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Solid Earth Discussions

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 Editor

I have been reading with extreme interest the paper submitted by Maurizio Ercoli et al. The paper transfers a long lived but also a now very sophisticated methodology of image processing/seismic attributes, developed within the O&G exploration domain, into the regional and fault interpretation using 2D seismic lines for seismic tectonic purposes. The aims of seismic attributes in this context is to unravel and enhance deep reflectors but also high angle features and then reframe those interpretative results to fine tune the discussion Norcia Mw earthquake. I am, in fact , rather surprised it took

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so long to use those techniques in this context, therefore I welcome this paper and I take the opportunity to make some constructive comments to the discussion triggered by this paper. I will be focusing more on the methodological aspect (given I have no experience on the Norcia seismotectonic area so I cannot make any comment on the tectonic implication of the results proposed). a) Frequency content: the authors introduce the properties of seismic stating that " The average frequency spectra display bandwidths ranging from few Hz up to 60-70 Hz, whilst NOR02 extends up to 100 Hz". Could they please clarify the significance of those numbers? usually a seismic line (especially onshore) barely reach those high frequency content below 1-2 second of depth. Therefore I am curious to see what the frequency decomposition and the distribution of those frequencies across the seismic line (through depth) look like. Source frequency in fact only partly relate with the frequency of the impulse signal coming from the source utilized..as the impulse will then convolve with an earth model losing by multi reflection and absorption the energy and therefore frequency content. Even a simple instantaneous frequency image would help. A frequency decomposition may help (if an interval velocity model can be assumed) to further constrain and understand the resolution, therefore estimate the thickness and therefore discuss the significance of some of the main reflectors. Given that there are no well core and well log to tie the seismic any sort of information to constrain the scale of those reflector need to be attempted.

b) Noise analysis. What is missing in the methodology and results description of this paper is a proper discussion of the noise content into the seismic and work done to isolate m understand and extract it before interpreting the seismic response using attributes. This is what in seismic interpretation we call conditioning process of the data. Every seismic lines or volume data include acquisition footprint, backscattered ground roll, migration operator aliasing, aliased shallow diffractions, multiples, and low reflectivity that falls below the ambient noise level. The expression of these noise features has negative value in mapping geology; such noise is also exacerbated by seismic attributes. So the author should discuss in depth the issues related to the seismic

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which imply, getting back to the pre stack data and processing aspect or re run an image processing conditioning. There has been a lot of literature and there are software's or algorithms producing filters called edge preservation or structural oriented edge preservation which help the interpreter to smooth low and high frequency oriented and random noise around the structure of interest (once recognized.); If they have not been tempted (comparing the image with attributes before and after the conditioning) that should be done to understand the seismic noise affecting the stacked image. Again the following paper should be taken into account in order to avoid to re invent the wheel with differently energy named attributes (I know those are the commercial name given into open source software): - Gersztenkorn, G., Marfurt, K.J., 1999. Eigenstructure-based coherence computations as an aid to 3-D structural and stratigraphic mapping. Geophysics 64, 1468e1479.

I also suggest to read on that line also the paper Pitfalls and limitations in seismic attribute interpretation of tectonic features Kurt J. Marfurt1 and Tiago M. Alves published into the seg AAPG interpretation: - Marfurt, K.J., Alves, T.M., 2015. Pitfalls and limitations in seismic attribute interpretation of tectonic features. Interpretation 3, 5e15. http://dx.doi.org/10.1190/INT-2014-0122.1. c) i notice that the authors have avoided to use coherency and dip related attributes . In some case they may help to unravel subtle details and more importantly to distinguish noise surrounding certain dipping structure. In some other they may be totally useless (if too much noise distributed is affecting the seismic). Again, a mention should be given by the authors if those attributes have been attempted. The papers that tempted this approach in 3D volume (which imply using modified algorithms) should be take into account when discussing the results. Those methodologies are in fact now moving beyond into detailing damage structures surrounding large scale faults , exploring strain/fault facies using various statistical and soon machine learning approach. Here some of the pioneering examples:

- C. Townsend, I.R. Firth, R. Westerman, L. Kirkevollen, M. Harde, T. Andersen Small seismic-scale fault identification and mapping Geol. Soc. Lond. Spec. Publ., 147

(1998), pp. 1-25 - Dutzer, H. Basford, S. Purves. Investigating fault-sealing potential through fault relative seismic volume analysis. Petroleum Geology Conference Series, vol. 7 (2010), pp. 509-515 - Chopra, S., Misra, S., Marfurt, K., 2011. Coherence and curvature attributes on pre-conditioned seismic dataset. Lead. Edge 32, 260e266. - Iacopini, D., Butler, R.W.H., Purves, S., 2012. Seismic imaging of thrust faults and structural damage: a visualization workïňĆow for deepwater thrust belts. First Break 30, 39e46.I, - Iacopini et al.Exploring the seismic expression of fault zones in 3D seismic volumes, JSG 2016 http://dx.doi.org/10.1016/j.jsg.2016.05.005 - Cunningham, Jennifer Elizabeth; Cardozo, Nestor; Townsend, Christopher; Iacopini, David; Wærum, Gard Ole (2019). Fault deformation, seismic amplitude and unsupervised fault facies analysis: Snøhvit Field, Barents Sea. Journal of Structural Geology. ISSN 0191-8141. Volume 118. p. 165-180. DOI: 10.1016/j.jsg.2018.10.010. where all the attributes are carefully discussed

Another attribute who may certainly help to visualize any sort of oriented structure without adding smoothing is the instantaneous phase and/or the cosine of it (called cosine of the phase). I suggest the following paper as reference as a nice explanation of the physics effect can be read: - Purves, S., 2014. Phase and Hilbert transform. Lead. Edge 34, 1246e1253

d) A different approach , that is now very important to guide the interpretation of certain seismic signal , come from the series of paper of the Bergen-Stavanger school running forward seismic modelling test. I suggest to read those papers and use them in the discussion when interpreting seismic, as they may be inspiring in discussing what the interpretation and acquisition pitfall who may biases the fault interpretation but also to compare what the results obtained in a more wide and up to date scientific framework.

- C. Botter, N. Cardozo, S. Hardy, I. Lecomte, A. Escalona. From mechanical modeling to seismic imaging of faults: a synthetic workflow to study the impact of faults on seismic. Mar. Petrol. Geol., 57 (2014), pp. 187-207 - C. Botter, N. Cardozo, I. Lecomte, A. Rotevatn, G. Paton. The impact of faults and fluid flow on seismic images of a relay

ramp over production time. Petrol. Geosci., 23 (2017), pp. 17-28

e) processing strategy: another approach has been taking by the Bruno&Improta work on the processing procedure to better image shallow structure using exploration data. Those need to be included in the discussion of the results obtained as well.

- Bruno et al. Ultrashallow seismic imaging of the causative fault of the 1980, M6.9, southern Italy earthquake by preâĂŘstack depth migration of dense wideâĂŘaperture data . GEOPHYSICAL RESEARCH LETTERS, VOL. 37, L19302, doi:10.1029/2010GL044721, 2010 - Improta et al. Detecting young, slowâĂŘslipping active faults by geologic and multidisciplinary highâĂŘresolution geophysical investigations:A case study from the Apennine seismic belt, Italy. JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 115, B11307, doi:10.1029/2010JB000871, 2010

I hope those comments may help to fine tune the paper and the discussion of the interpreted data proposed.

Best wishes David Iacopini

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