

Introduction

Fluids not only mobilise a variety of trace elements during both Alpine and Franciscan eclogite-facies metamorphism (e.g. Philippot and Selverstone, 1991; Sorensen et al., 1997), they are also thought to enhance rock deformation. To investigate the interplay of deformation and fluid-mediated mass transfer during subduction, we compared the bulk rock and mineral trace element chemistry within different eclogite terranes, to rock texture. Eclogites from Alpine localities (Voltri Massif, Monviso) represent both different P-T and fluid-rock regimes than those from the Franciscan Complex of California (USA).



Figure

Eclogites facies conditions when the three study areas were at their maximum recorded depth. Data from Brouwer et al., 2002 (Voltri MEL), Liou et al. 1998 (Voltri EE), Philippot and Selverstone, 1991 (Monviso), Sorensen et al., 1997 (Franciscan). Textures of the samples used for trace element spot analysis by LA-ICP-MS are tabulated. In all of the following figures, the sample numbers are followed by (c) for coronitic / gabbroic / undeformed, or by (m), indicating the sample is mylonitic / deformed.

Analytical techniques

Electron microprobe analyses were carried out at the JEOL 8900 at NMNH SI. Bulk rock chemistry was obtained by XRF analysis at NMNH SI, and ICP-MS at the geochemical laboratory of Washington State University. The LA-ICP-MS facility used at the University of Maryland consists of a Thermo Finnigan Element 2 single collector ICP-MS and a New Wave UP-213 deep UV Nd: YAG laser system. The data of Sun & McDonough (1989) were used for normalisation to MORB.

Phengite chemistry

K, Ba and Ti show different distributions in phengite in the three terranes.

In the Alps the phengites in Monviso generally contain less Ti than those in the Voltri Massif. Franciscan phengites are much Ti-richer, although their bulk rock is Ti-poorer.

Franciscan phengites have lower K/Ba than those from the Alps, mainly due to their 10 times higher Ba content.

In the alpine areas deformed samples generally show lower Ti in phengite than undeformed. In the Franciscan the trend appears to be opposite.



Figure 2

Log (K_2O / BaO) versus log TiO₂ in phengites of 10 samples from the three study areas, as analysed by electron microprobe.

So: Titanium (and likely other less mobile elements) in phengite does not depend on the bulk rock composition, and shows opposite trends (Franciscan vs Alps) with deformation. The Ti content of phengite is likely related to fluid activity. This suggests that in our sample suite fluid flow is unlikely to be deformation induced, and vice versa.

It is likely that the distribution of more mobile elements like the LILE depends even more on fluid activity.

References

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Figure 3

Trace element compositions of minerals obtained by LA-ICP-MS, grouped by mineral. Values are normalised to average MORB of Sun & McDonough (1989) and elements are in order of increasing mass. For comparison, the lower right graph shows the MORB normalised bulk chemistry of all samples

MORB normalised mineral chemistry

Bulk rock: our samples, especially those from the Franciscan, are enriched in LILE. Deformed samples (closed symbols) are more enriched than undeformed samples in virtually all measured trace elements, but otherwise the samples are similar. Apatite: Carries lots of LREE and also some HREE.

strongly depleted in Monviso.

from Monviso show) both types of behaviour.

Phengite: Strong enrichment in LILE, REE depletion. The variation between the terranes likely is the effect of fluids. In the Voltri massif few trace elements were enriched by fluids after an initial depletion event.

Titanite (and also Rt and IIm) : Enrichment in REE (not so much in HREE) and HFSE.

So: Different minerals carry different subsets of the trace element budget in eclogites. The minerals show variable behaviour, especially w.r.t. the light and middle REE. Phengite chemistry indicates different extents of fluids-rock interaction in the three terranes.

Conclusions

K, Ba and Ti show different distributions in phengites from Monviso, the Voltri massif and the Franciscan Complex. Phengite chemistry indicates that their trace element signature is entirely controlled by fluid activity, and not by deformation or bulk chemistry. Trace element distributions in minerals can be used to assess which minerals equilibrated with each other, and with exotic the fluids. Minerals may acquire their trace element signature from older minerals, that equilibrated with an earlier fluid, or with the bulk.

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- Epidote: Fans strongly at the LREE; lots of LREE in the Franciscan, much less in Voltri,
- Garnet: Attracts Y and the HREE. Some garnets are also enriched in the middle REE. Garnet



Figure 4

Bulk normalised mineral chemistry

metamorphism.

indicates that there may be an additional LREE host, possibly unanalysed apatite. phengite largely accounts for the LILE Sample M90-1A (c) shows a very similar trace element pattern.

So: Trace elements equilibrated between sets of 2, 3 or more minerals. Some minerals (Ep, Apt) inherit the trace element signature of other phases they apparently (partially) replace. LILE are mostly hosted by phengite, LREE by apatite and epidote, middle REE are taken up by apatite, epidote, titanite, and sometimes garnet, and the HREE are strongly enriched in garnet.

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VS35 (m), minerals bulk normalised VS36 (c), minerals bulk normalised Epidote Phengite — Titanite Garnet ⊂ H H H L C B S S C C B S S S Z ≺ S B EE43 (m), minerals bulk normalised EE53 (c), minerals bulk normalised T90-3A (m), minerals bulk normalised MH90-1A (c), minerals bulk normalised

Trace element compositions of all minerals analysed in each sample. Data obtained by LA-ICP-MS, grouped by mineral. Values are normalised to the bulk compositon of the sample, as obtained by XRF and INAA. The elements are in order of increasing mass.

Monviso: In VS35 (m) garnet and apatite show opposite behaviour, around D=1. Apt and Grt were in equilibrium and together account for the bulk trace element signature.

VS36 (c): Although garnet is still present, one epidote apparently inherited its signature from garnet. This points to inhomogeneous recrystallisation of this sample after peak

Gruppo de Voltri: In EE43 (m) one epidote inherited the HREE contents of apatite it replaced. This Ep was not in equilibrium with garnet, and is therefore probably retrograde.

EE53 (c): epidote and titanite equilibrated with garnet, ilmenite and rutile. The pattern

Franciscan: The garnet signature is distinctly different from that of the Alpine samples.

In sample T90-3A (m) garnet, apatite, epidote and titanite equilibrated w.r.t. the REE, while