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Interactive comment on "Cross-Diffusion Waves as a trigger for Multiscale, Multi-Physics Instabilities: Theory" *by* Klaus Regenauer-Lieb et al.

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We would like to thank the reviewers for the tremendous effort and careful review of this paper. We realize that the paper touches a number of challenging fundamental issues and is therefore more difficult and time-consuming to review than the average publication. We are extremely grateful for the patience and detailed feedback providing useful criticism and suggestion for modifications.

The reviews of the original paper suffered from two significant issues.

By not having the second paper available both reviewers were missing the important application of this paper presented in part 2. Unfortunately, the second part was not yet available to the reviewers at the time of their reviews as the submission had been delayed and the paper had not yet been released for viewing. The second part is now accessible to the reviewers and available on https://doi.org/10.5194/se-2020-149, in review, 2020.

Another significant problem was the deficient introduction which did not specify why this paper was focusing just on the theory aspect and how the two papers join together. The original intention was indeed to submit both papers in one cast but delays in the writing of the second manuscript led to a placeholder introduction in part 1. We apologize for this shortcoming.

The introduction has now been entirely rewritten. It includes the necessary link to the second part. It also lists the relevant background in terms of the GEOPROC themes, references, and prior work in the development of the new theory and explains the innovations in this paper that overcome the issues encountered in earlier attempts to address the dynamic regime of acceleration waves. The introduction also provides a short overview of the sections to come and in conjunction with the update and rewritten conclusion should present a clear logical structure of the paper.

This paper was written with the specific aim to derive and explain the new theory in detail which did not receive any criticism. Please find below the address of the specific points raised by the reviewers.

Angelo De Santis (Referee) general comment: This manuscript proposes an approach for coupling processes that the authors define “Multiphysics” because due to different kinds of instabilities. Although the work looks intriguing in approaching the problem with a complete and integrated view, in my opin- ion, there are some parts that are not yet clear. The main problem I found in reviewing this paper is that the authors sometime, instead of explaining directly the question, prefer to resort to another companion paper that, shamefacedly, is not yet available (at least to me). In general, I would suggest to describe the most important passages of that companion paper (a dedicated section would be useful), so also the present work can be self-consistent and explanatory.

Reply: That is an excellent suggestion. We have modified the introduction followed by a section summarizing the specific introduction to the second paper.

Angelo De Santis (Referee) general comment: Another important aspect is that if the new theory wants to replace the conventional present one, the latter should be concisely described and the critical issues pointed out, so justifying the replacement with the new one. This aspect is neglected.

Reply: We do not challenge the existing rate and state variable friction theory for earthquakes but have now explained much better in the introduction why it is necessary to introduce a new theory to overcome the shortfalls of the conventional theoretical and applied mechanics approach that has not yet been applied to earthquakes. Specifically, we contrast our approach in the introduction to the existing approach. The relevant section in the introduction reads:

" Before discussing a possible application of the new theory to the processes of earthquakes and faulting in our companion paper \citep{Geoproc2020b}, here we present a transdisciplinary approach bridging the gap between observations of instabilities from the molecular scale to the very large scale. The theory in this paper is written using approaches familiar to the theoretical and applied mechanics community. The original work is based on the 1960's work \citep{Hill_acceleration} building the foundation of theoretical approaches to localisation criteria, via the so-called acoustic tensor criterion, widely used in the engineering community \citep{Rudnicki75}. The approach focuses on standing wave quasi-static solutions based on vanishing speeds of acceleration waves. Surprisingly, little effort has been made to explore the rich wave field of the corresponding traveling wave solutions, probably because dynamic events are only of academic interest to the engineering plasticity community that focusses mainly on developing safety standards as well as limit analysis and design. A notable exception is the work of \cite{Benallal2004} who found that under dynamic conditions, unbounded growth of perturbations can be found in the short wavelength regime with divergence growth. This calls for an extension to the theoretical work of \cite{Hill_acceleration} which is presented here.

The dynamic field is, however, of special interest to the researcher in the area of earthquake and faulting instabilities. The state of the art in this field is defined by the influential experimental work of \cite{Dieterich79} including the early work on the application of the rate and state variable friction approach to earthquakes \citep{Tse1986}. The approach based on these laboratory-derived constitutive equations has reached a mature stage, and no attempt is made here to compare the rich field of findings with the present theory. We approach the problem from an entirely different angle through theoretical investigation of the mathematical solutions of the system of coupled partial differential THMC equations that deliver wave solutions with short-wavelength instabilities. In the course of developing the new approach, we describe wave physics phenomena that have previously not been reported in geophysical solids but are well known in a range of different fields from quantum systems to ocean waves \citep{Zakharov2004}. It is fair to say that the theory is rather in its infancy state, and special care needs to be taken before considering a direct application to the aforementioned systems. The first part, therefore, presents the theoretical derivation, and the second part delves into possible applications and proposed experimental tests to verify the applicability of the theory..”

Angelo De Santis (Referee) Specific comments Other points/doubts/comments Lines 10-11. The final sentence of the Abstract is not fully clear. The same problem is found in the main text.

Reply: This sentence is a preview on part 2 we now refer to part 2 and also include it in the abstract by saying

“Part 2 proposes an application to earthquakes showing that for extreme conditions, cross-diffusion waves can lead to an energy cascade connecting large and small-scales and cause solid-state turbulence.”:

Angelo De Santis (Referee) Specific comments Lines 12 and following. The Introduction is too short and poor.

Reply: corrected

Angelo De Santis (Referee) Specific comments Lines 50-52. Very interesting, ma not clear at all from this work. This sentence remains suspended, Also because of the reference to the companion paper which is not yet available.

Reply: We now refer to the second paper explicitly “We will discuss such possible precursor phenomena for earthquakes in part 2 \citep{Geoproc2020b}.”

Angelo De Santis (Referee) Specific comments Lines 63-64. This should be better explained and extended. Otherwise, also this sentence remains suspended.

Reply: We now refer to the second paper explicitly “In the supplementary material of part 2 \citep{Geoproc2020b} we will discuss possible experimental tests of the precursor phenomena.”

Angelo De Santis (Referee) Specific comments Line 91. Eq. 1. For dimensional coherence, the body force f should be alone, not multiplied by ro. Consequently, adapt in the following part of the text. Reply: yes, the body force needs to have rho removed, this is now adapted in the text Line 104. definition of I as Identity matrix should be moved below (after all this series of expressions).

Reply: the explanation is moved to the appropriate place

Angelo De Santis (Referee) Specific comments Line 119. Putting in the same name "elastic" and "plastic" looks contradictory. What do you mean? that the strain rate can be in different conditions? But this would be said in the text.

Reply: the incorporation of the yield phenomenon through the elasto-viscoplastic compliance is now better explained. We have added following text: " in this case $\boldsymbol{\dot \epsilon}'$ denotes the deviatoric strain rate which in the purely elastic case before yield is $\dot{\boldsymbol{\epsilon}}'= \dot{\boldsymbol{\epsilon}}'_{{e}} $ becoming post-yield the elasto-viscoplastic strain-rate defined by $\dot{\boldsymbol{\epsilon}}'=\dot{\boldsymbol{\epsilon}}'_{{e}} +\dot{\boldsymbol{\epsilon}}'_{{vp}}$. ${\dot \epsilon_0}$ is the equivalent elasto-viscoplastic volumetric strain-rate."

Line 287, Eq. 21a. Is here missing a dV_REV? Reply: yes it is missing and has been replaced

Angelo De Santis (Referee) Specific comments Lines 378-380. I cannot have access to this other work (Regenauer-Lieb et al., 2020) It would have interesting to have a look at it. Otherwise, I suggest mentioning the most significant passages of that work.

Reply: The manuscript is now available on https://doi.org/10.5194/se-2020-149 , in review, 2020.

Angelo De Santis (Referee) Specific comments Lines 403-404. Not convincing and neither clear. This point should be more clarified in this work (and not only referred to the companion paper). For instance, how is the new theory better than the conventional one that describes earthquake processes?

Reply: We have rewritten the entire conclusion in order to link up to the new introduction and explain that the meso-scale processes have been overlooked in conventional earthquakes and solid mechanics theories.

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