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Palaeogeographical evolution of the Egadi Islands (western Sicily, Italy). Implications for late Pleistocene and early Holocene sea crossings by humans and other mammals in the western Mediterranean

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Abstract

The continental shelf morphology offshore of western Sicily suggests that during the Last Glacial Maximum (LGM, 20 ka cal BP), two of the Egadi Islands, Favignana and Levanzo, were connected to Sicily by a wide emerged plain, while Marettimo was only separated from the other islands by a narrow channel. We studied the relative sea-level variation from the LGM until today, focussing on two important time slices: the Mesolithic (9.5–13 ka cal BP) and the Neolithic (6.5–7.5 ka cal BP). In this research, we discuss a sea-level rise model by means of geomorphological, archaeological and geophysical observations and new radiocarbon dating of marine and terrestrial fossil fauna. The results enabled us to provide a detailed palaeogeographical reconstruction of the focal area from the LGM until they became isolated. The evidence that has emerged from this research, in particular the radiometric data, supports the hypothesis that seafaring in the western Mediterranean area may have started between the early Mesolithic and late Epigravettian (between 8.4 and 13.5 ka cal BP), although it probably became a well-established practice only during the Neolithic.

1 INTRODUCTION

The relative sea-level variation that occurred from the Middle Pleistocene to the Holocene strongly modified continental and island coastlines. Human colonisation and animal dispersals, especially of mammals unable to swim, are closely linked to the morphological variations of the coast and to the occurrence of, albeit temporary, favourable conditions for colonisation.

Since the latest Pleistocene, *Homo sapiens* has been able to settle over increasingly wide areas by developing navigation techniques over time, although sweepstake dispersal episodes may have occasionally occurred even earlier (see below). In natural conditions, all mammals can swim, even though swimming is neither easy nor natural for many terrestrial mammal species. These have been able to cross stretches of sea as a function of their specific characteristics (Fish, 1996; Mazza et al., 2013; Palombo, 2018). Elephants and deer, for example, are great colonisers, as they can swim for many kilometres, which has allowed them to reach many Mediterranean islands. Most felines, primates and artiodactyls (e.g., boar and cattle) are poor swimmers, so their dispersal implies the presence of some, even discontinuous, terrestrial connection between island and continental coasts. Perissodactyla are particularly poor swimmers, because their suboptimal swim ability prevents even horses from crossing narrow water barriers.

Well-dated evidence of past human presences and/or finds of large mammals with scarce or no swimming ability allows us to reconstruct the possible palaeogeography of coastal and island territories they may have inhabited as well as determine the time frame when favourable conditions for dispersal existed (Palombo, 2018). In regard to *Homo sapiens* presences in the west Mediterranean Sea Basin, currently available radiocarbon dating supports the hypothesis that the first voyaging at sea by *Homo sapiens* dates back to the Neolithic (Mannino et al., 2014; Papoulia, 2017). This is also corroborated by evidence derived from the circulation of obsidian, whose origins are located, in this area of the Mediterranean, only in islands.

Mammal dispersal and island faunal dynamics and evolution mainly depend instead on the palaeogeographical setting and, in turn, on sea-level changes, geodynamics and the action of vertical tectonic movements, all of which condition coast-to-coast distances from continents to islands, their variation through time and consequently, the potential colonisation of an island by terrestrial continental species (see discussion in Palombo, 2018). The filtering power of a sea barrier also depends on the deepness and morphology of the sea floor, which may affect sea currents, hampering a successful colonisation even of continental islands close to the mainland coast or, conversely, facilitating long oversea dispersal of selected species. The objective difficulty of disentangling factors conditioning dispersal events makes it sometimes challenging to find indisputable explanations for some intriguing findings in unexpected insular contexts.

Since the dispersal dynamics of Pleistocene humans and large mammals in small archipelagos has been rarely scrutinised, we focussed on the Egadi Islands, considering Sicily only briefly. Using a multidisciplinary approach, we provide for the first time a palaeogeographical reconstruction of the Egadi archipelago palaeography (Fig.1) in different time slices. Our goals are as follows:

1) to review the evidence of prehistoric settlements on the Egadi Islands and of sea crossings by anatomically modern humans (AMH) within the area;
2) to review what is known about geomorphological and vertical tectonic movements in the studied area considering that vertical tectonic movements could have heavily modified the coastal morphology;
3) to review existing data, particularly that which has been presented in difficult to access literature;
4) to check a geophysical model proposed for the post-LGM sea-level rise comparing with our new data (AMS radiocarbon dates of mammal fossils and human food remains);
5) to calculate the erosional rates and thickness of bottom sediments that may affect palaeogeographical reconstructions by analysing the submarine morphology and stratigraphic succession;
6) to produce maps of the palaeogeographic evolution of northwestern Sicily and the Egadi Islands from the LGM to about 8 ka cal BP; and, ultimately,
7) to support the hypothesis that navigation in the Egadi archipelago was one of the oldest AMH voyages in the western Mediterranean as documented by radiocarbon dates.

1.1 Island colonisation: The facts of the matter

The colonisation of islands by prehistoric humans, particularly the arrival on Flores (Indonesia) of the ancestors of the endemic dwarf human species *Homo floresiensis,* is one of the most intriguing and debated questions in palaeoanthropology and palaeogeography (Dennel et al., 2014.

The time and mode of the human colonisation of some Mediterranean islands also divides researchers. The alleged human colonisation of Crete during the Middle Pleistocene is, for instance, a matter of debate (Strasser et al. 2010, 2011; Ferentinos et al., 2012; Tourloukis and Karkanas, 2012; Runnels et al., 2014; Phoca-Cosmetatou and Rabett, 2014; Leppard, 2014; Papoulia, 2017), and the presence of early-Middle/Late Pleistocene human populations in Sicily and Sardinia is still unproved (Antonioli et al., 2016; Palombo et al., 2017a).

The sporadic dispersal of humans on the Mediterranean islands is generally thought to have occurred by the end of the Last Glacial Period (Cherry, 1981), while a colonisation by boat and the continued presence of AMH have been generally considered to be a Holocene phenomenon, starting at about 7–8 ka cal BP (Cherry 1981; Cherry and Leppard, 2015; Dawson, 2011, 2013).

In Sardinia, human presence has been claimed to go back to the Last Glacial Maximum (LGM) due to the hypothetical 21 ka cal BP age of a human phalange found at the Corbeddu cave (Sondaar et al., 1995), but this age is presently discussed. The rich fossil record of Porto Conte bay, however, contains no evidence of human occupation during the Late Pleistocene despite the favourable environmental conditions for humans in this region (Palombo et al., 2017a). This fact suggests that the presence of AMH in Sardinia during the LGM was at best sporadic. At that time, the distance between Corsica and the mainland was about 13 km, a stretch of sea that would have required the regular use of boats to be bridged by enough people to establish a viable population on the Corso-Sardinian massif. Compelling evidence of AMH is provided by AMH remains found in Sardinia at the Corbeddu cave (Nuoro, Sardinia; 8.75 ka cal BP; Sondaar et al., 1995) and S'Omu S'Orku (Sardara, Sardinia; 8.5 ka cal BP; Melis and Mussi, 2016). In Corsica, signs of human presence at around 8.5 ka cal BP have been found, for instance, in the Teppa di U Lupinu cave (Salotti et al., 2008).

In summary, the available data from the main western Mediterranean islands suggest a doubtful presence of AMH in Sardinia during the LGM. A more consistent presence is documented in the Corso-Sardinian massif since the Mesolithic (about 8.5 ka cal BP).

The earliest arrival of AMH in Sicily dates to the LGM, when a temporary bridge connected Sicily to Calabria, as evidenced by Antonioli et al. (2016), up to the Maltese islands (Furlani et al., 2013). Results provided by the integrated analysis of morphobathymetric and lithological data and relative sea-level change (both isostatic and tectonic) support the hypothesis that a continental land bridge lasted for at least 500 years between about 21.5 and 20 ka cal BP, if not longer considering the erosion by marine currents that have lowered the seafloor since the LGM. Accordingly, evidence from Sicily suggests that AMH did not colonise the island before the LGM despite being present in southern Italy from at least 43 ka cal BP (Benazzi et al., 2012). The datum constitutes the latest possible date for the arrival of AMH on the islets of the Egadi archipelago, an event that has been poorly investigated. Deconstructing the evolution of the Egadi archipelago from the Middle Pleistocene to the present time by means of integrating geological, marine geological, geomorphological, palaeontological and archaeological data may provide clues on the colonisation dynamics of the area from the LGM to the Neolithic. We extended the palaeogeographic reconstruction from the Middle Pleistocene to the present because tectonic movements in the islands have been documented before MIS 5.5, while clear evidence confirms an almost vertical tectonic stability from MIS 5.5.

2 An overview of the Egadi Islands

2.1 Geological and morphological setting

The Egadi archipelago includes three investigated islands: Favignana, Levanzo and Marettimo (Fig. 1). Favignana Island is the closest to Sicily, about 7 km from the mainland coast and about 13 km from Trapani. Levanzo and Marettimo are about 13 and 36 km respectively from Trapani (Fig.1). Favignana is characterised by two uplifted and gently seaward-sloping (5°–10°) shore platforms shaping the Lower Pleistocene deposits (Pepe et al., 2018). The morpho-sedimentary evolution of the shore platforms was strongly influenced by sea-level changes, which determined the subaerial exposure of the continental shelf during sea-level minima (Agnesi et al., 1993; Agate et al., 1996; Agate et al., 1998; Antonioli et al., 2001).

The geological setting of western Sicily's offshore area (Fig. 2) originated from the collision between the Sardinia-Corsica microplate and the northern edge of the African continental margin, which began in the early Miocene (Bellon et al., 1977; Dercourt et al., 1986), which produced an east-southeast–verging tectonic stack with a thickness of 10 km (Gasparo Morticelli et al., 2016; Sulli, 2000). The Egadi archipelago represents the emergent segment of the tectonic stack that links the Sicilian to the Tunisian fold-and-thrust belt. The archipelago are formed by carbonate and terrigenous Meso-Cenozoic deposits pertaining to different palaeogeographic domains, covered by unconformable Plio-Quaternary pelagites and clastics.

Upper Pleistocene (Tyrrhenian Stage, MIS 5.5) calcarenite and biorudite outcrops (Incandela, 1996; Abate et al., 1997) are widely distributed in the eastern sector of Favignana, filling a pull-apart basin, as well as in the northwestern sector of the island. These deposits appear locally in Levanzo and Marettimo. In the offshore area around Favignana Island, post-LGM deposits consist of medium-coarse organogenic sands deriving from calcareous algae, molluscs, Bryozoa, *Serpulidae* and Foraminifera (D'Angelo et al., 1996). The fine fraction (sand and silt) decreases moving along the continental slope, while the terrigenous fraction is very poor in the deepest areas. In this area, the sedimentation rate is low, and bottom currents are strong, which sweep away the sediments deposited on the seabed (Colantoni et al., 1993a, 1993b; Agate et al., 1998).

Three fault systems offset the Mesozoic-Cenozoic and Lower Pleistocene deposits. First, north-to-south strike-slip faults reactivate/displace Miocene thrusts in some locations (Nigro and Renda, 2000; Renda et al., 2000; Gueguen et al., 2002; Giunta et al., 2009). The other faults are high-angle strike-slip structures oriented approximately either west-northwest (right-lateral) or north-northeast (left-lateral). Locally, Upper Pleistocene and MIS 5.5 (the Tyrrhenian Stage) deposits are affected by extensional and/or transcurrent tectonics (Abate et al., 1995; Nigro et al., 2000; Tondi et al., 2012).

2.2 Vertical tectonic movements: Evidence from the Egadi archipelago

The Egadi Islands may be considered as a stable or slightly uplifted area from at least MIS 5.5 (125 ka cal BP) onwards (Hearty, 1986; Antonioli et al., 2001; Antonioli et al., 2018). This is indicated by some MIS 5.5 biostratigraphical markers found within coastal deposits (Hearty, 1986; Antonioli et al., 2001) and the altitude of the related fossil tidal notch measured in respect to the present tidal notch. On Favignana (Fig. 3a), many outcrops of polygenic conglomerates containing fossil shells of warm-water species (sensu Antonioli et al., 2018), including *Persistrombus latus* (previously *Strombus bubonius*; Fig. 3b), are present in the northeastern area of the island at an altitude between 0 and 4 m above sea level (a.s.l; Abate et al., 1995). On the Levanzo Island (Fig. 3c), deposits consisting of marine conglomerates containing *P. latus* and large pebbles (Agnesi et al., 1993) can be observed an altitude of 3–5 m a.s.l. (Fig. 3d). Some Tyrrhenian fossil beaches are present on the island of Marettimo (Fig. 3f) between 5 and 9 m a.s.l. (Malatesta, 1957). In particular, some tidal notches with *Lithophaga* holes (Fig. 3g) are visible at the same altitude as the beach deposits (Malatesta, 1957; Antonioli et al., 2002).

2.3 Prehistoric colonisation of the Egadi archipelago

AMH populations colonised the islets of the Egadi archipelago from Sicily, where the oldest sites holding evidence of a human presence are dated to the Upper Palaeolithic (Grotta dell'Acqua Fitusa; radiocarbonically dated back to 16.6 ka cal BP; Azzi et al., 1973; Fig. 1; Tables 1, 2, 3). Epigravettian hunter-gatherer groups quickly spread across north Sicily to the Grotta dell'Ucceria on Favignana by 15.8 ka cal BP (Lo Vetro and Martini 2012; Martini et al., 2012a).

Available radiocarbon dates indicate that Late Epigravettian hunter-gatherers were present in the nearby Grotta d'Oriente (Favignana) at least a couple of millennia later (13.9 ka cal BP; Martini et al., 2012b; Colonese et al., 2011, 2014) and inhabited caves during the Mesolithic until about 7.3 ka cal BP (Di Salvo et al., 2012; Mannino et al., 2015; Fig. 1; Tables 1, 2, 3).

On Levanzo, the first human presence was documented at Grotta Schiacciata (Fig. 1) in a period (13.7 ka cal BP) almost overlapping that of the earliest occupation (Late Epigravettian) of Grotta d'Oriente. Grotta Schiacciata (Fig. 1) was probably inhabited until around the end of the Mesolithic according to the stratigraphy and the radiometric age of a *Phorcus turbinatus* shell (8.35 ka cal BP; Mannino and Thomas, 2010; Table 1). According to the data available in the literature, Grotta del Genovese (Fig. 1) was first inhabited around the same time (13.2 ka cal BP), nearly until the end of the Mesolithic (Tables 1, 2 and 3).

The excavations at the cave sites on Levanzo provide some information about the main animal resources exploited by the Late Epigravettian and Mesolithic hunter-gatherers. On Levanzo, as in most of northwestern Sicily, *Cervus elaphus* was the main hunted species, followed by *Bos primigenius* and *Equus hydruntinus*. *Sus scrofa* became an increasingly important prey in the

Holocene, along with marine resources (Cassoli and Tagliacozzo, 1982). The social importance of these mammals for the hunter-gatherers of Levanzo and Sicily, however, may have been more than mere sources of subsistence, given that the rock art figures of *B. primigenius* (followed by those of *E. hydruntinus*) were actually the most represented on the walls of Grotta del Genovese (Tusa et al. 2013). The presence of species poorly skilled at swimming, particularly *E hydruntinus*, were considered by Graziosi (1962) as an indication of the presence of a land bridge at that time connecting the present-day islands of Levanzo and Favignana to Sicily. In the lowest layer of Grotta del Genovese, some valves of *Cerastoderma glaucum* and *Tapes decussatus* were recovered during the most recent excavations (along with *Ostrea* sp.). This find suggests that sandy and muddy shores in lagoonal environments were present within the home range of the Epigravettian Levanzo hunter-gatherers and likely were commonly exploited marine resources as they would contain gastropods from the intertidal zone (Mannino and Thomas, 2004, 2007, 2010; Colonese, 2012; Colonese et al., 2014; Mannino et al., 2012b, 2014;Tufano et al., 2012).

2.4 Palaeontological and archaeological evidence from the Egadi archipelago: A synthetic overview

Fossils of terrestrial vertebrates have mainly been reported from the latest Pleistocene/Early Holocene anthropogenic deposits in nearly all the Egadi Islands. The most common species are wild boar, sheep and large bovid (*Bos*), possibly introduced by human pioneering populations. Among the wild species, red deer (who are quite good swimmers) possibly reached the Egadi Islands by sea inlets, while the hemione-like horse *E. hydruntinus* passed through a terrestrial path.

The most interesting fossil-bearing caves are located at a similar altitude along the northwestern side of the Punta Faraglione Triassic palaeocliff (Fig. 1). The five partly connected caves are variously named in the literature: i.e., Grotta dell'Ucceria 1 and 2, Grotta delle Pecore/Grotta del Cervo (Mannino, 1990), and Grotta della Madonna/Grotta delle Stalattiti. The latter, herein named Grotta dell'Ucceria, consists of two caves connected by a tunnel-like passage (Fig. 5). A band of *Lithophaga lithophaga* holes and some remnants of palaeosoils (Mannino, 1990), containing terrestrial (*Helix*) and marine (e.g., *Patella ferruginea*) shells and fragments of large mammal bones (*Cervus*, *Bos*), are present on the cavity walls (Mannino, 1990, 2006). Dalla Rosa (1870), who first explored the Grotta dell'Ucciria in 1870, reported the presence of some remnants of a fossiliferous breccia in the first chamber, where he collected a few shells, lithic artefacts and some isolated teeth and bone fragments of large mammals (*Equus*, *Sus*, *Cervus*, *Ovis*), likely food refuse left by Upper Palaeolithic humans. Vaufrey (1929) also mentioned the Punta Faraglione caves. Malatesta (1957) explored and described these cavities, providing some additional stratigraphical data and reporting the presence of some mammal remains (*E. hydruntinus*, *C. elaphus* and *B. primigenius*), mollusc shells (including *P. ferruginea*) and lithic implements in the Grotta dell'Ucceria. The author found the mammal remains in the same breccia already mentioned by Dalla Rosa (1870), still present on the eastern wall of the first chamber, on the ceiling at the end of the cave and as a residual block on the floor. The breccia overlays a thin layer of fine yellow sands, possibly of aeolian origin and is capped by a flowstone covering *L. lithophaga* holes present on the walls up to about 35 m a.s.l.

In the late 1980s, a Sapienza University of Rome (Italy) team made a survey at Punta Faraglione, exploring and taking samples from a cave they named Grotta delle Stalattiti/Grotta delle Pecore (Capasso Barbato et al., 1988, in agreement with the description and summary stratigraphical data provided by Capasso Barbato et al. (1988; e.g., the presence in the outermost chamber of a brown-reddish clayey layer, sandy-arenaceous, fossiliferous rock reworked from the remnants of the same sediment present on the cavity walls and grey-yellow sandy deposits in the first and second chambers; Fig.5). The Sapienza team collected a basal portion of a deer antler and a few elephant remains (cf. Palombo et al., in prep.) from the grey-yellow sandy-clayey layer of the second chamber and a few faunal remains in the reworked sandy sediment covering the first chamber floor (small [*Lepus* sp. and *Erinaceus europeus*] and larger mammals [*S. scrofa, Ovis* sp. and a middle-sized deer]). The authors claimed that the deer remains could belong to the endemic species *Megaceros* cf. *carburangelensis* (recte *Dama carburangelensis*), recorded in Sicily in sites belonging to the *Elephas* (recte *Palaeoloxodon) mnaidriensis* and San Teodoro/Pianetti faunal complexes (Masini et al., 2008; Palombo, 2018). The identification of the cervid is, however, based solely on a few phalanges and, therefore, its alleged presence on Favignana has to be considered with great caution. Capasso Barbato et al. (1988) considered the large mammal remains as food refuse of prehistoric hunter-gatherers, but a preliminary taphonomical analysis did not provide evidence of any anthropogenic signature on these bones.

3 METHODS

We undertook surveys on the Egadi Islands in order to carry out a geomorphological study of the coastal areas and to collect evidence from some caves in the form of anthropic food in order to obtain new radiocarbon dates. The surveys recovered nine samples: two in the Grotta dell'Ucceria on Favignana, four in the Grotta Schiacciata on Levanzo and three in the Grotta del Tuono on Marettimo (Fig. 1).

Position and elevation measurements were performed by a digital altimeter (Garmin Oregon 650) with a vertical accuracy of 50 cm, calibrated to the sea level along the nearby coast. Swath bathymetry data were acquired in the frame of the CARG, GEBEC and the MaGIC projects by using the Reson SeaBat 8111 and the Reson SeaBat 8160 Multi Beam. Data processing was performed by removing erroneous beams, noise filtering, processing navigation data and correcting for sound velocities. Different footprint resolutions depending on the depth, with a cell size of 10 m in the shelf and 20 m in the continental slope (mean resolution of 15 m), were used to obtain a digital terrain model (DTM). Bathymetric data derived from the digitalisation of the official nautical map ‘Isole Egadi’ (*Istituto Idrografico della Marina*) were used to integrate missing bathymetry data, as well as to establish a grid at 30 arc-second detail from the General Bathymetric Chart of the Ocean (GEBCO) database (http://www.gebco.net/data_and_products/gridded_bathymetry_data/).

High-resolution seismic data were recorded by using a 10 cubic inch water-gun with a shot interval of 6.125 m. Data were recorded with a single-channel streamer for 0.5 s two-way time at a 0.5 ms sampling rate. Seismic data were processed using the following operators: a) true amplitude recovery, b) time-variant gain c) a bandpass filter (200–700 Hz), d) swell filter, e) traces mixing, f) predictive deconvolution, g) time-varying gain and h) water column muting. The vertical resolution was up to 0.5 m in the near subsea floor. Following the analysis of acoustic facies, the thickness of the sediment and volcanic features were derived from time-to-depth conversion using velocities of 1,515 m/s, 1,700 m/s and 1,800 m/s for the water column and the pre- and post-LGM deposits, respectively. The obtained depth-converted section is displayed with a vertical exaggeration of 1:4 to better illustrate the stratal architecture and internal geometry of depositional units.

The palaeoshoreline reconstruction was obtained using Global Mapper 17 (www.globalmapper.com) and the Qgis software in order to produce maps at different levels of detail. The maps were suitable for highlighting the temporal evolution of palaeoshorelines and, therefore, the palaeomorphology of the land that connected the Egadi Islands to Sicily and the time of their detachment.

Selected fossils sampled in the caves of the Egadi Islands were radiocarbon dated at CEDAD (Centre for Applied Physics, Dating and Diagnostics) at the University of Salento in Lecce, Italy (Calcagnile et al., 2004). The samples underwent physical- and chemical-processing procedures aimed at extracting a suitable fraction of the sample, purifying the extracted material and converting it to graphite for the measurement of the radiocarbon age by the CEDAD AMS (accelerator mass spectrometry) system. Different chemical processing procedures were followed depending on the type of sample: bone collagen, shell carbonates and dental enamel.

For bone samples, the collagen fraction, extracted using the Longin method (Longin, 1971), was converted to carbon dioxide by combustion in sealed quartz tubes at 900°C, cryogenically purified and finally converted at 600°C to graphite by using hydrogen as a reducing agent and iron powder as a catalyst (D’Elia et al., 2004). Carbonate and enamel samples were crushed, sonicated in deionised water, attacked with H_2O_2 and then converted to carbon dioxide by acid hydrolysis with H_3PO_4. The extracted CO_2 was then converted to graphite, as already described for collagen.

The radiocarbon age of the samples was then calculated from the $^{14}C/^{12}C$ ratios measured with the AMS system after correcting for chemical and machine blanks and for isotopic fractionation by using the $\delta^{13}C$ term measured on line with the accelerator (Stuiver and Polach, 1977). Measurement uncertainty was conservatively calculated as the largest between the radiocarbon counting statistics and the scattering of the data from repeated measurements performed on each sample (Calcagnile et al., 2005).

Conventional radiocarbon ages were then calibrated in calendar ages by using the INTACAL13 and the MARINE13 curves for terrestrial and marine samples, respectively (Reimer et al., 2013). For the calibration of marine samples, a local reservoir correction factor $\Delta R = 45 \pm 21$ was taken as the average value for the Tyrrhenian Sea (Reimer and Mc Cormac, 2002).

4 NEW DATA

4.1 AMS radiocarbon dating

Nine specimens sampled from caves on Favignana (Grotta dell'Ucceria), Levanzo (Grotta Schiacciata) and Marettimo (Grotta del Tuono; Fig. 1) were AMS radiocarbon dated (Tables 1, 2 and 3). These finds were collected on brecciated deposits and on the present surface of the above-mentioned caves, so their dates simply provide us with a rough chronological estimation for possible times of occupation at these sites. AMH occupation has already been demonstrated in the case of Grotta della Ucceria (Lo Vetro and Martini 2012; Martini et al., 2012a) and Grotta Schiacciata (Mannino and Thomas, 2010). It is, thus, likely that the agents responsible for introducing the faunal specimens dated from these two sites were hunter-gatherers who consumed such animals. In the case of Grotta del Tuono, however, no excavations have taken place and no artefacts have been recovered during surveys for this study, which obtained a few faunal specimens instead. The presence of these cannot be attributed undisputedly to humans given the absence of anthropogenic taphonomic signatures, but the identical radiocarbon ages of marine and continental markers in the cave suggest an anthropic occupation of the cave. Nevertheless, during the late Pleistocene and early Holocene, AMH were most commonly responsible for the introduction of large terrestrial herbivores and marine molluscs to caves in Sicily and the Mediterranean in general. We decided to date a red deer tooth and a shell of the intertidal gastropod *Patella caerulea* to postulate possible times when prehistoric hunter-gatherers may have reached Marettimo as well as to gain useful data for understanding the historical biogeography of *C. elaphus*.

On Favignana, previously published radiometric ages had provided evidence for human presence on the island from at least around 15.8 (Grotta dell'Ucceria) to about 13.9 ka cal BP

(Grotta d'Oriente; Table 2). The analysis we performed on shells of *P. ferruginea* from Grotta dell'Ucceria yielded a range of 11.0–10.5 ka cal BP, which may indicate that the cave was inhabited at least until the end of the Younger Dryas, and therefore for a period of time longer than that previously attested by the 2005 excavations (Martini et al., 2012a).

On Levanzo, the radiometric ages (Table 1) obtained for the *P. ferruginea* shells (13.6–13.2 and 11.9–11.2 ka cal BP) and the terrestrial mammals (*B. primigenius* 9.1–8.7 and *E. hydruntinus* 7.4–7.0 ka cal BP) recovered from the brecciated deposits at Grotta Schiacciata roughly overlap with the chronological range (13.9–13.5 to 8.9–8.3 ka cal BP) already obtained by dating two *Phorcus turbinatus* specimens recovered by Bovio Marconi (1952; Mannino and Thomas, 2010), which extends a little further back in time than the range of *P. ferruginea*. Considering that both aurochs and the hemione-like horse were recovered from the late Mesolithic levels at Grotta Schiacciata (Mannino and Thomas, 2010; Table 1), the dates obtained for Grotta Schiacciata *B. primigenius* and *E. hydruntinus* have to be considered with caution.

Some interesting data come from the new studies we have performed at Marettimo. The AMS radiocarbon dates on the shell and red deer remains from Grotta del Tuono (Table 1) confirm the problems linked to dating dental enamel but also provide some hints for a working hypothesis on the possible chronology of a human presence on Marettimo.

The calibrated age range for the *P. ferruginea* (8.4–8.1 cal BP) falls in a time slice roughly contemporary to the so-called Mesolithic-Neolithic transition phase at Grotta dell'Uzzo (San Vito lo Capo, Trapani). The new radiocarbon dates obtained for Grotta del Tuono, including two from *C. elaphus* teeth belonging to the same mandible (Fig. 7d), differ by more than 4,000 calibrated years, with the dental enamel date (8.9–8.6 ka cal BP) being earlier than the collagen date (13.8–13.2 ka cal BP; Table 1).

Even on Levanzo, where Grotta dei Genovesi was also inhabited, if not continually, in the Neolithic as documented by the presence of fragments of Diana pottery fragments (Graziosi, 1962), the most recent radiocarbon date for Grotta dei Genovesi provides an age of 8.5–8.2 ka cal BP, coinciding with the Mesolithic-Neolithic transition phase at Grotta dell'Uzzo (Mannino et al., 2015).

Accordingly, it can be speculated that if the shells dated at Grotta del Tuono were actually collected by humans, they would represent evidence for human movement by boat across the channel. At that time, the continental part of the Egadi archipelago had separated from Marettimo.

4.2 Mammalian fauna

4.2.1 Favignana

The elephant (Fig. 4j) is undoubtedly the most intriguing fossil mammal found to date on this island. The calibrated age we have obtained (20.350–19.840 ka cal BP) makes it the youngest endemic *Palaeoloxodon* known to date in the western Mediterranean, opening a new window on the evolutionary dynamic of dwarf Sicilian elephants (Palombo et al., submitted)

4.2.2 Levanzo

The dates we obtained from the samples collected in the Levanzo caves provide useful clues for establishing the chronology of human occupation on the island (Tables 1, 2). The northwest part of Levanzo Island is of great interest due to the evidence of AMH occupation at Grotta del Genovese, a cave extensively studied by scientists, together with Grotta dei Capperi and Grotta Schiacciata, since the discovery of Palaeolithic parietal graffiti.

Grotta Schiacciata opens onto Cala Tramontana. It is a cavity about 10 m wide and 20–22 m long; the interior is large except for its posterior part (Fig. 6c), where a series of stalactites and thick sandstone layers make access difficult. The results of our morphological and stratigraphic investigations are summarised as follows. Chaotic deposits rich in marine shells (likely food refuse), angular clasts, fossil remains of large and small mammals (Fig. 6d, e, f, g, h) as well as flint artefacts, presumably Mesolithic in age, occur along the outer edges of the entrance. The morphology of this deposit and the fact that the cave is located at the top of a conoid fossil debris flow suggest that the remains were accumulated during a strong sediment flow event. The four shells and some mammal teeth we sampled yielded the following radiocarbon dates: 7.2 ka cal BP and 8.9 ka cal BP for the apatite of *E. hydruntinus* (Fig. 6i) and *B. primigenius* teeth (Fig. 6j), respectively, and 13.4 and 11.7 ka cal BP for two *P. ferruginea* shells (Fig. 6k; Table 2).

4.2.3 Marettimo

On Marettimo Island, many caves of various sizes have been shaped by wave action. The only samples of possible archaeological food remains were surface-collected at Grotta del Tuono. At this cave, we also sampled and studied a fossil deposit 30 m above sea level (northeast coast of Marettimo; Fig. 7a, b, c). This cave bears some morphological characteristics that make it unique throughout the Mediterranean.

The partially submerged cavity, located below the Castle of Punta Troia (Fig.7a), is about 45 m long and 35 m high. The cave bottom is located at about 7.5 meter below sea level (b.s.l.), and it drops quickly seaward to about 20 m. Starting from 25 m b.s.l., the carbonates are covered by sand and pebbles, although a flat corridor in the rock is present between 19 and 25 m b.s.l. In the cave, large pebbles rounded by the action of the sea are present on the floor and a terrestrial deposit is suspended at about 22 m a.s.l. (Fig. 7b) on the roof of a well-cemented continental breccia that filled the cave when the sea level was lower than today. This ledge can be reached today only using mountain-climbing techniques (Fig. 4b). The deposit (partially eroded) consists of scarcely cemented reddish coarse sands, containing a well-preserved mandible with some bones of a red deer (Fig 7d) and some *Patella caerulea* shells. The fossils protrude from the sand because the deposit overlaying the bottom of the cave was eroded by the sea.

4.3 Marine geological data

4.3.1 Geomorphological analysis of the offshore area

A morpho-bathymetric analysis highlighted a wide continental shelf, broken up with shoals and reefs (Fig. 8) and affected by the north-to-south–trending Marettimo canyon about 27 km offshore of Trapani, which separates the continental shelf into two sectors: (1) the islands of Favignana and Levanzo with the islets of Formica and Maraone on the eastern side connected to western Sicily and (2) the island of Marettimo on the isolated western sector (Figs. 1, 8). Between Favignana/Levanzo and western Sicily, depths are less than 40 m b.s.l.; the stretch of sea between Sicily and Favignana (Fig. 1) does not exceed 20 m in depth. The shelf edge is located at a depth of 120–150 m, while the continental slope reaches 1,000–1,100 m in depth. The Marettimo canyon reaches a maximum depth of -370 m, with sub-vertical flanks that diverge from south to north. The minimum width, corresponding to the minimum distance between the opposite shelf edges, is 1.8 km. This point coincides with the minimum depth of the channel, approximately at a depth of 180 m (Fig. 3). The canyon slopes are incised by various landslides, small channel heads and boulder deposits, which mark their present-day dismantling (Fig. 9).

4.3.2 Seismic stratigraphy

Seismic stratigraphic units were identified by their bounding discontinuities and are described on the basis of their stratal architecture and seismic characters (e.g., amplitude, lateral continuity and frequency of internal reflectors). Three seismic stratigraphic units were identified and labelled as U1, U2 and U3 from youngest to oldest (Fig. 10).

U1 is characterised by a succession of low- to medium-amplitude, discontinuous-to–locally continuous reflections, with a progradational internal configuration (Fig. 10b). This unit displays shelf facies, slope facies and basinal facies. One remarkable feature of the stratal terminations of U1 is the systematic basin and shelfward increase of individual seismic reflectors' amplitudes (Fig. 10b, c).

U2 is internally transparent or characterised by an outward-prograding sedimentary wedge with a variable amplitude, high-frequency and sigmoid progradational configuration of reflections and a partial lateral continuity downlapping on top of U1 (tU1 in Fig. 10b, c). U2 is wedge-shaped with a well-defined edge. The upper-bounding surface is upwardly convex and marked by a toplap termination of internal reflections, which becomes an erosional surface landward (ER1 in Fig. 10b).

U3 exhibits slightly seaward-dipping, well-defined, high-amplitude and laterally continuous reflections with parallel geometry. The top of U1 is defined by the seafloor (Fig. 10b, c). Based on its stratigraphic position, we associate U3 with the Upper Pleistocene-Holocene deposits formed during the transgressive and highstand stages of the last sea-level rise.

Feature SI exhibits a channel-filling seismic facies characterised by low-amplitude–to-chaotic reflectors with variable amplitude. This feature is limited both at its base and on top by erosional surfaces (ER2). The lower one truncates U1 deposits, while the uppermost part of the channel infills deposits.

4.3.3 Depositional architecture of seismic-stratigraphic units

The southwest continental shelf of Favignana Island, crossed by the seismic line Fav08 (Fig. 10), is characterised by a smooth and gently inclined seafloor (~0.5°) that becomes steeper along the upper slope (maximum value of 8°). Towards the southwest, a ~15 m deep, and ~1,800 m long moat aligned parallel to the regional bathymetric contours was also detected. Here the water depth reaches ~180 m at shot 3,750 and decreases again, moving southwestwards where it is ~164 m at the end of the profile.

The oldest seismic units recognised (U1) are progradational sequences bounded at the top by an erosional surface (ER1) and basinward by correlative conformities (Fig. 10b). These sequences correlate with outcropping Lower-Middle Pleistocene deposits on Favignana Island (Catalano et al., 1996; Incandela, 1996; Abate et al., 1997). U2 deposits appear as a ~1 km wide and ~50 m thick, shore-parallel, depositional body (Fig. 10b). When detectable, the internal reflector configuration of this body is progradational with a foreset slope of ~8°. Based on the stratigraphic position, we interpreted U2 as representative of the Lowstand Infralittoral Prograding Wedge (LIPW) formed during the sea-level lowstand associated with the LGM. The lower boundary of the LIPW is generally a landward, gently dipping (~1°) downlap surface (tU1). Southwestwards, the lateral continuity of the reflector tU1 is interrupted by an erosional surface (shot 3,200) and was traced again starting from shot 4,200 based on its stratigraphic position. This is a horizon of regional importance associated with the base of the LIPW, and thus can be dated to ~ 20 ka cal BP. Upper Pleistocene/Holocene deposits formed during the transgressive and highstand stages of the last sea-level rise (U3) exhibit an aggradational pattern. Their thickness varies slightly from ~8 m on the continental shelf to less than ~4 m in the upper slope and reach ~13 m at the end of the profile. On the whole, U2 and U3 pertain to the Late Quaternary depositional sequence corresponding to the last eustatic cycle.

4.4 Markers of sea-level change

The goal of this geomorphological research was to find some sea-level marker to calculate vertical tectonic movements and make precise paleoreconstructions. At Marettimo, 2 last interglacial tidal notches were measured at 8.10 ± 0.05 and 8.50 ± 0.25 m a.s.l. (Fig. 3e, g). Less continuous but well-carved tidal notches are present in Levanzo at between 8.5 and 9.5 m a.s.l. Both sets of notches were carved during MIS 5.5 based on the characteristics of fossiliferous deposits associated with this highstand (Antonioli et al., 2018). At Favignana, for instance, outcropping deposits containing *Persististrombus latus* (syn. *Strombus bubonius*) occur at Cala Monaci at 2–4 m a.s.l., while at Cala del Passo an analogous level present in a conglomerate facies rises up to 12 m a.s.l. (Figure 3b), showing small vertical movements of a few metres.

In regard to vertical tectonic movements that occurred before MIS 5.5, we observed such movements at Favignana. At Case Canino and at the western edge of the tunnel crossing the base of Monte Santa Caterina (Fig. 2b) between 36 and 40 m a.s.l., we found sandstone consisting of sandy layers with intercalated pebbles and well-cemented conglomerates about 2 m thick and containing marine fossils. The deposit, referred by Malatesta (1957) as ‘Tyrrhenian 1’ (corresponding to the late Middle Pleistocene), overlays Mesozoic dolomite layers. Also, we observed a very wide terrace/surface of about 20 km^2, slightly inclined towards the sea and separated by a steep slope from the MIS 5.5 terrace that extends along a flattened plateau at about 4–6 m a.s.l.

The presence of this terrace, directly overlaying the Mesozoic carbonates and irregularly distributed along the western plain of the island, indicates that originally it could have been much more extensive than today (Malatesta, 1957). Its remarkable geomorphological extension is inferable due to the presence of an inner margin at about 42 m a.s.l, detectable below an extensive detrital coverage near Case Canino, and of the *Lithophaga* holes at Grotta dell’Ucceria up to 39 m a.s.l., suggesting that the Canino terrace may also extend to this area.

4.5 Palaeogeographical reconstruction

The shoreline maps of the Egadi archipelago in this study were developed by considering it to be a quasi–tectonically stable area since MIS 5.5 and by constraining the post–20 ka cal BP sea-level change. In particular, 6 different time slices were considered (Fig. 11): a) the LGM (20 ka cal BP); b) the Late Glacial at 16 ka cal BP (the age of the earliest directly dated organic remains associated with the Upper Palaeolithic AMH occupation of the Egadi Islands at Grotta dell’Ucceria on Favignana, 13.5 ka cal BP; c) the oldest fossil food remains on the Egadi Islands at 13.5 ka cal BP; d) the beginning of the Holocene at 11.7 ka cal BP (which also coincides with the beginning of the Mesolithic); e) the middle of the Mesolithic at 9.85 ka cal BP; f) the beginning of the Neolithic, coinciding with the start of agro-pastoralism in northwestern Sicily at 8 ka cal BP (Mannino, 2014).

In order to assess the different water depths from 20 ka cal BP, we reconstructed progressive scenarios set during the above-mentioned time slices corresponding to different environmental and cultural changes. We took into account sea-level fluctuations, the sedimentation rate and the amount of eroded material in the frame of the evolutionary model of the Late Quaternary depositional sequence.

The main chronostratigraphic marker is represented by the unconformity formed during the LGM at the base of the lowstand and transgressive-highstand system tracts of the Late Quaternary depositional sequence (post–20 ka cal BP sediments; U2 and U3 in Fig. 10b). Correlating this unconformity from the shelf towards the canyon, we measured a thickness of 9.6 m above it, where the sea bottom appears not to be eroded, and we hypothesised the post–20 ka sequence to be continuous. We calculated a post–20 ka sedimentation rate of ~0.5 mm/yr, assuming the compaction of sediments as negligible. Taking into account the reference surface below the 20 ka unconformity, the thickness of sediments eroded above the canyon thalweg (corresponding to the present day maximum depth; Fig. 10c) was ~7 m. Accordingly, the physical prolongation of the 20 ka cal BP unconformity may be located at 174 m below sea level (b.s.l.), which represents our reference depth at 20 ka cal BP. In order to obtain the water depth at the different above-mentioned time slices, we took into account both the sediment thickness (calculated according to the post 20 ka cal BP sedimentation rate) and the sea-level position estimated on the basis of the glacio-isostatic model proposed by Lambeck (2011). As a result, for instance, the water depth calculated at 20 ka cal BP was ~45 m (Fig. 10d). This value was obtained by considering the present-day position at 174 m b.l.s. of the 20 ka cal BP unconformity and that at 20 ka cal BP the sea was 129 m below the present sea level (Lambeck et al., 2011).

Analysing high resolution DTM data and studying sea-level rise predictions (Lambeck et al., 2011) as defined for western Sicily allowed us to reconstruct the palaeogeography and palaeoshorelines corresponding to the time periods listed above. Based on our palaeogeographical reconstruction, the sea level was 129 m lower during the LGM (ca. 20 ka cal BP) than today (Fig. 11a). The island of Marettimo was separated from western Sicily by a narrow canyon. The distance at the minimum point between the two coastlines was about 1.8 km. Favignana and Levanzo were two hills connected to Sicily by a large flat expanse of land (Fig. 11a).

The oldest known archaeological deposits in the Egadi archipelago are those from Grotta dell’Ucceria on Favignana that date back to around 16 ka cal BP (Lo Vetro and Martini, 2012). We obtained a similar maximum age from a *P. ferruginea* specimen collected at Grotta Schiacciata on Levanzo, attesting that the two Egadi Islands connected to mainland Sicily were in all likelihood settled at the same time and not long after the earliest clear evidence for the occupation of Sicily

(Antonioli et al., 2016). At that time, according to Lambeck et al.'s model (2011), the sea level was 109 m lower than today, and Marettimo would have been separated from the coastline of Sicily by a strait of about 2.1 km (Fig. 11b). The oldest directly dated find from Marettimo is the red deer specimen that dates back to 13.5 ka cal BP, when the sea level was 84 m lower than today and the distance of the island from Sicily was about 6.8 km (Fig. 11c). At the beginning of the Mesolithic, which, as mentioned above, occurred around 11.7 ka cal BP, the sea level had risen up to -66 m. The minimum distance between Sicily and Marettimo coastlines was then about 9.1 km (Fig. 11d).

Evidence from this research and data available in the literature indicates that the middle of the Mesolithic was a key time for the human and mammal colonisation of the Egadi Islands. About 9.85 ka cal BP, the sea level was 43 m lower than today, and Favignana and Levanzo were still connected to Sicily (Fig. 11e), while the distance between Marettimo and the mainland was about 14.6 km. At the beginning of the Neolithic, the sea level was 18 m lower than the present-day level. Levanzo had become an island and was about 5 km from Favignana, while the distance between the Marettimo and Sicily coastlines was about 15.4 km.

According to our palaeographical reconstruction, Levanzo became an island around 9.20 ka cal BP, when the sea rose from -34 m to -33 m (Fig. 12a), while Favignana, Formica and Maraone were still connected to Sicily.

5 DISCUSSION

The palaeogeographical reconstructions may provide fresh clues for a better understanding the time and mode of AMH colonisation of the Egadi Islands as well as the dispersal of a few large mammals on this archipelago during the Pleistocene/Holocene transition. Any palaeogeographical reconstruction, however, depends on results obtained by geological studies (e.g., stratigraphy, marine geology, holocene sediment thickness and tectonic stability), but sound radiometric dates may provide crucial clues to disentangle the intriguing issue of AMH seafaring and settlement on the Egadi Islands.

Sometimes, however, results may be contradictory, as in the case of Grotta del Tuono, where the radiocarbon ages of two red deer teeth, obtained by means of different ^{14}C methods, differ: one (about 8.7 ka cal BP, Late Mesolithic) was close to that of *Patella* found in the same sandy level (8.3 cal BP), the other was definitely older (13.4 ka cal BP). It is rational to suppose that humans carried marine shells into the cave, but the same cannot be hypothesised for the deer due to the absence of any anthropological signature. If so, the *C. elaphus* skeleton from Grotta del Tuono was contemporary to the earliest dated Upper Palaeolithic deposits from Levanzo (Grotta di Cala del Genovese, Grotta Schiacciata). Accordingly, considering both the obtained ages, two different, but not necessarily alternative, scenarios can be hypothesised:

1) Given that the AMS radiocarbon dates obtained from the fossil of *C.elaphus* tooth and *Patella caerulea* are similar (about 8.7 and 8.3 ka cal BP respectively) (Table 1), a hypothetical Mesolithic-Neolithic (calibrated age: 8.9–8.6) transition age cannot be discounted.
2) Assuming the older age range to be accurate (about 13.4 ka cal BP), it would imply the *C. elaphus* was already present on Marettimo in the Late Glacial (Late Upper Palaeolithic), a period roughly contemporary to the earliest occupation of the caves on Levanzo, but the human presence cannot be demonstrated. At 13.4 ka cal, Marettimo was far from the mainland coast at about 7 km and 15.5 km at 8.7 ka cal BP. In both cases, red deer could have crossed the sea inlet by swimming, although reaching the island was likely easier for deer earlier, sometime after the LGM, when the island was separated from Sicily by a channel only a couple of kilometres wide. But the human food remains of *Patella caerulea* in the same layer suggest that the deer may have been hunted by AMH.

The interpretation of the archaeological record for the Egadi Islands in light of the palaeogeographical reconstructions generated in this paper allows us to propose some hypotheses on the time of and mode by which prehistoric humans entered the islands and when seafaring practices may have begun in the study area. Prehistoric archaeological evidence from Marettimo is extremely sparse and limited to a few flint and obsidian artefacts (Malatesta, 1957), which are poorly or not chronologically diagnostic. The date on the *P. caerulea* from Grotta del Tuono, however, postdates both the definitive isolation of Levanzo (9.25–9.0 ka cal BP) established here and the layer from Grotta d'Oriente in which two pieces of obsidian have been recovered (Lo Vetro and Martini, 2012; Martini et al., 2012b) in a Late Mesolithic context (Tab.1), radiocarbon dated between 9.0 and 8.5 ka cal BP

This, in turn, would be further confirmation that a seafaring practice in the southwestern Mediterranean area around the Mesolithic-Neolithic transition, a hypothesis fitting with the postulated pre-Neolithic visits of Pantelleria Island made to collect obsidian (Nicoletti, 2012).The evidence of seafaring around western Sicily in the Mesolithic is currently limited to a few pieces of obsidian, including those found at Perriere Sottano (eastern Sicily; Aranguren and Revedin, 1996). Compelling evidence for a human presence (albeit not necessarily continuous) is available both for Sardinia and Corsica at 8.5 ka cal BP (Mannino, 2014; Palombo et al., 2017a, 2017b). It is therefore rational to suppose that this may have been the time when hunter-gatherers regularly moved by boats across the central Mediterranean, even if they did not necessarily settle permanently on all the islands they visited, particularly on small isolated patches of land (Dawson 2014).

Evidence from Levanzo (e.g., Grotta di Punta Capperi, Grotta Schiacciata and Grotta del Genovese) indicates that after the island isolation (9.2–9.0 ka cal BP), different sites were regularly inhabited. Accordingly, the hunter-gatherer groups either occasionally or periodically reached the island or they constituted a permanently resident, but isolated, population. The hardships of isolation on a relatively small island was possibly more pronounced in the period when humans had not still fully developed the exploitation of marine resources (including the significant contribution of fishing to subsistence) that probably started in western Sicily during the Late Mesolithic (Cassoli and Tagliacozzo, 1982; Tagliacozzo, 1993; Mannino and Thomas, 2004, 2010; Mannino et al., 2015). Survival on small Mediterranean islands for hunter-gather groups would not have been easy due to their limited carrying capacity. This is possibly one of the reasons why small islands were not permanently settled anywhere in the Mediterranean before the development of an agro-pastoral economy during the Neolithic (Patton, 1996). It is worth noting, however, that the coexistence of AMH groups and wild herbivores on Levanzo during the final Epigravettian is supported by the well-known graffiti of the Genovese cave.

The signature of a marine transgression older than MIS 5.5 can be observed at Favignana but also on the northern coast of Sicily, in front of the Egadi archipelago. Stocchi et al. (2017) studied a stalactite sampled at an altitude of 100 m a.s.l. containing marine and continental layers and calculated a long-term linear uplift rate (during the Pleistocene) of 0.081 mm/yr. Applying these rates to the altitudes of the *Lithophaga* holes up to an altitude of 38 m a.s.l., it can be estimated that boring shells could be aged between MIS 11 and MIS 15. As a consequence, we can evaluate an uplift rate of less than 0.1 mm/yr of the Egadi Islands during the Middle Pleistocene. After 125 ka cal BP, the island must be considered tectonically stable.

The Marettimo channel represents an important geographic separation that isolated the two continental platforms. The first one constitutes an extension of Sicily westward, while the other isolated the Marettimo platform from Sicily during last lowstand. The canyon has a wavy edge that, at the nearest point, is only 1.8 km from the edge of the Sicilian platform.

The presence of landslide niches along the edge and the sub-vertical slopes of the canyon (Fig. 9) allows us to deduce failure processes along the canyon by the strong currents that characterise this portion. This evidence suggests there are still some active processes and allows us to hypothesise that in the past, the distance to the edge between the two platforms could have been less than 1.8 km.

6 CONCLUSION

In agreement with Antonioli et al. (2016), there was no AMH presence in Sicily (and consequently in the Egadi Islands) before the opening of the continental bridge with Italy (between

22 and 17 cal ka BP). On the basis of 1) the new data concerning the thickness of sediments on the continental shelf, 2) the vertical tectonic movements of the Egadi archipelago and 3) the new radiocarbon ages provided from mammal and AMH food remains, we have provided detailed maps showing the geographic variations of the Egadi archipelago from the LGM to the present using a precise DTM and the relative sea-level rise predictions published by Lambeck et al. (2011).

In particular, according to our reconstruction, Favignana Island separated from Sicily about 7.35 ka cal BP, and Levanzo separated about 9.2 ka cal BP. Conversely, Marettimo was not connected to Sicily during the LGM due to the presence of a deep channel about 1.8 km wide.

Levanzo and Favignana were connected to each other and to Sicily up to 9.25 ka cal BP; then, Levanzo separated and became an island. The connection of Levanzo and Favignana with the mainland is confirmed by the discovery of human remains dated to the Upper Palaeolithic (Late Epigravettian): 15.8 ka cal BP at Favignana and 13.4 ka cal BP at Levanzo (Table 1). Horses and men could have reached the island only by following a land path, as confirmed by the presence of the flat plain that today constitutes the continental shelf of Sicily. Moreover, the dates obtained for *B. primigenius* and *E. hydruntinus* (respectively 8.9 and 7.2 ka cal BP) suggest that these mammals survived on Levanzo about 1–2 ka after its separation from Sicily (9.25–9 ka cal BP).

In regard to Marettimo, the findings at Grotta del Tuono of food remains (*Patella*) together with *C. elaphus* suggest the presence of AMH on the island during the Mesolithic. Accordingly, the channel between Sicily or Favignana and Marettimo was crossed by boats between 8.9–8.6 ka cal BP (upper limit) and 13.7–13.2 ka cal BP (lower limit).

This study stresses the importance of a multidisciplinary approach to deconstruct complex issues by cross-referencing different data from apparently distant disciplines. It provides new data to update already suggested, but not demonstrated, hypotheses on the palaeogeographic setting, mammal dispersal and human colonisation in the Egadi archipelago. In particular, our results highlight that seafaring practices started in the Egadi archipelago (and probably in all of the Mediterranean Sea) between the Early Mesolithic (8.4 ka cal BP) and Late Epigravettian (13.5 ka cal BP), not in the Neolithic as previously supposed.

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Figures and tables captions:

Fig.1: Egadi Archipelago, geographical setting. 1) Grotta del Tuono, 2) Grotta di Punta Capperi, 3) Grotta Schiacciata, 4) Grotta del Genovese, 5) Grotte di Punta Faraglione, 6) Grotta d'Oriente, 7) Grotta dell'Uzzo, 8) Puntali cave, 9) Riparo del Castello, 10) Acqua Fitusa, 11) San Teodoro (Acquedolci), 12) Spinagallo and 13) Luparello cave.

Fig. 2: Geological sketch of the Egadi archipelago.

Fig. 3: MIS 5.5 highstand evidence on the Egadi archipelago: (a) Favignana, (b) MIS 5.5 deposit with *Persistrombus latus*, (c) Levanzo, (d) MIS 5.5 deposit with *Persistrombus latus*, (e) MIS 5.5 tidal notch, (f) Marettimo and (g) MIS 5.5 tidal notch.

Fig. 4: (a) Grotta dell'Ucceria (Favignana), (b) marine terrace that lies beneath the cave, (c, d) lithodomi holes at 39–40 m above sea level, (e, f) internal cave of Grotta dell'Ucciria, (g, h) chaotic deposit with fossil shells, (i) section of the excavation where the dwarf tooth was found (j) the dwarf elephant kept at the 'G.G. Gemmellaro' Geological Museum (Palermo, Italy).

Fig. 5: Summary sketch of the filled fossil sediments and geomorphological evolution of the caves of Ucceria (Punta Faraglione). (a) Aeolin sands sealing *Lithophaga* of Middle Pleistocene, (b) silty sands containing *Pulmonata* shells, (c) coarse sands and well-cemented breccias containing copious fossil meal remains (*P. ferruginea*, *Monodonta*, but also bones and teeth of large mammals) and (d) flowstone that seals the previous deposit.

Fig. 6: Levanzo, Grotta Schiacciata: (a) Cala Tramontana; (b) Grotta Schiacciata; (c) fossiliferous deposits located on the left and right side of the Grotta Schiacciata entrance; (d) inside of the cave; (e, f, g, h) chaotic fossiliferous deposits; and sampled mammal tooth and fossil remains of (i) *E. hydruntinus*, (j) *B. primigenius* and (k) *P. ferruginea*.

Fig. 7: The bathymetric profile (perpendicular to the entrance of the Grotta del Tuono) was made using a waterproof sonar and a GPS (Fig. 7e). The final interpretation (the altitude scale is 5 times

larger than the length) is that the deposit (still partially present today) was suspended, filled part of the cave and left a short fossil portion 25 m high inside the cave only after the marine ingression was removed. Through the naturally inclined plane (Fig. 7e), the hunter-sailors of Favignana had easy access to the cave where they ate meals. Marettimo does not have charcoal fossils or Epigravettian food remains (as in the Genovese cave) because Marettimo Island was always separated by a canyon during the LGM from the Favignana Levanzo Trapani block.

Fig. 8: Physiographic domains of northeast Sicily offshore sector: continental platform, continental slope and Marettimo canyon.

Fig. 9: Morphobathimetric data: Marettimo canyon, canyon shelf break, submerged landslide, landslide deposits and boulders deposits.

Fig. 10. Southwest-northeast high-resolution seismic reflection profile (a) across the Marettimo canyon. The geoseismic interpretation (b) shows the Lower-Middle Pleistocene progradational to aggradational sequence (U1), covered by the LIPW (U2) and the transgressive-highstand system tracts (U3) pertaining to the Upper Pleistocene depositional sequence. In the geological sketch (c), the present-day position of the canyon thalweg (*) points out. At this point, we reconstructed the progressive increase in water depth (d) until 20 ka cal BP, taking into account sea-level rise, sedimentation rate and erosional processes.

Fig. 11: Palaeoshoreline reconstruction of the Egadi and Sicily Islands from the LGM to the present day.

Fig. 12: Levanzo, Formica, Maraone and Favignana insulations.

Site	**Taxon**	**Analyte**	**Laboratory code**	**Radiocarbon date (BP)**	**δ^{13}C (‰)**	**Calendar age cal. BP (2σ)**	**Period (culture)**
Grotta della Ucceria (Favignana)	*Palaeoloxodon* sp.	dental enamel	LTL13870A	16650±80	-13.8±0.3	20350-19840	Upper Palaeolithic (Early Epigravettian)
Grotta della Ucceria (Favignana)	*Patella ferruginea*	shell	LTL14596A	9887±55	2.7±0.3	11000-10550	Mesolithic
Grotta Schiacciata (Levanzo)	*Equus hydruntinus*	dental enamel	LTL14592A	6282±60	-14.3±0.5	7410-7000	Neolithic
Grotta Schiacciata (Levanzo)	*Bos primigenius*	dental enamel	LTL15088A	8047±50	-21.6±0.4	9090-8720	Mesolithic
Grotta Schiacciata (Levanzo)	*Patella ferruginea*	shell	LTL14593A	10505±55	3.2±0.5	11880-11250	Upper Palaeolithic Mesolithic
Grotta Schiacciata (Levanzo)	*Patella ferruginea*	shell	LTL15089A	11996±75	7±0.4	13580-13190	Upper Palaeolithic (Late Epigravettian)
Grotta del Tuono (Marettimo)	*Patella caerulea*	shell	LTL14591A	7880±50	-6.9±0.6	8420-8120	Mesolithic-Neolithic Transition
Grotta del Tuono (Marettimo)	*Cervus elaphus*	dental enamel	LTL14590A*	7891±45	-18.3±0.4	8980-8580	Mesolithic
Grotta del Tuono (Marettimo)	*Cervus elaphus*	dentinal collagen	LTL15816A*	11617±150	-29.5±0.5	13760-13150	Upper Palaeolithic (Late Epigravettian)

Table 1. AMS radiocarbon dates undertaken for the present study at the Centro di Datazione e Diagnostica (CEDAD) laboratories in Lecce (Italy). The two radiocarbon dates indicated by the asterisk (i.e. LTL14590A and LTL5816A) have been undertaken on different tissues from the same individual. The radiocarbon dates have been calibrated with OxCal 4.3 (Bronk Ramsey and Lee 2013), using the IntCal13 calibration curve for terrestrial fauna and the Marine13 curve for the marine molluscs (Reimer et al. 2013). In the case of the latter, calibrated age ranges were corrected for the reservoir effect using the correction factor calculated for Sicily (ΔR = 71±50) by Siani et al.

(2000). The division in periods here and in the following tables is based on the chrono-sequence for Grotta dell'Uzzo (Mannino et al. 2015).

Site	Layer	Taxon	Analyte	Laboratory code	Radiocarbon date (BP)	Calend cal. B
Grotta d'Oriente (1972 excavation)[1]	B 40-60cm	*Phorcus turbinatus*	shell	OxA-15562	6955±36	7510-
Grotta d'Oriente (1972 excavation)[1,2]	B 100-114cm	*Phorcus turbinatus*	shell	OxA-14256	8159±37	8740-
Grotta d'Oriente (1972 excavation)[3]	Oriente X	*Homo sapiens*	bone	OxA-V-2364-37	8653±39	9690-
Grotta d'Oriente (1972 excavation)[3]	Oriente B	*Homo sapiens*	bone	KIA-36049	9275±45	10580-
Grotta d'Oriente (1972 excavation)[1,3]	Oriente B	*Homo sapiens*	bone	KIA-36050	9395±45	10730-
Grotta d'Oriente (1972 excavation)[3]	Oriente B	*Homo sapiens*	bone	KIA-36051	9440±40	10780-
Grotta d'Oriente (2005 excavation)[4-6]	5A	-	charcoal	LTL877A	7040±55	7970-
Grotta d'Oriente (2005 excavation)[4-6]	6B	-	charcoal	LTL876A	8619±65	9770-
Grotta d'Oriente (2005 excavation)[4-6]	6C	-	charcoal	LTL874A	8608±65	9740-
Grotta d'Oriente (2005 excavation)[4-6]	6D	-	charcoal	LTL875A	8699±60	9890-
Grotta d'Oriente (2005 excavation)[4-6]	7E	-	charcoal	LTL873A	12132±80	14200-
Grotta delle Uccerie[7-8]	4C	-	charcoal	LTL1516A	12958±90	15800-
Grotta delle Uccerie[7-8]	4D	-	charcoal	LTL1517A	13191±120	16210-
Grotta delle Uccerie[-8]	4E	-	charcoal	LTL1518A	12933±75	15740-

Table 2. AMS radiocarbon dates on materials from Upper Palaeolithic and Mesolithic sites on Favignana. The radiocarbon dates have been calibrated with OxCal 4.3 (Bronk Ramsey and Lee 2013), using the IntCal13 calibration curve for terrestrial fauna and the Marine13 curve for the marine molluscs (Reimer et al. 2013). In the case of the latter, calibrated age ranges were corrected for the reservoir effect using the correction factor calculated for Sicily ($\Delta R = 71\pm50$) by Siani et al. (2000). [1]Di Salvo et al. (2012); [2]Mannino and Thomas (2007); [3]Mannino et al. (2012a); [4]Martini et al. (2012b); [5]Colonese et al. (2011); [6]Colonese et al. (2014); [7]Martini et al. (2012a); [8]Lo Vetro and Martini (2012).

Site	Layer	Taxon	Analyte	Laboratory code	Radiocarbon date (BP)	Calendar age cal. BP (2σ)	Period (culture)
Grotta di Punta Capperi (2005 excavations)[1]	D su1 spit 2	*Phorcus turbinatus*	shell	OxA-16283	9835±45	10910-10500	Mesolithic
Grotta di Punta Capperi (2005 excavations)[1]	D su2 spit 4	*Phorcus turbinatus*	shell	OxA-16290	8570±45	9320-8960	Mesolithic
Grotta di Punta Capperi (1950s excavation)[1]	I spit 30	*Phorcus turbinatus*	shell	OxA-16291	8990±45	9790-9440	Mesolithic
Grotta Schiacciata (1950s excavation)[2]	IV spit 4	*Phorcus turbinatus*	shell	OxA-15559	8263±38	8940-8530	Mesolithic
Grotta Schiacciata (1950s excavation)[2]	IV spit 12	*Phorcus turbinatus*	shell	OxA-15561	12355±50	13940-13530	Upper Palaeolithic (late Epigravettian)
Grotta del Genovese (2005/06 excavations)	spit 4	*Phorcus turbinatus*	shell	OxA-15558	7999±39	8540-8250	Mesolithic-Neolithic Transition
Grotta del Genovese (2005/06 excavations)	spit 4	*Phorcus turbinatus*	shell	OxA-15560*	8003±37	8550-8270	Mesolithic-Neolithic Transition
Grotta del Genovese (2005/06 excavations)[3,4]	spit 6	*Phorcus turbinatus*	shell	OxA-14257	8166±37	8750-8400	Mesolithic
Grotta del Genovese (2005/06 excavations)[3,4]	spit 10	*Phorcus turbinatus*	shell	OxA-14258	10750±45	12410-11780	Upper Palaeolithic (late Epigravettian)
Grotta del Genovese (2005/06 excavations)[3,4]	spit 10	*Phorcus turbinatus*	shell	OxA-14352*	10750±45	12410-11780	Upper Palaeolithic (late Epigravettian)
Grotta del Genovese (2005/06 excavations)[3,4]	spit 12	*Phorcus turbinatus*	shell	OxA-14259	11200±45	12770-12530	Upper Palaeolithic (late Epigravettian)
Grotta del Genovese (1950 excavation)[5]	2m depth	*Patella ferruginea*	shell	Pi-119	9694±110	10810-10200	Mesolithic
Grotta del Genovese (1953 excavation)[6]	spit 5a lower	*Patella ferruginea*	shell	F-18	10175±300	12180-10340	Upper Palaeolithic (late Epigravettian)
Grotta del Genovese (1953 excavation)[6]	spit 6 lower	*Patella ferruginea*	shell	F-20	10110±300	12030-10250	Upper Palaeolithic (late Epigravettian)
Grotta del Genovese (1953 excavation)[6]	spit 6a lower	*Patella ferruginea*	shell	F-19	11710±295	13750-12590	Upper Palaeolithic (late Epigravettian)

Grotta del Genovese (1953 excavation)[7]	stratum 3	*Patella ferruginea*	shell	R-566	11180±120	12900-12270	Upper Palaeolithic (late Epigravettian)

Table 3. Radiocarbon dates on marine shells from Upper Palaeolithic and Mesolithic sites on Levanzo. *Ph. turbinatus* specimens were dated with the AMS radiocarbon dating, while aggregated samples of *P. ferruginea* were dated with conventional radiocarbon dating. The radiocarbon dates have been calibrated with OxCal 4.3 (Bronk Ramsey and Lee 2013), using the IntCal13 calibration curve for terrestrial fauna and the Marine13 curve for the marine molluscs (Reimer et al. 2013). In the case of the latter, calibrated age ranges were corrected for the reservoir effect using the correction factor calculated for Sicily (ΔR = 71±50) by Siani et al. (2000). [1]Mannino et al. (2012b); [2]Mannino and Thomas (2010); [3]Tufano et al. (2012); [4]Mannino and Thomas (2007); [5]Ferrara et al. (1968)

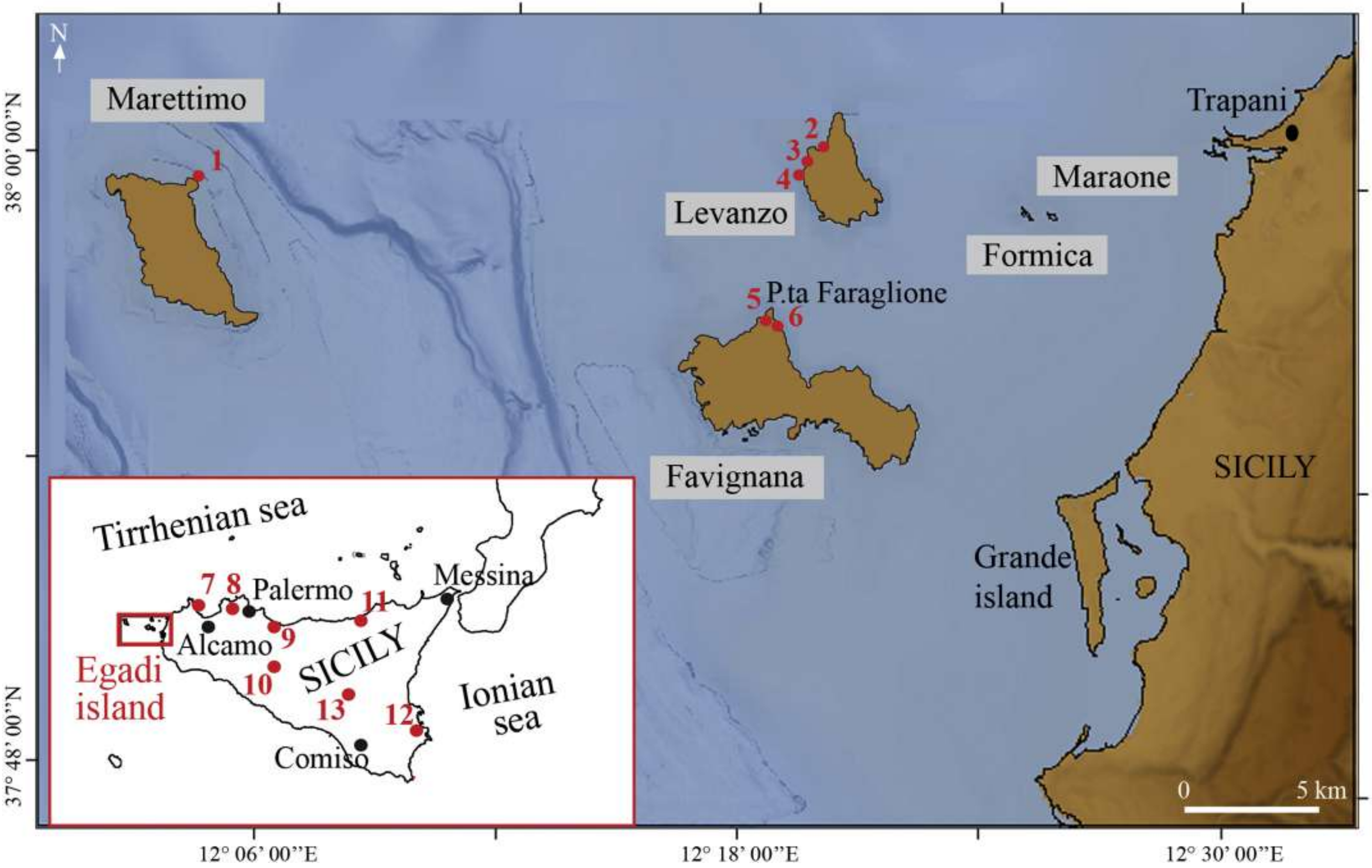
N
Marettimo
1
2
3
4
Levanzo
Trapani
Maraone
Formica
5
P.ta Faraglione
6
Favignana
SICILY
Grande
island
0
5 km
38° 00' 00''N
37° 48' 00''N
12° 06' 00''E
12° 18' 00''E
12° 30' 00''E
Tirrhenian sea
7
8
Palermo
11
Messina
Alcamo
9
SICILY
Egadi
island
10
13
12
Ionian
sea
Comiso

Figure 1

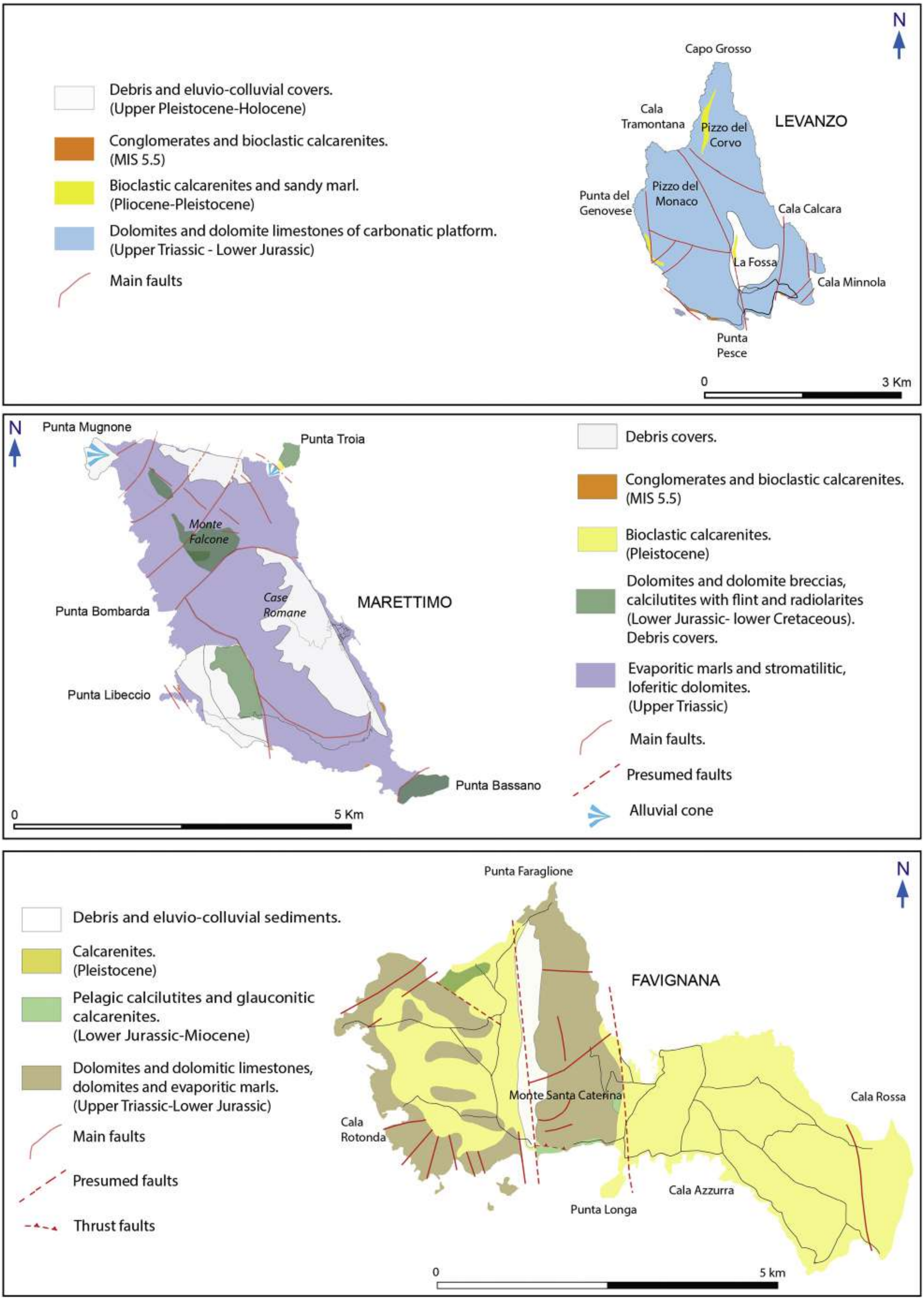
Debris and eluvio-colluvial covers. (Upper Pleistocene-Holocene)
Conglomerates and bioclastic calcarenites. (MIS 5.5)
Bioclastic calcarenites and sandy marl. (Pliocene-Pleistocene)
Dolomites and dolomite limestones of carbonatic platform. (Upper Triassic - Lower Jurassic)
Main faults
N
Capo Grosso
Cala Tramontana
Pizzo del Corvo
LEVANZO
Punta del Genovese
Pizzo del Monaco
Cala Calcara
La Fossa
Cala Minnola
Punta Pesce
0
3 Km
N
Punta Mugnone
Punta Troia
Monte Falcone
Punta Bombarda
Case Romane
MARETTIMO
Punta Libeccio
Punta Bassano
0
5 Km
Debris covers.
Conglomerates and bioclastic calcarenites. (MIS 5.5)
Bioclastic calcarenites. (Pleistocene)
Dolomites and dolomite breccias, calcilutites with flint and radiolarites (Lower Jurassic- lower Cretaceous). Debris covers.
Evaporitic marls and stromatilitic, loferitic dolomites. (Upper Triassic)
Main faults.
Presumed faults
Alluvial cone
Debris and eluvio-colluvial sediments.
Calcarenites. (Pleistocene)
Pelagic calcilutites and glauconitic calcarenites. (Lower Jurassic-Miocene)
Dolomites and dolomitic limestones, dolomites and evaporitic marls. (Upper Triassic-Lower Jurassic)
Main faults
Presumed faults
Thrust faults
Punta Faraglione
N
FAVIGNANA
Monte Santa Caterina
Cala Rotonda
Cala Rossa
Cala Azzurra
Punta Longa
0
5 km

Figure 2

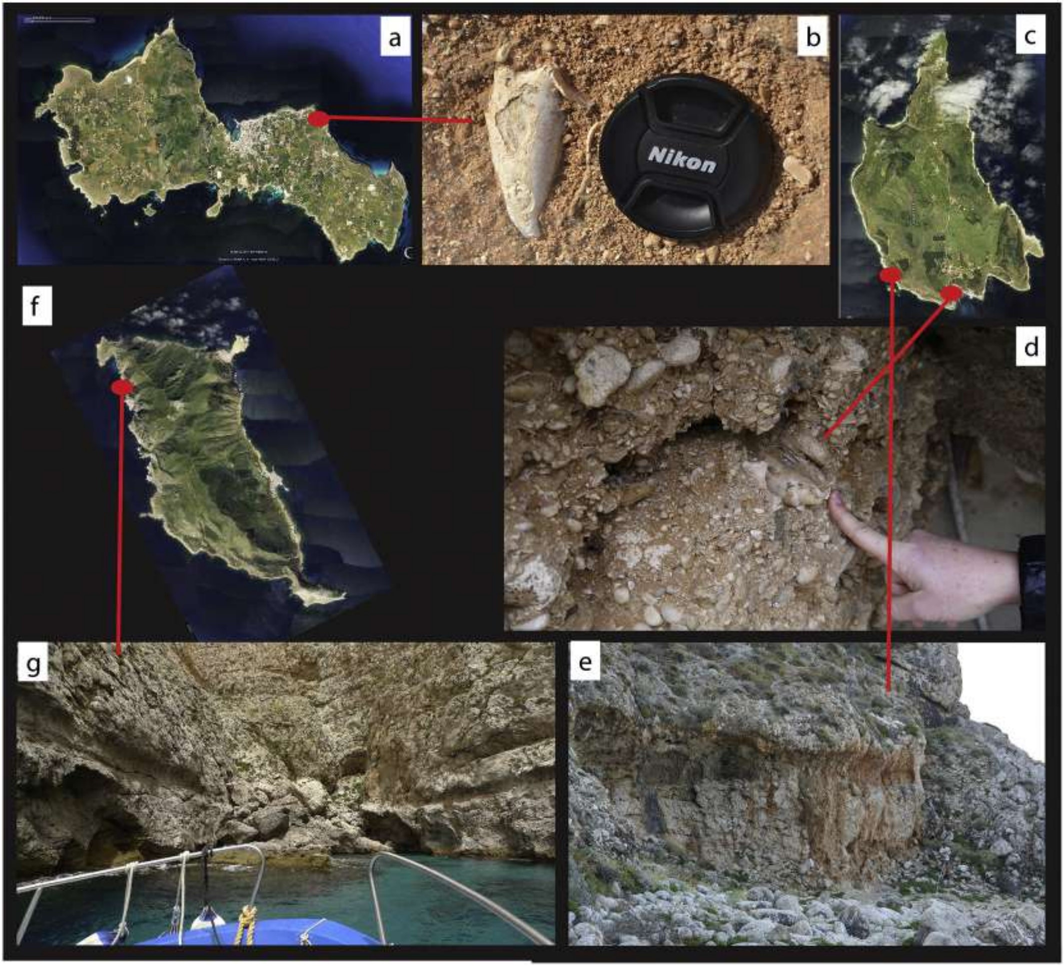

Figure 3

Figure 4

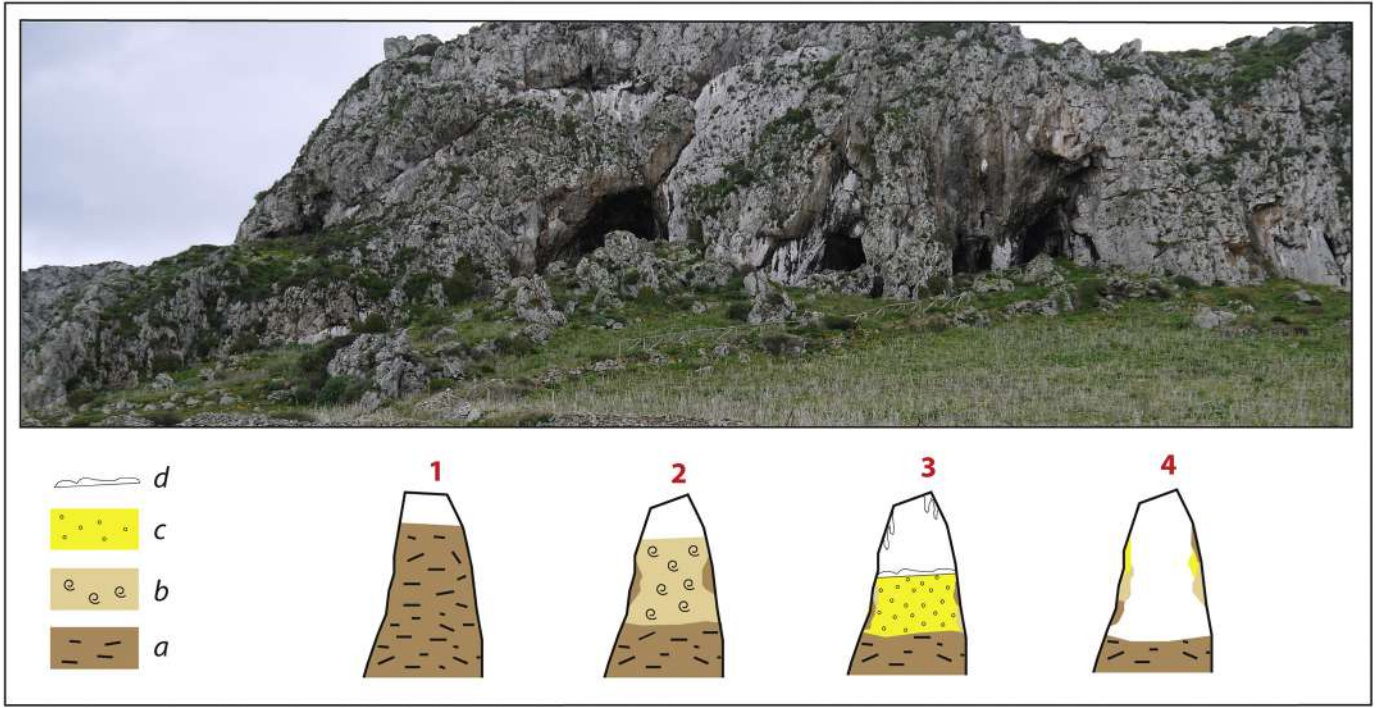

Figure 5

Figure 6

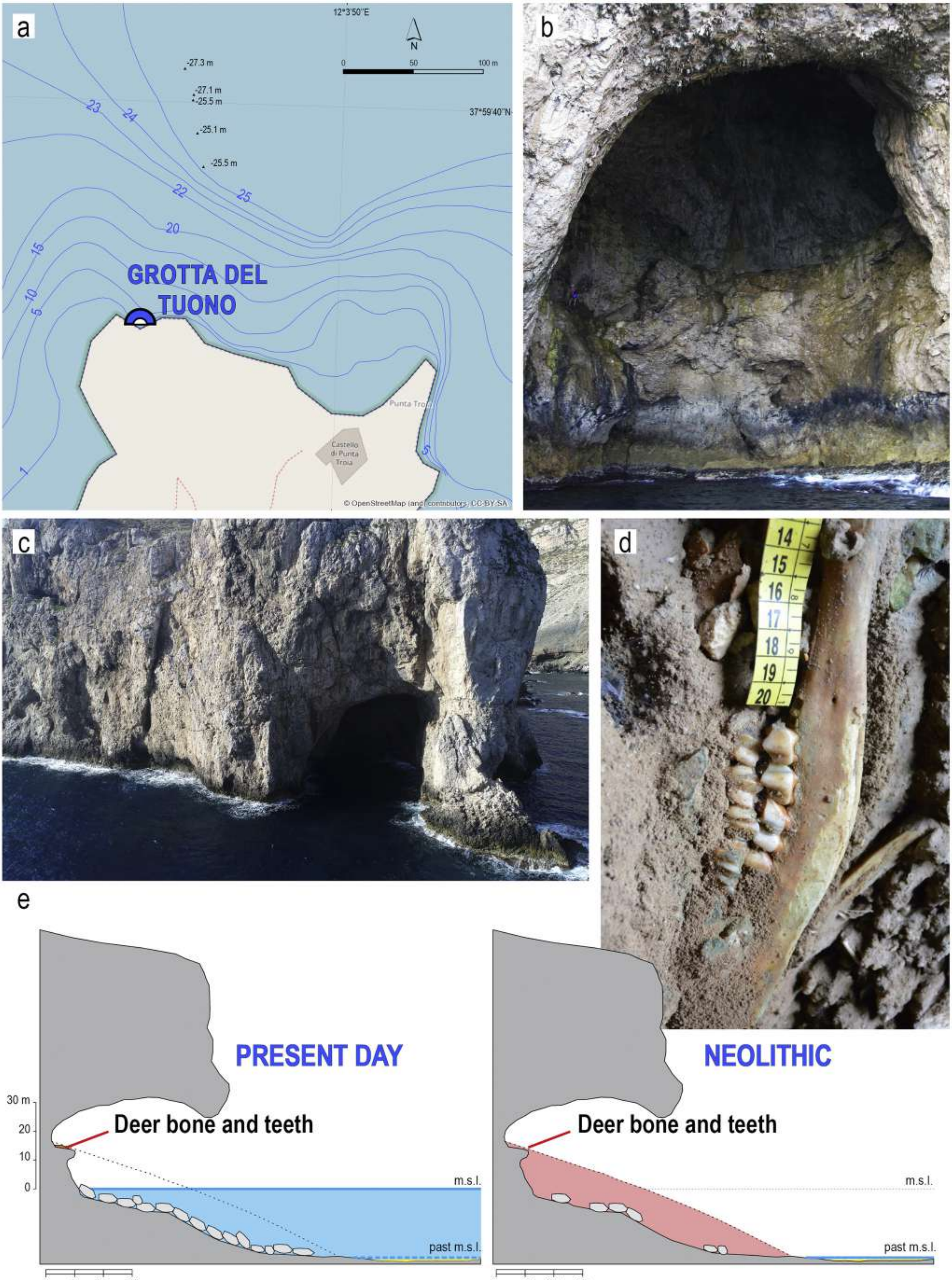
a
12°3'50"E
N
0
50
100 m
37°59'40"N
-27.3 m
-27.1 m
-25.5 m
-25.1 m
-25.5 m
23
24
22
25
20
15
10
5
1
5
GROTTA DEL TUONO
Punta Troia
Castello di Punta Troia
© OpenStreetMap (and) contributors, CC-BY-SA
b
c
d
14
15
16
17
18
19
20
e
PRESENT DAY
NEOLITHIC
30 m
20
10
0
Deer bone and teeth
m.s.l.
past m.s.l.
0
10
20
30 m
Deer bone and teeth
m.s.l.
past m.s.l.
0
10
20
30 m

Figure 7

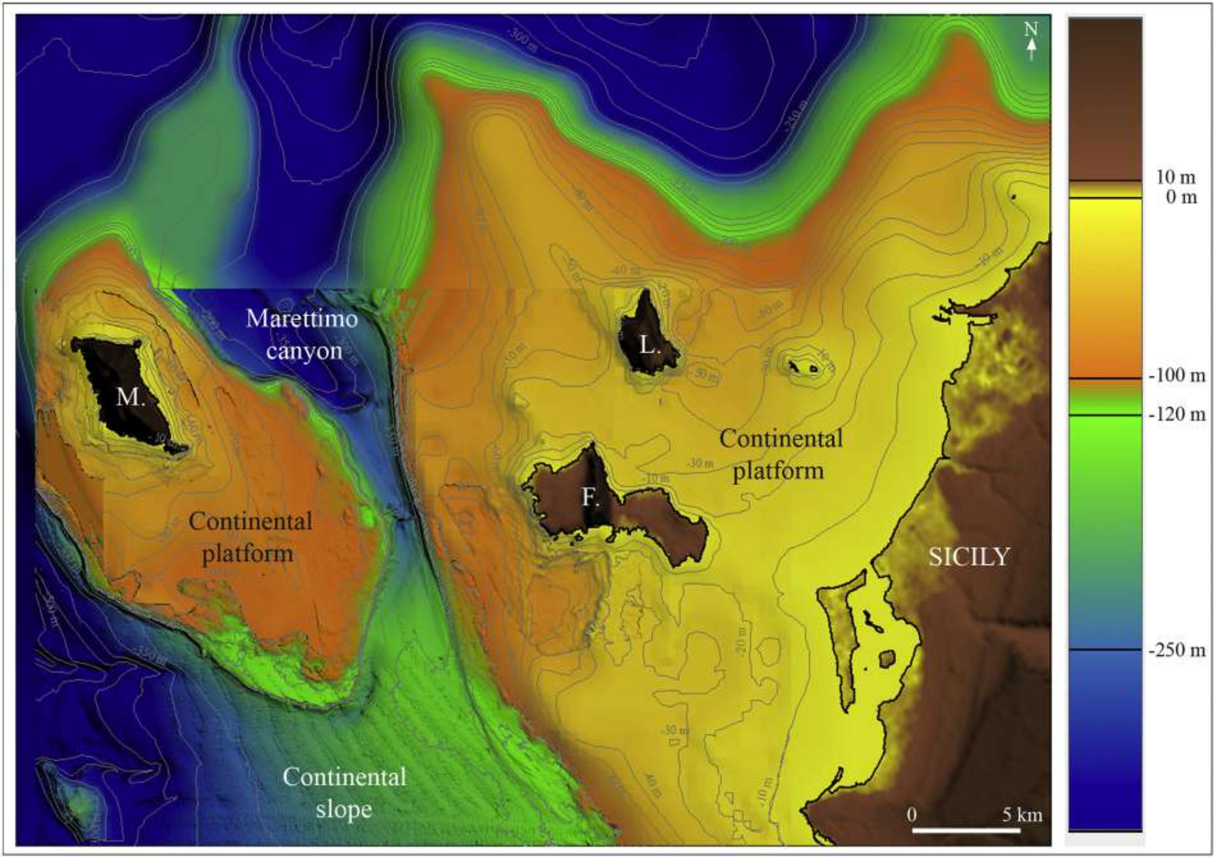
N
Marettimo canyon
M.
L.
F.
Continental platform
Continental platform
Continental slope
SICILY
0
5 km
-300 m
-250 m
-40 m
-30 m
-10 m
-20 m
-350 m
10 m
0 m
-100 m
-120 m
-250 m

Figure 8

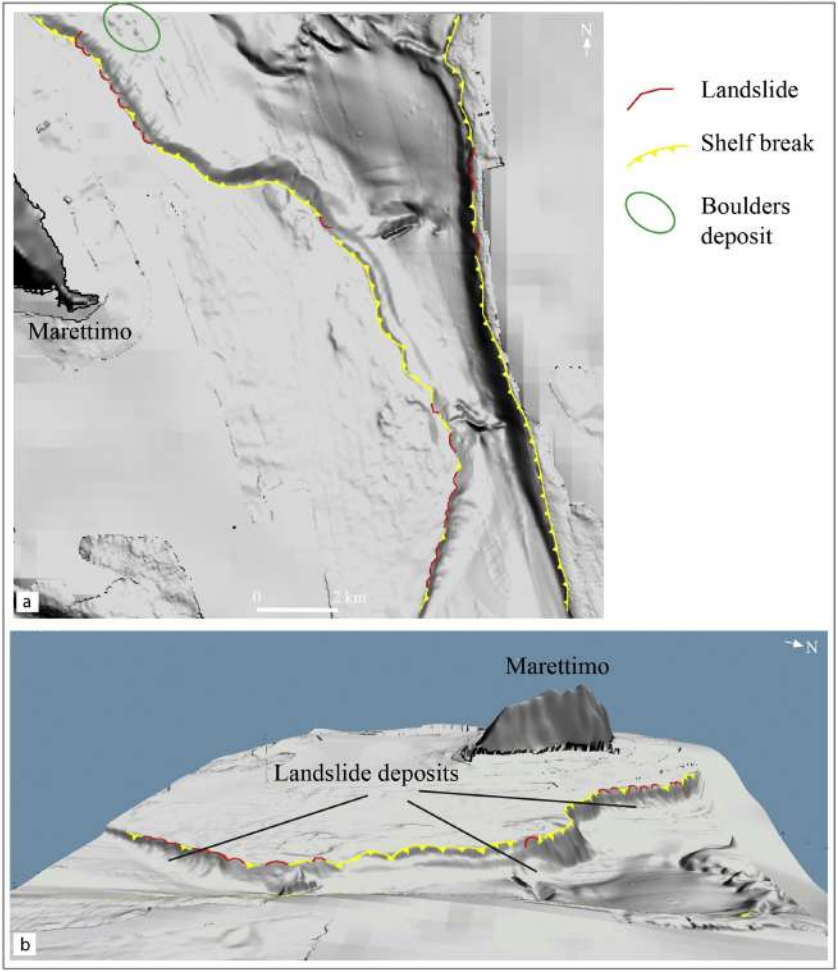
N
Landslide
Shelf break
Boulders deposit
Marettimo
0
2 km
a
N
Marettimo
Landslide deposits
b

Figure 9

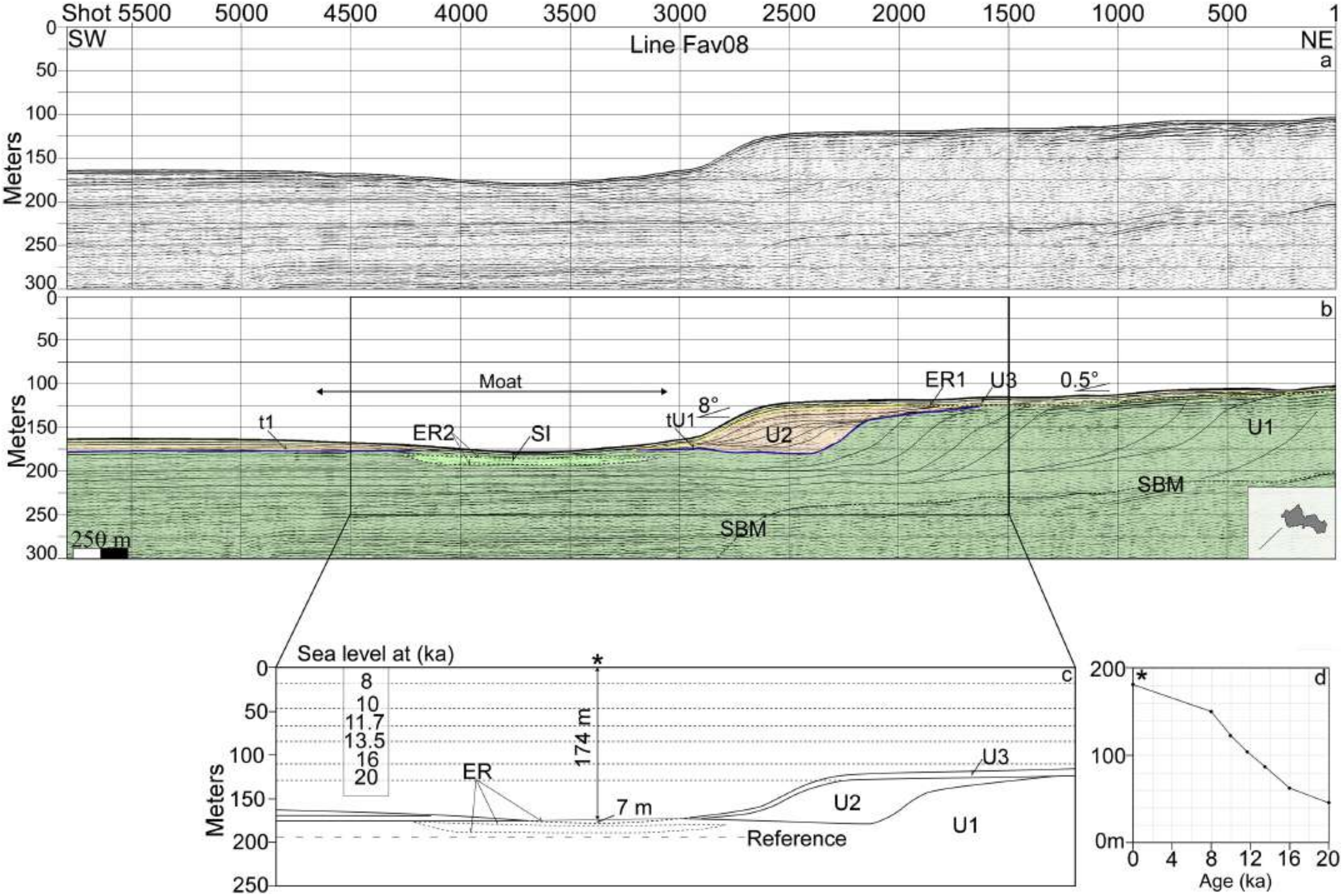
Shot 5500
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
1
SW
NE
Line Fav08
a
Meters
0
50
100
150
200
250
300
b
Moat
t1
ER2
SI
tU1
8°
U2
ER1
U3
0.5°
U1
SBM
SBM
250 m
Sea level at (ka)
8
10
11.7
13.5
16
20
*
174 m
7 m
ER
U3
U2
U1
Reference
c
d
200
100
0m
0
4
8
12
16
20
Age (ka)

Figure 10

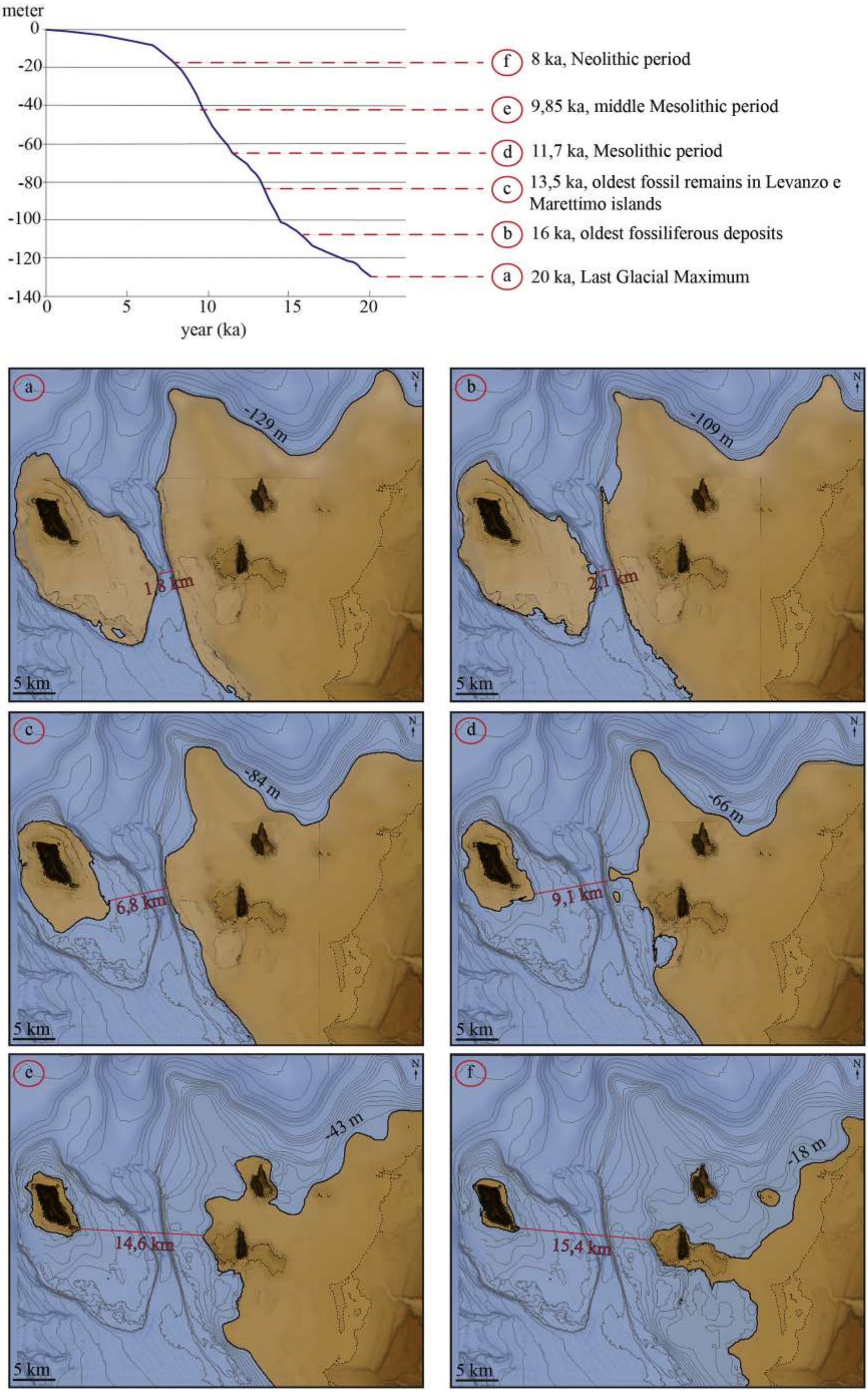
meter
0
-20
-40
-60
-80
-100
-120
-140
0
5
10
15
20
year (ka)
f 8 ka, Neolithic period
e 9,85 ka, middle Mesolithic period
d 11,7 ka, Mesolithic period
c 13,5 ka, oldest fossil remains in Levanzo e Marettimo islands
b 16 ka, oldest fossiliferous deposits
a 20 ka, Last Glacial Maximum
a
-129 m
1,8 km
5 km
N
b
-109 m
2,1 km
5 km
N
c
-84 m
6,8 km
5 km
N
d
-66 m
9,1 km
5 km
N
e
-43 m
14,6 km
5 km
N
f
-18 m
15,4 km
5 km
N

Figure 11

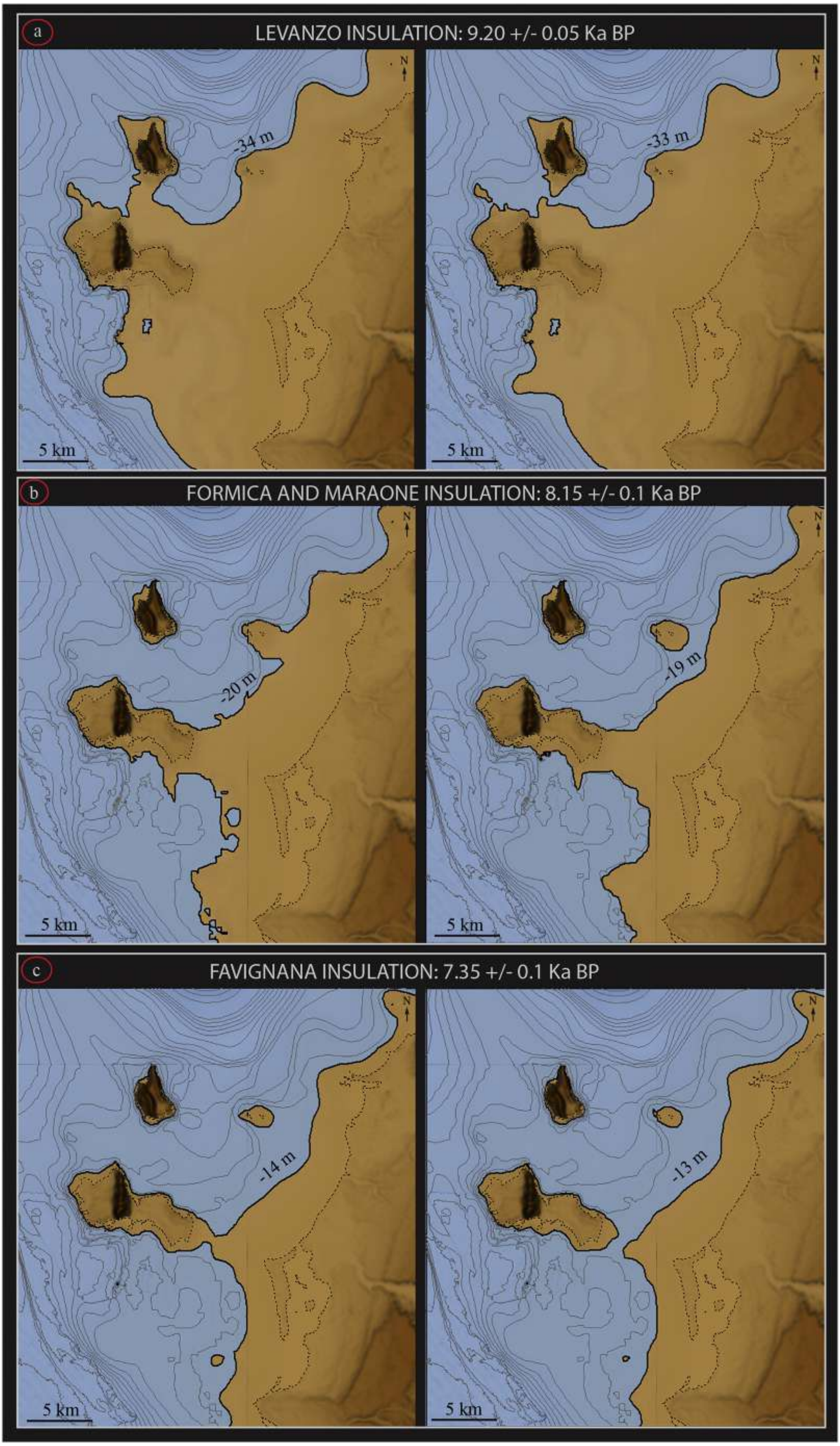
a
LEVANZO INSULATION: 9.20 +/- 0.05 Ka BP
N
-34 m
5 km
N
-33 m
5 km
b
FORMICA AND MARAONE INSULATION: 8.15 +/- 0.1 Ka BP
N
-20 m
5 km
N
-19 m
5 km
c
FAVIGNANA INSULATION: 7.35 +/- 0.1 Ka BP
N
-14 m
5 km
N
-13 m
5 km

Figure 12