

AperTO - Archivio Istituzionale Open Access dell'Università di Torino

**The pollen record from Grotta Romanelli (Apulia, Italy): New insight for the Late Pleistocene Mediterranean vegetation and plant use**

**This is a pre print version of the following article:**

*Original Citation:*

*Availability:*

This version is available <http://hdl.handle.net/2318/1830740> since 2022-01-07T10:57:18Z

*Published version:*

DOI:10.1016/j.revpalbo.2021.104577

*Terms of use:*

Open Access

Anyone can freely access the full text of works made available as "Open Access". Works made available under a Creative Commons license can be used according to the terms and conditions of said license. Use of all other works requires consent of the right holder (author or publisher) if not exempted from copyright protection by the applicable law.

(Article begins on next page)

## Journal Pre-proof

The pollen record from Grotta Romanelli (Apulia, Italy): New insight for the Late Pleistocene Mediterranean vegetation and plant use



Elda Russo Ermolli, Alessia Masi, Cristiano Vignola, Halinka Di Lorenzo, Lucrezia Masci, Fabio Bona, Luca Forti, Giuseppe Lembo, Ilaria Mazzini, Beniamino Mecozzi, Brunella Muttillio, Pierluigi Pieruccini, Raffaele Sardella, Laura Sadori

PII: S0034-6667(21)00201-3

DOI: <https://doi.org/10.1016/j.revpalbo.2021.104577>

Reference: PALBO 104577

To appear in: *Review of Palaeobotany and Palynology*

Received date: 9 August 2021

Revised date: 24 November 2021

Accepted date: 27 November 2021

Please cite this article as: E.R. Ermolli, A. Masi, C. Vignola, et al., The pollen record from Grotta Romanelli (Apulia, Italy): New insight for the Late Pleistocene Mediterranean vegetation and plant use, *Review of Palaeobotany and Palynology* (2021), <https://doi.org/10.1016/j.revpalbo.2021.104577>

This is a PDF file of an article that has undergone enhancements after acceptance, such as the addition of a cover page and metadata, and formatting for readability, but it is not yet the definitive version of record. This version will undergo additional copyediting, typesetting and review before it is published in its final form, but we are providing this version to give early visibility of the article. Please note that, during the production process, errors may be discovered which could affect the content, and all legal disclaimers that apply to the journal pertain.

**The pollen record from Grotta Romanelli (Apulia, Italy): new insight for the Late Pleistocene Mediterranean vegetation and plant use**

Elda Russo Ermolli<sup>1</sup>, Alessia Masi<sup>2-3</sup>, Cristiano Vignola<sup>2\*</sup>, Halinka Di Lorenzo<sup>1</sup>, Lucrezia Masci<sup>2</sup>, Fabio Bona<sup>4</sup>, Luca Forti<sup>4</sup>, Giuseppe Lembo<sup>5</sup>, Ilaria Mazzini<sup>6</sup>, Beniamino Mecozzi<sup>7</sup>, Brunella Muttillio<sup>5</sup>, Pierluigi Pieruccini<sup>8</sup>, Raffaele Sardella<sup>7</sup>, Laura Sadori<sup>2</sup>

<sup>1</sup> Department of Earth Sciences, Environment and Resources, University of Naples Federico II, Via Cinthia 21, 80126, Naples, Italy.

<sup>2</sup> Department of Environmental Biology, Sapienza University of Rome, Piazzale A. Moro 5, 00186, Rome, Italy.

<sup>3</sup> PaleoScience & History Group, Max Planck Institute for the Science of Human History, Kahlaische Str. 10, 07745, Jena, Germany.

<sup>4</sup> Department of Earth Science, State University of Milan, Via Mangiagalli 34, Milan, Italy.

<sup>5</sup> Department of Humanities, University of Ferrara, Corso Ercole I d'Este 32, 44121, Ferrara, Italy.

<sup>6</sup> IGAG CNR, Area della Ricerca di Roma 1 - Montelibretti, Via Salaria km 29,300, 00015, Monterotondo (Rome), Italy.

<sup>7</sup> Department of Earth Science, Sapienza University of Rome, Piazzale A. Moro 5, 00186, Rome, Italy.

<sup>8</sup> Department of Earth Science, Turin University, Via Valperga Caluso 35, 10125, Turin, Italy.

**Corresponding author:** Cristiano Vignola, [cristiano.vignola@uniroma1.it](mailto:cristiano.vignola@uniroma1.it)

## Abstract

Pollen analyses have been carried out on the infilling deposits of Grotta Romanelli (Apulia, Italy), a reference site for the Middle and Upper Palaeolithic of Italy. The analysis focused on *Terre rosse*, a fine unit till now ascribed to an interstadial phase following the Würm acme, and on the uppermost unit (*Terre brune*), recently dated to the latest Late Pleistocene-Early Holocene. Despite the diffuse barrenness and low pollen concentration of many levels, pollen data from Grotta Romanelli gives insights into the palaeoenvironmental setting of the deposits and their chronological attribution. The presence of *Olea* in all levels of *Terre rosse* strongly suggests their attribution to the Last Interglacial (Eemian), during which this plant was diffused in the Mediterranean area. The *Terre brune* deposition occurred when the environment was open, with rare trees and shrubs and prevailing steppe elements. This association reflects the climatic conditions of the Lateglacial, with evidence of both the warm interstadial Bølling/Allerød and the cold stadial Younger Dryas. Mediterranean, mesophilous and riparian arboreal elements are present, especially in the Early Holocene levels. Comparison with modern pollen material allowed some fossil grains, found in high amounts and in clusters, to be tentatively ascribed to the species *Crithmum maritimum* (Apiaceae), *Muscari comosum* and to *Asparagus maritimus/Ornithogalum* (Asparagaceae). The significant occurrence of such entomophilous plants reveals differential transportation inside the cave and, since most of them are edible and/or have medicinal properties, suggests an intentional introduction and possible use during time, by both Neanderthals and modern humans.

## Keywords

Eemian; Lateglacial; *Olea*; edible plants; Neanderthals; *Homo sapiens*

## 1. Introduction

The Italian Peninsula occupies a strategic position in the heart of the Mediterranean area, playing a pivotal role in the study of paleoenvironmental dynamics during the Quaternary (e.g. Suc et al., 1995, Sadori et al., 2013, Sardella et al., 2018). The wide latitudinal extension of this territory (47°-35°N), and the presence of a mountain chain (Apennines) all along this axis, causes a strong climatic gradient and marked regional differences. This variety of environmental conditions strongly impacted faunal and floral assemblages during the last 2.6 Ma, a period that experienced major climatic oscillations and a general drop in temperatures and humidity (e.g. Suc et al., 1995, Sardella et al., 1998, Sala and Masini, 2007, Bertini, 2010, Kustatscher et al., 2014, Combourieu-Nebout et al., 2015). In this context, the Apulia region represents a kind of “peninsula in the peninsula”, spanning for more than 350 km in the NW-SE direction and only 30 km along the SW-NE axis (Fig. 1a). The remarkable number of Middle Pleistocene to Holocene deposits makes this region a key territory for the study of the Quaternary terrestrial ecosystems in the Mediterranean area, especially concerning faunal assemblages.

The earliest archaeological research in Apulia took place in the late 1800s, with the discovery of a number of coastal caves, which yielded a rich paleontological record, including human fossils. Grotta Romanelli (GR) was discovered by Ulderigo Botti in 1874. The cave was inaccessible because it was completely filled by sediments, and therefore Botti focused his study on the breccia cropping out outside the cave (Botti, 1874). The first excavation campaigns were conducted by Paolo Emilio Stasi in the early 1900s and directed by Gian Alberto Blanc since 1914. These activities immediately had a great resonance in the international scientific community, bearing the first evidence of the Upper Palaeolithic in

Italy. Grotta Romanelli was the first site where the systematic palaeontological/archaeological and stratigraphical approach was applied by using a scientific method, still adopted today (Blanc, 1920, 1928, Sardella et al., 2018, 2019, Tarantini, 2018; Forti et al., 2020). The fieldwork activities continued until the early 1970s, directed by Istituto Italiano di Paleontologia Umana (Italian Institute of Human Paleontology), coordinated by Luigi Cardini.

In 2015, new multidisciplinary research started, coordinated by Sapienza, University of Rome, with the support of other research institutions and with the authorization of Soprintendenza Archeologia Belle Arti e Paesaggio, Brindisi & Lecce. The aim of this project is to update and redefine the stratigraphical and chronological context as well as to revise fossil remains (including *Homo*), artefacts, and cave and mobiliary art.

In the framework of this last research project, the first palynological analyses were carried out on the infilling deposits of the cave in order to give further constraints to the palaeoenvironmental context and its chronological implications. Due to the detritic nature of the deposits covering the Middle and Late Pleistocene, no continuous pollen sequence is available in Apulia, where only Holocene records were analysed (Caroli and Caldara, 2007, Di Rita and Magri, 2009). This makes the new data from GR particularly important in contributing to defining the palaeoenvironments of the Middle and Upper Palaeolithic.

## FIGURE 1

### 2. Study site

Grotta Romanelli (40°00'58" N, 18°26'01" E) is a cave located on the Ionian side of the Salento peninsula (southernmost part of Apulia, Italy), in the municipality of Castro (Lecce) (Fig. 1a). The Salento peninsula is part of the Apulia Carbonate Platform, and is composed of Jurassic-Cretaceous limestone and dolostone capped by Neogene to Quaternary sediments stretching between the Adriatic and Ionian Seas (Fig. 1b). Karstic landforms characterize this

territory, as testified by many coastal caves, sinkholes and karst fissures. The Ionian coast, between Otranto and Leuca, is characterised by steep sea-cliffs 50 to 100 metre high. In this area, many caves open into the steep coastline (e.g. Grotta Romanelli, Grotta Zinzulusa, Grotta delle Striare) or are submerged beneath the present sea level (e.g. Grotta Azzurra, Grotta Palombara). Grotta Romanelli opens at 7.3 m a.s.l into the Ciolo limestone Formation, a bioclastic calcarenite-calcirudite of the Upper Cretaceous, which is overlapped by the Castro limestone Formation, a fringing reef of the Oligocene (Pomar et al., 2014) (Fig. 1c).

The climate of Apulia is characterised by warm-dry summers and more humid conditions in autumn and winter, with isotherm gradients from North to South. Mean annual temperature and precipitation are typically Mediterranean (18°C and 575 mm respectively; Polemio and Lonigro, 2013) while climatic parameters vary in the hills and mountains of the Apennines, lying in the northern part of the region, where colder (and snowy) winters and cooler summers are attested. The local vegetation is characterised by the Mediterranean open forest growing on limestone substrates in the lower mesomediterranean bioclimatic belt (Biondi et al., 2004). Oak woods dominate and are mainly formed by holm oaks (*Quercus ilex* L.) and kermes oaks (*Q. coccifera* L.) often mixed with downy oaks (*Q. pubescens* Willdenow), even if local formations of the Macedonian oak (*Q. trojana* Webb) are also frequent in the central part of the region. Evergreen sclerophyllous elements are abundant, such as strawberry tree (*Arbutus unedo* L.), olive tree (*Olea europaea* L.), green olive tree (*Phillyrea latifolia* L.), lentisk (*Pistacia lentiscus* L.), Italian buckthorn (*Rhamnus alaternus* L.), myrtle (*Myrtus communis* L.), often mixed with mesophilous trees like manna ash (*Fraxinus ornus* L.), Christ's thorn (*Paliurus spina-christi* Miller), blackthorn (*Prunus spinosa* L.), almond-leaved pear (*Pyrus amygdaliformis* Villars) (Macchia et al., 2000). In the Salento peninsula kermes oaks and holm oaks form the main arboreal component of woods with shrubs such as lentisk,

Italian buckthorn, strawberry tree and myrtle. Worth of mention is the presence of Aleppo pine (*Pinus halepensis* Mill.) along the Salento Adriatic coast (Fady et al. 2003).

### 2.1. The deposits infilling the cave

The sedimentary succession of GR was firstly described by Stasi and Regalia (1904), who identified the main complexes infilling the cave. The stratigraphic scheme was implemented by Blanc (1920, 1928) and later enriched by radiometric dates in the 1950s and 1960s. Blanc reported a basal marine conglomerate (level K) directly covering the Upper Cretaceous carbonatic bedrock (level L, Fig. 2) and testifying to the submersion of the cave during the Last Interglacial period (Riss-Würm). On top of level K, Blanc (1928) reported traces of a fireplace and fossil bones of warm faunas including hippo, elephas and rhino. The thick level of calcareous breccia (level I) covering the beach (level K) was interpreted as the result of rock falls occurring within the cave during the same warm period, as testified by the presence of the same fauna, traces of fire and a few limestone tools (Blanc, 1928). A speleothem of ca. 20 cm (level H), sealing levels K and I, was considered the first evidence of a profound hydroclimatic change linked to the Würm glaciation (Blanc, 1928). Speleothem H is covered by the fine complex of *Terre rosse* (level G). This deposit was attributed to a warm and dry interstadial phase, following the Würm acme (*sensu* Blanc, 1928). Due to its aeolic origin and the diffuse occurrence of pachyderms, level G was associated with the existence of a wide coastal plain drained by rivers, formed in front of GR thanks to a marine regression. The chronological attribution proposed by Blanc (1928) was considered too young by several authors (e.g. Piperno, 1974, Masini et al., 1990, Sala et al., 1992, Sardella et al., 2014, 2018) who ascribed a more archaic character to both the faunal assemblages and lithic industries. The thin speleothem F, discontinuously covering the *Terre rosse* (Fig. 2), was as well ascribed to a period of enhanced precipitation associated at that time (Blanc, 1928) with the



last advance of the Würm glaciation. Thanks to the U/Th dating of speleothems H and F (Fig. 2, Table 1), the *Terre rosse* deposition was successively constrained to a period between <69,000 and ca. 40,000 yrs BP (Fornaca-Rinaldi and Radmilli, 1968), at present encompassing part of Marine Isotope Stage (MIS) 4 and MIS 3. These radiometric data confirmed the chronology of the lower part of the deposit previously proposed by Blanc.

Speleothem F marks the transition between the *Terre rosse* and the overlying *Terre brune* (levels A-E). The latter, ascribed to aeolian deposition during a cold and arid period (Blanc, 1928), was characterised by a rich fossil fauna with horses and birds, among others, typical of steppic environments, and ascribed to the last phases of the Würm glaciation. The successive radiocarbon dating of several samples from levels A to E (Table 1; Bella et al., 1958, Vogel and Waterbolk, 1963, Alessio et al., 1965) constrained the deposition of *Terre brune* to a period between ca. 11,000 and ca. 9000 yr BP, now corresponding to the Early Holocene.

#### FIGURE 2 - TABLE 1

The results of more recent AMS  $^{14}\text{C}$  dating, obtained by teeth and postcranial elements of mammal fossils collected from *Terre brune* (Table 1; Calcagnile et al., 2019, Sigari et al., 2021), expand and refine the previous chronology, with lower levels (level E *sensu* Blanc, 1920; Fig. 2) encompassing the Late Pleistocene-Holocene boundary and extending the chronology of the upper levels (level B *sensu* Blanc, 1920; Fig. 2) to the earliest Early Holocene.

Since the first discovery of modern human bones in *Terre brune* (Stasi and Regalia, 1904), fragmentary remains of at least six adults and six children were studied by Fabbri (1987) and compared to the Upper Palaeolithic populations of Italy and Europe. Very abundant lithic tools (more than 10,000), artifacts, and bone industry, attributed to the final Epigravettian, the so-called Romanellian (Mussi, 2002, Bietti, 2003), were recovered in *Terre brune*, demonstrating occupation by modern humans in different stratigraphic levels. No bone

artifact was recovered from the *Terre rosse* but the over 1000 limestone tools found in its basal levels and referred to the Middle Palaeolithic (Mousterian: Piperno, 1974, Spinapolice, 2008, 2018) indicate occupation by Neanderthals. The first evidence of their presence in the cave is provided by remains of fireplaces discovered below *Terre rosse*, associated with some limestone, flint, and quartzite tools (Blanc, 1928, Piperno, 1974).

### 3. Palaeoenvironmental and paleoclimatic data based on faunal assemblages

Preliminary palaeoenvironmental and paleoclimatic reconstruction of GR was performed by Blanc (1920, 1928), who interpreted *Terre rosse* on the basis of faunal finds as typical of warm and arid climatic conditions and *Terre brune* of cold climatic conditions.

The fossils from *Terre rosse*, never formally described or figured, were included in a faunal list more than one hundred years ago by Blanc (1920) (Table 2). A large revision is in progress to update the taxonomical attribution, as well as to investigate morphological and biometric adaptations in response to climate changes, and to get taphonomic data in relation to a possible human exploitation.

#### TABLE 2

In the last decade, the canid remains from *Terre rosse* were attributed to *Canis lupus* by Sardella et al. (2014), whereas the rhino sample from the same level was referred to *Stephanorhinus hemitoechus* (Falconer, 1868) by Pandolfi et al. (2017). Recently, the occurrence of *Lutra lutra* from *Terre rosse* was also confirmed by Mecozzi et al. (2021). The presence of this carnivoran is of considerable interest for paleoenvironmental reconstruction, since its ecological profile indicates a strong relation to large freshwater bodies (rivers or lakes). These kinds of habitats are no longer present in the southern part of Apulia, suggesting important landscape and hydrological changes during the late Quaternary. Moreover, 109 different bird species were identified, based on ca. 32,000 fossil remains from

*Terre brune* that currently represents the largest osteological Italian sample (Cassoli and Tagliacozzo, 1997). The species identified were prevalently adapted to cold-temperate climates (75% of the remains), referable to steppe and grassland environments. One of the most important climatic indicators for *Terre brune* is the great auk *Pinguinus impennis* (Linnaeus, 1758) (= *Alca impennis*), a North Atlantic and Subarctic marine species (Blanc, 1927, Cassoli and Tagliacozzo, 1997). The mammal fauna of *Terre brune* is dominated by *Cervus elaphus* (25.7%) and red fox, *Vulpes vulpes* (Linnaeus, 1758) (25.1%), followed by Regàlia ass *Equus hydruntinus* Regàlia, 1906 (21.7%) and *Bos primigenius* (19%). Other species are instead sporadic (Table 2). Of considerable interest is the presence of the Alpine marmot *Marmota marmota* (Linnaeus, 1758). Nowadays, this species inhabits alpine meadows and high-altitude pastures, typically on south-facing slopes from 1200-3000 m. Its findings in GR attests to the occurrence of open environments and cold climatic conditions, also supported by abundant remains of *E. hydruntinus* and *B. primigenius*. However, the rich sample of *C. elaphus* also suggests the presence of forests.

Iannucci et al. (2020) studied a large sample of *Sus scrofa* from the Quaternary record of Apulia, including the record from *Terre brune*. The results indicate that *S. scrofa* from GR had a smaller size, similar to the fossil record from the cooler stages of the Late Pleistocene in Apulia, significantly different from the Last Interglacial record of this region.

#### 4. Materials and methods

The palaeobotanical samples analysed in this work were collected from four different sections of the cave: one located in the western sector (SS1), two located in the northern sector (SS2 and SS3), and one located in the southern sector (SS4) (Fig. 3). Details concerning thickness and chronology of the sampled sections can be found in Fig. 4.

#### FIGURES 3, 4

Pollen analysis was carried out on 49 sediment samples (Fig. 4), 17 of which from *Terre rosse* (SS2 and SS4), and 32 from *Terre brune* (SS1, SS2, SS3, and SS4).

The amount of processed dry sediment varies from 2 to 5 grams. Samples were treated with standard laboratory procedures for the extraction of fossil pollen grains (e.g. HCl 37%, HF 40%, NaOH 10%) following Fægri and Iversen (1989). In addition to the above-mentioned procedures, ultrasonic sieving (11 µm) and floating with ZnCl<sub>2</sub> were carried out for increasing pollen concentration in all samples of *Terre rosse*. Pollen concentration was calculated by adding *Lycopodium* spores to the known amount of sediment (Stockmarr, 1971). The identification of pollen grains was based on atlases (Reille, 1992, 1995, 1998) and reference collections. Following Smit (1973), *Quercus robur* type groups pollen of deciduous oaks and *Quercus cerris* type those of semi-evergreen oaks plus *Q. suber*; *Q. ilex* and *Q. coccifera* are included in the *Quercus ilex* type. We used the tribe name Cichorieae for fenestrate pollen grains as this is the only European tribe of Asteraceae Cichorioideae with this feature (Florenzano et al., 2015).

In some levels, Apiaceae and non-colpate, ornamented pollen grains of monocot families (whose systematic was recently deeply revised, see Stevens, 2001 onwards) were recognised in significant amounts and in clusters. In order to possibly identify single species and discuss their significance in our pollen record, a comparison between fossil and modern pollen grains was attempted. The modern species were selected on the basis of their morphological pollen features and geographical distribution (coastal areas of the Mediterranean). In particular, the small (longest axis 20-25 µm) fossil grains of Apiaceae were compared with modern samples of the species *Ammi visnaga* (L.) Lam. (syn. *Visnaga daucooides* Gaertn.) (Plate I, 1-2), *Crithmum maritimum* L. (Plate I, 3-4), and *Trinia glauca* (L.) Dumort. (Plate I, 5-6). Concerning the reticulate/perforate monocot fossil pollen grains, they were compared with different Asparagaceae (*sensu* Stevens, 2001 onwards) species selected on the basis of their

pollen morphology, ecology and distribution (Pignatti, 1982): *Asparagus acutifolius* L. (Plate II, 1), *A. aphyllus* L. (Plate II, 2), *A. maritimus* (L.) Mill. (syn. *A. scaber*) (Plate II, 3), *Loncomelos pyrenaicus* (L.) L.D. Hrouda (syn. *Ornithogalum pyrenaicum* L.) (Plate II, 4), *Muscari comosum* (L.) Mill. (Plate II, 5), *Ornithogalum exscapum* Ten. (Plate II, 6), and *O. umbellatum* L. (Plate II, 7). The modern material, provided by the *Herbarium Sapienza* (Rome, Italy) and recovered in the proximity of the cave, was treated with acetolysis in order to remove the cytoplasm content and highlight the pollen wall morphology.

## 5. Results

*Terre rosse* are almost depleted in pollen while *Terre brune* have quite variable counts and concentration, whose values range from 67 pollen grains/g in sample B311 (SS1) to ca. 21,000 grains/g in sample B328 (SS4). Concentration values in *Terre rosse* are even lower, ranging from 0 in barren levels to 1390 grains/g in the richest sample (B317, SS4).

Due to the variable pollen content and the high values of Asteroideae and Cichorieae, raw data are presented in tables (Table 3 for *Terre rosse* and Tables 4, 5, 6 for *Terre brune*) instead of percentage diagrams. The bad preservation and resulting over-representation of Asteraceae (Cichorieae and Asteroideae), the low diversity and the very low pollen concentration are expected in cave records (Carrión et al., 1999, Navarro Camacho et al., 2000, Lebreton et al., 2010, Hunt and Fiacconi, 2018), and we are aware of the fact that different taphonomic biases occurred at GR, favouring the selective preservation of pollen grains in some levels. Nonetheless, the different pollen assemblages from *Terre rosse* and *Terre brune* samples seem to confirm that our pollen spectra represent source vegetation at both local and regional scales.

## TABLES 3-6

As a general remark, the basal part of *Terre rosse* (SS2 and SS4) provided samples richer than the upper part, which is almost barren in pollen (Table 3). The ubiquitous and main element in all samples is *Olea*, accompanied by a few other trees (e.g. *Quercus ilex* type, *Q. robur* and *Q. cerris* types, *Pinus*) and some frequent herb taxa (e.g. Asteroideae, Cichorieae, Asparagaceae, Brassicaceae, Caryophyllaceae, Poaceae, Apiaceae). A sporadic presence of *Abies* and *Fagus* is notable. It is worth mentioning the occurrence of considerable amounts of Asparagaceae pollen in two levels from section SS4 (B317 and B314) and a single occurrence in one level from SS2 (B331). The pollen grains of all Asparagaceae from *Terre rosse* show a high similarity with those of *Muscari comosum* (Plate II, 11-13). Comparison of the numerous grains of Apiaceae (often in clusters) found in the basal level of *Terre rosse* (B314, SS4) with modern pollen of selected taxa suggests similarities with the species *Trinia glauca* (L.) Dumort and *Crithmum maritimum* L. (Plate I, 9, 10, 12). The latter, currently present near the cave, shows a greater resemblance to our fossil grains.

Most of the pollen record from *Terre brune* is characterised by the overwhelming presence of Cichorieae, accompanied by other herb taxa (e.g. Asteroideae, Brassicaceae, Amaranthaceae, Poaceae, Ranunculaceae, Asparagaceae). Tree taxa are represented by sporadic elements of the mesophilous (e.g. *Q. robur* and *Q. cerris* types, *Ulmus*) and Mediterranean (e.g. *Q. ilex* type, *Juniperus*, *Olea*, *Cistus*, *Pistacia*) vegetation (Tables 4, 5, 6). Riparian trees are also present (e.g. *Tamarix*, *Alnus*, *Salix*, *Populus*). The basal part of *Terre brune* from SS1 shows a quite high pollen variability with respect to the upper part: at the bottom herb pollen prevails, whereas toward the top, in samples with very low pollen concentrations and counts, tree pollen dominates and even the well-resistant pollen grains of the Asteraceae family (Asteroideae, Cichorieae) are absent.

The pollen amount in *Terre brune* from SS4 is notable. Both the lower and upper levels show a selective preservation highlighted by the high amounts of Cichorieae, while peaks of single

taxa appear in the other samples. In level B326, the dominant taxon is *Juniperus*, accompanied by a few herbs (*Artemisia*, Ranunculaceae, Poaceae). On the other hand, level B328, which is the richest in pollen, displays very high amounts of Apiaceae and Asparagaceae together with Fabaceae, Ranunculaceae and Poaceae.

Also the pollen grains of Apiaceae from *Terre brune* are more similar to *Crithmum maritimum* (Plate I, 7, 8, 11), a Mediterranean species of the carrot family. Concerning the Asparagaceae, a convincing similarity is found between the fossil grains from *Terre brune* and the species *Asparagus maritimus* and *Ornithogalum* (Plate II, 8-10).

## PLATES I-II

### 6. Discussion

Carbonate rich cave sediments are characterised by the scarcity of pollen due to a number of limiting factors. The absence of waterlogged conditions and consequent chemical degradation (i.e. oxidation) can lead to differential preservation with possible over-representation of pollen grains more resistant to oxidation (e.g. Asteraceae; see also Carrión et al., 1999). Moreover, sedimentation is generally discontinuous, with events of erosion and redeposition (Hunt and Fiacconi, 2019; Spinapolice et al., 2021) and pollen can be transported either by water through the soil or by wind into the cave itself (Cremaschi et al., 2014), making uncertain the time lapse between pollen production and sedimentation. The role of humans and animals in pollen transportation is a further complication (Mercuri, 2008a, b) but can provide interesting knowledge on the cave occupation. The contribution of entomophilous and zoophilous pollen from local vegetation to cave records is attested through several vectors (Burney and Burney, 1993). In addition, the pollen counts and the number of taxa are generally so low that they do not allow a statistical representation. Despite these taphonomic biases, fossil pollen sequences from caves have been used to reconstruct past landscape in the

Mediterranean environments where lacustrine deposits are not common (e.g. Renault-Miskovsky, 1972, Gale et al., 1993, Carrión et al., 1999, Mancini et al., 2002, Kaniewski et al., 2004, 2005a-c, Karatsori et al., 2005, Polk et al., 2007, de Porrás et al., 2011, Peretto et al., 2020), as in the case of Apulia. As a matter of fact, pollen data from GR provides new insights into the palaeoenvironmental setting of the deposits, with implications on their chronological attribution, and into the possible plant use by humans.

### 6.1. Pollen evidence of changing climates and environments

Despite the general scarcity of pollen in all samples from *Terre rosse*, it is noteworthy that *Olea* is the only taxon which is always represented with the highest number of grains (Table 3). The wild olive is a thermophilous plant, typical of the Mediterranean vegetation, which colonizes the coastal areas, including rocky coasts, of the Mediterranean basin (Pignatti, 1982). Its presence in all samples is clear evidence that the sedimentation of *Terre rosse* occurred during a warm and probably arid period.

The high amount of *Olea* pollen in the *Terre rosse* samples stimulated us to carry out a comparison with the nearest continuous pollen records covering the last climatic cycles. In particular, at Valle di Castiglione, near Rome, *Olea* is sporadic all along the sequence (MIS 9a to MIS 1; Follieri et al., 1988) with the exception of MIS 5e, where it shows a significant peak reaching 10% (Fig. 5). The same behaviour can be noticed in the pollen records of Ioannina (Tzedakis and Bennett, 1995) and Tenaghi Philippon (Fletcher et al., 2013, Milner et al., 2016), in Greece, where the only significant peak of *Olea* is recorded during MIS 5e, being almost absent during the other intercepted interglacial stages (Fig. 5). At Monticchio (southern Italy), *Olea* has a peak during MIS 5e (Allen et al., 2000, Allen and Huntley, 2009) but the record ends at MIS 6, so it is not possible to say if it was present during older



interglacial phases. In the Massif Central (Velay, France) the *Olea* record is more variable and probably represents long-distance pollen transport, but clearly shows higher values during MIS 5e (Tzedakis et al., 2001). No separate curve for *Olea* is provided for the long pollen record of Carrizar de Villarquemado, in Spain (González-Sampéris et al., 2020)

All considered data suggest constraining *Terre rosse* to the Eemian (MIS 5e), confuting the stratigraphical attribution of Blanc (1920) that had ascribed this deposit to a warm and dry phase following the Würm acme, later ascribed to MIS3 by the U/Th dating (Fig. 2, Table 1; Fornaca-Rinaldi and Radmilli, 1968). From a paleontological viewpoint, the fossil assemblage from *Terre rosse* assumed an important role for the evolution of mammal palaeocommunities (e.g. Di Stefano et al., 1992, Mazza, 1995, Palombo et al., 2001). Considering the old U/Th age (Table 1), the record from *Terre rosse* was long deemed as the latest occurrence of *P. antiquus* and *H. amphibius*. Instead, an attribution of the *Terre rosse* mammal assemblage to MIS 5e is in agreement with the wide diffusion of these two large herbivores all along the Italian Peninsula during this stage, also confirming that their extinction could have occurred at the end of the Last Interglacial. A MIS 5e age for *Terre rosse* is also consistent with the presence of *L. lutra*, a carnivoran with an ecological profile indicating a strong relation to large freshwater bodies (rivers or lakes), habitats that are no longer present in the southern part of Apulia.

Very few cave records in the Mediterranean region provide evidence of the Last Interglacial period (Carrión et al., 1998, Ochando et al., 2020). In particular, the pollen sequence at Cueva de la Carihuela (Granada, southern Spain) covers most of the last glaciation starting at the end of the Last Interglacial, which is characterised by both a *Quercus-Olea* association and noteworthy pollen diversity of meso-thermophilous species (Carrión et al., 1998). In those basal levels of the cave deposits, *Olea* shows very high values, reaching 40%, before suddenly dropping until disappearing during the last glacial period.

The abundance of *Olea* recorded during MIS 5e all around the Mediterranean suggests that this warm phase was drier with respect to other interglacials. In southern Italy, the Last Interglacial was marked by the expansion of Mediterranean communities at low altitudes and even at middle altitudes, especially south of 43°N (Combourieu-Nebout et al., 2015). Pollen-based climate reconstructions for southern Italian sites show that Mean Temperature of the Coldest Month during MIS 5e was nearly as warm as during the Early Pleistocene interglacials. Nevertheless, annual precipitation remained low compared to the earlier interglacials (Combourieu-Nebout et al., 2015). The available quantitative estimates of climate and bioclimate parameters in western Balkans (Sinopoli et al., 2018, 2019) show that mean annual temperatures were rather high during MIS 5e, while mean annual precipitation resulted as a whole slightly lower with respect to the following interstadials of MIS 5 (MIS 5a and 5c).

#### FIGURE 5

Radiocarbon dates circumscribe most of *Terre brune* to the Lateglacial period and some levels to the beginning of the Holocene (see the chronostratigraphical scheme for NW Europe by Cohen and Gibbard, 2013). On the whole, the Lateglacial levels from the dated investigated sections can be correlated to both the interstadial Bølling/Allerød and to the stadial Younger Dryas. In fact, minor differences in pollen data seem to confirm the different environments, with arboreal pollen of mesophilous and Mediterranean trees prevailing on non-arboreal pollen of steppe taxa in the interstadial levels. In this respect, worth of mention is the quite ubiquitous presence of *Olea* in the northern sector (SS2 and SS3), with a peak in level B351 from SS3 (Table 5). Its occurrence clearly testifies to the expansion of thermophilous vegetation during the Bølling/Allerød interstadial. On the other hand the samples from SS4, for which radiocarbon dates are not available, suggest colder and dryer climatic conditions, with presence of *Artemisia* in the three lowermost levels (Table 6). The

most recent of them shows the remarkable abundance of the pioneer *Juniperus* (151 pollen grains out of 198). It is also interesting the presence of other arboreal plants such as *Tamarix* and *Quercus*. The upper levels of SS4 show an increase of trees. The plant environment is consistent with the changes that occurred at the end of the last glacial/start of the present interglacial in the Adriatic region and in the close Balkan area (Lowe et al., 1996, Combourieu-Nebout et al., 2013, Masi et al., 2018). The most interesting sample is B328 (Table 6): it represents an anomaly for the high pollen count (574 pollen grains), number of pollen types (19), and concentration (more than 21,000 pollen grains/g). The most striking features are the presence of entomophilous pollen in clusters (cf. *Crithmum maritimum*, *Asparagus maritimus/Ornithogalum*, Fabaceae) and the complete absence of Asteraceae, both Asteroideae and Cichorieae. Another peculiarity is the presence of pollen from riparian trees such as *Alnus*, *Tamarix* and *Salix*. The good state of preservation and the presence of pollen clumps should be related to faeces, possibly indicating frequentation of the cave at the beginning of the Holocene. The uppermost samples see the overwhelming presence of Cichorieae.

In most of *Terre brune* Asteraceae prevail, accompanied by other herbs. Even if oxidation processes have been already postulated for the over-representation of Asteraceae (Carrión et al., 1999), other taphonomic issues (such as pollen transport by animals and/or humans into the cave) should be taken into account (Lebreton et al., 2010). As a matter of fact, the overwhelming presence of these herbs in *Terre brune* can be associated with the Lateglacial landscape (see the MD90917 Adriatic core, Combourieu-Nebout et al., 2013), as clearly testified by their disappearance in the SS1 levels dated to the early Holocene (Table 4). The identification of alpine marmot (*M. marmota*) from the same deposits confirms the spread of dry pastures in the region. At GR the *quasi* ubiquitous presence of riverine tree pollen (*Alnus*,

*Salix*, *Tamarix*) refers to freshwater environments and might be fostered by the preferential transport of pollen through karstic canals.

Samples dated to the Holocene (B311, B312, B313 from SS1; Fig. 4a, Table 4) are almost depleted in pollen, with minor presence of herbs and a major component of trees. Mediterranean trees (e.g. *Q. ilex*) and pioneer plants such as *Juniperus* and Rosaceae (for the latter a possible use as fruit trees could be advanced) prevailed and preceded the following expansion of Holocene vegetation.

## 6.2. Human-environment interactions in Middle and Upper Palaeolithic

In the lower pollen samples of *Terre rosse* from both SS2 and SS4, we emphasize the presence (more abundant in SS4) of cf. *Muscari comosum* (grape hyacinth), a species of Asparagaceae family which is absent in the higher levels (Plate II, 11-13). This herb, typical of the Mediterranean coastal areas, grows in the olive zone and prefers limestone soils; its bulb (locally named “lampascione”) is consumed as a traditional food in Italy, and especially in Apulia. In the lowermost sample of SS4, noteworthy is also the presence of numerous single grains and clusters very similar to *Crithmum maritimum* (rock samphire/sea fennel), an edible wild plant typical of rocky marine coasts, with a wide latitudinal distribution, ranging from Great Britain and Ireland to North Africa and Canary Islands (Plate I, 12). Sea fennel is still part of the traditional food of Mediterranean countries either gathered from rocky shelters or cultivated and served as a vegetable with fish dishes. It was also used by sailors for its high content of C vitamin.

Grape hyacinth and sea fennel are both entomophilous herbs producing rather low pollen amounts, mostly dispersed by insects and not by wind. The high amount of their pollen grains found at the base of *Terre rosse* suggests transportation inside the cave by animals or

humans. Clumps of pollen may in fact be a marker of faeces, suggesting the ingestion of flowers (Mercuri 2008a) by animals and/or humans. It is worth stressing that, apart from the occurrence of cf. *Muscari comosum* and cf. *Crithmum maritimum*, pollen in *Terre rosse* is slightly more abundant in the lower samples (Table 3, from B331 to B317). In the same levels, new fossils and lithic tools, found during 2016-2019 excavations and currently under study, are added to those already collected during historical excavations (e.g. Stasi and Regalia, 1904, Blanc, 1920, 1928, Piperno, 1974). The majority of these materials, among which a rich sample of limestone artefacts referred to the Mousterian (Middle Palaeolithic), clearly indicates the occupation of the cave by Neanderthals (Piperno, 1974, Spinapolice, 2018). According to Blanc (1920), many fossils of large mammals display traces of exploitation, which strongly suggests that those animals had been hunted and consumed by Neanderthals. This aspect, however, will be clarified thanks to the new data obtained during the last excavations. By contrast, the upper levels of *Terre rosse* are depleted (or completely barren) in artefacts or bones. The scarcity of archaeological evidence from these levels was noted by Piperno (1974), who described 997 artefacts from the lower levels, out of 1105 recovered from the entire unit. The upper levels of *Terre rosse* are also very poor or completely barren in pollen (Table 3). This coincidence allows us to postulate that the relatively higher presence of pollen in the lower levels may be related to intentional transport by humans, probably for food or other purposes. Transport by animals on their furs cannot be ruled out. Despite Neanderthals are most often viewed as carnivores who derived the vast majority of their diet from meat, studies of Neanderthal tools and teeth from Eastern and Western European sites have shown that they were using several kinds of plants in their diets and, perhaps more importantly, in their medicinal and ritual traditions (Hardy et al., 2012, Salazar-García et al., 2013, Shipley and Kindscher, 2016, Power et al., 2016, 2018, Miras et al., 2020). Particularly interesting is the finding, among others, of *Muscari* remains in the

Shanidar grave (northern Iraq), in which a Neanderthal was buried with several plants recognized as having medicinal properties (Solecki, 1975).

As already stressed for *Terre rosse*, we found high amounts and clusters of cf. *Crithmum maritimum* (Plate I, 11) even in *Terre brune*, in addition to a great number of pollen grains (176 pollen grains in sample B328 of SS4) of *Asparagus maritimus/Ornithogalum* (Plate II, 8-10). As discussed for *Muscari*, since the pollination of Asparagaceae is entomophilous and pollen grains are big, the occurrence of these pollen grains could mean a preferential transportation inside the cave by animals and/or humans. On the other hand, the contribution to the human diet from plants of the local vegetation, having underground storage organs rich in starch and, therefore, being processed as a source of carbohydrates and energy, is documented since the earliest phase of the Upper Palaeolithic (Revedin et al., 2010). In contrast to the grape hyacinth found in *Terre rosse*, which has an edible bulb, a number of toxic species belong to the genus *Ornithogalum*. Nonetheless, if the bulbs are boiled, they can be consumed and the same is true for the flower stems, edible if cooked like the more common *Asparagus*. The use of such stems, which could be served as human food, was postulated for the Upper Palaeolithic of Europe (e.g. Jones, 2009). For all this evidence, we can assume that the consumption of these plants probably contributed to the essentially carnivore diet of the modern humans frequenting GR, also demonstrated by the abundant bone remains, mostly of birds, found throughout *Terre brune*. As a matter of fact, the archaeozoological analysis of mammal remains revealed that most of the fossils were hunted by humans, even if the presence of coprolites and bite marks also supports the frequentation of the cave by carnivorans for short times (Tagliacozzo, 2003). Similar results were reported by the analysis of bird bones from the same levels of *Terre brune*, with evident signs of butchering (i.e. cut marks and burning: Cassoli and Tagliacozzo, 1997, Cassoli et al., 2003). Moreover, the long-lasting occupation of the cave by *Homo sapiens* during the Upper

Palaeolithic is documented by a diversified record, which includes not only human fossils and lithic artefacts as already reported, but also hearts, mobiliary and parietal art (Blanc, 1928, Sardella et al., 2018, Sigari et al., 2021).

Although differential preservation of Asteraceae pollen could have occurred, the relative abundance of both Cichorieae and Asteroideae pollen in *Terre brune* (and their *quasi* absence in *Terre rosse*) is incontestable. It could have been tied to animal introduction (e.g. faeces) or to intentional transport as food, medicine, and/or ritual plants, since such herbs have leaves and seeds that may have been gathered by modern human (e.g. Riehl et al., 2015, Martkoplshvili and Kvavadze, 2015).

Other pollen taxa found at GR, including possible edible plants, are Amaranthaceae, Fabaceae and Poaceae, whose contribution to the diet of our ancestors is becoming well-known thanks to the study of plant microfossils from a variety of archaeological deposits (e.g. Piperno et al., 2004, Aura et al., 2005, Pryor et al., 2013, Power and Williams, 2018). In particular, the first-documented preference for Poaceae caryopses, as opposed to underground organs, in processing plant food with high nutritional value (i.e. flour), comes from Grotta Paglicci in northern Apulia, where oat starch grains from grinding tools of the early Upper Palaeolithic levels (ca. 31,600 years BP) have been studied (Mariotti Lippi et al., 2015).

## Conclusions

Notwithstanding the possible biases affecting pollen studies in caves (e.g. low pollen concentration and taphonomical issues), we have highlighted the different environments in which *Terre rosse* and *Terre brune* deposited. The attribution of *Terre rosse* to the Eemian is the main novelty of this study and was based on the presence, in the pollen spectra, of consistent amounts of olive tree, whose expansion is recorded all around the Mediterranean

area during MIS 5e. This new chronological attribution opens up interesting implications on the stratigraphical significance of the beach (level K) identified by Blanc (1920, 1928) below *Terre rosse* (level G), and ascribed to the Last Interglacial period (Riss-Würm). The cold character of the interposed speleothem (level H) suggests possibly assigning that marine highstand (beach, level K) to a previous interglacial phase. New U/Th dating of speleothems H and F, which is in progress, will help clarify the question.

The *Terre brune* deposition occurred when the environment was relatively open, with rare trees and shrubs and prevailing herbs. Mediterranean, mesophilous and riparian arboreal elements are present, with changes among sections and single samples.

The use of plants is not easily detectable through pollen in cave sites, where during most of Prehistory humans exploited wild plants. No particular evidence of accumulation of plants is found at GR, apart from some clusters of Apiaceae pollen, probably belonging to marine fennel, a wild, edible Mediterranean herb. The presence of some monocot pollen grains belonging to Asparagaceae suggest the possible consumption of bulbs and young sprouts by both Neanderthals and *Homo sapiens*. The interpretation of the high percentages of Asteraceae, a family to which numerous edible, medicinal, and ornamental herbs belong, is still open. Asteraceae pollen grains are almost absent in *Terre rosse*, whose sedimentation occurred in the Last Interglacial.

Still ongoing excavations at GR will hopefully provide new evidence about human-plant interactions and the environment of the last interglacial/glacial cycle, till now only partially known in southern Italy.

## Acknowledgements



Authors wish to thank Judy Allen and Chronis Tzedakis for sharing their raw pollen data from Monticchio and Ioannina. An acknowledgement to Mauro Iberite and Agnese Tilia for supporting in the selection of modern plant material, and to Maretta Colasante for her suggestions on Iridaceae pollen. Authors are also thankful to the Soprintendenza archeologia, belle arti e paesaggio delle province di Brindisi, Lecce e Taranto for the authorisation of the research and field activities (2015–2017 and 2018–2020, resp. R. Sardella) (Maria Piccarreta, Laura Masiello and Serena Strafella), as well as to Castro municipality, the Capitanerie di Porto di Castro e di Otranto, and Parco Naturale Regionale Costa Otranto S.M. di Leuca - Bosco di Tricase. Many colleagues helped during the fieldwork activities: Jacopo Conti, Alessio Iannucci, Dawid Adam Iurino, Dario Sigari and Flavia Strani. Ninì Ciccarese, Toto De Santis, Don Piero Frisullo, Luigi Fersini, Alberto Antonio Capraro, Michele Rizzo and Gruppo Speleologico Salentino for their continuous and precious logistic support. We thank Rosalia Gallotti, Biagio Giaccio, Filomena Ranaldo, Simona Rosselli and Enza Spinapolice for their useful suggestions and help.

Vincent Lebreton and two anonymous reviewers are deeply thanked for their fruitful comments on the original manuscript.

### **Funding sources**

This work was supported by Sapienza University of Rome (resp. Raffaele Sardella) grants Grandi Scavi 2016 (ref. SA116154CD9592F3), Grandi Scavi 2017 (ref. SA11715C81468801), Grandi Scavi 2018 (ref. SA1181642D3B3C58), Grandi Scavi 2019 (ref. SA11916B513E7C4B), Grandi Scavi 2020 (ref. SA120172B2C05E68).

### **Declaration of interests**

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

## References

Alessio, M., Bella, F., Bachechi, F., Cortesi, C., 1965. University of Rome Carbon-14 dates III. Radiocarbon 7, 213-222.

Allen, J.R.M., Huntley, B., 2009. Last Interglacial palaeovegetation, palaeoenvironments and chronology: a new record from Lago Grande di Monticchio, southern Italy. Quat. Sci. Rev. 28, 1521-1538.

Allen, J.R.M., Watts, W.A., Huntley, B., 2000. Weichselian palynostratigraphy, palaeovegetation and palaeoenvironment: the record from Lago Grande di Monticchio, southern Italy. Quat. Int. 73-74, 91-116.

Aura, J.E., Carrión, Y., Estrelles, F., Peres Jorda, G., 2005. Plant economy of hunter-gatherer groups at the end of the last Ice Age: plant macroremains from the cave of Santa Maira (Alacant, Spain) ca. 12000–9000 B.P. Veget. Hist. Archaeobot. 14(4), 542-550.

Bella, F., Blanc, A.C., Blanc, G.A., Cortesi, C., 1958. Una prima datazione con il carbonio 14 della formazione pleistocenica di Grotta Romanelli (Terra d'Otranto). Quaternaria 5, 87-94.

Bertini, A., 2010. Pliocene to Pleistocene palynoflora and vegetation in Italy: State of the art. Quat. Int. 225, 5-24.

Bietti, A., 2003. Caratteristiche tecnicotipologiche del "Romanelliano" di Grotta Romanelli (Castro Marina, Lecce). In: Fabri, P., Ingravallo, E., Mangia, A. (Eds.), Grotta Romanelli nel centenario della sua scoperta (1900-2000). Congedo Editore Galatina, Lecce, pp. 91-111.

Biondi, E., Casavecchia, S., Guerra, V., Medagli, P., Beccarisi, L., Zuccarello, V., 2004. A contribution towards the knowledge of semideciduous and evergreen woods of Apulia (southeastern Italy). *Fitosociologia* 41, 3-28.

Blanc, G.A., 1920. Grotta Romanelli I. Stratigrafia dei depositi e natura e origine di essi. *Archivio per l'Antropologia e la Etnologia* 50, 1-39.

Blanc, G.A., 1927. Sulla presenza di *Alca impennis* Linn. Nella formazione superiore di Grotta Romanelli in terra d'Otranto. *Archivio per l'Antropologia e la Etnologia* 58, 155-186.

Blanc, G.A., 1928. Grotta Romanelli II. Dati ecologici e paletnologici. *Archivio per l'Antropologia e la Etnologia* 58, 1-49.

Botti, U., 1874. Sulla scoperta di ossa fossili in Terra d'Otranto. *Bollettino Del Regio Comitato Geologico* 1, 7-8.

Bronk Ramsey, C. 2017. Methods for summarizing radiocarbon datasets. *Radiocarbon* 59, 1809-1833.

Burney, D.A., Burney, L.P., 1992. Modern pollen deposition in cave sites: experimental results from New York State. *New Phytol.* 124, 523-535.

Calcagnile, L., Sardella, R., Mazzini, I., Giustini, F., Brilli, M., D'Elia, M., Braione, E., Conti, J., Mecozzi, B., Bona, F., Iurino, D.A., Lembo, G., Muttillio, B., Quarta, G., 2019. New radiocarbon dating results from the Upper Palaeolithic–Mesolithic levels in Grotta Romanelli (Apulia, southern Italy). *Radiocarbon* 61, 1211-1220.

Caroli, I., Caldara, M., 2007. Vegetation history of Lago Battaglia (eastern Gargano coast, Apulia, Italy) during the middle-late Holocene. *Veg. Hist. Archaeobot.* 16, 317-327.

Carrión, J.S., Munuera, M., Navarro, C., 1998. Paleoenvironmental reconstructions of cave sediments on the basis of palynology: an example from Carihuela Cave (Granada, Spain). *Rev. Palaeobot. Palynol.* 99, 317-340.

Carrión, J.S., Munuera, M., Navarro, C., Burjachs, F., Dupré, M., Walker, M.J., 1999. The palaeoecological potential of pollen records in caves: the case of Mediterranean Spain. *Quat. Sci. Rev.* 18(8-9), 1061-1073.

Cassoli, P.F., Tagliacozzo, A., 1997. Butchering and Cooking of Birds in the Palaeolithic Site of Grotta Romanelli (Italy). *Int. J. Osteoarchaeol.* 7(4), 303-320.

Cassoli, P.F., Gala, M., Tagliacozzo, A., 2003. La caccia e l'utilizzo alimentare degli uccelli a grotta Romanelli durante le fasi finali del Pleistocene. In: Fabbri, P.F., Ingravallo, E., Mangia, A. (Eds.), *Grotta Romanelli nel centenario della sua scoperta (1900-2000)*, Congedo, Lecce, pp. 91-111.

Cohen, K.M., Gibbard, P.L., 2019. Global chronostratigraphical correlation table for the last 2.7 million years, version 2019 Q1-200. *Quat. Int.* 500, 20-31.

Combourieu-Nebout, N., Peyron, O., Bout-Roumazielles, V., Goring, S., Dormoy, I., Joannin, S., Sadori, L., Siani, G., Magny, M., 2013. Holocene vegetation and climate changes in the central Mediterranean inferred from a high-resolution marine pollen record (Adriatic Sea). *Clim. Past* 9, 2023-2042.

Combourieu-Nebout, N., Bertini, A., Russo Ermolli, E., Peyron, O., Montade, V., Klotz, S., Lebreton, V., Fauquette, S., Allen, J., Fusco, F., Goring, S., Huntley, B., Joannin, S., Magri, D., Orain, R., Sadori, L., 2015. Climate changes in the central Mediterranean and Italian vegetation dynamics since the Pliocene. *Rev. Palaeobot. Palynol.* 218, 127-147.

- Cremaschi, M., Zerboni, A., Mercuri, A.M., Olmi, L., Biagetti, S., di Lernia, S., 2014. Takarkori rock shelter (SW Libya): an archive of Holocene climate and environmental changes in the central Sahara. *Quat. Sci. Rev.* 101, 36-60.
- de Porras, M.E., Mancini, M.V., Prieto, A.R., 2011. Modern pollen analysis in caves at the Patagonian steppe, Argentina. *Rev. Palaeobot. Palynol.* 166, 335-343.
- Di Rita, F., Magri, D., 2009. Holocene drought, deforestation and evergreen vegetation development in the central Mediterranean: a 5500 year record from Lago Alimini Piccolo, Apulia, southeast Italy. *Holocene* 19, 295-306.
- Di Stefano, G., Petronio, C., Sardella, R., Savelloni, V., Squazzini, E., 1992. Nuove segnalazioni di breccie ossifere nella costa fra Castro Marina e Otranto (Lecce). *Il Quaternario – Ital. J. Quaternary Sci.* 5(1), 3-10.
- Fabbri, P.F., 1987. Restes humains retrouvés dans la grotte Romanelli (Lecce, Italie): étude anthropologique. *Bull. Mém Soc. Anthropol. Paris* 4(4), 219-247.
- Fady, B., Semerci, H., Vendramin, G.G. 2003. EUFORGEN Technical Guidelines for genetic conservation and use for Aleppo pine (*Pinus halepensis*) and Brutia pine (*Pinus brutia*). International Plant Genetic Resources Institute, Rome, Italy.
- Fægri, K., Iversen, J., 1989. *Textbook of Pollen Analysis*, 4th Edn. John Wiley & Sons, Chichester, New York, Brisbane, Toronto, Singapore.
- Fletcher, W.J., Muller, U.C., Koutsodendris, A., Christanis, K., Pross, J., 2013. A centennial-scale record of vegetation and climate variability from 312 to 240 ka (Marine Isotope Stages 9c-a, 8 and 7e) from Tenaghi Philippon, NE Greece. *Quat. Sci. Rev.* 78, 108-125.

Florenzano, A., Marignani, M., Rosati, L., Fascetti, S., Mercuri, A.M., 2015. Are Cichorieae an indicator of open habitats and pastoralism in current and past vegetation studies? *Plant Biosyst.* 149, 154-165.

Follieri, M., Magri, D., Sadori, L., 1988. 250,000-year pollen record from Valle di Castiglione (Roma). *Pollen et Spores* 30, 329-356.

Fornaca-Rinaldi, G., Radmilli, A.M., 1968. Datazione con il metodo  $^{230}\text{Th}/^{238}\text{U}$  di stalagmiti contenute in depositi musteriani. *Atti Soc. Toscana Sc. Nat.* 75(1), 639-646.

Forti L., Mazzini I., Mecozzi B., Sigari D., Sardella R., 2020. Grotta Romanelli (Castro, Lecce): Un sito chiave del Quaternario mediterraneo. *Geologicamente*, 2, 18-27.

Gale, S.J., Gilbertson, D.D., Hoare, P.G., Hunt, C.O., Jenkinson, R.D.S., Lamble, A.P., O'Toole C., Van der Veen M., Yates, G., 1993. Late Holocene environmental change in the Libyan pre-desert. *J. Arid Environ.* 24, 1-16.

González-Sampériz, P., Gil-Romea, G., García-Prieto, E., Aranbarri, J., Moreno, A., Morellón, M., Sevilla-Callejo, M., Leunda, M., Santos, L., Franco-Múgica, F., Andrade, A., Carrión, J.S., Valero-Garcés, P.L., 2020. Strong continentality and effective moisture drove unforeseen vegetation dynamics since the last interglacial at inland Mediterranean areas: The Villarquemado sequence in NE Iberia. *Quaternary Sci. Rev.* 242, 106425.

Hardy, K., Buckley, S., Collins, M.J., Estalrich, A., Brothwell, D., Copeland, L., García-Taberner, A., García-Vargas, S., de la Rasilla, M., Lalueza-Fox, C., Huguet, R., Bastir, M., Santamaría, D., Madella, M., Wilson, J., Cortés, A.F., Rosas, A., 2012. Neanderthal medics? Evidence for food, cooking, and medicinal plants entrapped in dental calculus. *Naturwissenschaften* 99, 617-626.

Hunt, C.O., Fiacconi, M., 2018. Pollen taphonomy of cave sediments: What does the pollen record in caves tell us about external environments and how do we assess its reliability? *Quat. Int.* 485, 68-75.

Iannucci, A., Gasparik, M., Sardella, R., 2020. First report of *Sus strozzi* (Suidae, Mammalia) from the Early Pleistocene of Hungary (Dunaalmás) and species distinction based on deciduous teeth. *Sci. Nat. Heidelberg* 107(1), 1-8.

Jones, M., 2009. Moving North: Archaeobotanical Evidence for Plant Diet in Middle and Upper Palaeolithic Europe. In: Hublin, J.J., Richards, M.P. (Eds.), *The Evolution of Hominin Diets. Vertebrate Paleobiology and Paleoanthropology*. Springer, Dordrecht, pp. 171-180.

Kaniewski, D., Renault-Miskovsky, J., Lumley, H. De, 2004. Madonna dell'Arma (San Remo, Italie): expression locale de la végétation ligure au cours du Paléolithique moyen. *Geobios* 37, 583-593.

Kaniewski, D., Renault-Miskovsky, J., Lumley, H. De, 2005a. Palaeovegetation from a *Homo neanderthalensis* occupation in Western Liguria: archaeopalynology of Madonna dell'Arma (San Remo, Italy). *J. Archaeol. Sci.* 32, 827-840.

Kaniewski, D., Renault-Miskovsky, J., Tozzi, C., Lumley, H. De, 2005b. Santa Lucia superiore (Toirano, Ligurie): reconstitution locale de la végétation ligure durant le Pléniglaciaire ancien. *Geobios* 38, 353-364.

Kaniewski, D., Renault-Miskovsky, J., Tozzi, C., Lumley, H. De, 2005c. Upper Pleistocene and Late Holocene vegetation belts in Western Liguria: an archaeopalynological approach. *Quaternary Int.* 135, 47-63.

Karatsori, E., Renault-Miskovsky, J., Lumley, H. De, Lebreton, V., 2005. Environnement de l'Homme de Néanderthal en Ligurie au Pleistocène supérieur. Analyse pollinique de la Caverna delle Fate (Finale Ligure, Italie). *Comptes Rendus Palevol* 4, 395-404.

Kustatscher, E., Roghi, G., Bertini, A., Miola, A. (Eds.), 2014. *Palaeobotany of Italy*. Pubblicazione del Museo di Scienze Naturali dell'Alto Adige n° 9. ISBN: 978-88-87108-06-4.

Lebreton, V., Messager, E., Marquer, L., Renault-Miskovsky, J., 2010. A neotaphonomic experiment in pollen oxidation and its implications for archaeopalynology. *Rev. Palaeobot. Palynol.* 162(1), 29-38.

Lowe, J.J., Accorsi, C.A., Bandini Mazzanti, M., Bishop, A., Forlani, L., van der Kaars, S., Mercuri, A.M., Rivalenti, C., Torri, P., Watson, C., 1996. Pollen stratigraphy of sediment sequences from crater lakes (Lago Albano and Lago Nemi) and the Central Adriatic spanning the interval from Oxygen isotope Stage 2 to present day. *Memorie dell'Istituto Italiano di Idrobiologia* 55, 71-98.

Mancini, M.V., Paez, M.M., Prieto, A.R., 2002. Paleoenvironmental changes during the last 7000 C-14 years in the forest-steppe ecotone, 47-48 degrees S, Santa Cruz Province, Argentina. *Ameghiniana* 9(2), 151-162.

Mariotti Lippi, M., Foggi, B., Aranguren, B., Ronchitelli, A., Revedin, A., 2015. Multistep food plant processing at Grotta Paglicci (Southern Italy) around 32,600 cal B.P. *Proc. Natl. Acad. Sci. USA* 112(39), 12075-12080.

Martkoplshvili, I., Kvavadze, E., 2015. Some popular medicinal plants and diseases of the Upper Palaeolithic in Western Georgia. *J. Ethnopharm.* 166, 42-52.



- Masi, A., Francke, A., Pepe, C., Thienemann, M., Wagner, B., Sadori, L., 2018. Vegetation history and palaeoclimate at lake Dojran (FYROM/Greece) during the late glacial and Holocene. *Clim. Past* 14(3), 351-367.
- Masini, F., Sala, B., Ambrosetti, P., Azzaroli, A., Ficcarelli, G., Kotsakis, T., Rook, L., Torre, D., 1990. Mammalian faunas of selected Villafranchian and Galerian localities. In: INQUA SEQS, Subcommission for European Quaternary Stratigraphy, Cromer Symposium, Norwich.
- Mazza, P., 1995. New evidence on the Pleistocene hippopotamuses of Western Europe. *Geologica Romana* 31, 61-241.
- Mecozzi, B., Iannucci, A., Bona, F., Mazzini, I., Pieruccini, P., Sardella, R., 2021. Rediscovering *Lutra lutra* from Grotta Romanelli (southern Italy) in the framework of the puzzling evolutionary history of Eurasian otter. *PLoS*, 1-14.
- Mercuri, A.M., 2008a. Human influence, plant landscape evolution and climate inferences from the archaeobotanical records of the Wadi Teshuinat area (Libyan Sahara). *J. Arid Environ.* 72, 1950-1967.
- Mercuri, A.M., 2008b. Plant exploitation and ethnopalynological evidence from the Wadi Teshuinat area (Tadrart Acacus, Libyan Sahara). *J. Archaeol. Sci.* 35, 1619-1642.
- Milner, A.M., Roucoux, K.H., Collier, R.E.L., Muller, U.C., Pross, J., Tzedakis, P.C., 2016. Vegetation responses to abrupt climatic changes during the Last Interglacial Complex (Marine Isotope Stage 5) at Tenaghi Philippon, NE Greece. *Quat. Sci. Rev.* 154, 169-181.
- Miras, Y., Barbier-Pain, D., Ejarque, A., Allain, E., Allué, E., Marín, J., Vettese, D., Hardy, B., Puaud, S., Mangado Llach, J., Moncel, M.H., 2020. Neanderthal plant use and stone tool function investigated through non-pollen palynomorphs analyses and pollen washes in the Abri du Maras, South-East France. *J. Archaeol. Sci. Rep.* 33, 102569.

Mussi, M., 2002. Earliest Italy: an overview of the Italian Palaeolithic and Mesolithic. Interdisciplinary contributions to Archaeology, Springer.

Navarro Camacho, C.N., Carrión, J.S., Navarro, J., Munuera, M., Prieto, A.R., 2000. An experimental approach to the palynology of cave deposits. J. Quat. Sci. 15, 603-619.

Ochando, J., Carrión, J.S., Blasco, R., Rivals, F., Rufà, A., Demuro, M., Arnold, L.J., Amorós, G., Munuera, M., Fernández, S., Rosell, J., 2020. Neanderthals in a highly diverse, mediterranean-Eurosiberian forest ecotone: The pleistocene pollen record of Teixonerres Cave, northeastern Spain. Quaternary Sci. Rev. 241, 106429.

Palombo, M.R., Azanza, B., Alberdi, M.T., 2001. Italian Mammal Bichronology from the latest Miocene to the Middle Pleistocene: a multivariate approach. Geologica Romana 36, 355-368.

Pandolfi, L., Boscato, P., Crezzini, J., Cuccia, M., Moroni, A., Rolfo, M., Tagliacozzo, A., 2017. Late occurrences of the narrow-nosed rhinoceros *Stephanorhinus hemitoechus* (Mammalia, Perissodactyla) in Italy. Riv. It. Paleont. Strat. 123(2), 177-192.

Peretto, C., Arzarello, M., Conortti, M., Bertolini, M., Cui, Q.Y., De Curtis, O., Lebreton, V., Lembo, G., Marquer, L., Peruccini, P., Ravani, S., Rufo, E., Sala, B., Talamo, S., Thun Hohenstein, U., 2020. Grotta Reali, the first multilayered mousterian evidences in the Upper Volturno Basin (Rocchetta a Volturno, Molise, Italy). Archaeol. Anthropol. Sci. 12, 67.

Pignatti, S., 1982. Flora d'Italia. Edagricole, Bologna.

Piperno, M., 1974. L'industria musteriana su calcare di Grotta Romanelli (Otranto). Mem. Ist. It. Paleont. Umana 2, 69-90.

Piperno, D.R., Weiss, E., Holst, I., Nadel, D., 2004. Processing of wild cereal grains in the Upper Palaeolithic revealed by starch grain analysis. Nature 430(7000), 670-673.

Polemio, M., Lonigro, T., 2013. Climate Variability and Landslide Occurrence in Apulia (Southern Italy). In: Margottini, C., Canuti, P., Sassa K. (Eds.), *Landslide Science and Practice*. Springer, Berlin, Heidelberg.

Polk, J.S., van Beynen, P.E., Reeder, P.P., 2007. Late Holocene environmental reconstruction using cave sediments from Belize. *Quat. Res.* 68, 53-63.

Pomar, L., Mateu-Vicens, G., Morsilli, M., Brandano, M., 2014. Carbonate ramp evolution during the late Oligocene (Chattian), Salento Peninsula, Southern Italy. *Palaeogeogr. Palaeoclimatol. Palaeoecol.* 404, 109-132.

Power, R.C., Williams, F.L., 2018. Evidence of Increasing Intensity of Food Processing During the Upper Palaeolithic of Western Eurasia. *J. Paleo. Arch.* 1, 281-301.

Power, R.C., Salazar-García, D.C., Henry A.G., 2016. Dental calculus evidence of Gravettian diet and behaviour at Dolní Věstonice and Pavlov. In: Svoboda, J. (Ed.), *Dolní Věstonice II: chronostratigraphy, paleoethnology, paleoanthropology*. Academy of Sciences of the Czech Republic, Institute of Archeology, Brno, pp. 345-352.

Power, R.C., Salazar-García, D.C., Rubini, M., Darlas, A., Harvati, K., Walker, M., Hublin, J.J., Henry, A.G., 2018. Dental calculus indicates widespread plant use within the stable Neanderthal dietary niche. *J. Hum. Evol.* 119, 27-41.

Pryor, A., Steele, M., Jones, M., Svoboda, J., Beresford-Jones, D., 2013. Plant foods in the Upper Palaeolithic at Dolní Věstonice? *Parenchyma redux*. *Antiquity* 87(338), 971-984.

Reille, M., 1992. *Pollen et spores d'Europe et d'Afrique du Nord*, Laboratoire de Botanique Historique et Palynologie, Université d'Aix Marseille III, Marseille.

Reille, M., 1995. *Pollen et spores d'Europe et d'Afrique du Nord - Supplément 1*, Laboratoire de Botanique Historique et Palynologie, Université d'Aix Marseille III, Marseille.

Reille, M., 1998. Pollen et spores d'Europe et d'Afrique du Nord - Supplément 2, Laboratoire de Botanique Historique et Palynologie, Université d'Aix Marseille III, Marseille.

Reimer, P.J., Austin, W.E.N., Bard, E., Bayliss, A., Blackwell, P.G., Bronk Ramsey, C., et al. 2020. The IntCal20 Northern Hemisphere radiocarbon age calibration curve (0–55 cal kBP). *Radiocarbon* 62, 725-757.

Renault-Miskovsky, J., 1972. Contribution à la paléoclimatologie du Midi méditerranéen pendant la dernière glaciation et le Post-glaciaire, d'après l'étude palynologique du remplissage des grottes et abris sous roche. *Bull. Mus. Anthrop. Préhist. Monaco* 18, 145-210.

Revedin, A., Aranguren, B., Becattini, R., Longo, L., Marconi, E., Mariotti Lippi, M., Skakun, N., Sinitsyn, A., Spiridonova, E., Stoboda, J., 2010. Thirty thousand-year-old evidence of plant food processing. *Proc. Natl. Acad. Sci. USA* 107(44), 18815-18819.

Riehl, S., Marinova, E., Deckers, K., Malina, M., Conard, N.J., 2015. Plant use and local vegetation patterns during the second half of the Late Pleistocene in southwestern Germany. *Archaeol. Anthropol. Sci.* 7(2), 151-167.

Sadori, L., Bertini, A., Combourieu-Nebout, N., Kouli, K., Mariotti Lippi, M., 2013. Palynology and Mediterranean vegetation history. *Flora Medit.* 23, 141-156.

Sala, B., Masini, F., Ficarelli, G., Rook, L., Torre, D., 1992. Mammal dispersal events in the Middle and Late Pleistocene of Italy and Western Europe. *Courier Forschung. Senckenberg* 153, 59-68.

Sala, B., Masini, F., 2007. Late Pliocene and Pleistocene small mammal chronology in the Italian peninsula. *Quat. Int.* 160, 4-16.

Salazar-García, D.C., Power, R.C., Sanchis Serra, A., Villaverde, V., Walker, M.J., Henry, A.G., 2013. Neanderthal diets in central and southeastern Mediterranean Iberia. *Quat. Int.* 318, 3–18.

Sardella, R., Abbazzi, L., Argenti, P., Azzaroli, A., Caloi, L., Capasso Barbato, L., Di Stefano, G., Ficarelli, G., Girotti, O., Kotsakis, T., Masini, F., Mazza, P., Mezzabotta, C., Palombo, M.R., Petronio, C., Rook, L., Sala, B., Torre, D., 1998. Mammal faunal turnover in Italy from the Middle Pliocene to the Holocene. *Med. Ned. Inst. Toeg. Geowet. TNO* 60, 499-511.

Sardella, R., Bertè, D., Iurino, D.A., Cherin, M., Tagliacozzo, A., 2014. The wolf from Grotta Romanelli (Apulia, Italy) and its implications in the evolutionary history of *Canis lupus* in the Late Pleistocene of Southern Italy. *Quat. Int.* 323, 179-195.

Sardella, R., Mazzini, I., Giustini, F., Mecozzi, B., Brilli, M., Iurino, D. A., Lembo, G., Mutillo, B., Massussi, M., Sigari, D., Tucci, S., Voltaggio, M., 2018. Grotta Romanelli (Southern Italy, Apulia): legacies and issues in excavating a key site for the Pleistocene of the Mediterranean. *Riv. It. Paleont. Strat.* 124(2), 247-264.

Sardella, R., Iurino, D. A., Mecozzi, B., Sigari, D., Bona, F., Bellucci, L., Coltorti, M., Conti, J., Lembo, G., Mutillo, B., Mazzini, I., 2019. Grotta Romanelli (Lecce, Southern Italy) between past and future: new studies and perspectives for an archaeo-geosite symbol of the Palaeolithic in Europe. *Geoheritage* 11, 1413-1432.

Shipley, G.P., Kindscher, K., 2016. Evidence for the Paleoethnobotany of the Neanderthal: A Review of the Literature. *Scientifica* 2016, <https://doi.org/10.1155/2016/8927654>.

Sigari, D., I. Mazzini, J. Conti, L. Forti, G. Lembo, B. Mecozzi, B. Mutillo, and R. Sardella, 2021. Birds and bovids: new parietal engravings at the Romanelli Cave, Apulia. *Antiquity*, 95.

Sinopoli, G., Masi, A., Regattieri, E., Wagner, B., Francke, A., Peyron, O., Sadori, L., 2018. Palynology of the Last Interglacial Complex at Lake Ohrid: palaeoenvironmental and palaeoclimatic inferences. *Quat. Sci. Rev.* 180, 177-192.

Sinopoli, G., Peyron, O., Masi, A., Holtvoeth, J., Francke, A., Wagner, B., Sadori, L., 2019. Pollen-based temperature and precipitation changes in the Ohrid Basin (western Balkans) between 160 and 70 ka. *Clim. Past* 15, 53-71.

Smit, A., 1973. A scanning electron microscopical study of the pollen morphology in the genus *Quercus*. *Acta Bot. Neerl.* 22, 655-665.

Solecki, R.S., 1975. Shanidar IV: a Neanderthal flower burial in northern Iraq. *Science* 190, 880-881.

Spinapolice, E.E., 2008. Technologie lithique et circulation des matières premières au Paléolithique moyen dans le Salento (Pouilles, Italie méridionale): perspectives comportementales. Doctoral dissertation, Sapienza Università di Roma and Université de Bordeaux 1, Rome/Bordeaux.

Spinapolice, E.E., 2018. Neanderthal mobility pattern and technological organization in the Salento (Apulia, Italy) in Borgia V., Cristani E. (Eds.): *Palaeolithic Italy. Advanced studies on early human adaptations in the Apeninne peninsula*, Sidestone Press Academics (Leiden), pp. 95-124.

Spinapolice, E.E., Zerboni, A., Talamo, S., Mariani, G.S., Gliganic, L.A., Buti, L., Fusco, M., Maiorano, M.P., Silvestrini, S., Sorrentino, R., Vazzana, A., Romandini, M., Fiorini, A., Curci, A., Meyer M.C., Benazzi, S., 2021. Back to Uluzzo – Archaeological, palaeoenvironmental, and chronological context of the Mid-Upper Palaeolithic sequence at Uluzzo C rock shelter (Apulia, Southern Italy). *J. Quat. Sci.* <https://doi.org/10.1002/jqs.3349>

Stasi, P.E., Regalia, E., 1904. Grotta Romanelli stazione con faune interglaciali calde e di steppa. Nota preventiva. Soc. It. Antropol. 1, 17-81.

Stevens, P. F., 2001 onwards. Angiosperm Phylogeny Website. Version 14, July 2017 [and more or less continuously updated since]." will do.  
<http://www.mobot.org/MOBOT/research/APweb/>.

Stockmarr, J., 1971. Tables with spores used in absolute pollen analysis, *Pollen and Spores* 13, 614-621.

Suc, J.P., Bertini, A., Combourieu-Nebout, N., Diniz, F., Leroy, S., Russo-Ermolli, E., Zheng, Z., Bessais, E., Ferrier, J., 1995. Structure of West Mediterranean vegetation and climate since 5.3 ma. *Acta Zool. Cracov.* 38(1), 3-16

Tagliacozzo, A., 2003. Archeozoologia dei livelli dell'Epigravettiano finale di Grotta Romanelli (Castro, Lecce). Strategie di caccia ed economia di sussistenza. In: Fabbri, P.F., Ingravallo, E., Mangia, A. (Eds.), *Grotta Romanelli nel centenario della sua scoperta (1900-2000)*, Congedo, Lecce, pp. 169-210

Tarantini, M., 2018. The multiple roots of an innovative excavation: G.A. Blanc at the Romanelli Cave, Italy (1914-1938). In: de Beaume, S.A., Guidi, A., Abadia, O.M., Tarantini, M. (Eds.) *New Advances in the History of Archaeology* (Archaeopress 2021), 30-41.

Tzedakis, P.C., Bennett, K.D., 1995. Interglacial vegetation succession: a view from southern Europe. *Quat. Sci. Rev.* 14, 967-982.

Tzedakis, P.C., Andrieu, V., Birks, H.J.B., de Beaulieu, J.-L., Crowhurst, S., Follieri, M., Hooghiemstra, H., Magri, D., Reille, M., Sadori, L., Shackleton, N.J., Wijmstra, T.A., 2001. Establishing a terrestrial chronological framework as a basis for biostratigraphical comparisons *Quat. Sci. Rev.* 20, 1583-1592.

Vogel, J.C., Waterbolk, H.T., 1963. Groningen Radiocarbon Dates IV. *Radiocarbon* 5, 63-202.

### List of Figures, Tables, and Plates

**Fig. 1.** Grotta Romanelli (Apulia, Italy). (a) Cave location. (b) Geological sketch. (c) Detail of the cave opening (in the square) located at about 7.3 m above the modern sea level.

**Fig. 2.** Grotta Romanelli (Apulia, Italy). The stratigraphic scheme after Blanc (1928) with the first results of radiocarbon and U/Th dating as reported in Table 1. For more details on the levels see the main text.

**Fig. 3.** Grotta Romanelli (Apulia, Italy). (a) Planimetry and (b) the cave interior with position of analysed sections. Legend: 1 - Cross section; 2 - Cave ceiling limit; 3 - Sea level; 4 - Bedrock; 5 - Sedimentary cave filling; 6 - Location of analysed sections.

**Fig. 4.** Grotta Romanelli (Apulia, Italy). Detail of analysed sections (a, b, c, d) and stratigraphical logs with position of pollen samples (red dots) and new calibrated radiocarbon dates (Greek letters) as reported in Table 1.

**Fig. 5.** Comparison of the *Cleae* record in continuous pollen sequences from Italy and Greece.

**Table 1.** Grotta Romanelli (Apulia, Italy). Chronology of the deposits: old and new dates. Ages are calibrated with OxCal v.4.4 (Bronk Ramsey, 2017) using the IntCal20 curve (Reimer et al., 2020). If not specified, the probability is above 90%. For samples labelled with P the collagen was extracted from bone fragments or from crushed bones and dated. Greek letters refer to dates reported in Fig. 4.

**Table 2.** Grotta Romanelli (Apulia, Italy). Faunal list from *Terre brune* (Tagliacozzo 2003) and *Terre rosse* (Blanc 1920).



**Table 3.** Grotta Romanelli (Apulia, Italy). Number of pollen grains of *Terre rosse* samples from SS2 and SS4 (from left to right, bottom to top sample, see Fig. 4c, d). Samples B332, B335 from SS2 and B319, B322 from SS4 are barren.

**Table 4.** Grotta Romanelli (Apulia, Italy). Number of pollen grains of *Terre brune* samples from SS1 (from left to right, bottom to top sample, see Fig. 4a).

**Table 5.** Grotta Romanelli (Apulia, Italy). Number of pollen grains of *Terre brune* samples from SS2 and SS3 (from left to right, bottom to top sample, see Fig. 4b, c).

**Table 6.** Grotta Romanelli (Apulia, Italy). Number of pollen grains of *Terre brune* samples from SS4 (from left to right, bottom to top sample, see Fig. 4d).

**Plate I.** Grotta Romanelli (Apulia, Italy). Reference pollen material (from the *Herbarium Sapienza* and the actual vegetation of the cave area): *Amni visnaga* 1-2; *Crithmum maritimum* 3-4; *Trinia glauca* 5-6. Apiaceae pollen grains from *Terre brune* (7, 8, 11) and *Terre rosse* (9, 10, 12) samples. Bars stand for 20 micron.

**Plate II.** Grotta Romanelli (Apulia, Italy). Reference pollen material (from different collections of the *Herbarium Sapienza*): *Asparagus acutifolius* 1; *Asparagus aphyllus* 2; *Asparagus maritimus* 3; *Loncomelos pyrenaicus* 4; *Muscari comosum* 5; *Ornithogalum exscapum* 6; *Ornithogalum umbellatum* 7. Asparagaceae pollen grains from *Terre brune* (8-10) and *Terre rosse* (11-13) samples. Bars stand for 20 micron.

**Table 1.** Grotta Romanelli (Apulia, Italy). Chronology of the deposits: old and new dates. Ages are calibrated with OxCal v.4.4 (Bronk Ramsey, 2017) using the IntCal20 curve (Reimer et al., 2020). If not specified, the probability is above 90%. For samples labelled with P the collagen was extracted from bone fragments or from crushed bones and dated. Greek letters refer to dates reported in Fig. 4.

| Sample           | Level | Material   | Lab. Code  | Radiometric age     | <sup>14</sup> C cal yr BP (2σ) IntCal20 | References                         |
|------------------|-------|------------|------------|---------------------|---|------------------------------------|
| First dating set |       |            |            |                     |   |                                    |
| A                |       | Charcoal   | GrN-2056   | 9880 ± 100          | 11745-11141                             | Vogel and Waterbolk, 1963          |
| A                |       | Charcoal   | GrN-2305   | 10320 ± 130         | 12623-11689                             | Vogel and Waterbolk, 1963          |
| A                |       | Humic acid | R-54       | 9050 ± 100          | 10502-9804                              | Alessio et al., 1965               |
| A                |       | Charcoal   | R-58       | 11800 ± 600         | 12800-12681                             | Alessio et al., 1964               |
| B                |       | Humic acid | R-56       | 11960 ± 320         | 13024-13237                             | reported in Alessio et al., 1964   |
| B                |       | Humic acid | R-56       | 11930 ± 500         | 15595-12846                             | Bella et al., 1958                 |
| C                |       | Charcoal   | GrN-2153   | 10190 ± 80          | 12497-11941                             | Vogel and Waterbolk, 1963          |
| C                |       | Charcoal   | GrN-2154   | 9790 ± 80           | 11402-11067                             | Vogel and Waterbolk, 1963          |
| D                |       | Charcoal   | GrN-2055   | 10640 ± 100         | 12770-12451                             | Vogel and Waterbolk, 1963          |
| F                |       | Stalagmite |            | 40000 ± 3250 (U/Th) |   | Fornaca-Rinaldi and Radmilli, 1968 |
| H                |       | Stalagmite |            | <69000 (U/Th)       |   | Fornaca-Rinaldi and Radmilli, 1968 |
| New dating set   |       |            |            |                     |   |                                    |
| GR2016-206       | B     | Bone       | LTL17293A  | 8048 ± 75           | 9135-8639                               | Calcagnile et al., 2019            |
| GR2016-162       | B     | Bone       | LTL17303A  | 8397 ± 45           | 9499-9393                               | Calcagnile et al., 2019            |
| RR529            | B-C   | Bone       | SacA 61166 | 9925 ± 45           | 11408-11234 (79.8%) <sup>a</sup>        | Sigari et al., 2021                |
| RR529-P          | B-C   | Collagen   | SacA 61170 | 9955 ± 45           | 11509-11245 (79.1%) <sup>a</sup>        |                                    |
| GR2017-464       | C     | Bone       | LTL17741A  | 9657 ± 65           | 11207-10770                             | Calcagnile et al., 2019            |
| GR2016-          | C     | Bone       | LTL        | 9822 ± 45           | 11319-11188 <sup>b</sup>                | Calcagnile et al., 2019            |

|              |   |          |               |            |                                     |                         |  |
|--------------|---|----------|---------------|------------|-------------------------------------|-------------------------|--|
| 158          |   |          | 17299A        |            |                                     |                         |  |
| GR2016-154   | C | Bone     | LTL<br>17295A | 9774 ± 40  | 11622-11261 <sup>γ</sup>            | Calcagnile et al., 2019 |  |
| GR2016-105   | C | Bone     | LTL<br>17292A | 11328 ± 60 | 13282-13110                         | Calcagnile et al., 2019 |  |
| RR9          | C | Tooth    | SacA 61166    | 10880 ± 50 | 12895-12736 <sup>δ</sup>            | Sigari et al., 2021     |  |
| GR2016-159   | C | Bone     | LTL<br>17300A | 10100 ± 80 | 11940-11388 <sup>ε</sup>            | Calcagnile et al., 2019 |  |
| GR2016-157   | C | Bone     | LTL<br>17298A | 10277 ± 45 | 12192-11822<br>(81.9%)              | Calcagnile et al., 2019 |  |
| GR2016-465   | C | Bone     | LTL<br>17740A | 10295 ± 75 | 12471-11120                         | Calcagnile et al., 2019 |  |
| GR2016-153   | D | Bone     | LTL<br>17294A | 10990 ± 50 | 13071-12816<br>(87.2%)              | Calcagnile et al., 2019 |  |
| GR2016-622   | D | Bone     | LTL<br>17737A | 11409 ± 85 | 13457-13159 <sup>ζ</sup>            | Calcagnile et al., 2019 |  |
| GR2016-581   | D | Bone     | LTL<br>17736A | 11685 ± 65 | 13666-13413<br>(88.1%) <sup>ζ</sup> | Calcagnile et al., 2019 |  |
| GR2016-156   | D | Bone     | LTL<br>17297A | 11092 ± 80 | 13886-13589<br>(78.8%) <sup>η</sup> | Calcagnile et al., 2019 |  |
| GR2016-616   | D | Bone     | LTL<br>17738A | 11858 ± 85 | 13870-13575<br>(81.7%) <sup>θ</sup> | Calcagnile et al., 2019 |  |
| GR2016-522   | D | Bone     | SacA 61167    | 10730 ± 45 | 12757-12677 <sup>ι</sup>            | Sigari et al., 2021     |  |
| GR2016-522-P | D | Collagen | SacA 61169    | 10455 ± 45 | 12402-12166<br>(43.9%) <sup>ι</sup> |                         |  |
| GR2016-779   | E | Bone     | SacA 61171    | 11440 ± 50 | 13442-13227<br>(88.2%) <sup>κ</sup> | Sigari et al., 2021     |  |
| GR2016-779-P | E | Collagen | SacA 61168    | 11120 ± 45 | 13117-12908 <sup>κ</sup>            |                         |  |

**Table 2.** Grotta Romanelli (Apulia, Italy). Faunal list from *Terre brune* (Tagliacozzo 2003) and *Terre rosse* (Blanc 1920).

| Species  | Common name              | Revised taxon  |
|--|--------------------------|--|
| <b><i>Terre brune</i></b>  |                          |  |
| <i>Bos primigenius</i> Bojanus, 1827   | aurochs                  |  |
| <i>Sus scrofa</i> Linnaeus, 1758   | wild boar                |  |
| <i>Cervus elaphus</i> Linnaeus, 1758   | red deer                 |  |
| <i>Capreolus capreolus</i> (Linnaeus, 1758)  | roe deer                 |  |
| <i>Equus hydruntinus</i> Regàlia, 1906   | Regàlia ass              |  |
| <i>Canis lupus</i> Linnaeus, 1758  | grey wolf                |  |
| <i>Felis silvestris</i> Schreber, 1777   | wildcat                  |  |
| <i>Lynx</i> sp. (Kerr, 1792)   | lynx                     |  |
| <i>Meles meles</i> (Linnaeus, 1758)  | Eurasian badger          |  |
| <i>Marmota marmota</i> (Linnaeus, 1758)  | alpine marmot            |  |
| <i>Martes martes</i> (Linnaeus, 1758)  | European pine marten     |  |
| <i>Lepus europaeus</i> Pallas, 1778  | European hare            |  |
| <i>Erinaceus europaeus</i> Linnaeus, 1758  | European hedgehog        |  |
| <i>Monachus monachus</i> (Hermann, 1779)   | Mediterranean monk seal  |  |
| <i>Delphinus delphis</i> Linnaeus, 1758  | common dolphin           |  |
| <b><i>Terre rosse</i></b>  |                          |  |
| <i>Elephas antiquus</i> (Falcoer and Cautley, 1847) (= <i>Palaeoloxodon antiquus</i> ) | Straight tusked elephant |  |
| <i>Rhinoceros merckii</i> (Jäger, 1839) (= <i>Stephanorhinus kirchbergensis</i> )      | Merck rhinoceros         | <i>Stephanorhinus hemitoechus</i> , narrow-nosed rhinoceros (Pandolfi et al. 2017) |
| <i>Hippopotamus amphibius</i> Linnaeus, 1758   | hippo                    |  |
| <i>Hippopotamus pentlandi</i> von Meyer, 1832  |                          |  |
| <i>Bos taurus</i> var. <i>primigenius</i> Bojanus, 1827<br>(= <i>Bos primigenius</i> ) | aurochs                  |  |
| <i>Cervus elaphus</i> , Linnaeus, 1758   | red deer                 |  |
| <i>Cervus elaphus</i> var. <i>corsicanus</i> Erxleben, 1777 (= <i>Cervus elaphus</i> ) |                          |  |

|  |                         |  |
|--|-------------------------|--|
| <i>Dama dama</i> (Linnaeus, 1758)  | fallow deer             |  |
| <i>Capreolus capreolus</i> (Linnaeus, 1758)  | roe deer                |  |
| <i>Equus caballus</i> Linnaeus, 1758<br>(= <i>Equus ferus</i> Boddaert, 1785)                  | wild horse              |  |
| <i>Hyaena crocuta</i> var. <i>spelaea</i> (Goldfuss, 1823) (= <i>Crocuta crocuta spelaea</i> ) | cave hyaena             |  |
| <i>Canis lupus</i> Linnaeus, 1758  | grey wolf               | <i>Canis lupus</i> , grey wolf<br>(Sardella et al. 2014)     |
| <i>Canis aureus</i> Linnaeus, 1758   | golden jackal           |  |
| <i>Meles taxus</i> (Linnaeus, 1758)<br>(= <i>Meles meles</i> )                                 | Eurasian badger         |  |
| <i>Lutra lutra</i> (Linnaeus, 1758)  | Eurasian otter          | <i>Lutra lutra</i> , Eurasian otter<br>(Mecozzi et al. 2021) |
| <i>Oryctolagus cuniculus</i> (Linnaeus, 1758)  | European rabbit         |  |
| <i>Pelagius monachus</i> (Hermann, 1779)<br>(= <i>Monachus monachus</i> )                      | Mediterranean monk seal |  |

**Table 3.** Grotta Romanelli (Apulia, Italy). Number of pollen grains of *Terre rosse* samples from SS2 and SS4 (from left to right, bottom to top sample, see Fig. 4c, d). Samples B332, B335 from SS2 and B319, B322 from SS4 are barren.

| Grotta Romanelli<br>(Apulia, Italy)                   | <i>Terre rosse</i> - SS2 |      |      |      |      | <i>Terre rosse</i> - SS4 |      |      |      |      |      |      |      |
|---|--------------------------|------|------|------|------|--------------------------|------|------|------|------|------|------|------|
|   | B331                     | B333 | B334 | B336 | B337 | B314                     | B315 | B316 | B317 | B318 | B320 | B321 | B323 |
| <i>Abies</i>  |                          |      | 2    |      |      |                          |      |      | 1    |      |      |      |      |
| <i>Pinus</i>  | 3                        | 2    | 3    | 3    |      | 6                        | 3    |      | 4    |      |      |      |      |
| <i>Alnus</i>  |                          |      |      |      |      |                          |      |      | 1    |      |      |      |      |
| <i>Carpinus</i>                                       |                          |      |      |      | 1    |                          | 1    |      |      |      |      |      |      |
| <i>Corylus</i>  |                          |      |      |      |      |                          |      |      | 1    |      |      |      |      |
| <i>Fagus</i>  |                          |      |      |      |      |                          |      |      | 1    |      |      |      |      |
| <i>Hedera</i>   |                          |      |      |      |      | 2                        |      |      | 1    |      |      |      |      |
| <i>Ligustrum</i>                                      |                          |      | 2    |      |      |                          |      | 1    |      |      |      |      |      |
| <i>Olea</i>   | 3                        | 4    | 8    | 2    | 1    | 3                        | 6    |      | 20   |      | 1    |      | 1    |
| <i>Myrtus</i>   | 1                        |      |      |      |      |                          |      |      |      |      |      |      |      |
| <i>Quercus ilex</i><br>type                           | 1                        |      |      | 1    |      |                          |      |      | 5    |      |      |      |      |
| <i>Quercus robur</i><br>and <i>Q. cerris</i><br>types | 1                        | 1    | 2    |      | 3    | 2                        | 3    |      | 8    |      |      |      |      |
| <i>Ulmus</i>  |                          |      |      |      |      |                          |      |      | 1    |      |      |      |      |
| Amaranthaceae   |                          |      |      |      |      |                          |      |      | 2    |      |      |      |      |
| Apiaceae  |                          |      |      |      |      |                          |      |      |      |      |      |      |      |
| cf. <i>Crithmum maritimum</i>                         |                          |      |      |      |      | 36                       |      |      |      |      |      |      |      |
| Artemisia   |                          |      |      |      |      | 1                        |      |      |      |      |      |      |      |
| Asparagaceae  |                          |      |      |      |      |                          |      |      |      |      |      |      |      |
| cf. <i>Muscari comosum</i>                            | 1                        |      |      |      |      | 4                        | 1    |      | 16   | 1    |      |      |      |
| <i>Asphodelus</i>                                     |                          |      | 1    |      |      |                          |      |      | 1    |      |      |      |      |
| Asteroidae  |                          | 2    | 1    |      |      | 1                        | 1    |      | 1    |      |      | 1    |      |
| Brassicaceae  | 4                        | 3    |      |      |      | 1                        |      |      | 6    |      |      |      |      |

|                                 |            |            |            |           |           |             |            |            |             |           |           |           |           |
|---------------------------------|------------|------------|------------|-----------|-----------|-------------|------------|------------|-------------|-----------|-----------|-----------|-----------|
| <i>Campanula</i>                |            |            |            |           |           | 1           |            |            |             |           |           |           |           |
| Caryophyllaceae                 |            |            |            | 1         |           | 4           | 1          |            | 3           |           |           |           |           |
| Cichorieae                      | 2          |            | 2          | 1         |           | 1           | 1          |            | 6           |           |           | 1         |           |
| Convolvulaceae                  |            |            |            |           |           |             |            |            | 1           |           |           |           |           |
| <i>Hypericum</i>                |            |            | 1          |           |           |             |            | 1          |             |           |           |           |           |
| <i>Knautia</i>                  |            |            |            |           |           |             |            |            | 1           |           |           |           |           |
| Lamiaceae                       |            |            |            |           |           | 3           |            |            |             |           |           |           |           |
| <i>Plantago</i>                 |            |            |            |           |           | 1           |            |            | 1           |           |           |           |           |
| Poaceae                         |            |            |            |           |           | 1           |            |            | 4           |           |           |           |           |
| Ranunculaceae                   |            |            |            |           |           |             |            |            | 1           |           |           |           |           |
| Rosaceae                        |            |            |            |           |           |             |            |            | 1           |           |           |           |           |
| Scrophulariaceae                |            | 3          |            |           |           | 1           |            |            | 1           |           |           |           |           |
| <i>Symphytum</i>                |            |            |            |           |           |             |            |            | 1           |           |           |           |           |
| <b>Total Sum</b>                | <b>16</b>  | <b>15</b>  | <b>22</b>  | <b>7</b>  | <b>0</b>  | <b>72</b>   | <b>18</b>  | <b>2</b>   | <b>89</b>   | <b>1</b>  | <b>1</b>  | <b>2</b>  | <b>1</b>  |
| <b>Pollen taxa</b>              | <b>8</b>   | <b>6</b>   | <b>9</b>   | <b>4</b>  | <b>1</b>  | <b>15</b>   | <b>9</b>   | <b>2</b>   | <b>25</b>   | <b>1</b>  | <b>1</b>  | <b>2</b>  | <b>1</b>  |
| <b>Concentration (grains/g)</b> | <b>213</b> | <b>150</b> | <b>169</b> | <b>86</b> | <b>95</b> | <b>1358</b> | <b>375</b> | <b>200</b> | <b>1390</b> | <b>19</b> | <b>20</b> | <b>37</b> | <b>13</b> |

**Table 4.** Grotta Romanelli (Apulia, Italy). Number of pollen grains of *Terre brune* samples from SS1 (from left to right, bottom to top sample, see Fig. 4a).

| Grotta Romanelli<br>(Apulia, Italy)     | <i>Terre brune</i> - SS1 |      |      |      |      |      |      |      |      |      |      |      |      |      |
|---|--------------------------|------|------|------|------|------|------|------|------|------|------|------|------|------|
|   | B300                     | B301 | B302 | B303 | B304 | B305 | B306 | B307 | B308 | B309 | B310 | B311 | B312 | B313 |
| <i>Juniperus</i>                        |                          |      | 2    | 2    |      |      | 3    | 9    |      | 2    |      | 4    |      |      |
| <i>Pinus</i>                            |                          | 1.5  | 5.5  | 1.5  |      | 4    |      |      |      |      |      |      |      | 2    |
| <i>Alnus</i>                            |                          |      |      |      |      |      |      |      |      |      |      | 1    |      |      |
| Ericaceae                               |                          |      |      |      |      |      |      |      |      |      | 1    |      |      |      |
| <i>Pistacia</i>                         |                          | 2    |      |      |      |      |      |      |      |      |      |      |      |      |
| <i>Populus</i>                          |                          |      |      | 1    |      |      |      |      |      |      |      |      |      |      |
| <i>Quercus ilex</i> type                |                          | 1    | 2    |      | 2    | 2    |      | 2    |      |      | 2    | 2    |      | 1    |
| <i>Quercus cerris</i> type              |                          | 2    | 2    |      |      |      |      |      |      | 2    |      |      |      |      |
| <i>Quercus robur</i> type               |                          |      | 3    | 2    |      |      | 4    | 4    | 3    |      |      |      |      |      |
| Rosaceae                                |                          |      |      |      |      |      |      | 1    |      |      | 7    |      | 1    | 1    |
| <i>Tamarix</i>                          |                          | 14   | 2    |      | 2    | 1    | 2    |      |      |      |      |      | 3    | 2    |
| <i>Ulmus</i>                            |                          |      |      |      |      |      |      |      |      | 2    |      |      |      |      |
| Amaranthaceae                           |                          | 2    |      | 1    | 3    | 5    |      |      |      |      | 2    | 1    | 1    |      |
| Apiaceae                                |                          |      |      |      |      |      |      |      |      | 1    |      |      |      |      |
| <i>Artemisia</i>                        |                          |      |      | 1    |      | 2    |      |      |      |      | 1    |      | 1    |      |
| Asparagaceae                            |                          |      |      |      |      |      |      |      |      |      |      |      |      |      |
| <i>Asparagus maritimus/Ornithogalum</i> |                          | 4    |      |      |      |      | 2    |      |      | 7    |      |      |      |      |
| Asteroideae                             | 5                        | 18   | 29   | 11   | 9    | 6    | 4    | 2    | 4    | 2    |      |      |      |      |
| Brassicaceae                            |                          | 2    | 4    |      |      |      |      | 3    |      |      | 8    |      |      |      |
| Caryophyllaceae                         |                          |      |      | 3    |      |      |      |      |      |      |      |      |      |      |
| <i>Centaurea cf. nigra</i>              |                          |      |      |      | 2    |      |      | 2    |      |      |      |      |      |      |



|  |            |              |               |              |              |              |              |              |              |            |            |           |           |           |
|--|------------|--------------|---------------|--------------|--------------|--------------|--------------|--------------|--------------|------------|------------|-----------|-----------|-----------|
| Cichorieae                             |            | 55           | 163           | 79           | 92           | 76           | 84           | 77           | 94           | 83         |            |           |           |           |
| Cyperaceae                             |            |              |               | 1            |              |              |              |              |              |            |            |           |           |           |
| Fabaceae                               |            | 18           | 1             |              |              |              |              | 2            |              |            | 1          |           | 1         | 1         |
| <i>Geranium</i>                        |            |              | 1             |              |              |              |              |              |              |            |            |           |           |           |
| Lamiaceae                              |            |              | 2             |              |              |              |              |              |              |            | 2          |           |           |           |
| <i>Limonium</i> gr.                    |            |              |               |              |              | 1            |              |              |              |            |            |           |           |           |
| <i>Papaver</i>                         |            | 4            |               |              |              |              |              |              |              |            |            |           |           |           |
| <i>Plantago</i>                        |            |              |               |              |              | 3            |              |              |              |            | 1          | 3         |           |           |
| Poaceae                                | 2          | 7            | 3             | 5            | 5            |              |              | 6            |              |            | 1          |           |           | 1         |
| Ranunculaceae                          |            | 8            | 8             |              |              |              | 6            |              |              |            | 4          | 1         | 2         | 1         |
| <i>Sanguisorba</i><br><i>cf. minor</i> |            |              |               |              |              |              |              | 2            |              |            |            |           |           |           |
| <i>Saxifraga</i>                       |            |              |               |              |              |              |              |              |              |            |            |           | 2         |           |
| <i>Scabiosa</i>                        |            |              | 2             |              |              |              |              |              |              |            |            |           |           |           |
| <i>Urtica</i>                          |            |              |               |              |              |              |              |              |              |            | 2          |           |           | 2         |
| <b>Total Sum</b>                       | <b>7</b>   | <b>138.5</b> | <b>229.5</b>  | <b>107.5</b> | <b>115.5</b> | <b>102.5</b> | <b>105</b>   | <b>110</b>   | <b>101</b>   | <b>101</b> | <b>30</b>  | <b>12</b> | <b>11</b> | <b>11</b> |
| <b>Pollen taxa</b>                     | <b>2</b>   | <b>14</b>    | <b>15</b>     | <b>11</b>    | <b>7</b>     | <b>10</b>    | <b>7</b>     | <b>11</b>    | <b>3</b>     | <b>8</b>   | <b>11</b>  | <b>6</b>  | <b>7</b>  | <b>8</b>  |
| <b>Concentration (grains/g)</b>        | <b>138</b> | <b>317.9</b> | <b>12,735</b> | <b>450.3</b> | <b>579</b>   | <b>101.8</b> | <b>107.9</b> | <b>107.5</b> | <b>110.5</b> | <b>893</b> | <b>267</b> | <b>67</b> | <b>86</b> | <b>68</b> |

**Table 5.** Grotta Romanelli (Apulia, Italy). Number of pollen grains of *Terre brune* samples from SS2 and SS3 (from left to right, bottom to top sample, see Fig. 4b, c).

| Grotta Romanelli<br>(Apulia, Italy) | <i>Terre brune</i> - SS2 |      |      |      |      | <i>Terre brune</i> - SS3 |      |      |      |      |      |
|-------------------------------------|--------------------------|------|------|------|------|--------------------------|------|------|------|------|------|
|                                     | B338                     | B339 | B340 | B341 | B342 | B354                     | B353 | B352 | B351 | B350 | B349 |
| <i>Juniperus</i>                    | 3                        | 1    |      |      | 2    | 2                        |      |      |      | 1    |      |
| <i>Pinus</i>                        |                          |      |      |      | 2    |                          |      | 2    |      |      | 2    |
| <i>Alnus</i>                        |                          | 1    |      |      |      |                          | 2    | 2    |      |      |      |
| cf. <i>Ligustrum</i>                |                          | 1    |      |      |      |                          |      |      |      |      |      |
| <i>Olea</i>                         |                          | 4    | 3    | 1    | 4    |                          |      | 2    | 16   |      | 3    |
| <i>Quercus ilex</i> type            | 2                        |      |      |      | 4    |                          |      | 3    | 5    | 2    |      |
| <i>Quercus cerris</i> type          |                          |      |      |      |      |                          |      |      | 2    |      |      |
| <i>Quercus robur</i> type           |                          |      | 3    |      | 4    |                          |      |      | 2    | 4    | 2    |
| Rosaceae                            |                          |      |      |      | 2    |                          |      |      |      |      |      |
| <i>Salix</i>                        |                          |      |      |      |      |                          |      |      | 2    |      |      |
| <i>Tamarix</i>                      |                          |      |      |      |      |                          | 2    |      |      |      |      |
| Amaranthaceae                       | 3                        | 3    | 6    | 4    |      | 3                        | 2    |      | 2    |      |      |
| <i>Artemisia</i>                    |                          | 6    | 8    |      |      |                          |      |      | 2    |      |      |
| Asteroidae                          | 2                        | 1    |      | 2    | 6    | 8                        | 16   | 6    | 6    | 8    |      |
| Brassicaceae                        | 6                        |      |      |      | 20   | 4                        |      | 9    | 3    | 2    |      |
| Caryophyllaceae                     |                          |      | 6    |      | 6    |                          |      | 2    |      | 2    |      |
| <i>Centaurea</i> cf. <i>nigra</i>   |                          |      |      |      |      |                          |      | 2    |      |      |      |
| Cichorieae                          | 85                       | 80   | 161  | 96   | 192  | 126                      | 11   | 86   | 94   | 87   | 91   |
| Fabaceae                            |                          |      |      |      |      | 1                        |      |      |      |      |      |
| Liliaceae                           |                          |      |      |      |      |                          |      | 1    | 5    | 4    |      |
| <i>Linum</i>                        |                          |      |      |      |      |                          |      |      | 1    |      |      |
| <i>Plantago</i>                     |                          | 1    |      |      |      |                          |      |      |      | 1    |      |
| Poaceae                             |                          | 4    |      |      |      | 3                        | 2    | 3    | 2    |      | 8    |
| Ranunculaceae                       |                          |      |      |      |      |                          | 2    | 1    | 2    |      |      |
| <i>Urtica</i>                       |                          |      |      |      |      |                          |      |      | 2    |      |      |
| <i>Thalictrum</i>                   |                          |      |      |      | 1    |                          |      |      |      |      |      |
| Valerianaceae                       |                          |      |      |      |      |                          | 3    |      |      |      |      |

|                                     |            |             |             |             |             |             |             |             |             |            |            |
|-------------------------------------|------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|------------|------------|
| <b>Total Sum</b>                    | <b>102</b> | <b>106</b>  | <b>187</b>  | <b>103</b>  | <b>243</b>  | <b>148</b>  | <b>40</b>   | <b>119</b>  | <b>146</b>  | <b>111</b> | <b>106</b> |
| <b>Pollen taxa</b>                  | <b>6</b>   | <b>12</b>   | <b>6</b>    | <b>4</b>    | <b>10</b>   | <b>8</b>    | <b>8</b>    | <b>12</b>   | <b>15</b>   | <b>9</b>   | <b>5</b>   |
| <b>Concentration<br/>(grains/g)</b> | <b>691</b> | <b>1787</b> | <b>3793</b> | <b>1292</b> | <b>9343</b> | <b>2655</b> | <b>1296</b> | <b>1140</b> | <b>1251</b> | <b>585</b> | <b>719</b> |

Journal Pre-proof

**Table 6.** Grotta Romanelli (Apulia, Italy). Number of pollen grains of *Terre brune* samples from SS4 (from left to right, bottom to top sample, see Fig. 4d).

| Grotta Romanelli<br>(Apulia, Italy)                     | <i>Terre brune</i> - SS4 |      |      |      |      |      |      |
|---|--------------------------|------|------|------|------|------|------|
|   | B324                     | B325 | B326 | B327 | B328 | B329 | B330 |
| <i>Juniperus</i>  |                          | 7    | 151  | 6    | 20   |      |      |
| <i>Pinus</i>  | 2                        | 1    |      |      |      | 1    | 4    |
| <i>Alnus</i>  |                          |      |      |      | 2    |      |      |
| <i>Cistus</i>   |                          |      |      |      | 3    |      |      |
| <i>Olea</i>   | 1                        |      |      |      |      |      | 3    |
| <i>Phillyrea</i>  |                          |      |      |      |      | 1    |      |
| <i>Quercus ilex</i> type                                | 2                        | 1    | 3    | 2    | 8    | 4    |      |
| <i>Quercus cerris</i> type                              |                          |      |      |      | 8    | 3    |      |
| <i>Quercus robur</i> type                               | 7                        |      |      |      |      |      | 5    |
| Rosaceae  |                          |      | 1    | 4    | 3    |      |      |
| <i>Salix</i>  |                          |      |      |      | 11   | 2    |      |
| <i>Tamarix</i>  |                          |      | 7    | 7    | 7    |      |      |
| <i>Ulmus</i>  |                          |      |      |      |      |      |      |
| Amaranthaceae   |                          |      | 1    | 1    | 1    |      | 5    |
| Apiaceae<br><i>cf. Crithmum maritimum</i>               |                          |      |      | 1    | 103  | 1    |      |
| <i>Artemisia</i>  | 2                        | 9    | 10   |      |      |      |      |
| Asparagaceae<br><i>Asparagus maritimus/ Omithogalum</i> |                          |      |      |      | 178  | 9    |      |
| Asteroidaeae  | 4                        | 1    | 3    |      |      | 5    | 10   |
| Brassicaceae  |                          |      |      |      | 7    |      | 10   |
| Caryophyllaceae   |                          | 1    |      | 2    |      |      | 3    |
| <i>Centaurea cf. nigra</i>                              | 1                        |      |      |      |      |      |      |
| Cichorieae  | 83                       | 1    |      |      |      | 82   | 157  |
| Fabaceae  |                          |      |      | 3    | 82   |      |      |
| Lamiaceae   |                          |      |      |      | 4    |      |      |
| <i>Plantago</i>   |                          | 2    | 1    | 3    | 4    |      | 3    |

|                                 |            |            |            |            |               |             |             |
|---------------------------------|------------|------------|------------|------------|---------------|-------------|-------------|
| Poaceae                         | 1          |            | 7          | 2          | 29            | 1           |             |
| Ranunculaceae                   |            | 1          | 11         | 13         | 80            | 2           | 3           |
| <i>Saxifraga</i>                |            |            |            |            | 17            |             |             |
| <i>Spergularia</i>              |            |            | 1          |            |               |             |             |
| <i>Urtica</i>                   |            |            | 2          | 1          | 5             |             |             |
| <b>Total Sum</b>                | <b>103</b> | <b>24</b>  | <b>198</b> | <b>41</b>  | <b>572</b>    | <b>111</b>  | <b>203</b>  |
| <b>Pollen taxa</b>              | <b>9</b>   | <b>9</b>   | <b>12</b>  | <b>12</b>  | <b>19</b>     | <b>11</b>   | <b>10</b>   |
| <b>Concentration (grains/g)</b> | <b>934</b> | <b>132</b> | <b>696</b> | <b>173</b> | <b>21,124</b> | <b>1281</b> | <b>4686</b> |

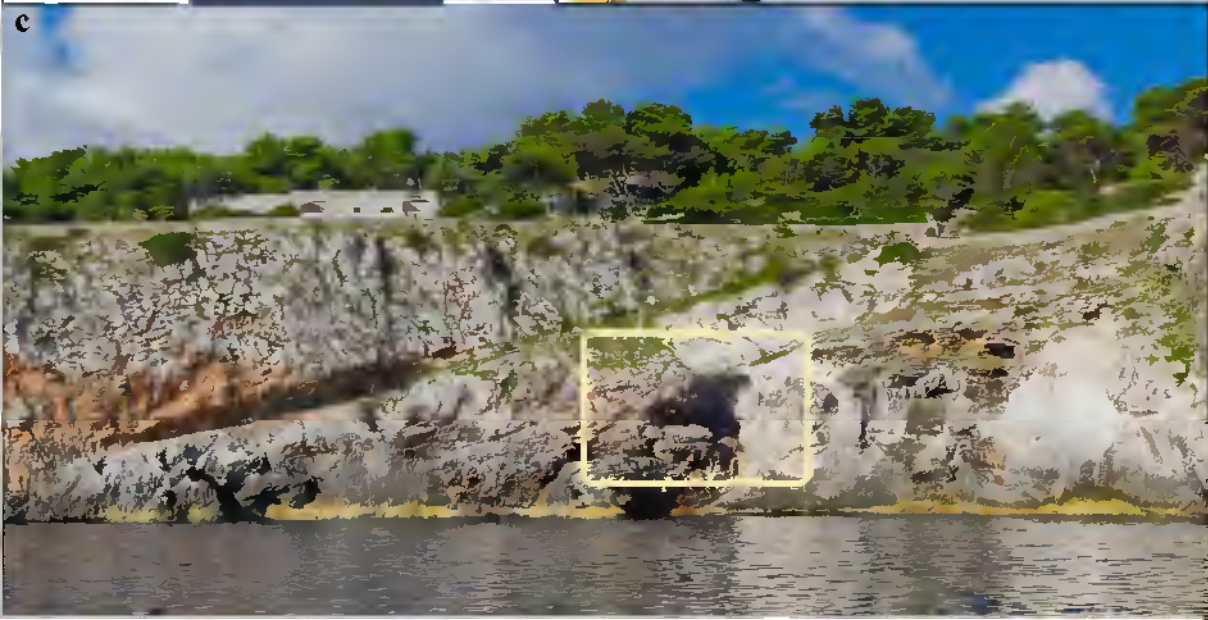
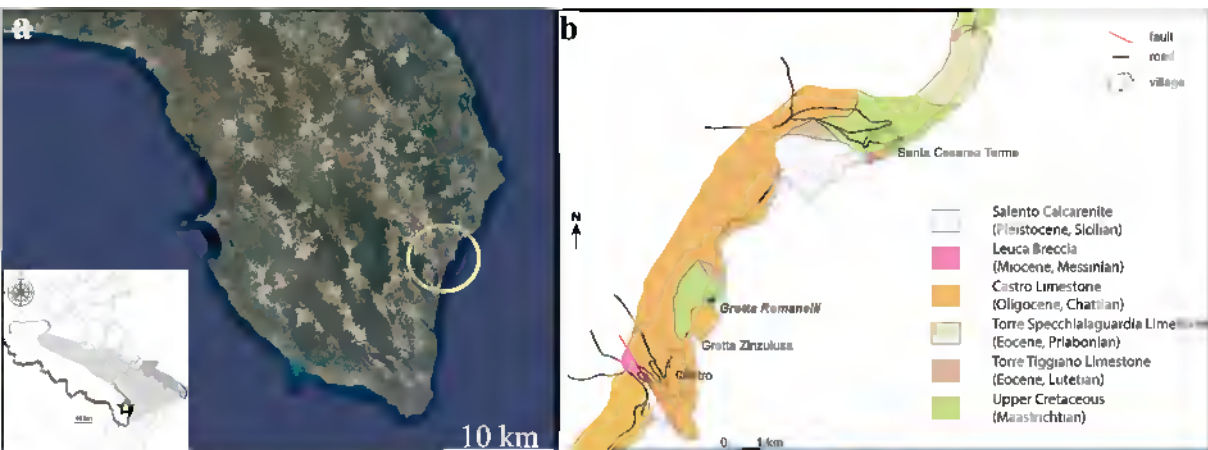
## Highlights

Pollen was preserved in Late Pleistocene/Early Holocene deposits of Grotta Romanelli

*Olea* pollen constraints the deposition of *Terre rosse* to the Eemian (MIS 5e)

Steppe herbs and rare arboreal pollen in *Terre brune* mark the Lateglacial

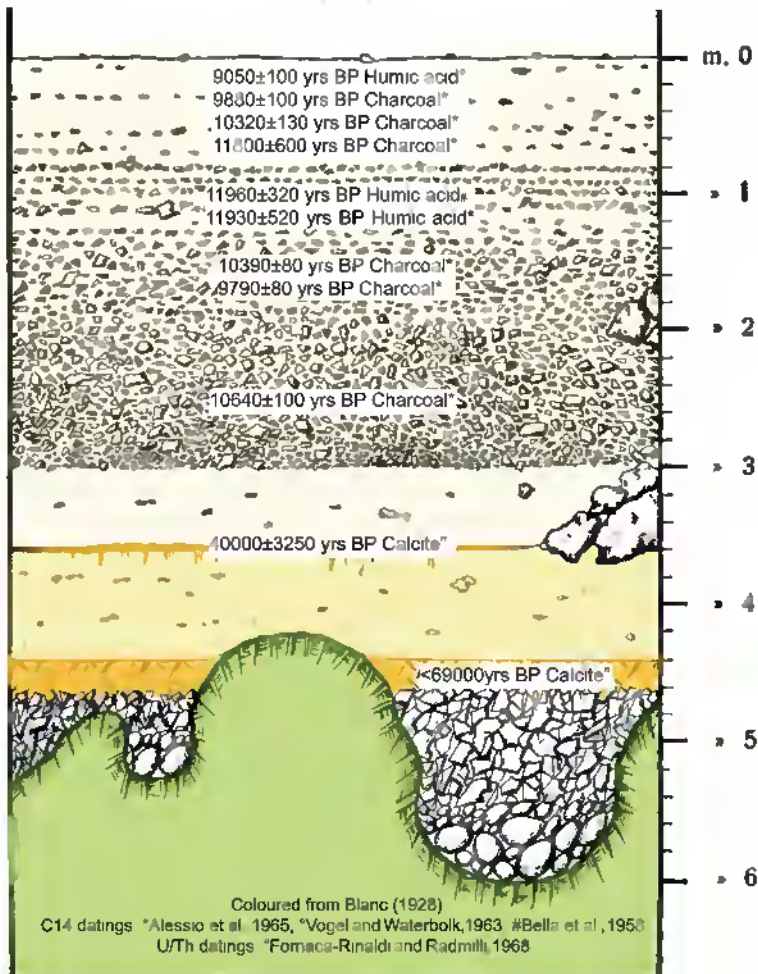
Clusters/high amounts of entomophilous pollen may reveal the use of plants by humans



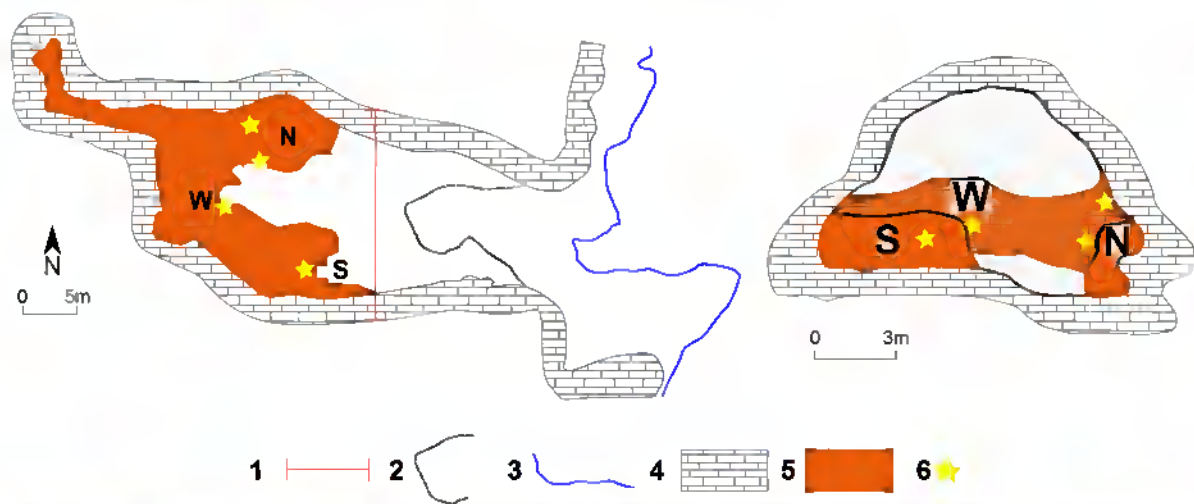
Terre brune

Terre rosse

A  
B  
C  
C1  
D  
E  
F  
G  
H  
I  
K  
L





**a****b****S****W****N**

SS 1



SS 3



SS 4



SS 2

