Millennial modifications of the coastal landscape of northwestern Corsica Island (Mediterranean Sea). Climatic vs anthropic drivers.

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Abstract

Mediterranean islands are recognized as very sensitive to climatic changes and anthropogenic disturbance being isolated areas with low resilience capability. Here, we provide new insights into the climatic and anthropic factors which influenced about 6000 years of coastal evolution of northern Corsica, the third largest island of western Mediterranean. A set of palynological, sedimentary and geochemical analyses were carried out on a core extracted from a coastal pond near Crovani (NW Corsica). The main aim was to reconstruct the regional drivers of landscape evolution in this sector of the western Mediterranean and compare it at broader scale. We showed that climate-induced and anthropogenic fires favoured the development of a dense Mediterranean maquis, dominated by *Erica* and *Quercus ilex*, during Middle Holocene (Age specific?). A short but intense terrestrial input in the Crovani pond recorded since ca. 3.3 ka BP was triggered by a decline in arboreal vegetation. This is consistent with a coeval process of runoff recorded in several coastal sites of northern Corsica, and related to a climate event occurred in western Mediterranean around 3.2 ka BP. We further provided evidence that the inception of agriculture is recorded at end of Middle Neolithic. This is much earlier than any archaeology evidence previously available in this sector of Corsica. However, the human impact determined a maquis degradation only since the first millennium BC, when the area also experienced the first phase of galena exploitation from the Argentella mines. In the last 500 years we found a major development of *Castanea* which is of purely anthropic origin being related to the cultivation of this species during the Genoese domination in Corsica. Finally, our data show evidence that atmospheric modifications of solar activity and North Atlantic Oscillation controlled the interplay among geomorphic, anthropogenic and ecological processes which have influenced the fluctuations of forest cover of Corsica in the last 6000 years.

Keywords: Corsica; Pollen, Palaeo-environment, geochemistry, western Mediterranean, Holocene, Geoarchaeology

1. Introduction

The island of Corsica hosts the largest number of coastal wetlands among the Mediterranean islands (Ghilardi, 2020). Most of them formed after the mid-Holocene sea-level stabilization which occurred in the Mediterranean Basin between 7000 and 6 000 cal. BP (Vacchi et al., 2016, 2018). Amongst the ~200 coastal wetlands of the island, brackish lagoons and coastal ponds are the most common geomorphological features (Ghilardi, 2020). Some of these wetlands, were the privileged sectors for Holocene vegetation reconstruction during the 1980s (Reille, 1984, 1991). In the last few years, many of these wetlands were the subject of multiproxy geoarchaeological research (Currás et al., 2017;

Ghilardi et al., 2017; Revelles et al., 2019; Vella et al., 2019) which evaluated the environmental impact of the anthropogenic activities, especially in Prehistoric and Protohistoric times, (Early Neolithic to Final Bronze Age, ca. 7500 BP to 2800 BP). Sediment chronostratigraphy, coupled with the study of multiple paleoecological proxies, including ostracods, molluscs and pollen, allowed to reconstruct both the coastal palaeogeography and the vegetation history of coastal Corsica since Early Neolithic times (Cardial culture, starting from ca. 7500 cal. BP). Indeed, Maurice Reille's palynological work realized on several coastal ponds (Reille, 1984, 1992a), has highlighted the high geoarcheological potential of this island, where earliest traces of human occupation started in the Mesolithic, through the study of the vegetation history to disentangle climate forcing and anthropogenic impacts on the landscape development along the shoreline. However, the pollen data were not provided with a robust chronology, which minimized their interest for the reconstruction of both human population dynamics and climate changes at centennial scale in the Mediterranean basin. To this regard, the information of pollen records from Corsica is paramount, given the strategic geographical location of the island, potentially sensitive to both the North Atlantic climate patterns and the north African atmospheric drivers (Sabatier et al., 2020), and at the same time crossroad for many European and North African populations in the conquest of the Mediterranean regions. In addition, although the pollen analyses of Maurice Reille were masterfully executed, they lack an accurate study of the non-pollen Palynomorphs and are not accompanied by independent palaeoenvironmental proxy data obtained from the same cores, which would have enhanced the reconstruction of the environmental changes.

The aim of this paper is to reconstruct the millennial coastal landscape evolution in northwestern Corsica, tracing back the main climatic and anthropic factors which influenced its changes, through a multidisciplinary approach. A stratigraphic and palynological analysis was conducted on a 6.25 m core extracted from a coastal pond at Crovani. The chronology of the new pollen record was based on 14 new ^{14}C dates which allowed to define the landscape evolution over the last ~6000 years. These data are crucial because the vegetation history of lowland Corsica still has prominent unsolved questions. For example, both the timing and drivers of the dynamics of *Erica* and other evergreen woody taxa is still poorly constrained in the area. According to Reille (1992a), *Erica* forest, representing the climax vegetation in lowland areas of western Corsica, underwent a major degradation process favouring the development of *Quercus ilex* woodland as a result of increasing human impact since the neolithization of the island. Eventually, *Erica* was largely replaced by *Quercus ilex* in a period encompassing the second half of the Middle Holocene and the first half of the Late Holocene (Sub-boreal period *sensu* Reille, 1992a, Carcaillet et al., 1997). Recent palynological studies conducted on coastal areas in Corsica (Revelles et al., 2019) confirmed the anthropic causation of this vegetation turn-over, but suggested that it might have occurred in correspondence with the simultaneous spread of the agropastoral practices during the Early Neolithic, hence significantly earlier than the period previously identified by Reille (1992a). Similar vegetation dynamics were reported also in the nearby Sardinia Island, where a clear development of *Quercus ilex* leading to the partial or complete replacement of the late successional *Erica* shrublands is recorded since the 6th millennium BP (Di Rita and Melis, 2013; Beffa et al., 2016; Melis et al., 2017, 2018). Differently from the aforementioned interpretations, Beffa et al. (2016) hypothesise that the prolonged dominance of *Erica* and the absence of evergreen oak forests in the first part of the Middle Holocene in Corsica and Sardinia were related to warmer/drier summers and cooler/moister winters than today. Such a climate regime, characterized by frequent and prolonged droughts during the spring and summer, causing severe damage to *Quercus ilex* forests, may have led to frequent seasonal wildfires advantaging communities dominated by *Erica scoparia* and *Erica arborea*, which are two extremely fire-adapted species able to quickly sprout and generate new aboveground biomass after frequent and intense fires. In contrast, *Quercus ilex* is considered to be severely affected by natural and anthropogenic wildfires (Colombaroli et al., 2009). According to Beffa et al. (2016), the orbitally-induced decline in summer insolation and rise in winter insolation, which accompanied the onset of the Neoglacial cooling in the Northern Hemisphere, drove the long-lasting expansion of *Q. ilex*, favoured by the cooler, wetter and shorter summers and dryer and warmer winters pervading the Late Holocene.

Another unresolved question is related to the controversial role of climate changes in modifying the vegetational landscape in Corsica. While at a millennial time scale the influence of climate changes on the vegetation development of the island is clearly recognized, the role of rapid climate changes (RCC) is seldom evoked in the regional palaeobotanical narrative. The apparent lack of vegetation responses to centennial climate changes was explained by both the overshadowing effect produced by the local resilient shrublands (Revelles et al., 2019) and the geographical position of Corsica within a possible climate-unsensitive watershed area between the central and western Mediterranean (Di Rita and Magri, 2019), two regions where RCC often produced moisture changes with opposite signs (Di Rita et al., 2018a)

A third key topic to be investigated is represented by the scarcity of knowledge on the origin and development of land use practices in north-western Corsica and their influence on landscape modifications. Until now, archaeological evidence that would indicate a development of agriculture (association of cereal cultivation and pastoral activities), along the shoreline of Corsica during Neolithic times, is scarce and there is clear geoarchaeological interest to elucidate this question based on palaeoecological data. Recognized Neolithic sites of the island have not yet delivered archaeological evidence of cereal cultivation and/or stockbreeding while osteological identification of mammals buried in sheltered caves from Southern and Northern Corsica have delivered important information about the development of stockbreeding during Neolithic times (Vigne, 1984, 1987). For this last cultural period, cereal cultivation has only been evidenced using pollen analyses in the Eastern plain of Corsica for Late Neolithic times (Currás et al., 2017), in the Saint Florent and Bonifacio-Piantarella areas for Late Neolithics and all along Neolithic times respectively (Revelles et al., 2019). In particular, Saint Florent site (Revelles et al., 2019; Revelles and Ghilardi, 2021), which is located North Corsica, and is the closest full palynological record has pointed out development of agriculture since at least Late Neolithic times (ca. 4000 cal. BC).

2. Study area

- *Present day landscape configuration and vegetation composition*

The Crovani pond is situated NW Corsica (Fig. 1) and lies in the western most part of a coastal plain of ~1 km² (Fig. 1A). The plain collects the waters from two catchment basins with intermittent flow: to the south the Argentella-Cardiccia streams (catchment basin ~6 km²) are incising metamorphic rocks (shales and micaschists) and sienogranite and to the north the Marconcellu-Fiuminale streams (total catchment area: ca. 23 km²) drains granodiorites, seniogranites, and Pliocene to Pleistocene screes in the lowermost river course (Fig. 1B). The Crovani wetland covers area of ~0.3 km² behind a thick coastal barrier ≤5.30 m amsl (Fig. 2), to the West, made up by large well rounded pebbles and cobbles (Fig. 2). The pond, placed at 0.75 m above the mean sea level (amsl) during winter, shows seasonal dryness during summer and does not have a direct connection to the sea.

The surrounding wetland is protected by its inclusion in the ZNIEFF (*Zone naturelle d'intérêt écologique, faunistique et floristique*) n. 940004139 '*Etang et zones humide de Crovani*', with the aim of preserving the following protected angiosperm species: *Euphorbia peplis* L., *Polygonum scoparium* Req. ex Loisel., *Ranunculus ophioglossifolius* Vill., *Staphisagria picta* (Willd.) Jabbour, *Tamarix africana* Poir., and *Vitex agnus-castus* L.. The pond is surrounded by a belt of the protected species *T. africana* to the west and to the north and is characterized by a wet meadow covered by palustrine species dominated by *Bolboschoenus maritimus* (L.) Palla, *Juncus acutus* L. and *Juncus maritimus* Lam. The coastal bar is occupied by a population of *Pistacia lentiscus* L. and, on the top of the beach, there is one of the most important Corsican populations of *Vitex agnus-castus* (https://inpn.mnhn.fr/zone/znieff/940004139). In spring, the very rare *S. picta* grows among the pebbles (Jeanmonod and Schlüssel, 2006). The woody vegetation of the site consists of a degraded *maquis* with *Erica arborea* L., *Arbutus unedo* L., *Pistacia lentiscus* L., *Phillyrea angustifolia* L. and sometimes also *Quercus ilex* L. (Reille, 1992a).

- *Local archaeology and history of the human occupation*

First evidence of settlement of Corsica dates back to the Mesolihtic (Lugliè, 2018) and large presence of Neolithic archaeological material allowing to reconstruct the settling history of the island during the spread of agriculture (Revelles et al., 2019). First evidence of early Neolithic cereal cultivation has been mainly identified in different sites of southern Corsica (Figs 1 and 3, Revelles et al., 2019). Northern Corsica also records a rich archaeological background with a Mesolithic to Early Neolithic occupation in the Nebbiu area, at Saint-Florent/Patrimonio sites (Revelles et al., 2019). Balagne is another important place for the human occupation in a coastal context, notably attested by the presence of the Early Neolithic site of La Petra, situated on a peninsula north of the modern town of L'Île Rousse (Weiss, 2010). Furthermore, the Luzzipeu sector (Fig. 1A) is under archaeological investigation in order to reconstruct its human occupation but remains still uncertain due to the paucity of recognized sites and uncovered archaeological material. However, there is an evidence of occupation during Final Neolithic times (starting from ca. 2800 cal. BC) at the Teghja di Linu site (Fig. 1A), a small village composed by huts where lithics have been discovered together with the probable oldest menhir statue of Corsica (Sicurani, 2008; Sicurani et Martinet, 2019; Ghilardi, 2020). Possible evidence of occupation during Late Neolithic times is argued but the lithics uncovered are still investigation to precisely date them (Sicurani and Martinet, 2019). Due to the presence of acidic soils, derived from the erosion of the granitic bedrock, preservation of biological remains and archaeological material in its stratigraphical context is difficult and there is no organic material left in the archaeological strata that could help to evaluate the type of activities developed at the Teghja di Linu site. Excavations conducted over the last two decades at this last site, located at an elevation of ~40 m amsl and distant from the Crovani pond of ~1.5 km, have revealed the existence of a habitat composed by a several circular large structures delimited by tremendous rounded granitic boulders. Unfortunately, the only domestic material uncovered is not helpful to understand the full organization of the site and its interactions with the surrounding landscape, in particular with the coastal area. Protohistoric times are little documented from an archaeological point of view in the Luzzipeu lowlands. Bronze Age sites are therefore situated more inland, generally settled on the tophills. Iron Age and Ancient times are also poorly documented. Recently, archaeological surveys have revealed the presence of tegulae within the 19^{th} to 20^{th} Century CE mining complex of the Argentella (Leleu, 2021) indicating an early exploitation of galena in the nearby Argentella catchment. There is no other evidence of Roman occupation recorded nearby. This low human occupation, dated from Bronze Age to Roman times, contrasts radically with the last millennium where Medieval archaeological remains are attested at San Larenzu and San Quilicu sites (Fig. 2). Both are Roman churches dated from the

11th Century CE and nowadays almost disappeared due to their gradual destruction. From the Genovese occupation to the French administration, the region was attractive for the exploitation of natural resources, especially galena minerals. Evidence for mining from the 16th to the early 20th Centuries has been recorded (Leleu, 2021) but its impact in terms of landscape changes have never been investigated.

3. Materials and Methods

3.1. Coring

A 50-mm vibrocore (COBRA TT equipment – Atlas Copco) 6.25 m long was drilled in the central part of the Crovani pond in August 2018 (Fig. 2). Authorization for drilling was delivered by the *Conservatoire du littoral*. The borehole was precisely levelled using Differential Global Positioning System equipment, thus giving an elevation of +0.75 m amsl (Fig. 2).

3.2. Loss on Ignition (organic matter and carbonate contents) measurements

Loss-on-ignition (LOI) measurements were performed at CEREGE, following Dean (1974) and Bengtsson and Enell (1986). Sediment samples of approximately 1 g were taken at 10 cm intervals throughout the sequence. After drying at 105°C to constant weight, the samples were heated to 550°C for 7 h to estimate the organic content. A second heating phase, to 920°C for a further 7 h, was undertaken to assess the proportion of carbonate.

3.3. Grain-size analysis

Samples used for Loss on Ignition measurements were also analyzed for ~~LASER~~ granulometry. The grain-size distribution of the fine fraction (<2 mm) was measured by laser diffraction granulometry at CEREGE. All samples were first heated to 450°C and mixed with a dispersing agent (0.3% sodium hexametaphosphate) to disaggregate the clay particles.

3.4. C/N analysis

The procedure used is called direct determination because it analyses the organic carbon content after extracting the inorganic carbon fraction from the sample.

First, 28 samples from the core were selected according to their organic matter content: a minimum of 5% by weight of organic matter is required to continue. The method used by Stax & Stein (1993) was used as a basis for the preparation of the samples. Several attacks with hydrochloric acid (HCl 37%) were carried out until the total disappearance of the carbonates. 10 ml of HCl are added to the sample in a glassy pill dispenser and left to operate under a hood for 24 hours. Then, the acid is diluted with Milli-Q water and the whole thing is left to settle overnight. The supernatant is evacuated. This rinsing operation is performed three times so that the pH of the sample reaches the value of 7 (pH paper test). Then the sample is dried in an oven at 40 °C. Finally, the powders recovered after drying are placed in tin cups. Accurate weighing is carried out and the samples are carefully enclosed in the cups, taking care to minimize the presence of air as much as possible. The cups are then placed in the elemental analyzer. This device incinerates the samples under an excess of oxygen and collects the combustion products in order to carry out its analysis. Results were obtained using an elementary analyzer (Vario Microcube, Elementar) coupled to a mass spectrometer (Isoprime 1000).

The purpose of the C/N ratio is to determine the origin of the organic matter present in the sediments analyzed. Generally, plants that live on the continent (vascular plants and ellulosic fibre plants) tend to have a high C/N ratio unlike algae and other aquatic plants. Ertel & Hedges (1985) report values of 15 for vascular plant debris isolated from the coast and 30 to 40 for cellulosic plants. Algae dominated environments have C/N ratios below 10 (Meyers, 1990, Hodell & Schelske, 1998).

3.5 Bulk mineralogy

About 1 gram of dried bulk sediment sample was handly ground for mineralogical analyses. X ray diffraction (XRD) patterns of non-oriented powders (Moore and Reynolds 1997) were acquired between 2 and 30° 2θ angle by using a Bruker D8-Advance Eco 1 Kw diffractometer equipped with a ceramic copper (Kα radiance with λ = 1.5418 Å). The XRD data measured under a current intensity of 25 mA and a voltage of 40 KV were recorded with a Lynxeye Xe energy dispersive detector in the laboratory AGEs at the University of Liège. The minerals were identified by their peak positions and their abundance was calculated from the intensity on selected diffraction peaks (Cook et al. 1975). More details on the semi-quantification method is given in Currás et al. (2017).

3.6. Pb isotopes

The bulk samples were digested using a tri-acid attack of HF/HNO_3/HCl in a laminar flow hood. The Pb purification was made by chromatographic technique on micro-columns of AG1-X8 resin at the AGEs Laboratory (for more analytical details see Weis et al., 2006). The Pb isotopes were measured by static multicollection in dry mode on a Nu Plasma I MC-ICP-MS instrument at the University of Brussels. Tl was used as an internal standard for mass bias correction. Instrumental drift was followed througth a sample standard bracketing method. Repeated measurements ((n = 17) of the NBS981 standard gave average values of $^{208}Pb/^{204}Pb$ (36.6974 ± 0.0078), $^{207}Pb/^{204}Pb$ (15.4925 ± 0.0028), and $^{206}Pb/^{204}Pb$ (16.9365 ± 0.0025). The values were normalized using the recommended NBS981 values

($^{208}Pb/^{204}Pb$ 36.7219 ± 61, $^{207}Pb/^{204}Pb$ 15.4963 ±17, $^{206}Pb/^{204}Pb$ 16.9405 ± 24) from Galer and Abouchami (1998). The Pb isotopes ratios were measured on 24 clayey samples retrieved in unit VI and VII with a ~5 cm sampling resolution between 11 and 260 cm (Table isotope Pb).

In addition, some Pb-bearing minerals were collected in different Corsican ores or mineralised veins on the Paleozoic granites from west Corsica (Fig. 5). We have sampled the main Pb mineral galena (PbS) and also some Pb-bearing minerals like arsenopyrite (FeAsS). Galena was sampled in the mine of Argentella, 2.5 km from the Crovani pond but also in the mine of Lozari (along the northern west coast, east of Ile Rousse) and in a mineralized vein in Prunelli (south of Porto - see locations on figure 1). In addition, an arsenopyrite mineral sample was collected in the Finosa Pb-Zn-Ag ore close to Ghisoni (Fig. 1).

3.7. AMS 14C dating.

The chronostratigraphy of the core was established using a series of 14 AMS radiocarbon determinations from charcoal, organic matter, plant remains and peat samples (Table S1). The analyses were made in the Poznan and Gliwice (Poland) Radiocarbon Dating Laboratories. A smoothing spline age-depth model (Fig. 3) was constructed using the software Bacon version 2.3 (Blaauw and Christen 2011) working on R environment for statistical computing. The Bayesian elaboration of the model is based on the 14 AMS dates calibrated by the program using the IntCal13 curve (Reimer et al., 2013).

3.8. Pollen analysis

Pollen analysis was carried out on 62 samples. Pollen extraction followed the standard procedures summarized by Magri and Di Rita (2015). The sediment was chemically treated with HCl (37%), HF (40%) and NaOH (10%). Tablets of exotic *Lycopodium* spores were added to known weights of sediment to estimate pollen concentrations.

Pollen grains and Non-Pollen Palynomorphs (NPPs) were identified by light microscope at 400 and 640 magnifications, with the help of both pollen morphology atlases (e.g., Reille, 1992b; Beug, 2004) and NPPs reference articles (e.g. Van Geel, 2001; Cugny et al., 2010; Gelorini et al., 2011). For ecological reasons, *Alnus,* aquatics, spores of ferns and other NPPs were not included in the basic sum used for the calculation of pollen frequencies. Microcharcoal analysis was carried out to reconstruct fire history, following the procedures described by Clark (1982). A series of 150 microscope fields were checked for each sample. Microcharcoals smaller than 5 µm were excluded from the sum. The computer program Psimpoll 4.27 (Bennett, 2009) was used to plot the percentage and concentration diagrams, as well as to subdivide the pollen record into 8 local assemblage zones, numbered from the base upwards and prefixed by the site abbreviation CRO, by means of the CONISS method (Grimm, 1987).

A REDFIT spectral analysis and a Wavelet transform using PAST 3.2 software (Hammer et al., 2001) were applied to the unevenly spaced time series represented by the Arboreal Pollen (AP) percentages, in order to detect the possible occurrence of a fundamental tempo in the forest cover changes. REDFIT allows direct processing of unevenly spaced time series without the usual detrend and resample applied to this type of record (Schulz and Mudelsee, 2002). The REDFIT spectral analysis was carried out through a Welch method with a frequency 'oversampling' and a number of 'segments' set at '5' and '1', respectively, so to ensure an adequate number of points along the frequency axis without modifying the resolution of the timeseries (Hammer et al., 2001). The time series was fitted to an AR1 red noise stochastic model, and the significance of the peaks in frequency was tested using both a χ^2 test and a Monte Carlo simulation. The Wavelet transform is a technique used for the identification of spectral signatures in time series often used in paleoclimate records, with the advantage of describing non-stationarities, such as discontinuities and changes in frequency or magnitude through time. The PAST 3.2 software was used with the application 'wavelets for unequal spacing', avoiding the significant and hard-to-quantify bias related to the process of detrending and resampling ~~a~~ timeseries.

4.Results

4.1.Borehole chronostratigraphy

Based on the laser grain size determination and on the organic matter/carbonate contents, six units are distinguished from the bottom to the top (Fig. 4).

Unit I is found in the lowermost part of the core and is identified between 6.25 and 5.95 m deep. It consists of a mixture of well-rounded pebbles cemented within a sandy matrix and gray clays containing from 2 to 5% of organic matter. However, due to the paucity of organic material, radiocarbon dating of this first sedimentary unit was impossible. Facies identification sounds difficult due to the lack of fossil fauna. However, based on the sedimentological information, two types of energy of deposition are identified: the first is controlled by terrestrial dynamics being characterized by the finest particles (grey clays). The second is controlled by coastal dynamics as indicated by the presence of well-rounded pebbles that which are analogue in shape and petrography to the sediments which compose the modern coastal barrier.

Unit II is found between 5.95 and 5.45 m in depth. It comprises medium to coarse grey sands with local intercalations of angular gravels (centimetric in size). Organic matter and carbonate contents are very low (1-2%), avoiding any radiocarbon dating of Unit II. No biomarkers are identified. The sharpness of the gravels indicates a short time of transportation with a probable origin from the upper part of the catchment of the Marconcellu stream.

Unit III is encountered between 5.45 and 3.73 m depth (~6300-5170 cal. BP; ~4350-3220 BC). It consists of homogeneous grey clays. Organic matter content ranges between 10 and 15% while carbonate content shows values comprised between 6 and 9%. Energy of deposition of Unit III is low and is indicative of a swamp.

Unit IV occurs from 3.73 to 2.95 m deep (5170-4762 cal. BP; 3220-2812 BC) and shows similar features with Unit II. It consists of coarse sands with intercalated layers of gravel with sharp edges, witnessing variations in the energy of deposition, in particular at the point of changeover with Unit III. Indeed, in the lowermost part of Unit IV, a layer of 15 cm consists of angular gravels without sedimentary matrix. Organic matter and carbonates contents (both < 2%) are low, similar to Unit II. To sum up, a phase of high energy of deposition is recorded from the late 4th and the early 3rd mill. BC (Late to Final Neolithic Times).

Unit V, found between 2.95 and 2.72 m (4762-4632 cal. BP; 2812-2682 BC), consists of organic coarse sandy clays. Organic matter content increases from upwards (1-7%). The carbonates content is lower than 2%.

Unit VI is found from 1.52 and 2.72 m in depth (4632-3420 cal. BP; 2682-1470 BC). Sedimentological parameters exhibit results similar to Unit V. It consists of organic clays with 10-20% of organic matter and ≤8% of carbonate. The XRD mineralogy (Figure SM mineralogy) reveals the dominance of detrital minerals (~50% of quartz, K-feldspars and plagioclase with traces of amphibole and chlorite). They are associated to clayey minerals (~30% of total undifferentiated clay), carbonates (3 to 8% of aragonite from biogenic fragments) and evaporites (8% < halite < 12% - Fig. 4). Radiocarbon dating of the unit is consistent with a time interval ranging from Late Neolithic times to the Middle Bronze Age.

Sedimentary Unit VII is identified in the uppermost 1.52 m depth (3420-0 cal. BP; 1470 BC-1950 AD). Homogeneous grey clays record numerous traces of oxidation corresponding to rootlets. The organic matter content is homogeneous (6 to 8%), while carbonate content is low (2-3%). The mineral association remains similar to unit VI. The main change concerns the abundance of the evaporites. A drop of halite abundance from 12 to 4% occurs between 166 and 150 cm, i.e. in the upper part of unit VII but close to the transition with unit VI (Fig. 4). This sedimentary unit shows conditions similar to the present-day marshy environments. It is noteworthy that around 1.35 m in depth, granulometry is coarser, composed by fine sands (mode 100 µm), while the rest of the unit is composed by homogenous grey clays. This change is also recorded by a positive excursion in detrital minerals (cumulated abundance over 70 %). It corresponds to a significant increase in quartz (28%) and plagioclase (25 %) and a relative drop in total clays (13%) (Figure SM mineralogy). Rate of sediment accumulation is very low with values of ~4.3 mm per century.

4.2.C/N results

The first two meters that cover the last four millennia were investigated for C/N ratio (Fig. 4). The averaged C/N ratio is high (> 10) and exceeds a value of 16 above 1.16 m suggesting a rather terrestrial origin of the organic matter. The values range between 11 to 14 from 1.16 to 2 m, indicating a mixture of organic matter from vascular plants and algae. The highest value (~30) measured at 1.36 m indicates an episode of high input of sediments of continental origin, with a mix of vascular plants and plant cellulosic. Between 1430 and 1262 BC, Crovani pond experienced an episode with a supply of organic matter composed by a mixture of vascular and cellulosic plants.

4.3. Lead isotopes analyses

The three Pb isotopic ratios evolve in parallel in the 260-upper cm (Fig SM isotopes). The $^{208}Pb/^{204}Pb$ ranges between 38.60 and 39.01 (average 38.9353 ±0.0019), the $^{207}Pb/^{204}Pb$ between 15.65 and 15.68 (average 15.6703 ±0.0007) and, the $^{206}Pb/^{204}Pb$ between 18.61 and 19.11 (average 19.02 ±0.0008) (Table SM isotopes). Even some scattering of the data is observed for the studied pre-Roman period (i.e., 93-260 cm), the isotopic Pb ratios depict a marked decreasing trend upwards. This major change starts at 73 cm (Fig. SM isotopes) during the Roman period and continues over the modern period. The lowest isotopic ratios are measured in the shallowest samples at 11 or 17 cm.

4.4.Pollen analysis and statistical analysis on pollen time series

The results of pollen analysis from Crovani are presented as: 1) a detailed percentage diagram, including most of the pollen taxa and the summary Arboreal Pollen (AP)/Non Arboreal Pollen (NAP) percentages plotted against age (Fig. 6); 2) a percentage diagram displaying the main non-pollen palynomorphs (Fig. 7); 3) a synthetic diagram including cumulative pollen percentages of ecological groups (labelled as conifers and other gymnosperms, riparian trees, deciduous trees, evergreen trees and shrubs, OJCV (*Olea*+*Juglans*+*Castanea*+*Vitis*), anthropogenic herbs, other herbs, coprophilous fungi, and saproxylic and phytopathogenic fungi), the AP percentage record, the concentrations of AP and NAP, the microcharcoals, and some climate proxies (Fig. 8).

The pollen preservation was good with percentages of undeterminable grains seldom exceeding 4%. An average of 310 pollen grains of terrestrial taxa per sample were counted. The biodiversity was represented by 92 different pollen taxa (terrestrial + aquatic plants) summed to 45 types of ferns, algae and fungi and other NPPs. The palynological richness, estimated by rarefaction analysis (Birks and Line, 1992), is always over 15 terrestrial pollen types per sample. Total pollen concentrations vary from 7000 to 321,000 terrestrial pollen grains per gram sediment. The features of the local pollen assemblage zones is summarized in the Supplementary material.

REDFIT and Wavelet analyses were applied to the unevenly sampled timeseries represented by the total AP percentages, since they showed a clear fluctuating trend (Fig. 9). The peaks of this record, mostly composed of more than one sample, appear to represent fluctuations in forest cover rather than random fluctuations due to pollen representation and preservation.

The results of the REDFIT exhibit a peak in power spectrum exceeding 95% of the false-alarm levels of both χ^2 and Monte Carlo tests, corresponding to a statistically significant periodicity of ca. 228 years (time=1/frequency), and less significant frequencies centred at 996 and 430 years, which however exceed 90% of the false-alarm levels of both χ^2 and Monte Carlo tests. The analysis of the Wavelet transform applied to the total AP time series highlights the occurrence of centennial oscillations (Fig. 9), the most significant ones being a band centered at ca. 1000 years and two cycles centered at 450 and 230 years respectively.

5. Discussion

5.1. Evolution of the vegetational landscape

During the Middle and Late Holocene, from ca. 6100 to 1000 cal. BP (4150 BC-950 AD), Crovani pond was surrounded by a dense *Erica*-dominated tall shrubland, accompanied by several evergreen elements, such as *Q. ilex*, *Phillyrea*, *Pistacia*, and wild *Olea*. This observation is consistent with other studies led in the Extreme South Corsica (Revelles et al., 2019) and on Cavallo island, situated in the strait of Bonifacio (Poher et al., 2017) (Figs 6 and 8). An almost continuous record of *Arbutus*, despite the low frequencies of its poorly dispersed pollen tetrads, indicates that strawberry trees was a common presence in the *Erica arborea* formations. The most degraded sectors of this *maquis* vegetation were probably occupied by law shrublands of *Cistus*, which probably played a prominent role in the dune and sandy soil vegetation together with *Olea*, *Pistacia* and other thermophilous shrubs, as reported from several coastal sites of western Corsica (Reille, 1992a).

The pollen record from Crovani provides new data to investigate the complex interplay between *Erica*-dominated and *Q. ilex*-dominated vegetation and their turnover in Corsica (Reille, 1992a; Revelles et al., 2019). Unlike the pollen analysis by Reille (1992a), which shows a temporary replacement of *Erica* with *Q. ilex* shrublands around ~4900 cal. BP (4300±120 ^{14}C date), our record, provided with a more robust chronological control, indicates continuously high frequencies of both *Erica* and *Q. ilex* from the onset of the sequence to ~2900 BP, without any replacement of *Erica* with

Q. ilex shrublands. Instead, our pollen record shows two temporary major increases in *Erica* at the expense of holm oaks in the time-intervals 4700-4300 and 3350-2900 cal. BP. Moreover, high frequencies and concentrations of *Erica* and *Q. ilex* concur in depicting a very dense *maquis* as also indicated by generally high values in the loss of ignition and a significant presence of saproxylic and phytopathogenic fungi, such as *Kretzschmaria deusta*, *Asterosporium* and Xylariaceae (Fig. 7), overall pointing to high values of biomass and of decomposed organic matter.

Bearing in mind the relationship between climate, fire, and evergreen vegetation advanced by Beffa et al. (2016), one may expect that also at Crovani climate-driven fires influenced the forest dynamics of this phase and possibly the production of forest biomass, consistently with a high concentration of microcharcoals (Fig. 8). However, the effect of fire does not fully agree with the interpretation of Colombaroli et al. (2009) and Beffa et al. (2016), who consider *Q. ilex* disadvantaged by both natural and anthropogenic fires. At Crovani site, high concentrations of microcharcoal, reflecting fires, correspond with high values of both *Erica* and *Q. ilex*. High values of *Q. ilex* and microcharcoal support the interpretation of Reille (1992a) and Carcaillet et al. (1997), suggesting that the development of holm oak in Corsica was triggered by anthropogenic fires. At Crovani, a substantial portion of the Mid-Holocene fires was probably related to human activity, which is witnessed by a significant presence of anthropogenic indicators (Figs 6-8). High frequencies of microcharcoal in zones CRO-1 and CRO-2 are consistent with the coeval high incidence of fires recorded in the region (Leys et al., 2013; Lastienne et al., 2020a, b), most of which are attributed to human activity. According to Lastienne et al. (2020b), since 5000 cal. BP humans have taken control of the fire regime through agro-pastoralism, favouring large and/or frequent fire events despite unfavourable climate conditions. For the same reason, the marked decrease in microcharcoal recorded at Crovani during the Late Holocene after ~3350 cal. BP, which matches a decrease in anthropogenic pollen indicators, may reflect a combination of decreased human activity and an unsuitable climate for fires.

Starting from ~2900 cal. BP, a general decline in *Erica*, opposed to an increase in holm oaks, led to a temporary turn-over of the two woody taxa, which occurred only between 2300 and 1900 cal. BP. In this time-interval, an increase in *Q. ilex*-type, accompanied by deciduous *Quercus* and *Quercus suber*-type, may have been strengthened also by forestry practices related to the exploitation of oaks in Roman times. For example, in the last ~2500 years, a clear development of cork oak was reported from some Corsican sites and related to cultivation (Reille, 1984, 1992a), similarly to Sardinia (Di Rita and Melis, 2013) and the western Iberian Peninsula (Carrión et al., 2000).

Between 1900 and 1000 cal. BP, a new moderate increase in *Erica* at the expense of *Q. ilex* is recorded, suggesting a new expansion of the native *Erica*-dominated shrublands.

Between 1000 and 500 cal. BP, a major degradation of the forest cover was recorded, with a massive decline of the tall *maquis* that was replaced by *Cistus*-dominated low shrubland. After ~ 500 BP, *Erica* and *Q. ilex* recovered, as recorded also in other sites of Corsica (e.g. Vella et al., 2019).

The modest oscillations of deciduous trees throughout the record (Fig. 7) suggest that they were scarcely involved in the environmental processes influencing the evergreen vegetation, probably because they were located at higher elevations in the island. The frequent finds of mesophilous trees such as *Fagus* and *Betula*, which require temperate and humid conditions, confirm that part of the pollen rain originated from the montane vegetation belt. The fingerprint of deciduous trees in the pollen record of Crovani, as in other coastal pollen records of Corsica (Reille, 1992a; Currás et al., 2017; Revelles et al., 2019), is clear due the steep topography of the island, which determined a relatively low distance of montane and sub-montane vegetation belts from the coast. However, it cannot be excluded that sparse stands of mixed oak communities may have been preserved also in humid areas at low elevations, especially inside floodplain and riparian woodlands, dominated by *Alnus*, with *Salix*, *Tamarix*, and possible wild *Vitis*, which are still documented in the area (Reille, 1992a).

Conifers are mostly represented by *Pinus* pollen, substantially reflecting the persistence of *Pinus nigra* subsp. *laricio* at montane and sub-montane elevations since the late glacial period (Leys et al. 2014). The occurrence of *Pinus pinaster* since the Bronze Age is probably related to human activity (Reille, 1992a). In addition to pine, conifers (Fig. 7) include both taxa mostly distributed in lowland and coastal areas, such as *Juniperus* and *Ephedra*, and taxa living in montane sectors, such as *Abies* and *Taxus*. Rare occurrences of *Picea*, whose current natural range does not include Corsica (Caudullo et al., 2016), are of distant origin.

5.2. Pollen evidence of hydrological processes

The local aquatic environment outlined by the pollen record ranged from brackish (6100-3400 cal. BP) to freshwater conditions (ca. 3400-present day). This is documented by the presence of strictly freshwater taxa, such as *Spirogyra*, *Zygnema* and *Myriophyllum*, salt-tolerant species, such as *Ruppia maritima*, and marine organisms, represented by foraminiferal linings, pointing to inputs of salt-water into the pond (Bellotti et al., 2016). This can be either related to a period of intermittent connection of the pond with the open sea or with a period of increased storminess. The absence of fossil faunal association does not allow to robustly reconstruct the nature of this backshore environment.

The lower part of the record (~6100 to ~4800 cal. BP) is characterized by high frequencies of *Spiniferites* sp. (Fig. 7), dinoflagellate cysts of high paleoecological and biostratigraphic value, whose ecological features are often difficult to retrieve due to the challenging task of identifying *Spiniferites* at the species level by routine observation in light microscopy (de Vernal et al 2018). The genus *Spiniferites* is characterized by marine species, but it cannot be excluded that some Mediterranean species live in freshwater environments (Kouli et al., 2001; Zonneveld et al., 2013). Based on pollen records obtained from the central Mediterranean, the presence of *Spiniferites* is often associated to brackish water (Di Rita et al., 2018b). Irrespective of water salinity, high frequencies of *Spiniferites* in the lower part of the Crovani sequence may reflect the pioneer stages of a hydrosere succession connected to the early phases of development of the coastal pond.

From ~4800 to ~3350 cal. BP (zone CRO-2), a significant increase in *Ruppia maritima*, a submerged angiosperm with a large salinity tolerance (Kantrud, 1991), coupled with occurrences of foraminiferal linings, highlights a brackish environment. It is consistent with the observed presence of halite in unit 6 (Fig. 4). Beds of *Ruppia maritima* usually occur on muddy sand and mud as submerged vegetation in brackish pools. They accumulate sediment and/or lie adjacent to areas that dry out and may be associated with terrestrial saltmarsh plants, forming a hydrosere succession in coastal wetlands (Rodwell, 2000).

Starting from ~3350 cal. BP, the abrupt decrease in *Ruppia* and the disappearance of most spores of fungi, coupled with a major increase in *Pseudoschizaea* (2%) and fern spores, are the results of complex sedimentological and edaphic changes leading to a lowering of the water level and to the establishment of the present-day marshy environments. *Pseudoschizaea* suggests both desiccation (Scott, 1992) and freshwater flows accompanied by erosive processes sometimes associated with runoff events (Pantaléon-Cano et al., 2003), while the disappearance of most fungal spores, the decrease in pollen concentrations, and the high percentages of Cichorioideae (Figs 6-8) can be interpreted as selective preservation of polynomorphs (Bottema, 1975; Havinga, 1984).

It is noteworthy that Reille (1992a) recorded a sharp drop in *Ruppia* at 150 cm depth and correlated it with a local change in sediment accumulation. This was caused by an event of forest clearance, followed by an increase in runoff, leading to the accumulation of a sandy layer and a significant development of ferns. In our record, a phase of increased terrestrial runoff, revealed by an input of organic matter of continental origin recorded by a positive excursion of C/N ratio at 1.36 m (~3250 cal. BP - Fig. 4) and by a significant increase in detrital minerals (SM Fig. Mineralogy), is not preceded by clear changes in AP percentages that may testify for a deforestation process, although there is a drop in AP concentrations ~3350 cal. BP. A clearance of local shrubs, represented by a sharp decline in *Erica* frequencies, was recorded only after ~3100 cal. BP (Figs 6 and 8). Summarizing, initially the opening of the vegetation did not change the composition of the shrubland, which was later affected by the drop of *Erica*. Sedimentological analyses indicate an increase of the granulometry within a broader context of swamp environment of deposition characterized by homogeneous clays. At ~1.35 m deep, there is an event of higher energy of deposition characterized by the punctual presence of coarse silts to fine sands. In the Canniccia pond, located SW Corsica, Vella et al. (2019) have identified a high detrital input dated also from ~3350 cal. BP. At a regional scale, South France records an intense phase of alluviation within the Rhone drainage basin (Berger et al., 2007) and for the Pyrenean mountains (Galop et al., 2007).

This is possibly explained by the occurrence of a cooler and more arid period which resulted in deforestation on a regional scale (Ghilardi et al., 2017), possibly related to an arid climate event, recognized in western Mediterranean pollen records (Carrión, 2002; Fletcher et al., 2013) and in speleothems from Tuscany located only ca. 200 km from Crovani (Regattieri et al., 2014). It is interesting to underline the fact that Eastern coast of Corsica did not record such important terrestrial input which seems to affect more intensively the Western side of the fourth largest Mediterranean island.

Since ~2900 cal. BP, a further expansion of ferns and other hydrophytes suggests stagnant water, which may have been produced by a lowering of the lake enhanced by the runoff processes and a salinity change towards more freshwater conditions. This change is confirmed by the observed drop in the halite content at the transition between unit 7 and 6 (Fig. 4).

Overall, the sequence dinoflagellates (*Spiniferites*) acquatic plants (*Ruppia maritima*) ferns profiled throughout the pollen record corresponds to a hydrosere succession, whose evolution is strictly related to the sediment infilling of lakes (Fig. 6). This ecological succession typically also involves reed swamp vegetation, here represented by pollen of Cyperaceae and partly of Poaceae, and *Alnus*, as intermediate and mature stages, respectively. In several coastal sedimentary archives of the central Mediterranean, temporary expansions of Cyperaceae and Poaceae are followed by an increase in *Alnus* (Magri et al., 2019 and references therein). At Crovani this pattern is especially clear in the interval between ~2600 and ~1700 cal. BP (Fig. 6), when complete hydrosere succession with a climax woodland stage occurred in marginal sectors of the basin, in relation to the lagoon reduction.

5.3. Human impact on the landscape

Human activity is evident throughout the pollen record with different intensity and type of land use. From the Late Neolithic to Eneolithic (from ~4000 to ~3250 BC), the continuous curve of cereal-type pollen testifies for early cultivations (Fig. 6). It is noteworthy that agriculture is also observed at Saint Florent site, starting from ~4000 cal. BC (Revelles et al., 2019), and only the extreme south of the island (Bonifacio-Piantarella area) exhibits continuous agricultural practices all along the Neolithic period, from ~5500 to ~2500 cal. BC. But, pollen results at Crovani reveal for the first time an earlier human occupation than suggested by archaeological findings: there is a clear evidence that agriculture, based on both cereal cultivation and stockbreeding, was practiced ~1000 years before the earliest trace of human occupation at the Teghja di Linu site.

This arable farming practice appears associated to livestock rearing activities, which contributed to the development of disturbed meadows, as highlighted by a significant record of *Sporormiella*, *Sordaria, and Podospora*, and by pollen indicators for Mediterranean pasturelands, such as *Carduus* type, *Plantago*, *Polygonum aviculare* type, as well as some species of the subfamilies Asteroideae and Cichorioideae (Desprat et al., 2013; Florenzano et al., 2015) (Figs 6 and 8). The high values of microcharcoal may partly reflect the use of fire for farming purposes, such as slush-and-burn practices, which however did not affect the fire-adapted local shrubland.

During approximately Early to Middle Bronze Age (from ~3250 to ~1250 BC), both cereal cultivation and livestock rearing appear less intense during the Late Bronze Age (from ~1250 to 1000 BC). Also the record of *Myrtus* during Middle Bronze Age and Late Bronze Age may be related to human activity as evidenced in other coastal sites of Corsica (Reille, 1992a). Archaeological history of Corsica indicates that Early to Middle Bronze age are periods of human implantation in the upper part of hills (*Casteddi*) when lowlands and coastal areas were less occupied (Pêche Quilichini, 2015). Palynological investigation conducted for Crovani pond and other coastal areas confirm this archaeological characteristic, even if in some coastal areas the Mid to Late Bronze Age records a phase of renewal of agriculture (Ghilardi et al., 2017).

In the Iron Age, cereals almost disappeared and only a scattered occurrences of pasture weeds (e.g., *Carduus*, *Plantago*, and *Rumex*) testifies to poor farming practices addressed to livestock rearing, which suggest a scarce human frequentation in the area (Fig. 6).

Human activity is also revealed by the record of cultivated trees (OJCV curve, Fig. 8), which may also include pollen of wild individuals of *Olea* and *Vitis* from the natural woodlands of Corsica (Reille, 1992a). Between ~350 BC and ~250 AD and after ~1450 AD, the OJCV record shows two major phases of tree cultivation. The first increase reflects a widespread exploitation of olive resources during the Roman Period, also documented by archaeological evidence (Terral et al., 2004). The second increase testifies for an intensification of *Olea* cultivation and the regional plantation of *Castanea* in the uplands during the last 500 years.

Until the mid-16th century, Corsica was managed through an extensive silvopastoral system with a double transhumance whereby people and herds moved between the winter grazing lands in the coastal plains and the mountain rangelands (Michon, 2011). Cereal cultivation was sporadic as shown by the lack of cereal-type pollen in our pollen record (Fig. 6). From 1548 throughout the 17th century, the Genoese Authority introduced the compulsory cultivation of chestnut, whose fingerprint is represented by a peak of *Castanea* in the upper zone of the Crovani record (Fig. 6). The consequence of this decree was a large reorganization of the food, economy, and socio-cultural systems, as shepherds slowly became chestnut growers and settled more permanently in mid-mountain villages. The chestnut culture fully developed during the 18th and 19th centuries, providing flour for daily meals, fodder for animals, and fruits for trade. By the end of the 19th century, the development of local industries and the related outflow of rural population toward urban centres determined the collapse of the chestnut culture (Michon, 2011).

Human impact on the forest cover is recorded since ~1000 BC (Iron Age) by a slight decrease in local woody taxa, mostly represented by evergreen trees and shrubs (Fig. 8), coupled with increases in both herbaceous vegetation and low *Cistus* dominated shrublands (Figs 6 and 8). Considering the poor farming practices of the last three millennia, this pattern mostly reflects clearance dynamics of the *Erica* shrubland at a regional scale. This is consistent with the human-induced opening of the forests recorded, in several other pollen sites of Corsica (Reille, 1992a; Revelles et al., 2019; Lastienne et al., 2020a), and in coastal sites of the central Mediterranean since ~1000- ~500 cal. BC (Di Rita and Magri, 2012). According to Roberts et al. (2019), after ~1000 BC human activity became the dominant causation in determining landscape openings in the Mediterranean regions.

Despite clear land use changes are recorded, human activities at Crovani did not completely transform the structure of the vegetation in terms of forest canopy, except for a temporary dramatic drop of *maquis* vegetation between 950 and 1450 AD (1000-500 cal. BP), for which a prominent anthropogenic causation cannot be ruled out. Pollen indicators of human activity are scarce in this period, but the reappearance of coprophilous fungi (*Sporormiella*) and the increase in *Castanea* and *Olea*, together with a slight increase in fire frequency, may reflect silvicultural practices addressed to the felling of shrublands to gain land available for both stock rearing and olive cultivation in the lowlands, as well as for chestnut cultivation in the uplands. Similar observation has been done in the Saint-Florent area where important deforestation is identified together with the coeval development of pastoral activities (Revelles et al., 2019), reflecting an extensive regional landuse during medieval times. It is noteworthy that this evolution in terms of land use is also accompanied by the building of several churches (Fig. 2) at the beginning of the 2nd millennium CE. To confirm this, between ~1000 and ~500 cal. BP, significant frequencies of *Pseudoschizaea* and *Glomus* suggest soil erosion (Fig. 7) and thus local deforestation.

The human activities may also be tracked from the Pb isotope signature of the Crovani sediments. The sedimentary Pb data measured on the upper 260 cm of the sedimentary sequence are aligned along a linear trend in a binary $^{208}Pb/^{206}Pb$ - $^{206}Pb/^{207}Pb$ diagram (Fig. 5). Such distribution indicates a mixing between two end-members, a natural end-member with higher isotope Pb ratios and a probable anthropogenic-derived end-member characterised by lower isotope ratios.

(a) The first end-member has been defined by the average signature of the 3 samples (196 to 260 cm). Those Chalcolitic samples are used to define the local detrital source with low isotopes ratios (i.e., $^{208}Pb/^{204}Pb$ = 38.9584 ± 0.0020, $^{207}Pb/^{204}Pb$ = $^{206}Pb/^{204}Pb$ 15,6719 ± 0.0008 and $^{206}Pb/^{204}Pb$ = 19,0775 ± 0.0008). This end-member represents the natural background end-member. The Pb isotope ratios of the sediments roughly decrease upwards from this end-member. The oldest pre-Roman samples (n= 19, 93-260 cm) are clustered with an average signature of 38.9667 ± 0.0235, 15,6716 ± 0.0007 and 19.0702 ± 0.0008 for $^{208}Pb/^{204}Pb$, $^{207}Pb/^{204}Pb$ and $^{206}Pb/^{204}Pb$, respectively. Note there is no significant difference in the Pb signature between the Bronze age samples (106-186 cm) and the Iron age samples (measured at 93 and 99 cm).

(b) A shift towards lower Pb isotope ratios is first marked for the Roman samples (53 and 73 cm) and, second for the modern samples (11-23 cm). The first Roman shift may be related to some exploitation of Pb ores. The isotope composition of both regional Pb-bearing ores and modern urban airbones (Bolhofer and Rosmann, 2001) are reported in order to confirm any anthropogenic contribution in the sediment Pb isotope composition. The isotope Pb ratios of the Roman and modern samples become closer and closer to the Corsican Pb minerals (Fig. 5). The analysed Pb-bearing minerals display close Pb isotope signatures, with an average composition of 1.1779 for $^{206}Pb/^{207}Pb$ and 2.0894 for $^{208}Pb/^{206}Pb$. The first decrease of the Pb isotopic ratio observed in the Roman Crovani sediments is in agreement with the historical exploitation of the Pb-Ag ores from the Argentella during the Roman period (Gauthier, 2006). The linear trend defined by the modern samples does not point towards the modern urban airbones but rather towards the Pb signature of the Sardinian ores (Stos-Gale et al., 1995). In the Covani sediments, Sardinia seems to be the most probable anthropogenic source of Pb among the main Pb mines exploited in the Mediterranean area since the Antiquity (in Greece, Turkey, Italy and Spain - see more details in Fagel et al. 2017).

5.4. Effects of Rapid Climate Changes on the coastal tree-cover

In the palaeobotanical narrative of Corsica, no clear tree-cover change has been attributed to a “Bond event” (Bond et al., 2001) (Fig 8) or other RCC of global interest, such as the 4.2 ka event (Bini et al., 2019), the Homeric minimum (2.8 ka BP) (Martin-Puertas et al., 2012) and the Little Ice Age (Trouet et al., 2009). These events have produced major changes in forest cover, although with opposite trends in central and western Mediterranean regions (Fletcher et al., 2013, Magny et al., 2013; Di Rita et al., 2018a).

The 4.2 cal. BP event, perceived in south-central Italy as an aridity crisis producing a forest decline, was not associated to a rapid response in the regional forest vegetation in Corsica and in the northern Apennines (Di Rita and Magri, 2019; Revelles et al., 2019). However, previous studies in Corsica have also shown that the 4.2 event played an influence on geomorphological and sedimentological processes, due to increased storm and fluvial activities as recorded in several western Mediterranean lagoon archives (Revelles et al., 2019 and references therein). In our record from Crovani, rapid fluctuations of the forest cover are found, marked by the maximum values of AP (92%) of the entire sequence at ca. 4450 cal. BP (Fig 6 and 8). Between 4700 and 3500 cal. BP, a long-lasting expansion of *Fagus* suggests permanent humid conditions during the Mid- to Late Holocene transition (Fig 6), which are recorded also in other montane (Reille, 1975; Reille et al., 1999) and coastal Corsican pollen sequences (Poher et al., 2017; Revelles at al., 2019). The development of beech corresponds to relatively wet climatic conditions in Southern France, as revealed by increased storm activity (Sabatier et al., 2012) (Fig 8), in Northern Italy (e.g.to lake-level highstands at Lake Ledro (Magny et al., 2012), and west-central Europe (Magny et al., 2013 and references therein). This pattern contrasts however with the drier conditions indicated by precipitation proxies from the speleothems of the Corchia and Renella caves in Tuscany (Zanchetta et al., 2016; Isola et al., 2019), which confirms a complex geographic expression of the 4.2 ka event (Bini et al., 2019).

The Homeric Minimum (2750-2550 cal. BP, Martin-Puertas et al., 2012) was associated to forest declines influenced by human impact and dryer climate conditions in many records of the south-central Mediterranean (Di Rita et al., 2018c). At Crovani it corresponds to a modest peak in AP, possibly related to slightly wetter conditions. Relatively higher precipitations were recorded in southern France from increased storm activity between 2800 and 2600 cal. BP (Sabatier et al., 2012) (Fig 8), and from lake-level highstands and pollen evidence at Lake Ledro (Magny et al., 2012; Peyron et al., 2017). More humid climate conditions were also found in the western Mediterranean, possibly associated to the negative NAO index that characterizes this interval (Fletcher et al., 2013).

During the Little Ice Age, the record of Crovani shows a marked increase in *Erica* and *Q. ilex maquis*, accompanied by a significant amount of cultivated trees related to orchards and conifer plantations (Figs 6 and 8). The development of natural and cultivated woody taxa was probably favoured by relatively wet climate conditions, which were also recorded in southern France (Sabatier et al., 2012; Benito et al., 2015), in correspondence to a mostly negative NAO index.

The archaeological and paleoenvironmental literatures do not provide noticeable examples of rapid and dry climate events in Corsica. As previously discussed, the complex sedimentological and deforestation pattern at ~3200. cal. BP might be related to an arid climate event. Besides, relatively dry and warm climate conditions may have contributed to produce the major forest decline recorded between 1000 and 500 cal. BP, limiting the sprout of the natural forest vegetation affected by felling activities. In the Western Mediterranean, the dry and warm climate of the Medieval Climate Anomaly is usually associated to an overall positive NAO index (Trouet et al., 2009) (Fig 8).

Sabatier et al. (2020) have found a strong relationship between total solar irradiance and NAO activity, influencing the air masses circulation responsible for the transport of Saharan dust conveyed to Corsica during the last ~3000 years. Through a wavelet analysis, they have shown that the NAO has been the main climatic forcing for centennial to decadal variations since ~1070 AD, with an increase in Saharan dust input during the positive NAO phases. Before ~1070 AD, the total solar irradiance (TSI) was the main forcing factor, with increases in African dust input during low TSI phases. Following the study by Sabatier et al. (2020), we applied REDFIT and Wavelet analyses to the total AP percentages to investigate the effects of the atmospheric circulation in the palaeoevironmental records of Crovani (Fig. 9). The prominent 230-year cycle found in our statistical elaboration by and large corresponds to the Suess-de Vries cycle of solar activity, which has been held responsible for environmental changes in several records around the world, including the Mediterranean (Castagnoli et al., 1992; Galloway et al., 2013; Di Rita, 2013; Degeai et al., 2014; Sabatier et al., 2020). The Suess-de Vries cycle is commonly identified as a conventional 210-year periodicity; however, an increasing number of studies demonstrates its non-stationary variability, which may have a range of ~200-300 years (Vecchio et al., 2017). Similarly, its expression in palaeoenvironment proxies shows a non-stationary periodicity (Galloway et al., 2013). A 230-year cycle was detected in direct proxies of solar magnetic activity, such as ^{14}C timeseries and naked-eye observations of sunspots (Ma and Vaquero, 2020).

Both the REDFIT and Wavelet spectra from Crovani show two less significant periodicities of ca. 430(450) and 1000 years (Fig. 9). The first one corresponds to the ca. 430-years and 450-year cycles detected by Sabatier et al. (2020) in the records of Saharan dust in Corsica, as shown by both TSI and ITCZ, although the authors attribute a low significance to this cycle. A 440-year cycle (together with a 230-year cycle) was found in $\delta^{13}C$ records of speleothems from Northern Iberia (Martin-Chivelet et al., 2011). Similar 400-years periodicities were recognized in various palaeoclimate proxies from both marine (e.g., Bond et al., 2001) and lake records (e.g., Yu and Ita, 2002; Wu et al., 2009) of Middle-Late Holocene. Martin-Chivelet et al. (2011) suggest that this periodicity is produced by climate forcing mechanisms related to changes in solar irradiance and North Atlantic circulation patterns. This hypothesis is supported by a 420-year cycle found by Stuiver and Braziunas (1989) in Holocene time series of ^{14}C production from tree rings,interpreted as a fundamental oscillation related to changes in the solar convective zone. Damon and Jirikowic (1992), however suggest that this periodicity may be a harmonic overtone of the Hallstattzeit cycle (2300-2400 years).

The last notable periodicity we found at Crovani is similar to a prominent ~1000-year cycle of moisture supply reported in proxy records from the western Mediterranean, especially during the Early Holocene, and associated to solar activity (Debret et al., 2009; Fletcher et al., 2013; Jiménez Moreno et al., 2020 and references therein).

Overall, our results show that the forest oscillations at Crovani present fundamental tempo of variability similar to the atmospheric forcing held responsible for the transport of Saharan dust to Corsica. Although its influence on the Corsican forest dynamics is far from being proven and the characterization of its underlying mechanisms is beyond the scope of this study, our results foster further investigations in this field.

6. Conclusions

The multidisciplinary dataset obtained for Crovani pond helps to reconstruct the past landscape configuration within an archaeological context. Our multiproxy results reveal a full history of the Human/Environments interactions within an insular context and helps to significantly improve and complete the archaeological knowledge. In addition, our results contribute to the lively discussion on the vegetation response to rapid climate changes, raising also new questions about planetary drivers of past atmospheric circulation and their possible influence on the forested ecosystems of this strategic region of the Mediterranean.

In particular, the following conclusions can be traced:

1) The results of pollen analysis show that a dense *Erica*-dominated shrubland rich in many evergreen elements characterized the landscape from ~6100 to ~1000 cal. BP, being temporarily replaced by mixed woodlands dominated by *Q. ilex* between 2300 and 1900 cal. BP. A major opening of the landscape occurred only between ~1000 and ~500 cal. BP, featured by a decline in *Erica*-dominated tall shrublands, paralleled by an expansion of *Cistus*-dominated low shrublands. Afterward, the tall shrubland formations recovered.
2) Fires played a prominent role in the development and maintenance of the *Erica*-dominated shrublands, especially during the Middle Holocene (from ~5900 to ~5200 cal. BP), when frequent and intense wild and anthropogenic fires boosted the sprout of *Erica* species. At Crovani, fires do not appear a limiting factor for the growth of *Q. ilex*. However, the origin and timing of the expansion of this species as the dominant element of the Corsican landscape is destined to remain a lively topic of debate unless new palaeobotanical records from lowland areas dated to the Early Holocene areas are studied. The general decrease of fires after ~3300 cal. BP may be explained by a combination of decreased human activity and climate unsuitable for fires.

3) Sedimentological data, Pollen and NPPs indicate that this wetland has been little influenced by marine incursions over the last six millennia. Moderate brackish conditions occurred only from Late Neolithic to part of the Bronze age while during the last three millennia general freshwater conditions prevailed. The sequential development of dinoflagellates, *Ruppia maritima*, and ferns appears to reflect a hydrosere succession, whose evolution is strictly related to the infilling of the lake. After ~3300 cal. BP, this ecological process was influenced by a sudden deposition of continental organic-rich sediments, following rapid deforestation and runoff of regional extension, possibly linked to an arid climate event occurred around ~3200 cal. BP.

4) Evidence for human activity is present throughout the pollen record but with important differences through time. Between ~6000 and ~5200 cal. BP, the continuous curve of cereal-type pollen testifies for the earliest cultivations in this area. Farming activities are also confirmed by the presence of disturbed meadows for livestock rearing, as indicated by the contemporary record of coprophilous fungi and pollen indicators of plants frequently living in Mediterranean pasturelands. However, since ~3300 cal. BP, indicators of cereal cultivation and stock rearing practices became scarce, and evidence for human activity comes from the record of cultivated trees, especially increasing around ~2000 cal. BP and after ~500 cal. BP. The former increase reflects olive exploitation during the Roman Period, the latter points to both olive cultivation in lowland areas and chestnut culture in the uplands. A clear forest degradation dates back to the last three millennia; it mostly reflects processes at a regional scale. A complete opening of the landscape was recorded only from ~1000 to ~500 cal. BP, probably caused by a combination of mining activity of Galena mineral within the Argentella catchment during medieval and Genovese times, and drier and warmer climate conditions related to the positive NAO index of the MCA.

5) Known rapid climate changes, such as the 4.2 ka BP event, the Homeric minimum, and the Little Ice Age, did not determine extensive deforestation as they did in several sites of the south-central Mediterranean. Conversely, at Crovani these phases correspond to slightly wetter conditions, in agreement with humid phases detected in southern France, northern Italy and other regions of the western Mediterranean.

6) The spectral analyses applied to total AP revealed a ~230-year cycle, in the bandwidth of the Suess-de Vries cycle, and other cyclicities attributed to the magnetic activity of the Sun, recognized also in other climate proxies from the Western Mediterranean. This suggest that the atmospheric modifications of solar activity and North Atlantic Oscillation should be considered in the interplay of geomorphic, anthropogenic and ecological processes that influence the fluctuations of forest cover of Corsica.

Acknowledgements

This article is a contribution of the PCR “Approche géoarchéologique des paysages de Corse a l’Holocène, entre mer et intérieur des terres « Tra Mare è Monti » programme, funded by the DRAC Corsica and directed by Matthieu Ghilardi. It is also part of the MISTRALS-PALEOMEX programme of CNRS (INEE-INSU scientific departments) and was funded by the ARCHEOMED workshop (Dir. Laurent Lespez).

Figure Captions

Figure 1. Location map of the study area and sites of previous palynological researches conducted over the last decade. A: Hydrography and archaeology of the catchment basins ending in the Crovani Bay; B: Geology and topography of the catcments basins ending in the Crovani Bay.

Figure 2. View of the Crovani pond, borehole and DGPS profile (AA') locations. The light blue line (dash) indicates the river course of the rivers

Figure 3. Age-Depth Model of Crovani sequence calculated through a Bayesian method using the computer program Bacon version 2.3 (Blaauw and Christen 2011)

Figure 4. …The relative abundance of halite is reported on the left side of the diagram.

Figure 5. Pb isotope results of Crovani pond sedimentary core LCr18 reported in a binary diagram $^{207}Pb/^{206}Pb$ versus $^{208}Pb/^{206}Pb$. The dashed line indicates the linear regression trend between the Crovani samples. Circles: Crovani samples reported by different colors according to their stratigraphical position, i.e. pre-Roman samples, Roman and modern samples. The black circle indicates the average signature of the local geological background defined by the oldest measured Chalcolitic samples. Black symbols: samples from different Pb-bearing mineral collected in West Corsica. The red triangle gives the averaged composition of modern airbornes collected above Roma in Italy (data from Bollhöfer and Rosman, 2001). Green squares: signature of Pb galene-rich ores from Sardinia. See text for more explanation.

Figure 6. Pollen percentage diagram of Crovani.

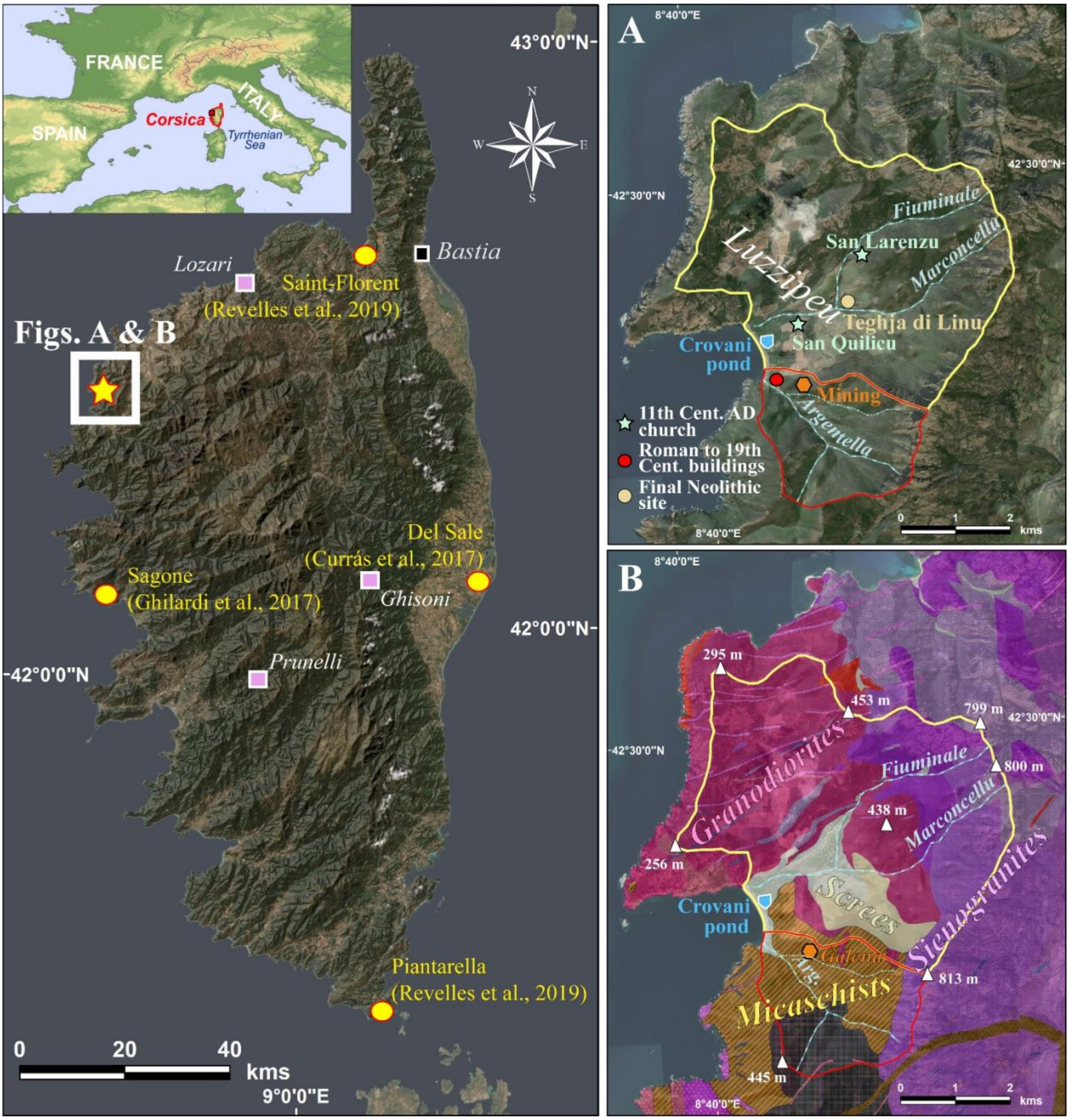
Figure 7. Percentage diagram of Non Pollen Palynomorphs from Crovani

Figure 8. Summary pollen diagram including the cumulative percentages of gymnosperms, riparian trees, deciduous trees, evergreen trees and shrubs, OJCV curve, anthropogenic herbs, other herbs, coprophilous fungi, and saproxylic and phytopathogenic fungi), the Arboreal Pollen percentage record, the concentrations of Arboreal Pollen and Non Arboreal Pollen, and the microcharcoals concentrations. The light blue bars indicate phases of high fluvial activity in Southern France (Sabatier et al., 2012). The orange bars indicate phases of dried climate conditions in South-Central Mediterranean (Di Rita et al., 2018). The NAO index is based on the reconstruction by Franke et al. (2018).

Figure 9. REDFIT and Wavelet analysis of the total Arboreal Pollen percentages.

Table 1. Pb isotopes data of the upper clayey 260 cm of the Crovani pond sedimentary sequence measured by MC-ICP-MS. All measurements were made on the bulk sedimentary fraction. The averaged composition of the international standard NBS 981 obtained during the session of analyse is given in comparison to its recommended composition Galer and Abouchami 1998. The measured composition of the sampled Pb-bearing minerals collected from Argentella and from other sites from West Corsica is reported in the lower part of the table.

Figure 1



FRANCE
SPAIN
ITALY
Corsica
Tyrrhenian Sea
43°0'0"N
42°0'0"N
9°0'0"E
N
S
E
W
Figs. A & B
Lozari
Bastia
Saint-Florent
(Revelles et al., 2019)
Del Sale
(Currás et al., 2017)
Sagone
(Ghilardi et al., 2017)
Ghisoni
Prunelli
Piantarella
(Revelles et al., 2019)
0
20
40
kms
A
8°40'0"E
42°30'0"N
Luzzipeu
Fiuminale
San Larenzu
Marconcellu
Teghja di Linu
San Quilicu
Crovani pond
Mining
Argentella
11th Cent. AD church
Roman to 19th Cent. buildings
Final Neolithic site
0
1
2
kms
B
295 m
453 m
799 m
800 m
438 m
256 m
813 m
445 m
Granodiorites
Fiuminale
Marconcellu
Screes
Sienogranites
Crovani pond
Micaschists

Figure 2

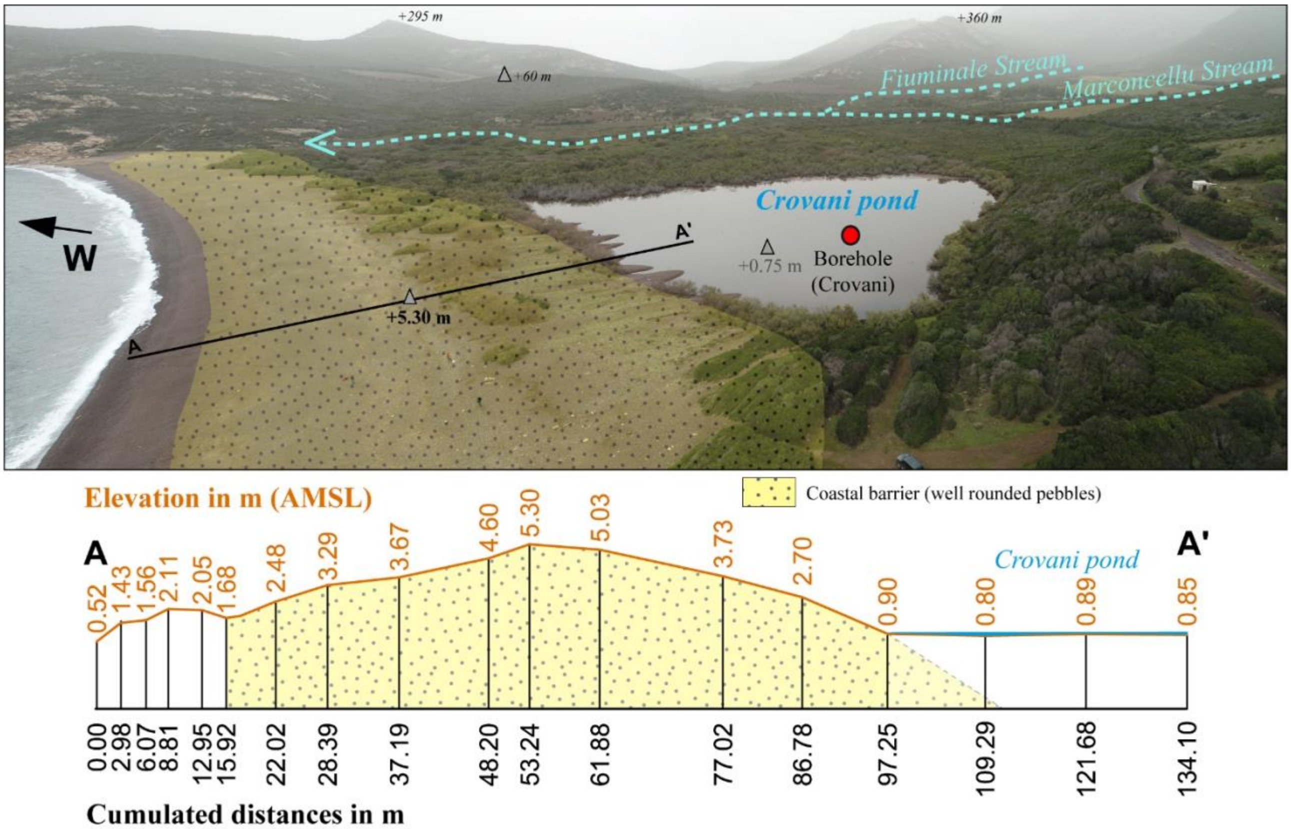

+295 m
+360 m
+60 m
Fiuminale Stream
Marconcellu Stream
Crovani pond
W
A
A'
+5.30 m
+0.75 m
Borehole
(Crovani)
Elevation in m (AMSL)
Coastal barrier (well rounded pebbles)
A
A'
Crovani pond
0.52
1.43
1.56
2.11
2.05
1.68
2.48
3.29
3.67
4.60
5.30
5.03
3.73
2.70
0.90
0.80
0.89
0.85
0.00
2.98
6.07
8.81
12.95
15.92
22.02
28.39
37.19
48.20
53.24
61.88
77.02
86.78
97.25
109.29
121.68
134.10
Cumulated distances in m

Figure 3.

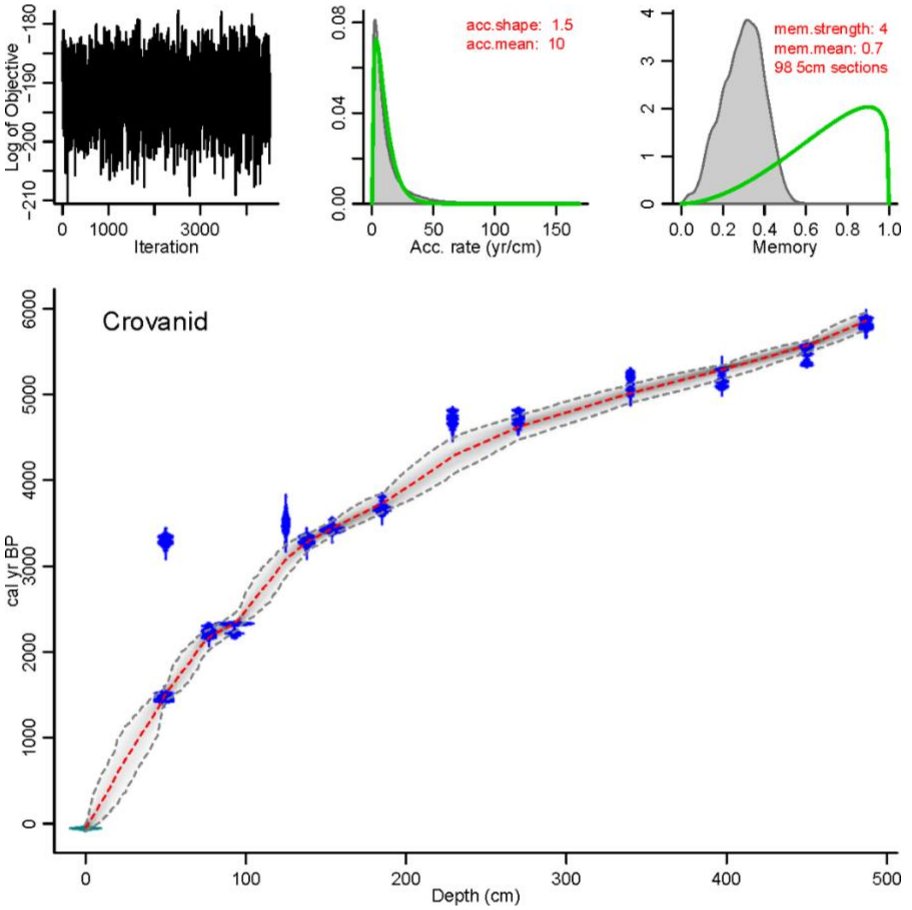
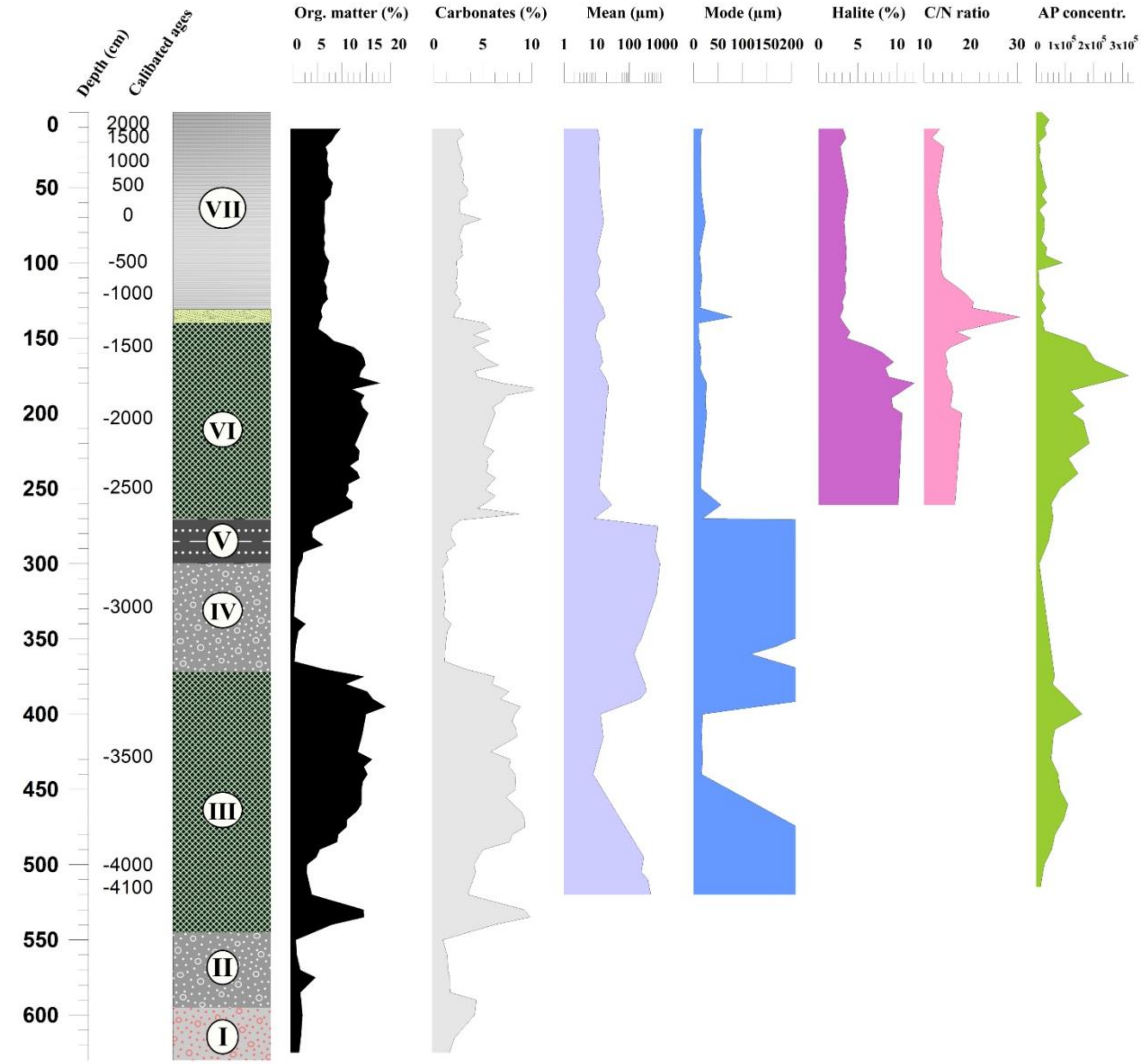

Log of Objective
Iteration
acc.shape: 1.5
acc.mean: 10
Acc. rate (yr/cm)
mem.strength: 4
mem.mean: 0.7
98 5cm sections
Memory
Crovanid
cal yr BP
Depth (cm)

Figure 4



Depth (cm)
Calibated ages
Org. matter (%)
Carbonates (%)
Mean (µm)
Mode (µm)
Halite (%)
C/N ratio
AP concentr.
VII
VI
V
IV
III
II
I

Figure 5

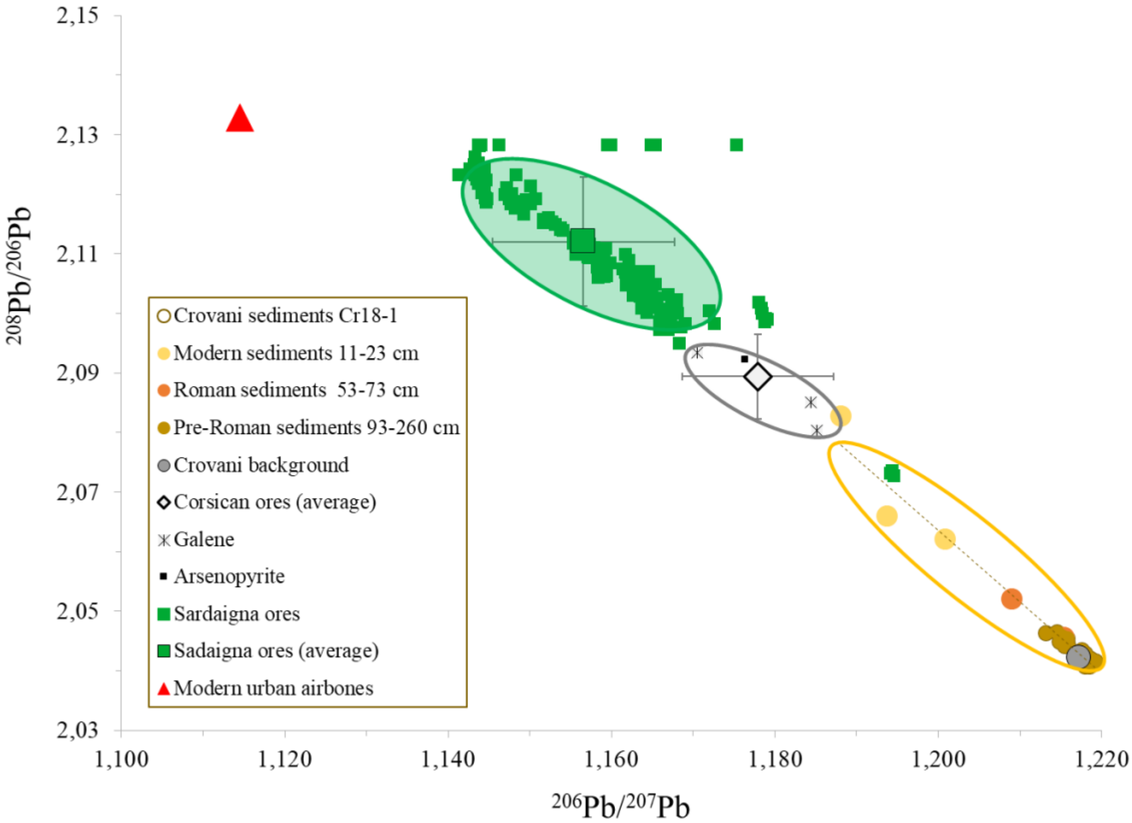

Crovani sediments Cr18-1
Modern sediments 11-23 cm
Roman sediments 53-73 cm
Pre-Roman sediments 93-260 cm
Crovani background
Corsican ores (average)
Galene
Arsenopyrite
Sardaigna ores
Sadaigna ores (average)
Modern urban airbones
$^{208}Pb/^{206}Pb$
$^{206}Pb/^{207}Pb$
2,15
2,13
2,11
2,09
2,07
2,05
2,03
1,100
1,120
1,140
1,160
1,180
1,200
1,220

Figure 6

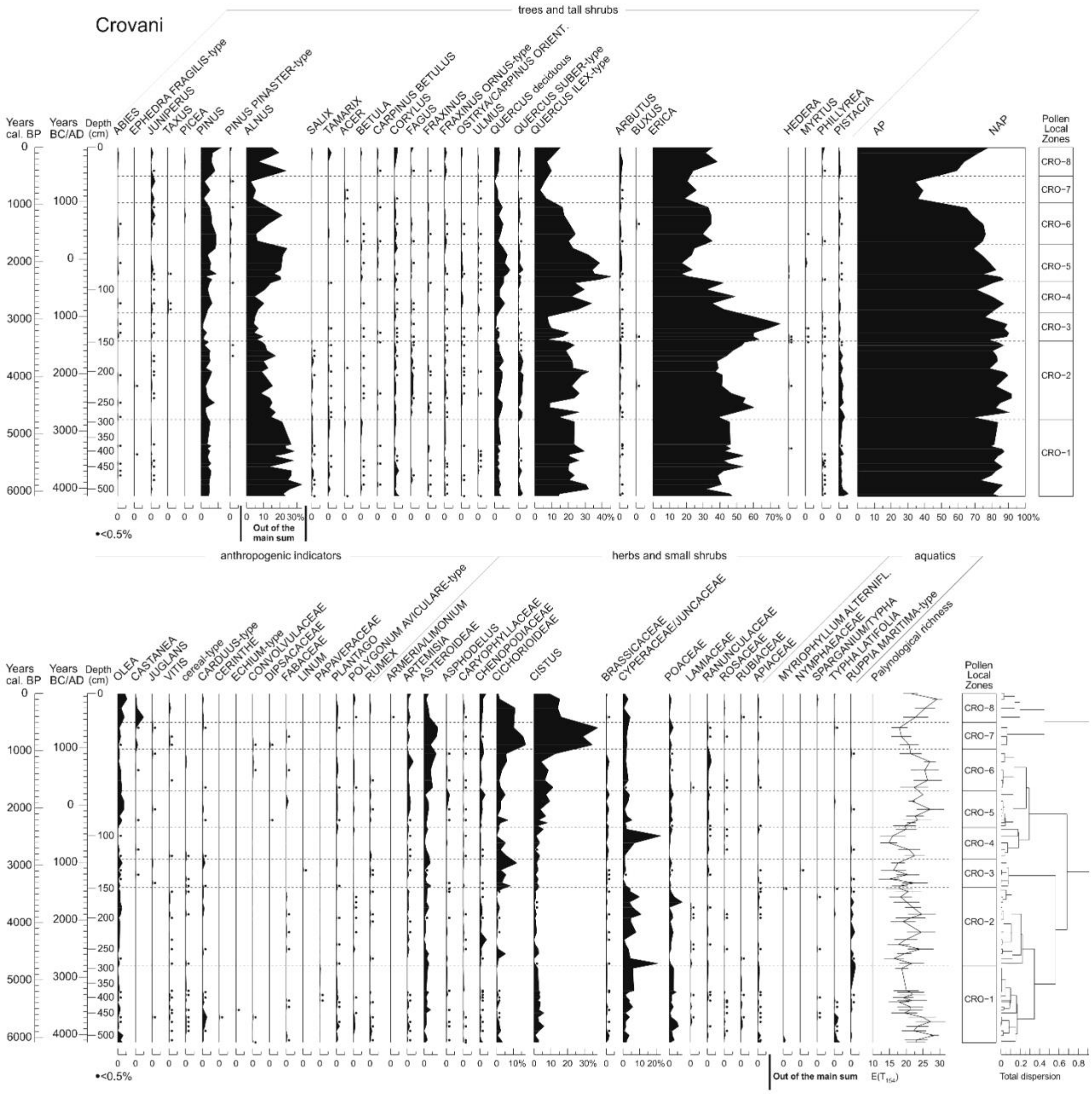
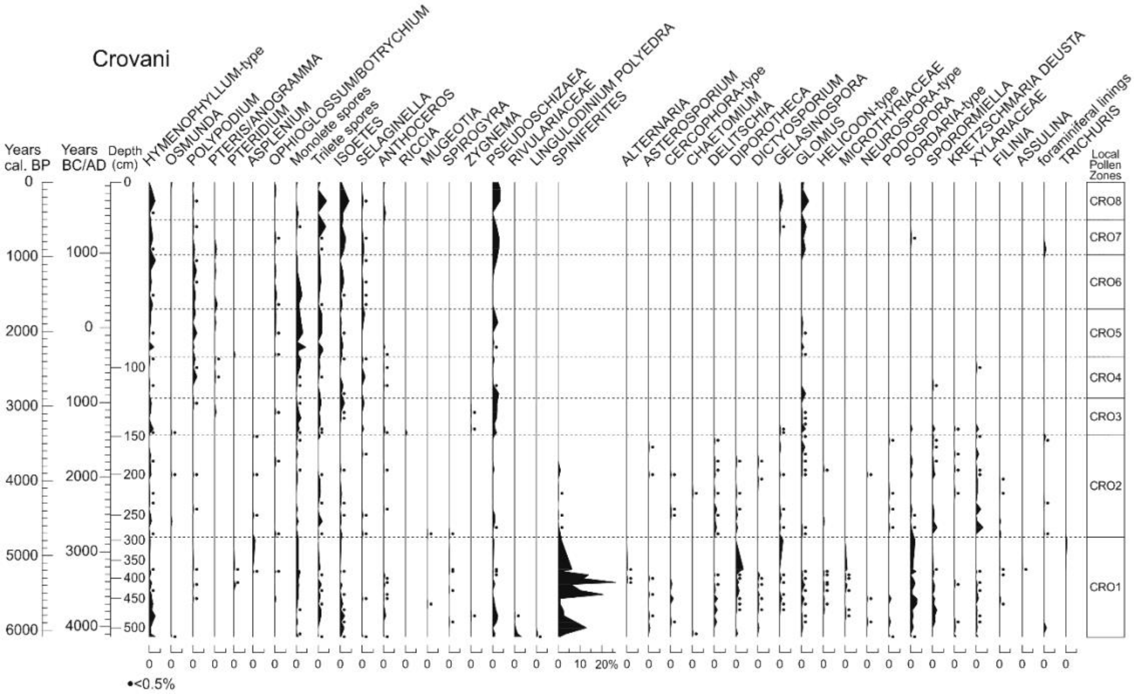

Crovani
trees and tall shrubs
Years cal. BP
Years BC/AD
Depth (cm)
ABIES
EPHEDRA FRAGILIS-type
JUNIPERUS
TAXUS
PICEA
PINUS
PINUS PINASTER-type
ALNUS
SALIX
TAMARIX
ACER
BETULA
CARPINUS BETULUS
CORYLUS
FAGUS
FRAXINUS
FRAXINUS ORNUS-type
OSTRYA/CARPINUS ORIENT.
ULMUS
QUERCUS deciduous
QUERCUS SUBER-type
QUERCUS ILEX-type
ARBUTUS
BUXUS
ERICA
HEDERA
MYRTUS
PHILLYREA
PISTACIA
AP
NAP
Pollen Local Zones
CRO-8
CRO-7
CRO-6
CRO-5
CRO-4
CRO-3
CRO-2
CRO-1
Out of the main sum
•<0.5%
anthropogenic indicators
herbs and small shrubs
aquatics
OLEA
CASTANEA
JUGLANS
VITIS
cereal-type
CARDUUS-type
CERINTHE
ECHIUM-type
CONVOLVULACEAE
DIPSACACEAE
FABACEAE
LINUM
PAPAVERACEAE
PLANTAGO
POLYGONUM AVICULARE-type
RUMEX
ARMERIA/LIMONIUM
ARTEMISIA
ASTEROIDEAE
ASPHODELUS
CARYOPHYLLACEAE
CHENOPODIACEAE
CICHORIOIDEAE
CISTUS
BRASSICACEAE
CYPERACEAE/JUNCACEAE
POACEAE
LAMIACEAE
RANUNCULACEAE
ROSACEAE
RUBIACEAE
APIACEAE
MYRIOPHYLLUM ALTERNIFL.
NYMPHAEACEAE
SPARGANIUM/TYPHA
TYPHA LATIFOLIA
RUPPIA MARITIMA-type
Palynological richness
E(T154)
Total dispersion

Figure 7



Crovani
Years cal. BP
Years BC/AD
Depth (cm)
HYMENOPHYLLUM-type
OSMUNDA
POLYPODIUM
PTERIS/ANOGRAMMA
PTERIDIUM
ASPLENIUM
OPHIOGLOSSUM/BOTRYCHIUM
Monolete spores
Trilete spores
ISOETES
SELAGINELLA
ANTHOCEROS
RICCIA
MUGEOTIA
SPIROGYRA
ZYGNEMA
PSEUDOSCHIZAEA
RIVULARIACEAE
LINGULODINIUM POLYEDRA
SPINIFERITES
ALTERNARIA
ASTEROSPORIUM
CERCOPHORA-type
CHAETOMIUM
DELITSCHIA
DIPOROTHECA
DICTYOSPORIUM
GELASINOSPORA
GLOMUS
HELICOON-type
MICROTHYRIACEAE
NEUROSPORA-type
PODOSPORA
SORDARIA-type
SPORORMIELLA
KRETZSCHMARIA DEUSTA
XYLARIACEAE
FILINIA
ASSULINA
foraminiferal linings
TRICHURIS
Local Pollen Zones
CRO8
CRO7
CRO6
CRO5
CRO4
CRO3
CRO2
CRO1
•<0.5%
10
20%

Figure 8

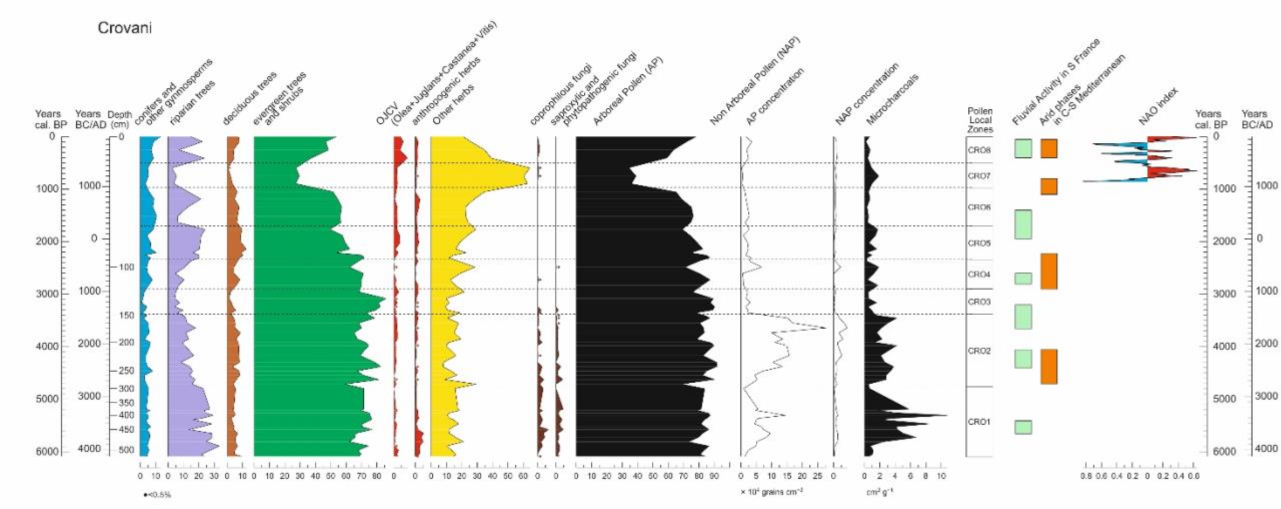

Crovani
Years cal. BP
Years BC/AD
Depth (cm)
conifers and other gymnosperms
riparian trees
deciduous trees
evergreen trees and shrubs
OJCV (Olea+Juglans+Castanea+Vitis)
anthropogenic herbs
Other herbs
coprophilous fungi
saproxylic and phytopathogenic fungi
Arboreal Pollen (AP)
Non Arboreal Pollen (NAP)
AP concentration
NAP concentration
Microcharcoals
Pollen Local Zones
Fluvial Activity in S France
Arid phases in C-S Mediterranean
NAO index
CRO8
CRO7
CRO6
CRO5
CRO4
CRO3
CRO2
CRO1
× 10³ grains cm⁻³
cm² g⁻¹
•<0.5%

Figure 9

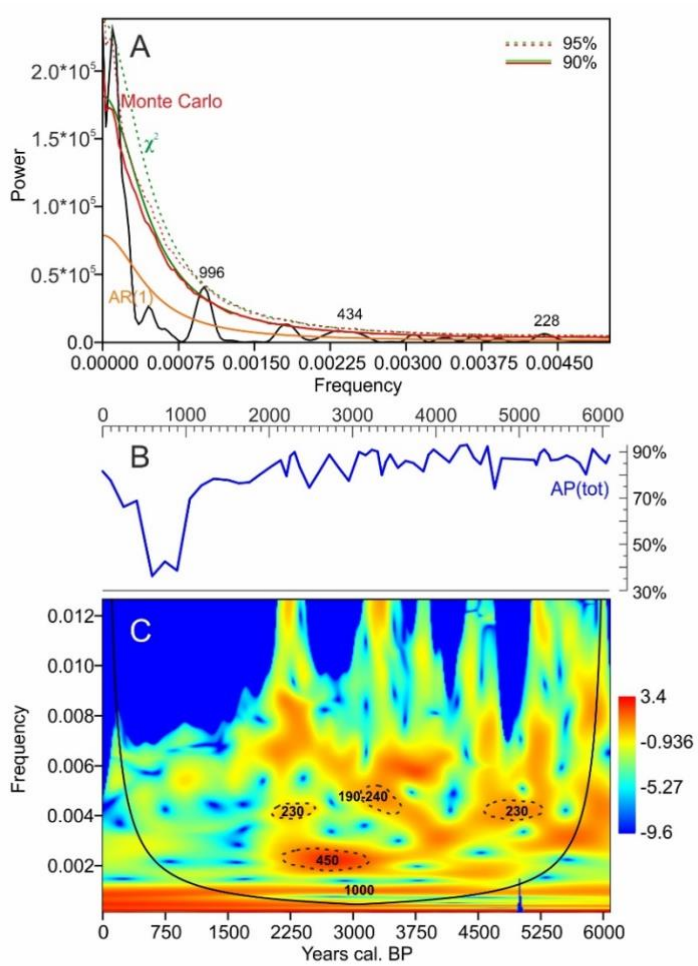

A
95%
90%
Monte Carlo
χ²
AR(1)
996
434
228
Power
2.0*10⁵
1.5*10⁵
1.0*10⁵
0.5*10⁵
0.0
0.00000 0.00075 0.00150 0.00225 0.00300 0.00375 0.00450
Frequency
0 1000 2000 3000 4000 5000 6000
B
AP(tot)
90%
70%
50%
30%
C
Frequency
0.012
0.010
0.008
0.006
0.004
0.002
3.4
-0.936
-5.27
-9.6
230
190-240
230
450
1000
0 750 1500 2250 3000 3750 4500 5250 6000
Years cal. BP

Table 1

Unit	Period	Depth (cm)	208/204	2se	207/204	2se	206/204	2se	208/206	2se	207/206	2se
1	Modern	11	38.5976	0.0020	15.6507	0.0007	18.6839	0.0008	2.0659	0.00004	0.83767	0,00
		17	38.7631	0.0017	15.665	0.0008	18.6114	0.0008	2.0827	0.00004	0.84169	0.00001
		23	38.7894	0.0019	15.6639	0.0009	18.8110	0.0008	2.0621	0.00005	0.83270	0.00001
2	Roman	53	38.868	0.0015	15.6670	0.0006	18.9420	0.0007	2.0520	0.00003	0.82710	0.00001
		73	38.9683	0.0023	15.6746	0.0009	19.0508	0.0008	2.0455	0.00004	0.82280	0.00001
3	Pre-Roman	93	38.9530	0.0020	15.6721	0.0007	19.0334	0.0008	2.0460	0.00003	0.82340	0.00001
		99	38.9542	0.0020	15.6712	0.0007	19.0416	0.0008	2.0480	0.00005	0.82230	0.00001
		106	38.9747	0.0031	15.6770	0.0012	19.0772	0.0014	2.0430	0.00006	0.82180	0.00001
		110	38.9798	0.0019	15.6776	0.0008	19.0838	0.0007	2.0426	0.00004	0.82150	0.00001
		116	38.9095	0.0020	15.6622	0.0006	19.0275	0.0008	2.0449	0.00004	0.82310	0.00001
		120	38.9001	0.0025	15.6680	0.0009	19.0080	0.0010	2.0464	0.00004	0.82430	0.00002
		126	38.9473	0.0019	15.6693	0.0007	19.0844	0.0008	2.0408	0.00004	0.82110	0.00001
		130	38.9769	0.0015	15.6739	0.0006	19.0927	0.0007	2.0415	0.00003	0.82094	0.00001
		136	38.9775	0.0018	15.6679	0.0006	19.0908	0.0007	2.0417	0.00004	0.82069	0.00001
		140	39.0073	0.0015	15.6777	0.0006	19.1066	0.0007	2.0416	0.00004	0.82053	0.00002
		146	39.0033	0.0017	15.6758	0.0006	19.0918	0.0007	2.0300	0.00004	0.82107	0.00001
		150	39,0000	0.0015	15.6749	0.0007	19.0846	0.0009	2.0435	0.00004	0.82133	0.00002
		156	39.0141	0.0016	15.6747	0.0007	19.1098	0.0007	2.0417	0.00004	0.82023	0.00001
		160	38.9589	0.0022	15.6639	0.0008	19.0763	0.0010	2.0423	0.00004	0.82111	0.00001
		166	38.9980	0.0016	15.6726	0.0006	19.0983	0.0006	2.0420	0.00003	0.82062	0.00001
		170	38.9681	0.0016	15.6704	0.0006	19.0516	0.0007	2.0454	0.00004	0.82253	0.00001
		176	38.9625	0.0022	15.6702	0.0008	19.0491	0.0008	2.0454	0.00003	0.82262	0.00001
		180	38.9555	0.0020	15.6696	0.0008	19.0501	0.0007	2.0449	0.00004	0.82254	0.00001
		186	38.9501	0.0014	15.6709	0.0005	19.0544	0.0006	2.0442	0.00004	0.82243	0.00001
		196	38.9717	0.0016	15.6733	0.0007	19.0965	0.0007	2.0408	0.00004	0.82073	0.00002
		200	38.9754	0.0019	15.6736	0.0007	19.0924	0.0009	2.0414	0.00004	0.82092	0.00001
		260	38.9280	0.0026	15.6689	0.0009	19.0434	0.0009	2.0442	0.00006	0.82278	0.00001
Average sediments Cr18-1			38,9353	0,0019	15,6703	0,0007	19,0238	0,0008	2,0467	0,0000	0,8237	0,0000
Standard NBS981												
measured value (n=17)			36.6974	0.0078	15.4925	0.0028	16.9366	0.0025				
recommanded value			36.7219	0.0061	15.4963	0.0017	16.9405	0.0024				

Corsican ores											
Argentella		38,5984	0,0017	15,6547	0,0006	18,55298	0,0008	2,0804	0,00004	0,84376	0,00001
Ghisoni	Galene	38,6879	0,0023	15,6667	0,0008	18,55532	0,00101	2,0850	0,00005	0,84430	0,00001
Prunelli		38,2992	0,0020	15,6310	0,0007	18,29543	0,00076	2,0934	0,00004	0,85437	0,00001
Lozari	Arsenopyrite	38,5185	0,0018	15,6496	0,0008	18,40960	0,00080	2,0923	0,00003	0,85010	0,00001

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