International Erasmus Mundus Master in

QUATERNARY AND PREHISTORY

Master Thesis :

Taphonomic approach of different post-depositional processes and archaeopalynologic study of Neolithic-Bronze Age landscape and settlement organisation from the site of Vallone Inferno (Sicily, Italy)

-

Nolwenn EMONET

Supervisor :

Isabel EXPOSITO BAREA

Academic year 2022/2023

Acknowledgement :

First of all, I would like to say a special thank you to my supervisor, Mrs. Isabel EXPOSITO BAREA. Isa, thank you for your supervision, your kindness, your “joie de vivre”, your patience and your constant help, which allowed me to learn and experiment with archaeopalynology and to finalize my master's degree !

I would like to thank the IPHES archaeobotany team and Isabelle CACERES, who warmly welcomed me into their office and laboratory during the year, and with whom I was able to take part in the VII Oikos congress organized by the Catalan Bioarchaeology Association. I would also like to thank Andreu OLLE, Josep Maria VERGES and Vincenza FORGIA, for allowing me to work on the archaeological site of Vallone Inferno. I would also like to thank Vincent LEBRETON and Liz CHARTON, who advised me to contact the archaeobotany team to carry out my internship at IPHES in Tarragona.
I would like to thank the Muséum national d'Histoire naturelle of Paris and the coordinators of the 'International Master of Quaternary and Prehistory' for these two intense years of Master's study. On the one hand, I would like to thank the 'Quaternary, Prehistory and Bioarchaeology' master's program for the high quality of its teaching and the organization of my first master's year. On the other hand, I would like to thank the organizers and professors of the Rovira i Virgili University and the IPHES of Tarragona for their hospitality and teaching during my second year of ERASMUS in Spain.

Finally, I would like to thank my folks for their encouragement, their patience and for all our moments! To Sarah Griviaud, Camille Lacorne, Elide Bruneli for giving me a taste of Sicilian vegetation! To my friends from high school & undergraduate studies, from the master's program, including the pépites from Paris and my friends from all over the world, from the rubia of Atapuerca and Wolschwiller excavation, my Viking friends from the North and the crazy lunch with the "don't ask why" team from IPHES (especially Lila). Special attention to my Family, my parents and my "bigger" sisters, as well as my second little family pequina Tamo and pequino Nat de la escuedra familia. And last but not least, a big thank you to Louise, who has been an undeniable support during these two years!

May the adventure continue over a San Miguel and flowers.

გაკოცე en la nalga izquierda, Graciès and ደህና እደሩ !

Table of content

1. Introduction

1.1. Presentation of the study

This Final Master's thesis focuses on the archaeopalynological study of level 3.4.a from the Vallone Inferno site (Scillato, Sicily) chronologically framed at Neolithic and Early Bronze Age period, through the analysis of pollen and Non-Pollen Palynomorps (NPPs).

Sicily is the largest island in the Mediterranean region, located in southern Italy .
In recent decades, Sicily has been the center of numerous archaeological research aimed at reconstructing the evolution of the vegetation and the history of the region settlements and their anthropic activities. Since 2008, new research has been carried out in the Madonie region of Sicily (Italy), especially on the site of Vallone Inferno located at Scillato. Indeed, this site has the particularity of being located at the crossroads of lowland and highland in the Madonie mountains and situated close to a water source, the Imera river. These characteristics make the Vallone Inferno rock shelter a high-potential site for seasonal pastoral settlement (Forgia et al., 2021, In process). Moreover, its long stratigraphic sequence extends over more than the last ten millennia and covers a period marked by climatic changes linked to the "4,2ka event", human settlements and development of various cultural practices. These had consequences for the evolution of vegetation, which have been recorded at numerous sites in South Sicily and the Mediterranean region in general. However, the number of research on the Northern Sicily is limited and the palaeoenvironnemental deposits of island is particular to the continent. For this reason, as part of this new multi-disciplinary research approach, archaeopalynological studies are realised to complete the previous studies already produced in order to complete the existing information.

The objective is to reconstruct the landscape and characterize the organization of human settlement in the period from the Middle Neolithic to the Early Bronze Age on a site located in the mountain Madonie region. Therefore, the particularity of this work lies in the fact that samples come from anthropic occupation and are obtained from horizontal sampling. Samples of the fireplace, from the inside of a bucket and from the *fumier* deposit were collected. The analysis of pollen and NPPs enabled us to identify the regional and local environmental composition, while limiting the taphonomic constraints of these archaeological micro-elements.

1.2. History of Sicilian archaeobotanical studies : vegetation responding to climatic and anthropogenic change over the Holocene period

Sicily is considered a key region of the Mediterranean, isolated from the continent by the strait of Messina, it represents a high level of ecosystem diversity and an impressive world heritage, thanks to its geographical position and rich history (Pasta et Speciale, 2021). Furthermore, this island is known for its relief such as its long mountain range that crosses northern Sicily and groups Madonie mountains to north-west and Nebrodi to north-east and influences the regional climate. The current Madonie park is framed by Imera river, covers more than 50,000 hectares, and has been the subject of several studies over the years (Daria et al., 1983 ; Forgia, 2019a).

Sicily's first archaeobotanical studies focused mainly on the island's early Neolithic and agro-pastoral activities (Pasta et Speciale, 2021). One of the earliest archaeobotanical studies in Sicily dates to the 20th century, when research was carried out on charred remains from the Grotta di San Teordore di Acquedolci (140m a.s.l.). These studies highlighted the floristic diversity of the Upper Paleolithic and the particularity of Sicilian ecological niches (Lona, 1949). After more than 40 years, Costantini published new studies on the exploitation of plants and the beginning of the domestication of cereals and leguminous in the Neolithic period in the Grotta dell'Uzzo (100m a.s.l.) in Sicily (Costantini, 1989 ; Costantini et al., 2014). In 1999, Leighton (1999) published a multidisciplinary study with a chapter devoted to the evolution of the plant landscape since the Lower Pleistocene and the settlement of the first farmers in Sicily (Leighton, 1999, p.15-16 & 51-57). The number of archaeobotanical studies has multiplied since the beginning of the 21st century, when palynological, anthracological and carpological studies were carried out to analyze the evolution of vegetation, climate and human cultures during the Holocene in south, east, west and central Sicily and its islands, as well as in southern Italy. These sites show the floral transition in Sicily between scrubland and the development of a Mediterranean forest, with dominant taxa varying according to the belts observed. This would be linked to a climatic change that occurred between 10,000 and 8000 cal. BP. Then, the 4.2.ka event caused a drying out with cooler temperatures, leading to a regression of these forests and amplified by human activities observed from the beginning of the Neolithic and intensified during the Metal Ages, aiming to the clearance of forest to create space for anthropic settlements and the development of agro-pastoral economies (Watts et al., 1996 ; Sadori et Narcisi, 2001 ; Castiglioni, 2008 ; Sadori et al., 2008 ; Tinner et al., 2009 ; Di Rita et Magri, 2009a, 2009b ; Noti et al., 2009 ; Bisculm et al., 2012 ; Calò et al., 2012 ; Joannin et al., 2012 ; Combourieu-

Nebout et al., 2013 ; Magny et al., 2013 ; Peyron et al., 2013 ; Tinner et al., 2016 ; Mercuri et al., 2020 ; Speciale et al., 2020 ; Pasta et Speciale, 2021 ; D'Agostino et al., 2022 ; Speciale et al., 2023).

1.3. Sicily island and Madonie region cultures during the prehistoric period : from sporadic remains to a region of pastoralism

The first indirect and sporadic traces of the hominid genus in Sicily date back to the Lower Palaeolithic, thanks to the discovery of lithic industry (Baldini et al., 1976 ; Recami et Baldini, 1977 ; Revedin Arborio Mella, 1984 ; Forgia et al., 2014 ; Di Maida, 2020). However, the first traces of settlement and colonization in Sicily date back to the Epigravettian period. In all, more than 20 sites have been dated to this period, spread across the entire island, including the grotta di San Teodoro and the grotta Addaura Caprara (Recami et Baldini, 1977 ; Mannino, 1989 ; Antonioli et al., 2016 ; Di Maida, 2020 ; Ruggieri, 2022). In the Madonie region, although indirect discoveries of human presence such as the local flint lithic artefacts found in the Marabilice valley (1500m a.s.l.) or the crockery and lithic artefacts from the Abisso del Vento site, the first human remains were found at the Vecchiuzzo Cave site (700m a.s.l.) and date from the Late Neolithic (Baldini et al., 1976 ; Mannino, 1989 ; Lauria et Messina, 2013). During the 6th millennium BC, the process of Neolithization conquered southern Italy and Sicily, with the arrival of farmers from the south-western part of Eurasia. The first traces of farming and stockbreeding are documented at the Grotta dell'Uzzo (100m a.s.l.), Grotta d'Oriente (50m a.s.l.) and Roccapalumba sites (540m a.s.l.), where evidence of pastoral activities has been uncovered. The continuity of these practices on the mid-slopes can be seen at numerous sites in Sicily, such as Valcorrente di Belpasso (551m a.s.l.) and Rochiella du Mineo (511m a.s.l.), or San Caterina di Paterno (150m a.s.l.), where livestock farming diversified to include ovicaprinae, cattle, suidae and equidae (Daria et al., 1983 ; Albarella et al., 2006 ; Maniscalco et al., 2015 ; Hofmanová et al., 2016 ; Italiano et al., 2018 ; Natali et Forgia, 2018a).

The origins of this practice can be traced back to the Alps and the Mediterranean coast, during the Mesolithic and early Neolithic periods, where hunter-gatherers and mixed farmers would have exploited the seasonal and complementary resources available in the environment. Pastoralism is distinguished from agro-pastoral activities by its exclusive herding activities. Vertical transhumance pastoralism, i.e. the seasonal movement of herds according to differences in altitude, was developed to improve land management in regions with high relief

(Geddes, 1983 ; Greenfield, 1999 ; Arnold et Greenfield, 2006). In Northern Sicily, transhumance pastoral research are mainly investigated and exposed by zooarcheaology, pottery, biomarkers, GIS analyze or lithic remains, however, the palynological research are less developed (Forgia et al., 2013 ; Tinner et al., 2016 ; Pasta et Speciale, 2021 ; Forgia et al., 2021 ; Martín et al., 2023 ; Forgia et al., In process ; Martín et al., In process).

1.4. Palynology

1.4.1. The discipline

Palynology is the field of archaeobotany that studies the pollens of flowering plants, the spores of non-flowering plants and "Non-Pollen Palynomorphs" (NPP). This discipline has existed for over a century. Today, palynology is studied for a variety of reasons. In particular, it has developed for medical reasons, in order to understand allergies, but also for food reasons, with the analysis of honey composition (Melissopalynology), or for legal reasons, with forensic studies (Horrocks et Walsh, 1998 ; Bui Thi et Girard, 2002). However, this micro-element analysis technique has mainly been used to reconstruct palaeoenvironments for almost a century. The aim is to reconstruct past climate change processes (Bennett et Willis, 2001) and understand the environment in which plants, animals and humans have evolved to the co-occurrence of pollen and NPPs in sediments (Moore et al., 1991).

1.4.2. Definition of Pollen and Non Pollen Palynomorphs

Pollen grains are produced by seed plants, angiosperms and gymnosperms (Moore et al., 1991). They correspond to the male gametophyte of plants, containing the male gametes. They are produced in the anthers of flower stamens. They are then dispersed into the environment by a different methods, including wind (anemophilous), insects (entomophilous) or water (hygrophilous) (Bennett et Willis, 2001). The distance covered by pollen and spores varies according to taxa and dispersal methods (Campbell et al., 2011). A minority of pollen grains fertilize the ovules containing the female gametes. The majority of unfertilized pollen is deposited uniformly on the ground in the form of pollen rain in the environment (Bennett et Willis, 2001). These pollens can be observed by palynologists (Moore et al., 1991). In terrestrial contexts, they are washed out by rain and sink into the soil as the water percolates, or they accumulate in lake sediments, peat bogs, ice, loess or cellar sediments (Bennett et Willis, 2001).

During pollen preparation, microfossils, known as Non Pollen Palynomorphs (NPPs), from a variety of origins can be observed. Their presence increases the number of paleoenvironmental indicators (Van Geel, 2006). These are microscopic elements produced by fungi, pteridophytes, algae, insects, plants or from unknown origin (Bennett et Willis, 2001).
Pteridophytes, bryophytes, algae and fungi produce spores (Moore et al., 1991). Spores are male gametophytes necessary for the reproduction of these organisms (Moore et al., 1991 ; Bennett et Willis, 2001). They are produced by cell division with chromatid separation during meiosis. They are produced in large numbers to ensure colonization of a territory (Moore et al., 1991). The spores are then dispersed into the environment by a variety of factors, such as the wind (Bennett et Willis, 2001). They then germinate to form a gametophyte bearing gametes (Moore et al., 1991).

Fungi spores are the most common NPPs (Van Geel, 1978a), with a short dispersal distance. Fungal fossils are most often found in dry environments, close to the production area. Fungi are saprotrophs or biotrops. Saprotrophic fungi, also known as decomposers, among which are coprophilous, or carbonicolous are colonizers of inert organic matter. Biotrophic or pathogenic fungi are colonizers of living organic matter such as (for example, *Fusarium* and *Puccinia*). They act as parasites of the plants, affecting their normal functioning and their intervention supposes, in many cases, the death of the same. Also included within the group of biotrophs are mycorrhizae, such as *Glomus*, very frequently identified in palynological analysis and which are a symbiosis between fungus and root where both fungus and plant, in their association, are benefited (Van Geel, 2006).

The possible contribution of NPPs is related to the trophic conditions in which the sediments were deposited. In general terms, the environment may be composed of eutrophic or organic-rich sediments, mesotrophic or oligotrophic or organic-poor sediments. Rhizopods, mainly "tecamebae", green algae and cyanobacteria (formerly known as blue algae) are particularly relevant in determining the characteristics and evolution of the trophic level of the medium (Van Geel, 1976 ; Jankovska et Komarek, 2000).
Remains of animal origin are also common in sediments, and their quantification is routinely included in palynological diagrams, although it is particularly difficult to establish the degree of reliability of the ecological information provided. These zooremains (or faunal remains) are

mainly fragments of chitin or entomolina associated with anatomical elements of insects, mites or arthropods. Although in some cases, the presence of one of these palynomorphs, such as *Trichuris*, can provide us with information about the presence of feces and, consequently, that of a certain producer organism. Generally, the main information that can be inferred from zoo remains is the possible presence of decomposing organic matter, which would favor the wandering of insects, mites, etc. In fact, insects have sometimes co-evolved with certain plants and only feed on one type of plant. They are also good indicators of climatic variations. The identification of these elements is necessary to complete the interpretations associated with the pollen spectrum. Even so, and when it comes to chitinous skeletal remains, we cannot completely ensure that they are contemporary with the sedimentary context in which they are found, since this type of organism can circulate freely in the sediments, crossing stratigraphic thresholds without difficulty (Van Geel, 2008 ; Campbell et al., 2011).

Stomata are some of the fragments of plant debris find on the pollen sheets. They are part of the structure of of the aerial part of plants and are responsible for gas and water exchange. They are good indicators of the local environment thanks to their short distance dispersion and are more frequent in lake deposit. Despite its easy taxonomic identification, they have a low abundance and doesn't allow to evaluate the abundance of a plant in the environment (Macdonald, 2001).

The co-occurrence of pollen structures and NPPs microfossils enables better taxonomic identification and therefore more precise ecological information. Furthermore, most NPPs have a longer geological history than angiosperm and gymnosperm pollen (Van Geel, 2006)

1.4.3. Characteristics of Pollen and NPP

1.4.3.1. Pollen morphology

The structure of pollen grains and spores has a similar morphology due to the mode of dispersal. However, each taxon has specific pollens and spores that enable them to be identified. Several criteria are observed. The criteria for identifying taxa are similar for the taxa that are closest in evolutionary terms. Archaeological pollens can be identified by comparison with present-day pollens of known species (Moore et al., 1991).

The shape and size of pollen vary between taxa. Most often, they are elliptical or spherical. On average, pollen grains are 20-40µm in size, but can vary from 10µm to 100µm. On average, spores have the same size spectrum as pollen (Bennett et Willis, 2001).

Pollens are made of a wall called exine. It is made up of cellulose, hemicellulose, lignin, peptides and sporopolenin. The latter provides strong protection during dispersal (Stanley et Linskens, 1975). The structure of the exine is complex, since it is subdivided into various layers (endexin and ektexin) and sublayers (tectum, infratectum and base) that have been described and ranked by various authors over time (Erdtman, 1948 ; Fægri, 1956 ; Renault-Miskovsky et al., 1976 ; Dupré, 1992 ; Sáez et Merino, 2004). The pollen grain is originally grouped in tetrads when it forms in the anther of the flower. The position of the grain in the tetrad gives it morphological characters that give rise to an external cover with different structural features (Moore et al., 1991). The outer part of the sporopollenin has different shapes and patterns, depending on the taxon. It may feature positive or negative relief ornamentation of varying sizes, such as spines, vesicles or fossae. Moreover, the surface of certain positive reliefs may join to form a new layer called a tectum, supported by columella (Bennett et Willis, 2001). It can also bear positive or negative ornamentation, which can be reticulated. The structure of the exine also presents variations in its thickness. These alterations in the surface of the grain are sometimes transformed into openings, in which the exine disappears. These "voids" in the exine facilitate the emission of the pollen tube which enables fertilization, in addition to allowing changes in pollen volume due to fluctuations in environmental humidity. The openings constitute one of the essential features for the identification of pollen based on its shape and distribution. Based on the shape of the openings, pollen grains are classified as: colpate (due to the presence of furrows); porate (by the presence of pores) and colporated (presence of furrows and pores) (Figure 1). The difference between furrow and pore is established by a proportion regarding the length and width of 2/1. As we have already said, the distribution of the openings is also a diagnostic element, and these voids can be located in the equator area, at the poles, or along the entire grain surface. Another important aspect to take into account is the number of openings. We can find pollen grains without openings (inaperturated), with only one of them (mono-aperturated), with two (diaperturated), and so on (Moore et al., 1991). Furthermore, some pollens have typical structures that make them easier to identify, such as *Pinus* and *Abies*, which are made up of 2 balloons (bladders) and are called bisaccate (Bennett et Willis, 2001) (Figure 1).

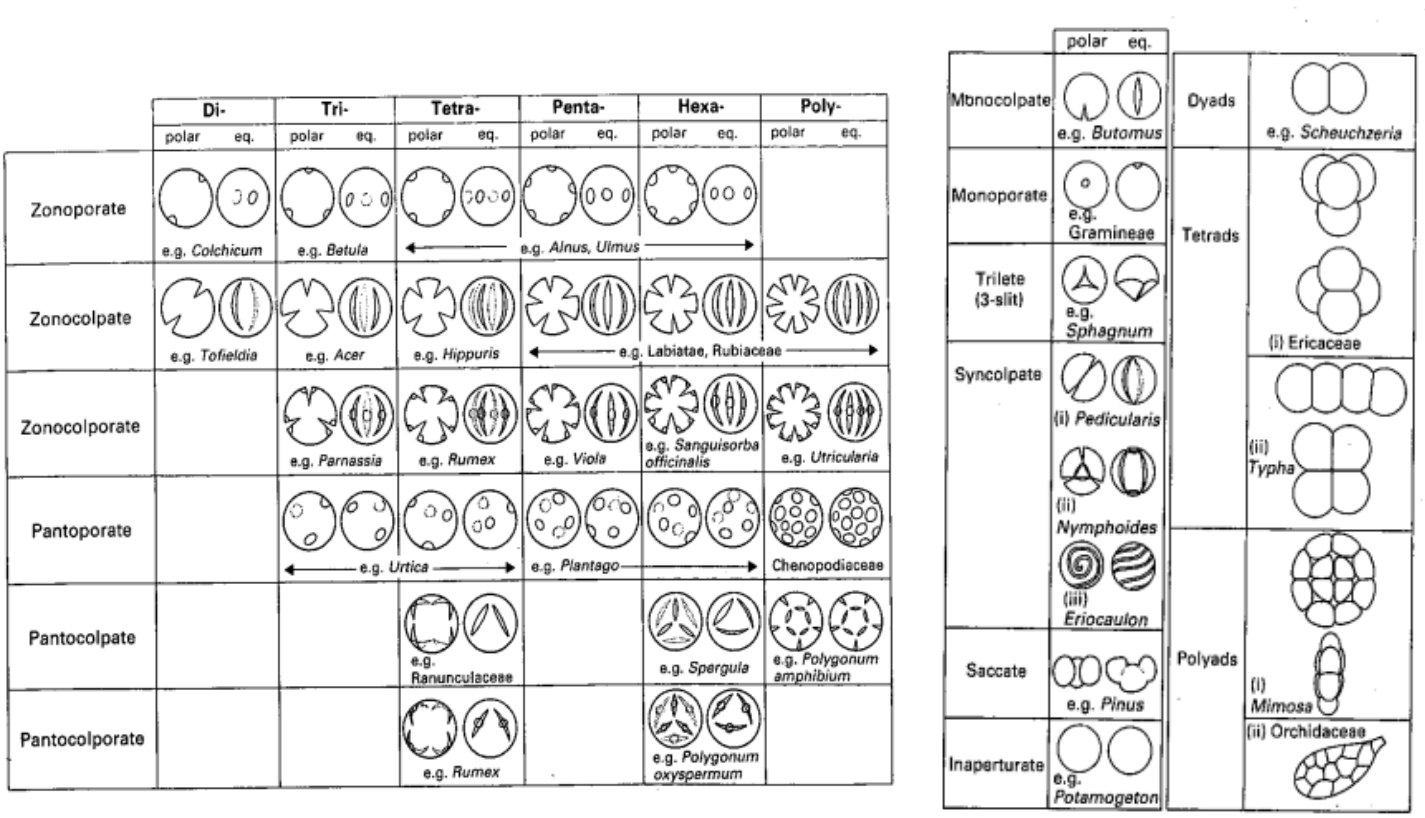

Figure 1 : A. Diagram showing the range of apertures number, position and character B. Table of polar and equatorial view of pollen (Moore et al., 1991)

The accuracy of taxonomic identification depends on these criteria. However, these are limited by certain factors, which can be linked to the state of preservation of the remains, or to the non-specific characteristics carried by the taxa. Identification is often limited to the family, such as Poaceae or Asteraceae. More rarely, certain species can be identified, such as *Corylus avellana* or *Plantago media*. On average, taxonomic identification is restricted to genera such as *Quercus*, *Betula* or *Erica* (Bennett et Willis, 2001).

1.4.3.2. NPP morphology

Over the past four decades, the systematic study of NPPs has developed thanks to research carried out by Van Geel (1978) and supplemented by Miola (2012). These studies aimed to discover and describe the morphology of micro-fossils that are not pollen. Today, the number of NPPs is counted at more than 1,300 and are high-resolution paleoecological indicators (Miola, 2012).

The recent history of the study of NPPs makes the identification of these elements complex. Furthermore, the classification of these palynomorphs is complicated by the diversity of identifications and descriptions which are not standardized. In recent years, studies have attempted to group and unify the identification criteria resulting in the publication of two monographs: Review of Palaeobotany and Palynology (Van Geel, 2008) and Vegetation History and Archaeobotany (Haas, 2010). This standardization of identification criteria has greatly accelerated thanks to the work of Miola (2012) who, in addition to having gathered the different typologies of palynomorphs, has associated these elements with their ecological significance and created a nomenclature of the different sources. The NPP nomenclature includes an acronym of the laboratory in which the palynomorph was identified and described and a number. Therefore, the NPPs identified by Bas Van Geel in the Hugo de Vries laboratory (University of Amsterdam) begin with HdV (Van Geel, 1976, 1978a, 2001, 2006, 2008). However, this nomenclature is not used for taxa identified to the species level such as the algal taxon *Closterium* cf. *kützingii* or *Chaetomium* (Van Geel et Hammen, 1978).

1.5. Palynology as an element of paleoenvironmental reconstruction

From the identification of pollens and NPPs, it is possible to reconstruct the evolution of the landscape and climate. The analysis of samples according to sediment sequence, combined with statistical studies, makes it possible to trace environmental changes over time at a specific location (Moore et al., 1991). It is then possible to compare pollen spectra from this site with others in the region, in order to trace climatic variations over time on a regional spatial scale. However, certain constraints must be taken into account when reconstructing a paleoenvironment (Bennett et Willis, 2001).

Indeed, the pollen assemblage depends not only on the size and type of sampling site, but also on the nature of the surrounding terrain and the type of vegetation. The proportion of each pollen type depends on the abundance of parent plants in the environment. Thus, the composition of the pollen rain is representative of the abundance of each taxon in the environment at a given time and place (Bennett et Willis, 2001). In an open landscape, pollen is widely dispersed and covers a large area. It accumulates remnants of all regional vegetation. In closed landscapes, on the other hand, circulation is limited by obstacles. The pollen representation is marked by a local accumulation of pollen and is representative of local vegetation (Campbell et al., 2011).

Another important factor is the spatial dispersion of the vegetation itself, as well as the distance between the mother plant and the sampling area. Similarly, the pollen production rate per plant and the dispersal mechanism are important factors to consider in pollen analyses. In addition, the robustness or fragility of certain specimens implies an analysis bias. Elements with a high preservation capacity are over-represented in the results, while the most fragile taxa will be under-represented because they have been degraded (Campbell et al., 2011).

The systematic study of NPP was not common until the last quarter of the last century (Combaz, 1964 ; Van Geel, 1976, 1978a ; Pals et al., 1980). The data provided by this type of microfossils are an essential complement to the interpretative data of plant associations. In addition to providing information about the characteristics of the sedimentation medium, they help to understand the taphonomic path that pollens and spores have undergone (Diot, 1991 ; López Sáez et López García, 1992).

Despite this, the main limitation that a study in which NPPs are added to conventional palynological analysis must face is the still limited knowledge about the value as a paleoecological indicator of some of the most frequently identified palynomorphs, in addition to the difficulty, also attributable to pollen, of the resolution in terms of the level of identification achievable.

1.6. Definition of Archaeopalynology

Palynological studies are used to analyze different types of sedimentary environments, such as peat bogs, soils, lake or sea beds, as well as archaeological deposits. The conservation of palynological elements varies according to the constraints and advantages of these environments. In general, records from bogs and lakes are well preserved and stratified. In contrast, archaeological sediments limit pollen preservation and restrict pollen analysis. (Bottema, 1975 ; Coûteaux, 1977 ; Turner et al., 1985 ; Bottema et Woldring, 1994).

On archaeological sites, the elements forming the stratigraphic sequences of the various types of archaeological site are not conducive to the proper preservation of palynological elements. In caves and rock-shelters, the sequences include breccias, boulders, stalagmitic crusts, sands and fireplaces. This type of composition inhibits archaeological deposition and sedimentation, resulting in limited preservation of archaeological features. At open-air sites, stratigraphic

sequences are predominantly gravels or sands. The post-depositional effects of these detrital geological elements prevent the preservation of palynological elements. Moreover, the open-air sites have shorter stratigraphic sequences than caves and rock-shelters (Carrión et al., 2009). In order to counter the problem of palynological taphonomy within sediments (Coles et Gilbertson, 1994), methodological research has developed over the last few decades (Carrión et Scott, 1999a ; Carrión et Van Geel, 1999b ; Prieto et Carrión, 1999 ; Navarro et al., 2001a, 2001b ; Carrión et al., 2009 ; Hunt et Rushworth, 2005 ; Pérez-Díaz et López-Sáez, 2012 ; Fiacconi et Hunt, 2015, 2017 ; Hunt et Fiacconi, 2018 ; Revelles et al., 2016 ; Revelles et Van Geel, 2017). Moreover, within archaeological sites, palynological elements undergo differential alteration caused by biological, chemical and physical processes that occur during their deposition and transport (

Figure 2). These factors are accentuated in caves (Bryant et Hall, 1993 ; Dimbleby, 1985 ; Faegri et Iversen, 1989 ; Hall, 1991). These alterations are also amplified by particular products of anthropic activities like hearths, *fumier* or detritus bucket (Delcourt et Delcourt, 1980 ; Davis, 1990 ; Bryant et Hall, 1993 ; Campbell, 1999 ; Prieto et Carrión, 1999 ; Camacho et al., 2001 ; Carrión, 2002 ; Carrión et al., 2000 ; López-Sáez et López-Merino, 2007 ; Lebreton et al., 2010 ; Expósito et Burjachs, 2016 ; Hunt et Fiacconi, 2018 ; Val-Peón et al., 2019).

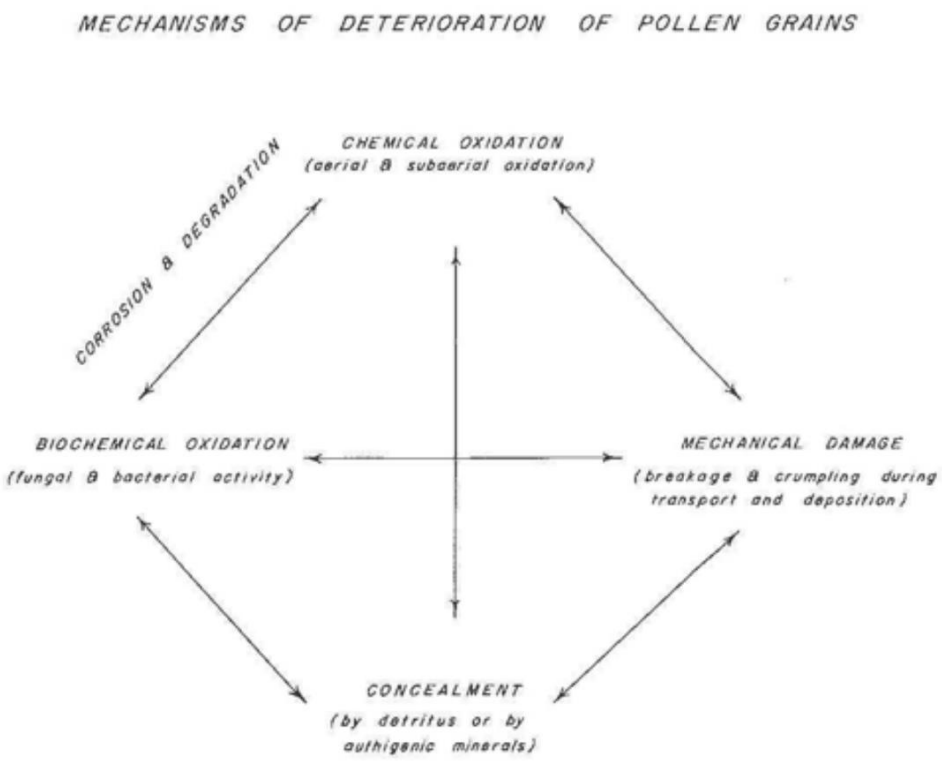

Figure 2 : Mechanisms of deterioration of pollen grains (Delcourt et Delcourt, 1980)

Despite the questioning of the relevance after the highlighting of preservation and representativeness problems on palynological elements, many researchers testify on the contribution of palynological studies on paleoenvironmental reconstruction, as long as those problems are considered and inserted in the studies (Leroi-Gourhan, 1973 ; Bui Thi, 1974, 1985 ; Bryant et Holloway, 1983 ; Dupré, 1986, 1988 ; Cattani et Renault-Miskovsky, 1989 ; Davis, 1990 ; Carrión, 1992 ; Horowitz, 1992 ; Simmons, 1993 ; Sánchez Goñi, 1993, 1996, 1994 ; Carrión et Scott, 1999a ; Carrión et Van Geel, 1999b ; Navarro et al., 2001a, 2001b).

1.7. Objectives

This study includes several objectives aimed at complementing recent studies with a multidisciplinary approach to understand the impact of anthropogenic activities during Holocene in Vallone Inferno and the Madonie region.

In order to do this, the aim is to identify the regional and local vegetation observed in the pollen rainfall of the cave as well as to determine the specific conditions of the rock shelter thanks to the local indicators of NPPs.

Then, relationship between taxa of pollens and NPPs according to the different origin of the sample from layer 3.4.a. will be analyzed to understand taphonomic history of the micro-elements and its resolution with respect to the previous results of the sequence.

After that, a reconstruction of the paleoenvironment of sub-layer 3.4.a. of the Vallone Inferno site, dated between the mid-Neolithic and the early Bronze Age, using pollen and NPPs analysis, will be realised. These results are then compared with previous palynological, anthracological, carpological and micromammal research to determine the evolution of the landscape during this period. They will also be compared with climate and paleoflora studies in the Mediterranean region.

Finally, the study will provide an understanding of the socio-economic and anthropic behavior of the mid-Neolithic and early Bronze Age period associated with Vallone Inferno sub-layer 3.4.a. These analyses are adding to the palynological, anthracological, lithic, pottery, biomarker carpology and zooarchaeological investigations carried out with the goal of evaluating the agro-pastoral activities practised during the occupation of the Vallone Inferno site, the Madonie region and in Sicily.

2. Site description of Vallone Inferno

2.1. Locality of Vallone Inferno

The Vallone Inferno site, also known as Fosso Inferno, is located in the municipality of Scillato (Palermo) on the western slope of the Madonie mountain range in the North of Sicily (**Erreur ! Source du renvoi introuvable.**) (Forgia et al., 2013 ; Natali et Forgia, 2018b ; Forgia et al., 2021). Its coordinates are 37° 52' 17.74" N and 13° RR 58.97" E . It is located at the foot of Mount Funasi, on the North slope (**Erreur ! Source du renvoi introuvable.**). The site is located in a mountainous karstic region, which altitude varies from 200m to 1,979m in the valley of the Imera river (Forgia et al., 2021). This is a flat terrain located at an altitude of 770m a.s.l, framed by a slight slope in the west part and a steep slope in the east, one of which is steep, highlighting the intense tectonic activity of the region. However, the formation of the valley and gorge is largely linked to its fluvio-karstic character process in the Mesozoic limestone (Forgia et al., 2013 ; Forgia, 2019a ; Ruggieri, 2022 ; Forgia et al., In process). The Massif is composed of Triassic- and Oligocene-dated rock sediments from the Imerese Basin. The

lithology is composed of alternating carbonates, siliceous and terrigenous with a mixture of limestone, flint, dolomite, marl, clay and radiolarite (Forgia et al., 2013).

It is located between the highest land (1600m a.s.l. and above) and the lowest land (around 500m a.s.l) (Forgia et al., 2013, 2021). GIS analysis has enabled the topography of the Vallone Inferno canyon to highlight a path to link the northern Imera valley to the summit of the Madonie mountains. Therefore, Vallone Inferno is a crossing point to access the high altitudes of the mountain range (Forgia et al., In process). The geographical location of Vallone Inferno is thus conducive to the establishment of a habitat thanks to its access to natural resources from both low and high grounds as well as the Imera (Forgia et al., 2021).

Figure 3 : Map of Sicily with locations of Vallone Inferno and the main mountains systems and a Madonie view from the Tyrrhenian Sea (Forgia, 2019a, modified)

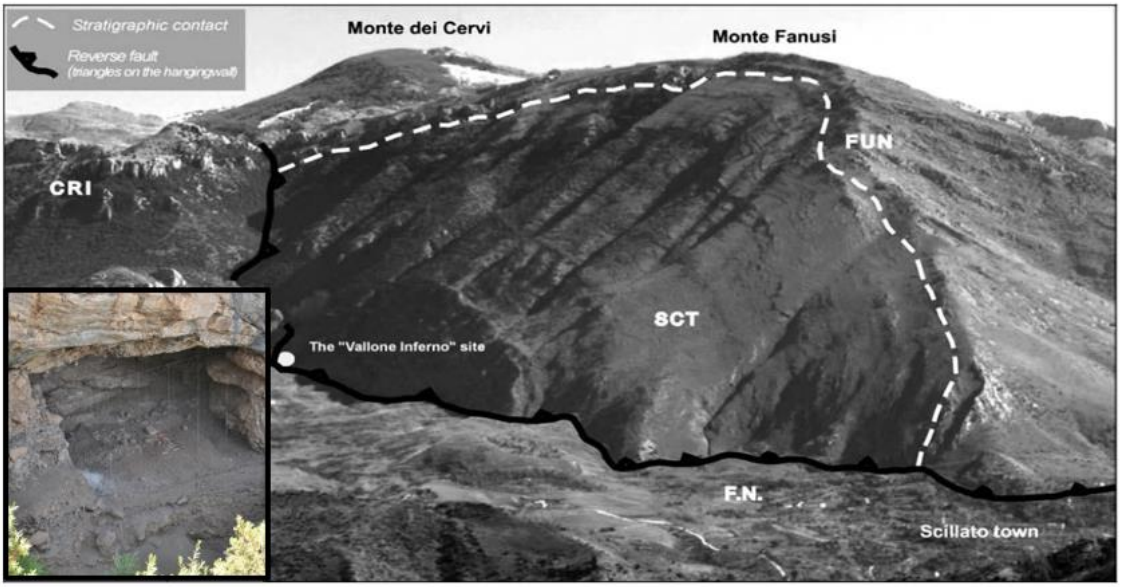

Figure 4 : Panoramic view and stratigraphic sketch of the Vallone Inferno site in the Madonie area (Palermo, Sicily)Imerese Bassin Domain : SCT : calcilutites with chert nodules alternating with radiocarbon-bearing marls (Upper Carnian-Reathian);FUN : dolomitic breccias (Lower Liassic); CRI : siliceous shales, radiolarian interbedded with resedimented calcareous megabreccias (Upper Liassic-Upper Cretaceus); Numidian Flysch Basin Domain; F.N. : Sandy pelites with interbedded arenaceous layers (Upper Oligocene-Lower Miocene (Forgia et al., 2013 modified)

2.2. History of excavation of the site of Vallone Inferno

The Vallone-Inferno site is a rock shelter in northern Sicily (Figure 1). It was discovered in 2007 during the GIS prospect of the region (Forgia et al., 2013). The site was chosen in the archaeological project concerning the Madonie region for its intermediate location and proximity to the stream (Forgia et al., 2013, In process). It is an important witness to the archaeological history of the region thanks to its long prehistoric and historical sequences. Its earliest archaeological traces date back to the beginning of Holocene and up to the Middle Ages (Forgia et al., 2013 ; López-García et al., 2013 ; Martín et al., 2023 ; Forgia et al., In process).

It has been the center of systematic archaeological excavation and research since 2008 (Forgia et al., 2013, 2021). In 2008, the first excavations were used to carry out a preliminary exploration of the sequence exposed to the erosive activities caused by the stream. From 2009 to 2011, a 30m2 area was delineated and excavated within the shelter. The deposits excavated extend from subcomplex 1.1 to subunit 3.3, as well as in the middle and inferior areas identified by the unit 3.4 and subcomplex 4.2. In all, more than 7,465 archaeological elements were identified in all the complexes after the end of 2022 season, including 1,678 from sub-complexes 3.1, 3.2 and 3.3, and 5,613 from sub-complex 3.4. Most of these are bone, tooth and pottery fragments. After 2011, samples of deposits have been extracted from all the layer and are analysed in lab as well as the macro-elements coordinates and extracted from the field (Forgia et al., In process).

Currently, the excavated surface of the Vallone Inferno site extends over more than 30m2 and more than 5m deep. However, the rock shelter is over 10m long and 6m deep. Its opening faces north, from where part of the Imera River can be seen (**Erreur ! Source du renvoi introuvable.**) (Forgia et al., 2013, 2021). Further excavations will be undertaken in the next few years in order to excavate complex 4, dated 9450±50 cal. BP, in which a hearth was previously identified (Forgia et al., In process).

Figure 5 : Pictures of the layer 3.4.a of Vallone Inferno Rock Shelter, in Sicily (Forgia et al., 2013)

2.3. Stratigraphy and sub-complex 3.4. of Vallone Inferno

The Vallone Inferno rock shelter is nearly completely buried by a thick deposit. The stratigraphy extends from the Neolithic to the Middle Ages and comprises four complexes (**Erreur ! Source du renvoi introuvable.**) (Forgia et al., 2013, 2021). Three of these complexes have yielded archaeological remains that are now being studied from different angles. Human activities have been dated using 14C AMS between 2601 cal BC and 644 AD (Table 1) (Forgia et al., 2013).

Complex 1 is the most recent and complex 4 the oldest. Complex 1 consists of a stone wall and a set of structures dated to the 20th century (Forgia et al., 2013, 2021)

Complex 2 is a 2.5m thick level of limestone breccia and clay that outcrops on one flank. It is composed of heterometric, angular fragments of massive, disorganized limestone supported by boulders and a few flints. Its lower limit is defined by an erosive surface. This complex contains no archaeological traces (Forgia et al., 2013, 2021)

Complex 3 consists of four layers composed of alternating fine, textured archaeological deposits and coarser sections. Subcomplexes 3.1, 3.2 and 3.3 suggest natural shaping following a period of abundant and rapid flooding (Forgia et al., 2021). Subcomplex 3.1 is filled with thermo-altered deposits with ash. The archaeological material is dated from 644 to 840 calAD, i.e. the Byzantine-Roman Empire period, thanks to analyses carried out on plant remains. Subcomplex 3.2. includes material dating from the Late Roman period, i.e. between 622-734calAD, thanks to charcoal analyses. Subcomplex 3.3. comprises alternating coarse, organic and thermo-altered deposits. It also contains artefacts dating from the late Roman period (Forgia et al., 2013). Subcomplex 3.4. consists of alternating coarse and fine deposits and organic matter. It contains prehistoric assemblages which includes four sedimentary cycles. Indeed, it is associated with the Middle Neolithic MN (5460-5220 cal BCE) and the Early Bronze Age EBA (1620-1420 cal BCE) (Table 1). Layer 3.4. is made up of eight sub-layers from a to h associated with the Bronze Age (3.4.a-d), the Copper Age (3.4.e-h) and a sub-layer 3.4.n associated with the Middle Neolithic. Seed studies have dated sub-layer 3.4.b. between 1643-1411 cal BC, while sub-layer 3.4.g. is dated between 2601 and 2309 cal BC from human bones (Forgia et al., 2013). However, these sub-layers have undergone complex deposition-erosion-deposition dynamics. The Neolithic deposits, i.e. sub-layer 3.4.n and the top of complex 4, were

destroyed by the erosive activity of the Inferno stream. The sedimentation phase of the more recent layers is marked by the presence of some Neolithic-dated artefacts mixed with deposits of Bronze Age human and animal activity. Erosion and the flat then sloping topography of the 3.4.n. sub-layer resulted in a mixing of the components of the upper sub-layers (Forgia et al., 2021, In process).

Complex 4 measures 2m and consists of two sub-complexes. The first is a partially open limestone breccia with little calcium carbonate cement. A fine brown silt loam forms the bond between these elements. The second sub-complex 4.2. is composed of alternating coarse elements and brown silty sands. The bottom is composed of two thin layers of ash. Charcoal analyses have dated this sub-layer to around 8918-8582 cal BC and testify to the settlement of the first hunter-gatherers on the site (Table 1) (Forgia et al., 2013).

Lab. code	Complex	Archaeological layer	Sample	Method	Conventional Radiocarbon Age (BP)	SD	Calibrated Rdiocarbon Age (CE/BCE) (2 sigma, 95%)	Calibrated Rdiocarbon Age (BP) (2 sigma, 95%)
DSH2816	3	3.1.l	Vegetal remain	AMS	1260	34	670-880	1320-1120 calBP
DSH2814	3	3.2.c	Charcoal	AMS	1332	26	650-780	1340-1220 calBP
DSH2815	3	3.4.b	Seed	AMS	3244	42	1610-1430	3600-3360 calBP
DSH1976	3	3.4.g	Human bone	AMS	3948	35	2580-2300	4500-4270calBP
Beta-408858	3	3.4.n	Charcoal	AMS	6340	30	5380-5210	
Beta-314642	4	4.2	Charcoal	AMS	9450	50	9120-8560	10860-10540calBP

Table 1 : Absolute ages of the Vallone Inferno levels with calibrate age in BCE and BP (López-García et al., 2013 ; Reimer et al., 2020 ; Forgia et al., In process)

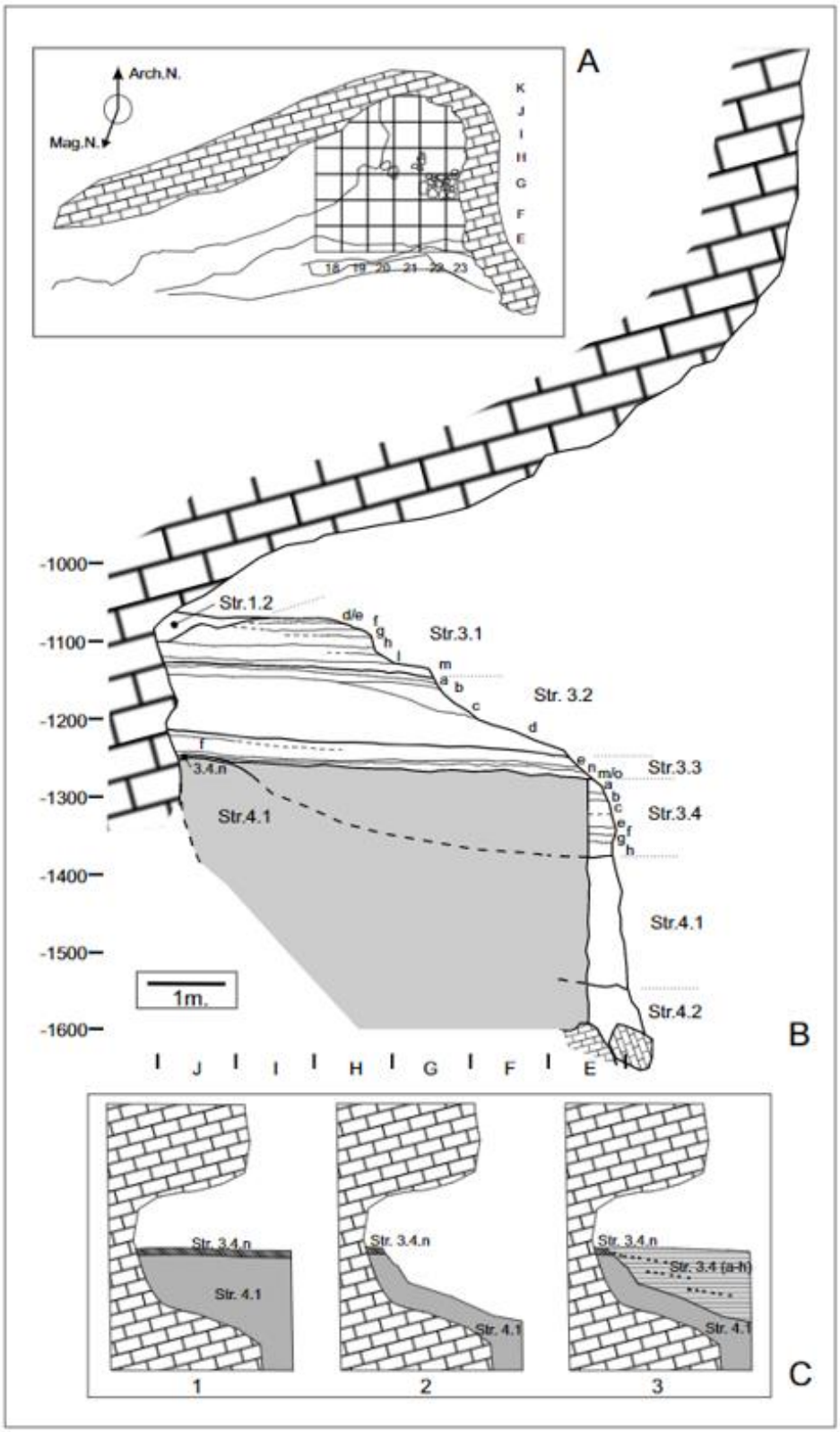

Figure 6 : Figures showing the stratigraphy of Vallone Inferno site A) General plan of Vallone Inferno archaeological area before the excavation B)Synthetic stratigraphic sequence ; the cut corresponds to the contact between lines 20 and 21 (although for units 3.1 to 3.3 it corresponds to the 19-20 contact) ; C) Deposition-erosion-deposition cycle of the Str. 3.4. (Forgia et al., 2013 modified)

2.4. Archaeological record from Vallone Inferno : Zooarcheology

2.4.1. Zooarchaeology and biomarkers : animals' evidence of pastoralism and hunting

The Vallone Inferno site is composed of an assemblage of 1,446 macrofaunal fragments from domestic and wild animals (Forgia et al., 2013). In the Neolithic and Bronze Age, animal resources came from both livestock and hunting (Martín et al., 2023)

.

Since the Neolithic, domesticated animals form most of the zoological spectrum. Caprine have been farmed significantly since prehistoric times. The economy of the populations relied essentially on the reproduction of caprines. These animals were raised on the site during the spring when they were still immature. Sheep and goats were raised for their meat and skins. Moreover, the presence of bones from a significant number of foetuses would indicate a desire to exploit milk. The Vallone Inferno site was thus used to breed and give birth to goats. In a lesser proportions, cattle and pigs were also raised in the shelter (Forgia et al., 2021 ; Martín et al., 2023). Vallone Inferno would have served as a seasonal sheepfold and intermediate camp area as the herds crossed the mountain range to access the uplands (Martín et al., 2023). These conclusions are supported by analyses of biomarkers in sediments. The presence of β-phytosterol and sterols (Epi-cop and Epi- 5β-stig) testifies to the presence of ruminants at the site during prehistoric times. Deoxycholic acid and lithocholic acid ratio show that Vallone Inferno shelter was used as an enclosure for ruminants (potentially ovicaprine) and pigs during Neolithic. However, wild species have also been identified at the Vallone Inferno site, including herbivores and carnivores. In particular, the presence of hunted animals has been demonstrated by the identification of cattle, wild boar, deer and leporidae during prehistoric times (Forgia et al., 2013, 2021 ; Martín et al., 2023).

During Early Bronze Age, the data are reduced occasioned by a limited number of zooarchaeological remains. The economic activities of animal husbandry seem to be in continuity with Neolithic practices, despite a change in the proportions of caprines and suids. The rock shelter has been used as a refuge during winter and spring seasons, corresponding to the period of gestation of the female domestic animals of the husbandry. Pig, sheep and goat mixt husbandry intensified in historic times (sub-complexes 3.1, 3.2 and 3.3), limiting the

supply of hunting animals such as fallow deer, red deer, leporidae and wild boar (Forgia et al., 2013, 2021 ; Martín et al., In process ; Vallejo et al., In process).

2.4.2. Micromammals : indicators of the paleoenvironment

Microvertebrate analysis at Vallone Inferno consists of an assemblage of 300 fragments from at least 170 species of microfauna. The microfaunal record includes anurans, reptiles, squamates, insectivores, chiropterans and rodents. Excavations of sub-layers 3.1, 3.2 and 3.3 are marked by an absence/reduction of microfauna that does not allow paleoenvironmental reconstruction (Forgia et al., 2013).

The layer 3.4. of the Vallone Inferno site contained the oldest traces of the species *Suncus etruscus*, *Muscardinus avellanarius* and *Eliomys quercinus* ever found in Sicily. All the bones were accumulated by avian predators and found in regurgitated pellets. Their analysis shows that layer 3.4. has an environment dominated by dry grasslands and wooded areas. 45% of the space is represented by a landscape of forests and open woodlands, according to the abundance of *Microtus savii*, *Apodemus sylvaticus* and *Glis glis* species. Dry and wet grasslands represent between 20% and 33% of the landscape within complex 3. Sub-layers from the oldest to the most recent show an increase in wet grasslands to the detriment of dry grasslands. These paleoenvironmental data were highlighted by the presence of *Erinaceus europaeus*, *Crocidura sicula* and *Microtus savii*. These interpretations were reinforced by the identification of reptile and amphibian species *Lacerta gr. L. viridis*, cf. *Podarcis* sp. and *Vipera gr. aspis* in sublayer 3.4. These species live in a rocky, Mediterranean forest environment (Forgia et al., 2013 ; López-García et al., 2013).

Thus, paleoenvironmental data deduced from the study of small mammals indicate a gradual opening up of the landscape, probably linked to human presence. They favoured deforestation of the vegetation and aridification, which reached its peak around 3500 years cal BP. This dry environment is reflected in the climatic parameters, which show a high average temperature of 16.6 +/- 0.5°C and low rainfall of 863 +/- 131mm (López-García et al., 2013). However, the aridity starts to decrease in the more recent sub-layer, with humid meadows. These findings are in line with previous paleoenvironmental studies. The climate was identical to the current

climate in the region, composed of a dry and temperate phase highlighted in previous paleoenvironmental analysis (Forgia et al., 2013).

2.5. Archaeological record from Vallone Inferno : pottery and lithics

Several types of pottery and lithic objects have been found at Vallone Inferno. These remains, although highly fragmented, testify to an evolution in cultural practices over the archaeological periods (Forgia et al., 2013, 2021 ; Martín et al., 2023).

Tricromica pottery, of which 178 remains have been identified, is present in the earliest Neolithic layers. They have also been identified in all layers of the sub-complex 3.4. caused by an erosion-deposition process (Forgia et al., 2013, 2021). This well-preserved *figuline* pottery features paint decorations in three different colours (beige, red and black). This type of *figuline* remains stand out from the 25 Neolithic fragments with incisions or no decoration. Pottery may have been used to store food and collect liquids such as milk as it is also shown by isotopic studies (McClure et al., 2018 ; Forgia et al., 2021 ; Martín et al., 2023). In Neolithic sublayer 3.4.n., one non-local flint flake and seven Lipari obsidian tools (flakes, chips and fragments) were identified. This suggests that pastoral activities such as hide processing and butchering could have therefore been highly dependent on obsidian (Forgia et al., 2013, 2021, In process)

Castellucio-type pottery appeared during the Early Bronze Age in Sicily and is present in layer 3.4.a-d. *Castellucio* handmade pottery is marked by a red color with engraved black geometric motifs. The development of mixed agro-pastoral activity is associated with the introduction of *Castellucio*-type pottery into the northern Sicilian region. This type of pottery was widespread in the east, west and south of the region (Copat, 2020). Its presence at Vallone Inferno reinforces the idea of significant agro-pastoral activity in the region and indicate the potential settlement of southern populations in the Madonie region. The Bronze Age is also marked by another type of pottery with grey-brown or achromatic surfaces and no decoration. Bronze Age lithic tools are composed of quartzite, obsidian and flint. They include nuclei, flakes, blades and fragments. Whereas Neolithic lithic artefacts seem to have been intended for a single activity, Bronze Age lithic artefacts are marked by multiple uses (Forgia et al., 2021).

Sub-complexes 3.1 and 3.2 yielded 520 Late Roman and Byzantine period finds. These fragments are mainly fragments of storage and transport objects such as jugs, amphorae,

kitchening ware and tile fragments. Subcomplex 3.3 comprises 129 fragments of amphora and kitchenware (Forgia et al., 2013).

2.6. Archaeological record from Vallone Inferno : Paleoanthropological remains

Paleoanthropological studies of the site have uncovered 211 specimens identified and 204 fragmented skeletal elements from Neolithic and Early Bronze Age individuals, spread in all the layers of the complex 3.4. Anthropogenic remains consist mainly of teeth (76%) including 31,9% of molars. Dental NMI indicates the presence of individuals of all age with five adults and four sub-adult. Sub-adult identified are composed of a baby, two infants and an adolescent. Adults are represented by a young adult, three indeterminate individuals and a ager individuals of more than 50 years old (Forgia et al., 2013 ; Moreno-Ibáñez et al., In process).

Postcranial elements are rarely represented and, despite the presence of every type of bones, they are mostly composed of bones of the extremities of the limbs. The presence of these paleoanthropic elements could suggest funerary use of the Vallone Inferno site at this period. However, the limited number of post-cranial bones may be due to post-depositional manipulation and potential reuse of space after burial, frequently observed in prehistoric collective burials (Forgia et al., 2013 ; Moreno-Ibáñez et al., In process).

2.7. Archaeological record : carpology, palynology and anthracology

Vallone Inferno has been the subject of several archaeobotanical studies over the last ten years. The first studies highlighted the difficulties of preserving palynological elements within Complex 3. In total, over 114 carpological elements have been identified, and 21 taxa are associated with crops, herbs and fruits. 19 taxa have been identified in anthracological remains and have helped to interpret landscape evolution (Forgia et al., 2013). New studies are currently being carried out to further analyze the carpological, anthracological and palynological remains of the various complexes at Vallone Inferno (Expósito et al., In process).

2.7.1. Actual vegetation of Vallone Inferno and Madonie park

The Madonie region is a place of high ecosystem richness and diversity within the Mediterranean basin and Sicily, thanks to variation of altitude and exposition to humid courants. Climatic factors are typical to a Mediterranean climate with an average annual precipitation is around 800mm and an average annual temperature is inferior to 18,5°C. It is composed of more than 1500 specific and infraspecific arboreal taxa. Furthermore, 170 species of vascular flora are endemic to Madonie Park, such as *Abies nebrodensis*. The flora is related to the North African, meridional Spain and Balkanic peninsula. The mountains of the region limit the range of certain species such as *Quercus petraea (Matt.) Liebl*., *Quercus cerris var. Gussonei (Borzi) Brullo*, *Ulmus glabra Huds.* or *Fagus sylvatica*. This high degree of biodiversity is favored by the altimetric and thermo-rainfall variability (Daria et al., 1983).

However, this biodiversity is currently threatened by human occupation in the region. This impact on vegetation has been marked for several millennia by agro-sylvo-pastoral activities. The expansion of living areas of agro-sylvo-pastoral plants and the decrease of waterways have led to the impoverishment of native flora and riparian flora. Despite this, some native species have developed thanks to a selection of cultivated species such as the cultivation of manna or the presence of centuries-old olive groves. This significant level of anthropization is noticeable on the forest cover surrounding the Vallone Inferno site. Indeed, a deterioration is visible on the climatophilic forest of *Quercus ilex* and the sclerophyllous undergrowth composed of *Pistacio lentisci* and *Rhamnetalia alaterni*. The flora also consists of *Acer campestre L., Ilex aquifolium L., Sorbus graeca Lodd. ex Schauer, Quercus pubescens* and *Quercetum ilicis*. Nearby, an area of intensive arboreal agriculture and pasture meadows is in contact with this forest. The Vallone Inferno refuge is framed by vegetation of scrubland and abandoned cultivated land testifying to pastoral activity. The presence on the northern flank of the gorge of *Pistacio lentisci* and *Rhamnetalia alaterni* indicates a dry climate during the summer periods. Similarly, the vegetation surrounding the Imera River is reduced to a few shrubs (*Salicetalia purpurea, Tamaricete*) due to the drying up of the watercourse (Expósito et al., In process).

2.7.2. Paleoenvironemental reconstruction of Vallone Inferno

Previous palynological studies have shown that complexes 3.4 and 3.2 have a dense mixed *Quercus* forest that clears out in sub-complex 3.1. The higher zones are made up of conifers, while a riparian forest forms in the riverside zones. Anthracological studies has detected the presence of a *Quercus* evergreen forest in sub-complex 3.4 with turnover in sub-complexes 3.1, 3.2 and 3.3 with a dominance of *Quercus* deciduous (Forgia et al., 2013). Nevertheless, current studies have enabled us to reconstruct more precisely the evolution of the landscape from Neolithic to Byzantine times (**Erreur ! Source du renvoi introuvable.**) (Expósito et al., In process).

The oldest complex, 3.4, dated from the mid-Neolithic to the early Bronze Age, reflects a gradual opening up of the landscape. Palynological studies show that the base of the complex is composed of a dense thermophilic mixed forest with *Ulmus* and *Quercus*. Heather, *Ephedra* and *Cistus* form the undergrowth. The riverside is surrounded by a forest of *Salix*, *Fraxinus* and *Ulmus*, complemented by wet meadows of *Cyperaceae* and *Typha-Sphagnum*. Anthracological studies also reveal a *Quercus* evergeen forest shared with *Quercus* deciduous and other meso-thermophilous trees (Expósito et al., In process). However, more recent sub-layers show a decrease in these trees and an increase in the presence of *Olea europaea* in complex 3.3 (Forgia et al., 2013 ; Expósito et al., In process). In the palynological record of complex 3.4, this change is reflected in a regression of vegetation cover until reaching a minimum around 3360 cal. BP, at the level of the last sub-layer of complex 3.4. (Expósito et al., In process).

This reduction in tree cover continued in the 7th to 9th century A.D. levels, within complexes 3.2 and 3.1. As a result, shrub and shrubby land flourished in the deforested areas. Also, pioneer trees such as *Pinus* sp. and cf. *Juniperus* are growing, attesting to the deterioration of the forest. The anthracological record shows an increase in *Quercus* sp. evergreen, *Rhamnus* and Fabaceae. However, this change in diversity is not visible among riparian species. Hygrophytic plants such as Cyperaceae and *Typha-Sparganium*, as well as Pteridophytes, are still highly developed. Similarly, riparian trees such as *Fraxinus* are important in anthracological representations. Despite this riparian constancy, open areas are thriving around Vallone Inferno and are composed of *Asteraceae*, *Plantago* sp., coprophilous fungi and an increase in cereal

documentation. This could indicate that human activity is once again a major factor in forest decline (Expósito et al., In process).

2.7.3. Human activity : from pastoral activity to agro-pastoral activities

Palynological, anthracological and carpological analysis of the archaeobotanical remains of complex 3 testify to an intensification of anthropization from the middle of the Neolithic to the 9th century AD. The first signs of land use for agro-pastoral purposes are identifiable as early as the Neolithic. However, evidence of intensive farming activity comes later, and is certainly established after the 7th century AD (Expósito et al., In process).

Traces of human activity from the Middle Neolithic to the Early Bronze Age are mostly associated with pastoral rather than agricultural activity. Indeed, the traces of pastoral activity in complex 3.4. consist of a few cereal pollen and wheat carpores. However, evidence of pastoral activity is more frequent, particularly in the last sub-layer. They are characterized by the presence of nitrophilous weeds, ruderal grasses and coprophilous fungi. Carpological remains of blackberries have also been interpreted as fodder. The anthracological record shows the exploitation of mesophilic forest species used as domestic fuel or in fodder for livestock. Finally, pastoral anthropic activity in complex 3.4. could explain the decline in forest cover from the Middle Neolithic to the early Bronze Age. The presence of animals would have necessitated the exploitation and destruction of forest areas for breeding and feeding domestic animals (Expósito et al., In process).

These anthropogenic activities intensified during the 7th to 9th century AD, when indicators of anthropogenic activity multiplied in addition to a decrease in forest cover. The proliferation of meadow and pasture plants, as well as nitrophilous ruderal plants, are evidence of an increase in pastoral practices. They bear witness to human settlement and livestock rearing. In addition, signs of cultivation are highlighted by the increase in pollen taxa of cereals, legumes and weeds surrounding crops and human settlements. Indeed, the high percentage of cereals with short-distance pollen dispersal indicates intensive activity close to the site (Expósito et al., In process). This view is reinforced by carpological studies indicating the presence of *Triticum aestivum/durum* in complex 3.3 showing that cereals grow in variability in 3.3. (Table 2). On the other hand, during these periods, the beginning of a development in arboricultural practices

and the use of domestic fuel is reflected by the carpological and anthracological remains of *Olea europaea*, *Ficus carica* and *Vitis vinifera* (Forgia et al., 2013 ; Expósito et al., In process).

Table 2: table of the carpological remains according to the complex of Vallone Inferno (Forgia et al., In process)

	3.1	3.2	3.3	Total	%	3.4	%
Crops							
Hordeum sp.	3		2	5	5,43		
Hordeum vulgare nudum	1			1	1,08		
Hordeum vulgare vulgare	1			1	1,08		
Lens culinaris		1		1	1,08		
Pisum sativum	1		1	2	2,17		
Triticum aestivum/durum	3		14	17	18,47	3	23,07
Triticum dicoccum			3	3	3,26		
cf. *Vicia faba*			1	1	1,08		
Rachis cf. *Triticum aestivum/durum*	2			2	2,17		
Total crops	11	1	21	33	35,86	3	23,07
Fruits							
cf. *Olea* sp.			2	2	2,17		
cf. *Pinus* sp.			1	1	1,08		
cf. *Quercus* sp.	12	3	5	20	21,74	7	53,84
Rubus fruticosus/idaeus	2			2	2,17		
Rubus sp.						1	7,69
cf. Vitis sp	1			1	1,08		
Vitis sp. (uncharred)	14			14	15,21		
Total fruits	29	3	8	40	43,45	8	61,53
Weeds							
Bromus sp.	3		1	4	4,34		
Carex sp.	2			2	2,17		
Fumaria officinalis						1	7,69
Galium aparine			1	1	1,08		
Leguminosae (Fabaceae)	4	1	3	8	8,69		
Malva sp.	1			1	1,08		
Total weeds	10	1	5	16	17,36	1	7,69
Rachis and Shoots cf. Rosaceae	2	1		3	3,26	1	7,69
TOTAL	**52**	**6**	**34**	**92**	**100**	**13**	**100**

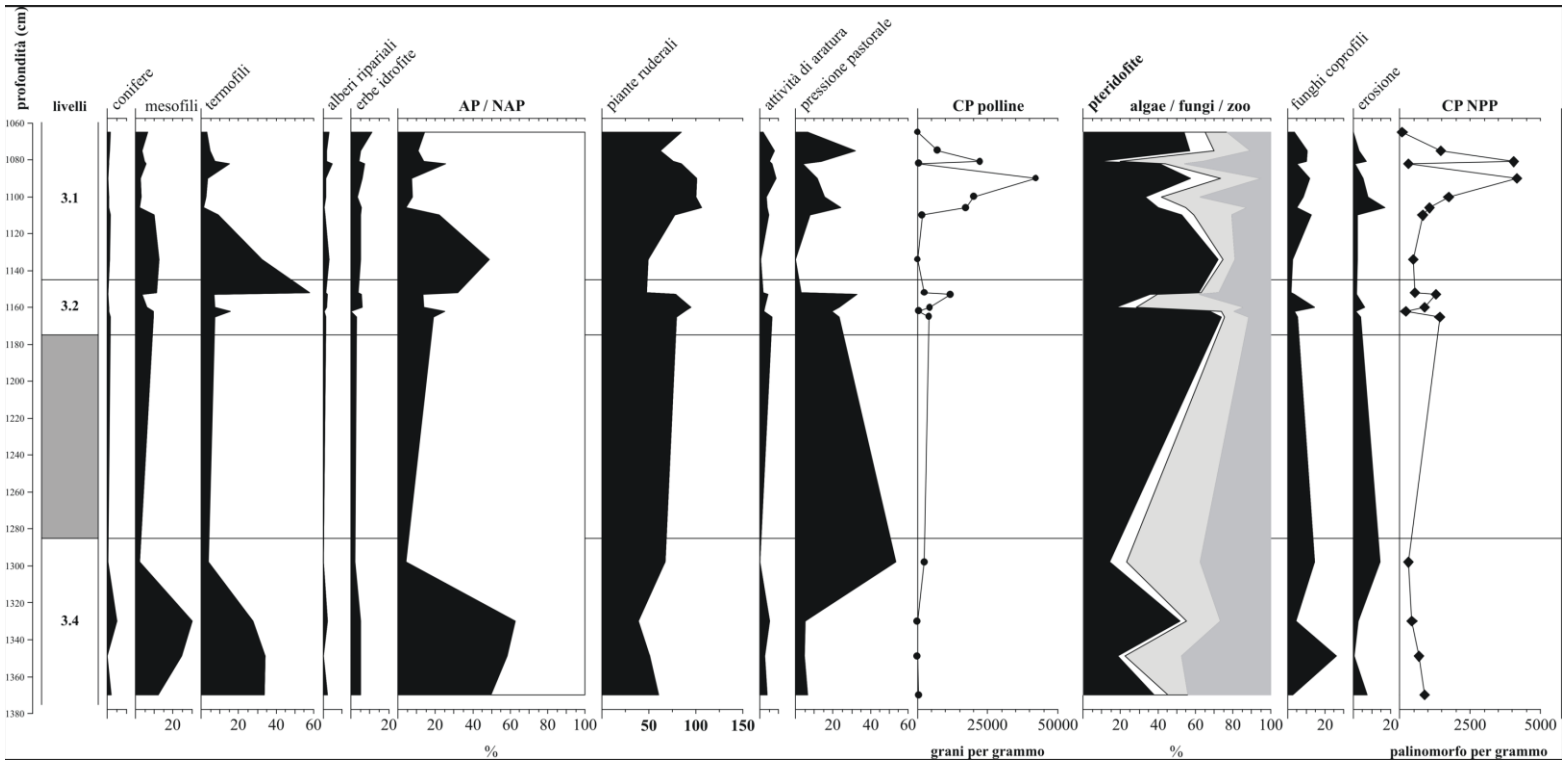

Figure 7 : Synthetic pollinic diagram pollen and NPPs from layer 3.4.a. of Vallone Inferno (Forgia et al., In process)

3. Methodology

The methodology of this study is composed of several steps which will allow the extraction and analysis of the thirteen samples from different zones of the layer 3.4.a. After sampling, pollen and NPPs will be extracted from the sediments using a laboratory protocol. They will then be

studied under a microscope to identify the taxa represented. Statistical analyses will be carried out to verify that each species is representative in the samples. Results will be presented in diagrams, correlation tables and cluster analysis.

3.1. Material

Thirteen samples were collected from different facies in layer 3.4.a. at Vallone-Inferno during the 2012 excavation campaign (

Table 3). They correspond to a dating between the Middle Neolithic and the Bronze Age (around 1610-1430 and 5380-5210 cal. BCE) (Table 1).

The Table 3 presents those samples and are named by the name of the square they have been extracted from followed by their altitude in the layer (

Table 3). It describes the origin of the sample, the composition of the samples before the pollen and NPPs extractions, the color of the sediments, the facies and the sterility of the samples. The thirteen samples were taken from different parts of the layer, using horizontal sampling. Indeed, layer 3.4.a. features several fireplaces (Focolare 1 and 2), a bucket (Fossetta) and a dung (fumier) produced by the incineration of animal excrement (

Figure 8 : Picture of the layer 3.4.a. of Vallone Inferno Rock Shelter. A) Of the facies R of the Dung. B) Of the fossette. C) Of the Focolare 1 and 2 D) Of Focolare 1 and Fossetta E) of Fumier and Focolare 1). *Fumier* can be described as archaeological sediment made of burnt animal dung and originated by human activities (Angelucci et al., 2009). Facies have been assigned to the samples during excavations. The facies, or lithofacies, are defined according to the physics sediment characteristics such as color, texture and content (Angelucci et al., 2009 ; Vergès et al., 2016a ; Angelucci et Anesin, 2012). Here, they are established according to their degree of cremation/color : white (B for Blanco), grey (G for grey), black (N for negro), brown (M for marron). However, one of the sterile samples appears to have an orange (G21-1277) or a black-brown colour for fertile samples from Focolare 2 (F20-1270a et b). These colour variations are probably due to differences in combustion intensity or the presence of phosphates in the dung (Angelucci et al., 2009). The sterility of the samples has been evaluated according to a methodology established for the palynological analysis of archaeological deposits (Bryant et Hall, 1993 ; Bryant et Holloway, 1983 ; Sánchez Goñi, 1993).

Origin	Fumier						Focolare 1		Focolare 2				Fossetta
Samples	F18-1281	F18-1285	F19-1282	G18-1277	G18-1278	G18-1281	G21-1269	G21-1277	F20-1268	F20-1270a	F20-1270b	F20-1272	F21-1273
Composition	Charcoal	Gravels	Charcoal, gravels, sands, silex	Charcoal, Gravels	Charcoal, gravels, sands, silex	Charcoal, gravels, sands, silex	Charcoal, gravels, sands, silex	Charcoal, gravels, sands, silex	Contamination pollen, gravels	Charcoal, gravels, sands, silex	Charcoal, gravels, sands	Charcoal, gravels, sands	Charcoal, gravels, sands, silex
Color	White	Grey	Grey	Grey	White	White	White	Orange	Black	Black-Brown	Black-Brown	Black	Brown
Facies	-	M	G	-	-	M	-	R	-	-	-	N	G
Results	Sterile	Sterile	Fertile	Sterile	Fertile	Sterile	Fertile	Sterile	Sterile	Fertile	Fertile	Fertile	Fertile

Table 3 : Table of the samples from the layer 3.4.a. of Vallone Inferno, dating between 3948+/-35 and 3244+/-42 cal BP (Forgia et al., 2013)

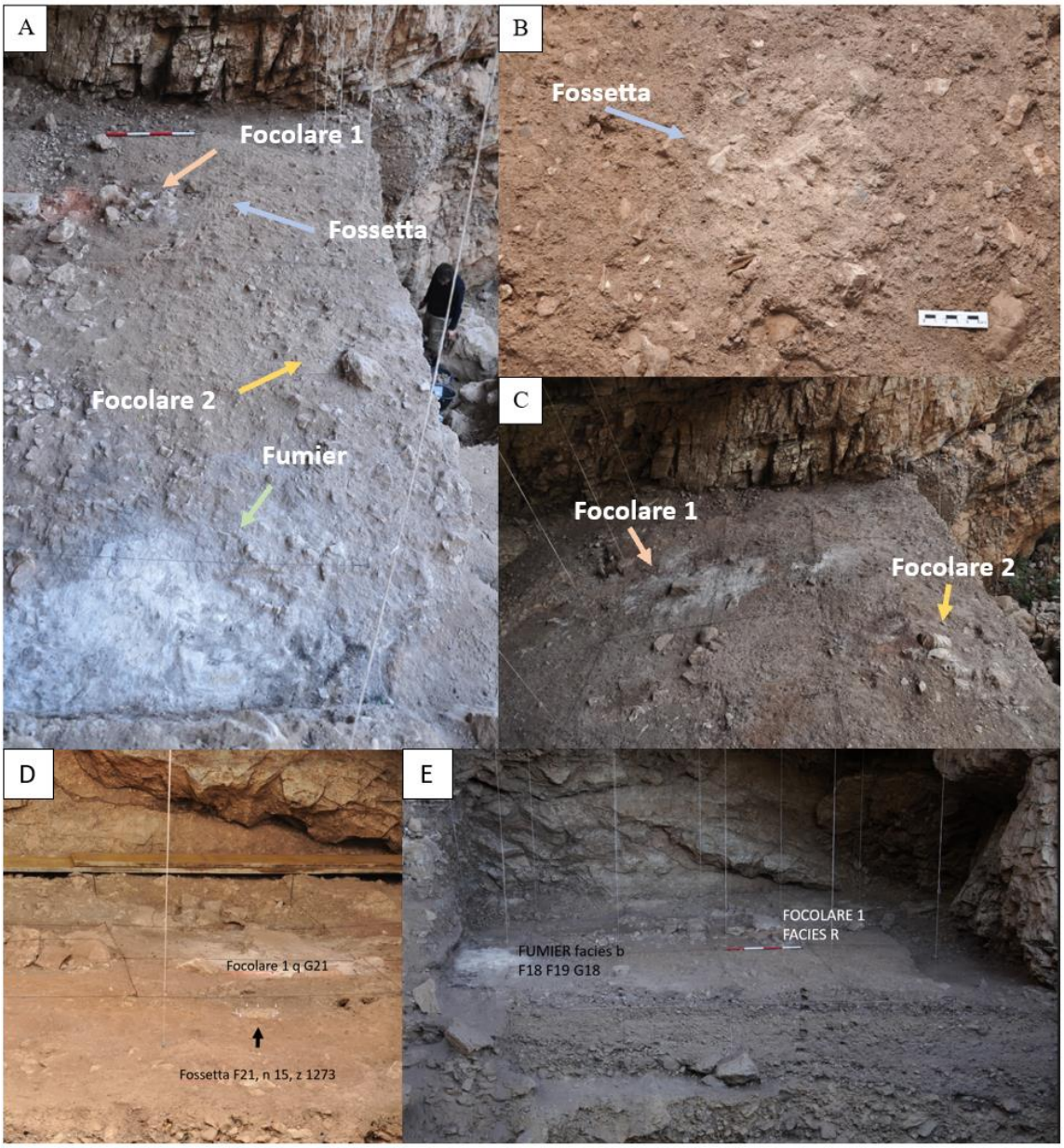

Figure 8 : Picture of the layer 3.4.a. of Vallone Inferno Rock Shelter. A) Of the facies R of the Dung. B) Of the fossette. C) Of the Focolare 1 and 2 D) Of Focolare 1 and Fossetta E) of Fumier and Focolare 1 (Forgia et al., 2013)

3.2. Extraction protocol of pollens and NPPs

The protocol was designed to extract pollen and NPPs and remove organic and mineral gangue. Samples were taken from the site and returned to the laboratories for analysis (**Erreur ! Source du renvoi introuvable.**A.). Samples were treated according to the modified Goeury et De Beaulieu (1979) methodology described by Burjachs et al. (2003) (Annex 1).

Around fifteen grams were taken from each sample (**Erreur ! Source du renvoi introuvable.**B.). The samples were sieved through 0.5mm sieves to recover the coarse sedimentary section (**Erreur ! Source du renvoi introuvable.**C.). Once dry, each sieve reject was weighed (**Erreur ! Source du renvoi introuvable.**D.).

The first step was to remove the carbonates (**Erreur ! Source du renvoi introuvable.**E.). 50% HCl was added until the acid reaction was complete, then water was added to the sample before it was centrifuged. Several cycles of washing - centrifugation were done to remove the supernatant containing acidic compounds (**Erreur ! Source du renvoi introuvable.**F. & G.).

The second step involved removing humic acids and other organic impurities (**Erreur ! Source du renvoi introuvable.**H.). For this, 10% Potassium Hydroxide was used, before being immersed in a bath to raise the temperature of the solution. The samples underwent several washing and centrifugation cycles to remove impurities in the supernatant. From the third wash onwards, a few drops of 50% HCl were added during the cycle.

The third stage consisted of floatation to homogenize and filtration of the samples to extract the pollen. After drying the samples, Thoulet liquor was added before centrifuging the elements (**Erreur ! Source du renvoi introuvable.**I.). They were then filtered through a glass fiber filter (**Erreur ! Source du renvoi introuvable.**J.). The addition of Hydrofluoric acid destroyed the filter and any remaining silicates, leaving only the pollen. Samples were washed to remove acid and 50% HCl fractions were added to remove any fluorosilicates that may have formed (**Erreur ! Source du renvoi introuvable.**K.). The sample was left to dry and was ready to be collected.

The final step in the extraction protocol was to mount the slides (**Erreur ! Source du renvoi introuvable.**L.). For this, the pollen had to be suspended in glycerine. It was important to measure the volume of glycerine deposited, to be able to place them on the slide and know the volume of waste collected. Samples were sometimes diluted with a few drops of glycerine if they still contained a high density of charcoal. The slide was covered with a coverslip and then

sealed with glue before being observed under a microscope (**Erreur ! Source du renvoi introuvable.**M.).

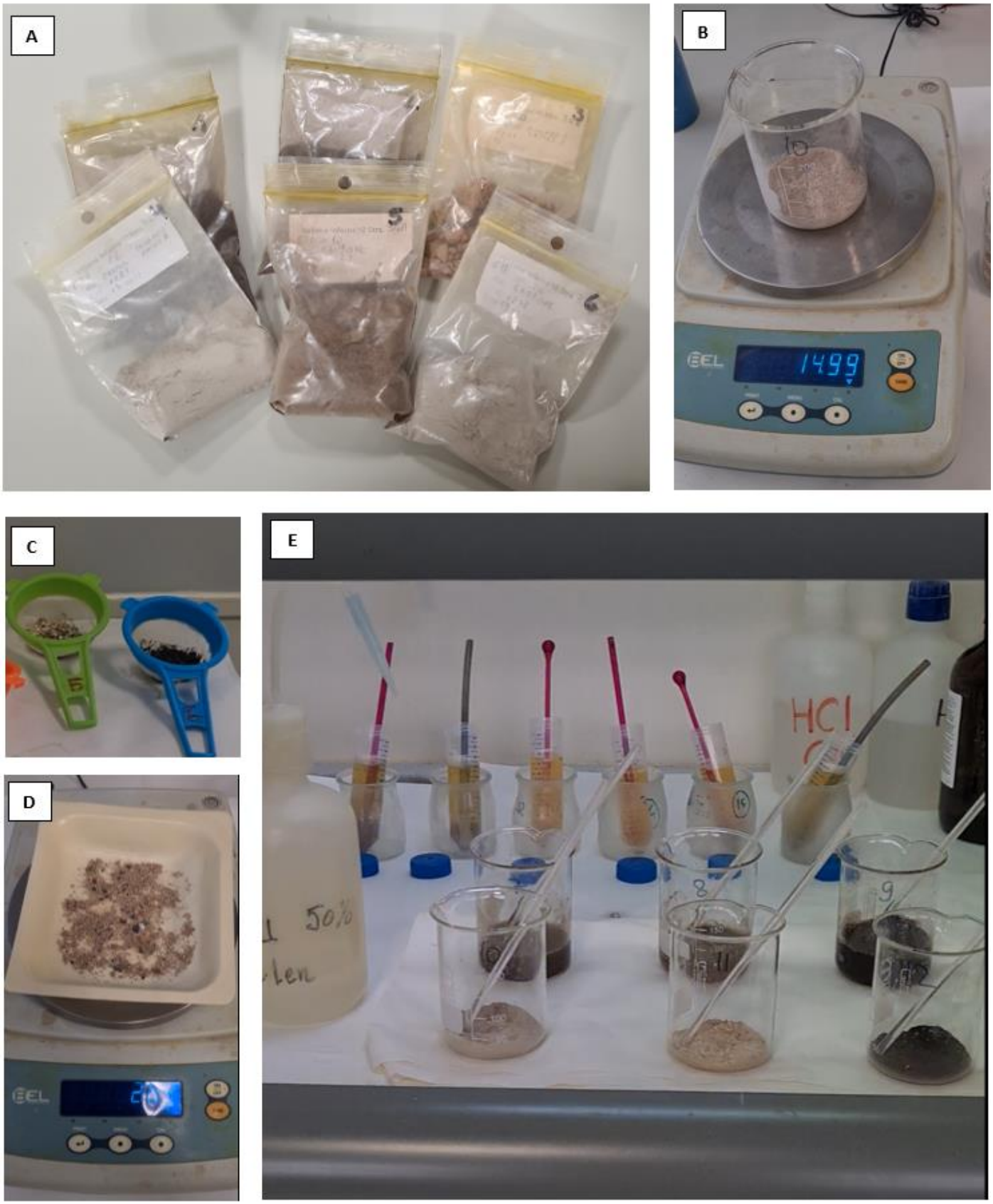

Figure 9 : Pictures of the extraction protocol of pollen and NPPs describe in Annex 1 (Goeury et De Beaulieu, 1979 ; Burjachs et al., 2003). A. Samples B. Sample Weight C. Sieving and D. Weight of coarse sedimentary E. Carbonate dissolution

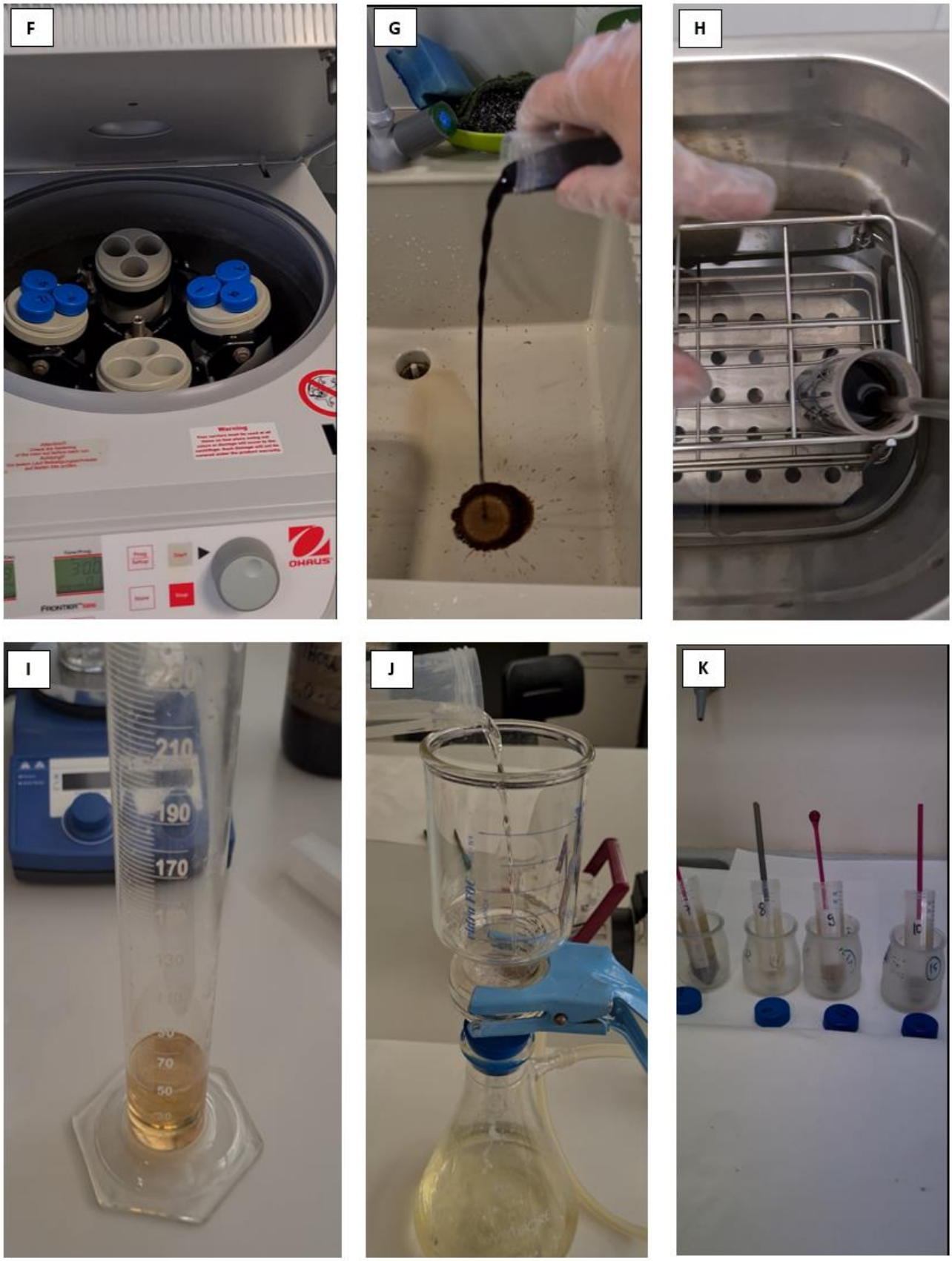

Figure 9 : Pictures of the extraction protocol of pollen and NPPs describe in Annex 1 (Goeury et De Beaulieu, 1979 ; Burjachs et al., 2003). F. Centrifugation G. Decant of KOH H. Water bath after removal of humic acids I. Flotation with Thoulet Liquor J. Filtering K. Removal filter and silica.

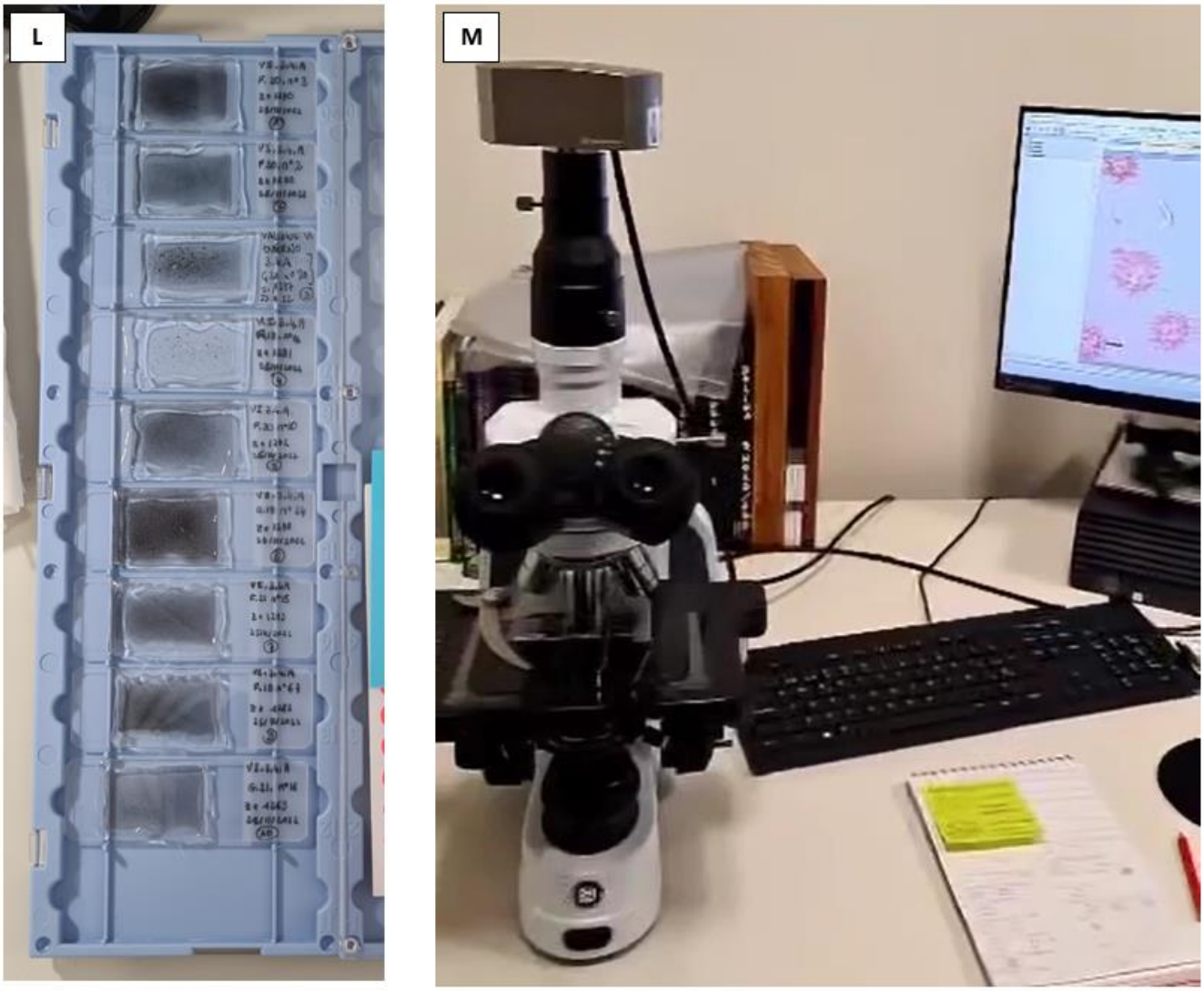

Figure 9 : Pictures of the extraction protocol of pollen and NPPs describe in Annex 1 (Goeury et De Beaulieu, 1979 ; Burjachs et al., 2003). L. Sample mounting M. Observation of the samples with the microscope

3.3. Pollen and NPPs identification

Slides were analyzed using an Olympus Cx41 optical microscope, at x600 magnification and sometimes at x1000 magnification for the finest details (**Erreur ! Source du renvoi introuvable.**M.). They were scanned along lines. On average, five lines were observed for each slide. All pollens, spores and NPPs identified were counted and catalogued.

Pollen and NPPs were identified by comparison with actual pollen and NPPs. They were compared with reference collections made up of slides with current pollens and NPPs. Fossil pollen, spores and NPPs were identified using published keys (Jarsen et Elsik, 1986 ; Moore et al., 1991 ; Reille, 1992, 1995 ; Van Geel, 1978a, 1986 ; Gelorini et al., 2011 ; Miola, 2012) and a modern pollen reference collection.

In order to identify the pollen taxon, shape, size, ornamentation, number, location and aperture type were examined. The structure, shape, size and colour of the NPPs were observed. It was sometimes possible to identify the species from which the pollen and NPPs originate, but most often identification stoped at family or gender rank.

3.4. Summation and determination of pollen concentration

Data processing and graphic representation were performed with the help of the software Tilia (Grimm, 1991-2016). The results are expressed in relative frequencies separately for pollen and NPPs. Pollen percentages of trees (AP), shrubs and herbs (NAP) were calculated based on a pollen sum, excluding Asteraceae and Cerealia-type because they have a specific pollination system and/or are favoured by anthropic activity. Regarding the NPPs, they are classified as pteridophytes (Pt), algae (A), fungi (F), undefined NPPs and plant remains (I) and zoo-remains (Z). Percentages were calculated on the basis of all palynomorphs identified, with the exception of those with an undetermined ecological affiliation and which could not be included in any of the identified taxonomic groups (*Pseudoschizaea*, HdV 303, HdV 128 and protists) and vegetal remains (stomata, woodvessels and others). Samples are arranged and grouped according to their spatial origin. The diagram is used to visualize the difference between the different pollen and NPPs sources in layer 3.4.A (Figure 12 : diagram of the relative frequencies of NPPs in the sub-layer 3.4.a. (Vallone Inferno). Points indicate frequencies below 2%. The line graph depicts the palynological concentration PC.

and Figure 12 : diagram of the relative frequencies of NPPs in the sub-layer 3.4.a. (Vallone Inferno). Points indicate frequencies below 2%. The line graph depicts the palynological concentration PC.
)

A synthetic diagram has been produced in which the pollen and NPP taxa appear grouped according to their ecological affinities (Behre, 1986 ; López Sáez et al., 1998, 2000 ; Galop et López Sáez, 2002 ; Ruiz-Zapata et al., 2006 ; Carrión et al., 2010 ; Hillbrand et al., 2012) (Figure 25).

For the palynological concentration (PC), we used the volumetric method proposed by Loublier (1978) with the following formula :

$$CP = \frac{\left(\frac{21\ x\ T}{\frac{n\ x\ 0{,}3}{v}}\right) x\ V}{p}$$

With :
21 : width of the cover slides
T : number of pollens counted
n : number of lines counted
0,3 : width of the microscopic field
v : volume of the residue mounted in the slide
V : volume of the residue obtained
p : weight of the samples

According to the methodology established for the palynological analysis of archaeological deposits, the viability of a samples is based on four reliability criteria : The minimum number of pollens counted per archaeological sample is 100-150, a minimum number of 300 to 500 grains per grams for concentration values, a minimum number of 20 identified taxa per sample and a maximum values of 50% indeterminable pollen (Bryant et Holloway, 1983 ; Bryant et Hall, 1993 ; Sánchez Goñi, 1993). The minimum number of NPPs is established when the minimum number of pollens has been reached. The results of all samples are shown in

Samples	Origin	Number of pollens counted	Number of taxa	Number of indeterminate pollen	Concentration values
F18-1281	Fumier	13	7	4	12,26
F18-1285	Fumier	1	1	0	1,81
F19-1282	Fumier	605	25	396	4087,38
G18-1277	Fumier	62	13	23	526,93
G18-1278	Fumier	174	15	95	1028,72
G18-1281	Fumier	1	1	0	2,44
G21-1269	Focolare 1	224	18	123	1777,50
G21-1277	Focolare 1	13	5	6	14,86
F20-1268	Focolare 2	78	14	14	68,06
F20-1270a	Focolare 2	374	23	119	1449,73
F20-1270b	Focolare 2	267	19	82	3526,66
F20-1272	Focolare 2	225	14	123	381,07
F21-1273	Fossetta	266	20	145	5645,11

Table 4, the number of indeterminate pollen from selected samples are in **Erreur ! Source du renvoi introuvable.** and the results by origin of extraction are presented in
Table 5.

3.5. Statistical application

Univariate analysis was produced to analyse the percentages of indeterminate pollens according to the samples in order to identify the extracted area with the most degraded pollen.
Mean of number of pollens, of NPPs identified, of pollen taxa and indeterminate pollen per sample was calculated to observe the differences of conservation regarding the area of extraction of the samples.

PAST 4.0. software was used to produce the multivariate statistical analyses (Santos, 1999). As a first step, a cluster analysis was carried out to assess sample ordination and observe the relationship between sample composition and origin. Taxa with more than 2% of all samples were selected and present in **Erreur ! Source du renvoi introuvable.**, **Erreur ! Source du renvoi introuvable.**, **Erreur ! Source du renvoi introuvable.** and

Figure 16 : Two-way hierarchical clustering analysis with Euclidean distance of NPPs present in layer 3.4.a. of Vallone Inferno

. Then, a two cluster analyses were produced, reflecting the percentage data of pollen and NPPs separated (Fig X and X). The algorithm used is the "Unweighted Pair Group Method with Arithmetic mean" (UPGMA). Groups are combined on the basis of the average distance between all members of the two groups. The use of relative frequencies, such as percentages, aims to manipulate Euclidean distances to understand sample similarities.

After, correlation analysis on percentages of pollen and NPPs from the set of selection fertile samples has been realised in order to observe the link between the correlation of the different pollens and NPPs. Finally, DCA has been realised on pollen and NPPs taxa with more than 0.75% to understand the link between the distribution of the fertile samples regarding the NPPs and pollen percentages.

4. Results

4.1. Palynological concentration and representative samples of the layer 3.4.a.

Samples	Origin	Number of pollens counted	Number of taxa	Number of indeterminate pollen	Concentration values
F18-1281	Fumier	13	7	4	12,26
F18-1285	Fumier	1	1	0	1,81
F19-1282	Fumier	605	25	396	4087,38
G18-1277	Fumier	62	13	23	526,93
G18-1278	Fumier	174	15	95	1028,72
G18-1281	Fumier	1	1	0	2,44
G21-1269	Focolare 1	224	18	123	1777,50
G21-1277	Focolare 1	13	5	6	14,86
F20-1268	Focolare 2	78	14	14	68,06
F20-1270a	Focolare 2	374	23	119	1449,73
F20-1270b	Focolare 2	267	19	82	3526,66
F20-1272	Focolare 2	225	14	123	381,07
F21-1273	Fossetta	266	20	145	5645,11

Table 4 : Values with the provenance structure, values of identified pollen, taxonomic richness, indeterminable pollen, pollen concentration and of the samples analyzed from level 3.4.a of Vallone Inferno. Shaded samples have been excluded from analysis.

Samples are heterogeneous. The number of taxa observed varies between 1 and 25 per sample. However, the number of unidentified pollens per sample is also very high. Palynological concentration within the thirteen samples is also highly variable. It fluctuated between 12.26 and 5,645.11 grains per gram (

Samples	Origin	Number of pollens counted	Number of taxa	Number of indeterminate pollen	Concentration values
F18-1281	Fumier	13	7	4	12,26
F18-1285	Fumier	1	1	0	1,81

F19-1282	Fumier	605	25	396	4087,38
G18-1277	Fumier	62	13	23	526,93
G18-1278	Fumier	174	15	95	1028,72
G18-1281	Fumier	1	1	0	2,44
G21-1269	Focolare 1	224	18	123	1777,50
G21-1277	Focolare 1	13	5	6	14,86
F20-1268	Focolare 2	78	14	14	68,06
F20-1270a	Focolare 2	374	23	119	1449,73
F20-1270b	Focolare 2	267	19	82	3526,66
F20-1272	Focolare 2	225	14	123	381,07
F21-1273	Fossetta	266	20	145	5645,11

Table 4).

According to these characteristics, some samples have been excluded from the diagrams and statistical analyses. Samples G21-1277 from focus 1, F20-1268 from focus 2 as well as F18-1281, G18-1281, G18-1277 and F18-1285 were excluded due to their low palynological concentration, number of taxa and pollens counted. They are shaded in the

Samples	Origin	Number of pollens counted	Number of taxa	Number of indeterminate pollen	Concentration values
F18-1281	Fumier	13	7	4	12,26
F18-1285	Fumier	1	1	0	1,81
F19-1282	Fumier	605	25	396	4087,38
G18-1277	Fumier	62	13	23	526,93
G18-1278	Fumier	174	15	95	1028,72
G18-1281	Fumier	1	1	0	2,44
G21-1269	Focolare 1	224	18	123	1777,50
G21-1277	Focolare 1	13	5	6	14,86
F20-1268	Focolare 2	78	14	14	68,06
F20-1270a	Focolare 2	374	23	119	1449,73
F20-1270b	Focolare 2	267	19	82	3526,66
F20-1272	Focolare 2	225	14	123	381,07

F21-1273	Fossetta	266	20	145	5645,11

Table 4 (Bryant et Holloway, 1983 ; Bryant et Hall, 1993 ; Sánchez Goñi, 1993).

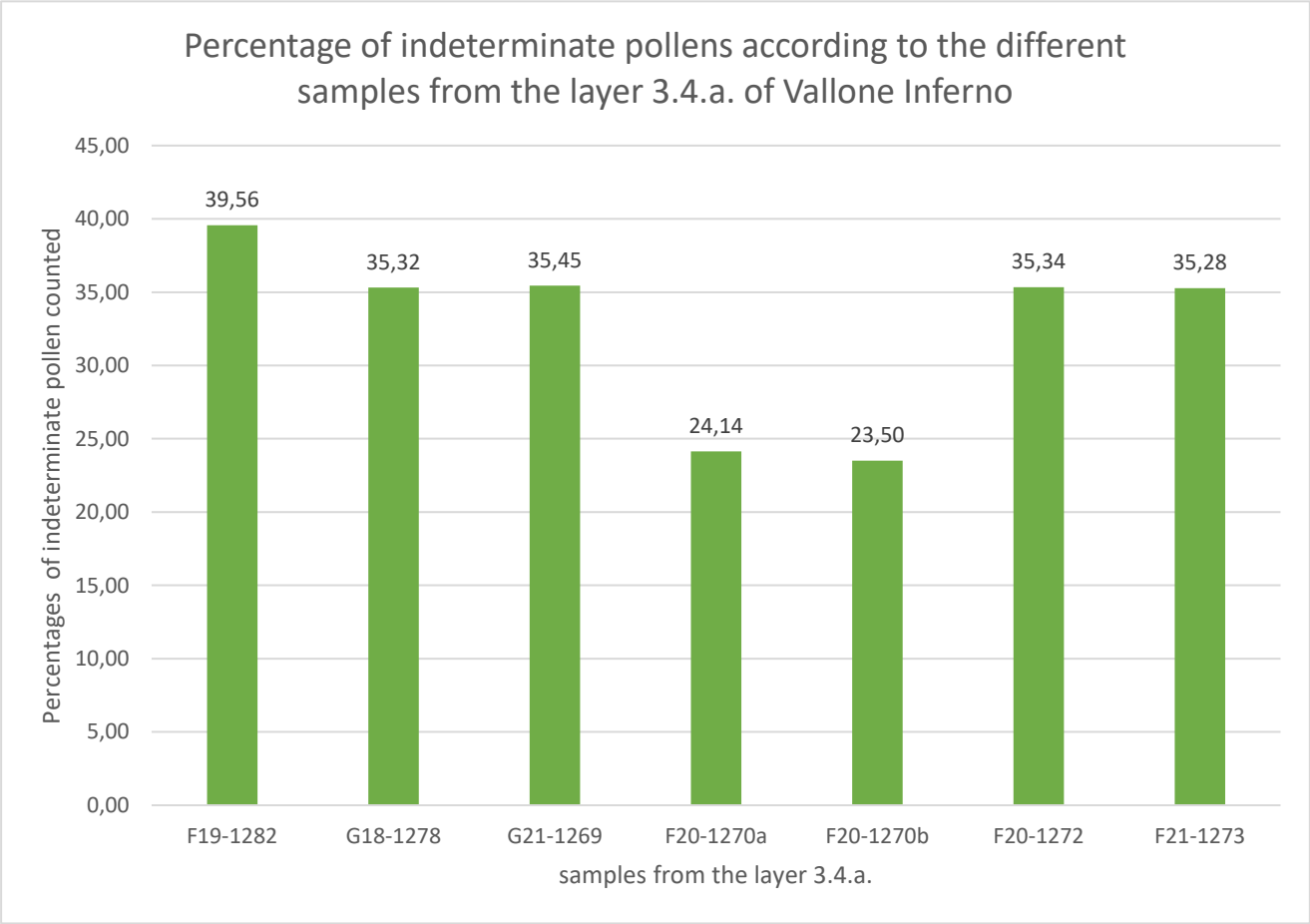

Figure 10 : Histogram of the percentage of indeterminate pollens according to the different samples from the layer 3.4.a. of Vallone Inferno

The sample with the main percentage of indeterminate, presented in the **Erreur ! Source du renvoi introuvable.**, pollens is F19-1282 from the fumier. Then, G18-1278 from the fumier, G21-1269 from Focolare 1, F20-1272 from the Focolare 2 and F21-1273 from Focolare 2 has the same number of pollen indeterminate (35,45-35,28%). The sample F20-1270a and b from Focolare 2 have the smaller number of indeterminate pollens.

Mean and concentration	Focolare 1	Focolare 2	Fumier	Fossetta
Mean number of pollens counted per sample	224	288,7	389,5	266
Mean of NPPs identified per sample	81	92,33	84	110
Mean of pollen taxa per sample	18	18,7	20	20
Mean indeterminate pollen per sample	123	108	245,5	145
Percentage of mean indeterminate pollen per sample (%)	35,45	27,23	38,66	35,28
Concentration value	1777,50	1785,82	2558,05	5645,11

Table 5 : table of the mean number of pollens and NPPs identified counted, mean of pollen taxa, mean of indeterminate pollen per sample and concentration value according to the extraction origin of the samples selected from the layer 3.4.a. of Vallone Inferno

The grouping of taxa by origin shows the differential impact of taphonomic processes on pollen and NPPs (

Table 5). In the set of samples selected according to the criteria indicated above, we note that the bucket is the sampling site with the greatest taxonomic richness of pollen and NPPs, generating a very high palynological concentration. In contrast, the Focolare are marked by low taxonomic diversity and palynological concentration. The sample from Focolare 1 and 2 show a significant similarity about the taxonomic diversity and abundance. However, the percentage of indeterminable pollen per sample is relatively low compared to other extraction sites, especially for Focolare 2. *Fumier* has a high pollen richness associated with taxonomic diversity, favoring a relatively high palynological concentration. However, *fumier* has the highest indeterminate pollen value. When making this comparison, it should be borne in mind that 2/3 of the manure samples, 1/2 of the samples from focus 1 and 1/4 from focus 2 have been eliminated from the calculation of the averages.

4.2. Diagram of the pollen of the layer 3.4.a. of Vallone Inferno

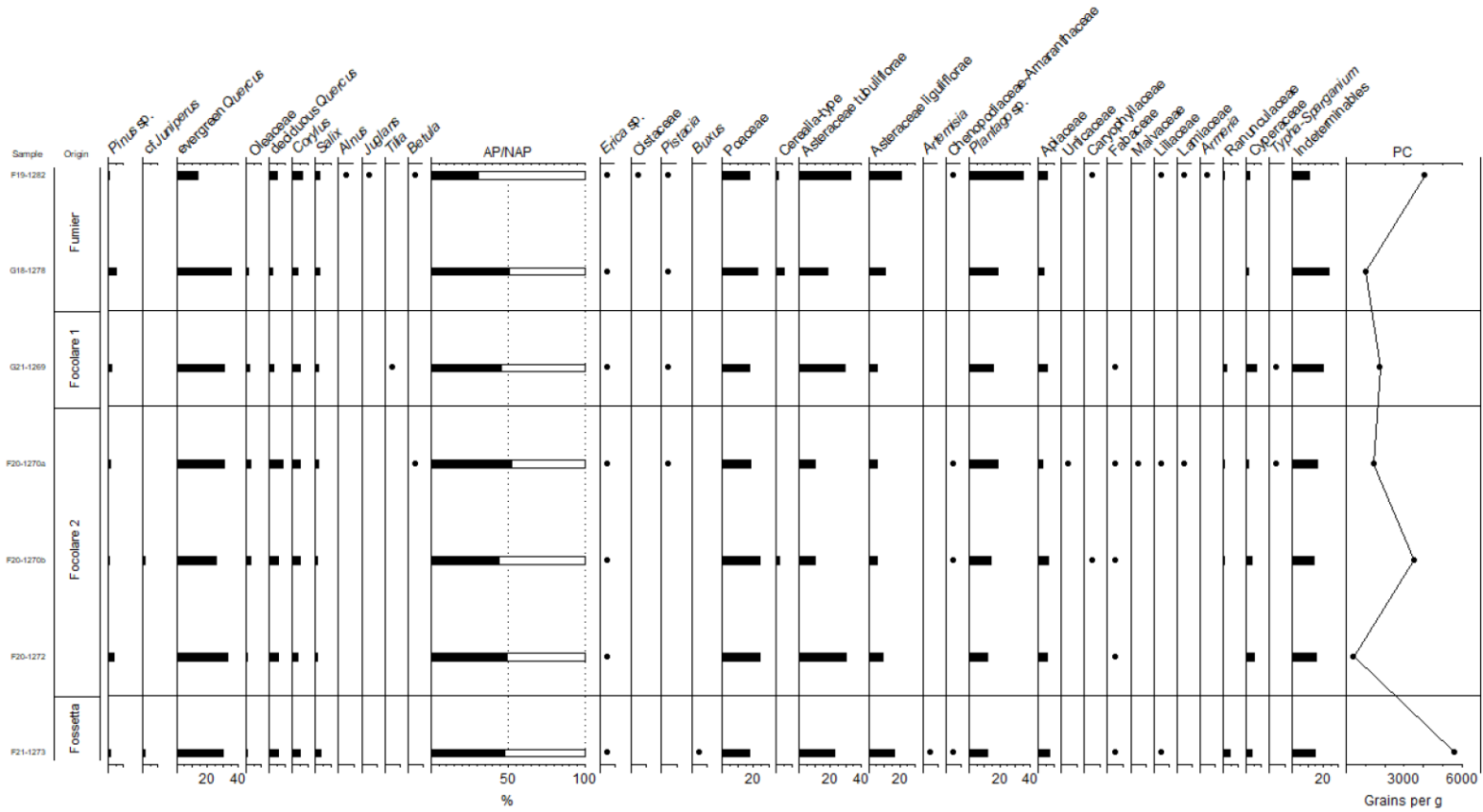

Figure 11 : diagram of the relative frequencies of pollens in the layer 3.4.a. (Vallone Inferno). Points indicate frequencies below 2%. The line graph depicts the palynological concentration PC and is indicated in grains per gram.

Most sites show equal proportions of tree and non-tree pollen. On average, across all samples, 45% are tree pollens (

Annex 2). These tree pollens are represented by 10 different taxa. Non-tree pollens are made up of 22 taxa including 4 taxa of shrubs, 17 taxa of grasses including 2 taxa of hygrophilous plants.

The vegetation of the Middle Neolithic and Early Bronze Age is composed of a typical mixed formation by evergreen elements of a Mediterranean thermophilic nature that coexist with mesic deciduous taxa (Figure 11 : diagram of the relative frequencies of pollens in the layer 3.4.a. (Vallone Inferno). Points indicate frequencies below 2%. The line graph depicts the palynological concentration PC and is indicated in grains per gram.

). Tree pollens are dominated by Mediterranean vegetation thanks to a very high proportion of evergreen Quercus (28.4%) (

Annex 2). The frequency of Oleaceae pollen is more restricted (1.63%). Deciduous forest is the second most prevalent vegetation type in the samples. It is represented by deciduous Quercus (5.34%) and Corylus (4.91%), Juglans (0.14%) and Tilia (0.14%). Local riparian trees identified as Salix (2,24%) and Alnus (0,1%) are present in small proportions. The pollens of Pinus sp. (2.27%), cf Juniperus (0,54%) and Betula (0,07%), probably present in the higher altitude, are identified (

Annex 2).

Non-arboreal pollens show the greatest diversity with 22 different taxa. Shrubs are poorly represented in samples according to their abundance with *Erica* sp. (1.36%), *Pistacia* (0.86%), Cistaceae (0.14%) and *Buxus* (0.11%). However, shrubs are generally underrepresented because they are autogamous, and thus are less represented in the pollen rain. The most represented herbaceous taxa are Poaceae (20.34%), Asteraceae tubuliflorae (22.06%), Asteraceae liguliflorae (10.37%) and *Plantago* sp. (18.13%). Cerealia-type represent a smaller proportion (0.59%). Ruderal plants are also highlighted by a lower proportion but a high diversity of plants such as Apiaceae (5,47%), Ranunculaceae (1.23%), Fabaceae (0.87%), Caryophyllaceae (0.46%), Armeria (0.27%), Lamiaceae (0.13%), Urticaceae (0.11%) and *Artemisia* (0.11%). The non-negligible proportion of hygrophilous plants according to abundance is carried by Cyperaceae (3.39%) and *Typha-Sparganium* (0.2%). However, their presence and the riparian trees indicates the presence of a water source near the site.

Fossetta :

La Fossetta consists of a single sample, F21-1273. Its palynological concentration is high (5645,11 grains per dry gram of sediments, (Figure 11 : diagram of the relative frequencies of pollens in the layer 3.4.a. (Vallone Inferno). Points indicate frequencies below 2%. The line graph depicts the palynological concentration PC and is indicated in grains per gram.

,

Samples	Origin	Number of pollens counted	Number of taxa	Number of indeterminate pollen	Concentration values
F18-1281	Fumier	13	7	4	12,26
F18-1285	Fumier	1	1	0	1,81
F19-1282	Fumier	605	25	396	4087,38
G18-1277	Fumier	62	13	23	526,93
G18-1278	Fumier	174	15	95	1028,72
G18-1281	Fumier	1	1	0	2,44
G21-1269	Focolare 1	224	18	123	1777,50
G21-1277	Focolare 1	13	5	6	14,86
F20-1268	Focolare 2	78	14	14	68,06
F20-1270a	Focolare 2	374	23	119	1449,73
F20-1270b	Focolare 2	267	19	82	3526,66
F20-1272	Focolare 2	225	14	123	381,07
F21-1273	Fossetta	266	20	145	5645,11

Table 4) and AP represent 47.9% of the pollen (Annexe 2). The mediterranean trees are essentially evergreen *Quercus* (29.8%) and some Oleaceae (0,8%). A smaller portion of AP is represented by deciduous *Quercus* (5.8%) and *Corylus* (5.0%). Riverside trees are represented by *Salix* (3.3%). The presence of Pinus (1,7%) and cf Juniperus (1,7%) and has also been identified. The identified shrubs are Erica sp. (1,7%) and Buxus (0,8%). The herbs correspond to Asteraceae tubuliflorae (22.9%), Poaceae (17.4%), Asteraceae liguliflorae (16.5%), Apiaceae (7.4%), *Plantago* sp. (12.4%), Ranunculaceae (4.1%), Liliaceae (2.5%) and Chenopodiaceae-Amaranthaceae (0.8%), Fabaceae (0.8%) and Artemisia (0.4%). Higrophilous herbs are represented by Cyperaceae (3.3%).

Focolare 2 :

Focolare 2 is represented by three samples: F20-1272, F20-1270b and F20-1270a. On average, the samples have a variable palynological concentration (3526.66 and 381.07 grains per dry gram of sediment, Figure 11 : diagram of the relative frequencies of pollens in the layer 3.4.a. (Vallone Inferno). Points indicate frequencies below 2%. The line graph depicts the palynological concentration PC and is indicated in grains per gram.

,

Samples	Origin	Number of pollens counted	Number of taxa	Number of indeterminate pollen	Concentration values
F18-1281	Fumier	13	7	4	12,26
F18-1285	Fumier	1	1	0	1,81
F19-1282	Fumier	605	25	396	4087,38
G18-1277	Fumier	62	13	23	526,93
G18-1278	Fumier	174	15	95	1028,72
G18-1281	Fumier	1	1	0	2,44
G21-1269	Focolare 1	224	18	123	1777,50
G21-1277	Focolare 1	13	5	6	14,86
F20-1268	Focolare 2	78	14	14	68,06
F20-1270a	Focolare 2	374	23	119	1449,73
F20-1270b	Focolare 2	267	19	82	3526,66
F20-1272	Focolare 2	225	14	123	381,07
F21-1273	Fossetta	266	20	145	5645,11

Table 4). Overall, the proportion of AP is equal (44.3% and 52.2% ; Annexe 2). The samples are mainly composed of Mediterranean trees such as *Quercus* evergreen (33.3-25.4%) and Oleaceae (3.2-1%). Deciduous trees consist of deciduous *Quercus* (9-5.9%) and *Corylus* (5.4-3.9%). Riparian trees are represented by *Salix* (2.4-1%). The regional trees are represented by *Pinus* sp. (3.9-1.1%). Among the shrubs, only *Erica* sp. (2-0.4%) was identified in the samples. The herbaceous plants found, mostly ruderals plants, are Poaceae (24.5-18.4%), Asteraceae tubuliflorae (30.2-10.1%), Asteraceae liguliflorae (8.9-5.2%), *Plantago* sp. (18.4-11.8%), Apiaceae (6.5-3.1 %), Fabaceae (2-1.1%), Ranunculaceae (1.1-0.4%) and Chenopodiaceae-Amaranthraceae (1.1-0 %). We also found the hygrophilous Cyperaceae (4.9-1.6%). Crops is represented by Cerealia (1.5-0%) and Faboideae (2-1.1%).

There are certain peculiarities in the composition of the samples. The F20-1270a sample includes great diversity. In addition to the taxa identified above, there are also *Betula* (0.4%), *Pistacia* (0.8%), Liliaceae (1.2%), Urticaceae (0.8%), Malvaceae (0.4%), Lamiaceae (0.4%) and the hygrophilous *Typha-Sparganium* (0.4%). Similarly, sample F20-1270b is also composed of cf *Juniperus* (1.6%), Caryophyllaceae (2.2%) and in this case, the presence of Cerealia-type (1.5%) has been identified. The sample F20-1272 does not contain additional taxa, however, we note the high percentage abundance of Asteraceae tubuliflorae in this sample (30.2%) unlike the other two samples (10.2 and 10.1%).

To summarise, the samples of Focolare 2 have very similar AP percentages in the taxonomic representation. The palynological concentrations are divergent, especially in the sample F20-1272, which presents the minimum values. This sample is also peculiar because of its low diversity of taxa and its high presence of Asteraceae tubuliflorae. The other sample presents a high variety of taxa, particularly for F20-1270a. The singularity of F20-1270b is the presence of Cerealia-type.

Focolare 1 :

A single sample represents the Focolare 1: G21-1269. Its palynological concentration is rather low (1777.5 grains per dry gram of sediment, Figure 11 : diagram of the relative frequencies of pollens in the layer 3.4.a. (Vallone Inferno). Points indicate frequencies below 2%. The line graph depicts the palynological concentration PC and is indicated in grains per gram.

,

Samples	Origin	Number of pollens counted	Number of taxa	Number of indeterminate pollen	Concentration values
F18-1281	Fumier	13	7	4	12,26
F18-1285	Fumier	1	1	0	1,81
F19-1282	Fumier	605	25	396	4087,38
G18-1277	Fumier	62	13	23	526,93
G18-1278	Fumier	174	15	95	1028,72
G18-1281	Fumier	1	1	0	2,44
G21-1269	Focolare 1	224	18	123	1777,50

G21-1277	Focolare 1	13	5	6	14,86
F20-1268	Focolare 2	78	14	14	68,06
F20-1270a	Focolare 2	374	23	119	1449,73
F20-1270b	Focolare 2	267	19	82	3526,66
F20-1272	Focolare 2	225	14	123	381,07
F21-1273	Fossetta	266	20	145	5645,11

Table 4). The proportion of non-arboreal pollen is 54.5% (Annexe 2). The Mediterranean tree pollens are mainly led by *Quercus* evergreen (30.7%) and then Oleaceae (2%). A few deciduous trees have been identified such as *Corylus* (5.0%), deciduous *Quercus* (3.0%) and *Tilia* (1%). Regional trees are represented by *Pinus* sp. (2%) and riparian by *Salix* (2%). Non-arboreal pollens contain some pollens of shrubs like *Erica* sp. (2%) and *Pistacia* (2%). The identified are Asteraceae tubuliflorae (29,5%), Poaceae (17.8%), *Plantago* sp. (15.8%), Apiaceae (5.9%) and Asteraceae liguliflorae (5,4%), Ranunculaceae (2%) and Fabaceae (1%). Hygrophilous Cyperaceae (6.9%) and Typha-Sparganium (1%) were also identified.

Fumier :

Fumier is represented by two samples. G18-1278 and F19-1282 have different concentrations (respectively 1028.72 and 4087.38 grains per dry gram of sediment, Figure 11 : diagram of the relative frequencies of pollens in the layer 3.4.a. (Vallone Inferno). Points indicate frequencies below 2%. The line graph depicts the palynological concentration PC and is indicated in grains per gram.

,

Samples	Origin	Number of pollens counted	Number of taxa	Number of indeterminate pollen	Concentration values
F18-1281	Fumier	13	7	4	12,26
F18-1285	Fumier	1	1	0	1,81
F19-1282	Fumier	605	25	396	4087,38
G18-1277	Fumier	62	13	23	526,93
G18-1278	Fumier	174	15	95	1028,72
G18-1281	Fumier	1	1	0	2,44
G21-1269	Focolare 1	224	18	123	1777,50
G21-1277	Focolare 1	13	5	6	14,86

F20-1268	Focolare 2	78	14	14	68,06
F20-1270a	Focolare 2	374	23	119	1449,73
F20-1270b	Focolare 2	267	19	82	3526,66
F20-1272	Focolare 2	225	14	123	381,07
F21-1273	Fossetta	266	20	145	5645,11

Table 4). While G18-1278 has an AP percentage of 50.6%, F19-1282 has a lower concentration of 30.6% (

Annex 2). Mediterranean trees are mainly composed of *Quercus* evergreen (35.4-13.4%). Messicole trees are represented by deciduous *Quercus* (5.3-2.5%) and *Corylus* (6.2-3.8%). *Salix* (2.9-2.5%) make up the riverside forest. The other trees are *Pinus* sp. (5.1-0.5%). The compound shrubs are *Erica* sp. (1.3-1.0%) and *Pistacia* (1.9-1.3%). Herbs are represented by *Plantago* sp. (34.9-19%), Asteraceae tubuliflorae (33.1-18.4%), Asteraceae liguliflorae (21-10.3%), Poaceae (22.8-17.2%), Apiaceae (5,7-3.8%) and the hygrophilous Cyperaceae (1.9-1.3%). Cerealia-type (2.3-0.3%) was also found.

The samples have certain particularities. The sample G18-1278 presents Oleaceae (1.3%). Sample F19-1282 is composed of a very high diversity in addition to the taxa described above. We note the presence of *Juglans* (1.0%), *Betula* (0.5%), *Alnus* (0.5%), cf *Juniperus* (0.5%), Cistaceae (1.0%), *Armeria* (1, 9%), Caryophyllaceae (1.0%), Liliaceae (1.0%), Ranunculaceae (1.0%), Chenopodiaceae-Amaranthraceae (0.5%) and Lamiaceae (0.5%).

In summary, *fumier* samples present many contrasts. Sample F19-1282 has lower palynological contraction and taxonomic diversity than G18-1278, which may be linked to the fact that the samples are affected by differential conservation. Moreover, the percentage of AP of F19-1282 is the smallest observed in the sequence. It is due to the decline of *Quercus* evergreen. In contrast, in these samples Asteraceae, *Plantago* sp. and other plants are more represented.

4.3. Diagram of the NPP of the sub-layer 3.4.a.

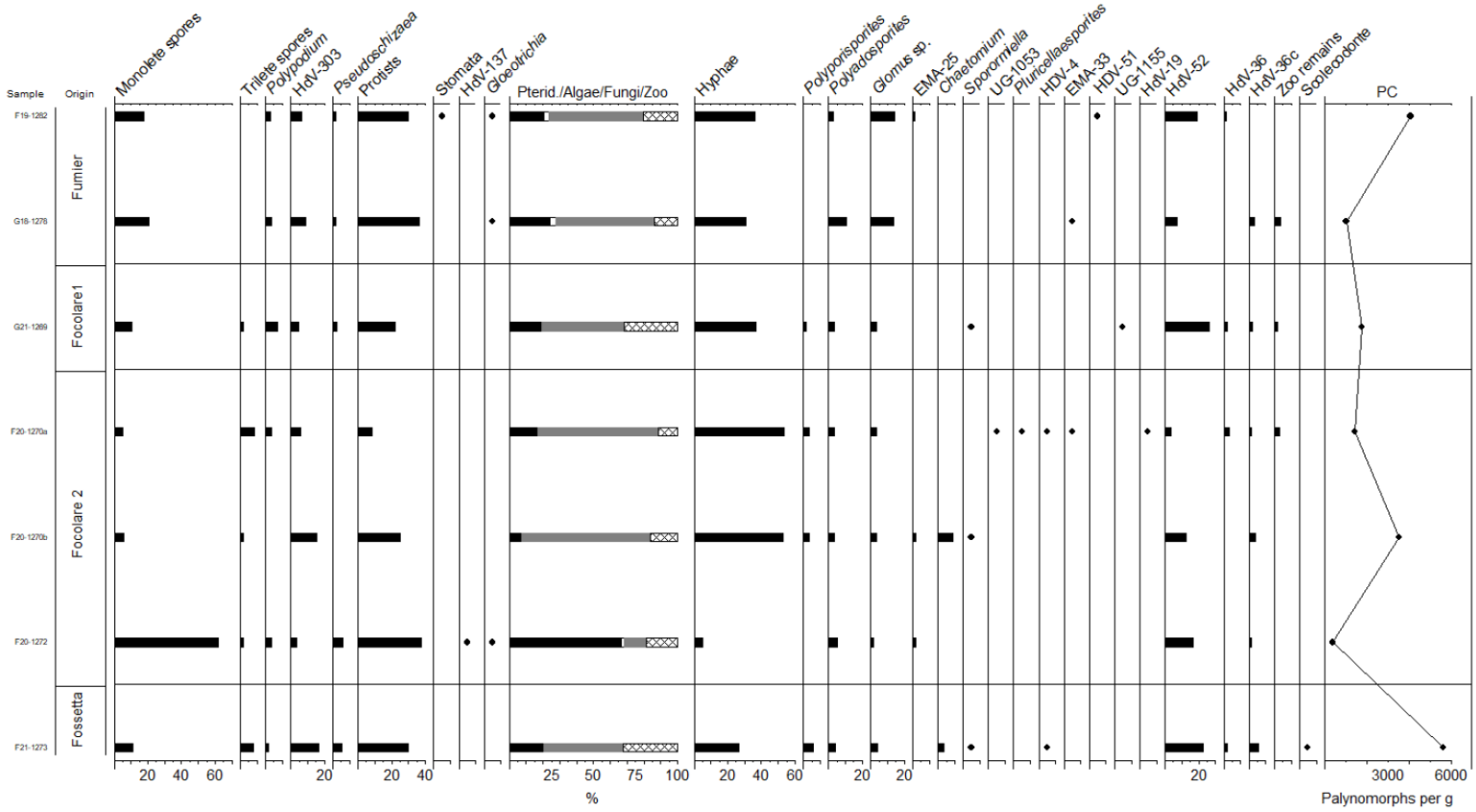

Figure 12 : diagram of the relative frequencies of NPPs in the sub-layer 3.4.a. (Vallone Inferno). Points indicate frequencies below 2%. The line graph depicts the palynological concentration PC.

Non-pollen Palynomorphs of the layer 3.4.A. from the Vallone Inferno site are very diverse (Fig X, Appendix 3). In the majority of samples, fungi (53,26%) are the most represented group. They are followed by micro-organisms of animal origin (20,60%) and pteridophytes (25,03%) which are composed of 6 taxa and 3 taxa respectively. Algae are very rare (1,14%) and are represented by a single taxon (

Annex 3).

Pteridophytes are essentially monolete spores (18.87%) (Figure 12 : diagram of the relative frequencies of NPPs in the sub-layer 3.4.a. (Vallone Inferno). Points indicate frequencies below 2%. The line graph depicts the palynological concentration PC.

,

Annex 3). A lower frequency is associated with trilete spores (3.1%) and *Polypodium* (3.11%). The only identified algal taxon is the Cygnemataceae *Gloeotrichia* (1.14%). However, their presence was only highlighted in three samples. Fungi are both the most represented group in the majority of samples but also those that show the greatest diversity with 13 taxa identified in total. Hyphae (34.49%) and mycorrhizae *Glomus* sp. (6.31%) are the most frequently identified taxa. Coprophilous fungi are present in these samples through the taxa *Polyadosporites* (4.63%), *Polyporisporites* (2.06%), *Chaetomium* (1.84%) and *Sporormiella* (0.79%). Fungi types EMA-33 (0.73%), EMA-25 (0.7%), HDV-4 (0.51%), UG-1155 (0.26%), *Dyctiosporites* (0.24%), *Pluricellaesporites* (0.24%), HdV-19 (0.24%) and HdV-51 (0.20%) are rare in all samples. Finally, among the animal remains, HDV-52 (15.33%) are mostly represented. HDV-36 (1.20%) and HDV-36c (2.56%) are present in almost all samples. Some other animal fragments were also highlighted in a few samples (1.21%). *Scolecodonts* (0.27%) was identified in only one sample. The NPPs of microorganisms of unknown origin are represented by 5 taxa including Protists (27.10%) and HDV-303 (8.71%) which represent the largest majority of this group. In the minority, we find *Pseudoschizea* (2.53%), stomata (0.13%) and HdV-37 (0.13%).

Fossetta :

The Fossette is composed of a high diversity of NPPs (Figure 12 : diagram of the relative frequencies of NPPs in the sub-layer 3.4.a. (Vallone Inferno). Points indicate frequencies below 2%. The line graph depicts the palynological concentration PC.

,

Annex 3). The majority of NPPs are fungi, such as hyphae (26.4%), *Polyporisporites* (5.7%), *Polyadosporites* (3.8%), *Glomus* sp. (3.8%) and *Chaetomium* (3.8%). *Sporormiella* (1.9%) and HdV-4 (1.9%) complete the fungal taxa. The second largest group of NPPs includes animal remains. HDV-52 (22.6%) and HDV-36c (5.7%) characterised a significant proportion. HDV-36 (1.9%) and the Scolecodonts (1.9%) complete this animal group. Pteridophytes are carried by a small quantity of spores monolete (11.3%) and trilete (7.5%) as well as some *Polypodium* (1.9%). No algae were identified in this sample. The unknown ecological origin plant microorganisms are Protists (30.0%), HdV-303 (16.4%) and *Pseudoschizaea* (5.5%).

Focolare 2 :

The three samples represented by the Focolare 2 are not uniform (Figure 12 : diagram of the relative frequencies of NPPs in the sub-layer 3.4.a. (Vallone Inferno). Points indicate frequencies below 2%. The line graph depicts the palynological concentration PC.

Figure 12 : diagram of the relative frequencies of NPPs in the sub-layer 3.4.a. (Vallone Inferno). Points indicate frequencies below 2%. The line graph depicts the palynological concentration PC.

,

Annex 3). Pteridophytes have a wide variability. Among this group, one can identify monolete spore (61.7-5.0%), trilete spore (8.3-1.7%) and *Polypodium* (3.3-0%). Fungi are present across many taxa. Coprophilous fungi are represented in all samples by *Polyadosporites* (5-3,3%) and *Polyporisporites* (3,6-3,3%). We also note the presence of hyphae (53,3-52,7%), of *Glomus* sp. (3,6-1,7%), EMA-25 (1,8-1,7%) in all the samples. The animal remains are composed of HDV-52 (16,7-3,3%) and HDV-36c (3,6-1,7%). The unknown ecological origin plant microorganisms are represented by Protists (37,4-8,6%) and HdV-303 (15,2-3,5%).

The samples have some diversities, and some taxa are only found on one sample. In sample F20-1272, the only Algae identified in the Focolare 2 samples are *Gloeotrichia* (1,7%). The unknown ecological origin plant microorganisms are also represented by *Pseudoschizaea* (6,1%) and HdV-37 in this sample. The sample F20-1270b contains more coprophilous fungi such as *Chaetomium* (9,1%) and *Sporormiella* (1,8%). The sample F20-1270a is characterised by the abundance of the fungi UG-1053 (1,7%), HDV-4 (1,7%), *Pluricellaesporites* (1,7%), EMA-33 (1,7%), HdV-19 (1,7%), UG-1053 (1,7%) and the zoo-remains HDV-36 (3,3%).

To summarise, while samples F20-1270b and F20-1270a look alike, F20-1272 appears to be different. Its high composition of spore monolete and Protists stands out from the other samples which are mainly made up of hyphae. The diversity of sample F20-1272 is carried by the presence of *Gloeotrichia* algae while the other two samples have a larger number of fungi taxa (Annexe 3).

Focolare 1 :

Focolare 1 is represented by a sample, G21-1269, with a majority of fungal hyphae (36.8%) (Figure 12 : diagram of the relative frequencies of NPPs in the sub-layer 3.4.a. (Vallone Inferno). Points indicate frequencies below 2%. The line graph depicts the palynological concentration PC.

,

Annex 3). In addition to hyphae, fungi include *Polyadosporites* (3.5%), *Glomus* sp. (3.5%) and *Polyporisporites* (1.8%). This sample is marked by the presence of *Sporormiella* (1.8%) and UG-1155 (1.8%). The other major components are animal microorganisms of the HDV-52 type (26.3%). Other than HDV-52, microorganisms of animal origin are divided into HDV-36 (1.8%), HDV-36c (1.8%) and other undetermined animal remains (1.8%). Pteridophytes contain a majority of monolete spores (10.5%), *Polypodium* (7.0%) and some trilete spores (1.8%). Plant microorganisms of unknown origin are mainly Protists (22.2%) and some HdV-303 (4,9%) and *Pseudoschizaea* (2.5%) (Annexe 3).

Fumier :

The two samples G18-1278 and F19-1282 from *fumier* are almost identical (Figure 12 : diagram of the relative frequencies of NPPs in the sub-layer 3.4.a. (Vallone Inferno). Points indicate frequencies below 2%. The line graph depicts the palynological concentration PC.

,

Annex 3). The pteridophytes of the two samples are mainly monolete spores (20.7-17.4%) supplemented by *Polypodium* (3.4-2.9%). These two samples show *Gloeotrichia* algae (3.4-2.9%). The fungi are mainly hyphae (36.2-31,0%) as well as *Glomus* sp. (14.5-13.8%) and some *Polyadosporites* (10.3-2.9%). They are distinguished by the identification of certain fungi : G18-1278 contains EMA-33 (3.4%) while F19-1282 contains of *Dyscomycetes* (1.4%) and HdV-51 (1.4%). They are also distinguished by the frequency and taxonomic identification of animal microorganisms. They both contain HdV-52(18,8-6,9%). In sample G18-1278, HDV-36c (3.4%) as well as other organisms of animal origin (3.4 %) are identified. F19-1282 has some traces of HdV-36 (1.4%). The particularity of sample F19-1282 is also the presence of microorganisms of unknown ecological origin, in which stomata could be identified (0.9%). However, they both contain Protists (36,4-30,1%), HdV-303 (9,1-6,2%) and *Pseudoschizaea* (1.8%).

4.4. Cluster analysis of the Pollen and NPPs from the sub-layer 3.4.a.

The pollen spectra identified in all the samples should be identical because of their contemporary origin, however, the cluster analysis shows distinct groups and their significant dissimilarities comes from the lack of conservation of pollen caused by destructive processes. For this reason, we also considered the NPP elements in order to establish different diagenetic

and preservation patterns, due to their local distribution. Naturally, the expected results involved the entailment of samples from similar structures that we supposed to have had a similar diagenetic history.

4.4.1. Cluster analysis of the Pollen from the layer 3.4.a. of Vallone Inferno

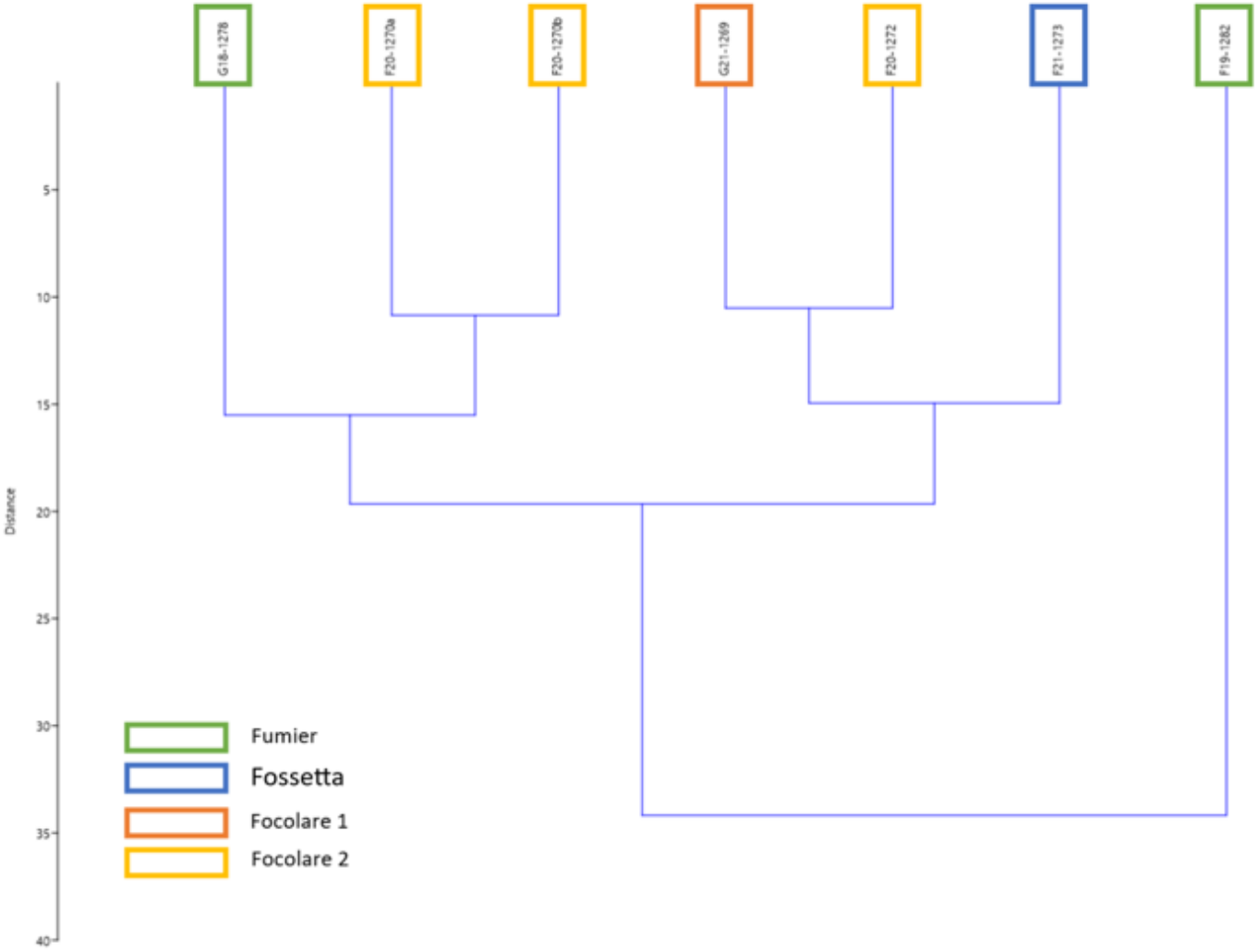

Figure 13 : Cluster analysis with Euclidean distances of the pollen from the layer 3.4.a. of Vallone Inferno

Erreur ! Source du renvoi introuvable. shows the results of the cluster analysis of pollens from the layer 3.4.A of Vallone Inferno. Two main groups are identifiable within this tree, separating sample F19-1282 (*fumier*) from the rest of the other samples. Within a second group a subdivision of two groups is visible with F20-1270a, F20-1270b and G18-1278 then G21-1269, F20-1272 and F21-1273. Within each subdivided group, the samples with the greatest

affinities are F20-1270a and F20-1270b from Focolare 1, and G21-1269 and F20-1272, from Focolare 1 and Focolare 2 respectively.

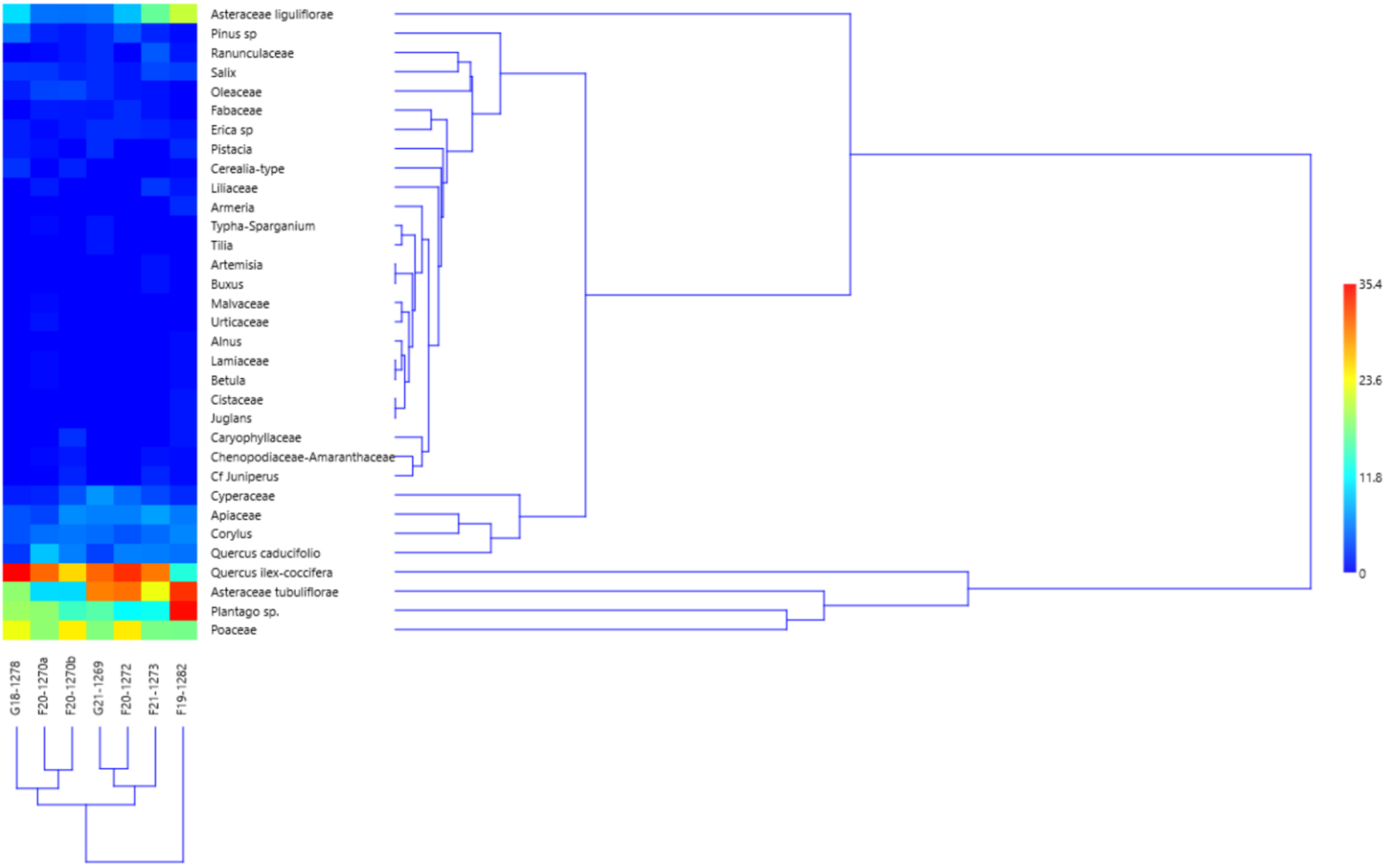

Figure 14 : Two-way hierarchical clustering analysis with Euclidean distance of pollens present in layer 3.4.a of Vallone Inferno

Two-way hierarchical clustering analysis shows similarity groups within pollens (**Erreur ! Source du renvoi introuvable.**). Four main groups emerge from this tree: The first group is made up of evergreen *Quercus*, Asteraceae tubuliflorae, *Plantago* sp. and Poaceae. The second group consists of an isolated taxon, the Asteraceae liguliflorae. The third group comprises

Cyperaceae, deciduous *Quercus*, *Corylus* and Apiaceae. Finally, the fourth group includes *Pinus* sp., Ranunculaceae, *Salix*, Oleaceae, Fabaceae, *Erica* sp., *Pistacia*, Cerealia-type, Liliaceae, *Armeria*, *Typha-Sparganium*, *Tilia*, *Artemisia*, *Buxus*, Malvaceae, Urticaceae, *Alnus*, Lamiaceae, *Betula*, Cistaceae, *Juglans*, Caryophyllaceae, Chenopodiaceae-Amaranthaceae and cf *Juniperus*.

No common clustering is observed between the samples cluster analysis and the taxa cluster analysis (**Erreur ! Source du renvoi introuvable.**). However, the first groups with *Quercus*, Asteraceae tubuliflorae, *Plantago* sp. and Poaceae as well as Asteraceae liguliflorae seem to have the greatest impact on sample hierarchy. Samples from the group of F20-1270a, F20-1270b and G18-1278 and the group of G21-1269, F20-1272 and F21-1273 share moderately abundant P*lantago* sp., Poaceae and wild grasses. They also all have a high proportion of evergreen *Quercus*. The difference between these two groups lies in the Asteraceae tubuliflorae : the group of F20-1270a, F20-1270b and G18-1278 has a low proportion compared to the group of G21-1269, F20-1272 and F21-1273. Within these two groups, the greatest difference appears to be in Asteraceae liguliflorae. G18-1278 has a higher proportion of Asteraceae liguliflorae than F20-1270a and F20-1270b. This sample also has a higher proportion of Asteraceae tubuliflorae than the other two samples. F21-1273 has a higher percentage of Asteraceae liguliflorae compared to G21-1269 and F20-1272. On the contrary, the proportion of Asteraceae tubuliflorae is slightly lower in sample F21-1273 than in samples G21-1269 and F20-1272. The sample F19-1282 contains many different factors. Asteraceae tubuliflorae and *Plantago* sp. are very abundant. Asteraceae liguliflorae is also high compared to the other samples. Evergreen *Quercus*, on the other hand, is very low in proportions.

To summarise, the samples do not show a significant pollen spectrum difference between one another because of their contemporaneity. The differences are limited to the presence or absence of some low abundant taxon or set of taxa. The cluster seems to have grouped in function of the abundance of various taxa. However, as the samples have different origins and, therefore suffer from different taphonomical processes, this grouping does not seem significant. Despite this, the most different sample seems to be F19-1282, as we highlighted before in the cluster analysis, due to its abundant value of *Plantago* sp. and Asteraceae tubuliflorae as well as its low representation of evergreen *Quercus*. Those taxa are associated with *fumier* or sheepfold contexts.

4.4.2. Cluster analysis of the NPPs from the sub-layer 3.4.a.

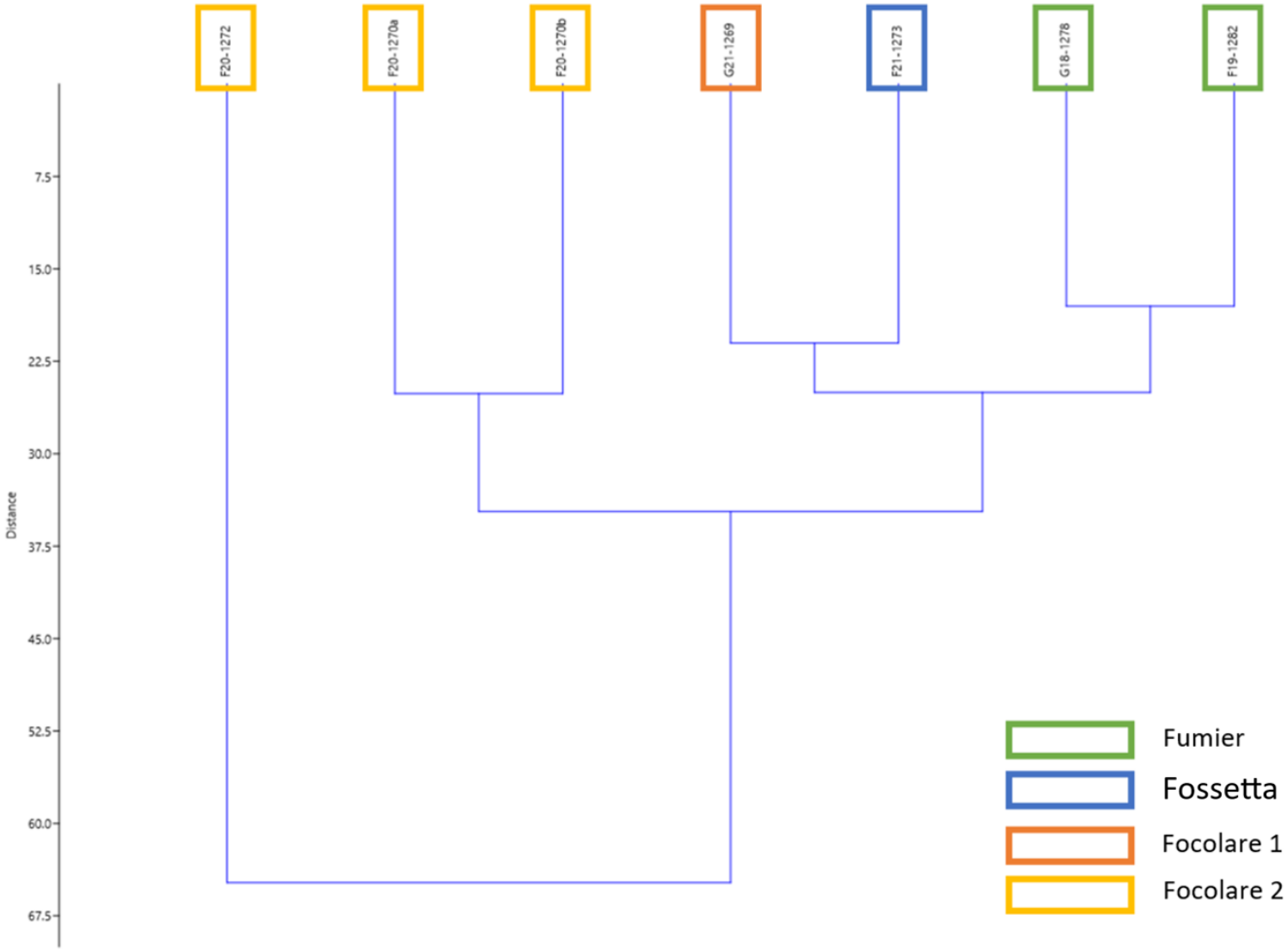

Figure 15 : Cluster analysis with euclidiean of NPPs from the layer 3.4.a. of Vallone Inferno

The results of cluster analysis of NPPs from layer 3.4.A. of Vallone Inferno show two main groups separating sample F20-1272 from Focolare 2 from the other samples (**Erreur ! Source**

du renvoi introuvable.). The second group is subdivided into two, grouping samples F20-1270a and F20-1270b from Focolare 2 and samples G18-1278, F19-1282, G21-1269 and F21-1273. Within the latter group, two other groups stand out: G18-1278 and F19-1282 from the *fumier*, and G21-1269 and F21-1273 from Focolare 1 and Fossetta.

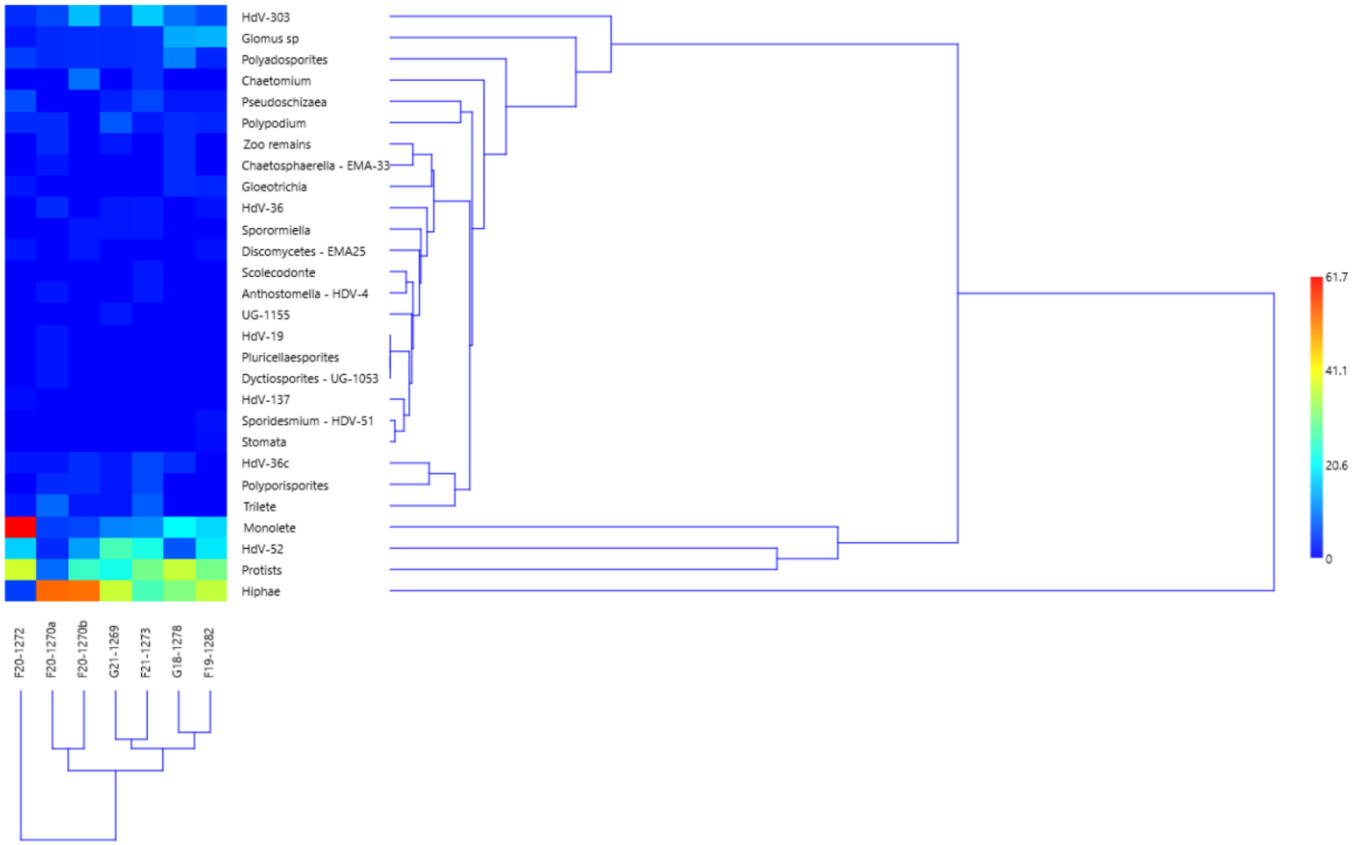

Figure 16 : Two-way hierarchical clustering analysis with Euclidean distance of NPPs present in layer 3.4.a. of Vallone Inferno

Cluster analysis of the NPPs shows the presence of two main groups, separating the hyphae from the other NPPs (

Figure 16 : Two-way hierarchical clustering analysis with Euclidean distance of NPPs present in layer 3.4.a. of Vallone Inferno

). The second group can be subdivided in two other groups, by grouping Protists, HdV-52 and Monolete spores and another group of HdV-303, *Glomus* sp., *Polyadosporites*, *Chaetonium*, *Pseudoschizaea*, *Polypodium*, Zoo remains, *Chaetosphaerella*, *Gloetrichia*, HdV-36, *Sporormiella*, EMA-25, *Scolecodonte*, HdV-4, UG-155, HdV-19, *Pluricellaesporites*, UG-1053, HdV-137, HdV-51, Stomata, HdV-36c, *Polyporisporites* and Trilete spores.

As seen in the diagram of NPPs (

Figure 16 : Two-way hierarchical clustering analysis with Euclidean distance of NPPs present in layer 3.4.a. of Vallone Inferno

Figure 16 : Two-way hierarchical clustering analysis with Euclidean distance of NPPs present in layer 3.4.a. of Vallone Inferno

), F20-1272 appears atypical compared to the other samples. It has a higher composition of monolete spores, indicating a humid environment, of Gloetrichia, present in oligotrophic environments, and of other pteridophyte taxa. It shows no markers typical of a burnt sample, but signs of intense erosion and some fungal activity. Its taphonomic history appears to be different from that of the other Focolare 2 samples. Thus, this sample may not have come from Focolare 2, or the erosive elements may have destroyed traces of the agent naturally present in the hearths and then been colonized by ferns and mosses.

The elements from Focolare 2 (F20-1270a and F20-1270b) have a high hyphae composition, which could indicate the growth of fungi in the charcoal present in the fireplace. Indeed, the NPPs diagram (Figure 12 : diagram of the relative frequencies of NPPs in the sub-layer 3.4.a. (Vallone Inferno). Points indicate frequencies below 2%. The line graph depicts the palynological concentration PC.

) had shown that these samples were composed of numerous fungi such as UG-1053, HDV-4, *Pluricellaesporites*, EMA-33, HdV-19, UG-1053 as well as coprophilous *Chaetonium* and *Sporormiella* fungi.

Similarly, sample G21-1269 Focolare 1 and sample F21-1273 from the Fossetta and samples G18-1278 and F19-1282 from the *Fumier* have a high composition of hyphae and fungi including *Sporormiella*, *Polyporisporites*, *Polyadosporites* and *Chaetonium*, *Dyscomycetes*

which may be attributed to a high colonization activity of saprophytic fungi in the coals, detrital elements of the Fossetta and defecatory elements of the *Fumier*. The presence of a high composition of Zooremains also indicates a high level of decomposing organic matter. Their taphonomic history could therefore be similar to the other two samples F20-1270a and F20-1270b from Focolare 2. However, the samples from Focolare 1, Fossetta and *Fumier* seem to be marked by current erosive activity and recolonization by pteridophytes. These activities are more marked in the *Fumier* samples and can be favored by the oligotrophic area, highlighted by the presence of the algae *Gloeotrichia.* The rich nutriments can be linked to the decomposition of defecatory elements induced by fungi.

4.5. Correlation analysis of the Pollen and NPPs from the sub-layer 3.4.a.

The correlation analysis (CA) aims to identify the links between the taxa of pollen and NPPs found in the environments in layer 3.4.a. In this study, a first CA has been released on pollen (CA1) and a second on NPPs (CA 2). A third CA has been realised on pollen et NPPs together (CA3) to observe the links between them. The negative correlations (more than -40) are written in red. The positive correlations are highlighted in colour (Blue for PollenxPollen, orange for NPPsxNPPs and Green for NPPsxPollen). A gradient of color intensity shows, from light to dark, the increase of cc

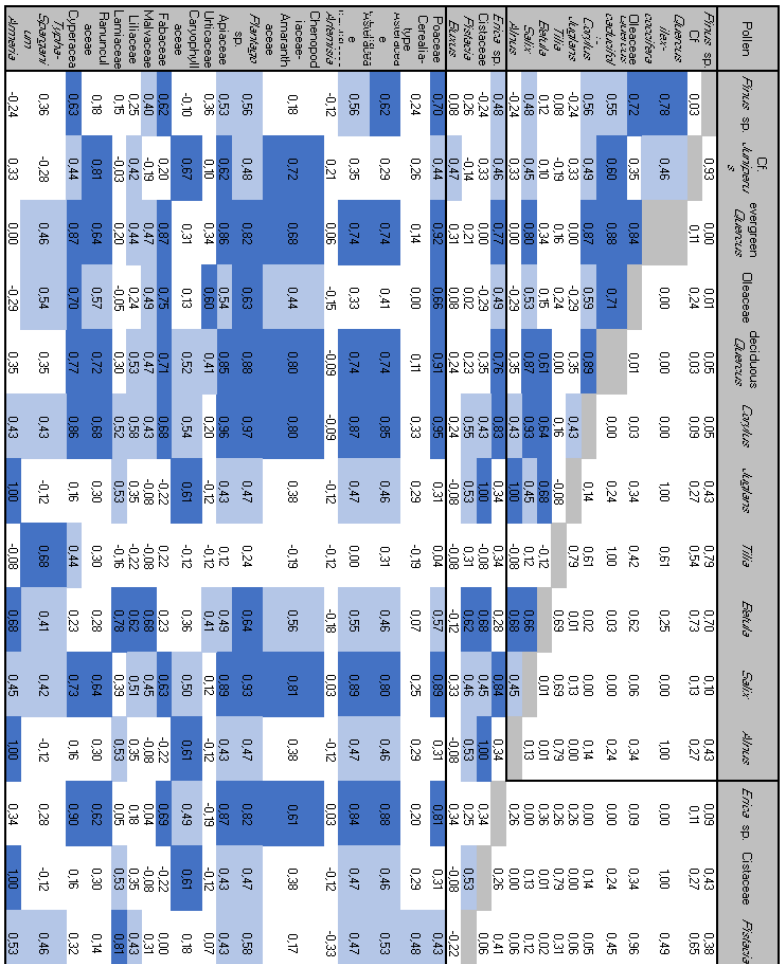

Figure 17: Correlation analysis with Spearman's distances of the pollen from the layer 3.4.a. of Vallone Inferno (CA1)

Protists	Stomata	HdV-137	*Gloeomichia*	Hiphae	*Polyporisporites*	*Polyadosporites*	*Glomus* sp.	*Discomycetes - EMA25*	*Chaetomium*	*Sporormiella*	*Dictiosporites - UG-1053*	*Pluricellaesporites*	*Anthostomella - HDV-4*	*Chaetosphaerella - EMA-33*	*Sporidesmium - HDV-51*	UG-1155	HdV-19	HdV-52	HdV-36	HdV-36c	Zoo remains	*Scolecodonte*
0,07	0,30	0,11	0,03	0,12	0,89	0,04	0,65	0,15	0,97	0,94	0,70	0,70	0,93	0,93	0,30	0,61	0,19	0,01	0,93	0,56	0,80	0,17
0,47	0,47	0,38	0,66	0,26	0,00	0,10	0,06	0,52	0,07	0,33	0,06	0,06	0,01	0,45	0,47	0,38	0,54	0,13	0,17	0,06	0,53	0,59
0,88	0,61	0,61	0,60	0,34	0,90	0,84	0,94	0,94	0,26	0,94	0,61	0,61	0,85	0,85	0,61	0,10	0,57	0,39	0,90	0,35	0,90	0,50
0,00	0,44	0,80	0,58	0,79	0,15	0,10	0,52	0,33	0,05	0,32	0,80	0,80	0,34	1,00	0,44	0,80	0,40	0,16	0,35	0,07	0,38	0,93
0,01	0,35	0,09	0,08	0,77	0,90	0,03	0,44	0,35	0,95	0,89	0,28	0,28	0,85	0,49	0,35	0,35	0,54	0,00	0,37	0,25	0,96	0,27
	0,19	0,11	0,03	0,85	0,76	0,01	0,28	0,02	0,27	0,68	0,30	0,30	1,00	0,58	0,19	0,80	0,93	0,01	0,72	0,15	0,33	0,85
0,39		0,79	0,02	0,45	0,54	0,69	0,29	0,06	0,69	0,45	0,79	0,79	0,69	0,69	0,00	0,79	0,69	0,19	0,39	0,21	0,54	0,69
0,46	-0,08		0,10	0,30	0,54	0,12	0,18	0,06	0,69	0,45	0,79	0,79	0,69	0,69	0,79	0,79	0,69	0,44	0,39	0,89	0,54	0,69
0,59	0,63	0,47		0,86	0,23	0,03	0,82	0,03	0,45	0,14	0,61	0,61	0,45	0,45	0,02	0,61	0,45	0,31	0,71	0,47	0,86	0,45
0,06	0,23	-0,31	-0,06		0,11	0,41	0,96	0,63	0,42	0,58	0,19	0,19	0,34	0,45	0,45	0,61	0,65	0,11	0,15	0,21	0,28	0,25
0,09	-0,19	-0,19	-0,36	0,46		0,36	0,23	0,92	0,01	0,09	0,15	0,15	0,00	0,57	0,54	0,35	0,65	0,18	0,13	0,03	0,57	0,36
0,70	0,12	0,45	0,61	0,25	0,28		0,29	0,13	0,55	0,66	0,69	0,69	0,55	0,15	0,69	0,69	0,55	0,03	0,46	0,05	0,50	0,84
-0,32	0,32	-0,40	0,07	-0,01	-0,36	-0,32		0,62	0,44	0,03	0,60	0,60	0,44	0,92	0,29	0,60	0,97	0,48	0,34	0,20	0,12	0,44
0,63	0,53	0,53	0,60	0,15	0,03	0,44	-0,15		0,30	0,85	0,61	0,61	0,44	0,44	0,06	0,61	0,44	0,09	0,59	0,93	0,23	0,44
0,33	-0,12	-0,12	-0,23	0,24	0,72	0,18	-0,23	0,31		0,06	0,69	0,69	0,22	0,55	0,69	0,69	0,55	0,26	0,92	0,02	0,36	0,22
0,13	-0,23	-0,23	-0,43	0,17	0,49	-0,13	-0,61	-0,06	0,54		0,45	0,45	0,74	0,26	0,45	0,22	0,26	0,40	0,64	0,29	0,55	0,74
-0,31	-0,08	-0,08	-0,16	0,39	0,42	0,12	-0,16	-0,16	-0,12	-0,23		0,00	0,01	0,01	0,79	0,79	0,03	0,52	0,07	0,89	0,10	0,69
-0,31	-0,08	-0,08	-0,16	0,39	0,42	0,12	-0,16	-0,16	-0,12	-0,23	1,00		0,01	0,01	0,79	0,79	0,03	0,52	0,07	0,89	0,10	0,69
0,00	-0,12	-0,12	-0,23	0,29	0,73	0,18	-0,23	-0,23	0,36	0,10	0,68	0,68		0,17	0,69	0,69	0,22	0,78	0,04	0,18	0,49	0,17
-0,17	-0,12	-0,12	0,23	0,23	0,17	0,42	-0,03	-0,23	-0,18	-0,34	0,68	0,68	0,41		0,69	0,69	0,22	0,34	0,53	0,84	0,03	0,55
0,39	1,00	-0,08	0,63	0,23	-0,19	0,12	0,32	0,53	-0,12	-0,23	-0,08	-0,08	-0,12	-0,12		0,79	0,69	0,19	0,39	0,21	0,54	0,69
-0,08	-0,08	-0,08	-0,16	0,15	0,28	0,12	-0,16	-0,16	-0,12	0,37	-0,08	-0,08	-0,12	-0,12	-0,08		0,69	0,11	0,39	0,89	0,27	0,69
-0,03	-0,12	-0,12	-0,23	0,14	0,14	0,18	-0,01	-0,23	-0,18	-0,34	0,61	0,61	0,36	0,36	-0,12	-0,12		0,74	0,05	0,28	0,58	0,55
0,67	0,39	0,23	0,30	0,47	0,40	0,60	-0,22	0,49	0,33	0,26	-0,19	-0,19	0,09	-0,29	0,39	0,47	-0,10		0,17	0,09	0,89	0,39
0,11	0,26	-0,26	-0,11	0,43	0,44	0,23	-0,29	-0,16	-0,03	0,14	0,52	0,52	0,58	0,19	0,26	0,26	0,56	0,40		0,31	0,08	1,00
0,42	-0,37	0,04	-0,22	0,37	0,60	0,55	-0,38	0,03	0,63	0,32	0,04	0,04	0,40	0,06	-0,37	0,04	0,32	0,49	0,31		0,76	0,18
-0,30	-0,19	-0,19	-0,05	0,33	0,17	0,21	-0,45	-0,36	-0,28	0,18	0,47	0,47	0,21	0,59	-0,19	0,33	0,17	-0,04	0,50	0,09		0,36
0,06	-0,12	-0,12	-0,23	0,34	0,28	-0,06	0,23	-0,23	0,36	0,10	-0,12	-0,12	0,41	-0,18	-0,12	-0,12	-0,18	0,26	0,00	0,40	-0,28	

Figure 18: Correlation analysis with Spearman's distances of the NPPs from the layer 3.4.a. of Vallone Inferno (CA2)

NPP & Pollen	Pinus sp	Cf Juniperus	Quercus ilex-coccifera	Oleaceae	Quercus caducifolio	Corylus	Juglans	Tilia	Betula	Salix	Alnus	Erica sp	Cistaceae	Pistacia	Buxus
Pinus sp		0,93	0,00	0,01	0,05	0,05	0,43	0,79	0,70	0,10	0,43	0,09	0,43	0,38	0,79
Cf Juniperus	0,03		0,11	0,24	0,03	0,09	0,27	0,54	0,73	0,13	0,27	0,11	0,27	0,65	0,10
Quercus ilex coccifera	0,78	0,46		0,00	0,00	0,00	1,00	0,61	0,25	0,00	1,00	0,00	1,00	0,49	0,30
Oleaceae	0,72	0,35	0,84		0,01	0,03	0,34	0,42	0,62	0,06	0,34	0,09	0,34	0,96	0,79
Quercus caducifolio	0,55	0,60	0,88	0,71		0,00	0,24	1,00	0,03	0,00	0,24	0,00	0,24	0,45	0,44
Corylus	0,56	0,49	0,87	0,59	0,89		0,14	0,61	0,02	0,00	0,14	0,00	0,14	0,05	0,44
Juglans	-0,24	0,33	0,00	-0,29	0,35	0,43		0,79	0,01	0,13	0,00	0,26	0,00	0,06	0,79
Tilia	0,08	-0,19	0,16	0,24	0,00	0,16	-0,08		0,69	0,69	0,79	0,26	0,79	0,31	0,79
Betula	0,12	0,10	0,34	0,15	0,61	0,64	0,68	-0,12		0,01	0,01	0,36	0,01	0,02	0,69
Salix	0,48	0,45	0,80	0,53	0,87	0,93	0,45	0,12	0,66		0,13	0,00	0,13	0,12	0,28
Alnus	-0,24	0,33	0,00	-0,29	0,35	0,43	1,00	-0,08	0,68	0,45		0,26	0,00	0,06	0,79
Erica sp	0,48	0,46	0,77	0,49	0,76	0,83	0,34	0,34	0,28	0,84	0,34		0,26	0,41	0,26
Cistaceae	-0,24	0,33	0,00	-0,29	0,35	0,43	1,00	-0,08	0,68	0,45	1,00	0,34		0,06	0,79
Pistacia	0,26	-0,14	0,21	0,02	0,23	0,55	0,53	0,31	0,62	0,46	0,53	0,25	0,53		0,47
Buxus	0,08	0,47	0,31	0,08	0,24	0,24	-0,08	-0,08	-0,12	0,33	-0,08	0,34	-0,08	-0,22	
Poaceae	0,70	0,44	0,92	0,66	0,91	0,95	0,31	0,04	0,57	0,89	0,31	0,81	0,31	0,43	0,15
Cerealia-type	0,24	0,26	0,14	0,00	0,11	0,33	0,29	-0,19	0,07	0,25	0,29	0,20	0,29	0,48	-0,19
Asteraceae tubuliflorae	0,62	0,29	0,74	0,41	0,74	0,85	0,46	0,31	0,46	0,80	0,46	0,88	0,46	0,53	0,23
Asteraceae liguliflorae	0,56	0,35	0,74	0,33	0,74	0,87	0,47	0,00	0,55	0,89	0,47	0,84	0,47	0,47	0,39
Artemisia	-0,12	0,21	0,06	-0,15	-0,09	-0,09	-0,12	-0,12	-0,18	0,03	-0,12	0,03	-0,12	-0,33	0,68
Chenopodiaceae-Amaranthaceae	0,18	0,72	0,68	0,44	0,80	0,80	0,38	-0,19	0,56	0,81	0,38	0,61	0,38	0,17	0,38
Plantago	0,56	0,48	0,82	0,63	0,88	0,97	0,47	0,24	0,64	0,93	0,47	0,82	0,47	0,58	0,12
Apiaceae	0,53	0,62	0,86	0,54	0,85	0,96	0,43	0,12	0,49	0,89	0,43	0,87	0,43	0,43	0,31
Urticaceae	0,36	0,10	0,34	0,60	0,41	0,20	-0,12	-0,12	0,41	0,12	-0,12	-0,19	-0,12	0,07	-0,12
Caryophyllaceae	-0,10	0,67	0,31	0,13	0,52	0,54	0,61	-0,12	0,36	0,50	0,61	0,49	0,61	0,18	-0,12
Fabaceae	0,62	0,20	0,87	0,75	0,71	0,68	-0,22	0,22	0,23	0,63	-0,22	0,69	-0,22	0,00	0,22
Malvaceae	0,40	-0,19	0,47	0,49	0,47	0,43	-0,08	-0,08	0,68	0,45	-0,08	0,04	-0,08	0,31	-0,08
Liliaceae	0,25	0,42	0,44	0,24	0,53	0,58	0,35	-0,22	0,62	0,51	0,35	0,18	0,35	0,43	0,49
Lamiaceae	0,15	-0,03	0,20	-0,05	0,30	0,52	0,53	-0,16	0,78	0,39	0,53	0,05	0,53	0,81	-0,16
Ranunculaceae	0,18	0,81	0,64	0,57	0,72	0,68	0,30	0,30	0,28	0,64	0,30	0,62	0,30	0,14	0,51
Cyperaceae	0,63	0,44	0,87	0,70	0,77	0,86	0,16	0,44	0,23	0,73	0,16	0,90	0,16	0,32	0,16
Typha-Sparganium	0,36	-0,28	0,46	0,54	0,35	0,43	-0,12	0,68	0,41	0,42	-0,12	0,28	-0,12	0,46	-0,12
Armeria	-0,24	0,33	0,00	-0,29	0,35	0,43	1,00	-0,08	0,68	0,45	1,00	0,34	1,00	0,53	-0,08
Indeterminables	0,62	0,32	0,77	0,54	0,80	0,91	0,46	0,31	0,63	0,90	0,46	0,78	0,46	0,67	0,15
Monolete	0,62	0,16	0,49	0,18	0,36	0,57	0,31	0,16	0,14	0,40	0,31	0,58	0,31	0,53	0,16
Trilete	0,58	0,24	0,86	0,72	0,70	0,69	-0,22	0,27	0,23	0,68	-0,22	0,69	-0,22	0,02	0,44
Polypodium	0,23	-0,39	0,18	-0,08	-0,05	0,27	0,16	0,48	0,23	0,19	0,16	0,23	0,16	0,61	-0,08
HdV-303	0,06	0,46	0,35	0,09	0,45	0,33	0,23	-0,08	0,11	0,50	0,23	0,50	0,23	-0,15	0,47
Pseudoschizaea	0,37	0,18	0,31	0,04	0,30	0,35	0,28	0,28	-0,03	0,29	0,28	0,57	0,28	0,21	0,40
Protists	0,29	0,41	0,40	0,04	0,48	0,39	0,39	-0,08	0,06	0,42	0,39	0,65	0,39	-0,03	0,31
Stomata	-0,24	0,33	0,00	-0,29	0,35	0,43	1,00	-0,08	0,68	0,45	1,00	0,34	1,00	0,53	-0,08
HdV-137	0,40	-0,19	0,23	0,08	0,16	0,08	-0,08	-0,08	-0,12	0,00	-0,08	0,34	-0,08	-0,22	-0,08
Gloeotrichia	0,29	0,02	0,13	-0,11	0,30	0,34	0,63	-0,16	0,35	0,39	0,63	0,46	0,63	0,36	-0,16
Hiphae	0,46	0,36	0,59	0,46	0,53	0,71	0,23	0,15	0,46	0,52	0,23	0,32	0,23	0,68	0,00
Polyporisporites	0,36	0,46	0,77	0,67	0,63	0,65	-0,19	0,28	0,17	0,67	-0,19	0,59	-0,19	0,03	0,57
Polyadosporites	0,75	0,12	0,65	0,46	0,63	0,59	0,12	0,12	0,18	0,63	0,12	0,72	0,12	0,24	0,12
Glomus sp	-0,52	-0,28	-0,60	-0,71	-0,48	-0,22	0,32	-0,16	0,12	-0,18	0,32	-0,34	0,32	0,40	-0,16
Discomycetes - EMA25	0,15	0,45	0,39	0,13	0,55	0,52	0,53	-0,16	0,27	0,44	0,53	0,64	0,53	0,06	-0,16
Chaetomiu	0,12	0,77	0,52	0,38	0,44	0,41	-0,12	-0,12	-0,18	0,41	-0,12	0,49	-0,12	-0,32	0,61
Sporormiella	0,04	0,54	0,34	0,42	0,17	0,11	-0,23	0,37	-0,34	0,07	-0,23	0,23	-0,23	-0,31	0,37
Dyctiosporites - UG-Pluricellaesporites	0,40	-0,19	0,47	0,49	0,47	0,43	-0,08	-0,08	0,68	0,45	-0,08	0,04	-0,08	0,31	-0,08
Anthostomella - HDV-4	0,36	0,21	0,57	0,42	0,52	0,49	-0,12	-0,12	0,41	0,57	-0,12	0,28	-0,12	0,07	0,68
Chaetosphaerella - EMA	0,59	-0,28	0,34	0,42	0,29	0,29	-0,12	-0,12	0,41	0,42	-0,12	0,06	-0,12	0,36	-0,12
Sporidesmium - HDV-51	-0,24	0,33	0,00	-0,29	0,35	0,43	1,00	-0,08	0,68	0,45	1,00	0,34	1,00	0,53	-0,08
UG-1155	0,08	-0,19	0,16	0,24	0,00	0,16	-0,08	1,00	-0,12	0,12	-0,08	0,34	-0,08	0,31	-0,08
HdV-19	0,08	-0,28	0,07	0,11	0,20	0,01	-0,12	-0,12	0,36	0,08	-0,12	-0,20	-0,12	0,03	-0,12
HdV-52	0,32	0,45	0,55	0,26	0,56	0,66	0,39	0,47	0,14	0,55	0,39	0,78	0,39	0,35	0,31
HdV-36	0,17	0,23	0,41	0,39	0,58	0,46	0,26	0,26	0,58	0,48	0,26	0,23	0,26	0,31	0,26
HdV-36c	0,51	0,40	0,57	0,51	0,43	0,33	-0,37	0,04	-0,24	0,28	-0,37	0,36	-0,37	-0,18	0,50
Zoo remains	0,53	-0,07	0,36	0,68	0,30	0,21	-0,19	0,33	0,21	0,19	-0,19	0,00	-0,19	0,27	-0,19
Scolecodon	0,12	0,21	0,11	-0,15	-0,09	0,14	-0,12	-0,12	-0,18	0,03	-0,12	0,03	-0,12	0,16	0,68

Figure 19 : Correlation analysis with Spearman's distances of the pollen and NPP from the layer 3.4.a. of Vallone Inferno (CA3) (1st Part)

NPP & Pollen	Poaceae	Cerealia-type	Asteraceae tubuliflorae	Asteraceae liguliflorae	Artemisia	Chenopodiaceae-Amaranthaceae	Plantago sp.	Apiaceae	Urticaceae	Caryophyllaceae	Fabaceae	Malvaceae	Liliaceae	Lamiaceae	Ranunculaceae
Pinus sp	0,01	0,43	0,02	0,05	0,70	0,55	0,05	0,06	0,23	0,74	0,02	0,17	0,41	0,62	0,55
Cf Juniperus	0,13	0,39	0,34	0,24	0,49	0,01	0,10	0,02	0,73	0,01	0,51	0,54	0,16	0,92	0,00
Quercus ilex coccifera	0,00	0,64	0,00	0,00	0,85	0,01	0,00	0,00	0,25	0,31	0,00	0,11	0,13	0,52	0,02
Oleaceae	0,01	1,00	0,16	0,28	0,62	0,14	0,02	0,06	0,03	0,67	0,00	0,09	0,43	0,87	0,04
Quercus caducifolio	0,00	0,73	0,00	0,00	0,78	0,00	0,00	0,00	0,17	0,07	0,01	0,11	0,06	0,32	0,01
Corylus	0,00	0,27	0,00	0,00	0,78	0,00	0,00	0,00	0,51	0,06	0,01	0,14	0,04	0,07	0,01
Juglans	0,30	0,35	0,11	0,11	0,69	0,20	0,11	0,14	0,69	0,03	0,47	0,79	0,24	0,06	0,32
Tilia	0,90	0,53	0,30	1,00	0,69	0,53	0,44	0,70	0,69	0,69	0,47	0,79	0,47	0,61	0,32
Betula	0,04	0,82	0,12	0,05	0,55	0,05	0,02	0,09	0,17	0,22	0,45	0,01	0,02	0,00	0,35
Salix	0,00	0,42	0,00	0,00	0,92	0,00	0,00	0,00	0,70	0,08	0,02	0,13	0,08	0,19	0,02
Alnus	0,30	0,35	0,11	0,11	0,69	0,20	0,11	0,14	0,69	0,03	0,47	0,79	0,24	0,06	0,32
Erica sp	0,00	0,52	0,00	0,00	0,92	0,03	0,00	0,00	0,54	0,09	0,01	0,89	0,55	0,86	0,03
Cistaceae	0,30	0,35	0,11	0,11	0,69	0,20	0,11	0,14	0,69	0,03	0,47	0,79	0,24	0,06	0,32
Pistacia	0,15	0,10	0,06	0,11	0,28	0,58	0,04	0,14	0,83	0,55	1,00	0,31	0,15	0,00	0,64
Buxus	0,61	0,53	0,45	0,19	0,01	0,20	0,70	0,30	0,69	0,69	0,47	0,79	0,09	0,61	0,07
Poaceae		0,24	0,00	0,00	0,78	0,00	0,00	0,00	0,45	0,07	0,00	0,11	0,10	0,13	0,05
Cerealia-type	0,35		0,50	0,32	0,35	0,35	0,21	0,17	0,35	0,04	0,69	0,53	0,95	0,23	1,00
Asteraceae tubuliflorae	0,83	0,20		0,00	0,93	0,12	0,00	0,00	1,00	0,29	0,05	0,61	0,17	0,25	0,06
Asteraceae liguliflorae	0,86	0,30	0,89		0,57	0,02	0,00	0,00	0,85	0,20	0,05	0,36	0,08	0,15	0,11
Artemisia	-0,09	-0,28	-0,03	0,17		0,65	0,57	0,85	0,55	0,55	1,00	0,69	0,52	0,44	0,54
Chenopodiaceae-Amaranthaceae	0,76	0,28	0,45	0,65	0,14		0,00	0,00	0,65	0,01	0,05	0,20	0,06	0,23	0,01
Plantago	0,92	0,37	0,83	0,82	-0,17	0,74		0,00	0,45	0,04	0,03	0,19	0,09	0,13	0,01
Apiaceae	0,93	0,40	0,84	0,88	0,06	0,81	0,92		0,85	0,02	0,02	0,44	0,08	0,18	0,01
Urticaceae	0,23	-0,28	0,00	-0,06	-0,18	0,14	0,23	0,06		0,55	0,45	0,01	0,07	0,37	0,35
Caryophyllaceae	0,52	0,57	0,32	0,38	-0,18	0,71	0,57	0,63	-0,18		0,59	0,69	0,83	0,44	0,13
Fabaceae	0,75	-0,12	0,55	0,55	0,00	0,56	0,59	0,65	0,23	0,16		0,06	0,53	0,86	0,16
Malvaceae	0,46	-0,19	0,15	0,27	-0,12	0,38	0,39	0,23	0,68	-0,12	0,53		0,09	0,06	0,78
Liliaceae	0,47	0,02	0,40	0,51	0,20	0,54	0,49	0,50	0,52	0,06	0,19	0,49		0,01	0,04
Lamiaceae	0,44	0,36	0,34	0,42	-0,23	0,36	0,45	0,39	0,27	0,23	0,06	0,53	0,67		0,79
Ranunculac	0,55	0,00	0,53	0,46	0,19	0,68	0,69	0,71	0,28	0,44	0,41	0,09	0,56	0,08	
Cyperaceae	0,85	0,24	0,83	0,70	-0,15	0,56	0,84	0,87	0,06	0,45	0,78	0,16	0,23	0,15	0,65
Typha-Sparganium	0,37	-0,28	0,34	0,20	-0,18	0,14	0,46	0,26	0,41	-0,18	0,55	0,68	0,20	0,27	0,28
Armeria	0,31	0,29	0,46	0,47	-0,12	0,38	0,47	0,43	-0,12	0,61	-0,22	-0,08	0,35	0,53	0,30
Indeterminables	0,86	0,32	0,89	0,84	-0,11	0,58	0,95	0,84	0,20	0,38	0,50	0,39	0,50	0,46	0,61
Monolete	0,57	0,40	0,81	0,68	-0,06	0,10	0,53	0,62	-0,09	0,12	0,25	-0,12	0,35	0,37	0,25
Trilete	0,71	-0,21	0,56	0,59	0,16	0,58	0,59	0,65	0,23	0,06	0,96	0,53	0,34	0,06	0,53
Polypodium	0,21	0,02	0,46	0,38	0,20	-0,13	0,22	0,25	-0,15	-0,17	0,16	0,16	0,14	0,43	-0,05
HdV-303	0,40	0,08	0,34	0,46	0,46	0,55	0,33	0,44	-0,29	0,40	0,24	-0,08	0,08	-0,17	0,39
Pseudoschizaea	0,32	-0,02	0,73	0,52	0,06	-0,04	0,32	0,39	-0,21	-0,06	0,15	-0,32	0,24	0,00	0,33
Protists	0,49	0,17	0,65	0,61	0,23	0,31	0,37	0,53	-0,34	0,38	0,23	-0,31	0,05	-0,10	0,28
Stomata	0,31	0,29	0,46	0,47	-0,12	0,38	0,47	0,43	-0,12	0,61	-0,22	-0,08	0,35	0,53	0,30
HdV-137	0,23	-0,19	0,39	0,27	-0,12	-0,19	0,00	0,12	-0,12	-0,12	0,40	-0,08	-0,22	-0,16	-0,26
Gloeotrichia	0,38	0,37	0,61	0,59	-0,23	0,06	0,41	0,36	-0,23	0,30	-0,06	-0,16	0,00	0,20	-0,08
Hiphae	0,66	0,53	0,47	0,43	-0,17	0,54	0,68	0,67	0,34	0,40	0,33	0,39	0,59	0,68	0,52
Polyporisporites	0,61	-0,05	0,38	0,47	0,28	0,72	0,58	0,64	0,17	0,21	0,78	0,42	0,39	0,03	0,70
Polyadosporites	0,70	0,28	0,76	0,68	-0,21	0,28	0,63	0,58	-0,06	0,18	0,51	0,12	0,06	0,03	0,21
Glomus sp	-0,34	0,41	-0,31	-0,16	-0,23	-0,11	-0,23	-0,27	-0,47	0,09	-0,56	-0,16	-0,04	0,40	-0,41
Discomycetes - EMA25	0,59	0,36	0,54	0,52	-0,23	0,48	0,50	0,62	-0,23	0,78	0,36	-0,16	-0,06	0,13	0,22
Chaetomiu	0,41	0,25	0,16	0,33	0,36	0,71	0,33	0,55	-0,18	0,50	0,46	-0,12	0,15	-0,23	0,58
Sporormiella	0,08	-0,16	0,06	-0,02	0,54	0,21	0,13	0,26	0,10	0,13	0,22	-0,23	0,02	-0,43	0,63
Dyctiosporites - UG-Pluricellaesporites	0,46	-0,19	0,15	0,27	-0,12	0,38	0,39	0,23	0,68	-0,12	0,53	1,00	0,49	0,53	0,09
	0,46	-0,19	0,15	0,27	-0,12	0,38	0,39	0,23	0,68	-0,12	0,53	1,00	0,49	0,53	0,09
Anthostomella - HDV-4	0,46	-0,28	0,29	0,49	0,41	0,56	0,38	0,40	0,41	-0,18	0,55	0,68	0,72	0,27	0,44
Chaetosphaerella - EMA	0,37	0,21	0,17	0,32	-0,18	0,14	0,38	0,14	0,41	-0,18	0,23	0,68	0,20	0,27	-0,13
Sporidesmium - HDV-51	0,31	0,29	0,46	0,47	-0,12	0,38	0,47	0,43	-0,12	0,61	-0,22	-0,08	0,35	0,53	0,30
UG-1155	0,04	-0,19	0,31	0,00	-0,12	-0,19	0,24	0,12	-0,12	-0,12	0,22	-0,08	-0,22	-0,16	0,30
HdV-19	0,10	-0,28	-0,11	-0,09	-0,18	0,11	-0,01	-0,15	0,36	-0,18	0,18	0,61	0,15	0,23	-0,14
HdV-52	0,59	0,17	0,81	0,59	-0,06	0,38	0,62	0,70	-0,20	0,39	0,40	-0,19	0,27	0,15	0,64
HdV-36	0,37	-0,37	0,39	0,27	0,00	0,37	0,47	0,32	0,58	-0,03	0,28	0,52	0,65	0,33	0,61
HdV-36c	0,41	0,12	0,27	0,23	0,09	0,35	0,26	0,37	0,06	0,04	0,48	0,04	0,19	-0,18	0,41
Zoo remains	0,21	-0,11	0,17	0,00	-0,28	-0,08	0,35	0,07	0,77	-0,28	0,17	0,47	0,24	0,06	0,28
Scolecodon	0,06	0,21	0,11	0,23	0,41	0,14	-0,03	0,20	-0,18	-0,18	0,00	-0,12	0,52	0,27	0,19

Figure 20 : Correlation analysis with Spearman's distances of the pollen and NPP from the layer 3.4.a. of Vallone Inferno (CA3) (2nd Part)

NPP & Pollen	Cyperaceae	Typha-Sparganium	Armeria	Indeterminables	Monolete	Trilete	Polypodium	HdV-303	Pseudoschizaea	Protists	Stomata	HdV-137	Gloeotrichia	Hiphae	Polyporisporites	Polyadosporites
Pinus sp	0,02	0,23	0,43	0,02	0,02	0,04	0,44	0,83	0,21	0,33	0,43	0,17	0,33	0,12	0,22	0,00
Cf Juniperus	0,13	0,36	0,27	0,29	0,59	0,42	0,19	0,11	0,57	0,17	0,27	0,54	0,95	0,22	0,11	0,69
Quercus ilex coccifera	0,00	0,12	1,00	0,00	0,09	0,00	0,57	0,24	0,30	0,17	1,00	0,44	0,66	0,03	0,00	0,02
Oleaceae	0,01	0,06	0,34	0,05	0,55	0,01	0,79	0,78	0,90	0,89	0,34	0,79	0,71	0,11	0,01	0,12
Quercus caducifolio	0,00	0,25	0,24	0,00	0,22	0,01	0,87	0,12	0,32	0,10	0,24	0,61	0,32	0,06	0,02	0,02
Corylus	0,00	0,14	0,14	0,00	0,04	0,01	0,37	0,27	0,24	0,18	0,14	0,80	0,26	0,01	0,02	0,03
Juglans	0,61	0,69	0,00	0,11	0,30	0,47	0,61	0,44	0,35	0,19	0,00	0,79	0,02	0,45	0,54	0,69
Tilia	0,14	0,01	0,79	0,30	0,61	0,38	0,10	0,80	0,35	0,80	0,79	0,79	0,61	0,61	0,35	0,69
Betula	0,44	0,17	0,01	0,02	0,64	0,45	0,44	0,71	0,92	0,85	0,01	0,69	0,24	0,12	0,57	0,55
Salix	0,00	0,15	0,13	0,00	0,17	0,01	0,54	0,08	0,33	0,15	0,13	1,00	0,18	0,07	0,01	0,02
Alnus	0,61	0,69	0,00	0,11	0,30	0,47	0,61	0,44	0,35	0,19	0,00	0,79	0,02	0,45	0,54	0,69
Erica sp	0,00	0,36	0,26	0,00	0,04	0,01	0,45	0,08	0,04	0,02	0,26	0,26	0,11	0,29	0,03	0,01
Cistaceae	0,61	0,69	0,00	0,11	0,30	0,47	0,61	0,44	0,35	0,19	0,00	0,79	0,02	0,45	0,54	0,69
Pistacia	0,28	0,12	0,06	0,01	0,06	0,95	0,03	0,63	0,48	0,91	0,06	0,47	0,23	0,01	0,92	0,42
Buxus	0,61	0,69	0,79	0,61	0,61	0,13	0,80	0,11	0,17	0,30	0,79	0,79	0,61	1,00	0,04	0,69
Poaceae	0,00	0,21	0,30	0,00	0,04	0,01	0,49	0,18	0,29	0,09	0,30	0,45	0,20	0,01	0,03	0,01
Cerealia-type	0,43	0,35	0,35	0,28	0,17	0,50	0,95	0,80	0,94	0,58	0,35	0,53	0,21	0,06	0,86	0,35
Asteraceae tubuliflorae	0,00	0,25	0,11	0,00	0,00	0,05	0,12	0,25	0,00	0,02	0,11	0,19	0,03	0,11	0,19	0,00
Asteraceae liguliflorae	0,01	0,51	0,11	0,00	0,01	0,03	0,20	0,11	0,07	0,03	0,11	0,36	0,03	0,14	0,10	0,01
Artemisia	0,63	0,55	0,69	0,71	0,85	0,59	0,50	0,11	0,85	0,45	0,69	0,69	0,45	0,58	0,36	0,49
Chenopodiaceae-Amaranthaceae	0,05	0,65	0,20	0,04	0,74	0,04	0,68	0,05	0,91	0,30	0,20	0,53	0,86	0,06	0,01	0,35
Plantago	0,00	0,11	0,11	0,00	0,06	0,03	0,46	0,28	0,29	0,21	0,11	1,00	0,17	0,01	0,04	0,02
Apiaceae	0,00	0,39	0,14	0,00	0,02	0,02	0,41	0,14	0,19	0,06	0,14	0,70	0,23	0,01	0,02	0,04
Urticaceae	0,85	0,17	0,69	0,51	0,78	0,45	0,63	0,34	0,49	0,25	0,69	0,69	0,45	0,25	0,57	0,84
Caryophyllaceae	0,12	0,55	0,03	0,20	0,70	0,85	0,57	0,17	0,84	0,19	0,03	0,69	0,32	0,17	0,49	0,55
Fabaceae	0,00	0,05	0,47	0,08	0,42	0,00	0,61	0,43	0,63	0,44	0,47	0,18	0,85	0,27	0,00	0,07
Malvaceae	0,61	0,01	0,79	0,19	0,70	0,06	0,61	0,80	0,28	0,30	0,79	0,79	0,61	0,19	0,15	0,69
Liliaceae	0,46	0,52	0,24	0,08	0,24	0,26	0,66	0,81	0,44	0,88	0,24	0,47	1,00	0,03	0,18	0,85
Lamiaceae	0,62	0,37	0,06	0,11	0,21	0,86	0,15	0,57	1,00	0,75	0,06	0,61	0,52	0,01	0,92	0,93
Ranunculac	0,02	0,35	0,32	0,03	0,40	0,06	0,88	0,19	0,27	0,36	0,32	0,40	0,79	0,07	0,01	0,49
Cyperaceae		0,13	0,61	0,00	0,02	0,00	0,36	0,41	0,10	0,12	0,61	0,29	0,41	0,05	0,02	0,02
Typha-Sparganium	0,44		0,69	0,07	0,93	0,03	0,11	0,71	0,92	0,35	0,69	0,69	0,45	0,18	0,07	0,55
Armeria	0,16	-0,12		0,11	0,30	0,47	0,61	0,44	0,35	0,19	0,00	0,79	0,02	0,45	0,54	0,69
Indeterminables	0,76	0,51	0,46		0,03	0,06	0,24	0,22	0,12	0,14	0,11	1,00	0,10	0,01	0,08	0,01
Monolete	0,63	0,03	0,31	0,60		0,42	0,07	0,96	0,00	0,07	0,30	0,11	0,03	0,12	0,89	0,04
Trilete	0,74	0,59	-0,22	0,54	0,24		0,54	0,32	0,46	0,47	0,47	0,38	0,66	0,26	0,00	0,10
Polypodium	0,28	0,47	0,16	0,35	0,52	0,19		0,57	0,37	0,88	0,61	0,61	0,60	0,34	0,90	0,84
HdV-303	0,25	-0,11	0,23	0,37	-0,01	0,30	-0,17		0,41	0,00	0,44	0,80	0,58	0,79	0,15	0,10
Pseudoschizaea	0,48	-0,03	0,28	0,46	0,77	0,22	0,27	0,25		0,01	0,35	0,09	0,08	0,77	0,90	0,03
Protists	0,45	-0,28	0,39	0,43	0,51	0,22	0,05	0,73	0,70		0,19	0,11	0,03	0,85	0,76	0,01
Stomata	0,16	-0,12	1,00	0,46	0,31	-0,22	0,16	0,23	0,28	0,39		0,79	0,02	0,45	0,54	0,69
HdV-137	0,32	-0,12	-0,08	0,00	0,47	0,27	0,16	-0,08	0,48	0,46	-0,08		0,10	0,30	0,54	0,12
Gloeotrichia	0,25	-0,23	0,63	0,47	0,59	-0,13	0,16	0,17	0,51	0,59	0,63	0,47		0,86	0,23	0,03
Hiphae	0,56	0,40	0,23	0,66	0,45	0,34	0,29	0,08	0,09	0,06	0,23	-0,31	-0,06		0,11	0,41
Polyporisporites	0,64	0,52	-0,19	0,51	0,04	0,88	0,04	0,42	0,04	0,09	-0,19	-0,19	-0,36	0,46		0,36
Polyadosporites	0,65	0,18	0,12	0,71	0,57	0,47	0,06	0,47	0,61	0,70	0,12	0,45	0,61	0,25	0,28	
Glomus sp	-0,45	-0,23	0,32	-0,20	-0,14	-0,53	0,02	-0,20	-0,23	-0,32	0,32	-0,40	0,07	-0,01	-0,36	-0,32
Discomycetes - EMA25	0,58	-0,23	0,53	0,34	0,42	0,20	-0,03	0,29	0,28	0,63	0,53	0,53	0,60	0,15	0,03	0,44
Chaetomiu	0,45	-0,18	-0,12	0,17	0,01	0,51	-0,34	0,56	0,02	0,33	-0,12	-0,12	-0,23	0,24	0,72	0,18
Sporormiella	0,33	0,10	-0,23	0,06	-0,02	0,29	0,02	0,30	0,04	0,13	-0,23	-0,23	-0,43	0,17	0,49	-0,13
Dyctiosporites - UG-Pluricellaesporites	0,16	0,68	-0,08	0,39	-0,12	0,53	0,16	-0,08	-0,32	-0,31	-0,08	-0,08	-0,16	0,39	0,42	0,12
Anthostomella - HDV-4	0,23	0,41	-0,12	0,40	0,03	0,72	0,06	0,29	0,06	0,00	-0,12	-0,12	-0,23	0,29	0,73	0,18
Chaetosphaerella - EMA	0,06	0,41	-0,12	0,46	0,03	0,23	0,06	0,00	-0,21	-0,17	-0,12	-0,12	0,23	0,23	0,17	0,42
Sporidesmium - HDV-51	0,16	-0,12	1,00	0,46	0,31	-0,22	0,16	0,23	0,28	0,39	1,00	-0,08	0,63	0,23	-0,19	0,12
UG-1155	0,44	0,68	-0,08	0,31	0,16	0,27	0,48	-0,08	0,28	-0,08	-0,08	-0,08	-0,16	0,15	0,28	0,12
HdV-19	-0,17	0,36	-0,12	0,08	-0,39	0,19	-0,17	0,26	-0,19	-0,03	-0,12	-0,12	-0,23	0,14	0,14	0,18
HdV-52	0,78	0,20	0,39	0,66	0,67	0,44	0,26	0,41	0,80	0,67	0,39	0,23	0,30	0,47	0,40	0,60
HdV-36	0,27	0,58	0,26	0,56	0,03	0,40	0,04	0,28	0,27	0,11	0,26	-0,26	-0,11	0,43	0,44	0,23
HdV-36c	0,44	0,06	-0,37	0,28	0,18	0,54	-0,28	0,51	0,34	0,42	-0,37	0,04	-0,22	0,37	0,60	0,55
Zoo remains	0,21	0,59	-0,19	0,41	0,08	0,19	0,04	-0,26	-0,01	-0,30	-0,19	-0,19	-0,05	0,33	0,17	0,21
Scolecodon	0,06	-0,18	-0,12	0,03	0,40	0,16	0,20	0,03	0,33	0,06	-0,12	-0,12	-0,23	0,34	0,28	-0,06

Figure 21 : Correlation analysis with Spearman's distances of the pollen and NPP from the layer 3.4.a. of Vallone Inferno (CA3 (3rd part))

NPP & Pollen	Glomus sp	Discomycetes - EMA25	Chaetomium	Sporormiella	Dyctiosporites - UG-1053	Pluricellaesporites	Anthostomella - HDV-4	Chaetosphaerella - EMA-33	Sporidesmium - HDV-51	UG-1155	HdV-19	HdV-52	HdV-36	HdV-36c	Zoo remains	Scolecodonte
Pinus sp	0,07	0,62	0,70	0,89	0,17	0,17	0,23	0,03	0,43	0,79	0,79	0,29	0,57	0,08	0,06	0,70
Cf Juniperus	0,35	0,12	0,00	0,06	0,54	0,54	0,49	0,36	0,27	0,54	0,36	0,13	0,46	0,17	0,83	0,49
Quercus ilex coccifera	0,03	0,18	0,07	0,26	0,11	0,11	0,04	0,25	1,00	0,61	0,82	0,05	0,16	0,04	0,23	0,71
Oleaceae	0,01	0,67	0,20	0,15	0,09	0,09	0,15	0,15	0,34	0,42	0,73	0,38	0,18	0,08	0,01	0,62
Quercus caducifolio	0,10	0,05	0,13	0,58	0,11	0,11	0,07	0,34	0,24	1,00	0,52	0,04	0,04	0,15	0,31	0,78
Corylus	0,48	0,07	0,17	0,73	0,14	0,14	0,09	0,34	0,14	0,61	0,97	0,01	0,11	0,28	0,49	0,64
Juglans	0,29	0,06	0,69	0,45	0,79	0,79	0,69	0,69	0,00	0,79	0,69	0,19	0,39	0,21	0,54	0,69
Tilia	0,60	0,61	0,69	0,22	0,79	0,79	0,69	0,69	0,79	0,00	0,69	0,11	0,39	0,89	0,27	0,69
Betula	0,70	0,37	0,55	0,26	0,01	0,01	0,17	0,17	0,01	0,69	0,22	0,64	0,04	0,42	0,49	0,55
Salix	0,56	0,13	0,16	0,83	0,13	0,13	0,04	0,15	0,13	0,69	0,80	0,05	0,10	0,36	0,53	0,92
Alnus	0,29	0,06	0,69	0,45	0,79	0,79	0,69	0,69	0,00	0,79	0,69	0,19	0,39	0,21	0,54	0,69
Erica sp	0,26	0,02	0,09	0,45	0,89	0,89	0,36	0,84	0,26	0,26	0,50	0,00	0,45	0,23	1,00	0,92
Cistaceae	0,29	0,06	0,69	0,45	0,79	0,79	0,69	0,69	0,00	0,79	0,69	0,19	0,39	0,21	0,54	0,69
Pistacia	0,18	0,86	0,28	0,30	0,31	0,31	0,83	0,23	0,06	0,31	0,91	0,23	0,31	0,56	0,38	0,60
Buxus	0,60	0,61	0,03	0,22	0,79	0,79	0,01	0,69	0,79	0,79	0,69	0,30	0,39	0,09	0,54	0,01
Poaceae	0,25	0,03	0,16	0,78	0,11	0,11	0,12	0,21	0,30	0,90	0,74	0,03	0,21	0,16	0,49	0,85
Cerealia-type	0,17	0,23	0,42	0,61	0,53	0,53	0,35	0,49	0,35	0,53	0,35	0,58	0,22	0,71	0,72	0,49
Asteraceae tubuliflorae	0,31	0,06	0,61	0,84	0,61	0,61	0,34	0,58	0,11	0,30	0,72	0,00	0,19	0,38	0,57	0,71
Asteraceae liguliflorae	0,61	0,07	0,27	0,94	0,36	0,36	0,09	0,29	0,11	1,00	0,76	0,03	0,37	0,45	0,99	0,45
Artemisia	0,44	0,44	0,22	0,06	0,69	0,69	0,17	0,55	0,69	0,69	0,55	0,85	1,00	0,77	0,36	0,17
Chenopodiaceae-Amaranthaceae	0,72	0,10	0,01	0,49	0,20	0,20	0,05	0,65	0,20	0,53	0,73	0,21	0,22	0,24	0,79	0,65
Plantago	0,44	0,09	0,27	0,68	0,19	0,19	0,21	0,21	0,11	0,44	0,97	0,02	0,10	0,39	0,24	0,93
Apiaceae	0,38	0,03	0,05	0,40	0,44	0,44	0,17	0,64	0,14	0,70	0,62	0,01	0,29	0,22	0,82	0,51
Urticaceae	0,11	0,44	0,55	0,74	0,01	0,01	0,17	0,17	0,69	0,69	0,22	0,51	0,04	0,84	0,00	0,55
Caryophyllaceae	0,77	0,00	0,08	0,66	0,69	0,69	0,55	0,55	0,03	0,69	0,55	0,19	0,92	0,89	0,36	0,55
Fabaceae	0,05	0,22	0,11	0,48	0,06	0,06	0,05	0,45	0,47	0,47	0,55	0,17	0,36	0,09	0,58	1,00
Malvaceae	0,60	0,61	0,69	0,45	0,00	0,00	0,01	0,01	0,79	0,79	0,03	0,52	0,07	0,89	0,10	0,69
Liliaceae	0,90	0,86	0,61	0,94	0,09	0,09	0,01	0,52	0,24	0,47	0,61	0,38	0,02	0,54	0,43	0,07
Lamiaceae	0,17	0,66	0,44	0,14	0,06	0,06	0,37	0,37	0,06	0,61	0,44	0,63	0,27	0,55	0,85	0,37
Ranunculac	0,17	0,48	0,04	0,02	0,78	0,78	0,13	0,68	0,32	0,32	0,64	0,02	0,03	0,17	0,35	0,54
Cyperaceae	0,12	0,04	0,12	0,28	0,61	0,61	0,44	0,85	0,61	0,14	0,57	0,00	0,38	0,13	0,49	0,85
Typha-Sparganium	0,44	0,44	0,55	0,74	0,01	0,01	0,17	0,17	0,69	0,01	0,22	0,51	0,04	0,84	0,03	0,55
Armeria	0,29	0,06	0,69	0,45	0,79	0,79	0,69	0,69	0,00	0,79	0,69	0,19	0,39	0,21	0,54	0,69
Indeterminables	0,50	0,25	0,59	0,84	0,19	0,19	0,18	0,12	0,11	0,30	0,80	0,01	0,05	0,35	0,16	0,93
Monolete	0,65	0,15	0,97	0,94	0,70	0,70	0,93	0,93	0,30	0,61	0,19	0,01	0,93	0,56	0,80	0,17
Trilete	0,06	0,52	0,07	0,33	0,06	0,06	0,01	0,45	0,47	0,38	0,54	0,13	0,17	0,06	0,53	0,59
Polypodium	0,94	0,94	0,26	0,94	0,61	0,61	0,85	0,85	0,61	0,10	0,57	0,39	0,90	0,35	0,90	0,50
HdV-303	0,52	0,33	0,05	0,32	0,80	0,80	0,34	1,00	0,44	0,80	0,40	0,16	0,35	0,07	0,38	0,93
Pseudoschizaea	0,44	0,35	0,95	0,89	0,28	0,28	0,85	0,49	0,35	0,35	0,54	0,00	0,37	0,25	0,96	0,27
Protists	0,28	0,02	0,27	0,68	0,30	0,30	1,00	0,58	0,19	0,80	0,93	0,01	0,72	0,15	0,33	0,85
Stomata	0,29	0,06	0,69	0,45	0,79	0,79	0,69	0,69	0,00	0,79	0,69	0,19	0,39	0,21	0,54	0,69
HdV-137	0,18	0,06	0,69	0,45	0,79	0,79	0,69	0,69	0,79	0,79	0,69	0,44	0,39	0,89	0,54	0,69
Gloeotrichia	0,82	0,03	0,45	0,14	0,61	0,61	0,45	0,45	0,02	0,61	0,45	0,31	0,71	0,47	0,86	0,45
Hiphae	0,96	0,63	0,42	0,58	0,19	0,19	0,34	0,45	0,45	0,61	0,65	0,11	0,15	0,21	0,28	0,25
Polyporisporites	0,23	0,92	0,01	0,09	0,15	0,15	0,00	0,57	0,54	0,35	0,65	0,18	0,13	0,03	0,57	0,36
Polyadosporites	0,29	0,13	0,55	0,66	0,69	0,69	0,55	0,15	0,69	0,69	0,55	0,03	0,46	0,05	0,50	0,84
Glomus sp		0,62	0,44	0,03	0,60	0,60	0,44	0,92	0,29	0,60	0,97	0,48	0,34	0,20	0,12	0,44
Discomycetes - EMA25	-0,15		0,30	0,85	0,61	0,61	0,44	0,44	0,06	0,61	0,44	0,09	0,59	0,93	0,23	0,44
Chaetomiu	-0,23	0,31		0,06	0,69	0,69	0,22	0,55	0,69	0,69	0,55	0,26	0,92	0,02	0,36	0,22
Sporormiella	-0,61	-0,06	0,54		0,45	0,45	0,74	0,26	0,45	0,22	0,26	0,40	0,64	0,29	0,55	0,74
Dyctiosporites - UG-	-0,16	-0,16	-0,12	-0,23		0,00	0,01	0,01	0,79	0,79	0,03	0,52	0,07	0,89	0,10	0,69
Pluricellaesporites	-0,16	-0,16	-0,12	-0,23	1,00		0,01	0,01	0,79	0,79	0,03	0,52	0,07	0,89	0,10	0,69
Anthostomella - HDV-4	-0,23	-0,23	0,36	0,10	0,68	0,68		0,17	0,69	0,69	0,22	0,78	0,04	0,18	0,49	0,17
Chaetosphaerella - EMA-	-0,03	-0,23	-0,18	-0,34	0,68	0,68	0,41		0,69	0,69	0,22	0,34	0,53	0,84	0,03	0,55
Sporidesmium - HDV-51	0,32	0,53	-0,12	-0,23	-0,08	-0,08	-0,12	-0,12		0,79	0,69	0,19	0,39	0,21	0,54	0,69
UG-1155	-0,16	-0,16	-0,12	0,37	-0,08	-0,08	-0,12	-0,12	-0,08		0,69	0,11	0,39	0,89	0,27	0,69
HdV-19	-0,01	-0,23	-0,18	-0,34	0,61	0,61	0,36	0,36	-0,12	-0,12		0,74	0,05	0,28	0,58	0,55
HdV-52	-0,22	0,49	0,33	0,26	-0,19	-0,19	0,09	-0,29	0,39	0,47	-0,10		0,17	0,09	0,89	0,39
HdV-36	-0,29	-0,16	-0,03	0,14	0,52	0,52	0,58	0,19	0,26	0,26	0,56	0,40		0,31	0,08	1,00
HdV-36c	-0,38	0,03	0,63	0,32	0,04	0,04	0,40	0,06	-0,37	0,04	0,32	0,49	0,31		0,76	0,18
Zoo remains	-0,45	-0,36	-0,28	0,18	0,47	0,47	0,21	0,59	-0,19	0,33	0,17	-0,04	0,50	0,09		0,36
Scolecodon	0,23	-0,23	0,36	0,10	-0,12	-0,12	0,41	-0,18	-0,12	-0,12	-0,18	0,26	0,00	0,40	-0,28	

Figure 22 : Correlation analysis with Spearman's distances of the pollen and NPP from the layer 3.4.a. of Vallone Inferno (CA3) (4th part)

Numerous positive correlations were observed from the correlative analyses, enabling us to define several pollen groups and NPPs.

On **Erreur ! Source du renvoi introuvable.**, among tree-cover pollen, there is a strong positive correlation between evergreen *Quercus*, Oleaceae, deciduous *Quercus*, *Corylus* and *Salix*. There was also a less intense positive correlation between *Quercus* cad, *Corylus*, *Juglans* and *Betula*. Among NAP pollen, there was a strong correlation between *Erica* sp., Poaceae, Asteraceae tubuliflorae, Asteraceae liguliflorae, *Plantago* sp., Apiaceae, Fabaceae, Cyperaceae. Cistaceae and *Armeria* as well as *Pistacia* and Lamiaceae form two different groups of positive correlation. Amaranthaceae-Chenopodiaceae is positively weaker correlated with Caryophyllaceae and Ranunculaceae. *Artemisia* and Cerealia-type do not seem to correlate with other pollen. Correlations between arboreal and non-arboreal plants show positive correlations between some of the groups identified. There is a strong correlation between the major groups evergreen *Quercus*, Oleaceae, deciduous *Quercus*, *Corylus*, *Salix* and *Erica* sp., Poaceae, Asteraceae tubuliflorae, Asteraceae liguliflorae, *Plantago* sp., Apiaceae, Fabaceae, Cyperaceae. This correlation is particularly significant between the taxa evergreen *Quercus*, deciduous *Quercus*, *Corylus* and Poaceae, as well as for *Salix*, *Corylus*, *Plantago* sp. and Apiaceae. Outside these groups, there is a strong correlation between the *Juglans*, Cistaceae, *Alnus* and *Armeria* groups.

On **Erreur ! Source du renvoi introuvable.**, among the NPPs, there is no correlation inside pteridophytes and zooremains groups. Among NPPs of unknown origin, HdV-303, *Pseudoschizaea* and protists have a strong correlation. Among fungi, *Polyporisporites*, *Chaetomium* and *Anthostomella* show a strong correlation. *Dyctiosporites*, Pluricellaesporites, *Anthostomella*, *Chaetosphaerella* and HdV-19 were the major groups in the correlative analysis of fungi NPPs. The coprophilous fungi *Chaetomium* and *Polyporisporites* are weakly positively correlated with *Sporormiella*. Correlating all NPP groups, we see that monolete spores, *Pseudoschizaea*, *Polyadosporites*, *Gloeotrichia*, protists and HdV-52 are strongly correlated. Likewise, trilete spores are strongly correlated with *Polyporisporites* and *Anthostomella* and HdV-36c, as well as slightly with coprophilous fungi (*Sporormiella* and *Chaetomium*). Stomata, *Gloeotrichia* and *Sporidesmium* are positively correlated.

On **Erreur ! Source du renvoi introuvable.** , combining pollen correlations and NPPs, we also observe positive correlations. There is a strong positive correlation between trilet spores/evergreen *Quercus*/Asteraceae tubuliflorea/HdV-52/Fabaceae, *Juglans*/*Sporodesmium*/Stomata/*Alnus*/Cistaceae/*Armeria*, *Tilia*/UG-1155, Malvaceae/ *Pluricellaesporites*/*Dyctiosporites*.

On **Erreur ! Source du renvoi introuvable.**, we observe a weak positive correlation between *Glomus* sp. and Cerealia-type as well as *Pistacia* and Lamiaceae. On the contrary, *Glomus* sp. is negatively correlated with many taxa, such as trilete spores, HdV-137, *Sporormiella*, zooremains, *Pinus* sp., *Quercus* (evergreen and deciduous), Oleaceae, Urticaceae, Fabaceae, Ranunculaceae and Cyperaceae. We also note that *Sporormiella* and *Gloeotrichia* and Lamiaceae are negatively correlated.
Furthermore, when looking at the indeterminate pollen, we note major positive correlations with deciduous *Quercus*, *Corylus*, *Salix*, Poaceae, Asteraceae (tubuliflorae and liguliflorae), *Plantago* sp. and Apiaceae.

4.6. Detrended Correspondence Analysis of the pollen and NPPs from the layer 3.4.a. of Vallone Inferno

The Detrented Correspondance Analysis (DCA) aims to identify the links between the taxa of pollens and NPPs and the samples in layer 3.4.a. Taxa with less than 0.75% of presence have been excluded.

DCA	Axis 1	Axis 2	Axis 3	Axis 4	Total
Eigenvalue	0,12	0,03	0,003	0,00008904	0,15
Percentage	80,81	16,84	2,29	0,058	100

Table 6 : Eigenvalues and % of each axis from the DCA performed on pollen and NPPs of layer 3.4.a. from the layer 3.4.a.of Vallone Inferno

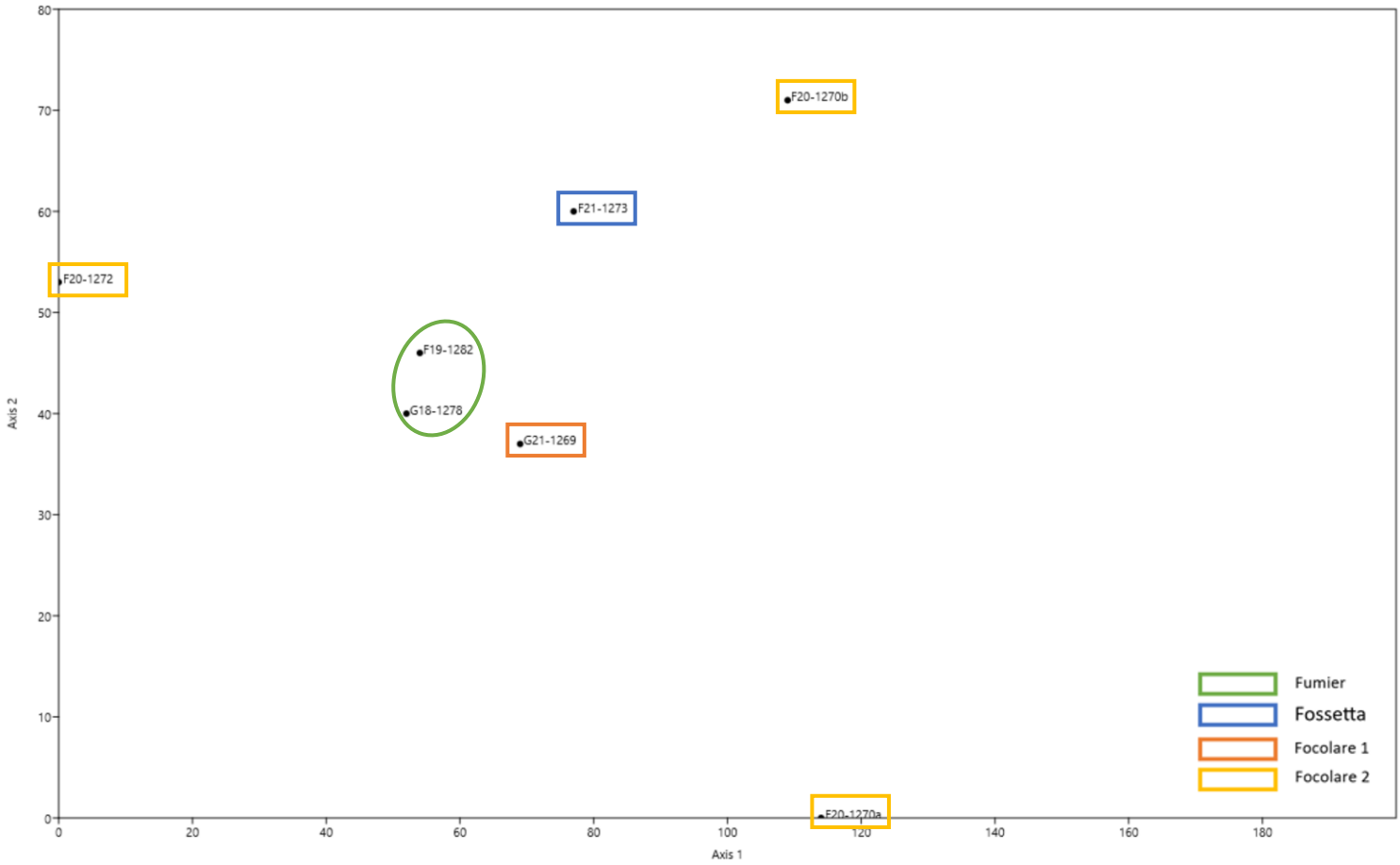

Figure 23 : Zoom of the samples from the scatter plot the DCA performed on NPPs and pollen from the layer 3.4.a.of Vallone Inferno

Spatial analysis of the samples shows the presence of a cluster at the center of the scatter plot (Figure 23) made up of samples G21-1269, G18-1278, F19-1282, F21-1273 and F21-1270b. The latter sample is slightly eccentric according to the positive values of axis 2. Nevertheless, this sample group is central compared to axes 1 and 2. In contrast, F20-1272 and F20-1270a are isolated from the rest of the samples. F20-1272 is isolated along axis 1 and F20-1270a is isolated along axis 2. Combining these samples with their extraction origin shows the wide dispersion of the Focolare 2 samples. Along axis 1, samples F20-1270a and b have a similar value and F20-1272 appears very off-center. On the contrary, along axis 2, F20-1272 and 1270b are close and F20-1270a is excluded. These three samples are scattered around the other samples. Fumier samples G18-1278 and F19-1282 show very strong coherence, with a certain proximity to Focolare 1 sample G21-1269 and Fossetta sample F21-1273. Sample F20-1273, from Focolare 2, shows a certain closeness to the group of samples of various origins, in

particular to the Fossetta sample. The manure samples are particularly close. They are strongly correlated with the Focolare 1 and Fossetta samples. In contrast, the Focolare 2 samples are extremely scattered, particularly those from Focolare 2. The concordances between the origin of extraction of the hearths do not seem to reflect a particular pattern, whereas the manure seems to show a strong coherence, and a strong resemblance to that of the Fossetta and Focolare 1.

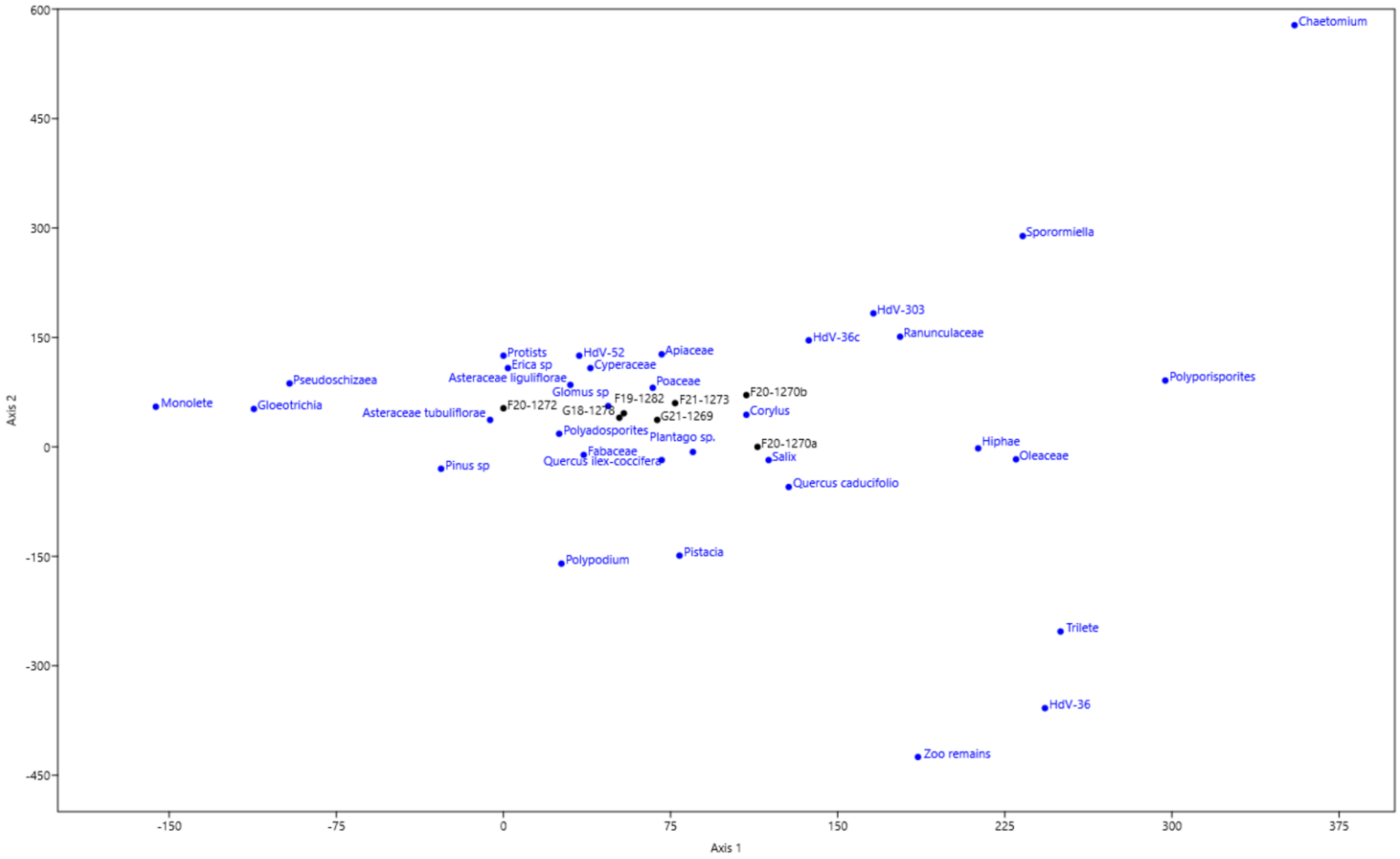

Figure 24 : Scatter plot of the DCA performed on the NPPs and pollen from the layer 3.4.a.of Vallone Inferno

Figure 24 shows the distribution of pollen taxa and NPPs and provides an understanding of sample dispersion. Analysis of the first DCA shows that the greatest diversity and difference of pollen and NPPs is linked to Axis 1 at over 81% (Table 6). It can be seen that the positive values of this axis are made up of small pollen of tricolporate or triporate shape. These pollens are mostly anemophilous and are related to tree taxa. As far as NPPs are concerned, positive values are associated with a high concentration of organic matter and the proliferation of fungi. Negative values, on the other hand, are associated with pollen of larger size and more complex shape (saccate, tricolporate with significant ornamentation, tetrad). Most of these pollens are

zoophilous, reflecting strong anthropozoogenic pollen contributions. The NPPs show evidence of soil erosion and remobilization associated with high humidity, potentially caused by flooding.

Taking all the taxa into account, we can see that the isolation of samples is not strongly marked and that all the samples present a certain coherence. Nevertheless, sample F20-1272 is isolated because of its high composition of large and zoophilous pollen, and therefore its high anthropozoogenic contribution or a better resistivity of large pollen to fire. The NPPs show very high erosive activity marked by local-scale moisture. Sample F20-1270a, on the other hand, appears to be isolated by its composition of small, anemophilous pollen. The NPPs are marked by a high concentration of organic matter and a proliferation of fungi. Similarly, F20-1270b appears to be unusual in that it contains a high proportion of small pollen of anemophilous and zoophilous origin and a marked proliferation of coprophilous fungi, indicating an anthropozoogenic contribution as well as a high level of organic matter. The central group of samples (G21-1269, G18-1278, F19-1282, F21-1273) seems to be made up of a mixture of pollen of various sizes, both anemophilous and zoophilous, with significant erosive action and organic matter. Nevertheless, there are some differences within the group. Samples F19-1282 and G18-1278 seem to be more closely related due to their composition of large, zoophilic pollen and highly developed erosive activity, whereas G21-1269 and F21-1273 are more similar due to the presence of small, anemophilous pollen and slightly abundant organic matter in which fungi have developed.

To summarize, the *fumier* samples (G18-1278, F19-1282) have a pollen composition close to that of the Fossetta (F21-1273) and Focolare 1 (G21-1269), as they are composed of a mix of large/small anemophilious/zoophilious pollen, with abundant erosive activity and organic matter. Nevertheless, the *fumier* seems to have a composition of large, zoophilous pollen with marked erosive activity, whereas the Fossetta and Focolare 1 have pollen rain with less content of pollen contributed by animals in which fungi and organic matter proliferate. Focolare 2 is highly diverse, with F20-1272 containing a large quantity of large pollen with a significant anthropozoogenic contribution and very high erosive activity in a locally humid environment where ferns proliferate. In contrast, F20-1270a has predominantly small, anemophilous pollen, with an abundance of fungi including coprophilous fungi. Finally, F20-1270b has a majority of small anemophilous and zoophilous pollen with a high level of organic matter.

5. Discussion

Pollen and NPP analyses are used in this archaeobotanical study on several levels. Firstly, their interpretation aims to reconstruct the paleoenvironmental and landscape context from the mid-Neolithic to the Early Bronze Age. In addition to this, palynological components characterize the organization of human settlements and the exploitation of land for multiple activities. Finally, these analyses serve to understand the taphonomic history of the microelements undergone from their different dispersal and deposition to their discovery.

Mediterranean	Mesophilous	Ruderal plants	Hygrophyte	Crops
Buxus	*Betula*	*Artemisia*	Cyperaceae	Cerealia-type
Cistus	*Corylus*	Asteraceae	Ranunculaceae	Faboideae
Olea	*Juglans*	Caryophyllaceae	*Typha-Sparganium*	Malvaceae
evergreen *Quercus*	Deciduous *Quercus*	Apiaceae		Coprophilous
Pteridophyte		Lamiaceae	Livestock pressure	*Chaetomium*
monolete spores	*Tilia*	Poaceae	Chenopodiaceae-Amaranthaceae	*Sporormiella*
trilete spores	Riverside	Conifers		Erosion
Polypodium	*Alnus*	cf. *Juniperus*		*Glomus* sp.
	Salix	*Pinus* sp.	*Plantago* sp.	*Pseudoschizaea*

Table 7 : Table of the taxa identified categorized according to their ecological meaning from the layer 3.4.a. of Vallone Inferno (Behre, 1986 ; López Sáez et al., 1998 ; Galop et López Sáez, 2002 ; Carrión et al., 2010 ; Ruiz-Zapata et al., 2010)

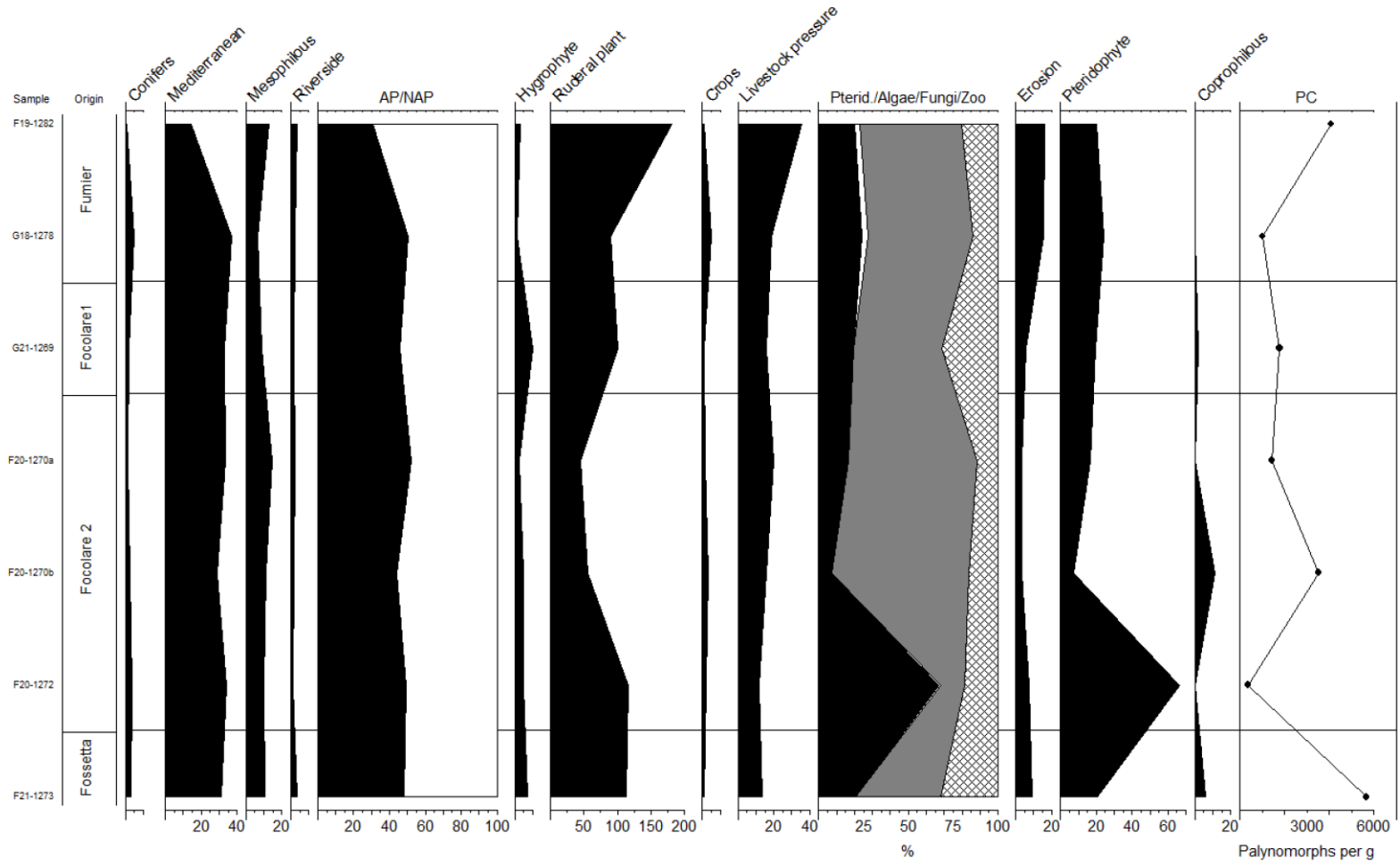

Figure 25 : Synthetic pollinic diagram of the layer 3.4.a. of Vallone Inferno

5.1. Vegetation of the layer 3.4.a at Vallone Inferno

Pollen analysis of the layer 3.4.a. of the Vallone Inferno site reveals that the landscape around 3600-3360 cal. BP is formed by a mixed meso-thermophile forest of evergreen and deciduous *Quercus*. The Thermo-mediterranean forest dominates the arboreal spectrum and marks the persistence of the secondary forest. It is made up of evergreen *Quercus* (Holm oak and oak) and some Oleaceae (Olive tree). Meso-deciduous broadleaf forest elements are also widely established in the arboreal spectrum. It is mainly represented by deciduous *Quercus* (Oak) and *Fraxinus sp* (Ash tree). It is completed by *Juglans* (Walnut tree) and *Tilia* (Lime tree), which make up less than 2% of the palynological record. Similarly, anthracological analyses reveal the dominance of charcoals corresponding to local deciduous *Quercus* vegetation associated with evergreen *Quercus* and meso-termophilous forest trees (Expósito et al., In process). The palynological record indicates the existence of a riparian forest composed of *Alnus* (Alder) and *Salix* (Willow) as well as *Ulmus* (Holm). In addition to this, the forest is complemented by typical wetland hygrophytic herbaceous species such as Cyperaceae (Sedges) and *Typha-Sparganium* (Bulrush/Esparganium). These plants may have proliferated near water sources such as the Imera River located close to the rock shelter (Forgia et al., 2013).

On a regional scale, a forest of *Pinus* (Pine), *Juniperus* (Juniper) and *Betula* (Birch) has developed in the possible high altitudes or in less rich zones of the Madonie region. Their anemophilous pollen dispersal favors a long-distance pollen transport despite the poor conservation of *Juniperus*.

The spectra of non-arboreal plants is dominant in layer 3.4.a. It accounts for 55% of the taxonomic abundance of the palynological record. Below the canopy, the undergrowth is composed of meso-thermophilous and sclerophyllous shrubs such as *Erica* (Heather), Cistaceae (Rockrose), *Pistacia* (Lentisk) and *Buxus* (Bux). They make up a small proportion of NAP, however, their presence is under-represented due to their autogamous reproduction; these pollens are therefore rarely part of the pollen rain. With the exception of the hygrophytic herbaceous plants described above, the herbaceous plants are essentially ruderal plants, nitrophilous and weeds such as Poaceae (wild Grass), Asteraceae, Apiaceae, *Artemisia*, Lamiaceae, *Plantago* sp. (Plantain) and Urticaceae. Some crop elements are identified as Cerealia-type and Fabaceae as well as adventitious plants such as Malvaceae, Caryophyllaceae and Chenopodiaceae-Amaranthaceae.

5.2. Local cave conditions visible into the layer 3.4.a.

One of the most important features of caves and rock shelters is the humidity generated by the enclosed karstic rock environment. Under-rock shelters are less sensitive to these variations, with temperature, humidity and light levels close to those observed outdoors. Nevertheless, these parameters depend on the depth of the rock shelter (Coles et al., 1989 ; Goldberg et Sherwood, 2006 ; Ruggieri, 2022). Vallone Inferno is a 10-metre-deep rock shelter (Forgia et al., 2013). Within the taxon corpus, this humidity is visible through the presence of hygrophylitic plants such as Cyperaceae and *Typha-Sparganum*. However, it could be linked to plants surrounding the Imera water stream. Rock shelter humidity is evidenced by the existence of NPPs whose growth is limited to the local environment. Thus, the presence of algal palynomorps such as *Gloeotrichia* and *Spyrogyra* testify to local wet environments (Van Geel et al., 1989). The wet nature combined with the light gradient and alkaline composition of the substrate, explains the development of ferns at the entrance of caves and in rock shelters (Coles et al., 1989 ; Mason-Williams et Benson-Evans, 1996). In layer 3.4.a. of Vallone Inferno, the proportion of pteridophytes, made up of fern and mosses, is significant and would indicate high luminosity inside the rock shelter or close to its opening (Mason-Williams et Benson-Evans, 1996).

Furthermore, layer 3.4.a. of Vallone Inferno is rich in organic matter. In fact, this layer contains a high concentration of zooremains, *Glomus* sp. mycorrhizae and remains of fungal hyphae. Among the fungi identified are saprophytic and biotrophic fungi, which are colonizers and decomposers of inert organic matter and parasites of living matter. More specifically, the presence of coprophilous fungi such as *Sporormiella*, *Chaetomium* and *Polyporisporites* has been detected (Van Geel, 2006, 2008 ; Campbell et al., 2011). Van Geel et al. (2003 ; 2006) was the first to identify the link between coprophilous fungi spores in archaeological sites and their proliferation in livestock areas. *Sporormiella*-type, *Chaetomium and Neurospora* ascopores are indicators of the presence of *fumier* and a population of domestic herbivores in the vicinity of the archaeological site. Therefore, several studies in Europe and in Sicily have used those results to highlight the role of coprophilous fungi spores as a pastoral activity indicators and to identify dung connected to significative amount of organic matter (Davis, 1987 ; Van Geel, 2001 ; Van Geel et al., 2003 ; López-Sáez et López-Merino, 2007 ; Cugny et

al., 2010 ; Feeser et O'Connell, 2010 ; Menozzi et al., 2010 ; Ahmed et Cain, 2011 ; Cugny, 2011 ; Angelucci et Anesin, 2012 ; Hillbrand et al., 2012).

Thus, the local rock shelter ecosystem identified in layer 3.4.a. develops in a slightly humid environment. The high light levels and humidity have also favoured the proliferation of ferns. This layer contains a significant concentration of organic matter, enabling fungi to develop and zooremains to be decomposed. The specific conditions inside the rock shelter, related to its morphology and the various taphonomic events taking place inside the rock shelter, have led to singular depositional and post-depositional processes resulting in differential pollen preservation.

5.3. A taphonomic approach to the pollen and NPPs assemblage from layer 3.4.a.

From dispersal to discovery, pollen and NPPs have undergone numerous depositional and post-depositional processes. In archaeological deposits, these processes affect pollen and NPPs, thus altering the pollen spectrum. Biotic agents such as bacteria, fungi or insects, as well as abiotic agents such as oxidation or vertical movement, infer differential preservation (Bryant et Holloway, 1983 ; Bryant et Hall, 1993). At the Vallone Inferno site, this approach is necessary in view of the extraction origin of the samples. In fact, all the samples were taken either from the dung, from two different fireplaces or from a bucket. While the pollen rain is supposed to represent a certain unit by the contemporaneity of its formation, each of these zones has its own taphonomic processes and is caused by oxidation, mechanical processes and various biological agents. In this study, the contribution of NPPs is highlighted by their reflection of the local environment. Different factors have been observed to understand the different impacts of the taphonomical dynamics on the pollen and NPPs.

5.3.1. Sources of the dispersion and depot of pollen rain visible through our sampling of layer 3.4.a. in the Vallone Inferno rock shelter

Pollen deposition within the Rock Shelter have a limited dispersion and is representative of a mixture of pollen from the landscape, corresponding mainly to anemophilous plants, and a strong contribution of zoophilous pollen from local vegetation (Van Campo et Leroi-Gourhan,

1956 ; Coles et al., 1989 ; Navarro et al., 2001a, 2001b ; Hunt et Fiacconi, 2018). The rock-shelter pollen rainfall reflects a specific deposit induced by a particular depositional process deriving from the regional vegetation and transport and dispersal mechanisms such as water, air and animal/insect (Coles et al., 1989).

Within layer 3.4.a. of Vallone Inferno, the anemophilous pollens identified are numerous and abundant. They come from the taxa *Alnus*, *Artemisia*, *Betula*, Cerealia-type, Chenopodiaceae, *Corylus*, Cyperaceae, *Juglans*, *Juniperus*, Oleaceae, *Pinus* sp., *Plantago* sp., Poaceae, *Quercus* (evergreen and deciduous), *Salix*, *Typha-Sparganium*, Urticaceae. Zoophilous plants (entomophilous especially) are Apiaceae, *Armeria*, Asteraceae, *Buxus*, Caryophyllaceae, Cistaceae, *Erica* sp., Fabaceae, Lamiaceae, Liliaceae, Malvaceae, Ranunculaceae, *Salix* and *Tilia*. Thus, the existence of a major aerial transported contribution is confirmed at the Vallone Inferno site in view of the more restricted abundance of Asteraceae (Navarro et al., 2001a).

In addition, some pollen and spores from anemophilous and zoophilous plants may have undergone secondary deposition and differential redistribution thanks to entry and transit of animals, herds and human by : the external transport of pollen hanging on the vector from the local vegetation in which it travelled, pollen transported in the intestines from the consumption of certain plants and found in the faeces, by the supply of food from outside by animals or by bioturbation of sediments produced by organisms (Coles et al., 1989 ; Campbell, 1991a ; Carrión et al., 1999 ; Navarro et al., 2000 ; Hunt et Rushworth, 2005 ; Hunt et Fiacconi, 2018). At the Vallone Inferno site, cattle rearing has been identified in the prehistoric levels and would therefore very much indicate a supply of pollen clinging to animals and on humans during use of the cave (Forgia et al., 2013 ; Martín et al., 2023 ; Forgia et al., In process). In addition, the presence of coprophilous fungi (*Chaetomium*, *Sporormiella* and *Polyporisporites*) and dung in layer 3.4.a. indicates a certain supply of pollen transported in animal intestines and an important source of pollen from excrement in the cave (Davis, 1987 ; Van Geel, 2001 ; Van Geel et al., 2003 ; López-Sáez et López-Merino, 2007 ; Ahmed et Cain, 2011 ; Cugny et al., 2010 ; Feeser et O'Connell, 2010 ; Menozzi et al., 2010 ; Cugny, 2011 ; Angelucci et Anesin, 2012 ; Hillbrand et al., 2012).

While the dispersal of anemophylous and zoophylous pollen in a cave is largely dependent on depth and proximity to the edges of the rock shelter, the centrality and small radius of the

sampling area does not allow these differences to be visualized (Van Campo et Leroi-Gourhan, 1956 ; Coles et al., 1989 ; Prieto et Carrión, 1999 ; Navarro et al., 2001a, 2001b ; Hunt et Fiacconi, 2018). Consequently, a similar deposit would then be expected due to the small sampling area and contemporaneity of the samples. However, differential preservation differences are highlighted in the samples thanks to multivariate analysis and result from the destructive action of multiple post-depositional processes.

5.3.2. Differences of conservation of pollen and NPPs and analyse of palynological concentration et indeterminate pollens

While univariate and multivariate statistical analyses show a certain similarity in the composition and number of taxa identified in Vallone Inferno layer 3.4.a. from a contemporary deposit, they also illustrate a difference in the proportion of certain specific taxa as well as variations in palynological concentrations linked to multiple post-depositional taphonomic processes.

5.3.2.1. Fossetta analysis

The analysis of the Fossetta is based on the study of a single sample, F21-1273, whose palynological concentration is particularly high compared to the samples from the *fumier* or the fireplaces. Nevertheless, the percentage of indeterminate pollen is moderate, corresponding to 1/3 of the pollen identified. Cluster analysis shows that in the Fossetta, *Plantago* sp. appears slightly under-represented compared to the other samples. However, the homogenization of the proportions of herbaceous and arboreal plants, as well as anemophilous and zoophilous plants, combined with the high palynological concentration, could indicate better pollen conservation.

Analysis of the Fossetta NPPs indicates a high proliferation of fungi and zooremains. These palynomorphs testify to the high concentration of organic matter and the acidity associated with its composition (Van Geel, 2001, 2006 ; Angelucci et Anesin, 2012). Among the fungi identified, the presence of coprophilous fungi indicates the presence of animal detritus. The high concentration of *Chaetomium* is also significant for its more specific association with human settlement and would testify to human detritus (Van Geel, 2001). On the other hand, the

low concentration of *Glomus* sp. mycorrhizae demonstrates the low remobilization of the substrate, which would correspond to the cumulative nature of Fossetta (Van Geel et al., 2003).

Thus, the high concentration of organic matter may have favored pollen preservation and the proliferation of saprophytic fungi in the Fossetta. However, in the absence of data on the usefulness of this pit, it is not possible to determine the exact origin of its favourable conservation and the link with other extraction areas. Nevertheless, in view of its state of preservation and the high level of organic matter, a link with a sediment input in common with the manure is possible.

5.3.2.2. Fireplace analysis

In general, fire samples in layer 3.4.a. have a low palynological concentration caused by extreme oxidation. This is due to the fact that fire damage or destruction is rapid when oxygen is available (Bryant et Hall, 1993 ; Expósito et Burjachs, 2016 ; Val-Peón et al., 2019). However, the three samples have large concentration differences. This difference could be due to different post-depositional processes or a different input of organic material.

Pollen oxidation varies according to the taxon observed and is linked to the structure of the exine and the abundance of sporopollenin. The taxa Asteraceae, *Quercus*, *Pinus*, *Fagus* and *Tilia* show strong preservation under strong oxidation, in contrast to the taxa *Corylus*, *Alnus*, *Ulmus*, *Populus*, *Acer*, *Salix* and *Fraxinus* (Havinga, 1967 ; Bryant et Holloway, 1983 ; Lebreton et al., 2010). In the samples from layer 3.4.a. at Vallone Inferno, within Focolare 2, sample F20-1272 is particularly different from samples F20-1270a and b. Cluster analysis shows that Poaceae and evergreen *Quercus* are slightly over-represented, while Asteraceae liguliflorae appears to be under-represented in all samples from the Focolare 2. Concerning the composition of samples F20-1270 a and b, they appear strongly similar in the Cluster Analysis of pollen and NPPs with a particularly low composition of Asteraceae tubuliflorae and liguliflorae, while *Quercus* evergreen is significant in comparison to all samples. According to the DCA, both samples have a high anemophilic pollen composition. Expósito et Burjachs (2016) suggest that the high pollen concentration and the taxonomic diversity preserved in samples from hearths and, more specifically, from intense cremation facies, could be due to the fact that pollen deposition occurs after the fire ceases to be active. In this way, pollen

disturbance would be limited and the pollen would be more representative of the surrounding vegetation, which would explain the lower rate of indeterminate pollen. In addition, the Focolare 2 location near the entrance to the rock shelter favours the deposition of anemophilous pollen, which is observed in samples F20-1270a and b. Analysis of the NPPs shows the strong influence of fungi. F20-1270 b has a high composition of coprophilous fungi. Hyphae imply colonization of charcoal by fungi. *Dictyosporites* is a saprophytic fungus that indicates decomposition of material, and *Chaetomium* is a lignicolous fungus that could indicate decomposition of dead wood found in hearts (Van Geel et al., 2003).

A comparison between Focolare 1 and 2 shows a marked difference in facies color. In fact, the hearths are composed of a base of blackish organic sediments, identified in the Focolare 2 samples, covered by a layer of white ash, identified in Focolare 1 (Goldberg et Sherwood, 2006). In general, this degree of combustion is also undergone by pollens, whose thermal alteration causes the flow to darken according to the level of combustion (Campbell, 1999). In the Vallone Inferno layer, the pollen composition of Focolare 1 is close to that of Focolare 2 samples F20-1270 a and b, with a high anemophilous pollen composition and low palynological concentration. However, there is also a high composition of Asteraceae tubuliflorae, whose over-representation may be due to the origin of its contribution or to differential preservation (Behre, 1986 ; Lebreton et al., 2010).

Within Focolare 2, sample F20-1272 is particularly different from samples F20-1270 a and b. Indeed, F20-1272 has more intense blackish facies, whereas F20-1270a and b have a facies described as black-brown. This difference is linked to the significant thickness of the hearth and the partial combustion of the sediments, giving the sediments a black-brown appearance (Goldberg et Sherwood, 2006). Thus, the difference in palynological concentration, number of pollen taxa and would be partly due to the intensity of combustion, the possible more peripheral location of samples F20-1270a and b or deposition between combustion structures (Val-Peón et al., 2019). Moreover, the large and zoophilous pollens predominance in these samples could be related to their resistivity to fire. Nevertheless, a second post-depositional process described later in the discussion could reinforce the particular characteristics of sample F20-1272.

5.3.2.3. Fumier analysis

Fumier are a very particular accumulation because of their biogenic composition, with an animal and plant origin, as well as their anthropogenic material. Evidence of anthropogenic markers is abundant in archaeological sediments (Angelucci et al., 2009). This is a combination of ash and partially burnt dung from domestic animals such as sheep, goats or cattle settled in caves (Expósito et Burjachs, 2016).

A heterogeneity is observed in the richness and abundance of palynological elements of the fumier. Palynological concentration analyses showed that 2/3 of the *fumier* samples had to be excluded from the study remains. However, these selected samples have a high variety and quantity of pollens and NPPs. Indeed, while sample F19-1282 has a high palynological concentration and number of taxa, those of G18-1278 are average. These two samples are associated with different facies: F19-1282 is associated with a grey facies, while G18-1278 is associated with a white facies, reflecting the different layer of *fumier* with layer of burn dung, partially burnt and unburnt (Angelucci et al., 2009). However, the difference of concentration could be linked to a composition of *fumier* with higher concentration of ash (Goldberg et Sherwood, 2006). Similarly, there is a spatial difference between samples, with the deepest samples located at the border of the excavation zone (Square F18-G18) being more often sterile. Angelucci et al. (2009) analysis of *fumier* showed a positive correlation between sterility and depth, due to the significant thickness of the *fumier*, despite the deposited and reworked nature of this type of accumulation. Similarly, the lateral variability of concentration is reinforced by the level of combustion of the elements and the amount of ash deposited in the *fumier* (Angelucci et al., 2009). Moreover, the pH of the *fumier* induces poor pollen preservation favoring sample sterility (Havinga, 1967 ; Hunt et Fiacconi, 2018 ; Val-Peón et al., 2019). The proportion of indeterminate pollens is particularly high in Vallone Inferno *fumier*. This could be partly due to microbial and fungal activity causing biochemical oxidation of the pollens (Elsik, 1971). Havinga (1967) has shown that microbial activity is greater on pollen whose wall has already been oxidized, and that this causes corrosions when the pH is high.

Pollen composition is also very different between *fumier* samples. While the DCA shows a similar composition of the samples due to the similarity of pollen grand sizes and zoological origins, the Cluster Analysis indicates an anomalous proportion of pollen concentration for F19-

1282 compared to all the samples. It has a very high proportion of *Plantago* sp. and Asteraceae, while its concentration of evergreen *Quercus* is very low. The over-representation of zoophilous herbaceous pollen and fern spores could be linked to zoo-anthropogenic inputs. This combination was brought into the cave by guts (guano and dung), by fur and feet through consumption or by snagging (Campbell, 1999 ; Val-Peón et al., 2019). Indeed, analysis of herbivore dung by Navarro et al. (2001a) shows an over-representation of Lamiaceae, Olea, Cistaceae, Asteraceae and Poaceae, while *Pinus* is under-represented. However, according to Carrión et al. (2000) and Carrión (2002), the pollen spectrum of biogenic animal material is the best analogue of local and regional vegetation in terms of number of taxa and palynological concentration. Therefore, it is possible that the resistivity of grand size pollen to fire induced this differential conservation.

Regarding NPPs, the *fumier* samples from layer 3.4.a. is marked by the absence of coprophilous fungi. These saprophytic fungi are regularly identified in dung thanks to their resistance to the digestive processes of herbivorous animals (Davis, 1987 ; Van Geel, 2001 ; Van Geel et al., 2003 ; López-Sáez et López-Merino, 2007 ; Ahmed et Cain, 2011). The very local, poorly dispersed development of these fungi and the limited sampling can only partially explain their absence, as they are identified in layer 3.4.a. of the rock shelter (Van Geel et al., 2003). Nevertheless, the *fumier* samples show a high concentration of hyphae associated with the very high concentration of mycorrhizal of *Glomus* sp. The presence of these elements indicates ongoing sediment erosion and remobilization of the substrate in the *fumier* with accumulation of excrement by piled on the sediment surface to facilitate burning activities (Van Geel, 2001 ; Angelucci et Anesin, 2012 ; Vergès et al., 2016b). In addition, the over-representation of Asteraceae tubuliflorae and liguliflorae and *Pinus* identified thanks to Cluster Analysis in these samples are often considered markers of pollen preservation. However, their over-representation can be interpreted as reliable taphonomic indicators of erosion and re-sedimentation (Hunt et al., 2015).

Thus, one hypothesis submitted to explain the absence of coprophilic fungi in these samples is the sanitization of *fumier* by fire activity and the perpetual remobilization of *fumier* to burn off the entire *fumier* layer and limit the spread of bacteria and fungi (Vergès et al., 2016b). A second hypothesis concerning the concomitance of another post-depositional process, described later in the discussion, and highlighted by the high concentration of *Pseudochizaea*, algal

palynomorph and monolete spore would also explain this absence of coprophilous fungi and this difference in pollen composition within the samples.

5.3.2.4. Fumier and Focolare 2 : Consequence of wet/dry cycle of pollen of layer 3.4.a.

The interpretation of *fumier* elements is complicated by the alteration of pollens in the humid karstic environment. Indeed, the presence of *Gloeotrichia* and an abundance of monolete spores is essentially identified in the pollens found in the *fumier*. These samples also contained *Pseudoschizaea*, an algal palynomorph that can develop especially during torrential rainfall in particularly arid conditions (Van Geel et al., 1989). The association of these NPPs could be evidence of flooding and wet-dry cycles within the rock shelter. These cycles are highly damaging to pollen. Campbell, (1991) notes that pollens with multiple apertures are mostly affected by exine thinning. In our samples, DCA showed a low proportion of small periporate, triporate and tricolpate pollen (Ranunculaceae, *Corylus*, Oleaceae, *Quercus* deciduous, *Pistacia*, *Quercus* evergreen, *Plantago* sp.), whereas large pollen with a thick exine layer are more strongly represented (*Pinus* sp., Asteraceae tubuliflorae, Asteraceae liguliflorae, *Erica* sp., Cyperaceae, Poaceae, Fabaceae). Thus, the difference in palynological concentration but the concordance in the proportion of indeterminate pollen could indicate that these cycles have a differential and partial impact, not leading to total destruction in the first wet-dry cycles. Nevertheless, the accumulation of cycles and compaction could accentuate deterioration to the point of total destruction of large numbers of pollen. In addition, their impact is amplified by chemical oxidation, coming from sediments during water evaporation during arid and biological periods, whose wet periods favor bacterial growth and corrosion (Delcourt et Delcourt, 1980 ; Holloway, 1989 ; Prieto et Carrión, 1999 ; Campbell, 1991b ; Navarro et al., 2001a, 2001b). This post-depositional process could also explain the high presence of *Glomus* sp. mycorrhizae and the absence of coprophilous fungi in *fumier* samples (Van Geel, 2001).

Sample F20-1272 is very unusual compared to the other samples from Focolare 2. Its pollen composition is similar to that of sample G21-1269 from Focolare 1, as well as G18-1278 and F19-1282 from *fumier*, thanks to its slightly high composition of Asteraceae tubuliflorae and Asteraceae liguliflorae. However, F20-1272 has a particularly low palynological concentration (381 grains per g) and a high percentage of indeterminate pollen (35.34%) compared to the

other samples in the focus. Bryant et Hall (1993) indicate that a concentration of less than 1000 grains per gram has undergone very strong post-depositional alteration. This difference is also reflected in the composition of NPPs, with a high presence of *Gloeotrichia*, monolete spore and *Pseudoschizaea* and very few Hyphae. These characteristics were previously described in *fumier* samples F19-1282 and G18-1278. This similarity could therefore be due to the fact that all three samples underwent a common post-depositional process, i.e., repeated flooding of part of the cave causing wet-dry cycles and damaging pollens (Delcourt et Delcourt, 1980 ; Holloway, 1989 ; Prieto et Carrión, 1999 ; Campbell, 1991b ; Navarro et al., 2001a, 2001b). The difference in exposure of the Focolare 2 samples to this process could be due to the deeper burial of sample F20-1272 compared to samples F20-1270a and b. Therefore, the large damages on pollen and coprophilous fungi produced by cremation and sanitizing burning process occurring in fireplaces and *fumier* are slightly amplified by the humidity conditions of the cave resulting in flooding of some area of the rock shelter.

5.3.3. Summary of taphonomic processes and remarks

The post-depositional processes in the rock shelter are numerous and from diverse origins complicating their interpretation. While the deposits are contemporary, differences are observed between each of the samples. In general, all pollen taxa are represented in all samples.

Pollen preservation appears to be better in biogenic materials, as demonstrated by samples F19-1282 from the *fumier* and F21-1273 from the Fossetta (Angelucci et al., 2009). However, comparison of this sample reveals the contribution of secondary deposition of pollens transported by herbivores into the cave. Indeed, the *fumier* has a higher proportion of zoophilous pollen, whereas the Fossetta has proportions shared between zoophilous and anemophilous (Campbell, 1999 ; Carrión et al., 2000 ; Navarro et al., 2001a ; Carrión, 2002 ; Val-Peón et al., 2019). The absence of coprophilous fungi development in *fumier* samples could be linked to sanitizing burning of dung producing the *fumier*. Moreover, these samples show a post-depositional impact from possible repetitive flooding, with pollen damaged by the accumulation of wet-dry cycles. This wet-dry cycle would result in pollen deterioration, increasing the number of undetermined pollen (Delcourt et Delcourt, 1980 ; Van Geel et al., 1989 ; Holloway, 1989 ; Prieto et Carrión, 1999 ; Campbell, 1991b).

The Focolare 2 sample F20-1272 is marked both by pollen degradation caused by wet/dry cycles and by the extreme oxidizing action of fire. Fire is particularly destructive for pollens. Fireplaces have the lowest palynological concentration rates, where the effect of extreme oxidation seems to indicate a non-preferential destruction of pollen taxa. Yet, in these hearths, a large amount of anemophilous pollen is detected but probably comes from a secondary input after fire activity (Havinga, 1967 ; Bryant et Hall, 1993 ; Lebreton et al., 2010 ; Expósito et Burjachs, 2016 ; Val-Peón et al., 2019). In comparison, heavily burnt or unburnt *fumier* have a high concentration variation visible between F19-1282 and G18-1278 of the *fumier*. However, here the multivariate analyses highlighted the connection to *fumier* sample G18-1278 and sample G21-1269, which have a very strong resemblance. They have the same white facies, palynological concentration, percentage of indeterminate pollen and an almost identical pollen composition. These similarities point to a connection between the two samples and shows the similar intensity of cremation.

Finally, the taphonomic analysis provides information both on the conservation of pollen in the cave and on the management of the rock shelter. The analysis of anemophilous and zoophilous pollen dispersion in pollen rainfall does not indicate a repartition associated with the morphology of the rock shelter. They indicate that all the extraction zones are connected by zoo-anthropic action and the manipulation of organic matter. The hearts and the Fossette attested of the human settlement in the rock shelter and the fumier of the animal contribution to the rock shelter pollen rainfall. The Fossetta is also potentially linked for fuel use. In addition, the location of the *fumier* and the passage of herbivores result in highest levels of humidity and erosion, while the areas closer to the border are less humid, allowing the formation of fungi. There is therefore a possible choice of location between areas dedicated to animals and those dedicated to humans. Regarding the representation of the regional and local vegetation, all the samples show differences about the proportion in the pollen rainfall. However, the high percentage of zoophilous contribution in fumier can be compensated by the high percentage of anemophilous inside the hearths. Therefore, high precaution has been taken to deduce information from this corpus of samples and has to be compared with a regional sites and with a multidisciplinary approach in order to understand the climatic and human impact of the vegetation.

5.4. Climatic parameters and vegetal landscape during the Late Holocene at Sicily and the eastern Mediterranean

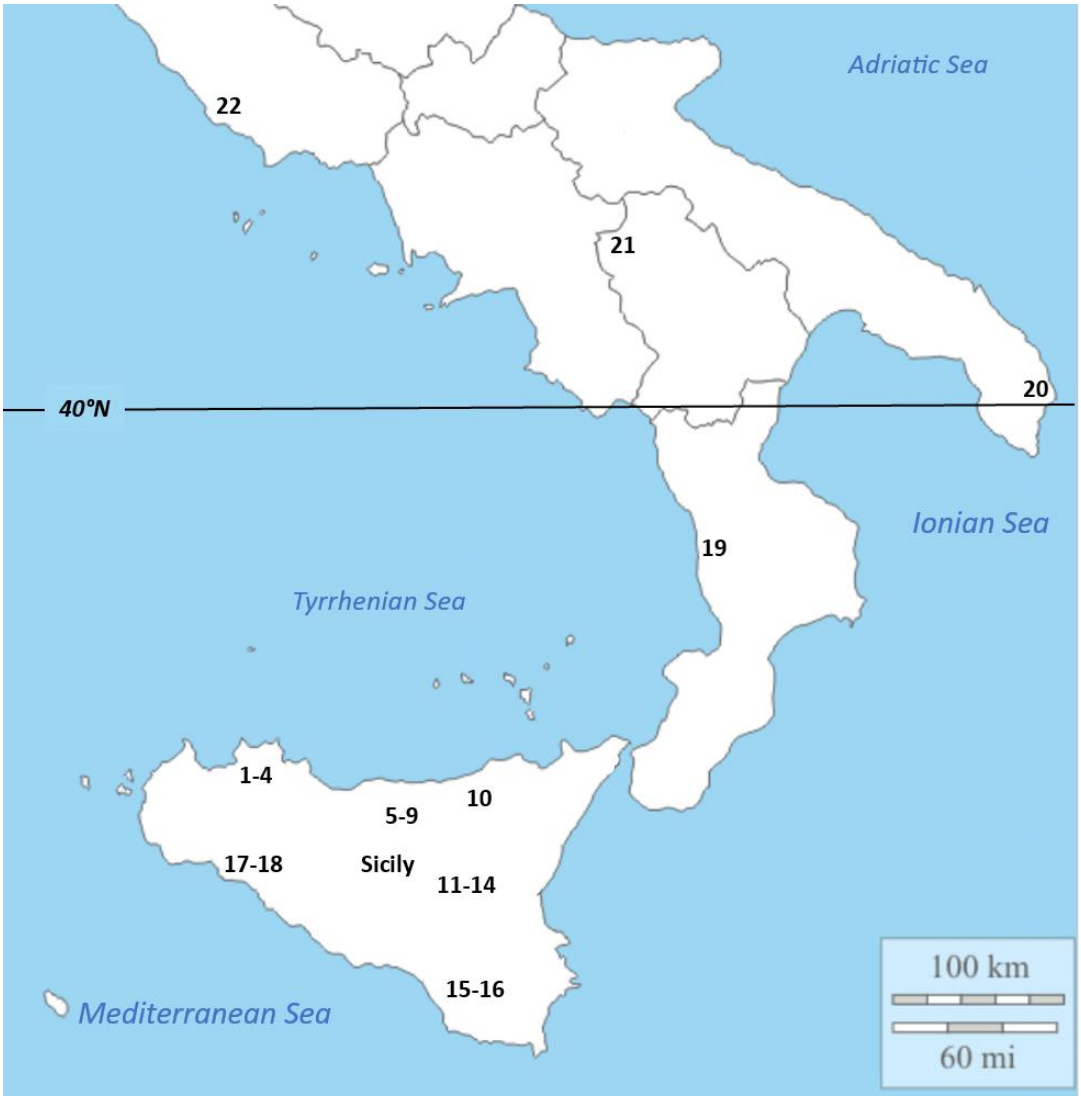

Figure 26 : Map showing the 40° North-South gradient and locations of the sites in Sicily describe in our study 1. Gorgo Tondo (783 m a.s.l.) 2. Gorgo Lungo (877 m a.s.l.) 3. Grotta dell'Uzzo (100m a.s.l.) 4. Bommartino (600m a.s.l.) 5. Urgo Pietra Giordano (1,323 m a.s.l.) 6. Gorgo Pollicino (1,289 m a.s.l.) 7. Vallone Inferno (770 m a.s.l.) 8. Marcato Cixé (1,200 m a.s.l.) 9. Mura pregne (440 m a.s.l.) 10.Urio Quattrocchi (1,044 m a.s.l.), 11.San Marco di Paterno (150m a.s.l.) 12.Valcorrente di Belpasso (551m a.s.l.) 13. Lago di Pergusa (670 m a.s.l.), 14. Case Bastione (610 m a.s.l.) 15. Biviere di Gela (7 m a.s.l.), 16.Castellucio (878m a.s.l.)17. Lago Preola (6 m a.s.l.), 18. Gorgo Basso (6 m a.s.l.), 19. Lago di Trifoglietti (1048 m a.s.l.), 20. Lago Alimini Piccolo (1 m a.s.l.), 21. Laghi di Monticchio (656 m a.s.l.), 22. Grotta Mora Cavorso (715 m a.s.l.). Sites 1–4 are located around Sicani Mountains on northwest of Sicily, the sites 5–9 are located in the Madonie Mountains, 10 are located in the Nebrodi Mountains, 11-14 in the lowland on the center of Sicily, 15-16 on the Mediterranean south-western of Sicilian Sea coast, 17-18 on the Mediterranean south-eastern of Sicilian Sea coast and 19-22 on the Southern Italy.

The comparison of the layer 3.4.a and the rest of the vegetation of the sequence reflects the opening of a mixed Meso-thermo Mediterranean forest with a transition to a more open grassland during the Holocene (Expósito et al., In process). These elements are corroborated by micromamal studies and the abundance of *Microtus (Terricola) savii, Apodemus sylvaticus, Glis glis* species, which indicate the presence of an open forest/forest landscape. It indicates a be-seasonal climate with average temperature of 16.6 +/- 0.5°C and low rainfall of 863 +/- 131mm (López-García et al., 2013). Compared to the archaeopalynologic analyses of the older layer of the complex 3.4.c-g, the stability of evergreen *Quercus* abundance and the emergence of shrubs *Erica,* Cistaceae and *Pistacia*, at the expanse of deciduous *Quercus* and other deciduous plants, show an increase of sclerophyllous plants and herbaceous (Apiaceae, Asteraceae, Poaceae, *Plantago* sp.) as well as a reduction of AP. It reflects the persistence of high insolation, while precipitation would be reduced. Moreover, riverside plants, hygrophytic plants and ferns are less represented than in older and younger periods. Furthermore, the proportion of *Pseudoschizaea*, indicators of erosion in aridity conditions, appears higher in the level 3.4.a. than in the other level of the stratigraphy (Van Geel et al., 1989 ; Expósito et al., In process). This change could be interpreted as a small dryer climate during a short period of the Late Holocene and already highlighted by micromammals research at Vallone Inferno (López-García et al., 2013 ; Kouli et al., 2015 ; Mariotti Lippi et al., 2018). Nevertheless, the presence of hygrophytic plant and NPPs *Gloeotrichia*, and *Spyrogyra* could implie open warmer eu-mesotrophic freshwater an temporary spring close water source remnant inside the rock shelter of surrounding Imera river and highlight the importance of stream water in arid climate for the choice of the site location combining relatively high area and proximity to water source, already observed in Stromboli island (Van Geel et al., 1989 ; Di Renzoni et al., 2016).

Interpretations of the landscape from layer 3.4.a. have to take into account the climatic change originating from the "4.2ka event", which is marked by a crisis of aridity (Carrión et Van Geel, 1999b ; Magny et al., 2013 ; Peyron et al., 2013) and by the cultural activity that has been developing in the Sicilian regions since the beginning of the Upper Paleolithic (Cattani et Renault-Miskovsky, 1989 ; Noti et al., 2009 ; Bisculm et al., 2012 ; Forgia et al., 2013, 2021 ; Costantini et al., 2014 ; Tinner et al., 2016 ; Copat, 2020 ; Pasta et Speciale, 2021 ; Martín et al., 2023).

Thus, interpretation of aridification of the climate would be in concordance with the climate turnover and 40° North-South gradient (Figure 26), highlighting a spatial discontinuity in humidity and temperature during the Holocene. The period between 10300 and 4500 cal. BP reflects significant humidity, while temperature increases after 7000 cal. BP (Combourieu-Nebout et al., 2013 ; Magny et al., 2013 ; Peyron et al., 2013). These changes of humidity have been registered in different sites in Sicily and in the south of Italy. Indeed, the data from the site Lago di Pergusa (670m a.s.l.) in the inland of central-eastern Sicily indicates a regression of the lake level and the proliferation of *Olea*, *Ulmus* and *Pistacia* between 7200 and 3000cal BP ending by the absence of freshwater (Sadori et Narcisi, 2001 ; Sadori et al., 2008). Lago di Preola in south-western of Sicily, reached a peak of level decline around 4500 cal BP (Calò et al., 2012). In Lago di Trifoglietti (1048 m a.s.l.) in the south of Sicily, the lake level drops after 6000 cal. BP and became a peatland. However, at a centennial-scale, humidity peaks have been recorded between 5200-4400 et 3500-2500 cal BP (Joannin et al., 2012). Thus, a turnover caused by a decline in humidity should appear in the evolution of the Vallone Inferno vegetation linked to the "4.2ka cal BP event" (Combourieu-Nebout et al., 2013 ; Magny et al., 2013 ; Peyron et al., 2013). The climate should thus be cooler and drier. Regarding the paleaoenvironmental reconstruction of the VII – IX sec. AD period, the composition of thermophilic plants in the layer 3.4.a. appears to be less important, highlighted in the anthracological record by the presence of *Olea europaea*. Furthermore, the opening of the vegetation is shown by the increase of steppic indicators and could indicate a local aridification caused by the deforestation (Kouli et al., 2015 ; Expósito et al., In process). However, the fluctuation of humidity levels in relation to earlier and recent framing of the Middle and Late Holocene periods is difficult to demonstrate due to the lack of stratigraphic, archaeological and archaeobotanical data and caused by erosion (Forgia et al., 2013, 2021). Nevertheless, a shift in the time frame between the 4.2 ka BP event and the start of the regression is visible. The climatic impact should be observable from the earliest layers of the 3.4. complex, whereas in our case, regression seems to begin only in the most recent layers. The consequences of erosive activity on anthropogenic deposits do not allow us to trace the evolution of vegetation in response to the short period of aridification triggered by the 4.2. ka event and necessitates a comparison of the environment on a regional scale. Moreover, this time frame could also be caused by the particular ecosystem niche of the mountainous Madonie region located between the northern coat and inland of Sicily.

5.5. Regional evolution of the vegetation : temporal differences caused by altitude parameters and inland/coastland variations

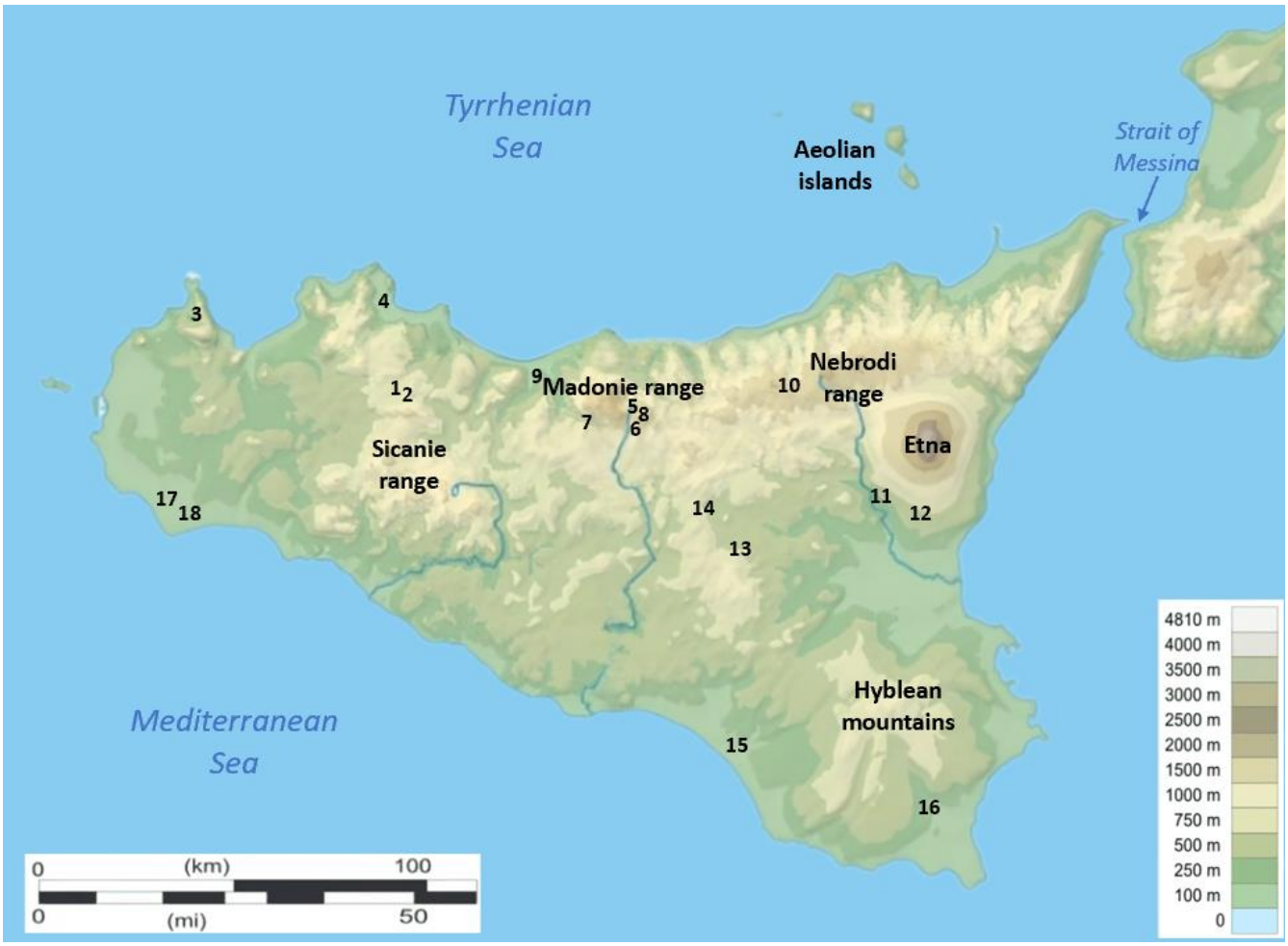

Figure 27 : Map showing the relief and locations of the sites in Sicily describe in our study 1. Gorgo Tondo (783 m a.s.l.) 2. Gorgo Lungo (877 m a.s.l.) 3. Grotta dell'Uzzo (100m a.s.l.) 4. Bommartino (600m a.s.l.) 5. Urgo Pietra Giordano (1,323 m a.s.l.) 6. Gorgo Pollicino (1,289 m a.s.l.) 7. Vallone Inferno (770 m a.s.l.) 8. Marcato Cixé (1,200 m a.s.l.) 9. Mura pregne (440 m a.s.l.) 10.Urio Quattrocchi (1,044 m a.s.l.), 11.San Marco di Paterno (150m a.s.l.) 12.Valcorrente di Belpasso (551m a.s.l.) 13. Lago di Pergusa (670 m a.s.l.), 14. Case Bastione (610 m a.s.l.) 15. Biviere di Gela (7 m a.s.l.), 16.Castellucio (878m a.s.l.)17. Lago Preola (6 m a.s.l.), 18. Gorgo Basso (6 m a.s.l.), 19. Lago di Trifoglietti (1048 m a.s.l.), 20. Lago Alimini Piccolo (1 m a.s.l.), 21. Laghi di Monticchio (656 m a.s.l.), 22. Grotta Mora Cavorso (715 m a.s.l.). Sites 1–4 are located around Sicani Mountains on northwest of Sicily, the sites 5–9 are located in the Madonie Mountains, 10 are located in the Nebrodi Mountains, 11-14 in the lowland on the center of Sicily, 15-16 on the Mediterranean south-western of Sicilian Sea coast, 17-18 on the Mediterranean south-eastern of Sicilian Sea coast

The climatic change has been recorded at numerous sites throughout Sicily and is visible at all altitudes and in all types of vegetation belts (

Figure 27). Recent research by Tinner et al. (2016) on the paleoenvironments of the Urgo Pietra Giodano site (1,323m a.s.l.) in the Madonie region showed the growth and then stability of a particularly dense Oro-Mediterranean beech-holly forest between 7,000-4500cal BP (AP = 80%) until it collapsed at 4,150- 3,650 cal BP and recovered (AP 70-80 %) between 3,650-2,950 cal BP (Tinner et al., 2016). In the Nebrodi nearby mountain range, at Urio Quattrochi (1044 m asl), the evergreen broad leaved forest of the Supra-Mediterranean belt started to decrease after 5000 cal BP (Bisculm et al., 2012). In the Sicanie mountain, to the west of the Madonie region, the sites of Gorgo Tondo (783m a.s.l.), at the same altitude as Vallone Inferno, show the beginning of the regression of the Meso-Mediterranean deciduous-evergreen forest around 3300 cal BP (*Q. pubescents*- and *Q. cerris*-type with admixed *Q. ilex, Ulmus, Fraxinus* and *Hedera helix* decrease). Forest disturbance is also evidenced by the presence of *Pteridium aquilinum* at the Gorgo Lungo site (877 m a.s.l.), where the onset of forest decline could not be determined. At both sites, this phase is followed by a re-conquest of the landscape by forest between 2,600-1,850 cal BP (Tinner et al., 2016). Thus, at the scale of the northern Sicilian mountains, the decline of the various forests seems to have impacted all the sites, starting with the Oro-Mediterranean and Supra-Mediterranean belts and then the Meso-Mediterranean belt. This phase is followed by a regression in forest covering at all sites, with the same time lag between belts. Regarding Vallone Inferno, the decrease observed between the layer 3.4c-g and 3.4a. appears at the same time as the Meso-Mediterranean belt Sicanie forest and later than the Oro-Mediterranean and Supra-Mediterranean belts of Nebrodi-Madonie region (Expósito et al., In process).

The Lago di Pergusa site (670m a.s.l.) (

Figure 27) in the in-land of Sicily shows a decrease in forest cover as early as 4400 Meso-Mediterranean cal. BP, then an increase after 3300cal BP thanks to the expansion of *Olea* (Sadori et Narcisi, 2001 ; Sadori et al., 2008). The coastal site of Biviere di Gela (7m a.s.l.) in south-eastern Sicily bears witness to the change in vegetation in the Thermo-Mediterranean evergreen forest, where the decline began around 5000 cal BP and the maquis peaked around

4300 cal BP (Noti et al., 2009). However, the south-west Sicilian sites of Lago Preola (6m a.s.l.) and Gorgo Bosso (6m a.s.l.) show no change in the Thermo-Mediterranean evergreen forest between 7000 and 2600cal BP (Tinner et al., 2009 ; Calò et al., 2012). Thus, we can observe a shift in vegetation in the different areas of Sicily, with a marked decrease in forest first in the south-east coast, then in the center and finally in the north of Sicily, and no change in the south-west region, which aligns with the forest transition observed in layer 3.4c-g and 3.4a. of Vallone Inferno (Expósito et al., In process). However, while comparing data between coastal (south-west/east), inland (center) and in-between (north) regions, no temporal transition is visible.

This vegetation change is also visible in southern Italy, where the Lago Alimini Piccolo site (1m a.s.l.), located south of latitude 40°, shows a regression of the Meso-Mediterranean forest cover between 4350-3900 cal. BP caused by the displacement of the North African high pressure zone and human pressure (Di Rita et Magri, 2009a, 2009b). On the contrary, the Laghi di Monticchio (656m a.s.l.) and Grotta Mora Cavorso (715m a.s.l.) sites, located north of latitude 40°, show a forest increase around 4000cal BP with an increase in *Quercus*, *Corylus*, Oleaceae and hygrophytic plants (Watts et al., 1996 ; D'Agostino et al., 2022).

To summarise, forest regression is highlighted in studies in paleoenvironmental reconstruction of Vallone Inferno, where the value of arboreal pollen abundance decreases in the layer 3.4.a. compared to the older layer (60 to 45-10%) and appears before around 3600-3360 cal. BP (Expósito et al., In process ; Forgia et al., In process). To compare with the sites in the North region, this regression appear later than in the Oro and Supra-Mediterranean forests of the Madonie-Nebrodi mountain region (Bisculm et al., 2012 ; Tinner et al., 2016). However, the chronological phase seems to be in line with the results found at other sites in the Meso-Mediterranean belt of the Sicanian mountains, although it is less pronounced (Tinner et al., 2016). Nevertheless, it would be older than those observed in more distant Meso-Mediterranean regions such as central Sicily and southern Italy (Sadori et Narcisi, 2001 ; Sadori et al., 2008 ; Di Rita et Magri, 2009a, 2009b) and from the Thermo-Mediterranean forest of south-west coast of Sicily (Noti et al., 2009 ; Tinner et al., 2009). In general, in Sicily, the opening of the forest, caused by the aridification and amplified by human activities, starts before the dates associated with the layer 3.4.a. of Vallone Inferno, except in the nearest sites of the similar belt. However, the origin of the decrease of the forest on the sites of Sicanie appears to be generated mainly by human activities (Tinner et al., 2016). The similarities resulting from comparison with regional

sites suggest that the event “4.2.ka” may not be the origin of the forest decline but the general aridification tendancy could be implied. However, forest decline may have begun earlier but is not visible due to soil erosion of the Middle Holocene and the Middle of Late Holocene stratigraphy. Furthermore, studies carried out at the Lago di Pergusa site (670m a.s.l.) have shown anomalies between the results of O18, AP curves and microcharcoals, highlighting a lesser impact of climate on vegetation and, on the contrary, a significative signal of human impact (Sadori et al., 2008). Thus, another explanation for this change in vegetation and the xeric environment could be linked to the consequence of the mobility and intensification of human settlements as well as the practical difference of agro-pastoral activities in Sicily (Mercuri et al., 2010).

5.6. Use of plant during the Middle Neolithic and Early Bronze Age at Vallone Inferno

In addition to climatic parameters and landscape vegetation reconstruction as well as taphonomic conservation studies, pollens and NPPs are exploited to understand the socio-economical use of the space. They are direct and indirect indicators of the management of the area for pastoral and agricultural activities and human settlement. These indicators through diagrams can highlight the intensity of the anthropic impact on a landscape (Behre, 1981, 1986). Li et al. (2008) propose five criteria frequently used by palynologists to assess the presence of human activity through a palynological record : 1) forest decline 2) pioneer plant proliferation 3) abrupt change in pollen concentration and richness 4) concomitance of cereal plant pollen and crop-land weed 5) occurrence of plants associated with pastoral activity and nitrophilous plants. The relevance of these criteria is accentuated by the accumulation of evidence of activities and the comparison of other non-palynological factors.

5.6.1. Forest decline and fire dynamics

During the Neolithic, and more particularly in the early Bronze Age, the decrease of forest is visible throughout the southern Mediterranean region and Sicily has been interpreted as the cause of climatic change accentuated by human land use (Di Rita et Magri, 2009a, 2009b ; Rolfo et al., 2016 ; Mercuri et al., 2019 ; Pasta et Speciale, 2021). Based on these criteria, an analysis of the landscape over time in the Vallone Inferno palynological sequence reveals the slow opening-up described previously, as linked to an increase in herbaceous taxa to the

detriment of meso-arboreal plants as long as the maintenance of evergreen *Quercus* in the complex 3.4. (Expósito et al., In process). In the Mediterranean region, evergreen sclerophyllous dominance in the vegetation is attributed to anthropogenic disturbance and causes an increase of aridity (Mercuri et Sadori, 2013). Layer 3.4.a., located at the heart of the stratigraphic sequence, bears witness to the start of the vegetation change around 3600-3360 cal. BP. However, this decrease remains slight compared to the recent layer of Roman and Byzantine periods, where the value falls maximum to 4,3% (Expósito et al., In process).

Furthermore, anthracological studies in layer 3.4.a. of Vallone Inferno has shown the predominance of Thermo-Mesophilous taxa such as deciduous *Quercus* and *Fraxinus* in the complex (Expósito et al., In process). Many authors have demonstrated the role of fire during Early Bronze Age for the clearance of landscape in order to create place for agriculture crops, for human huts settlement or for pastoral paddock (Noti et al., 2009 ; Bisculm et al., 2012 ; Tinner et al., 2016 ; Speciale et al., 2020 ; D'Agostino et al., 2022). In the layer 3.4.a. of Vallone Inferno, the use of fire during this period is reinforced by the presence of *Neurospora* sp., a fungi that grows on the charcoal of certain woods (Van Geel, 1978b ; Expósito et al., In process). At Vallone Inferno, we can suppose the use of fire clearance but the selection of certain taxon of woods for domestic fire activities can clearly be observed in the layer 3.4.a. In addition to these fire activities, at the Case Bastione (610m a.s.l.) site in central Sicily, forest loss was caused by the logging of *Quercus* trees to build huts (Speciale et al., 2020). Thus, these fire-clearing and timber harvesting activities for plant construction could partly explain and correspond to the change in vegetation and the xeric environment observed at the Vallone Inferno site in the complex 3 (Expósito et al., In process).

Therefore, the overuse of trees for anthropic activities, preferentially focusing on deciduous *Quercus*, could have induced the AP proportion decrease during the Early Bronze Age observed in the layer 3.4.a. In the complex 3.2 and 3.1 of the sequence, the intensification of clearance by fire seems to increase during Roman and Byzantine periods and provokes the decrease of evergreen *Quercus* in addition to deciduous *Quercus* and *Fraxinus*, as represented in the rise of anthracological remains of those trees in the sub-complex (Expósito et al., In process).

5.6.2. Change of floral composition proportion : pioneer plant flowering and anthropogenic plants indicators

In the layer 3.4.a., while the proportion of *Quercus* deciduous pollen is less important than in the other older layer, some plants considered to be resprout and pioneer plants are visible in the rain pollen and have increased slightly. In particular, *Erica* sp. and Cistaceae have appeared in the environment associated with the layer 3.4.a. They are present in low proportions, but their autogamous mode of reproduction minimizes their representation in palynological analyses. In addition, the positive correlation, observed in the samples of the layer 3.4.a., between *Erica* sp., and cf. *Juniperus* with some herbs such as Ranunculaceae, Apiaceae or Asteraceae tubuliflorae, as well as the DCA index favouring the presence of *Plantago* sp. found in the same samples as *Pistacia*, reinforces the idea of a decline in certain trees caused by management of wild forests. It also suggests the development of shrub heath typical of degraded forest soils in favour of anthropogenic herbaceous plants (Visset et al., 2002 ; López Sáez et López Merino, 2005 ; Di Rita et Magri, 2009a, 2009b ; Kouli et al., 2015). A few pollens of *Corylus*, *Alnus, Pinus* sp. and *Betula*, considered pioneer trees, were observed in the pollen record of the layer 3.4a. However, the presence of *Alnus* is probably linked to the Imera river, the valley's water source, and *Betula* and *Pinus* sp. pollen may come from regional inputs (Kouli et al., 2015). Nevertheless, the maintenance of the clearance of forest and continuous anthropic activity may have prevented the development of a developed pioneer forest and favoured the development of shrub at the end of the Early Bronze Age.

In the pollen record of the layer 3.4.a., different potential anthropogenic taxa have been identified, linked to diverse human activities. Anthropogenic plants are defined as "species that human activities help to disperse and distribute" (Li et al., 2008). The Anthropogenic Pollen Indicators (API) are numerous in archaeological sites. The most common are *Artemisia*, *Centaurea*, Asteraceae (including Cichoreiae), *Plantago* sp. (including *Plantago lanceolata*), cereals, *Urtica*, Chenopodiaceae-Amaranthaceae, Poaceae and Fabaceae (including *Trifolium*-type). The increase of the curve of OJC (Oleaceae-*Juglans*-*Castanea*) also indicate the anthropic impact of the management of the forest and the cultivation of fruits (Behre, 1981, 1986; Li et al., 2008; Mercuri et al., 2013a, b, 2019; Kouli et al., 2015). Regarding the layer 3.4.a. of Vallone Inferno samples, the major rise of pollen proportion is associated with Asteraceae tubuliflorae, Asteraceae liguliforae (including Cichoriae), Apiaceae and *Plantago*

sp. This significant representation in the vegetation implies the impact of humans on the environment. We also noticed that the proportion of *Artemisia*, Cerealia-type, Urticaceae, Ranunculaceae, Fabaceae, *Juglans* and Oleaceae in the layer 3.4.a. slight growth compared to the older layer 3.4.c-g. and the high constant proportion of Poaceae between the Middle Neolithic and Early Bronze Age and could be induced by human modification of the ecological niche. In majority, those taxa can be associated with anthropic activities. All these plants are presented in (Table 7) including weeds and ruderal plants, cultivated plants and crop-lands weeds, plants indicators of pastures and grasslands as well as coprophilous fungi. However, some plants and taxa are associated with several activities because of their taphonomic rank. Taxon identification is often limited to genus or family. Furthermore, certain anthropogenic plants have several anthropical meanings because of their taxanomic level. Combining and multiplying approaches can therefore be the key to supporting palynological research and pinpointing the possible causes of landscape evolution as well as identify the anthropic activities (Bottema, 1975 ; Behre, 1981, 1986 ; López Sáez et López Merino, 2005 ; Li et al., 2008 ; Mercuri et al., 2013, 2019 ; Florenzano et al., 2015).

5.6.3. Pastoral activities and human settlements over agricultural activities

5.6.3.1. Low influence of agricultural indicators

Pollen indicators of agricultural activity in layer 3.4.a. are rare. They are represented by direct factors such as Cerealia-type, which are cultivated plants (Figure 25). This low proportion of cereals is also highlighted in the archaeocarpological record. In fact, only three grains of *Triticum aestivum/durum* were found in the entire 3.4 complex (Table 2) (Expósito et al., In process). Their presence can be explained by the long distance of crops to Vallone Inferno and their transport of forage in pottery from low land (Bottema, 1992 ; López Sáez et López Merino, 2005). On the other hand, the pollen signs of agriculture are also visible through the presence of weeds such as Fabaceae, Poaceae or Malvaceae (Table 7). Weeds are defined as "organisms that can bread and thrive in an artificial habitat" (Li et al., 2008). However, these taxa are the subject of debate over their association with cultivated plants, due to the diversity of species included in these taxonomic groups (Van Geel et al., 2003 ; Farris et al., 2010). Furthermore, the correlation analyses do not present a correlation between Cerealia-type and any other taxa. Given the scarcity of crops and weeds palynological and carpological indicators, the site does not appear to be used for intensive agricultural activities. Furthermore, the absence of

significant curve of pollen OJC does not reveal the fruit tree culture of those plants, yet widespread in southern Italy since the Bronze Age, even in the during Roman and Byzantine periods at Vallone Inferno (Expósito et al., In process). The lack of correlation between the plants indicates anthropic impact on the landscape and *Juglans* reinforces the idea that this taxon is not used for fruit production. In the case of *Corylus*, the correlation is quite significant. However, the absence of carpological evidence does not allow us to attest to their exploitation (Mercuri, 2013). Therefore, agricultural practices do not seem to be the main activities for the economic system of Vallone Inferno site during the Neolithic and Early Bronze Age. Indeed, evidence of agricultural activities are scare in the layer 3.4.a. and the proportion of their indices are sparse. However, the recurrent presence of Cerealia-type and Fabaceae pollen in more recent periods could indicate the practice of these practices as early as the Roman and Byzantine periods. In contrast to southern Sicily, where agricultural activities are major (Noti et al., 2009 ; Tinner et al., 2009 ; Calò et al., 2012), northern sites are marked by the development of pastoral activity during Neolithic and Bronze Age (Van Wonterghem et Jole Bovio, 1980 ; Pasta et Speciale, 2021 ; Tinner et al., 2016).

5.6.3.2. Pollen of pastoral indicators and their limits Human settlements and synanthropic indicators

The differences between Pollen pastorals indicators (PPI) and human settlement indicators (HIS) depends on many factors such as the region or the type of soil. Concerning the HIS, the main ecological groups of pollen are formed by ruderal plants. Behre, (1981a) defines these plants as taxa representative of a nearby human settlement. In layer 3.4.a. of Vallone Inferno, the ruderal plants identified are Asteraceae, Poaceae, *Artemisia*, Apiaceae, Lamiaceae and Caryophyllaceae (Table 7). They indicate human presence and intensity of occupation of the territory.

The presence of pastoral activities on the land induced a change in the environments caused by the over-grazing and trampling of domestic animals. In the Mediterranean region, the pressure imposed by goat and sheep have induced the change of forested areas into maquis shrublands, slightly observed and already described in the layer 3.4.a.
However, the major pollen indicators of pastoral activity can be Chenopodiaceae-Amaranthaceae, *Plantago* sp., Poaceae, Urticaceae, Asteraceae, Fabaceae, Ranunculaceae and

coprophilous fungi are the main NPPs identify to characterize pastoral activities (Table 7) (Bottema, 1975, 1992 ; Behre, 1981, 1986 ; Van Geel et al., 1984 ; Mazier et al., 2006, 2009 ; Menozzi et al., 2010 ; Papanikolaou et al., 2011 ; Mercuri et al., 2013, 2019 ; Florenzano et al., 2015 ; Florenzano, 2019 ; Expósito et al., In process). *Sporormiella*-type, *Chaetomium and Neurospora* ascopore are indicators of the presence domestic herbivores in the vicinity of the archaeological site (Van Geel et al., 2003 ; Van Geel, 2006 ; López-Sáez et López-Merino, 2007 ; Cugny et al., 2010 ; Feeser et O'Connell, 2010 ; Menozzi et al., 2010 ; Cugny, 2011 ; Hillbrand et al., 2012).

According to the whole sequence, the percentage of Asteraceae liguliflorae almost doubled between the beginning of the complex 3.4 and the complex 3.2. (Expósito et al., In process). However, a debate is currently open on the anthropic meaning of the Asteraceae liguliflorae et tubuliflorae. Indeed, Cichorieae, fenestrate pollen corresponding to one of the Asteraceae tribes, has been interpreted in two different ways on archaeological sites according to the researcher 1) over-representation can be attributed to taphonomy impact and a better conservative ability in acid soil thanks to their resistant wall of exine (Bottema, 1975 ; Dimbleby, 1985 ; Hall, 1991) or 2) their high proportion is a consequence of the herbivores action and browsing resulting in selection of plants (Behre, 1981, 1986). The recent studies have demonstrated that the over-representation cannot be only the effect of exine oxidation and the high percentage of Cichorieae is good indicator of pasture land and grazing indicators (Bottema, 1975 ; Navarro et al., 2001b ; Mazier et al., 2006, 2009 ; Lebreton et al., 2010 ; Florenzano et al., 2015). In the layer 3.4.a. of Vallone Inferno, the strong positive correlation between Asteraceae and indeterminate pollen shows indeed, as an impact that the presence of Asteraceae is not only linked to a differential conservation and over-representation. Nevertheless, the slight correlation between Asteraceae (tubuliflorae and liguliflorae) and coprophilous (*Chaetomium* and *Sporormiella*) implies that the increase in Asteraceae in rain pollen is not entirely linked to the presence of pastoral activities. One explanation would be that on the layer 3.4.a. of Vallone Inferno site, Asteraceae corresponds to a ruderal plant indicative of the increase in human settlements in the region (Behre 1981).

Nevertheless, these taxa remain strongly correlated with *Plantago* sp., Apiaceae, Ranunculaceae and Poaceae. The co-occurrence of *Plantago* sp. Ranunculaceae, Chenopodiaceae, Fabaceae and Apiaceae positively correlated with coprophilous fungi

suggests pastoral activity on the layer 3.4.a. of Vallone Inferno (Behre, 1986 ; Mazier et al., 2006, 2009 ; Mercuri et al., 2010 ; Cugny, 2011 ; Mercuri et Sadori, 2013). Indeed, animal husbandry leads to a forcing of floral composition and could result in a mixing of markers according to species within taxa, which would be indicative of both pastoral activities and intensification of human settlements. For example, feeding and reproduction facilitate the development of Fabaceae and Asteraceae. Trampling favours the development of *Plantago* sp., while dung deposition increases soil nitrogen and the growth of nitrophilous plants such as Urticaceae and *Plantago* sp. (Mercuri et al., 2013). The lack of correlation and the low quantity of Urticaceae do not attest to human presence and pastoral activities. On the contrary, its low level could indicate that the organogenic soil remained weak on the environment during the Early-Bronze Age and that human settlement did not cause a strong enrichment of nitrogen in the soil (Mazier et al., 2006, 2009 ; Mercuri Bandini Mazzanti Florenzano Montecchi Rattighieri et al., 2013). Nevertheless, NPPs indicators characterize an environment marked by rich organic matter enrichment in the soil, thanks to coprophilous fungi, which indicate an organogenic soil in the layer 3.4.a. of Vallone Inferno (Van Geel et al., 1984, 1989 ; Menozzi et al., 2010). The presence of palynomorph algal and the positive correlation between Cyperaceae, Fabaceae and Ranunculaceae, identified earlier as PPI, could be interpreted as the presence of some water inside the rock shelter in the form of puddles in the layer 3.4.a.

Similarly, the role of Poaceae in landscape evolution is particularly ambiguous. On the one hand, the stronger, more significant positive correlation of Poaceae with the two species of *Quercus*, *Corylus* than with the two taxa of Asteraceae would indicate that the presence of Poaceae in the landscape is not essentially linked to human settlement. On the other hand, the proportion of Poaceae increases drastically in more recent periods, while that of arboreal species declines and reinforces the ubiquity of this taxa (Expósito et al., In process). Moreover, the strong correlation with *Plantago* sp., Apiaceae and Poaceae indicates that some species of the Poaceae may have been reinforced by local grazing activity forced by pastoral activity (Mazier et al., 2006 ; Mercuri et al., 2010). Mazier et al. (2006) showed that the co-occurrence of *Plantago lanceolata* and Chenopodiaceae with tree species would indicate a lightly grazed woodland environment in the layer 3.4.a. The application of these results to the Vallone Inferno site is reinforced by the correlation between Chenopodiaceae and Apiaceae taxa and woodland species. Furthermore, the presence of *Rubus* sp. seeds and charcoal of *Olea europaea, Fraxinus*

and *Quercus* in complex 3 are indicated as sources of animal nutrients for forage (Expósito et al., In process ; Martín et al., In process).

Therefore, combination of NPPs and pollen allowed the identification of PPI and HIS on the layer 3.4.a of Vallone Inferno. In this study and in the Madonie region, Asteraceae liguliflorae and tubuliflorae are associated with HIS group. The co-occurrence of these taxon and the shrub *Pistacia* could imply its inclusion in this group of HIS herbs and its presence could be a consequence of the intensification of human settlements on the site related to the destruction of the forest. The PPI identified are *Plantago* sp., Fabaceae, Ranunculaceae, Apiaceae et Chenopodiaceae. *Chaetomium, Polyporisporites* et *Sporormiella* coprophilous fungi are also indicators of pastoral activities. However, pollen identification rank limits the determination and the association of pollen to an indicator group and some taxon may have multiple symbolism related to different species. The presence of Poaceae is particularly ambiguous and seems to be naturally represented in the landscape more than a result of anthropic activities. Nevertheless, the slight increase of Asteraceae and *Plantago* sp. show the intensification of the impact of human settlement whereas the effect of pastoral activities on the landscape appears less affecting in the layer 3.4.a.

5.6.3.3. The comparison with the archaeological remains and sites in Sicily

The revolution between the Middle Neolithic and Early Bronze Age implies change in cultural practices resulting in local vegetation changes. The transition led to the regression of AP, fire activities, disturbance of the soil and rising of shrub and herbs caused by the intensification of human settlements and the slight pastoral activities.

In Sicily, farming and herding activities began during the Neolithic period in coastal areas and in low-lying regions where the forest is less dense and use to practice intensive but small-scale pastoralism and later nomadism pastoralism (Geddes, 1983 ; Arnold et Greenfield, 2006 ; Albarella et al., 2006 ; Mercuri et Sadori, 2013 ; Maniscalco et al., 2015 ; Natali et Forgia, 2018a ; Forgia, 2019a ; Forgia et al., In process) (

Figure 27). In particular, the sites of Urio Quattrochi (1044m a.s.l.), Grotta dell'Uzzo (100m a.s.l.) , San Marco di Paterno (150m a.s.l.), Valcorrente di Belpasso (551m a.s.l.) and Urgo

Pietia Giordano (1,323m a.s.l.) show traces of farming activities (Costantini, 1989 ; Bisculm et al., 2012 ; Costantini et al., 2014 ; Maniscalco et al., 2015 ; Tinner et al., 2016 ; Natali et Forgia, 2018a). In the palynological register, the Urgo Pietia Giordano site (1,323m a.s.l.) shows a slight opening up of oro-Mediterranean forest and open grasslands composed of Poaceae and Cichorioideae indicating low land use in the Middle Neolithic in the region (Tinner et al., 2016). Urio Quattrochi (1044m a.s.l.) shows the increase of microcharcoal with culture of cereals and figs during the Neolithic and therefore the possible opening of the forest caused by the development of agro-pastoral activities (Bisculm et al., 2012).

Later, between the Copper Age and the Early Bronze Age, the development of new technologies enabled humans to exploit less accessible territories such as the interland or high altitudes, where the use of fire and the development of activities led to the opening up of the forest (Natali et Forgia, 2018a) (

Figure 27). This favored the establishment of the culture of short- and medium-distance transhumance of herds, allowing seasonal movements at medium and high altitudes (Geddes, 1983 ; Greenfield, 1999 ; Arnold et Greenfield, 2006). These practices increased, stabilized and became more specialized during the Bronze Age, with a wider living and movement zone for the animals. Animals, particularly goats in the Neolithic, were raised in the lowlands where agriculture was highly developed. Development of mixed agro-pastoral activity is associated with the introduction of *Castellucio*-type pottery into the northern Sicilian region. The mobility of Sicilian settlers encouraged the sharing of cultures and the dispersion of this type of pottery *Castellucio*, originate from the eponymous site in the heart of the Hyblean mountains, to the south-west and east of Sicily (Copat et al., 2017 ; Copat, 2020). The northern region of Sicily seemed to be excluded from the *Castellucio* culture zone, until the discoveries in the Vallone Inferno. On the site, the transition between the Neolithic and Early Bronze Ages is marked by the replacement of *Tricromica figulina* pottery in the Neolithic and *San'Ippolito* pottery during the Copper Age and then *Castellucio* pottery in the Early Bronze Age, as well as lithic artefacts (Forgia et al., 2013, 2021). This type of pottery marks the beginning of the Bronze Age, whereas the Copper Age is composed of *San'Ippolito* pottery, identified in layer 3.4.e. Nevertheless, vegetation does not present variation following the Neolithic activities at Vallone Inferno (Expósito et al., In process).

In line with this, the opening of the forest and the development of a grassland caused by human settlement begins during the transition between the Middle/Late Copper Age and the Early Bronze Age. This impact may be linked to population intensification or to the arrival of new, more invasive practices (Iannì, 2009). At Vallone Inferno, one seed from the layer 3.4.b. provides a date around 3600-3360 cal. BP where the chronology on human bones of the layer 3.4.g is dated around 4500-4270cal BP. However, the first traces of *Castellucio* pottery were observed in layer 3.4.d. and pollen analysis of samples from complex 3.4. shows that the most recent layer studied, except for 3.4.a., is layer 3.4.c. Thus, the start of deforestation would have begun just after the arrival of the *Castellucio* culture at Vallone Inferno and around 3600-3360 cal BP (Forgia et al., 2021 ; Expósito et al., In process ; Forgia et al., In process). The plants most identified at this time are Asteraceae liglulifloraе and tubuliflorae, *Plantago* sp., Poaceae and *Quercus* evergreen. The abundance of these herbaceous plants indicates the presence of human settlement near the cave, with deciduous *Quercus* being exploited for domestic purposes such as fire (Expósito et al., In process). According to palynological studies of layer 3.4.a., this would have been mainly exploited for pastoral activities in this period. Indeed, the site would have been used as sheepfold for a season, during the goat breeding period over winter, until the foetuses are born in spring and the milk is harvested (Forgia et al., 2013 ; McClure et al., 2018 ; Martín et al., 2023 ; Vallejo et al., In process ; Martín et al., In process). The comparison of these new archaeopalynological data with the archaeological dataset is thus in complete agreement.

Comparing, on a regional scale, the divergence of the curves between delta O18 and AP cover at Lago di Pergusa (670 m a.s.l.) and Case Bastione (610 m a.s.l.) indicates the start of intense anthropic impact on vegetation around 4300 cal BP. These sites also show the exploitation of deciduous *Quercus* and *Fraxinus* for the construction of huts, which appear more "individualized" from the Early Bronze Age onwards, testifying to a change in the design of human settlements during *Castelluccio* culture. Vegetation evolution is very similar to the layer 3.4.a. of Vallone Inferno, with *Quercus*, Gramineae and Chenopodiaceae are still abundant, *Corylus*, *Fagus* and Ericaceae are decreasing at the expense of *Olea*, *Ulmus*, *Pistacia*, *Artemisia* and *Plantago* sp., which are increasing, and Cerealia-type remains low (Sadori et Narcisi, 2001 ; Sadori et al., 2008 ; Giannitrapani et al., 2014 ; Speciale et al., 2020). This decline is also visible in south-west Sicily, according to palynological records from the Biviere di Gela site in the Hyblean region, cradle of the *Castellucio* culture, linked to the Copper and Bronze Age

transition (around 4300 to 3500 cal BP) and the “4.2 event of aridity. The decline of the evergreen *Quercus* forest and the increased sclerophyll shrubs and *Olea* reach its peak around 4300 cal BP. The association of this decline with an increase in fire activity indicates a disruption and management of the forest, in association with indicating agro-pastoral activity at this period (Noti et al., 2009 ; Copat et al., 2017). Those pastoral activities are also highlighted by the presence of *Castellucio* pottery and remains of goats, but also of cattle and pigs as in the layer 3.4.a. of Vallone Inferno (Iannì, 2009 ; Giannitrapani et al., 2014 ; Chilardi et Crispino, 2017 ; Martín et al., 2023). The change in cultivation is thus potentially linked to a response by human settlements to the evolution of vegetation forced by climatic aridity and human mobility in the interland and highland of Sicily (Natali et Forgia, 2018a). The spatio-temporal comparison of vegetation change discussed earlier in this study indicates a similarity of ecosystems with the Gorgo Tondo (783 m a.s.l.) and Gorgo Lungo (877 m a.s.l.) sites, as well as a concordant temporal marking of agro-pastoral activities (Tinner et al., 2016).

Nevertheless, data from the south-east of the region seem to indicate a time difference in the arrival of the *Castelluccio* culture (Copat et al., 2017). Similarly, the study of the coastal sites of Lago Preola (6 m a.s.l.), et Gorgo Basso (6 m a.s.l.) testifies to a lack of vegetation response to aridification of the climate as well as to anthropic activities before 2600 cal BP (Tinner et al., 2009 ; Calò et al., 2012). Yet, the *Castellucio* pottery has been identified in Lago Preola (6 m a.s.l.) (Copat et al., 2017).

Therefore, one of the major changes in the transition between the Copper Age and Early Bronze Age would be linked to the intensification and diversification of pastoral practices, the increase in the population and its funerary practices. These settlements from southern culture seem to have had a greater impact on local vegetation than the Neolithic populations, who were already agro-pastoralists. Furthermore, palynological analyses are consistent with the *Castelluccio* culture spreading from the south-west, not the south-east, through central Sicily and Mount Etna to the mountains of Madonie and Sicanie. They would have spread from the southern coasts into the hinterland and then into the mountainous regions of northern Sicily, as it also shown in the layer 3.4.a. of Vallone Inferno regarding the timing of the decrease of forest and the rising of herbaceous zoo-anthropogenic apport in the pollen rainfall. For the most recent Bronze Age periods, archaeological sites are clustered near the coast, such as Mura Pregne (440m a.s.l.), or in the hills, such as Bommartino (600m a.s.l.), where *Castellucio* pottery has

been identified. Together, these sites form a network of open-air sites sharing the same culture and used for the development of vertical transhumance, highlighted by GIS studies (Forgia, 2019a, 2019b). However, the anthropic impact on vegetation does not seem to have been caused exclusively by the spread of the *Castellucio* culture and human, since the Aeolian Islands in northern Sicily are also affected by this change, even though none of this pottery has been found there (Mercuri et al., 2020).

6. Conclusion

The investigations carried out in this study demonstrate the scope and diversity of palynological analysis in archaeology. It has enabled us to trace the evolution of the landscape and human cultural practices, taking into account the potential consequences of climate change observed on a regional scale and the anthropization of the environment for agro-pastoral purposes. However, archaeopalynology is a science limited by the differential conservation of botanical micro-remains within stratigraphic sediments into rock shelter, which undergo numerous taphonomic and anthropic processes, revealing a partial reconstruction of the environment and practices. In addition to this, univariate and multivariate statistical analyses highlight the importance of links between samples and their different origins, while reflecting both taphonomic issues and ecological similarities. Nevertheless, by comparing the palynological results of the sequence with the average of the samples from layer 3.4.a., within the anemophilous contributions, we observe that the strong correlation between indeterminate pollen and Asteraceae, identified as HIS and zoophilous pollen, would be an anthropozoogenic contribution and therefore linked to a change in vegetation associated with their installation. In addition, an increase in the contribution of *Plantago* sp., identified as API, but also a maintenance of evergreen *Quercus* and a decrease in deciduous *Quercus* were highlighted. The difference in the percentages of these two tree species, with physically and chemically similar pollens, implies a regional issue not caused by post-depositional processes. Furthermore, the multidisciplinary and regional approach corroborates the representativeness of the pollen corpus for reconstructing vegetation, its evolution and its response to human activities.

The taphonomic history of the rock shelter pollens and NPPs collected in layer 3.4.a. is very particular. This does not seem to be due to the morphology of the rock shelter. However, despite the contemporaneity of the samples, they show a differential preservation of pollens according to the post-depositional processes undergone. The impact of fire on pollen shows a massive, rapid and non-differential destruction of pollen due to extreme oxidation. On the other hand, in biogenetic material such as *fumier* or detrital bucket, pollen preservation is greater but favors slow deterioration. For the fumier, this differential conservation could be the results of mobilization of the substrats and sanitizing burning dung. In contrast, the absence of this activities in these Fossetta favour the proliferation of fungi and bacteria. Moreover, the presence of algal palynomorphs in the deepest areas of the layer would indicate variations in humidity and erosion in the sediments, with water evaporation leading to increasingly degradation during wet/dry cycles. The existence of these palynomorphs at the heart of a hearth shows that this activity is not induced by the presence of animals but is due to the specific conditions of the rock shelter and the percolation of sediments followed by a phase of aridity. The disposition of *fumier* at this level of the rock shelter could therefore be the result of management, which the distribution of anemophilous and zoophilous pollens seems to highlight. Indeed, the ratio of zoophilous pollen to anemophilous pollen in the *fumier* is in majority, indicating a significant contribution of pollen by the animals through their feeding and their herbaceous habitat zones. However, while these samples enable us to understand the consequences of certain post-depositional processes, they cause an analytical bias in rainfall pollen for interpreting changes in vegetation. Nevertheless, the combination of all the samples limits this problem of differential preservation and allows us to deduce information on paleoenvironments and human settlements. Furthermore, multidisciplinary research and comparisons of sites appears to be a key approach to reconstructing human settlements and reconstructing the evolution of the landscape and local climate during archaeological periods, in order to palliate taphonomic gaps.

Joining the results from layer 3.4.a. with the rest of the Vallone Inferno palynological sequence reveals a regression in Meso-Thermo Mediterranean forest cover, with a decline in tree species such as deciduous *Quercus* in favor of sclerophyllous shrub species, such as *Pistacia* and *Erica* sp., and herbaceous species such as Asteraceae tubuliflorae and liguliflorae, *Plantago* sp. and Poaceae. The development of these xerophytic plants indicates an aridification of the climate, also identified through a study of micromammals. However, comparison with regional sites

shows that it is not induced by the "4.2ka" event, but could be the result of a general, slight climate trend towards lower humidity, as well as the development of anthropogenic activity.

The evidence of human settlement and pastoral activities in the palynological record of layer 3.4.a. is multiple. Indeed, through the low number of decreasing tree species and the maintenance of evergreen *Quercus*, human management of the forest seems to be the main factor in the evolution of vegetation around 3600-3300 cal BP, in contrast to the impact of climate change, which appears to be mitigated. In fact, in addition to anthracological data, the deciduous *Quercus* species is subject to anthropic selection as fuel for domestic hearth production. Deforestation has led to the proliferation of shrubby plants, possibly the result of forest cleaning, and herbaceous plants. In particular, Asteraceae tubuliflorae and liguliflorae plants bear witness to human settlement in the region. Zooarchaeological, anthracological, lithic and pottery data all point to human settlement in the Upper Palaeolithic and the middle of Neolithic periods. However, the erosive activity associated with the rock shelter conditions does not allow us to attest to the vegetative response to this settlement. On the contrary, the dating of layer 3.4.a. to 3600-3300 cal BP and the discovery of *Castellucio* pottery link the tree regression to the end of the Copper Age and the Early Bronze Age. During this period, the human economy was based on pastoral activity and the breeding of goats, cattle and pigs, as can be seen from zooarchaeological and biomarker data. These pastoral activities are also perceptible in the palynological data from layer 3.4.a., where the herbaceous *Plantago* sp., Fabaceae, Ranunculaceae, Apiaceae and Chenopodiaceae have been identified, as well as the coprophilous fungi *Chaetomium*, *Polysporisporites* and *Sporormiella*. The distribution of zoophilous pollens within the rock shelter and the existence of a *fumier* deposit support this idea. On the contrary, agricultural activity remained underdeveloped during this period, which is corroborated by the small amount of material in the carpological analysis.

A comparison of these data on human settlement and deforestation on a Sicilian scale demonstrates the birth of the *Castellucio* culture from the coasts and lowland areas of the south-west, before spreading into the hinterland and the highland of the south-east and center of the island. This culture frequently seems to be associated with an increase in human settlement, transhumance pastoral activity and a regression in forest cover. The conquest of high-altitude lands implies a change in pastoral activity strategy, with the development of vertical pastoralism. In addition to zooarchaeological, pottery and lithic data, palynological data from

layer 3.4.a. support the hypothesis of the installation of this culture and the particular pattern identified with their installation. Therefore, Vallone Inferno is a major site in the Madonie region of northern Sicily proving the continuity of the spread of the *Castellucio* culture in this region resulting in forest decrease as well as vertical pastoral activity thanks to its location between low and high altitudes, as well as its proximity to the river Imera.

7. Perspectives

To complete this preliminary study, future research might focus on a different approach.
Firstly, from a taphonomic point of view, further analysis of the samples from layer 3.4.a. is recommended. Indeed, it could be interesting to observe the cause of pollen indeterminacy as well as the level of pollen degradation according to extraction areas. This is necessary in order to identify in greater detail the origins, causes and consequences of the biological, chemical and mechanical deterioration hypothetically highlighted during this study on hearths, *fumier* and buckets. Similarly, sampling of sediments from areas that have not undergone this post-depositional process is important to demonstrate the level of differential conservation caused by hearths, *fumier* and buckets. On the other hand, it might be interesting to analyze samples located close to the borders and in the center of the rock shelter to observe potential differences in pollen deposition.
Secondly, in terms of the evolution of vegetation, analysis of newly excavated samples from earlier periods may help to understand the response of the environment to the climatic changes observed on the Mediterranean scale involving variations in humidity and temperature, in addition to the "4.2" and "8.2 ka" climatic events. Similarly, a study of phytoliths, which are more resistant, could complement the analyses carried out and help understand the paleo-ecology of layer 3.4.a.
Finally, further palynological analyses are needed to prove the concomitance of the spread of the Early Bronze Age *Castellucio* culture or the Copper Age *San'Ippolito* culture from the south-west to the northern mountains of the Madonie region with the opening up of the forest and the establishment of pastoral activity. For example, analysis of sites located in the lowlands

of the Madonie region could determine whether these areas were used for agricultural activities. In addition, a palynological analysis of the Mura Pregne site (400m a.s.l.), located on the northern coast of Sicily, or the Rocche (Roccapalumba) site (411m a.s.l.), where traces of pastoral activity and *Castellucio* pottery have been found, could help to visualize the consequences on vegetation of the development and spread of this culture within the Madonie region. Also, a more in-depth analysis of the differences between Neolithic and Metal Age cultural practices, with the different types of vegetation response, would help to understand the possible causality of changes in practices potentially forced by climatic changes, as some authors have already attempted to expose.

References

AHMED S., CAIN R. (2011) – Revision of the genera Sporormia and Sporormiella, *Canadian Journal of Botany*, 50, p. 419-477.

ALBARELLA U., TAGLIACOZZO A., DOBNEY K., ROWLEY-CONWY P. (2006) – Pig Hunting and Husbandry in Prehistoric Italy: a Contribution to the Domestication Debate, , 72.

ANGELUCCI D.E., ANESIN D. (2012) – Sedimenti e suoli, natura e cultura : considerazioni geoarcheologiche sulla genesi delle stratificazioni archeologiche in ambiente montano,

ANGELUCCI D.E., BOSCHIAN G., FONTANALS M., PEDROTTI A., VERGÈS J.M. (2009) – Shepherds and karst: the use of caves and rock-shelters in the Mediterranean region during the Neolithic, *World Archaeology*, 41, 2, p. 191-214.

ANTONIOLI F., PRESTI V.L., MORTICELLI M.G., BONFIGLIO L., MANNINO M.A., PALOMBO M.R., SANNINO G., FERRANTI L., FURLANI S., LAMBECK K., CANESE S., CATALANO R., CHIOCCI F.L., MANGANO G., SCICCHITANO G., TONIELLI R. (2016) – Timing of the emergence of the Europe-Sicily bridge (40-17 cal ka BP) and its implications for the spread of modern humans, *Geological Society Special Publication*, 411, p. 111-144.

ARNOLD E., GREENFIELD H.J. (2006) – The origins of transhumant pastoralism in southern Europe.,

BALDINI G., CASSATARO U., LONGO E., RECAMI A. (1976) – Recenti scoperte suI paleolitico siciliano, *Natura*, 67, p. 125-127.

BEHRE K.E. (1986) – Anthropogenic indicators in pollen diagrams, *Rotterdam: A.A. Balkema*.

BEHRE K.E. (1981) – The interpretation of anthropogenic indicators in pollen diagrams, *Pollen et Spores*, 23, p. 225-245.

BENNETT K.D., WILLIS K.J. (2001) – Pollen, *in* J. P. Smol, H. J. B. Birks, W. M. Last, R. S. Bradley, et K. Alverson (dir.), *Tracking Environmental Change Using Lake Sediments:*

Terrestrial, Algal, and Siliceous Indicators, , Dordrecht, Springer Netherlands (Developments in Paleoenvironmental Research), p.5-32. https://doi.org/10.1007/0-306-47668-1_2.

BISCULM M., COLOMBAROLI D., VESCOVI E., VAN LEEUWEN J.F.N., HENNE P.D., ROTHEN J., PROCACCI G., PASTA S., LA MANTIA T., TINNER W. (2012) – Holocene vegetation and fire dynamics in the supra-mediterranean belt of the Nebrodi Mountains (Sicily, Italy): HOLOCENE VEGETATION AND FIRE DYNAMICS IN SICILY, *Journal of Quaternary Science*, 27, 7, p. 687-698.

BOTTEMA S. (1992) – Prehistoric cereal gathering and farming in the Near East: the pollen evidence, *Review of Palaeobotany and Palynology*, 73, 1, p. 21-33.

BOTTEMA S. (1975) – The interpretation of pollen spectra from prehistoric settlements (with special attention to liguliflorae), , Palaeohistoria 17, p. 17-35.

BOTTEMA S., WOLDRING H. (1994) – Bronze Age and Byzantine pollen of the Kestel tinmine (Turkey) and its possible origin : practical and experimental pollen analysis in archaeological context. O. K. Davis (dir.), , Aspects of archaeological palynology : methodology and applications. AASP Contribution Series 29, p. 7-15.

BRYANT V.M., HALL S.A. (1993) – Archaeological Palynology in the United States: A Critique, *American Antiquity*, 58, 2, p. 277-286.

BRYANT V.M., HOLLOWAY R.G. (1983) – 5 - The Role of Palynology in Archaeology, *in* M. B. Schiffer (dir.), *Advances in Archaeological Method and Theory*, , San Diego, Academic Press p.191-224. https://www.sciencedirect.com/science/article/pii/B9780120031061500109.

BUI THI M. (1985) – Conservation des pollens et leur interprétation en milieu archéologique., *in* J. Renault-Miskovsky et M. Girard (dir.), *Notes et monographies techniques*, , Paris, France, Éditions du CNRS. p.23-37.

BUI THI M., GIRARD M. (2002) – L'archéopalynologie, discipline aux multiples facettes!, , MANIERES DE FAIRE... MANIERES DE VOIR. DE L'OBJET A l' INTERPRETATION.

BUI THI M.A. (1974) – *Contribution à l'étude du transport et de la sédimentation des pluies polliniques dans un abri sous roche, l'abri Vaufrey (Dordogne)*, Université de Bordeaux, Bordeaux, France

BURJACHS F., LOPEZ SAEZ J.A., IRIARTE-CHIAPUSSO M. (2003) – Metodología arqueopalinológica, *in* , Museu d'Arqueologia de Catalunya, Barcelona, p.9-16.

CALÒ C., HENNE P.D., CURRY B., MAGNY M., VESCOVI E., LA MANTIA T., PASTA S., VANNIÈRE B., TINNER W. (2012) – Spatio-temporal patterns of Holocene environmental change in southern Sicily, *Palaeogeography, Palaeoclimatology, Palaeoecology*, 323-325, p. 110-122.

CAMACHO C., CARRIÓN J., MUNUERA M. (2001) – Tafonomía polínica en la Cueva del Ardacho (Albacete, España), *Cuaternario y geomorfología: Revista de la Sociedad Española de Geomorfología y Asociación Española para el Estudio del Cuaternario, ISSN 0214-1744, Vol. 15, Nº. 1-2, 2001, pags. 61-74*, 15.

CAMPBELL G., MOFFETT L., STRAKER V. (2011) –*Environmental Archaeology: A guide to the theory and practice of methods from sampling and recovery to post-excavation,*

CAMPBELL I. (1999) – Quaternary pollen taphonomy: examples of differential redeposition and differential preservation, *Palaeogeography, Palaeoclimatology, Palaeoecology*, 149, p. 245-256.

CAMPBELL I.D. (1991a) – Experimental mechanical destruction of pollen grains, *Palynology*, 15, 1, p. 29-33.

CAMPBELL I.D. (1991b) – Experimental Mechanical Destruction of Pollen Grains, *Palynology*, 15, p. 29-33.

CARRIÓN J., FERNÁNDEZ S., GONZALEZ SAMPERIZ P., LEROY S., BAILEY G., LÓPEZ-SÁEZ J.A., CASAS F., GIL-ROMERA G., ANTÓN M., GIL-GARCÍA M., PARRA I., SANTOS L., LÓPEZ P., YLL E.I., DUPRÉ M. (2009) – Quaternary pollen analysis in the Iberian Peninsula: the value of negative results, *Internet Archaeology*, 25, p. 1-53.

CARRIÓN J.S. (2002) – A taphonomic study of modern pollen assemblages from dung and surface sediments in arid environments of Spain, *Review of Palaeobotany and Palynology*, 120, 3, p. 217-232.

CARRIÓN J.S. (1992) – Late Quaternary pollen sequence from Carihuela Cave, southeastern Spain., *Review of Palaeobotany and Palynology*, 71, p. 37-77.

CARRIÓN J.S., FERNÁNDEZ S., GONZÁLEZ-SAMPÉRIZ P., GIL-ROMERA G., BADAL E., CARRIÓN MARCO Y., LÓPEZ MERINO L., LÓPEZ SÁEZ J.A., FIERRO E., BURJACHS F. (2010) – Expected trends and surprises in the Lateglacial and Holocene vegetation history of the Iberian Peninsula and Balearic Islands., *Rev. Palaeobot. Palynol.*, 162, p. 458-475.

CARRIÓN J.S., MUNUERA M., NAVARRO C., BURJACHS F., DUPRÉ M., WALKER M.J. (1999) – The palaeoecoloical potential of pollen records in caves: the case of Mediterranean Spain, *Quaternary Science Reviews*, 18, 8, p. 1061-1073.

CARRIÓN J.S., SCOTT L. (1999a) – The challenge of pollen analysis in palaeoenvironmental studies of hominid beds: the record from Sterkfontein caves, *Journal of Human Evolution*, 36, 4, p. 401-408.

CARRIÓN J.S., SCOTT L., HUFFMAN T., DREYER C. (2000) – Pollen analysis of Iron Age cow dung in southern Africa, *Vegetation History and Archaeobotany*, 9, 4, p. 239-249.

CARRIÓN J.S., VAN GEEL B. (1999b) – Fine-resolution Upper Weichselian and Holocene palynological record from Navarrés (Valencia, Spain) and a discussion about factors of Mediterranean forest succession, *Review of Palaeobotany and Palynology*, 106, 3, p. 209-236.

CASTIGLIONI E. (2008) – I resti botanici, in Maniscalco L., a cura di, Il Santuario dei Palici, , , Un centro di culto nella valle del Margi, Palermo, p. 365-386.

CATTANI L., RENAULT-MISKOVSKY J. (1989) – La réponse des végétations aux variations climatiques quaternaires autour des sites archéologiques du Sud de la France et du Nord-Est de l'Italie, , Il Quaternario 2, p. 147-170.

CHILARDI S., CRISPINO A. (2017) – Castelluccio (Noto). Nuove datazioni dall'abitato. ISTITUTO ITALIANO DI PREISTORIA E PROTOSTORIA NOTIZIARIO DI PREISTORIA E PROTOSTORIA -4.III Neolitico ed età dei Metalli Sardegna e Sicilia, *NOTIZIARIO DI PREISTORIA E PROTOSTORIA*.

COLES G.M., GILBERTSON D., HUNT C., JENKINSON R.D.S. (1989) – Taphonomy and the palynology of cave deposits, *Cave Science - Transactions British Cave Research Association*, 16, p. 83-89.

COLES G.M., GILBERTSON D.D. (1994) – The Airfall-pollen Budget of Archaeologically Important Caves: Creswell Crags, England, *Journal of Archaeological Science*, 21, 6, p. 735-755.

COMBAZ A. (1964) – Palynofacies Analysis, *in* D. G. Jenkins (dir.), *Applied Micropalaeontology*, , Dordrecht, Springer Netherlands p.205-218. https://doi.org/10.1007/978-94-017-0763-3_5.

COMBOURIEU-NEBOUT N., PEYRON O., BOUT-ROUMAZEILLES 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), *Climate of the Past*, 9, 5, p. 2023-2042.

COPAT V. (2020) – On pots, people and cultural landscape: The Hyblean Mountains (Sicily) in the Early Bronze Age, *Journal of Archaeological Science: Reports*, 30, p. 102219.

COPAT V., COSTA A., PICCIONE P. (2017) – Castelluccio painted pottery: shared repertoires and local identity. A case study from Early Bronze Age Sicily, *In: Bergerbrant, S., Wessman, A., (Eds.)*, p. 109-126.

COSTANTINI L. (1989) – Plant exploitation at Grotta dell'Uzzo, Sicily: new evidence for the transition from Mesolithic to Neolithic subsistence in southern Europe, *in Foraging and farming the evolution of plant exploitation*, p.197-206.

COSTANTINI L., PIPERNO M., TUSA S. (2014) – La néolithisation de la Sicile occidentale d'après les résultats des fouilles a la grotte de l'Uzzo (Trapani), *in* J. Courtin, J. Guilaine, J.-L. Roudil, et J.-L. Vernet (dir.), *Premières communautés paysannes en Méditerranée occidentale : Actes du Colloque International du CNRS (Montpellier, 26-29 avril 1983)*, , Paris, CNRS Éditions (Hors collection), p.397-405.

COUTEAUX M. (1977) – A propos de l'interprétation des analyses polliniques de sédiments minéraux, principalement arché ologiques H. Laville et J. Renault-Miskovsky (dir.), , Approche écologique de l'homme fossile, Supplément du Bulletin de l'Association Française pour l'Etude du Quaternaire 47, p. 259-276.

CUGNY C. (2011) – *Apports des microfossiles non-polliniques à l'histoire du pastoralisme sur le versant nord Pyrénéen : entre référentiels actuels et reconstitution du passé*, phdthesis, Université Toulouse le Mirail - Toulouse II https://theses.hal.science/tel-00854984.

CUGNY C., MAZIER F., GALOP D. (2010) – Modern and fossil non-pollen palynomorphs from the Basque mountains (western Pyrenees, France): the use of coprophilous fungi to reconstruct pastoral activity, *Vegetation History and Archaeobotany*, p. 391.

D'AGOSTINO A., DI MARCO G., MARVELLI S., MARCHESINI M., MARTÍNEZ-LABARGA J.M., ROLFO M.F., CANINI A., GISMONDI A. (2022) – Pollen record of the Late Pleistocene-Holocene stratigraphic sequence and current plant biodiversity from Grotta Mora Cavorso (Simbruini Mountains, Central Italy), *Ecology and Evolution*, 12, 11, p. e9486.

DARIA B., ACCORSI C.A., AROBBA D., M B., BERTOLANI M., BIONDI E., BRAGGIO G., CIUFFI G., T D., RAGIONE D., LUISA F., MA G., F L., MONTANARI C., PAOLI P., RAIMONDO F., M R., TREVISAN G. (1983) –*(064A) Recherches paléobotaniques sur les Monts Madonie.*

DAVIS O.K. (1990) – Caves as sources of biotic remains in arid western North America., *Palaeogeography, Palaeoclimatology, Palaeoecology*, 76, p. 331-348.

DAVIS O.K. (1987) – Spores of the dung fungus Sporormiella: Increased abundance in historic sediments and before Pleistocene megafaunal extinction, *Quaternary Research*, 28, 2, p. 290-294.

DELCOURT P.A., DELCOURT H.R. (1980) – Pollen preservation and quaternary environmental history in the Southeastern United States, *Palynology*, 4, 1, p. 215-231.

DI MAIDA G. (2020) – The earliest human occupation of Sicily: A review, *The Journal of Island and Coastal Archaeology*, 17, 3, p. 402.

DI RENZONI A., LOPES L., MARTINELLI M.C., PHOTOS-JONES E. (2016) – The relationship between early settlements in arid environments and sources of water supply: the case of the Bronze Age site of San Vincenzo, Stromboli, Italy, *in Proceedings of the 6th Symposium of the Hellenic Society for Archaeometry*, , British Archaeological Reports Ltd (Stromboli archEOLogIE), p.187-193.

DI RITA F., MAGRI D. (2009a) – Holocene drought, deforestation and evergreen vegetation development in the central Mediterranean: a 5500 year record from Lago Alimini Piccolo, Apulia, southeast Italy, *The Holocene*, 19, 2, p. 295-306.

DI RITA F., MAGRI D. (2009b) – Holocene drought, deforestation and evergreen vegetation development in the central Mediterranean: a 5500 year record from Lago Alimini Piccolo, Apulia, southeast Italy, *The Holocene*, 19, 2, p. 295-306.

DIMBLEBY G.W. (1985) – The palynology of archaeological sites, *in Academic Press*, , London.

DIOT M.F. (1991) – Le palynofaciès en Archéologie: intérêt de son étude, *Revue d'Archéométrie*, 15, p. 54-62.

DUPRE M. (1986) – Contribution de l'analyse pollinique à la connaissance du paléoenvironnement en Espagne, , L'Anthropologie 90, p. 589-591.

DUPRE M. (1992) – Palinologia. Cuadernos técnicos de la SEG 5, , p. 1-33.

DUPRE M. (1988) – Palinología y Paleoambiente. Nuevos datos españoles. Referencias. Servicio de Investigación Prehistórica, *in* , Valencia.

ELSIK W.C. (1971) – MICROBIOLOGICAL DEGRADATION OF SPOROPOLLENIN, *in* J. Brooks, P. R. Grant, M. Muir, P. Van gijzel, et G. Shaw (dir.), *Sporopollenin*, , Academic Press p.480-511.

ERDTMAN G. (1948) – Did Dicotyledoneus plants exist in early Jurasic times?, , Geol. Foun. Stockh. Forh. 70:, p. 265-271.

EXPÓSITO I., BURJACHS F. (2016) – Taphonomic approach to the palynological record of burnt and unburnt samples from El Mirador Cave (Sierra de Atapuerca, Burgos, Spain), *Quaternary International*, 414, p. 258-271.

EXPÓSITO I., SPECIALE C., PICORNELL L., ALLUÉ E. (In process) – Il record archeobotanico. In: Vallone Inferno (Madonie, Sicilia). Attività umana, ambiente e paesaggio: gli ultimi settemila anni.,

FÆGRI K. (1956) – Recent trends in palynology., *The Botanical Review*, 22, p. 9: 639-664.

FAEGRI K., IVERSEN J.I. (1989) –*Textbook of pollen analysis*, vol. 4th edn by K. FAEGRI, P. E. KALAND, K. KRZYWINSKI, Chichester, UK, Publisher John Wiley and Sons, 328 p.

FARRIS E., FILIGHEDDU R., DEIANA P., FARRIS G.A., GARAU G. (2010) – Short-term effects on sheep pastureland due to grazing abandonment in a Western Mediterranean island ecosystem: A multidisciplinary approach, *Journal for Nature Conservation*, 18, 4, p. 258-267.

FEESER I., O'CONNELL M. (2010) – Late Holocene land-use and vegetation dynamics in an upland karst region based on pollen and coprophilous fungal spore analyses: an example from the Burren, western Ireland, *Vegetation History and Archaeobotany*, 19, 5, p. 409-426.

FIACCONI M., HUNT C.O. (2017) – Palynology of surface sediments from caves in the Zagros Mountains (Kurdish Iraq): Patterns and processes, *Review of Palaeobotany and Palynology*, 239, p. 66-76.

FIACCONI M., HUNT C.O. (2015) – Pollen taphonomy at Shanidar Cave (Kurdish Iraq): An initial evaluation, *Review of Palaeobotany and Palynology*, 223, p. 87-93.

FLORENZANO A. (2019) – The History of Pastoral Activities in S Italy Inferred from Palynology: A Long-Term Perspective to Support Biodiversity Awareness, *Sustainability*, 11, 2, p. 404.

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 Biosystems*, 149.

FORGIA V. (2019a) –*Archaeology of Uplands on a Mediterranean Island: The Madonie Mountain Range In Sicily*, Cham, Springer International Publishing (UNIPA Springer Series)

FORGIA V. (2019b) – Mura Pregne: una revisione dei dati archeologici e una ricostruzione virtuale del sito, , 15, p. 25-49.

FORGIA V., MARTÍN P., LÓPEZ-GARCÍA J.M., OLLÉ A., VERGÈS J.M., ALLUÉ E., ANGELUCCI D.E., ARNONE M., BLAIN H.-A., BURJACHS F., EXPÓSITO I., MESSINA A., PICORNELL L., RODRÍGUEZ A., SCOPELLITI G., SINEO L., VIRRUSO G., ALESSI E., DI SIMONE G., MORALES J.I.,

PAGANO E., BELVEDERE O. (2013) – New data on Sicilian prehistoric and historic evolution in a mountain context, Vallone Inferno (Scillato, Italy), *Comptes Rendus Palevol*, 12, 2, p. 115-126.

FORGIA V., OLLÉ A., VERGÈS J.M. (2021) – Early pastoral communities in the mountains of Sicily. Prehistoric evidence from Vallone Inferno (Scillato) in the palaeoenvironmental framework of the Madonie mountain range, *Journal of Anthropological Archaeology*, 61, p. 101238.

FORGIA V., OLLÉ A., VERGÈS J.M. (In process) –*Vallone Inferno (Madonie, Sicilia) Attività umana, ambiente e paesaggio: gli ultimi settemila anni*

FORGIA V., PETRUSO D., SINEO L. (2014) – Il popolamento umano della Sicilia: una revisione interdisciplinare, *Archivio per l'Antropologia e la Etnologia*, CXLIV.

GALOP D., LOPEZ SAEZ J.A. (2002) – Histoire agraire et paléoenvironnement: les apports de la palynologie et des microfossiles non-polliniques., *Trab. Antropol. e Etnol.*, 42, p. 161-164.

GEDDES D.S. (1983) – Neolithic transhumance in the Mediterranean Pyrenees, *World Archaeology*, 15, 1, p. 51-66.

GELORINI V., VERSCHUREN D., VERBEKEN M. (2011) – Diversity and palaeoecological significance of non-pollen palynomorph assemblages in East African lake sediments, *Afrika Focus*, 24, p. 140-141.

GIANNITRAPANI E., IANNÌ F., CHILARDI S., ANGUILANO L. (2014) – Case Bastione: A Prehistoric Settlement in the Erei Uplands (central Sicily), *Origini*, XXXVI, p. 181-211.

GOEURY C., DE BEAULIEU J.L. (1979) – À propos de la concentration du pollen à l'aide de la liqueur de Thoulet dans les sédiments minéraux., *Pollen et Spores*, XXI, p. 239-251.

GOLDBERG P., SHERWOOD S.C. (2006) – Deciphering human prehistory through the geoarcheological study of cave sediments, *Evolutionary Anthropology: Issues, News, and Reviews*, 15, 1, p. 20-36.

GREENFIELD H.J. (1999) – Introduction. In Transhumant Pastoralism in southern Europe: Recent Perspectives from Archaeology, History, and Ethnography, , edited by Laszlo Bartosiewicz and Haskel Greenfield.

GRIMM E.C. (1991) – Tilia, version 2.1.1. Tilia-graph and TGView, Springfield. http://museum.state.il.us/pub/grimm/tilia/.

HAAS J.N. (2010) – Vegetation History and Archaeobotany, *Vegetation History and Archaeobotany*, 19, p. 389-389.

HALL S.A. (1991) – Progressive deterioration of pollen grains in south-central U. S. rockshelters, *Journal of Palynology*, 26, p. 159-169.

HAVINGA A.J. (1967) – Palynology and pollen preservation, *Review of Palaeobotany and Palynology*, 2, 1, p. 81-98.

HILLBRAND M., HADORN P., CUGNY C., HASENFRATZ A., GALOP D., HAAS J.N. (2012) – The palaeoecological value of Diporotheca rhizophila ascospores (Diporothecaceae, Ascomycota) found in Holocene sediments from Lake Nussbaumersee, Switzerland., *Rev. Palaeobot. Palynol.*, 186, p. 62-68.

HOFMANOVÁ Z., KREUTZER S., HELLENTHAL G., SELL C., DIEKMANN Y., DÍEZ-DEL-MOLINO D., VAN DORP L., LÓPEZ S., KOUSATHANAS A., LINK V., KIRSANOW K., CASSIDY L.M., MARTINIANO R., STROBEL M., SCHEU A., KOTSAKIS K., HALSTEAD P., TRIANTAPHYLLOU S., KYPARISSI-APOSTOLIKA N., UREM-KOTSOU D., ZIOTA C., ADAKTYLOU F., GOPALAN S., BOBO D.M., WINKELBACH L., BLÖCHER J., UNTERLÄNDER M., LEUENBERGER C., ÇILINGIROĞLU Ç., HOREJS B., GERRITSEN F., SHENNAN S.J., BRADLEY D.G., CURRAT M., VEERAMAH K.R., WEGMANN D., THOMAS M.G., PAPAGEORGOPOULOU C., BURGER J. (2016) – Early farmers from across Europe directly descended from Neolithic Aegeans, *Proceedings of the National Academy of Sciences of the United States of America*, 113, 25, p. 6886-6891.

HOLLOWAY R. (1989) – Experimental mechanical pollen degradation and its application to Quaternary age deposits, *Texas Journal of Science*, 41, p. 131-145.

HOROWITZ A. (1992) – Palynology of Arid Lands, *Elsevier*.

HORROCKS M., WALSH K.A.J. (1998) – Forensic palynology: assessing the value of the evidence, *Review of Palaeobotany and Palynology*, 103, 1, p. 69-74.

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?, *Quaternary International*, 485, p. 68-75.

HUNT C.O., GILBERTSON D.D., HILL E.A., SIMPSON D. (2015) – Sedimentation, re-sedimentation and chronologies in archaeologically-important caves: problems and prospects, *Journal of Archaeological Science*, 56, p. 109-116.

HUNT C.O., RUSHWORTH G. (2005) – Pollen taphonomy and airfall sedimentation in a tropical cave: the West Mouth of The Great Cave of Niah in Sarawak, Malaysian Borneo, *Journal of Archaeological Science*, 32, 3, p. 465-473.

IANNI F. (2009) – La Muculufa Santuario: considerazioni tecnologiche, morfologiche e stilistiche sulle classi vascolari e lo stile di Muculufa, , p. 243-263.

ITALIANO F., CORREALE A., DI BELLA M., FORESTA MARTIN F., MARTINELLI M.C., SABATINO G., SPATAFORA F. (2018) – The neolithic obsidian artifacts from roccapalumba (Palermo, italy): First characterization and provenance determination, *Mediterranean Archaeology and Archaeometry*, 18, p. 151-167.

JANKOVSKA V., KOMAREK J. (2000) – Indicative value of Pediastrum and other coccal green algae in palaeoecology., , p. 59-82.

JARSEN D.M., ELSIK W.C. (1986) – Fungal palynomorphs recovered from recent river deposits, Luangwa valley, Zambia., *Palynology*, 10, p. 35-60.

JOANNIN S., ELISABETTA B., DE BEAULIEU JACQUES-L., BERNARDO L., MAGNY M., PEYRON O., VANNIÈRE B. (2012) – Pollen-based reconstruction of Holocene vegetation and climate in

Southern Italy: the case of Lago di Trifoglietti, *Climate of the Past Discussions*, 8, p. 2223-2279.

KOULI K., MASI A., MERCURI A.M., FLORENZANO A., SADORI L. (2015) – Regional Vegetation Histories: An Overview of the Pollen Evidence from the Central Mediterranean, *Late Antique Archaeology*, 11, 1, p. 69-82.

LAURIA G., MESSINA A. (2013) – The Cave of Vecchiuzzo: anthropology, paleopathology and hierarchy of the human group with a statistical overview (Petralia Sottana – Palermo, Italy), , Vol. CXLIII, p. 145-156.

LEBRETON V., MESSAGER E., MARQUER L., RENAULT-MISKOVSKY J. (2010) – A neotaphonomic experiment in pollen oxidation and its implications for archaeopalynology, *Hyper Article en Ligne - Sciences de l'Homme et de la Société*.

LEIGHTON R. (1999) –*Sicily Before History: An Archaeological Survey from the Palaeolithic to the Iron Age*, Cornell University Press, 324 p.

LEROI-GOURHAN A. (1973) – Analyses polliniques. Préhistoire et variations climatiques quaternaires., *in Les méthodes quantitatives d'étude des variations du climat au cours du Pléistocène*, , Paris, France p.61-66.

LI Y., ZHOU L., CUI H. (2008) – Pollen indicators of human activity, *Chinese Science Bulletin*, 53 (9), p. 1281-1293.

LONA F. (1949) – I carboni dei focolari paleolitici della grotta di San Teodoro (Messina), , Rivista di Scienze Preistoriche, 4, p. 187-193.

LOPEZ SAEZ J.A., LOPEZ GARCIA P. (1992) – Dinámica del paisaje: un modelo de interpretación a través de la Paleopalinología. J. F. Martín Duque (dir.), *Jornadas sobre el Paisaje: Transformaciones del Paisaje en áreas de influencia de grandes núcleos urbanos*, p. 375-385.

LOPEZ SAEZ J.A., LOPEZ MERINO L. (2005) – Precisiones metodológicas acerca de los indicios paleopalinológicos de agricultura en la Prehistoria de la Península Ibérica,

LOPEZ SAEZ J.A., VAN GEEL B., FARBOS-TEXIER S., DIOT M.F. (1998) – Remarques paléoécologiques à propos de quelques palynomorphes non-polliniques provenant de sédiments quaternaires en France., *Rev. Paléobiologie,*, 17, p. 445-459.

LOPEZ SAEZ J.A., VAN GEEL B., MARTINEZ-SANCHEZ M. (2000) – Aplicación de los microfósiles no polínicos en Palinología Arqueológica, *in Actas 3o*, , Adecap, Porto, Vila-Real, Portugal,setembro de 1999, Oliveira Jorge, V. (Ed.) p.11-20.

LÓPEZ-GARCÍA J.M., BLAIN H.-A., PAGANO E., OLLÉ A., VERGÈS J.M., FORGIA V. (2013) – THE SMALL MAMMALS (INSECTIVORES, BATS AND RODENTS) FROM THE HOLOCENE ARCHAEOLOGICAL SITE OF VALLONE INFERNO (SCILLATO, LOWER IMERA VALLEY, NORTHWESTERN SICILY), *RIVISTA ITALIANA DI PALEONTOLOGIA E STRATIGRAFIA*, 119, 2.

LÓPEZ-SÁEZ J.A., LÓPEZ-MERINO L. (2007) – Coprophilous fungi as a source of information of anthropic activities during the Prehistory in the Amblés Valley (Ávila, Spain): The archaeopalynological record, *Revista Española de Micropaleontología*, 38, p. 49-75.

LOUBLIER Y. (1978) – Application de l'analyse pollinique à l'étude du paléoenvironnement du remplissage Würmien de la grotte de L'Arbreda (Espagne)., *in* , Académie de Montpellier (U.S.T.L.), Montpellier.

MACDONALD M.G. (2001) – CONIFER STOMATA, *in Tracking Environmental Change Using Lake Sediments.*, .

MAGNY M., COMBOURIEU-NEBOUT N., DE BEAULIEU J.L., BOUT-ROUMAZEILLES V., COLOMBAROLI D., DESPRAT S., FRANCKE A., JOANNIN S., ORTU E., PEYRON O., REVEL M., SADORI L., SIANI G., SICRE M.A., SAMARTIN S., SIMONNEAU A., TINNER W., VANNIÈRE B., WAGNER B., ZANCHETTA G., ANSELMETTI F., BRUGIAPAGLIA E., CHAPRON E., DEBRET M., DESMET M., DIDIER J., ESSALLAMI L., GALOP D., GILLI A., HAAS J.N., KALLEL N., MILLET L., STOCK A., TURON J.L., WIRTH S. (2013) – North–south palaeohydrological contrasts in the central Mediterranean during the Holocene: tentative synthesis and working hypotheses, *Climate of the Past*, 9, 5, p. 2043-2071.

MANISCALCO L., PALIO O., PRIVITERA F., TURCO M. (2015) – L'alimentazione nella preistoria tra l'Etna e la Piana di Catania, *50ma Riunione Scientifica dell'Istituto di Preistoria e Protostoria*, Preistoria del cibo., 27.

MANNINO G. (1989) – L'abisso del Vento, *Sicilia Archeologica*, 52, p. 49-54.

MARIOTTI LIPPI M., MERCURI A.M., FOGGI B., DEPARTMENT OF BIOLOGY, UNIVERSITY OF FLORENCE, VIA LA PIRA 4, 50121 FLORENCE, ITALY (2018) – The "Mediterranean Forest": A Perspective for Vegetation History Reconstruction, *Interdisciplinaria Archaeologica - Natural Sciences in Archaeology*, IX, 2, p. 207-218.

MARTÍN P., MESSANA C., DI SIMONE G. (In process) – Allevamento e caccia nel massiccio delle Madonie (Sicilia) durante la preistoria e il periodo altomedievale: studi zooarcheologici nel sito di Vallone Inferno,

MARTÍN P., MESSANA C., DI SIMONE G., ALLUÉ E., EXPÓSITO I., OLLÉ A., VERGÈS J.M., FORGIA V. (2023) – Animal husbandry in Sicilian prehistory: The zooarchaeological perspective from Vallone Inferno (Scillato, Palermo), *Journal of Archaeological Science: Reports*, 48, p. 103813.

MASON-WILLIAMS M., BENSON-EVANS K. (1996) – Summary of results obtained during a preliminary investigation into the bacterial and botanical flora of caves in South Wales, *KIP Articles*. https://digitalcommons.usf.edu/kip_articles/5153.

MAZIER F., GALOP D., BRUN C., BUTTLER A. (2006) – Modern pollen assemblages from grazed vegetation in the western Pyrenees, France: a numerical tool for more precise reconstruction of past cultural landscapes, *The Holocene*, 16, 1, p. 91.

MAZIER F., GALOP D., GAILLARD M.J., RENDU C., CUGNY C., LEGAZ A., PEYRON O., BUTTLER A. (2009) – Multidisciplinary approach to reconstructing local pastoral activities: an example from the Pyrenean Mountains (Pays Basque), *The Holocene*, 19, 2, p. 171-188.

MCCLURE S.B., MAGILL C., PODRUG E., MOORE A.M.T., HARPER T.K., CULLETON B.J., KENNETT D.J., FREEMAN K.H. (2018) – Fatty acid specific δ13C values reveal earliest Mediterranean cheese production 7,200 years ago, *PLOS ONE*, 13, 9, p. e0202807.

MENOZZI B.I., ZOTTI M., MONTANARI C. (2010) – A non-pollen palynomorphs contribution to the local environmental history in the Ligurian Apennines: a preliminary study, *Vegetation History and Archaeobotany*, 19, 5-6, p. 503-512.

MERCURI A.M., ASSUNTA F., N'SIALA I., OLMI L., SOGLIANI F., ROUBIS D. (2010) – Pollen from archaeological layers and cultural landscape reconstruction: Case studies from the Bradano valley (Basilicata, southern Italy), *Plant Biosystems*, 144, p. 888 — 901.

MERCURI A.M., BANDINI MAZZANTI M., FLORENZANO A., MONTECCHI M.C., RATTIGHIERI E. (2013) – Olea, Juglans and Castanea: The OJC group as pollen evidence of the development of human-induced environments in the Italian peninsula, *Quaternary International*, 303, p. 24-42.

MERCURI A.M., BANDINI MAZZANTI M., FLORENZANO A., MONTECCHI M.C., RATTIGHIERI E., TORRI P. (2013) – ANTHROPOGENIC POLLEN INDICATORS (API) FROM ARCHAEOLOGICAL SITES AS LOCAL EVIDENCE OF HUMAN-INDUCED ENVIRONMENTS IN THE ITALIAN PENINSULA, *Annali di Botanica*, 3, 0, p. 143-153.

MERCURI A.M., CANNAVÒ V., CLÒ E., DI RENZONI A., FLORENZANO A., RATTIGHIERI E., YOON D., LEVI S.T. (2020) – Palynology of San Vincenzo-Stromboli: Interdisciplinary perspective for the diachronic palaeoenvironmental reconstruction of an island of Sicily, *Journal of Archaeological Science: Reports*, 30, p. 102235.

MERCURI A.M., FLORENZANO A., BURJACHS F., GIARDINI M., KOULI K., MASI A., PICORNELL-GELABERT L., REVELLES J., SERVERA-VIVES G., TORRI P., FYFE R.M. (2019) – From influence to impact: The multifunctional land-use in Mediterranean prehistory emerging from palynology of Archaeological sites (8.2-2.8 ka BP), *The Holocene*, 29, 5, p. 830-846.

MERCURI A.M., SADORI L. (2013) – Mediterranean Culture and Climatic Change: Past Patterns and Future Trends, *in The Mediterranean Sea: Its History and Present Challenges*, p.507-527.

MIOLA A. (2012) – Tools for Non-Pollen Palynomorphs (NPPs) analysis: A list of Quaternary NPP types and reference literature in English language (1972–2011), *Review of Palaeobotany and Palynology*, 186, p. 142-161.

MOORE P.D., WEBB J.A., COLLINSON M.E. (1991) –*Pollen Analysis*, Blackwell Scientific Publications, 216 p.

MORENO-IBÁÑEZ M.Á., HERNANDO R., LOZANO M. (In process) – Studio antropologico e paleopatologico dei resti umani di Vallone Inferno,

NATALI E., FORGIA V. (2018a) – The beginning of the Neolithic in Southern Italy and Sicily, *Quaternary International*, 470, p. 253-269.

NATALI E., FORGIA V. (2018b) – The beginning of the Neolithic in Southern Italy and Sicily., , Quat. Int. 470, p. 253-269.

NAVARRO C., CARRIÓN J., MUNUERA M., PRIETO A. (2001a) – Cave surface pollen and the palynological potential of karstic cave sediments in palaeoecology, *Review of Palaeobotany and Palynology*, 117, 4, p. 245-265.

NAVARRO C., CARRIÓN J.S., NAVARRO J., MUNUERA M., PRIETO A.R. (2000) – An experimental approach to the palynology of cave deposits., , J. Quat. Sci., 15, p. 603-619.

NAVARRO C., PRIETO A.R., GARCÍA J.S.C., GINER M.M., NAVARRO CARMEN, PRIETO A.R., GARCÍA J.S.C., GINER M.M. (2001b) – Sedimentación y distribución superficial de palinomorfos en cuevas del SE Ibérico, implicaciones en paleoecología, *Anales de biología*, 23, p. 103-132.

NOTI R., LEEUWEN J., COLOMBAROLI D., VESCOVI E., SALVATORE P., LA MANTIA T., TINNER W. (2009) – Mid- and late-Holocene vegetation and fire history at Biviere di Gela, a coastal lake in southern Sicily, Italy, *Vegetation History and Archaeobotany*, 18, p. 371-387.

PALS J.P., VAN GEEL B., DELFOS A. (1980) – Palaeoecological studies in the Klokkeweel Bog near Hoogkarspel (Province of Noord-Holland)., , Review of Palaeobotany and Palynology 30, p. 371-418.

PAPANIKOLAOU A.D., FYLLAS N.M., MAZARIS A.D., DIMITRAKOPOULOS P.G., KALLIMANIS A.S., PANTIS J.D. (2011) – Grazing effects on plant functional group diversity in Mediterranean shrublands, *Biodiversity and Conservation*, 20, 12, p. 2831-2843.

PASTA S., SPECIALE C. (2021) – Comunità umane e piante in Sicilia: una lunga (prei)storia, in Militello P., Nicoletti F., Panvini C., a cura di, La Sicilia Preistorica. Dinamiche interne e relazioni esterne,

PEREZ-DIAZ S., LOPEZ-SAEZ J.A. (2012) – Paleopaisaje y dinámica antrópica durante la Protohistoria alavesa. Una perspectiva paleoambiental., *Cuadernos de Arqueología de la Universidad de Navarra*, 20, p. 153-183.

PEYRON O., MAGNY M., COMBOURIEU-NEBOUT N., GORING S., BRAYSHAW D., JOANNIN S., KOULI K., DE BEAULIEU JACQUES-L., ELISABETTA B., KOTTHOFF U., PROSS J., SADORI L., FLETCHER W., DESPRAT S. (2013) – Quantitative reconstruction of the Holocene climate in the Mediterranean basin inferred from marine and continental pollen records: model/data comparison, , p. 5252.

PRIETO A.R., CARRIÓN J.S. (1999) – TAFONOMÍA POLÍNICA: SESGOS ABIÓTICOS Y BIÓTICOS DEL REGISTRO POLÍNICO EN CUEVAS, *Publicación Electrónica de la Asociación Paleontológica Argentina*, 6, 1.

RECAMI A., BALDINI G. (1977) – La scoperta del paleolitico antico nella sicilia orientale e nuove notizie sulla preistoria siciliana, *Natura alpina*, 27, 8, p. 205-216.

REILLE M. (1992) – Pollen et Spores d'Europe et d'Afrique du nord., *Laboratoire de Botanique Historique et Palynologie, Marseille*.

REILLE M. (1995) –*Pollen et Spores d'Europe et d'Afrique du Nord (Supplément 1)*, Laboratoire de Botanique Historique et Palynologie, CNRS, Marseille.

REIMER P., AUSTIN W.E.N., BARD E., BAYLISS A., BLACKWELL P.G., BRONK RAMSEY C., BUTZIN M., CHENG H., LAWRENCE EDWARDS R., FRIEDRICH M., GROOTES P.M., GUILDERSON T.P., HAJDAS I., HEATON T.J., HOGG ALAN.G., HUGHEN K.A., KROMER B., MANNING S.W., MUSCHELER R., PALMER J.G., PEARSON C., VAN DER PLICHT J., REIMER R., RICHARDS D.A., SCOTT E.M., SOUTHON J.R., TURNEY C.S.M., WACKER L., ADOLPHI FLORIAN, BÜNTGEN U., CAPANO M., FAHRNI S., FOGTMANN-SCHULZ ALEXANDRA, FRIEDRICH R., MIYAKE F., OLSEN

JESPER, REINIG F., SAKAMOTO M., SOOKDEO A., TALAMO S. (2020) – The IntCal20 Northern Hemisphere radiocarbon age calibration curve (0-55 cal kBP), *Radiocarbon*, 62, 4, p. 725.

RENAULT-MISKOVSKY J., GIRARD M., TROUIN M. (1976) – Observations de quelques pollens d'Oléacées au microscope électronique à balayage, *Bulletin de l'Association française pour l'étude du quaternaire*, 13, 2, p. 71-86.

REVEDIN ARBORIO MELLA A. (1984) – Industrie del Paleolitico inferiore dalla Sicilia orientale, *Rivista du scienze preistoriche*, XXXIX, 1-2, p. 272-287.

REVELLES J., BURJACHS F., VAN GEEL B. (2016) – Pollen and non-pollen palynomorphs from the Early Neolithic settlement of La Draga (Girona, Spain), *Review of Palaeobotany and Palynology*, 225, p. 1-20.

REVELLES J., VAN GEEL B. (2017) – Human impact and ecological changes in lakeshore environments. The contribution of non-pollen palynomorphs in Lake Banyoles (NE Iberia), *Review of Palaeobotany and Palynology*, 232, p. 81-97.

ROLFO M.F., ACHINO K.F., FUSCO I., SALARI L., SILVESTRI L. (2016) – Reassessing human occupation patterns in the inner central Apennines in prehistory: The case-study of Grotta Mora Cavorso, *Journal of Archaeological Science: Reports*, 7, p. 358-367.

RUGGIERI R. (2022) – Karst of Sicily : A Journey Inside and Outside the Island's Mountains, *in KARST OF SICILY : A journey Inside and Outside the Island's Mountains*, , Switzerland p.380-401.

RUIZ-ZAPATA M.B., GÓMEZ GONZÁLEZ C., LÓPEZ SÁEZ J.A., DORADO-VALIÑO M., VALDEOLMILLOS-RODRÍGUEZ A., GIL-GARCÍA M. (2006) – Paleoambiente y usos del suelo durante el Holoceno reciente en la Tolla Collado de el Berrueco (Sierra de Guadarrama Madrid), *Geogaceta*, 40, p. 227-230.

RUIZ-ZAPATA M.B., GÓMEZ GONZÁLEZ C., LÓPEZ-SÁEZ J.A., GIL-GARCÍA M., SANTIESTEBAN J.O., MEDIAVILLA R., DORADO-VALIÑO M., VALDEOLMILLOS-RODRÍGUEZ A. (2010) – Detección de la actividad antrópica durante el Holoceno reciente, a través de la asociación de palinomorfos polínicos y no polínicos en dos depósitos higroturbosos (El Berrueco y Rascafría) en la Sierra de Guadarrama, Madrid., , Rev. Española Micropaleontol., 38, p. 355-366.

SADORI L., NARCISI B. (2001) – The Postglacial record of environmental history from Lago di Pergusa, Sicily, *The Holocene*, 11, 6, p. 655-671.

SADORI L., ZANCHETTA G., GIARDINI M. (2008) – Last Glacial to Holocene palaeoenvironmental evolution at Lago di Pergusa (Sicily, Southern Italy) as inferred by pollen, microcharcoal, and stable isotopes, *Quaternary International*, 181, 1, p. 4-14.

SAEZ J.A.L., MERINO L.L. (2004) – Precisiones metodológicas acerca de los indicios paleopalinológicos de agricultura en la Prehistoria de la Península Ibérica, , Nova Série, Vol. XXVI.

SANCHEZ GOÑI M.F. (1993) –*Criterios de base tafonómica para la interpretación de análisis palinológicos en cueva: el ejemplo de la región cantábrica*, Fumanal, M. P. y Bernabeu, J., València, Universitat de València, 117-130 p.

SANCHEZ GOÑI M.F. (1996) – Les changements climatiques du Paléolithique Supérieur. Enquête sur le rapport entre paléoclimatologie et préhistoire, *Zephyrus*, 49, p. 3-36.

SÁNCHEZ GOÑI M.F. (1994) –*The identification of European upper palaeolithic interestadials from cave sequences.*, vol. AASP Contributions Series 29, 161-182 p.

SANTOS D. (1999) – PAST PAleontological STatistics, *in Reference manual*, , Natural History Museum, University of Oslo. https://www.academia.edu/35430927/PAST_PAleontological_STatistics_Reference_manual.

SIMMONS I.G. (1993) – Vegetation change during the Mesolithic in the British Isles: some amplifications, *in* F. M. Chambers (dir.), , Dordrecht, Springer Netherlands p.109-118.

SPECIALE C., BENTALEB I., COMBOURIEU-NEBOUT N., DI SANSEBASTIANO G.P., IANNÌ F., FOUREL F., GIANNITRAPANI E. (2020) – The case study of Case Bastione: First analyses of 3rd millennium cal BC paleoenvironmental and subsistence systems in central Sicily, *Journal of Archaeological Science: Reports*, 31, p. 102332.

SPECIALE C., LAROSA N., SPATAFORA F., CALASCIBETTA A.M.G., SANSEBASTIANO G.P.D., BATTAGLIA G., PASTA S. (2023) – Archaeobotanical and Historical Insights on Some Steps of Forest Cover Disruption at Ustica Island (Sicily, Italy) from Prehistory Until Present day, *Environmental Archaeology*, 28, 4, p. 312-327.

STANLEY R.G., LINSKENS H.F. (1975) – Pollen. Biology, Biochemistry, Management. Berlin, Heidelberg and New York, , 29, 3, p. 492-492.

TINNER W., VAN LEEUWEN J.F.N., COLOMBAROLI D., VESCOVI E., VAN DER KNAAP W.O., HENNE P.D., PASTA S., D'ANGELO S., LA MANTIA T. (2009) – Holocene environmental and climatic changes at Gorgo Basso, a coastal lake in southern Sicily, Italy, *Quaternary Science Reviews*, 28, 15, p. 1498-1510.

TINNER W., VESCOVI E., VAN LEEUWEN J.F.N., COLOMBAROLI D., HENNE P.D., KALTENRIEDER P., MORALES-MOLINO C., BEFFA G., GNAEGI B., VAN DER KNAAP W.O., LA MANTIA T., PASTA S. (2016) – Holocene vegetation and fire history of the mountains of Northern Sicily (Italy), *Vegetation History and Archaeobotany*, 25, 5, p. 499-519.

TURNER C., BUI THI M., GIRARD M. (1985) – Problems and pitfalls in the application of palynology to pleistocene archaeological sites in Western Europe., *in* , Paris, France, Éditions du CNRS. p.347-373.

VALLEJO A., FORGIA V., VERGÈS J.M., GOROSTIZU-ORKAIZTEGI A., COUCEIRO-COUTO T., SANTORI-ROSA G., SÁNCHEZ-ORTEGA A. (In process) – Biomarcatori organici come strumento per identificare le attività pastorali e alimentari a Vallone Inferno,

VAL-PEÓN C., EXPÓSITO I., SOTO M., BURJACHS F. (2019) – A taphonomic approach to the pollen assemblage from layer M of the Abric Romaní archaeological site (NE Iberian Peninsula), *Review of Palaeobotany and Palynology*, 270, p. 19-39.

VAN CAMPO M., LEROI-GOURHAN A. (1956) – Note préliminaire à l'étude des pollens fossiles de différents niveaux des grottes d'Arcy-sur-Cure, *Bulletin du Muséum national d'histoire naturelle*, 28, 3, p. 326-330.

VAN GEEL B. (1976) – *A palaeoecological study of Holocene peat bog sections, based on the analysis of pollen, spores and macro- and microscopic remains of fungi, algae, cormophytes and animals.*, Ph.D. Thesis, University of Amsterdam, Amsterdam,

VAN GEEL B. (1978a) – A palaeoecological study of Holocene peat bog sections in Germany and The Netherlands, based on the analysis of pollen, spores and macro- and microscopic remains of fungi, algae, cormophytes and animals., , p. 1-120.

VAN GEEL B. (1978b) – A palaeoecological study of holocene peat bog sections in Germany and The Netherlands, based on the analysis of pollen, spores and macro- and microscopic remains of fungi, algae, cormophytes and animals, *Review of Palaeobotany and Palynology*, 25, 1, p. 1-120.

VAN GEEL B. (1986) – Application of fungal and algal remains and other microfossils in palynological analyses, *Handbook of Holocene Palaeoecology and Palaeohydrology*, p. 497-505.

VAN GEEL B. (2008) – Forty years of non-pollen palynomorphs: a state of the art,

VAN GEEL B. (2006) – Non-Pollen Palynomorphs, *in Terrestrial, Algal, and Siliceous Indicators*, p.99-119.

VAN GEEL B. (2001) – NON-POLLEN PALYNOMORPHS, *in Tracking Environmental Change Using Lake Sediments.*, .

VAN GEEL B., BUURMAN J., BRINKKEMPER O., SCHELVIS J., APTROOT A., VAN REENEN G., HAKBIJL T. (2003) – Environmental reconstruction of a Roman Period settlement site in Uitgeest (The Netherlands), with special reference to coprophilous fungi, *Journal of Archaeological Science*, 30, 7, p. 873-883.

VAN GEEL B., COOPE G., HAMMEN T. (1989) – Palaeoecology and stratigraphy of the lateglacial type section at Usselo (the Netherlands) | Semantic Scholar,

VAN GEEL B., DE LANGE L., WIEGERS J. (1984) – RECONSTRUCTION AND INTERPRETATION OF THE LOCAL VEGETATIONAL SUCCESSION OF A LATEGLACIAL DEPOSIT FROM USSELO (THE NETHERLANDS), BASED ON THE ANALYSIS OF MICRO- AND MACROFOSSILS, *in Acta Botanica Neerlandica*, p.535-546.

VAN GEEL B., HAMMEN T. (1978) – Zygnemataceae in Quaternary Colombian sediments, *Review of Palaeobotany and Palynology*, 25, p. 377-391.

VAN WONTERGHEM F., JOLE BOVIO M. (1980) – La Grotta del Vecchiuzzo presso Petralia Sottana, *L'Antiquité Classique*, 49, 1, p. 586-587.

VERGES J.M., ALLUE E., FONTANALS M., MORALES J.I., MARTIN P., CARRANCHO Á., EXPOSITO I., GUARDIOLA M., LOZANO M., MARSAL R., OMS X., EUBA I., RODRIGUEZ A. (2016a) – El Mirador cave (Sierra de Atapuerca, Burgos, Spain): A whole perspective, *Quaternary International*, 414, p. 236-243.

VERGÈS J.M., BURGUET-COCA A., ALLUÉ E., EXPÓSITO I., GUARDIOLA M., MARTÍN P., MORALES J.I., BURJACHS F., CABANES D., CARRANCHO Á., VALLVERDÚ J. (2016b) – The Mas del Pepet experimental programme for the study of prehistoric livestock practices: Preliminary data from dung burning, *Quaternary International*, 414, p. 304-315.

VISSET L., CYPRIEN A.-L., CARCAUD N., OUGUERRAM A., BARBIER D., BERNARD J. (2002) – Les prémices d'une agriculture diversifiée à la fin du Mésolithique dans le Val de Loire (Loire armoricaine, France), *Comptes Rendus Palevol*, 1, 1, p. 51-58.

WATTS W.A., ALLEN J.R.M., HUNTLEY B., FRITZ S.C. (1996) – Vegetation history and climate of the last 15,000 years at Laghi di Monticchio, southern Italy, *Quaternary Science Reviews*, 15, 2, p. 113-132.

Figures

Tables

Annex

Annexes

- **Sample Weight (about 10-20 g)**

- **Carbonate dissolution** (HCl-50%)

- **Sieving (mesh size: 0,5 mm)**

Centrifugation
Decant

Washing
Homogenize
Centrifugation
Decant
} Repeat twice

- **Removal of humic acids** (NaOH-10%)

Heating in a water bath for 10 minutes
Centrifugation

Washing
Homogenize
Centrifugation
Decant
} Repeat twice. Wash one time more adding two drops of HCL (50%)

- **Flotation** (*Thoulet Liquor* 2.1 cm^3/g)

Homogenize
Centrifugation

- **Filtering** (glass fiber filters)

- **Removal filter and silica** (HF-48% for 1-hour minimum)
At the end, add a fraction of HCl and clean the plastic dipstick with distilled water

Centrifugation

Washing
Homogenize
Centrifugation
Decant
} Repeat twice

- **Sample mounting**

*All of the centrifugations: 3 minutes at 2500 rpm

IPHES

Annex 1 : summary of the extraction protocol of pollen and NPPs (Goeury et De Beaulieu, 1979 ; Burjachs et al., 2003)

Pollen	Origin	Fumier		Focolare 1	Focolare 2			Fossetta	MEAN
	Taxons	F19-1282	G18-1278	G21-1269	F20-1270a	F20-1270b	F20-1272	F21-1273	
AP	*Pinus* sp.	0,5	5,1	2	1,6	1,1	3,9	1,7	2,27
	Cf. *Juniperus*	0,5	0	0	0	1,6	0	1,7	0,54
	evergreen *Quercus*	13,4	35,4	30,7	30,6	25,4	33,3	29,8	28,37
	Oleaceae	0	1,3	2	3,1	3,2	1	0,8	1,63
	deciduous *Quercus*	5,3	2,5	3	9	5,9	5,9	5,8	5,34
	Corylus	6,2	3,8	5	5,1	5,4	3,9	5	4,91
	Juglans	1	0	0	0	0	0	0	0,14
	Tilia	0	0	1	0	0	0	0	0,14
	Betula	0,5	0	0	0,4	0	0	0	0,13
	Salix	2,9	2,5	2	2,4	1,6	1	3,3	2,24
	Alnus	0,5	0	0	0	0	0	0	0,07
NAP	*Erica* sp.	1	1,3	2	0,4	1,1	2	1,7	1,36
	Cistaceae	1	0	0	0	0	0	0	0,14
	Pistacia	1,9	1,3	2	0,8	0	0	0	0,86
	Buxus	0	0	0	0	0	0	0,8	0,11
	Poaceae	17,2	22,8	17,8	18,4	24,3	24,5	17,4	20,34
	Cerealia-type	0,3	2,3	0	0	1,5	0	0	0,59
	Asteraceae tubuliflorae	33,1	18,4	29,5	10,2	10,1	30,2	22,9	22,06
	Asteraceae liguliflorae	21	10,3	5,4	5,3	5,2	8,9	16,5	10,37
	Artemisia	0	0	0	0	0	0	0,8	0,11
	Chenopodiaceae-Amaranthaceae	0,5	0	0	0,4	1,1	0	0,8	0,40
	Plantago sp.	34,9	19	15,8	18,4	14,6	11,8	12,4	18,13
	Apiaceae	5,7	3,8	5,9	3,1	6,5	5,9	7,4	5,47
	Urticaceae	0	0	0	0,8	0	0	0	0,11
	Caryophyllaceae	1	0	0	0	2,2	0	0	0,46
	Fabaceae	0	0	1	1,2	1,1	2	0,8	0,87
	Malvaceae	0	0	0	0,4	0	0	0	0,06
	Liliaceae	1	0	0	1,2	0	0	2,5	0,67
	Lamiaceae	0,5	0	0	0,4	0	0	0	0,13
	Ranunculaceae	1	0	2	0,4	1,1	0	4,1	1,23
	Cyperaceae	1,9	1,3	6,9	1,6	3,8	4,9	3,3	3,39
	Typha-Sparganium	0	0	1	0,4	0	0	0	0,20
	Armeria	1,9	0	0	0	0	0	0	0,27
SUM	AP	30,6	50,6	45,5	52,2	44,3	49	47,9	45,73
	NAP	69,4	49,4	54,5	47,8	55,7	51	52,1	54,27

Annex 2 : Table of the percentage of pollens from the samples of the layer 3.4.a. of Vallone Inferno

NPPs	Origin	Fumier		Focolare 1	Focolare 2			Fossetta	MEAN
	Taxons	F19-1282	G18-1278	G21-1269	F20-1270a	F20-1270b	F20-1272	F21-1273	
Pteridophyte	Monolete spore	17,4	20,7	10,5	5	5,5	61,7	11,3	18,87
	Trilete spore	0	0	1,8	8,3	1,8	1,7	7,5	3,01
	Polypodium	2,9	3,4	7	3,3	0	3,3	1,9	3,11
Indefinite NPP	HdV-303	6,2	9,1	4,9	5,7	15,2	3,5	16,4	8,71
	Pseudoschizaea	1,8	1,8	2,5	0	0	6,1	5,5	2,53
	Protists	30,1	36,4	22,2	8,6	25	37,4	30	27,10
	Stomata	0,9	0	0	0	0	0	0	0,13
	HdV-137	0	0	0	0	0	0,9	0	0,13
Oligotrophic algae	*Gloeotrichia*	2,9	3,4	0	0	0	1,7	0	1,14
Fungi	*Glomus* sp.	14,5	13,8	3,5	3,3	3,6	1,7	3,8	6,31
	UG-1053	0	0	0	1,7	0	0	0	0,24
	Hyphae	36,2	31	36,8	53,3	52,7	5	26,4	34,49
	Polyporisporites	0	0	1,8	3,3	3,6	0	5,7	2,06
	Polyadosporites	2,9	10,3	3,5	3,3	3,6	5	3,8	4,63
	Chaetomium	0	0	0	0	9,1	0	3,8	1,84
	Sporormiella	0	0	1,8	0	1,8	0	1,9	0,79
	EMA25	1,4	0	0	0	1,8	1,7	0	0,70
	Pluricellaesporites	0	0	0	1,7	0	0	0	0,24
	HDV-4	0	0	0	1,7	0	0	1,9	0,51
	EMA-33	0	3,4	0	1,7	0	0	0	0,73
	HDV-51	1,4	0	0	0	0	0	0	0,20
	UG-1155	0	0	1,8	0	0	0	0	0,26
	HdV-19	0	0	0	1,7	0	0	0	0,24
	UG-1053	0	0	0	1,7	0	0	0	0,24
Zoological remains	HdV-52	18,8	6,9	26,3	3,3	12,7	16,7	22,6	15,33
	HdV-36	1,4	0	1,8	3,3	0	0	1,9	1,20
	HdV-36c	0	3,4	1,8	1,7	3,6	1,7	5,7	2,56
	Zoo remains	0	3,4	1,8	3,3	0	0	0	1,21
	Scolecodonte	0	0	0	0	0	0	1,9	0,27
SUM	Pteridophyte	20,3	24,1	19,3	16,7	7,3	66,7	20,8	25,03
	Indefinite NPP	38,9	47,3	29,6	14,3	40,2	47,8	51,8	38,56
	Algae	2,9	3,4	0	0	0	1,7	0	1,14
	Fungi	56,5	58,6	49,1	71,7	76,4	13,3	47,2	53,26
	Zoo remains	20,3	13,8	31,6	11,7	16,4	18,3	32,1	20,60

Annex 3 : Table of the percentage of NPPs from the samples of the layer 3.4.a. of Vallone Inferno

Absolute/relative chronology	Vegetation dynamics	Fire dynamics	Land use inferred	References
Ca. 10250 cal. BP	Open woodland vegetation / open forest ecosystems, with deciduous and evergreen oaks			(Bisculm et al., 2012)
9700 – 6800 cal. BP	Densely forested area: beech-dominated forests.		Low human impact	(Bisculm et al., 2012)
7000–6500 cal BP, 5050–4550 BC Middle Neolithic	Open land: grasslands	Anthropogenic fire impact both on Nebrodi and Madonie sites	Human indicators: Cerealia-type Forest disruption	(Bisculm et al., 2012 ; Tinner et al., 2016)
6650-5650 cal BP, 4700 – 3700 BC *Late Neolithic – Early Copper age*	Secondary forest with abundant *Ilex aquifolium*			(Bisculm et al., 2012 ; Tinner et al., 2016)
4500 cal BP, 2550 BC Late Copper/Early Bronze Age transition	Grassland establishment both in Madonie and Nebrodi	Burning activity (at Marcato Cixè - Madonie, Tinner et al., 2016)		(Bisculm et al., 2012 ; Tinner et al., 2016)
4200-3800 cal BP, 2250-1850 BC Early Bronze Age	Grassland establishment both in Madonie and Nebrodi	Burning activity (at Marcato Cixè – Madonie)		(Bisculm et al., 2012 ; Tinner et al., 2016)
2800-2600 cal BP, 850-650 BC Early Iron age	Grassland establishment both in Madonie and Nebrodi			(Bisculm et al., 2012 ; Tinner et al., 2016)
800-700 cal BP, AD 1150-1250 Medieval Time	Grassland establishment both in Madonie and Nebrodi			(Bisculm et al., 2012 ; Tinner et al., 2016)

Annex 4 : Vegetation, fire dynamics and inferred land use in northern Uplands of Sicily (Madonie and Nebrodi) between 10250 cal BP and the Medieval period (Forgia, 2019a)

Résumé :

Ces dix dernières années, le site de Vallone Inferno a montré son importance pour comprendre les pratiques et installations préhistoriques humaines dans le nord des montagnes siciliennes de Madonie au travers d'une approche multidisciplinaire. L'une des théories avancées serait l'exploitation du site comme point de croisement pour le pastoralisme de transhumance vertical en lien avec les cultures du Néolithique, de l'Âge de Cuivre et de l'Âge de Bronze en réponse à des variations climatiques tendant vers une aridité. De ce fait, de nouvelles recherches palynologiques sont nécessaires pour compléter ces résultats et tenter de mieux comprendre l'évolution de la végétation en fonction des changements climatiques et des activités anthropiques au sein de l'abri sous-roche. De plus, l'archéopalynologie est un domaine fréquemment remis en question pour la conservation partielle des pollens, amplifié dans les abris sous-roche et grottes. C'est pourquoi, une étude taphonomique de pollens venant de quatre zones d'extraction particulières (foyers, fumier, fossette) ont été analysées pour déterminer l'impact des processus post-dépositionnels sur les pollens. Ainsi, des pollens et Non-Pollen Palynomorphes (NPP) de la couche 3.4.a. ont été extraits, montés, identifiés et comparés à des référentielles.

L'analyse des résultats taphonomiques démontrent une conservation différentielle des pollens en fonction de la zone d'extraction avec une meilleure conservation des milieux biogéniques par rapports aux zones de foyers. La détérioration rapide dans les foyers implique une destruction importante au contraire des milieux biogéniques où la destruction est plus lente et le nombre de pollen indéterminés plus importants. De plus, la distribution des pollens anémophiles et zoophiles diffère de la zone d'extraction avec une majorité de pollens zoophiles dans le fumier et anémophiles dans les foyers. Une activité érosive impacte la préservation des pollens dans les profondeurs de la couche provoquée par les variations d'humidité de l'abri.

Les recherches sur le paléoenvironnement ont montré une ouverture de la forêt Méso-Thermo Méditerranéenne et le développement de plantes xérophiles, indiquant une aridification, qui ne semble pas liée à l'évènement « 4.2 ka ». Néanmoins, la régression de la couverture forestière serait provoquée par une intensification des installations humaines et des activités pastorales au cours de la transition entre l'Âge du Cuivre et le début de l'Âge de Bronze. En effet, des similitudes sont observées entre la dispersion de la culture *Castellucio*, le pastoralisme de transhumance et un changement de la végétation menant à une régression forestière et une augmentation des plantes herbacées.

Abstract

Over the last ten years, the Vallone Inferno site has demonstrated its importance in understanding prehistoric human practices and settlements in the northern Sicilian Madonie mountains through a multidisciplinary approach. One of the theories put forward is that the site was used as a crossroad for vertical transhumance pastoralism in connection with Neolithic, Copper Age and Bronze Age cultures, in response to climatic variations tending towards aridity. As a result, further palynological research is required to complement these results and to better understand the evolution of vegetation in response to climatic changes and anthropogenic activities within the rock shelter. Moreover, archaeopalynology is a field that is frequently called into question for the partial preservation of pollens, amplified in rock shelters and caves. For this reason, a taphonomic study of pollens from four specific extraction zones (hearth, *fumier*, buckets) are analyzed to determine the impact of post-depositional processes on pollens. A study of pollen and Non-Pollen Palynomorphs from layer 3.4.a. was extracted, mounted, identified and compared with reference materials.

Analysis of the taphonomic results shows a differential preservation of pollen depending on the extraction zone, with biogenic environments better preserved than hearth zones. Rapid deterioration in hearths implies significant destruction, whereas in biogenic environments, destruction is slower and the number of undetermined pollens is greater. Moreover, the distribution of anemophilous and zoophilous pollen differs from the extraction zone, with a majority of zoophilous pollen in the *fumier* and anemophilous pollen in the hearth. In addition, erosive activity has an impact on pollen preservation deeply in the layer, caused by variations in the humidity of the rock shelter.

Paleoenvironmental research has shown an opening up of the Meso-Thermo Mediterranean forest and the development of xerophilous plants indicating an aridification that does not seem to be linked to the "4.2 ka" event. Nevertheless, the decline in forest cover is thought to have been caused by an intensification of human settlement and pastoral activities during the transition between the Copper Age and the early Bronze Age. Indeed, a parallel has been observed between the dispersal of the *Castellucio* culture, transhumance pastoralism and a change in vegetation leading to forest regression and an increase in herbaceous plants.

Resumen

En los últimos diez años, el yacimiento de Vallone Inferno ha demostrado su importancia para comprender las prácticas y asentamientos humanos prehistóricos en el norte de las montañas Madonie sicilianas a través de un enfoque multidisciplinar. Una de las teorías propuestas es que el yacimiento se utilizó como encrucijada para el pastoreo de trashumancia vertical en relación con las culturas del Neolítico, la Edad del Cobre y la Edad del Bronce, en respuesta a las variaciones climáticas tendentes a la aridez. En consecuencia, nuevas investigaciones palinológicas son necesarias para complementar estos resultados y comprender mejor la evolución de la vegetación en respuesta a los cambios climáticos y a las actividades antropogénicas dentro del abrigo rocoso. Además, la arqueopalinología es un campo frecuentemente cuestionado por la conservación parcial de los pólenes, amplificada en abrigos rocosos y cuevas. Por esta razón, se analiza un estudio tafonómico de pólenes procedentes de cuatro zonas específicas de extracción (hogar, fumero, cubos) para determinar el impacto de los procesos postdeposicionales sobre los pólenes. Se extrajo, montó, identificó y comparó con materiales de referencia un estudio de pólenes y palinomorfos no polínicos procedentes de la capa 3.4.a.

El análisis de los resultados tafonómicos muestra una conservación diferencial del polen en función de la zona de extracción, con una mejor conservación en los medios biogénicos en comparación con las zonas de focolare. El rápido deterioro en los focos implica una destrucción importante, mientras que en los ambientes biogénicos la destrucción es más lenta y el número de pólenes indeterminados es más grande. Además, la distribución del polen anemófilo y zoófilo difiere de la zona de extracción, con una mayoría de polen zoófilo en el *fumier* y de polen anemófilo en los focolares. Además, la actividad erosiva influye en la conservación de los pólenes en las profundidades de la capa, provocada por las variaciones de humedad del abrigo rocoso.

Las investigaciones sobre el paleoambiente han mostrado una apertura del bosque Meso-Thermo mediterráneo y el desarrollo de plantas xerófilas, lo que indica una aridificación que no parece estar vinculada al evento "4,2 ka". No obstante, se cree que la disminución de la cubierta forestal se debió a una intensificación de los yacimentos humanos y de las actividades pastorales durante la transición entre la Edad del Cobre y los inicios de la Edad del Bronce. De hecho, se ha observado un paralelismo entre la difusión de la cultura *Castellucio*, el pastoreo trashumante y un cambio en la vegetación que condujo a una regresión de la cubierta forestal y a un aumento de las plantas herbáceas.