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Supporting Information for

# Buried alive: imaging the November 9, 2022 Mw 5.5 earthquake source on the offshore Adriatic blind thrust front of the Northern Apennines (Italy).

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## Introduction

These supporting materials consist of geophysical data from the Marche Region offshore area that were analyzed to define the geological structures involved in the Pesaro Offshore 2022 seismic sequence.
Seismic reflection profiles were interpreted and calibrated with well-logs data to reconstruct the tectonic setting of the area where the earthquake occurred and understand its origin. Figure S1 shows three multichannel seismic profiles, publicly available from the ViDEPI and CROP databases (https://www.videpi.com; https://www.crop.cnr.it/) that were analyzed and integrated with other subsurface data available from the literature (subsurface stratigraphic and structural maps).
The original seismic reflection profiles B-402 and B-403 were acquired and processed in 1967; the CROP M16 seismic profile was acquired in 1995 and processed in 1997. A conversion from raster to SEG-Y format using the Wiggle2segy Matlab application

(Buttinelli et al., 2022; Sopher, 2018) was applied to the data selected from the ViDEPI database to enhance their interpretation and integration with other subsurface data. Figure S2 shows the same seismic profiles after applying the Automatic Gain Control (ACG) scaling attribute in Opendtect 6.6. Figure S3 shows the restored version of the geological section derived from interpreting the B-402 seismic profile. The restoration was performed using the Fault Parallel Flow and Flexural Slip unfolding methods (Egan et al., 1997; Tanner, 1989; Kane et al., 1997). The restored horizon is the Top FUC, a regional reference marker clearly visible in all the seismic profiles. Top FUC is younger than the end of the Mesozoic extensional tectonic phase (e.g., the offset on the Mesozoic normal faults was not restored) and is older than the Plio-Pleistocene contractional tectonic phase. The restoration supports the geometrical feasibility of faults and folds in the geological sections.

Historical and instrumental earthquakes with Mw ≥ 5.5 that affected the northern Marche coastal and offshore area are reported in Table S1 (CPTI15; Rovida et al., 2022). For each earthquake, is indicated the date, the moment magnitude (Mw), the macroseismic intensity based on the European Macroseismic Scale (EMS-98), and the effects on the natural environment (CFTI5Med; Guidoboni et al., 2018). For the localities affected by tsunamis, their intensity according to the Sieberg-Ambraseys (Ambraseys, 1962) and Papadopoulos and Imamura (Papadopoulos & Imamura, 2001) scales, and a description of the effects are also indicated based on the ITED catalogue (Maramai et al., 2021).

Detailed information on the seismic network and velocity model used by the Italian Seismic Network are provided in Margheriti et al. (2021) and Marchetti et al. (2016), respectively.

Table S2 summarizes the main parameters of various focal mechanism solutions for the Pesaro earthquake mainshock that occurred on 9 November 2022 at 06:07:25 (UTC). Here the most important parameters are the strike, dip, and rake of the two nodal planes. The angular deviations of different solutions are rather limited, showing a good agreement between one another. This information was used to compare the focal mechanism with the geological faults in the earthquake region.

**Figure S1.**

Un-interpreted versions of the seismic profiles after the conversion from raster to SEG-Y format using Wiggle2Segy (Sopher, 2018) for B-402 and B-403.

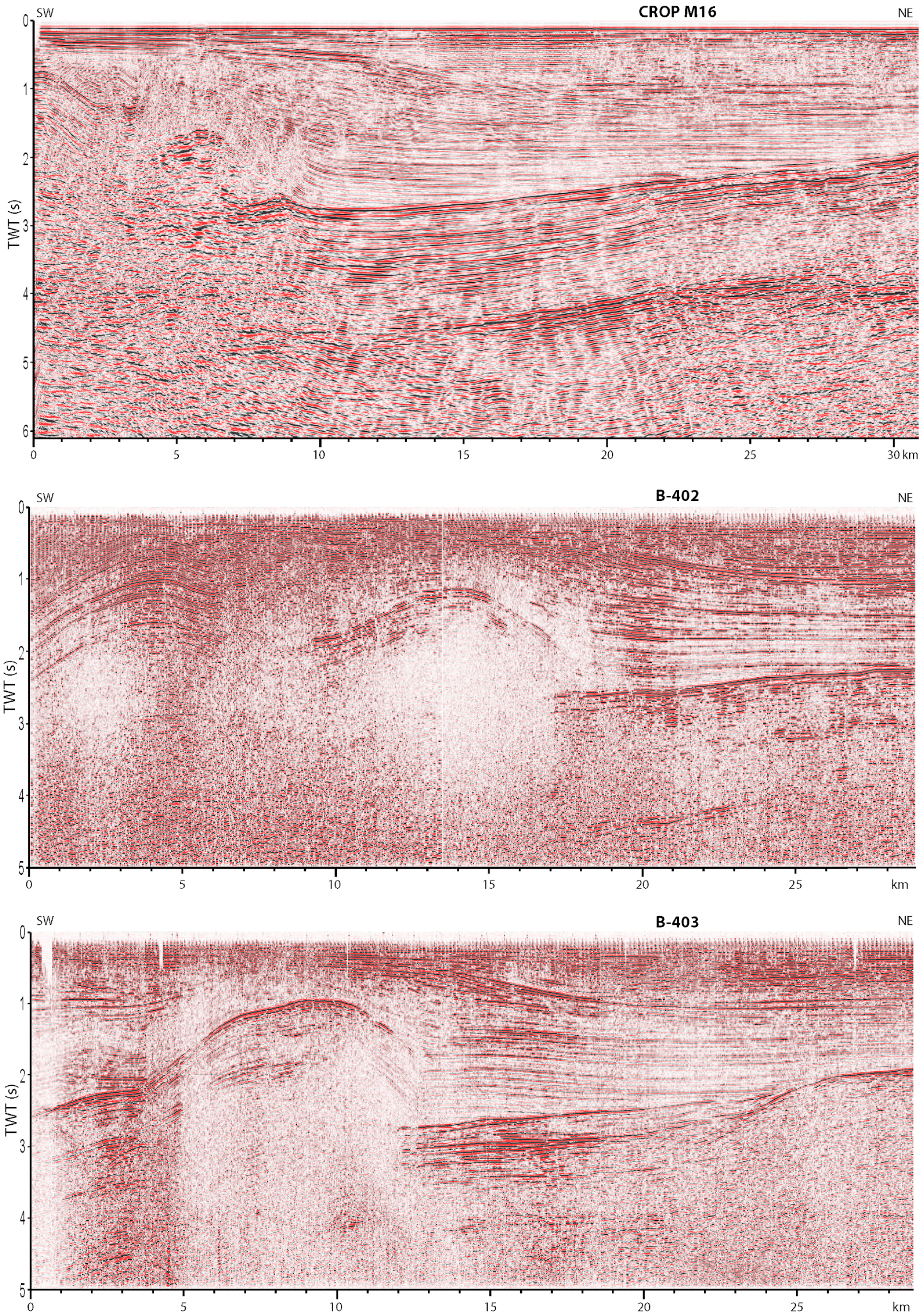

**Figure S2.**

Un-interpreted versions of the seismic profiles with the Automatic Gain Control (AGC) scaling attribute application. The window of application is 500 ms. The interpreted version is shown in Figure 3 of the manuscript.

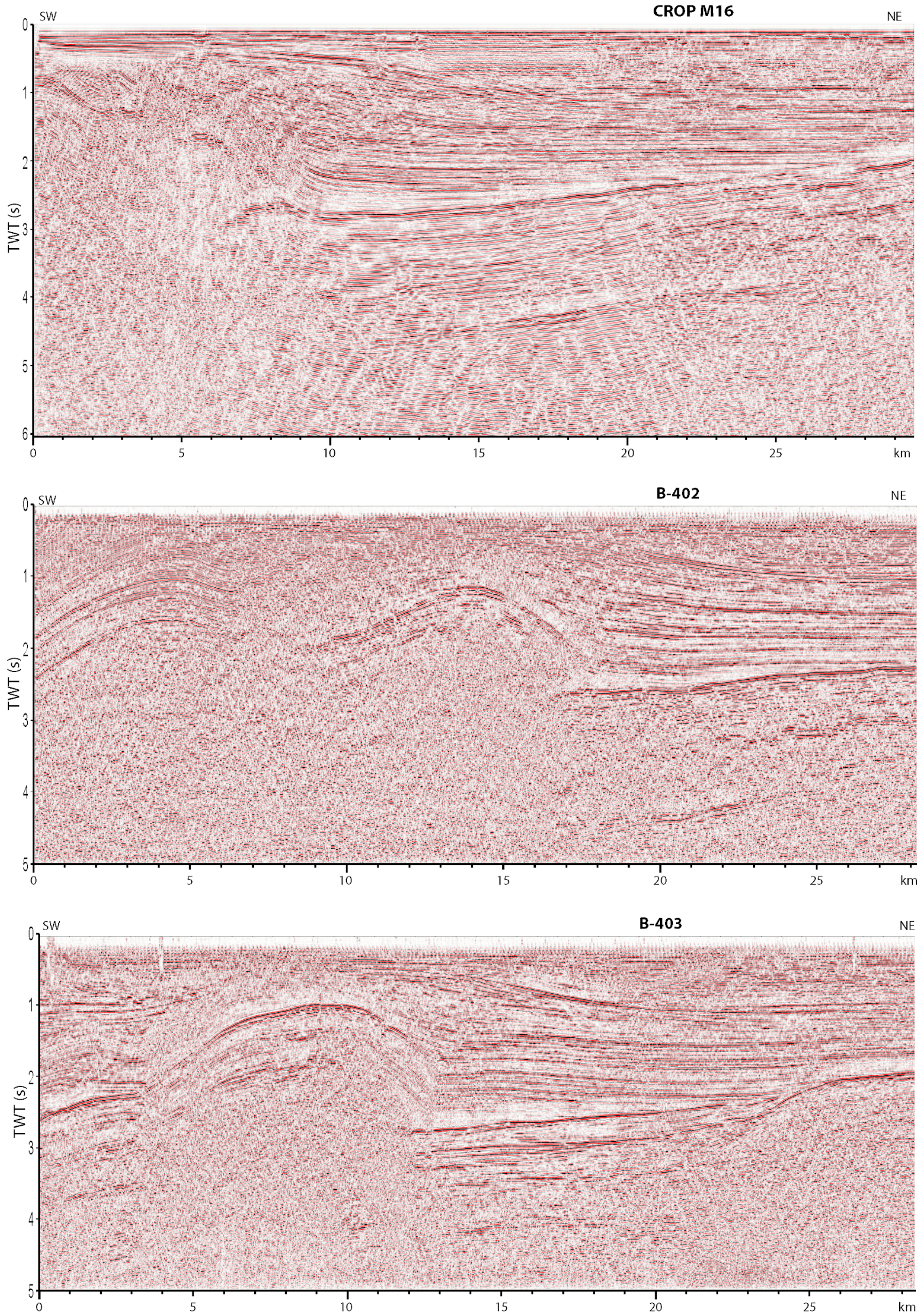

**Figure S3.**

Restoration of the geological section shown in Figure 4d of the manuscript derived from the interpretation and depth-conversion of seismic profile B-402. Restoration method Fault Parallel Flow and Flexural Slip unfolding. The reference horizon for the restoration is the Top FUC. The (*) mark indicates that the deformation is due to the secondary back-thrust and has not been considered before the final unfolding.

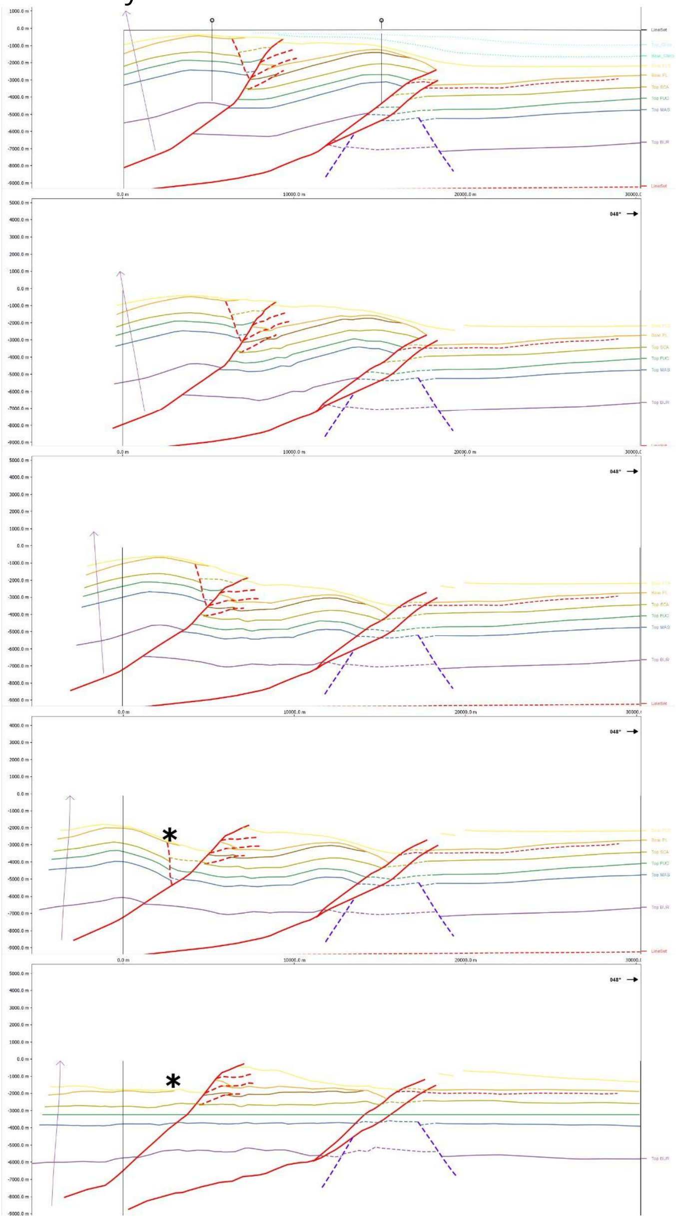

**Table S1.**

Historical and instrumental earthquakes having Mw ≥ 5.5 of the northern Marche coastal (and offshore) area (CPTI15; Rovida et al., 2022), associated effects on the natural environment (CFTI5Med; Guidoboni et al., 2018, 2019), and locality affected by tsunamis, with Intensity and descriptions (EMTC; Maramai et al., 2021). SA: Intensity Sieberg-Ambraseys scale; PI: Intensity Papadopoulos and Imamura scale; *unspecified day; **EMS-98 scale; Gruppo Operativo QUEST, 2022.

| ID | Date | $M_w$ | Io | Main effects on environment | Locality affected by tsunami | Tsunami effects/Notes | Tsunami Intensity |
|---|---|---|---|---|---|---|---|
| 1 | Sep 1269* | 5.6 | VIII | The earthquake triggered a large landslide that fell into the sea on the eastern side of Monte Conero. There are historical reports that the tsunami waves reached the coasts of Dalmatia. | n.a. | No record | n.a. |
| 2 | 14 Apr 1672 | 5.6 | VIII | - | Rimini | Eyewitnesses observed a sea withdrawal followed by an inundation of the shore for about 15 m. Some fishermen that were at sea close to the Rimini coast observed an unusually strong sea agitation. | SA: 3<br>PI: IV |
| 3 | 23 Dec 1690 | 5.6 | VIII | Four fractures opened on Monte Conero, from which bituminous material leaked. Fractures opened in Sirolo and a landslide occurred on the eastern side of the Sirolo hill. | Ancona | The boats touched the sea bottom and then they lifted up being shaken due to the sea water agitation. | SA: 3<br>PI: IV |
| 4 | 25 Dec 1786 | 5.7 | VIII | In the area surrounding Rimini, cracks opened up in the ground. In the gypsum quarries of the hilly area around Rimini many boulders collapsed. | n.a. | No record. Notice, however, that the historical center of Rimini was located over 1 km from the seaside, and that the earthquake occurred in the middle of Christmas night. | n.a. |
| 5 | 17 Mar 1875 | 5.7 | VIII | A fracture 1 km long and 15 cm wide opened up along the road between Cervia and Cesenatico. In the square of Cesenatico a crack - several meters long - opened parallel to the canal. Numerous cavities were also formed in Cervia and Cesenatico, from which jets of water escaped. | Rimini, Cervia, Cesenatico, Pesaro, Ancona | At Rimini many fishermen that were in the sea felt the shock. At Cervia the sea violently flooded a large stretch of beach. In the canal at the harbor of Cesenatico a remarkable increase in wave motion was observed. An increase in wave motion was also observed at Pesaro and an increase in the harbour was observed. At Ancona an eyewitness on the beach noted sudden waves coming from the sea that was previously calm. | SA: 3<br>PI: IV |
| 6 | 17 May 1916 | 5.8 | VIII | Anomalous waves formed in a channel near Retinella (Rovigo). | n.a. | No record | n.a. |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 7 | 16 Aug 1916 | 5.5 | VI | In Cattolica small cracks formed and four springs formed in the sea about 50 m from the beach. From them the water flowed with a 50 cm high jet; the sea at that point was 40 cm deep. | Mouth of Tavollo River, close to Pesaro | A fisherman who was in his boat about 700 m from the shore said that the sea was calm until suddenly just before the shock he noted four waves about 20 cm high travelling from the open sea towards the beach. When the waves came to his boat, his fishing tools moved and rose from the sea bottom where they were moored. Then, the waves reached the beach. | SA: 2<br>PI: IV |
| 8 | 2 Jan 1924 | 5.5 | VII-VIII | In Senigallia the temporary disappearance and reappearance of the waters of the Misa River was reported. | n.a. | No record | n.a. |
| 9 | 30 Oct 1930 | 5.8 | VIII | - | Ancona | High tide impinged on the coast, and the sea boiled. The tsunami waves broke off the moorings of an American ship and slammed it against the dock. The fence of the harbour office was almost completely pulled out, and the docks were heavily damaged. Many fishermen who were on their vessels in the harbour quickly disembarked, frightened by the extraordinary movement of the water. | SA: 4<br>PI: VI |
| 10 | 9 Nov 2022 | 5.5 | V** | - | n.a. | No record | n.a. |

**Table S2.**

Focal mechanism solutions of the Pesaro earthquake occurred on 9 November 2022 at 06:07:25 (UTC) from various agencies. Data sources:

1) https://www.eas.slu.edu/eqc/eqc_mt/MECH.NA/20221109060727/index.html;
2) http://terremoti.ingv.it/event/33301831;
3) https://www.ldeo.columbia.edu/~gcmt/projects/CMT/catalog/NEW_QUICK/E202211090607A.ndk;
4) http://geoscope.ipgp.fr/index.php/en/catalog/earthquake-description?seis=us7000infp;
5) http://geofon.gfz-potsdam.de/eqinfo/event.php?id=gfz2022vync;
6-8) https://www.emsc-csem.org/Earthquake/tensors.php?agency=&date=2022-11-09 (last accessed on 24/11/2022). In each row, the original data have been rearranged to have Strike2, Dip2, and Rake2 consistently representing the SW dipping plane.

| | Agency | Moment (dyne-cm) | Mw | Depth (km) | Strike1 | Dip1 | Rake1 | Strike2 | Dip2 | Rake2 |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | SLU/USGS | 2.75E+24 | 5.56 | 8 | 325 | 60 | 95 | 135 | 30 | 81 |
| 2 | INGV | 2.44E+24 | 5.5 | 6 | 316 | 57 | 94 | 128 | 34 | 84 |
| 3 | GCMT | 4.61E+24 | 5.7 | 12 | 321 | 66 | 92 | 135 | 24 | 85 |
| 4 | IPGP | 6.28E+24 | 5.8 | n.d. | 305 | 66 | 78 | 153 | 27 | 115 |
| 5 | GFZ-GEOFON | n.d. | 5.7 | 10 | 310 | 73 | 85 | 145 | 17 | 104 |
| 6 | OCA via CSEM | n.d. | 5.9 | 4 | 315 | 70 | 90 | 135 | 20 | 90 |
| 7 | CPPT via CSEM | n.d. | 5.7 | 12 | 314 | 66 | 85 | 147 | 25 | 102 |
| 8 | INGV via CSEM | n.d. | 5.7 | 12 | 309 | 64 | 85 | 142 | 27 | 101 |