



Evidence of Upper Pleistocene-Holocene tectonic activity along the Longhere-Fadalto-Cadola line (eastern Southern Alps, NE Italy)

Franceschet, Angela (1,2), Poli Maria Eliana (2), Patricelli Giulia (2), Paiero Giovanni (2), Marchesini Andrea (2), Abu Zeid Nasser (3)

- (1) University of Trieste, Department of Life Science. angela.franceschet@phd.units.it.
 (2) University of Udine, Department of Agricultural, Food, Environmental and Animal Sciences.
 (3) Teamgeofisica.ceg: Centro di Elaborazione dati Geofisici (Ferrara, Italy).

Abstract: We made paleoseismological investigations on the eastern part of the Bassano-Valdobbiadene Thrust Auct., i.e. the left lateral Longhere-Fadalto-Cadola transpressive fault. The study area lies at the Pliocene-Quaternary front of the eastern Southern Alps, a S-SE verging active thrust-and-fold belt characterized by moderate to high seismic hazard and risk, where some historical earthquakes registered $M_w \geq 6$. The Bassano-Valdobbiadene Thrust Auct. extends with NE-SW trending at the base of the Venetian Prealps, where the Jurassic-Cretaceous carbonate succession overthrusts the Palaeozoic Turbidites and Miocene Molasse. In the framework of the National Seismic Microzonation Project, we carried out a paleoseismological study following preliminary morphotectonic and geophysical investigations, to assess the recent activity and capability of Longhere-Fadalto-Cadola transpressive fault. The paleoseismological trenches, dug on upper Pleistocene-Holocene sediments, reveal clear evidences of recent tectonic activity, possibly related to the 1873 Alago earthquake (I_{max} X MCS, M_w 6.3).

Key words: Paleoseismology, transpressive fault system, seismic hazard, eastern Southern Alps, NE Italy.

INTRODUCTION

The eastern Southern Alps (ESA) is a S-verging fold-and-thrust belt, evolving from the middle Miocene up to the Present. Their development occurred in the Neogene-Quaternary time interval (Doglioni & Bosellini, 1987; Castellarin et al., 1992; Fantoni et al., 2002), related to the Nealpine compressional event. The ESA present architecture largely results from the interaction between the Jurassic-Cretaceous continental rifting and the change in plate kinematics occurred at the end of the early Cretaceous. During the Mesozoic, the former Triassic-Jurassic platform was split into NNE-SSW-trending structural blocks, bounded by normal faults (Bosellini, 1973). When extension ended, a convergence between Adria-Africa and Europe lithosphere plates started. This compressional regime controls the evolution of the Alps up to their present setting, and the Mesozoic normal faults were frequently reactivated and inverted during the Neogene contractional events (Castellarin & Cantelli, 2000; Doglioni, 1992; Galadini et al., 2005). The major deformation phases in the external Venetian Prealps occurred during the Messinian-Pliocene ("Adriatic phase" on Castellarin & Cantelli, 2000) under NW-SE-oriented maximum horizontal stress. This contractional phase activated major thrust system, such as the Bassano-Valdobbiadene, Polcenigo-Montereale, Cansiglio and Montello-Conegliano thrust-systems (Castellarin & Cantelli, 2000). This tectonic phase is still active, and during Pliocene and Quaternary it caused the propagation of the external front toward the piedmont venetian plain that represents its foreland (Galadini et al., 2005; Caputo et al., 2010; Fig. 1).

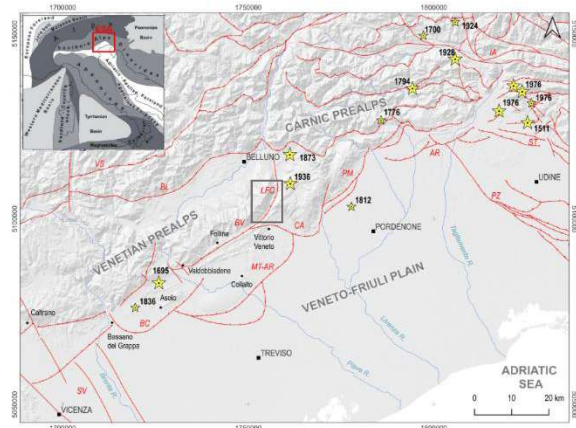


Figure 1: Structural sketch map of the eastern Southern Alps (SR: EPSG 6708). Yellow stars indicate the historical and instrumental $M \geq 5.5$ earthquakes that hit ESA during the last millennium (Rovida et al., 2022). Legend: BC: Bassano-Cornuda Th.; BL: Belluno Th.; BV: Bassano-Valdobbiadene Thrust-system; CA: Cansiglio Th.; LCF: Longhere-Fadalto Cadola line; MT-AR: Montello-Arcade Th.; PM: Polcenigo-Montereale Th. The black box notes the study area of Fig. 2.

Between Bassano del Grappa and Vittorio Veneto localities, most of the late Miocene to Pleistocene deformation at the ESA front is accommodated by the Bassano-Valdobbiadene (BV) and Montello thrust-systems (Castellarin & Cantelli, 2000). The BV Th. tectonic activity continued up to the Holocene and the strain field obtained from geodetic data (horizontal GPS and terrestrial vertical levelling data) indicated that the BV Th. is the structure with the highest seismogenic potential in the Venetian Prealps (Barba et al., 2013). In particular, within the study area, the left-lateral closure of the Bassano-Valdobbiadene thrust (i.e. the Longhere-Fadalto-Cadola line), overthrusts the Jurassic-Cretaceous calcareous units on the Palaeocene turbiditic sequences and Miocene Molasse (Antonelli et al., 1990) along the inherited western border



between the Friuli Carbonatic Platform, in the east, and Belluno basin, in the west (Fig. 2).

From the seismological point of view, the area experienced several $M \geq 5.5$ earthquakes over the last millennium (Rovida et al., 2022; Fig. 1). In particular, the Alpagò-Vittorio Veneto-Cansiglio Mt. area was affected by two strong events: the 29th June 1873 ($I_{\max}$ X MCS e M_w 6.3) Alpagò earthquake and the 18th October 1936 ($I_{\max}$ VIII MCS e M_w 6.1) Cansiglio earthquake. While the 1936 event is attributed to the Cansiglio source (Sirovich & Pettenati, 2004; Galadini et al., 2005; Burrato et al., 2008), Galadini et al. (2005) associated the 1873 event of Alpagò to the Polcenigo-Montebelluno seismogenic source, but it cannot be ruled out that the seismogenic source of this seismic event could be associated to the Longhere-Fadalto-Cadola transpressive fault.

Goals and Methods

In the framework of the Vittorio Veneto Seismic Microzonation Project a series of seismotectonic investigations in the Lapisina valley were carried out along the possible surficial expression of the Longhere-Fadalto-Cadola fault trace, following the Geological map of Italy, sheet 063 Belluno (Costa et al., 1996; Fig. 2).

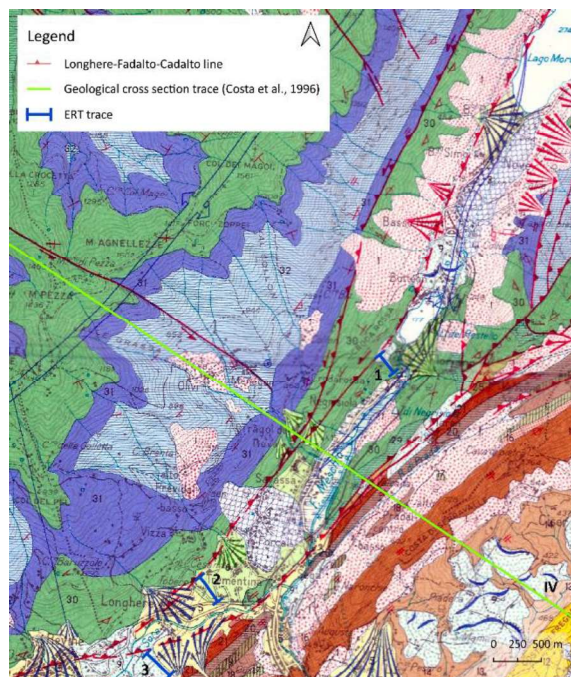


Figure 2: Geological map and geological cross section (n. IV, green line) of the Lapisina valley (from 063 "Belluno" sheet of the Carta Geologica d'Italia at the 1:50000 scale). (Costa et al., 1996). Blue lines are Electrical Resistivity Tomography (ERT) investigations and illustrate the trench sites.

Our research investigated the recent activity of the Longhere-Fadalto-Cadola line and its possible relationship with the 1873 Alpagò earthquake ($I_{\max}$ = X MCS, M_w = 6.3).

We adopted a multidisciplinary approach combining morphotectonic analysis, geophysical survey and paleoseismological study. Using 1-m resolution LiDAR-derived Digital Elevation Model (DEM), provided by the Provincia of Treviso, we identified some morphological anomalies along the Longhere-Fadalto-Cadola line, potentially linked to its recent tectonic activity (i.e. offset of geomorphic markers, slope breaks, tilted surfaces, drainage anomalies, land-surfaces suspended over the present valley bottom. Subsequently, Electrical Resistivity Tomography (ERT) surveys were achieved to image the shallow subsurface and to better identify the near-surficial fault traces (Fig. 3 and Fig. 5).

Based on morphological and geophysics results, we selected some trench sites across the possible surface trace of the LFC line. Paleoseismological trench walls were cleaned, mapped at 1:10 scale thanks to a 1 x 1 m string grid, and documented with orthomosaics and 2D models. Radiocarbon samples collected from the trench units were dated at Beta Analytic to constrain the age of the deposits.

Paleoseismological trenches

Vittorio Veneto 1 - Pian della Torre locality

The first trench was dug on the "Pian della Torre" terrace, located ≈ 40 m above the present Lapisina Valley, on the SE slope of the Visentin Mt. (Fig. 2). From the geological point of view the eastern slope of the Visentin Mt. corresponds to the eastern limb of the carbonatic anticline (Costa et al., 1996; Fig. 2). Moreover, the geomorphological map (Pellegrini, 2000) indicate that the terrace consists of fluvio-glacial deposits related to the late stages of Piave Glacier retreat after the Last Glacial Maximum (LGM). At the base of the relief, a wide detrital talus is present. ERT data revealed a lateral resistivity contrast in Late Glacial sediments (Fig. 3). We dug a 22 m-long and 2.5 m-depth paleoseismological trench across this anomaly.

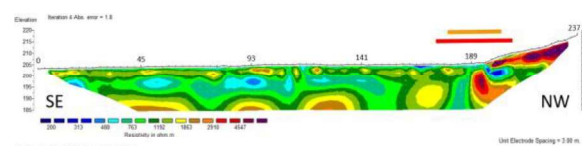


Figure 3: Electrical Resistivity Tomography (ERT1) investigation of "Pian della Torre", Vittorio Veneto. The red line indicates the main resistivity anomaly while the orange one notes the trench trace.

The trench exposed kame deposits (13-16 ka BP), overlaid by anthropogenic fills. Clast lithology reflects the Fadalto landslide source area, whose first activation occurred between the Late Glacial and the final glacier retreat, around 16 ka BP (Pellegrini & Surian, 1996; Pellegrini et al., 2006). The composition of the clasts without dolomites and other Triassic lithology typical of the upper Piave catchment, confirms a local sediment provenance. Therefore, we can suppose that the age of the "Pian della Torre" deposits is subsequent the Fadalto landslide. Deposits show a sub-horizontal setting typical of alluvial



sedimentation. Conversely, the NW sector of the trench shows tilted gravels, dipping SE at 50-60°. Moreover, a middle-high angle SE-verging reverse fault (300/55) affects units B and C with a vertical throw of about 10-15 cm (Fig. 4), indicating post-LGM surface deformation.

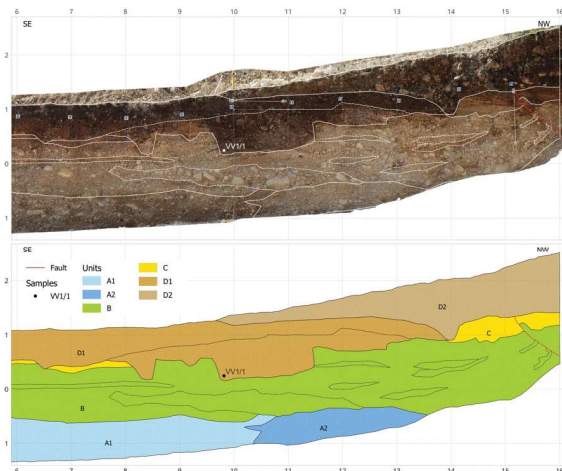


Figure 4: Paleoseismological log of Trench of Pian della Torre Street (Vittorio Veneto). In the NW sector a SE-verging thrust-fault displaces the kame deposits of Upper Pleistocene age.

Vittorio Veneto 2 - Cesana Street

ERT investigations acquired across a pronounced morphological scarp near the locality of Cesana revealed significant subsurface resistivity contrasts (Fig. 5). Geological and geomorphological maps (Costa et al., 1996; Pellegrini, 2000) attribute this scarp to fluvial erosion, affecting LGM glacial and fluvio-glacial deposits. However, since this morphological scarp coincides with the Longhere-Fadalto-Cadola line trace as mapped in the CARG-063 Belluno sheet, we verified whether the scarp could also be related to the recent tectonic activity of the LFC line. Here we dug a paleoseismological trench, 12 m-long.

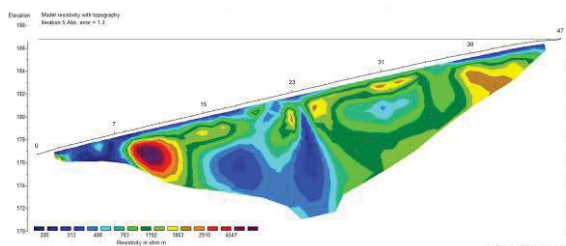


Figure 5: Electrical Resistivity Tomography (ERT2) investigations of "Cesana Street", Vittorio Veneto. The red line notes the main resistivity anomaly while the orange one notes the trench trace.

The about 2,5 m-high trench wall exposed alluvial and fluvioglacial deposits, overlaid by agricultural soil, that locally contains anthropogenic fills, with some artefacts. No radiocarbon datable samples were found. However, post-LGM fan deposits are cut and displaced by a high-angle reverse fault that propagates up to the base of the agricultural soil, whose involvement cannot be excluded. The vertical throw observed is at least 0.21 m, testifying post-LGM tectonic activity of the LFC line.

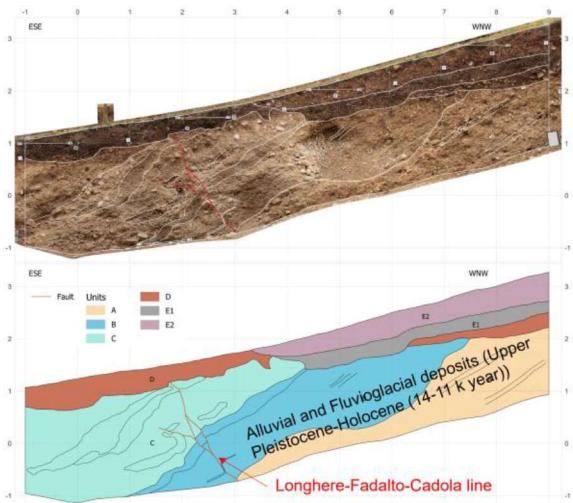


Figure 6: Paleoseismological Trench of Cesana Street (Vittorio Veneto). A high-angle reverse fault cut and displace Upper Pleistocene-Holocene fan deposits, propagating up to the base of the agricultural soil, whose involvement cannot be excluded.

Vittorio Veneto 3 - Longhere locality

Near Longhere locality, a third trench exposed very interesting evidence of both seismically induced liquefaction and fault-related deformation. In the northern sector, Late Glacial sands and gravels, belonging to fluvioglacial units A and B (16-13 ka cal BP), quickly change in bedding attitude: from S-vergent lower angle dip to high angle (340/85) close to the northern scarp (Fig. 7a). Southernmost, sands and gravels rich in matrix (unit C) registered strong paleoliquefaction events. They are overlaid by a colluvial deposit (unit D) radiocarbon dated between 3103-2923 cal BP and 2423-2341 cal BP (Fig. 7b).



Figure 7: (a) Evidence of fault-related deformation: sands and gravels of the fluvioglacial units A and B with high angle (340/85) close to the northern scarp; (b) Evidence of seismic shaking: sand and gravels liquefactions (unit C) on the south part of the excavated wall.

DISCUSSION AND CONCLUSION

Results from presented paleoseismological trenches testify the activity of the Longhere-Fadalto-Cadola line during the post-LGM period. Late Glacial deposits are deformed and displaced even if we cannot rule out that also the ploughed soil could be affected by deformation (see for example Vittorio Veneto 2, Cesana trench). In this context, the absence of historical deposits precludes the possibility to associate observed deformation with a historical event.



Nevertheless, according to the Italian Technical Commission for Seismic Microzonation (2015) and the ITHACA guidelines (ISPRA, 2022), a fault showing evidence of activation within the last 40 ka is classified as active. The Longhere-Fadalto-Cadola line meets this criterion at all investigated sites, with significant implication for the high local seismic hazard.

At present, no historical earthquake is conclusively associated with the LFC line. According to the Italian earthquake catalogues, the most recent earthquake happened in the study area, possible referable to this fault, is the 1873 Alpago's earthquake (Mw 6.3). Although the event is currently attributed to the Polcenigo-Montereale system, our new paleoseismological evidence does not exclude the possibility that the LFC line activated during the 1873 earthquake. Further investigations are required to validate this hypothesis, in order to constrain the seismogenic source of the 1873 Alpago's earthquake.

Overall, the results highlight the relevance of the LFC line as an active structure in the Venetian Prealps and underscore its possible contribution to the high seismic hazard of the area.

Acknowledgements: This work was carried out thanks to the support of the Vittorio Veneto Municipality in the framework of the National Project of Macroseismic Zonation: active and capable faults – FAC

REFERENCES

- Antonelli, R., Barbieri, G., Dal Piaz, G. V., Dal Pra, A., De Zanche, V., Grandesso, P., Mietto, P., Sede, R., & Zanferrari, A., 1990. *Carta Geologica del Veneto alla scala 1:250000*. (S. R. per il territorio Regione veneto & Università degli Studi di Padova, Eds.). Firenze: S.E.L.C.A.
- Barba, S., Finocchio, D., Sikdar, E., & Burrato, P., 2013. Modelling the interseismic deformation of a thrust system: Seismogenic potential of the Southern Alps. *Terra Nova*, 25(3), 221–227. <https://doi.org/10.1111/ter.12026>
- Battista Pellegrini, G., Surian, N., & Albanese, D., 2006. Landslide activity in response to Alpine Deglaciation: the case of the Belluno prealps (Italy). In *Geogr. Fis. Dinam. Quat* (Vol. 29).
- Bosellini, A., 1973. Modello geodinamico e paleotettonico delle Alpi Meridionali durante il Giurassico-Cretacico. Sue possibili applicazioni agli Appennini. Accordi B. (Ed.), *Moderne vedute sulla geologia dell'Appennino*. *Acc. Naz. Lincei*, 183, 163–205.
- Burrato, P., Poli, M. E., Vannoli, P., Zanferrari, A., Basili, R., & Galadini, F., 2008. Sources of Mw 5+ earthquakes in northeastern Italy and western Slovenia: An updated view based on geological and seismological evidence. *Tectonophysics*, 453(1–4), 157–176. <https://doi.org/10.1016/j.tecto.2007.07.009>
- Caputo, R., Poli, M. E., & Zanferrari, A., 2010. Neogene-Quaternary tectonic stratigraphy of the eastern Southern Alps, NE Italy. *Journal of Structural Geology*, 32(7), 1009–1027. <https://doi.org/10.1016/j.jsg.2010.06.004>
- Castellarin, A., & Cantelli, L., 2000. Neo-Alpine evolution of the Southern Eastern Alps. *Journal of Geodynamics*, 30, 251–274.
- Castellarin, A., Cantelli, L., Fesce, A. M., Mercier, J. L., Picotti, V., Pini, G. A., Prosser, G., & Selli, L., 1992. Alpine compressional tectonics in the Southern Alps. Relationships with the N-Appennines. *Ann. Tectonicae*, 6, 62–94.
- Castellarin, A., Nicolich, R., Fantoni, R., Cantelli, L., Sella, M., & Selli, L., 2006. Structure of the lithosphere beneath the Eastern Alps (southern sector of the TRANSALP transect). *Tectonophysics*, 414(1–4), 259–282. <https://doi.org/10.1016/j.tecto.2005.10.013>
- Commissione tecnica per la microzonazione sismica, 2015. *Linee guida per la gestione del territorio in aree interessate da Faglie Attive e Capaci (FAC), versione 1.0*.
- Costa, V., Doglioni, C., Grandesso, P., Masetti, D., Pellegrini, G. B., & Tracanna, E., 1996. Foglio 063 “Belluno” e Note Illustrative. *Carta Geologica d'Italia alla scala 1:50000. Memorie Descrittive Della Carta Geologica d'Italia*, 1–74.
- Doglioni, C., 1992. Relationships between Mesozoic extensional tectonics, stratigraphy and Alpine inversion in the Southern Alps. *Eclogae Geol. Helv.*, 85/1, 105–126.
- Doglioni, C., & Bosellini, A., 1987. Eoalpine and mesoalpine tectonics in the Southern Alps. *Geologische Rundschau*, 76/3, 735–754.
- Fantoni, R., Barbieri, C., Catellani, D., Castellarin, A., Di Giulio, A., & Pessina, C., 2002. The record of south-Alpine events in the Venetian foreland and foredeep. *Geol. Palaont. Mitt. Innsbruck*. <https://www.researchgate.net/publication/275532356>
- Galadini, F., Poli, M. E., & Zanferrari, A., 2005. Seismogenic sources potentially responsible for earthquakes with $M \geq 6$ in the eastern Southern Alps (Thiene-Udine sector, NE Italy). In *Geophysical Journal International* (Vol. 161, pp. 739–762). <https://doi.org/10.1111/j.1365-246X.2005.02571.x>
- Pellegrini, G. B., 2000. Carta geomorfologica d'Italia alla scala 1:50000: Foglio 063 Belluno e note illustrative. *Servizio Geologico d'Italia. Regione Veneto*, 141.
- Pellegrini, G. B., & Surian, N., 1996. Geomorphological study of the Fadalto landslide, Venetian Prealps, Italy. *Geomorphology*, 15(3–4), 337–350. [https://doi.org/10.1016/0169-555X\(95\)00079-K](https://doi.org/10.1016/0169-555X(95)00079-K)
- Rovida, A., Locati, M., Camassi, R., Lolli, B., Gasperini, P., Antonucci, A., Azzaro, R., Bernardini, F., D'amico, S., Ercolani, E., Rossi, A., Tertulliani, A., & Meletti, C., 2022. *Catalogo Parametrico dei Terremoti Italiani (CPTI15), versione 4.0*. Istituto Nazionale Di Geofisica e Vulcanologia (INGV). <https://doi.org/10.13127/cpti/cpti15.4>
- ISPRA, 2022. ITHACA–Italy HAZard from CAPable faults. Inventario delle Faglie Capaci in Italia. Guida alla consultazione e all'utilizzo. *Servizio Geologico d'Italia*, 33.
- Sirovich, L., & Pettenati, F., 2004. Source inversion of intensity patterns of earthquakes: A destructive shock in 1936 in northeast Italy. *Journal of Geophysical Research: Solid Earth*, 109(10). <https://doi.org/10.1029/2003JB002919>