1417 / Bianchi et al. / Effects of Energy Dissipation on Precursory Seismicity During Earthquake Preparation

Round 1

Reviewer 1:

The study presents an interesting analysis of a published fracture test based on a combined analysis of recorded mechanical data and acoustic emissions with post mortem microstructures and a numerical model of the test. The paper is well written in general but some clarifications are needed as indicated below.

Specific comments:

Line 77: In the context of the paper it may be important to distinguish between *global* stress by loading and the unknown *local* stress on the grain scale.

Line 81 and below: It would be helpful to provide more details about the test, such as loading rate, confining pressure, fluid pressure if any. Also some characteristics of Berea sdst. should be given upfront not in the discussion.

Fig.1 shows progressive localization in the modelling. This is likely also shown in the temporal evolution of AE hypocenter distributions. It would be helpful to show some meaningful snapshots. Would there be some correspondence in terms of onset of localization between model and AE event distribution?

Line 106: Presumably calibration of sensors was done at ambient pressure, is there any change known at elevated pressure?

Line 112: That may not be correct. Sensor coupling was found to affect AE results (see for example Kwiatek et al., 2013; Manthei and Plenckers Appl. Sci. 2018, 8, 1595; doi:10.3390/app8091595.

Line 173: I must admit that I found the description of the projections from 3D to 2D difficult to follow.

Line 240: Again, it would be helpful to have some idea how the AE hypocenter distribution evolved as strain localized.

Fig. 3 The events in the diagrams likely come from very different regions as strain localizes. Fig. 3c confused me a bit. Given the fact that AE activity increases drastically towards failure, and deformation localizes, I would have expected most (yellow) events to plot near N. As described in Dresen et al. 2020 we found that the fault plane variability of AEs decreased approaching failure suggesting that a set of AE nodal plane progressively aligned with the macroscopic fault along with a temporal increase in DC components of events (which seems to be the case here comparing Fig 4b,c).

Fig 4d: I didn't see blue arrows in my copy. Are these micrographs taken near the fault or in the wall rock?

Line 342-344: This is a very interesting point. As shown in Stanchits & Dresen 2010, Fig 3, DOI: https://doi.org/10.1051/epjconf/20100622010 we found a decrease in b with constant or slightly decreasing stress, which supports the conclusion given here that the change in b-value may not so easily be related to increase in the far-field stress. So is it the stress level or the damage level that's indicated by decreasing b-value. Since we do not know the local stress during crack localization that may well increase, this is difficult to answer, I believe. Could sophisticated modelling as shown here help?

I enjoyed reading the paper and look forward seeing it published after minor revisions. I hope my comments were useful for the authors.

Sincerely,

Georg Dresen

<u>Reviewer 2:</u>

Bianchi et al. analyze results from numerical models and experiments on Berea sandstone to characterize the relationship between the b-value of the magnitude distribution of acoustic emissions, the faulting style, the proximity to macroscopic failure (differential stress), and dissipation. They thus investigate a key outstanding problem related to detecting precursors to earthquakes: whether the b-value changes as a large earthquake approaches, and what physical mechanisms produce this change. The manuscript is well-written and logically organized, and presents compelling and interesting results. I suggest that it could be published with minor revisions. One main concern I have is about the similarity between the model and experiments (comment #14). Please see the attached document with detailed comments.

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1. Abstract: It would be useful if the abstract specified what the "faulting style" means here. Mode I vs. shear fractures?
2. Line 42: "A smaller b-value indicates a higher likelihood of larger earthquakes, while a larger b-value suggests a predominance of smaller earthquakes" Another way to describe the difference between large and small b-values is with localization. More localized fracture networks with a few large fractures will tend to have smaller b-values than less localized fracture networks composed of similar sized fractures.
3. Line 83: "The sample failed in brittle manner producing a number of AEs recorded on a array of sixteen piezo-electric transducers (PZT)." I would rewrite as "The sample failed in a brittle manner producing a number of AEs recorded on an array"
4. Line 85: "H-MEC is a two-dimensions (x1-x3 space, see Fig. 1a) fully coupled solid-fluid phase seismo-hydro-mechanical code governed by poro-elasto-visco-plastic rheology (Gerya, 2019; Yarushina and Podladchikov, 2015). During failure, accelerated deformation was observed as an increase in the bulk volumetric strain rate and the rate of AEs. A relationship between the average mechanical dissipation and these experimental metrics were clearly observed (Fig. 1c), lending credence to the model". From this paragraph, it was not clear to me at first if you were describing previous work or new results. I think here you are describing the work of Bianchi et al. (2024), but this was confusing at first.
5. Methods: line 166. "We note that these should be treated with care due to the dependency of plunge angles on the the reference system." Note the repeated "the". Also, what does a vertical faulting style indicate here? I guess they are not parallel to the direction of the maximum compressive stress, as one would assume.
6. Figure 3c: Is it the case that higher differential stresses are associated with either normal faulting or thrust faulting styles, and that lower differential stress is associated with the intermediate (vertical fault) case? Why would this occur?
7. Figure 3a: What is the mechanical explanation for the lack of normal faulting or thrust faulting styles in the laboratory? Was it expected to find a predominance of strike-slip faulting styles? This is perhaps linked to the difference in the faulting styles identified as associated with minimum b-values (strike-slip for the lab and thrust for the field).
8. Line 286: "The majority of the AE source mechanisms (Fig. 4a) are found to be in the lower half of the Hudson net slightly towards the anticrack and negative linear vector dipole (LVD) regions, which are indicative of compressive source mechanisms." Is this because opening mode fractures release less acoustic energy when they open or propagate? So the AE method is less likely to identify these types of fractures.
9. Line 289: "Microseismicity (Tape and Tape, 2012b,a) and numerical models (van der Baan and Chorney, 2019) predict that for materials with a Poisson's ratio below $\nu = 0.25$, some dispersion in the source mechanisms that link LVD (+) and LVD (-) is expected (Fig. 4c)." I do not understand what "dispersion in the source mechanisms"

means here. Please clarify.
10. Figure 5: Maybe it is the size of the y-axis of the plots, but the decrease in b-value with increasing differential stress does not look that meaningful. I wonder what the Pearson (linear) correlation coefficient between the mean differential stress and b-value for each data point shown in (a) would be. Or is there a good reason to only consider the median b-value? Anyways it would be useful to quantify this correlation more precisely.
11. Line 342, "These results suggest that while differential stress may show an inverse correlation with b-value, it may be a secondary effect and, decreases in b-value, may better explain the extent of damage (or localized damage) in a fault zone." But if the dissipation is linked to the proximity of macroscopic failure, and thus the differential stress, then there should be a strong positive correlation between dissipation and differential stress. I'm not sure we can differentiate between the effects of dissipation and differential stress on the b-value when dissipation and differential stress are strongly correlated.
12. Line 364, and in the caption of Fig 6.: Please specify that these fields are from the numerical model. Or indicate otherwise, if I am mistaken.
13. In Fig 6: it would be useful to know what the loading curve (axial strain vs. differential stress) of these simulations look like, and where the three phases fall on this curve. In particular, I'm surprised that the total volumetric strain field is dominated by compaction in stage II, in the yielding regime. Typically, the stress conditions at C' or the onset of dilatancy defined by Brace occurs before the macroscopic yielding recognized in the decrease in the slope of the axial strain and differential stress. But maybe in the plots you sum together the strain field throughout several loading steps? See the figure below from Paterson & Wong (2005). This textbook describes that "The stress level of the onset of dilatancy, commonly designated C′ following Brace and co-workers, is usually observed to be between one-third and two-thirds of the macroscopic fracture stress, although in some cases dilatancy may be detected earlier or, in the case of porous rocks, only very near the fracture stress (Brace 1978)". So maybe there is a difference in the expected timing of C' in low porosity and porous rocks. But I'm not sure how you included the influence of the porous structure of the sandstone in the numerical models, or if we would expect C' to occur very near the failure stress in the numerical models, or much learning in loading, as in the figure below (representative of low porosity rocks).
14. From Fig 6 and Section 5.2, although you describe qualitatively some agreement between the numerical models and the experimental observations, it would be useful to show a more quantitative comparison between the models and the experiments. At the moment, it's difficult to assess how similar the modes of deformation are in the models and experiments. For example, could you plot the percentage of explosion/implosion of AE sources (or the value along the vertical axis between explosion and implosion on Fig 4) with loading in the experiments, and on the same plot, the volume of the model that hosts dilation or compaction with loading?

Round 2

<u>Reviewer 1:</u>

The authors present a revised version of a manuscript that I reviewed previously. The revisions clarified all the points I made in the initial review and here I just noted some minor typos and provided a comment and a suggestion.

(Lines referring to Bianchi_et_al_2024_Seismica_diff_V1_V2).

Line 165: …. axis to be ***be*** perpendicular (correct typo)

Line 363: ….it was found to decrease even when the ***stress*** remained constant.

What we found was that the GLOBAL stress (from the load measured by the load cell) was constant, we know nothing about the LOCAL stress.

Line 372: …. relating ***accelearted*** deformation (correct typo)

Line 442 and below, comment: Increasing similarity in focal mechanisms during run-up to failure is a common observation in lab tests (both stick slip and intact sample) and the recent work of Karimpouli et al. (2023) (doi.org/10.1016/j.epsl.2023.118383) have shown that this likely is indeed an important feature among others such as b-value and space-time relations of events for time-to-failure forecasting (well, at least in the lab).

Line 465: The numerical model helps to identify the micromechanisms…

I would recommend to change to: The numerical model ***in combination with microstructure analysis*** helps to identify the micromechanisms…

The manuscript is ready for publication from my end.

Sincerely

Georg Dresen

<u>Reviewer 2:</u>

The authors have responded to all of my concerns. I suggest that this work may be published.