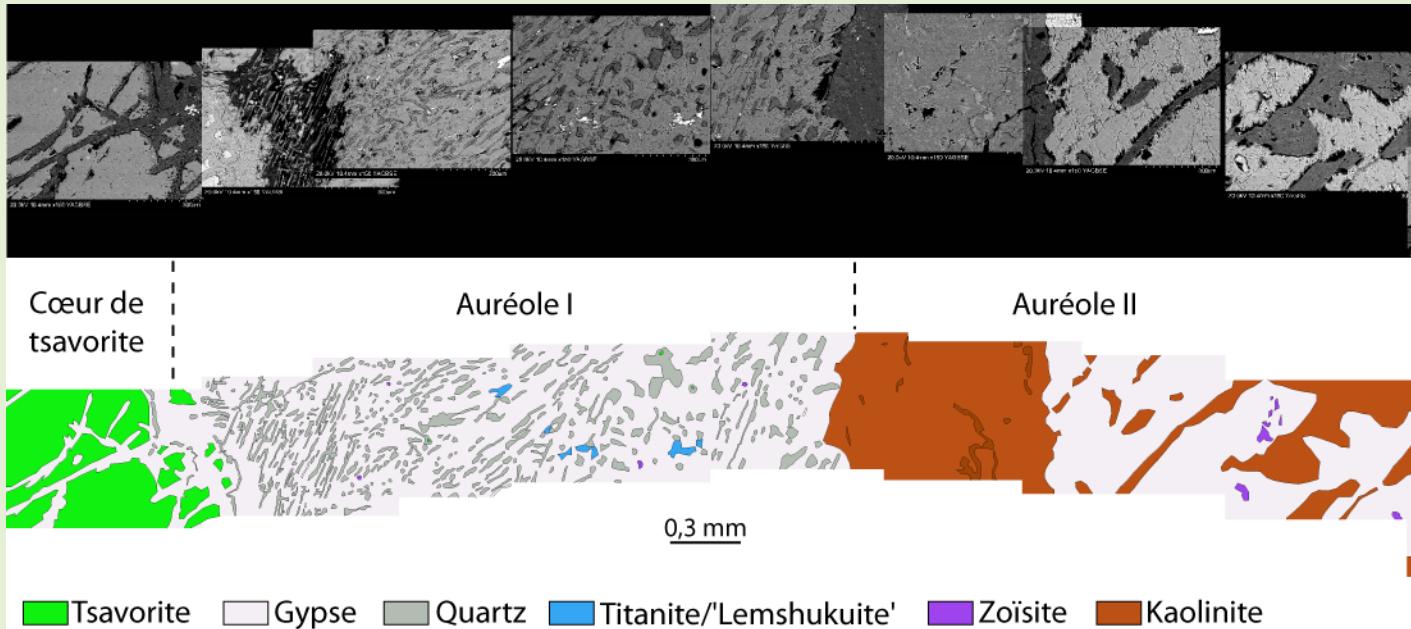


CSGB_{I}

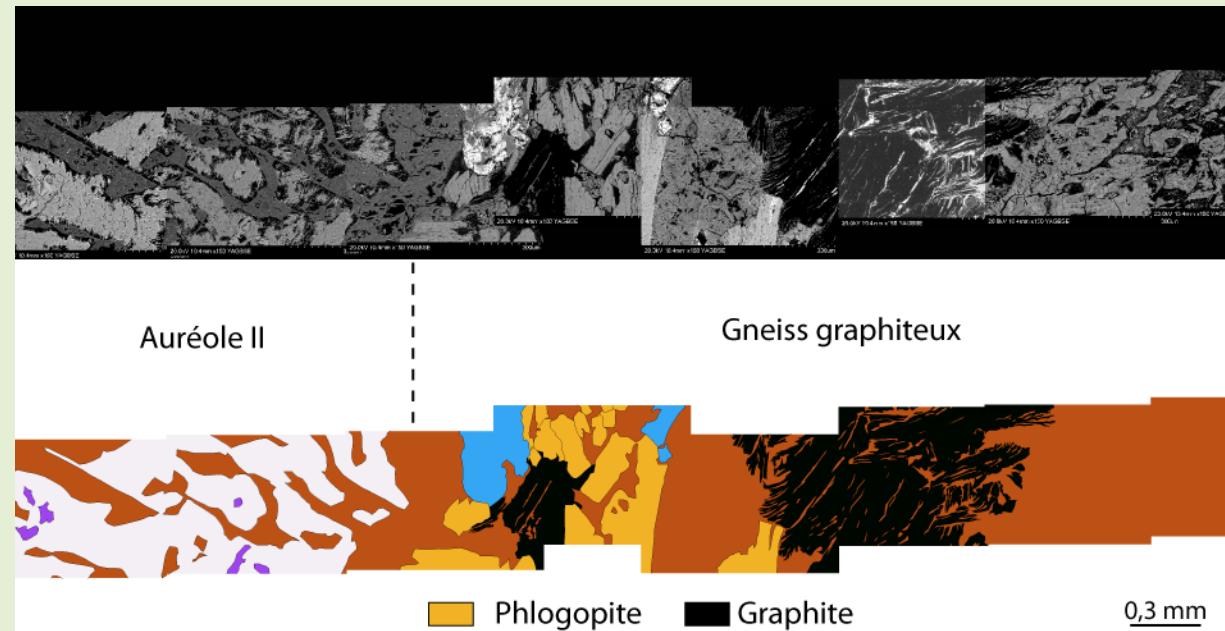
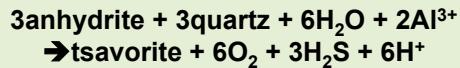




The nodules N_I



Anhydrite → Tsavorite

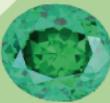
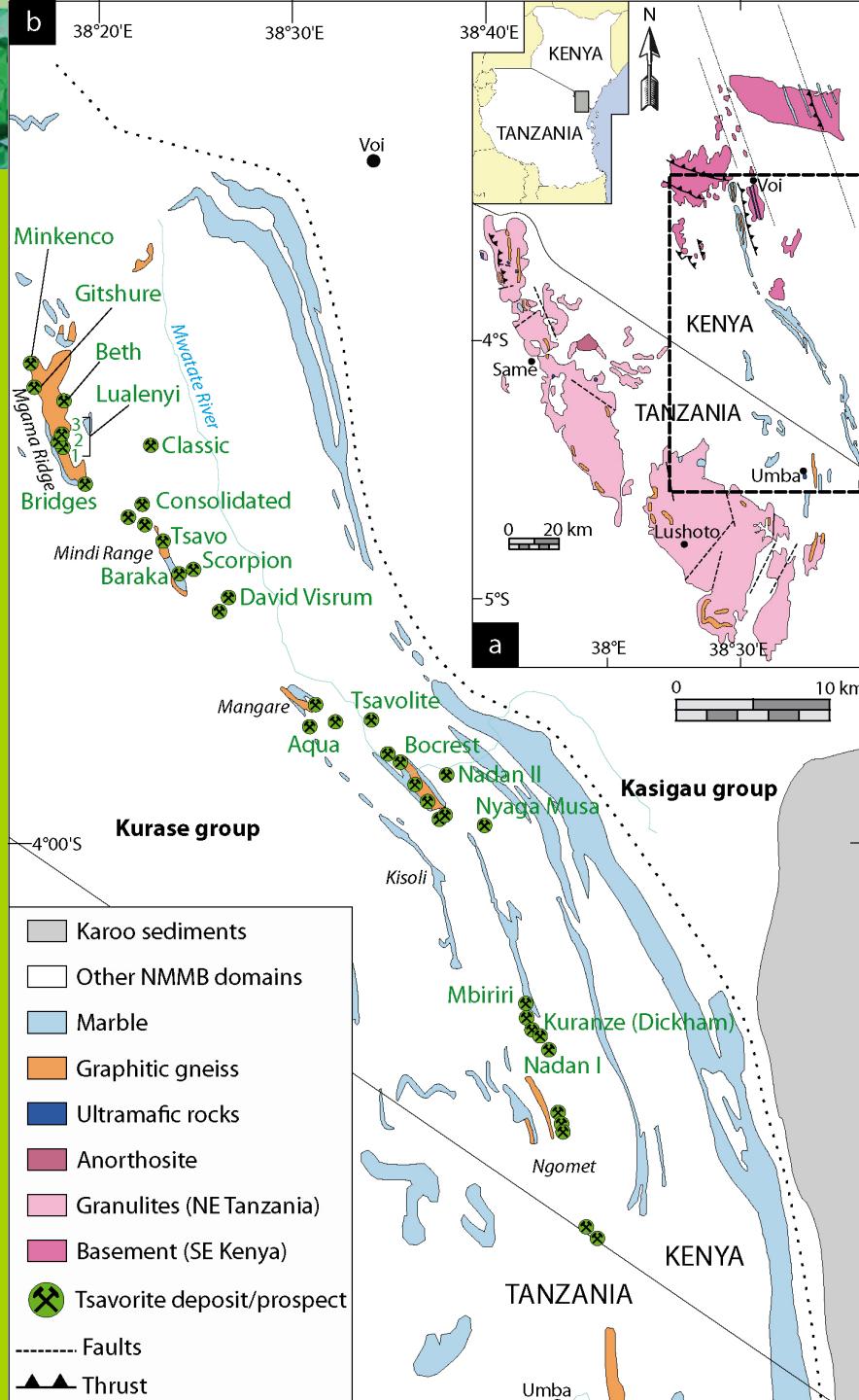




3. The deposits of Kenya

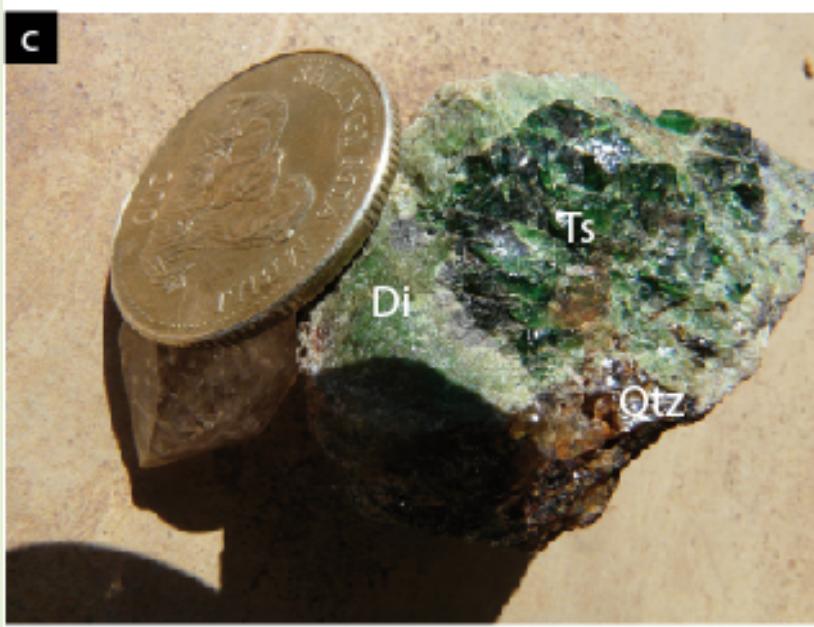
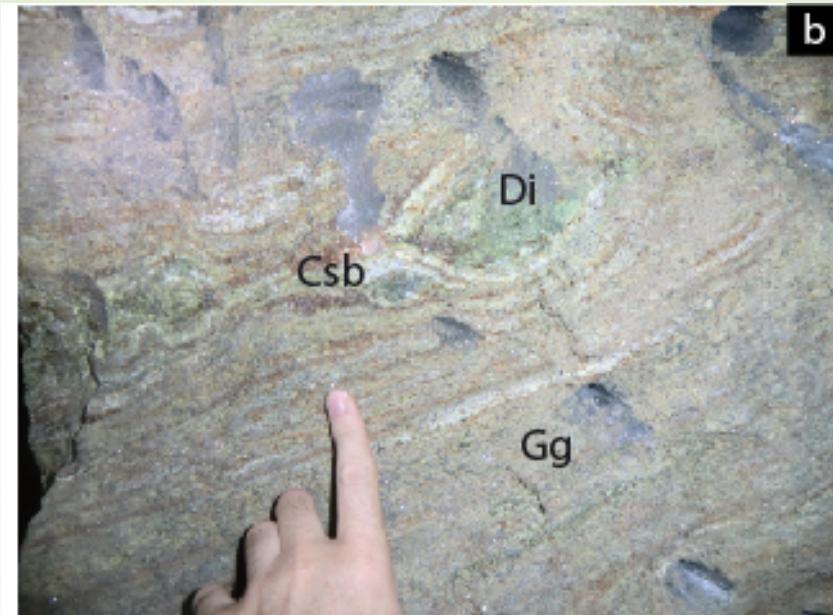
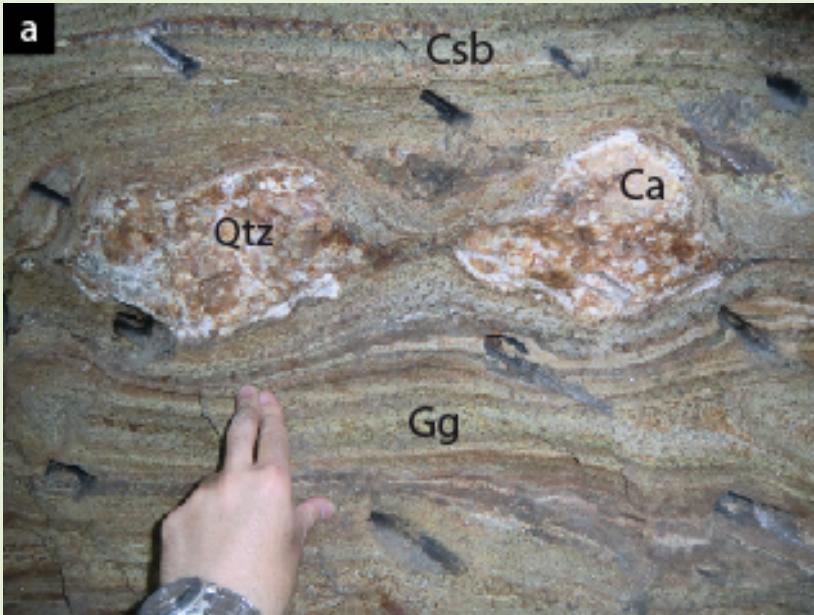


The tsavorite mines





The nodules N_{II} (Davis mine)



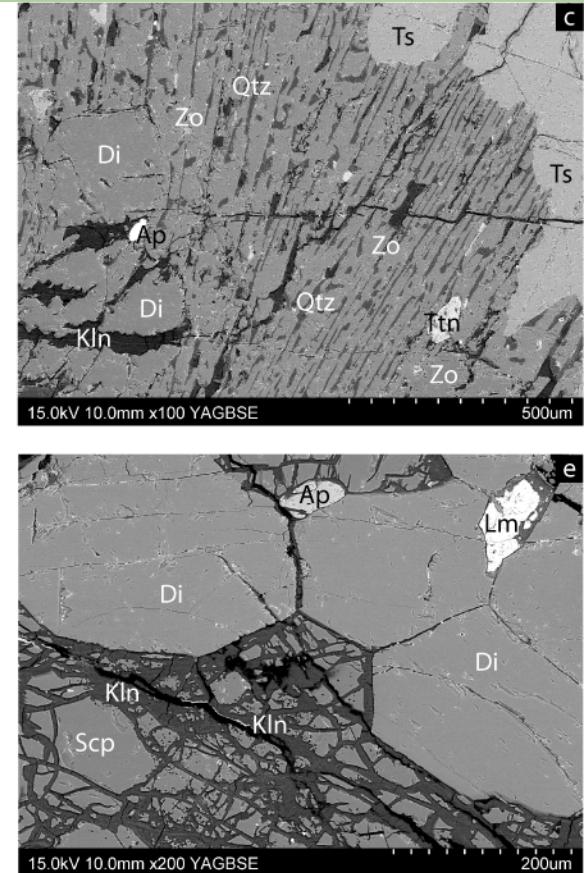
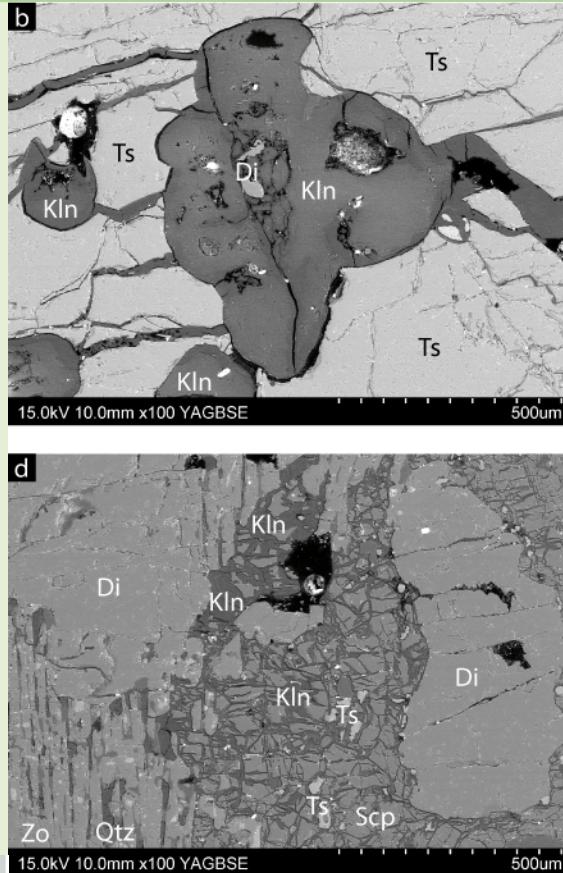
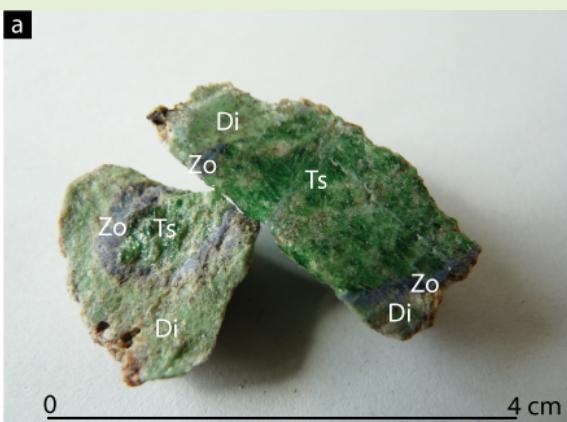
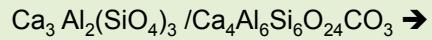


The nodules N_{II} (Davis mine)

Diopside → Tsavorite



Tsavorite/Scapolite → Zoïsite



Ap = apatite;

Kln = kaolinite;

Scp = scapolite;

Ttn = titanite;

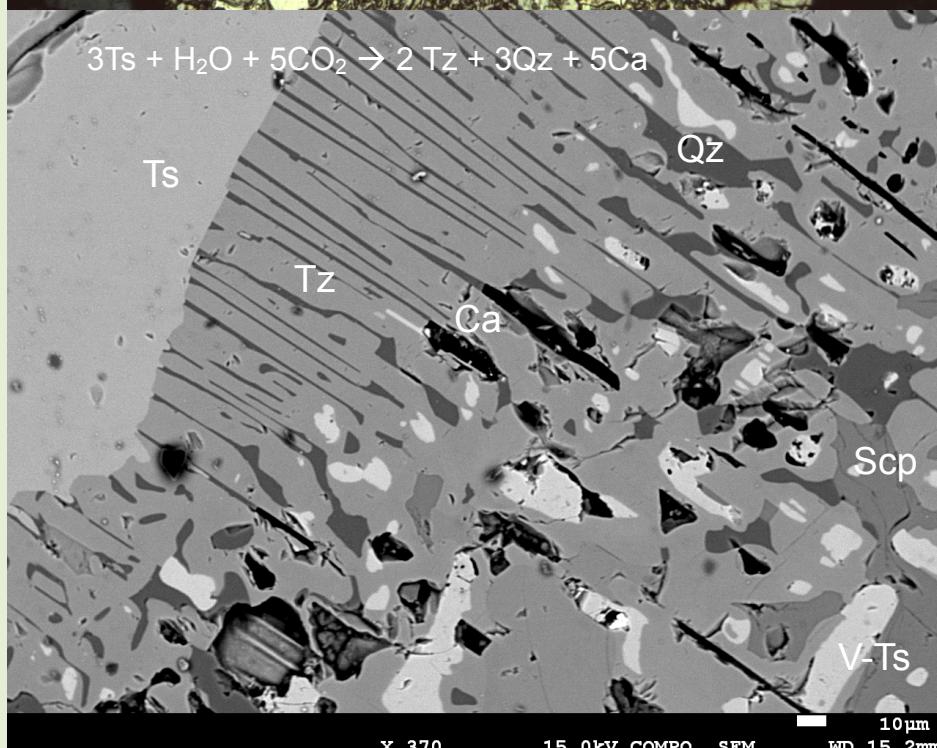
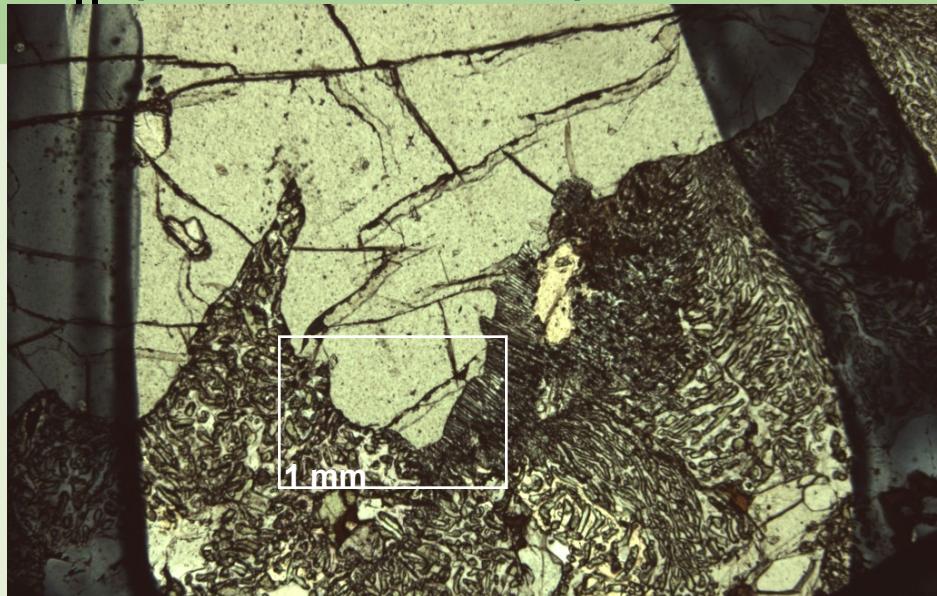
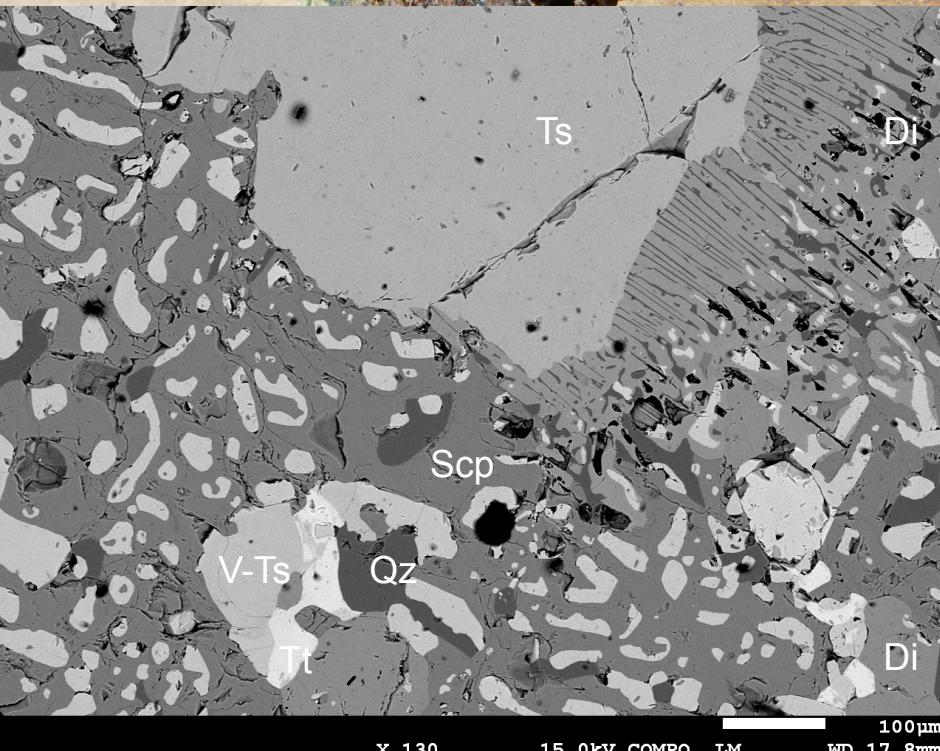
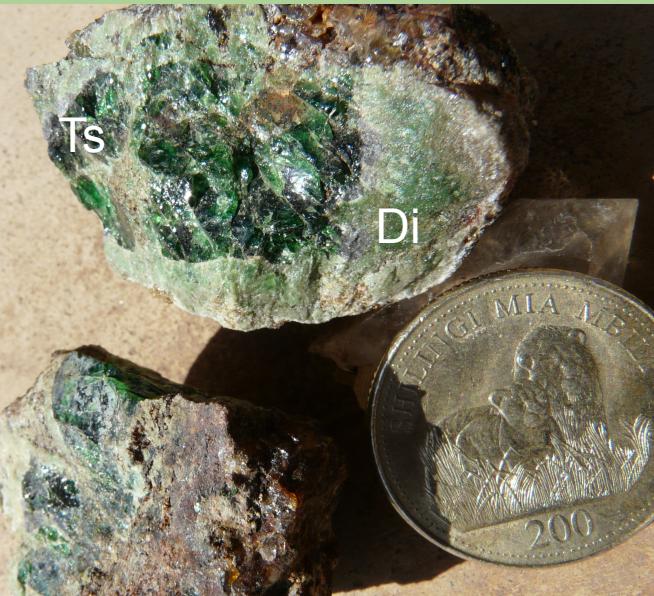
Di = diopside;

Qtz = quartz;

Ts = tsavorite;

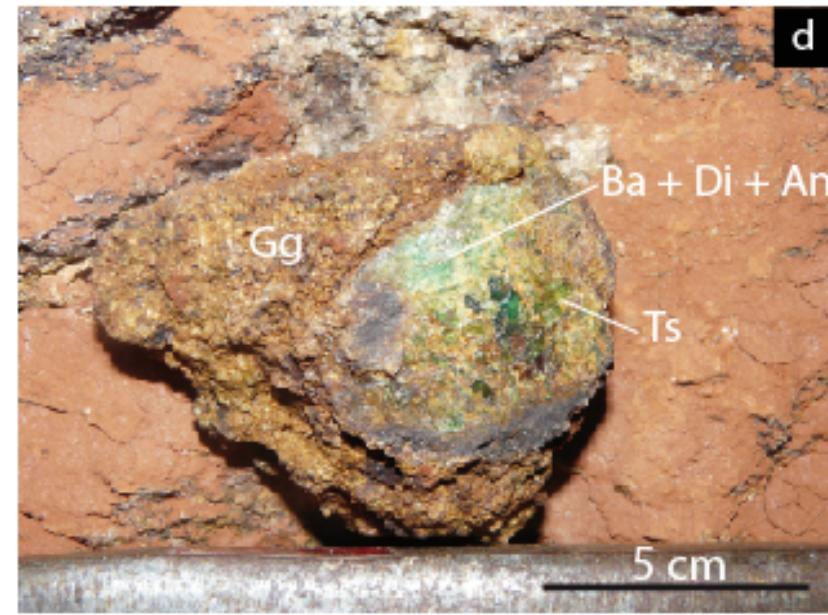
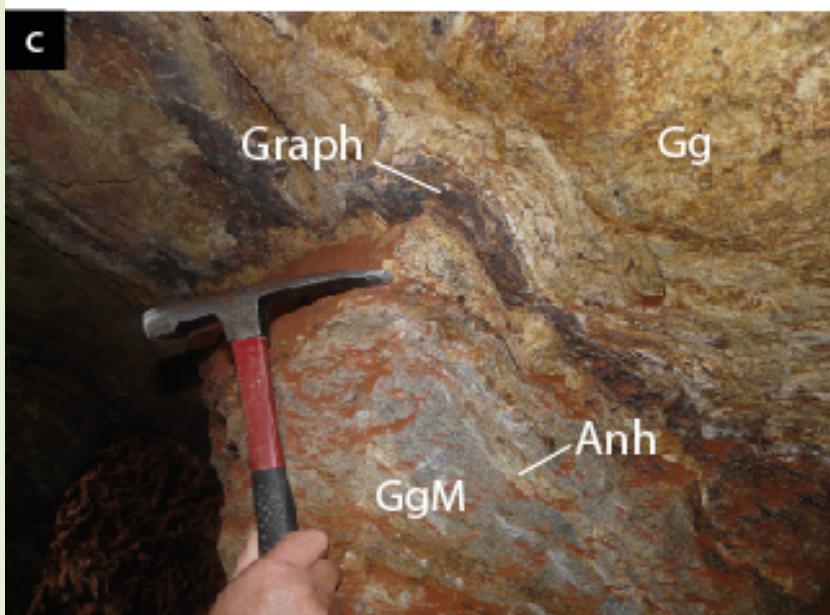
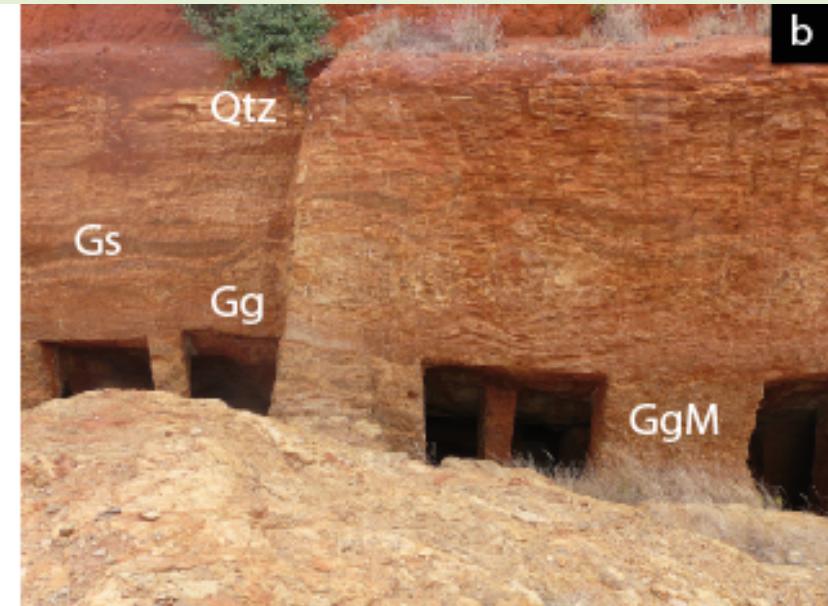
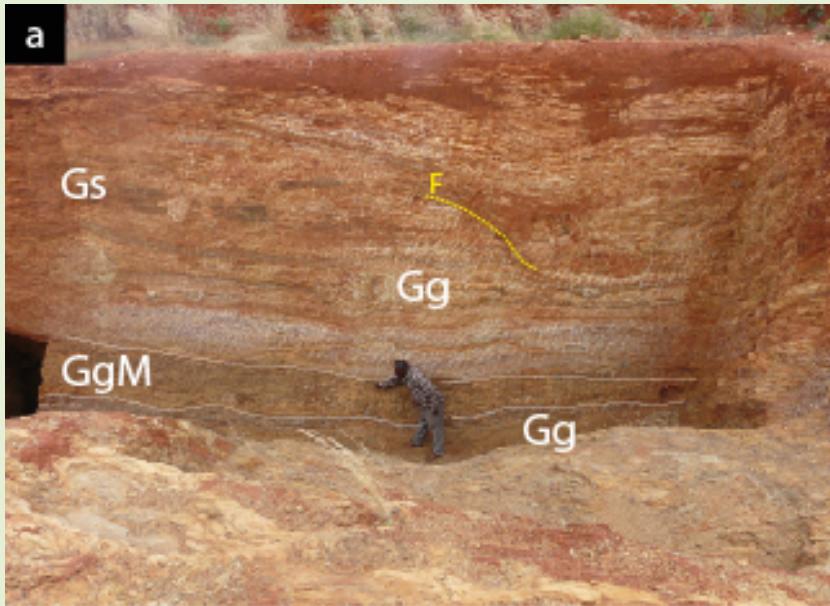
Zo = zoïsite

The nodules N_{II} (Davis mine)



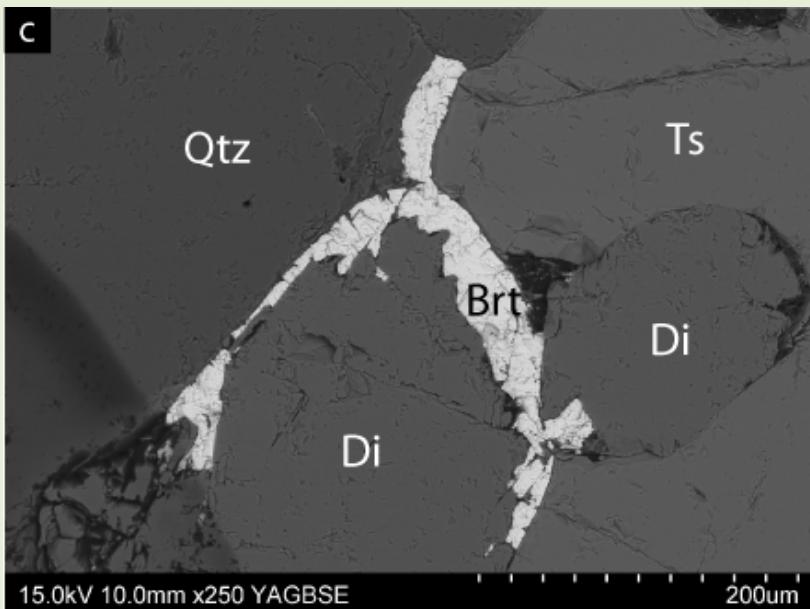
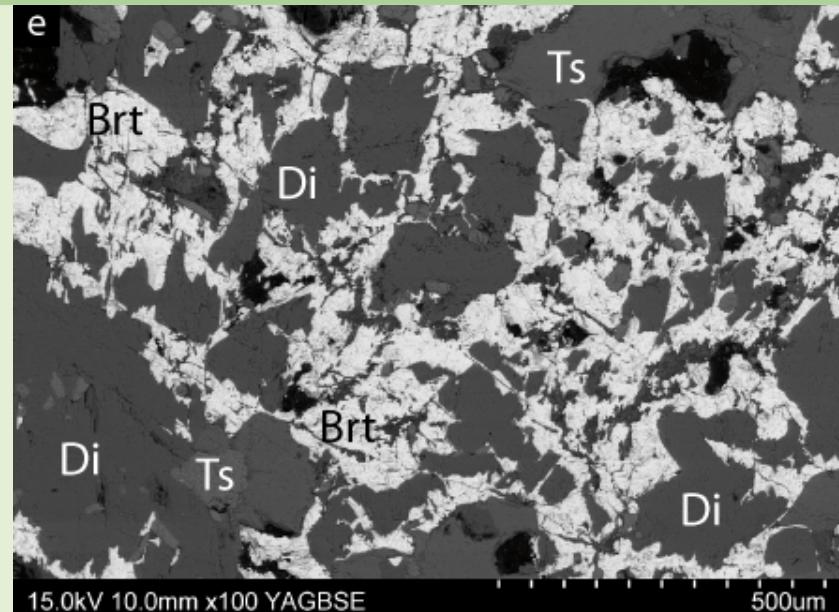
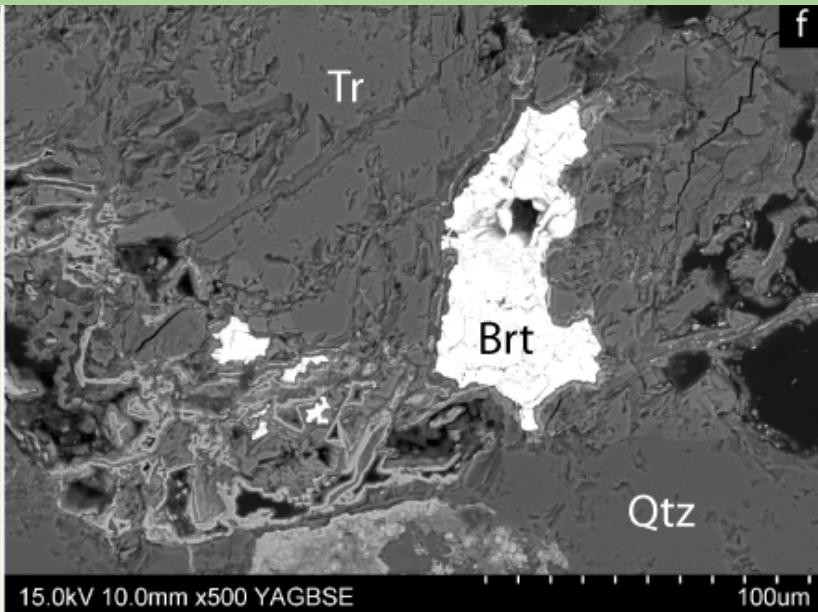


The nodules N_{II} (Nadan mine)





The nodules N_{II} (Nadan mine)



Brt = barite (BaSO_4);

Di = diopside;

Qtz = quartz;

Ts = tsavorite;

Tr = tremolite;

Barite → (Tremolite) →
Diopside → Tsavorite



The nodules N_{II} (Tsavolite mine)





The meta-evaporites of Classic mine

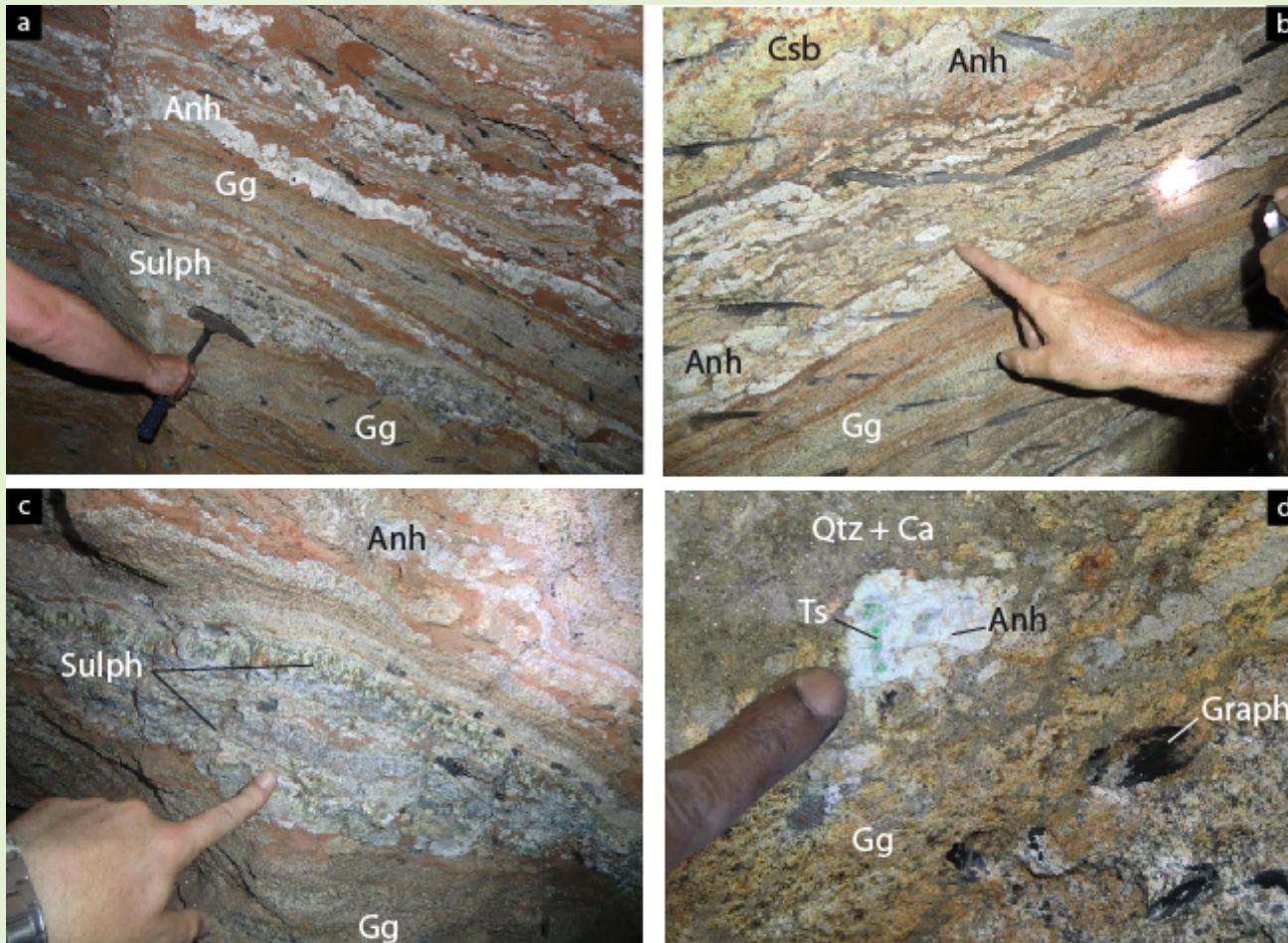
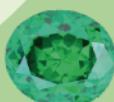


Fig. 7



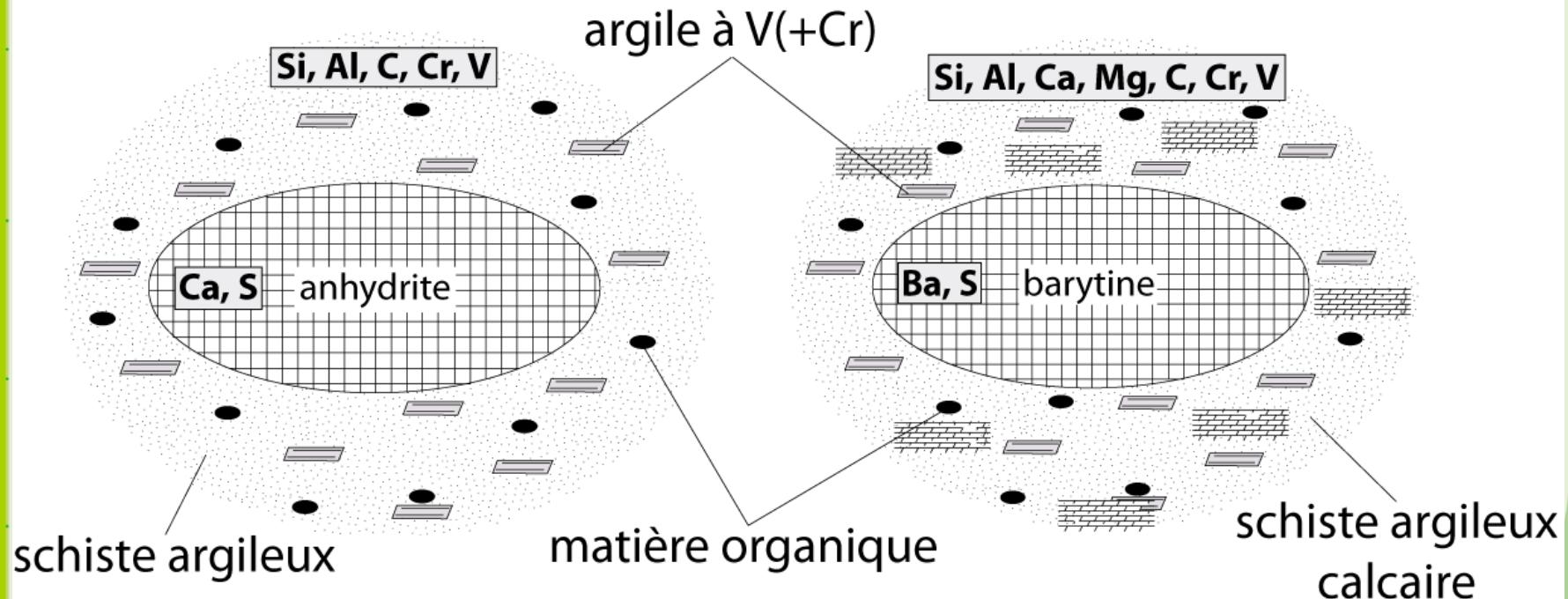


THE FORMATION OF NODULES

Nodule N_I

Nodule N_{II}

① *Protolith*



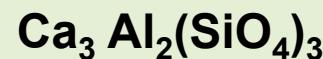
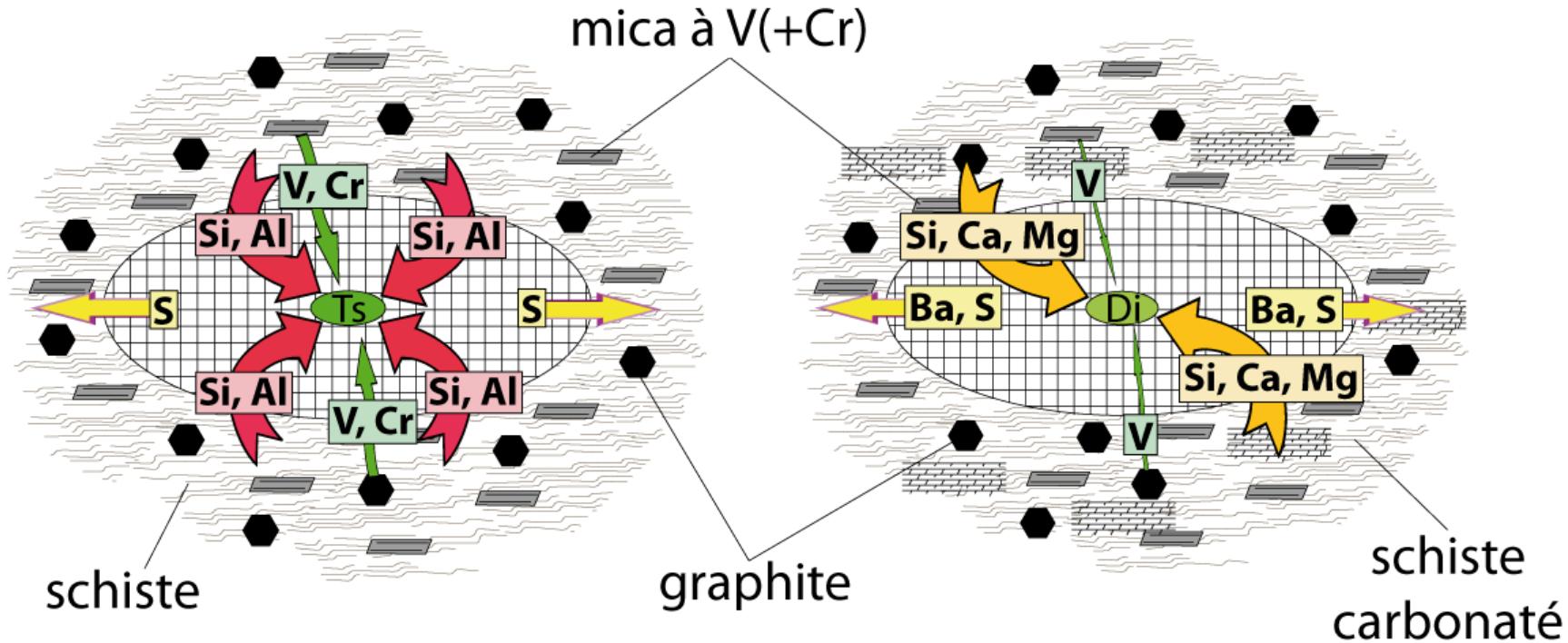


THE FORMATION OF NODULES

Nodule N_I

Nodule N_{II}

② *Début du métamorphisme prograde*



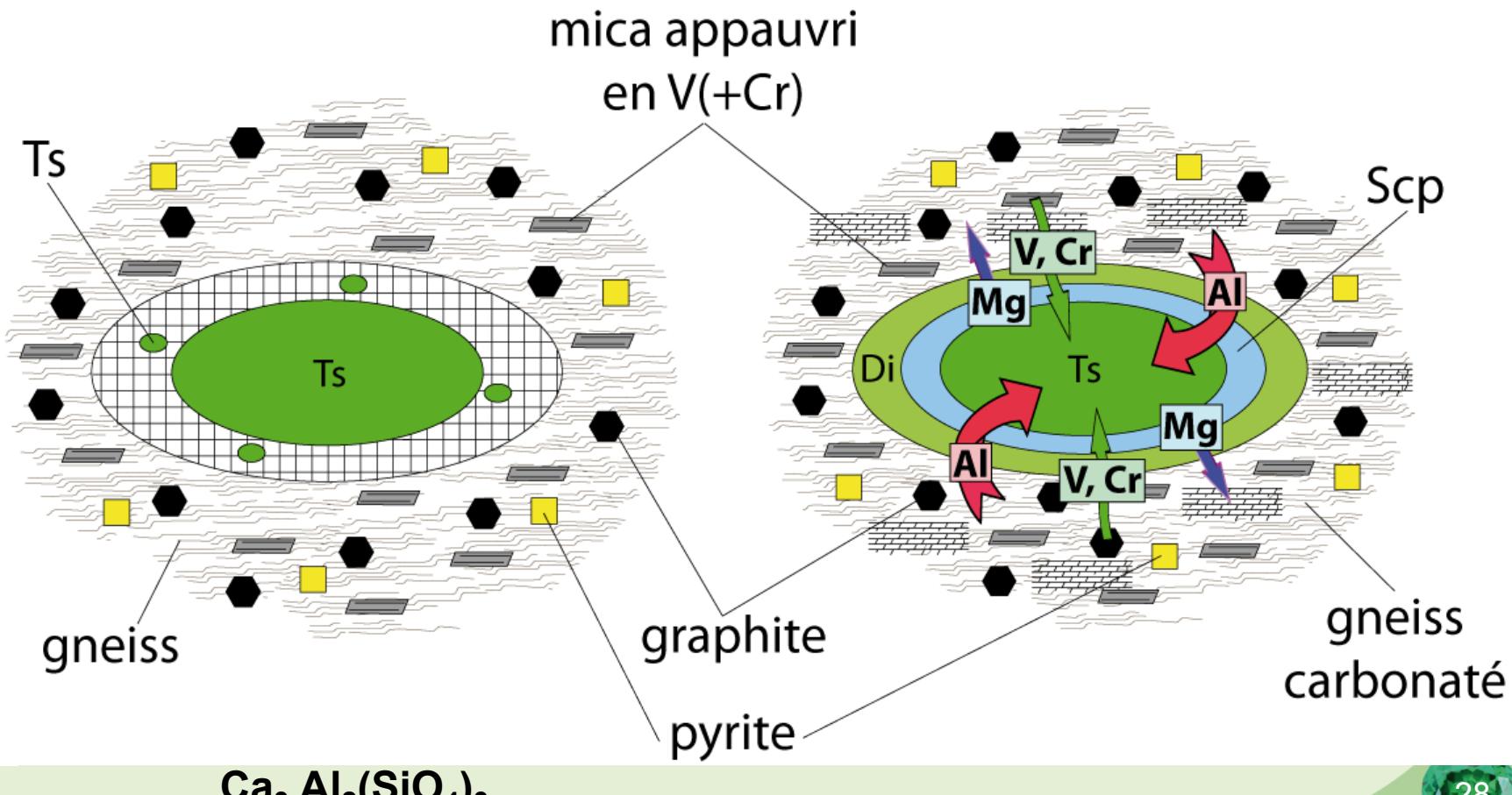


THE FORMATION OF NODULES

Nodule N_I

Nodule N_{II}

③ *Fin du métamorphisme prograde*



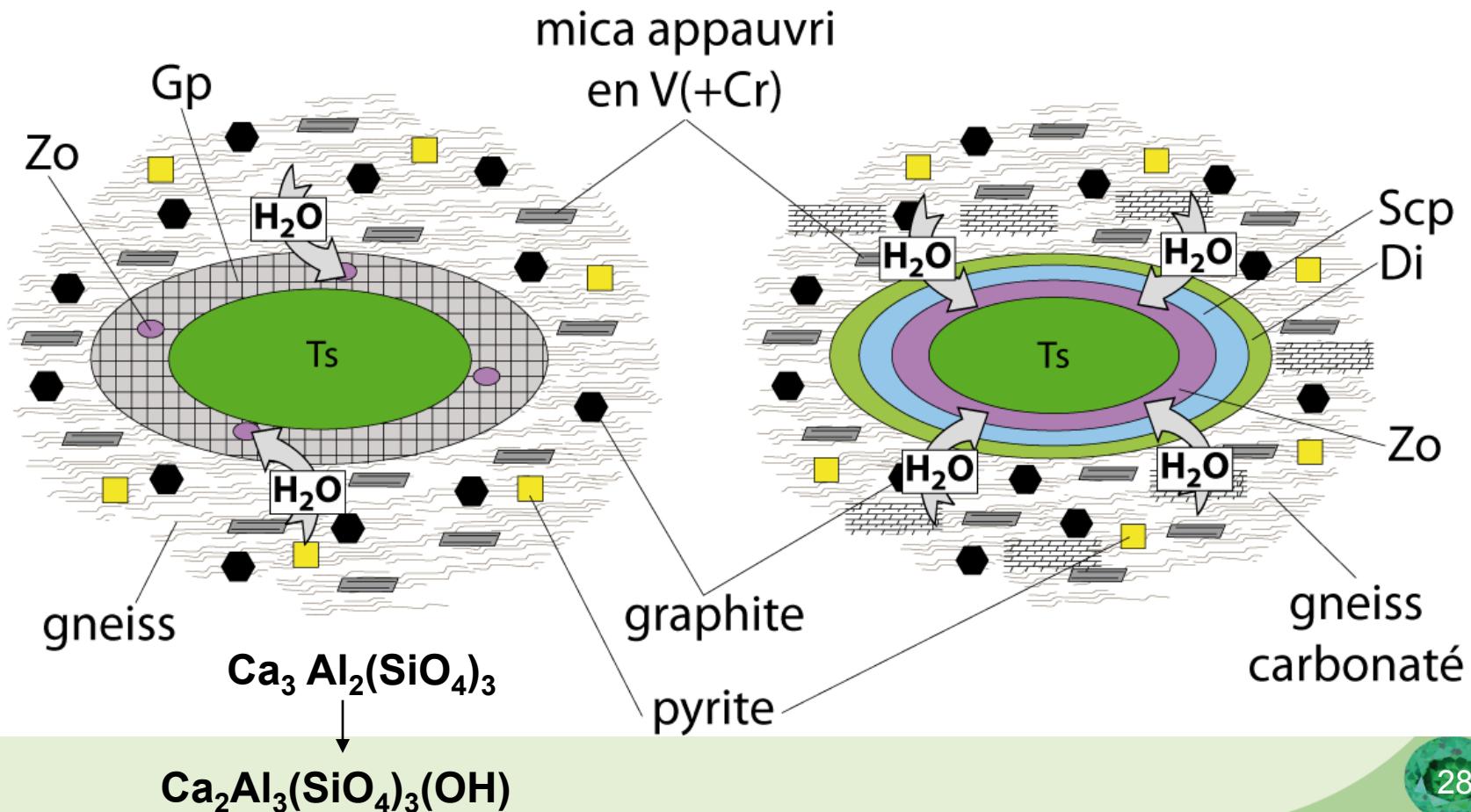


THE FORMATION OF NODULES

Nodule N_I

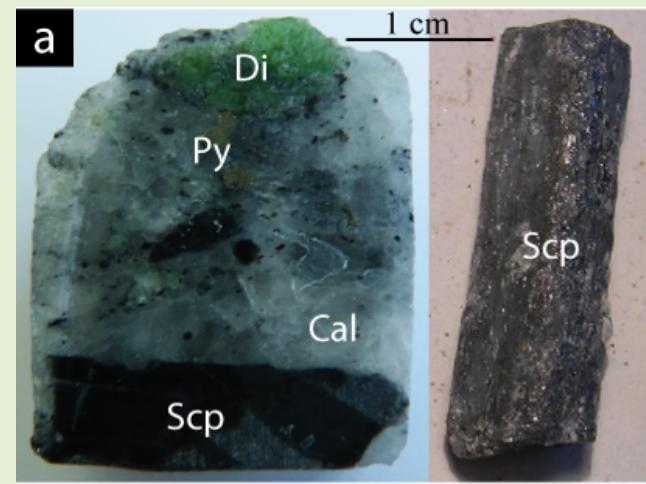
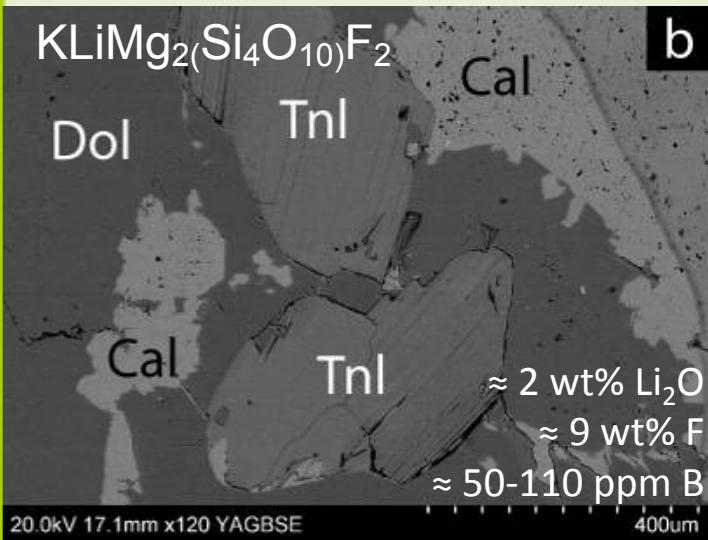
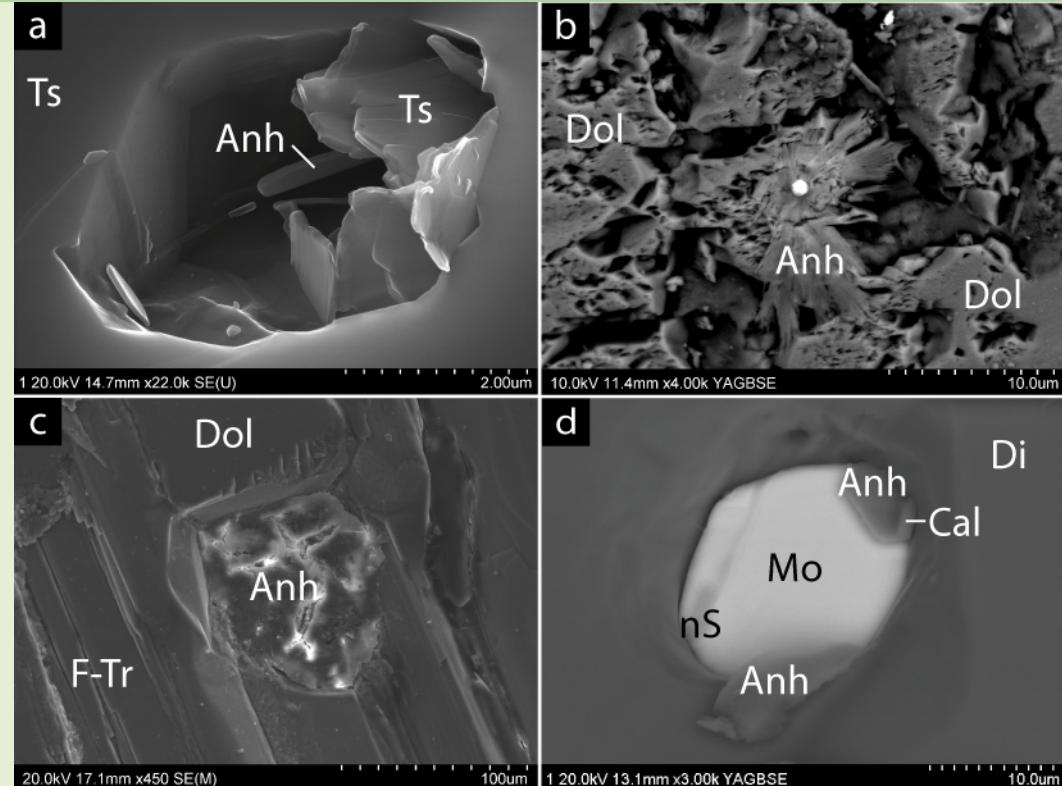
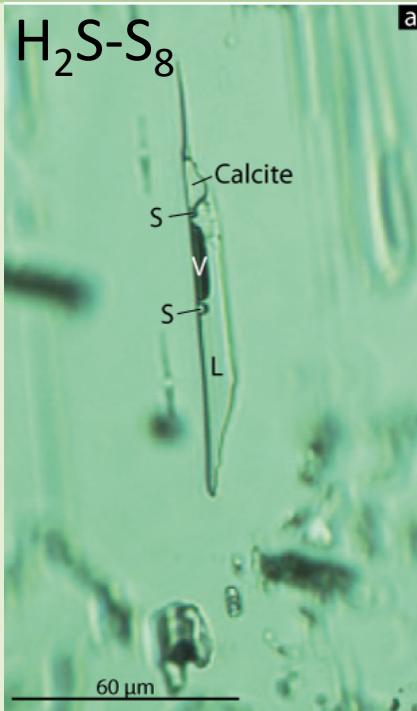
Nodule N_{II}

4 Métamorphisme rétrograde



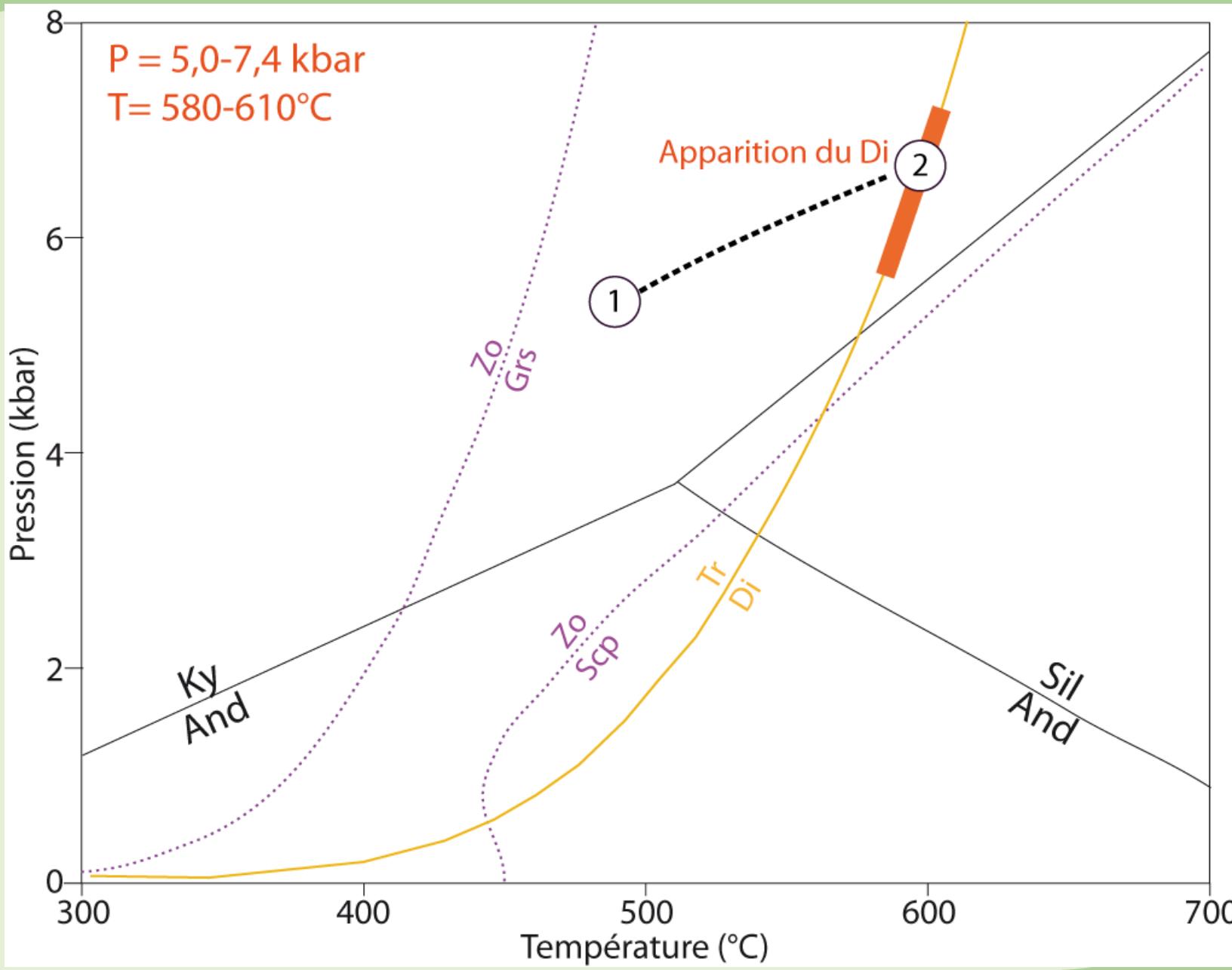


Markers of evaporites



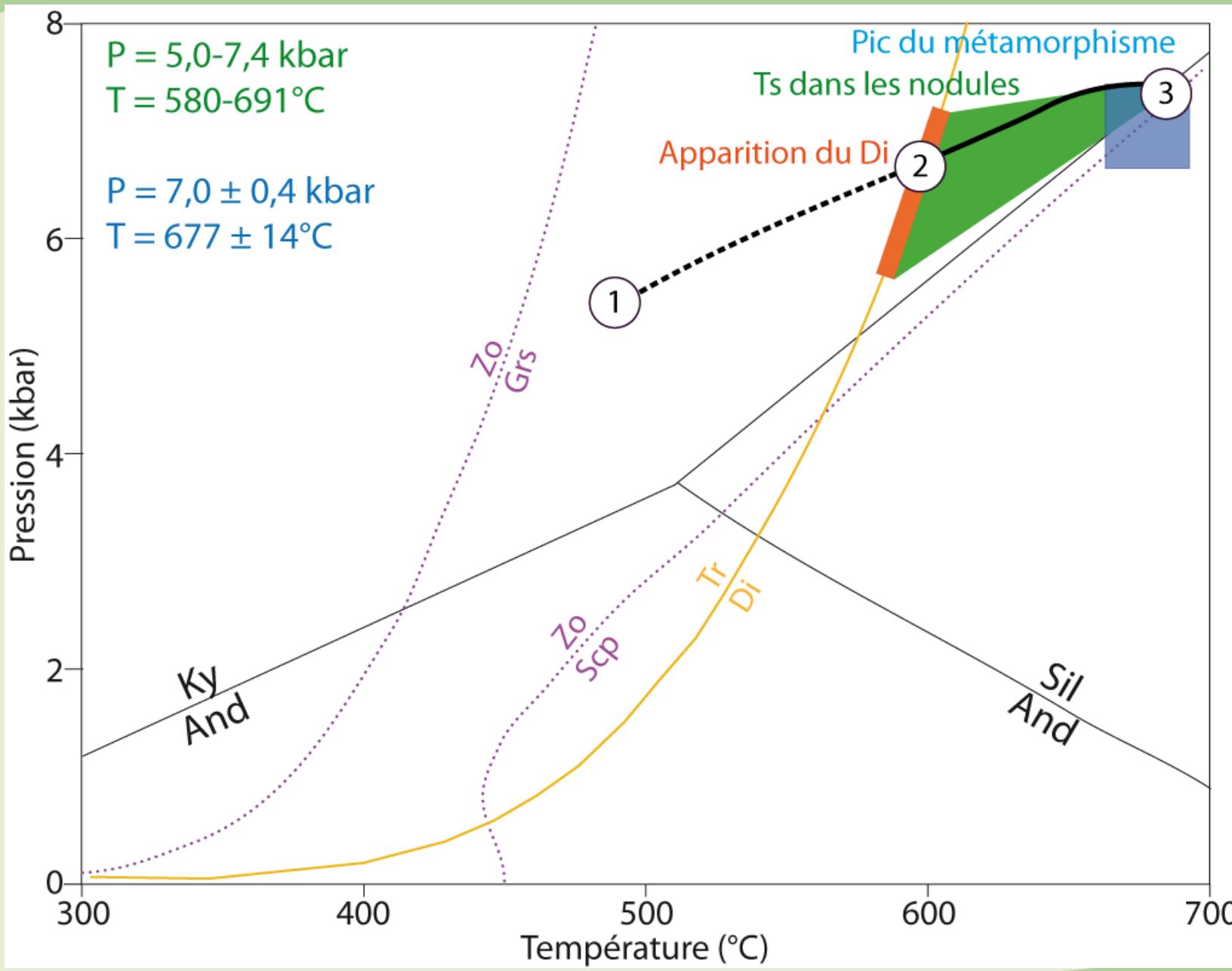


Conditions of metamorphism



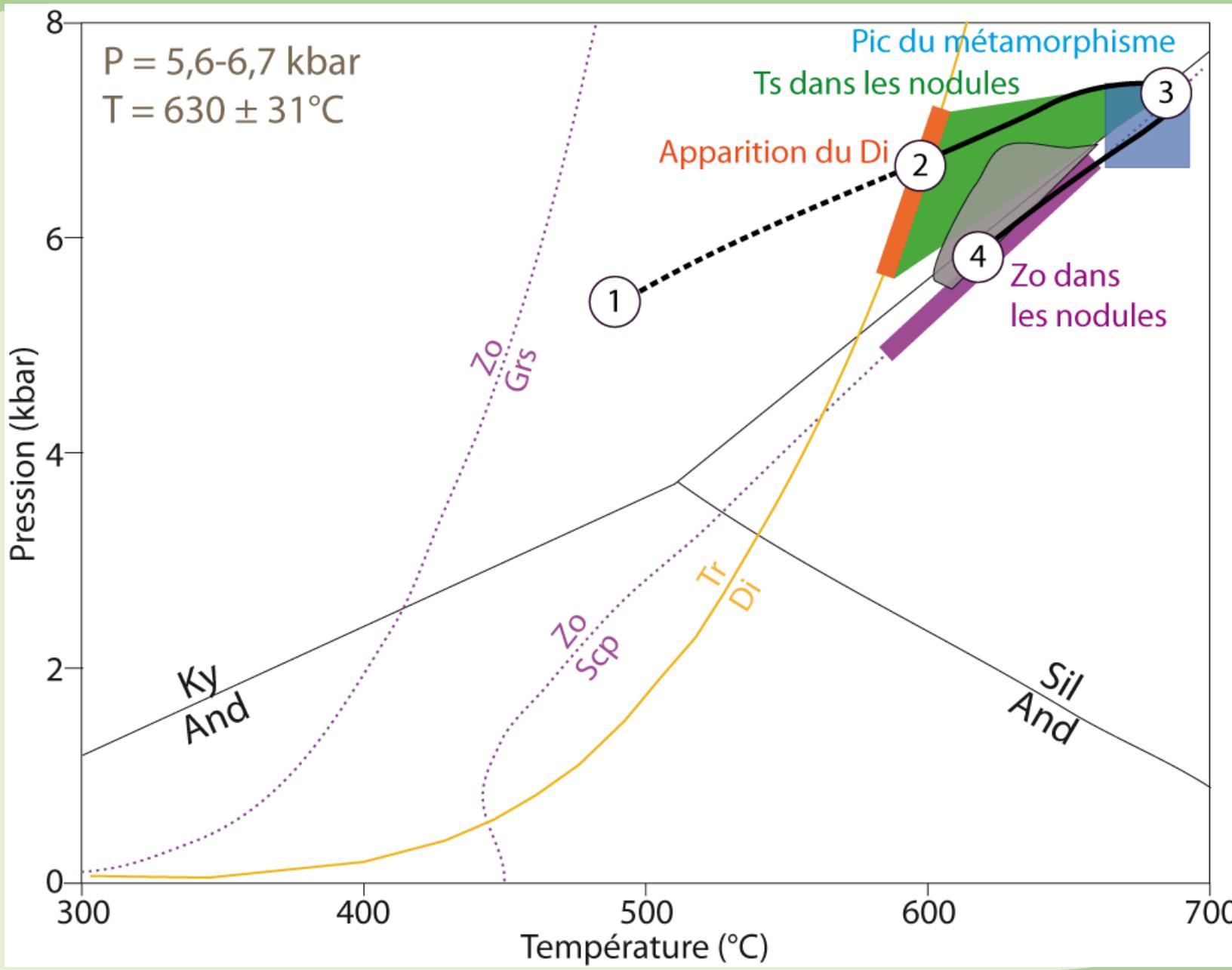


Conditions of metamorphism



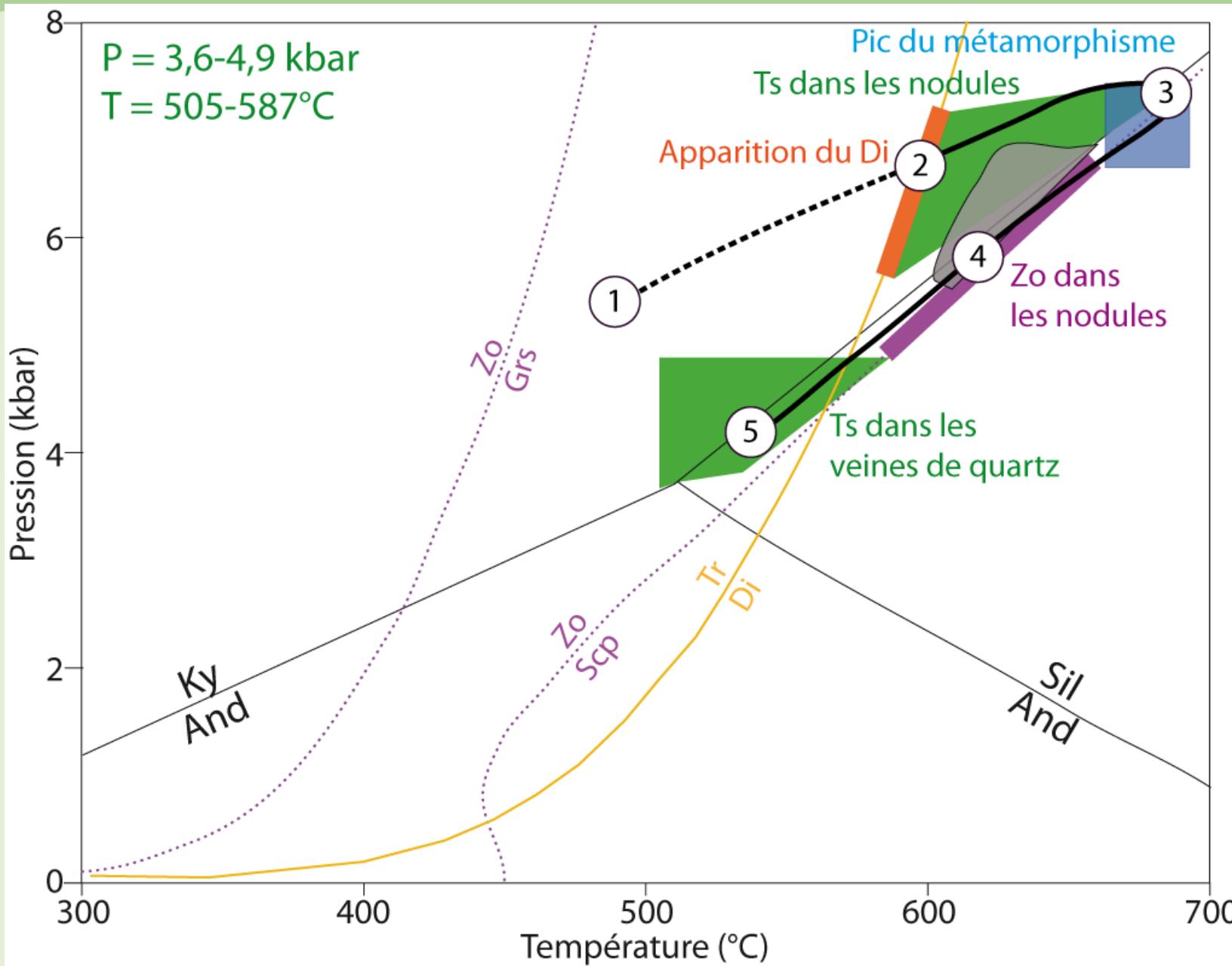


Conditions of metamorphism



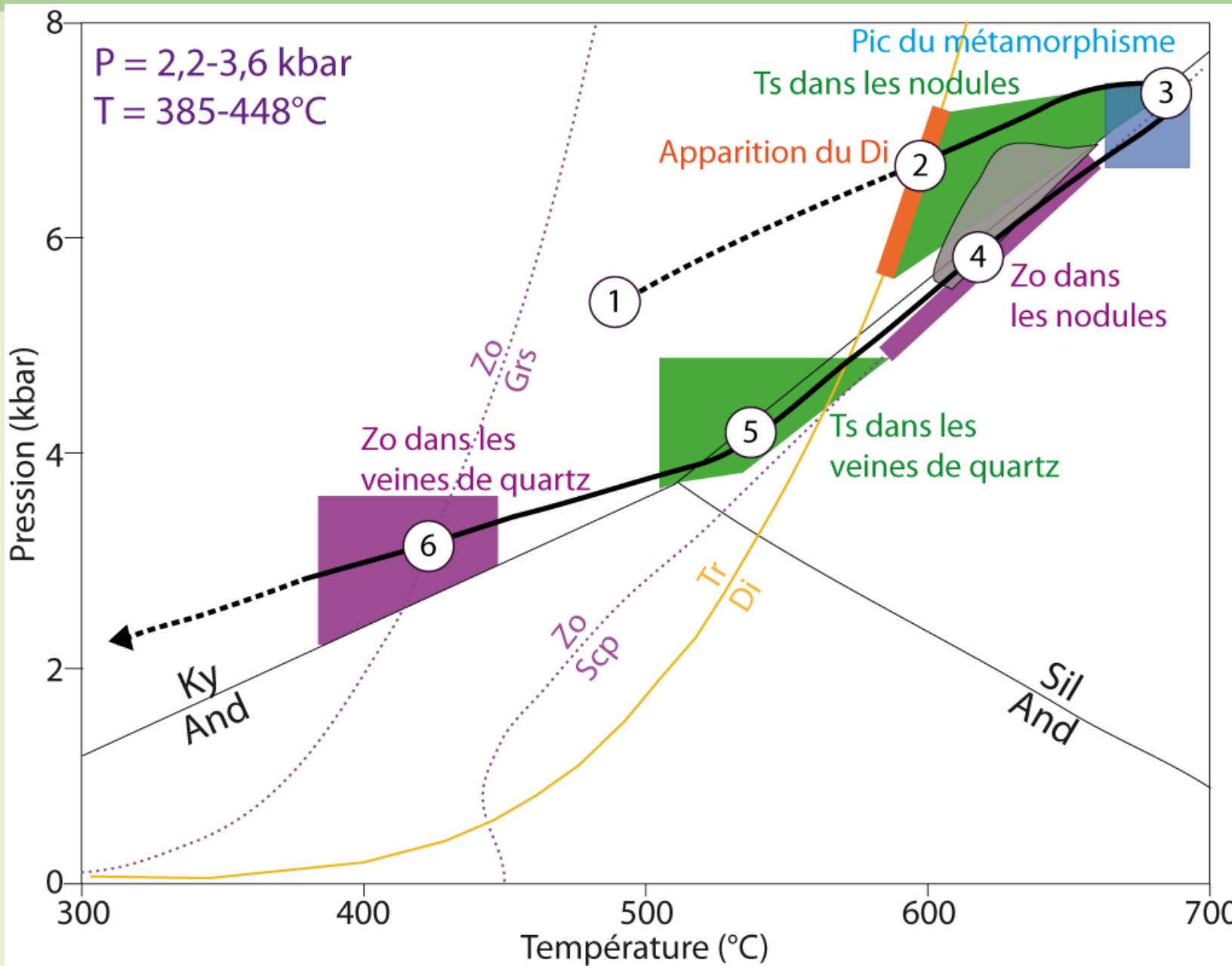


Conditions of metamorphism





Conditions of metamorphism



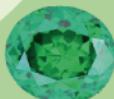


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4. Geochronology

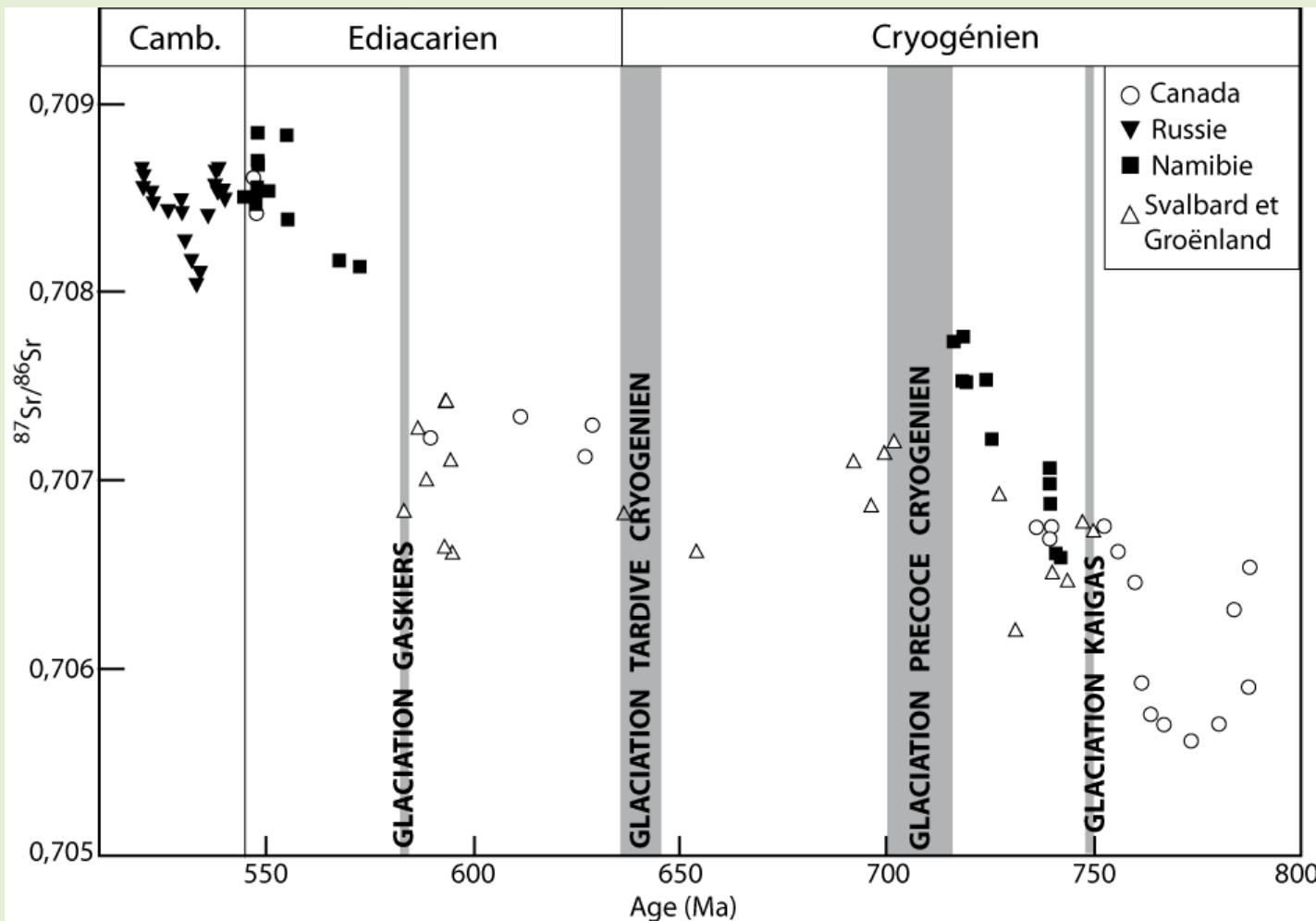


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Age of the protoliths

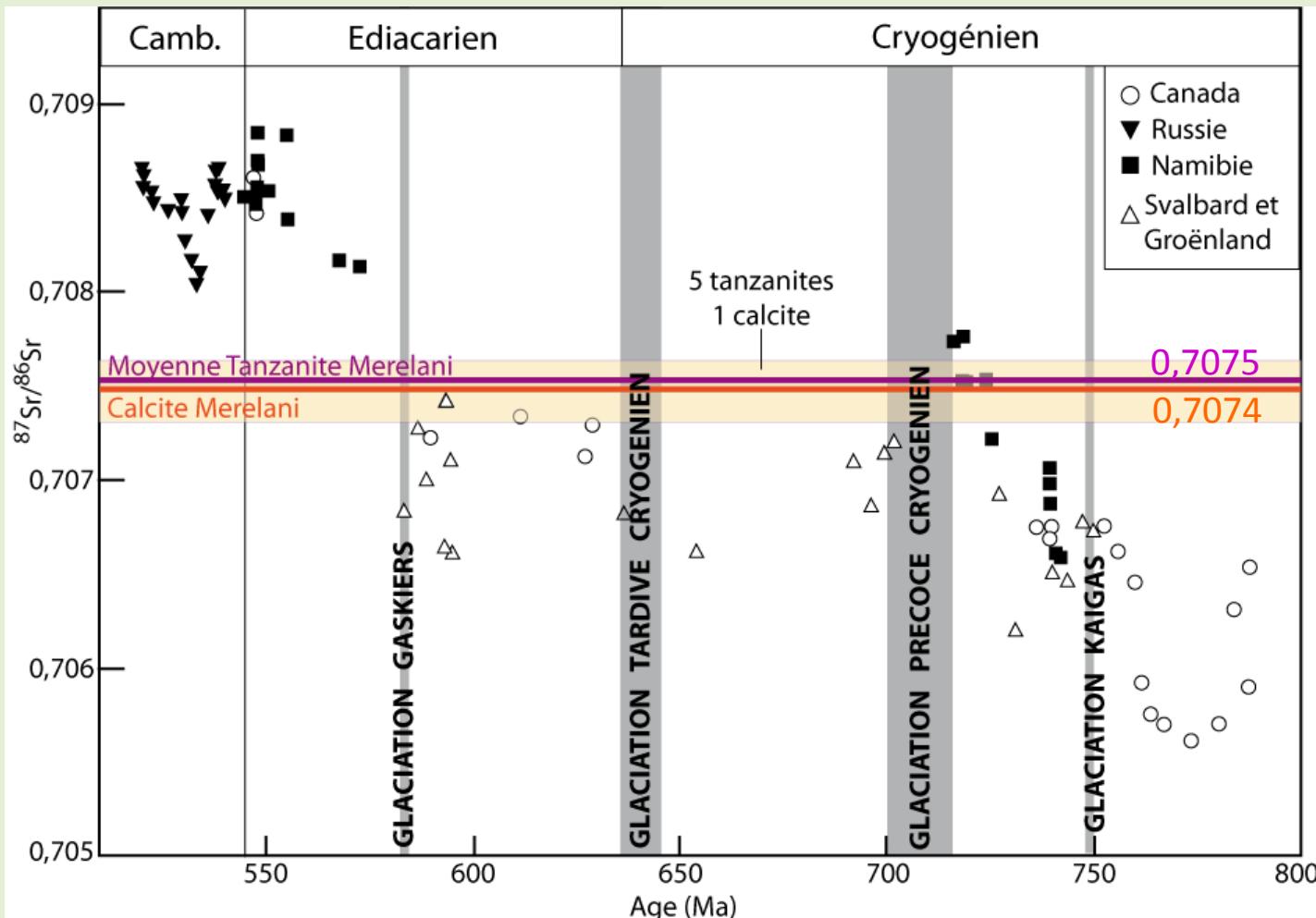


After Jacobsen et Kaufman (1999)

Neoproterozoic water: $0,7055 < {^{87}\text{Sr}}/{^{86}\text{Sr}} < 0,7080$



Age of the protoliths

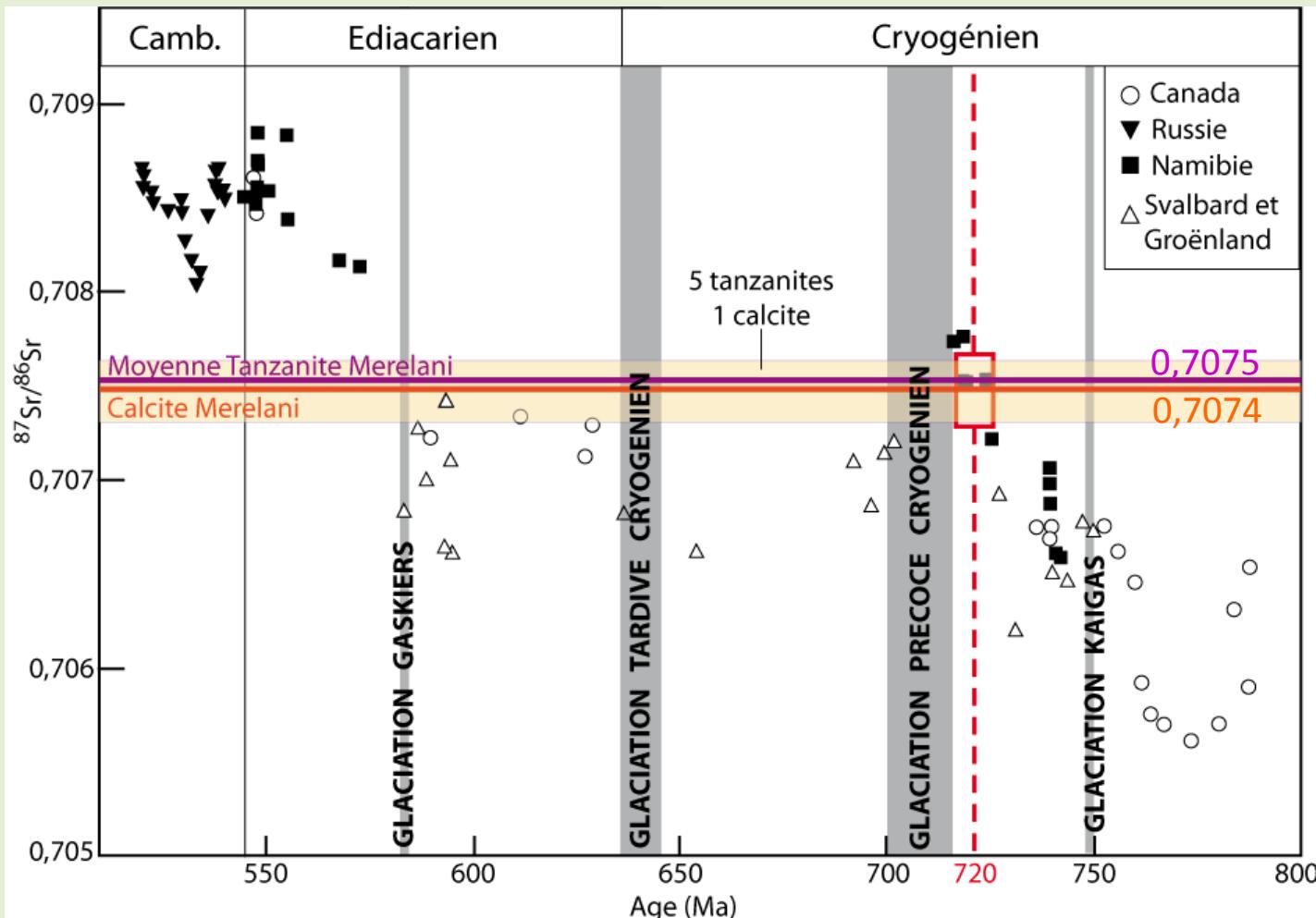


Collaboration with the Université Libre de Bruxelles

Neoproterozoic water: $0.7055 < ^{87}\text{Sr}/^{86}\text{Sr} < 0.7080$



Age of the protoliths

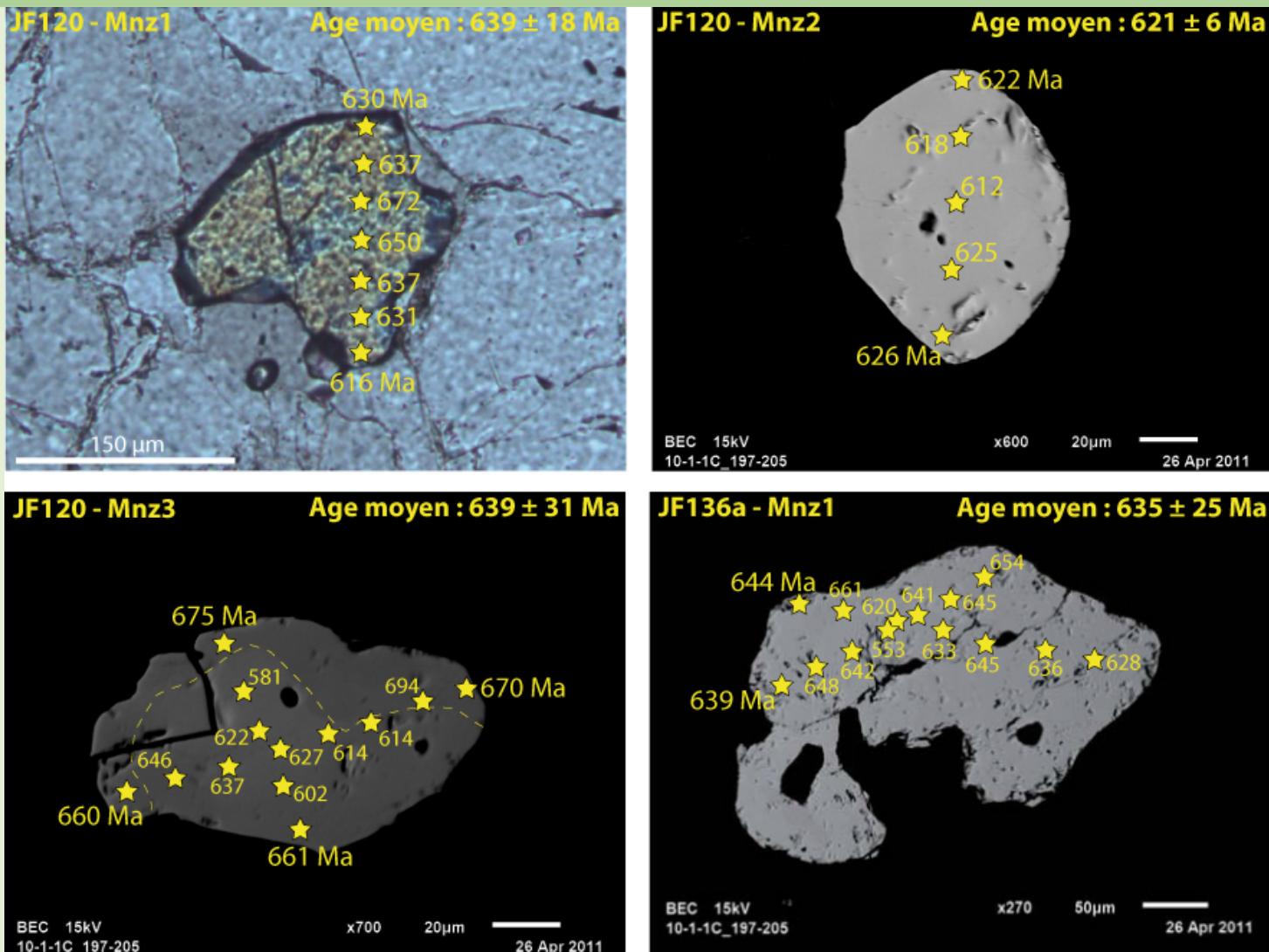


Collaboration with the Université Libre de Bruxelles

Neoproterozoic water: $0,7055 < {^{87}\text{Sr}}/{^{86}\text{Sr}} < 0,7080$



Age of metamorphism



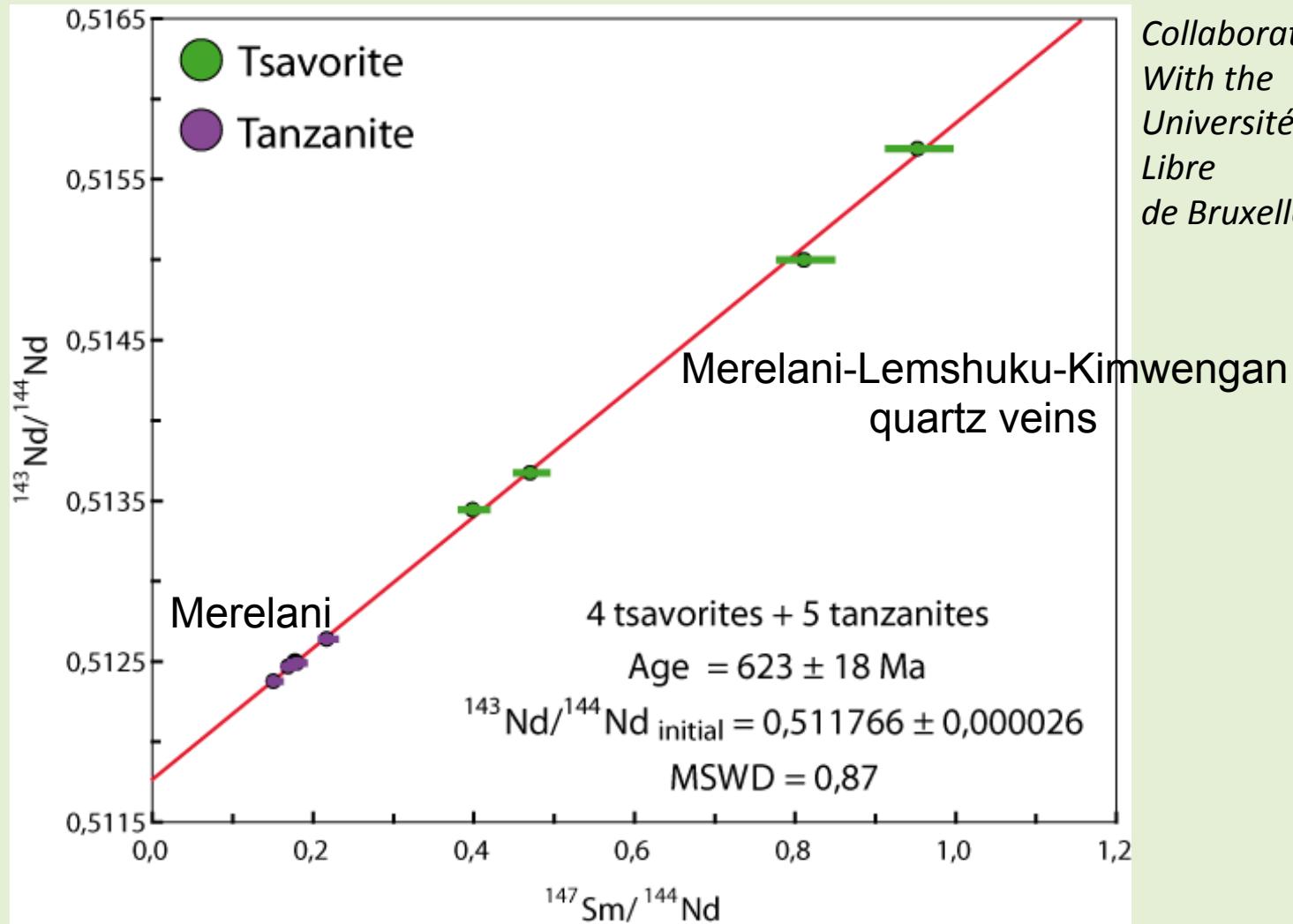
$$t \approx 634 \pm 22 \text{ Ma}$$

For comparison: $650 < t < 620$ Ma (Tanzania)



Age of the mineralization

Collaboration
With the
Université
Libre
de Bruxelles

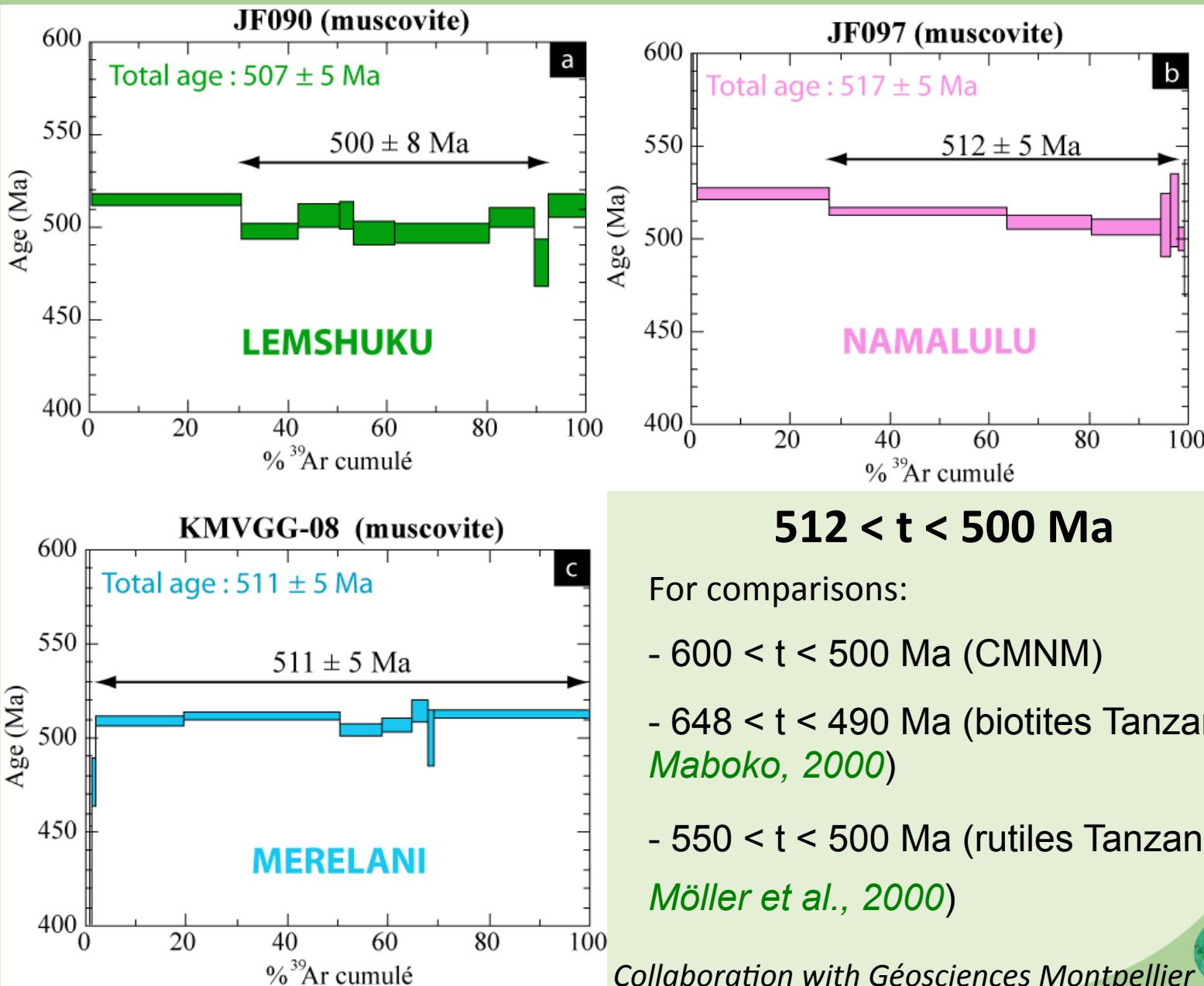


For comparison at Merelani:

- 600 Ma ($^{207}\text{Pb}/^{206}\text{Pb}$ sur uraninite; *Malisa, 1987*)
- 585 ± 28 Ma (fission tracks on tanzanite; *Naeser & Saul, 1974*)



Age of cooling



© J. Feneyrol



4. Chemistry of tsavorites



© J. Feneyrol

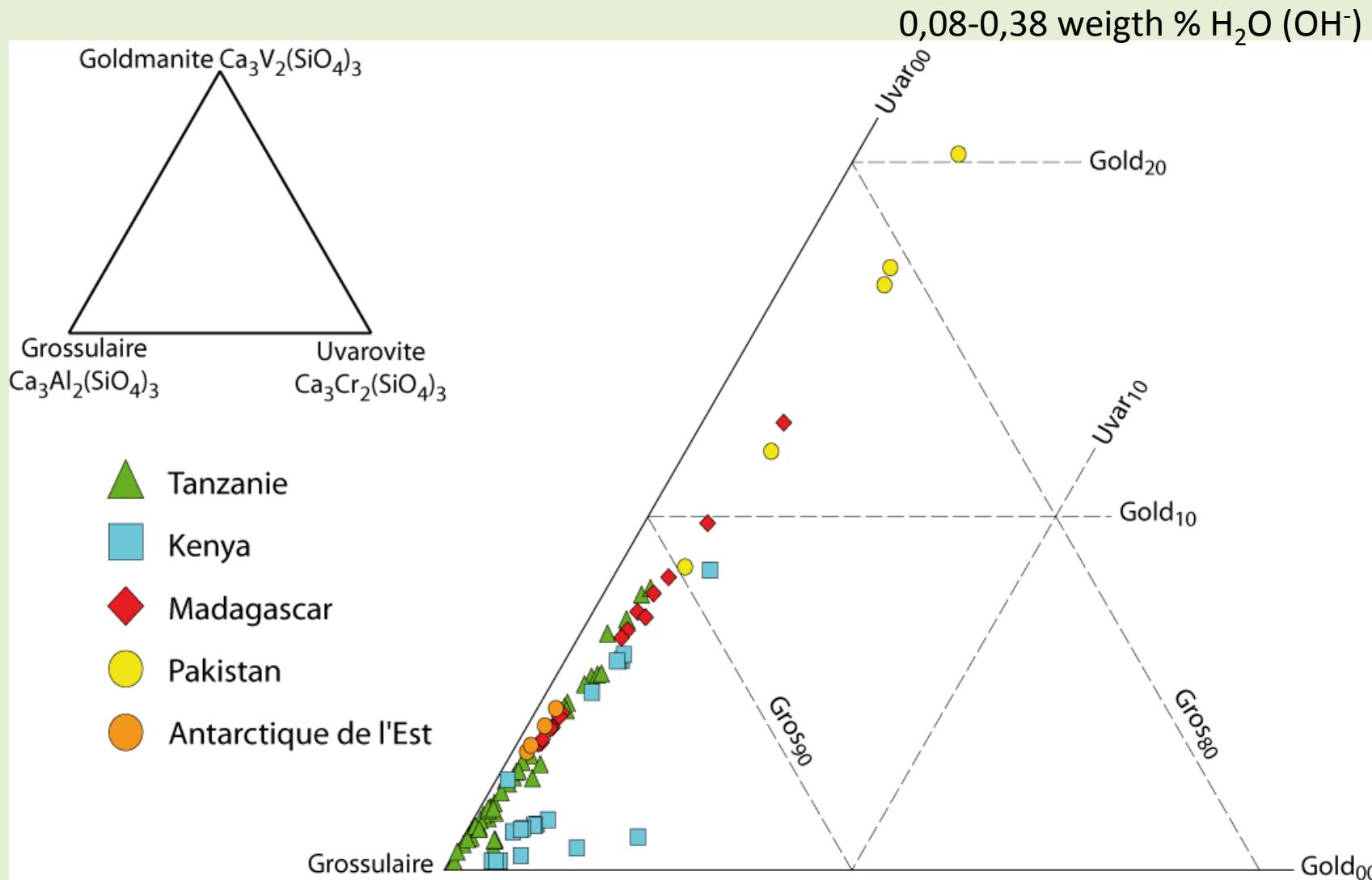


© J. Feneyrol



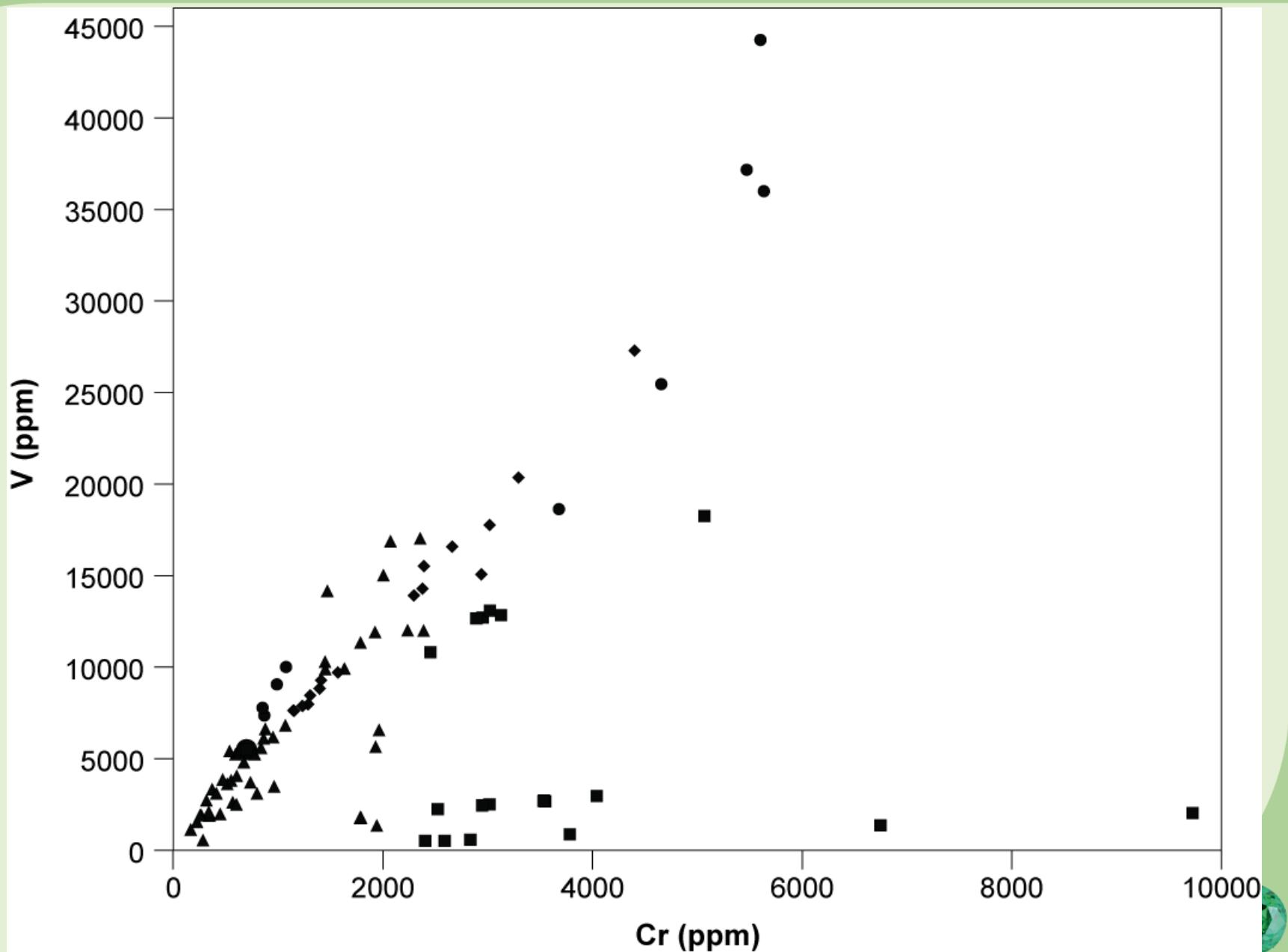
CHEMICAL COMPOSITION

1296 analyses on 95 crystals from 23 deposits



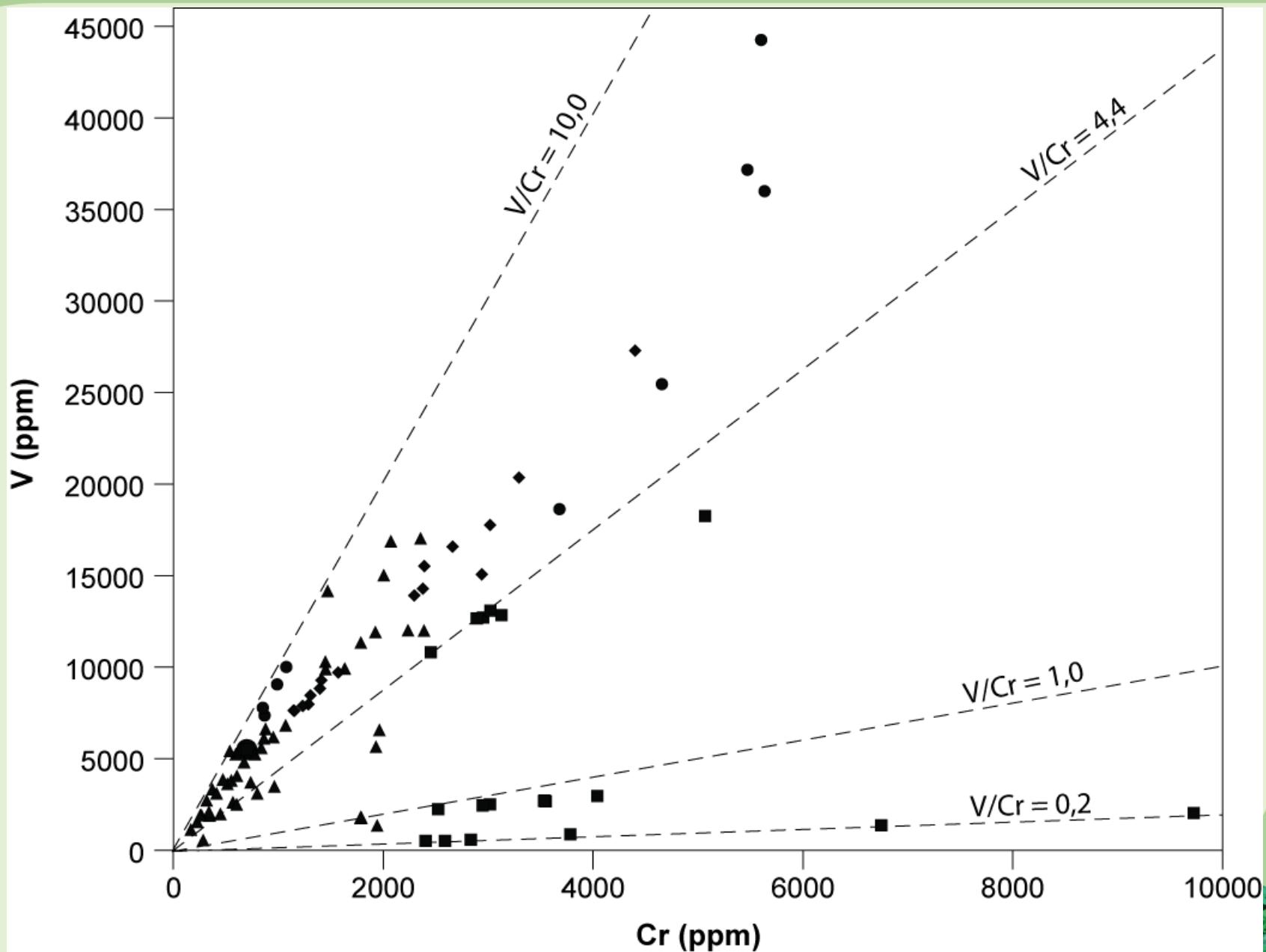


Vanadium and chromium



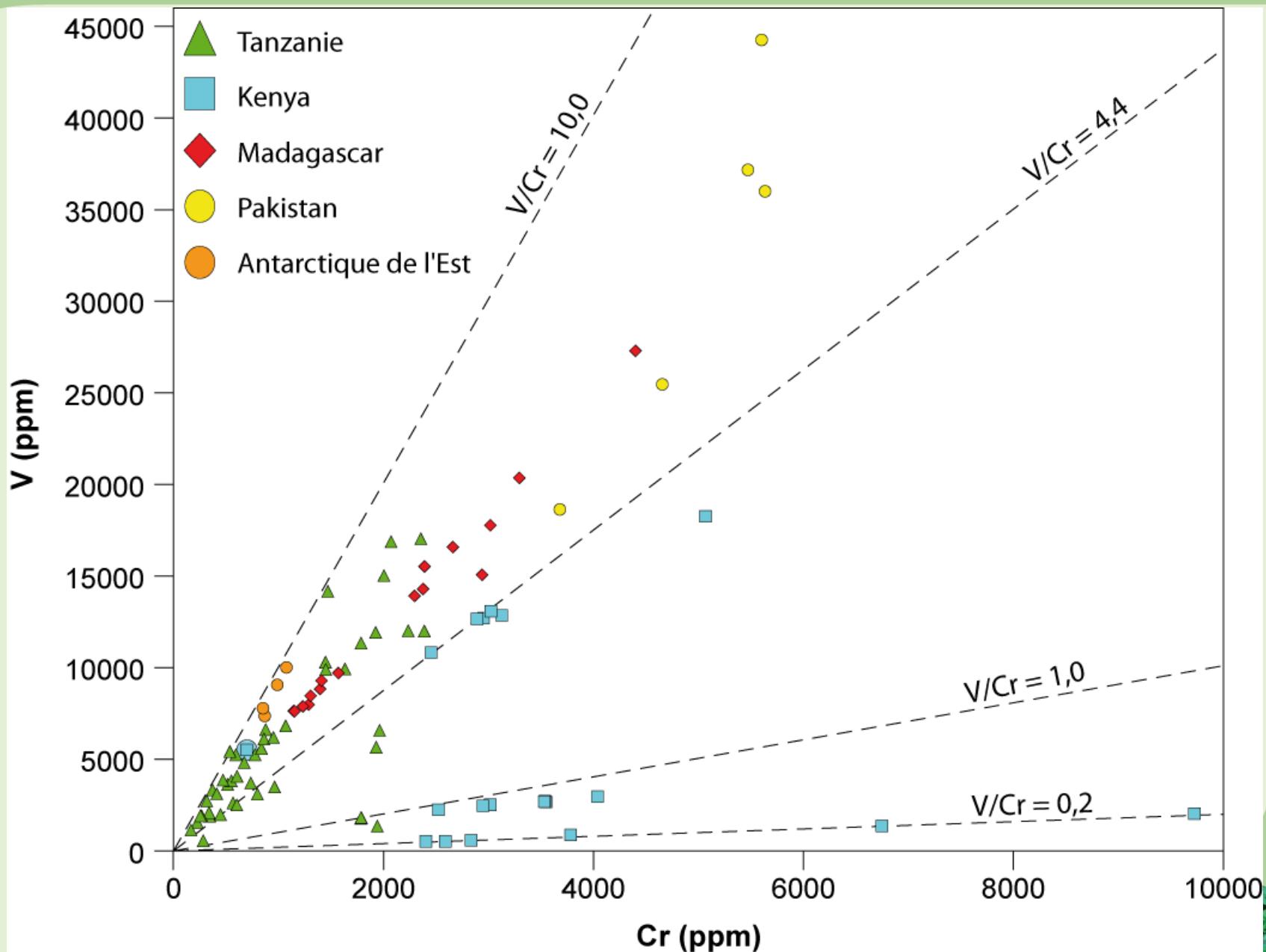


Vanadium and chromium



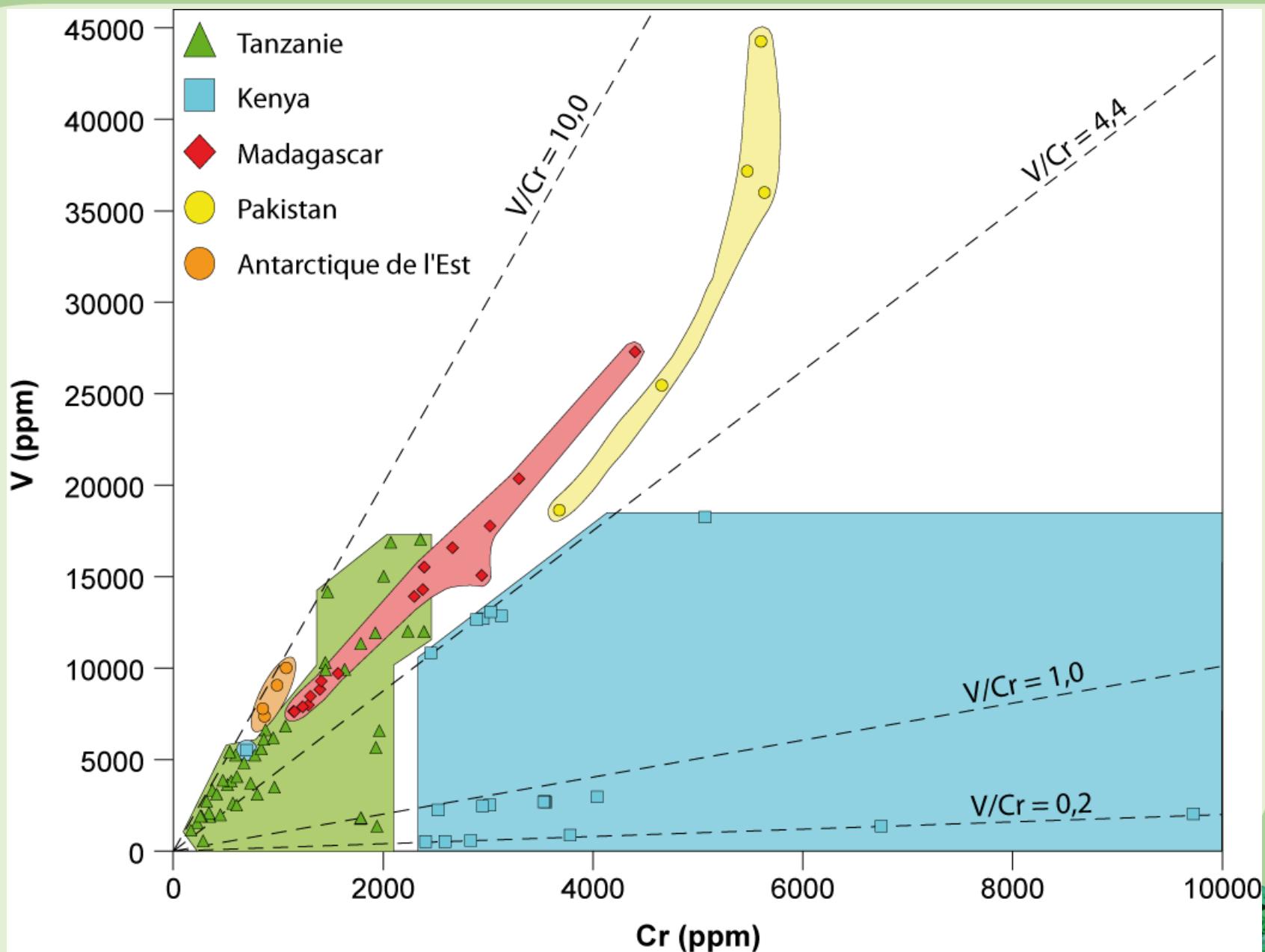


Vanadium and chromium



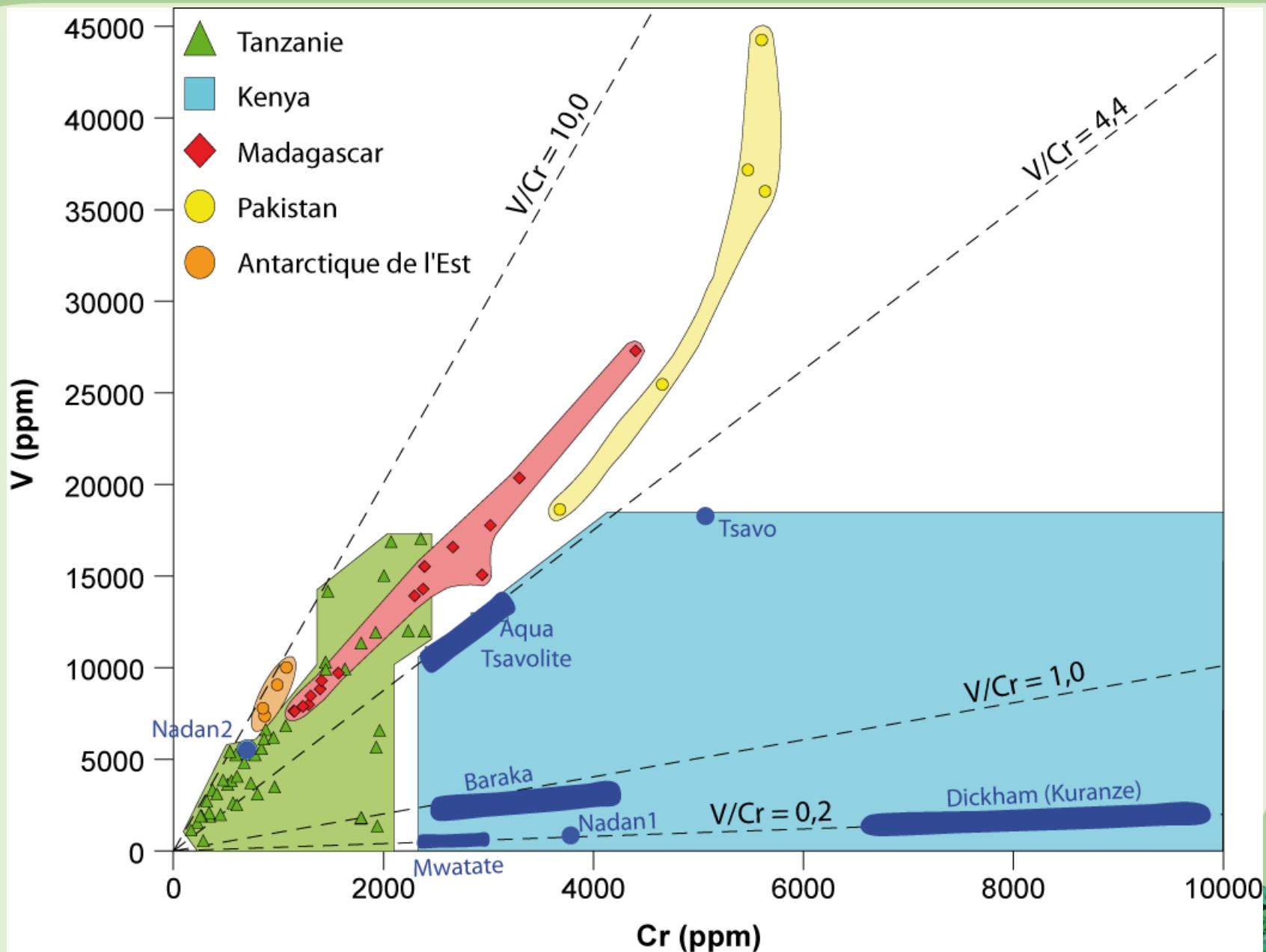


Vanadium and chromium



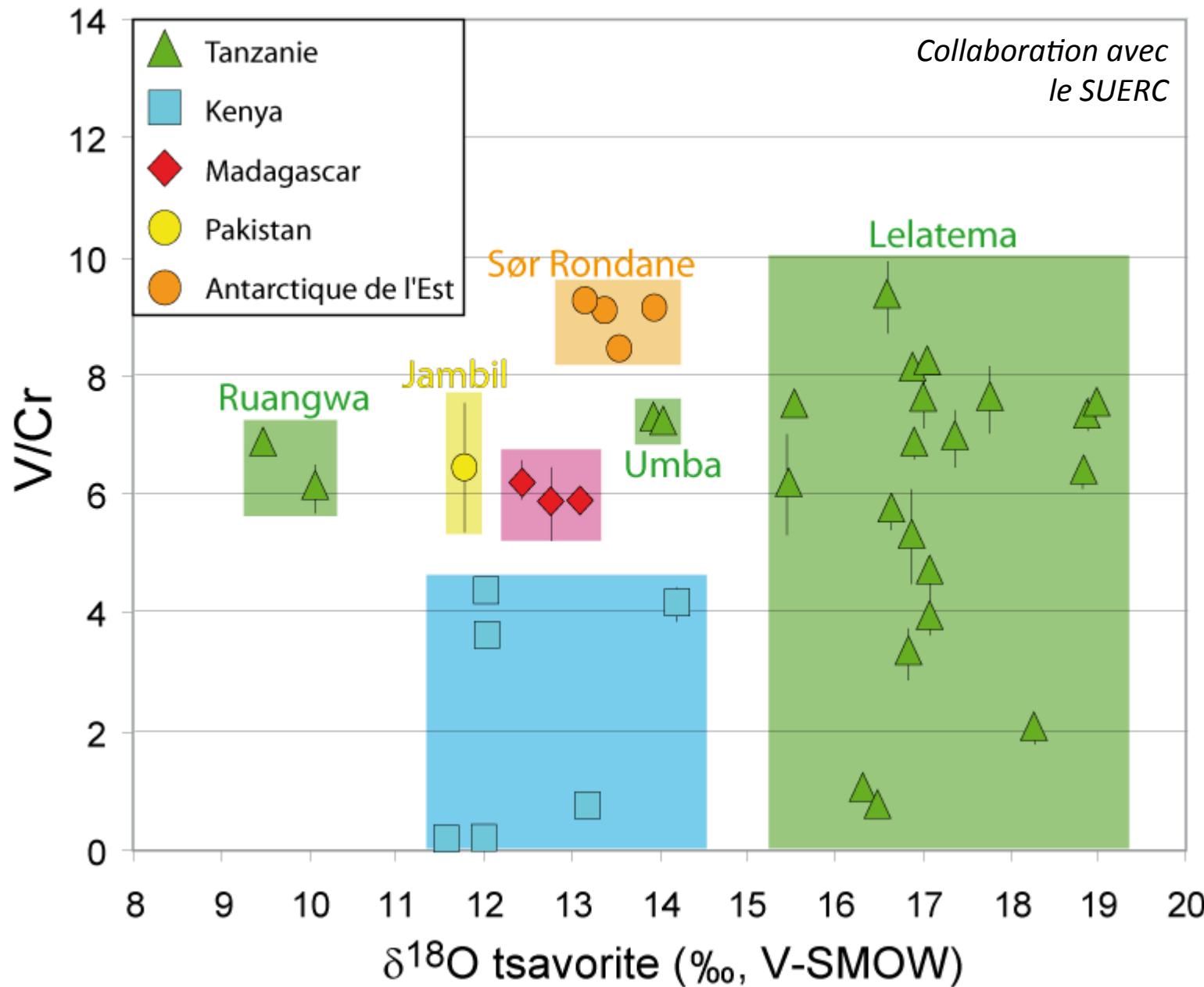


Vanadium and chromium



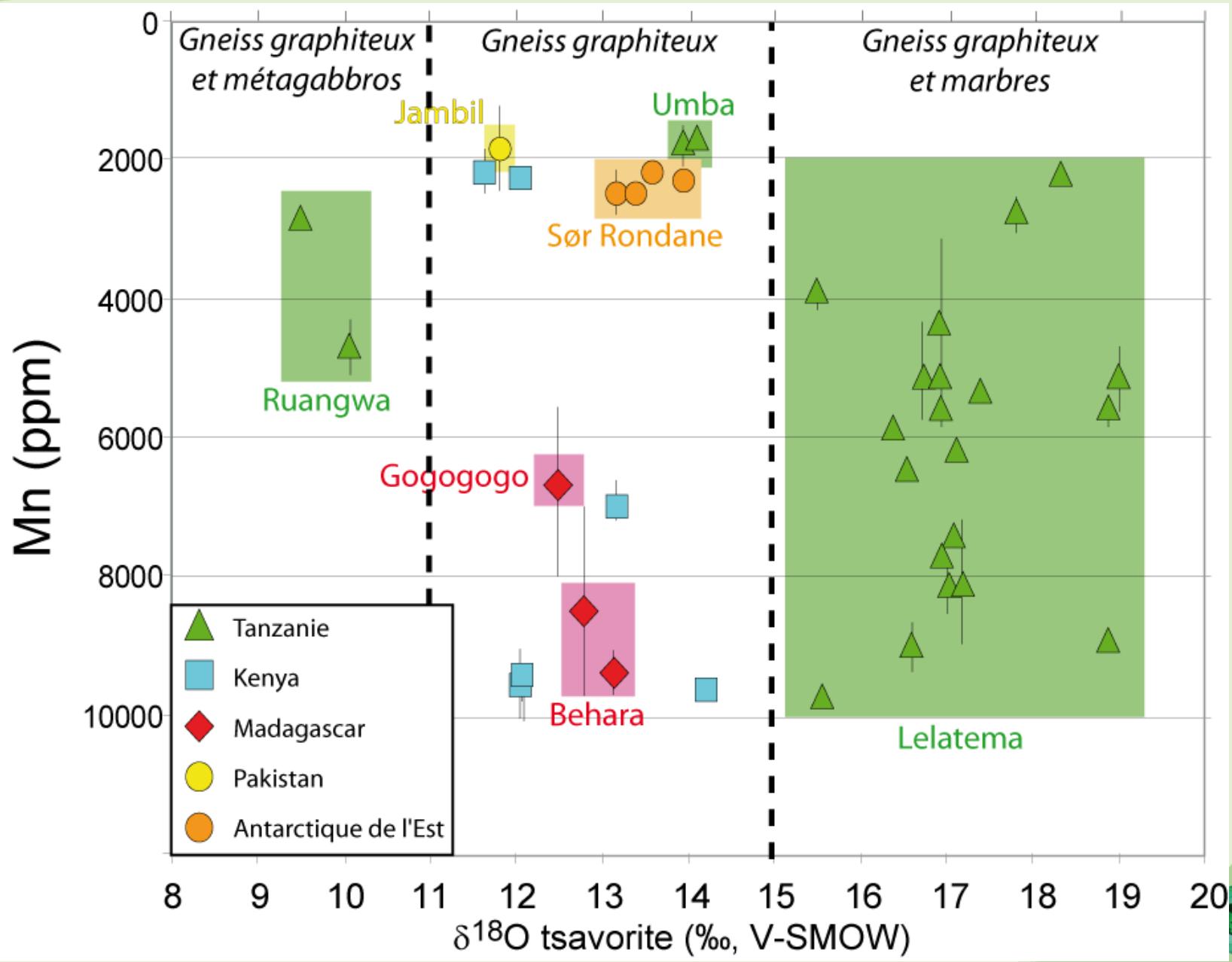


Vanadium, chrome et $\delta^{18}\text{O}$

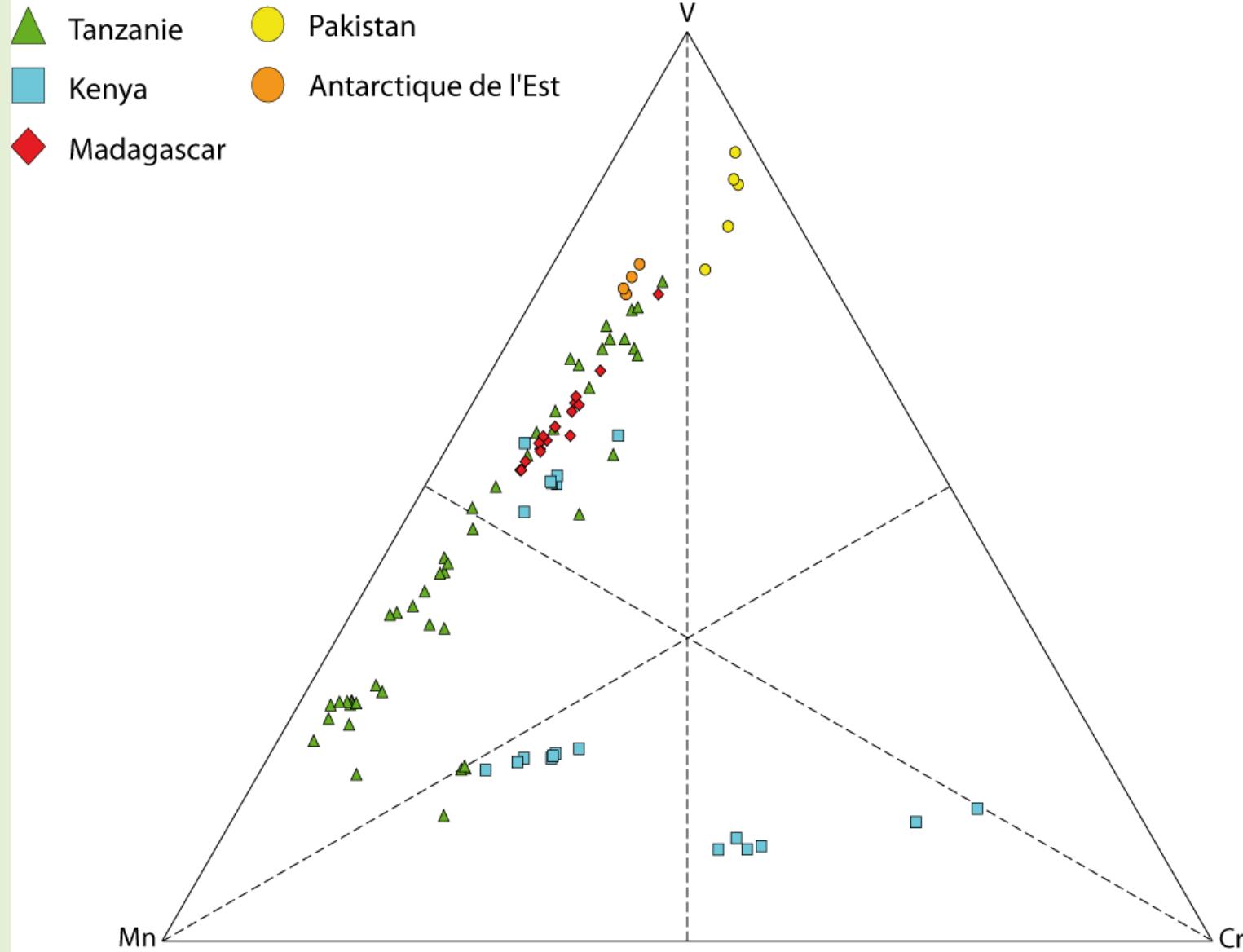




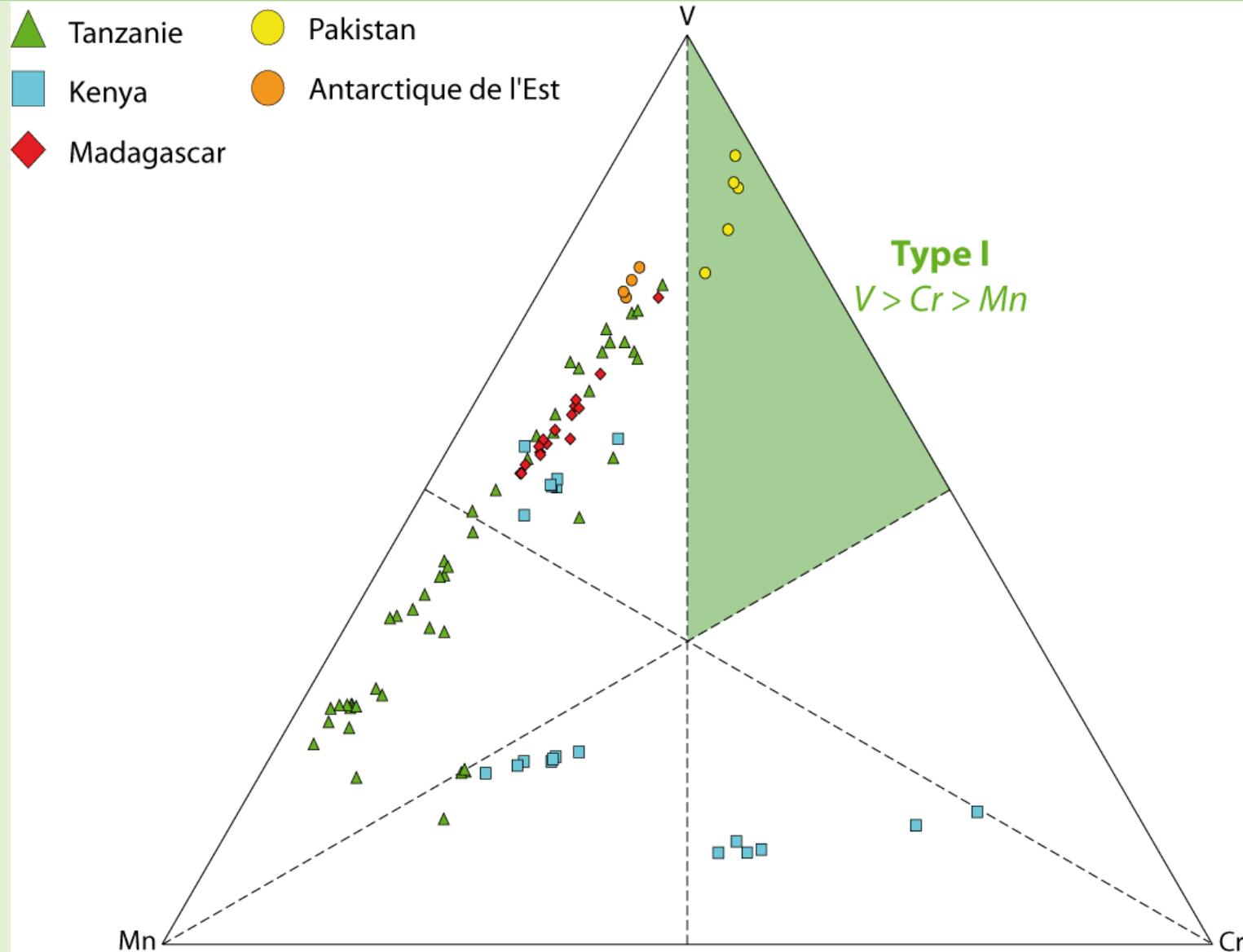
manganèse et $\delta^{18}\text{O}$



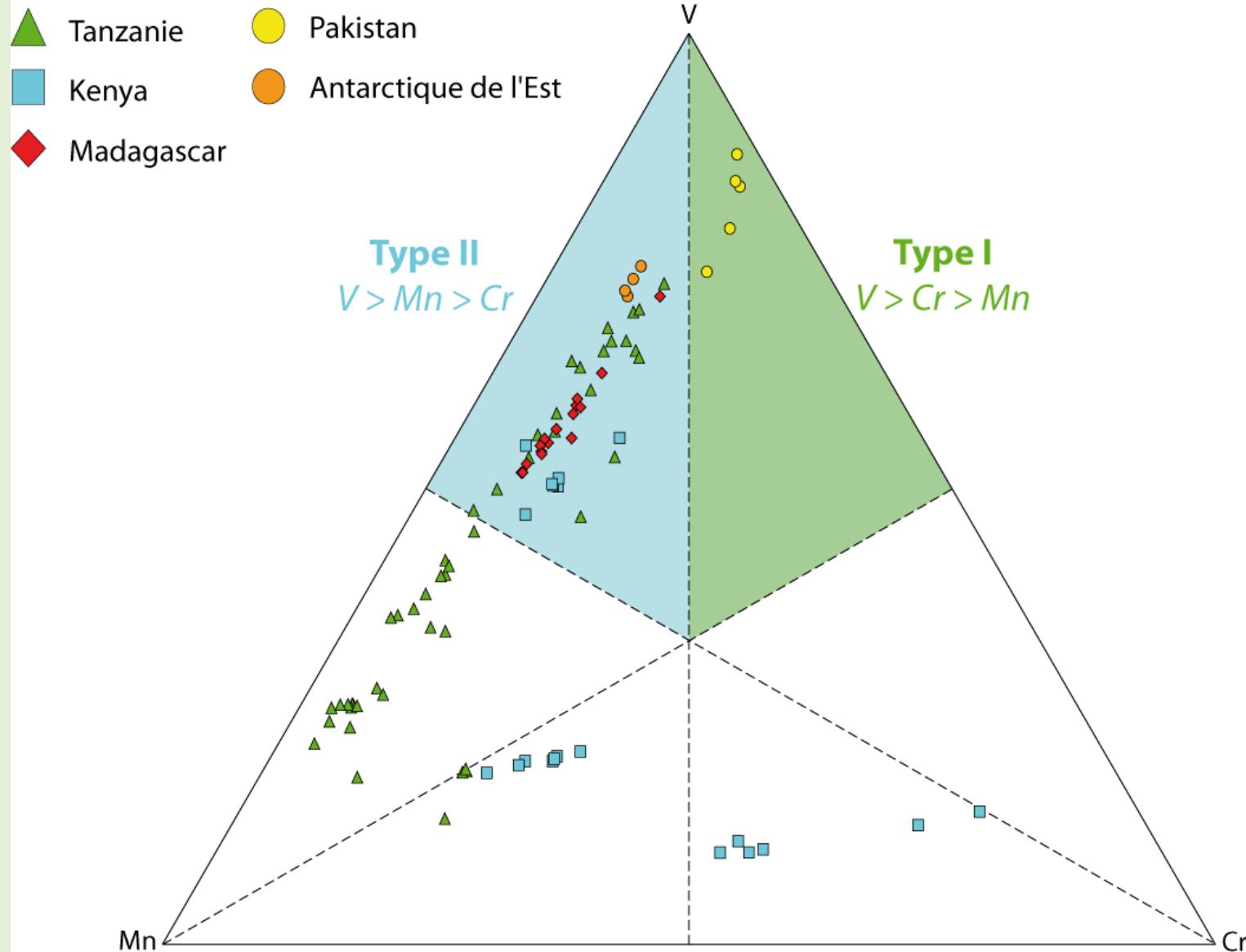
Chemical typology



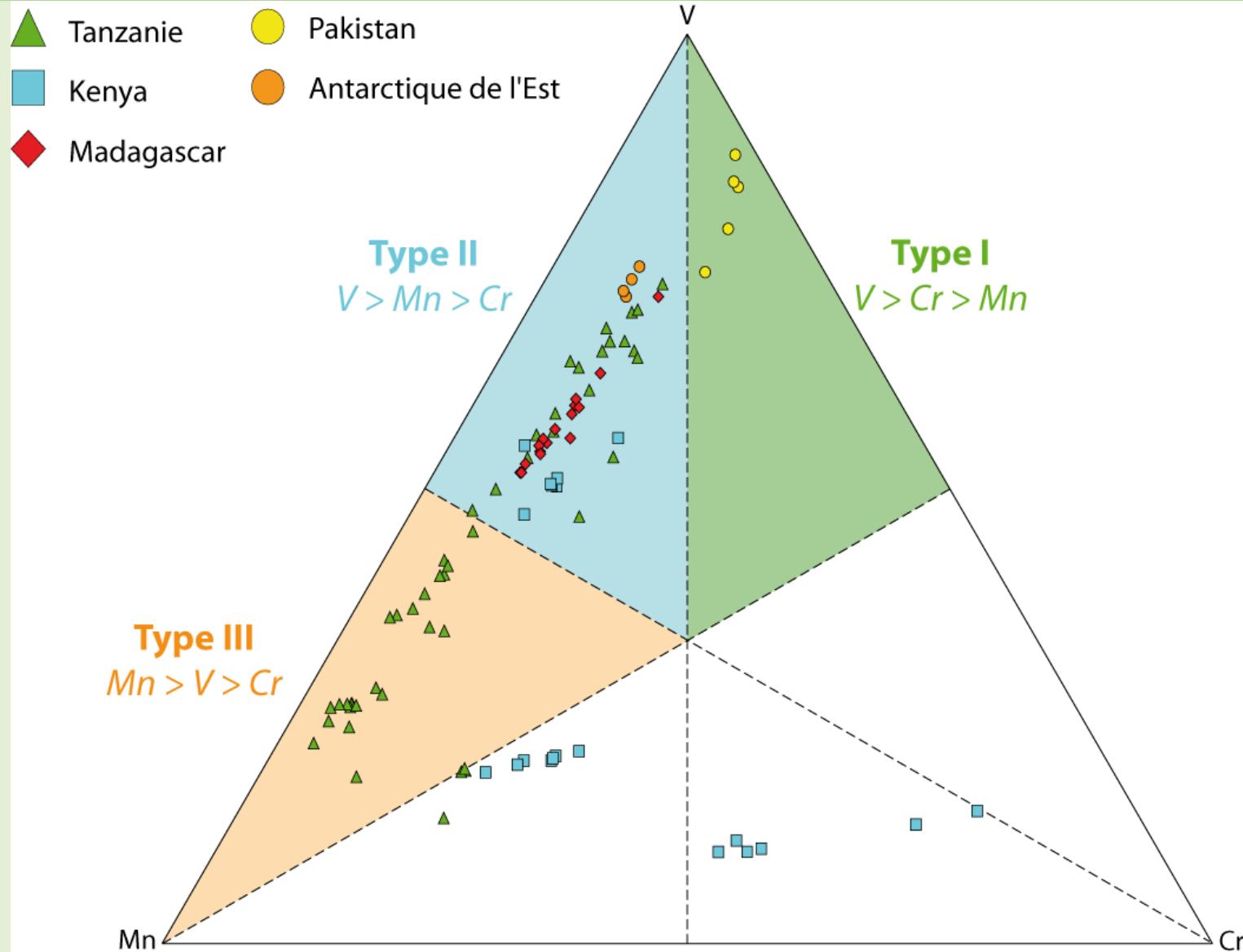
Chemical typology



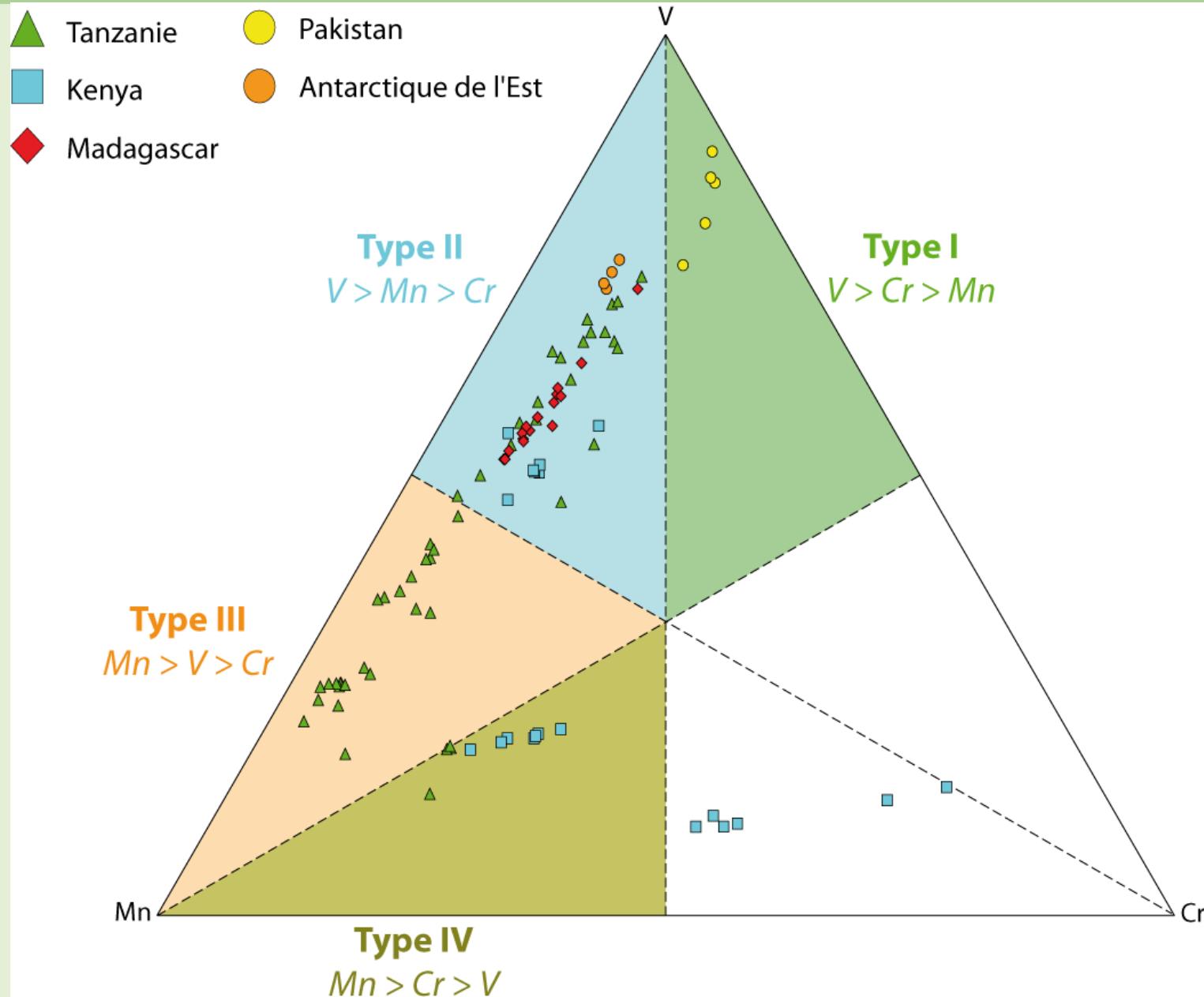
Chemical typology



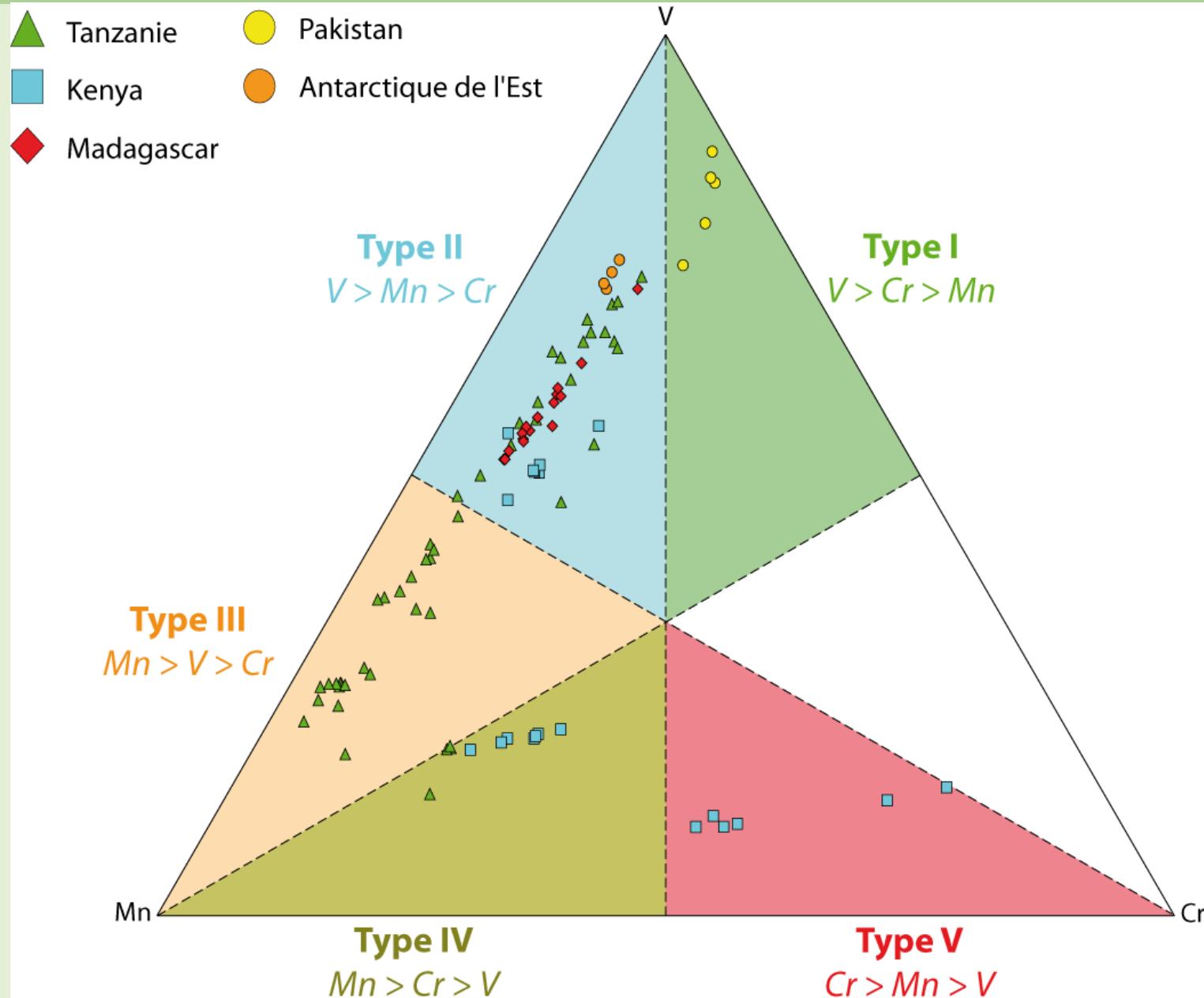
Chemical typology



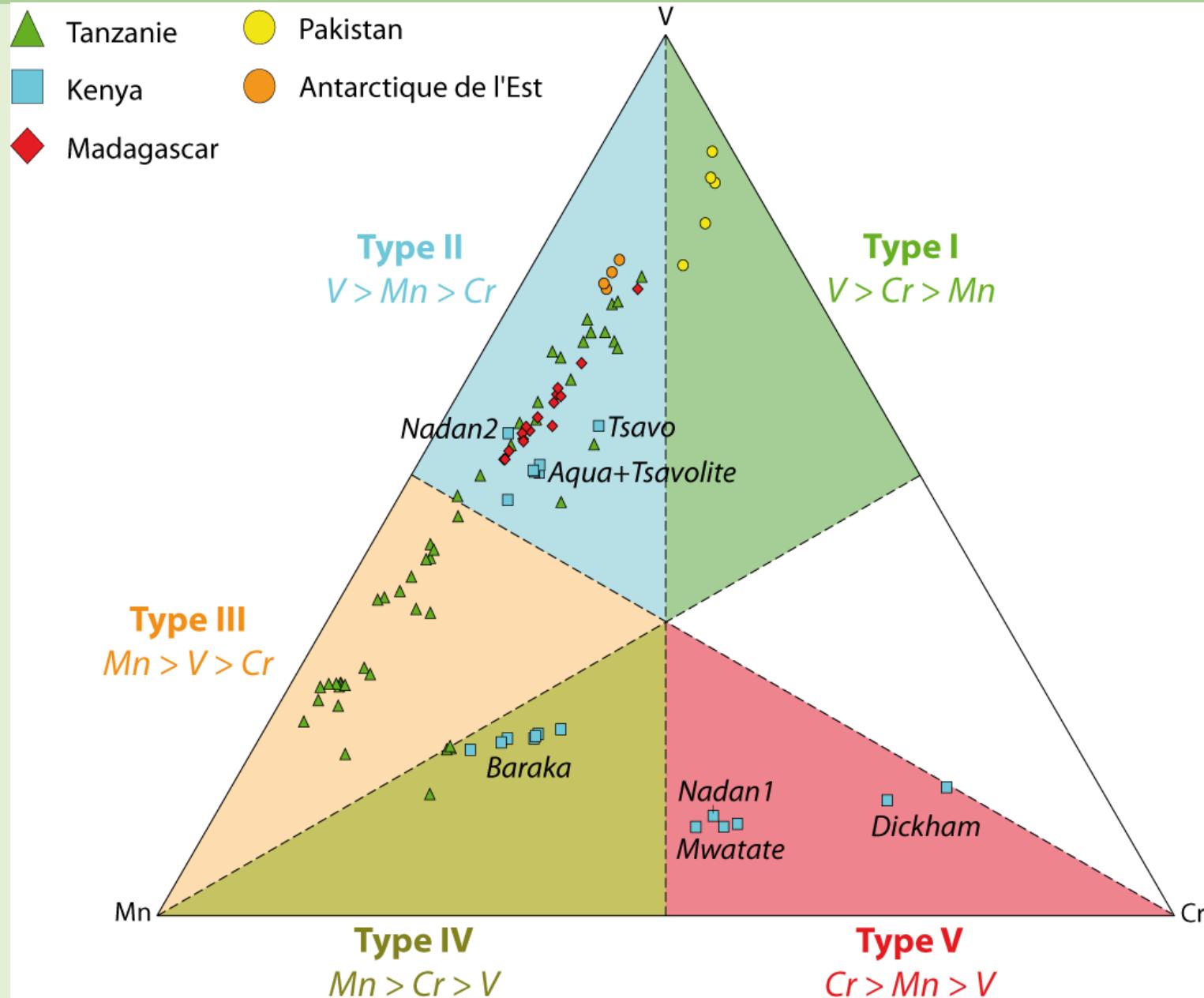
Chemical typology



Chemical typology



Chemical typology





© V. Pardieu



© V. Pardieu

6. Metallogenetic model



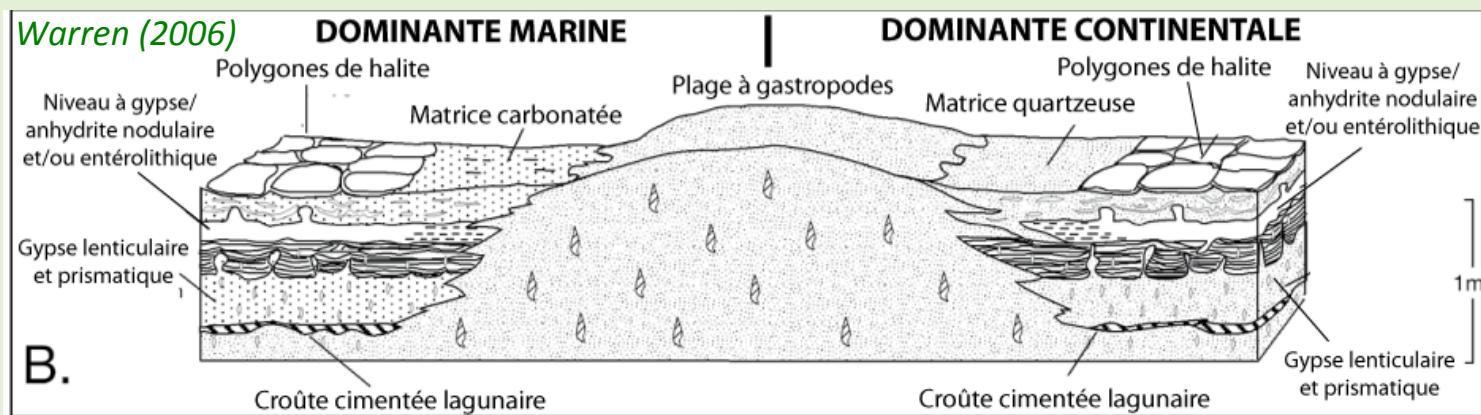
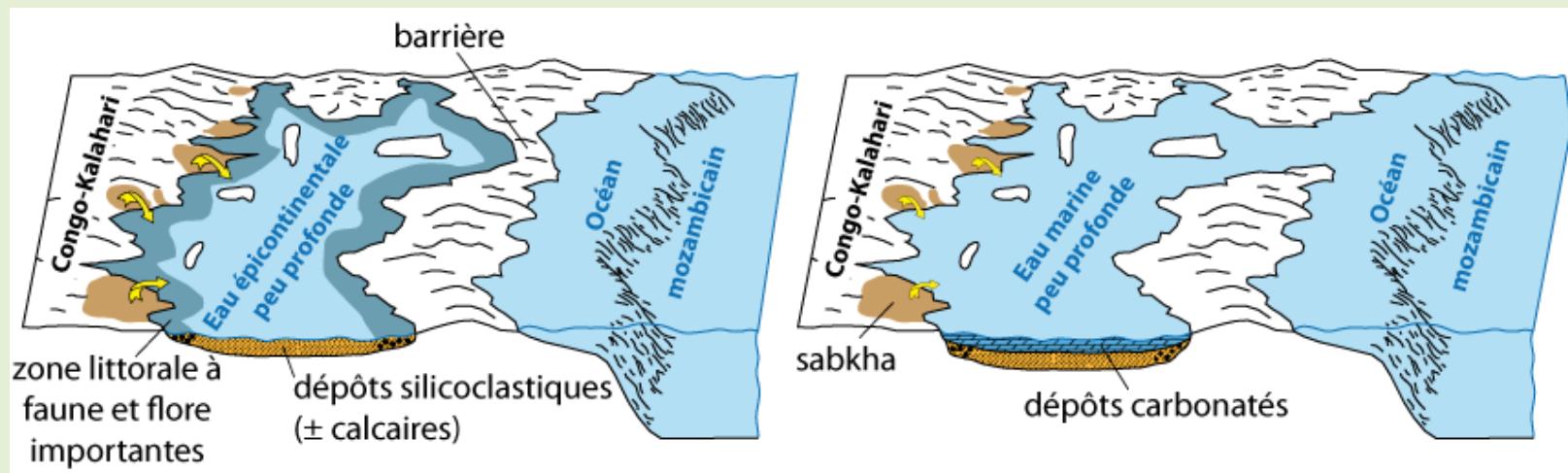
© V. Pardieu



Environnement of sediment deposition

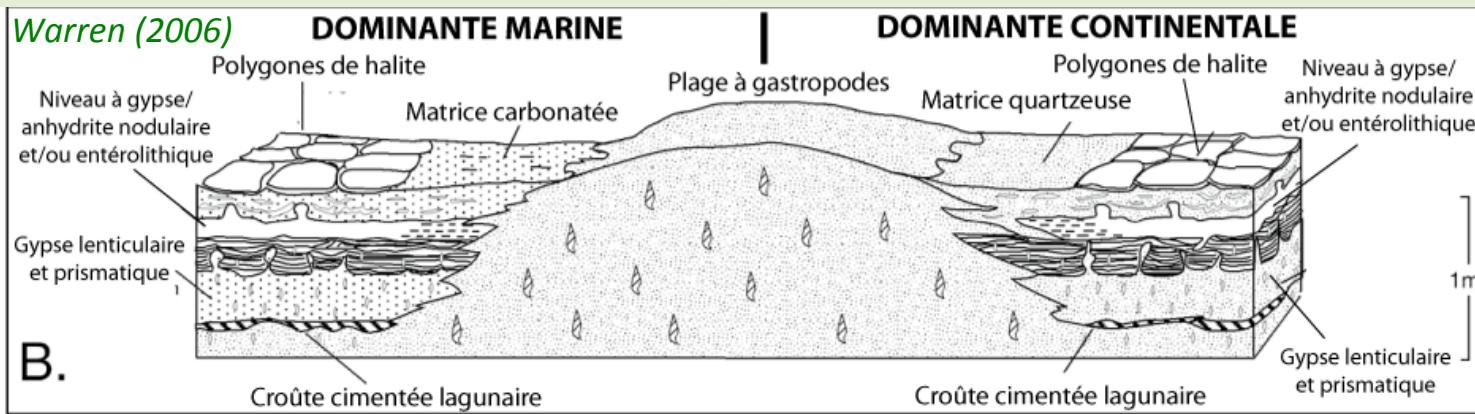
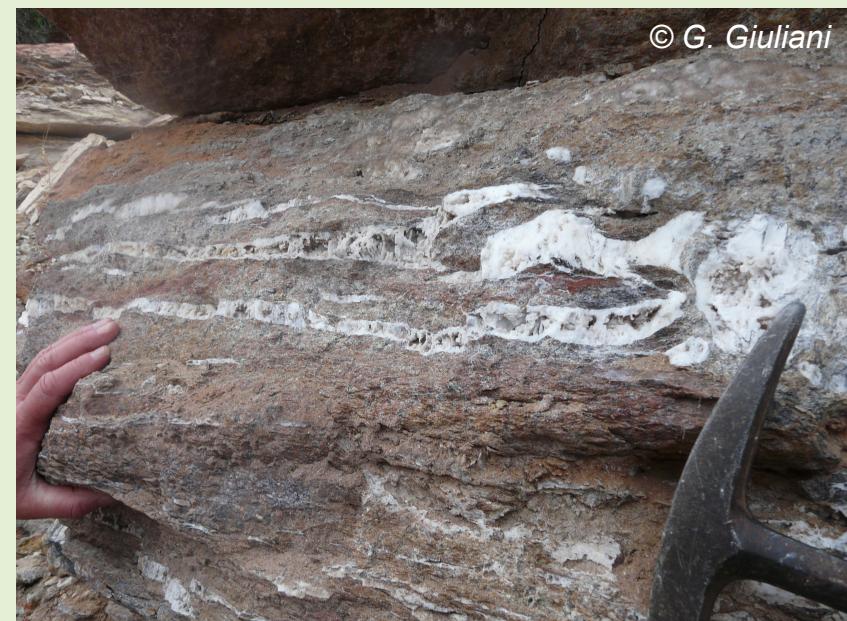
- detritic imput (silicoclastics)
- marine imput (carbonates and Ca-rich sediments, organic matter)
- continental imput (evaporites)

→ ZONES OF INTENSE EVAPORATION
CALLED « MARINE SABKHA »



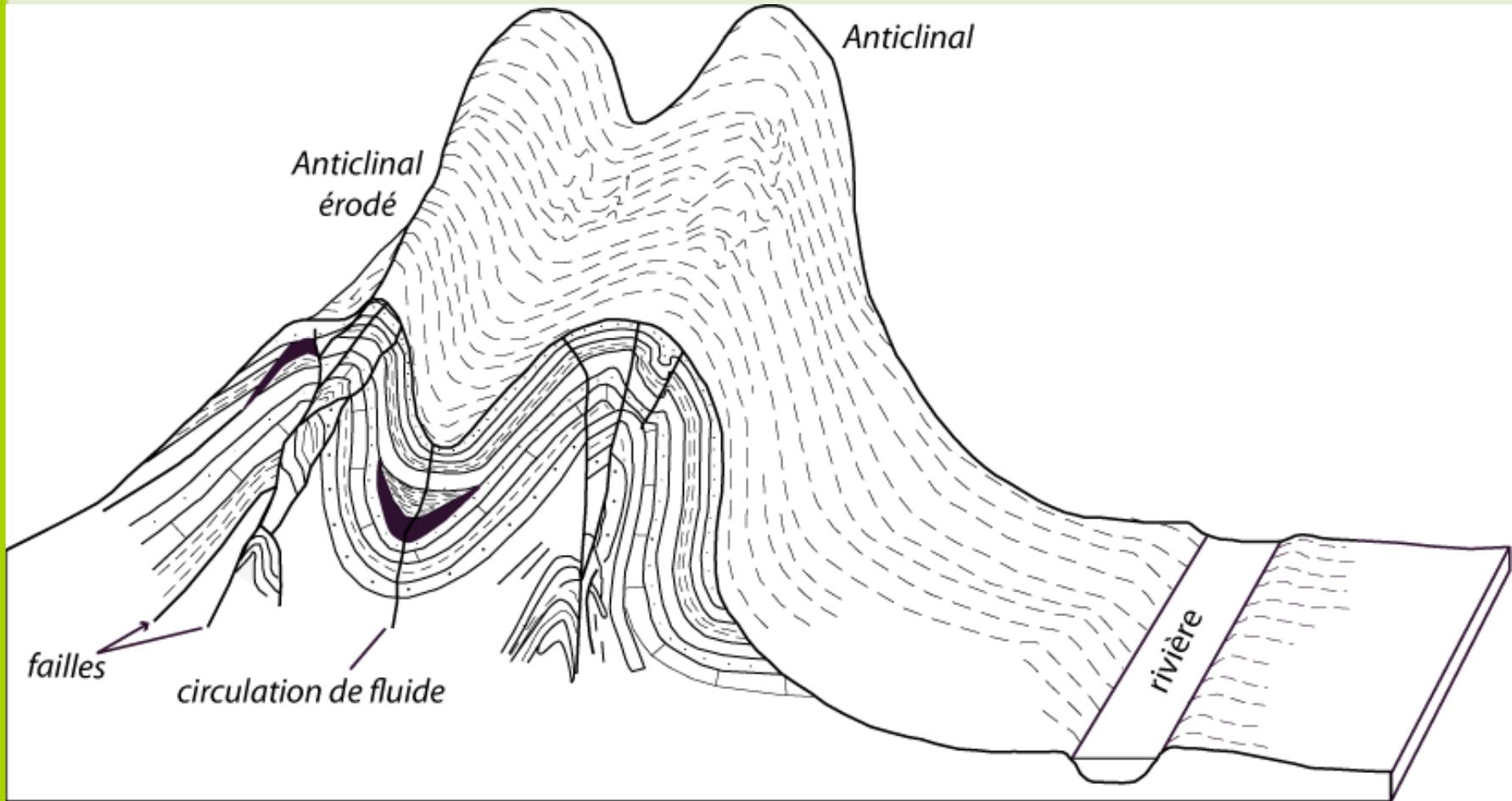


Environnement de dépôt des sédiments



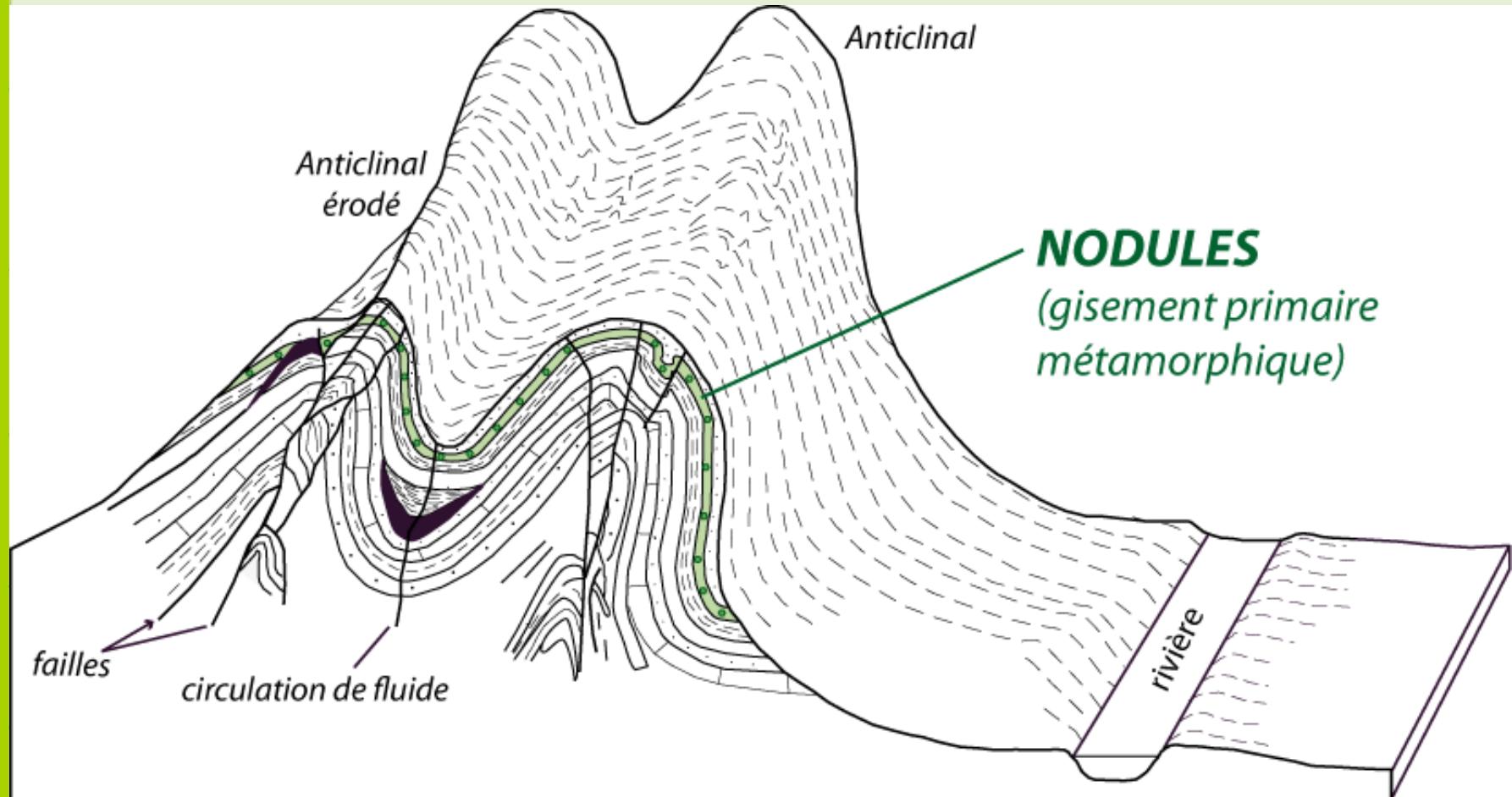


THE DIFFERENT TYPES OF DEPOSITS



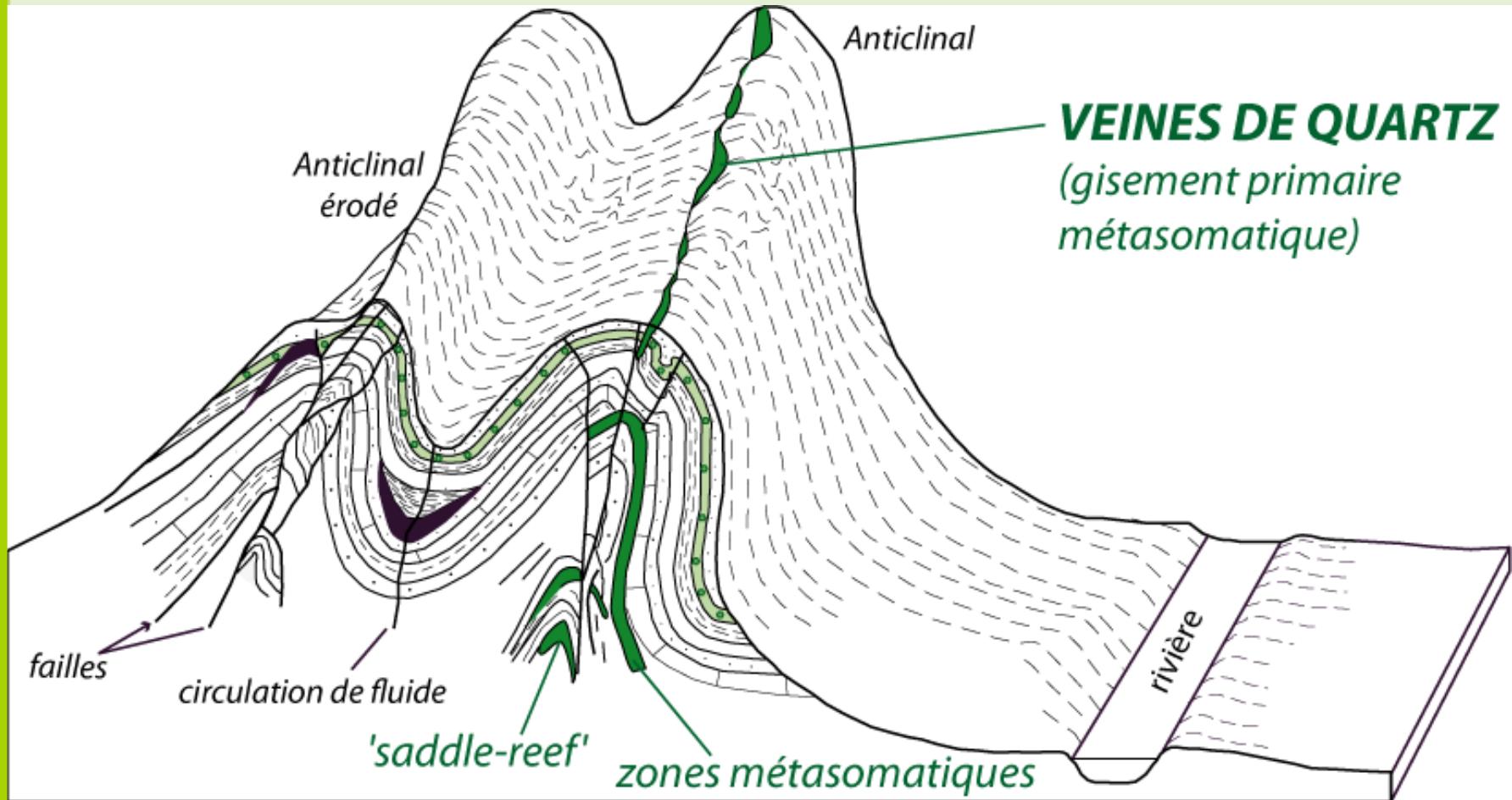


THE DIFFERENT TYPES OF DEPOSITS



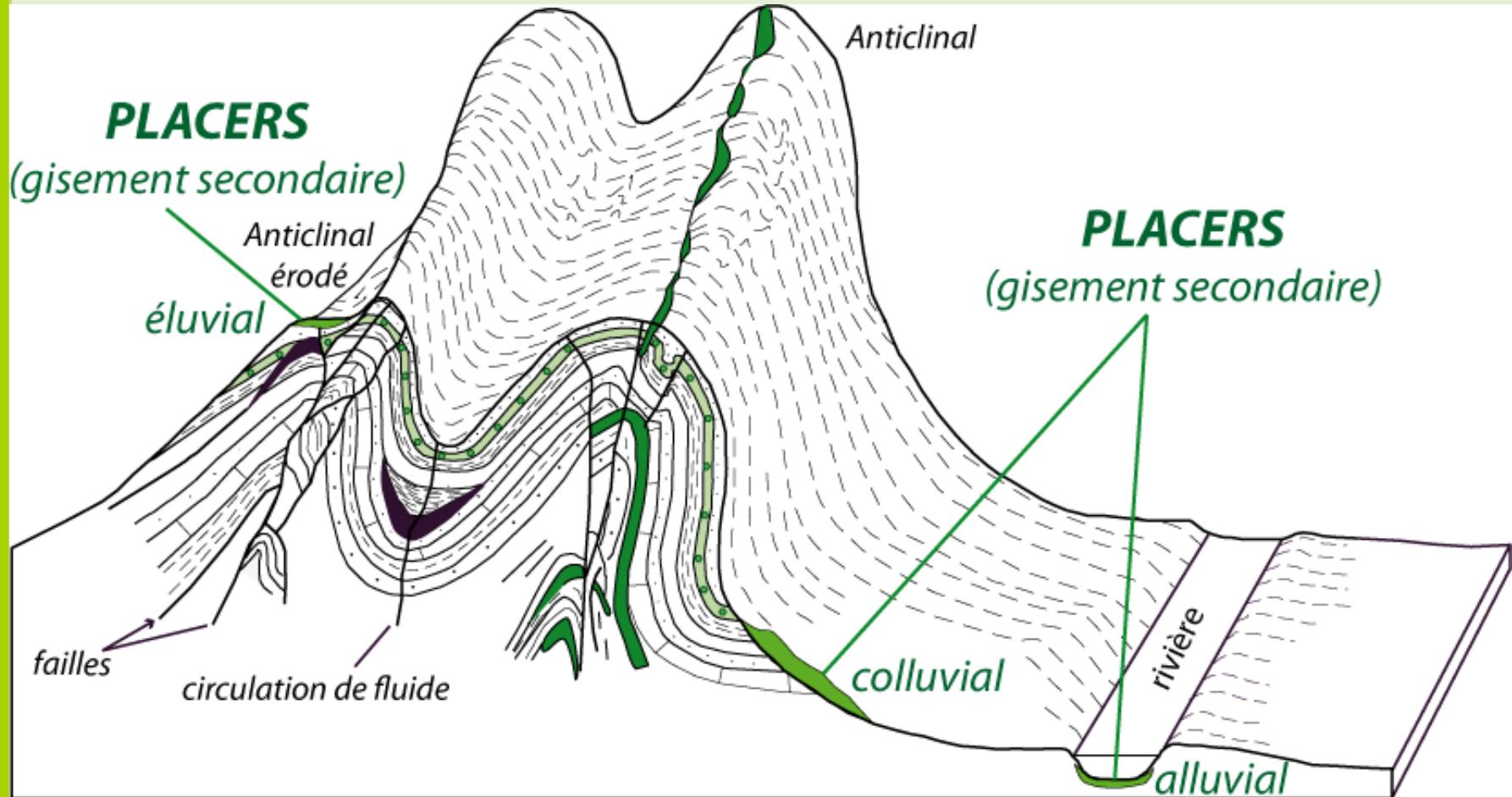


THE DIFFERENT TYPES OF DEPOSITS





THE DIFFERENT TYPES OF DEPOSITS



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CONCLUSIONS



© G. Giuliani



© Gemshare



What to remember...

Tsavorite = V-Mn-Cr-bearing green garnet grossular

Typical gem from the
Neoproterozoic Metamorphic Mozambique Belt
(Tanzania, Kenya, Madagascar, Pakistan, East Antarctica)

Unique host-rock= **graphitic gneiss and calc-silicates**
associated meta-evaporites

Three types of mineralization = **nodules, quartz veins, placers**

Two types of control = **lithological and structural**

Two distinct episodes for tsavorite formation



Guides of prospecting

In the field...



The ()
ary



Gemmological applications

What to remember:

New definitions for tsavorite,
based on the trace elements contents
(V-Mn-Cr chemical typology)

Presence of OH⁻ in the tsavorite structure

Better knowledge on **the coloration of tsavorites**
(V³⁺, Cr³⁺, Mn²⁺, Fe²⁺-Ti⁴⁺)

A proposal for the identification of the **geographic origin** of
tsavorites from their contents in **V, Cr, Mn** and their **δ¹⁸O**

A proposal for the identification of the
type of deposit from their δ¹⁸O

Thanks for your attention

