Review: **Fault-controlled dolomitization in the Montagna dei Fiori Anticline (Central Apennines, Italy): Record of a dominantly pre-orogenic fluid migration**

This paper presents field, petrographic, isotopic, and fluid-inclusion thermometric and compositional analyses of the different dolomitization and calcite veining events that affected Lower Jurassic rocks within the Montagna dei Fiori Anticline. The authors conclude that dolomitizing fluids show evidence of interaction with underlying units and therefore infer that dolomitization was fault related and occurred in two main episodes, before and during the Apenninic orogeny.

This manuscript is organized in a logical manner and the data presented appears to be of high quality. Conclusions are for the most part well supported by the data presented in this study. My main concerns are: 1) A proper assessment of the spatial distribution in outcrop of the different structural diagenetic products is missing. Moreover, their relationship with the anticline and faults is difficult to establish because no orientation… etc. data are provided. It seems like an opportunity was missed to use outcrop exposures to their full extent. 2) Description of cross-cutting relations of the different calcite-filled veins and dolomite cements is vague. Breccias need to be properly described and documented, probably in their own section. Fracture cements described as vein cements (CV) are presumably also present in the host rock, although no description nor documentation are provided. In that case, the use of CV to refer to these cements would be inappropriate. 3) Isotopic signatures and fluid inclusion temperature and salinity ranges of most cement types overlap, but they are used to relate them to different tectonic/fluid events. The one I am having most trouble with is: why would D3 be considered hydrothermal if the temperatures of inclusions in these cements are exactly the same as those of inclusions in D2, which are not considered hydrothermal? Also, Sr/Sr in D3 are much higher than in D4 but both are considered to have been precipitated from the same fluids? 4) The impact of this work would benefit from a discussion of the implications of fault-related dolomitization processes in general, with application for porosity/permeability evolution and fluid-flow in analogous, dolomitized, carbonate-hosted reservoirs and aquifers within similar structures. What is the main driver for fluid circulation? What changes are required in the system to go from dolomite to calcite cementation? When and why did this occur? 5) How is this study better than that of Ronchi (2003)? In which way did it advance the field?

This work would benefit from a final edit by a native English speaker. Below I provide some suggestions to improve the language and punctuation, but the authors should take these with care because (warning!) English is not my first language. I would recommend publication of this manuscript after the concerns raised here have been properly addressed.

Specific comments:

1) Abstract: The abstract can be shortened substantially, yet it is missing key information. It provides too much detail of some aspects of this work but lacks equivalent detail in other cases. For example, why are calcite-filled veins not mentioned here? Weren't they a main focus of this study? A more succinct and balanced abstract is required. Also, the abstract would benefit from a "punchline" or statement of the broader implications of this work at the end. What did you learn about the extent of dolomitization near faults? How is this relevant for porosity/permeability evolution and fluid flow in dolomitized, carbonate-hosted hydrocarbon reservoirs and aquifers?
2) Introduction: You may want to consider adding a short statement about why some fault-zones become dolomitized but others don't. What are the requirements? What can you learn from outcrops that you cannot from core alone? I would say that the main benefit would be the opportunity to assess the spatial distribution of dolomitized zones, and individual diagenetic events, in 3D. Addition of such a field-relations analysis would greatly improve the impact of this work.
3) Geologic setting: This section is a bit long and could be shortened.
4) Methodology: A few things are missing:
    - How large of a geographic area did you sample?
    - How did you decide which areas to sample for isotopic analyses? Did you image them first? How? How confident are you that you didn't mix different cements when sampling?
    - How many fluid inclusions in your FIAs? What was your reproducibility and error? How did you make sure you did not measure stretched inclusions?
    - Documentation of where hand samples came from is very poor. This can be improved by showing the location of the thin sections on outcrop photos, and their spatial relationship with faults etc. These might need to be included in an appendix due to space restrictions, but it is important.
5) Field observations
    - What is the spatial distribution of the dolomitized geobodies?
    - And of the veined sections?
    - 6 outcrop locations are marked on Figure 2 but distributions of the different types of cements are only shown in one image (figure 5b). These are very important relations to assess fluid pathways and the evolution of dolomitization.
    - What are the orientations of CV1–CV4 cement-bearing fractures?
6) Petrography
    - How much calcite cement is there in the breccias? What are the textures? Why are these not included in your diagenetic evolution analysis? How do cements in breccias relate to those in host rocks? Are cements in the host rocks affected by brecciation? Show examples.

- How did dolomitization affect porosity in both host rock and fault rocks? How does porosity compare between limestones and dolostones?
- Some of the petrographic relationships mentioned need to be backed by images (see my line-specific comments)
- The order in which dolomite cements and vein-calcite cements are mentioned needs to be improved.
- What is the relationship between MC and D1/D2? Where is this documented?
- What is the distribution of CV cements in the host rock (see Laubach, 2003)? This should be properly documented and reported. I don't think vein cement is an appropriate term for these calcite cements. Also, keep in mind that the occlusion of fracture porosity by postkinematic cements can significantly postdate the timing of the opening of the fracture (see Ukar and Laubach, 2016). In other words: the timing of fracturing and cementation are not the same. Keep that in mind in your descriptions.
- The observation of CV3 in breccias is quite interesting. Document and show images. What other cements are there in breccias? How did you establish the relative timing of these cements and others? Breccia cements should not be referred to as vein cements.
- What are the spatial distributions of the different cement types?

7) Geochemistry
   - What are the isotopic characteristics of MC and fibrous cements?
   - Interpretations, especially for Sr ratios, should be moved to the discussion
8) Fluid inclusions
   - Show images of the different types of fluid inclusions, especially the FIAs.
   - The graphs used to summarize fluid-inclusion thermometric results are not appropriate because key information is lost. Same for salinity. Please replot the data so that the temperature range for each individual FIA is shown. Did you measure an equal amount of FIAs for each type of cement? Otherwise, frequency would not very meaningful in Fig. 13 because it would be sample and cement availability dependent.
   - Why are CV temperatures not shown in these graphs?
9) Discussion
   - This section can be significantly shortened by avoiding repetition of results.
   - I think parental fluid calculations should be shown in the results section, not in the discussion.
   - Use parallel writing style for stable isotopes and Sr discussion.
   - D3 shows significantly higher Sr/Sr than D4. How can both be related to the same event and derived from similar fault-related fluids? D1 and D2 are also fault-related. Why the differences in isotopic signatures, especially if all are related to basement-rooted faults???

- The association of D3 and D4 with bed-parallel and shear fractures is mentioned for the first time in the discussion. This needs to be mentioned in the results. Are the cements themselves sheared? Show evidence.
- Discuss the spatial distribution of the different cement and vein/breccia types. What do they indicate about fluid-flow patterns?
- The orientation of CV1–CV4-bearing fractures needs to be taken into account in the structural interpretation
- Section 5.3: Without a better documentation of the orientations and field relations of the different cements and fracture types it is difficult to assess the validity of the inferred paragenetic sequence and the association of the different cements and structures with tectonic events. Some of the spatial and cross-cutting relationships between different types of cements are first mentioned in this section. Such descriptions should be moved to the results section.
- What is the driver for fluid circulation? Why are they Mg-rich fluids? What do fluid-inclusion salinities indicate?
- Why do you go from dolomite replacement and cementation to calcite cementation?
- How are your findings relevant for porosity/permeability evolution and fluid flow in dolomitized, carbonate-hosted hydrocarbon reservoirs and aquifers associated with similar reservoir-scale structures?
- How are your conclusions applicable to dolomitization processes associated with faults in general? How far can dolomitizing fluids travel and to what extent do they alter the mechanics and porosity/permeability of the host rock? What are the consequences for fluid-flow in these rocks?

10) Conclusions
    - More thought needs to go into the conclusions section.
    - I don't think enough data are presented in this study, especially of cross-cutting relationships and orientations of the different "deformation structures" to support the structural interpretation presented in the conclusions. For example, where is the evidence that the opening-mode fractures (no orientations or relationships within the anticline are reported!) and normal faults mentioned in this study are associated with contractional tectonics of the Apenninic orogeny?
11) Figures and figure captions need work, especially the model shown in Figure 15 (see comments in figure caption).

Lines 29-31: This needs to be re-written. Layer-parallel shortening would not give place to layer-parallel stylolites. Extensional faulting by itself either. Involvement in the Apenninic thrust wedge of what?

Lines 48-54: May I suggest you take a look at the recently published Ferraro et al. (2019) paper for a description of the diagenetic evolution of carbonate fault rocks in the central and southern Apennines?

Lines 54-58: You may want to consider adding a short statement about why some fault zones become dolomitized but others don't. What are the requirements?

Lines 58-61: What can you learn from outcrops that you cannot from core alone? I would say that the main benefit would be the opportunity to assess the spatial distribution of dolomitized zones, and individual diagenetic events, in 3D. Perhaps a missed opportunity in this work?

Line 67: I don't see Bugarone in Figure 1.

Line 69: I don't see catel Manfrino Dolostones in Figures 1 or 2.

Lines 72-73: How is your study better than Ronchi (2003)?

Lines 76-78: In Figure 2 it appears that dolomitized bodies are found quite far away from faults, beyond the typical lateral extent of fault damage zones. What is the explanation? Why are some faults associates with dolomitization while others aren't? Does it have to do with age of faults? Other factors? This would be a good topic for the discussion.

Line: 84: I would have liked to see more "field mapping" of the extent of D1–D5 and CV1–CV4 in this work.

Line 87: This sentence should start with a different word than "therefore". What provides insights? How?

Lines 88-89. Yes. This needs to be discussed in the discussion.

Lines 90-92: Yes. This needs to be discussed in the discussion.

Line 96: evolution of the Apennines has been proposed to be the result of

Line 98: since the Late Cretaceous

Line 103: The Central Apennines involve

Line 110: lower part of the Burano Formation

Line 115: Deposition of the Hettangian–Sinemurian Calcare Massiccio Formation, with a total thickness …

Line 117: following facies are present

Line 125: deepening-upward trend

Line 137: olistolith model

Lines 138-145: So, does this evidence favor the fault-related model or does this evidence provide an alternative model? Why does this sentence start with ‘However”?

Line 151: at a high angle

Line 162-163: 60 samples distributed across how big of an area?

Line 164: What structures?

Line 187: Vienna Pee Dee Belemnite

Line 215: In order to perform high resolution

Lines 220-221: bed-perpendicular stylolites

Lines 224-230: This belongs in the Geological Setting.

Line 225: There is no evidence of dolomitization

Lines 231-234: Location names need to be included in figure captions.

Lines 235-239: This seems out of place. Start by describing mesoscale relations and distributions of dolomitized geobodies. Then focus on hand-sample and petrographic details.

Line 235: in fault cores are typically

Line 237: is “main slip surface” a better term?

Line 238: cut by rather than overprinted. Are dolomite-filled veins intra- or intergranular?

Line 239: calcite cement

Line 241: cross-cutting bedding surfaces

Line 242: from a few meters to hundreds of meters

Line 243: and the lower part of

Line 246: High amplitude (>1 mm), bed-parallel stylolites

Line 247-248: How does porosity differ between limestones and dolostones?

Line 253: grain-supported intervals

Lines 259-260: Evidence?

Line 265: we can’t see the displacement mentioned in Figure 2A, site 1

Line 267-268: Are they overprinting or overgrowing? Show evidence. We also cannot see the distribution of the different cements at outcrop scale.

271-272: On what basis did you establish that the replacive dolomite within the host rock (D1) and lining fractures is the same?

Lines 275-276: solid inclusions of what? Insert figure call out for concentric zonation.

Line 281: sweeping extinction

Line 282: In some crystals, one… what types of solid and fluid inclusions?

Lines 286-291: Mark locations on map/figure captions and call out the figure.

Line 290-291: Scaglia Formation in the hanging wall.

Lines 293-295: This needs to be moved up

Line 305: bed-parallel shear fractures

Lines 308 on: There is a problem with CV introduction. What does it stand for? Must introduce them in chronological order. If the calcite cement is in veins it is most likely in the host rock as well (see Laubach, 2003). I don't think calling it vein cement is appropriate.

Line 308: What porosity?

Lines 318-320: Show outcrop photo?

Line 319: bed-perpendicular rather than bedding because that's what you use elsewhere. Make sure term usage is consistent throughout.

Line 321: bed-parallel stylolites. CV1 usually shows (often means time. Correct elsewhere in the manuscript).

Lines 324-326: Show image of CV2 in tension gashes

Line 332: extensional fault's master (main?) plane

Line 339-340: More evidence that the use of CV to refer to calcite cements that occur in a variety of textures and petrographic relations is not appropriate.

Lines 361-364: Why is this mentioned here and not with the rest of the calcite cements?

Line 396: I see 3 values plotted for Scaglia.

Lines 398-399: Interpretation. Move to discussion. Same comment for previous paragraphs.

Lines 401-411: This belongs in the Methods section.

Lines 409 and 439: all-liquid inclusions

Lines 439-445: This belongs in the Methods section.

Lines 469-470: This belongs in the methods/results. Why did you avoid them? Could mottled D be a different type than those reported?

Lines 471-474: Move to methods. Report parental fluid calculations in the results section.

Line 478: Progressively higher than what?

Line 481: siliciclastic rocks,… Correct here and elsewhere.

Line 493: , or values recorded… Add references.

Lines 499 and 505: Replace comparable with similar. Here and elsewhere.

Line 507: stylolitization of the host rock (otherwise we do not know what dissolution etc. you are referring to).

Lines 527-528: fluids related to Late Messinian… overlying Upper Miocene Laga Formation and their possible…

Line 543: burial-related temperature

Line 544: it is unlikely that the..

Line 546: located at higher stratigraphic levels

Line 564: calcite cements (FC) in grain-supported stratigraphic levels of the CMF is interpreted to be…

Line 570: bed-parallel stylolties

Line 574 and 575: are cut by

Line 579: Figure 15A call out.

Line 585: We cannot see the distribution described in Figure 2A.

Line 587: attributed to post-rift

Line 588: Although an absolute age cannot be provided,

Line 603: bed-parallel fractures. This is the first mention of shear veins for D4. Are the cements sheared? Show evidence.

Line 604: Contractional deformations? How? Describe relationships better. Bed-perpendicular dilation alone would not cause shear.

Lines 608-610: First mention of this. Move to results.

Lines 618-619: bed-parallel veins

Line 622: fragments suggests that… late-stage evolution

Line 624: bed-perpendicular stylolites

Line 624-629. This is way too long. In any case, there is new information here that needs to be moved to the results section.

Line 629: low homogenization temperatures of fluid inclusions trapped within these cements

Lines 638-642: So, how is your study better? How are your conclusions applicable to dolomitization processes associated with faults in general?

Figures: Documentation of where samples came from is poor. Locations of samples need to be shown on outcrop photos and/or detailed maps. Add in appendix if space is limited.

Figure 1: Tiny name in a) is unreadable. Mark location of cross-section (A-A') shown in d).

Figure 2: Add names of each field site to the figure caption.

Figure 3: The picture in a) is too close up to see the context. Mark distribution of D1 etc. as in Fig 5d. Why isn't there more on these breccias (c) in the manuscript? Explain what arrows point to. Pressure solution seams. You are not showing intensity (it would be a number). Perhaps say showing abundant pressure solution seams. What are the abutting relationships? Which abuts which? Move arrow in b) so that the vein is actually visible. Are the other white pods also considered "veins"?

Figure 4: Show spatial distribution of D1, D3, CV1… etc. at the outcrop scale. The sentence seems to say that CV1 veins are dolomitized. Is that what you really mean? What is the dolomite type in b) and c)? Good opportunity to show cross-cutting relationships summarized in Figure 14.

Figure 5: What field site(s) and formation(s) are these from? In b) the zone shown in c) is marked as only having D1 but as D1 + D2 in c). Which one is correct? Any CV2-CV4 here?

Figure 6: What field site is this? rimmed by fibrous cements (FC), which are overgrown by mosaic cements (MC). overprinted. bed-parallel stylolites. D1cements lining a fracture. What do

arrows point to in f) If it is D1, then what is to the right of it? Line 1123: which is cemented by CV1 in the center.

Figure 7: What field site(s) and formation(s) are these from? What is beyond D3 in e) and f)? Is D3 only present in breccias in this site? What is the CL signal of D3 in breccias and how did you establish correspondence with D3 in host rocks? What is the context of the sample? in e) and f)

Figure 8: What field site(s) and formation(s)? D3 and D4 are not cross-cutting but it appears that D4 overgrows D3. What is the D4 arrow in b) exactly pointing to? What cement is in the rhomb on the upper right corner? d) I am having a hard time seeing the microfracture. What CV is this? Or do you have dolomite-filled veins as well? Where are these described? What other cements are in e) and f) and what do arrows point to? Lines 1141-1150 belongs in the discussion.

Figure 9: What field site(s) and formation(s)? If D4 also occurs in fractures why is it not called vein cement as in your CV scheme? What other cements and/or host rock are in these photographs? Add labels.

Figure 10: These photographs are too close up to see the context. Outlining obscures fractures in a). c-d) These do not look like tension gashes to me (as mentioned in text?). Mislabeled as CV2 on the picture (?) but CV3 in the figure caption.

Figure 11: What field site(s) and formation(s)? What is a) a sample of? And the rest? Show field context.

Figure 12: Why aren't these figures in color? The symbols are too similar and they are hard to distinguish from one another. I would assign a color to each formation and a symbol to each diagenetic feature.

Figure 13: These plots are not very useful because key information is lost. Plot homogeneization and ice melting T ranges so that variability within individual FIAs is captured. Color would help, Also, where are the data for CV cements?

Figure 15: The fracture in a) would not have that orientation if sigma 1 were vertical. Indicate which fault you are referring to in b). The vein in b) would not develop in that orientation if sigma 1 were horizontal. Also, keep in mind that the timing of cementation of the veins by postkinematic cements (see Ukar and Laubach, 2016) postdates timing of opening of the fracture. Don't mix the two! I had no idea that CV4 is restricted to the MdFF until now, because it is not mentioned anywhere in the text. How do you reconcile D3 to be surrounding breccia clasts within the MdFF in this model and sequence?

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