Review

Epidote dissolition-precipitation during viscous granular flow: a micro-chemical ins osotope study

Authors

Veronica Peverelli, Alfons Berger, Martin Wille, Thomas Pettke, Pierre Lanari, Igor M. Villa and Marco Herwegh

Summary

The authors investigate a deformed epidote-quartz vein in the Central Alpine Aar massif in order to deduce metasomatic conditions during different deformation events and -mechanisms active during viscous deformation of the polymineralic vein. Petrological and isotope-geochemical data are interpreted together with micro-structural data in a way that the deformed and recrystallized epidote-quartz vein records fluid-mediated epidote crystallization through different deformation mechanisms that were active contemporaneously. The isotope-geochemical data suggest that externally derived syn-deformational fluids mixed with internal trace element reservoirs are supporting the dissolution and re-precipitation of epidote and controlling its isotope geochemistry. Furthermore, the authors interpret the observed textures to be the result of subgrain rotation recrystallization of quartz that caused significant grain size reduction and enabled grain-boundary sliding of the quartz-dominant parts of the deformed vein. Creep cavities resulting from grain-boundary sliding are interpreted to serve as nucleation and growth sites for the recrystallizing epidote that is formed by dissolution of pre-existing epidote and is structurally controlled re-precipitating.

General comment

The manuscript is generally well written in correct grammar and wording. The topic of the manuscript is interesting for structural geology as well as for petrology and geochemistry. The topic is of general relevance as it investigates a global process, i.e. fluid mediated dissolution and re-precipitation of metamorphic minerals, in a local example. The geochemical data presented in this manuscript are of high quality and display a wealth of information about the effect of fluid mediated syn-metamorphic element transport on age determinations in metamorphic minerals. The manuscript is therefore well suited for publication in EGUsphere. However, I see a major shortcoming of the manuscript in the fact that the authors not only interpret the geochemical and textural data in an isotope-geochemical way, but also try to deduce a certain deformation mechanism, i.e. grain boundary sliding, as well as a certain fluid transport mechanism, i.e. granular fluid pumping, from the investigated samples. Whereas the reader can easily follow the authors' arguments regarding the nature and chemistry of the metamorphic fluid that serves as element transport medium for the precipitation of a second epidote generation in their samples, the interpretation of the data in terms of a certain deformation mechanism is highly speculative and not supported by the presented data. I suggest to redirect the focus of the manuscript away from the structural interpretation and put more emphasis on the interpretation of the geochemical data in terms of element transport properties of the metasomatic fluid.

Apart from this major criticism there is a small number of points that should be addressed in a revised version of the manuscript. In general, most of the figures, at least in the version

that I got, are too small and of mediocre quality. Several of the features that are supposedly shown in the figures are actually not (well) visible, hence it is sometimes difficult for the reader to follow the authors' arguments.

Furthermore, some of the paragraphs need substantial reworking, such as the section of the geological setting as well as parts of the sample description.

However, I generally found the manuscript interesting in a geochemical way and I am looking forward to its publication. Nevertheless, I think the manuscript needs some major revisions and a slight change in its focus, as the micro-structural data does not support the viscous granular flow model for the observed structure.

In the following I will give some detailed comments on specific text passages.

Specific comments

Line 32: … and by the physical conditions …

Line 34: … this type of interpretation …

Line 50: as there is a large number of publications that concentrate on fluid fluxes in deforming and static environments I wonder whether the authors should speak of "rare characterization" of those fluids.

Lines 57-59: This sentence is reporting results and interpretations and is a bit odd in the introduction.

Line 64: I see that the importance of epidote for geochemical and petrological processes might be underestimated, but to claim that it has important implications on the structural evolution of the continental crust …, that sounds a bit odd ;-).

Line 66: Fig. 1 is too schematic. The reader cannot really oversee the position of the Aar massif in the Alpine chain. I am not sure whether this is important, but if the authors decide to talk about the regional geology this should be a bit more precise.

Lines 69-71: what is meant by the polycyclic basement? Please be more specific.

Lines 72-73: … and mainly records Alpine deformation … . What else deformation apart from Alpine?

Lines 81 ff.: The documentation of the metamorphic conditions in and the metamorphic evolution of the Aar massif could be a bit more structured and concise.

Lines 89-90: Miocene and Permian ages? Either you should skip this information or be more precise here.

Line 92 and following: Can you please tell the reader what NAGRA is and be a bit more informative about the Grimsel test site.

Line 94: What is the characteristic pattern of shear zones?

Line 95: … runs oblique to a steeply dipping shear zone … . Oblique to which direction?

Figure 2 is not very informative. What are the different lines in a)? Both, a) and b) are way too small.

Lines 97-100: why are there three samples described although only one of them is investigated? The information about the other two samples is not used throughout the entire paper, or am I wrong?

Figure 2 is informative, but too small and the weak foliation mentioned in line 114 is not visible.

Line 120: abundances of what?

Line 121: Grimsel-1? Has this sample been introduced before?

Lines 123-124: It would be nice if there were some pictures that demonstrate the different deformation mechanisms in the different layers.

Lines 125-127: This sentence is an interpretation and should be moved to the discussion.

The methods section is very detailed and precise!

Line 223: Which microstructural domains? Please define.

Line 226: This epidote layer … . Is that layer 1? If so, please mention.

Lines 235-236: Pictures of the recrystallized quartz would be nice.

Lines 244-246: the irregular and curved epidote grain boundaries are not visible in Fig. 6 nor are the euhedral grains highlighted.

Lines 254 ff.: What is the Zener relation? I am not sure whether the ordinary reader of that journal is aware of that, especially as the connected citation of Herwegh et al., 2010 does not appear in the reference list.

Lines 256-257: … may have favored dislocation glide, … . This is interpretation and should go to the discussion. Furthermore, if this quartz grain is so important that it gets 2 lines in section 5.1.2. why is the figure showing it in the appendix?

Line 275: It is not fully clear to me where layers 2 and 3 are visible in Fig. 10.

Line 285: Would it be possible to perform a microprobe mapping of the epidote 2 crystals with a higher spatial resolution in order to see whether they are zoned? I think 1µm resolution should be possible.

Fig. 11: What is the red area in Fig. 11c? Are those epidote 2 analyses?

Fig. 12: the CL contrast within the quartz grains is barely visible. In the figure captions b) is missing. I guess b) shows a transmitted light image of the CL/BSE image.

Line 321: what is the “geological heterogeneity”?

The presentation of the isotope data is very good and convincing. I also find the interpretation of the geochemical data very convincing until the authors start the discussion about the deformation mechanisms in line 386.

Line 386 ff: The authors state correctly that dynamic granular fluid pumping is ONE mechanism that is enabling an effective fluid migration and element transport. However, in the following they do not present convincing evidence that this mechanism was actually active nor do they discuss other mechanisms that enable the establishment of an interconnected transport matrix. Fluid transport along interconnected grain boundaries seems to be very common in metamorphic rocks and solely the texture that is resembling

the potential structure of cavities resulting from grain boundary sliding is not really convincing.

Lines 402 ff.: In contrast to the afore paragraph the discussion about the fluid source and the fluid-mediated element transport is very clear and convincing.

Line 421: Better: … the major and trace element chemical composition … .

Line 423: couldn't the system be fluid buffered as well?

Line 429: … of all measured elements … .

Line 438: I do not agree that "this result bears important implications on epidote crystallization mechanisms."

Line 440: Epidote A is chemically zoned, thus there are different "generations" and as there is no documentation of the zoning properties (step-like, oscillating, gradual) pulsating fluid fluxes cannot be ruled out. The MSWD just says that within the certain age population there is no difference visible.

Lines 443 ff. as well as Fig. 11: It would be nice to see whether there is a correlation between the Pb/Sr plot and the LA spot position within the epidote A grains (e.g., a core-rim Pb and Sr correlation in Fig. 11).

I hope my comments and suggestions are helpful and can be used to improve the manuscript. I apologize for the long time I needed for the review and send my best regards from Gothenburg

Matthias Konrad-Schmolke