SEISMIC ATTRIBUTES ANALYSIS TO ENHANCE DETECTION OF GEOLOGICAL SUBSURFACE FEATURES ACROSS THE 2016-2017 EARTHQUAKE AREA (CENTRAL ITALY)

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Introduction. Seismic reflection profiles are commonly used in geological interpretation for the detection of seismogenic faults and horizons of regional significance involved in seismic breakups. Recently, a strong earthquake sequence struck the central Italy region (9 earthquakes with Mw≥5), culminating with a Mw 6.5 mainshock on 30 October 2016. An area of about 60 km was involved along the central Apennines, due to the activation of a complex fault system oriented in a NNW-SSE direction (Chiaraluce *et al.*, 2017; Lavecchia *et al.*, 2016; Pucci *et al.*, 2017). After the seismic crisis, we started a project for the geological reconstruction of this region mainly through interpretation of unpublished seismic sections provided by Eni S.p.a. We first focused our study across a 54 km long ENE-WSW transect intercepting both Norcia and Mt. Vettore normal faults, and the Mt. Sibillini thrust. Unfortunately, in such cases quality

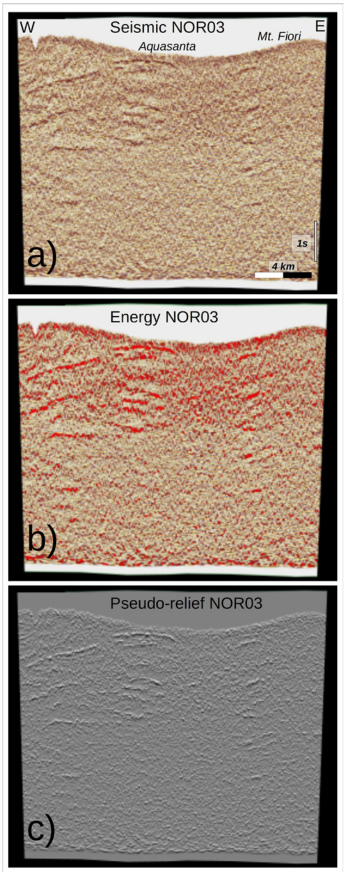

Fig. 1 - Attribute analysis on the Seismic line NOR3 (Acquasanta and Mt. dei Fiori area): a) standard amplitude section; b) Energy attribute calculated on NOR3; c) Pseudo-Relief in grey scale computed on NOR3.

of vintage seismic reflection lines can be poor due to several reasons: very different acquisition periods (over 30 years, since 1970) that means different equipments, technologies and acquisition configuration used (e.g. Vibroseis or dynamite sources, different CDPs folding and acquisition parameters etc..). In spite of this, such kind of dataset represents, at the present day, an unrepeatable opportunity in terms of seismic records. Moreover, availability of raw data from oil and gas companies offers a valuable possibility for reprocessing through more modern techniques (Stucchi *et al.*, 2006) or for seismic attribute analysis (Taner *et al.*, 1979). The potential and benefits of a seismic attributes application are continuously improving due to the increasing power of PCs and to the continuous developments of new attribute algorithms (Chopra and Marfurt, 2008), with some interesting application even on GPR data (Ercoli *et al.*, 2015, 2012). In this work, we present a first application on the aforementioned seismic lines, in order to provide new data through an improved visualization. We computed instantaneous amplitude, phase and frequency attributes, to allow the interpreters producing a better and more efficient interpretation of the main geologic units and discontinuities.

Data and method. The dataset encompasses almost 85 unpublished 2D seismic reflection profiles located along and across the entire study area. Here, we present the first results obtained along a transect crossing the Apennines at the Castelluccio di Norcia basin. The seismic SEG-Y files were loaded into the GPL OpendTect software (http://dgbes.com/), by using stored CDP coordinates and a common seismic datum. The seismic profiles belonging to this ENE-WSW transect show subsurface features down to a depth of 5 s (twt, corresponding to 10–12 km), that allow us to infer a new subsurface geological model. Attribute analysis methods may allow to evaluate (http://doc.opendtect.org):

- strong reflective layers and signal strength, through the "*Instantaneous Amplitude*" (or Trace Envelope and "*Energy*"), as a discriminator for acoustic impedance contrasts, sequence boundaries, bed thickness and thin-beds, spatial correlation lithologic variations;
- spatial continuity and discontinuity of reflections, through the "*Instantaneous Phase*", making strong events clearer and emphasizing discontinuities like faults, pinch-outs etc. Among the instantaneous phase attributes family, the "*Cosine of the Instantaneous Phase*" (or "normalized amplitude") has the benefit to be continually smooth, providing the +/-180 degree discontinuity, so that strong and weak events exhibit equal strength;
- low frequency anomalies as fracture zone indicator and bed thickness indicator, through the "*Instantaneous Frequency*", higher frequencies and lower frequencies suggest sharp interfaces (e.g. thinly laminated shales), and massive bedding geometries, respectively;
- another interesting attribute is represented by the "*Pseudo-Relief*", particularly useful in 2D seismics, allowing to create a more consistent image for an easier interpretation of faults and horizons. It consists in two steps: a first "Energy" attribute (RMS amplitude) computation is followed by the application of a Hilbert transform.

During this work, we computed those new attribute sections by using the standard time migrated seismic lines as input. Furthermore, we increased their interpretability also through the use of multi-attribute display, that provides unprecedent images, by combining physically independent waves quantities (e.g. amplitude, phase and frequency), that highlighted peculiar geophysical signatures of geological units and structural features.

Results and conclusions. In this work, we provide some new seismic images that may contribute to better constrain the subsurface geological interpretation of the area affected by the destructive 2016-2017 earthquake sequence. We focused in particular on the sector affected by the Mw 6.5 mainshock. Some features embedded on the original seismic lines have been enhanced. A strong reflection generated by a sub-horizontal horizon below Castelluccio di Norcia/Mt. Vettore sector should correspond to the Top Basement (Porreca *et al.*, 2017). The attributes, computed on NOR3 (beneath Acquasanta and Montagna dei Fiori anticlines, Fig. 1a) and NOR2 (beneath Norcia and Castelluccio di Norcia basins, Fig. 2a), show clear low-angle, west-dipping, high reflective horizons, enhanced in particular by amplitude attributes (e.g. Energy, Fig. 1b). Such reflectors represent strong acoustic impedance contrasts, interpretable as well-known reference horizons in central Apennines (Carbonates and Marne a Fucoidi Fm., Porreca *et al.*, 2017). These reflector geometries help draw also the location of the low angle main thrusts. Even the location and geometries of the seismogenic normal faults can now be inferred more easily: high angles structures are shown close to the surface, as indeed visible on the outcrops. Then, their tracking in depth is aided by exploiting the discontinuity of some thin reflectors sets, limited in length and enhanced by attributes: such faults show a progressively angle decrease in depth (Porreca *et al.*, 2017). The computed attributes reveal unprecedent details on the organization of the fault zone patterns, not visible in the standard unmigrated and migrated data. Such features are particularly emphasized by the Cosine Phase and Pseudo-Relief attributes (Figs. 1c and 2b, overlapped in transparency on the standard data), as well as by the Energy attribute. Those fault zones are particularly evident on the sides of the two main basins (Norcia and Castelluccio di Norcia, details in Fig. 2d). Their display highlights high complexity due to minor subparallel fault patterns surrounding the main W-dipping structures and their antithetics. The frequency attributes highlight the depositional characteristics of the basins, and clearly display at high resolution the units infilling the two aforementioned basins. These are characterized by higher frequency contents mainly close to the surface (green colors on Fig. 2c), whilst more in depth the blue colors (low frequency content) are predominant, indicating massive bedding geometries (Top Basement). It is interesting to notice how the high frequency sectors of the basins are laterally limited by the normal faults alignments (e.g. in Fig. 2, mainly beneath the Castelluccio basin). Here, sharp lateral transitions to lower frequencies (blue colors) are apparent and enhanced by the Pseudo-Relief displayed in transparency. In

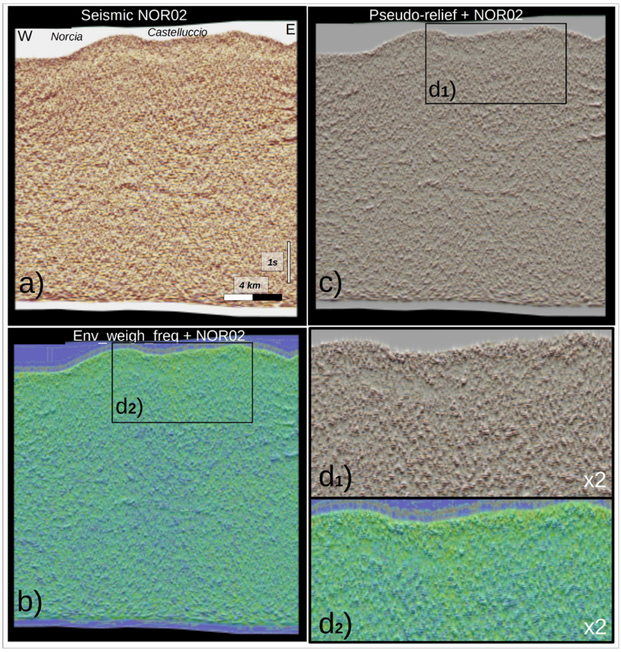

Fig. 2 - Attribute analysis on the seismic line NOR2 (Norcia and Castelluccio di Norcia area); a) standard amplitude section; b) NOR2 Pseudo-Relief, displayed in transparency over the standard amplitude seismic; c) Envelope Weighted frequency displayed in transparency over the NOR2 Pseudo-Relief; d) details of Figs. 2b and 2c showing the Castelluccio Basin.

conclusion, we provide a first application of attribute analysis on seismic sections across the central Apennines. Our results provide new subsurface images of the epicentral area. The study confirms that the attribute analysis represents, even on vintage seismic section of variable quality, an efficient aid for the interpreters to shed light on the deep structures of regional and seismogenic importance.

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