Solid Earth Discuss.,
https://doi.org/10.5194/se-2019-153-AC2, 2020

Solid Earth Discussions

Interactive comment on "Diagenetic evolution of fault zones in Urgonian microporous carbonates, impact on reservoir properties (Provence – SE France)" *by* Irène Aubert et al.

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Received and published: 9 January 2020

Dear referee, I am pleased to send you the revised version of our paper on "Diagenetic evolution of fault zones in Urgonian microporous carbonates, impact on reservoir properties (Provence – SE France). You will find enclosed in the supplement, the comments and corrections to your remarks. They are listed together with the actions made: - Comments are in italics - Corrections validated are emphasized in green - Corrections with a red bold part are considered un-useful or inappropriate You will see that most of corrections have been respected as you requested. Best regards, Irène Aubert

I. General remarks by the referee #2 - The English language and grammar needs

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to be improved. The use of the article “the” as well as singular and plural is often misplaced. I understand, such things may be difficult and maddening for non-native speakers (I am non-native myself), but at least consistency can be paid attention to. As an example: “fluids-rock interactions” (line 8) vs. “fluid-rock interactions” (line 11) vs. “fluids-rock interaction” (line 37). Also the use of lower- and upper-case needs to be consistent (“early Aptian”, “Early Aptian”, “early cretaceous”, “Late-Cretaceous”, “Late cretaceous”, “La Fare”, “La fare”: : :). Such things are very annoying and only distract the reader from the scientific content. - Done

- Also typos are frequent, e.g. “height cement stages” (lines 17 and 206) instead of “eight cement stages”, or “d18C” (header of table 2) instead of “d18O”. - Done

- Throughout the manuscript, the structure needs to be improved. Repetitions of content frequently occur. One example in lines 113-124 “The structure of both polyphaser fault zones results from three tectonic events: [list of events]. These tectonic events impacted the fault zone and fault core structure.” - Done. The structure of this part has been modified

- Consistency is needed in decimal places. Occasionally two or one decimal places are given for the same type of data. - Done

- Consistency is needed on writing out numbers (e.g., “2” vs “two”, “62” vs “A hundred and eighty-nine” (line 250)). - Done We decided to write the numbers at the beginning of sentences in letter and in the rest of the sentence in digit. Introduction: - The introduction is quite chaotic and difficult to follow. It repeatedly jumps from describing lithology/stratigraphy to describing fault zones. Moreover, though the sentences are not identical, their content is often repetitive. Corrections have been realized after referee 1 comments

- The authors should reconsider if they want their study area only to be understood as an outcrop analogue to Middle East carbonate reservoirs. - the precision has been added. “Although Urgonian microporous carbonates of Provence are analogue to Middle East reservoirs, the analogy can be extended to other faulted microporous carbonate reservoirs.” (lines 52 to 54)

Geological context / Data Base - Same as in the introduction, there is a mixing and jumping of the description of stratigraphy and structure. This needs to be clearly separated. - Here the basin stratigraphic evolution is related to the structural evolution. As they are closely related, it is difficult to separate them.

- Figure 1 caption starts with “Geological context of the study area”, but only a geographical outline of France is shown. Also coordinates are missing, and it is essentially impossible for someone not familiar with the study area to readily locate it. Marking the study area in the map inset with a rectangle much larger than the area of interest and only providing “near Marseille (Fig. 1A)” (line 76) is not sufficient. We added a regional map and coordinates within the figure 1 to precise the location of the study area.

- In the chapter “Data Base” it is not clear if its content is derived from the authors analysis or from existing literature. If it is the former, it should be moved to the results chapter. Done. The structure of this part has been modified

- The data base deals with faults, sub-faults, sets, transects, units, etc.. This easily gets very complicated and therefore it is paramount that the paragraphs are well structured to guide the reader through this complexity. Unfortunately, at the moment, this is not the case. As an example: Line 106 “The set one, constituted of F3 and F4, is: : :”. The problem here is that F3 and F4 have not been defined before. Hence, the reader does not understand this abbreviation and is left in confusion. Done. The terms have been defined

Results: - In Figure 3c, pore types are shown. First, the resolution of the photos must be improved. And second, and this is now maybe more a matter of perspective, but it seems that the two blue pores are just the result of grains falling out of the sample during thin section preparation. Either way, from the picture shown, it is very difficult to reconcile that the host rock has a porosity larger 10 %. - The quality of the photos correspond to resolution of the Olympus_ BH2 microscope and to a Zeiss_ MR C5 camera. The porosity of the sample is mainly due to micro-porosity (the precision has been added) “From thin sections impregnated with blue-epoxy resin, a porous rock-type with φ>10% mainly in micritized grains as microporosity and moldic porosity” (lines 70-71). Moldic porosity only represent $\sim$1% of the porosity in such microporous carbonates (see Fournier et al 2011; Léonide et al., 2014, Fournier et al ; 2014). The majority of porosity is within the micro-pore of the micrite (non-visible on the photo; size < 10μm; (Deville de Periere et al. 2011)). In any case the porosity related to grain falling is <1% of the total porosity.

- Subchapter “Carbonate and Oxygene Isotopes”: This is again about consistency, and please excuse for being picky: 189 measurements have been made on 16 samples and 32 thin sections (Line 250; set aside the confusion of what the difference between thin section and sample is), and these distribute on 49 bulk rock, 48 vein, 40 fault rock, and 26 intergranular space measurements. The latter list however adds up to “only” 163 measurements. And table 2 shows even 204 measurements. How do these numbers fit? The correction have been done. We homogenized the number of measurements

Chapter IV, 2: Fault related diagenesis - The start of this chapter deals about potential dilation and I am afraid this discussion is on a weak basis. The authors themselves mention that “[dilation processes under low confining pressure] is only possible in highly porous granular media.” (line 344). It is my impression that this attribute does not apply to the here analyzed rock, which is described as cemented and only comprising “>10 % porosity but located in the grains” (line 336), i.e. secondary porosity due to partially dissolved grains. As a comparison, Alikarami & Torabi (2015), to which the authors often refer in this regard, deal with quartz sand with porosities of 33-45 % of primary origin. This is a significant difference. - When the dilation band nucleate, the host rock was not totally cemented and presented porosity higher than the current one. Though, we made a more marked separation between description of dilation bands within highly porous rock and Castellas host rock.

- In line 358 it is claimed: “In the Urgonian carbonates of La Fare sector, dilatant processes enhanced fluid circulation in the rock along the deformation bands and led to the cementation of C1b”. Unfortunately, deformation bands in the study area have neither been mentioned nor described before and thereafter in the manuscript. - The instability of dilation bands would have led to a collapse of these structures. Moreover, as the dilation bands occurred as an incipient faulting mechanisms, the later fault development and reactivation would have altered the dilation band morphology.

Line 381-400 deal with formation temperatures of cement generation C3: “- For the calculation, “the formula of Ali (1995)” is used. 1. Ali (1995) presents more than one formula. 2. Ali (1995) is not the original reference! It is Epstein et al. (1953) and Craig (1965) that needs to be cited. 3. As far as I know (I might be mistaken), the equation of Epstein et al. (1953) is based on biogenic calcite. The authors might want to check the equation of Kim & O’Neil (1997, Geochimica et Cosmochimica Acta) for inorganic calcite. Though in the end it might as well not make a significant difference for the authors calculation. - “temperature of initial fluids: 33_C to 34_C (Littler et al., 2011)” 1. What is meant with “initial fluids”? 2. Littler et al. (2011) present own data on paleo-sea-surface temperatures, which they set in comparison with existing data. The temperature range extends beyond 33-34_C. 3. If original data of Littler et al. (2011) is used, this means that data of the Hauterivian (133-129 Ma) is used. The authors however give an age estimate for C3 as _Cenomanian (101-94 Ma). This may be a significant age difference and suitability of the Hauterivian temperatures for the calculation needs at least be discussed. 4. If the data quoted by Littler et al (2011) is used, then the original work needs to be cited. - “meteoric water: -4.0 d18O (Robinson et al., 2002)” 1. This is the same as with Littler et al. (2011). Robinson et al. (2002) present data from the Barremian, whose suitable application needs to be discussed. 2. The -4.0 value is an average of Robinson et al. (2002) data. 3. Most important: the -4.0 d18O of Robinson et al. (2002) refers to d18O of carbonate and not to d18O of the fluid from which the carbonate precipitated. - Line 393: “We calculated a C3 fluid temperature 40_C and 60_C.“ 1. As the authors do not guide through the calculation and how the parameters have been applied, it is impossible to follow how these values have been determined. - For the calculation of the formation depth, a geothermal gradient of 26.4_C/km (Ali, 1995) is used. Such precision is quite ambitious." - We removed this part. We decided to remove this part from the manuscript for 2 reasons: (1) to shorten the "fault related diagenetic" part and, (2) δ18O during Durancian uplift (Aptian/Albian) was difficult to estimate. Moreover, the association of burial/uplift curve and δ13C values allow an interpretation of the fluid origin. "As C3 cementation occurred during the Durancian uplift and denudation, C3 most probably did not cemented at high depth (depth of maximum 500m; Fig. III. 9C4).The negative δ13C values tend corroborate that it would rather be a meteoric fluid than a marine fluid." (lines 353-356)

- Line 395: "The negative d13C values tend to indicate that it would rather be a meteoric fluid than a marine fluid." 1. The presented d13C data range from -2.09 to +1.22. Did the authors rather mean d18O? 2. Why does it indicate rather a meteoric fluid? This needs to be discussed. The d18O (VPDB) carbonate value does not per se indicate the type of fluid from which the carbonate precipitated. This depends on the formation temperature. - δ13C is the good isotope here. Depletion of δ13C values tend to indicate a meteoric influence.

- Line 399: "As C3 cementation occurred during the Durancian uplift and denudation, C3 most probably did not cemented at high depth (Fig. 9C4). More probably, C3 fluids were meteoric burial fluid which were upwelled under tectonic stresses". 1. What are the arguments for the formation age of C3? This has not been discussed before. It is simply claimed here that it formed during the Durancian uplift. Why can it not be related to e.g. the Pyrenean shortening? - Cross-cutting relationships have been added within part "diagenetic evolution of the fault zones – discussion" lines 266 to 275

2. Whether true or not, the authors need to better explain in more detail why fluid upwelling is the likely process. From the current information given, it is difficult to follow the line of reasoning. - Modifications effected.

In the conclusions, line 547-550: “All diagenetic stages [: : :] result from low temperature flows with important meteoric water input. This low temperature disproves any hydrothermal influence. Therefore, both fault zones were not linked to high depth basement faults.” - Set aside the uncertainty in determining formation temperature and source of fluid, absence of hydrothermal fluids does not permit conclusions on the deep structure of a fault. The fault may very well be connected to a basement fault, but the fracture connectivity may just be poor. - Modifications effected the paragraph has been modified. “All diagenetic stages, including cementation and dolomitization, result from low temperature flows with important meteoric water input. This low temperature flows associated with the deformation and cementation types and, the lack of mineralisation specific to high temperature flows disprove any hydrothermal influence.” (lines 502-505)

Please also note the supplement to this comment:
https://www.solid-earth-discuss.net/se-2019-153/se-2019-153-AC2-supplement.pdf

Interactive comment on Solid Earth Discuss., https://doi.org/10.5194/se-2019-153, 2019.

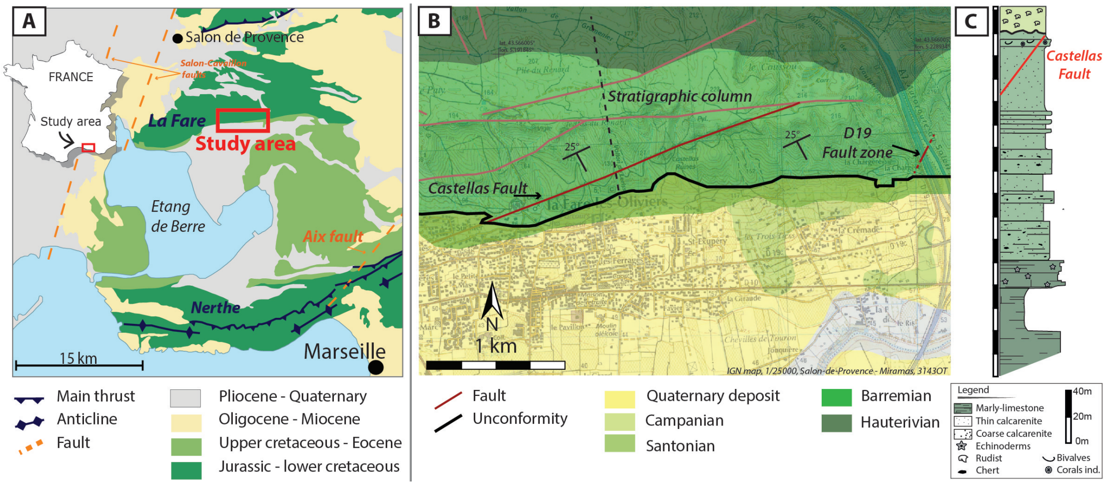

Fig. 1.

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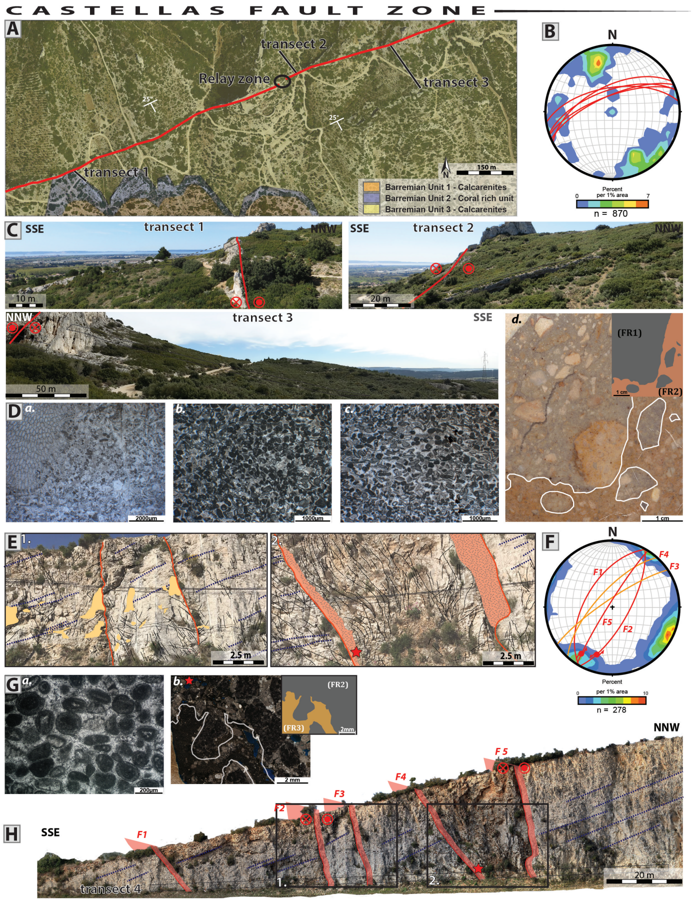

Fig. 2.

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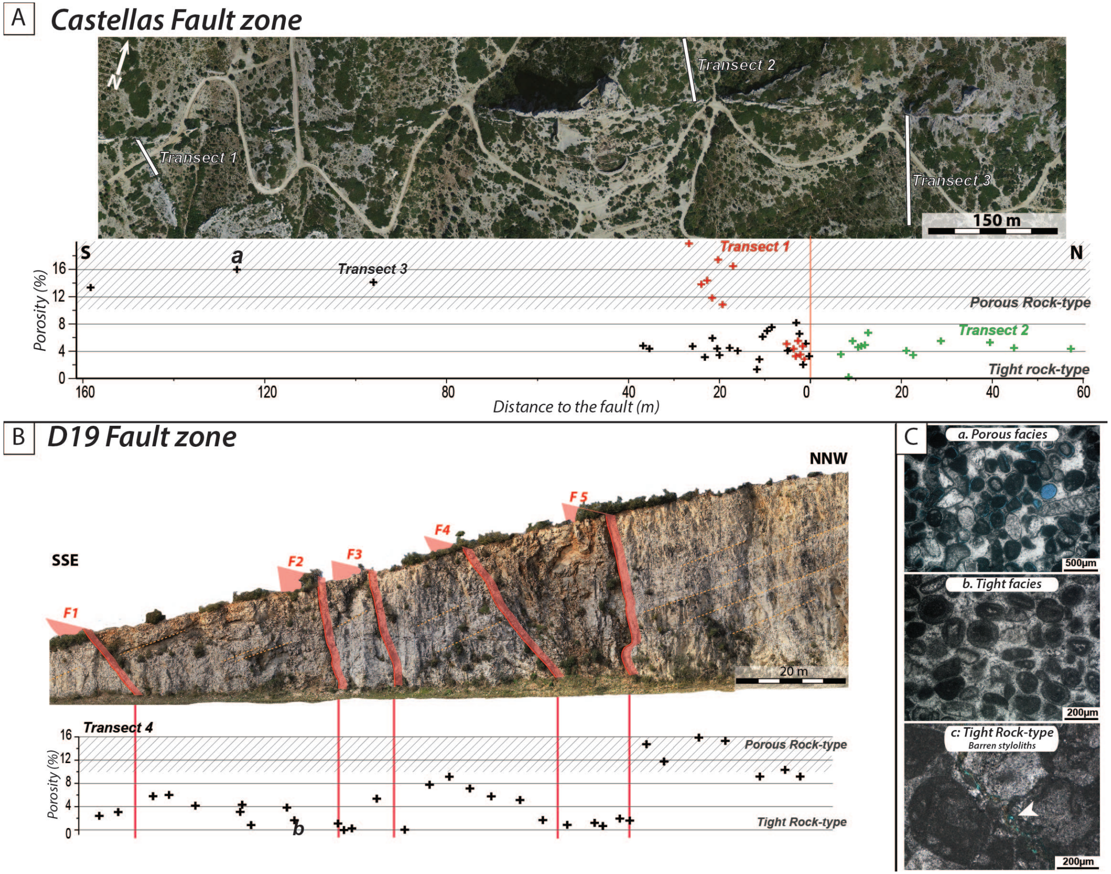

Fig. 3.

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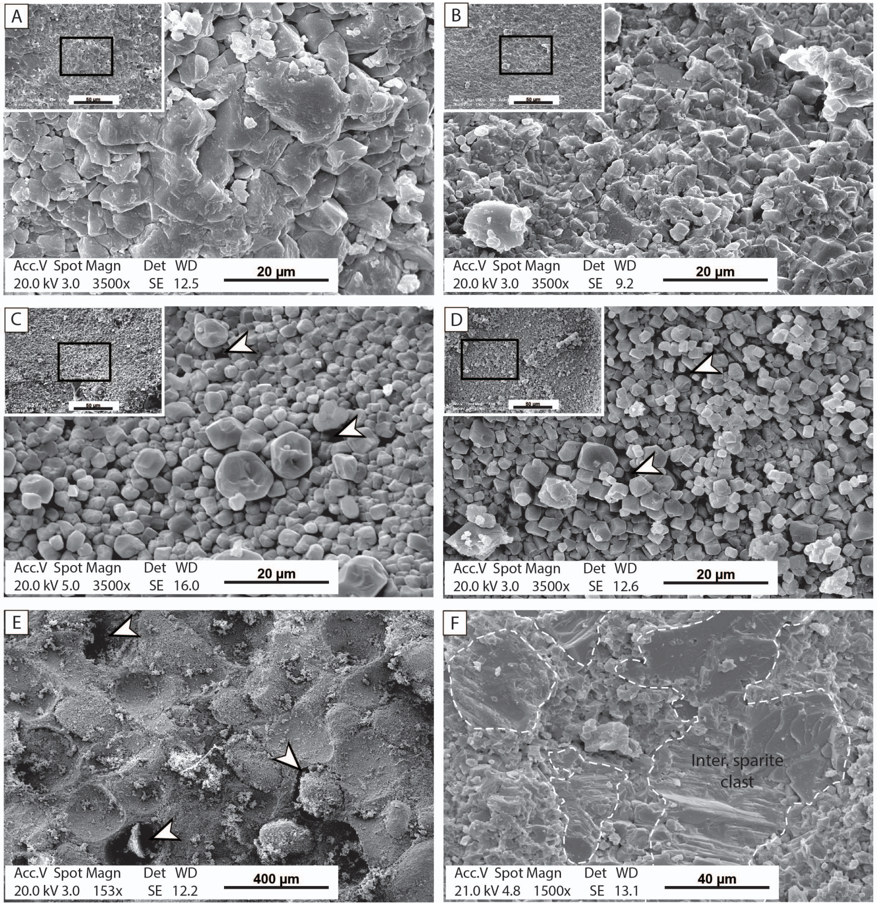

Fig. 4.

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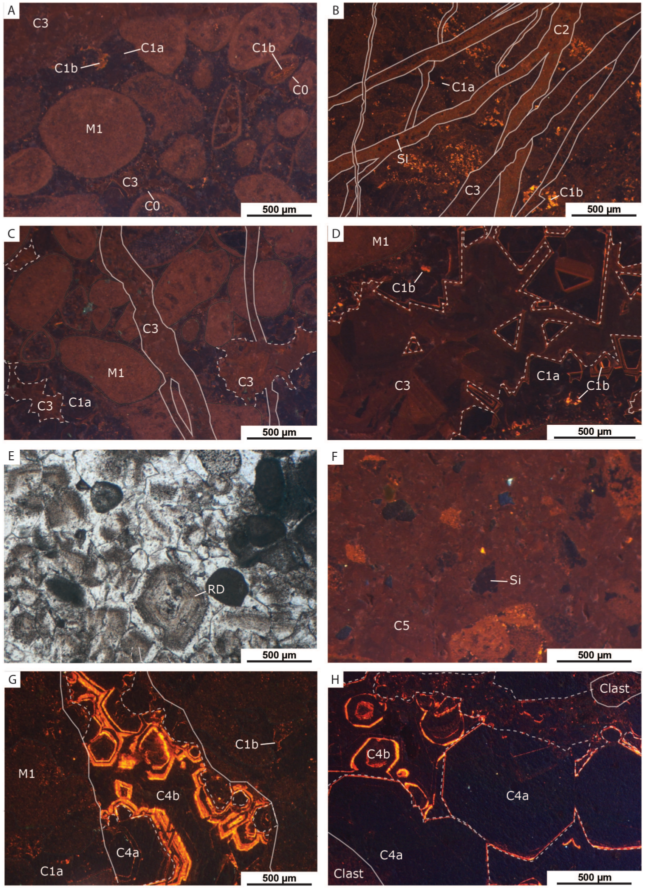

Fig. 5.

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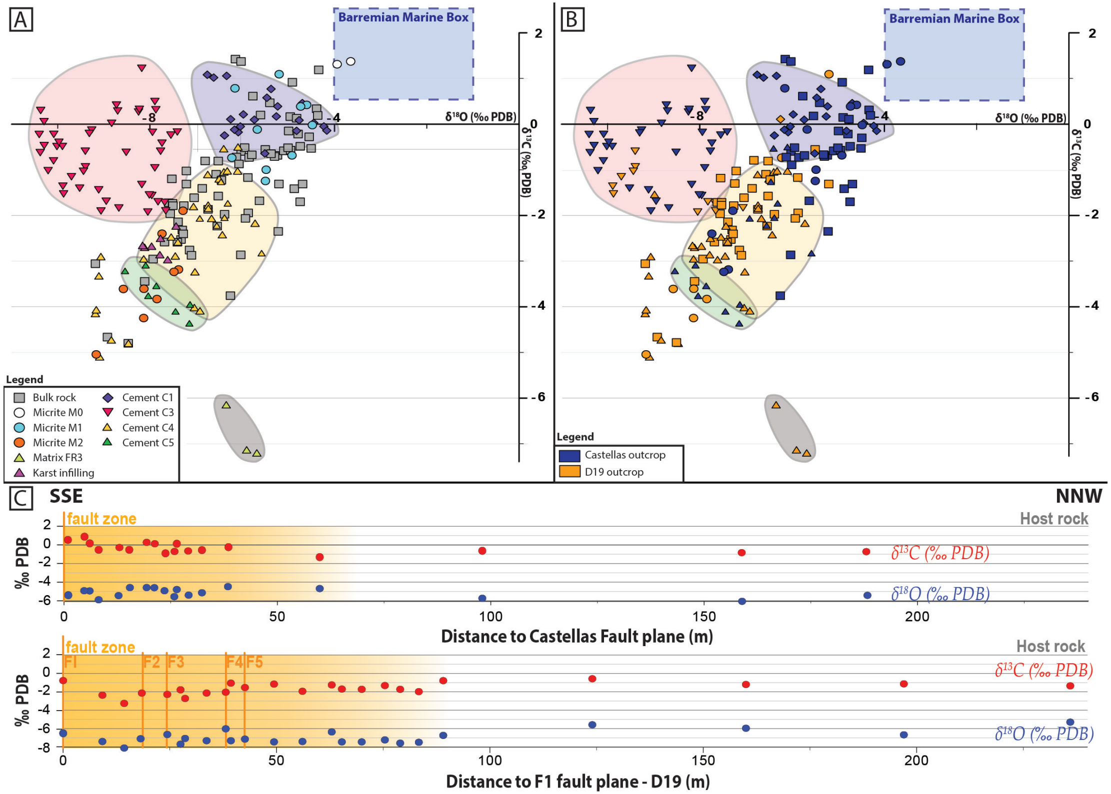

Fig. 6.

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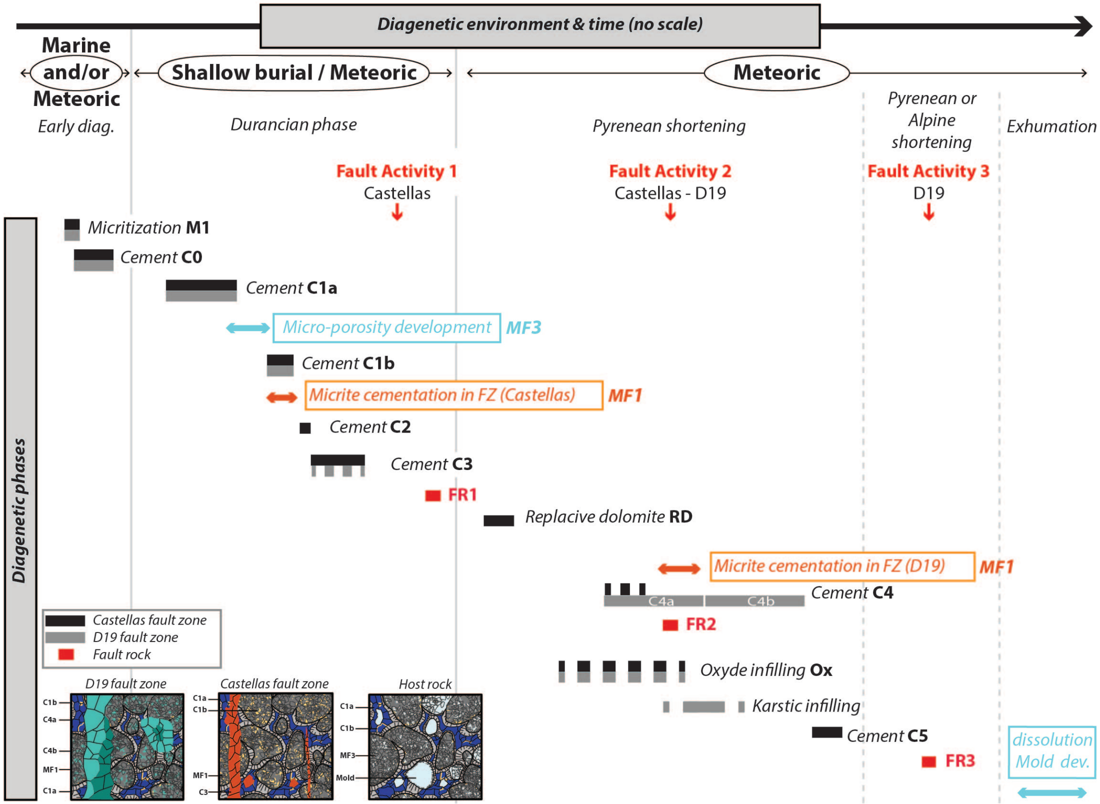

Fig. 7.

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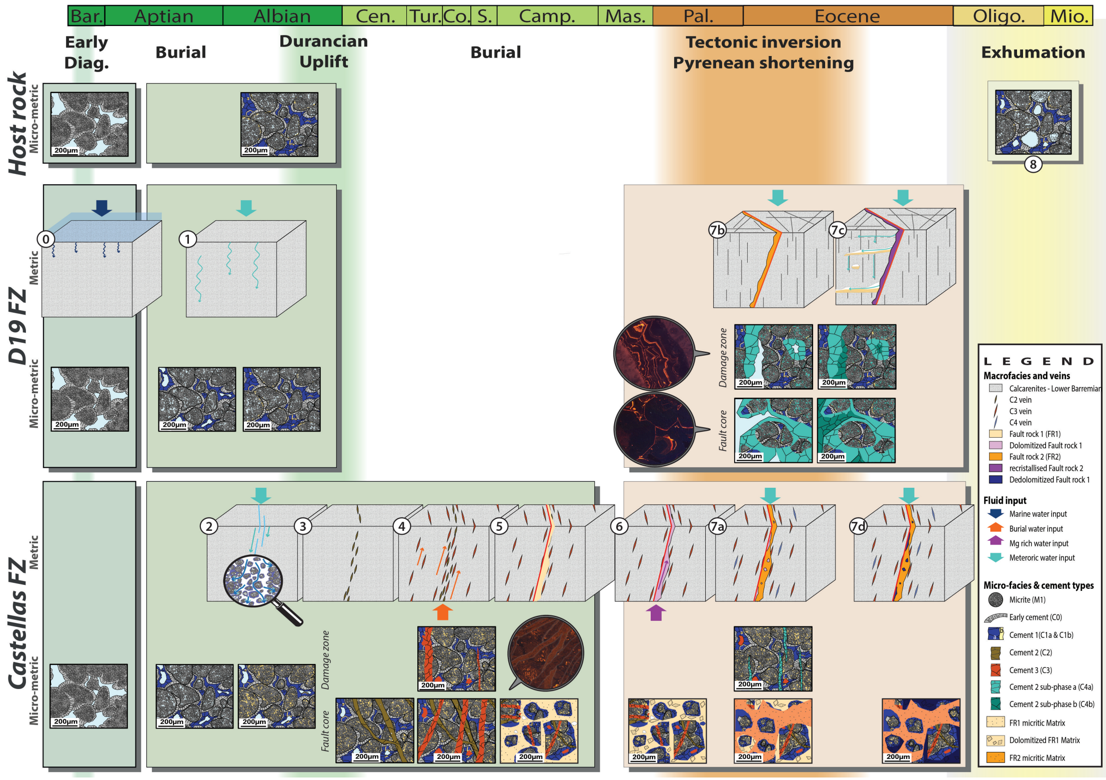

Fig. 8.

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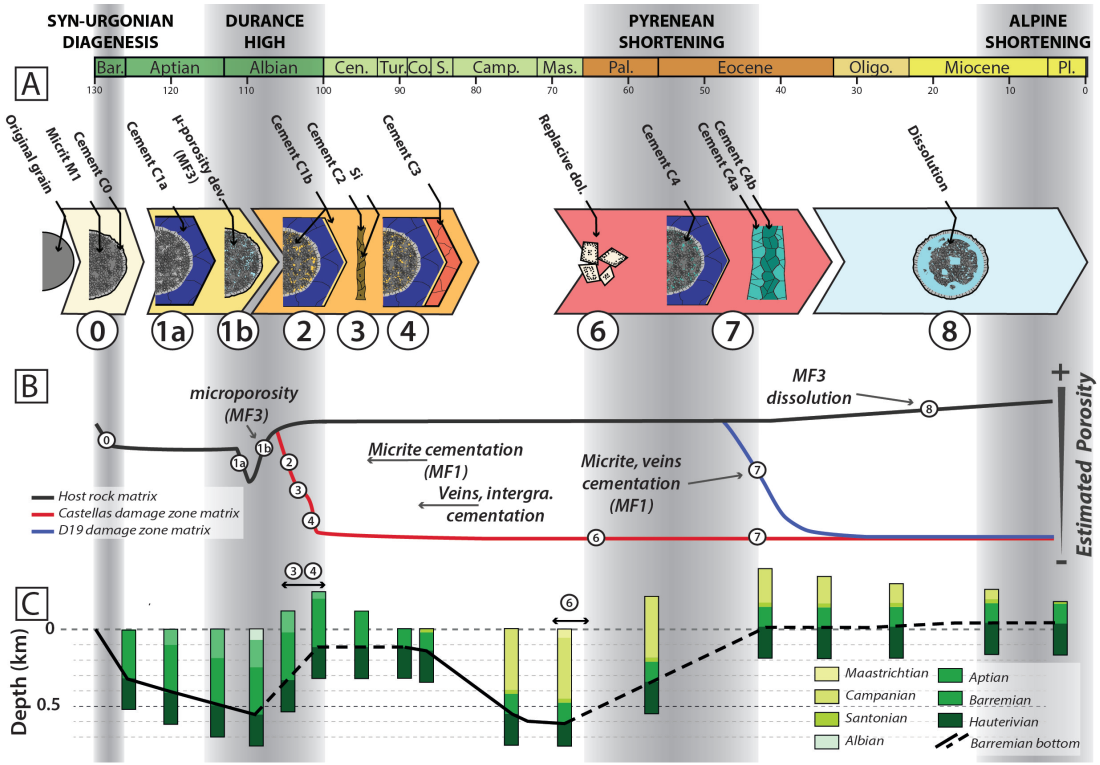

Fig. 9.

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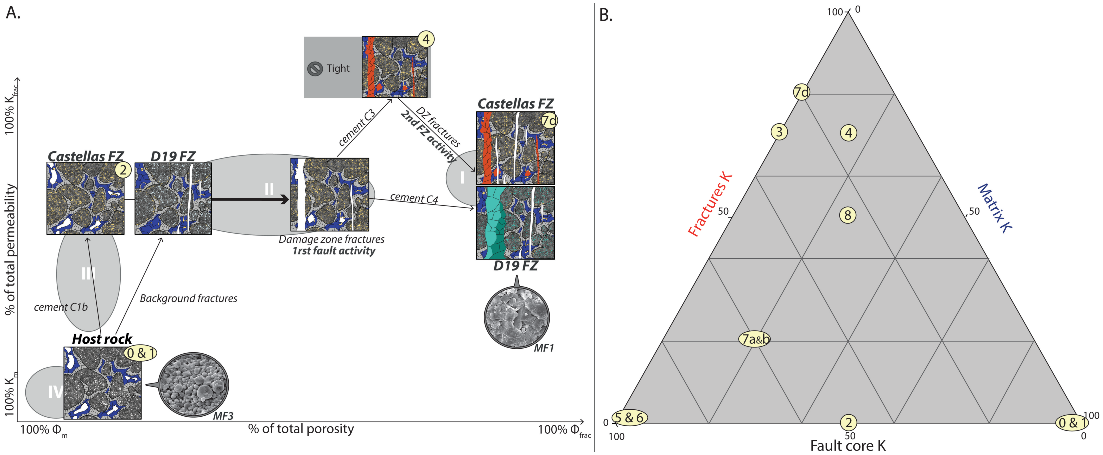
A.
Tight
Castellas FZ
D19 FZ
Host rock
cement C1b
Background fractures
Damage zone fractures
1rst fault activity
cement C3
DZ fractures
2nd FZ activity
cement C4
MF1
MF3
% of total permeability
% of total porosity
B.
Fractures K
Matrix K
Fault core K

Fig. 10.