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Geomorphological and paleoenvironmental evolution in the prehistoric framework of the coastland of Mondragone, southern Italy

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ABSTRACT

Using morphological, stratigraphic, paleoecological and geoarcheological data, as well as radiocarbon datings, we reconstructed the evolution of the coastal plain of Mondragone, in the northern sector of the Campania Plain, during the last 40 kyr. The Late Pleistocene-Holocene morphodynamics of this coastland were mainly dictated by mutual interaction between tectonics, sea-level fluctuations, Quaternary volcanic eruptions, and subsidence. These processes also influenced the dynamics of prehistoric and proto-historic human populations. Actually, the discovery over the last 25 years of several archaeological sites referable to Upper Paleolithic-Early Iron Age as well as the recent finding of artifacts, fauna and, for the third time in Campania, of Neanderthal human remains in the Roccia San Sebastiano cave, demonstrates that the coastal plain of Mondragone had always hosted human settlements. This constant frequentation is confirmed by, both emerged and submerged, ruins of Roman age and Middle Ages, and the high level of urbanization of the modern town. The interpretation of four borehole stratigraphic sequences down to 22 m bgl, of microfossils analysis and sediment *facies* highlighted the succession of transition, from marine to freshwater, and continental paleoenvironments in this coastal plain. These wetlands developed in climatic conditions that varied from glacial (Würm) to postglacial phases. Some deposits are interpreted as marshy sediments accumulated in shallow, elongated ponds behind sandy beach or dunes, which existed almost up to the present. The reconstruction of landscape morphodynamic evolution shows that after the "super eruption" of the Campanian Ignimbrite (~39 kyr BP) the physiography abruptly changed. A wide gulf characterized by gray tuff cliffs and facing northwest formed, along the littoral between the Garigliano and the Volturno river mouths during the volcanic stasis of the Phlegrean Fields, which lasted about ten thousand years after the violent ignimbrite eruption. In this period, the presence of Neanderthal and of a settlement in the Roccia San Sebastiano cave, at the foot of Mt. Massico, is proven by the findings of an excavation. Later (~20 kyr BP - Holocene), subsidence and sea-level rise activated strong erosion processes due to the postglacial marine ingression, with a consequent rapid shoreline recession and the genesis of transition environments. Finally, according to the results of previous multidisciplinary research carried out on other Campania coastal plains, adjacent or not to the studied area, distinct generations of post-Campanian Ignimbrite - Holocene coastal lakes (lagoons, ponds) and waterlogged environments (marshes, quagmires) were recognized, slightly below and at the current sea-level.

1. Introduction

The minor coastal plain of Mondragone is located in southern Italy in the northern sector of the wide Campania Plain. It is a coastal and alluvial territory where the Garigliano and Volturno rivers flow. The Mondragone plain, at present densely urbanized, is bordered to the west by the Tyrrhenian Sea, to the east by the Apennine chain offshoots and contains the extinct Roccamonfina volcano.

Since 2001 systematic archaeological excavations of the significant prehistoric deposit, referable to the Upper Paleolithic, have been

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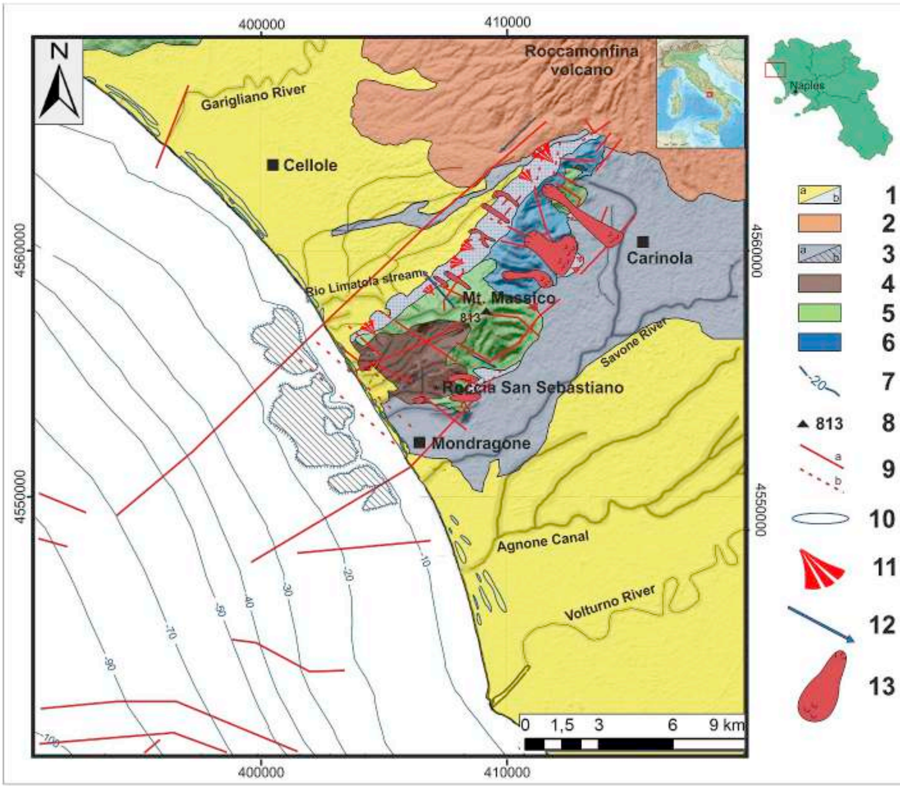

Fig. 1. Geological map of the coastal plain of Mondragone in northern Campania, southern Italy: 1, sedimentary rocks: a, reworked pyroclastics, fluvial-marine, lacustrine and aeolian deposits of the Campania Plain; b, silty-sandy seafloor of the Gaeta Gulf (Quaternary); 2, lavas and pyroclastics of the Roccamonfina volcano (Middle-Late Pleistocene); 3, Campanian Ignimbrite (~39 kyr BP, De Vivo et al., 2001): a, continental; b, submerged; 4, terrigenous deposits in flysch *facies* (Miocene); 5, limestone and dolomitic limestone, interbedded with levels of conglomerate in clay matrix (Cretaceous); 6, oolitic limestone and dolomite (Upper Lias); 7, isobath (m bsl); 8, altitude (m asl); 9, fault: a, certain; b, presumed or concealed; 10, dune ridge; 11, alluvial fan; 12, stream incision; 13, landslide pile.

carried out in the cave discovered along the Roccia San Sebastiano cliff (Belluomini et al., 2002, 2007; Lavino et al., 2003; Collina and Gallotti, 2006, 2007; Collina et al., 2008), which was unknown until 1999 because its entrance was obstructed by an ancient landslide pile.

Currently, this site represents the only documented physical evidence of Paleolithic frequentation stratigraphically analyzed in the broad territory between the coastland of northern Campania and southern Latium regions. In particular, for the richness of its deposits, the cave of Roccia San Sebastiano represents one of the most notable frequentations during the Middle and Upper Paleolithic in southern Italy. The reconstruction of different paleoenvironmental contexts and of the related population dynamics in the period between the most ancient Paleolithic presence (40 kyr BP) and the most recent phases of protohistoric frequentation (3000 yr BP), also supported by boreholes and radiometric dating, complete the dynamic evolution of the territory of Mondragone from prehistoric times to the present.

2. Geological and tectonic setting

The landscape of Mondragone (Fig. 1), in the northwestern sector of the Campania region, includes a littoral strip (Litorale Domitio) of about 27 km in length, stretching between the towns of Castel Volturno and Cellole. This area is characterized by two level zones structured in the Late Quaternary, bordered by the high-morphological carbonate relief of Mt. Massico: the first one (NW) is a part of the Garigliano River alluvial plain, the second one (SE) lies in the Campania Plain with the Volturno River mouth (Billi et al., 1997).

The physiographic structure is characterized by two coastal basins with different rates of subsidence, as evidenced by the thickness of Plio-Quaternary sediments sampled in boreholes along the plains (Aprile et al., 2004). Actually, the thickness of Plio-Quaternary units in the floodplains of Garigliano and Volturno rivers is about 700 m and over 3000 m, respectively (Ippolito et al., 1973). Mt. Massico corresponds to a morpho-structural high, set along faults of anti-Apennine direction (NE-SW) which separate it from the two coastal depressions. These dislocations are also evident in the seismic profiles (Bartole, 1984; Mariani and Prato, 1988) and may be linked to transcurrent faults with left movement. The formation of the Volturno-Garigliano depression (*graben*), as in other peri-Tyrrhenian basins that border the continental margin of the Italian Peninsula, is linked to the opening stages of the Tyrrhenian Sea, which is considered an inter-arc basin characterized by a passive margin (Fabbri et al., 1981; Mendelson et al., 1988; Patacca et al., 1990).

The substratum of these structural depressions outcrops at Mt. Massico, as a limestone-dolomite succession in *facies* of marine platform, deposited between Triassic and Upper Cretaceous (Vallario, 1966; Bergomi et al., 1969). Sgrosso (1974) recognizes in this area the Campania-Lucania carbonate platform units in overthrust on the Abruzzo-Campania platform ones. Miocene sediments of Mt. Massico are represented by limestone with bryozoans and *Lithothamnium* Auct., marly limestone with *Orbulina* Auct. and other terrigenous successions with different *facies*.

Quaternary deposits, outcropping along the mountain foothills and in the plains, consist of pyroclastics, large alluvial fans and fluvial-lacustrine sediments. In the whole coastal strip, the outcroppings include aeolian deposits arranged in dune ridges, currently coming apart in pieces, and sandy current beach sediments, nowadays in a dismantling phase (Balassone et al., 2016). Quaternary volcanic units are the products of the Roccamonfina district, in the northern area, and the Phlaegrean Fields, in the southern sector, where they are attributed to the Campanian Ignimbrite (hereinafter CI; Barberi et al., 1978; Scandone et al., 1991; De Vivo et al., 2001). In particular, in some distal places at Mondragone and at 100 km south in Salerno, the ignimbrite consists of two main parts *sensu* Sparks et al. (1973). The basal layer is predominantly of phenocrysts of clinopyroxene, sanidine and plagioclase, and lithic clasts consisting of altered, poorly sorted brown tuffs, trachytic lavas and hornfelsed lavas; the top consists in 10–20 cm of fine-grained and generally pale gray to yellowish ignimbrite. This is overlayed by a coarser grained and darker gray ignimbrite, the uppermost part is commonly yellowish due to diagenetic alteration (Fisher et al., 1993).

Regarding the coastal depressions, the first data relating to transgressive-regressive successions, which indicate a phase of marine ingression, refer to deposits of the Pliocene. These sediments were found in the underground of the Garigliano Plain (AGIP, 1977) and outcrop in the Sele Plain, to the south, in the Gulf of Salerno. On the basis of data provided by surveys for hydrocarbon exploration carried out in Castel Volturno in the 50s, Ippolito et al. (1973) hypothesize that the subsidence in the Campania Plain began during the Upper Pliocene. Instead, Cinque et al. (1987), reinterpreting the biostratigraphic data of the same boreholes, believe that subsidence started at the beginning of the Pleistocene.

Boreholes carried out in Castel Volturno and Tricase indicate the deposition of large sedimentary volumes in marine and transition environments, alternating with pyroclastics, in the Campania Plain during the Lower-Mid Pleistocene (Santangelo et al., 2010), similar to those of the current Phlegrean Fields lagoons, 12–25 km to the south, or similar to Mediterranean brackish environments (De Pippo et al., 2004, 2007; Stamatopoulos et al., 2014).

The presence of shallow marine environments shows that the average rates of sedimentation were able to offset the subsidence. The filling of this depression, as well as the interaction between marine and river inputs coming from the Apennines, is also due to the volcanic activity of vents currently buried in the plain. Actually, the boreholes show a complex morphology, probably related to buried volcanoes (*e.g.*, Parete volcano), whose products are sometimes of underwater *facies* (Barberi et al., 1980; Cinque et al., 1987).

In general, this period is characterized by intense vertical ground movements that, lowering in several stages the marginal areas of the carbonate massifs, progressively determined the eastward extension of the plain and the consequent migration of coastline in the same direction (Brancaccio et al., 1991). The Garigliano Plain is characterized by transition and marine sediments, suggesting a substantial subsidence with an average rate of 0.2 mm/yr since the Tyrrhenian (Bordoni and Valensise, 1998).

The evolution of these two coastal sectors differs during the Late Pleistocene: the Garigliano Plain becomes a more stable area, as evidenced by the presence of deposits related to MIS 5.5 at about 7 m asl; however, the study of numerous core samples in the Volturno Plain shows that marine deposits related to the same stage are buried at about −65 m bsl (Romano et al., 1994), showing a substantial rate of subsidence in this plain. The complex interaction between glacio-hydro-isostatic, subsidence and volcano-tectonic phenomena is highlighted by the stratigraphy of these boreholes in the whole Campania Plain (Aprile et al., 2004), in which the marine sedimentation repeatedly intercalates with a substantial amount of pyroclastics erupted by volcanoes in the Latium and Campania regions. These interactions have led to low rates of subsidence, and to a progressive westward migration of the coastline during the Pleistocene, followed by an eastward retreat of the shoreline during the Holocene.

2.1. Geomorphological features

According to Semerano (1984, 2001), the modern toponym *Mondragone* is a compound word very likely formed by the contraction and union of "*Mons"* and *"Draconis"*: both terms come from Latin, the first means "mount", the second one with the Greek component Δρακ− of Δρακων, deriving from Θαργ-, Ταργ means "path". The last word is attested to in the Akkadian base stem *tarqu(m)* corresponding to the assonant Neo-Babylonian *daraggu*, which is also present in Tarragona (*Tarraco*) the name of the Spanish coastal town of Roman origin. The meaning is "guide", "path", and thus indicates a certain pathway or track along the mountain. Therefore, from the pre-Hellenistic period Mondragone probably preserves the meaning of "mount of the path".

The coastal plain of Mondragone (Fig. 2) extends between the slopes of Mt. Massico and Mt. Petrino and the Tyrrhenian coastland, to the southwest of the mouth of the Garigliano River and to the northwest of that of the Volturno River. The reconstruction of ancient shorelines in the last 2500 years, from the sixth century BC up to the present, in the area between Lago Patria to the southeast and Mondragone to the northwest (Cocco et al., 1980, 1982, 1994), shows a substantial progradation of the shoreline, with the concavity of the coast towards the west in the first period and a gradual formation of a deltaic apparatus. In the 20th century the progradational trend decreased, and over the last few decades vast coastal sectors were affected by accelerated erosion. This phenomenon is probably related to intense human activity and to low discharge of river sediments to the coast (Cocco et al., 1994; Pennetta et al., 2016a), and is also due to subsidence, to short warm-arid climate crises as well as to the damming of the Garigliano and Volturno rivers since the 50s (Donadio et al., 2017a, 2017b).

Subsidence in this area lasted until historical times. This is confirmed by the presence of ruins from the Graeco-Roman Period (Cocco et al., 1996a, 1996b; Pennetta et al., 2016b) along the sea bottom off the town of Mondragone, down to about a depth of 10 m bsl. These ruins are the remains of the ancient city of *Sinuessa* (III century BC; Pagano, 1974). The current morphology of the coastal strip is connected to the presence of beaches which gradually prograded until the 50s, and also to the formation of dunes which never exceeded 6 m asl in height.

Recent bathymetric and underwater geolithological surveys between the Volturno River mouth and abeam Mt. Massico highlighted the morphology of the submerged coastal sector, generally characterized by a slightly sloping sandy bottom. However, in the underwater area in front of Mt. Massico and Mt. Petrino, a rocky bank extends parallel to the coast for about 6 km, at a depth ranging from 8 to 15 m bsl. The bedrock is flattened at the top and cracked, and consists of volcanoclastics from the Phlegraean Fields attributed to the CI (Cocco et al., 1996b). On this large marine abrasion terrace, at about 9 m bsl deep some Roman artifacts were identified, amongst which piers (*pilae*) of a probable dock structure and the remains of a Roman road paved with limestone blocks. The latter were unveiled for the first time during an underwater geoarchaeological survey in 2012. This road was found along the seabed at a depth of 3 m bsl at a lee at a short distance away from the submerged ignimbrite bank.

The road, which was found for the first time in 2012 (Pennetta et al., 2016b), extended from east to west; it was in axis with the road segment on the beach and partially buried by aeolian deposits (Cocco et al., 1994). Moreover, on the tuff platform at a depth of 11 m bsl a carved millstone was discovered, confirming a high rate of subsidence in the last 1700 years (Pennetta et al., 2016b).

3. Methods

Three long on site surveys were carried out, in 2007, 2008 and 2009, and new campaigns started in 2012 and 2015 during which geomorphological, paleoecological and archaeological data were collected along the coastal plain, the hills and inside the Roccia San Sebastiano cave. In particular, sampling was performed from the foot of Mt. Petrino toward the present-day shoreline, both during surveys and drillings.

Four boreholes, down to 22 m below ground level, were carried out in the coastal plain (Fig. 3). These boreholes were drilled in the center of the plain, along a NW-SE alignment, far from the foothills and outcrops of limestone, carbonate debris and CI deposits, with the aim of characterizing the stratigraphic sequence of transition environments, and correlating them to the dated archaeological remains of the Roccia San Sebastiano cave. The cores were described on site for the log reconstructions, then accurately plotted and correlated to each other and then compared with other boreholes carried out during previous and more recent surveys (Fig. 4, Table 1), found in the literature (Cocco et al., 1996a; Comune di Mondragone, 2003; Aprile et al., 2002, 2004; VIGOR, 2014).

Sediment samples were extracted from the borehole for sedimentological analyses, both granulometric and morphometric, as well as for analysis of microfossils.

Fifty core samples were studied in order to investigate the palaeoecological features of the sediments drilled in the study area. The

Fig. 2. The minor coastal plain of Mondragone is bordered to the east (a) by the limestone reliefs of mounts Massico and Petrino (west-east view), where Roccia San Sebastiano cave is located (RSS with black arrow). To the west (b) the plain is characterized by a gently sloping landscape (east-west view) dissected by the Petrino Stream, with some relic alluvial fans, and is intensely urbanized close to the seashore.

samples, with a dried weight of 200 g, were disaggregated, washed with water through 120 mesh sieves (125 μm) and analyzed. Ostracod assemblages were quantitatively studied. Species are listed in Tables 2 and 3. The Total Number of Valves (TNV; Table 2) and Minimum Number of Individuals (MNI; Table 3) were counted. The number of valves includes all the juvenile and adult valves, while number of individuals was calculated by adding the greater number between right and left adult valves to the number of adult carapaces. When only young shells occurred, the number of specimens was set equal to one.

Standard archaeological surveys were carried out with the aim of recognizing, classifying and dating the findings (Fig. 3), as well as correlating their distribution to the palaeomorphology of the landscape. Excavations in the cave of Roccia San Sebastiano were conducted to reconstruct the lithological-archaeological stratigraphic sequence, and attribute ages to the horizons with ^{14}C dating on animal bone fragments. Two datings, from the surface to the bottom of the excavation in the cave (Rome-2447, Rome-2111; Fig. 5, Table. 4), were conducted in the CNR laboratory of the Institute of Environmental Geology and Geoengineering at Monterotondo - Rome, Italy. The results of ^{14}C dating were calibrated by radiocarbon calibration software programs OxCal and Calib Rev 7.1.0. In both software programs, the mathematical analysis of data is related to the IntCal13 curve (Reimer et al., 2013). The confidence level corresponds to 2σ of calibrated intervals (95.4% of relative area under probability distribution).

Moreover, along the Volturno River banks and Mt. Petrino, other geoarchaeological and geomorphological investigations of the exposed stratigraphic sequence were carried out to identify the local availability of lithic raw materials employed in the lithic industry discovered in the Roccia San Sebastiano cave. Finally, all the data were analyzed with standard methodologies and treated with a GIS software, with the aim of obtaining 2D and 3D digital terrain and substratum models useful for the morphological evolution study and the paleoenvironmental reconstruction.

4. Results

The multidisciplinary studies highlighted the geoenvironmental and geoarchaeological features of the coastal plain at the foot of the Roccia San Sebastiano cave, contributing to the geomorphological and paleoecological reconstruction of the landscape during the last 40 kyr. The results are described and discussed below.

4.1. Stratigraphy

The paleoenvironmental and paleogeographic reconstruction of the Mondragone plain, in the area overlooking Mt. Massico, was performed using four continuous core boreholes (CS1, CI2, CS3, LV4) down to 22 m bgl. Furthermore, our study included the analysis of six previous drillings (S1-S6) extended down to 15 m bgl for the seismic upgrading of the urban and territorial master plan of the town of Mondragone (Comune di Mondragone, 2003), as well as the scientific literature (Cocco et al., 1996b; Aprile et al., 2004) and a deep drilling (VM) down to 300 m bgl carried out within the scientific project VIGOR (www.vigor-geotermia.it) by IAMC-CNR of Naples in 2014 (Fig. 4, Table 1). The stratigraphy consists in alternating layers of sand, fine silt and clay, interspersed with silty-clay horizons and layers of peat. These are attributable to a series of sandy and ash-rich pyroclastics, deposited in continental environment. In borehole LV4, from about 10 m bgl, these deposits are followed by rubefact or purplish sediments with centimetric sub-rounded pebbles, both of black lavas and pyroclastites, sparse grayish pumice up to 5 cm diameter, blunt and altered, with a

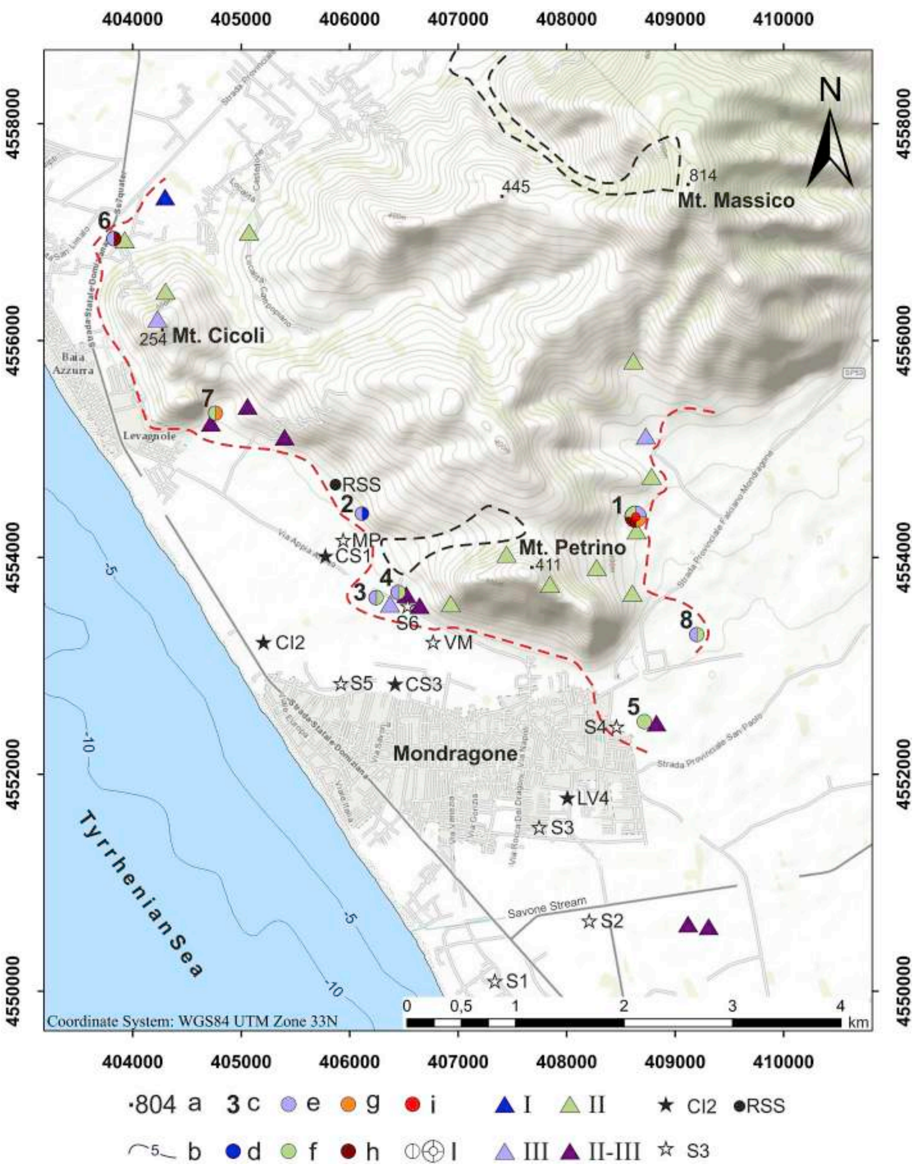

Fig. 3. Prehistoric and historic sites in the territory of Mondragone: a) altitude (m asl); b) isobaths (m bsl); c) number of sites recently discovered: 1, Arivito; 2, Roccia San Sebastiano; 3, Incaldana 15–19 m asl; 4, Incaldana 20–25 m asl; 5, Starza; 6, Sant'Eufemia; 7, Bagni Solfurei; 8, San Pietro; d) Middle Paleolithic; e) Upper Paleolithic; f) Neolithic; g) Eneolithic; h) Bronze Age; i) Iron Age; l) site referable to two or more chronological phases; Roman numerals indicate the sites described by Arthur (1991): I, Paleolithic-Neolithic; II, Eneolithic-Bronze Age; III, Late Bronze Age-Early Iron Age; II-III, uncertain phase between II and III period. Black dashed line indicates some probable areas of supply of chert pebbles found as lithic industry in the Roccia San Sebastiano cave (see Fig. 5 for details); red dashed line represents the inland limit of the transition environments; solid star indicates the four boreholes carried out in the plain during PRIN Project (2008), open star those from the literature (see Table 1 and the text for details); RSS, location of the Roccia San Sebastiano cave. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

flame structure. These deposits represent the semicoherent and altered *facies* of the CI, with radiometric age of about 39 kyr BP (De Vivo et al., 2001). The stratigraphic sequence was also confirmed in five of the six boreholes carried out in 2003 (S1-S5), however the remaining one (S6) was entirely made of calcareous coarse debris from the proximal piedmont environment. In particular, the stratigraphic correlation between the twelve boreholes (Table 3) showed a good correspondence between the various types of horizons, *i.e.* debris, pyroclastic, transition and fossil. On the basis of lithology, grain size and textural features, the following main paleoenvironments were identified:

- calcareous piedmont debris, from proximal to distal, more superficial and from 2.5 (CS1) up to over 15 m (S6) in thickness;
- transition freshwater, fossiliferous, consisting of clay and silt levels; swamp, pond and freshwater environments, from 1.2 up to 4.2 m thickness (S5, CS3);
- proximal marine, fossiliferous, sandy-silty grained (LV4);
- continental plain, mainly consisting in a massive ash-rich pyroclastic deposit or by ignimbrite, more or less altered, ranging from about 8 to 18 m in thickness (S4, S5, CS1, VM);
- carbonate bedrock, with formation thickness (> 270 m), locally fractured and karstified (VM).

Summarizing, the stratigraphic sequence down to 20 m bgl (Table 1) was constituted by an alternation of *facies* of freshwater and continental environment, with the presence of peat levels (S1, S2, S5, CS3) down to 10 m bgl. At about 5, 11 and 20 m bgl, intercalations of fossiliferous marine proximal *facies* were recognized (S1, S5, CI2), while at the base coherent continental volcanic *facies* prevail (MP, LV4, VM), lying on the deep carbonate bedrock over 33 m bgl (VM). The morphology and depth of CI of known age, found in boreholes within the range of 10–33 m bgl, were reconstructed.

For the paleoenvironmental and morphodynamic modeling purposes of the study area, the main focus was on data and interpretation of the four boreholes CS1, CI2, CS3 and LV4, which are thoroughly described and discussed in the subsequent sections.

4.2. Paleoecology

Thirty samples were barren, twenty yielded microfossil remains. Assemblages consisted of ostracod and bivalve shells, gastropod shells and opercula, charophyte oogonia, serpulid tubes and sponge spicules. Fourteen ostracod species were recorded, including two (*Candona* sp. and *Ilyocypris* sp.), which were identified at generic level due to the poor state of preservation.

Ostracod abundance ranged from zero (samples CS1-2, CS1-6, CS1-

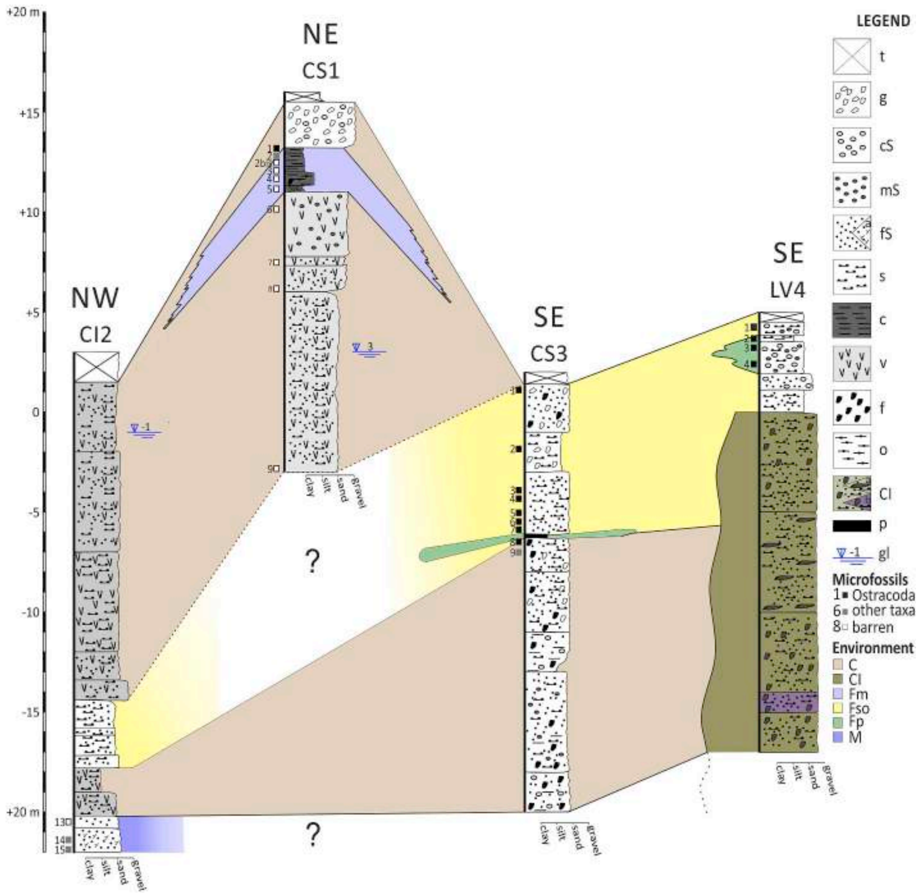

Fig. 4. Stratigraphic correlation between the four drillings carried out in the plain of Mondragone. Legend: t, top soil; g, gravel; cS, coarse sand; mS, medium sand; fS, fine sand: s, silt; c, clay; v, volcanic ash; f, lava fragment; o, organic matter; CI, Campanian Ignimbrite: a, with flattened shards, b, *facies* from purple to brown; p, peat; gl, groundwater level. Microfossils: solid square, Ostracoda; gray square, other taxa; open square, barren. Enviroment: C, continental; CI, Campanian Ignimbrite; Fm, cold mesohaline; Fso, swamp oligohaline; Fp, pond; M, marine. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

7, CS3-9, LV4-1, excluding barren ones) to 7408 valves per 100 g in the sample CS3-4 and 672 specimens per 100 g in the sample CS3-7. In the CS3-3 sample the highest values of diversity indices were recorded (Table 3). Samples CS3-2 and CS3-5 showed the maximum number of species (seven). Palaeoecological interpretations were based on the modern scientific literature regarding freshwater ostracod distribution (*i.e.* Hiller, 1972; Vesper, 1975; Henderson, 1990; Belis, 1997a, 1997b; Meisch, 2000). The results of the core analysis were as follows:

4.2.1. Core CS1

Nine samples belonging to the core CS1 were studied, five proved barren and four fossiliferous, and generally showed assemblages with low abundance and diversity. In the samples CS1-7 (8.6–8.5 m bgl), CS1-6 (5–4.9 m bgl) and CS1-2 (3.3–3.2 m bgl), fossil remains were exclusively represented by serpulid tubes, while in the uppermost sampled level (CS1-1, 3–2.9 m bgl) also gastropod fragments and rare ostracod valves (*Candona neglecta* and *Ilyocypris* sp.) were present.

Table 1

Data of analyzed boreholes carried out in the coastal plain and correlated stratigraphy to those from the literature: seven previous drillings (Cocco et al., 1996a; Comune di Mondragone, 2003) and the first 30 m of the deep drilling of VIGOR project (www.vigor-geotermia.it). The top of CI in the boreholes lies at 10–15 m bgl, while on the facing seabed outcrops at 7/17 m bsl depth (Pennetta et al., 2016a). Legend: LD, limestone debris; PT, reworked pyroclastics and transition environment deposits; PL, peat level; MA, marine deposits; CI, Campanian Ignimbrite; CA, carbonate substratum. Geographic coordinate system is WGS84. For further details see Figs. 1, 3 and 4.

n°	borehole	latitude N	longitude E	reference	Height (m asl)	Lenth (m bgl)	stratigraphy (± m)					
							LD	PT	PL	MA	CI	CA
1	MP	41°07′59.81″	13°52′48.83″	Cocco et al., 1996a	22	22	+22/ +19.3	+19.3/ +8.3	–	–	+8.3/ +0.4	–
2	S1	41°05′49.39″	13°53′48.58″	Comune di	4	15		+4/-11	−6/-7	−7/-11	–	–
3	S2	41°06′06.45″	13°54′25.46″	Mondragone, 2003	3			+3/-12	−2.5/-4	–	–	–
4	S3	41°06′33.89″	13°54′08.11″		4			+4/-11	–	–	–	–
5	S4	41°07′05.08″	13°54′34.88″		21			+21/+6	–	–	–	–
6	S5	41°07′17.95″	13°52′48.05″		3			+3/-12	−0.2/-1.2 −1.5/-2	−2/-6.2	–	–
7	S6	41°07′41.02″	13°53′19.57″		59		+59/ +44	–	–	–	–	–
8	CS1	41°07′55.52″	13°52′38.77″	PRIN, 2008	16	19		+16/-3	–	–	–	–
9	CI2	41°07′28.65″	13°52′13.00″		3	22		+3/-19	–	−17.5/-18.9	–	–
10	CS3	41°07′18.15″	13°53′06.23″		2			+2/-20	−6.1/-6.3	–	–	–
11	LV4	41°06′43.00″	13°54′14.99″		5			+5/-4	–	–	−4/-17	–
12	VM	41°07′29.66″	13°53′23.67″	VIGOR, 2014	5	300		+5/-10	–	–	−10/-28	−28/-295

Table 2
Quantitative distribution of ostracod (TNV = total number of valves) and semi-quantitative distribution of the remaining taxa (a = abundant, c = common, u = uncommon, r = rare, vr = very rare). Number of valves of ostracod includes all the juvenile and adult valves.

TAXA	height (-m bgl)	CS1				CS3								
		samples				samples								
		8.60–8.50	5.00–4.90	3.30–3.20	3.00–2.90	9.00–8.90	8.30–8.20	8.00–7.90	7.50–7.40	6.90–6.70	6.30–6.20	5.90–6.00	3.80–3.70	1.90–1.80
		7	6	2	1	9	8	7	6	5	4	3	2	1
Ostracoda														
Candona neglecta Sars, 1887					17			1120		416	9376	640	280	
Candona sp.							10							
Cypria ophtalmica (Jurine, 1820)								2720	144	240	64			
Cypria reptans Bronshtein, 1928									48	192	288	832	8	
Cypridopsis elongata (Kaufmann, 1900)														
Cypridopsis sp.								2144						
Darwinula stevensoni (Brady and Robertson, 1870)								4832	3328	3952	4256	1120	1424	
Fabaeformiscandona balatonica Daday, 1894									176					
Fabaeformiscandona fabaeformis (Fischer, 1851)								64		16	96		16	12
Ilyocypris sp.					1									
Mixtacandona laisi (Klie, 1938)														
Pseudocandona lobipes (Hartwig, 1900)													16	
Pseudocandona marchica (Hartwig, 1899)										16		68	40	
Pseudocandona sarsi (Hartwig, 1899)								96		928	736	624	96	
SERPULIDAE		c	u	vr	c	r	u	a	a	a	a	a	c	r
BIVALVIA						vr	r	u	u	c	u	u	c	
GASTROPODA					c		u	c	r	u	u	u	c	u
CHARACEAE							r	c	c	r	u	c	c	r
PORIFERA														

TAXA	height (-m bgl)	LV4				CI2		
		samples				samples		
		2.70–2.60	1.90–1.80	1.35–1.25	0.90–0.80	21.90–21.80	21.40–21.30	20.60–20.50
		4	3	2	1	15	14	13
Ostracoda								
Candona neglecta Sars, 1887			2	4				
Candona sp.								
Cypria ophtalmica (Jurine, 1820)								
Cypria reptans Bronshtein, 1928								
Cypridopsis elongata (Kaufmann, 1900)		4	4	4				
Cypridopsis sp.								
Darwinula stevensoni (Brady and Robertson, 1870)								
Fabaeformiscandona balatonica Daday, 1894								
Fabaeformiscandona fabaeformis (Fischer, 1851)								
Ilyocypris sp.								
Mixtacandona laisi (Klie, 1938)		21	234	56				
Pseudocandona lobipes (Hartwig, 1900)								
Pseudocandona marchica (Hartwig, 1899)			4					
Pseudocandona sarsi (Hartwig, 1899)			8	4				

(*continued on next page*)

Table 2 (*continued*)

TAXA	LV4				CI2		
height (-m bgl)	samples				samples		
	2.70–2.60	1.90–1.80	1.35–1.25	0.90–0.80	21.90–21.80	21.40–21.30	20.60–20.50
	4	3	2	1	15	14	13
SERPULIDAE	r	c	u	r			
BIVALVIA							
GASTROPODA		u	r	u			
CHARACEAE							
PORIFERA					u	u	u

4.2.2. Core CI2

The sediments recovered in the CI2 drilling were devoid of calcareous microfossils. Siliceous sponge spicules were found, associated with silty quartz sands, only in the lower part of the section (from 21.9 to 20.5 m bgl), while the samples of the upper part (19.2–3.7 m bgl) were barren.

4.2.3. Core CS3

The low part of the drilling (21–11.1 m bgl) was made up of deposits devoid of fossil remains. In the following two samples microfossils were rare and very poorly preserved and carbonaceous plant remains frequently occurred. The sample CS3-9 (9–8.9 m bgl) yielded rare serpulid tubes and fragmented bivalves. Gastropod fragments, rare and carbonified charophyte oogonia and reddened valves of *Candona* sp. were added to the CS3-8 (8.3–8.2 m bgl) assemblage. In the levels ranging from CS3-7 (8–7.9 m bgl) to CS3-2 (3.8–3.7 m bgl) abundance and diversity increased; characean, serpulid, mollusc and ostracod remains were common. Ostracod species richness ranged from four to seven, diversity indexes were relatively high (Table 3). Assemblages were dominated by *Darwinula stevensoni*, *C. neglecta* and *Cypria ophtalmica*: the sum of the frequency of these species commonly exceeded 90% of the assemblage. In the uppermost sample (CS3-1, 1.9–1.8 m bgl) rare mollusc, serpulid and characean remains were found together with a monospecific ostracod fauna represented exclusively by juveniles of *Fabaeformiscandona fabaeformis* (Table 3).

4.2.4. Core LV4

The main part of the section, from the base (20.4 m bgl) up to the sample LV4-5 (3.9–3.8 m bgl) included exclusively barren sediments. The following four samples were fossiliferous, serpulid and gastropod remains were the commonest microfossils. Ostracod assemblages, generally poor in abundance and diversity, were dominated by *Mixtacandona laisi*. The maximum number of species was found in the sample LV4-3, (1.9–1.8 m bgl) showing five ostracod species.

5. Prehistoric settlement

Practically unknown until a few years ago, the Prehistory of the Mondragone (Caserta) area emerged in its importance thanks to the results of systematic surveys undertaken since 1999 by the University of Naples Federico II, and later by the University of Rome La Sapienza, and the Archaeological Museum Biagio Greco of Mondragone together with the Archeological Superintendence under the direction of two of the authors (Marcello Piperno and Carmine Collina). Several prehistoric sites are currently known, among which the most important are attributed to the initial (Arivito) and final phase of the Upper Palaeolithic (Incaldana - Roccia San Sebastiano), to the Neo-Eneolithic (Arivito, Starza, Bagni Solfurei, San Pietro) and to the Bronze Age (Bagni Solfurei, Sant'Eufemia).

Equally important are the collections attributed to the Early Iron Age and to the Archaic Age in the localities of Arivito and Monte Petrino (Guidi, 2007; Guidi and Saracino, 2010; Maritan et al., 2011). Moreover, since 2001, the Archaelogical Museum Biagio Greco has been carrying out regular excavation campaigns of the most important Upper Palaeolithic deposit in the large cave opening in the locality of Roccia San Sebastiano (Lavino et al., 2003; Belluomini et al., 2002, 2007; Piperno, 2003, 2006; Collina and Gallotti, 2007; Collina and Piperno, 2011; Ruiu et al., 2012), which represents the only evidence of Palaeolithic frequentation systematically and stratigraphically studied in the territory comprised between the northern Campania coast and the southern Latium coast.

On the basis of such evidences, the geoarchaeological project was aimed at producing a detailed territorial study to gain insight into the dynamics of the frequentation and peopling of the area during different pre- and protohistoric periods, and to continue the systematic research at Cave of Roccia San Sebastiano, considering the particular importance

Table 3
Quantitative distribution of ostracod (MNI = minimum number of individuals) species. The number of individuals was calculated by adding the greater number between right and left adult valves to the number of adult carapaces. When only young shells occur, the number of specimens was set equal to one.

TAXA height (-m bgl)	CS1	CS3								LV4		
	s.	samples								samples		
	3.00–2.90	8.30–8.20	8.00–7.90	7.50–7.40	6.90–6.70	6.30–6.20	5.90–6.00	3.80–3.70	1.90–1.80	2.70–2.60	1.90–1.80	1.35–1.25
	1	8	7	6	5	4	3	2	1	4	3	2
Ostracoda												
Candona neglecta Sars, 1887	j		128 j		16 j	544 j	16 j	8 j			j	j
Candona sp.		6										
Cypria ophtalmica (Jurine, 1820)			480 j	32 j	16 j	j						
Cypria reptans Bronshtein, 1928				j	j	j	48 j	8				
Cypridopsis elongata (Kaufmann, 1900)										1 j	2	2
Cypridopsis sp.			j									
Darwinula stevensoni (Brady and Robertson, 1870)			640 j	352 j	192 j	608	48 j	192 j				
Fabaeformiscandona balatonica Daday, 1894				48 j								
Fabaeformiscandona fabaeformis (Fischer, 1851)			j		j	j		j	j			
Ilyocypris sp.	1											
Mixtacandona laisi (Klie, 1938)										5 j	70 j	24 j
Pseudocandona lobipes (Hartwig, 1900)								j				
Pseudocandona marchica (Hartwig, 1899)					16		32	8 j			2	
Pseudocandona sarsi (Hartwig, 1899)			32 j		64 j	64 j	32 j	8 j			2 j	j
abundance (individuals per 100 g)	1	3	672	224	168	656	88	120	1	3	39	15
number of species	2	1	6	4	7	6	5	7	1	2	5	4
Shannon H	0.69	0	1.21	0.74	1.36	1.14	1,55	0.86	0	0,45	0,47	0.72
Simpson 1-D	0.5	0	0.63	0.36	0.63	0.61	0.78	0.35	0	0.28	0.19	0.35

and richness of the preserved prehistoric deposits. In order to achieve the first aim, the localities of pre- and protohistorical interest already discovered in the Mondragone area were localized through a GPS application.

These data allowed to set up a computerized cartographic data base through a GIS application for the implementation of the archaeological and environmental information (Fig. 3).

5.1. Population of Mondragone territory during the Aurignacian

Lithic materials highly dispersed on the surface of a large area at Arivito, at the foot of the southern slope of Mount Massico, have been repeatedly found during field surveys that have been carried out since 1985. In particular, the site is bordered by Poggio Pianella to the north, by Pezza di Caso and Mt. Petrino to the west, by the Storito channel to the east and by the road connecting Falciano del Massico with Mondragone to the south. Thanks to the surveys, about 3000 manufactured products of various types of flint and jasper were collected. The most characteristic typological elements included blade tools such as scrapers, careenated and nose end-scrapers, burins, denticulate and notched pieces, which suggest that the lithic industry of Arivito is ascribable to the Aurignacian. The Arivito site is part of a regional framework in which the presence of Aurignacian human groups is attested to mainly by cave deposits.

Remarkably, evidence of the widespread presence of anatomically modern man indicates that a population settled in Campania at the beginning of the Upper Paleolithic. In particular, findings were uncovered in: the Castelcivita Cave on the slope of Alburni Mts, 140 km to the southeast of the study area, frequented between 33 and 30 kyr BP; the Aurignacian sequence highlighted in the Cala Cave at Marina di Camerota in Cilento, 180 km to the southeast; the discovery of lithic industry in Serino open air site, 90 km to the southeast near Avellino.

5.2. The population of the Mondragone territory between the Neolithic and the Bronze Age

Settlement occurrence and evolution during the sixth millennium BC cannot be fully understood without adequate paleoenvironmental reconstruction. There are three significant elements that characterized the ancient landscape: (i) a very different coastland with a shoreline shifted several kilometers westward; (ii) the presence of lagoons, swamps and ponds in the area behind the dunes and the shoreline, now completely dried up or filled with recent transition or volcanic sediments; (iii) the importance of the Mt. Massico carbonate relief, at that time as today, whose last southwestern offshoot, Mt. Petrino, dominates the modern town of Mondragone.

The presence of lithic material of the Neolithic in some sites (with the exception of Arivito) located along the edges of ancient coastal ponds (Bagni Solfurei, Starza, San Pietro, Incaldana; Fig. 3) and the almost complete absence of ceramics are two factors which can be observed in the area of the Circeo promontory in southern Latium, where the environmental characteristics were the same as those of the coastal pond sites during that same period. The possibility of using a territory particularly suitable for fishing, shellfishing and hunting small game, especially avifauna, might have encouraged the population to practice such activities more than land farming.

The scenario changed with the Eneolithic (about 3500–2300 BC; ~5.5–4.3 yr BP). In addition to evidence of blades and cusps of arrow

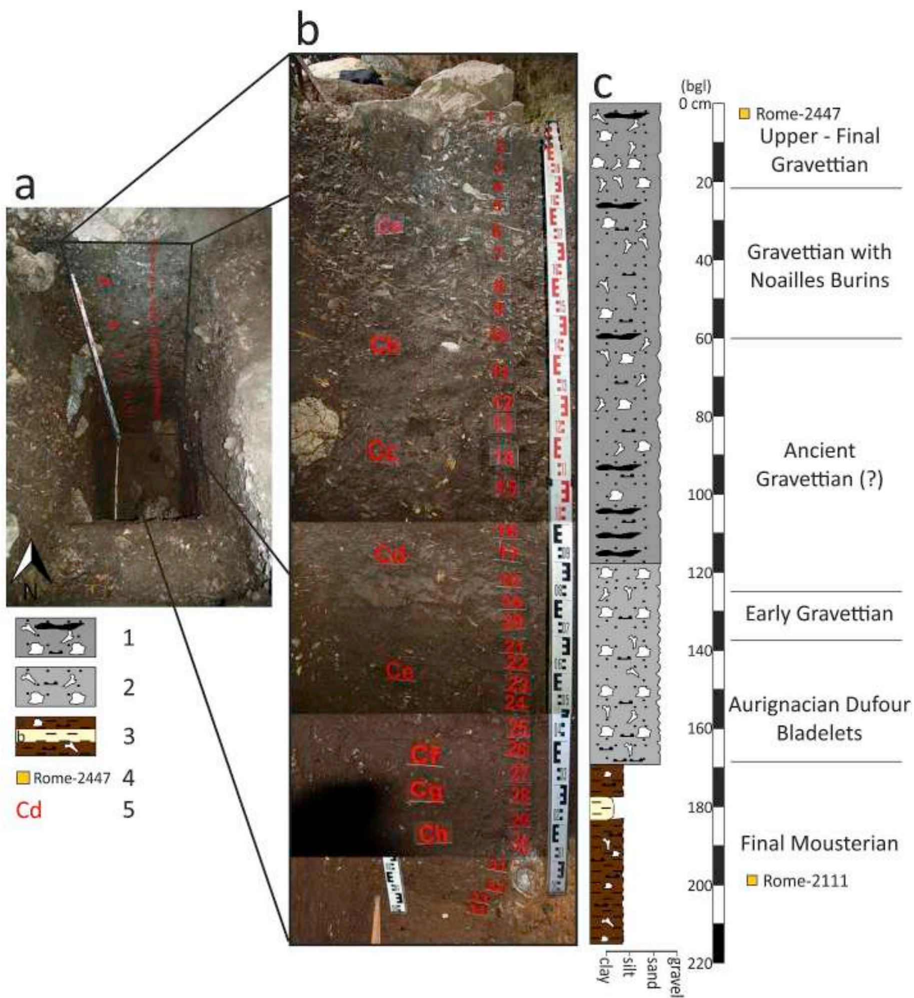

Fig. 5. Stratigraphy of the excavation inside the Roccia San Sebastiano cave: 1) brownish sandy silt deposit, with concretions due to freshwater flow and stagnation; the matrix, upward coarsening, contains abundant lithic industry and very abundant faunal remains, intentionally fragmented; towards the base, traces of coal levels and coarse carbonate cobbles are present; 2) sandy silt deposit, reddish-brown and very compact, with limestone pebbles; remnants of coal and numerous remains of fauna with different degrees of burning are present; 3a) reddish clay, very compact, with scarce limestone gravel, remains of fauna and a horizon, with volcanic lithics, coeval to the CI deposition; 3b) thin yellowish level of sediment alteration; 4, ^{14}C dating sample (see Table. 4); 5, sedimentary unit. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Tables 4
^{14}C dating and calculated calibration dating *sensu* Reimer et al. (2013) of samples collected in the excavation of Roccia San Sebastiano cave (see Fig. 5 and the text for details).

sample	Elevation (m asl)	^{14}C (yr BP)	σ (yr)	OxCal (calBC)	Calib (calBC)
Rome-2447	35.5	19570	± 210	22121–21076	22111–21069
Rome-2111	33.5	38960	± 950	42806–39768	42549–39611

from Arivito and, not far from this site, of a beautiful flint dagger with opaque retouching found at Impiso Bridge, probably attributable to a funerary equipment, the most important finding is that of Bagni Solfurei. The copious amount of pottery found here, finally confirms the presence of a small stable village that probably resembled the one recently discovered and excavated in Maccarese, also found near the shore of a small coastal lake, now dried. The presence of spindle whorls provided the first indication of spinning and weaving activities. Regarding the typology, the above mentioned ceramics and the mentioned dagger belong to the repertoire of the *facies* of Gaudo, present between Campania and southern Lazio.

Between the advanced stage of the Ancient Bronze Age and the beginning of the Middle Bronze Age, corresponding to the first half of the second millennium BC, there was a process of selection and concentration of settlements, which in that age stood on the slopes of the reliefs of Sant'Eufemia and Arivito. This explains why the settlements where located further inland than those of Neolithic and Eneolithic, as the soils would become farmable only with the introduction of the animal-drawn plow. In this age an independent metallurgical production developed, as evidenced by the discovery in Carinola of a storage place with hundreds of bronze axes, of which, unfortunately, only one remained.

A similar situation is attested for the advanced stage of the Middle Bronze Age and the Bronze Age (about 1500–1200 BC), periods to which both the Arivito site and the one identified in Francolise, located on a defended tableland near the left bank of Savuto River, belong respectively. The greater importance of sheep farming and in particular of seasonal short-range transhumance combined with new defensive requirements of the proto-historic communities, as observed in many other parts of central Italy, seems to be the explanation of the occupation of Monte Petrino in the Late Bronze Age (about 1200–960 BC).

6. The cave of Roccia San Sebastiano

In the following sections information and data on the artifacts found in excavations carried out in the cave of Roccia San Sebastiano (Fig. 5)

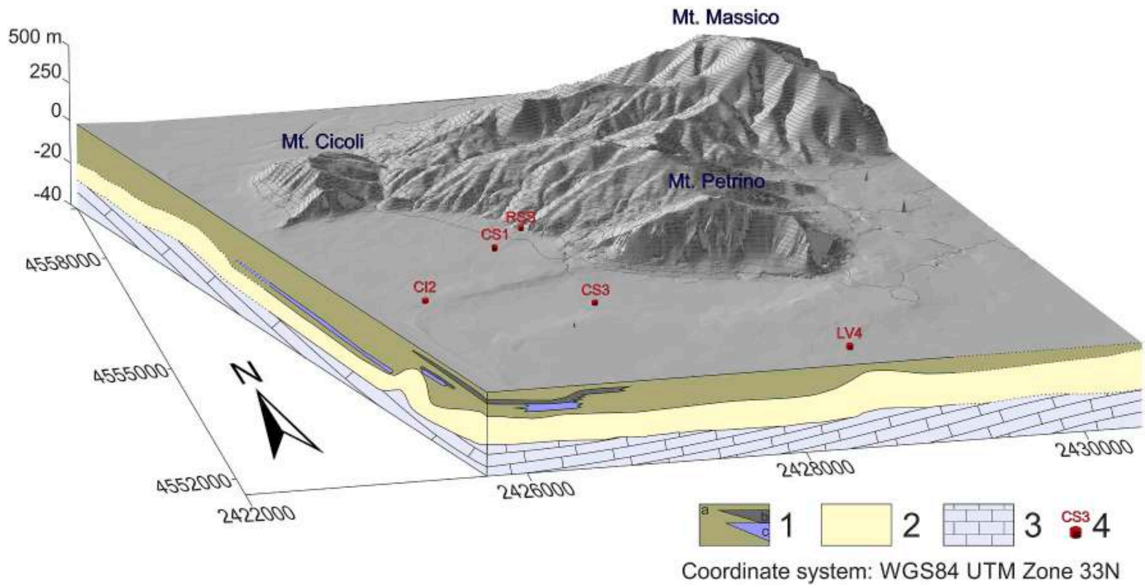

Fig. 6. Tridimensional Digital Terrain Model (SW-NE view) by GIS of landscape and its underground stratigraphic sequence, resulting from interpretation of georeferenced logs of drillings carried out along the coastal plain of Mondragone and from the literature, as well as from the excavation inside the cave of Roccia San Sebastiano. Legend 1, reworked pyroclastics: a, peat level; b, marine deposit; 2, Campanian Ignimbrite; 3, carbonate substratum; 4, borehole. RSS indicates the position of Roccia San Sebastiano cave.

over the last 15 years are provided. These findings, classified by age and typology, help to better reconstruct the paleoenvironmental conditions of the Mondragone territory over the last 40 kyr. Systematic excavation campaigns have been conducted in the area since 2001 under the scientific direction of Marcello Piperno and Carmine Collina and have resulted in the partial exploration of an important Pleistocene deposit, extraordinarily rich in archaeological and paleontological remains.

6.1. The archaeological sequence

The cave of Roccia San Sebastiano is currently the only site where periodic and detailed stratigraphic surveys were conducted (Belluomini et al., 2007; Collina et al., 2008). It is a tectono-karstic cave, which opens at the foot of the southern slope of Mt. Massico, characterized by Cretaceous limestone outcrops attributable to the paleogeographic units of Mt. Matese - Mt. Maggiore, the structure of which delimits the northern sector of a large tectonic depression (*graben* of Campania Plain). The cave is divided into two parts: a shelter of about 12 m in length and 3 m in depth on average and a room whose dimensions are not yet determinable, as it is still partially obstructed by reworked soils. The lithic industry consists of several thousand artifacts that testify to a long attendance of this cave during different phases of the Gravettian. The stratigraphic investigations have allowed for the exploration of the first level in place (C) along a surface of about 4 m^2, and have revealed the stratigraphic sequence by an assay of 2 m^2, located inside the excavation area which extended down to a depth of about 1 m bgl. A georadar survey and a control core, carried out in 2005, did not identify the carbonate bedrock, and have highlighted that the stratigraphic sequence continues for at least another 3 m in thickness (Belluomini et al., 2007). The discovery of two cores and a point of Levallois technique in the reworked levels of the upper part of deposit, indicated the presence of Mousterian levels, probably inside the cave, due to a Neanderthal attendance in the Mondragone coastal plain. The deeper excavation evidenced a thick stratigraphic and cultural sequence.

At the present state of the research at least six major phases, from different Gravettian horizons to Aurignacian until the Final Mousterian level, have been recognized in the deposit. The chronological framework is based on ^{14}C dating of the fauna, ranging from 38.980 ± 950 kyr BP to 19.570 ± 210 kyr BP. Amongst the findings a tooth of child attributed to Neanderthal was found in the Mousterian levels (Fig. 5):

Layers 1–4 (Level C) – Recent Gravettian with high percentage of burins and substantial presence of microlithic and hypermicrolithic points and backed blades.

Layers 5–10 – Gravettian with Noailles burins – moderate percentage (1–5%) of Noailles and paranoailles burins, abundant presence of microlithic and hypermicrolithic points and backed blades.

Layers 11–18 – Early Gravettian – decrease in burins and hypermicrolithic backed elements with high percentage of backed tools, reaching about 60%.

Layers 19–21 – Initial Gravettian with marginal backed elements – absence of hypermicrolithic backed elements, increase in denticulates and notches, increase in *pièces esquillées*. Among the end-scrapers thick forms appear and pieces with marginal retouch increase. Bone and antler objects are also present.

Layers 22–26 – Aurignacian with Dufour bladelets– in these layers it is possible to observe the presence of the typical Dufour bladelets and pieces with marginal retouch with an increase in bone artifacts. The Aurignacian is characterized by the production of bladelets with trapezoidal section obtained from small pebble cores. The bladelets are wider than those employed in the production of backed elements during the Gravettian.

Layers 27–34 – Final Mousterian– the lithic industry, that includes cores, flakes, points, and side-scrapers, mainly made of flint, quartzite and limestone, is characterized by the presence of the Levallois technology. Such a method allows to obtain flakes with strongly predetermined dimensional, technical, and morphological features, whose butt is often facetted or dihedral. The tools are represented by points, notches and side scrapers. The tools are often of small size and sometimes present a tendency towards microlithism. The Mousterian levels evidence a *facies* that is both different from the Mousterian in the area of Circeo in coastal south Latium and about 10 kyr more recent. The study of the evolution of the lithic complex from these layers will be very important in order to understand the dynamics of the transition from Middle Paleolithic to Upper Paleolithic.

6.2. Gravettian context

The first dating of the C Level obtained on burned bones in the Laboratory of Geochemistry of the University of Rome La Sapienza gave an age of 19,570 ± 210 years BP (Belluomini et al., 2007). Calibration 1σ places this age in a time range between 23.8 and 23 kyr BP, at the peak of the last glaciation (Würm). The excavation of C level and of the other Gravettian levels in total returned more than 20,000 stone artifacts, as well as a large amount of faunal remains. Some incomplete human fragments all belong to the post-cranial skeleton of a single individual (*H. sapiens*).

6.3. Faunal remains

A first taxonomic classification performed on the faunal remains from C Level and the layers 1–6 (Ruiu et al., 2012) provided evidence of a high rate of horse remains (*Equus caballus*), hydruntin (*Equus hydruntinus*) and aurochs (*Bos primigenius*), followed in lesser quantities by remains attributable to red deer (*Cervus elaphus*), to chamois (*Rupicapra* sp.) and more rarely to boar (*Sus scrofa*). Among the carnivores, wolf (*Canis lupus*) and fox (*Vulpes vulpes*) remains were present. The hunting of adults and young animals especially of equines, deer and wild oxen, was very common. The ecological and environmental picture emerging from the analysis of the frequencies of the ungulates from the Gravettian levels of Roccia San Sebastiano (Ruiu et al., 2012) is referable to an open forest habitat, probably related to a cool stadial phase. Along the whole stratigraphic series cervids are always more abundant than the "chamois-ibex" association. The small variations observed between the strata may be attributed mainly to differences in the number of bone remains that influenced the proportions among species, rather than to actual climatic oscillations. During the formation of the Gravettian deposit climatic conditions were probably almost constant favoring the development of a coastal plain where herds of aurochs, hydruntines and horses lived, while on the inland relief there were wooded regions with red deer, wild boar and roe deer as well as rocky areas with chamois and ibex (Ruiu et al., 2010).

6.4. Lithic technology

The technological approach is useful to recognize the cognitive implications of the lithic production, and the deep understanding of the relations between man and environment (Boëda, 1991, 2005; Geneste, 1991; Inizan et al., 1994).

The lithic series analyzed in the C level of Roccia San Sebastiano cave shows a highly specialized behavior, directed to the production of backed bladelets, small backed points and tools (largely *microgravettes*), often of microlithic size, accounting for about 75% of the totality of the instruments. The remaining part of the latter is constituted for 60% by burins, whose numerical importance would seem to be directly correlated to the production of the elements with backed edges. At the present state of research, still in progress, a typological repertoire with such a strong specialization is unprecedented in the context of contemporary lithic productions, or immediately preceding, of sites located on the Tyrrhenian coast of central and southern Italy. Different kinds of raw materials were used in the lithic production (jasper, quartzite, sandstone), but the main component is represented by flint. Most microgravettes were manufactured with flint of local origin, although among these there were some fabricated with allochthonous raw materials, probably coming from the inland Apennine. The question of a non-local origin of raw material arises particularly for some varieties of red flint (*Scaglia rossa*), well distinguishable for their different consistency compared to the rest of sample. In most cases the original source is represented by small-to-medium size pebbles (3–5 cm) of flint, easy to find along the sandy and pebbly banks of some watercourses near the site where outcrops of carbonate formations with lists and chert nodules are present: *i.e.*, along Mt. Petrino (Fig. 3) and about 30 km away in Triflisco area on the Volturno River (Servizio Geologico d'Italia, 1966, 1969; Bergomi et al., 1969).

6.5. Symbolic manifestations

Special symbolic significance has been ascribed to several dozen fragments of bones (diaphysis, parts of blades or pelvis, ribs, etc.) showing evident traces of cuts and incisions made with flint artifacts. Many of these cuts, often limited to small areas on the bone surface, and frequently at the tendon or muscle attachments, were caused by the stripping and dismemberment of wild game. However, in many other cases the incisions extend for several centimeters along large stretches of bone. It seems that, as observed in other caves with Upper Paleolithic deposits, these bone cuts were made for aesthetic reasons, like the engraved pebbles, and are still difficult to interpret. A clast of a sandstone pebble (about 4 × 5 cm), broken anciently, shows evident engravings that seem to outline the profile of a horn of bovid (Belluomini et al., 2007). That figurative element is common in the mobiliary art of the Italian Upper Paleolithic: in particular, the engraving on the pebble of Roccia San Sebastiano resembles the profile of the head of a bovid engraved on a pebble found in the Paleolithic deposit of the Grotta delle Mura, a cave at Monopoli in Apulia, southern Italy. The ornaments include some atrophic deer canines with suspension hole and a perforated shell of a marine gastropod *Tritia neritea*, a sea snail species still present on the sandy seabed in front of the coastal plain, used as a necklace element.

7. Discussion

Morphoevolutionary reconstruction and prehistoric population dynamics are strictly interconnected. Actually, during the deposition of CI, ~39 kyr BP, landscape modeling was mainly driven by Würm fluvial-glacial processes in a prograding coastal plain wider than present one, which reached a peak around 20 kyr BP (LGM, Last Glacial Maximum; Clark et al., 2009). At that time, caves were fundamental shelters for the survival of local small groups of prehistoric populations, like the one of Roccia San Sebastiano, elevated relative to the alluvial plain.

The consequent rapid deglaciation during the Late Pleistocene until the beginning of the Holocene, favored the development of a waterscape scenario with several riverine and marshy environments, due to the abundance of freshwater in a temperate climate. Also some brackish lagoons have developed as a result of marine ingression, due to postglacial sea-level rise, in a rapidly retreating coastal plain.

7.1. Geomorphology

Stratigraphic logs and excavations carried out along the coastal plain of Mondragone and in the cave of Roccia San Sebastiano, respectively, confirm the alternation of different environments during the last 40 kyr: from continental volcaniclastic to transition types, and among these from fluvial-glacial to marshy and to the marine ones (Fig. 6). In particular, tectonics and subsidence, deposition of huge volumes of volcanic tephra and postglacial sea-level rise strongly changed the morphology of this coastland during Late Pleistocene - Holocene. About 39 kyr BP, during CI emplacement, the shoreline was coincident with the current depth of 60 m bsl (Waelbroeck et al., 2002), and the mainland extended for some tens of kilometers westward. Subsequently, the slight sea-level rise during the Holocene and until Roman age (Lambeck et al., 2004a, 2004b, 2011), together with local effects due to volcano-tectonics, subsidence and recent littoral drift (Pennetta et al., 2016b), have further modified the coastal physiography. Various morphoevolutionary dynamics and palaeoenvironmental phases in the modeling of the present landscape occurred, as discussed and summarized hereinafter.

7.2. Paleoecology

The interpretation of microfossils analysis allow us to recognize different paleoenvironments and related waterscapes. 60% of the studied samples was barren due to unfavourable palaeoecological conditions or to post-mortem dissolution of microfossil remains. In fact, acidic waters, resulting from volcanic activities or accumulation of organic matter, can dissolve calcareous shells (for references see Aiello et al., 2007a, 2007b, 2012), while siliceous remains are not damaged by a low pH environment.

The assemblages of the cores CS1, CS3 and LV4, consist exclusively of freshwater species, indicating a paleoenvironmental framework characterized by sedimentation in continental waters. On the other hand, three samples recovered from the core CI2 yielded siliceous spicules pertaining to sea sponges showing the presence of a marine paleoenvironment. Assemblage composition shows that in the study area paleoecological factors varied in space and time. The core CS1 low abundance - low diversity assemblages indicate rather unfavourable conditions for life or fossil preservation. The marked dominance of *C. neglecta* in the sample CS1-1 indicates the presence of relatively cold ($T < 20\,^{\circ}C$) mesohaline (5–18‰) waters with high calcium content. In the samples CS3-9 and CS3-8 poor calcareous assemblages and carbonified plant remnants suggest low-oxygen swampy waters, possibly with a slightly low pH. The relatively rich and well-preserved calcareous microfossils occurring in the CS3-7 - CS3-2 interval show a rapid evolution of this paleoenvironment. Ostracod assemblages are characterized by *D. stevensoni*, *C. neglecta*, *C. ophtalmica* and *Pseudocandona sarsi*, indicating fresh, quite, oligohaline (0.5–5‰) waters with a paleodepth of about 0–6 m. The presence of characean oogonia suggests that deposition occurred in clear waters. In the upper part of the section (sample CS3-1) the presence of an impoverished assemblage including *F. fabaeformis* is probably related to the decreased depth (not exceeding 3 m) and width of the stretch of water. Low-abundance assemblages found in the core LV4 are characterized by interstitial taxa (*M. laisi)* and forms typical of small bodies of water (*Cypridopsis elongata*, *P. sarsi*). Deposition possibly occurred in a pond of relatively brief duration.

The core CI2 deposits lack calcareous microfossils, showing exclusively siliceous spicules pertaining to demosponges (Porifera). Spicules are both monaxon and tetraxon and show that marine waters reached the study area.

7.3. Paleolithic settlement

Geomorphological and paleoenviromental data indicate that territorial conditions were favorable for human population during the Paleolithic. From the final Mousterian to the Gravettian the plain of Mondragone was characterized by the presence of persistent freshwater environments after the deposition of CI, ~39 kyr BP. During the marine regression a wide coastal plain emerged, creating the ideal habitat for equids and aurochs. The subsistence of the human groups living in the cave was based on the capture of red deer, aurochs and hydruntine, and, to a lesser extent, of chamois.

The preliminary technological analysis of lithic assemblages from the Upper and Middle Paleolithic sequence of the Roccia San Sebastiano cave confirms the presence of highly specialized lithic systems. These are related to strategies of raw materials management linked to the availability of different lithic sources in the surrounding landscape and fluvial courses. From Gravettian to Mousterian, different kinds of raw materials were employed in the lithic production, characterized mainly by flint and, to a lesser degree, by jasper; other types of rock such as quartzite and limestone were also employed. The blanks are represented in most cases by medium and small sized flint pebbles. The morphological analysis of the original flint pebbles evidences that these were shaped in a fluvial, even torrential, environment. Such data have been clearly evidenced in the Gravettian and Aurignacian phases and basically confirmed in the levels attributed to the Mousterian occupation.

In conclusion, the results of this multidisciplinary research disclose several perspectives of study for the analysis of territorial behavior during Paleolithic population:

1. The understanding of techno-economic systems, as far as the analysis of the lithic production, is concerned. The general finality is the reconstruction of the technical systems adopted at the Cave of Roccia San Sebastiano and, more generally, in the entire area during different Prehistoric times. In this sense, an approach based on the concept of *chaîne opératoire* will be adopted; this will allow to place every object in its precise context and in the appropriate landscape through the identification of the technical processes related to its production, such as raw material exploitation, tool production, utilization and final disposal.
2. Sedimentological analysis, aimed at the characterization of deposition and erosion processes in the cave through a detailed definition of the micro- and macro-stratigraphic evidence of the Archaeo-stratigraphic Units identified during the excavations.
3. The study of the dynamics of settlements during the different phases of frequentation. The next research program will have to focus on the possible presence of transition levels between the Middle and Upper Paleolithic in the archaeological sequence of the Roccia San Sebastiano cave. Future geomorphological campaigns will also help to understand the chronological and stratigraphical relationship between CI eruption and Mousterian levels. This objective is an important key to understanding the territorial behaviors of the last Neanderthals in the Tyrrhenian versant of southern Italy.

8. Conclusions

The analysis and interpretation of lithostratigraphic, geomorphological, palaeoecological and geoarchaeological data of the Mondragone coastal plain show a rather complex morphological evolution due to diachronic interactions between glacio-eustatic variations, volcano-tectonics and subsidence, dynamics of prehistoric populations and anthropization during the last glacial (Würm) and the post-glacial periods.

The observation of main landforms of the Mondragone territory, the analysis of stratigraphic sequence of four drillings and the comparison with those from the literature, the study of sediments and paleoecological analysis of core samples, the examination and dating of artifacts and samples collected in excavations inside the Roccia San Sebastiano cave, have enabled us to reconstruct the main morpho-evolutionary phases of the area during the Late Quaternary. In particular, we have reconstructed the paleoenvironmental evolution of this coastland between 40 kyr BP and the Roman age (2 kyr BP) up to the present.

Microfossil assemblages displayed the presence of paleoenvironments dominated by a sedimentation in continental waters. Features of ostracod assemblages, including abundance, simple diversity and state of preservation, varied between the examined levels. Assemblages indicate a certain variety of ecological conditions, since the species that compose them are present in different freshwater environments. A marine paleoenvironment is inferred by the presence of siliceous spicules of marine sponges in a few levels of CI2 core, where calcareous fossil remains are lacking.

Based on multidisciplinary results, the morphological evolution of the coastland shows three main phases:

8.1. Pre-CI (Upper Pleistocene; > 39 kyr BP)

Between the Upper Pliocene and the Lower Pleistocene, a marine and/or brackish sedimentation occurred in the *graben*, structured during the previous tectonic phase. This sedimentary process lasted until the Middle Pleistocene, also due to subsequent tectonic phases which formed a low-morphostructural landscape. Subsequent tectonic phases of marginal reliefs caused the eastward gradual migration of the shoreline until the beginning of the Upper Pleistocene. The likely date of the probable palaeo-sea notch observed at about 30 m asl along the carbonate cliff near the quarry in Incaldana at Mt. Petrino could be traced to just before this epoch. Instead, in the studied area no marine forms (notches, terraces) of the Tyrrhenian (generally at 6–8 m asl) were observed, most probably because they were covered in detrital-alluvial deposits rather than eroded.

8.2. Post-CI (Upper Pleistocene – mid-Holocene)

The dating (~39 kyr BP, Rome-2111; see Fig. 5 and Table. 4) of the base level of excavation in the Roccia San Sebastiano cave definitely matches the CI date. Actually, about 39 kyr BP, when the sea level was lower than the current one of about 60 m and the coastline in the Mondragone area was located several kilometers to the west, the emplacement of CI occurred. This formation, outcropping southeast of Mt. Petrino and northwest of Mt. Massico, widely extends in underwater environment between about 8 and 15 m bsl in depth. In particular, on the seabed in front of Mt. Massico and Mt. Petrino the tuff bank extends parallel to the shoreline for over 6 km and is flattened, forming a large marine terrace. The latter shows sinuous transverse incisions dissected in subaerial environment by watercourses, and in southeast direction it is bordered by a straight paleo-sea cliff. CI is also in the underground at 10–15 m bgl, intercepted in boreholes CS1 and LV4 as altered *facies*. The absence of CI in boreholes CI2 and CS3, the presence of fossiliferous marine deposits containing siliceous spicules of sponges in core CI2 (between 21.9 and 20.5 m bgl) and of reworked pyroclastics in the drillings from the literature, allow to hypothesize the existence of a large marine bay. This bay, bordered in southwest and southeast direction by the CI cliff and to the northeast by the carbonate relief of Mt. Petrino, featured shallow water communicating with the open sea to the northwest, and was modeled during the post-glacial sea level rise. Subsequently and until the Holocene the bay was gradually filled up, despite the subsidence, due to the abundant supply of volcaniclastic sediments by the streams of Vulcano Laziale (NW) and the Phlegrean Fields (SE) volcanoes. The latter were also deposited as a result of eruptions that occurred over 8000 years BP (Di Girolamo et al., 1984; Rosi and Sbrana, 1987; Monti et al., 2011; Scarpati et al., 2015). The sedimentary filling resulted in the progradation of this sector of coastal plain, with westward migration of the shoreline and development of continental aquatic environments, the presence of which is confirmed by the discovery of typical freshwater fauna in levels from 8.3 m bgl in borehole CS3 and 2.7 m bgl in LV4. Since freshwater micro-faunas have been found up to 1.25 m and 1.8 m bgl in LV4 and CS3 cores, respectively, these environments were filled up very recently with debris and alluvial deposits. The latter are mainly formed by reworked pyroclastics and locally by intercalations of limestone gravel lobes of the alluvial fans emplaced at the southwest foot of Mt. Petrino. The continental aquatic environments were preserved by a NW-SE dune ridge (over 50 km long), formed during the Graeco-Roman Period, partially dismantled today due to erosion and anthropization but still observable as relic hummocky forms.

8.3. Mid-Holocene – present-day

During the Holocene climatic optimum (HCO, ~6 kyr BP) the sea level raised about 1 m above the present one, eroding the coastline that retreated of tens of meters. In this period coastal dunes and large lagoons were formed, but have in part disappeared. This phase consists of two subphases, with different evolutionary dynamics:

a. *Middle Bronze Age - Roman age (3.8 - 2 kyr BP)*. There was a gradual erosion and modeling of CI outcrops, located in the sea at a distance ranging from a few dozen to some hundred meters far from the coastline of the Greek period (3.8 kyr BP) until the Roman age (2 kyr BP). Development of coastal dune and backdune humid environments occurred (3.8–2.5 kyr BP). Underwater avalanche in the Ischia Island (3–2.4 kyr BP), about 40 km to the south, with genesis of a tsunami which hit the study area as well (de Alteriis et al., 2010; Tinti et al., 2011). Construction of the Roman road paved with limestone blocks, transversal to the coast between Mt. Petrino and the shoreline, was completed by cutting the Graeco-Roman dune. Currently the Roman road is partly buried by the post-Roman sandy beach. A segment of paved road in alignment with the buried trait on the mainland, on the seabed at 3 m bsl deep and about 350 m from the shore, was discovered during recent geoarchaeological surveys in 2012 (Pennetta et al., 2016b). Differential lowering of coastal sector with marine terraces modeled in the CI, characterized by Roman times structures, ranging from 3 m bsl (road remains) and 9 m bsl (*pilae*). The overall lowering is at least −6/-7 m compared to the current sea level, considering a hydro-glacial-isostatic adjustment of 1 m since Roman times, in tectonically stable areas (Anzidei et al., 2003; Lambeck et al., 2004a, 2004b). These data are also confirmed by the presence, in the underground of the coastal plain, of the top of CI intercepted at 10–15 m bgl in the boreholes, above which marine fossil sediments, fluvial-marshy, lagoon and reworked volcaniclastic deposits lie.

b. *Roman age – present (2 kyr BP – current)*. Since Roman times to the present, the subsidence has caused a lowering of the CI substrate, probably at a slower rate than in the past, and the abandonment of the Roman colony of *Sinuessa*, also known for its thermal baths. The prograding littoral, with a dune of 4–6 m in height, has been retreating since the mid-50s, and the dune appears almost completely dismantled and strongly anthropized. The downlift of this coastal sector, based on geoarchaeological elements down to 4.5 m bsl in depth, from Roman times to the present, has varied between 2.4 and 2.7 mm/yr in the last 1700 years. According to Pennetta et al. (2016b), soil lowering is attributable to recent tectonics due to a fault along the southwestern side of Mt. Massico which dislocated the CI, or to a reactivation of a NE-SW fault which triggered the volcano-tectonic collapse of the eastern flank of Roccamonfina volcano in the Late Pleistocene (de Rita and Giordano, 1996; Cimarelli and de Rita, 2010), as well as the contraction due to the cooling of the magma chamber.

Briefly, the main phases of the morphological evolution, which structured the current coastland during the Late Quaternary, can be summarized as follows:

i Eruption and emplacement of CI (~39 kyr BP) inside a previous wide gulf (paleogulf of Gaeta) during the Würm, in a fluvial-palustrine territory (alluvial plain of paleo-Volturno River) with the shoreline positioned about 10 km off (west) and the sea level 60 m lower than the current one; the coastal area was delimited inland (east) by carbonate reliefs, with ascertained attendance of Neanderthal individuals in the Roccia San Sebastiano cave at Mt. Massico;

ii Formation of a bay (6–8 km wide) bordered to the east by mounts Massico and Petrino, and to the northwest by cliffs modeled in the CI (~39-20 kyr BP) in periglacial environment;

iii Rapid retreat of the shoreline and of CI cliffs between the maximum glacial peak and the Holocene (~20–11.7 kyr BP), due to interaction between postglacial sea-level rise, volcano-tectonics and subsidence; consequent modeling of marine terraces, development of lagoons and marshes in the coastal plain until the Holocene climatic optimum (HCO, ~6 kyr BP);

iv Remodeling of the CI marine terraces during the postglacial, characterized by accessory forms of marine (microcliffs, sea notches, pebbly paleo-beaches), tidal (rockpools) and continental (channels, gullies) environments, until the second Holocene warm climate peak (~3.3 kyr BP; Anderson et al., 2007); recent tectonics (~2.5–1.7 kyr BP) and subsidence up to the present (Pennetta et al., 2016b).

Geoarchaeological analysis confirms that the territory of Mondragone was attended by groups of Neanderthals and Sapiens during the last glaciation, between 40 and 20 kyr BP. This is evidenced by numerous bone fragments as remains of hunting activity, by combustion traces and artifacts, and by a primary tooth of a Neanderthal with estimated age of 9 years dated ~39 kyr BP, same age as the CI eruption, discovered in the Roccia San Sebastiano cave.

The ground lowering due to subsidence, earthquakes and volcano-tectonics lasted up to historical times, as confirmed by the presence along the seabed in front of the town of Mondragone, down at a depth of about 9 m bsl, of some structures of the colony of *Sinuessa* of Graeco-Roman Period.

Results obtained so far encourage the perspectives of future research aimed at increasing stratigraphic and paleoenvironmental knowledge in some sectors of the coastal plain, both emerged and submerged, even through excavations in other still unexplored caves along the same limestone cliff.

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