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Geological and geo-structural characterization of the Montemurro area (Southern Italy) inferred from audiomagnetotelluric survey

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ABSTRACT
This paper presents the results obtained by an audio-magnetotelluric (AMT) survey carried out crossing the western sector of Montemurro village (Southern Italy) affected by an intense hydro-geological instability. The AMT investigation was aimed to settle the question concerning the possible prosecution toward SE of the Eastern Agri Fault System whose surficial evidences could be blinded by extensive landslides phenomena and by anthropization of the territory. The AMT profile was oriented in NE-SW direction, orthogonal to the main geological structures of the investigated area. It crossed longitudinally the area affected by instability. The AMT model provides new insights on already known faults (i.e. Montemurro Faults) and imaged their in-depth immersion thus answering to still open geological question in the investigated areas. Furthermore, the high resolution of the model allowed the imaging of the boundaries, in terms of resistivity contrast, between material affected/unaffected by the sliding dynamics or characterized by an higher water content. The results provide new knowledge about the geological and geoelectrical structures in the area. They will be fully integrated with the results of the on-going research activities in the area and will represent an additional step for the multiscale and multiparametrical characterization of the Agri Valley geological setting.

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Introduction
The complexity of the geological framework where landslide phenomena develop requires multidisciplinary studies including geological and soils mapping, geotechnical and geognostic investigations. Different sensors and methodologies are able to range large spatial scales (i.e. Perrone et al. 2014). For example, satellite images and aero-
Photogrammetric surveys can cover large portion of subsoil and facilitate a multi-temporal analysis defining the geomorphologic features (scarps, terraces and trenches) of the landslides and their evolution. Conversely, in situ geognostic and stratigraphic investigations provide punctual and detailed information concerning geotechnical properties of the samples and, by means of inclinometers, allow to monitor also very slow rates of soil movements.

In the frame of the Project ‘Development and integration of innovative techniques of Earth Observation for landslides monitoring in a test site of the Agri Valley’, an integrated approach was adopted to characterize the Verdesca landslide (VL) (700 m-long and 325 m-large), near Montemurro village, and its surrounding areas. Summa et al. (2015) reported the compositional and physical-mechanical characterization of samples collected in three holes equipped with an inclinometer. From field geological and geomorphology surveys integrated with geognostic investigation and TDR (time domain reflectory) measurements, Gueguen et al. (2015) defined a detailed geological setting of the area surrounding the Verdesca landslide and recognized reciprocal stratigraphic or tectonic contacts between the outcropping formations. As a result, the landslide was classified as a rotational slip evolving downstream into a translational slip. The slip zone has been identified at depths ranging between 16 and 20.5 m.

Giocoli et al. (2015) presented the results of geophysical surveys as Electrical Resistivity Tomography (ERT) and the Horizontal-to-Vertical Spectral Ratio by earthquakes and ambient noise measurements performed on the landslide. In particular, the ERT provides information on electrical resistivity variations with depth. Electrical resistivity is a parameter very sensitive to water content and influenced by the lithology and porosity of the rock. The main results of Giocoli et al. (2015) concern the reconnaissance of the different lithological units involved by slope deformation, the detection of the shear surface and the geometry and thickness of the landslide body. A presumed tectonic control in the origin and evolution of the landslide is hypothesized by Giocoli et al. (2015).

All the above mentioned surveys provided a complete characterization of the Verdesca landslide characteristics, however many issues related to the geostructural context of the area interested by the landslide are still not resolved (i.e. large scale geological–structural setting and fault geometry at depth). For these reasons, we planned and realized an audio magnetotelluric survey, as it represents the best solution when it is necessary to investigate several hundred metres in depth preserving a good lateral resolution.

In areas affected by landslides phenomena, the audio magnetotelluric technique can be applied to define the structural/geological setting, to reconstruct the spatial distribution of the material involved in the instability, to highlight the limits, in terms of resistivity contrast, between affected/unaffected material respectively and to provide information about the dynamics involved in the landslide generation/evolution.

The AMT profile, composed of 10 soundings distributed over a transect line 2.7 km long, was oriented NE-SW and longitudinally crosses the Verdesca landslide. The profile direction was chosen in order to be orthogonal to the fault systems (i.e. Montemurro Fault) which, according to Giocoli et al. (2015), may be partially responsible for the sliding phenomena. The results of the AMT survey are thus expected to provide new in-depths information on geo-structural setting of the investigated area.
Geological settings

The High Agri Valley Basin

The High Agri Valley Basin is an inter-mountain basin located within the axial sector of the Southern Apennines (Figure 1), an east-verging fold-and-thrust belt developing from Late Oligocene to Early Pleistocene due to the eastward migration of the Apennine (e.g. Doglioni et al. 1996; Gueguen et al. 1997; Gueguen et al. 1998; Pescatore et al. 1999; Bucci et al. 2014).

The tectono-stratigraphic units involved in the Lucanian Apennines are derived from the Afro-Adriatic paleomargin deformation. From west to east we can recognize: the Cretaceous to Oligocene Liguria-Piedmont oceanic units of the Liguride and Sicilide Complex; the Late Triassic to Tertiary Apennine Platform carbonate units; the Late Paleozoic to Tertiary Lagonegro Basin units (e.g. Scandone 1967; Ogniben 1969; D’Argenio et al. 1975; Mostardini and Merlini 1986; Carbone et al. 1991; Roure et al. 1991; Monaco et al. 1998; Cello et al. 2000a; Menardi Noguer and Rea 2000; Lentini et al. 2002; Tavarnelli and Prosser 2003; Piedilato and Prosser 2005). Eastward thrust sheet top silicoclastisc deposits (e.g. Gorgoglione Flysch) are emplaced during Tertiary upon tectono-stratigraphic units indicated above (Butler and Tavarnelli 2006) and references therein).

The High Agri Valley Basin evolution starts in the Lower Pleistocene and continues till Holocene due to transtension and extension processes responsible for two high-angle

Figure 1. Redrawn of the schematic geological map of the High Agri Valley (Gueguen et al. 2015). MMFS: Monti della Maddalena Fault System; EAFS: Eastern Agri Fault System. The black square indicates the area investigated in this paper.
fault systems, the Eastern Val d’Agri Fault System described by Cello et al. (2000a, 2000b, 2003), Bucci et al. (2014) and references therein, along the NE flank of the basin, and the Monti della Maddalena Fault System of Maschio et al. (2005), along the southern flank. The above mentioned fault systems are supposed to be causative of large seismic events such as the M7.0 1857 Basilicata earthquake (Branno et al. 1985), whose macroseismic field covered a wide sector of the Southern Apennines chain. The basin is filled by continental clastic Quaternary units which overlay the pre-quaternary bedrock and are represented by coarse-grained slope deposits (Di Niro and Giano 1995; Boenzi et al. 2004) and clastic deposits from an alluvial and lacustrine environment (Di Niro et al. 1992; Giano et al. 2000). The arrangement of these deposits suggests that five generations of slope and alluvial fan systems have developed along the eastern margin of the valley from Pleistocene to Holocene (Giano 2011).

Montemurro area

The area surrounding the village of Montemurro, although largely exploited for cultivations and oil extractions, does not show dramatic signs of surface land degradation (Imbrenda et al. 2014; Simoniello et al. 2015). It is located on the left orographic side of the Agri Valley and is characterized by outcrops of mainly continental clastic Quaternary deposits of slope, alluvial and lacustrine environments (Figure 2). These deposits, together with the fault systems, are responsible for the seismic activity in the area.

Figure 2. Geo-structural map of the investigated area. The geographic information was projected to a common UTM zone 33 under the WGS84 datum. The figure also shows the location of the AMT soundings (red triangles) and of ERT survey (blue line) carried out by Giocoli et al. (2015).
deposits rest on a bedrock formed by the Tertiary siliciclastic sediments (Gorgoglione and Albidona Formation) which are observed in several outcrops distributed mainly uphill from the village of Montemurro, and in the more engraved ditches.

The Gorgoglione Flysch formed from Middle Langhian to Lower Tortonian in a piggy-back context during the Apennines compressional deformation phase that produced the Irpinian Basin (Boenzi and Ciaranfi 1970; Carbone et al. 1988; Loiacono 1993; Boiano 1997; Butler and Tavarnelli 2006). It is composed of three sequences of terrigenous sediments (arenaceous and arenaceous-conglomeratic; arenaceous-marly; siltly-arenaceous-marly), interbedded and repeated several times at different stratigraphic levels, marking several pulsating torbiditic events (Boenzi and Ciaranfi 1970; Mutti and Normark 1987; Critelli and Loiacono 1988). In the studied area, the pelitic-arenaceous facies prevails. The main outcrops are NE of the village of Montemurro. The northern part of the village is also located on the Gorgoglione Flysch, with several buildings directly resting on massive sandstones. The pelitic-arenaceous sequence, exposed in these outcrops, is mainly composed of grey, yellowish or whitish quartz-feldspar sandstones, with grey or brown silty marls and interbedded silty clays. The decimetric to metric sandstone layers often show yellow ochre surfaces altered with whitish veins, carbonatic cement—filled, and vertical graded bedding characterized by breccias with millimetre and centimetre pebbles at the base. These basal breccias rest on the underlying pelitic level with a very sharp contact, while the upward transition to the finer level is more gradual. Gogoglione Flysch is in stratigraphic unconformity with Albidona Formation that outcrops a few km NW outside of the study area but has been observed only at depth within the log of the Costa Molina 2 well (Stabile et al. 2014; Balasco et al. 2015).

The Albidona Formation represents the higher part of a larger torbiditic sequence and is formed of an alternance of grey-yellowish arenites, marls and silty clays and of the characteristic megastrata of white carbonates. The age of the Albidona Fm. is still a matter of debates that are far beyond the scope of this paper. Nevertheless, in the High Agri Valley can be observed many duplicate within the Albidona Fm. suggesting that this flyschoid sequence has been sedimented in different times in distinct palaeogeographic domains already partially deformed.

The continental clastic Quaternary sequence rests on an angular unconformity truncating the Miocene bedrock. It is represented by alluvial fan, alluvial plain and lacustrine deposits corresponding to the middle and upper intervals of the Complesso Val d’Agri of Di Niro et al. (1992).

In 2010, Zembo proposed a new allostratigraphic model for the basin’s deposits fitting better its tectono-stratigrafic history. The ‘Agri Valley Allogroup’, up to 100 m thick, is composed of four unconformity-bounded units, representing distinct depositional intervals related to regional tectonics and environmental changes, overlaying the Lower Pleistocene deposits of the Spinoso Conglomerate Formation (Zembo et al. 2009; Zembo 2010). From bottom to top, the Agri Valley Allogroup is composed of Pietra del Pertusillo Alloformation, Valle del Nasillo Alloformation, Vallone dell’Aspro Alloformation (VAA) and Torrente Casale Alloformation (TCA). This sequence reflects a progradation of fan systems in a lacustrine-palustrine setting, followed by expansion of a new alluvial-fluvial system (Zembo 2010). In the investigated area, only the VAA and the TCA formations outcrop.
Most of the Pleistocene deposits affecting the studied area can be attributed to the Vallone dell’Aspro Alloformation, characterized by coarse to fine sands and stratigraphically lower greenish to grey silty clay and clayey silts, interbedded with organic-rich peaty levels. Both upward and downward, along the stratigraphic sequence, clast-supported coarse conglomerates and sandy gravels can be observed. The upper conglomerates show imbricated pebbles of different composition, mainly arenaceous and subordinately siliceous and igneous, while the composition of the lower gravels, often characterized by a reddish sandy matrix, is mainly dolomitic, calcitic, siliceous and arenaceous, with rarer clasts of varicoloured argillites and metamorphic rocks (Zembo 2010). This alloformation corresponds to an axial braided alluvial system where the water and sediment supply was both from main stream and transverse alluvial fans. This environment was also characterized by outcast refilled channels, pools and ponds, temporary lacustrine-palustrine settings associated to flood events, interfluves areas, as shown by the mollusks assemblages typical of open vegetated zones, organic layers representative of standing swamp area and flash flood laminated structures (Pisegna Cerone 2008; Zembo 2010).

The Torrente Casale Alloformation crops out only in the topographically higher areas and is characterized by clast-supported massive conglomerates, with a yellowish sandy matrix and a heterometric cobble to boulder sized clastic component, mainly represented by the sandstones of the Gorgoglione Flysch and the Albidona Formation cherts, igneous and metamorphic clasts. The sandy component increases downwards and appears as matrix-supported sandy gravels with polygenic millimetre to centimetre clasts, and as yellow ochre sands. The same characters can be recognized in other outcrops in the study area.

The contact between the Torrente Casale and Vallone dell’Aspro Alloformation deposits is a composite surface, erosional in the north and depositional towards the basin, based upon a weathering profile composed of a fersiallitic/brunified pedocomplex with two paleosols corresponding to two erosion episodes (Zembo 2010).

The Quaternary continental deposits, that stratigraphically overly the Miocene bedrock in onlap relationship, are plan-parallel, arranged in subhorizontal to gently south-dipping strata towards the basin depocenter.

Regarding the tectonic issue, due to the intense anthropization of the territory and to the diffusion of landslides, the few outcrops providing structural information are found in the small valleys. However, two main sets of faults can be recognized. The first one is oriented roughly N130° mainly showing a transtensional kinematic and is linked with the East Agri Fault System (Benedetti et al. 1998, Maschio et al. 2005). The second sets is composed of normal faults oriented roughly N60° and can be interpreted as a consequence of the South-East migration of the Apennine orogene (Doglioni et al. 1996; Gueguen et al. 1997; Gueguen et al. 1998; Pescatore et al. 1999; Bucci et al. 2014).

**AMT data and analysis**

In the magnetotelluric (MT) method, the subsurface electrical conductivity is obtained by using the natural electromagnetic (EM) fields as source in the frequency range
[10⁻⁵ – 10⁵ Hz]. The principles of the technique were first introduced by Tikhonov (1950) and Cagniard (1953). In the earth, EM waves are considered as planar in geometry and propagating vertically downward. EM waves travel diffusively so that high-frequency (short wave-length) waves penetrate a relatively short distance, while low-frequency (long wavelength) waves reach greater depths. In particular the audio-magnetotelluric (AMT) refers to recording >100 Hz to 10 kHz. So, the AMT method allows to obtain information on the electrical resistivity structure of the subsoil from tens of metres from the surface down to hundreds of metres in depth in a number of geotectonic applications (i.e. Vallianatos and Makris 2000).

The AMT-MT method requires a simultaneous time series measurement of co-located orthogonal components of magnetic (Hₓ-NS and Hᵧ-EW) and electric (Eₓ-NS and Eᵧ-EW) field. Magnetic fields are recorded using induction coil magnetometers placed on the ground and the electric fields recorded using steel electrodes.

In the frequency domain, orthogonal components of E and H are linearly related through the complex impedance tensor \( Z \) (Berdichevsky and Dmitriev 2008):

\[
\begin{bmatrix}
E_x(\omega) \\
E_y(\omega)
\end{bmatrix} = \begin{bmatrix}
Z_{xx}(\omega) & Z_{xy}(\omega) \\
Z_{yx}(\omega) & Z_{yy}(\omega)
\end{bmatrix} \begin{bmatrix}
H_x(\omega) \\
H_y(\omega)
\end{bmatrix}
\]

Equation 1 holds assuming that the source fields are homogeneous plane waves.

The complex off-diagonal elements of \( Z \) at a varying frequency are then used to obtain the apparent resistivity (Ω•m) and phase (degrees):

\[
\rho^a_{ij}(\omega) = \frac{1}{\mu_0 \omega} |Z_{ij}(\omega)|^2, \phi_{ij} = \tan^{-1}\left(\frac{\text{Im}(Z_{ij})}{\text{Re}(Z_{ij})}\right)
\]

where \( i, j = x,y, \omega = 2\pi/T \) and \( \mu_0 \) is the magnetic permeability of the vacuum.

In the simpler case of an isotropic layered (1D) Earth, the diagonal elements \( Z \) are zero and \( Z_{xy} = -Z_{yx} \). In the case of an isotropic two-dimensional (2D) Earth, the diagonal elements \( Z \) are still zero but \( Z_{xy} \neq Z_{yx} \). If the measuring frame is not coincident with the geoelectrical structure orientation, then all the elements of \( Z \) are different from 0. In this case, the tensor can be rotated to the coordinate system where observed electric and magnetic fields are parallel and orthogonal to the structure. In this rotated coordinate system \( Z_{xx} = Z_{yy} = 0 \), the off diagonal elements of \( Z \) are generally different and define two transverse electric (TE) and transverse magnetic (TM) (Chave and Jones 2012).

The AMT data were collected in 2012 by using a Stratagem EH-4 system manufactured by Geometrics. 10 AMT sites were acquired, with an average interstation distance shorter than 300 m; their position was chosen in such a way to define a ~2.7 km long transect line crossing the whole area interested by the Verdesca landslide and to be orthogonal to the main geological structure of the area (see Giocoli et al. 2015; Gueguen et al. 2015). Figure 2 shows the exact position of each AMT site along with the main geological structures (landslide body and faults) and the pre-existing geophysical investigation performed in the area.

In each AMT site, both the induction coils and the electrical lines (50 m-long dipoles) were installed in the N-S and E-W acquisition frame and data have been
acquired in the frequency range \([10 \sim 10^5 \text{ Hz}]\). To obtain an improved signal-to-noise ratio, a controlled source was used in the frequency range from 1000 Hz to 64,000 Hz. The controlled source, part of the STRATAGEM acquisition system, is a small moment unit \((400 \text{ Am}^2)\) which was moved in a different location for each of the 10 acquired sites in order to be always in the optimum condition (i.e. plane wave and higher signal to noise ratio).

Data quality of AMT survey was generally high thanks to relatively long recordings, to instrument sensitivity (32-bit) and for the low anthropization level of the investigated area.

**Strike estimation and dimensionality analysis**

Before performing any data modelling, the dimensionality of the electrical structure of the investigated area and the associated geoelectrical strike were recovered. These information can be obtained by applying several methods; among all it is worth to remind the ones proposed by Swift \((1967)\), Groom and Bailey \((1989)\), McNeice and Jones \((2001)\), Bibby et al. \((2005)\) and Weaver et al. \((2000)\) (WAL procedure). In the present work, the dimensionality analysis has been performed by means of the WAL procedure. Data errors and threshold values, as specified by Martí et al. \((2004)\), were included in the analysis. WAL procedure is based on the definition and on the analysis of rotational invariants \((a \text{ set of } 7 \text{ invariants namely } I_{1-7})\) of the Impedance tensor, i.e. onsets of parameter computed from the observed impedance tensor values that do not depend on the direction of the observing axes, and of a not independent invariant, as, by algebraic manipulation, it can be derived from the first four invariants.

The first two invariants, \(I_1\) and \(I_2\), are combinations of the real and imaginary parts of the trace and antitrace of the response tensor. \(I_3\) and \(I_4\) contain information about the strength of the 2D anisotropy, ranging from 0 in a 1D case to 1 for infinite anisotropy. \(I_5\), \(I_6\) and \(I_7\), are related to galvanic distortion.

The possible dimensionality analysis outputs depends on the numerical values assumed by the invariants and by \(Q\). If the data are noise-free, for a 1D Earth, \(I_3\) to \(I_6\) are all zero and \(I_7\) is undefined. The last three invariants plus \(Q\) provides information when the underlying structure is 3-D or if it can be described by a 2-D model affected by a galvanic distortion.

The results of the dimensionality analysis are shown in Figure 3. As it can be seen, the dimensionality of the subsurface can be considered mostly 1D or 2D/2D distorted. Locally, both in space and frequency, the WAL analysis indicates a 3D structure of the subsoil. Only few ‘undetermined’ cases are present testifying the good quality of the data.

Taking into account these results, a 2D inversion scheme can be considered appropriate to model the AMT dataset. The WAL analysis, where a 2D dimensionality is recovered, allows to estimate the geoelectrical strike and to undistort/decompose the AMT data in a reference frame compatible with the recovered strike direction (Martí et al. \(2004, 2009\)). For the present AMT dataset, the strike analysis shows prevalent \(\sim \text{N } 135^\circ\) orientation of the geoelectrical structures which is compatible
with the orientation of the main geological structure in the area. It has to be noted that the strike determination generally suffers the 90° ambiguities present in impedance analysis.

**Modeling**

Considering the information above mentioned on the retrieved geoelectrical strike (N 135°), the AMT transfer functions were corrected for distortion and derived in the appropriate strike direction.

The 2D inversion were performed by using the non-linear conjugate 2D inversion algorithm of Rodi and Mackie (2001). This algorithm finds the smoothest resistivity model (Tikhonov Regularization) that fits the data. A regularization parameter τ controls the trade-off between the quality of the fit and the smoothness of the model. The optimum τ value represents compromise between the data fit and the model smoothness (see e.g. Bedrosian et al. 2004). In the following analysis, TM and TE modes have been simultaneously inverted maximizing the advantage connected to both the mode inversion. TM and TE modes complement each other’s (i.e. Berdichevsky and Dmitriev 2008). Inverting only TM mode, conductive structures can be well imaged and a good sensitivity to near surface structures as well as to the lithosphere resistance and deep faults can be achieved. On the other hand, inverting only TE mode, a better accuracy, in imaging resistive structures and better sensitivity to deep structures, can be obtained; furthermore, TE mode is less affected by static shift problems even in mountains regions (Berdichevsky and Dmitriev 2002).
Before obtaining the final model, several inversion tests were performed using different values for the regularization parameter $\gamma$. The inversion results were also checked with respect to the inversion parameters and to different starting model. The final model here presented, was obtained starting from a homogeneous half space ($10 \Omega\text{m}$). The choice of using a such conductive starting model is based on the results of the ERT investigations performed in Giocoli et al. (2015). In particular, the model shown is the one related to the regularization parameter $\gamma$ for which the knee of the L-curve (obtained by plotting roughness against r.m.s. data misfit for models with a range of smoothing parameters) was observed. This condition ensured the model to be balanced between the requirements for a spatially smooth model that honours the measured data an acceptably low data misfit (Hansen 1992).

During the inversion process, a major weight on fit was set on phase (phase values are not affected by static shifts) by assigning larger error floors to the apparent resistivities than to the phases: 5% for phases and 10% for resistivities. Using these settings, the root-mean-square (rms) misfit of the final model (Figure 4) is 1.5.

The 2D resistivity model shows marked resistivity variations both in depth and along the profile. The shallower subsoil strata (from the ground surface up to 50 m in depth) are generally characterized by low resistivity values. A thickening of this conductive layer can be observed, along the profile, between 400 m and 800 m and between 1600 m and 2100 m. The highly conductive shallow anomaly that can be observed between site AMT2 and AMT3 can be related to a higher water content of the subsoil. During the acquisition phase of these AMT sites, notwithstanding the soil slope and the absence of atmospheric precipitation in the days before the fieldwork operations, the instrument installation areas were characterized by a muddy clayish soil with a high water content.

The deeper layers are, on the other hand, more resistive except for the two conductive areas (marked with the capital letter ‘A’ and ‘B’). As it can be seen in Figure 5, which shows the comparison between raw data (observed data) and the model responses (calculated data) for electrical resistivity and phase for both modes

![Figure 4](image-url). AMT resistivity model obtained by the joint inversion of TE and TM modes. The meaning of the capital letters ‘A’ and ‘B’ is described in the text. The figure also shows the projection of the ERT survey carried out by Giocoli et al. (2015) along the AMT profile.
(TE and TM mode), the conductive area ‘A’ is a feature of both the observed and calculated data. As regard as the feature ‘B’, its presence in the observed data is less evident; it cannot be excluded that ‘B’ is a consequence of the presence of the Pertusillo lake (less than 500 m away from AMT-site 10).

**Geological interpretation of the Audio-Magnetotelluric data**

From a structural point of view, the main question about the studied area is to locate the prosecution toward SE of the EAFS (Figure 1) considering that its surficial evidences are masked by extensive landslides phenomena and by the anthropization of the territory. The obtained resistivity model (Figure 4) gives useful information on this issue.

As shown on Figure 6, there is a good agreement between the AMT model features and the main geological units and structures of the investigated area. The AMT profile intersects the siliciclastic sediments of the Gorgoglione Flysch (GF) and basin deposits of the Vallone dell’Aspro Alloformation (VAA). The Verdesca Landslide (VL) is located in the middle of the AMT profile and mainly involves the above mentioned geological formations. The surficial conductive bodies (delimited by white
dotted line in Figure 6) can be associated to the slide deposits and to areas characterized by a high water content.

The more resistive areas (R1, R2 and R3 in Figure 6) are associated to Tertiary siliciclastic sediments (ascribable mainly to Albidona Formation, AF) whose presence in depth is widely reported in literature (Monaco et al. 1998; Cello et al. 2000a; Zembo 2010; Gueguen et al. 2015; Giocoli et al. 2015). Variations in composition and degree of fracturing of these sediments may lead to the difference in resistivities (R1, R2 and R3) observed below the landslide bodies.

As regards the vertical conductivity anomaly ‘A’, extending from the surface up to ~300 m a.s.l. and laterally confined by the two resistivity bodies R1 and R2, it is spatially well correlated with faults observed during field surveys and reported in the geo-structural map (as blinded or guessed faults). The anomaly ‘A’ may be related to the fault trend in depth. From the features of ‘A’, it is thus be possible to define the dip of the faults (marked as f1, f2 and f3). The f3 setting is also supported by evidences found during the field geological survey. Similar considerations can be done for the discontinuity between R2 and R3 where the f4 fault could be interpreted in the AMT model. By comparing the structural interpretation of the AMT model with the results of the ERT surveys previously performed (blue trace in Figure 2, Giocoli et al. 2015) a good agreement exists where the two different kinds of survey overlap. Moreover, thanks to the higher investigation depth of the AMT model relative to the ERT sections, it is possible to evaluate the in-depth extension of ‘A’ whose presence, according to the geological interpretation, may be due to the Tertiary siliciclastic sediments with an higher degree of fracturation and thus water saturated.

Figure 6. 2D-Model with geo-structural interpretation.
The conductive body ‘B’ is not correlated to any specific geological and/or tectonic structure, because it represents more likely an artefacts of the inversion process ascribable to the off-profile large conductive body pervaded by the water of the Pertusillo artificial lake.

Conclusion

The characterization of the Verdesca landslide is based on the quantification of the sliding volumes (in terms of lateral and vertical extension of the landslide body) and through the characterization of the geo-structural setting which control the sliding dynamics and/or where the landslide takes place. While surficial information can be better inferred by applying near surface techniques, for the large scale geo-structural reconstruction, deeper investigations are required. To this aim, an AMT survey was carried out on a profile crossing the Verdesca landslide.

The main AMT model features not only allowed the imaging of the limits, in terms of resistivity contrasts, between material affected/unaffected respectively by the sliding dynamics, but also provided hints on the space orientation of the tectonic structures. The features of f1-3, whose surficial evidence is almost totally lacking due to landslide dynamics which make these faults hardly detectable during a field geological survey, are instead well imaged in the AMT model.

In conclusion, the results of the AMT campaign provide a better understanding of the geological and geoelectrical structures in the area involved by the Verdesca Landslide. Further they will be fully integrated with the results of the on-going research activities in the area and will represent an additional step for the multiscale and multiparametrical characterization of the Agri Valley geological setting.

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Disclosure statement

No potential conflict of interest was reported by the authors.

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