Mantle and crust interaction in post-collisional setting, a case study of lamprophyric-granitic composite dykes of northern Aigoual pluton, French Massif Central

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Summary

- Introduction
- Objectives and Methodology
- Results and Discussion

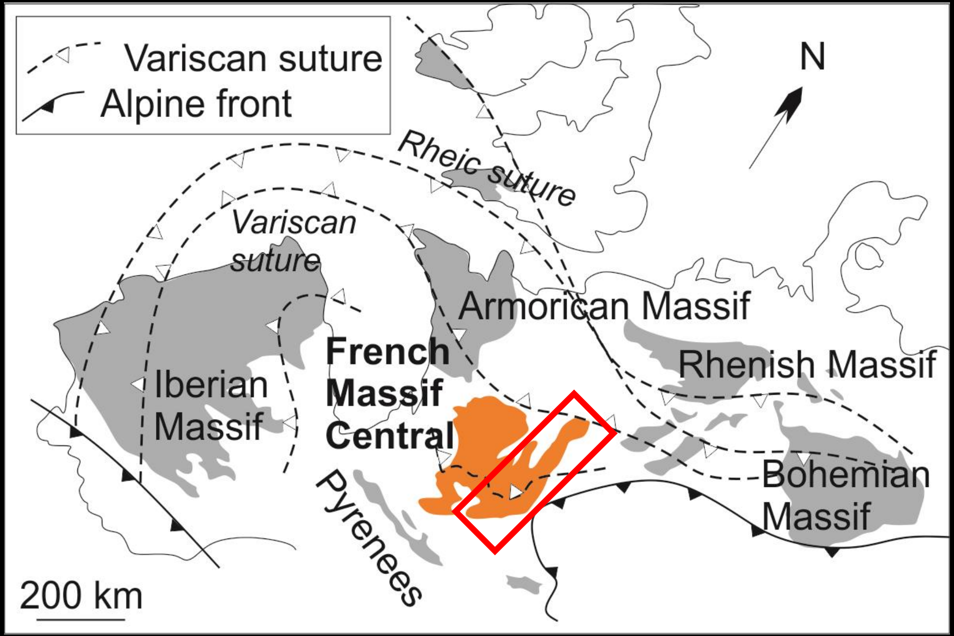
    Chapter II – paper in preparation to submission

    Chapter III – general discussion

- Conclusions

Introduction

- Variscan belt – Gondwana + Laurussia = Pangea
- French Massif Central – inner part of the Variscan belt, exposing allochthonous and parautochthonous units at different crustal levels



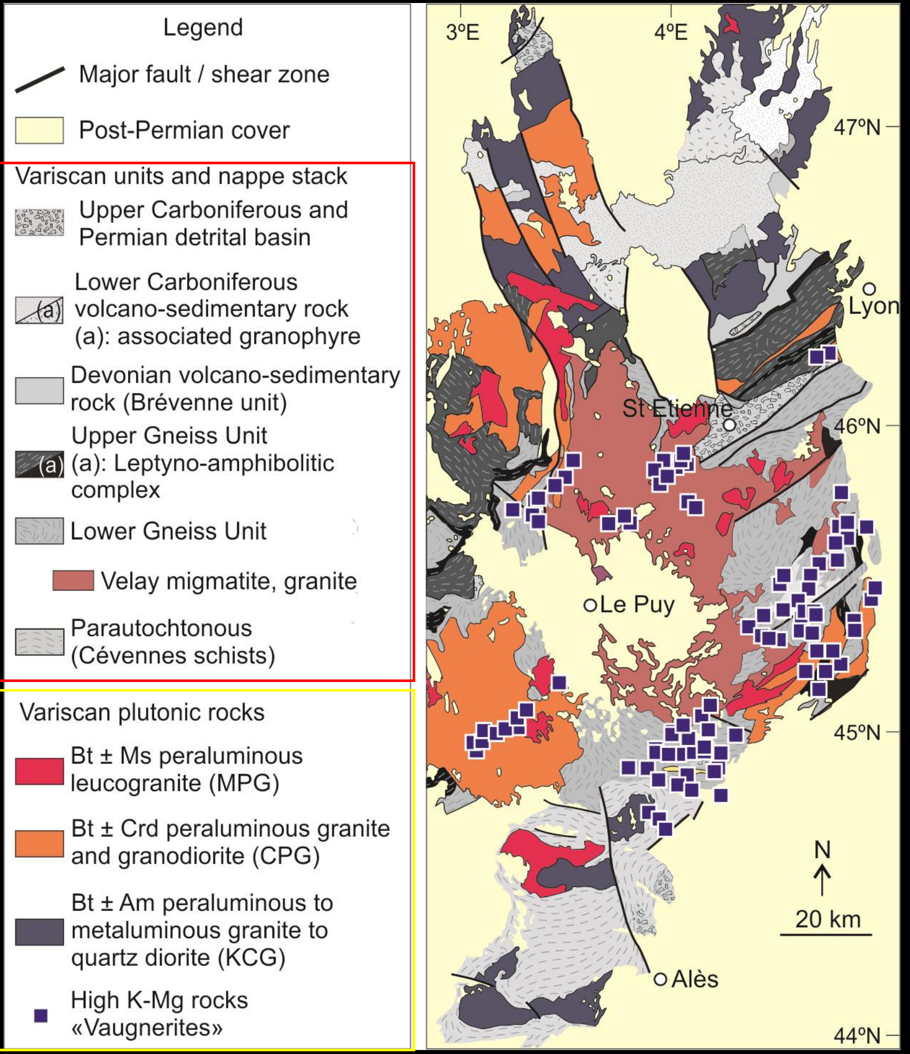
Modified from Moyen et al. (2017)

Ordovician to Carboniferous

South-verging nappe stack metamorphic units

- Opening of oceanic basins (500 – 450 Ma)
- Closure and subduction (420 – 360 Ma)
- Proper collision (350 – 320 Ma)

Post-collisional magmatic rocks



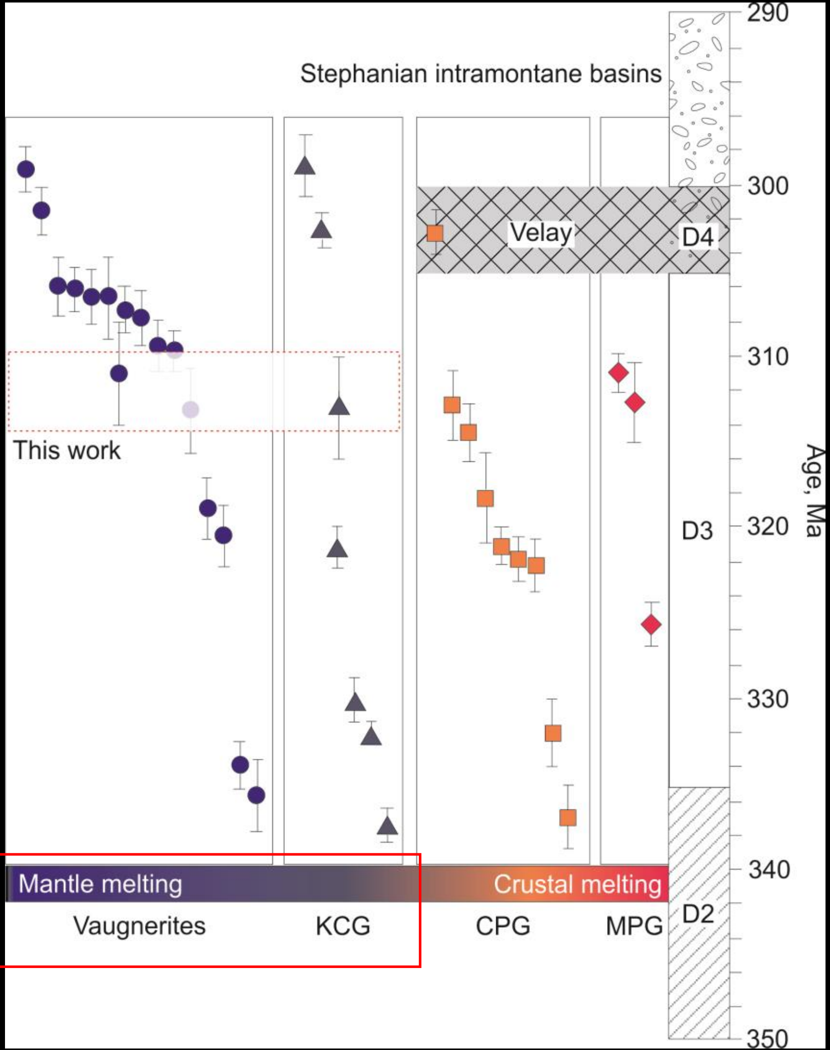
Modified from Couzinié et al. (2016)

- Extensive and long-lived ~40 Ma magmatism

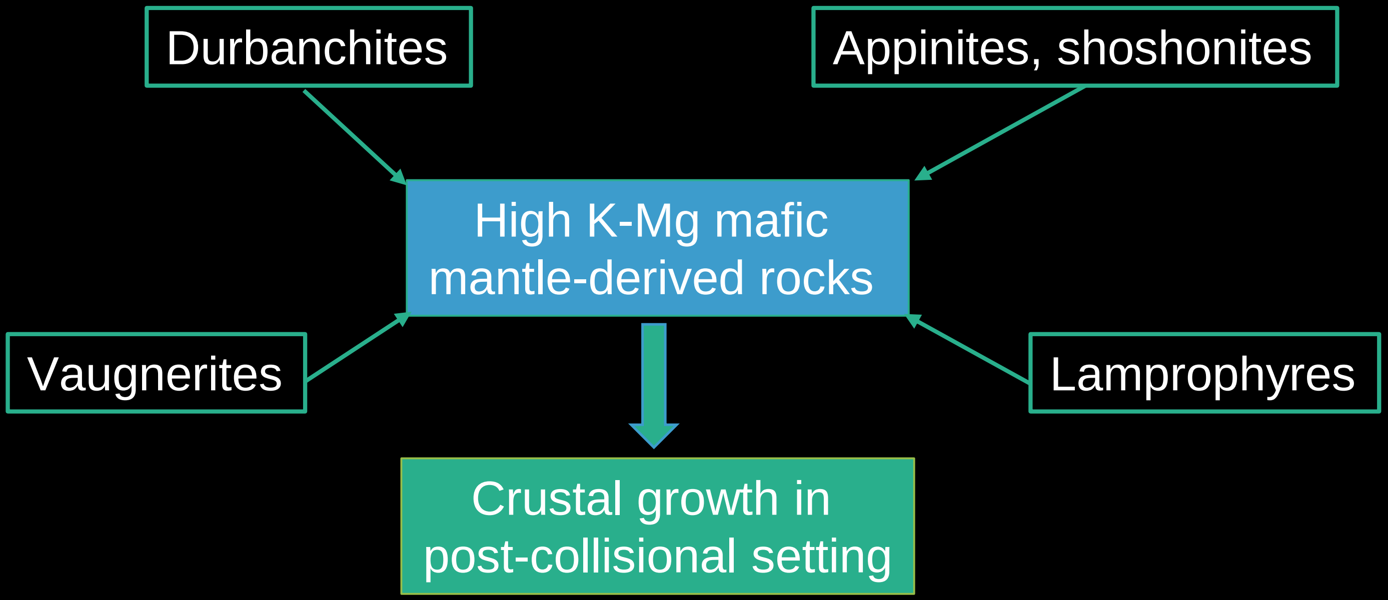
~ 40 Ma

High K-Mg mafic rocks → Mantle melting

Granites → Crustal melting



Modified from Laurent et al. (2017)



Potassic to ultrapotassic diorites, gabbros and/or lamprophyres; metaluminous composition with intermediate SiO_2 contents (55-70 wt%). (von Raumer et al. 2014; Laurent et al. 2017).

High K-Mg mafic mantle-derived rocks

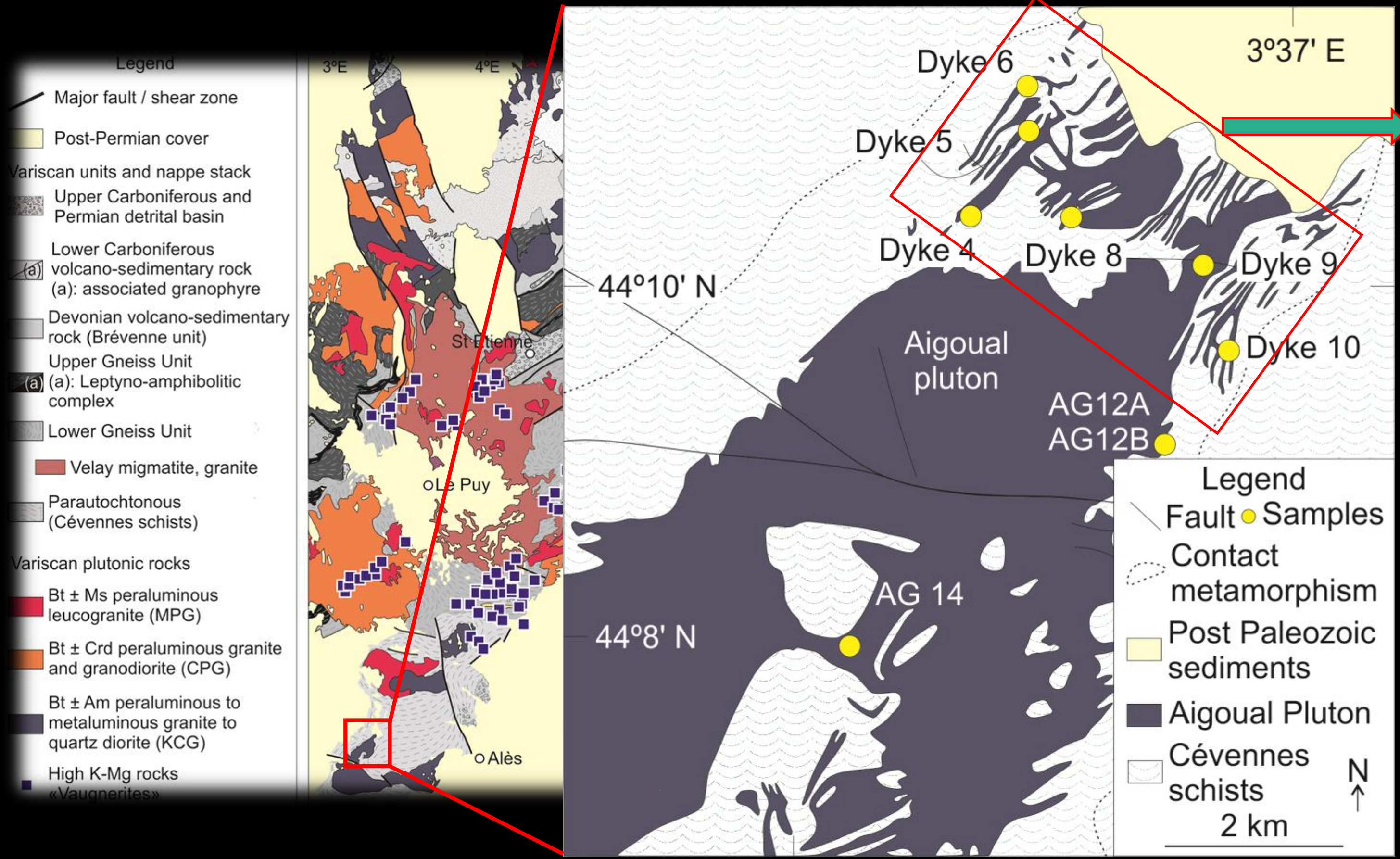
↓

Despite being well defined in space and time, the role of the mafic magmatism in post-Variscan setting is still debated…

- Differentiated magmas from the mafic rocks or the products of hybridization between the latter and crustal melts;

- The balance between crustal growth by addition of new mantle-derived material and recycling of crust in the mantle in post-collisional sites is poorly understood.

NNE composite dykes on the border of Aigoual pluton



Lamprophyre

Granite

Modified from Talbot et al. (2005).

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Objectives and Methodology

- The objective consists in the petrogenesis of the lamprophyres and granites;
- Constraint the mantle contribution in the post-collisional magmatism in FMC and consequently implications for crustal growth.

- Field work and sampling
- Petrography and mineral chemistry
- Whole-rock major and trace elements
- Sr-Nd-Hf isotopes in whole-rock
- U-Pb and Lu-Hf isotopes in zircon
- Oxygen isotopes in quartz and feldspar

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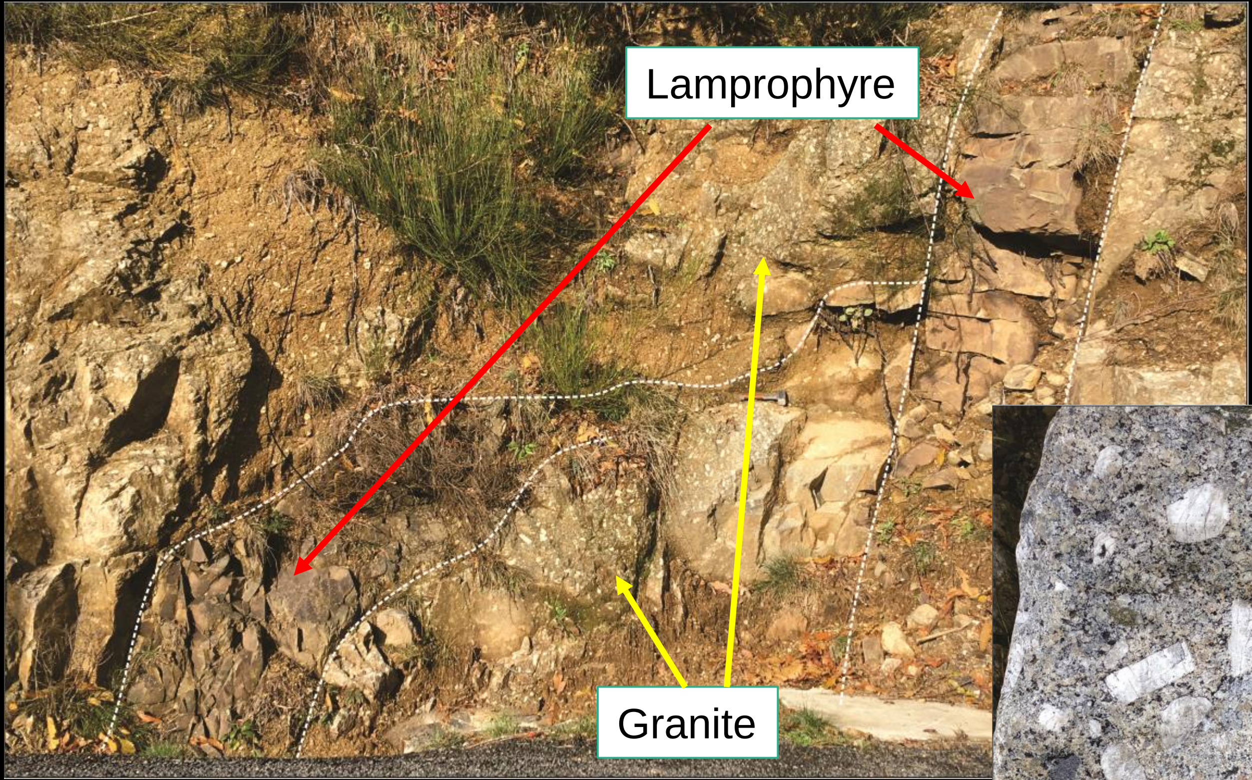
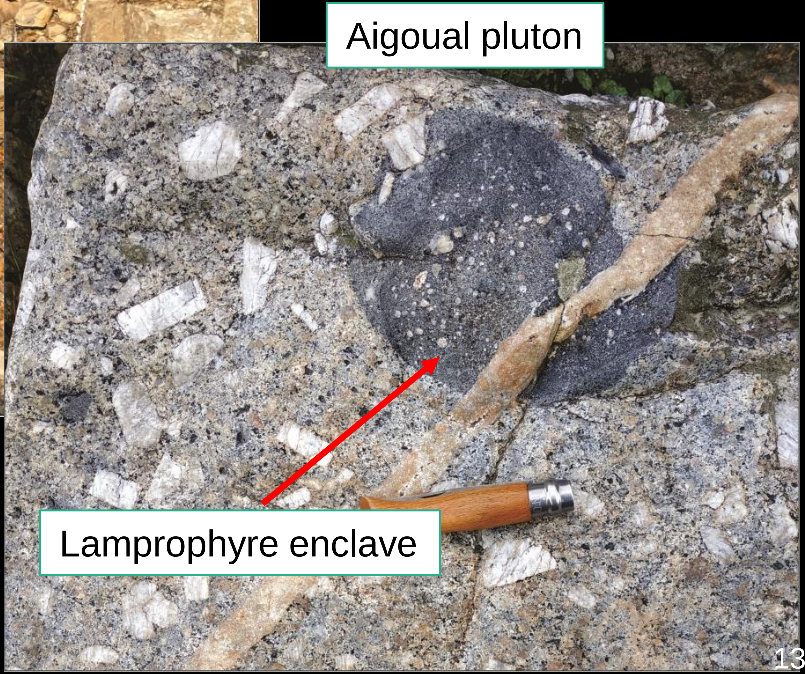
Results and Discussion

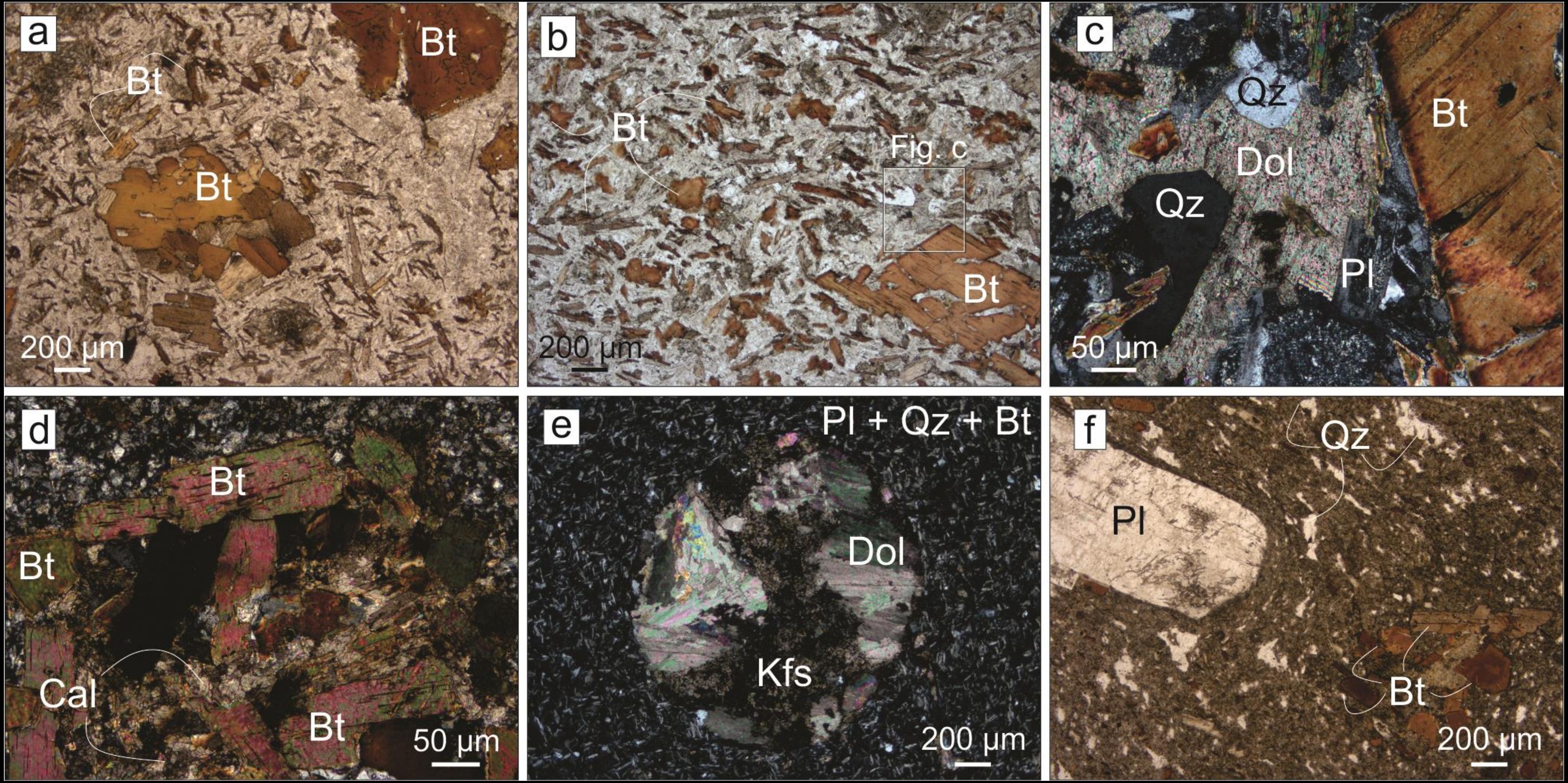
- Field relationships

Lamprophyre → Granite

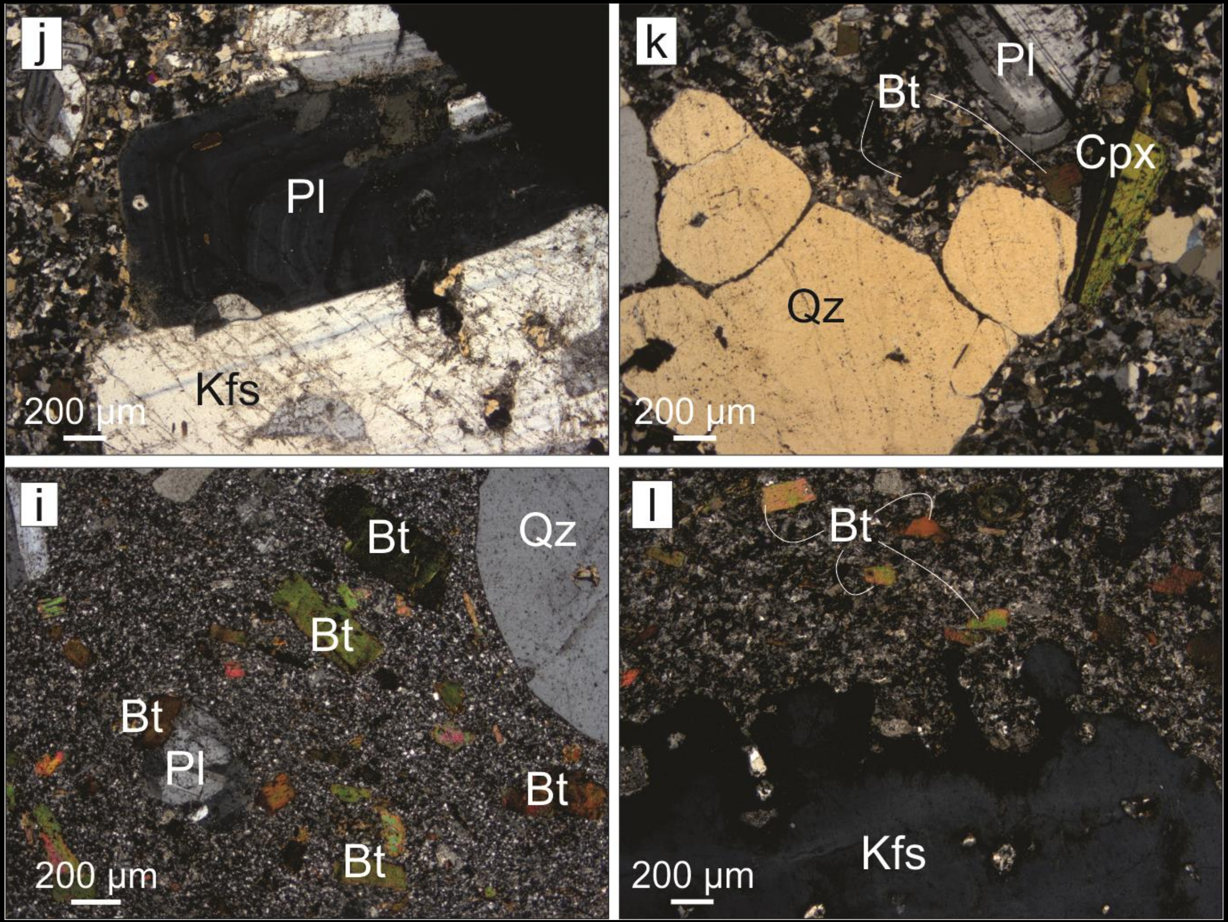

Lamprophyre
Granite


Aigoual pluton
Lamprophyre enclave

Petrography – lamprophyres

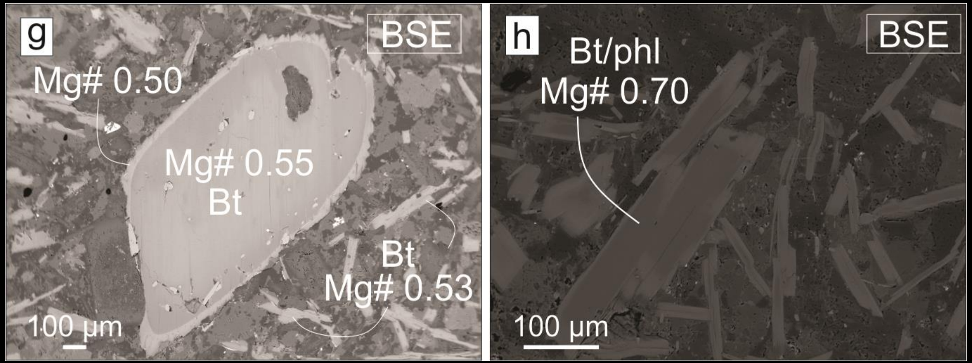


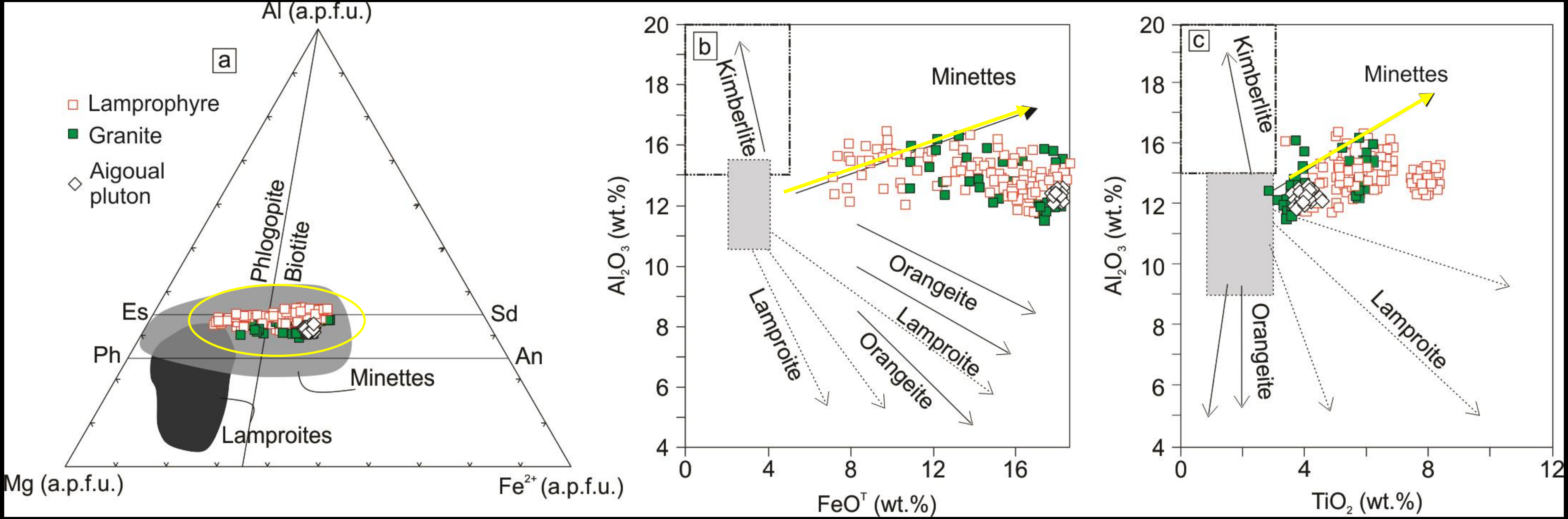
- Petrography – granites



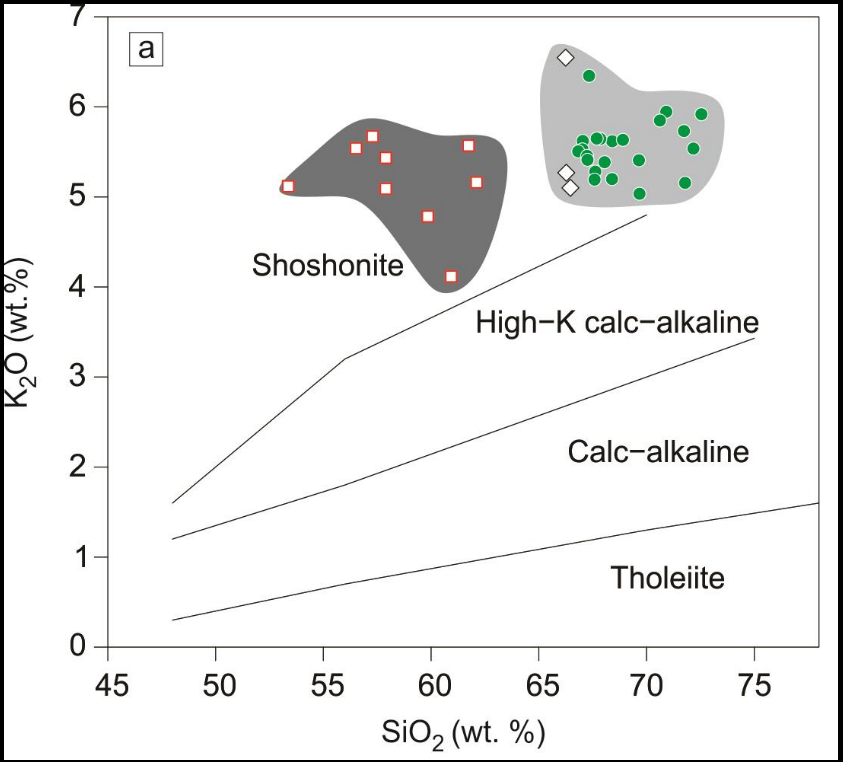
- Mineral chemistry

Mineral chemistry of mica – lamprophyres, granites and Aigoual pluton

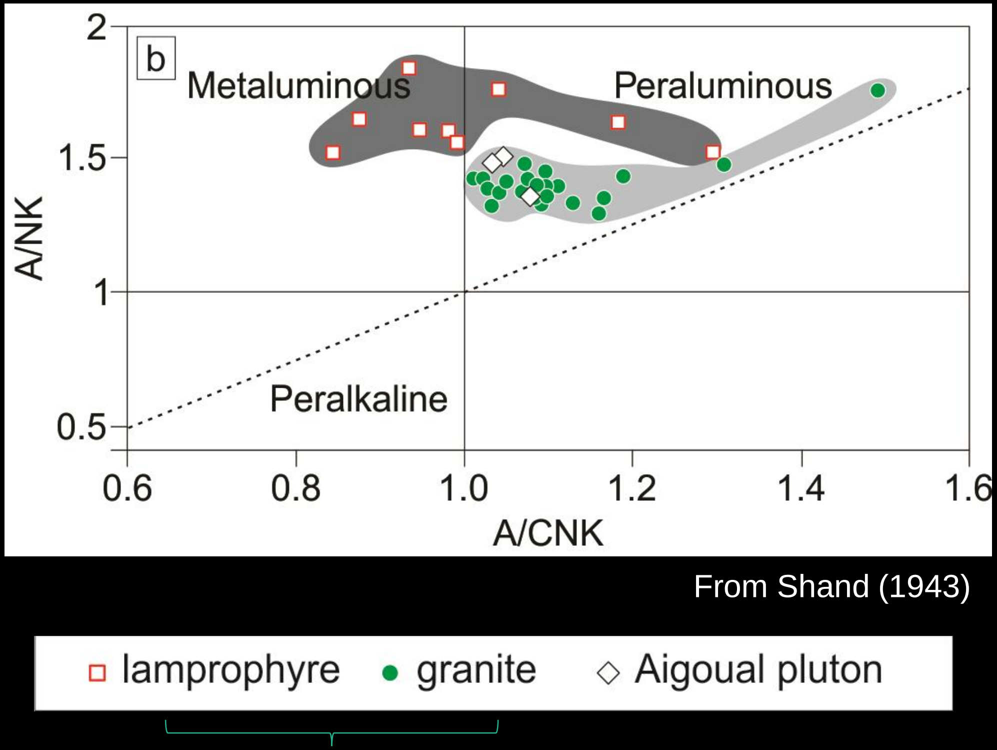




Whole-rock major elements

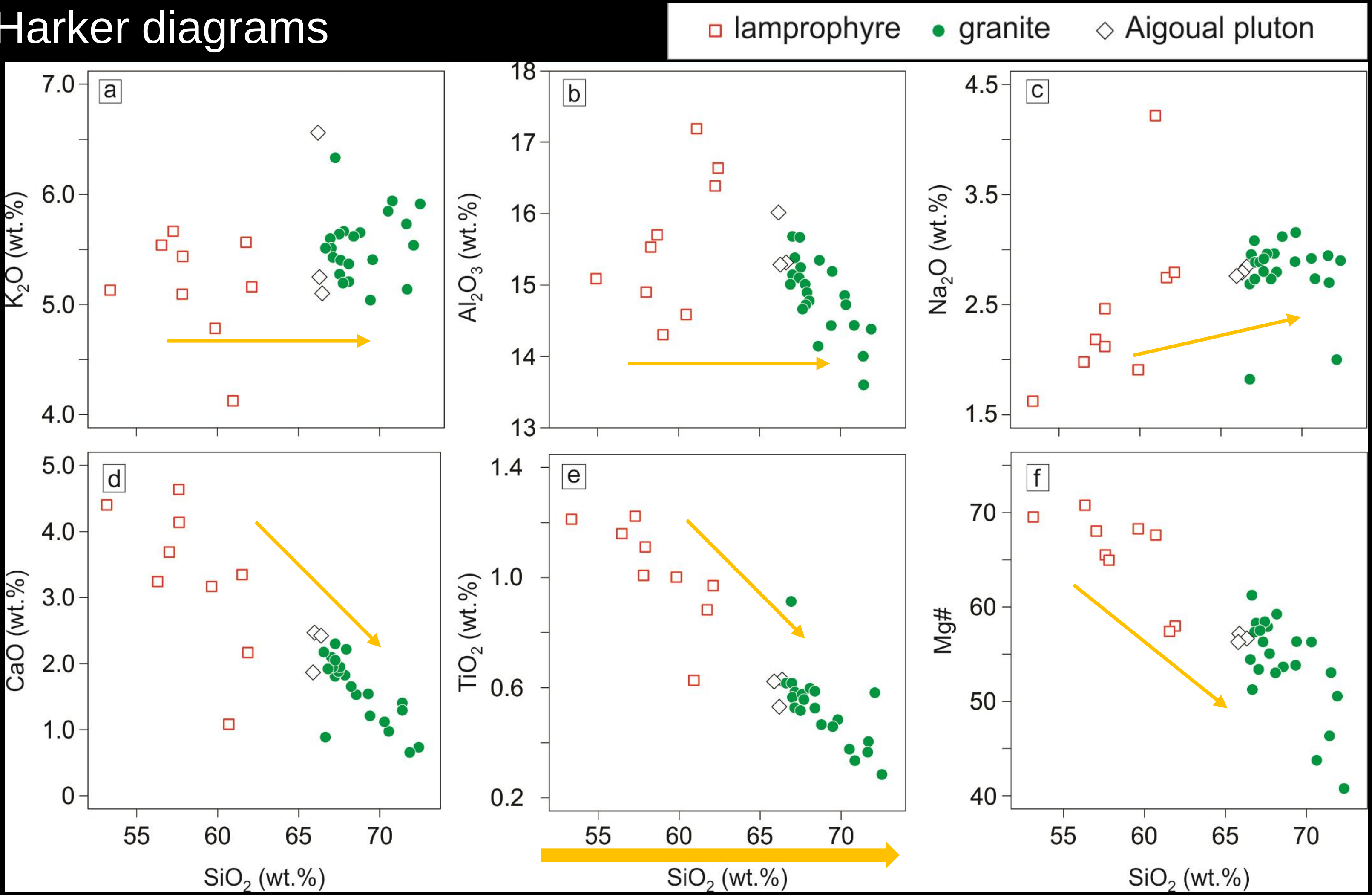


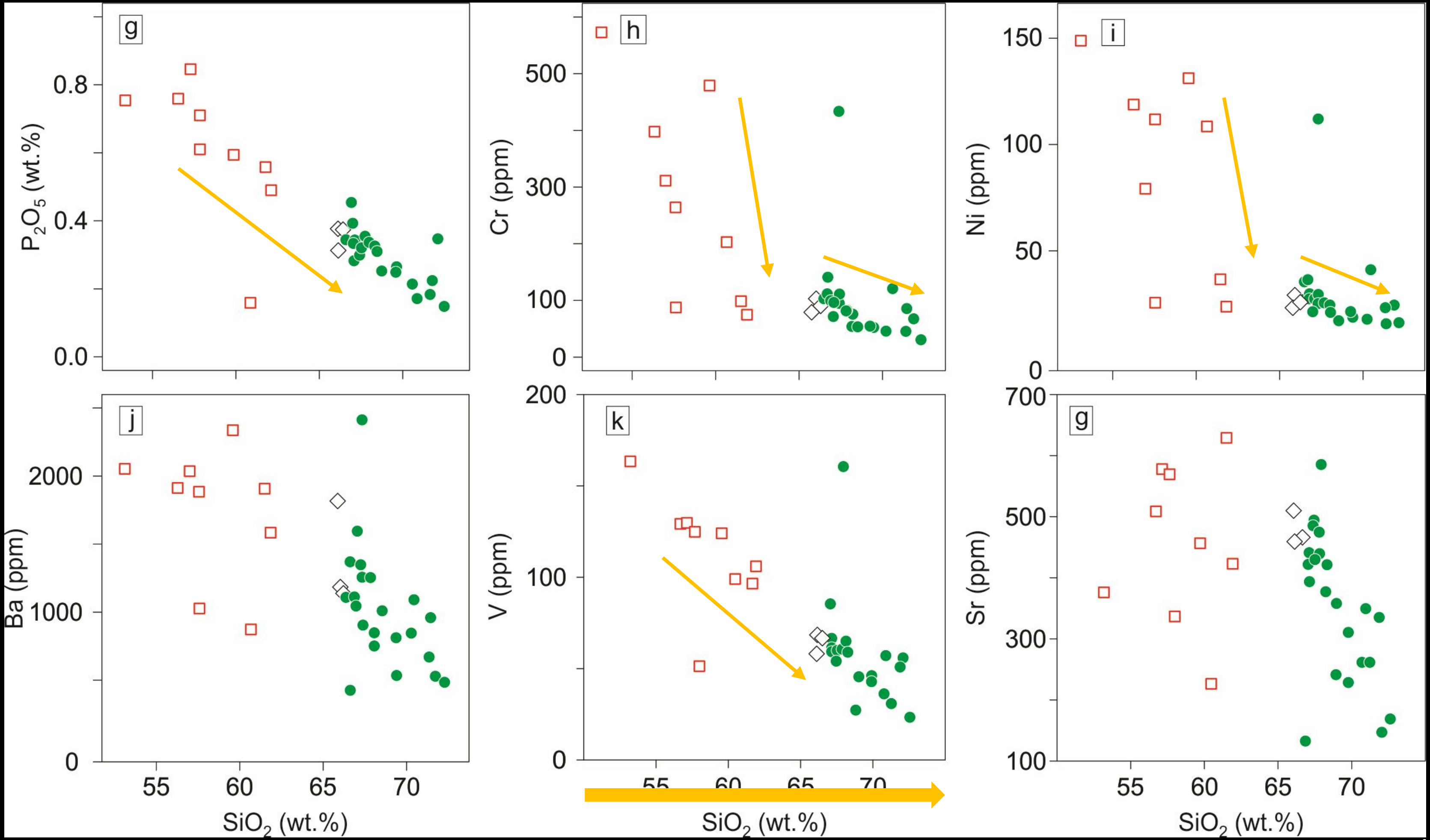
From Peccerillo and Taylor (1976)



From Shand (1943)

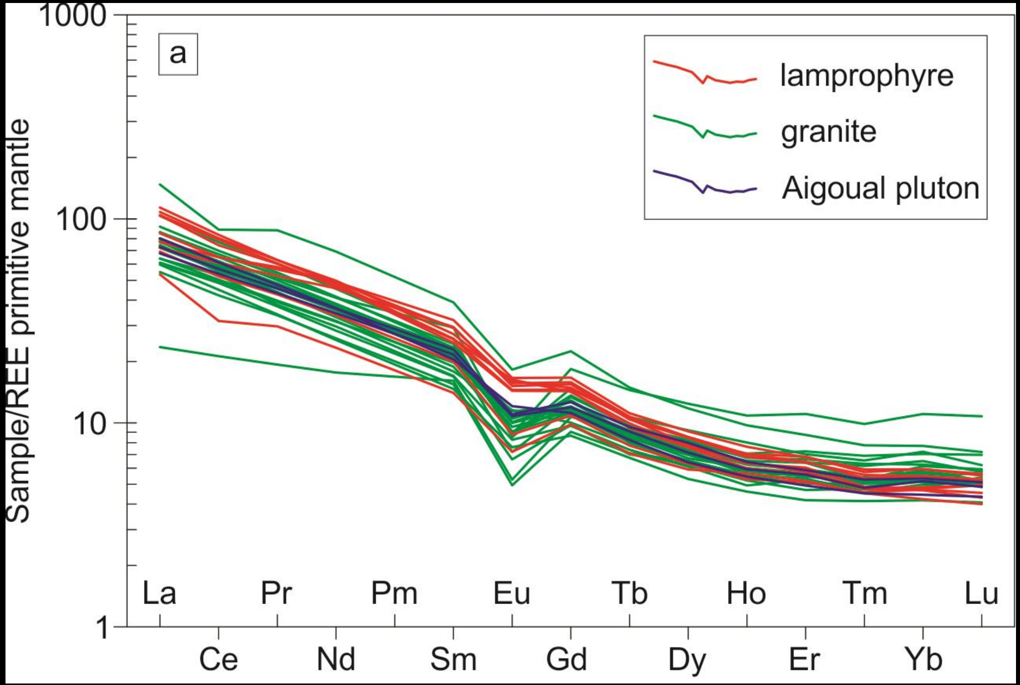
- Harker diagrams



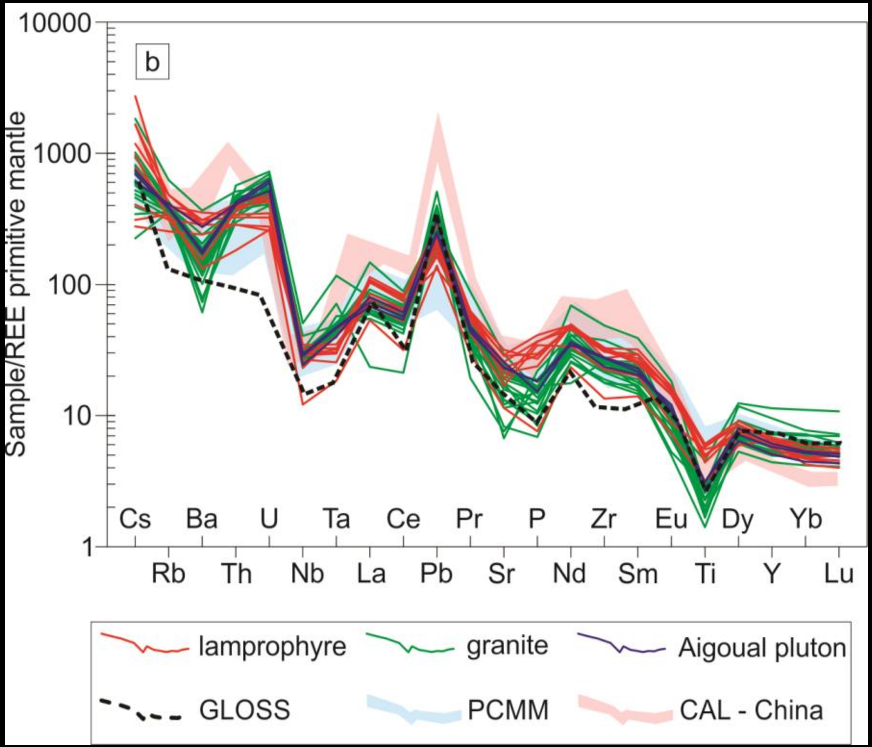


g
h
i
j
k
g
P2O5 (wt.%)
Cr (ppm)
Ni (ppm)
Ba (ppm)
V (ppm)
Sr (ppm)
SiO2 (wt.%)
SiO2 (wt.%)
SiO2 (wt.%)

- Trace element patterns



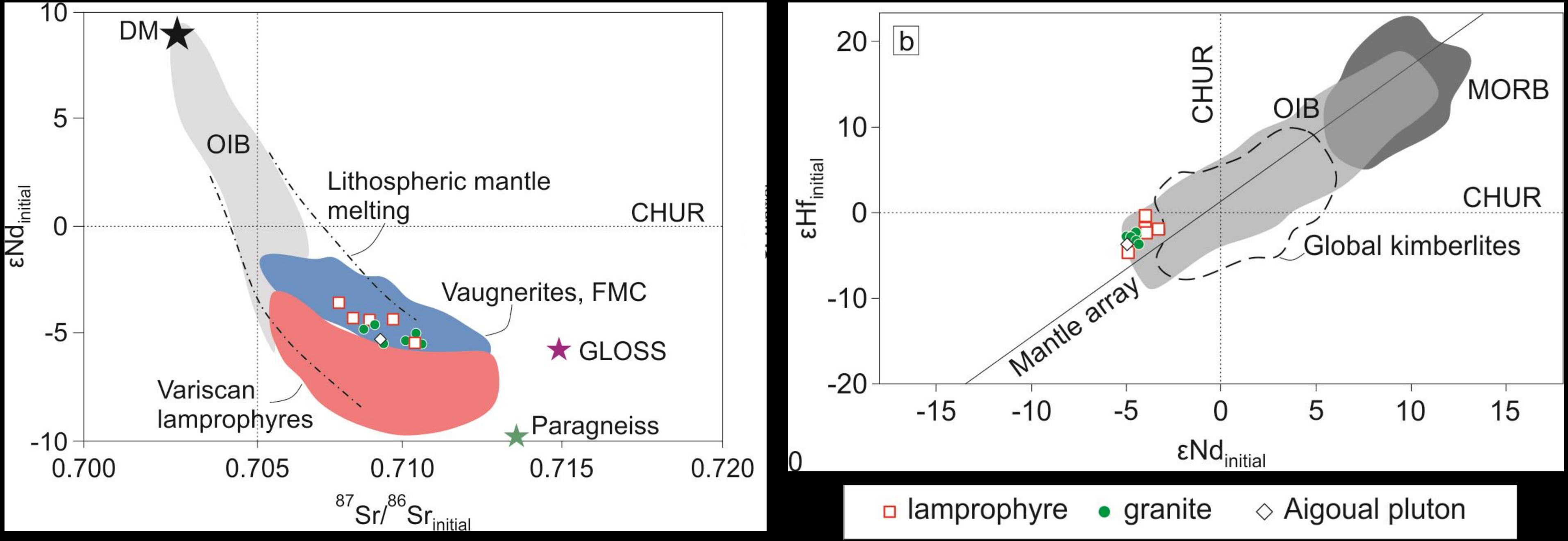
Normalized to the primitive mantle from McDonough and Sun (1995)



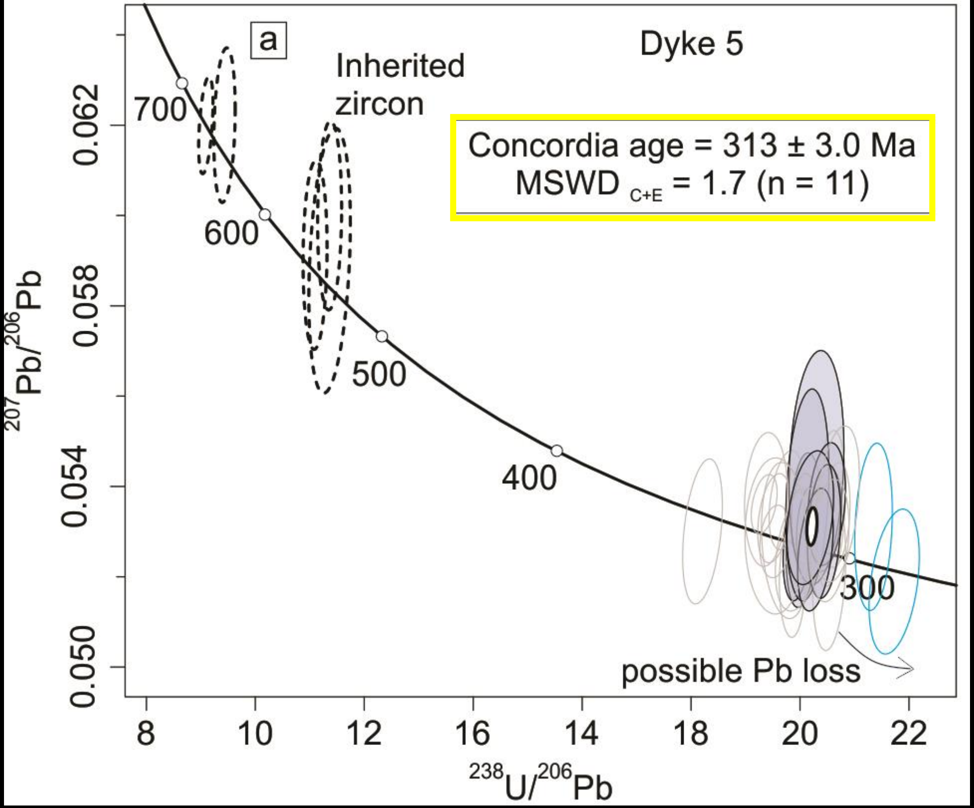
GLOSS - Plank and Langmuir (1998);
PCMM – Couzinié et al. (2016);
CAL – China – Calc-alkaline lamprophyre from Su et al. (2017).

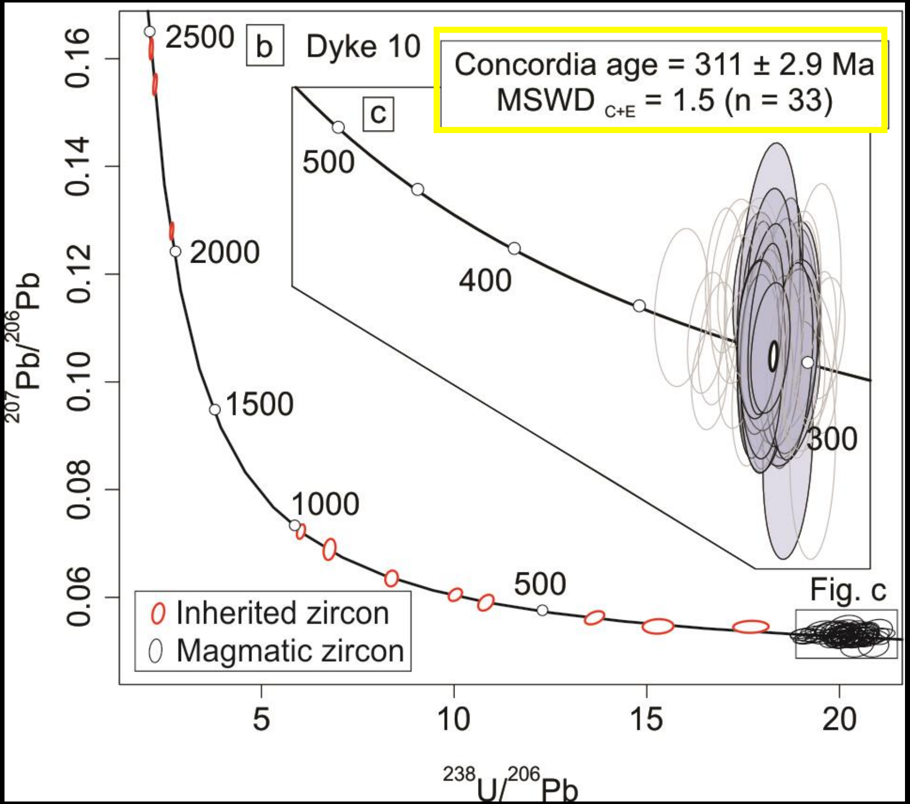
- Whole-rock Sr-Nd-Hf isotopes

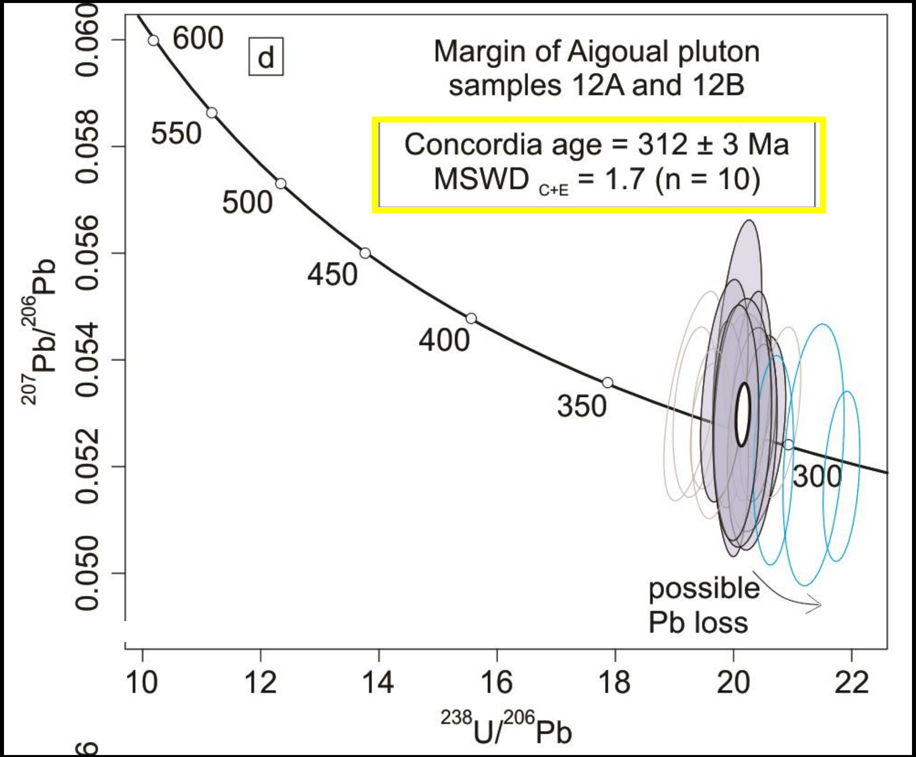
  - ✓ Lamprophyres and granites display similar ƐNd and ƐHf and $^{87}Sr/^{86}Sr_{initial}$
  - ✓ Subchondritic ƐNd and ƐHf and high $^{87}Sr/^{86}Sr_{initial}$ values

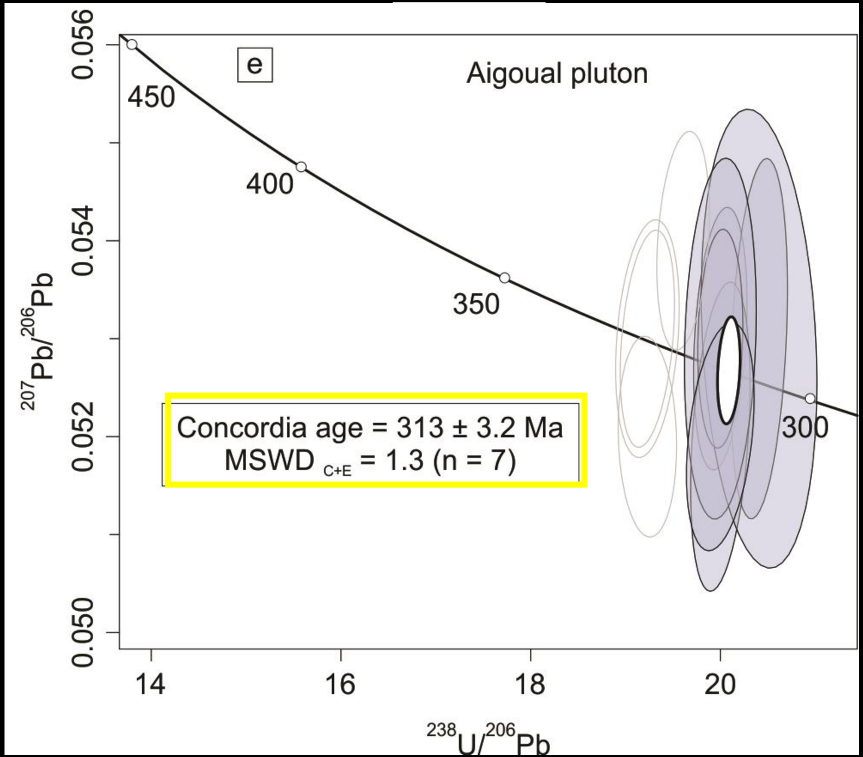


- Zircon U-Pb ages







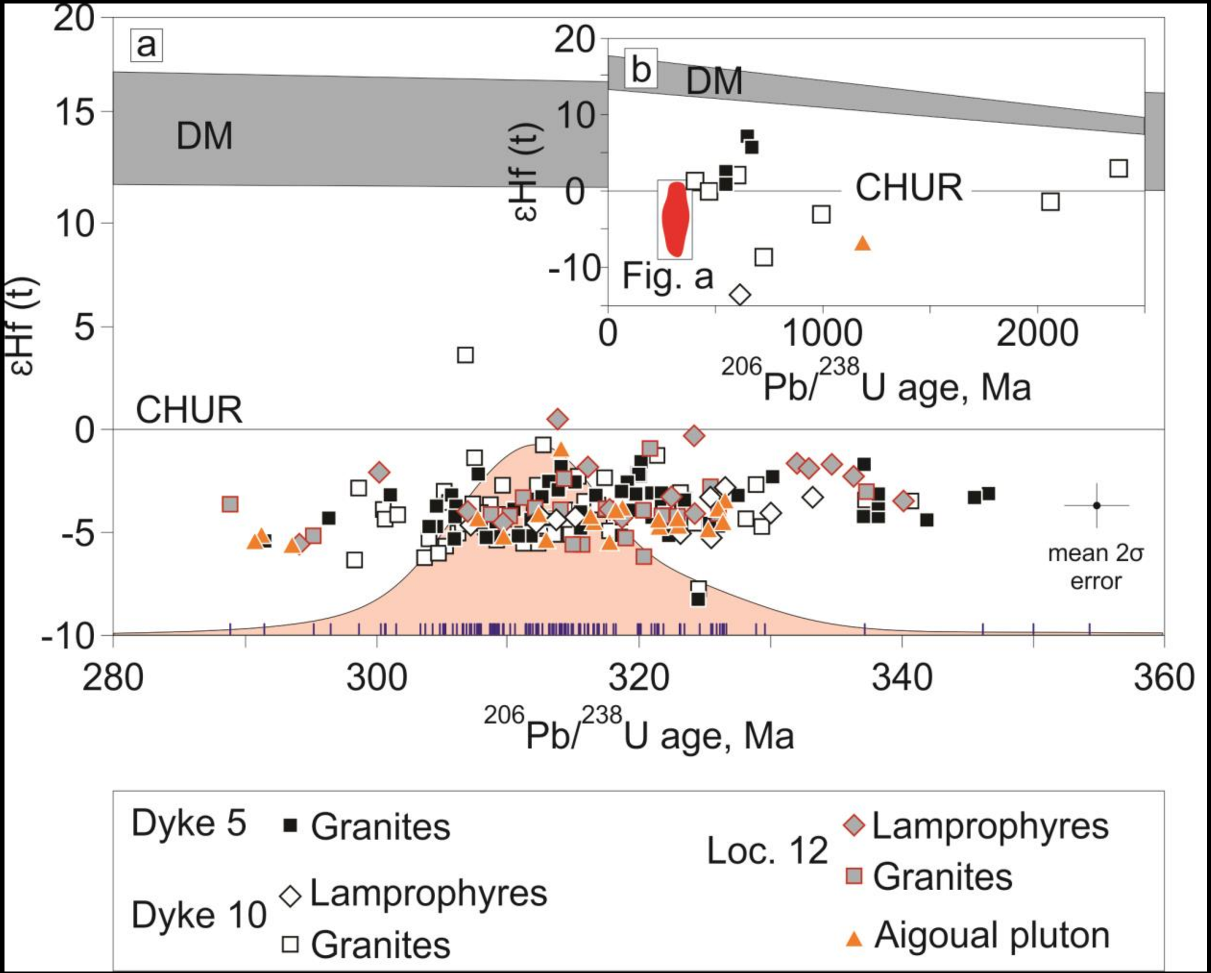


- ✓ Dykes and the Aigoual pluton show the same crystallization age within uncertainties

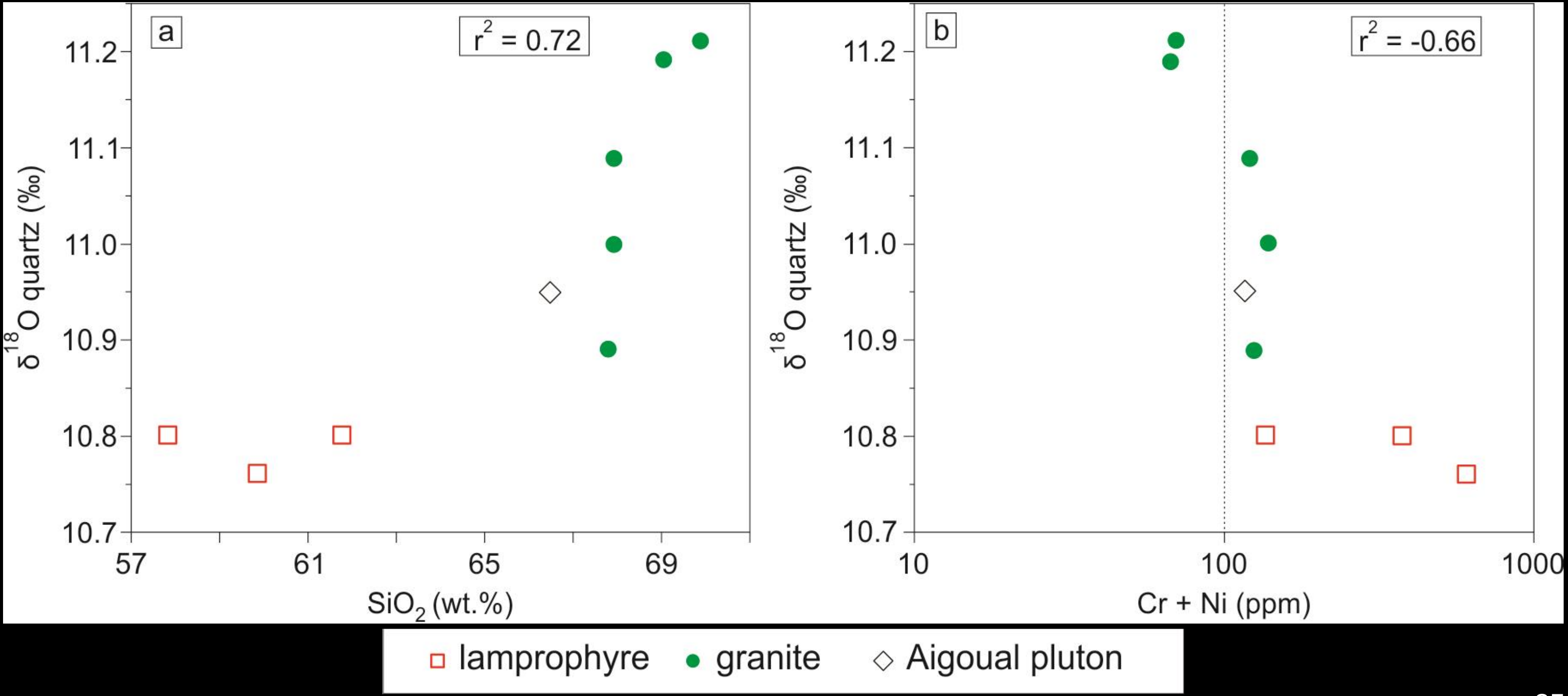
- Zircon Lu-Hf isotopes

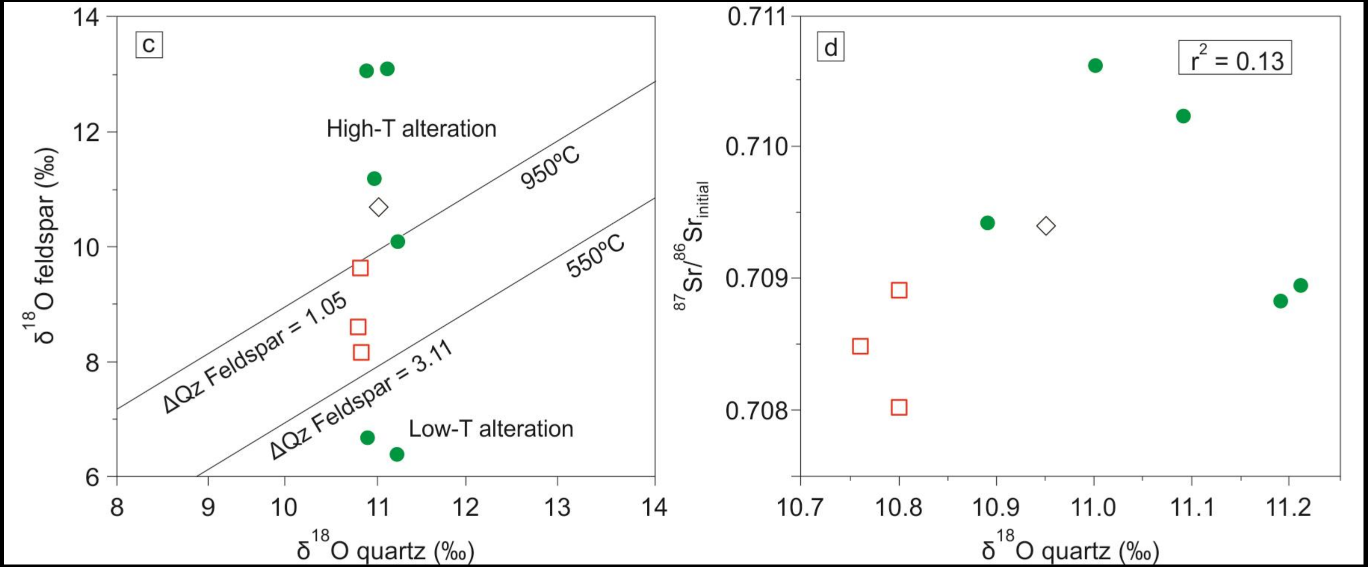
✓ Subchondritic ƐHf values;

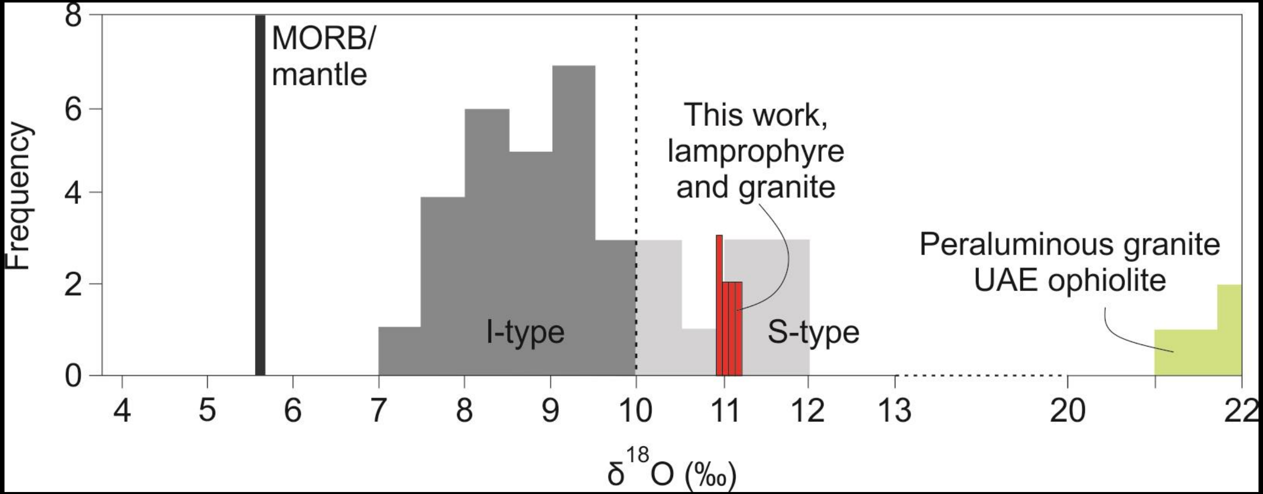
✓ Narrow variation with more than 90% of the data plotting between -5 and -1.6



- Oxygen isotopes in quartz and feldspar
  - Quartz δ¹⁸O values vary from 10.76 to 11.21‰ (±0.15‰)




c
High-T alteration
950ºC
550ºC
ΔQz Feldspar = 1.05
ΔQz Feldspar = 3.11
Low-T alteration
δ18O feldspar (‰)
δ18O quartz (‰)
d
r2 = 0.13
87Sr/86Sr initial
δ18O quartz (‰)


MORB/
mantle
This work,
lamprophyre
and granite
Peraluminous granite
UAE ophiolite
I-type
S-type
Frequency
δ18O (‰)

Origin of lamprophyres

“Mantle like” composition

- Moderate to high compatible element contents:
  - Cr (74 – 572 ppm)
  - Ni (23 – 148 ppm)
  - High Mg# (up to ~ 60)

↓

Mantle-derived source for this component of the composite system

“Crustal like” composition

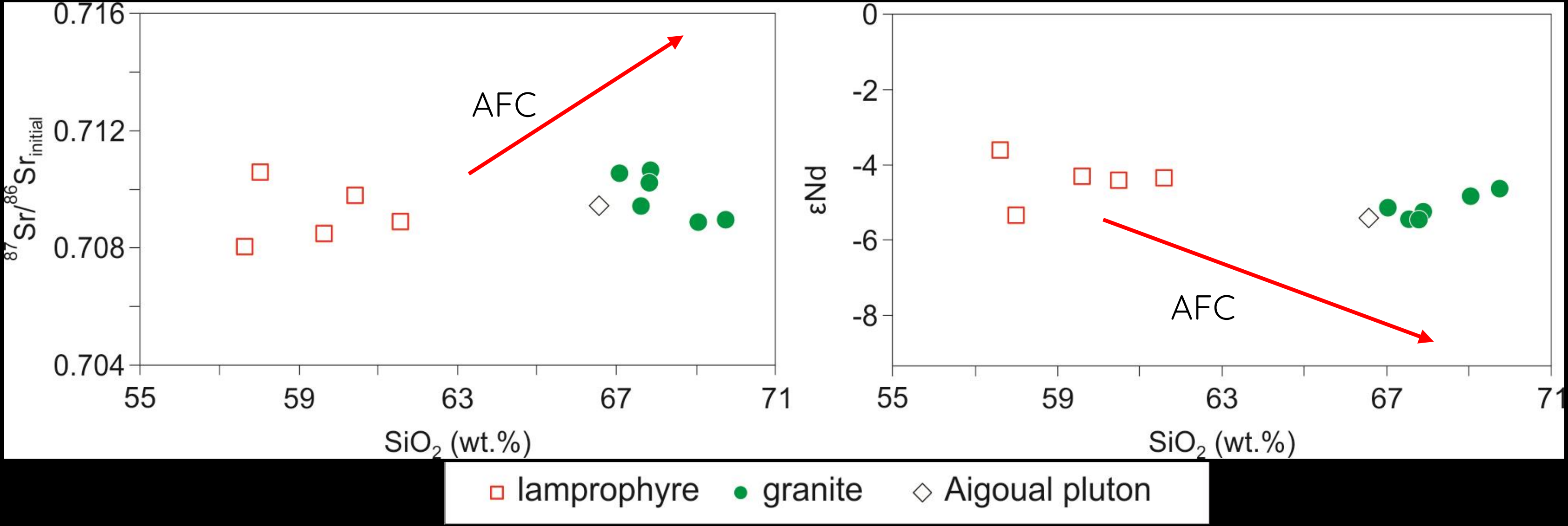
- LILE (K_2O, Sr, Rb, Ba, Pb, V), LREE;
- Depletion in HFSE such Nb, Ta and Ti in relation to the primitive mantle;
- Subchondritic ƐNd and ƐHf values
- $\delta^{18}O$ values that are 5‰ higher than depleted mantle

- The crustal-like signatures of lamprophyres can result from two process:

Assimilation of crust and/or fractional crystallization from a primitive basaltic liquid (AFC process)

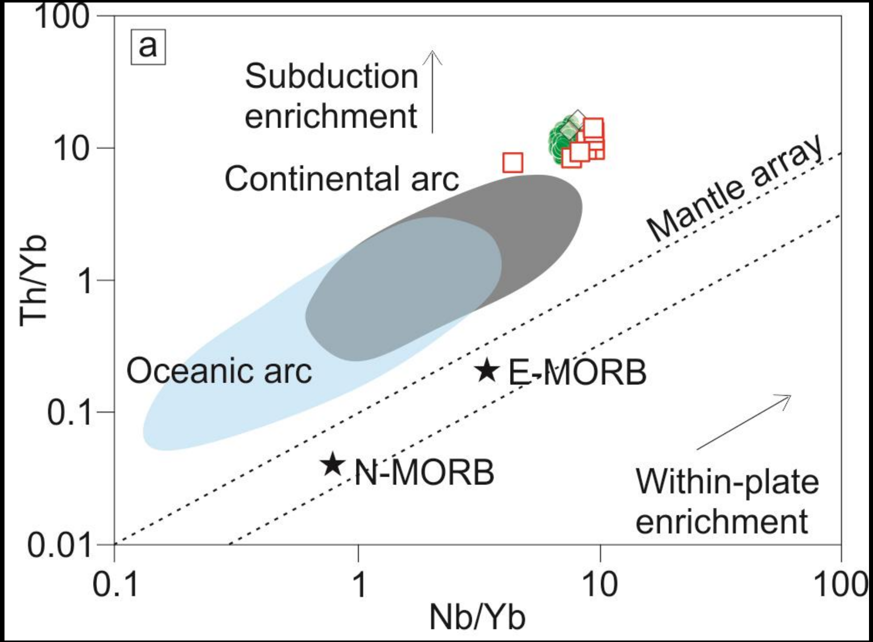
Partial melting of a mantle-source already enriched and metasomatized by fluids or magma derived from crustal material during the subduction stage preceding continental collision

Assimilation of crust and/or fractional crystallization from a primitive basaltic liquid (AFC process)

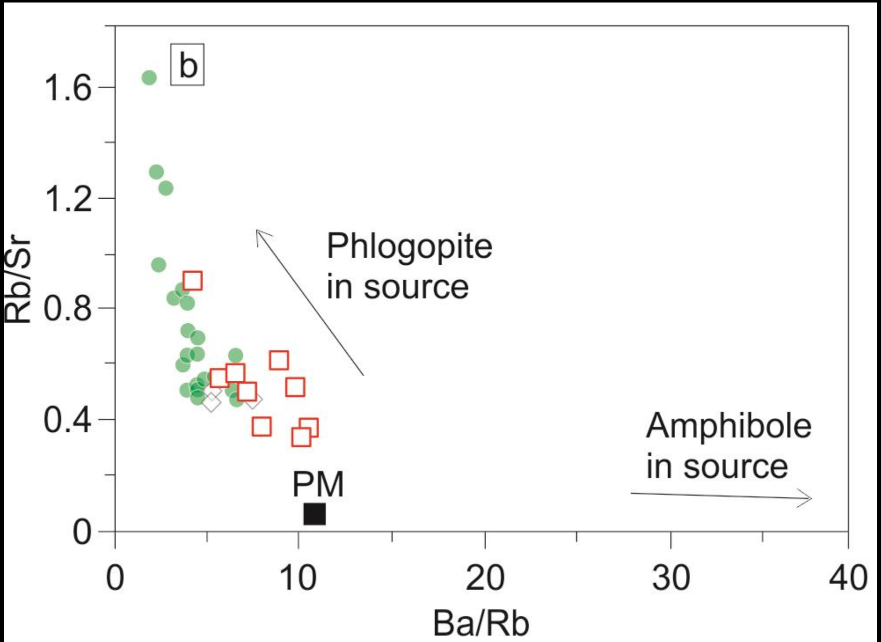


- No correlation between Mg#, Cr, Ba, Ni and $^{87}Sr/^{86}Sr_i$, ƐNd, ƐHf - isotopic enrichment did not result from crustal contamination;
- Lamprophyres and others high K-Mg are ubiquitous in FMC and intrude several lithologies from the nappe pile. All these rocks display similar signatures to lamprophyres reported in this work and point to enriched mantle as the most likely source

Partial melting of a mantle-source already enriched and metasomatized by fluids or magma derived from crustal material during the subduction stage preceding continental collision



Magmas derived from mantle sources modified by subducted components usually differ from MORBs and OIB by enrichment in Th and Nb compared to Yb



Higher Rb/Sr and lower Ba/Rb ratios strongly indicate that phlogopite was the dominant hydrous phase in the source

- ✓ Enrichment in Th and Nb compared to Yb;
- ✓ Phlogopite was the dominant hydrous phase in the source;
- ✓ Similar to modern sediments (Global subducted sediments – GLOSS; Plank and Langmuir 1998) - jagged spidergrams marked by low Nb-Ta-Ti concentrations and elevated Th-U and Pb;
- ✓ Low $^{87}Sr/^{86}Sr_i$ ratios are consistent with mantle enrichment during the Silurian-Devonian subduction – Variscan belt

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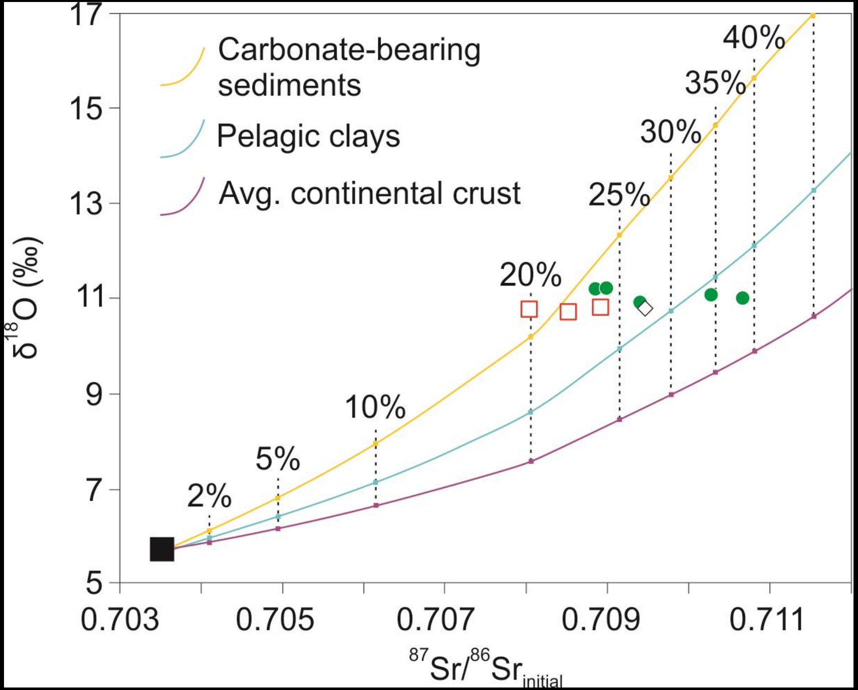
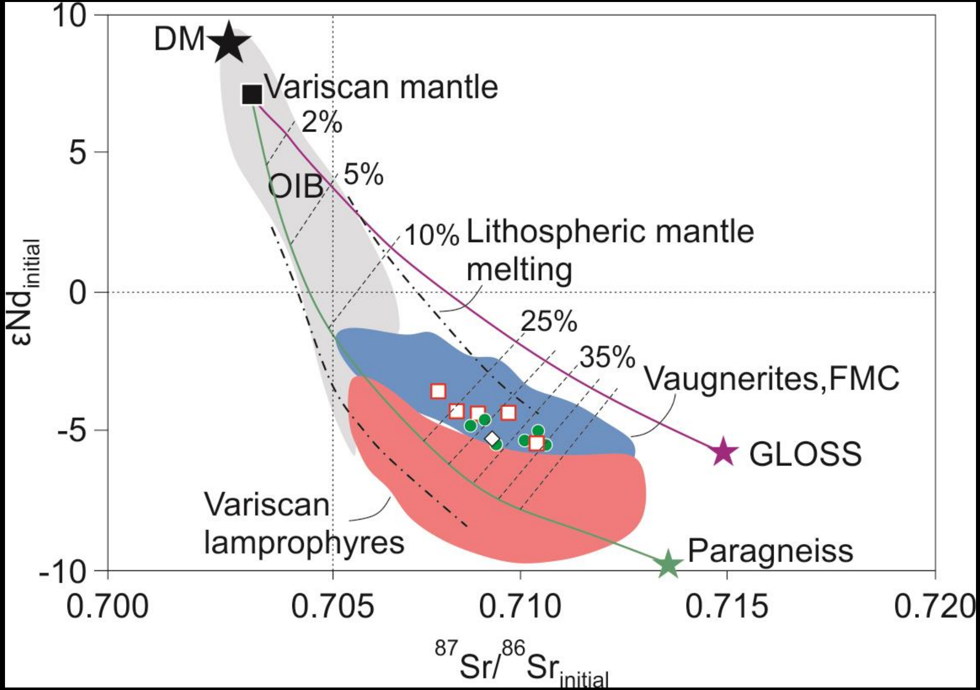
Enriched lithospheric mantle source

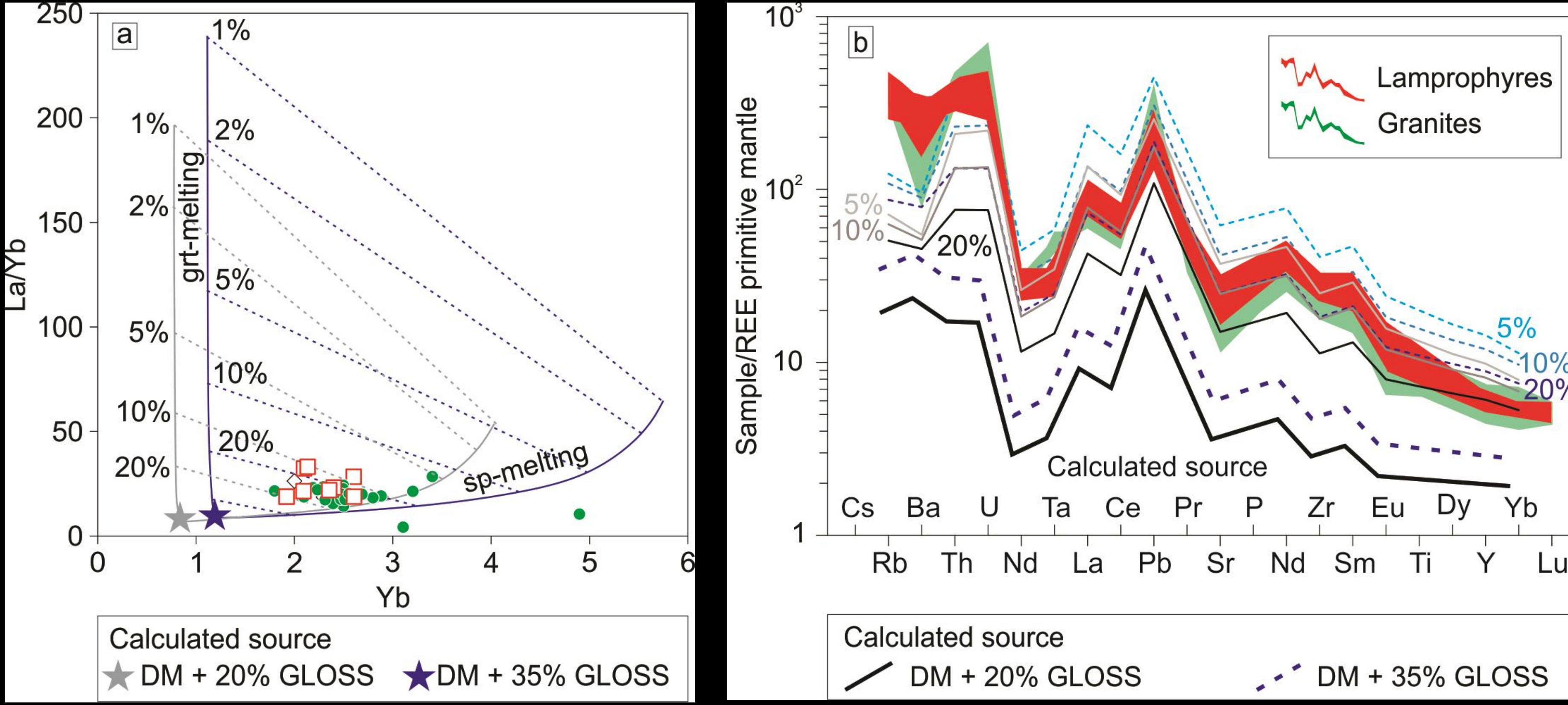
Nature of the mantle source?

- Modelling using $^{87}Sr/^{86}Sr_{initial}$ values, ƐNd and oxygen isotopes in quartz





Partial melting conditions



Shallow depth in spinel-lherzolite facies source in the absence of garnet

Origin of granites

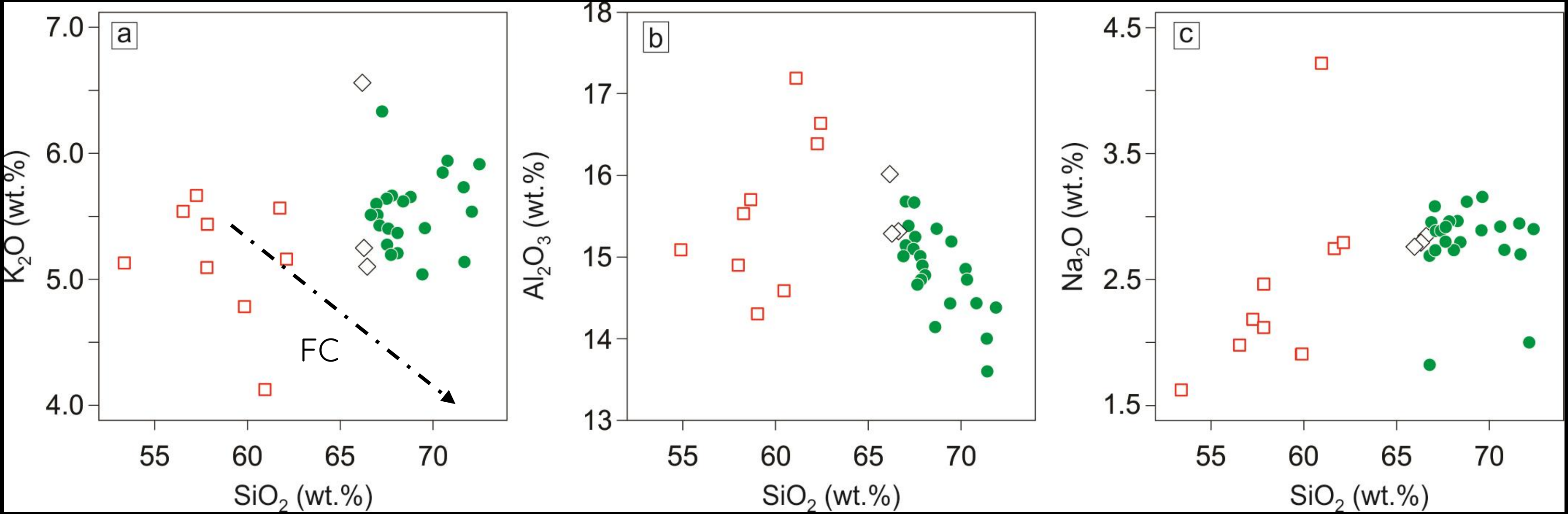
- ✓ The studied dykes are composite and include co-magmatic lamprophyric and granite components;
- ✓ Granites and lamprophyres show a mixture of “crust-like” and “mantle-like” geochemical features;
- ✓ Similar isotopic signatures.

1. The lamprophyres and the granites are related by differentiation processes such as fractional crystallization, although remelting of underplated lamprophyres would result in broadly the same patterns; the lamprophyres differentiated during intrusion into the crust;

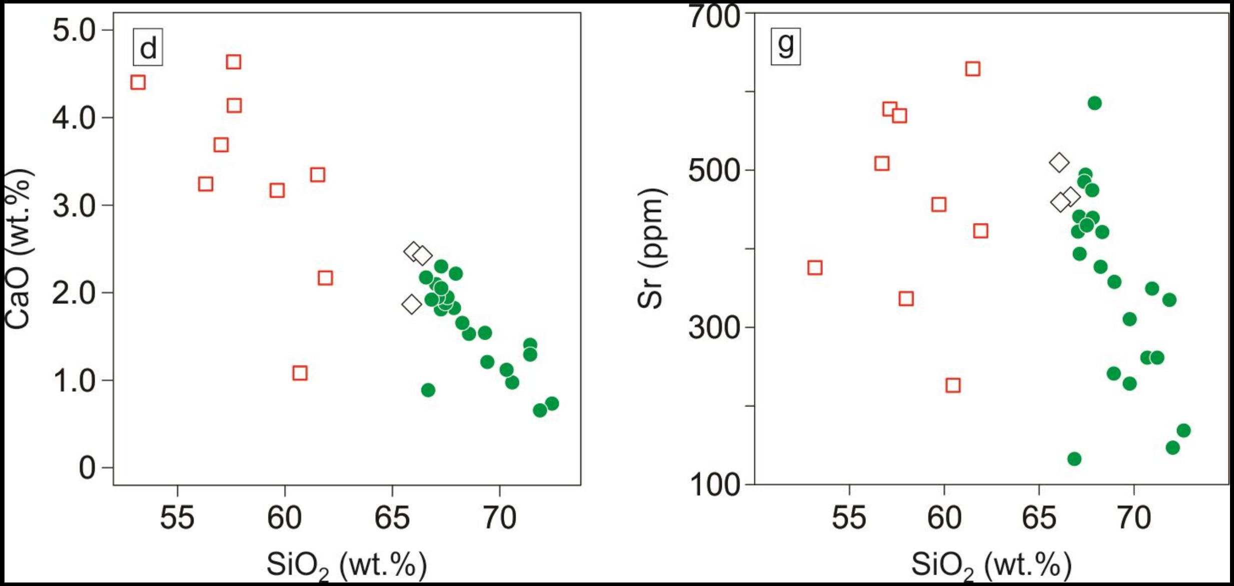
2. The lamprophyres and the granites represent distinct magmas, an enriched-mantle derived magma for the lamprophyres and a crust-derived magma for the granites, that mingle and mix at the emplacement site

3. The granites and the lamprophyres are both direct products of melting of the enriched mantle source but in different proportions

1. The lamprophyres and the granites are related by differentiation processes such as fractional crystallization (FC)



The increase in volume and size of megacrysts of K-feldspar in the granitic component demonstrate that a considerable decrease in K_2O is expected in fractional crystallization in high-K magmas.



- ✓ No cumulate textures are observed in lamprophyres;
- ✓ The high Cr (30 – 140 ppm; 80.9 on average and in some cases over 100 ppm in a granite with SiO2 = 70 wt.%) and Ni (14 – 40 ppm; 24.4 on average) content in the granites are inconsistent with fractional crystallization playing an important role in the formation of granite.

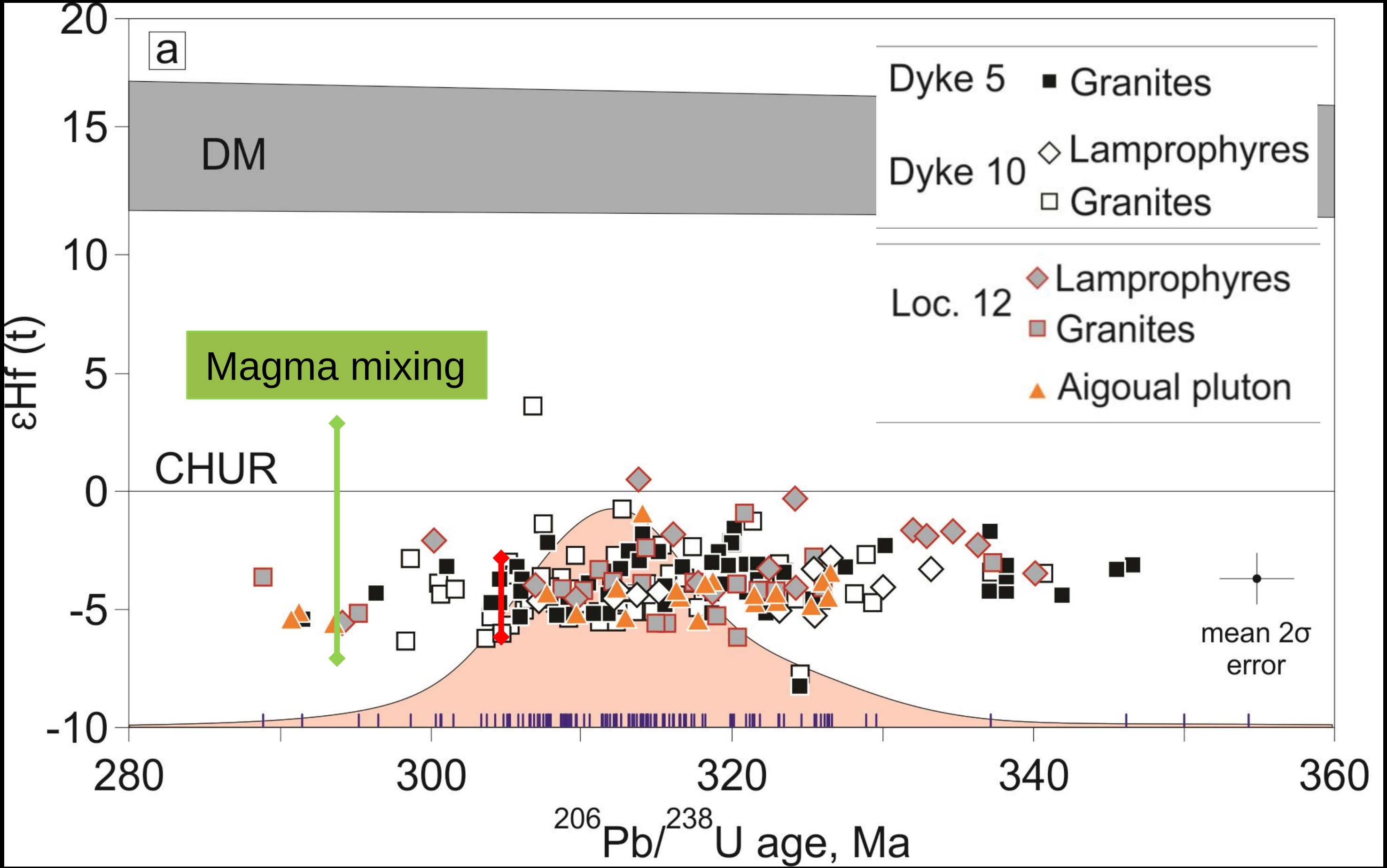
1. The lamprophyres and the granites are related by differentiation processes such as fractional crystallization

2. The lamprophyres and the granites represent distinct magmas, an enriched-mantle derived magma for the lamprophyres and a crust-derived magma for the granites, that mingle and mix at the emplacement site

- ✓ Petrological evidence - ca. 10% of zircon xenocrysts in granites from composite dykes;
- ✓ Corroded of quartz xenocrysts mantled by carbonate and amphibole in lamprophyre;
- ✓ Linear trends observed in many (but not all) binary plots between lamprophyre and granite might indicate magma mixing between these two end members, however, similar trends are observed in fractional crystallization or partial melting processes

Radiogenic isotopes are generally not fractionated during melting or crystallization and are the best tools to decipher open-system processes such as magma mixing

In-situ Lu-Hf isotopic analysis in zircon



- ✓ The ƐHf values from lamprophyres and granites are similar and overlap, pointing that mixing within different and contrasting magmas did not play an important role;

- ✓ The narrow range in $\delta^{18}O$ values between lamprophyres and granites (less than 0.5‰) is more consistent with a source related variation or homogenization of the magma than mixing between two different and contrasting magmas;

- ✓ Although crustal-derived melts are regionally widespread in FMC, the Aigoual pluton lacks purely crustal granites, e.g. in the form of peraluminous cordierite- and muscovite-bearing rocks that are ubiquitous in the FMC;

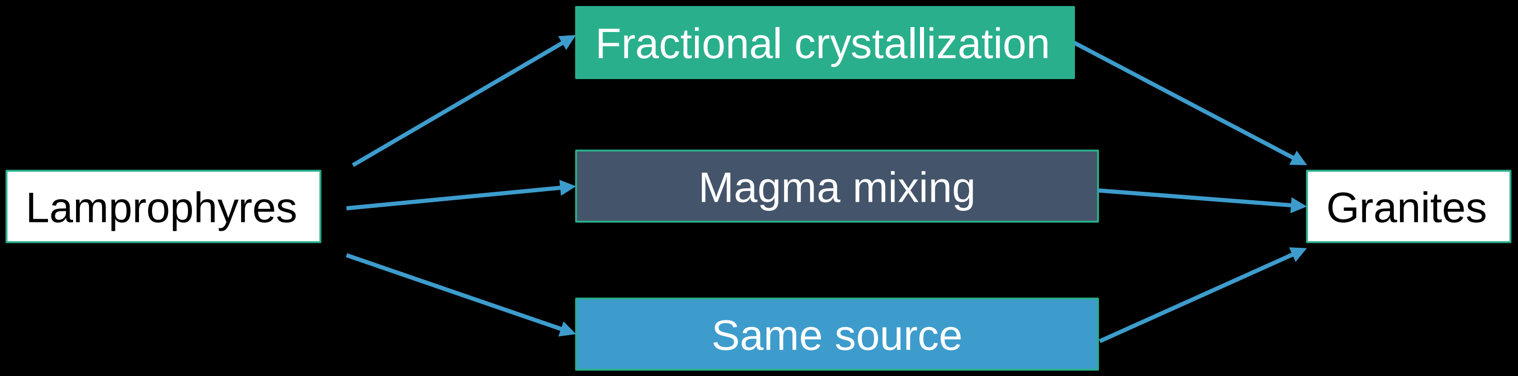
- ✓ The lack of well-defined mixing trends for major elements, trace elements and isotopes alike suggests that magma mixing was not a dominant process;

- ✓ A minimal degree of assimilation is likely.

2. The lamprophyres and the granites represent distinct magmas, an enriched-mantle derived magma for the lamprophyres and a crust-derived magma for the granites, that mingle and mix at the emplacement site

3. The granites and the lamprophyres are both direct products of melting of the enriched mantle source but in different proportions

- ✓ Co-magmatic relation between lamprophyres and granites and very similar isotopic signatures;
- ✓ Experimental studies – peridotite + sediments or peridotite/lherzolite + granitic melt → post-collisional K-rich magmatism;
- ✓ Recent studies (Förster et al. 2020, 2021) → mixing between peridotite and sediment can reach high SiO_2 contents (> 67%) and major and trace element compositions matching those in this work.

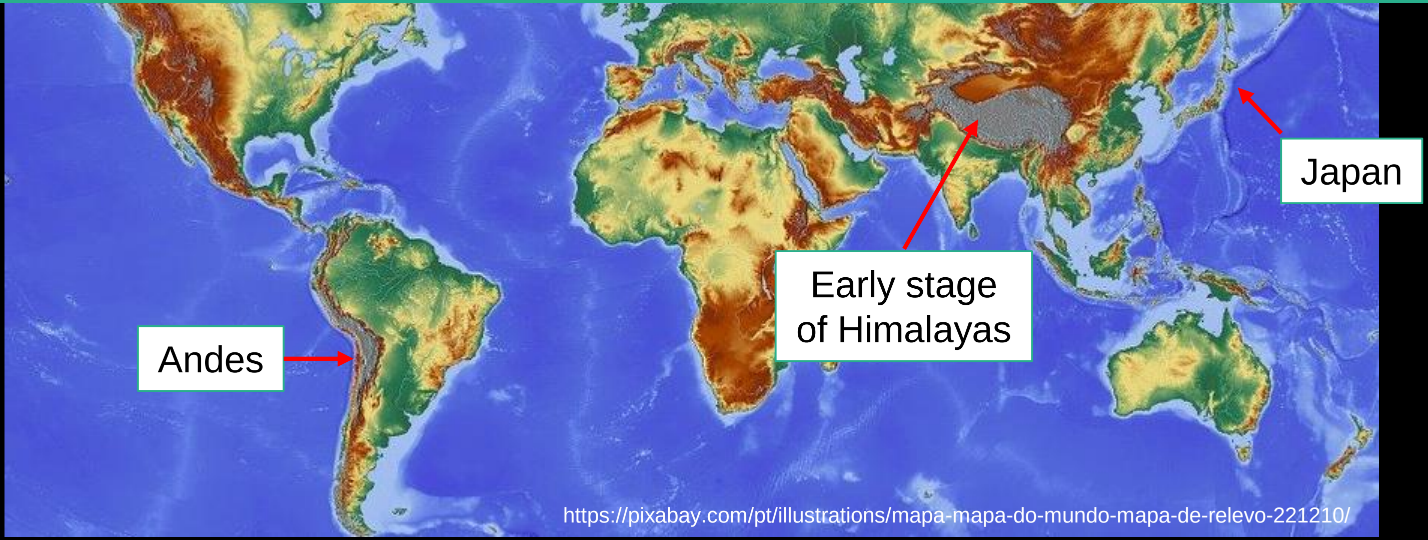


✓ Both lamprophyres and granites display evidence of crustal recycling in different ways and addition of new mantle-derived material as seen in the high contents of compatible elements such Cr, Ni, MgO and FeO.

Implications for crustal growth

- The crust grows when new mantle-derived material is added to the continent

Arc settings - large amounts of mantle-derived mafic and intermediate magmas (and their differentiates) are added to the crust



However, this does not necessarily imply significant long-term crustal-growth, because arc settings display poor preservation potential. A high proportion of the generated crust may be recycled back to the mantle shortly after formation (Condie 2014; Korenaga 2018; Scholl and von Huene 2009; Stern 2011)

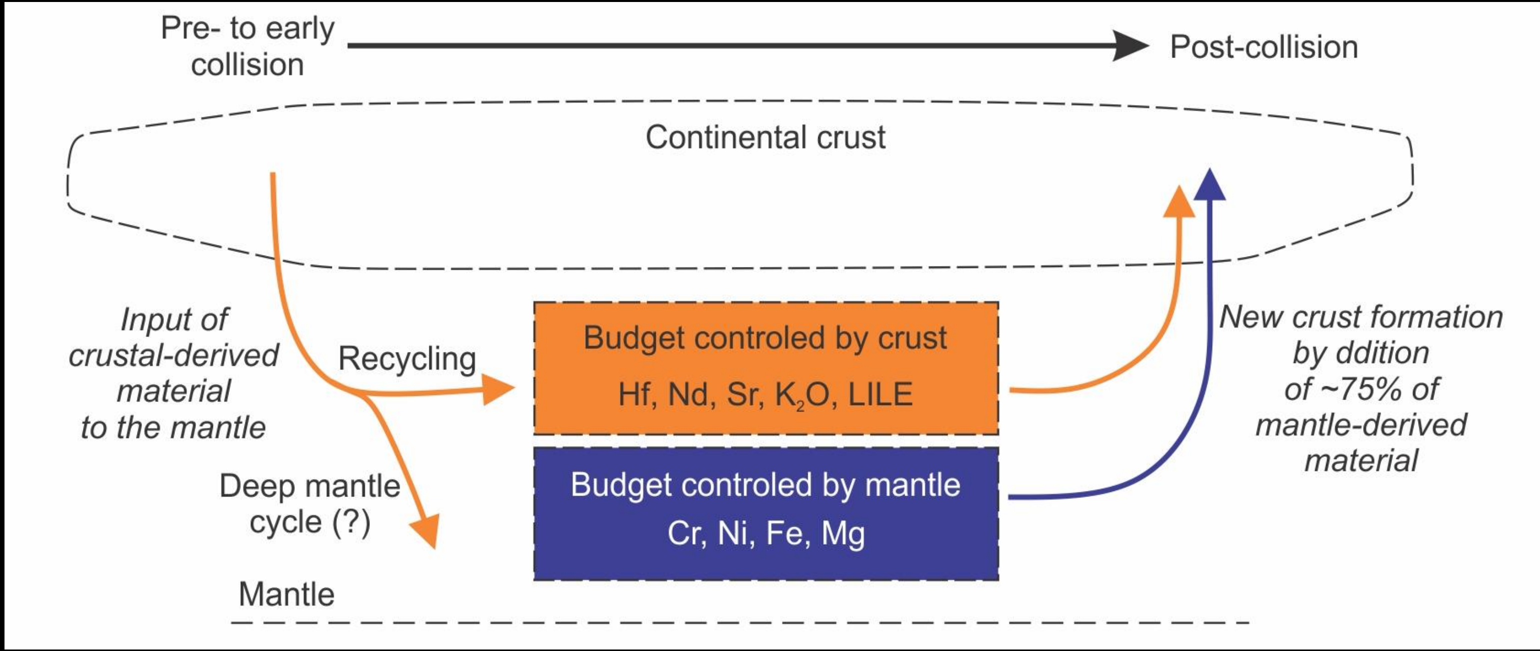
Post-collisional setting

- ✓ Less efficient than arc settings in producing new continental crust;
- ✓ Highest potential for preservation in the geological record (Hawkesworth et al. 2009, 2010; Spencer et al. 2015).

Post-collisional settings may represent significant contributions for the long-term crustal growth

Post-collisional setting

- ✓ Addition of new mantle-derived material is not identified by usual isotopic systems such as Rb-Sr, Sm-Nd and Lu-Hf

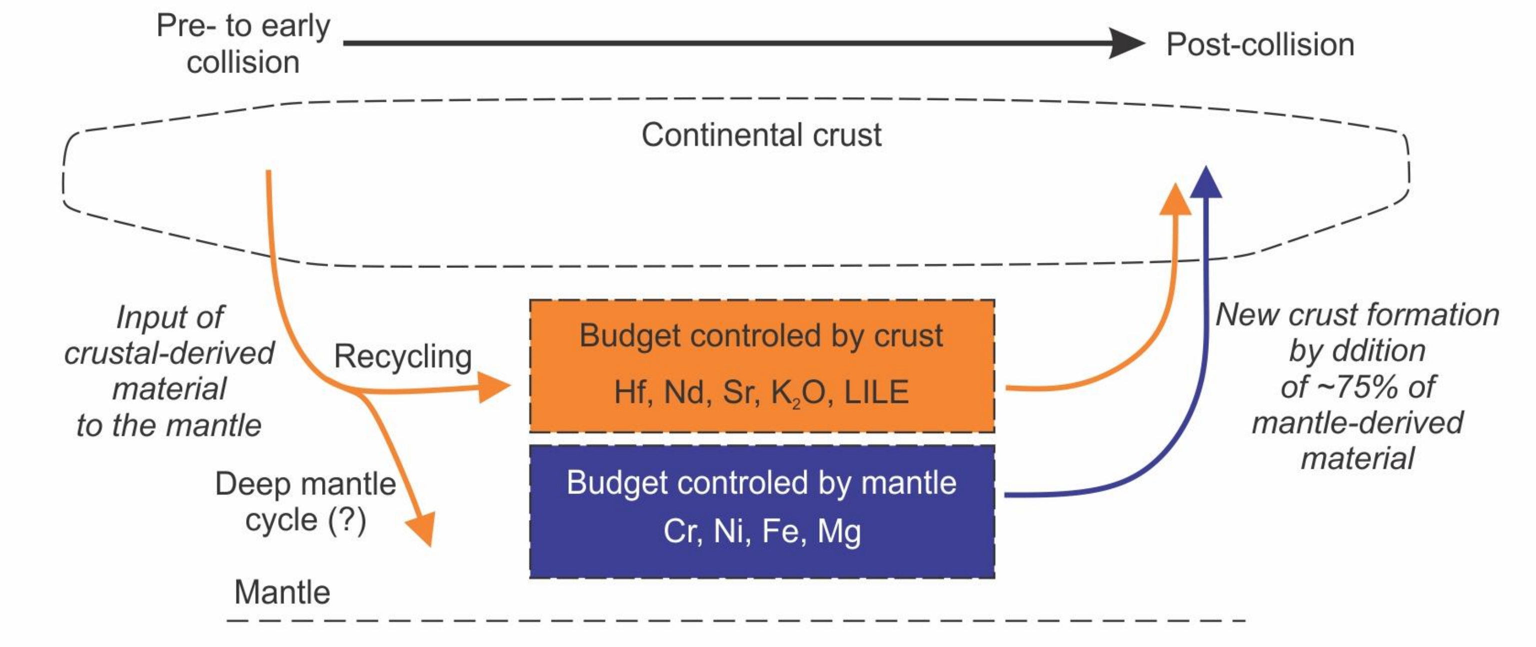


Modified from Couzinié (2018)

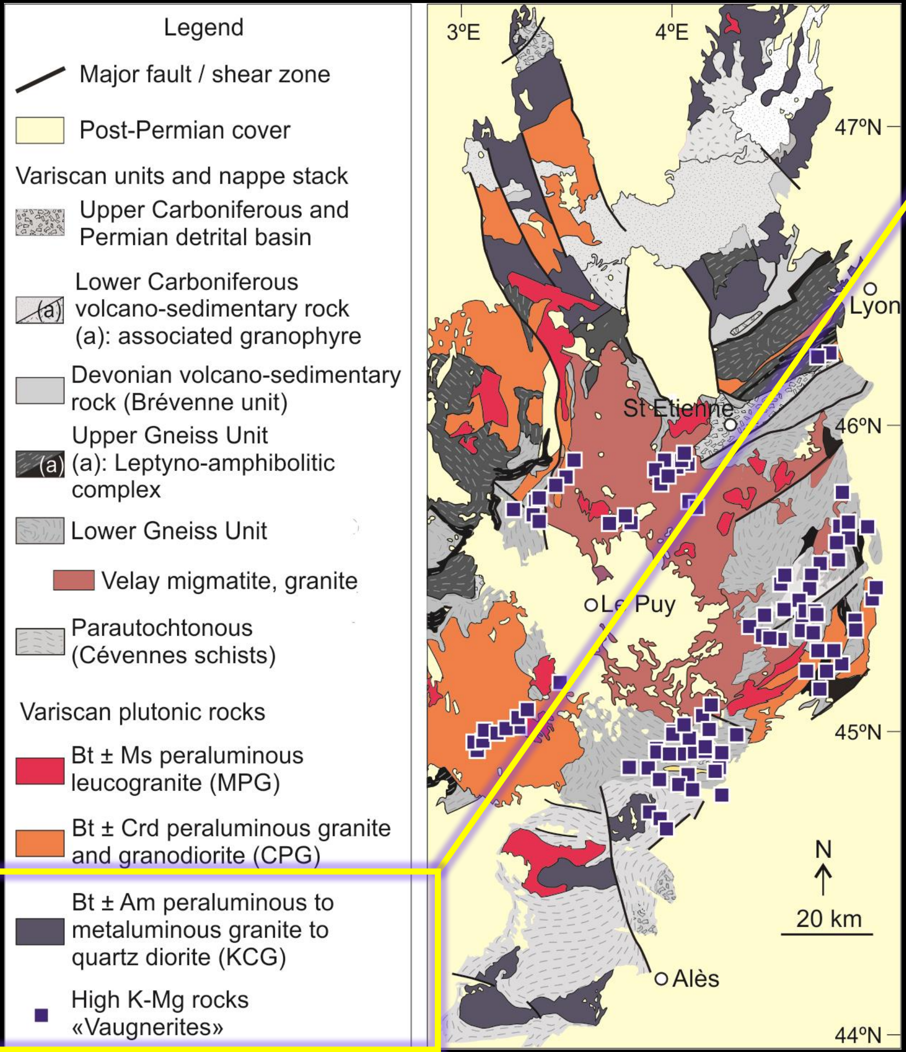
~25% of crustal material is recycled back to the continental crust

~75% of mantle-derived material is added to the crust corresponding new crust formation

The mantle-derived material is evidenced by the mafic character and the high contents of compatible elements that ultimately came from the mantle.



Modified from Couzinié (2018)



High K-Mg rocks + KCG plutons

35% of the outcrop surface of granites in FMC

+

Geochemical modelling display between 65 – 80% of the material came from the mantle

↓

22 – 28% of the magmatic material in FMC came from the mantle

↓

Crustal growth

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Conclusions

1) Lamprophyres and granites are co-magmatic and coeval with the emplacement of Aigoual pluton – between 311 and 313 Ma;

2) Lamprophyres display high contents of compatible (Cr, Ni, Fe, Mg) and incompatible elements (LILE, K_2O, Ba, Pb, Sr) and crustal-like signatures in both radiogenic and stable isotopic systems;

Partial melting and mixing modelling suggest this dual geochemical signature results from 10 – 20% of partial melting in the spinel-lherzolite stability field of a source composed by mixing between 20 – 35% of sediments and 65 – 80% peridotite;

3) Granites display trace elements and isotopic signatures alike lamprophyres and have a mantle-derived component involved in their petrogenesis. The intimate relation (physically and geochemically) between lamprophyre and granite in a system of composite dykes of northern Aigoual pluton provide constraints about the mantle contribution in the granites from FMC;

4) Although the isotopic signatures being broadly controlled by the crustal component in the mantle, approximately 70% of the material comes from the mantle and thus corresponds new crust formation;

5) Lamprophyres and granites from composite dykes represent significant addition of new crust in a post-collisional setting.

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Thank you!

Obrigada!

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Mantle and crust interaction in post-collisional setting, a case study of lamprophyric-granitic composite dykes of northern Aigoual pluton, French Massif Central

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