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First palynological results from Spila nad Procjepom cave, Mljet island (Croatia)

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Abstract

This paper presents the first results of palynological research from the Spila nad Procjepom cave, situated in the Mljet National Park, Croatia. The palynological data obtained, enables a partial insight into the local vegetation cover, temporal changes in the vegetation during the accumulation of studied deposits (at ca. 3500 cal years BP), and post-depositional processes that influenced the palynomorph assemblage. Results of palynofacies analysis indicate changes from fluvial (channel deposits), through palustrine to terrestrial environments. Although the interpretation of changes in plant cover, due to the lack of statistical significance, should be taken with caution, preserved pollen types confirm the dominance of the Mediterranean evergreen forest vegetation on Mljet island. Moreover, a high proportion of non-arboreal pollen (NAP) indicates some level of forest degradation, ranging from Mediterranean open forest to degraded maquis. Abundant charcoal additionaly confirms that the cave was inhabited by humans.

1. INTRODUCTION

1.1. General background

Caves often have well preserved sediments that contain valuable palaeontological and archaeological materials, and consequently, cave sediments are interesting because they may contain important records of past environments. In Croatia, the palynological analysis of cave sediments has rarely been performed (KUREČIĆ et al., 2021). Cave palynological investigations in the surrounding region are also scarce (DOLÁKOVÁ, 2014; D'AGOSTINO et al., 2022). Even though palynology is very promising, it is also very challenging. Pollen taphonomy in caves depends on a diverse number of factors: primarily production, dispersal, transport, deposition and post-depositional processes (COLES et al., 1989; HUNT & FIACCONI, 2018). The impact of animals and humans upon the composition of palynomorph assemblages is also very important. Therefore, the aim of this study was to apply a combination of palynofacies and palynomorph analyses in cave sediment research. More specific objectives were: (i) to obtain additional information about the local vegetation plant cover in the past of the Adriatic area, (ii) to obtain information about temporal changes in the vegetation of that area, and (iii) to enable a better understanding of the post-depositional processes affecting the palynomorph assemblage.

1.2. Location, physical environment and vegetation

Spila nad Procjepom cave (also known as the Briježica or Špilja kod Nerezinoga dola) is situated on the southern slope of Briježina Hill at 210 m a.s.l. overlooking Procjep Bay in the Mljet National Park (Fig. 1). The cave is a 35 m long chamber partly filled with sediments, formed in the Jurassic–Cretaceous dolostones with limestone intercalations (HUSINEC, 2002). The entrance (dimension 6 x 2 m) is oriented towards the southwest and the open sea. The entrance part of the cave is dry with a few remains of the flowstones that are no longer active, while the back of the cave is hydrologically active where drip water is still circulating, and flowstones are growing. The sediments studied in this research were sampled from the SE profile of test pit Sonda II in the back part of the cave, in the vicinity of a large flowstone (Fig. 2). The area of the Mljet National Park, as well as the entire island, belongs to the macro-geomorphological region of South Dalmatia, with the archipelago and the meso-geomorphological region of the South Dalmatian Archipelago (BOGNAR, 1999). According to Köppen's classification, the island of Mljet belongs to the Mediterranean climate with hot summers (Csa) (ŠEGOTA & FILIPČIĆ, 2003). It means that winters are mild with abundant rainfall, in opposition to the long, dry and hot summers with frequent sunny days. The average annual air temperature on the island is 16.7 °C and it is one of the warmest areas in Croatia. The amplitude of average monthly air temperature values indicates the large thermal influence of the sea. Spring is cooler (due to the marine cooling effect) than the relatively warm autumn. The lowest mean monthly temperature is measured in January and February (8.8 °C each) and the highest values in July and August (26.0 °C and 25.8 °C, respectively). Average annual precipitation varies between 815 mm and 1021 mm, depending on the location and altitude (ŠPANJOL et al., 2016). Due to its geographical position, the island of Mljet is located in the Mediterranean Biogeographical Region. Plant cover of the island belongs to the Stenomediterranean (near coastline), Eumediterranean (inland area) and Hemimediterranean (inland higher altitudes) vegetation zones (TRINAJSTIĆ, 1998; ŠPANJOL et al., 2016). Only in the

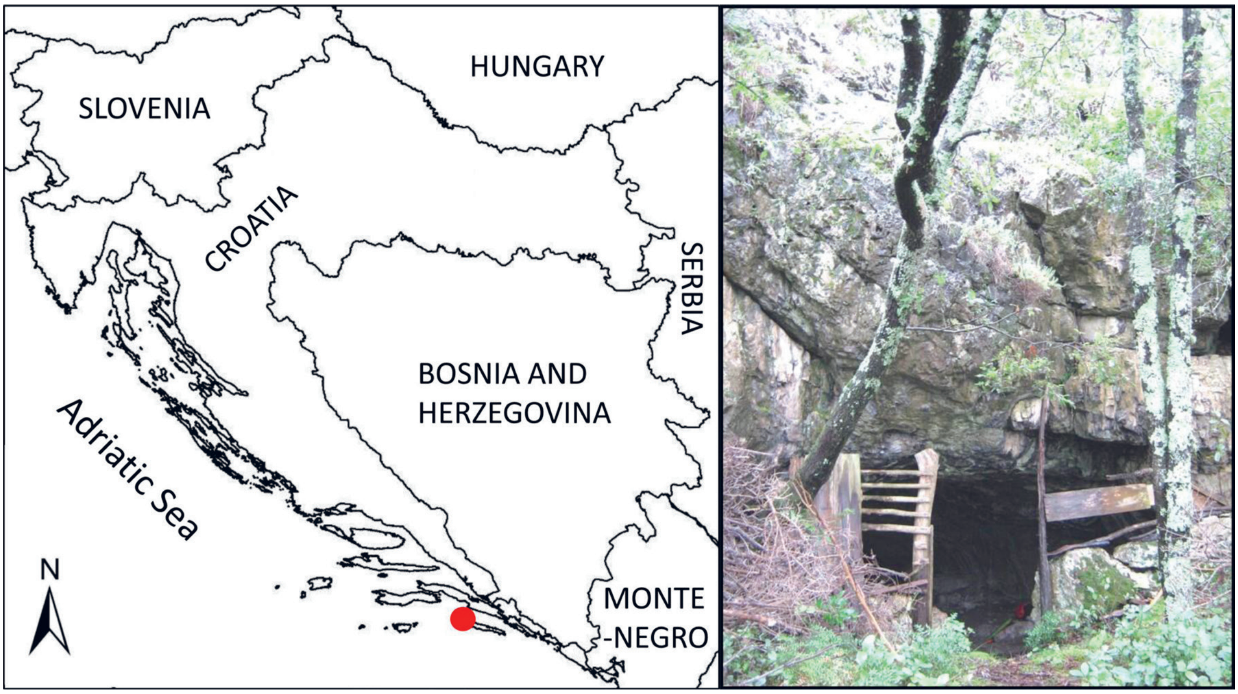

Figure 1. Geographical location (red dot) and the entrance of the Spila nad Procjepom cave (island of Mljet).

Figure 2. Plan of the Spila nad Procjepom cave with locations of the test pits Sonda I (S I) and Sonda II (SII). Sampled profile of SII is marked with a bold line.

latter zone, do deciduous plants with a focus on *Ostrya carpinifolia* SCOP. have an important role (TRINAJSTIĆ, 1998). The other two vegetation zones are dominantly evergreen. So even though the island is nowadays almost completely covered with evergreen forest vegetation, it was not the case in the past. Forest habitats are the dominant type of vegetation, occupying more than three quarters of the island area (MESIĆ et al., 2009). Today the dominant forest trees are holm oak (*Quercus ilex* L.) and Aleppo pine (*Pinus halepensis* L.). Most of the National Park is overgrown by maquis (ŠPANJOL et al., 2016), and various degradation stages of holm oak forests (UGARKOVIĆ et al., 2019), while garrigues vegetation occupies only a small area (MESIĆ et al., 2009). The most abundant species of the maquis layer are evergreen trees, such as the strawberry tree (*Arbutus unedo* L.), mock privet (*Phillyrea media* L.), tree heath (*Erica arborea* L.), Chios mastic (*Pistacia lentiscus* L.), common myrtle (*Myrtus communis* L.) and laurustinus (*Viburnum tinus* L.), followed by carob (*Ceratonia siliqua* L.), olive (*Olea europaea* L. var. *sylvestris* BROT.), laurel (*Laurus nobilis* L.), and others. Among conifers, the most abundant is the genus *Juniperus* represented by brown-berried juniper (*Juniperus oxycedrus* L. ssp. *oxycedrus*), large-berried juniper (*Juniperus oxycedrus* L. ssp. *macrocarpa* (SM.) BALL) and Phoenicean juniper (*Juniperus phoenicea* L.). Pine forests, after maquis, represent the most abundant form of forest vegetation in the Park, while the large preserved Aleppo pine trees testify to the widespread appearance of the former autochthonous pine forests of Mljet (ŠPANJOL et al., 2016).

1.3. Previous palynological and archaeological research

The island of Mljet has been palynologically investigated several times, e.g. BEUG (1967), JAHNS & VAN DEN BOGAARD (1998), and JAHNS (2002) so the Holocene vegetation changes are mostly well known. According to JAHNS (2002) who brings a synthesis of palaeovegetational changes, in the period preceding the Common Era, four main steps in vegetation development can be recognized: the deciduous *Quercus* woodland was replaced by the evergreen *Juniperus-Phillyrea* community before ca. 7500 years BP, the latter was succeeded by the evergreen *Quercus ilex* woodland ca. 6000 years BP, followed by the *Pinus* dominated forest shortly after ca. 3000 years BP.

Archaeologically and palaeontologically, the Spila nad Procjepom cave was investigated during five campaigns over the last 12 years (from 2010 to 2022) in collaboration with the Public Institution of the "Mljet National Park". Two test pits were dug: Sonda I ("S I") near the entrance and Sonda II ("S II") in the inner part of the cave. While the silty, topmost sediments were rich in the remains of domesticated animals (mainly sheep and goats), marine fauna (fish and molluscs) and archaeological material (mainly pottery) spanning from the Copper Age to Medieval time (OROS SRŠEN et al., 2013; MAUCH LENARDIĆ et al., 2017), the flowstone discovered beneath provided a much older age. The sediment deposition in the cave lasted at least from the Last Interglacial (MIS 5e), however, the breccia and the dolostone debris beneath could be of MIS 6 age or older (OROS SRŠEN et al., 2017).

2. MATERIALS AND METHODS

2.1. Fieldwork

Three palynological samples were taken from the Sonda II ("S II") test pit in order to investigate the preservation of palaeobotanical remains in the cave deposits of Spila nad Procjepom. Test pit "S II" was chosen due to its well-preserved layers. The front-layer of the soil was cleared to a depth of 5 cm, and discarded to eliminate potential contaminants. Three samples were taken from the southeastern profile of the pit (Fig. 3), from different sublayers of Layer 4 that were chosen for its well-preserved fine-grained sediments. Layer 4 is mostly grayish brown silty clay (10YR-4/2) with various amounts of charcoal, hearth ash, as well as some burnt clay. All sublayers contain excellently preserved Holocene palaeontological/zooarchaeological remains, including sheep and goats and marine molluscs, as well as prehistoric archaeological material: pottery and a few stone tools (OROS SRŠEN et al., 2013). Samples for palynology were taken from the grayish-brown sediment that represents deposits less affected by human-produced fire (hearths – white/orange inclusions of profile on Fig. 3):

- Sample P1 – Layer 4, sublayer 3: Overall sediment is yellowish-brown silty clay with charcoal particles and intercalations of grayish clay. Visible burrowing holes point to recent bioturbation. Sample P1 was taken at a depth of 0,60 m from the pit surface (sediment top).
- Sample P2 – Layer 4, sublayer 4: Mostly reddish-brown silty clay with numerous charcoal hearth remains, with intercalations of dark brown to gray silty clay. Sample P2 was taken at a depth of 0,80 m from the pit surface (sediment top).
- Sample P3 – Layer 4, sublayer 4: Mostly grayish-brown silty clay with reddish and yellowish intercalations and traces of ash. Sample P3 was taken at a depth of 1,10 m from the pit surface (sediment top).

One charcoal sample (Z – 5203) was collected from the hearth in Layer 4, sublayer 4 at 0,90 m from the pit surface during the excavation in 2012. The position of the hearth is 10 cm below sample P2. The charcoal sample was sent for radiocarbon dating (AMS ^{14}C) at the Institute of Ruđer Bošković in collaboration with the University of Georgia, Center for Applied Isotope Studies. It is calibrated by Intcal20.14c (REIMER et al., 2020), with the error at the 1σ-level.

2.2. Laboratory work

2.2.1. Sample preparation

The samples were processed for palynological analysis in the laboratory of the Croatian Geological Survey. For each sample ap-

Figure 3. Sampling spots (P1, P2, P3) of Layer 4 (Sonda II test pit).

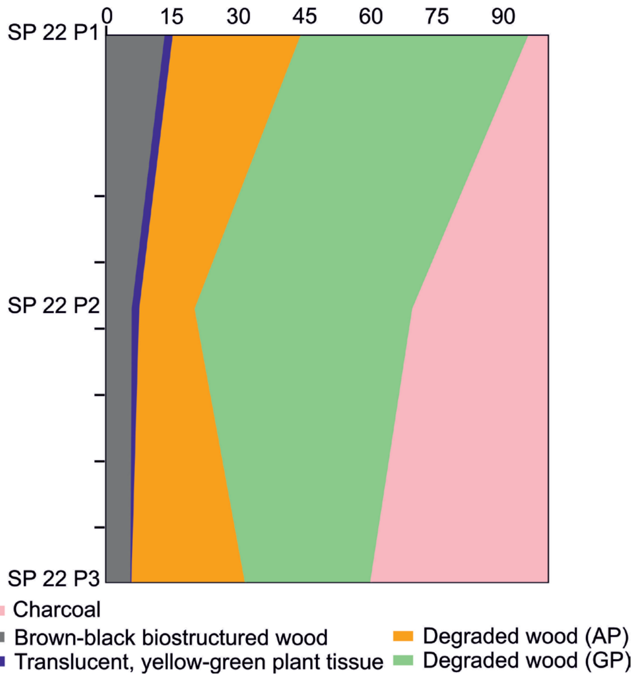

Figure 4. Phytoclasts ratio.

prox. 18-30 g sediment was cleaned and crushed. Two *Lycopodium* tablets (Batch no. 280821291; 13761 spores/tablet) were added to each sample at the start of the processing to calculate palynomorph concentration according to MAHER (1981). The preparation procedure included treatment with cold HCl (20%) to remove the carbonates, and sodium pyrophosphate ($Na_4P_2O_7$) to prevent coagulation, according to the standard techniques described in MOORE et al. (1991). Heavy liquid ($ZnCl_2$, specific gravity 2.1 kg/l) was applied to separate the organic matter from the undissolved inorganic fraction. The organic residue was sieved through a 10 µm mesh. For palynofacies analysis slides were mounted in glycerin jelly, and the rest of the material was mixed in silicon oil for palynomorph analysis. Microscopic analyses were performed using a Leica DM2500 microscope at x50, x100, x200, x400 and x630 magnifications combined with the differential interference contrast (DIC). Photomicrographs were taken using a Leica MC190 HD camera connected to the Leica LAS EZ software. Sediment samples, organic residues and palynological slides are curated at the Department of Geology, Croatian Geological Survey.

2.2.2. Palynofacies analysis

For palynofacies analysis, a minimum of 300 sedimentary organic particles were counted. There are three main categories: amorphous organic matter (AOM), phytoclasts and palynomorphs (TYSON, 1995). In this paper, we distinguish subcategories: preserved phytoclasts (translucent, yellow-green plant tissue, and brown-black biostructured wood) and transformed phytoclasts (amorphous particles, gelified particles, and charcoal). Amorphous particles (AP) appear with diffuse but recognizable outlines that occasionally have residual internal structures. Gelified particles (GP) present a homogeneous texture, variable colour (brown to amber), true outlines, and commonly angular shape, only occasionally with dulled angles. Charcoal particles are completely opaque, angular, and usually planar, black fragments. Samples are plotted in ternary diagrams using the software Past 4.13 (HAMMER et al., 2001). We used different types of diagrams to present the results. One of the more comprehensive diagrams used in palynofacies studies is the APP diagram (AOM-Phytoclast-Palynomorph ternary diagram) presenting differences in relative proximity to terrestrial organic matter sources, transport paths, and the redox status of the depositional environments (TYSON, 1995). We also used two more ternary diagrams: “Amorphous OM/Preserved Phytoclasts/Transformed Phytoclasts” and “Opaque/Amorphous/Gelified Particles” (OP/AP/GP) to estimate the origin of the sedimentary organic matter (SOM) (aquatic/terrestrial), its source areas (vegetation, soils, river), and controls of early diagenetic changes (aerobic/anaerobic conditions, advanced oxidation) introduced by SEBAG et al. (2006b). To illustrate the origin (i.e. terrestrial or aquatic) and state of degradation of the organic particles samples, SEBAG et al. (2006b) proposed four optical indices: (i) “AOM contents” to quantify the aquatic contribution; (ii) “preserved phytoclasts / transformed phytoclasts ratio” to calculate the degree of degradation of the terrestrial fraction; (iii) “OP contents” to distinguish the allochthonous fraction from the fluvial origin; (iv) “GP/AP ratio” to differentiate the pedogenic or subaquatic degradation of terrestrial plant debris. To obtain information about the origin of the terrestrial fraction, we plotted a diagram with “OP contents” and “GP/AP ratio”. In order to have an overview of the organic particle amounts in the sediments, we introduced “OM concentration” (particles/g) that is calculated by the following formula: OC = ((number of *Lycopodium* spores added) x (number of particles counted)) / ((number of *Lycopodium* spores counted) x (weight of dry sediment processed in grams)).

2.2.3. Charcoal analysis

Samples for microscopic charcoal analysis were prepared as part of routine pollen analysis. They were counted as palynofacies particles. Particles in the < 50 µm size bracket were not measured because of their great abundance and minimal influence on the total charcoal sum, according to WHITLOCK & LARSEN (2001). Macroscopic charcoal (> 100 µm) was analysed from sediment sieved at 125 µm during the preparation procedure for pollen analysis. All particles that were black with shiny surfaces were considered to represent charcoal fragments. A qualitative approach was used to gain a general view of the fire history. Identification of pollen and plant spores followed standard keys, eg. MOORE et al. (1991) and BEUG (2015). A minimum of 100 palynomorphs were counted (five to six slides per sample) because the abundance was very low. All terrestrial pollen and spores were included in the pollen calculation sum. Indeterminable pollen counts were included in the total pollen sum because exclusion could result in bias in favour of well-preserved types (KAPP et al., 2000). When calculating the palynomorph percentages, the sum of all established pollen grains and spores, excluding algae and modern spores, was taken as 100%. The determination of pollen and spores was carried out according to the Engler classification system. Palynological results, including changes in the arboreal/non-arboreal pollen (AP/NAP, i.e. woody vs. herbaceous plants), were presented as pollen percentage histograms, tables, and plates.

3. RESULTS

3.1. Radiocarbon dating

The radiocarbon date of one charcoal sample (Z – 5203/UGAMS 14722) has yielded a date of 3160±25 years BP (3276 – 3448 cal years BP/ 1439 cal years BC).

3.2. Palynofacies

Organic matter concentrations are relatively high ranging from 53.254 (SP22 P2) to 155.923 (SP22 P3) particles per gram. Pa-

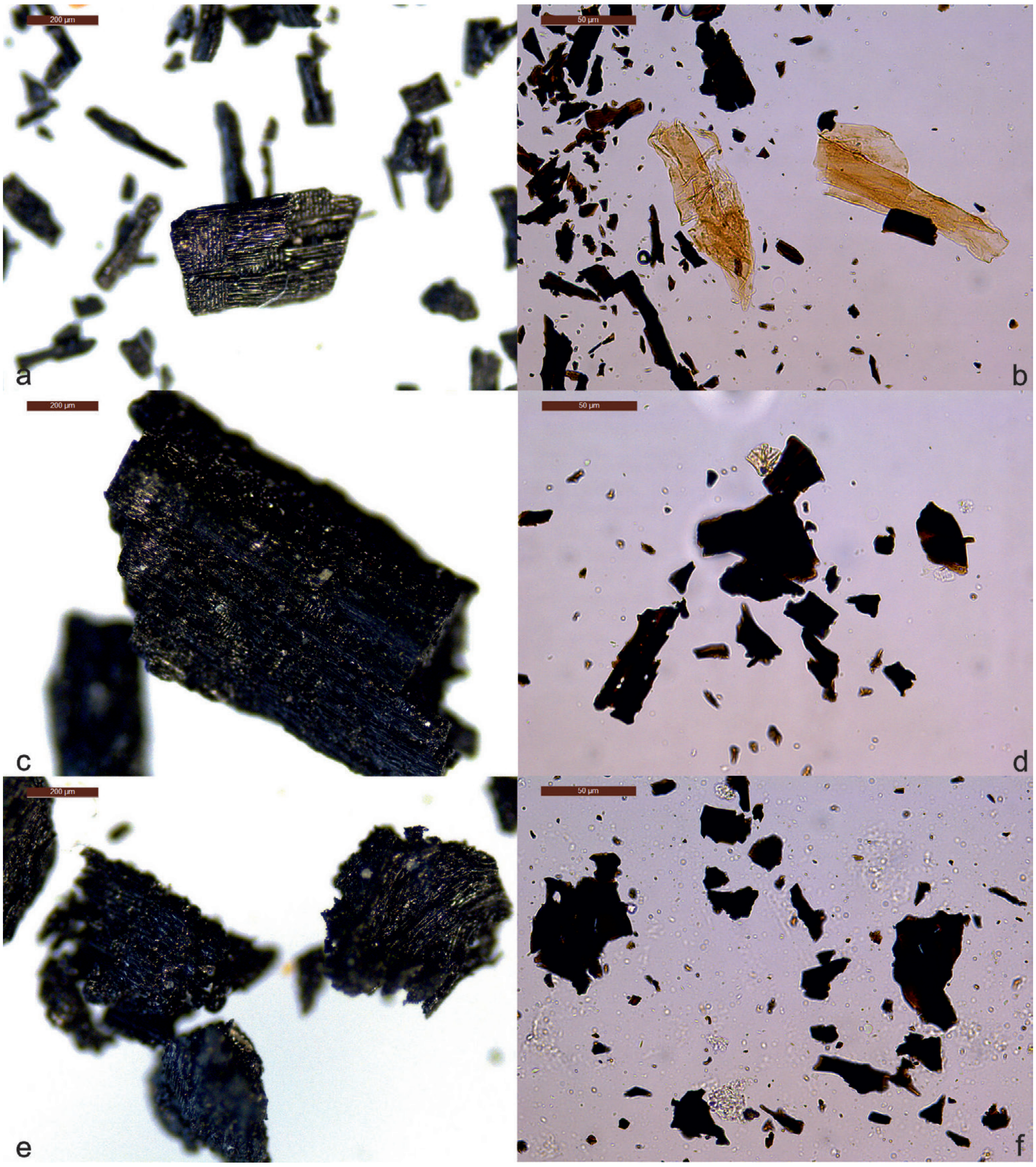

Figure 5. Palynofacies SP 22 P-1 a-b; SP 22 P-2 c-d; SP 22 P-3 e-f. The scale bar is 200 µm for a, c, e and 50 µm for b, d, f.

lynofacies of all three studied samples are dominated by phytoclasts (Suppl. 1), mostly degraded woody tissue. Translucent, yellow-green plant tissue (cuticle and membranous fragments) and amorphous organic matter are very rare (Fig. 4). In all three samples macroscopic charcoal (>100 µm) is abundant (Fig. 5 a,c,e). In sample SP22 P3 charcoal is the most abundant particle type. Its ratio decreases in sample SP22 P2 and it has the lowest abundance in palynofacies of sample SP22 P1. At the same time, in sample SP22 P1 the degraded wood ratio increases, as well as the brown-black biostructured wood clasts (Fig. 5).

3.3. Palynomorphs

Palynomorph concentrations are relatively low ranging from 1366 to 3225 palynomorphs per gram (Suppl. 2). The obtained materials made it possible to establish three spore-pollen complexes that characterize the deposits of the Spila nad Procjepom cave. Selected samples of palynomorphs are given in Fig. 6. In the established complexes, the pollen of woody and herbaceous plants is approximately equal in proportions. However, they have several differences (Suppl. 2). It is important to note that in the macerates of all samples, redeposited pollen from more ancient deposits was noted in different amounts, as well as modern spores of Polypodiaceae

3.3.1. SP22 P3

The palynomorph assemblage of sample SP22 P3 comprises 33.8% AP and 35.3% NAP. Distinctive features of the assemblage are the highest percentage of spores (20.7%) of all three samples, belonging mainly to Polypodiaceae, the lowest amount of Ericaceae pollen (1.7%), as well as the highest content and taxonomic diversity of pollen from aquatic plants (Suppl. 2). The group of woody plants is dominated by Oleaceae pollen (23.2%) and closely followed by *Pinus* pollen (13.9%). The group of herbaceous plants is dominated by Cichoriaceae pollen (12.2%). The pollen of Poaceae and Asteraceae was recorded in approximately equal proportions, at 6.9% and 5.2%, respectively, with *Valeriana* pollen at 2.6%. Single pollen grains of Caryophyllaceae and Lamiaceae were also noted (Suppl. 2). A characteristic feature of the complex is the highest content and taxonomic diversity of hygrophilous pollen: Cyperaceae (2.6%), *Typha latifolia* (1.7%),

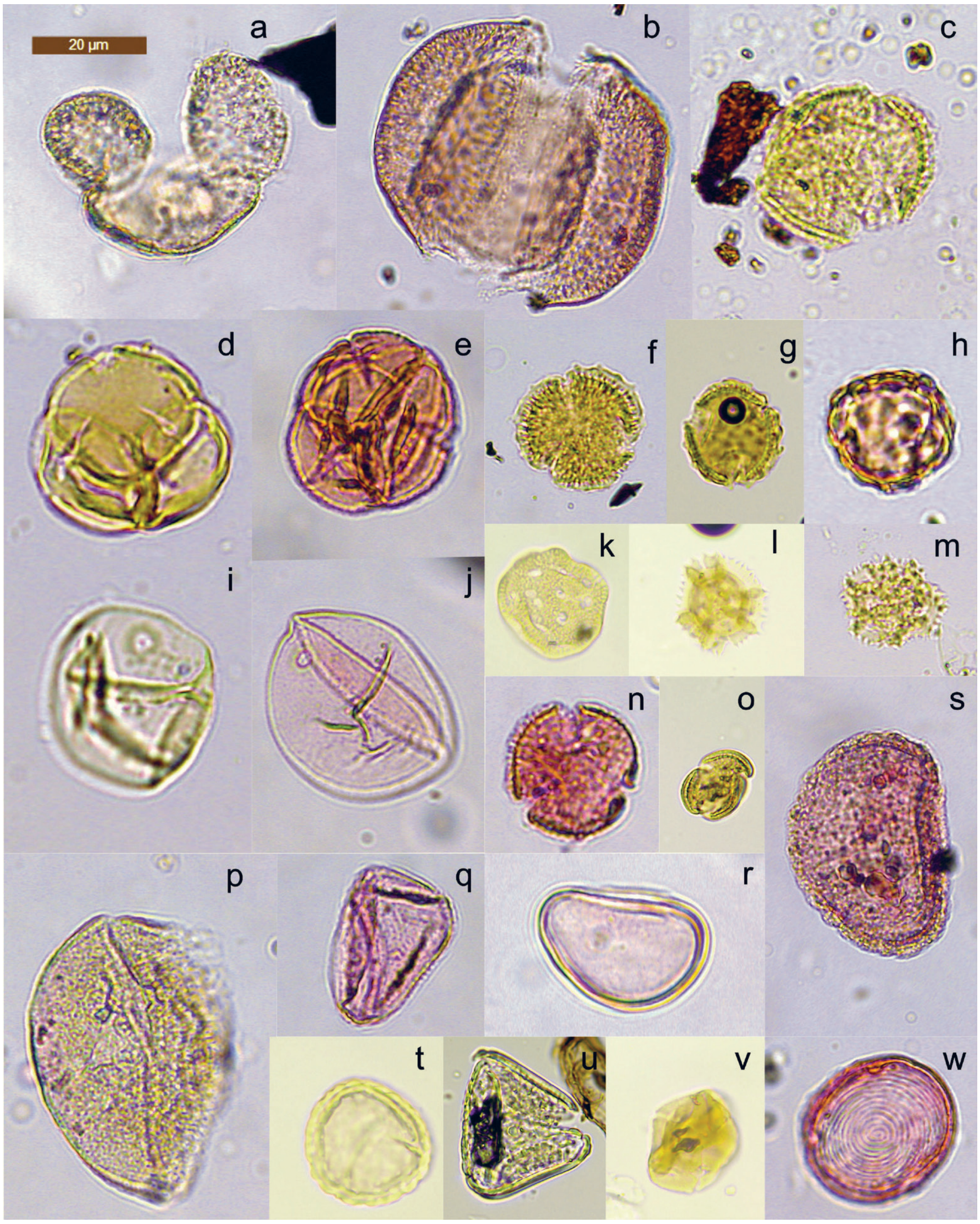

Figure 6. Palynomorphs from the deposits of the Spila and Procjepom cave: (a)-(b) *Pinus*, (c) Oleaceae, (d)-(e) Ericaceae, (f)-(g) Asteraceae, (h) Chenopodiaceae, (i)-(j) Poaceae, (k) Caryophyllaceae, (l)-(m) Cichoriaceae, (n) Celastraceae, (o) *Artemisia*, (p) Liliaceae, (q) Cyperaceae, (r)-(s) Polypodiaceae, (t) *Selaginella*, (u) *Anogramma*, (v) Redeposited pollen, (w) *Pseudoschizaea*. The scale bar is 20 µm.

Liliaceae (1.7%), Alismataceae (0.8%). The highest number of spores of Polypodiaceae was also recorded in sample SP22 P3 (Suppl. 2).

3.3.2. SP22 P2

In the palynomorph assemblage of sample SP22 P2, the AP reaches 43.8%. Compared to the assemblage described above, the amount of *Pinus* pollen in its composition has decreased to 9.3%. However, the composition of prevailing pollen types, as well as the amount of Oleaceae pollen, remained at the level of the previous sample complex (22.2%). A distinctive feature of the complex is the relatively high content of Ericaceae pollen (11.2%) and the appearance of Celastraceae pollen. Compared to the previous complex, the NAP amount has slightly increased (39.8%). This group doubled the amount of Asteraceae pollen (11.9%), with an accompanying high percentage of Cichoriaceae pollen (15.7%). Poaceae pollen content decreased to 5.9%, and only a single *Ephedra* pollen grain was noted. Compared to the previous palynomorph assemblage, the amount of Caryophyllaceae pollen has doubled (1.9%), while *Valeriana* pollen reached 1.9%. Aquatic plants are represented by *Typha latifolia* pollen (2.6%). The spores belong mainly to Polypodiaceae and sporadically to *Selaginella*. A *Pseudoschizaea* algae was also recorded (Suppl. 2).

3.3.3. SP22 P1

The palynomorph assemblage of the SP22 P1 sample reaches 44.2% of AP, while this group contains the highest quantities of *Pinus* pollen (18.5%). The composition of angiosperm pollen is dominated by pollen grains of Oleaceae (18.5%). Ericaceae (4.8%) is of subordinate importance. A distinctive feature of the complex in sample SP22 P1 is the presence of pollen from broad-leaved species: *Quercus*, *Ostrya* and *Acer* (in total 2.4%). The AP and NAP are equal in proportion (44.2%). This group is dominated by the pollen of Cichoriaceae (13.2%) and Asteraceae (11.7%). The pollen of Poaceae (8.5%) acts as a subdominant. Pollen grains of Caryophyllaceae (3.2%) and *Artemisia* (1.5%), *Valeriana* (1.5%), as well as single pollen from Solanaceae and Lamiaceae were observed. The group of aquatic plants is represented by the pollen of *Typha latifolia* (1.5%). Spores belong mainly to Polypodiaceae. Also, single spores of *Anogramma*, as well as the alga *Pseudoschizaea* were noted.

4. DISCUSSION

4.1. Depositional environment

A relatively small amount of organic residue in all three samples with a high proportion of the opaque or semi-opaque phytoclasts indicates an oxic environment (TYSON, 1995), where other organic compounds are selectively destroyed. The APP diagram (Fig. 7) shows the absolute domination of phytoclasts in all the analysed samples, indicating a pronounced input of terrestrial organic material (TYSON, 1995). The dominance of structured phytoclasts in the total organic residue in all of the analysed samples indicates the pronounced input of terrestrial organic components. Short fluvial transport is evident in phytoclasts' structure, angularity and the fact that the clasts are unsorted (TYSON, 1995; MENDONÇA FILHO et al., 2017). Black oxidized phytoclasts (charcoal) were derived from fires (wildfires or anthropogenic fires), providing direct evidence of burning (TYSON, 1993; 1995). In the microscopic material, opaque particles are not always charcoal, but rather gelified phytoclasts because higher temperatures convert the material to ash through glowing combustion, while lower temperatures may only lightly scorch the material, but not char it (WHITLOCK & LARSEN, 2001). Since charcoal is produced between temperatures of 280°C and 500°C, microscopic charcoal abundance increases during local fires. However, other proxy records, such as macroscopic charcoal or lithological changes, are needed to confirm if the fire was local. Abundant macroscopic charcoal (>100 µm) in all of the samples, coupled with charcoal, hearth ash, and some burnt clay in sediment, confirms the local fire event. The "preserved/transformed phytoclasts ratio" allows quantification of the degree of degradation of the terrestrial fraction. In the "AOM/Preserved phytoclasts/Transformed particles" ternary diagram (Fig. 8), the domination of transformed particles indicates a high plant-derived content (SEBAG et al., 2006a). SEBAG et al. (2006a) concluded that the "Preserved/transformed phytoclast ratio" decreases from production (i.e. litters) to depositional area (ditch, pond, alluvial deposits, etc.). In samples from the Spila nad Procjepom cave, the abundance of transformed particles points towards the soil origin. Typical soil assemblages are dominated by transformed phytoclasts (SEBAG et al., 2006a). The ratio between opaque, amorphous, and gelified particles is presented in the "Opaque/Amorphous/Gelified Particles" ternary diagram (Fig. 9). More illustrative is the diagram of the "OP" and "GP/AP ratio" (Fig. 10). The "OP contents" increases with the oxidation of terrestrial

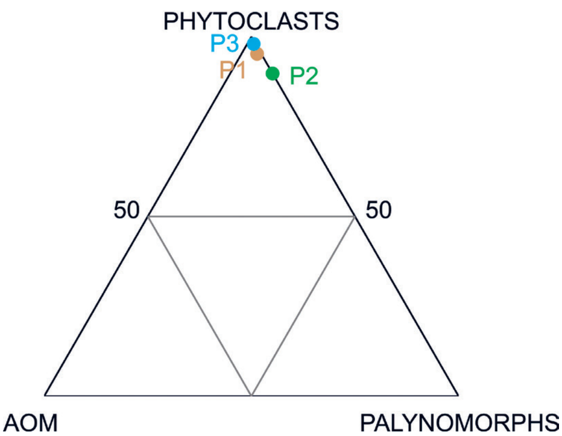

Figure 7. Palynofacies (APP) ternary diagram.

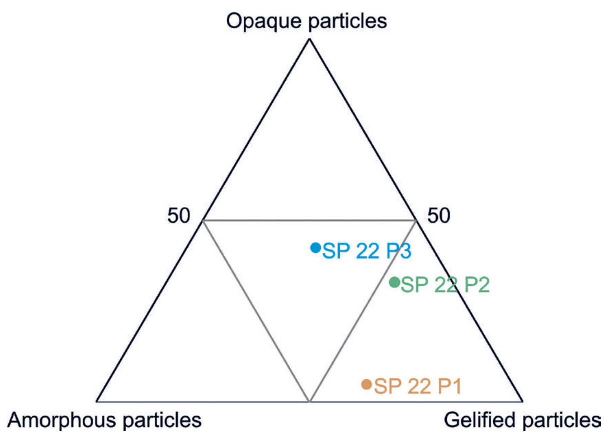

Figure 9. Opaque/ Amorphous/ Gelifies Particles (OP/AP/GP) ternary diagram.

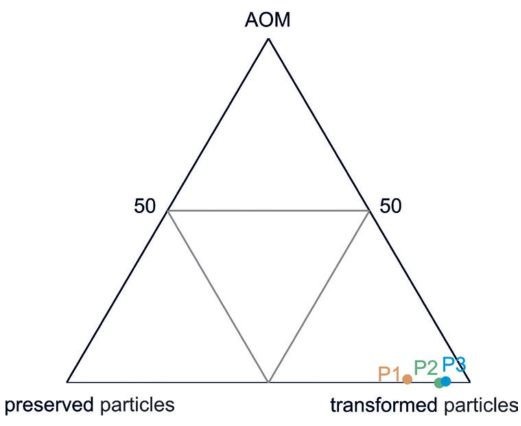

Figure 8. Amorphous OM/ Preserved Phytoclasts/ Transformed Phytoclasts ternary diagram.

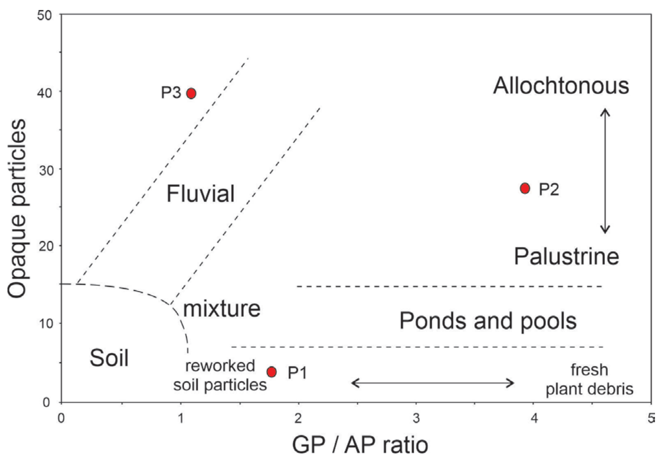

Figure 10. Origin of the terrestrial fraction.

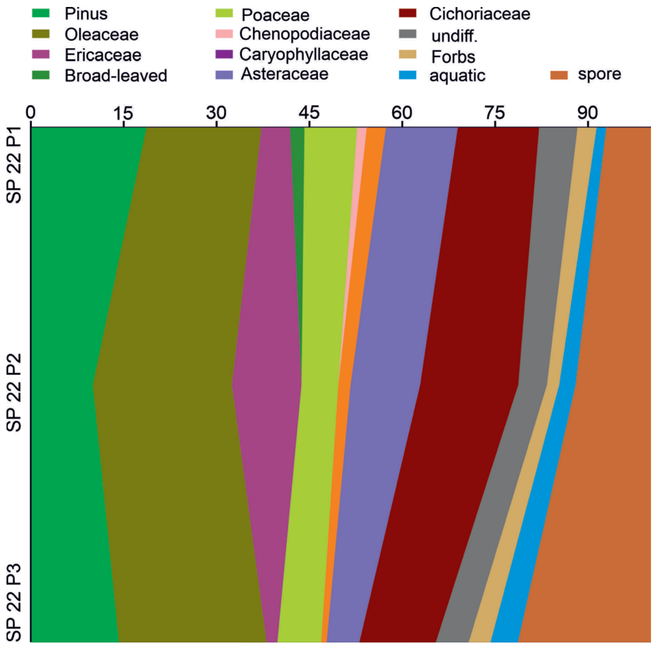

Figure 11. Composition of plant groups during the formation of deposits in the Spila Cave.

source materials. The "GP/AP ratio" is used to discriminate sites that have material reworked from the soil as opposed to sites where fresh plant debris falls directly into a basin and decays (SEBAG et al., 2006b). "OP contents" allows the recognition of fluvial (high values) and palustrine (low values) environments. The "GP/AP ratio" allows the distinction of soil (low values) and plant (high values) supplied areas. GP formation is related to the degradation of plant tissues in aquatic environments (pools, ponds, lakes) or anaerobic conditions (catotelm of peat, hydromorphic soils). It is often observed in hydromorphic soils (NOËL et al., 2001). In the analysed samples, the domination of GP points to the degradation of plant tissues in aquatic and/or anaerobic conditions, especially in the sample SP22 P1, derived from hydromorphic soils, while SP22 P2 and SP22 P3 indicate a fluvial influence. Comparing the data from this study with data presented by SEBAG et al. (2006b), SP22 P3 could be indicative of a fluvial origin (channel deposits), SP22 P2 of palustrine, and SP22 P1 of terrestrial origin (OF horizons sensu BAIZE & GIRARD (2009) related to Oe horizons (Orthoeutric) from the World Reference Base (IUSS WORKING GROUP WRB, 2007, 2014)), moderately decomposed organic matter. A similar situation to sample SP22 P3 was observed in the Lower Cerovačka Cave (Mt. Velebit, Croatia) where sample DC-SP 1 indicates a fluvial palaeoenvironment confirmed by sedimentological data (KUREČIĆ et al., 2021).

4.2. Vegetation history

Due to a limited number of samples, and the fact that there was no sample taken from the surface near the entrance of the cave, which is a prerequisite for palaeofloristic reconstructions, the presented reconstructions of vegetation have a preliminary character. Considering the above facts, the materials for the palynological study did not allow biostratigraphic dating of the analysed sediments, which is only a partial obstacle in the interpretation of local temporal changes in vegetation.

In all the studied deposits (SP22 P3, SP22 P2 and SP22 P1), Oleaceae were the principal, dominant component within the woody plants, while the composition of subdominants changed over periods of time (Fig. 11, Suppl. 2). Although our pollen samples are not statistically significant due to the low pollen counts, well represented Oleaceae pollen speak in favour of olive-dominated stands at a distance of less than 500 meters from the cave (FLORENZANO et al., 2017). Moreover, the aerobiological research conducted in Babino Polje, the largest settlement on the island of Mljet whose inhabitants are mainly involved in the olive and vine cultivation, confirmed the relative dominance of airborn Oleaceae pollen in recent time (VOLARIĆ-MRŠIĆ, 1984). In contrast, pine pollen is not overrepresented as it may be expected due to recent plant cover on the island of Mljet, suggesting that *Pinus* probably did not participate in the local or extra-local vegetation. According to CONNOR et al. (2004), pine trees are found near the sampling site only when its pollen comprises 35-50%, and these values were not reached in any of the studied samples. Within the herbaceous plants, pollen from Cichoriaceae, Asteraceae, Poaceae, Chenopodiaceae, and Caryophyllaceae were well represented. These families also include the largest number of drought-resistant taxa which complete their life cycle in one growing season and survive unfavourable conditions in the form of seeds. Additionally, Caryophyllaceae, Poaceae and Chenopodiaceae are indicators of open-ground vegetation in the Mediterranean area (FYFE et al., 2018; IZDEBSKI et al., 2020). Thus, herbaceous vegetation of all of the afore-mentioned taxa is widespread in the recent island flora (REGULA-BEVILACQUA & ILIJANI, 1984), as it was during the late Quaternary in the broader Mediterranean area (SUC et al.). Locally, the hydromorphic conditions are marked by the presence of *Typha latifolia* in all the analysed samples. This aquatic taxon is a common wetland element and refers to water depths within the range of 10–60 (–100) cm (ŠUMBEROVÁ, 2011), and requires a mean July temperature above 15.7 °C (SCHENK et al., 2018). The aquatic-wetland component is highlighted in the SP22 P3 sample by the appearance of Alismataceae and Cyperacea pollen and the highest percentage of spores.

Our results correlate very well with the zonation presented for southern Dalmatia by JAHNS (2002) and BASS (2008). JAHNS & VAN DEN BOGAARD (1998) divided the *Quercus ilex* period into three subzones (C1-C3). Whereas the *Q. ilex* remains at a relatively constant level, the associated vegetation is different. In subzone C1 *Juniperus* dominate, in subzone C2 *Erica* and in subzone C3 *Pinus*. In the samples from Spila nad Procjepom, Ericaceae have greater values than others and we can presume that the sediment in the cave was deposited during the subzone C2 (*Quercus ilex – Erica*) ranging from approximately 4370 years BP to 2670 years BP (JAHNS, 2002), which is in accordance with our radiocarbon dating. Furthermore, detailed sedimentological analyses are planned in order to shed more light on the genesis of the sediments and cave.

4.3. Taphonomic processes

It is known that periodic wetting and drying of cave deposits as well as human activity (burning) can lead to extremely poor pollen preservation (HUNT & FIACCONI, 2018). Pollen taphonomy in caves depends solely on transport paths and the depositional environment. Contemporary pollen must have entered the cave via aeolian transport or fluvial input or was brought in by animals/humans. Animals could have easily picked up pollen from foliage in the vicinity of the cave during grazing and brought it to the cave on their fur and feet or in their gut contents (COLES et al., 1989). Daisy family, Asteraceae (entomophilous pollen), which have a great share in the pollen assemblage from Spila nad

Procjepom cave could have been brought by bees, flies or beetles (HUNT & FIACCONI, 2018). This is in accordance with NAVARRO et al. (2001) who concluded that the amount of the zoophilous pollen (Asteraceae/Cichorioideae) increased from the direction of the cave entrance into the inner parts.

Ground-living animals such as foxes, badgers, porcupines and rodents may be significant importers of pollen (HUNT & FIACCONI, 2018). In the Spila nad Procjepom cave, a small amount of rodents' remains were recorded (MAUCH LENARDIĆ et al., 2017). According to CONNOR et al. (2004), *Pinus* pollen was probably brought from the other areas. Although *Quercus ilex* forests were recorded in the previous palynological research conducted on cores taken from the Mljet lakes (JAHNS & VAN DEN BOGAARD, 1998; JAHNS 2002), and it is native to the island, a statistically non-relevant amount of its pollen was found in the cave sediment. This could be due to preservation or accumulation factors. *Quercus* pollen could be under-represented because of its susceptibility to corrosion and oxidation (HAVINGA, 1964). He noted that the percentage of *Quercus* in the original pollen flora is much higher than in pollen found in sediment. An alternative cause for the evergreen oak decline in the vegetation record could be due to anthropogenic influence during the Greco-Roman colonization of the eastern Adriatic shores (BASS 2008). On the other hand, Ericaceae pollen is abundantly represented. More plausible than the idea of differential preservation is that animals, like sheep and goats, the remains of which were found in these sediments (BASS, 2008; OROS SRŠEN et al., 2013), influenced the pollen distribution more than wind or water. They could have easily picked up pollen from foliage in the vicinity of the cave during grazing. Findings of the palynomorph *Pseudoschizaea*, probably related to the Zygnemataceae family, indicate the runoff due to periods of enhanced soil erosion (LEROY et al., 2007) confirmed by palynofacies. ESTIARTE et al. (2008) also point out that *Pseudoschizaea* is indicative of erosive processes, particularly when occurring with taxa such as Asteraceae, that are known as markers of edaphic processes. This is also the case in Spila and is confirmed by the palynofacies indicating the pronounced input of terrestrial organic material. VAN DE SCHOOTBRUGGE et al. (2024) concluded that *Chomotriletes* is the valid senior synonym of a variety of taxa, including *Pseudoschizaea* and *Concentricystes*. They considered it as a freshwater organism cyst, dominant in floodplain soils and ephemeral freshwater lakes. Since *Polypodium* is highly resistant to oxidation and corrosion (HAVINGA, 1964) it could be over-represented in samples from the soil. On the other hand, some forms that are not resistant to oxidation and corrosion are poorly preserved and indeterminable.

5. CONCLUSIONS

The obtained data showed the effectiveness and prospects of complex palaeontological research in the study of cave sediments. Results of palynological analysis enable a partial insight into the local plant cover, temporal changes in the vegetation during the accumulation of studied deposits and post-depositional processes that influence the palynomorph assemblage. According to the results of palynofacies analysis, the provenance of the deposited samples ranges from a fluvial environment (channel deposits), through palustrine to hydromorphic soils. The results of the spore-pollen analysis allowed reconstruction of the differences in the composition of the vegetation cover that existed during the accumulation of the studied sediments. In all three analysed samples, the proportion of AP is slightly higher than NAP. Moreover, in all samples, Oleaceae pollen forms the basis of forest vegetation. The fact that pine pollen is not overrepresented, and olive pollen is present in the same quantity, indicates that the former was presumably absent from local/extra-local vegetation, and the latter probably grew nearby. Although the interpretation of changes in plant cover, due to the lack of statistical significance, should be taken with caution, preserved pollen types confirm the dominance of the Mediterranean evergreen forest vegetation on the island of Mljet. Additionally, a high proportion of NAP pollen types indicate some level of forest degradation, ranging from Mediterranean open forest to degraded maquis. Sediment was most likely deposited during the subzone C2 (*Quercus ilex – Erica*) ranging from approximately 4370 years BP to 2670 years BP which was confirmed by radiometric dating. The biostratigraphic dating of sediments, as well as the detailed reconstructions of palaeoenvironments, is possible only with the use of multidisciplinary studies including a broader set of analyses (e. g. palaeomagnetism, cosmogenic $^{26}Al/^{10}Be$ burial dating of coarse sediment, environmental magnetic studies of speleothems) and interpretation. Therefore, more detailed research is planned and will continue at the Spilja nad Procjepom cave shortly, to offer a more comprehensive insight into the depositional palaeoenvironment.

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Supplement 1. Palynogacies

SAMPLE		SP 22 P1	SP 22 P2	SP 22 P3
WOODY PHYTOCLASTS	Brown-black biostructured wood	51	21	25
	Translucent, yellow-green plant tissue	7	6	1
	Degraded wood (AP)	110	44	113
	Degraded wood (GP)	196	173	125
	Corroded charcoal	9	87	125
	Lath-shaped charcoal	2	6	39
	Equant-shaped charcoal	5	14	12
	Charcoal	16	107	176
Preserved phytoclasts		58	27	26
Transformed phytoclasts		322	324	414
TOTAL PHYTOCLASTS		380	351	440
AOM		4	0	2
PALYNOMORPHS	Bisaccate pollen	1	3	1
	Angiosperm pollen	7	21	3
	Spores	6	10	3
	Freshwater algae	1	6	0
TOTAL		399	391	449
Lycopodium - batch 280821291		3	11	3
OM "concentration" (particles / g)		120791	53254	155923

Supplement 2. The content of palynomorphs

SAMPLE	SP 22 P1	SP 22 P2	**SP 22 P3**
spore	9 7.0%	18 11.8%	24 20.7%
Pinus subgenus *Pinus* (Diploxylon)	24 18.5%	15 9.8%	16 13.9%
Oleaceae	24 18.5%	34 22.2%	27 23.2%
Ericaceae	6 4.8%	17 11.2%	2 1.7%
Ostrya	1 0.8%	0 0.0%	0 0.0%
Quercus	1 0.8%	0 0.0%	0 0.0%
Acer	1 0.8%	0 0.0%	0 0.0%
Celastraceae	6 4.8%	17 11.2%	2 1.7%
Ephedra	0 0.0%	1 0.6%	0 0.0%
Cyperaceae	0 0.8%	0 0.0%	0 0.0%
Poaceae	11 8.5%	9 5.9%	8 6.9%
Chenopodiaceae	2 1.6%	0 0.0%	0 0.0%
Asteraceae	15 11.7%	17 11.9%	6 5.2%
Artemisia	2 1.5%	0 0.0%	0 0.0%
Cichoriaceae	17 13.2%	24 15.7%	14 12.2%
Caryophyllaceae	4 3.2%	3 1.9%	1 0.8%
Solanaceae	1 0.8%	0 0.0%	0 0.0%
Lamiaceae	1 0.8%	0 0.0%	1 0.8%
Valeriana	2 1.5%	3 1.9%	3 2.6%
Typha latifolia	2 1.5%	4 2.6%	2 1.7%
Liliaceae	0 0.0%	0 0.0%	2 1.7%
Alismataceae	0 0.0%	0 0.0%	1 0.8%
undiff.	6 4.5%	7 4.6%	6 5.2%
Pseudoschizaea	1	1	0
Redeposit pollen	5	20	2
Modern Polypodiaceae	10	22	35
ex. *Lycopodium*	50	96	120
mass (g)	30.00	18.37	26.30
Ls (18584)	2	2	2
Pollen sum	129	153	116
Concentration	2367	2388	1012
Total sum of pollen and spores	129	153	116
Sum of arboreal pollen	57 44.2%	67 43.8%	45 38.8%
Sum of non-arboreal pollen	57 44.2%	61 39.8%	41 35.3%
Sum of spores	9 7.1%	18 0.0%	24 0.8%