Recent tectonic activity of the Budoia-Aviano Thrust: the example of the Late Pleistocene-Holocene Artugna alluvial fan (eastern Southern Alps, NE Italy)

Maria Eliana Poli[1,2,*], Giulia Patricelli[1,2,4], Emanuela Falcucci[3], Stefano Gori[3], Enzo Rizzo[2,4], Giovanni Paiero[1], Andrea Marchesini[1], Angela Franceschet[1,5], Davide Russo[2,4], Paola Boldrin[4], Aaron Sobbe[4], and Riccardo Caputo[2,4]

[1]Università di Udine, Dipartimento di Scienze AgroAlimentari, Ambientali e Animali, Udine, Italy
[2]Centro Interuniversitario per la Sismotettonica 3D con Applicazioni Territoriali (CRUST), Chieti, Italy
[3]Istituto Nazionale di Geofisica e Vulcanologia, Osservatorio Nazionale Terremoti, Rome, Italy
[4]Università di Ferrara, Dipartimento di Fisica e Scienze della Terra, Ferrara, Italy
[5]Università di Trieste, Dipartimento di Scienze della Vita, Trieste, Italy

Corresponding author: eliana.poli@uniud.It

Introduction and seismotectonic setting

In the framework of the PRIN2020 "*Fault segmentation and seismotectonics of active thrust systems: the Northern Apennines and Southern Alps laboratories for new Seismic Hazard Assessments in northern Italy (NASA4SHA)*", we made a multidisciplinary and multiscale seismotectonic study on the Budoia-Aviano Thrust which is an external splay of the larger Polcenigo-Montereale fault system located in the western Carnic Prealps (Friuli, NE Italy).
The investigated area is part of the external Pliocene-Quaternary front of the eastern Southern Alps (ESA) where geodetic (GNSS) time series [Devoti et al., 2011; Serpelloni et al., 2016; Areggi et al., 2023] show a crustal shortening rate of about 2-3 mm/yrs. In the Carnic Prealps, the external front of ESA consists in a series of arch-shape WSW-ENE trending, SSE verging presently mostly believed as blind thin-skinned thrusts, affecting the Late Pleistocene-Holocene piedmont Friuli Plain [Galadini et al., 2005; Poli et al., 2021; 2024]. In particular, the Polcenigo-Montereale Thrust System (Figure 1), where the Mesozoic Friuli Carbonate Platform overthrust the Neogene Southalpine Molasse, extends from the Caneva to Montereale Valcellina towns and consists of a series of S-verging splays that show evidence of recent tectonic activity: the Aviano-Budoia and the Vigonovo thrusts, respectively [Poli et al., 2015].
According to the currently available catalogue of historical seismicity (the DBMI Catalogue [Locati et al., 2022]) the area was hit by some historical destructive earthquakes, like the 1776 Tramonti (Mw = 5.78, Io = 8-9); the 1794 Alpi Carniche (Mw = 6.04, Imax = 9); the 1812 Sequals (Mw = 5.7; Imax = 7-8); the 1873 Alpago (Mw = 6.3; Imax = 9-10) and the 1936 Cansiglio (Mw = 6.1; Imax = 9) earthquakes. Concerning the instrumental seismicity (from 1977 to Present), we distinguish the area of Claut that was hit by frequent medium-to-low seismic events (max magnitude 4.3, 1996-04-13 earthquake; [Bernardis et al., 1996]). In this contest, Galadini et al. [2005] indicate the Polcenigo-Montereale Thrust System as the seismogenic source of the aforementioned 1873 Alpago earthquake.

Methodology

The area was analysed by means of a multidisciplinary and multiscale approach that includes:

1. Morphotectonic investigations with analysis of high-resolution Digital Elevation Model provided by the Friuli Venezia Giulia Region in order to define possible morphotectonic

features across the investigated area. In case of morphological surface anomalies, we performed detailed field surveys to verify whether they indicate active, progressively growing, fault-related anticlines (drainage anomalies, uplifted and/or tilted palaeosurfaces, scarps) (Figure 2).

2. Mu tiscale geophysical surveys, encompassing a range of techniques, each providing different insights into the studied fault system. By applying a range of geophysical techniques at different scales of investigation, the proposed methodology in the study involved the use of deep and shallow Electrical Resistivity Tomographies (hereafter ERT) [Rizzo et al., 2004], and Ground-Penetrating Radar (hereafter GPR) techniques to upscale the understanding of buried geological structures and identify optimal sites for the excavation of palaeoseismological trenches (Figures 3 and 4).
3. Palaeoseismological trenches, excavated where morphotectonic analyses and geophysical survey indicate possible shallow-to-surficial effects of tectonic activity. Two trenches (BU1 and BU2 in Figure 3) were dug to achieve detailed geometric (trend, size, depth), kinematic (slip vector, cumulative displacement, slip per event), dynamic (maximum expected magnitude) and chronological (slip-rate and mean recurrence interval) parameters for seismotectonic assessments. Radiocarbon dating on the Late Pleistocene-Holocene continental deposits were carried out by Beta Analytic.

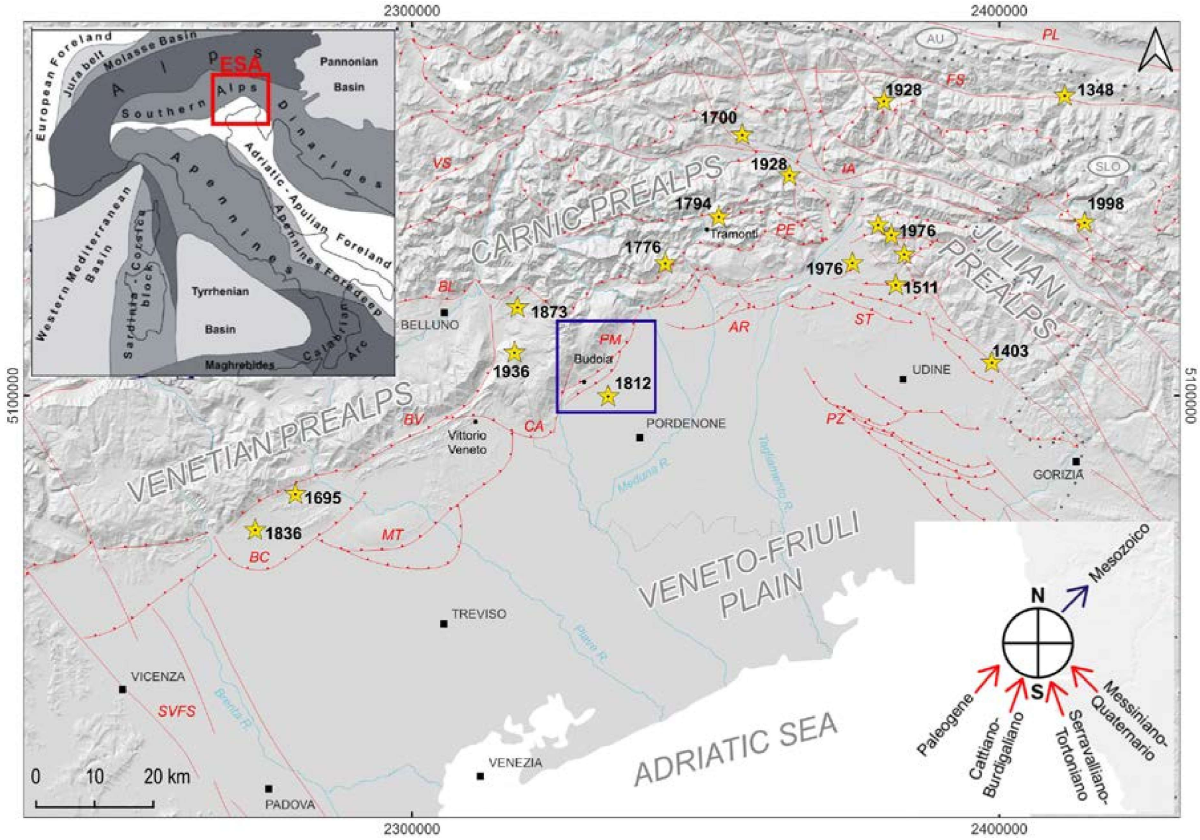

Figure 1 Structural sketch map of the Eastern Southern Alps. Blue rectangle is the study area. Yellow stars are the M>5.5 historical and instrumental seismic events during the last millennium. AR: Arba-Ragogna Th., BC: Bassano-Cornuda Th., BL: Belluno Th., BV: Bassano-Vittorio Veneto Th., CA: Cansiglio Th., FS: Fella-Sava f., IA: Idrija-Ampezzo fs., MT: Montello Th., PE: Periadriatic Th., PL: Periadriatic Lineament, PM: Polcenigo-Montereale Th., PZ: Pozzuolo Th., ST: Susans-Tricesimo Th., SVFS: Schio-Vicenza fault-system., VS: Valsugana Th.

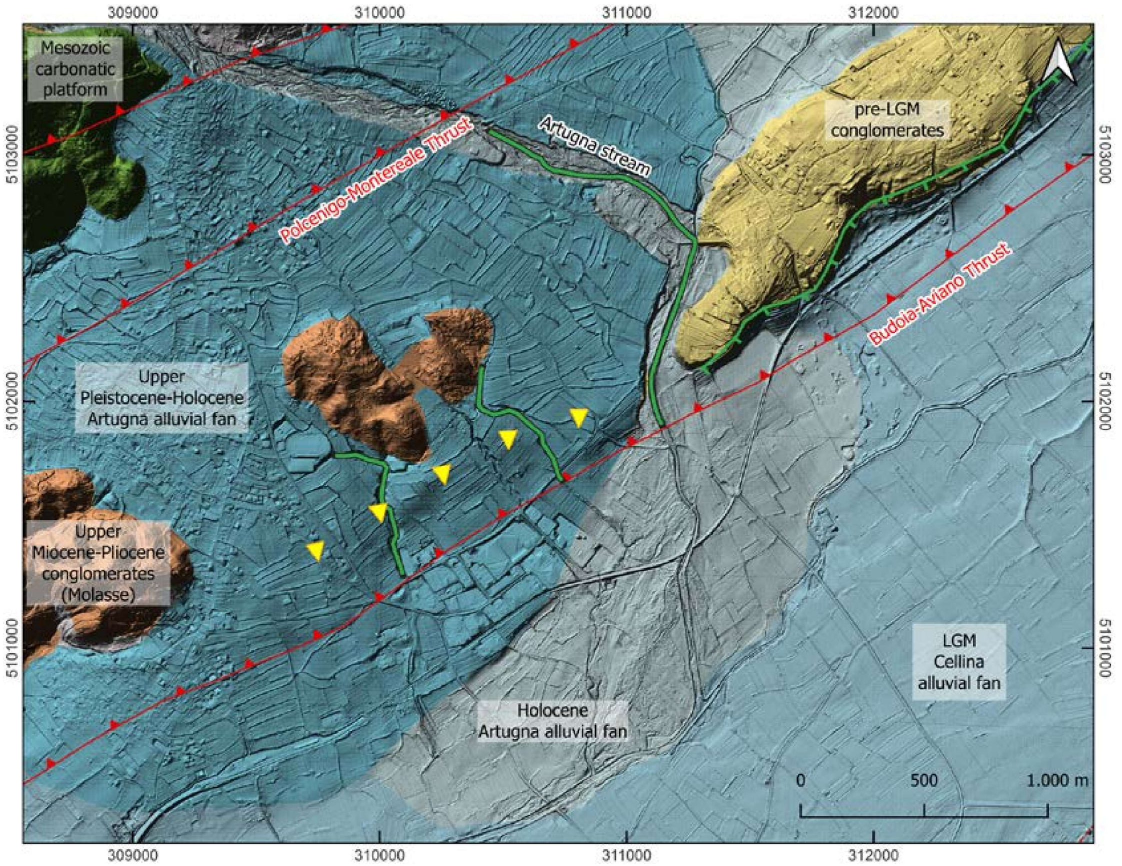

Figure 2 Morphotectonic evidence of fault-related anticline growth on the Upper Pleistocene-Holocene alluvial fan of the Artugna River. Yellow triangles: surficial warping; green line: drainage anomalies; green line with ticks: scarp.

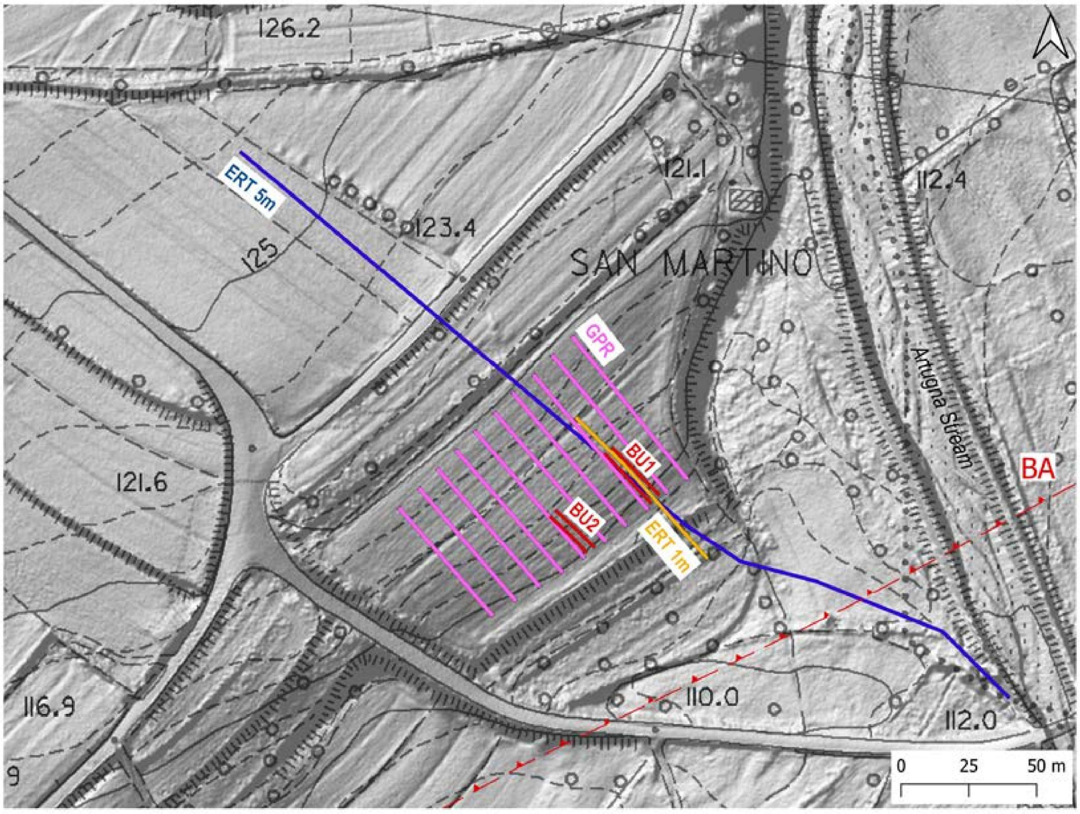

Figure 3 Geophyisical profiles (pink line: GPRs; blue and yellow: deep and shallow ERTs) and palaeoseismological trenches (BU1 and BU2) carried out on the Artugna alluvial fan.

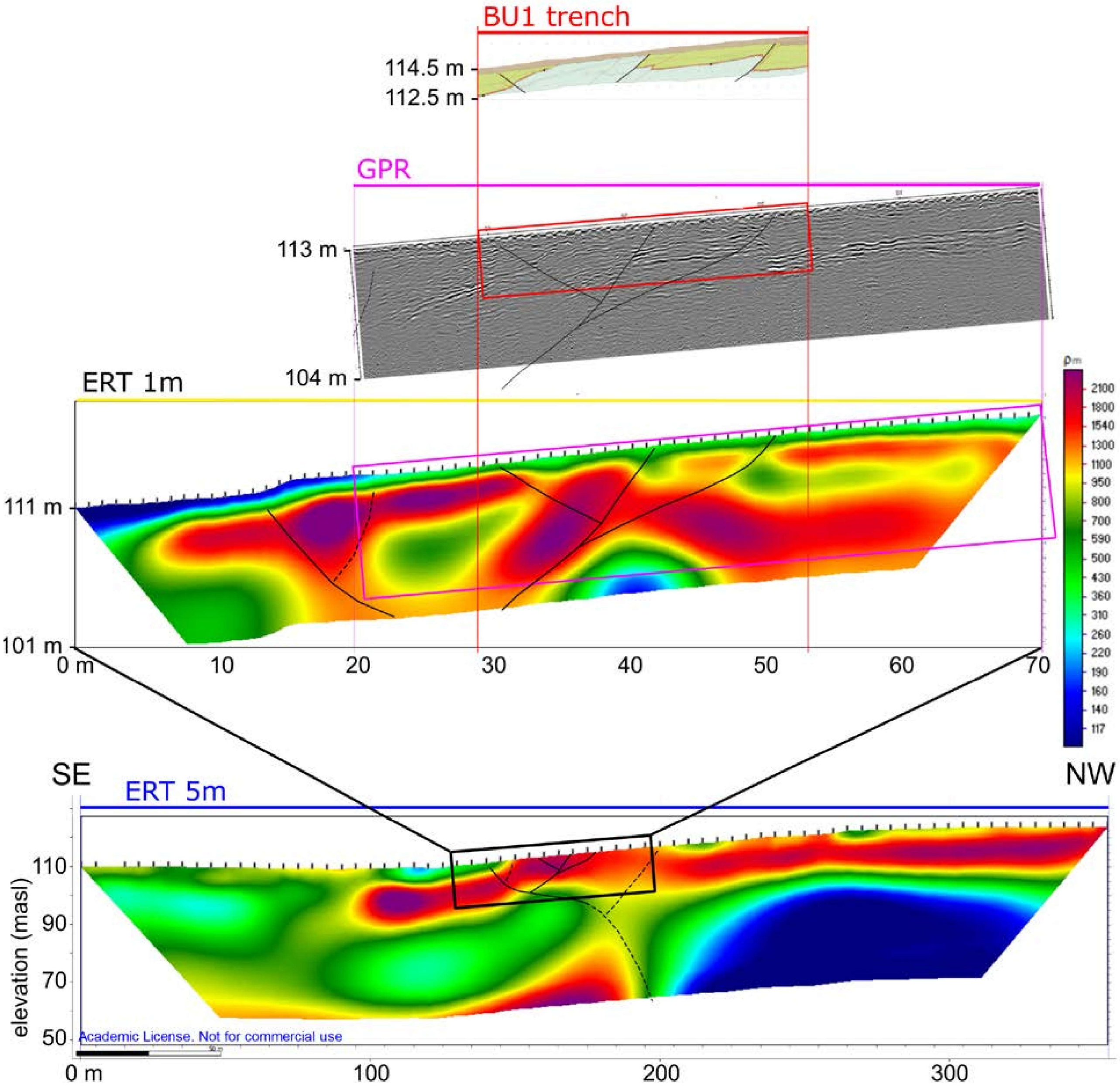

Figure 4 Multiscale investigations workflow. (a): from ERT 5m to ERT1m; (b): from ERT1m to palaeoseismological trench [Rizzo et al., 2024].

Results

The excavated trenches intersected Upper Pleistocene-Holocene sands and gravels of the Artugna River alluvial fan displaced by a set of medium-to-high angle, N-verging reverse faults. At about 2 m-depth from the ground surface, we identified a palaeosoil separating two alluvial fan units. Radiocarbon dating of the palaeosoil sample gave an age of 16,310-16,050 cal. B.C. The palaeoseismological analysis allowed us to estimate a cumulative slip, measured on all the observed fault planes on the order of at least 4.5 m (Figure 5).
The reverse fault planes identified within the two trenches define circa 20 m-wide area of surficial deformation, developed in the hanging-wall block of the main S-verging thrust plane (not intersected by the trenches) and characterized by an ENE-WSW trending.

Figure 5 The western wall of the Budoia 1 trench.

Considering the overall dimensions of this deformation area, both along- and across-strike, this poses a critical issue for such intensely urbanised area, characterised by industrial complexes, urban centres and sensitive infrastructures of Budoia and Aviano localities. Therefore, the palaeoseismological evidence collected so far provide crucial information for more properly estimating the seismic hazard of the area, either relative to ground shaking scenarios and surface faulting-deformation assessments. Both aspects should be indeed carefully considered during regional planning of land use and when developing actions for seismic risk mitigation.

References

Areggi, G., Pezzo, G., Merryman Boncori, J.P., Anderlin, L., Rossi, G., Serpelloni, E., Zuliani,D., and Bonini, L., (2023). *Present-day surface deformation in North-East Italy using In-SAR and GNSS data*. Remote Sensing, 15 (1704). https://doi.org/10.3390/rs15061704

Bernardis, G., Poli, M.E., Renner, G., Snidarcig, A., and Zanferrari, A., (1996). *Le tre sequenze sismiche del 1996 a Claut (Prealpi Carniche)*. Atti del 15° Convegno GNGTS, Roma 11-13 novembre 1996, 343-348, Roma.

Devoti, R., Esposito, A., Pietrantonio, G., Pisani, A., and Riguzzi, F., (2011). *Evidence of large scale deformation patterns from GPS data in the Italian subduction boundary*. Earth Planet. Sci. Lett., 311, 230-241. https://doi.org/10.1016/j.epsl.2011.09.034

Galadini, F., Poli, M.E., and, Zanferrari, A., (2005). *Seismogenic sources potentially responsible for earthquakes with M > 6 in eastern Southern Alps (Thiene-Udine sector, NE Italy)*. Geophysical

Journal International, 161, 739-762. https://doi.org/10.1111/j.1365-246X.2005.02571.x
Locati, M., Camassi, R., Rovida, A., Ercolani, E., Bernardini, F., Castelli, V., Caracciolo, C.H., Tertulliani, A., Rossi, A., Azzaro, R., D'Amico, S., and Antonucci, A. (2022). *Database Macrosismico Italiano (DBMI15), versione 4.0*. Istituto Nazionale di Geofisica e Vulcanologia (INGV). https://doi.org/10.13127/DBMI/DBMI15.4
Poli, M.E., Monegato, G., Zanferrari, A., Falcucci, E., Marchesini, A., Grimaz, S., Malisan, P., and Del Pin, E. (2015). *Seismotectonic characterization of the western Carnic pre-alpine area between Caneva and Meduno (Ne Italy, Friuli)*. DPC-INGV-S1 Project "Base-knowledge improvement for assessing the seismogenic potential of Italy" (D6/a2.1).
Poli, M.E., Falcucci, E., Gori S., Monegato, G., Zanferrari, A., Affatato, A., Baradello, L., Böem, G., Dal Bo, I., Del Pin, E., Forte, E., Grimaz, S., and Marchesini, A., (2021). *Paleoseismological evidence for historical ruptures along the Meduno Thrust (eastern Southern Alps, NE Italy)*. Tectonophysics, 818. https://doi.org/10.1016/j.tecto.2021.229071
Poli, M.E., Patricelli, G., Monegato, G., and Zanferrari, A., (2024). *Structural inheritances, fault segmentation and seismogenic potential at the front of the eastern Southern Alps (central Carnic Prealps, NE Italy)*. Tectonophysics, 883. https://doi.org/10.1016/j.tecto.2024.230390
Rizzo, E., Colella, A., Lapenna, V., and Piscitelli, S., (2004). *High-resolution images of the fault controlled High Agri Valley basin (Southern Italy) with deep and shallow Electrical Resistivity Tomographies*. Physics and Chemistry of the Earth, 29 (4-9), 321-327. https://doi.org/10.1016/j.pce.2003.12.002
Rizzo E., Giampaolo V., Mucchi F., Boldrin P., De Martino G., Poli M.E., Patricelli G., Marchesini A. and Caputo R. (2024). *Multiscale geophysical investigation on the Budoia-Aviano thrust system (NE Italy): first results*. GNGTS 2024.
Serpelloni, E., Vannucci, G., Anderlini, L., and Bennett, R.A., (2016). *Kinematics, seismotectonics and seismic potential of the eastern sector of the European Alps from GPS and seismic deformation data*. Tectonophysics, 688, 157-181. https://doi.org/10.1016/j.tecto.2016.09.026