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Catastrophic landslide of medieval Portonovo (Ancona, Italy)

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ABSTRACT

This paper is a case study about a natural catastrophic event that caused a human disaster in the medieval Benedictine enclave of Santa Maria in Portonovo—a large landslide involving some 5 million cubic meters of rock, which suddenly collapsed from the northeastern flank of the Monte Conero anticline hurling down from 400 m elevation over the littoral zone of the Portonovo bay, ~9 km south of the Adriatic port city of Ancona. This landslide is the largest of the Conero Riviera, a 16-km-long, seismically active high coast with cliffs overhanging directly over the sea, which is therefore particularly prone to landsliding. While the landslide risk along the Conero Riviera has been evaluated by the local municipal authority, the risk in the Portonovo bay, a very popular beach resort, has been somewhat underestimated inasmuch as the huge landslide was previously considered, by geologists and geoengineers, to be a prehistoric event and therefore unimportant in the context of prevention plans aimed at assessing the hydrogeological instability of this area. We approached our study by surveying the area of the landslide using detailed ground truthing and geological mapping, and defining the geomorphology and lithologic composition of the landslide from head to toe. Radiocarbon dating of neritic mollusk shells from the autochthonous sediments underlying the landslide toe, which were retrieved from two drill cores from the toe of the landslide deposit, indicated that the landslide occurred in historical times, contrary to common belief that it occurred in prehistory. We then reconstructed the history of environmental changes of the Portonovo bay prior to, and subsequent to the landslide event using a detailed facies analysis of these two drill cores and of a third one drilled through the center of the landslide body. Written documentation about the medieval history of Portonovo, including an old map of the northeastern face of Monte Conero, which shows no evidence for the landslide, suggests that it occurred in the early fourteenth century, destroyed the strategic harbor of Novo Porto, and caused the definitive abandonment of the three-centuries-old Benedictine abbey of Santa Maria in A.D. 1320. The lithologic, structural, and rheologic setting of the steep northeastern flank of the Monte Conero anticline provided the predisposition for the huge medieval landslide, a structural setting possibly weakened by unusually intense seismic activity that affected the Conero Riviera from the late thirteenth to the early fourteenth centuries. The same structural and lithologic settings are found today on the slopes adjacent to the western side of the medieval detachment scar, thus representing a serious threat for the stability of the area and a high risk for imminent large landsliding, which may have grave consequences for present-day infrastructure and inhabitants of the popular Portonovo beach resort. Therefore, we present this work on the giant Portonovo landslide as an example of how interdisciplinary scientific investigation on hydrogeologically unstable areas may help in preventing human disasters.

INTRODUCTION

The problem of "hydrogeological instability" in Italy, which is defined by Italian governmental law no. DL152/2006 as "the condition that characterizes areas where both natural and anthropogenic processes, related slope, soil, and water bodies, determine hazardous conditions on the territory" (e.g., Giulivo et al., 2013), appears almost daily in Italian news and in vexing political debates. The reason is that flooding and landslide events have been occurring more often in all regions of Italy in recent years, probably exacerbated by the meteorological effects of climate change (violent and concentrated rainstorms and consequent flashfloods), and aggravated by inadequate politics of land reclamation and control (inattentive public administrations, wdeforestation, overbuilding, intense agriculture, insufficient maintenance of riverbeds, etc.). Furthermore, the Italian peninsula, which is situated in a relatively wet Mediterranean temperate climatic zone, is particularly prone to hydrogeological instability owing to the fact that ~75% of its densely populated territory is constituted by mountains and hills, and thus slopes (ISTAT, 2013). Moreover, all of mountainous Italy, over the southern Alpine and Apennine active accretionary orogens, is moderately to strongly seismic (INGV, 2004), and coseismic ground fractures, which develop during seismic sequences, enhance the permeability of the bedrock, thus increasing the probability of slope failure.

The hydrogeological instability situation in the Marche region (outlined in the insert of Fig. 1A), particularly regarding landsliding (e.g., Principi et al., 2007), reflects the general situation of the whole country. Moreover, this region, which represents the eastern front of the Northern Apennine accretionary wedge (e.g., Argnani et al., 2006, and references therein), is seismically active.

While major seismic events, which have affected this region in the past two millennia, are retraceable in historical documentations such as ecclesiastic annals and civil chronicles of various dioceses and municipalities (Rovida et al., 2011), historical documentations of landslides, even large, catastrophic ones, are scarce and/or ambiguous. Only in recent years are damaging landslides punctually reported in the media, whether newspapers, TV, or the Internet,

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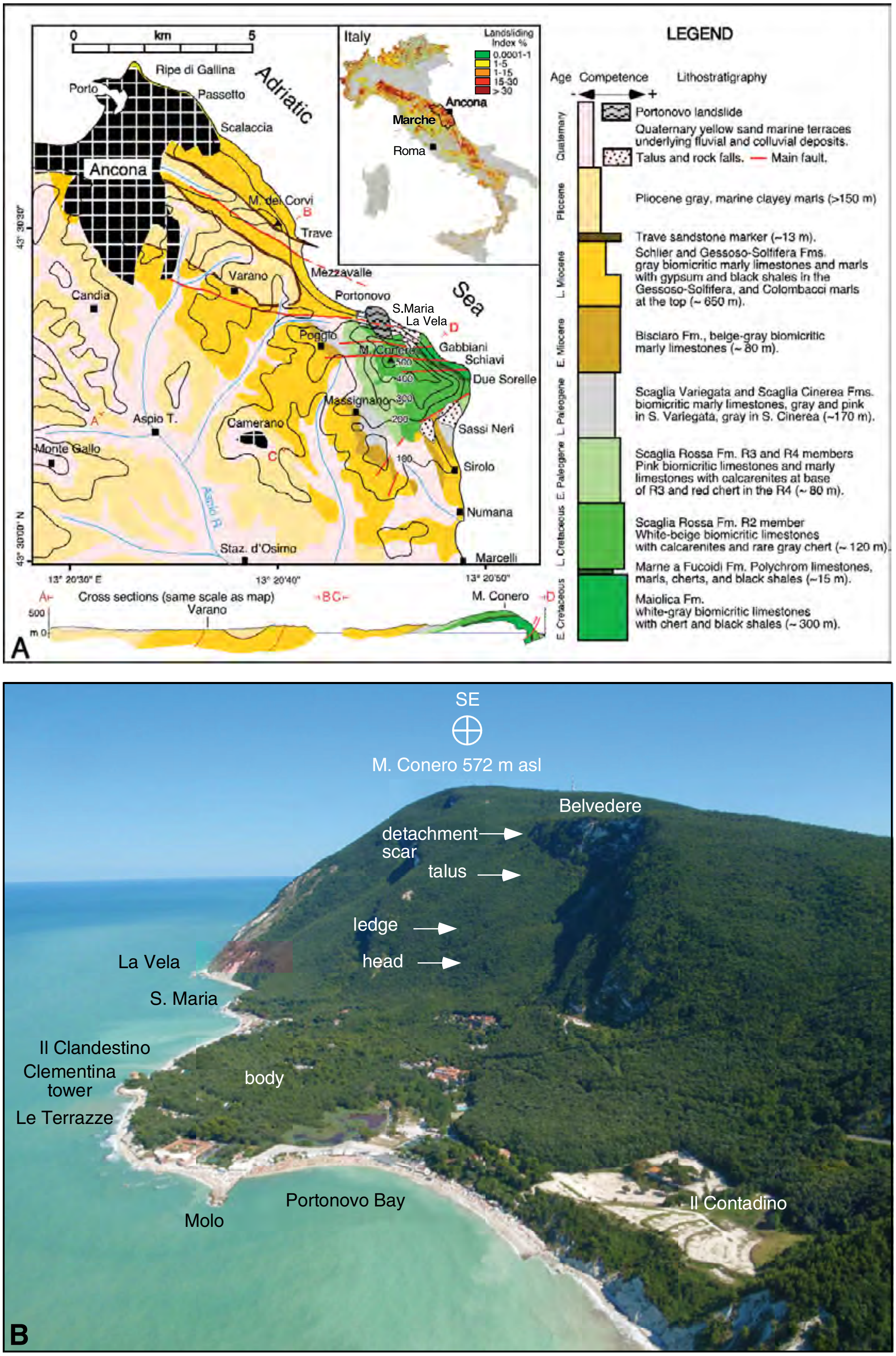

Figure 1. (A) Geologic map and cross sections of the Conero promontory, simplified, redrawn, and slightly amended from Servizio Geologico d'Italia (1963) and Coccioni et al. (1993). (B) View of Monte Conero and the Portonovo bay as seen from the cliffs of Mezzavalle showing the physiographic components of the Portonovo landslide.

and only exceptional events, which caused large infrastructure damage and/or many victims, have a chance to be remembered in history books. This is the case of the San Lazzaro landslide, which occurred on 13 February 1934 near Fossombrone (northern Marche) and resulted in the sudden collapse of the southwestern slope of the Monti della Cesana anticline, made up of strongly fractured limestones of the Scaglia Rossa Formation for an estimated 6×10^5 m^3 of fallen rocks (a sort of rock avalanche). This landslide caused the destruction of several houses, 11 victims, and the interruption of the railroad and the state highway Via Flaminia (Savelli, 2004). Another striking recent case is given by the Barducci landslide, which occurred on the night of 13 December 1982 in the northeastern outskirts of the city of Ancona. This complex landslide slowly moved on a front ~2.5 km along the coast, affected an area of ~2.2×10^6 m^2, destroyed or irreparably damaged 280 city buildings, and deformed a long stretch of the coastal highway and railroad (e.g., Coltorti et al., 1985; Crescenti et al., 1986; Agostini et al., 2013). In this case, the culprit was a prolonged period of heavy rain, which led to the yielding point of stability in deeply fractured Pliocene clay-rich formations making up the bedrock of the hilly coast. Coseismic ground fractures may have developed during a long seismic sequence 10 yr earlier, which started on January 1972 and ended in July of the same year. Among more than 500 events, the strongest occurred on June 16 with a magnitude of 4.7 (e.g., Stucchi, 1988a, and references therein). Apart from severe damage to buildings, coseismic landslides in the Ancona territory are not reported. Nevertheless, the Barducci landslide of 1982 has since remained under strict surveillance by a geoengineering service team of the City of Ancona via continuous laser and global positioning system (GPS)–geodetic monitoring, and analysis of data from several geognostic wells (Cardellini and Osimani, 2008).

In this paper, we recount our interdisciplinary study of the huge Portonovo landslide, ~8 km SE of Ancona, from a "big history" perspective (e.g., Alvarez et al., 2011; Rodrigue et al., 2015, and references therein). This approach, which stems from original geologic and geochronologic data presented herein for the first time, aims at a comparison with, and reinterpretation of historical documentation of this exceptional landslide, which had been previously considered, by geologists and geotechnicians, a prehistoric event and therefore unimportant in the context of the present hydrogeological instability of this area. This leads us toward a realistic evaluation of the risk that a similar event may happen in the nearest future, and the suggestion of action that local civil authorities shall take to prevent such a possible future catastrophe.

METHODS AND TECHNIQUES

We started our study by analyzing the geomorphology, lithologic composition, and stratigraphy of the landslide from head to toe, and then we reconstructed the geographic and environmental changes of the Portonovo bay subsequent to the landslide through sedimentary facies and biolithostratigraphic analyses of three shallow drill cores, which penetrated the body and the toe of the landslide deposit down to prelandslide continental and marine sediments, eventually reaching Oligocene and Miocene bedrock formations. Continuous coring operations were carried out by local specialized geotechnical companies using double-barrel and lined, 100-mm-diameter corers. Outcrop mapping and ground truthing were conducted on foot using published geologic base maps (Servizio Geologico d'Italia, 1963, 1:100,000 scale and 1:25,000 scale; Coccioni et al., 1993, 1:20,000 scale; Regione Marche, 2003, 1:10,000 scale), and 1:5000 scale topographic maps of Regione Marche (2000), as well as light detection and ranging (LiDAR) imaging of the area with a pixel definition of 2 m^2. This helped us to redraw the landslide of Portonovo in better detail than ever before (e.g., Regione Marche, 2003; Aringoli et al., 2014, and references therein), for a sound interpretation of its geomorphology (Figs. 2A–2B), and cross-section physiography (Fig. 2C). Unfortunately, multibeam morphobathymetry and high-resolution seismic reflection data, or boreholes probing the immediate offshore of the Portonovo landslide lobe, which would have been critical for accurately assessing the thickness of the landslide deposit now underwater, were not available for our study and, as far as we know, have never been done in previous investigations.

Some 30 rock samples were collected from in-place bedrock outcrops, loose landslide debris, and drill cores for accurate lithologic, sedimentologic, and biostratigraphic assessments in standard thin sections and in >63 μm washed residues using cold acetolysis treatment following the method of Lirer (2000). Planktonic foraminiferal associations were used to identify bio-chronozones according to the biostratigraphic zonations of Premoli Silva and Sliter (1995) for the Cretaceous Period, Wade et al. (2011) for the Paleogene Period (E, O, and P Zones), and Iaccarino et al. (2007) for the Miocene Epoch (MMi Zones). One-hundred grams of dried sand samples from the cores were wet-sieved using a 63 μm polyester monofilament screen under running tap water, and the residues were dried under an infrared (IR) lamp at a temperature of ~60 °C. The residues were then dry-sieved with a graded stack of small steel sieves for compositional and textural grain-size analyses. Mollusk shells larger than 500 μm were selectively handpicked from washed residue samples from cores MOL-S1 and MOL-S2, cleaned in an ultrasonic distilled water bath for over 1 h, rinsed, and dried under a IR lamp at ~60 °C. Despite the fact that the cores were preserved practically untouched in their original plastic core cases in a storage room for some 16 yr, no signs of weathering nor contamination were visible. Mollusk shells were perfectly preserved, still maintaining their colorful pigment patterns. Therefore, the shells provided excellent carbonate material for radiocarbon dating, which was performed at the Beta Analytic radiocarbon dating laboratory in Miami, Florida (http://www.radiocarbon.com). Finally, information about the history of the Portonovo bay and the surrounding Conero region was gathered from various sources retrieved in local public libraries and available on the Internet.

PRECARIOUS CONERO RIVIERA

The coastal area of the Ancona territory, which is represented by the promontory of the Conero Riviera, is particularly prone to landsliding owing to the fact that it is an active high coast (e.g., Vannoli et al., 2004; Aringoli et al., 2014) with cliffs directly overhanging the sea (Fig. 1A; see also Angeli, 1999). The whole 9 km coastal stretch between the port of Ancona and the bay of Portonovo, as well as the shorter stretch on the south side of the Conero promontory between the towns of Sirolo and Marcelli, is made up of incompetent Neogene marly formations, and small- and medium-size landslides and rock falls (i.e., of tens to thousands of cubic meters in rock volume) occur practically every year somewhere along the Conero Riviera, mainly in wet and sea-stormy winter months. The central, more prominent part of the promontory is represented by Monte Conero (572 m above sea level [asl]), a NE-verging, almost recumbent blind thrust-anticline (see cross section C-D in Fig. 1A) made up of relatively competent, Early Cretaceous to late Paleogene pelagic limestone formations (see legend in Fig. 1A). The cliffs along the coastal stretch between the Portonovo bay and the Sassi Neri beach (see Fig. 1A for location) are studded with landslide scars and rock-fall deposits (e.g., Regione Marche, 2003), which testify to recent and relatively frequent collapse events involving rock masses in the order of tens to thousands cubic meters.

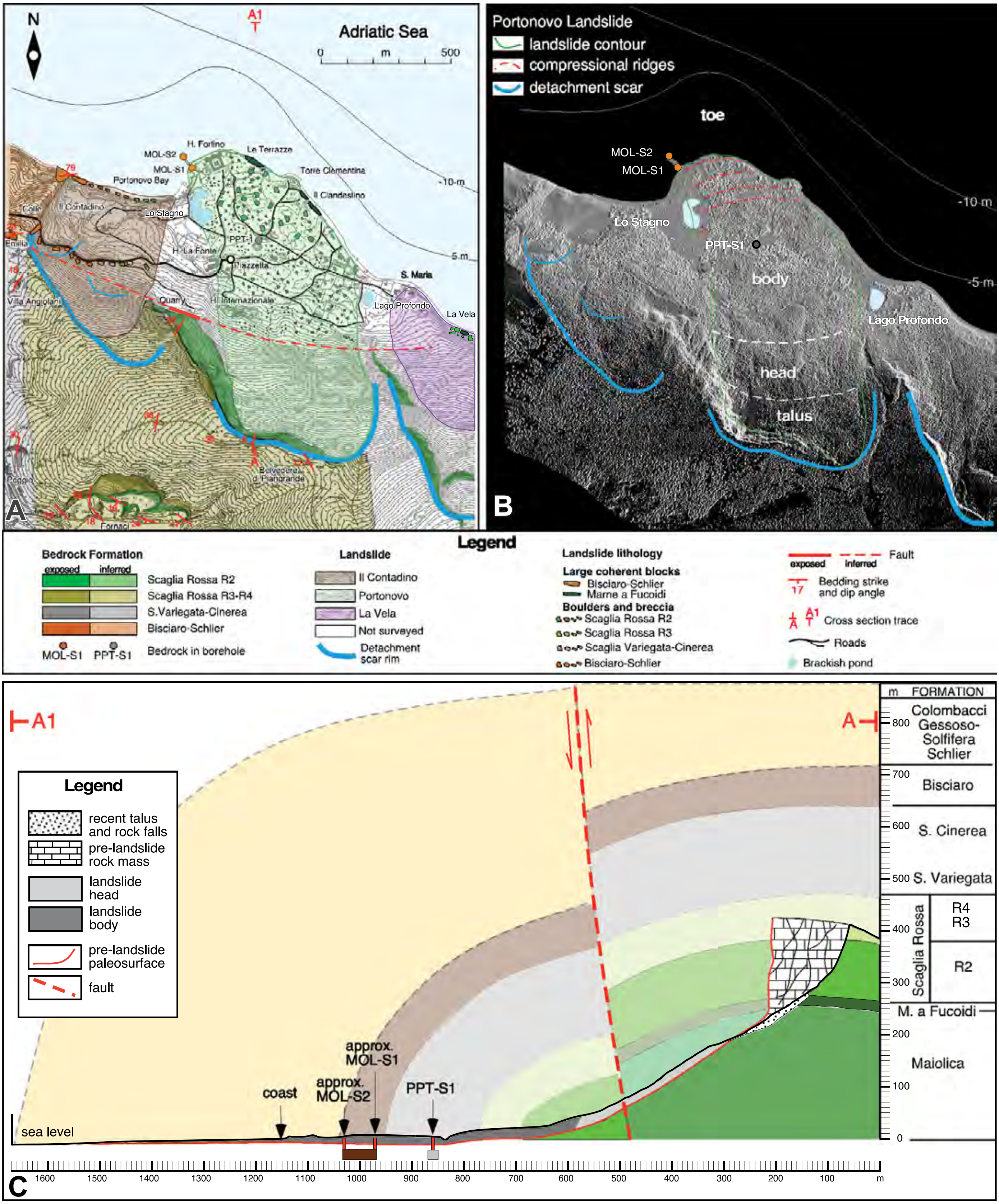

Figure 2. (A) Geologic map of the Portonovo area. (B) High-definition light detection and ranging (LiDAR) image of the Portonovo area highlighting the physiographic components of the landslide. (C) Geological cross-section A-B (as in Fig. 2A) of the Portonovo landslide.

The danger of landslides along the Conero Riviera has been evaluated by Angeli (1999), as well as the authority of the City of Ancona, which deliberated regulations forbidding public access in several beaches. This is the case for the picturesque Due Sorelle beach, the Schiavi beach, where sometime in the middle of the last century, a rocky landslide buried the entrance of a now legendary cave (Recanatini, 1997), and the Gabbiani beach, where a collapse occurred some 15 yr ago, or even the small rock fall on the cliff up above the medieval abbey of Santa Maria, which occurred in the winter of 2014. The popular beach of Mezzavalle was also interdicted by the municipal authority, but despite this, thousands of bathers every summer challenge the danger and sunbathe along the beach right at the foot of the cliffs. Disappointing for geologists, the beaches at the foot of Monte dei Corvi, which hosts the global stratotype section and point (GSSP) for the Tortonian Stage (Hilgen et al., 2005), have also been recently restricted due to landsliding. Noteworthy to recall is a massive rock fall over the popular Sirolo beach, which was triggered by an earthquake with local magnitude M_L 4.4 on 22 August 2013 at 08:44 h (peak of the tourist season but fortunately nobody got hurt). This particular instance of a landslide triggered by an earthquake actually occurred in the midst of a seismic sequence, which started on July 22 with a moderately strong earthquake of magnitude 4.9.

The largest of all landslides of the Conero Riviera is represented by the land lobe that contours the Portonovo bay, a very popular beach resort rewarded with the Blue Flag label by the international Foundation for Environmental Education (FEE) every year since 2010 (Fig. 1B). This landslide exhibits a cirque-shaped, subvertical detachment scar some 600 m wide and 150–200 m high and represents a sudden, all-at-once collapse of a rock mass conservatively estimated by us to be 5×10^6 m^3 (i.e., an order of magnitude larger than the San Lazzaro landslide mentioned earlier).

LANDSLIDE GEOMORPHOLOGY, FACIES STRATIGRAPHY, AND RADIOCARBON GEOCHRONOLOGY

Despite a thick Mediterranean forest cover, the geomorphology of the Portonovo landslide is at first sight recognizable from a distance in all its geomorphic components (Fig. 1B). However, it must be pointed out that the whole area of Portonovo, from the locality called Il Contadino to La Vela, is covered by the deposits of three major landslides, which can be recognized by three distinct detachment scar lineations and lithologic compositions (Fig. 2A). The western landslide, here dubbed Il Contadino, is a complex structure made up of several small landslides, some of which are very recent, superposed on a much larger landslide, a detrital roto-translational slump according to the classification of Varnes (1978). The body of this landslide is made up of breccia from various formations such as Scaglia Variegata, Scaglia Cinerea, Bisciaro, and Schlier, while the foot, which is exposed along the beach bluff, is made up of large coherent, back-rolled blocks of well-bedded marly limestones and marls with a planktonic foraminiferal association characterized by *Globoquadrina dehiscens*, *Catapsidrax dissimilis* (MMi2 Zone), and *Globigerinoides altiapertus* (MMi2b Zone) belonging to the Burdigalian, i.e., the transition between the upper Bisciaro Formation and the lower Schlier Formation (Fig. 3A). The eastern landslide, dubbed La Vela in Figure 2A, can be classified as a rock translational slump (Varnes, 1978). The body of this landslide is made up of Cretaceous Scaglia Rossa limestone breccia resting on a steep slope plunging directly into the sea, while the foot is made up of brecciated multicolor marls and black shales derived from the Marne a Fucoidi Formation (Fig. 3B). The landslide in between these two is the great landslide of Portonovo, which is remarkably similar, in terms of geometry and size, to the huge and more famous Marcus landslide (Fig. 4), a Pleistocene structure located in the McDowell Mountains Park in Arizona (Douglass et al., 2004, and references therein; see also Arizona State University, 2015). Next, we provide a detailed description of the Portonovo landslide from head to toe.

Detachment Scar

The conspicuous detachment scar cliff visible looking up from the Portonovo beach is best seen from the locality called Belvedere, at the northern rim of Piangrande (see Fig. 1B for location). Here, the eastern side of the cirque-shaped detachment scar offers an ~150 m vertical exposure of the subhorizontally bedded R2 and R3 members of the Scaglia Rossa Formation (Fig. 5), with all the stratigraphic details described by Montanari and Koeberl (2000, p. 239–246). Lithologic, sedimentary, and micropaleontologic facies of this succession are readily identifiable in the field by visual inspection using a hand lens, and this allowed us to recognize, in loose hand samples, the redistribution of the collapsed and dismembered rock body over the whole area of the landslide deposit. In this exposure of the detachment scar, as well as in other quarry outcrops on the west side of the Conero anticline (e.g., the Fornaci quarries on the east of the village of Poggio in Fig. 2A), the R2 member of the Scaglia Rossa exhibits its peculiar proximal facies of white calcarenitic grain flows and turbidites interbedded with whitish-beige pelagic biomicritic limestones made up of planktonic foraminifera (i.e., globotruncanids and heterohelicids) suspended in a coccolith matrix (Montanari et al., 1989). The top of the R2 member is marked by an ~2-cm-thick, greenish-gray Cretaceous-Paleogene boundary clay (the Cretaceous-Tertiary boundary iridium-rich clay layer of Alvarez et al., 1980; see also Montanari et al., 1983; Montanari, 1991), which, in the Conero area, is found ~80 cm below an ~2–5-m-thick calcirudite marker bed locally referred to as the MegaT or Livello Marchesini (Montanari, 1991; Coccioni et al., 1993; Montanari and Koeberl, 2000). Thus, this thick MegaT marker represents the first detrital bed of the basal Paleogene R3 member of the Scaglia Rossa Formation, which is placed in the foraminiferal P1b Zone (Montanari and Koeberl, 2000). Above it, the Scaglia Rossa presents a marly facies typical of the basal Paleogene (P1c Zone) throughout the Umbria-Marche basin (Montanari et al., 1989, and references therein), but here in the Conero area, such a marly lithofacies exhibits a greenish-gray color, unlike the deep pink color of the same unit exposed anywhere else in the region. Above this marly interval, the R3 member becomes more calcareous (P2 Zone) and assumes its typical pink color (see Fig. 5). Some 9–10 m above the Cretaceous-Paleogene boundary, the pink pelagic limestones of the R3 member are interrupted by yet another ~2-m-thick white calcarenitic megabed pertaining to the planktonic foraminiferal zone P3 (see P3 marker in Fig. 5). The rest of the R3 member, as seen in the quarry exposures near Poggio (see map notes in Coccioni et al., 1993) exhibits its typical pink color and is devoid of calcarenitic beds. However, in the quarries of Fonte d'Olio, on the western limb of the anticline near Sirolo, the pelagic limestones of the R3 and R4 members of the Scaglia Rossa Formation exhibit a whitish color (see Coccioni et al., 1993; Montanari and Koeberl, 2000; Fig. 8.3 *in* Ciarapica and Passeri, 2001).

Head

The lower part of the detachment scar cliff is covered by a thickly forested talus deposit down to the ~200 m contour line, where a subtle break in slope, like a ledge (indicated in Fig. 1B, and topographic profile in Fig. 2C), marks the upper limit of what we interpret as the landslide head. The lower limit of this physiographic part of the landslide is tentatively drawn along the next break in slope at the ~50 m contour line, near the Hotel Internazionale (see location in

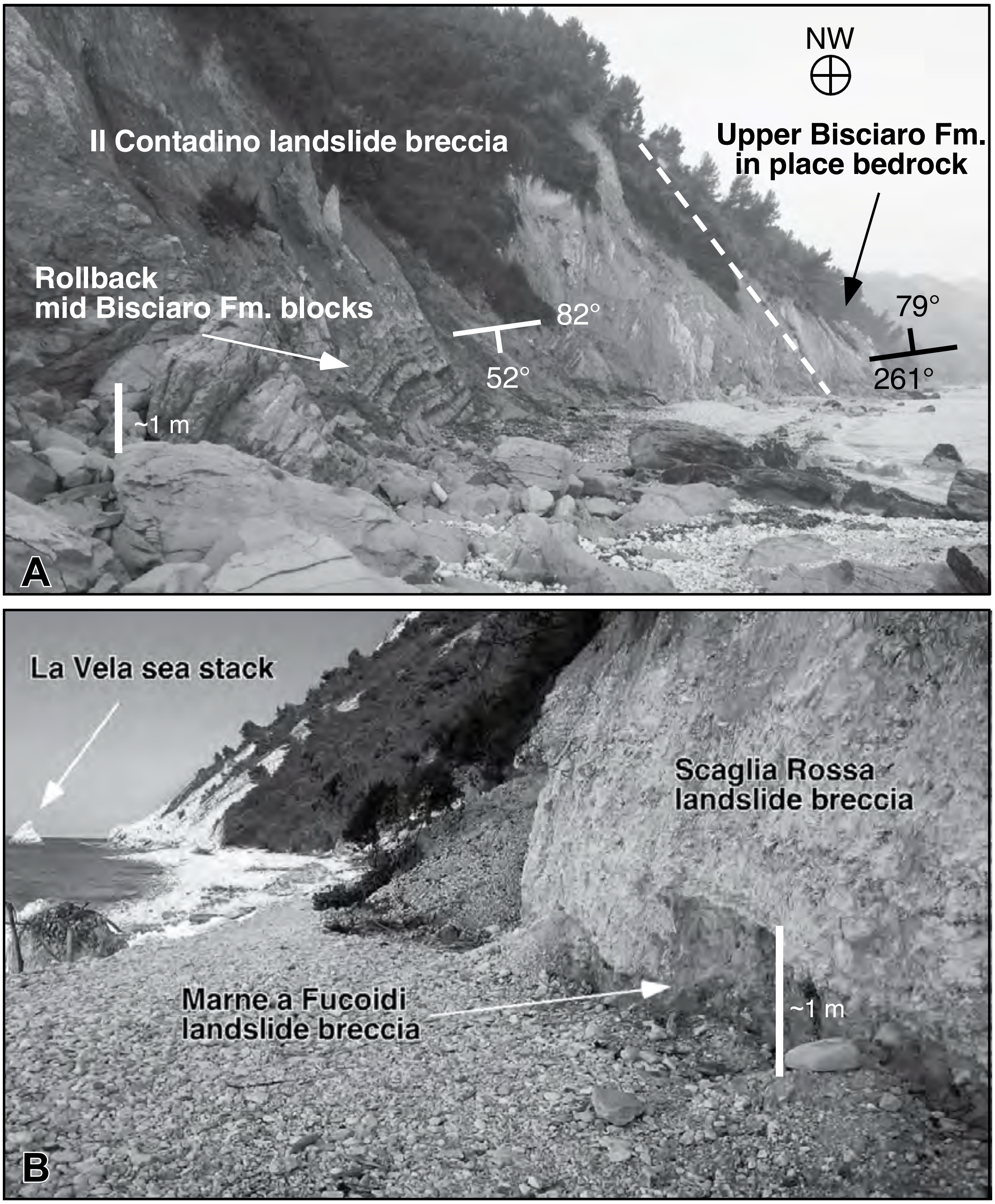

Figure 3. (A) Panoramic view of the foot of the Il Contadino landslide. (B) Panoramic view of the foot of the La Vela landslide.

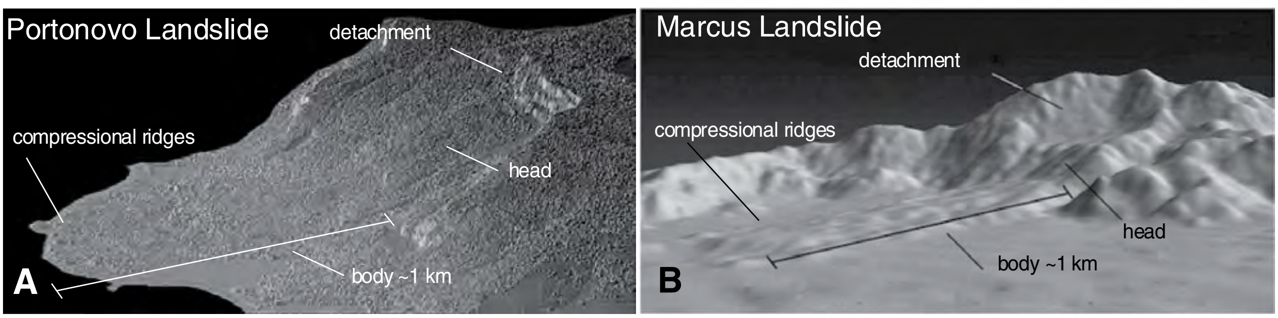

Figure 4. (A) Light detection and ranging (LiDAR) digital elevation model (DEM) of the Portonovo landslide compared to (B) a similar MicroDEM image of the giant Marcus landslide in the McDawell Mountains Park in Arizona (from Arizona State University, 2015).

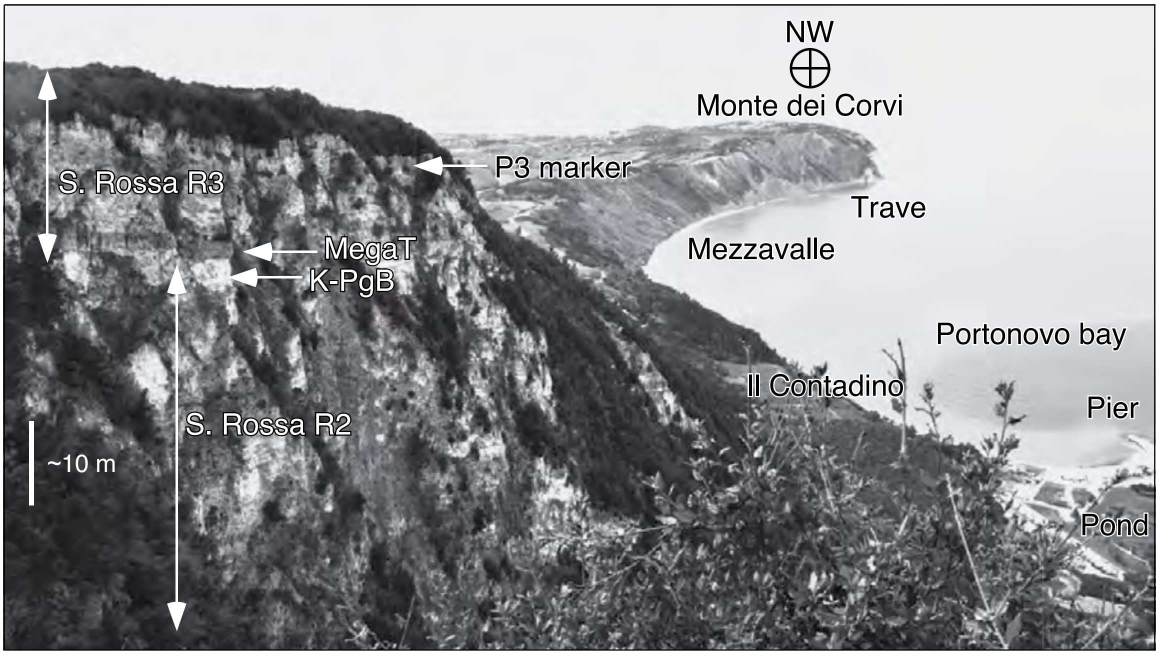

Figure 5. Panoramic view of the detachment scar and the underlying Portonovo bay (photo courtesy of Pierluigi Stroppa), with indications of stratigraphic markers through the exposed Scaglia Rossa R2 and R3 members. K-PgB—Cretaceous-Paleogene boundary; P3—planktonic foraminiferal zone P3.

Fig. 2A). There is not much we can say about the lithologic composition, nor the structure of this upper part of the landslide, because this steep, densely forested area is devoid of outcrops and is dangerous due to frequently falling rocks, preventing us from accessing it to obtain an accurate ground-truthing survey.

Body

The body of the landslide, which covers an area of ~240 × 10^3 m^2 making up the land lobe of Portonovo, is today covered by a dense first-generation Mediterranean forest, which masks its geomorphic features (Fig. 6A). However, old panoramic postcard photos taken in the 1950s, when Portonovo was still uncovered by such vegetation, reveal a pronounced hummocky geomorphology characterized by small hills ~10 m high (Figs. 6B). High-definition LiDAR imaging actually reveals that these hills, in the outer part of the land lobe, are aligned along arched ribs, which we interpret here as landslide compressional ridges (Fig. 2B). These hills are made up of breccia and boulders (up to cubic meter size) of Cretaceous pelagic limestones and calcarenites, all derived from the R2 member of the Scaglia Rossa Formation.

In the outer, seaward part of the land lobe, crosscuts of the landslide body are exposed along the bluffs over the Le Terrazze and Il Clandestino beaches (see Fig. 2A for location), and both these outcrops expose strongly deformed yet stratigraphically coherent sections of the Marne a Fucoidi Formation and the overlying lowermost member of the Scaglia Rossa Formation (Figs. 7A–7B). The Le Terrazze section starts with the Selli Level, an ~2-m-thick marker horizon made up of thin radiolarite and black shale beds, which represent the regional expression of the basal Aptian oceanic anoxic event 1 (OAE-1; Coccioni et al., 1989). The Selli Level, and the overlying Marne a Fucoidi Formation, made up of green-gray and reddish-brown pelagic marly limestones and marls interbedded with black shales, constitute a rheologically weak lithologic unit sandwiched between the hard, cherty limestones of the underlying Maiolica Formation and the overlying, equally competent limestones of the Scaglia Bianca (Cenomanian) and Scaglia Rossa (Turonian to Ypresian) Formations. In the Conero area, the Marne a Fucoidi Formation is actually interrupted by a series of hiatuses and is directly overlain by the pelagic and calcarenitic limestones of the Scaglia Rossa R2 member (Montanari, 1979; Coccioni et al., 1993; see legend in Fig. 1A). A noteworthy feature is a large boulder (i.e., a couple of cubic meters at least) of a white, very fine calcarenitic limestone (indicated in Fig. 7B) cropping out from the pebbly beach right in front of Il Clandestino beach resort, which probably represents one of those thick, fine-grain calcarenitic turbidites making up the base of the R2 member of the Scaglia Rossa exposed in the Pirolo promontory, on the east side of the Due Sorelle beach (Montanari, 1979; Coccioni et al., 1993; see Fig. 1A for location). Similar "erratic" boulders emerge from the sea some 40 m distance from the Hotel Fortino Napoleonico beach, but the lobate 5 m isobath contour line offshore of Portonovo (Figs. 2A–2B) suggests that the foot (and/or the toe) of the landslide may extend underwater for some 300 m from the present-day coastline.

The bedrock, onto which the landslide deposit rests, is not exposed in either coastal bluffs of Le Terrazze and Il Clandestino beaches. Nevertheless, the autochthonoue bedrock was reached at a depth of ~16.5 m below present sea level (i.e., 22.5 m core depth) in a borehole we drilled in October 2015 in the car park of La Torre, some 300 m inland from the Le Terrazze beach (see PPT-S1 in Figs. 2A–2B for location), right in the middle of the landslide body. Planktonic foraminiferal associations indicated a Chattian age (late Oligocene) for the coherent gray marly limestone at the bottom of the core (unit 4 in Fig. 8B), i.e., the middle or upper part of the Scaglia Cinerea Formation (Coccioni et al., 2008). However, the base of the landslide deposit (units 1 and 2 in Fig. 8B), which is made up of Cretaceous Scaglia Rossa limestone breccia overlying green, gray, and reddish marls with black shales and purplish-red chert clasts of the Marne a Fucoidi Formation, thus reflect-

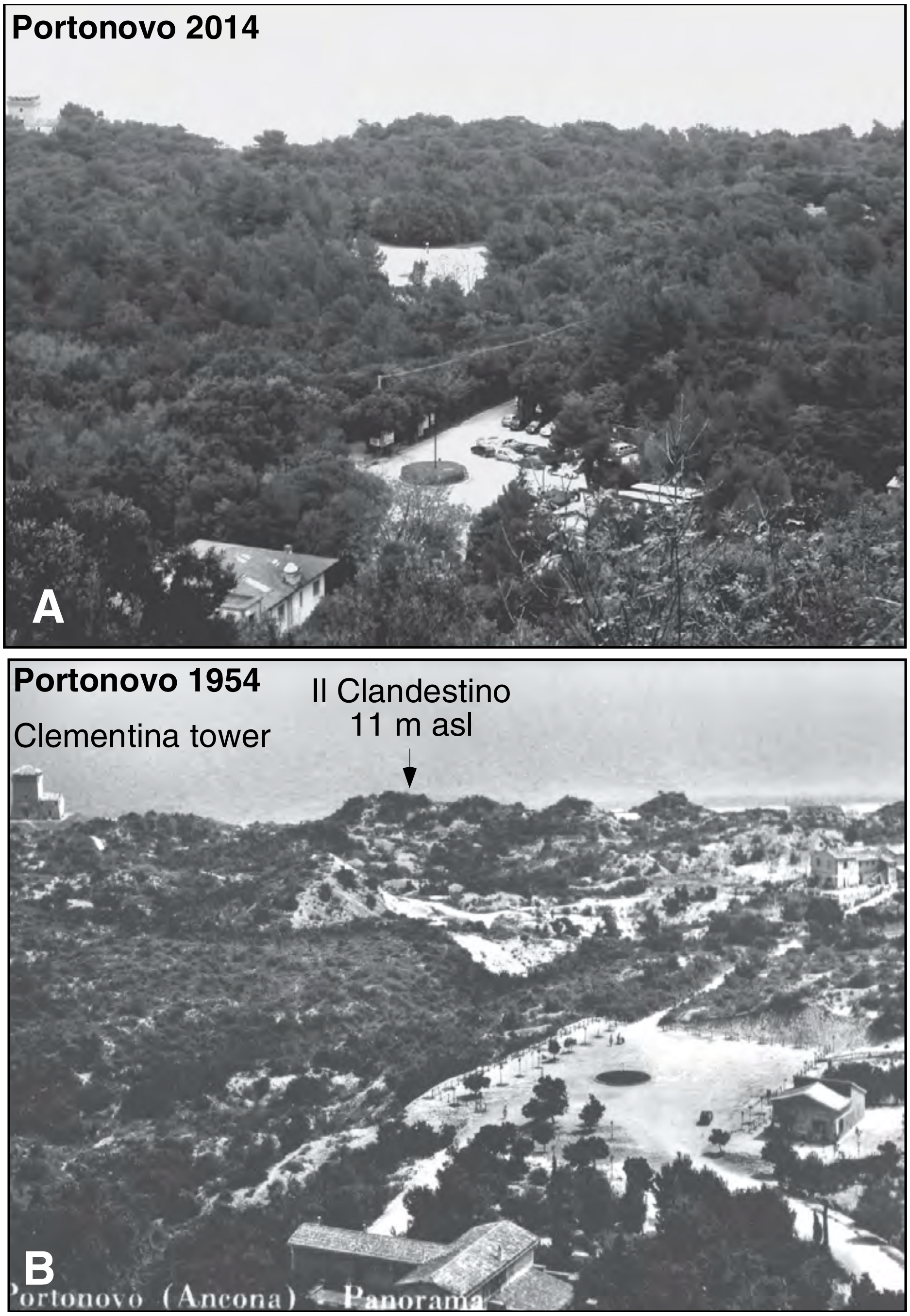

Figure 6. (A) Panoramic view of the body of the Portonovo landslide presently covered by a thick, first-generation Mediterranean forest. (B) Approximately the same view in an old postcard (courtesy of Aldo Roscioni) when the geology of the Portonovo land lobe was still mostly uncovered by vegetation, and the landslide compressional ridges were well recognizable.

ing the exact same jumbled-up lithostratigraphy exposed in the Le Terrazze and Il Clandestino bluffs, is found at a depth of ~11 m below sea level. In between this landslide breccia and unit 4 at the bottom of the borehole (the coherent Scaglia Cinerea marly limestone bedrock), there is a 5.5-m-thick unit 3 made up of a compacted, homogeneous gray clay, which contains a minor fraction of sand-size grains composed of gray, whitish, and pink limestones and marls, along with angular grains of gray and red chert, and abundant, poorly preserved and matrix-encrusted tests of planktonic and benthic foraminifera derived from Paleogene Scaglia Rossa R4, Scaglia Variegata, and Scaglia Cinerea Formations. The best-preserved, and thus recognizable planktonic foraminifera, such as "*Paragloborotalia*" *pseudokugleri*, indicate the O7 Zone of late Oligocene age. We interpret this unit as a colluvial continental deposit, which filled up a geomorphologic depression formed on the relatively soft Scaglia Cinerea bounded to the south by the relatively competent limestones of the Eocene Scaglia Variegata and Scaglia Rossa R4 member, and to the north by equally competent marly limestones of the lower Miocene Bisciaro Formation (see cross section in Fig. 2C). Unfortunately, the lack of carbonaceous material (i.e., vegetal remains) or biogenic carbonate (i.e., mollusk shells or bones) prevented radiocarbon dating of this prelandslide colluvial deposit.

Toe: Facies Stratigraphy and Geochronology

While field surveying, geomorphic analysis, and lithostratigraphic reconnaissance gave us a fairly clear and complete picture of the Portonovo landslide, as synthesized in Figures 2A–2C, the recovery of two drill cores through what we consider the toe of the landslide on the northwestern edge of the land lobe, labeled as MOL-S1 and MOL-S2 (Figs. 2A–2B and 9A–9B), gave us the opportunity to define the facies stratigraphy of the sediments deposited prior to, and after the landslide event (Figs. 10A–10B). Moreover, the cored sediments contain neritic mollusk shells, which allowed radiocarbon dating, thus permitting a radioisotopic assessment of the age of the landslide event (Table 1). Both cores went through the modern beach deposit (unit 2 in Fig. 10B) to then intercept the landslide breccia with base at ~7.5–8 m core depth (unit 3 in Fig. 10B). In MOL-S1, the breccia horizon is ~50 cm thick and is made up of small (10–20 mm) angular clasts of whitish globigerinid pelagic limestones, possibly derived from the Lower Paleogene formations from Scaglia Rossa R3 to Scaglia Variegata, gradually passing upward to a mix of angular clasts and rounded pebbles of unit 2. This breccia unit is devoid of mollusk shell remains, which start to appear at ~6.9 m core depth, characterized by unmistakable blue-violet shell fragments of *Mytilus galloprovincialis* (black mussels) associated with rare fragments of other robust infratidal mollusk shells, such as probable *Murex*, *Nassa*, *Natica*, possibly *Clamis*, *Cardium*, and others, i.e., mollusk genera found in the present-day pebbly beach of Portonovo. The fine fraction of sample MOL-S1–6.8 m, in addition to small gastropod and bivalve shells, con-

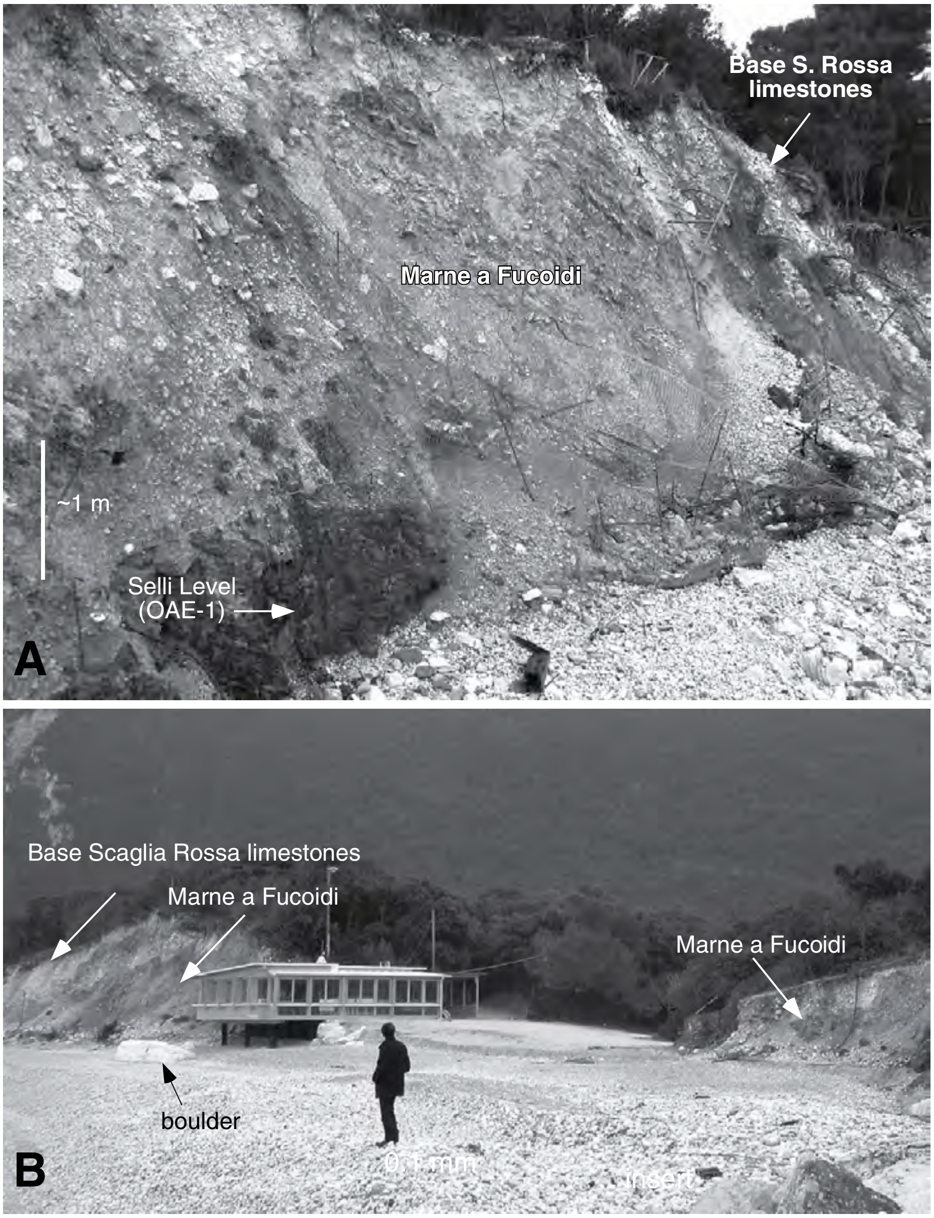

Figure 7. (A) Outcrop of the Marne a Fucoidi Formation in the bluff of Le Terrazze beach. OAE-1—oceanic anoxic event 1. (B) Marne a Fucoidi exposed on the bluffs near Il Clandestino beach resort. A large boulder emerging from the pebbly beach and made up of a fine-grained calcarenite from the basal Scaglia Rossa Formation is indicated by the arrow.

tains a diversified association of ostracod shells, none of which had paired and closed valves, and among which *Cytheridea acuminata neapolitana*, *Hemicytherideis elongata/turbida*, and *Loxoconcha* cf. *agilis/turbida* were identified. Noteworthy to report is the finding of a couple of rusty iron pieces in samples collected at 6.9 and 6.8 m core depth, a sign of ancestral anthropogenic beach pollution. Two small samples of handpicked mussel shell fragments taken at 6.8 and 6.6 m core depth yielded calibrated radiocarbon ages of post–A.D. 1700 (Table 1).

The landslide breccia in MOL-S2, however, is ~2.3 m thick and is made up of a mix of boulder-size clasts of mostly pink pelagic limestones (Fig. 10A), the planktonic foraminiferal associations of which indicate biozones spanning the P2 Zone (lower R3 member of the Scaglia Rossa Formation) to the P4c Zone (middle R3 member), and whitish pelagic limestones with globotruncanids and heterohelicids of the uppermost Maastrichtian R2 member (Fig. 10B). These formations are the ones that are found today stacked up on the western side of the detachment scar, and possibly the breccia deposit represents the western fringe of the landslide body. The breccia, now buried under 5 m of modern beach deposit, may represent the onland continuation of a boulder reef, which was emerging in the immediate offshore of the Portonovo beach prior to the construction of the old pier in the mid-1950s (as indicated in Fig. 9B), and it seems to be the western termination of the outer compressional ridge of the landslide body (Fig. 2B). However, at the base of this boulder breccia deposit (7.3 m core depth in MOL-S2), a green-gray marly limestone clast contains planktonic foraminiferal species pertaining to the Priabonian E15 Zone, thus derived from the Scaglia Variegata Formation. This formation is not exposed on the western landslide scar cliff, but it must be present near the densely forested northwestern rim of the Il Contadino landslide detachment scar. The lower part of the Scaglia Variegata Formation, with a planktonic foraminiferal association characterized by *Acarinina topilensis* and *Morozovella lehneri* (E10–E11 Zones of mid-Eocene age), is exposed in the backyard of Villa Angiolani (see Fig. 2A for location), whereas limestone blocks in the float of the cultivated field near the Hotel Emilia, and a small road-cut outcrop nearby, contain *Globoquadrina dehishens* and *Catapsydrax dissimilis* (MMi2 Zone), and *Globigerinoides altiaperturus* (MMi2b Zone) of mid-lower Burdigalian age, thus belonging to the mid-upper Bisciaro Formation. Clasts of Scaglia Variegata limestones are also found in the landslide debris in the road cut along the lower trait of the main access road to Portonovo, starting at the intersection with the secondary road that descends down to Il Contadino plateau (see Fig. 2A for location). From all this, we can hypothesize that the western fringe of the Portonovo landslide debris hurling down toward the sea captured and dragged rock blocks from the preexisting body of the older Il Contadino landslide.

Below the landslide breccia, both drill cores retrieved an ~4-m-thick deposit of fine-medium sand (unit 4 in Fig. 10B). The fine fraction of this sand contains rounded lithoclast grains derived from practically all the carbonate formations surrounding the Portonovo bay, along with abundant planktonic and benthonic foraminiferal tests mostly derived from the soft, marly Miocene and Pliocene formations making up the northwestern littoral zone of the bay (i.e., the Mezzavalle beach; see Fig. 1A for location). On the other hand, the medium-grain-size fraction of this sand is characterized, besides the same lithoclastic component found in the fine fraction, by a well-diversified meiofauna of mollusks, both bivalves and gastropods, and ostracods, including specimens of the families Cytherideidae,

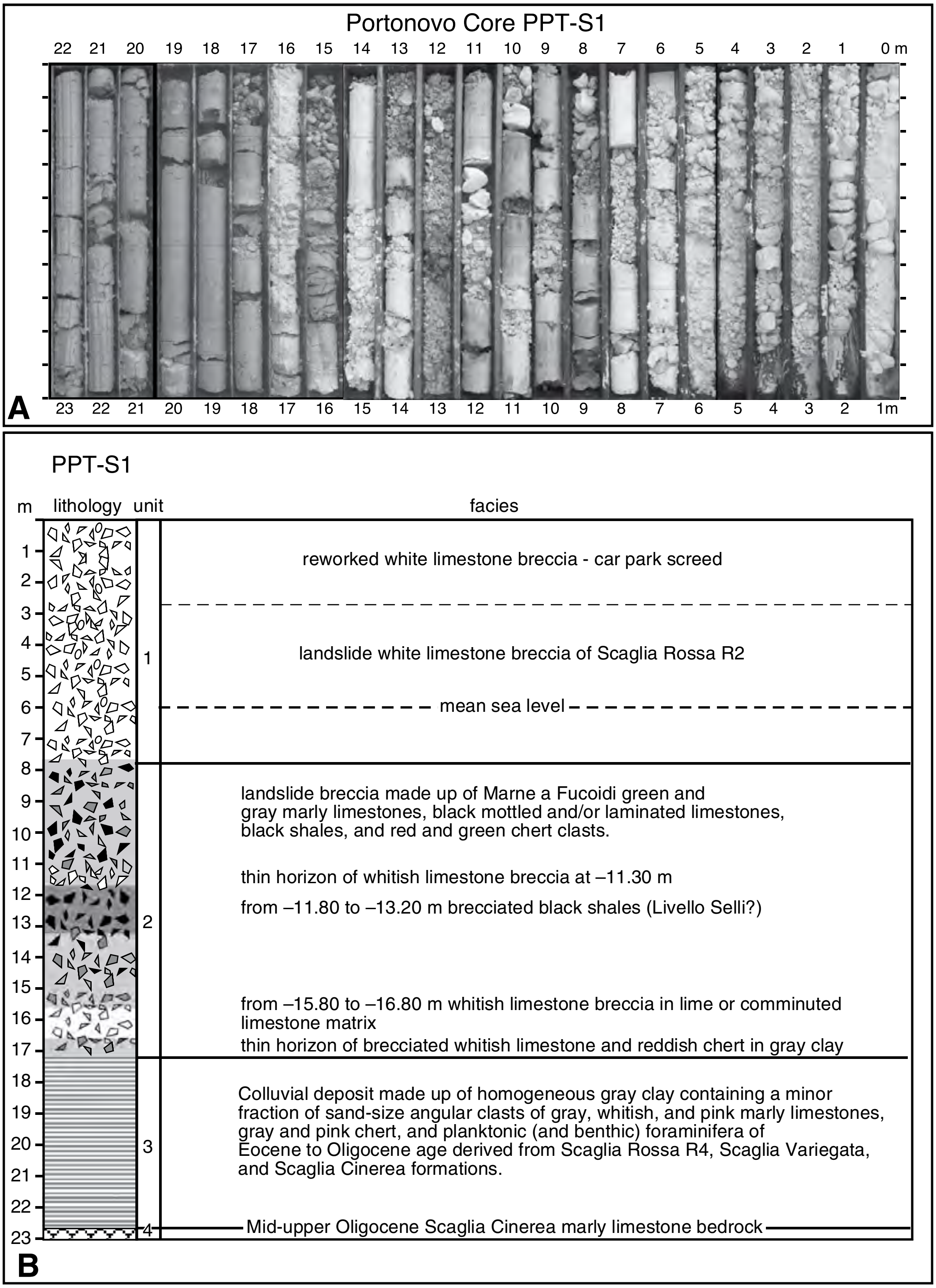

Figure 8. (A) The PPT-S1 core, and (B) its synoptic stratigraphy.

Trachyleberididae, Cyprodeidae, Neonisididae, Bairdiidae, Neocytherideidae, and Loxochochidae. Numerous bivalve and most of the ostracod shells are found still with paired, closed valves, indicating that the sand was deposited at a water depth below sea wave action, i.e., ~3–4 m water depth at most in the present-day Portonovo offshore. This subtidal sand unit 4 rests on top of an ~1-m-thick pebbly sand unit 5 in both cores, which we interpret as an infratidal beach deposit. Radiocarbon dating of handpicked shells of the distinctive and most abundant, amber-colored *Bittium* cf. *simplex* (a small gastropod), taken at the base of unit 5 (12.8 m depth in MOL-S2) and at the top of unit 4 in the same core (7.5 m depth), yielded calibrated calendar ages (2σ confidence) of 4575–4395 B.C., and A.D. 110–320, respectively (Table 1). A sample of assorted mollusk shells taken at 8.1 m depth in core MOL-S1 (i.e., immediately below the thin landslide breccia horizon) yielded a calibrated calendar age of A.D. 695–890 (Table 1).

The basal unit 6, cored in both MOL-S1 and MOL-S2 sites at ~13 m core depth, is represented by gray marly limestones, the plankonic foraminiferal associations of which indicate an Aquitanian MMi2a Zone in MOL-S2 (mid-

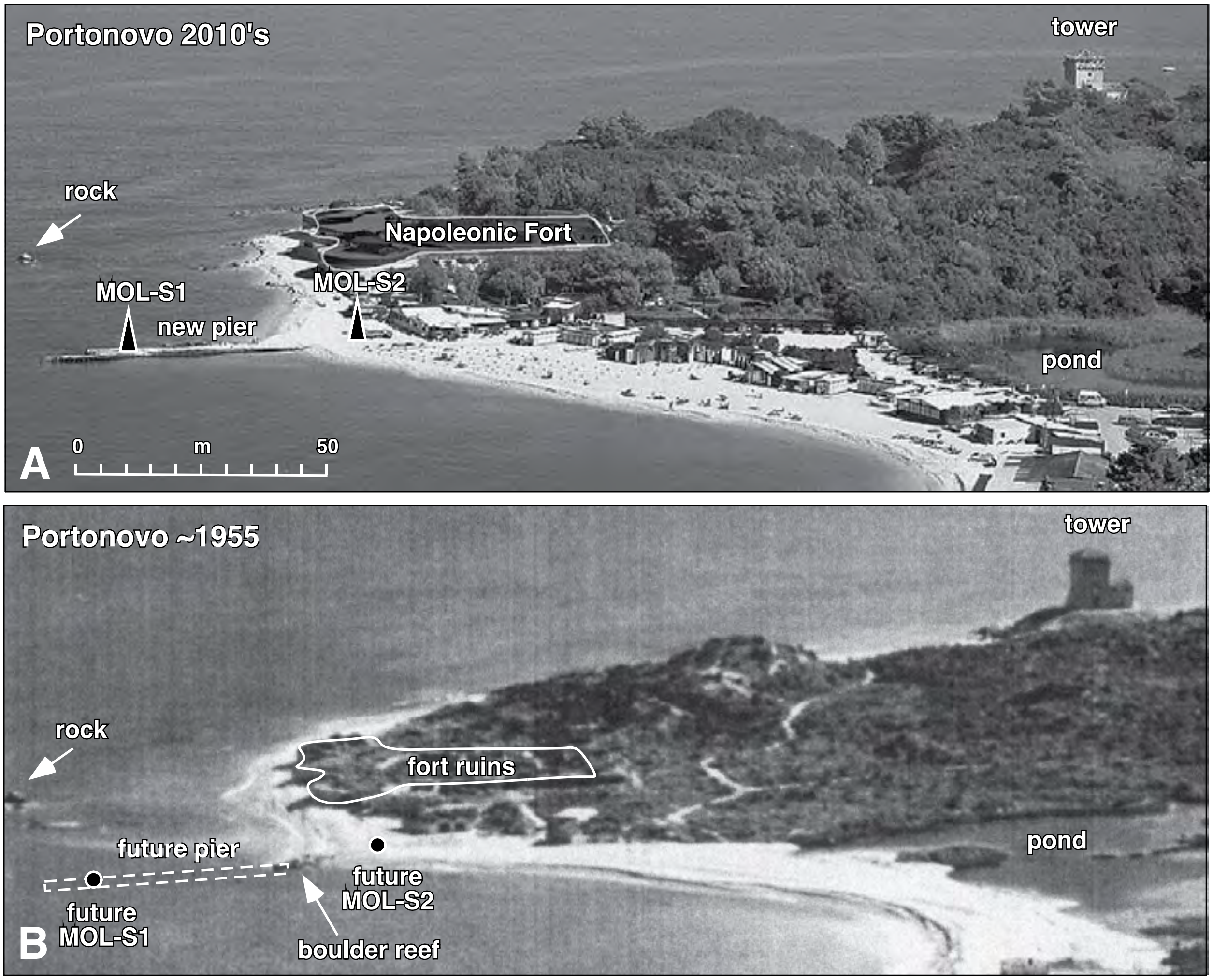

Figure 9. (A) Recent panoramic view of the Portonovo beach showing the location of the drill cores MOL-S1 and MOL-S2. (B) The same view in an old photograph taken in the mid-1950s (courtesy of Aldo Roscioni) prior to the construction of the old pier and the restoration of the Napoleonic fort; note the boulder reef emerging from the pebbly littoral zone, which is now buried under the new pier.

Bisciaro Formation), and a slightly younger MMi2b Zone in MOL-S1 (upper Bisciaro Formation; e.g., Sandroni, 1985; Coccioni et al., 1994; Montanari et al., 1997; Mader et al., 2001; Hüsing et al., 2010). These foraminiferal associations are slightly older than the one recognized in the upper Bisciaro Formation exposed on the rocky cliff at the western end of the Portonovo beach, at the base of Il Colle, with bedding attitude (strike and dip) of 261°/79°NW (see Figs. 2A and 3A for location), which contains planktonic foraminiferal taxa pertaining to the MMi4 Zone (Burdigalian-Langhian transition). Therefore, the marly limestones found at the base of both cores MOL-S1 and MOL-S2, which on visual inspection during the coring exhibited steeply dipping, parallel fracture planes possibly representing bedding (Mainiero, 1999), are stratigraphically consistent with the on-land outcrop of upper Bisciaro-Schlier units, and may represent the in-place bedrock of the Portonovo bay existing prior to the landslide.

In summary, the geomorphological, stratigraphic, compositional, and radioisotopic evidence documented herein suggests that the landslide forming the Portonovo land lobe came down in historical times all at once, and not in different, successive episodes, as otherwise suggested by Ciarapica and Passeri (2001), and prograded seaward over the shallow offshore for 1 km or more from the detachment site.

INTEGRATED EVENT STRATIGRAPHY OF THE LANDSLIDE

The detailed facies analysis and radiocarbon dating of the drill cores described herein allow us to reconstruct the environmental history of the Portonovo bay, placing the landslide event in a geochronologic framework. The infratidal pebbly sand horizon (unit 5 in Fig. 10B) resting on top of the Lower Miocene marly limestone of the Bisciaro Formation at the transition to the overlying Schlier Formation represents a marine strath terrace analogous to the present-day coastal environment of the Conero Riviera, from Monte dei Corvi up north to Ripe di Gallina (see Fig. 1A for location). Here, the strata of the Bisciaro and lower Schlier Formations form elongated reefs paralleling the foot of the coastal cliffs, which constituted for centuries an ideal recovery area for fisherman, and even for fish farming (Carini, 2008). This is the case of the second century Roman *piscina* recently discovered at Scalaccia by Profumo and Taccaliti (2006). Another good example of these coastal reefs is represented by the so-called *mesole* at

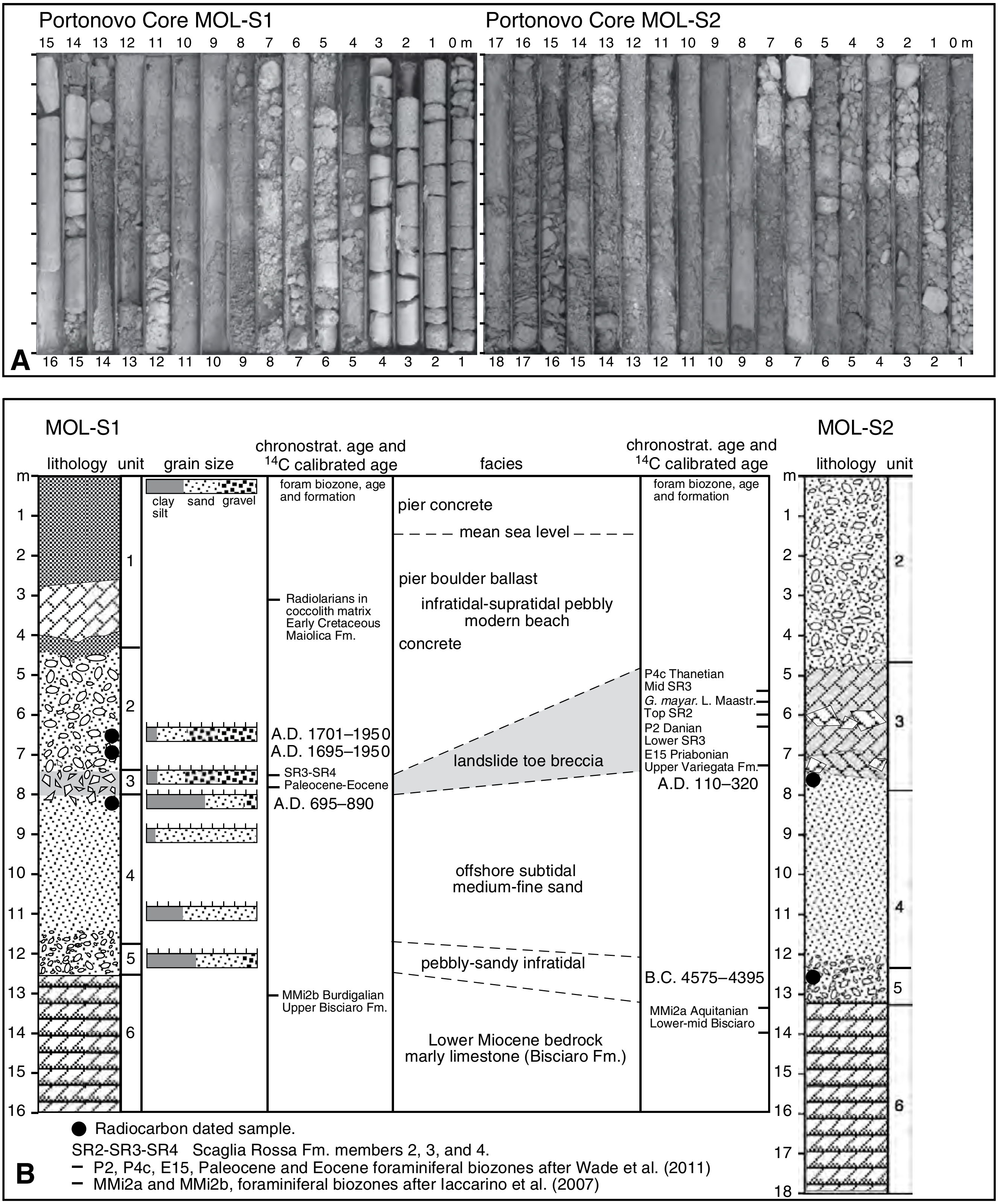

Figure 10. (A) The MOL-S1 and MOL-S2 cores (photographs taken 15 yr after the coring). These cores were commissioned by the City of Ancona to a local geotechnical company in 1999 for a geognostic study and restructuring work of a by-then-decrepit concrete pier originally built in the early 1960s (Mainiero, 1999). The drill rig of MOL-S1 was placed at the far edge of the old pier, whereas MOL-S2 was set some 45 m farther in on the beach gravel (see Figs. 9A–9B). (B) Synoptic stratigraphy and correlation of the MOL-S1 and MOL-S2 cores.

TABLE 1. RADIOCARBON AGES AND CORRECTED CALENDAR AGES FROM NERITIC MOLLUSK SHELLS FROM PORTONOVO DRILL CORES MOL-S1 AND MOL-S2 AS DEDUCED FROM AMS ^{14}C ANALYSIS

Lab code Beta Analytic	Sample name and core depth (m)	Locality	Material shell $CaCO_3$	Measured radiocarbon age (yr B.P.)*	$\delta^{13}C$ (‰)	Conventional radiocarbon age (yr B.P.)*	2σ calibration (calendar age)
405486	MOL-S2-6.7	Portonovo beach	*M. galloprovincialis* mussels	250 ± 30	–2.7	620 ± 30	Cal A.D. 1705 to post-1950
405942	MOL-S2-6.8	Portonovo beach	*M. galloprovincialis* mussels	280 ± 30	–2.8	640 ± 30	Cal A.D. 1695 to post-1950
407817	MOL-S1-8.1	Portonovo old pier	Assorted mollusks	1340 ± 30	–0.8	1740 ± 30	Cal A.D. 695–890
397373	MOL-S2-7.5	Portonovo beach	*B. simplex* gastropod	1870 ± 30	+0.5	2290 ± 30	Cal A.D. 110–320
397374	MOL-S2-12.8	Portonovo beach	*B. simplex* gastropod	5750 ± 30	+0.3	6160 ± 30	Cal 4575–4395 B.C.

Notes: Accelerator mass spectrometry (AMS) radiocarbon dating was performed at Beta Analytic Inc. (Florida) following methods and techniques in http://www.radiocarbon.com/accelerator-mass-spectrometry.htm.

*Dates are reported as radiocarbon yr B.P., where "present" = A.D. 1950.

the foot of the Monte dei Corvi cliff (see Fig. 1A for location), which make up submerged rocky ribs (1–2 m water depth), an ideal habitat for the proliferation of *Mytilus galloprovincialis* colonies (see Fig. 2 *in* Cleaveland et al., 2002). The ~4-m-thick, medium-fine sand unit overlying the strath terrace at Portonovo indicates a marine transgression (i.e., deepening of the seafloor and recession of the coastline), which started some 6500 yr ago, as suggested by the radiocarbon age of neritic gastropods contained in the infratidal pebbly sediment resting on top of the in-place bedrock (unit 5 in Fig. 10B), and terminated sometime in the Middle Ages, with the sudden arrival, in the bay, of the landslide debris. The landslide practically caused an instantaneous local regression, i.e., a seaward progradation of the coastline.

The medium-fine sand immediately underlying the landslide breccia, with its content of neritic bivalves and ostracods with paired and closed valves, indicates a water depth of at least 3–4 m, in any case, deeper than wave action and certainly not an infratidal environment. On the other hand, the pebbly sand on top of the landslide breccia horizon in core MOL-S1, with its content of broken pieces of robust mollusk shells, indicates an infratidal environment evolving upward to the modern pebbly beach. In particular, the presence of *Mytilus galloprovincialis* suggests a rocky infratidal or shallow subtidal environment (this sessile bivalve would not grow on a sandy substratum), which would have been provided by limestone boulders of the landslide's toe.

The colluvial clay unit 3 in core PPT-S1 (Fig. 8B), which underlies the landslide breccia at ~11 m below present sea level, indicates that at the time of the landslide, this site was located inland from a paleoseashore, which was running in a NW-SE direction south of the offshore represented by the neritic sand of unit 4 in cores MOL-S1 and MOL-S2. This continental colluvium deposit may represent a geomorphic depression formed on the relatively soft upper Scaglia Cinerea Formation, suggesting that the coastline, prior to the landslide, ran from about the Lo Stagno pond to the Lago Profondo pond (see Fig. 2A for locations). In summary, the landslide caused a drastic environmental change of the bay. However, the time of this dramatic environmental event is poorly constrained by the radioisotopic dates presented here in Table 1.

The calibrated calendar age of A.D. 695–890 of the seashells immediately below the landslide breccia in core MOL-S1 undoubtedly indicates that the landslide did not occur, contrary to common belief (Parco del Conero, 1995; Coccioni et al., 1993; Aringoli et al., 2014), in prehistoric times. It must be said, however, that the landslide mass hurling down and over the shores of Portonovo, all the way to the neritic offshore, may have plowed and removed the superficial stratum of the soft, sandy seafloor, and therefore the radiocarbon age of the seashells may be significantly older than the age of the landslide event. In fact, the much older calendar age of A.D. 110–320 for the seashells immediately below the more massive breccia body in core MOL-S2 supports this idea of seafloor plowing and sediment removal. The same thing may be said for the landslide body breccia, which may have plowed the soft colluvium clay deposit in core PPT-S1. On the other hand, the mussel shells found ~1.3 m above the base of the landslide breccia, which yielded an imprecise calibrated age of A.D. 1700 to post-1950, may represent an infratidal or beach environment that developed, in this place, sometime after the landslide event. Nevertheless, the Clementina watchtower, which was built in 1716 by order of Pope Clement XI on the most external mound of the Portonovo landslide's body (which we interpreted as a compressional ridge; see Fig. 2B), provides an upper limit to the age of the landslide event. In summary, radioisotope geochronology and the historical Clementina tower suggest that the Portonovo landslide happened between ca. A.D. 800 and A.D. 1716.

HISTORICAL RECORD

Testimony of an Ancient Map

Once we established, on a radioisotopic geochronological basis, that the great landslide of Portonovo occurred in historical times after the ninth century A.D., we turned our attention to written history in search for any documentation that would have given an indication of a more precise date for such a large, catastrophic event. In doing so, we ran into an old landscape map depicting the Portonovo side of Monte Conero as viewed from the sea, which included some 47 toponyms and detailed graphic representations of a number of anthropic and geomorphic features (Fig. 11A), many of which no longer exist. This map, supposedly preserved in the Cathedral's Capitol Archive in Ancona, was produced by canonical historian Monsignor Giuliano Saracini in 1640 (Saracini, 1675), who copied and apostilled (i.e., authenticated) it from an ancient, probably medieval parchment (Albertini, 1824; Presenza, 1981; Piazzini and Stacchiotti, 1989; Recanatini, 2000; Dubini, 2005). Unfortunately, we searched in vain for Saracini's 1640 notes at the archive, which would have contained both original parchment and his redrafted map, but the curator told us that he could not find them possibly, because they were "misplaced," or "lost," or maybe "taken away."

The image shown in Figure 11A is from a JPEG color photograph kindly provided to us by Mr. Aldo Roscioni, owner of the Hotel Fortino Napoleonico in Portonovo, and it is the same picture as the one reproduced, and described in detail, by Piazzini and Stacchiotti (1989), and Dubini (2005). The most suggestive feature of this elusive map is the Arab number *1249* written sideway on the upper-left corner with the same handwriting of all other numbers indicating various toponyms. Is *1249* the date of the original parchment map redrawn by Monsignor Saracini in 1640 (e.g., Piazzini and Stacchiotti, 1989), or just an archival code and not a date, as historian Barbara Dubini suggested to us in a personal communication on May 2015? Whatever the date of the original parchment, a careful observation of the map suggests that it depicts the landscape of Portonovo prior to the great landslide. We reached this conclusion after evaluating the significance of the numerous and accurately mapped toponyms representing geologic and geomorphic features. Most of these features are recognizable today, once the map is

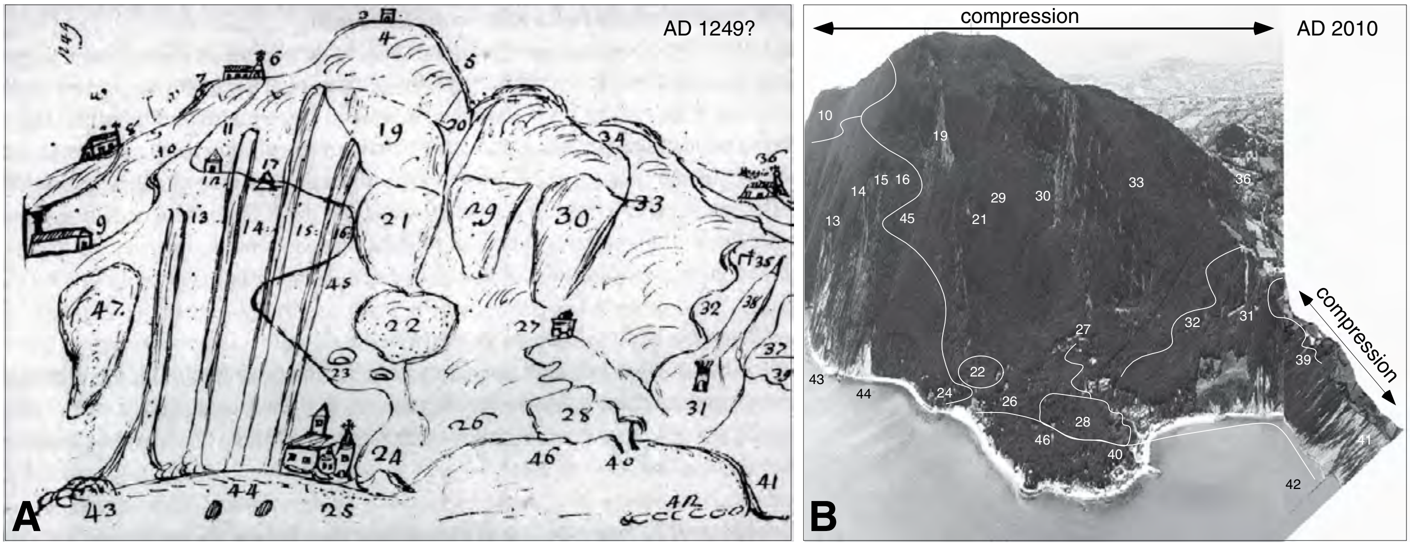

Figure 11. (A) Photograph of a map of the northeastern side of Monte Conero as seen from the sea, redrawn by Monsignor Giuliano Saracini in 1640 from an old parchment (Saracini, 1675; unknown size; courtesy of Aldo Roscioni). The numbered toponyms are literally translated in English from the legend transcribed by Piazzini and Stacchiotti (1989): (1) and (2) are missing in both legend and map; (3) *Tower on top of the Mountain for the guard of the vessels in the sea*; (4 and 5) *Inaccessible cliff in front of the tower*; (6) *Church of Saint Peter of the Camaldolesi friars*; (7) *their Hermitage with many convent cells in the woods*; (8) *Chapel of Saint John Baptist in the woods*; (9) *Church of Saint Benedict with house above a crag*; (10) *Steep route to go there*; (11) *Precipitous route that goes to the other side*; (12) *Little chapel of Saint Joseph hosting a hermit*; (13) *Gully called Sassetto*; (14) *Precipitous red gully*; (15) *Saint John gully*; (16) *White Gully*; (17) *Little chapel of Saint John*; (18) *Little chapel of Saint Paul below a crag for a hermit*; (19) *Terrible stony crag*; (20) *Ciriesa valley over the hump of Low Mountain*; (21) *Ravine of Chiarone*; (22) *Big lake called Profondo*; (23) *Furnace to cook stones* [to make lime]; (24) *Saint Mary of Portonovo with the big Monastery*; (25) *Wall ruins of said Monastery fallen in the sea*; (26) *stony hills with bushes difficult to walk through*; (27) *Fountain with a big Water Head which falls from above*; (28) *Lake called Pond of sweet water with a perimeter of 2 miles* [open] *to the Sea*; (29) *Valley called Sanguineto*; (30) *Valley called San Bucheto*; (31) *Tower on a hill to Guard* [ship] *landings*; (32) *Nasty and steep little trail*; (33) *Big valley descending from above*; (34) *Burrow of the Fox*; (35) *Little chapel called the Figurine* [i.e., tabernacle]; (36) *The Castle of Poggio*; (37) *Tavern*; (38) *Public ditch*; (39) *Public route where you can go on a horse*; (40) *Mouth of the Lake with Palisades*; (41) *Cliffs facing east*; (42) *Long rocky reefs at water surface called il Trave* [the beam]; (43) *Sea stacks at the foot of said Gully* [n. 13]; (44) *Tall, pointy rock in the sea …* [today a tall sea stack there is called La Vela, translation: the sail]; (45) *Very difficult road coming from Saint Peter down to the Madonna of Portonovo*; (46) *Shoal that the sea makes called Calcagno*; (47) *Shady valley of dry stumps and stones*. (B) Panoramic view of Monte Conero from the sea, the same as in Figure 1B, but distorted by "compression" to be compared with the landscape map of Saracini (1675).

compared with a present-day image of Monte Conero as seen from the sea (Fig. 11B), opportunely deformed following "compression," a drawing technique commonly used by medieval cartographers and landscape artists (e.g., Piero della Francesca and Leonardo da Vinci; see Borchia and Nesci, 2012). For example, the "*Precipitous red gully*" of n. 14 in Figure 11A refers to a steep ravine through Paleocene Scaglia Rossa pink limestones, or n. 16 "*White gully*" refers to the whitish limestones of the Cretaceous Scaglia Rossa, while n. 19 "*Terrible stony crag*" refers to the Cretaceous Scaglia Rossa cliffs making up the detachment scar of the La Vela landslide and the homonym sea stack (n. 44), and n. 21 "*Ravine of Chiarone*" refers to the steep, ephemeral creek on white rocks (*chiaro*, translation: clear), which feeds the n. 22 "*Big lake called Profondo*" and also n. 27 "*Fountain with a big water head falling from above*," which is still present today, although almost dry, near the Hotel La Fonte (see Fig. 2A for location). However, what is resoundingly missing in this map is the land lobe, which makes up the present-day bay of Portonovo. The coastline runs essentially straight along the Portonovo littoral zone, from n. 26 all the way to the beach below n. 31 "*Tower on a hill to Guard* [ship] *landings*" (no longer existing). In the place of the land lobe, the old map shows a n. 28 "*Lake called Pond of sweet water with a perimeter of 2 miles* [open] *to the sea*" by way of n. 40 *"Mouth of the lake with palisades*." Today, there is a vestige of this rather large, previously existing coastal lake—a small, shallow pool of brackish water still called Lo Stagno (which means the pond), located at the northwestern edge of the landslide body (see Fig. 2B for location). However, the detailed description of such a large, no-longer-existing freshwater lake with palisades is inconsistent with the map redrawn by Monsignor Saracini in 1640 (Piazzini and Stacchiotti, 1989). A lake with a perimeter of 2 miles (3.2 km) would cover the whole area of the Portonovo lobe, from Lo Stagno to Lago Profondo, whereas the two brackish water pools are distinctly reported in Saracini's map in their present-day locations, and with their present-day shapes: a roundish shape for Lago Profondo and a more irregular, rectangular shape for Lo Stagno, separated by an area n. 26 described as "*stony hills with bushes difficult to walk through*." This description reflects the hummocky terrain present today in that area, which is made up of compressional ridges and cumuli of the landslide's body breccia. This suggests that in 1640, Monsignor Saracini corrected the old, original parchment map (i.e., made an apostille of it), adding or changing features that were known to exist at that time.

Our interpretation is that the large freshwater coastal lake that opened to the sea via a mouth protected by palisades was a nautical camber, i.e., a small new port (in fact Novo Porto; see following), which was destroyed sometime in the Middle Ages (possibly after A.D. 1249), buried under the huge, catastrophic landslide, which suddenly came down from the Scaglia Rossa limestone crags protruding from the edge of Belvedere di Piangrande (see Fig. 1B for location), and bound by no-longer-existing n. 29 "*Valley called Sanguineto*" and n. 30 "*Valley called San Bucheto*." This interpretation inspires the hypothesis that the brackish water pond called Lago Profondo, located near the Santa Maria abbey, may represent the vestige of the eastern termination of the large coastal lake, which would have originally formed in a NW-SE–elongated topographic depression formed over a relatively soft Scaglia Cinerea marlstone (i.e., the colluvial clay deposit found below the landslide breccia in core PPT-S1 described earlier).

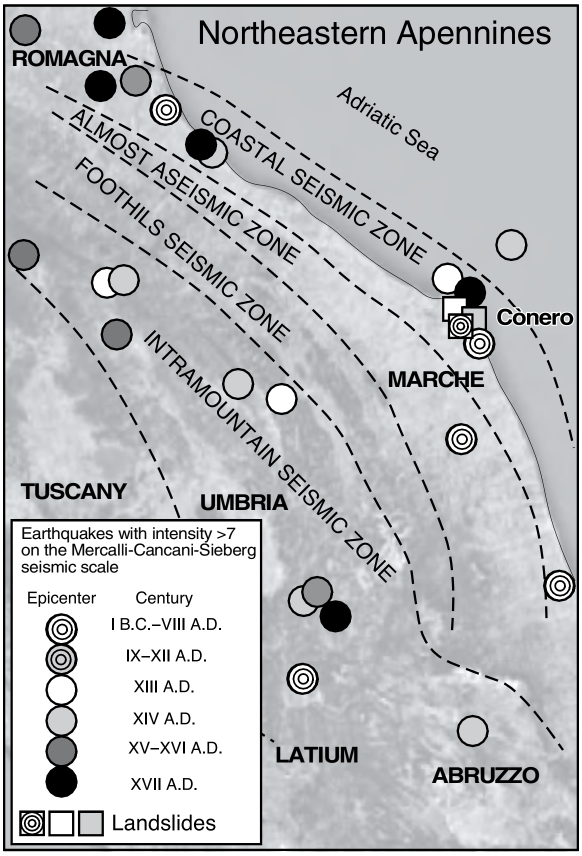

Figure 12. Simplified seismic zonation of the Umbria-Marche (U-M) Apennines (after Lavecchia et al., 1994) and locations of strong historical seismic events and landslides from the first century B.C. to the seventeenth century A.D., as documented in Table 2. MCS—Mercalli–Cancani–Sieberg.

Little Big History of Portonovo

The exact date of the Portonovo catastrophic landslide remains somewhat vague. Radiocarbon geochronology indicates a post–ninth century Middle Ages time, whereas the elusive map of Saracini (1675) suggests that the landslide may have occurred after A.D. 1249., and yet one may think that a huge event like this should have been recorded in some historical document such an ecclesiastic or a civil chronicle. After all, important towns such as Numana, Camerano, Castelfidardo, Osimo, or Ancona had been thriving since Picenian times, long before the Marche region fell under the control of the Romans in the third century B.C. Portonovo itself had been occupied by a Benedictine enclave since A.D. 1034, when the abbey of Santa Maria was constructed (e.g., Natalucci, 1965, 1967; Piva, 2012). Therefore, we tried to retrace the history of Portonovo in the light of the written documentation of strong earthquakes that affected the Umbria-Marche region since the first century B.C. (Rovida et al., 2011; see Fig. 12), presuming that such a large landslide may have been triggered by an earthquake, and we cross-checked that historical record with the main human and/or natural events that punctuated the history of Portonovo (Table 2). However, we have to point out that the Latin term *terrae motus* is not ubiquitously translated to "*motion of the earth*" nor to "*earthquake*" (*terremoto* in Italian), but rather to a more generic "*land movement*," which may mean either a seismic jolt or a landslide (e.g., Stucchi, 1988b). The list of historical seismic events by Rovida et al. (2011) reported those that caused infrastructural damage and/or victims, as documented in one or more sources over a geographical area, and not of a single *terrae motus* event, which occurred in just one specific locality and which can be referred to as a *land movement*, and thus a landslide (see also Guidoboni et al., 2007). For instance, the *terrae motus* that broke in A.D. 56 (Table 2) and destroyed the great Roman temple of *Potentia* (Percossi Serenelli, 2001), located 3 km north from the mouth of the Potenza River (14 km south of Portonovo), was definitively an earthquake, and not a landslide, which in any case would not occur on a flat coastal plain. On the other hand, the *terrae motus* of A.D. 558 (Enciclopedia Italiana, 1935), which devastated most of the city of Numana, sitting on the coastal cliffs 6 km SE of Portonovo (see Fig. 1A for location), was probably a localized landslide, and no seismic event is reported in any historical document in the region (Rovida et al., 2011; Guidoboni et al., 2007).

The actual written history of Portonovo started in A.D. 1034, when some donors, probably a certain Stefano di Germano, a feudatory noble man from the castle of Poggio, leased to the Benedictine abbot Paolo, a country estate of 35 *modioli* (i.e., land and lots) so he could build the church dedicated to the Blessed Virgin Mary "… *in novo Portu, subtus montem qui vocatur Conero*" (translation: "… in [the locality of] New Port at the foot of the mountain called Conero"; Piva, 2012; see also Provincia di Ancona, 2015, and Dubini, 2005, and references therein). This is a striking piece of historical information because the parchment cited by Piva (2012), apparently written by Anconetan notary Michele on July 7, 1034 (Provincia di Ancona, 2015), refers to the existence of a harbor, a new port, possibly the nautical camber with palisades open to the sea and consisting in a large freshwater coastal lake described by Saracini (1675) (see previous section). Yet, we think that this *Novo Porto* is to be considered a strategic harbor rather than a commercial port because, beside the fact that it was badly connected to the hinterland by a n. 45 "*Very difficult route coming from Saint Peter down to the Madonna of Portonovo*" and a n. 32 "*Nasty and steep little trail*" (Fig. 11A), it had a copious freshwater spring at a very short distance from the docking place (n. 27 in Fig. 11A), and fresh, uncontaminated water was essential for long-course cruisers. Moreover, there is the fact that Ancona was quite a busy port during the turbulent years between the end of the eleventh century and the late thirteenth century, not only by commercial freighters, but also by military cruisers. In fact, these are the years of the crusades, and Ancona was an important dock of departure, and return, for crusaders fighting against the Muslims in the Middle East. Saint Francis of Assisi, among others, in 1219 dur-

TABLE 2. SEISMIC HISTORY OF THE NE APENNINES FROM THE FIRST CENTURY B.C. TO THE SEVENTEENTH CENTURY A.D. AND HISTORICAL EVENTS AT PORTONOVO

Year	Locality	Event—intensity MCS	Source
100 B.C.	SE Marche Picenum	Seismic—I_{max} 8.5	Guidoboni et al. (2007)
99 B.C.	U-M Apennines Norcia	Seismic—I_{max} 9	Guidoboni et al. (2007)
76 B.C.	U-M Apennines Rieti	Seismic—I_{max} 10	Guidoboni et al. (2007)
63 B.C.	U-M Apennines Spoleto	Seismic—I_{max} 8	Guidoboni et al. (2007)
56 B.C.	Conero Riviera Potentia	Seismic—I_{max} 8.5	Guidoboni et al. (2007)
101 A.D.	Abruzzo Apennines S. Valentino	Seismic—I_{max} 9.5	Guidoboni et al. (2007)
558 A.D.	Conero Riviera Numana	Landslide	Enciclopedia Italiana (1935)
725 A.D.	Romagna coast Ravenna	Seismic—I_{max} 8.5	Guidoboni et al. (2007)
1034 A.D.	Portonovo S. Maria Abbey	Human	Piva (2012)
1209 A.D.	Abruzzo Apennines	Seismic—I_{max} 9	Guidoboni et al. (2007)
1249 A.D.?	Conero Riviera Portonovo	Prelandslide map	Saracini (1675)
1269 A.D.	Conero Riviera	Seismic—I_{max} 8	Guidoboni et al. (2007)
1270 A.D.	U-M Apennines Sansepolcro	Seismic—I_{max} 8	Guidoboni et al. (2007)
1279 A.D.	U-M Apennines	Seismic—I_{max} 9	Guidoboni et al. (2007)
1294 A.D.	Portonovo maximum prosperity	Human	Dubini (2005)
1298 A.D.	Conero Riviera Numana	Landslide	Bislani (2015)
1303 A.D.	Conero Riviera offshore	Seismic—I_{max} 9	Guidoboni et al. (2007)
1308 A.D.	Romagna coast Rimini	Seismic—I_{max} 7	Guidoboni et al. (2007)
1319 A.D.	Conero Riviera Portonovo	Landslide	Dubini (2005)
1320 A.D.	Portonovo evacuation	Human	Dubini (2005)
1328 A.D.	U-M Apennines Valnerina	Seismic—I_{max} 10	Guidoboni et al. (2007)
1352 A.D.	U-M Apennines Sansepolcro	Seismic—I_{max} 8.5	Guidoboni et al. (2007)
1389 A.D.	U-M Apennines Gubbio	Seismic—I_{max} 8.5	Guidoboni et al. (2007)
1458 A.D.	U-M Apennines Valtiberina	Seismic—I_{max} 8.5	Guidoboni et al. (2007)
1483 A.D.	SE Romagna	Seismic—I_{max} 8.5	Guidoboni et al. (2007)
1504 A.D.	NE Tuscany Bibbiena	Seismic—I_{max} 7	Guidoboni et al. (2007)
1509 A.D.	Romagna Faenza	Seismic—I_{max} 7	Guidoboni et al. (2007)
1559 A.D.	U-M Apennines Valtiberina	Seismic—I_{max} 8	Guidoboni et al. (2007)
1570 A.D.	Marche region	Climate change	Moroni (2012)
1570 A.D.	Northern Romagna	Seismic—I_{max} 8	Guidoboni et al. (2007)
1599 A.D.	U-M Apennines Valnerina	Seismic—I_{max} 9	Guidoboni et al. (2007)
1624 A.D.	Northern Romagna Argenta	Seismic—I_{max} 9	Guidoboni et al. (2007)
1631 A.D.	U-M Apennines Annifo	Seismic—I_{max} 7	Guidoboni et al. (2007)
1672 A.D.	Romagna coast Rimini	Seismic—I_{max} 8	Guidoboni et al. (2007)
1688 A.D.	Romagna	Seismic—I_{max} 9	Guidoboni et al. (2007)
1690 A.D.	Conero Riviera	Seismic—I_{max} 8.5	Guidoboni et al. (2007)
1720 A.D.	Portonovo Clementina tower	Human	Provincia di Ancona (2015)
1810 A.D.	Portonovo Napoleon Fort	Human	Provincia di Ancona (2015)

Note: U-M—Umbria-Marche; MCS—Mercalli–Cancani–Sieberg seismic scale.

ing the Fifth Crusade left from Ancona for his famous mission to meet and talk about peace with the Sultan al-Malik al-Kamil, nephew of Saladin, in Damietta (Egypt).

From the first century B.C. until the mid-thirteenth century A.D., the historical record of Rovida et al. (2011) lists a half a dozen strong earthquakes in the Umbria-Marche Apennines, and a few others in the adjacent regions of Abruzzo and Romagna, but then, with an earthquake epicentered in the Conero Riviera in September 1269, its seems that this region, particularly along the compressional tectonic front of the Apennine orogen (i.e., the seismic coastal zone of Lavecchia et al., 1994 *in* Fig. 12; see also Lavecchia et al., 2003, 2007; Vannoli et al., 2004; DISS Working Group, 2015), entered into a phase of strong seismic activity with the succession of eight important seismic events (Table 2).

The strong earthquake of September 1269 is the one best documented by historical reports in the CFTI catalogue of Guidoboni et al. (2007). The famous canonical historian Muratori (1726a) transcribed a report by Ricobaldus Ferrarensis, a notary from the Emilian city of Ferrara (1246–1318), that briefly mentioned a landslide that occurred at "*montem Anconae*," i.e., Monte Conero, and this is perhaps the only original historical reference of an important landslide possibly contemporary with the seismic event in the Conero Riviera around 1269. Moreover, Muratori (1726b) also transcribed a report by Francesco Pipino, a Dominican archivist from Bologna (ca. 1270–1328), very similar to the aforementioned report of Ricobaldus Ferrarensis but with the added detail that sea waves generated by the landslide of Monte Conero reached the coasts of Dalmatia, some 120–150 km to the east of the Conero Riviera across the Adriatic Sea. We think that this historical piece of information should be taken with a grain of salt, (1) because there is no original documentation of anomalous waves (tsunami?) that bashed the coasts of Dalmatia in September 1269, which are protected by the scarcely populated Kornati archipelago, and so it is not clear where and how Francesco Pipino got this information, and (2) because it is difficult to imagine how a landslide body some 10–15 m thick, with a surface of 240×10^3 m^2 making up the land lobe of Portonovo, of which about half has transgressed over the a 500 m stretch of coastline, and which would have displaced a small mass of shallow neritic water in the order of 2×10^6 m^3, could possibly generate waves big enough to be capable of traveling across the Adriatic Sea for 150 km all the way to Dalmatia (i.e., the Kornati islands) without dissipating down to normal and thus unnoticeable sea storm waves.

Bislani (2015 and references therein) reported, from historical documents of the City of Castelfidardo, that in 1298, Numana "… from a very acrimonious *terremoto* suddenly subsided and from the waters of the nearby sea miserably submerged …." This catastrophic event is not reported in the historical earthquake archive of Rovida et al. (2011; see also Guidoboni et al., 2007), and it likely refers to a big landslide, not an earthquake. In about the same period, the Benedictine enclave of Portonovo reached a peak of prosperity (Sella, 1950; Dubini, 2005), with a large inflow of tithes coming from various churches scattered in the territory of Monte Conero. According to Sella (1950), the abbey of Santa Maria in Portonovo in turn paid a tithe of 90 *libre*, 5 *soldi*, and 20 *denari* (apparently a large amount of money) to the Diocese of Ancona in the years 1290–1292, suggesting that up to that time, the abbey was still prosperous. However, in October 1319, the Portonovo Benedictines wrote to the bishop Nicolò degli Ungari begging the permission to be transferred in Ancona after a "…*terrae motum quasi quotidie et ultra solitum donantur*…; TR. … an almost daily and [one] unusual *terrae motum* happened to them" (as transcribed from an original parchment preserved in the Cathedral's Capitol Archive in Ancona by Barbara Dubini, personal communication on May 2015; see also Dubini, 2005). Again, no earthquake is reported with that date in the list of historical earthquakes of Rovida et al. (2011), and so this *terrae motum* may well refer to an *ultra solitum* (i.e., extraordinary) landslide. In fact, the parchment studied by Dubini (2005) also says that the Abbot Thomas and a few fellow monks were killed by that landslide. After a few months, on 17 January 1320, the abbey of Portonovo was abandoned definitively, and the monks transferred to the convent of Saint Martin in Ancona.

After the departure of the Benedictine monks, the abbey entered into a state of degradation and dilapidation, occasionally occupied, in the following centuries, by hermits, pilgrims, fishermen, pirates, and military. Portonovo became a French military presidium in 1810 during the Napoleonic Kingdom of Italy, when the fort was built to defend the bay and its precious freshwater spring from the frequent incursions of Barbary pirates, and the dilapidated church of Santa Maria was utilized as a "Santa Barbara," an ammunition depot. Finally, the Benedictine abbey was reclaimed and restored in 1894 by architect Giuseppe Sacconi, official superintendent of the monuments of the Marche region (Provincia di Ancona, 2015).

The historical documentation we briefly cited here leads to the cautious conclusion that the Portonovo landslide may have occurred between 1292 (maximum documented prosperity of the abbey) and 1319, when the Benedictines forwarded their plea to quickly abandon the place devastated by a large landslide, but no more explicit date of the catastrophe seems to be reported in historical literature. However, the possibility that the huge landslide came down after the panicky Benedictines left such a dangerous place in 1320 cannot be excluded a priori. In an article on historical landscape and environmental crises of the Marche region, Moroni (2012, and references therein) reported that starting in 1570, climate changes attributed to the so-called "Little Ice Age" caused a significant increase of catastrophic events such as floods and landslides throughout this territory. During this climatically critical period, a strong earthquake epicentered near Sirolo with an estimated maximum intensity (I_{max}) of 9 on the Mercalli-Cancani-Sieberg (MCS) seismic scale, broke in 1690, causing some damage to buildings in Ancona (Rovida et al., 2011). However, although such a strong earthquake is likely to have triggered landslides along the precarious cliffs of the Conero Riviera, there is no historical source revealing huge coseismic landslides in the Portonovo area. In summary, we could not find any historical recording of the great landslide of Portonovo in post-Renaissance times prior to 1716, when the Clementina tower was constructed on top of the landslide deposit. So the most plausible hypothesis is that the Portonovo landslide occurred in the year(s) immediately before the quick evacuation of the Benedictines from the Santa Maria abbey in January 1320. This event did not necessarily occur in direct coincidence with a major earthquake, but possibly at a time when the large mass of fractured Scaglia Rossa limestone protruding from the edge of Belvedere di Piangrande, and sitting on top of the rheologically weak Marne a Fucoidi Formation, gave way suddenly after being weakened by a long sequence of seismic jolts, and having surpassed the yielding point of internal cohesion.

DISCUSSION AND CONCLUSIONS: PRESENT LANDSLIDE RISK AT PORTONOVO

The danger of landsliding along the Conero Riviera was technically evaluated by Angeli (1999), but the question remains of whether or not a catastrophic landslide like Portonovo may happen again in the nearest future. From our study, it emerges that three main geologic factors predisposed the eastern slope of Monte Conero to give away and crash down on medieval Novo Porto, regardless of whether or not the trigger of the collapse was a seismic event or particular meteorological conditions, or a combination of the two. The first factor is the presence of an important NW-SE–striking fault, which runs exactly at the base of the collapsed cliff (see Figs. 1A and 2A–2C), in the proximity of the hinge of the almost recumbent Monte Conero blind thrust-anticline (Vannoli et al., 2004). This structure may be a seismically active fault and may cause opening of fractures during local strong seismic events, which are well recorded in the historical catalogue and in the numerous instrumentally documented seismic sequences that have affected the Ancona area in the past century or so, including the long sequence in the year 1972 mentioned earlier herein (Stucchi, 1988a). Frequent earthquakes along this seismic zone would increase fracturing in the hanging wall, thus enhancing the permeability and influencing the water level along the potential sliding surface. The second factor is the micro- and mesostructure of brittle Scaglia Rossa limestones making up the rock body of the hanging wall, which are characterized by thin bedding crisscrossed by dense systems of conjugate extensional joints and pressure-solution cleavage (Díaz General et al., 2015). Finally, the third factor is that the Scaglia Rossa succession rests on top of the rheologically weak and incompetent Marne a Fucoidi Formation, practically a frail, unsteady foot holding up all that rickety body of rock. Such a structural situation still exists on the precarious cliffs above the Due Sorelle beach, which, in fact, bears the geomorphologic evidences of an ancient large landslide (Angeli, 1999; see also Fig. 6 *in* Aringoli et al., 2014). The Scaglia Rossa limestones plunging into the sea above the La Vela sea stack bear these structural predispositions, but the foot of that slope is still fairly intact, although small rock falls happen frequently in this site. The problem, as we see it, remains at Portonovo.

The western side of the cirque-shaped landslide scar is, in fact, made up of strongly fractured Scaglia Rossa limestones exposed on a 150-m-high cliff, gently dipping downslope (Fig. 5). The upper part of this unstable mass of rock, which gravitates on the weak Marne a Fucoidi horizon and threatens the Hotel Internazionale right at the foot of the cliff (Fig. 2A), has been in part harnessed by the City of Ancona (Stefano Cardellini, February 2015, personal commun.), but it seems to us that this geotechnical intervention is nothing more than a palliative. It is predictable that the whole mass of rock, which can be estimated in the order of 10^5 m^3 (the size of the San Lazzaro landslide mentioned earlier; Savelli, 2004), may break loose at any time, possibly triggered by an earthquake (quite frequent in the Conero area) with the complicity of climate change. In fact, the Marne a Fucoidi constitutes an impermeable seal upon which an aquifer forms (consider the old spring near the Hotel La Fonte in Figures 2A and 11A-B), and excess meteoric water may further imbrue this clay-rich, incompetent formation, rendering it even weaker than it normally is.

In conclusion, our interdisciplinary study of the Portonovo landslide has put us in the uncomfortable position of appearing as a Cassandra, inevitably causing alarmism when we depict the western side of the Belvedere rim as a Damocles' sword threatening the popular Portonovo resort, and yet this study, even though it concentrates on one historical event of limited extent, could serve to raise the attention regarding the general problem of prevention of natural disasters, which civil communities anywhere else around the world should take into serious consideration in the light of hydrogeological instability of their densely populated territories, now more than ever aggravated by climate change. Our recommendation for the Portonovo situation, which can be transmitted to local authorities worldwide for their specific territorial situations, is that the Ancona municipality should promote and actuate a prevention plan to avoid a possible disaster by performing a detailed geological survey of the western Belvedere cliff, and derive quantitative modeling of the volume and kinematics of the feared future landslide. This would permit the local authorities to intervene with a preventive evacuation of the area, and relocation of the endangered infrastructure.

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