Using marine deposits to understand terrestrial human environments: 6000-year old hyperpycnal flash-flood events and their implications

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Abstract

Offshore sedimentary deposits preserved in submarine canyons in southern Calabria, Italy, provide evidence for mid-Holocene (ca. 6000 BP) erosion and the transportation of organic-rich floodplain sediments by flash-flood (hyperpycnal) flows from the San Pasquale River. Marine geophysical surveys (bathymetry, side-scan sonar) and diver reconnaissance revealed an unusual offshore peat deposit containing plant macrofossils representing local habitats, potentially reflecting human modified landscapes. The 20-30 cm thick organic deposit included a large tree trunk, well-preserved seeds, leaves, sticks and other delicate organics. Textural and microfossil (foraminifera) analysis of associated sediments (sands and muds) indicate that these deposits resulted from hyperpycnal flood events that were deposited as sediment gravity flows within gullies on the canyon margins. Whilst the value of studying *in situ* submerged prehistoric landscapes is well documented, we demonstrate that reworked floodplain deposits preserved in offshore environments can provide useful palaeoenvironmental information that may not be preserved in terrestrial settings. The botanic archive preserved in submarine flood deposits at San Pasquale affords a unique insight into the local environment in which people lived during the Final Neolithic.

Highlights

1. Excellent preservation of organic deposits in offshore setting.

2. Utility of secondary deposits for understanding palaeolandscape and enriching the onshore archaeological record.

3. Long traditions of flash-flooding on the southern Italian coast that date back to prehistory

Keywords

Submerged Prehistory

Hyperpycnal floods

Final Neolithic

Calabria

1.0 Introduction

Coastlines structure human life: they afford access to marine resources, allow travel and inter-regional contact, concentrate population, and furnish points of reference in cultural landscapes (Robb and Farr, 2005:26). The study of coastal prehistoric activity can contribute to our understanding of several central issues, including Mesolithic forager presence, the spread of the Neolithic, and ancient and modern agriculture, subsistence and inter-regional exchange (i.e. Bailey et al., 2017:8; Bell 2007:3), but in many regions, our knowledge of past coastal environments is limited. This is due to a number of environmental and taphonomic factors that result in poor preservation of archaeological and palaeoenvironmental records; these may include the geomorphology of the coast, tectonics, erosion and sedimentation, and historic and contemporary coastal modification. Knowledge of past changes in coastal environments is also skewed by the questions that we have traditionally been interested in and the types of archaeology we have done. For example, coastal archaeology in the Mediterranean has focussed overwhelmingly upon ports and harbours. Whilst the archaeology of submerged landscapes has gained interest in the last decade, it has focussed on regions of greatest potential for preservation (Bailey and Flemming, 2008; Benjamin et al., 2011:290; Erlandson, 2001).

The underwater archaeological potential of submerged landscapes on continental shelves is now widely recognised (Bailey et al., 2012; Bailey et al., 2017). Previous work has tended to focus on tectonically stable regions where gradual shelving or shallow continental shelves have been affected by postglacial marine transgression (see Flemming et al., 2017 and chapters therein). These tend to be regions with the greatest lateral displacement of palaeocoastlines, where inundation has created potential for *in situ* preservation of terrestrial sites or landforms. Locally steep shelf areas on tectonically active coastlines are, in contrast, generally regarded as of low potential for the preservation of submerged prehistory because of geodynamic conditions (Flemming et al., 2017:4) and their potential has been under explored.

In this paper, we report on the discovery of mid-Holocene (ca. 6000 BP) floodplain sediments preserved in offshore environments on the tectonically active coast of southern Calabria, Italy (Figure 1). Floodplain sediments were deposited by episodic flash-flood events within deep (> 400 m) submarine canyons formed at the mouth of the San Pasquale River (Figure 1) and contain a rich palaeobotanical archive of Late Neolithic coastal environments. These findings challenge previous assumptions that tectonically active shelf areas have limited potential as palaeoenvironmental archives. We show, in contrast, that the unique preservation of botanical remains in flash-flood deposits (hyperpycnites) can provide palaeoenvironmental data that are otherwise unavailable from terrestrial sediment archives. Submarine canyons are a common feature of the shelf in southern Italy (Casalbore et al., 2011; Ridente et al., 2014) and in other tectonically active coastlines in the Mediterranean. Our results indicate that these settings should not be overlooked as potential sources for palaeoenvironmental and palaeoecological data.

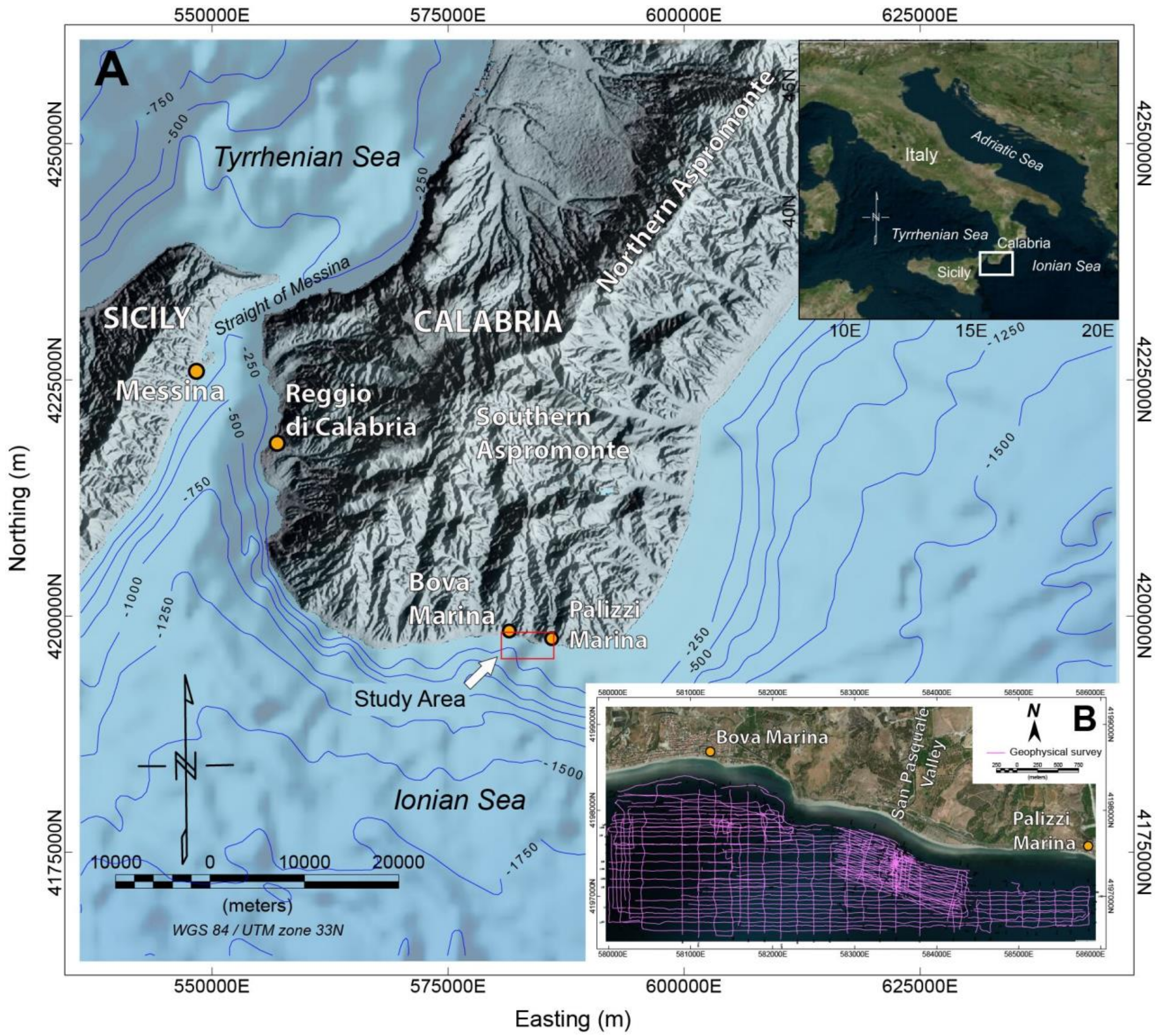

Figure 1. A) Location of Bova Marina study area in southern Calabria. Generalized shelf and offshore bathymetry also shown (contour interval 250 m). B) Geophysical survey area (6 km^2) showing sonar survey track lines (200 kHz side-scan, single-beam bathymetry).

2.0 Study Area

2.1 Geological Setting

The San Pasquale valley is located 3 km to the east of the town of Bova Marina, on the south coast of Calabria, Italy (Figure 1). The geology of the region is dominated by the Aspromonte massif, a plateau of folded metamorphic rocks, which rise steeply from the coast to a height of ca. 2000 masl (metres above sea-level) (Robb, 1997; Robb and Van Hove, 2003). The San Pasquale River drains from the uplands towards the coast, along a narrow alluvial valley, with steep sided slopes. The San Pasquale is a short (7-8 km), low-sinuosity braided river with coarse gravels and cobbles that typifies the river systems of Calabria and Sicily (Casalbore et al. 2011). Close to the coast (~ 5 km), the San Pasquale incises through the Early Miocene Stilo Capo d'Orlando Formation, which is composed of conglomerates and marine mudstones containing abundant planktic (Globigerinides and *Orbulina*) and benthic foraminifera (Cavazza and DeCelles, 1993; Patterson et al., 1995). Incision through these poorly indurated, highly erodible mudstones has resulted in steep valley side slopes, with smaller gullies along the margin (Figure 2).

The coastline at San Pasquale is a narrow littoral plain backed by coastal foothills (Brondi et al., 2003; Antonioli et al., 2017:346). It has a narrow, steeply shelving shelf, which is tectonically active, whilst the ephemeral rivers (*fiumare*) transport a high sediment load from the nearby mountain drainages (for Sicilian comparison see Casalbore et al., 2011). The coastal foothills are dissected by wide alluvial valleys occupied by *fiumare*, which are subject to seasonal flash-flooding during the wet season. The San Pasquale River is one such *fiumara*; like most, today it has been canalised and is seasonally dry.

2.2 Vegetation

The southern Calabrian landscape is dominated by Mediterranean species that vary with altitude. The coast is the driest zone with as little as 600 mm of annual precipitation, whilst ca.2000 mm fall in the highlands of the Aspromonte (Le Pera and Sorriso-Valvo, 2000). The broad valleys of the larger rivers are primarily used for agriculture, including grain, vines and bergamot orchards. The higher denuded slopes of the clay terraces have little economic use today bar as occasional pasture. Coastal vegetation is dominated by macchia or maquis, Mediterranean scrub, which includes many aromatics such as mints, thyme and oregano, interspersed with olive and figs and other small trees such as *Quercus ilex* (holm oak) and the non-native *Opuntia ficus-indica* (prickly pear cacti). Whilst a typically dry southern Mediterranean vegetation today, it has not always been this way. Historically, the higher mountains inland have had dense conifer and hardwood forests; in 1847 the author and artist Edward Lear described the hillsides around Bova as covered in dense woodland (Lear, 2003:34). Coastal development in the last century has caused dramatic changes to the local environment, as have reclamation of marshes (*bonifica*) and aridification. The San Pasquale valley itself has a long history of land use and has been modified by the construction of agricultural terraces.

2.3 Archaeological and Palaeoenvironmental Context

Despite its long record of human occupation and central Mediterranean position, there has been little archaeological research focused on the prehistory of southern Calabria. As such, extensive archaeological research along the San Pasquale coast formed part of a broader study of the prehistoric landscape of the region around the *Comune di Bova* in southern Calabria by the Bova Marina Archaeological Project. Whilst evidence for the Palaeolithic and Mesolithic in the region remains sparse, a number of Neolithic (8000-5500 BP), Copper Age (5500-4400 BP) and Bronze Age (4400-3000 BP) sites have been identified and excavated since the start of the Project in 1997 (Robb, 2002; Robb and Van Hove, 2003; Robb, 2004; Robb and Michelaki, 2007; Robb, 2007). As part of *Magna Grecia*, this area is better known for its Classical archaeology. The Roman site of Deri is located near the modern San Pasquale River mouth; the Classical Greek site of Mazza stands upon a hill immediately overlooking it.

In the Bova area, prehistoric materials have been found at all elevations from the coast to the mountains. Two Neolithic sites have been excavated: Penitenzeria, a Stentinello settlement (7500-7000 BP) with a short but intense period of occupation and, Umbro, a nearby rockshelter, which revealed sporadic activity across the Neolithic from the Stentinello, Early to Middle Neolithic, to the Diana Late Neolithic phase (7700-6000 BP). The rockshelter at Umbro was re-used briefly at the end of the Copper Age (5000-4500 BP) (see Robb, 2002; Robb and Van Hove, 2003; Robb, 2004; Robb and Michelaki, 2007; Robb, 2007). A number of Bronze Age sites are also known, with two excavated (Umbro, 3800-3500 BP), and Sant'Aniceto, 3100-2900 BP). Both excavated Neolithic sites contained local pottery, undecorated, Impressed and Stentinello ware, alongside a small sample of imported ware, polished stone axes, flint, chert and obsidian tools. This indicates knowledge of local raw material sources within the landscape (Michelaki et al., 2012; Michelaki et al., 2015) alongside participation in wider networks of trade and exchange within Calabria and across the Straits of Messina to Sicily and the Aeolian islands (Farr, 2003; 2006; Robb and Farr 2005:28). Little archaeobotanical or faunal material was preserved. However, that which was recovered reflected a typical Neolithic economy including domesticated animals: sheep/goat, cow, pig and dog, and cereal remains including three carbonised grains of *Hordeum vulgare* (barley). No local proxy palaeoenvironmental record exists for the Calabrian coast.

In the San Pasquale valley, there is also surface evidence for Neolithic occupation, although sites may either have been lost in areas where clay subsoil has been exposed by erosion, or, covered by alluvium of up to 4 metres deep in the valley bottom directly adjacent to the San Pasquale River. Surface finds include Impressed Ware pottery about 500 m from the stream, and an obsidian fragment close to the stream mouth.

Evidence of wider regional Holocene climate and palaeoecological variations are limited to pollen records captured in marine cores that only preserve a limited selection of pollen due to wind-blown bias (Antonioli et al., 2017; Di Rita et al., 2018), or inland lacustrine records (Follieri et al., 1998; Allen et al., 2000 Joannin et al 2012). From the available data, Antonioli et al. (2017:365) suggest the Italian coast would have been dominated by *Pinus* in the highlands and deciduous *Quercus* along lower elevations on the coast. Sicilian records show a general trend toward open vegetation with Mediterranean evergreen shrubs such as *Pistacia* developing into dense maquis (Mediterranean shrub) between 7000 cal BP and 5000 cal BP (Noti et al., 2009; Tinner et al., 2009). This ties to a general shift from a cool wet climate 8000-7000 BP to warmer and drier conditions 7000-3600BP (Le Pera and Sorriso-Valvo, 2000).

As part of the Bova Marina Project's research into the evolution of the coastal landscape, a geomorphological survey was undertaken along the coast. This included a preliminary offshore diver survey in 2005 to identify geological outcrops along the coast between San Pasquale and Bova Marina (see Figure 2).

During the survey a dense, thick (20-30 cm) organic unit consisting of seeds and sticks, was found at -27mbsl (metres below sea level) (05WP12 BS4; Figures 2, 3 & 5). A small stick from this deposit at -27m was dated by AMS to 6190-5940 cal BP, (05WP12 BS4, Beta-207156, Beta Analytic, Florida, U.S.A.; Figure 8). This date corresponds to the Final Neolithic in this region, characterised by Diana style pottery. No archaeological remains were identified during the survey, but the unusual nature of the deposit and its possible sea-level implications instigated further geological studies.

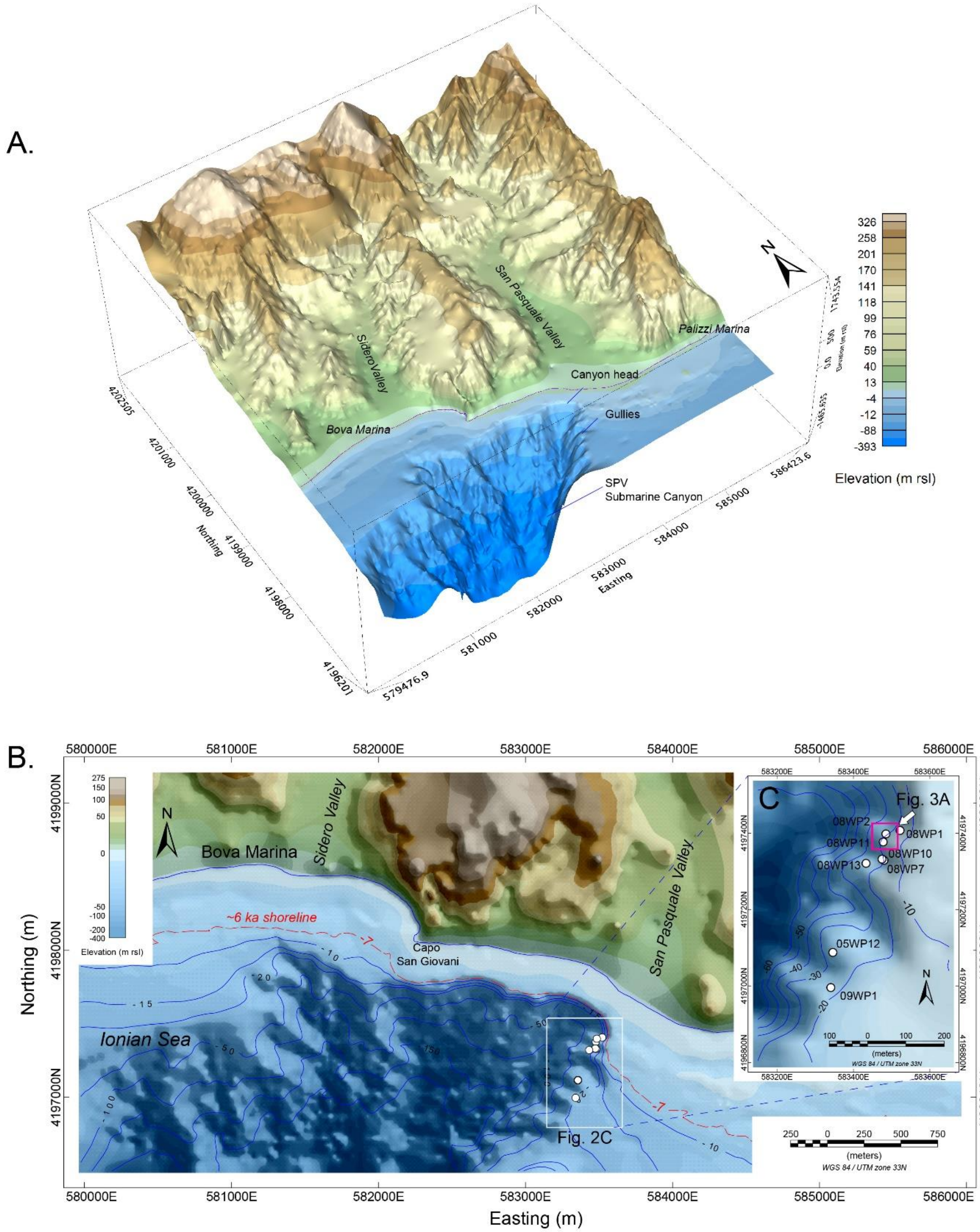

Figure 2. A) Digital elevation model (DEM) showing topography of San Pasquale River valley (SPRV) and submarine canyon (elevation in meters relative to sea level). Submarine canyon reaches a depth of >

300 m within 1 km of the shoreline. Outcrops of Holocene and older sediments were discovered in several steep gullies on the eastern margin of the SPRV submarine canyon. B) Bathymetry map for 6 km^2 inshore area between Bova Marina and Palizzi Marina. Red contour shows the approximate position of the 6000 BP shoreline (~ 7 m depth) based on sea-level curve in Figure 3; estimated shoreline position does not take into account subsequent sedimentation. C) Detailed map showing location of outcrops and diver waypoints on the eastern San Pasquale valley canyon margin.

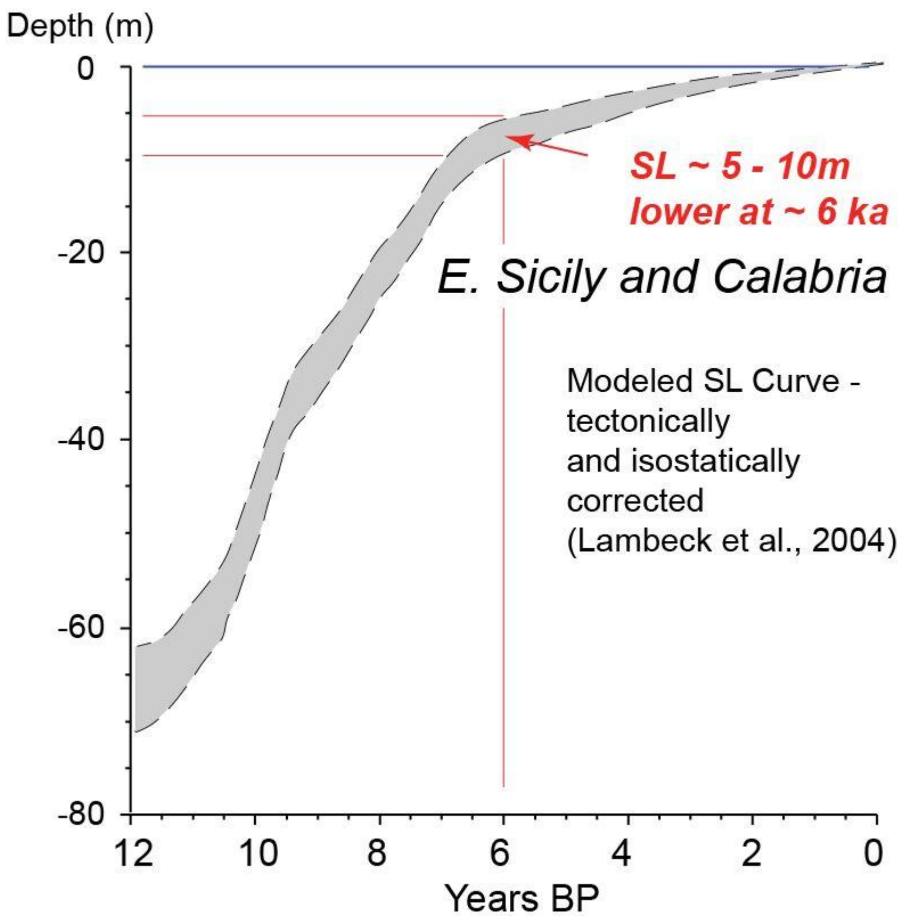

Figure 3. Modeled sea-level curve for Calabria and Sicily from Lambeck et al. (2004) showing the approximate depth for the 6000 BP shoreline.

3.0 Materials and Methods

3.1 Geophysical and Diver Surveys

In 2008 and 2009, marine geophysical mapping and underwater surveys using SCUBA were conducted across a 6 km^2 inshore area between Bova Marina and Palizzi Marina (Figure 1B). The geophysical survey was collected using a Knudsen 320BP single-beam 200 kHz echosounder and side-scan sonar system with sonar transducers side-mounted on a 5-m inflatable boat. Survey navigation and data positioning were provided by an onboard differential-GPS. A total of 250 line-km of single-beam bathymetry data were acquired in water depths of up to 400 m and corrected for transducer draft and diurnal tidal variations. Bathymetry data were then interpolated using a minimum curvature algorithm (Sonnenburg and Boyce, 2008) with 10 m grid cells to produce a colour-shaded bathymetric model (Figures 2A, B). Bathymetry data were combined with available digital topographic data (NASA Shuttle Radar Topography Mission, 3 second global coverage) to produce a continuous land-sea digital elevation model. Side-scan sonar swaths were collected in water depths of < 30 m and mosaiced (Figure 4A) to assist in interpretation of the submarine canyon geomorphology and to identify underwater outcrops for coring and sampling (Figure 4B).

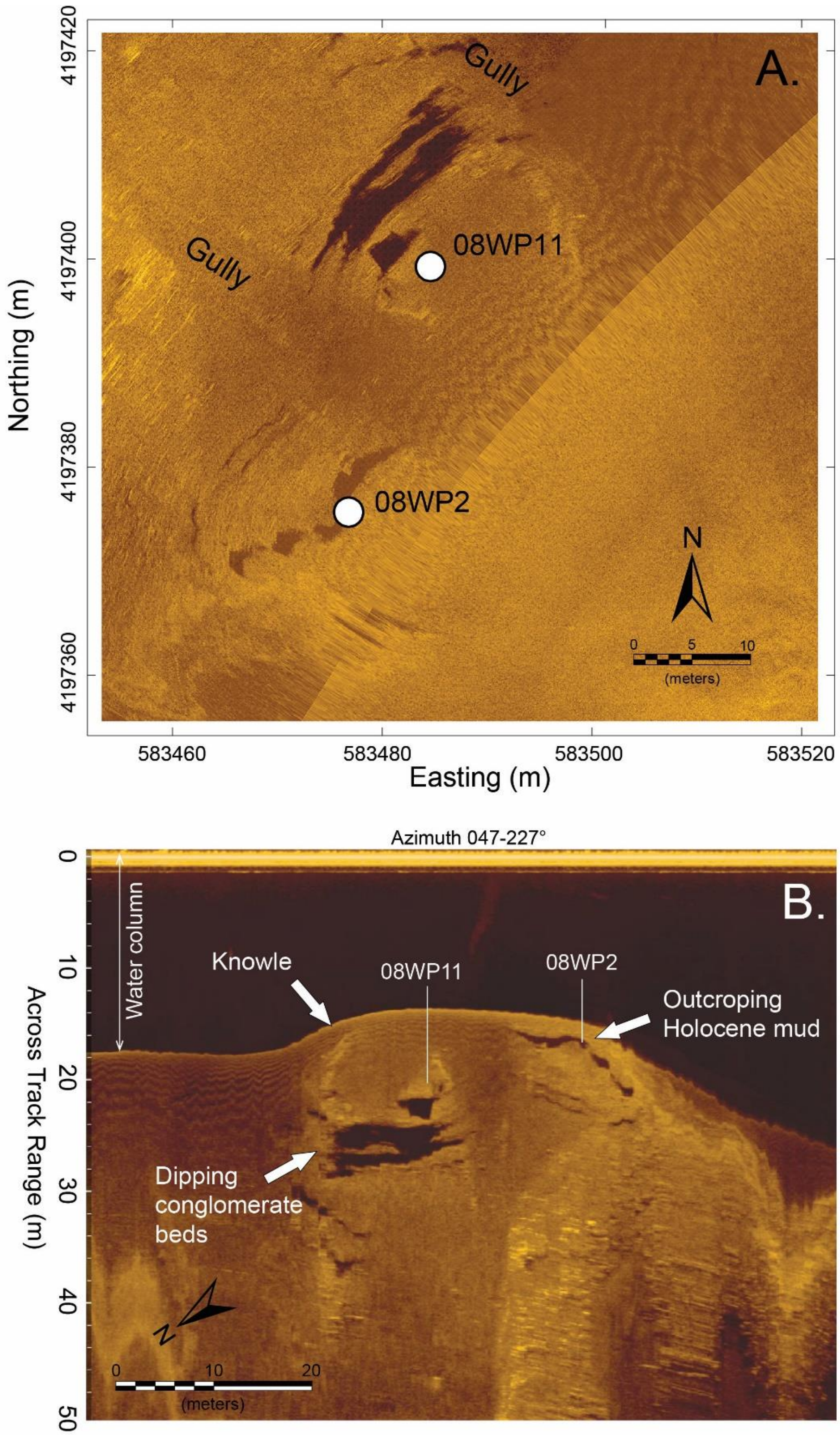
A.
Gully
Gully
08WP11
08WP2
N
0 5 10
(meters)
4197420
4197400
4197380
4197360
Northing (m)
583460
583480
583500
583520
Easting (m)
Azimuth 047-227°
B.
Water column
Knowle
08WP11
08WP2
Outcroping
Holocene mud
Dipping
conglomerate
beds
N
0 10 20
(meters)
0
10
20
30
40
50
Across Track Range (m)

Figure 4. A) Side-scan mosaic showing outcrops exposed in eastern canyon wall at waypoints 08WP2 and 08WP11 (location of image shown in Fig. 2C). B) Portion of side-scan swath showing exposed strata on northwest face of 'knowle' formed by erosion of gullies into canyon margin. At waypoint 08WP11, conglomerate beds overlie Early Miocene mudstones and are draped by Holocene muds containing abundant *Posidonia* roots and fragments (see Figure 9).

Diver underwater surveys in 2008 and 2009 identified and mapped several well-exposed stratigraphic exposures (08 waypoint numbers) along the eastern margin of the San Pasquale submarine canyon. Cores were collected in several stepped outcrops (09WP1) near the organic bed found in 2005 (05WP12) (Figures 2, 6, 7 & 9). A total of 6 sediment cores were taken along an easterly transect in 25-27 m water depth (Figure 6) for sediment and microfossil analysis (Figures 7 & 11). Bulk samples of exposed organic material were also collected at several locations for palaeobotanical analysis and radiocarbon dating (BS2,3,4) (Figures 7 & 8). All waypoints and coring sites were located using a surface deployed hand-held GPS and depths were measured using a tidally calibrated depth gauge.

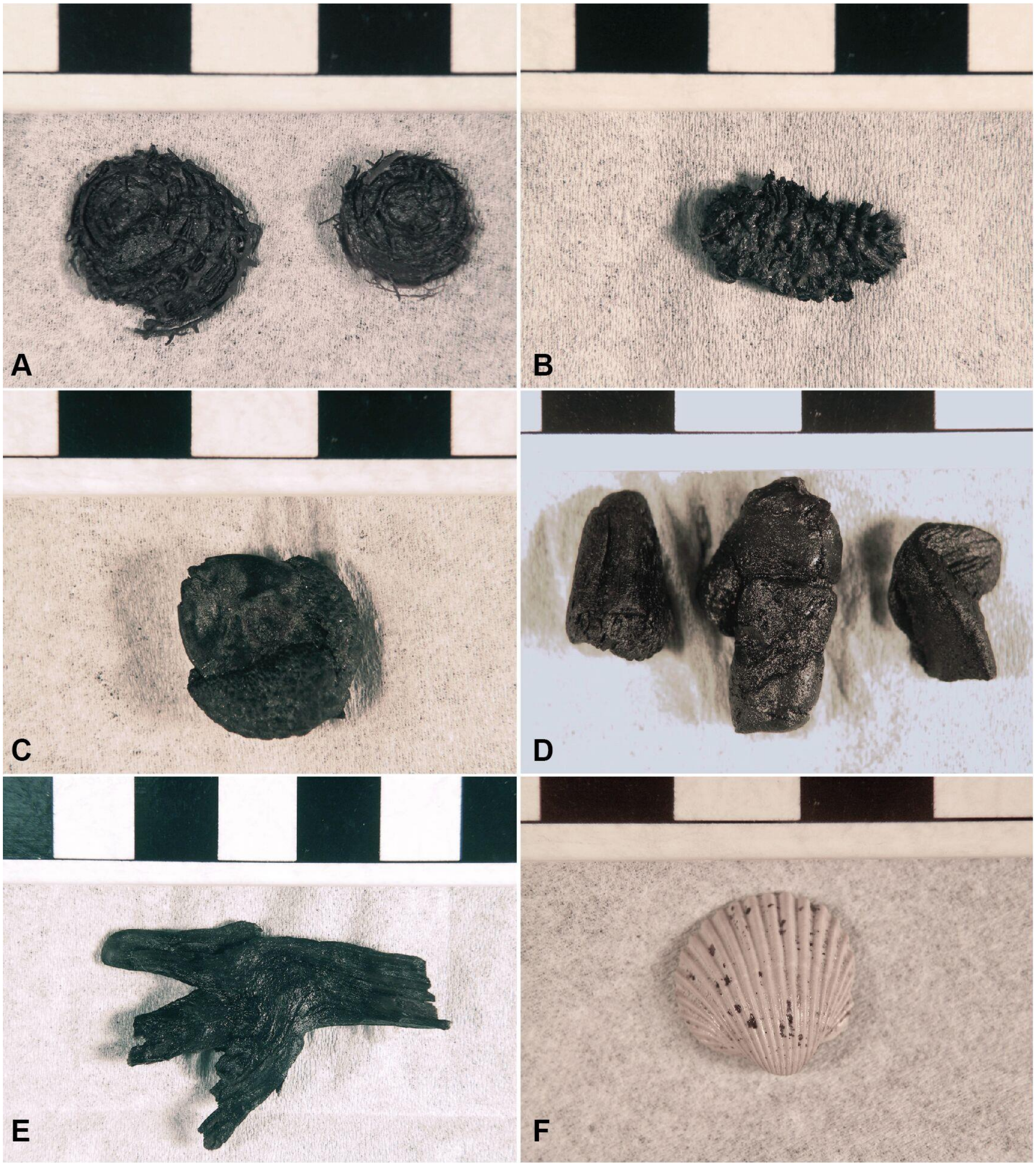

Figure 5. Well preserved organics from bulk sample at 05WP12. A) *Medicago polymorpha*, toothed medic, B) *Picea* cone (or *Pinus* ?), C) *Quercus* sp. acorn in its cupule, D) charcoal fragments, E) twig, F) *Cerastoderma glaucum*, an estuarine or lagoonal bivalve.

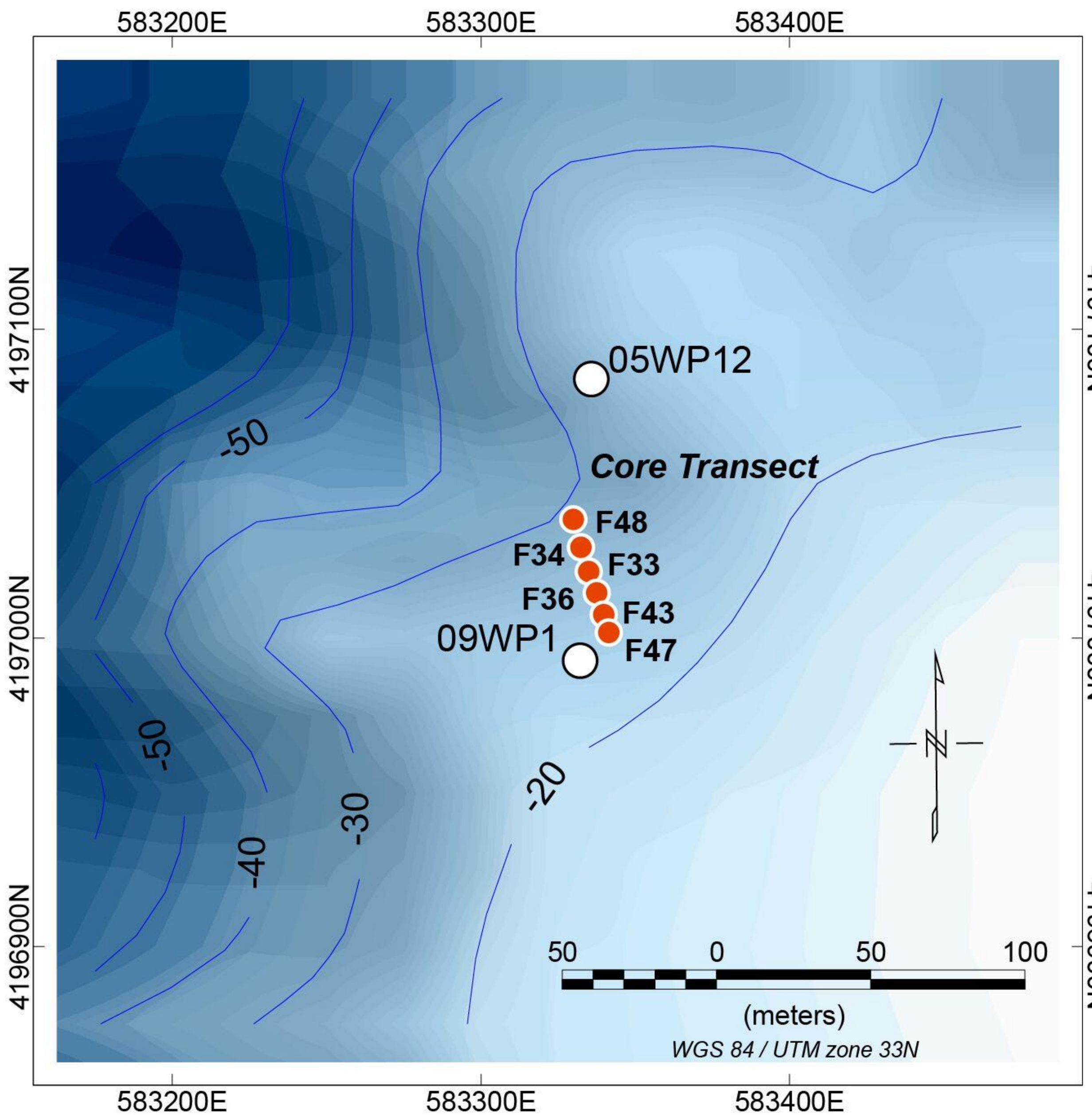

Figure 6. Detail of bathymetry map (see Figure 2) showing locations of core transect at locality 09WP1 and relationship with site 05WP12. In 2005, an organic bed containing well-preserved tree branches and plant macrofossils was exposed at 05WP12 but was subsequently buried and could not be relocated in 2009. The core transect at 09WP1 is located in the same gully but on the eastern side.

3.2 Sedimentology and Micropalaeontology

The cores were logged and sampled at 1 cm intervals for particle size and microfossil analysis. Laser-particle size analysis used standard techniques (Beckman Coulter LS 230; Donato et al., 2009). Loss-on-ignition was measured following the procedure in Heiri et al. (2001).

Micropalaeontological samples (3-4 cm^3) were sieved using a 45-µm screen to remove the muds then oven dried at 35° C and further sieved at 250-µm sieve for microfossil identification. Samples were examined using a binocular dissecting microscope (x 60) to identify and quantify the number of hematite-stained planktic foraminifera that originated from the Miocene mudstones within the San Pasquale River valley (specimens / cm^3). Many of the specimens also showed diagenetic alteration including overgrowths, infills, and fragmentation. During the microfossil investigation, gypsum crystals were also observed and quantified.

3.3 Palaeoecology

In addition to core samples, large (> 500 cm^3) bulk samples (BS2, 3) were taken from organic beds exposed within the terraced outcrop profile (and also in cores) for archaeobotanical analysis and radiocarbon dating (Figure 6, 7 & 8). These samples were dominated by waterlogged remains of plant macrofossils with remarkable levels of preservation. Three samples ranging from 400-600 mm were analysed (see Table 1 supplementary material). To extract the plant remains, the samples were soaked in hot water in order to disaggregate the matrix and free the organic material. They were then passed through a series of geological sieves with mesh diameters of 1mm, 0.5mm and 0.3mm. The separate fractions were examined under a low-powered stereomicroscope (x8 - x56) and the plant remains picked out. The remains were identified using the author's (AC) reference collection and Cappers et al. (2006).

4.0 Results

4.1 Geophysical Survey

Bathymetric surveys revealed a network of northwest to northeast-oriented submarine canyons that are aligned with the general trend of the San Pasquale and Sidero river valleys (Figure 2). The San Pasquale canyon is up to 1 km in width and descends to a water depth of > 400 m within 1.5 km of the shoreline. The canyon headwall is defined by arcuate slump scars in 8-10 m water depth, about 200-250 m from the shoreline. The eastern margin of the San Pasquale canyon is incised by 10-20 m deep erosional gullies that have a northwest-southeast orientation, indicating possible structural control (Figure 2B). The gullies expose the Miocene mudstone bedrock and overlying unconsolidated sediments (Figure 4). Submarine canyons of similar scale and morphology have been documented on the Sicilian coast and have been attributed to retrogressive slope failure as a result of erosional scour by hyperpycnal flows generated during flash-flooding of *fiumare* (Casalbore et al., 2011). Mass failures can also be triggered by cyclic wave loading of the seabed and ground shaking during earthquakes (Ridente et al., 2014).

Figure 4 shows side-scan images of a portion of the northeastern margin of the San Pasquale submarine canyon. Here, slope failure and the erosion of gullies has exposed indurated Miocene mudstones and overlying conglomerates. Conglomerates are capped by up to 1-2 m of Holocene marine muds. Areas of low backscatter within gullies indicate the presence of less reflective, fine grained sediments, likely recording failure and downslope transport of Holocene muds into the submarine canyons (Figure 4).

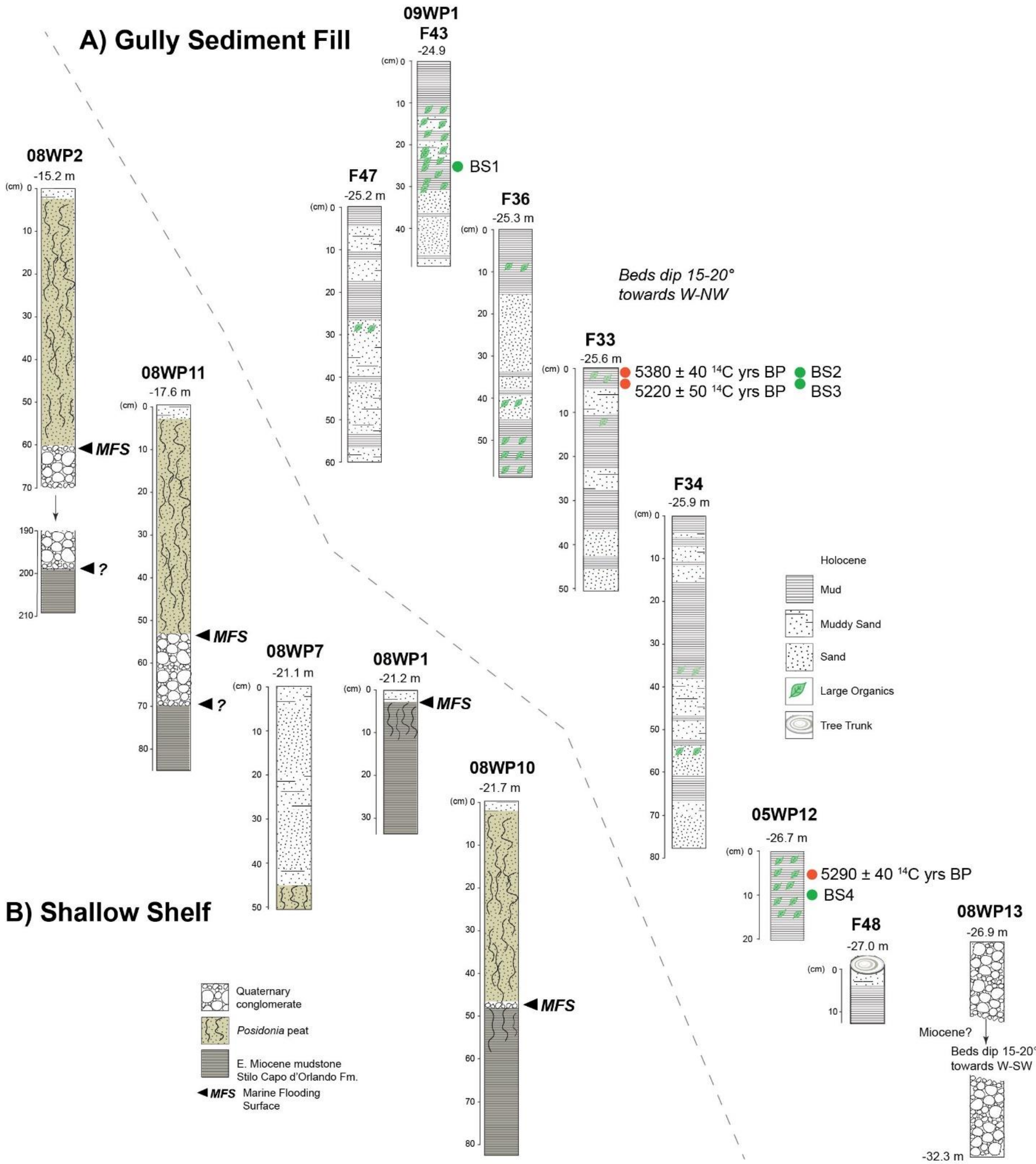

Figure 7. A) Core transect at 09WP01 showing stratigraphy and lithofacies in submarine gully fill (location shown in Figure 6). B) Shallow shelf stratigraphy as exposed in outcrops closer to the San Pasquale River, showing stratigraphic relationships with Neogene bedrock.

Contact between *Posidonia* muds and underlying framework supported (fluvial?) conglomerate is interpreted as a marine flooding surface (MFS).

4.2 Stratigraphy

4.2.1 Shallow Shelf

The outcrop stratigraphy in shallow shelf areas (-15 to 22m) exposed closer to the head of the submarine canyon consisted of Miocene mudstones overlain by a conglomerate of variable thickness that is likely Quaternary in age and likely alluvial in origin, but was modified through the Holocene marine transgression (08WP2, 11) (Figure 7). The mudstones were compact and semi-consolidated and more erosion resistant than overlying unconsolidated recent Holocene muds and sand deposits. Outcrops of the conglomerate showed some evidence of marine bioencrustation (e.g. barnacles, serpulids), but the encrustation could have also occurred more recently with outcrop exposure. In some locations, the conglomerate unit was missing (08WP7,1), or very thin (08WP10). Overlying the conglomerate, was a *Posidonia* rooted peat, containing shell fragments, pebbles and/or interbeds of Holocene marine muddy sand. Large vertical outcrops of conglomerate (> 5 m thick) were also found in deeper locations (08WP13) with beds dipping ~15-20° from horizontal to the W-SW. The conglomerates are likely part of the Early Miocene Stilo Capo d'Orlando Formation, but could also be of Quaternary age (Cavazza and Celles, 1993, Patterson et al., 1995).

4.2.2 Gully Sediment Fill

The stepped outcrops at 09WP1 extended from ~ 25- 27 m depth and exposed mud and sand units containing distinct organic beds (~20-30 cm) that were laterally discontinuous (Figure 7 & 9). The beds were generally dipping ~15-20° towards the W-NW following the general trend of gullies that are eroded into the eastern margin of the San Pasquale valley submarine canyon (Figure 2). The edges of sections showed prominent “pop-up” ridges suggesting that exposure of strata on the valley walls was due to a submarine failure and mass wasting events. The valleys appear to have formed within eroded Stilo Capo d’Orlando Fm. units, a large vertical face and promontory was found ~ 250 m NW of 05WP12 that had similar characteristics to that of 08WP13.   At the base of the valley section a large tree trunk with a root ball was found imbedded in intact basal beds of muddy sand that had a similar depth to the organic bed found in 2005 (05WP12) (Figure 10). The upper exposed surface of the tree was bored with *Teredo navalis*, but the borings did not look recent as the upper boring holes were eroded and exposed. The root ball had embedded cobbles and pebbles indicating it had been eroded from a river-bank/floodplain environment. Whilst we do not have a radiocarbon date for the wood, it was located at a similar stratigraphic level as the organic bed at 05WP12 (6000-6200 BP). The radiocarbon age for the upper and lower organic beds in the valley fill indicate approximately one meter of deposition over a maximum duration of 300 years but sedimentation rates may have been considerably faster as the ages of the organic beds are very similar (Figure 8).

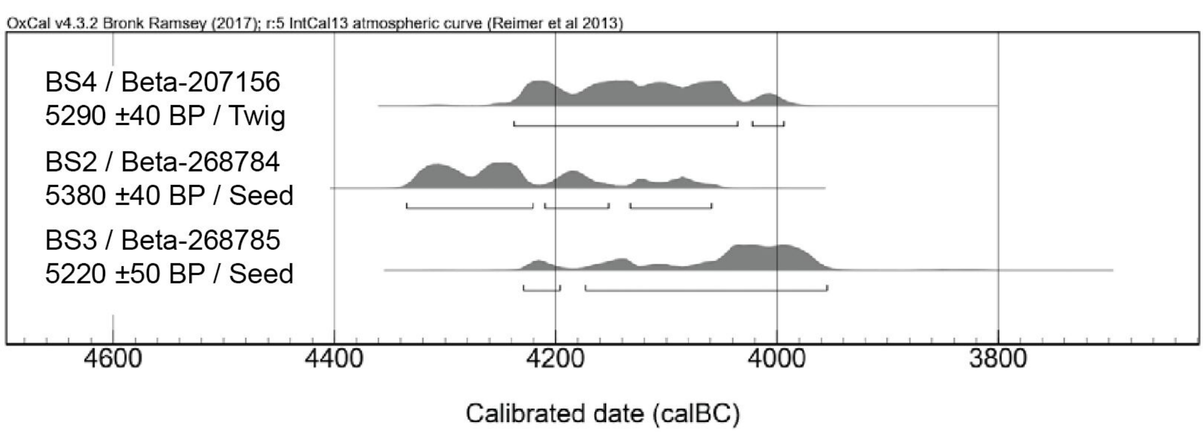

Figure 8. Radiocarbon ages and OxCal calibrated age range. See Figure 7 for stratigraphic position and calibration methods.

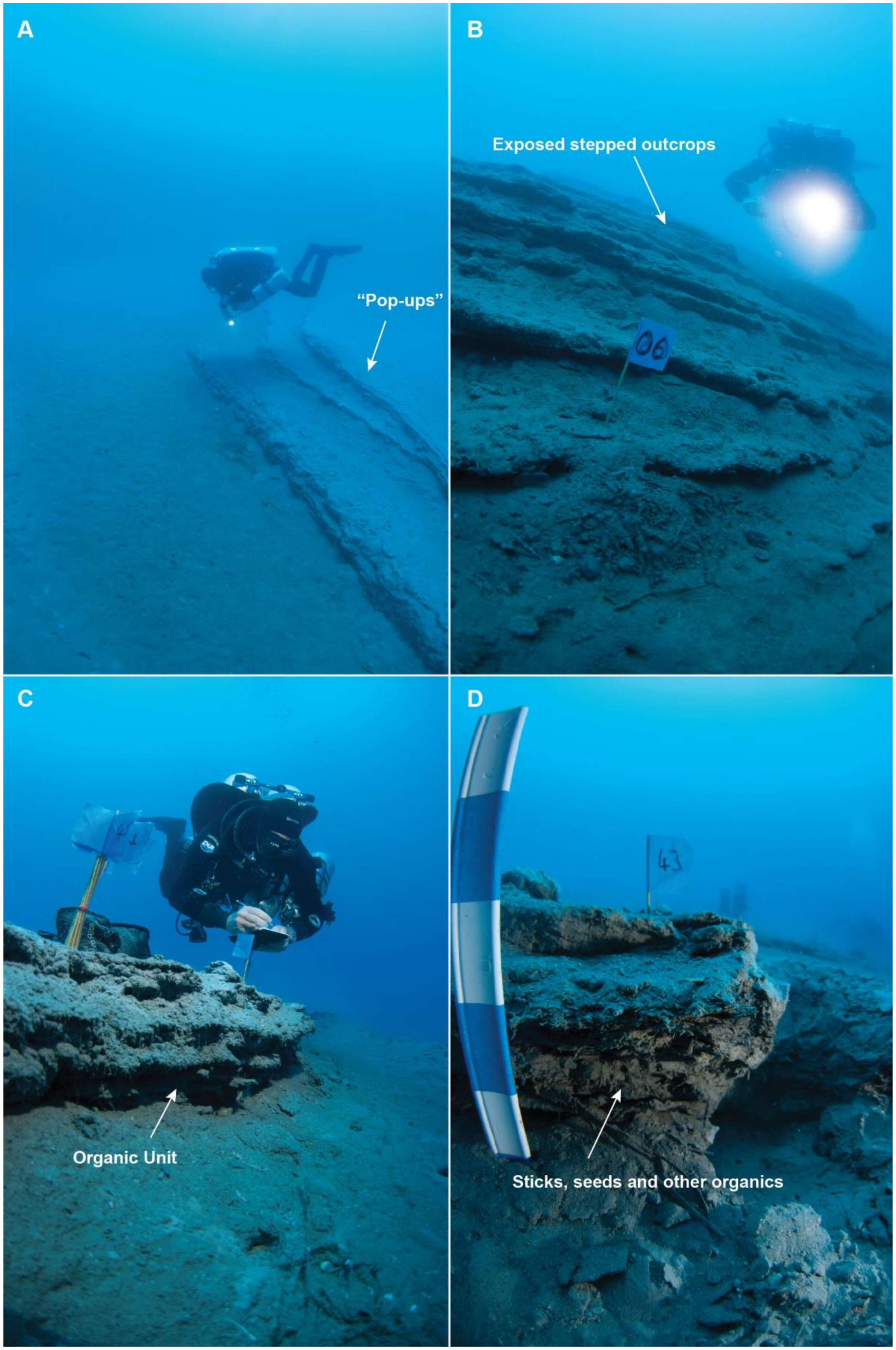
A
“Pop-ups”
B
Exposed stepped outcrops
06
C
Organic Unit
D
43
Sticks, seeds and other organics

Figure 9. A) and B) Prominent stepped ('terraced') outcrop profile formed by differential erosion of interbedded sand, mud and organic layers. Prominent ridges or 'pop-ups' at the edge of the beds suggests a prior sediment failure event (failure scarp). C) Organic beds were compressed and laterally thinned along the exposure. D) Photograph showing the dense concentration of organics, including seeds and branches in 20 cm thick organic layer in core F43 (see Figures 7 & 11 for further detail).

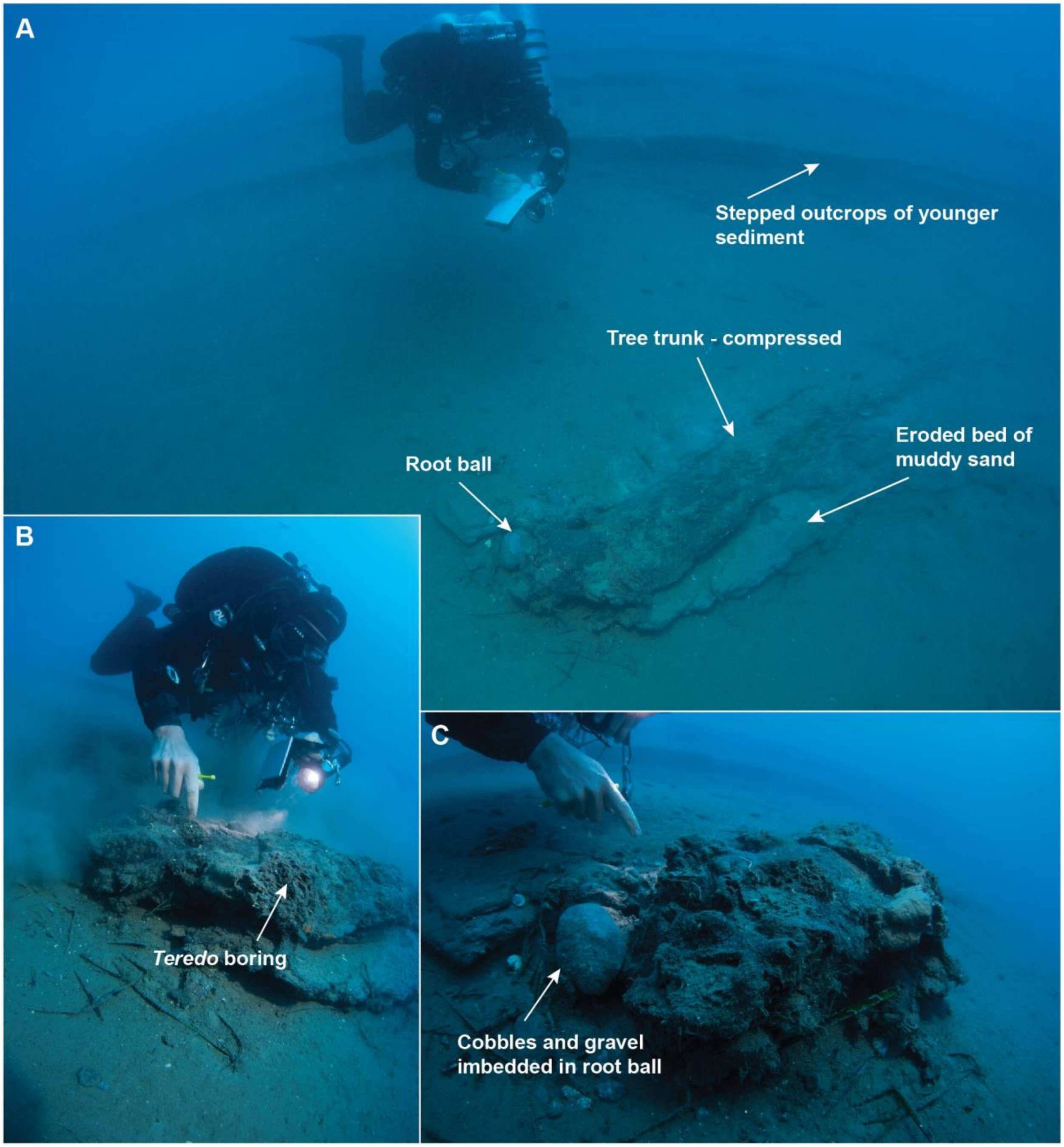

Figure 10. *A) Tree trunk embedded in muddy sand at the bottom of the valley fill (F48; Figure 7). Trunk was compressed and flattened. B) The outer surface of the trunk was bored by Teredo navalis, but the borings were partially eroded, exposing the burrow interior, indicating they were not*

recent. C) The tree root ball was intact and contained cobbles and pebbles, suggesting it was likely eroded during a flood event and transported downslope by sediment gravity flows.

4.3 Core Analyses

Within the cores, a number of event horizons can be seen suggesting episodic events of deposition of organic material within turbidity plumes (Figures 7 & 11). Particle size analysis revealed sequences of coarsening sand fining upwards to layers of fine silt, indicative of turbidity currents or storm deposits (Drake, 1999; Sommerfield and Nittrouer, 1999). The organic facies are unsorted and include coarser grained sedimentary material and rounded pebbles, occasional shells, together with charcoal and plant debris capped with fine silt layers. In all the cores, except F36, smaller event horizons are also evident in addition to the larger turbidity flows. These are indicative of minor flood events from the river mouth; they carry less debris and have fewer microfossils indicating a more localised provenance for the sediment.

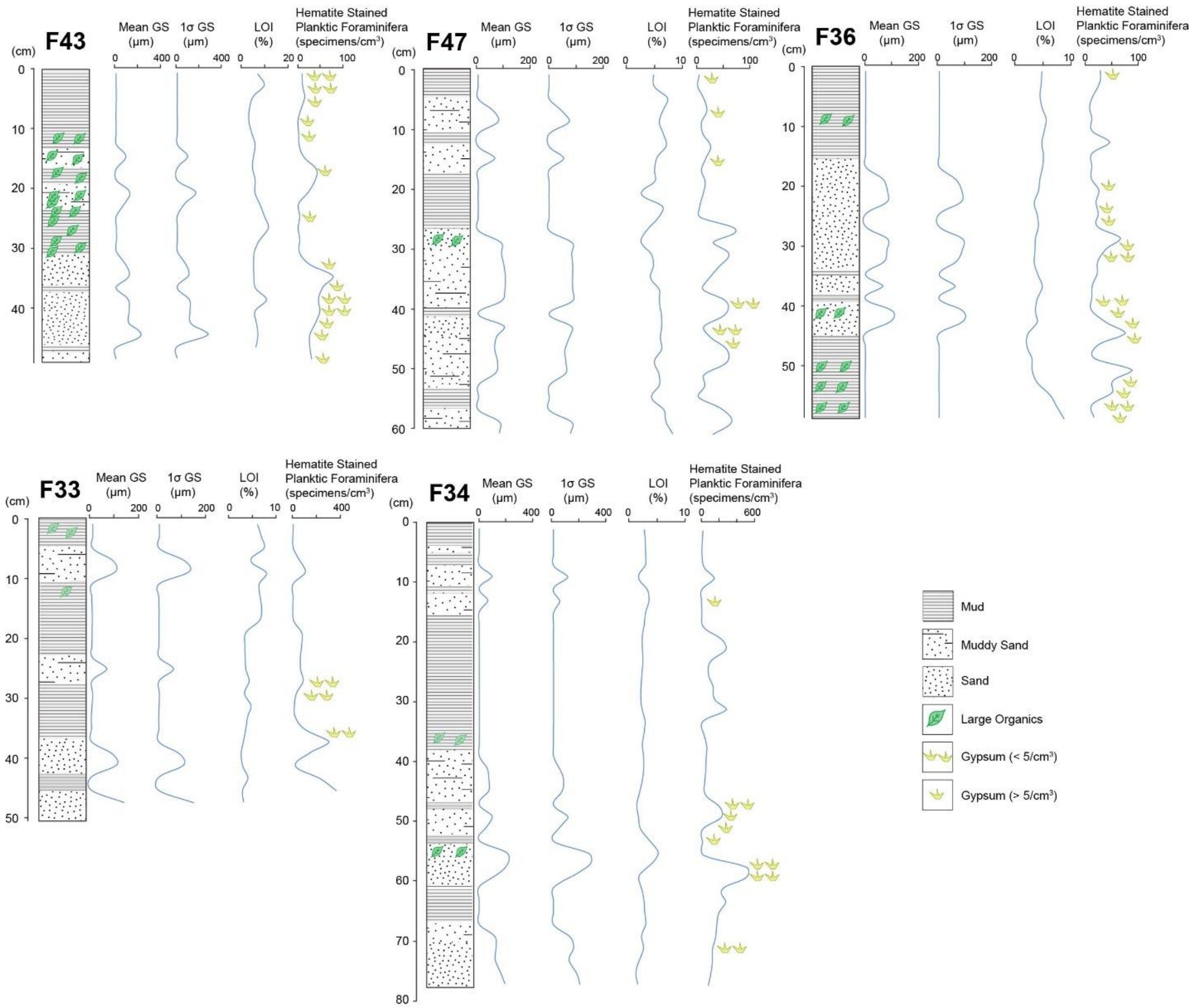

Figure 11. Core analyses including particle-size, loss on ignition (LOI) and abundance of hematite stained foraminifera and gypsum clusters.

The micropalaeontological analysis of the cores indicates the sediment source. Hematite stained planktic foraminifera including undistinguished globigerinids and *Orbulina* that were often fragmented (Patterson et al., 1995; Reinhardt et al., 2000) (Figure 12). These specimens originated from weathered outcrops along the San Pasquale River valley and were transported directly from that source through flood events or through storms on to the shallow shelf. In addition, some of the tests showed gypsum overgrowths, but individual crystals and clusters were also found that may have formed in floodplain sediments or within the Miocene mudstones (Figure 12). There was a tendency towards increased hematite stained foraminifera and gypsum content with increased grain-size and organic content. The delicate fragile nature of the gypsum and the floodplain organic matter, suggests periods of direct transport from source to sink, with little residence time on the shallow shelf.

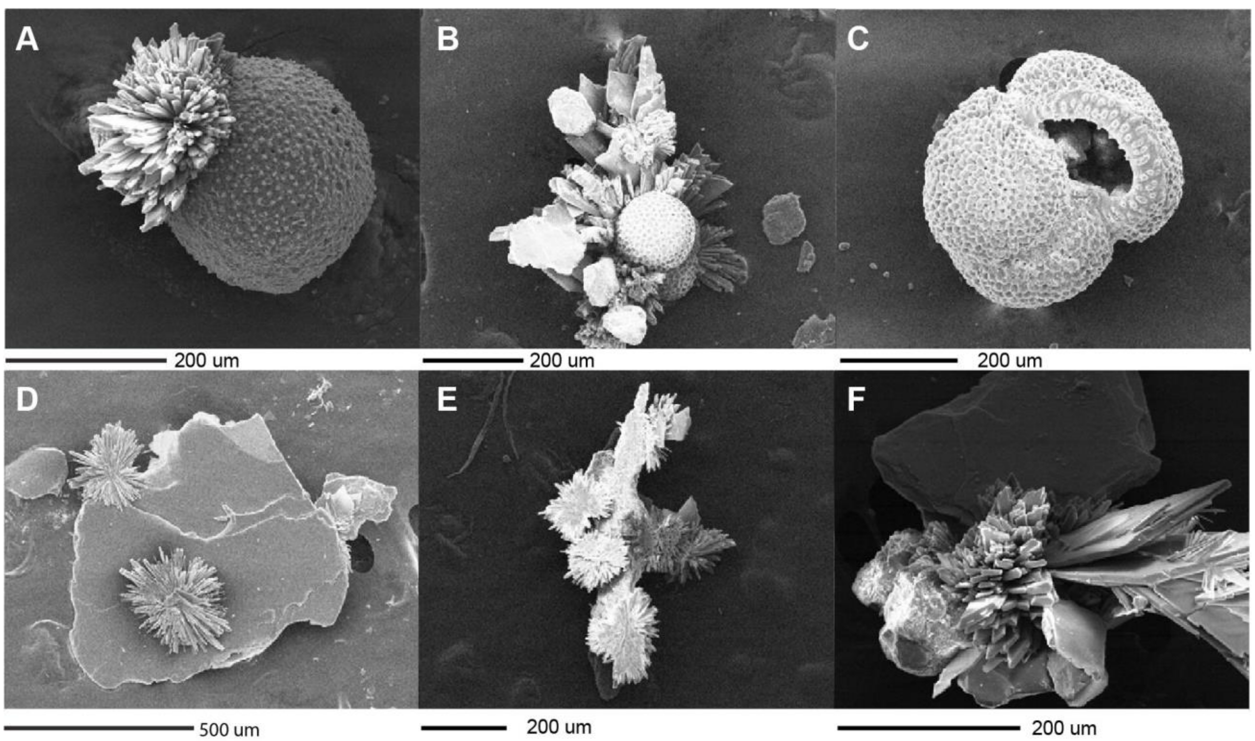

Figure 12. SEM images showing: A) gypsum crystals on an *Orbulina* fragment, B) Gypsum clusters with planktic foraminifera test, C) Miocene planktic foraminifera showing oxy-hydroxide coating and interior diagenetic calcite or gypsum. D) – F) details of gypsum crystals.

4.4 Palaeoecology

Three samples from the organic strata were studied for plant remains. These samples were dominated by waterlogged remains of plants including seeds, leaves and other plant parts (Table 1, supplementary material). A mosaic of habitats including woodland, aquatic/wetland, and terrestrial open and coastal species is represented.

All three samples consisted of very compacted organic material with little or no inorganic material. Radiocarbon dates were taken on material from samples 2 and 3 (6280-6010 cal BP and 6180-5900 cal BP respectively) (see Figure 8). All samples contained identifiable woody remains of twigs and larger branches. Leaf fragments, including those of ferns (*Pteridophyte*) and mosses (*Musci*), and other plant remains such as seeds were present (see Table 1, supplementary material). Readily identifiable remains of oak (*Quercus sp.)* acorns and their cupules were present in all three samples. Whole pine cones were present in the bulk samples, as were a few cone bracts in samples 1-3. Charcoal was recorded in all three samples and in some cases was of sufficient size to be identifiable. In addition to charcoal, some plant remains were preserved by charring, including remains of barley (*Hordeum vulgare*).

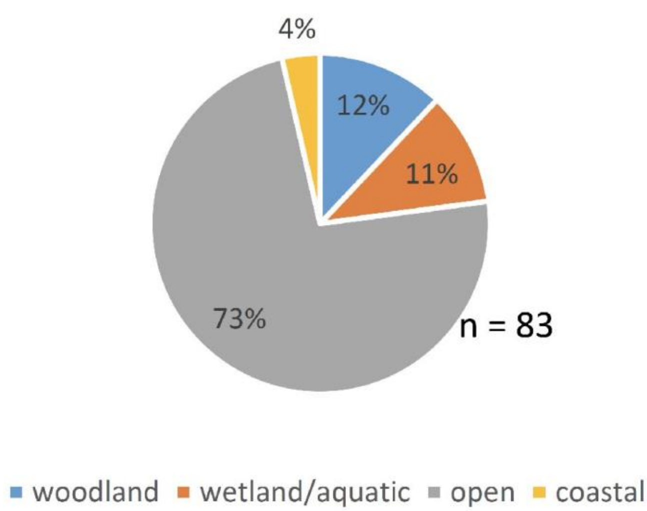

Figure 13. Overall percentage of taxa per habitat type in botanical samples BS2 and BS3 (see Figure 7) with detailed identification and quantities provided in Supplementary Material Table 1**.**

5.0 Discussion

5.1 Origin of Terrestrial Organic Beds

The extraordinary preservation of unsorted organic matter, including not only twigs and branches but also the fine component of leaves, seeds and wood, is unusual under normal sedimentary deposition on shelves; in most events where organic material is transported into the marine system, the fine sediments (i.e. fine silt, mud) remains in suspension and is dispersed. As such it was initially hypothesised that the organic sediments were deposited in a rapid sedimentary event such as a rapid depositional landslide – potentially related to an earthquake or tsunami event – or to meteorological or hydrological factors, such as heavy and prolonged precipitation (Kyoji and Canuti, 2009). A rapid mass wasting event, or series of events, is also suggested by the presence of preserved tree trunks and larger branches within cobble-rich deposits.

The detailed core analysis indicates rapid depositional sedimentary events of varying scale, whilst the lack of post depositional bioturbation further supports the interpretation of rapid burial. The unsorted nature of the sediment deposits suggests the organic material was deposited within a debris flow. As the energy of the turbulent flow waned, the finer sediment settled out of suspension, rapidly capping the organic horizon and thus preventing the finer organic material from being washed away. It is the rapid burial within this anoxic environment that led to the excellent levels of organic preservation. These sedimentary sequences are likely to have been deposited by hyperpycnal flows triggered by flash-flood events.

In the offshore zone, hyperpycnal flows can carry large concentrations of silt clay and mud in addition to organic matter; they are important sediment transport mechanisms that move continental sediments out into deep water (Lamb and Mohrig 2009; Felix et al., 2006; Mulder et al., 2003; Piper and Normark, 2009). However, the importance of these episodic events for the transportation of sediment onto the continental shelf has been relatively understudied (Khan et al., 2005; Syvitski et al., 1999; Traykovski et al., 2000; Wheatcroft and Borgeld, 2000) and has never been considered in relation to potential archaeological preservation. Offshore density flows, such as turbidity currents, occur when sediment laden water flows down slope (Lamb and Mohrig, 2009; Mulder and Syvitski 1995; Mulder et al., 2003). Hyperpycnal flows are a form of density flow that occur on the shelf when there is an increase in both fluvial flow discharge and sediment load. When density of the sediment-laden water coming from the fluvial outflow exceeds the density of the target basin water, the flow will plunge, resulting in a hyperpycnal flow. Lamb et al. (2008) determined that approximately 40g/l of suspended sediment is required to produce a large enough density contrast to produce a plunging flow. Whilst the concentrations of suspended sediment needed to generate a turbidity current can vary depending on salinity and environment (Felix et al., 2006), a significant source of sediment and outflow needs to be available to produce a hyperpycnal flow. The resulting sedimentary deposits, hyperpycnites, can be specifically linked to flash-flood events, and can reflect flood duration and flow velocity (Mulder et al. 2003).

The environment of the San Pasquale valley fits well with this interpretation. The steep sided valley and seasonal storms mean that the *fiumara* is prone to flash-flooding and increased outflow. In this region active tectonics and the potential for mass wasting events, such as landslides and coastal slumping, mean that sediment loads can be high, generating the conditions necessary for hyperpycnal flows to form. The organic horizons may have occurred rapidly as a result of one specific event or represent a series of events more chronologically distinct. AMS radiocarbon dating suggests these events occurred at some point between 6280-5900 BP (Figure 8). If these horizons represented modern sedimentary events carrying recently eroded prehistoric material from another source, it would be unlikely the organic component would be so well preserved; equally, intermixing of wash-in material is unlikely. The high level of preservation indicates that the organic material must have been rapidly transported and buried. As such we can conclude that these event horizons represent isolated flash-flood and hyperpycnal mud flows that occurred in prehistory, thus providing a window into the nature of the landscape and palaeoenvironment of the San Pasquale valley at that time.

The Mediterranean area has a climate that consists of warm wet winters and dry hot summers. Rains in the winter can be very heavy and a large amount of rain can fall in a very short time (Grove and Rackham, 2003). These deluges can saturate the ground very quickly, especially late in the rainy season when the soil is already close to water holding capacity. When this happens, the water runs off over the surface and can carry the soil and the vegetation with it down the river valley in a torrent. If incorporated into an offshore mudflow, or hyperpycnal flood, these rafts of vegetation and organic material are quickly deposited and buried in fine mud.

Recently, Casalbore et al. (2011) documented the effects of flash-flood hyperpycnal flows generating shallow water landslides at *fiumare* mouths in in the western Messina Straits, documenting sediment transport patterns. Although they did not document any significant terrestrial organic concentrations, they did document an eroded tree offshore, similar to the tree with preserved root-ball documented in our study.

5.2 Terrestrial Palaeoecology

The presence of charred material and charcoal could be interpreted as resulting from human activity in the area, or, may have been caused by natural fire such as that induced by lightning strikes. However, the charred cereal remains, in the form of a rachis fragment (sample 1) and a single grain (sample 2) of barley (*Hordeum vulgare*) suggest some local human activity. Grain remains often become carbonised during plant processing; *Hordeum vulgare* was also found on the nearby Neolithic sites of Umbro and Penitenzeria.

The presence of moss remains (leaves and stems) and fern pinnule fragments suggests that there were damp, shaded areas, and it is most likely that these remains are associated with the tree species such as oak and possibly pine (*Pinus* sp). The presence of alder (*Alnus glutinosa*), silver birch (Betula pendula) and hazel (*Corylus avellana*) suggests the presence of deciduous woodland, with some areas being wet enough to support alder (Clapham, 1999). It is most likely that the slopes and edges of the San Pasquale valley had areas of deciduous woodland, with some pine on the higher drier slopes. This was bordered towards the river by a wetland consisting of common reed (*Phragmites australis*), reedmace (*Typha* sp), sedges (*Cyperus* sp), grey club-rush (*Schoenoplectus tabernaemontani*), rushes (*Juncus* sp) and spike-rush (*Eleocharis* sp). Aquatic species including fool's water-cress (*Apium nodiflorum*) and soft hornwort (*Ceratophyllum submersum*) were growing in the more open water away from the fringe of wetland plants.

The largest number of plant taxa in the samples were of open habitats (Figure 13). This type of habitat is abundant within the Mediterranean landscape and the taxa present here could well represent a wide range of different types of open habitat including bare ground (and cultivation), such as the medicks (*Medicago* sp), fumitory (*Fumaria* sp), and pheasant's-eye (*Adonis* sp). Other open habitats may have consisted of shrubs and undershrubs such as heather (*Erica* sp), and rosemary (*Rosmarinus* sp), other areas may have been covered with grassland with a mixture of grasses and other wild-flowers (see for example: Blamey and Grey-Wilson, 1993; Stace, 2010).

The location of this mosaic of open land is difficult to assess. It is most likely that the river in the past, as now, may well have been seasonal, or with a perennial small volume of flowing water. The river channel may have been braided with gravel and sand islands on which many of these plant taxa could grow, creating a very varied openly vegetated landscape. Coastal environments were also present and indicated by a small number of taxa in the samples, including sea beet (*Beta vulgaris*), sea holly (*Eryngium maritmum*), and radish (*Raphanus raphanistrum*) and salt marshes (*Limonium* sp).

5.3 Archaeological Implications

Whilst steep coastal shelves are less likely to preserve submerged sites *in situ*, they can still preserve secondary deposits that contribute to our understanding of the local palaeoenvironment and aid reconstruction of coastal landscapes; enriching our interpretation of terrestrial archaeology. Indeed, it is the very instability of these coastlines that provides excellent conditions for preservation; sedimentary and tectonic events cause rapid erosion and deposition that can create excellent preservation environments for organic material in the marine environment. In addition, the ongoing dynamism of these landscapes mean that these archives are not simply buried in deep sediment but have the potential to be rapidly exposed on the seabed by further sedimentary or tectonic events, making them detectable and accessible. These active coastal zones, whilst not the traditional geomorphological setting for the preservation of submerged landscape archaeology or *in situ* palaeoenvironmental deposits, can hold transported sedimentary archives that are significant for understanding prehistoric coastal landscapes and land use.

In the case of the southern Italian Neolithic, but also more widely in the Mediterranean, our knowledge of the botanical environment is limited. With the exception of rare waterlogged sites, such as La

Marmotta (Fugazzola Delpino et al., 1993) and a few pollen cores (Magny et al., 2011; Tinner et al., 2009; Noti et al., 2009), our knowledge of the plants surrounding Neolithic sites is restricted to preserved remains, often charred, excavated from terrestrial sites. This skews discussions of palaeoecology in the Mediterranean Neolithic to domesticated species, particularly grains, or to tree cover associated with climate reconstructions from the pollen records. Yet when attempting to understand Neolithic life, it is clear that such a limited environmental reconstruction affects our understanding of the past. To understand the local vegetation is to provide context to activity and diet, to bring the landscape to life with meals, perfumes, colour and flavour. It changes how we visualise and interpret the past. This is particularly relevant to understanding the Neolithic, where a nuanced understanding of local landscape may help to better comprehend subsistence changes, pastoralism and the introduction of agriculture.

Furthermore, the dynamic nature of these coastlines reminds us that landscapes are active, ever changing processes, rather than static backdrops for prehistoric activity or archaeological research. Destructive flash-flooding and erosion are common around the Mediterranean today; especially on the steeply shelving central Mediterranean coasts (Casalbore et al., 2011). Such coastal flooding is often blamed upon modern deforestation and overgrazing, which lead to the loss of the plant cover securing the soil, and thus to subsequent erosion. When combined with increased coastal development (Antonioli et al., 2017:345), landslides and flash-flood events become a serious geohazard for modern urban planning and Integrated Coastal Zone Management. The potential *longue durée* to these events is overlooked. Within the archaeological record, markers for specific weather events are hard to identify; the archaeological record is usually better suited to reconstructions on the scale of climate and patterns of temperature and rainfall. Therefore, contexts that help us understand reoccurring weather events, and sedimentary events that shaped the landscape, and lives of the people within it in prehistory, are of particular interest. If our goal is to understand the coastal zone and to integrate the onshore-offshore narratives, the potential of these steeply shelving, tectonically active coastal landscapes should not be overlooked.

In addition to adding to our knowledge of the general palaeoecology of the San Pasquale valley at the end of the Neolithic, these samples tantalizingly suggest a human-modified landscape. The presence of barley, oats and legumes suggests human presence close by. Meanwhile, many of the species present are typical of those colonising the margins of human-disturbed environments (i.e. spotted and toothed medicks, sainfoin, fumitories, fat hen and clover) and this may reflect land clearance. When viewed as a whole, these samples seem to capture the beginnings of change within the San Pasquale valley, from the natural vegetation of the gallery forests along the river course, to one that is adapting to continuous disturbance, most likely, due to nearby human activity, resulting in the production of maquis and garrigue that is characteristic of the region today. It is also noted, how many of the taxa recovered within these samples represent plants that have human uses, for food (brambles, figs, capers, oats, barley, legumes, wild carrot, chicory, rosemary, mints, oregano, basil, hops), medicinal purposes: vervain, valerian, wormwood, black nightshade, soapwort and St John’s Wort, or other practical purposes (flax and reeds). Indeed, this is a rich assemblage which, even without directly associated archaeological material, suggests a human-created landscape at or close to the mouth of the San Pasquale River; it gives us unique evidence complementing normal finds-based archaeological knowledge of landscapes. Such a location would have combined a perennial source of fresh water, access to a rich range of resources from multiple terrestrial, littoral and marine environments, and a potentially useful inlet for launching and landing boats. Yet the flash-flooding that carried this raft of vegetation out to sea, and rapidly buried it on the shelf, also attests the potential dangers of living in such a location, in prehistory as much as today.

It is within the Aspromonte foothills, on high ground or rocky promontories overlooking the sea, where the majority of prehistoric finds have been made (Robb et al., 2008). The foothills of the Aspromonte may have been an attractive place to live in prehistory, with fresh water springs, cooler air, raw materials and good visibility. However, the lack of archaeological evidence in the fertile river valleys and coastal corridor has been considered surprising, especially with the evidence that maritime trade and coastal contact was important (evidenced by the high concentration of Liparian obsidian and Sicilian flint in the lithic record) (Farr 2006). If seasonal flash-flood events, and landslides were indeed features of these *fiumare* and steep shelving coastline, did prehistoric communities choose higher ground for their settlements in the past? Or, has any direct evidence of occupation been eroded? According to the Italian landslide inventory I. F. F. I. project (Guerrieri, et al., 2008) extremely rapid debris flows account for 14.9% of landslides in Italy and identification of these geohazards plays an important role in urban planning and protection of cultural heritage.

From our series of short cores, it is not possible to comment on the potential frequency of offshore hyperpycnal events; more recent organic deposits may have been eroded and older events may be buried within the offshore plateau. However, flash-floods are common in the region today but are attributed to coastal development, changes in land use, aridification and variations in precipitation patterns in relation to current climate change. The existence of an offshore flood deposit predating historic land use intensification and coastal development is significant. Could flash-floods in prehistory also relate to modification of the land, increased pastoralism and land clearance? The palaeoecological data recovered from these samples suggests human activity in the valley and the introduction of human modifications to this landscape. Further coring onshore will enable flood sequences to be identified and enable the palaeo frequency of these events to be analysed. This in turn could help resolve questions surrounding the lack of preserved prehistoric sites directly on the coast.

6.0 Conclusions

This research is significant for a number of reasons beyond elucidating our understanding of the coastal geology and dynamics of the shelf. Due to the narrow shelf, uplift and the active tectonic nature of the coast, this region would not be targeted for maritime archaeological survey for submerged landscapes. However, the very active nature of this coastal landscape has preserved organic remains that can inform us about several interesting issues: the local palaeoenvironment, through species that are rarely preserved on land; probable cultivation and land clearance; the nature of the river valley and coastal zone in the past; and finally, the *longue durée* of flash-flooding in the region that predates the historic records of land clearance from which it was believed to have resulted.

The preserved organic data enriches our understanding of the local palaeoenvironment and the nature of the landscape in the Final Neolithic for this region. Whilst the known terrestrial sites preserve very little organic material, these deposits reveal a rich mosaic of local habitats, much damper than today with a wide variety of taxa, including the local weeds, herbs and wild flowers that are rarely preserved in the terrestrial record. Additionally, these deposits provide potential evidence for land clearance and agriculture that are supported by the archaeological record on nearby sites. The longstanding archaeological survey in the area provides us with the archaeological context of what people were doing within this landscape through the Neolithic and into the Bronze Age (Robb 2002) but little is known about the Final Neolithic and Copper Age in this region. Whilst not an archaeological site, these organic deposits have archaeological relevance for this period, suggesting ongoing activity within this local landscape, but also revealing the dynamic nature of this landscape.

Viewing the offshore palaeoenvironmental data alongside the regional archaeological narrative begins to blur the boundaries between 'maritime' and terrestrial data, and the division between coastal landscapes and submerged prehistory. In a landscape like that of southern Calabria, the coastal zone is highly dynamic; appreciating this dynamism in the past helps us to understand how people lived within their landscape in prehistory. The environment shapes people's activity, movement and perception of time (Ingold, 2000:189). Rather than determining human activity the environment can be seen to add texture (Evans, 2003:45), providing an additional dimension to the narratives we tell about the past (Thomas, 1996:91). This is particularly true in the active coastal environment. Therefore, to understand prehistoric activity, and the presence or absence of archaeological material in the coastal zone, it is necessary to understand the specific local coastal dynamics alongside narratives of regional and global environmental change.

This research highlights the value of shelf sedimentary archives for understanding local onshore environments and serves as a reminder that landscapes, whether terrestrial or submerged, are active, ever changing processes, rather than static backdrops for archaeological research.

Acknowledgements

This research has been funded by the Arts and Humanities Research Council (Grant AH/E00783X/1) and the McDonald Institute for Research, Cambridge (Farr and Robb) and Natural Sciences and Engineering Research Council of Canada (Boyce and Reinhardt).

We thank Professor Martin Jones for his guidance with the archaeobotanical material and Dr Rob Scaife for his support and analysis of samples for potential pollen preservation; Dr Fabio Filianoti and the Mediterranean University of Reggio Calabria; Daniel Riordan, Dan MacKay and Jeremy Gabriel for diving assistance and logistics; the Soprintendenza di Reggio Calabria for their continued support for the Bova Marina Archaeological Project; and our colleagues on the Bova Marina Archaeological Project (Meredith Chesson, Glenn Dunaway, Lin Foxhall, Paula Lazrus, Kostalena Michelaki, and David Yoon) for their help and advice during fieldwork.

References

Allen, J. R. M., Watts, W. A., Huntley, B., 2000. Weichselian palynostratigraphy, palaeovegetation and palaeoenvironment: the record from Lago Grande di Monticchio, southern Italy. Quaternary International, 73-74, 91-110. https://doi.org/10.1016/S1040-6182(00)00067-7

Antonioli, F., Chiocci, F. L., Anzidei, M., Capotondi, L., Casalbore, D., Magri, D., Silenzi, S., 2017. The Central Mediterranean, in: Flemming, N. C., Harff, J., Moura, D., Burgess, A., Bailey, G. N. (Eds.), Submerged Landscapes of the European Continental Shelf: Quaternary Palaeoenvironments. COST European Cooperation in Science and Technology, Wiley Blackwell, Oxford pp. 341-376.

Bailey, G. N., Flemming, N. C., 2008. Archaeology of the continental shelf: Marine resources, submerged landscapes and underwater archaeology. Quaternary Science Reviews, 27, Issues 23-24, 2153-2165. https://doi.org/10.1016/j.quascirev.2008.08.012

Bailey, G., Sakellariou, D. & members of the SPLASHCOS network, 2012. SPLASHCOS: Submerged Prehistoric Archaeology and Landscapes of the Continental Shelf. Antiquity Project Gallery 86(334): http://www.antiquity.ac.uk/projgall/sakellariou334/

Bailey, G. N., Harff, J., Sakellariou, D., 2017. Archaeology and Palaeolandscapes of the Continental Shelf: An Introduction, in: Bailey, G. N., Harff, J., Sakellariou, D. (Eds.), Under the Sea: Archaeology and the Palaeolandscapes of the Continental Shelf. Coastal Research library, volume 20, Springer, Switzerland, pp. 1-20. DOI 10.1007/978-3-319-53160-1

Bell, M. 2007. Prehistoric Coastal Communities: The Mesolithic of western Britain. CBA Research Report 149, Council for British Archaeology, York.

Benjamin, J., Bonsall, C., Pickard, C., Fischer, A., 2011. (Eds.) Submerged Prehistory. Oxbow, Oxford.

Blamey, M., Grey-Wilson, C., 1993. Mediterranean Wild Flowers. Harper Collins, London.

Brondi, A., Cicero, A. M., Magaletti, E., Giovanardi, F., Scarpato, A., Silvestri, C., Spada, E., Casazza, G., 2003. Italian Coastal Typology for the European Water Framework Directive, in: Özhan, E. (Ed.), Proceedings of the Sixth International Conference on the Mediterranean Coastal environment. MEDCOAST E 03, 7-11 October 2003, Ravenna. Vol II, 1179-1188.

Cappers, R. T. J., Bekker, R. M., Jans, J. E. A., 2006. Digital seed atlas of the Netherlands. Barkhuis Publishing & Groningen University Library, Groningen.

Casalbore, D., Chiocci, F. L., Scarascia Mugnozza, G., Tommasi, P., Sposato, A., 2011. Flash flood hyperpycnal flows generating shallow water landslides at fiumara mouths in Western Messina Straits (Italy). Marine Geophysical Research, 32, 257-271. https://doi.org/10.1007/s11001-011-9128-y

Cavazza, W., DeCelles, P. G., 1993. Geometry of a Miocene submarine canyon and associated sedimentary facies in southeastern Calabria, southern Italy. Geological Society of America Bulletin, 105, 1297-1309.

Clapham, A. J., 1999. The Characterisation of two mid-Holocene submerged forests. Unpublished PhD thesis, Liverpool John Moores University, Liverpool.

Di Rita, F., Fletcher W. J., Aranbarri, J., Margaritelli, G., Lirer, F., Magri, D., 2018. Holocene forest dynamics in central and western Mediterranean: periodicity, spatio-temporal patterns and climate influence. Nature Scientific Reports, 8, 8929. DOI:10.1038/s41598-018-27056-2

Donato, S. V., Reinhardt, E. G., Boyce J. I., Pilarczyk, J. E., Jupp, B.P., 2009. Particle-size distribution of inferred tsunami deposits in Sur Lagoon, Sultanate of Oman, Marine Geology, 257, 54-64.

Drake, D. E., 1999. Temporal and spatial variability of the sediment grain-size distribution on the Eel shelf: the flood layer of 1995. Marine Geology, 154, 169–182. https://doi.org/10.1016/S0025-3227(98)00111-X

Erlandson, J. M., 2001. The archaeology of aquatic adaptations: paradigms for a new millennium. Journal of Archaeological Research, 9, 287-350. DOI: 10.1023/A:1013062712695

Evans, J. G., 2003. Environmental Archaeology and the Social Order. Routledge, London and New York.

Farr, R. H., 2003. Analisi dell'industria litica proveniente dai siti di Umbro e Penitenzeria, Bova Marina, Calabria. Atti, XXXVII Calabria 2002, Riunione Scientifica dell'Istituto Italiano di Preistoria e Protostoria 38, 757-760.

Farr, R. H., 2006. Seafaring as social action. Journal of Maritime Archaeology, 1, 85–99. doi.10.1007/s11457-005-9002-7

Felix, M., Peakall, J., McCaffrey, W.D., 2006. Relative importance of processes that govern the generation of particulate hyperpycnal flows: Journal of Sedimentary Research, 76, 382–387 doi: 10.2110/jsr.2006.022.

Flemming, N. C., Harff, J., Moura, D., Burgess, A., Bailey, G. N., 2017. (Eds.), Submerged Landscapes of the European Continental Shelf: Quaternary Palaeoenvironments. COST European Cooperation in Science and Technology, Wiley Blackwell, Oxford. doi:10.1002/9781118927823

Follieri, M., Giardini, M., Magri, D., Sadori, L., 1998. Palynostratigraphy of the last glacial period in the volcanic region of central Italy. Quaternary International, 47-48, 3-20.

Fugazzola Delpino, M. A., D'Eugenio, G., Pessina, A., 1993. La Marmotta. Bullettino di Paletnologia Italiana, 48, 181-342.

Grove, A. T., Rackham, O., 2003. The Nature of Mediterranean Europe: An Ecological History. Yale University Press, Yale and London.

Guerrieri, L., Triglia, A., Iadanza, C., 2008. The I. F. F. I. Project (Italian landslide inventory): Methodology and Results Experts meeting on guidelines for mapping areas at risk of landslides in Europe JRC, Ispra 23-24 October2007:https://esdac.jrc.ec.europa.eu/Library/Themes/ Landslides/Meeting102007/Landslides_IFFI.pdf (accessed on 15/07/2019)

Heiri, O., Lotter, A. F., Lemcke, G., 2001. Loss on ignition as a method for estimating organic and carbonate content in sediments: reproducibility and comparability of results. Journal of Paleolimnology, 25, 101-110. https://doi.org/10.1023/A:1008119611481

Ingold, T., 2000. The perception of the environment, essays on livelihood, dwelling and skill. Routledge, Abingdon and New York. ISBN-13: 978-0415617475

Joannin, S. et al., 2012. Pollen-based reconstruction of Holocene vegetation and climate in southern Italy: the case of Lago Trifoglietti. Climate of the Past 8, 1973-1996.

Khan, S. M., Imran, J., Bradford, S., Syvitski, J., 2005. Numerical modelling of hyperpycnal plumes Marine Geology, 222-223, 193-211. https://doi.org/10.1016/j.margeo.2005.06.025

Kyoji, S., Canuti, P. (Eds.), 2009. Landslides: Disaster Risk Reduction. Springer, Berlin and Heidelberg. https://doi.org/10.1007/978-3-540-69970-5_30

Lamb, M.P., Myrow, P.M., Lukens, C., Houck, K., Strauss J., 2008, Deposits from wave-influenced turbidity currents: Pennsylvanian Minturn Formation, Colorado, USA: Journal of Sedimentary Research, 78, 480-498 doi: 10.2110/jsr.2008.052.

Lamb, M. P., Mohrig, D., 2009. Do hyperpycnal-flow deposits record river-flood dynamics? Geology 37(12), 1067-1070. doi: 10.1130/G30286A.1

Lambeck, K., Antonioli, F., Purcell, A., Silenzi, S., 2004. Sea level change along the Italian coast for the past 10,000 years. Quaternary Science Reviews, 23, 1567-1598. https://doi.org/10.1016/j.quascirev.2004.02.009

Lear, E., 2003. Diario di un viaggio a piedi, Reggio Calabria e la sua Provincia (25 Luglio-5 Settembre 1847) Laruffa Editore, Reggio Calabria.

Le Pera, E., Sorriso-Valvo, M., 2000. Weathering, erosion and sediment composition in a high-gradient river, Calabria, Italy. Earth Surface Processes and Landforms 25(3), 277-292. https://doi.org/10.1002/(SICI)1096-9837(200003)25:3%3C277::AID-ESP79%3E3.0.CO;2-Z

Magny, M., Vannière, B., Calo, C., Millet, L., Leroux, A., Peyron, O., Zanchetta, G., La Mantia, T., Tinner, W., 2011 Holocene hydrological changes in south western Mediterranean as recorded by lake-level fluctuations at Lago Preola, a coastal lake in southern Sicily, Italy. Quaternary Science Reviews, 30, 2459-2475 https://doi.org/10.1016/j.quascirev.2011.05.018

Michelaki, K., Hancock, R. G. B., Braun, G. V., 2012. Using provenance data to assess archaeological landscapes: an example from Calabria, Italy. Journal of Archaeological Science 39, 234-246 doi:10.1016/j.jas.2011.08.034

Michelaki, K., Braun, G. V., Hancock, R. G. B., 2015. Local Clay Sources as Histories of Human–Landscape Interactions: a Ceramic Taskscape Perspective J Archaeol Method Theory (2015) 22, 783–827 doi:10.1007/s10816-014-9204-0

Mulder, T., Syvitski, J., Migeon, S., Faugeres, J., Savoye, B., 2003. Marine Hyperpycnal Flows: Initiation, behavior and related deposits. A review. Marine and Petroleum Geology, 20, 861-882. http://dx.doi.org/10.1016/j.marpetgeo.2003.01.003

Mulder, T., Syvitski, J., 1995. Turbidity currents generated at river mouths during exceptional discharges to the world oceans. Journal of Geology, 103, 285-299. https://doi.org/10.1086/629747

Noti, R., van Leeuwen, J. F. N., Colombaroli, D., Vescovi, E., Pasta, S. C., La Mantia, T., Tinner, W., 2009. Mid- and Late-Holocene vegetation and fire history at Biviere di Gela, a coastal lake in southern Sicily, Italy. Vegetation History and Archaeobotany, 18, 371-387. doi: 0.1007/s00334-009-0211-0

Patterson, R.T., Blenkinsop, J., Cavazza, W., 1995. Planktic foraminiferal biostratigraphy and 87Sr/86Sr isotopic stratigraphy of the Oligocene-to-Pleistocene sedimentary sequence in the southeastern Calabrian microplate, southern Italy, Journal of Paleontology, 69(1), 7-20.

Piper, D. J. W., Normark, W. R., 2009. Processes that initiate turbidity currents and their influence on turbidites: A marine geology perspective. Journal of Sedimentary Research, 79, 347-362. https://doi.org/10.2110/jsr.2009.046

Reinhardt, E. G., Patterson, R. T., Cavazza, W., Blenkinsop, J., 2000. Use of Bulk-Rock Samples for Strontium Isotope Analysis: Implications of Differential Diagenesis on High Precision Results: Chemical Geology, 164, 331-343.

Ridente, D., Martorelli, E., Bosman, A., Chiocci, F. L., 2014. High-resolution morpho-bathymetric imaging of the Messina Strait (Southern Italy). New insights on the 1908 earthquake and tsunami. Geomorphology, 208, 149-159.

Robb, J. E. 1997. Bova Marina Field Survey: Preliminary Report, 1997 season. University of Cambridge.

Robb J. E. 2002. Scavi Neolitici e di Età del Bronzo ad Umbro, Bova Marina, Reggio Calabria. Atti, XXXV Lipari 2000, Riunione Scientifica dell'Istituto Italiano di Preistoria e Protostoria, 35, 955-958.

Robb, J. E., van Hove, D. 2003. Gardening, foraging, and herding: Neolithic land use and social territories in southern Italy. Antiquity, 77, 241-254.

Robb, J. E. 2004. Il Neolitico dell'Aspromonte meridionale. Atti, XXXVII Calabria 2002, Riunione Scientifica dell’Istituto Italiano di Preistoria e Protostoria 38, 175-188.

Robb, J. E., Farr, R. H., 2005. Substances in motion: Neolithic Mediterranean “Trade”, in: Blake, E., Knapp, A. B., (Eds.) The Archaeology of Mediterranean Prehistory. Blackwell Studies in Global Archaeology, 6. Blackwell Publishing Ltd., Chichester, pp. 24–46.

Robb, J. E., Michelaki, K., 2007. Agency, skill, and creativity: pottery decoration in Neolithic southern Italy, in Madsen, N., Jensen, H., Jessen, M. (Eds.) Excavating the Mind: cross-sections through culture, cognition and materiality. Aarhus University Press, Aarhus.

Robb, J. E. 2007. Scavi Neolitici a Umbro e Penitenzeria (Bova Marina, Calabria): Rapporto Preliminare. In Laganà, C. and Tinè, V. (Eds.) La Preistoria della Calabria: Atti del 2 Convegno, Pellaro: Gruppo Archeologico Pellarese.

Robb, J. E., Chesson, M., Farr, R. H., Lazrus, P., Michelaki, K., White, C., Wolff, C., Yoon, D., 2008. Bova Marina Archaeological Project: preliminary report, 2008 session. University of Cambridge.

Sommerfield, C. K., Nittrouer, C. A., 1999. Modern accumulation rates and a sediment budget for the Eel shelf: a flood-dominated depositional environment, Marine Geology, 154, 1-4, 227-241 https://doi.org/10.1016/S0025-3227(98)00115-7.

Sonnenburg, E. P., Boyce, J. I., 2008. Data-fused digital bathymetry and side-scan sonar as a base for archaeological inventory of submerged landscapes in the Rideau Canal, Ontario, Canada. Geoarchaeology, 23, 654-674.

Stace, C., 2010. New Flora of the British Isles. 3rd Edition. Cambridge University Press. Cambridge.

Syvitski, J.P., Morehead, M.D., 1999. Estimating river-sediment discharge to the Eel margin, northern California. Marine Geology, 154, 13-24.

Thomas, J., 1996. Time, Culture and Identity, an interpretative archaeology. Routledge, London and New York.

Tinner, W., van Leeuwen, J. F. N., Colombaroli, D., Vescovi, E., van der Knaap, W.O., Henne, P.D., Pasta, S., D'Angelo, S., La Mantia, T. 2009. Holocene environmental and climatic changes at Gorgo Basso, a coastal lake in southern Sicily, Italy. Quaternary Science Reviews 28, 1498-1510. https://doi.org/10.1016/j.quascirev.2009.02.001

Traykovski, P., Geyer, W. R., Irish, J. D., Lynch, J. F., 2000. The role of wave-induced density-driven fluid mid flows for cross-shelf transport on the Eel River continental shelf. Continental Shelf Research, 20, 2113-2140.

Wheatcroft, R. A., Borgeld, J. C., 2000. Oceanic flood deposits on the northern California Shelf: large-scale distribution and small-scale physical properties. Continental Shelf Research, 20, 2163.

Supplementary Material

Table 1. Palaeobotanical data from analysis of diver collected organic bulk samples (see locations in Figures 2, 6 & 7 in paper). Table shows originating sample, taxa and common name of plant macrofossil material. Associated habitats of taxa provided, please refer to the key provided below.

Key to modern habitats of plant taxa presented in Table 1

	Wet/Aquatic
a	Aquatic

we	Wetland, streams/riversides, marshes
	Coastal
co	Coastal, seashores
sm	Salt marshes, salt flats
	Open
c	Cultivated, fields
f	Fallow
g	Garrigue
gr	Grassland
h	Hedgerows, roadsides
0	Olive groves, orchards, gardens, vineyards
r	Rocky places, sandy/stony pastures
wa	Waste places, disturbed ground
	Woodland
m	Maquis
s	Scrub
w	Woodland

Sample no.			**1**	**2**	**3**
Volume (ml)			**400**	**500**	**600**
Taxa	**Common name**	**habitat**			
Waterlogged					
Pinus sp	pine	r,w,			
cone bract			1		2
seed wing fragment			2		
cf *Ceratophyllum submersum*	soft hornwort	a			
seed fragments					1
Fumaria sp	fumitory	c,w,h,r,f			
seed			1		

seed fragments			37	4	
Adonis annua	pheasant's-eye	c,wa,o			
achene fragments					1
Onobrychis cf *vicifolia*	sainfoin	g,c,wa,h			
pod					1
Ornithopus compressus	compressed bird's-foot	g,r,gr,h			
pod			5		
pod fragments			1	5	
Scorpiurus muricatus	scorpiurus	c,wa,h			
fruit segments				6	1
fruit segment fragments				4	
Medicago polymorpha/arabica	toothed/spotted medick	c,wa,f,r,h			
fruit			7	35	52
fruit fragments			70	89	26
Medicago sp	medicks	c,wa,f,r,h			
fruits				2	
immature fruits				4	
fruit fragments				3	
Trifolium sp	clovers	c,f,gr,r,wa,we			
calyx			4	20	
calyx fragments			2		

Legume pod fragment	Pea family			1	
Rubus sp	bramble	w,h,r			
seeds			13		
seed fragments			64	11	
Agrimonia sp	agrimony	gr,wa,o			
seeds			1		
Rosaceae (*Rubus*/*Rosa* sp)prickles	Rose family		25	32	17
cf *Humulus lupulus*	hops	h,w			
seed			1		
seed fragments			2		
Ficus carica	fig	c,o			
seeds			9	1	2
seed fragments			179		
Quercus sp	oak	m,g,w,r			
immature acorn with cupule			2		
whole acorns			4		
acorn fragments			17	21	11
whole cupules			4	3	
immature whole cupules				3	2
cupule fragments			104	44	58
Betula pendula	silver birch	w,s			
cone scales				1	

seeds				4	
Alnus glutinosa	alder	w,we			
fruits			1	35	3
fruit fragments				6	2
female cones				8	12
cone scales			6	66	
cone rachis fragment			1		
Corylus avellana	hazel	w,s			
nutshell fragments			4	1	
Euphorbia helioscopa	sun spurge	c,w			
seeds			1		
seed halves			14		
seed fragments			16	1	
Euphorbia peplus	petty spurge	c,f,wa,we,co,h			
seeds			5		
Viola sp	violets	r,s,w,g,c			
seeds			1		
seed fragments			1		
Linum sp (small seeded)	flax	c,wa,gr			
seed				1	
Hypericum sp (type 1)	St. John's-wort	co,r,gr,we,w,h,s			
seeds			6		
seed fragments			4		

Hypericum sp (type 2)	St. John's-wort	co,r,gr,we,w,h,s			
seeds			4		
Lythrum portula/hyssopifolia	water purslane/grass-poly	we,c			
seeds			1		
cf *Daphne gnidium*	daphne	m,g,w,r			
seed fragments			1		
Thymelaea hirsuta	thymelaea	g,gr			
seeds			2		
seed fragments			15		
cf *Capparis spinosa*	caper	r,co			
seeds			1		
seed fragments			4		
Sinapis sp/*Cakile* sp	mustard/sea rocket	c,wa,f,co			
silicula beak			1		
Raphanus raphanistrum	wild radish	c,f,wa,h,co			
whole pod segment					1
pod fragments					2
cf *Limonium* sp	sea lavender	co			
seeds			4		
seed fragments			1		
Rumex sp	docks	co,c,w			
fruit				2	

nutlets			14	1	
nutlet fragments			2		
perianth				1	
valves				1	
Moehringia cf *pentandra*	moehringia	s			
seeds			1		
Stellaria media	chickweed	c,wa,f			
seeds				2	
seed fragments				1	
Cerastium sp	mouse-ear	w,h,gr			
seeds			1		
Stellaria sp/*Cerastium* sp	chickweed/mouse-ear	w,h,r,c,wa,f,gr			
seeds			9		
seed fragments			3		
Sagina sp	pearlwort	wa,co			
seed			1		
Silene gallica	small-flowered catchfly	c,f,wa,co			
seeds			6		
seed fragments			14		
Saponaria officinalis	soapwort	r,s			
seed fragments			2		

cf *Gypsophila* sp	gypsophilia	c,wa			
seed			1		
Chenopodium album	fat hen	c,f,h,o,co			
seeds				1	
Beta vulgaris (2-seeded)	sea beet	co,sm,c			
Fruit			2		
Fruit caps			3	1	
Montia fontana	blinks	we			
seed			3		
seed fragments			3		
Anagallis arvensis	scarlet pimpernel	c,f,wa,h,co			
seed			1		
cf *Calluna vulgaris/Erica* sp	ling	m,w,we,s,			
fruits			4	4	
cf *Erica* sp	heather	m,w,we,s,			
seeds			1		
Myosotis sp	forget-me-not	w,h,wa, we			
seeds			1		
Solanum nigrum	black nightshade	c,wa			
seeds			1		
lump of seeds (berry fragment)					2
Veronica sp	speedwell	c,wa,f,gr,o,h			
seeds				1	

Stachys sp	woundwort	gr,h,o,g,f,co			
nutlets			3		
Clinopodium vulgare	wild basil	gr,r,w,s,h			
nutlet			1		
Origanum sp	wild oregano	r,s,h,g			
nutlets			2		
Mentha sp	mints	we,c,o			
nutlets			5	1	2
Rosmarinus sp	rosemary	m,g,s,w,co			
leaf fragments			1		
Verbena officinalis	vervain	wa,r,gr,we			
seeds			3		
Cirsium sp	thistles	gr,s,w,c,o			
achenes			5		2
achene fragments			2	4	
Cnicus sp	blessed thistle	g,c,f,wa,o			
achene			1		
Cichorum intybus	chicory	g,gr,f,c,h,co			
achene				1	
Picris cf *echioides*	bristly oxtongue	gr,wa,c,h,o			
achene			3		
achene fragments			1	3	
Sonchus oleraceus	smooth sow-thistle	c,wa,f,h,o			

achene			1	1	
Lactuca serriola	prickly lettuce	c,f,wa,r,			
achene			1		
Artemesia sp	wormwood/mugwort	c,f,wa,gr,co			
achene			7		
Glebionis coronaria	crown daisy	c,f,wa,h,g,co			
flowerbud			1		
Senecio sp	ragwort	c,f,wa,h,co			
achene				4	
Calendula arvensis	field marigold	c,f,wa,h,o			
achene			1		
achene fragments			11		
Eupatorium cannabinum	hemp-agrimony	gr,we			
achene fragments			1		
Asteraceae indet	Daisy family				
achenes			7	1	
achene fragments			1		
phyllaries			11	1	
flower bases			2		
Sambucus ebulus	dwarf elder/danewort	s,h,we,c			
seeds			5		
seed fragments			5		

Valerianella locusta	common corn salad	c,f,m,g,			
seed fragments			35	7	1
Valerianella dentata	narrow-fruited corn salad	c,f,m,g,			
seeds			2		
seed fragments			3		
cf *Centranthus* sp	valerian	r,co			
seed				1	
Knautia sp	field scabious	gr,h,w			
fruits				5	
fruit fragments				5	
Scabiosa sp	scabious	r,wa,f,co,c,h,g			
achene			2		
achene fragments			1		
Cf *Eryngium maritimum*	sea holly	co			
mericarp			1		
Apium nodiflorum	fool's water-cress	we			
mericarps			2		1
mericarp fragments			1		
Daucus sp	carrot	gr,h,r,c,co			
mericarp			14	15	
mericarp fragments			1		
cf *Krubera perigrina*	krubera	c,f			

mericarp					1
Apiaceae indet	carrot family				
mericarp			1		
? Flowerheads					10
Typha sp	reedmace	we			
seeds			2	1	
Juncus sp	rushes	we			
seeds			2		
Schoenoplectus *tabernaemontani*	grey club-rush	we,co			
nutlets				1	
Eleocharis sp	spike-rush	we			
nutlets					4
Cyperus sp	sedges	we			
nutlets			4		
Phragmites australis	common reed	we,co			
rhizome fragment				1	
Poaceae	grasses				
culm node			1	5	8
lemma					1
Small Poaceae	grasses				
caryopsis			2		
Other plant remains					

Musci			132	100+	100+
leaf fragments inc Pteridophyte pinnae			211	1000+	1000+
Tree buds			13	10	16
Tree bud scales			146	25	6
large wood fragments			100+	100+	100+
Plant remains indet					
petals				3	
Other remains					
Cneococcum geophilum	soil fungus				
sclerotia			100+	1	1
Insect remains			48	10+	
Charred					
Hordeum vulgare 2-row	barley	c			
rachis fragment			1		
Hordeum vulgare	barley	c			
grain				1	
Vicia sp/*Lathyrus* sp	vetch/vetchling	c,wa,h,gr,g			
seed					1
Medicago polymorpha/arabica	toothed/spotted medick	c,wa,f,r,h			
fruit					2
Medicago sp	medicks	c,wa,f,r,h			

seed			1		
Lolium sp	ryegrass	c,wa,f,gr			
caryopsis fragment			1		
Avena sp	(wild) oats	c,f,wa,o			
awn fragment			1		
Small Poaceae	grasses				
caryopsis			4		
culm node			1		1
Tree bud			2		
Charcoal fragments			60	140	34