

## ***Interactive comment on “Using Seismic Attributes in seismotectonic research: an application to the Norcia’s Mw = 6.5 earthquake (30th October 2016) in Central Italy” by Maurizio Ercoli et al.***

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Dear reviewer2,

on behalf of all my co-authors I really thank you for the time spent to revise our manuscript. We are sure that all the suggestions and positive comments provided in the document “se-2019-108-RC2” will contribute to improve our work. We have also appreciated the detailed comments and corrections provided in the document “se-2019-108-RC2-supplement”, that will be extremely useful during the revision.

Before providing a complete review of the paper, in this short reply we attempt to an-

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swer to some of your considerations provided in “se-2019-108-RC2”.

We are glad that this manuscript based on an attribute analysis application in seismotectonics may be of interest of geologists and geophysicists working in active tectonics. Regarding your main paper issues, we reply hereafter point by point.

1) REV2: it needs still some work in the structure of the writing and, most important, more work in the interpretation of the data or, at least, it needs to show more clearly all the interpretations the authors are doing.

Authors: As also remarked in the reply to REV1, we are surely going to improve the structure of the writing, using all your suggestions (see following points). We will also work on the data interpretation and presentation, trying to better clarifying to what extent it is constrained by the seismic data-set.

2) REV2: I am not an expert in the analysis of this type of data (onshore seismic data across rocky regions), but I have many difficulties to identify the same structures the authors are interpreting.

Authors: we explicitly declared that the quality of our data-set is limited, however, as we mentioned: a) this is very common in on-shore, rocky areas; b) they are the only available seismic data, and unravelling the subsurface structure is crucial for a better comprehension of the seimo-tectonic work. As far as possible, we will try to improve the image quality and readability of the described seismic sections, aiming to provide clear evidences also to readers with limited confidence with attribute analysis. However, we remark that seismic interpretation always encompasses some subjectivity, especially when the data are not “self-explaining”, as when working with vintage datasets on mountainous areas. The use of integrated attributes can contribute to give additional suggestions and indications, that not always are self-explanatory evidences.

3) REV2: At the end, I have had the impression that the authors have extended the surface map structures in depth following some possible alignments. My question is,

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would have they interpreted the same structures without the surface information? To me, there is a high uncertainty in the interpretation of the alignments in the seismic profiles that, then, I have problems to believe the final structural model proposed in the manuscript.

Authors: The answer is yes, we actually have tried, as a first instance, to extend in depth the surface structures reported in literature and mapped after the most recent geological/structural surveys, and later following possible seismic alignments enhanced by attributes. So, we have basically started by the available information, because we think that starting from the surface geological/structural data, specifically in an area characterized by overall poor subsurface records, it would be the best approach to better constrain any analysis. However, because not all the fault segments show outstanding surface expressions, we have interpreted similar alignments given by reflectors discontinuity (e.g. amplitude, phase differences highlighted by attributes) as secondary faults splays/fault zones. This research of a trade-off between surface and deep evidences of faulting is due, as remarked in the introduction, to the poor data availability for the area. Regarding the interpretation, we clearly agree that there is a certain degree of uncertainty; but we used a conservative approach, just marking the structures that are clearly “seismically” evident, that in our opinion would be also traced without surface evidences. The antithetic (SW-dipping fault) of Norcia, for example, speculated in the past by some authors without clear evidences, is imaged in our data and it is the first time that is it recognized in a reflection dataset. Finally, we are conscious that there are several different models proposed for the area: we provide new information which can be helpful in order to validate/constraint one of them. As also structural analysis of exposed outcrops, seismic interpretation has clearly a certain degree of subjectivity: for example, no one “saw” low-angle normal faults before the concept was introduced. So, in this case our interpretation is driven by the background information that: a) the studied region is affected by intense extensional tectonics, generally disrupting previous compressional belt; b) the knowledge of the position of some major normal faults exposed at the surface (possibly connected to the earthquakes mainshocks). In ad-

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dition, we are totally conscious that our data-set is not comparable with modern 3-D seismic surveys of recent basins and offshore areas, where a much larger degree of objectivity can be reached by seismic interpretation.

REV2: Following there are some general comments on the different sections. I also provide a commented manuscript that hope will help to improve the quality of the manuscript and the presented results. Despite my criticism, to be intended solely as constructive, I warmly encourage the authors to make any effort for the publication of this manuscript, because of the relevance of the proposed approach and objectives.

Authors: We really appreciate the positive comments, and we'll do our best to improve the results and the overall quality of the manuscript.

REV2: 1. Introduction - I think that in general the introduction needs to be restructured to emphasize the main aspects of what authors wants to expose. It is a very confusing introduction. I am not a native English speaker and I have found some errors, so I think that a native English speaker should review the final version of the manuscript.

Authors: Thank you, we will revise the errors also using your punctual corrections and specific comments, properly re-arranging the introduction. Once the main scientific and technical issues will be solved, we will evaluate the opportunity of a final revision of the text by an English mother tongue expert.

REV2: 2. Geological framework - This section of the manuscript is a little bit confusing and difficult to follow. The authors jump from one topic to another in some paragraphs and is difficult to understand the geological structure of the area. I think it is necessary some organization. Begin for the big geological units, as done. Then, explain the structures, the fault systems in the area. Continue with the basins object of study. Finally talk about the seismicity in the area and the recent earthquakes and the faults that show surface rupture. In addition, I recommend the authors to be consistent with the names of the units, faults, for example, the Laga foredeep domain is referred in three or four different ways, and that is confusing.

Authors: Following the concerns of the REV2, we will reorganize this chapter, in order to introduce the concepts in a more clear and logical way, carefully checking and making consistent the names of the units.

REV2: 3. Data -The authors mention a couple of times the supporting information, but in fact the information is provided in tables and figures in the manuscript. Also, the figures in the supporting information are not correctly identified and some errors of profiles identifications are present and must be corrected.

Authors: In the supporting material we have added the high-resolution version of the figures because the pdf print considerably reduces the quality of the images, that we are conscious are important to evaluate the outcomes of our work. In addition, we have provided tables with additional information on the data, plus the conventional seismic sections in amplitude to help the readers in the comparison with the attribute images. We will fix all the issued suggested in this comment.

REV2: 4. Methods - Authors comments that they have tested several post-stack attributes, but it is not clear at all why they select ones and not others. Maybe it is not necessary to explain this? I am not an expert in seismic attribute analysis.

Authors: Sure, we will add this explanation to the text. Meanwhile, we hope you can find an exhaustive answer also in our reply to the Jacopini's document above.

REV2: 5. Results - To me it is necessary to include in the supplementary information the profiles (original and attribute analysis) without any interpretation and each one on one page at a bigger scale.

Authors: we added the original profiles in the supplementary material, plus the high-resolution images of the interpreted attribute profiles. We'll consider the possibility to remove the interpretation from these profiles and to increase the size of the images as well.

REV2: The profiles on the manuscript show arrows pointing to specific features that at-

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tract the attention towards the author's interpretation. For example, in Fig2c the authors points with red arrows to some discontinuity (?) but at the same time the arrows mask reflectors around. I could point to similar features (orange arrow in the corresponding figure on my commented manuscript) that could point to a normal fault dipping to the W? That suggests me that the authors are just looking for structures that have been recognized at surface and not for all the other possible structures in the area/profiles. But again, without the un-interpreted profiles it is difficult to compare observations.

Authors: As remarked above, we have used this solution of the arrows to leave a certain freedom to readers in the detection of the seismic features, because we think that a standard line drawing basically tends to mask the actual seismic evidences. However, we can consider to enhance some details on the images, as a thin line drawing to highlight the main discontinuities. As discussed above, uninterpreted profiles might be added (as supplementary material) in order to allow the reader to better check of the proposed interpretation. Regarding the orange arrow proposed by the rev2, we clearly cannot exclude that there are many other similar structures. We are not only focusing on the structures visible at surface (as remarked, the Norcia antithetic fault doesn't have clear surface evidences), but simply we have specifically concentrated our study on the two basins interested by the recent seismic events (Norcia and Castelluccio di Norcia). The line CAS01 in fact, in its westernmost part, is crossing the Cascia basin, on which we did not focus our analysis. We initially thought to cut this line only showing the Eastern part (to the South of Norcia), but we finally decided to show the entire section. We'll eventually consider to cut this part during the revision if this fact confuses the readers.

REV2: I would recommend to describe each profile independently pointing to the observations done in each attribute profile and follow the same structure from one profile to the other. Begin with the seismic section and describe what you see and what is or could correspond the observed artefacts, then, the EN section with the specific observations, after, the EG section and, finally, the PR section. This makes things easy

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to the reader and not necessary to jump from one profile to the other and return. I suggest to identify the different high-dipping lineaments in the figures with letters (e.g., L1, L2, : : ) and then refer to them in the text. It would be much easier for the reader to understand to which lineament the authors are referring.

Authors: Thank you for the suggestions, we'll try to do this in the revised manuscript, trying also to avoid to furnish repetitive and potentially tedious descriptions.

REV2: In profile NOR02 the relationship between horizons T, H and the west-dipping lineament interpreted as bounding the CNb is not clear. In lines 256-259 it is said that horizon H is interrupted by horizon T, which crosses all the profile from east to west and dipping to the west. Later on, in lines 275-276 it is said that a west-dipping lineament truncates and disrupts horizons (discontinuities) T and H. In general, to me is very difficult to interpret the lineaments in all the profiles (as pointed in a number of comments in the manuscript) but in that case I think that the authors are proposing different interpretations for the same observations. This needs to be clarified.

Authors: We will improve the text clarifying the relations between horizon H, the (W-dipping) low angle thrust fault T and the (W-dipping) high angle normal faults of the area, to better explain the structural complexity of this sector.

REV2: 6. Discussion and conclusions - As said in various comments I have problems to interpret the steep discontinuities on the different seismic profiles (amplitude and attributes). All the discussion is based on the authors interpretation and since I cannot interpret the same things, I cannot support it. But I am not a specialist in this type of seismic interpretations.

Authors: Following all your suggestions, as discussed above, we are confident that the proposed interpretation will result clear and possibly convincing. We will better remark in the text that vertical (and sub-vertical) features cannot be directly imaged on seismic section due to physical limits of the methodology. Such structures can be inferred considering lateral amplitude and especially phase discontinuities, which are

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better highlighted by specific attributes rather than by reflection amplitude. We will improve the discussion and the images supporting our results, specifically to help the non-expert in seismic attributes to better understand the seismic features enhanced by this approach, as well as the conceptual differences and meaning.

Yours sincerely, Maurizio Ercoli and co-authors.

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Interactive comment on Solid Earth Discuss., <https://doi.org/10.5194/se-2019-108>, 2019.

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