Evolution of F and Cl relative to lithophile trace elements in oceanic crust, from oceanic to subduction metamorphisms in Western Alps

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Introduction

Ophiolites in Western Alps represent fragments of oceanic lithosphere subducted and then uplifted during the closure of Tethys sea. Metagabbros in such ophiolite record different stages of geodynamic cycle from oceanic metamorphism (low pressure - high temperature, oceanization), to subduction metamorphism reaching eclogite facies (Fig. 1). Here, we present results of trace element measurements to establish the systematics of element fractionation during the prograde metamorphism of the metagabbros.

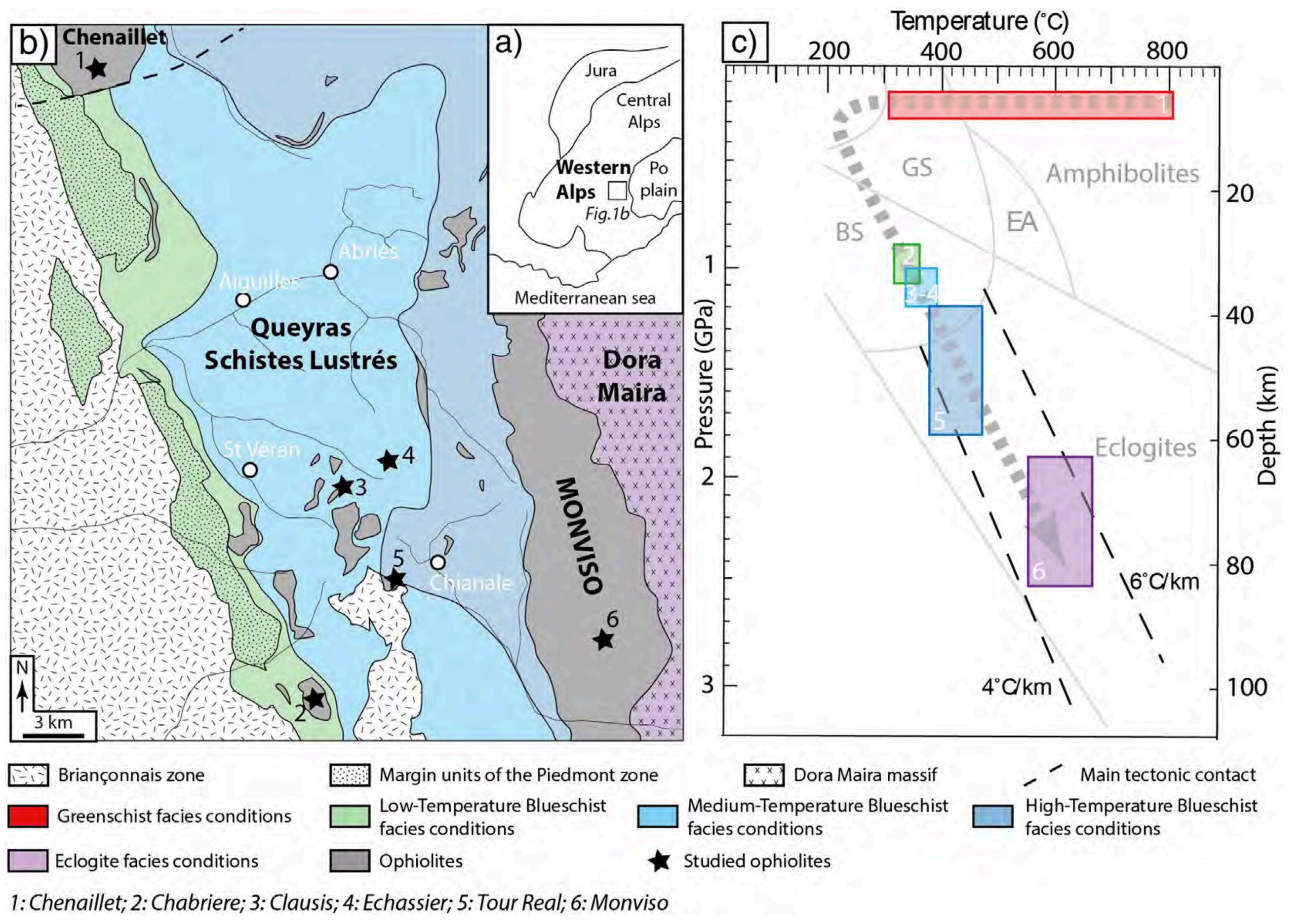
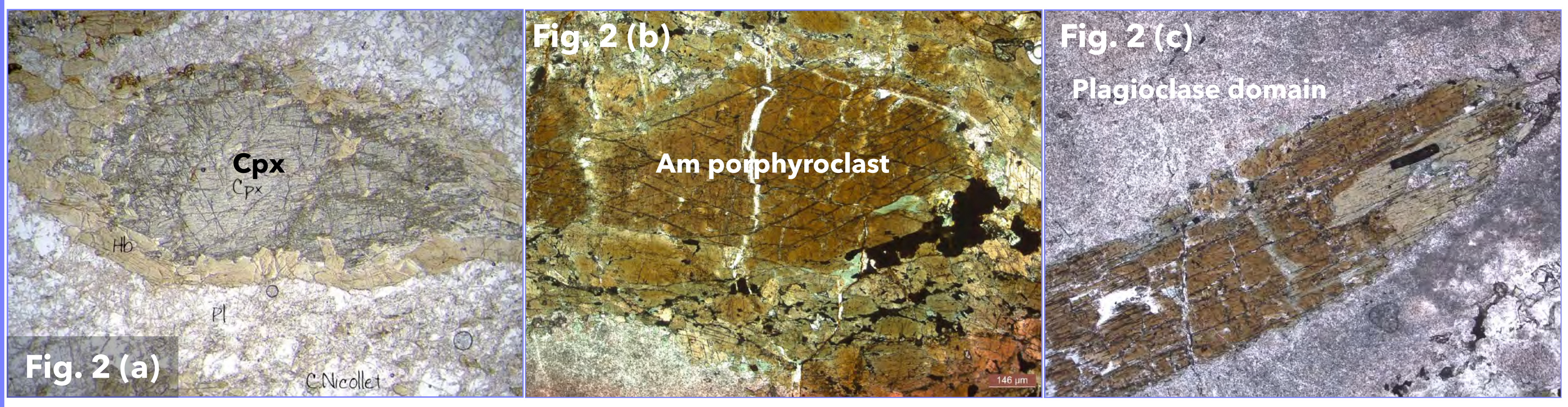


Fig. 1 (a) A schematic map of the Western Alps indicating the location of the studied area as a small box. (b) A metamorphic map of the studied area showing the locations of the studied ophiolites with numbered stars. The colors correspond to metamorphic facies. (c) Pressure and temperature estimates of the studied ophiolites shown as numbered boxes corresponding to the samples. The gray background grid shows metamorphic facies. Modified after Debret et al. (2016).

These metagabbros show complex mineral textures representing multiple stages of metamorphism (Fig. 2). Because of this complexity, a bulk analysis cannot represent a chemical composition of a single PT condition. Instead, LA-ICPMS (LMV-UCA) measurements were acquired for individual phases, and the data were interpreted on the basis of the paragenetic mineral assemblages corresponding to different facies. Furthermore, the trace elements data are compared with previously published Li, B, F and Cl data (Debret et al. 2016) to investigate the fractionation of these with respect to lithophile trace elements.

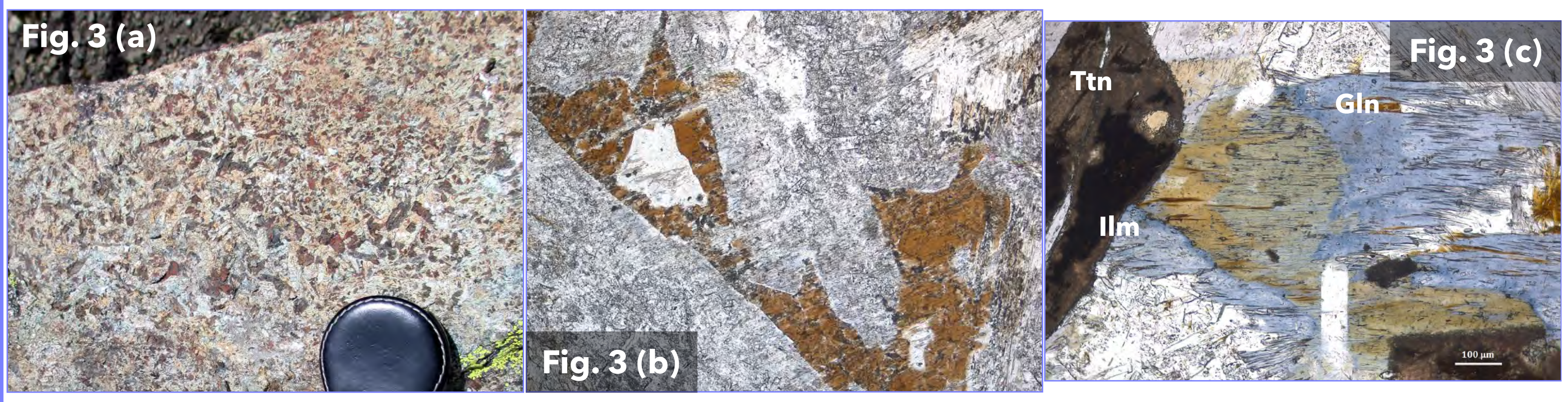
Samples

Chenaillet: Oceanization



Chenaillet ophiolite represents a metamorphosed oceanic lithosphere, little affected by alpine subduction event (e.g. Caby, 1995). The coarse-grain metagabbro pods show a syn- to post-magmatic deformation during cooling. They are composed of clinopyroxene relic, amphiboles, titanite, chlorite, ilmenite, titano-magnetite, albite, and epidote (Fig. 2). Three generations of amphiboles are identified: (1) amphibole porphyroclasts (brown), (2) amphibole coronas (brown to green, Fig. 2a), and (3) actinolites. Plagioclase is replaced by an aggregate of small albite and epidote grains. Actinolite is found in the plagioclase domain and rims of cpx and amphibole.

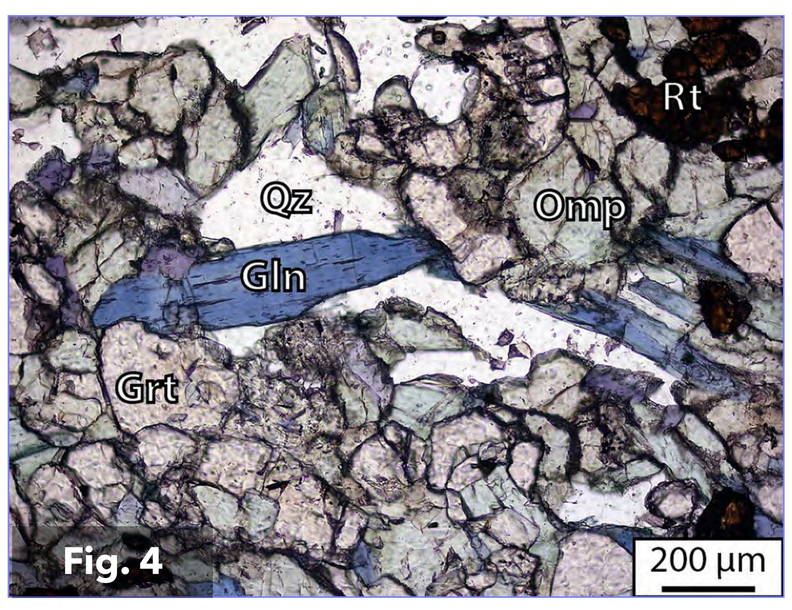
Queyras *Schistes Lustrés* complex: Blueschist facies



Boudinaged metagabbro pods (Chabriere, Clausis, Echassier, and Tour Real; Fig. 1) are found in the Queyras *Shistes Lustrés* complex, which is a metamorphosed sedimentary accretionary wedge strongly deformed during alpine subduction (e.g. Lagabrielle and Polino, 1988). The Queyras metagabbros record various blueschist facies PT conditions (Fig. 1). They are composed of clinopyroxene relic, amphiboles, ilmenite, titanite, glaucophane, lawsonite, and chlorite. Cpx and dark brown amphibole are formed at magmatic conditions along with plagioclase (Fig. 3ab; ophitic texture). Also, there are other brown amphiboles formed at subsolidus conditions. Ilmenite is surrounded by titanite, and glaucophane replaces low pressure amphiboles (Fig. 3c). In these rocks, textural relationships indicate a paragenesis of glaucophane, lawsonite and titanite.

Monviso: Eclogite facies

Monviso ophiolite, located in the extreme East of the studied area (Fig. 1), extends over 45 km and is composed of hectometer-size lenses of metabasites, embedded within highly deformed serpentinites with rare metasedimentary rocks (e.g. Lombardo et al., 1978). The massif records conditions in eclogite facies with a metamorphic peak conditions estimated at 580-620 °C and 1.9-2.1 GPa (Schwartz et al. 2001). The metagabbros display heterogeneous deformation, which is characterised by porphyroblast stretching and the banding. Compared to the metagabbros of Queyras, the eclogite are characterised by a decrease of glaucophane and lawsonite (transformed to zoisite) abundance, disappearance of titanite due to crystallisation of idiomorphic garnet, omphacite, quartz, and rutile (Fig. 4). The textural relationship shown in Fig. 4 suggests that glaucophane constitutes a paragenetic relation with a garnet-omphacite-quartz-rutile assemblage. Lawsonite or zoisite is also present in equilibrium with these minerals.



Main points

Mass-balance model identified elements dominantly hosted by one phase.

Summary of elements dominantly hosted by single phase

Oceanization	Blueschist	Eclogite
Am-porphyroclasts: **F, Sr,** La, Ce, Nd, Zr, Nb	Glaucophane: **Li,** F, Cl, V, Zr	Omphacite: **Li, Sr,** Cl, V, La, Ce, Nd
Cpx: Li, V, Cr	Titanite: **Nb**	Garnet: **Y,** Gd, Yb
Feldspar: Sr, Ba	Lawsonite: **Sr,** Ba, La, Ce	Rutile: **Nb,** Zr
		Phengite: Rb, Ba

Bold numbers indicate the elements of which >95% are found in single phase, otherwise >70%.

Evolution of oceanic crust

Model bulk composition determined for each metamorphic stage allows us to illustrate the geochemical evolution of oceanic crust (Fig. 5).

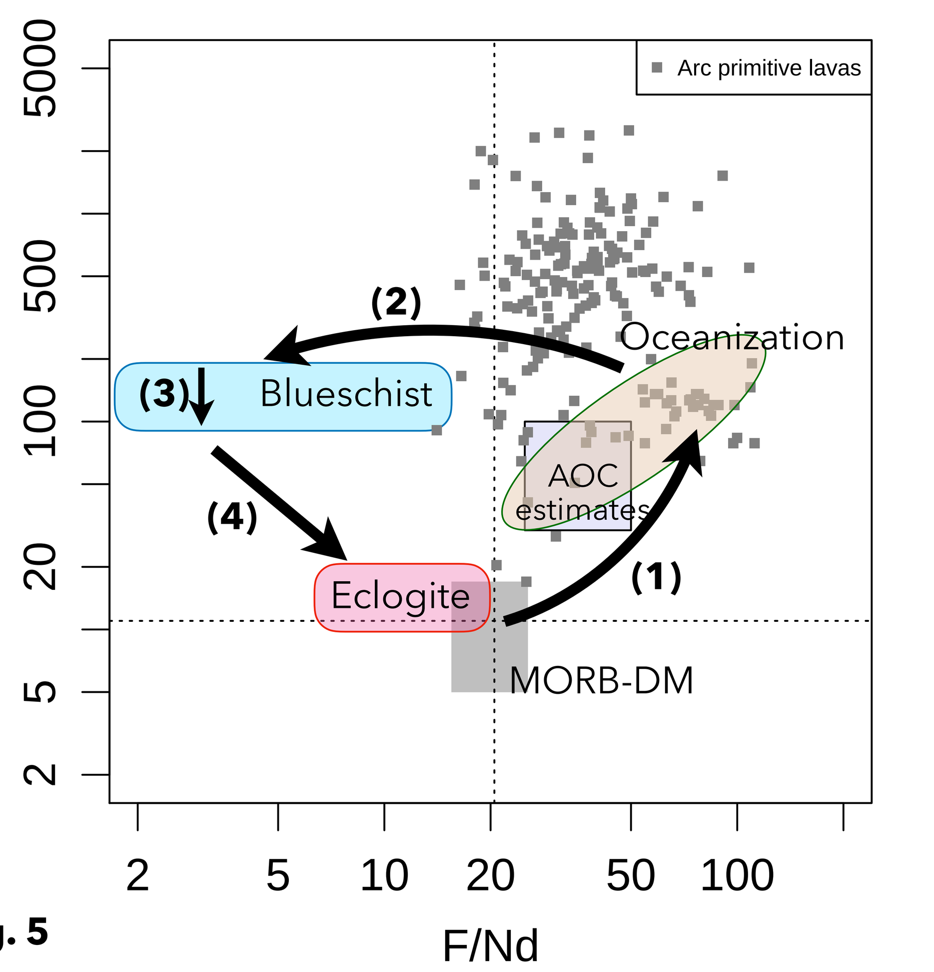


Fig. 5

(1) F and Cl are gained compared to other lithophile elements during oceanization (Fig. 7).

(2) F is lost during the initial stage of subduction (up to blueschist facies; Fig. 5).

(3) Gradual Cl loss during blueschist dehydration may occur (Fig. 9).

(4) Further loss of F and Cl (and Nd) during eclogite formation produces the composition similar MORB, but depleted in F/Nd.

Implications to chemical geodynamic of subduction zone

- Chenaillet ophiolite shows extreme halogen additions during oceanization.
- High F and Cl flux observed in arc lavas is derived from the subduction of an oceanized (= altered) lithosphere.
- Monviso eclogite composition is complementary to that of arc lavas. Furthermore, subduction of such eclogite suggests that a recycled slab component may possess lower F/Nd values than those of MORB-DM.

Oceanization - Making altered oceanic crust - Chenaillet

- Model bulk compositions of metagabbros are globally consistent with literature whole rock data as well as MORB and AOC. As metagabbros re-equilibrate to lower T assembly, bulk REE content decreases (Fig. 6).
- Low-T amphiboles contain less TiO_2, leading to low trace element abundance. F and Cl abundances decrease less than those of Nb and Nd, leading to the positive correlation in Fig. 7.
- Trace element ratios in amphiboles are comparable to those of the bulk.

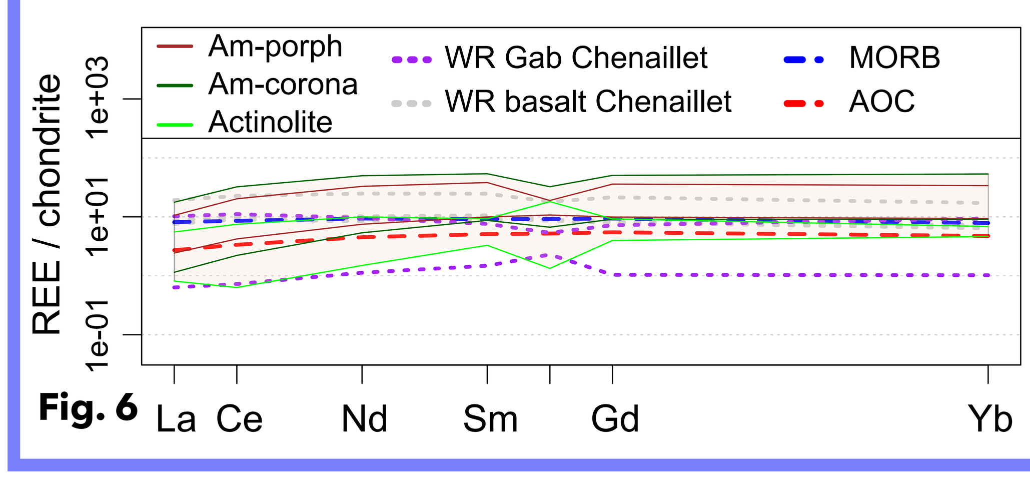


Fig. 6

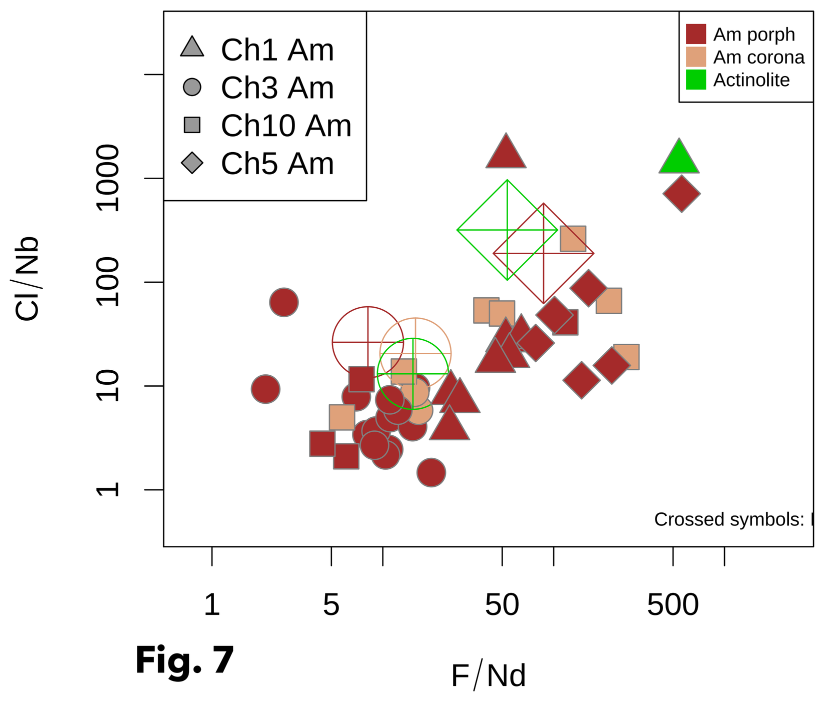
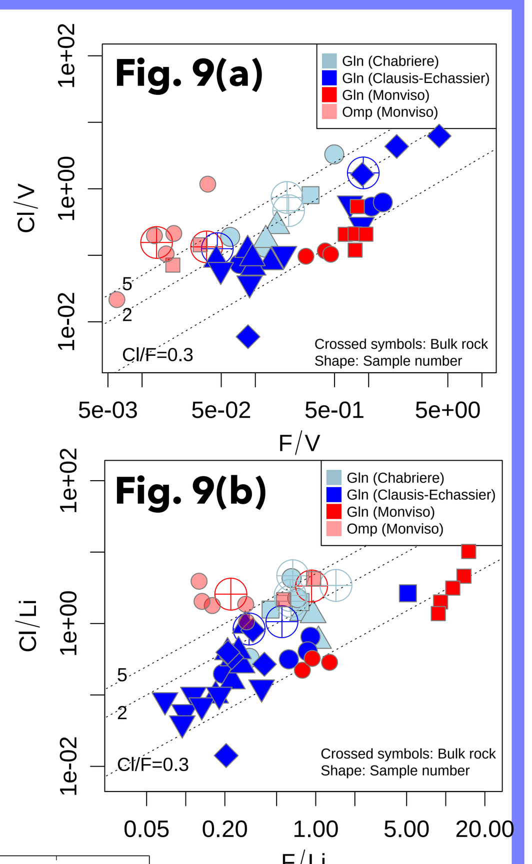


Fig. 7

Subduction dehydration - Queyras - Monviso

- Model metagabbro compositions in blueschist facies are similar to those expected for oceanic crust (Fig. 8).
- Trace element ratios in certain minerals can represent that of the model bulk composition (Fig. 9).
- Cl/F ratios in glaucophane decrease gradually during the prograde metamorphism. This suggests the preferential incorporation of F in glaucophane as its mode decreases with dehydration (Fig. 9).
- Eclogite formation results in significant F reduction compared to Cl, accompanied by LREE reduction (Fig. 10).



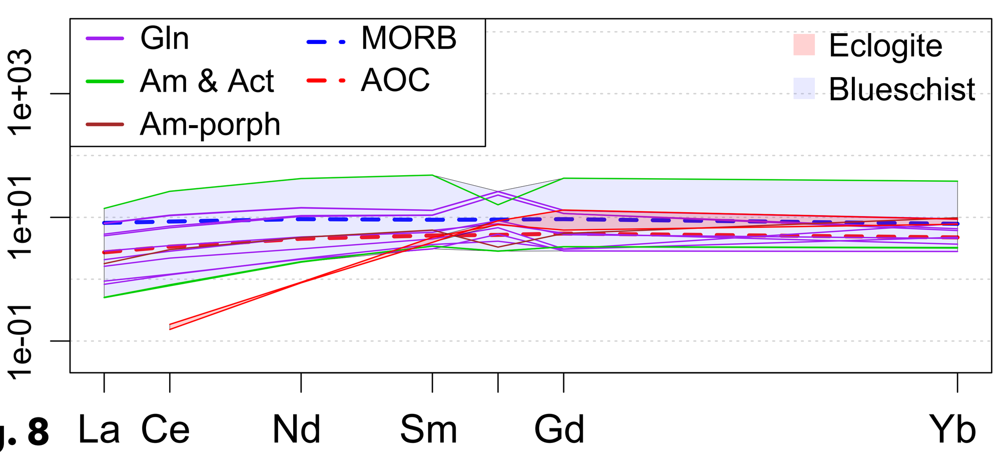


Fig. 8

Fig. 10