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Project Report

From the Ground to the Public: Old and New Fossil Discoveries from Kefalonia–Ithaca UNESCO Global Geopark and Their Value in Research, Education, and Local Palaeontological Heritage

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Abstract: Fossils play a crucial role in geoparks contributing to their scientific, educational and recreational aspects. The purpose of the project "Study and promotion of the palaeontological heritage of Kefalonia–Ithaca UNESCO Global Geopark" is the overall consideration of the palaeontological record of the geopark and its utilization with a holistic approach. Excavations took place in 11 new excavation sites and a total of more than 1000 specimens were recovered belonging to 13 major groups (ammonites, barnacles, belemnitida, bivalves, brachiopods, corals, fish, foraminifera, gastropods, plant leaves, rudists, scaphopods, and sea urchins). After being conserved and identified by the scientific staff, the specimens, along with replicas, were exhibited in two newly developed exhibitions at the Information Centres. The exhibitions were inspired by science labs as spaces of exploration, research, discovery and experience. Moreover, an educational package was prepared consisting of different activities for all ages. It presents how life, landscapes, and climate have changed over time and how living things responded to those changes.

Keywords: Kefalonia; Ithaca; macrofauna; geoparks; fossils

1. Introduction

UNESCO Global Geoparks (UGGp) are single, unified geographical areas where sites and landscapes of international geological significance are managed with a holistic concept of protection, education and sustainable development [1]. Fossils play a crucial role in geoparks for several reasons, contributing to the scientific, educational and recreational aspects of these protected areas [2]. They provide invaluable insights into Earth's history, including the evolution of life forms and changes in environmental conditions over geological time. They serve as a record of past ecosystems, helping scientists understand ancient biodiversity and the interactions between different species. Geoparks can serve as living laboratories for scientific research. Fossil-rich areas within geoparks may be important for ongoing palaeontological studies, leading to new discoveries and a deeper understanding of Earth's history [3]. Additionally, fossils offer educational opportunities for visitors, students, and researchers. They provide tangible evidence of Earth's history and the processes

that have shaped the planet. Geoparks often use fossils as educational tools to teach about palaeontology, geology, and the importance of preserving natural heritage. They offer exceptional opportunities to support schools as outdoor classrooms and serve as incubators for sustainable development, sustainable lifestyles, and the appreciation of natural and cultural diversity. Education focused on sustainability stands as one of the core pillars within any geopark, alongside geoconservation and geotourism [4,5]. Moreover, they are a major attraction for tourists visiting geoparks. Visitors are often fascinated by the opportunity to see and learn about ancient life forms and geological processes. Interpretative programs and guided tours focused on fossils enhance the recreational experience for visitors, making geoparks more appealing as destinations [6–9].

On the other hand, geoparks play a crucial role in the conservation of fossil sites. By protecting these sites, geoparks contribute to the preservation of Earth's natural heritage and help prevent the illegal trade and collection of fossils. Preserving fossils in their natural context allows the interpretation of the geological and palaeontological history of an area, contributing to a sense of place.

Amongst the European Geoparks Network, there are at least 80 geoparks that take advantage of their palaeontological wealth in different ways, such as the development of palaeontological parks, museums in closed and open spaces, tourist routes, educational programs, summer schools, etc. [2]. It is a particularly large community for the exchange of opinions and good practices with the aim of the development of each geopark.

In summary, fossils are integral to the overall mission of geoparks, contributing to scientific research, education, cultural heritage, tourism, and conservation efforts [10]. They offer a unique window into the Earth's history and help connect people to the natural world. Thus, managing the palaeontological heritage of a geopark contributes to nature conservation as well [11].

The project "Study and promotion of the palaeontological heritage of Kefalonia–Ithaca UNESCO Global Geopark" was implemented during 2022–2023. The study area is the Kefalonia–Ithaca UGGp, Ionian Sea, Greece (Figure 1). Its purpose is the overall consideration of the palaeontological record of the geopark and the utilization of part of it in the appropriate way for promotion.

The geopark itself is rich in different fossil taxa of multiple geological periods. Further research was needed in order to answer a crucial scientific question. To what extent do fossils in the geopark serve as indicators of changes in biodiversity over geological time?

Additionally, an interesting aspect that had to be taken into account is the raised interest of the local people in the fossils of their area in combination with the high interest of the tourists. Thus, a holistic approach to the fossils of the geopark has been attempted and is presented herein. The project was implemented on behalf of the geopark by the Laboratory of Palaeontology and Stratigraphy (Geology Department, University of Patras, Patras, Greece).

1.1. Kefalonia–Ithaca UNESCO Global Geopark

The Kefalonia–Ithaca UGGp consists of an island complex belonging to the Heptanese (Ionian Sea, Greece). It has been a member of the GGN since 2021. Until now, 53 geosites and 11 georoutes within its area have been evaluated and established [12]. Its surface area reaches 3006 km^2 and includes 913.075 km^2 of land and 2092.9 km^2 of marine area. Its 37,736 inhabitants (2021 census, Hellenic Statistical Authority) live mainly in the coastal settlements of the island. Ithaca follows in size, with a 117 km^2 surface area. In winter, 3333 residents (2021 census, Hellenic Statistical Authority) live on the island, but in the summer the population more than doubles. The local residents in the geopark's area are mostly occupied with agriculture, fishery, and tourism. Tourism in particular plays an important role in the economic development of the area. The cultural heritage of the Kefalonia–Ithaca UGGp is very rich and diverse, with several archaeological monuments and intangible heritage. Ithaca is, after all, the homeland of Odysseus, its ingenious mythical king, and his

stories and doings are well known all over the world through Homer's poems The Odyssey and The Iliad.

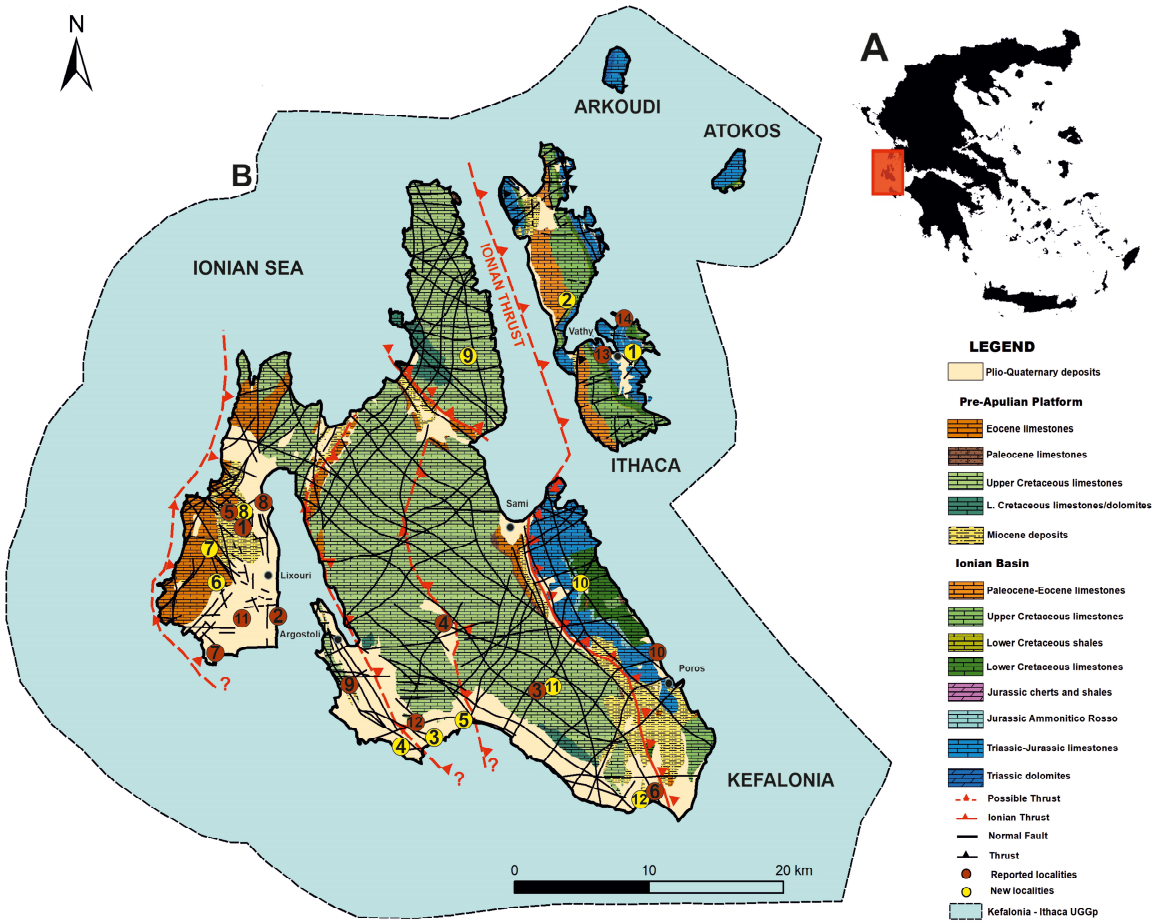

Figure 1. (**A**) Map of Greece. The red box indicates the study area. (**B**) Geological map of Kefalonia–Ithaca UNESCO Global Geopark (UGGp). Yellow points from 1 to 12 show the excavation sites: 1. Aqueduct in Vathy, 2. Monastery of Katharon, 3. Klimatsias beach, 4. Paliolinos beach, 5. Agios Thomas beach, 6. Chavdata, 7. Kaminarata, 8. Skineas Quarry, 9. Karya, 10. Atros, 11. Mt. Aenos, and 12. Katelios beach. Red points from 1 to 14 represent the reported fossiliferous localities, based on the literature: 1. Vlychata, 2. Lepeda, 3. Mt. Aenos, 4. Valsamata, 5. Skineas Quarry, 6. Katelios beach, 7. Kounopetra, 8. Livadi, 9. Minia, 10. Poros, 11. Mantzavinata, 12. Spartia, 13. Cave of Nymphs, and 14. Skinos beach.

1.2. Geology of the Geopark

The Mesozoic and early Cenozoic rocks found in Greece today were formed at the bottom of the Tethys Ocean. Subsequently, due to the submersion of the Tethys Ocean due to the collision of the Eurasian and African tectonic plates, the geotectonic zones of Greece developed forming the External and Internal Hellenides. Hence, the modern Mediterranean Sea constitutes a remnant of the Tethys Ocean.

The islands of Kefalonia and Ithaca consist of the westernmost part of the External Hellenides. They are located very close to the Greek Arc, which is the most tectonically active region in Europe [13]. Moreover, in the marine area northwest of Kefalonia, there is a very scientifically important and rare tectonic feature, the Kefalonia Transform Fault Zone, where the characteristics of the subducted plate are demonstrated at a low depth where scientists can study them in detail.

The geological structure of Kefalonia (Figure 1) consists of two different geotectonic zones (alpine formations) of the External Hellenides, with an overall NNW–SSE orientation [14,15]. The Pre-Apulian or Paxos zone in the west is relatively autochthonous and

covers most part of the island (483.4 km^2), while the Ionian zone which appears in the southeastern part of the island in a smaller area (68.72 km^2) is thrusted over the previous one [14,16].

The front of this thrust with an NNW–SSE orientation passes through the NW end of Ithaca and the SE part of Kefalonia. In addition, Plioquaternary formations (post-Alpine orogeny formation) can be identified, which settle unconformably on the older ones [17,18]. The island of Ithaca is built almost exclusively by the Ionian zone formations, and mainly by the Ionian carbonate series deposited between the Jurassic (201–145 My) and Eocene (56–33.9 My). The Ionian zone on Ithaca was completed with the Oligocene–Middle Miocene flysch formation (33.9–13.82 My).

The Pre-Apulian or Paxos zone is the most external zone of the External Hellenides, and is considered to constitute the easternmost part of the Apulian plate which extends to the southeastern edge of the Italian peninsula. It depicts the most recent and active orogenesis in Europe. The Pre-Apulian zone of Kefalonia island is characterized by a continuous sequence of neritic carbonate rocks (dolomites, limestones, and marly limestones), with its deposition starting at the Lower Cretaceous (145–100.5 My) and developing until the Upper Miocene (12–5.332 My) [19].

Specifically, the lithological formations that occur in the Pre-Apulian zone, starting from the oldest, consist of the Lower Cretaceous formations (145–100.5 My) which occupy a small but important area, as they occur only on the island of Kefalonia. It is distinctive that these rocks are the oldest ones of the Pre-Apulian zone found on the surface of the island and consist of dolomites and limestones.

This is followed by the Upper Cretaceous (100.5–66 My), made of strongly fractured and karstified white limestones, rich in fossils of sea organisms such as rudists, and which have the largest distribution on the island. Subsequently, the Paleocene (66.5–56 My) occurs, consisting of thin-layered pelagic limestones, followed by the Eocene (56–33.9 My), consisting of unbedded or thick-bedded neritic limestones containing large Foraminifera, and which in Kefalonia are located stratigraphically conformably on top of the formations of the Cretaceous (145–66 My).

Finally, the Pre-Apulian zone concludes with the Miocene formation (23.03–5.332 My), made of marly sediments, often sandstones, alternating with brecciated limestones, which replace the typical clastic sediments of the other geotectonic zones.

The oldest formations of the Ionian zone are Triassic "Breccia", which is a mixture of brecciated limestones, dolomites, and gypsum. Above them occurs a carbonate sequence of the Upper Triassic (230–201 My)–Middle Lias (190–183 My), which includes massive, light-coloured, thick-bedded limestones with fossil algae, and limestones with cherts, corresponding to the neritic "Pantocrator Formation".

This formation covers a major part of the area in relation to the other formations of the Ionian zone. The subsequent formation is the Ammonitico Rosso of Upper Lias–Lower Dogger age (approximately 183–170 My). These mainly consist of red, thin-bedded, partly platy limestones with thin marl intercalations, containing Toarcian Ammonites (183–174 My). Limestones with cherts and clay shales with "Posidonia" of Middle Dogger–Malm age (174–145 My) follow.

The Jurassic–Cretaceous formations (201.3–100.5 My) are represented by the well-bedded pelagic limestones of the Vigla Formation, which alternate with layers of cherts. Respectively, the Upper Cretaceous (100.5–66 My) is represented by massive rudist-bearing brecciated limestones. The Paleocene (66.5–56 My) consists of fine-grained limestones, followed by the Eocene (56–33.9 My) which is represented by unbedded Nummulite bearing marly limestones. The Ionian zone is completed with the occurrence of the Oligocene–Middle-Miocene flysch formation (33.9–13.82 My).

The geological structure of the Kefalonia and Ithaca islands is completed with the post-Alpine orogeny formation, which consists of Pliocene marls (5.333–2.58 My), as well as with Quaternary (2.588 My until now) marine sediments and terrestrial formations.

The Ionian zone on the island of Kefalonia occurs in a much smaller area, in contrast to Ithaca, where it covers the entire island. Specifically in Kefalonia, it appears only in the southeastern part of the island and is thrust, as we have mentioned above, over the Paxos zone. The lithological formations of the Ionian zone in the two islands mainly consist of limestones from the Jurassic (201.3–145 My) to the Eocene (56–33.9 My), as well as Late Triassic dolomites (237.2–201.3 My).

2. Materials and Methods

The project was structured in different stages. Detailed bibliographic research was conducted in order to prepare a database regarding the scientific research that has been conducted in the study area and the places where the fossil findings have been stored. The "repatriation" of these fossils was not possible. For this reason, casts were prepared by specialized scientific personnel. A detailed geologic overview took place throughout a time period of 9 months. New sites were mapped, and the fossils were extracted and prepared using both mechanical and chemical methods. Preparation involves the removal of surrounding material or any substance that obstructs the clear visibility of fossils. There are various methods of preparation, including mechanical techniques utilizing tools such as mallets and chisel air pens (or air scribes) that directly interact with the material to be removed, termed "mechanical preparation". Alternatively, preparation can also be achieved through chemical means, namely a dilute acetic acid.

Open excavation days were scheduled in order to familiarize the public with the scientific procedure. The fossils were stored at the Laboratory of Palaeontology and Stratigraphy (Geology Department, University of Patras). They were appropriately prepared, conserved, and determined. However, in some cases, the preservation condition of the fossils was not good enough. The characteristic morphological features that would allow the identification at the species level were not visible even after the application of different preparation methods and the careful study of the specimen. Thus, identification was only possible at the genus or even family level. This reduces the deduced ecological information and allows only general comparisons with similar excavation sites.

Systematic sampling revealed a significant number of specimens (more than 1000), belonging to 13 major taxonomic groups, of which 1 has been determined to the family level, 53 to the genus level, and 38 to the species level (Table 1). The most abundant fossils with numbers more than 50 were the gastropods *Turritela*, *Nassarius*, and *Vermetus*, the bivalves *Glycymeris* and *Pecten*, the scaphopod *Antalis*, and the large foraminifers *Heterostegina* and *Nummulites*. There were high numbers (between 10 and 50) of the sea urchin *Spatangus* cf. *purpureus*, the brachiopod *Terebratula*, the bivalves *Radiolites*, *Pecten* (*Aequipecten*) *gaudryi*, *Pecten jacobeus*, *Arca noae*, and *Ostrea edulis*, the gastropods *Nassarius semistriatus*, *Conus*, *Oligodia spirata*, *Fusinus*, *Cochlis*, *Cerithium* cf. *alucastrum*, and the scleractinian corals *Cariophylia* and *Flabellum*. Sparidae, Dikotyledon leaves, and ammonites also existed in high numbers. All other identified fossils existed in small numbers ranging from 1 to 10. They were prepared and curated at the Laboratory of Palaeontology and Stratigraphy (Geology Department, University of Patras) and entered its collections under the prefix PC.UP (Palaeontological Collection. University of Patras). The results of the project have been handled with a multi-level perspective that includes scientific, educational, and cultural approaches.

Table 1. Identified taxa per excavation site. The column 'Abundance Level' is used for semi-quantitative evaluation, with the following ranges: F for 1–10 individuals, M for 10–50 individuals, and A for more than 50 individuals.

No	Excavation Site	Age		Excavated Taxa	Abundance Level
12	Katelios beach Kefalonia	Pliocene	Bivalves	*Ostrea* sp.	F
				Spondylus sp.	F

Table 1. *Cont.*

No	Excavation Site	Age		Excavated Taxa	Abundance Level
5	Agios Thomas beach	Pliocene	Sea urchin	*Spatangus* cf. *purpureus*	M
				Echinolampas sp.	F
			Brachiopod	*Terebratula* sp.	M
			Bivalves	*Pecten* (*Aequipecten*) *gaudryi*	M
				Pecten jacobaeus	M
				Pecten (*Aequipecten*) sp.	F
				Ostrea sp.	F
				Flexopecten sp.	F
				Pecten aff. *jacobaeus*	F
				Ostrea edulis	M
			Barnacles	*Balanus* sp.	F
3	Klimatsias beach Kefalonia	Pliocene	Gastropods	*Aporrhais uttingeriana*	F
				Nassarius clathratus	F
				Hexaplex trunculus	F
				Nassarius semistriatus	M
				Turritella sp.	A
				Diodora italica	F
				Diodora sp.	F
				Xenophora crispa	F
				Xenophora sp.	F
				Galeodea echinophora	F
				Ranella olearium	F
				Ranella sp.	F
				Sveltia varicosa	F
				Conus sp.	M
				Oligodia spirata	M
				Bolma rugosa	F
				Cerithium varicosum	F
				Jujubinus sp.	F
				Bolinus brandaris	F
				Nassarius sp.	A
				Fusinus sp.	M
				Cochlis sp.	M
				Vermetus sp.	A
				Cerithium cf. *alucastrum*	M
			Bivalves	*Glycymeris nummaria*	F
				Aequipecten opercularis	F
				Aequipecten sp.	F
				Chama gryphoides	F
				Ostrea edulis	F
				Anomia ephippium	F
				Arca noae	M
				Glycymeris sp.	A
				Talochlamys multistriata	F
				Manupecten pesfelis	F

Table 1. *Cont.*

No	Excavation Site	Age		Excavated Taxa	Abundance Level
3	Klimatsias beach Kefalonia	Pliocene	Bivalves	*Nucula* sp.	F
				Jupiteria fissistriata	F
				Varicorbula gibba	F
				Arca sp.	F
				Cardita (*Actinobolus*) *monilifera*	F
				Pecten jacobaeus	F
				Venus sp.	F
				Pinna nobilis	F
				Ostrea sp.	F
				Pecten (*Aequipecten*) *gaudryi*	A
				Flexopecten sp.	F
				Glossus humanus	F
			Cnidaria	*Caryophyllia* sp.	M
				Flabellum sp.	M
			Scaphopod	*Antalis* sp.	A
			Sea urchin	*Spatangus* sp.	F
			Brachiopod	*Terebratula* sp.	M
			Barnacles	*Balanus* sp.	F
			Plantae	Dicotyledon leaves	F
			Vertebrates	Osteichthyes	F
6	Chavdata Kefalonia	Pliocene	Gastropods	*Cochlis* sp.	F
				Nassarius sp.	F
				Turritella sp.	M
				Oligodia sp.	M
				Aporrhais sp.	F
				Vexillum sp.	F
			Cnidaria	*Flabellum* sp.	F
			Scaphopod	*Antalis* sp.	A
7	Kaminarata Kefalonia	Upper Miocene	Brachiopod	*Terebratula* sp.	F
			Bivalves	*Pecten* (*Aequipecten*) sp.	M
				Ostrea sp.	F
				Flabellipecten sp.	F
			Foraminifera	Heterostegina	A
			Vertebrates	*Carcharhinus* sp.	F
8	Skineas quarry Kefalonia	Upper Miocene	Vertebrates	*Otodus megalodon*	F
				Hemipristis serra	F
				Carcharhinus sp.	F
				Isurus sp.	F
				Sparidae	M
			Sea urchins	*Clypeaster campanulatus*	F
			Bivalves	*Ammusium* sp.	F
				Pecten (*Aequipecten*) sp.	M
				Pecten sp.	F

Table 1. *Cont.*

No	Excavation Site	Age		Excavated Taxa	Abundance Level
4	Paliolinos beach Kefalonia	Upper Miocene	Plantae	Dicotyledon leaves	M
				Monocotyledon leaves	F
			Vertebrates	Osteichthyes	F
2	Monastery of Katharon Ithaca	Paleocene-Eocene	Foraminifera	*Nummulites* sp.	A
9	Karya Kefalonia	Cretaceous	Bivalves	*Hippurites* sp.	F
11	Aenos Kefalonia	Cretaceous	Bivalves	*Radiolites* sp.	M
				Hippurites sp.	F
10	Atros Kefalonia	A. Toarsian-E. Aalenian	Ammonites	*Calliphylloceras* sp.	F
				Phymatoceras sp.	F
				Mercaticeras sp.	F
				Lytoceras sp.	F
				Erycites sp.	F
				cf. *Brodieia* sp.	F
				Merlaites sp.	F
				Belemnitida	F
1	Aqueduct in Vathy Ithaca	A. Toarsian-E. Aalenian	Ammonite	*Ammonites*	M

Both the excavated fossils and the prepared casts are being exhibited in the Information Centres of the Geopark in Argostoli (Kefalonia) and Anogi (Ithaca). Simplified and comprehensive information regarding each fossil's morphological characteristics, depositional palaeoenvironment, and age was also prepared. This information accompanies the exhibition, along with information regarding the geopark area and the fossil sites. In order to introduce the two new exhibitions to the public, awareness events took place. Moreover, in-formal educational activities were prepared for different ages [20]. A worksheet, two educational games, two creative activities, and an outdoor educational game, focusing on the collected fossils from the excavations conducted on the islands of Kefalonia and Ithaca, were created. All educational activities were designed for individuals of all ages, focusing mainly on the younger generation, aiming to raise awareness about geological and palaeontological heritage and its connections to other aspects of physical, cultural, and intangible heritage. The designed educational activities align with SDG 4 [20], and more specifically with outcome target 4.7: education for sustainable development. Fossils are used to reconstruct past ecosystems and past climate changes. This way, people learn to recognize changes in biodiversity happening today due to climate change and are urged to take action against it.

The methodology that was followed proved successful. Nevertheless, there were some limitations in the implementation of this project. The limited overall duration of the project posed difficulties in the management of the high number of material extracted. Moreover, because of the volume and nature of the excavated material (many times it was hard limestone material), its transportation to the Laboratory of Palaeontology and Stratigraphy of the University of Patras was challenging. A large part of the project was dedicated to fieldwork. This posed the expected difficulties (weather conditions, bad or no road network to the excavation sites, high financial requirements, etc.). The poor preservation conditions of certain fossils rendered their identification difficult, as previously mentioned.

3. Results

3.1. Fossils of Kefalonia–Ithaca UGGp—Past Research

The bibliography regarding the macrofossil archive of Kefalonia–Ithaca UGGp is limited. However, in the past, some excavations have taken place (Figure 1), and the fossils have been stored at relevant institutions, mainly the National Kapodistrian University of Athens. More specifically, part of the right maxilla of a *Hippopotamus* sp. specimen was found near Mantzavinata village, SW Kefalonia, in Quaternary deposits. Due to the preservation condition of the specimen, no further identification was attempted [21]. Several years later, Theodorou et al. [22] raised a new elephant species, Elephas (Palaeoloxodon) cephallonicus, based on cranial remains found in Quaternary conglomerate deposits north of Poros, SE Kefalonia. However, according to [23,24], the referred material did not present any degree of endemicity and thus should be considered a member of the European late Pleistocene elephant *Palaeoloxodon antiquus*. The species is only known by a partial maxillar fragment that is heavily eroded. Nevertheless, it has important palaeontological value for the local society because it can show the notable differences in the islands' fauna from the past to the present. An elephant molar fragment was also found near Minies, SW Kefalonia, but it is unknown whether it can be attributed to *Palaeoxodon* [22]. Remains of *Cervus elaphus* have been found on Ithaca Island [23], specifically in the Cave of the Nymphs, with the skeletal elements being stored in the Archaeological Museum of Ithaca. Furthermore, in late Tortonian deposits in Skineas, Paliki Peninsula, West Kefalonia, a few rib fragments and part of a tusk from *Metaxytherium* cf. *medium* were found. These finds are very important since they are the only sirenian findings found anywhere in Greece besides Crete [25]. As far as invertebrates are considered, they are represented by several taxa in the literature and show far greater diversity than the vertebrate one mentioned above. North of Lixouri, West Kefalonia, extensive tertiary deposits are present, with more than half of the beds being full of bivalves and gastropods [26]. In Kefalonia in general and specifically in Kateleios (SE Kefalonia), there are several Neogene bivalves found [27], and most of them notably belong to the *Chlamys scabrella* acme zone [27]. Middle Jurassic brachiopods from different genera were found in Mount Avgo, East Kefalonia and in Cape Schinos, central Ithaca [28,29]. In Cape Kounopetra and in the Lixouri area (Lepeda), SW Kefalonia, a middle Pleistocene terrace is present with multiple beds very rich in bivalves and gastropods, with some of them bearing as well scaphopods, corals and echinoderms. Messinian echinoderms from Kefalonia Island have also been reported by [30]. At the NW part of Mount Aenos, South Kefalonia, Upper Cretaceous limestones are mainly characterized by the abundance of rudists and rudist fragments [31]. In Livadi, West Kefalonia, similar rudist fragments were detected inside the local carbonate deposits [31]. Pliocene sediments rich in Pectinidae, Ostreidae, and Echinidae have been found in the geosites of Ai Helis and Agios Thomas [12]. Also, a diverse assemblage of Gelasian fish otoliths has been found in Akrotiri (South Lixouri) [32]. No other published literature refers to the macrofauna of the Geopark area. Thus, the Geopark's fossil archive remains poor.

3.2. Fossils of Kefalonia–Ithaca UGGp—New Sites

Sampling took place in twelve (12) different sites (ES) of the geopark area (Figure 1). They cover a geologic time span covering the Jurassic Period (ES10: Atros-Kefalonia and ES1: Vathy Aqueduct), the Cretaceous Period (ES11: Aenos and ES9: Karya), the Paleogene Period (ES2: Moni Katharon), and the Neogene Period (Miocene: ES8: Skineas, ES7: Kaminarata, Pliocene: ES3: Klimatsias, ES5: Agios Thomas, ES 12: Katelios, ES6: Chavdata, and ES4: Paliolinos). Most of the newly excavated sites are located in the Paliki Peninsula, the southern part of Cephalonia Island (except the Karya site, which lies on the northern part of the island) and the central part of Ithaca Island. Most of the older excavated sites occupy the same part of the geopark, revealing that the southern part of Kefalonia and the central part of Ithaca are richer in fossiliferous sites.

Among the Jurassic sites, Atros of Kefalonia (ES10) and the Vathy Aqueduct of Ithaca (ES1) are the most noteworthy. In these sites, ammonites were recorded for the first time in

the geopark area. In these areas, the characteristic formation known as Ammonitico Rosso has been recorded [15]. It consists of thin bedded limestones alternating with red cherts and red clay-schists. This formation was formed at the bottom of the Tethys Ocean in a deep-sea environment approximately 183–170 million years ago (Toarcian E. Aalenian). At least seven different ammonite genera (*Calliphylloceras*, *Phymatoceras* (Figure 2c), *Mercaticeras*, *Lytoceras* (Figure 2d), *Erycites*, cf. *Brodieia*, and *Merlaites*) have been identified. Their preservation state has not allowed their identification to the species level, but the genera present are comparable to the ammonites of Lefkada Island [33]. Moreover, a specimen of Belemnitida has also been recovered. Ammonites are very common fossils worldwide [34], especially in the Ammonitico Rosso Facies found throughout central and southern Europe. Ammonites are amongst the most studied fossils, and Ammonitico Rosso itself is one of the most studied as well as most unusual facies developed in the Tethys Ocean, mainly during the Jurassic Period. Ammonites from Ammonitico Rosso have been excavated on several occasions in Italy (e.g., [35–40] and others), but they have been also found in other European regions such as Hungary [41], Portugal [42], Slovakia [43], Spain [44], Turkey [45], East Crimea [46], and Greece [33,47]. Especially in Spain, Ammonitico Rosso Facies with ammonites have been included in the List of Geological Sites of International Importance developed by the Spanish Geological Survey (IGME). Thus, they are conserved and strictly protected as part of the Sierras Subbeticas UGGp [48]. Accordingly, ammonites that were found in the frame of this study add information on the expansion of the Ammonitico Rosso Facies in the Tethys Ocean. The identification of the specimens to the genus level does not allow assemblage comparisons. Further excavations and detailed identification would allow the extraction of localized ecological information.

Aenos mountain is the highest mountain in Kefalonia (1628 m). The lower parts of its southwestern slopes are composed of Lower Cretaceous dolomites (145–100.5 Ma). The upper stratigraphic levels are occupied by Upper Cretaceous limestone (100.5–66 Ma). The carbonate sediments of this site have also been formed in the shallow platforms of Tethys. Rudists can be found in large numbers, both intact and in fragments. They are preserved in situ by the geopark as geosites (geosite 38) and have been studied as thin sections on several occasions in the past (e.g., [48–50]). Although their extraction from the hard sediment has proven difficult, specimens of *Radiolites* sp. (Figure 2g) and *Hippurites* sp. have been retrieved intact (ES11). In northern Kefalonia Island, near the village of Karya, Upper Cretaceous (100.5–66 Ma) thick bedded limestones with the same origin as Aenos dominate. Rudists of the genus *Hippurites* (Figure 2j) are the most common fossils found here (No 9). Rudists were widespread worldwide during the Mesozoic era, primarily inhabiting regions around the circum-equatorial belt. They are known to have lived in various locations including the United Kingdom, West China, the region surrounding the Mediterranean, Mexico, the Middle East, the southern United States of America, Saudi Arabia, and other areas [51]. They are also common in many sites in Greece. However, their excavation from sites in the area and exhibition in the information centres of the geopark are considered crucial. They are by far the most abundant fossils in the area and help local tourists and people understand the marine origin of the rocks that lie today high up on the mountain.

Moreover, in northern Kefalonia Island, remains and/or casts of gastropods have also been excavated (Figure 2j), though their preservation condition is poor. Thus, their presence is documented but no further determination has been possible.

The Monastery of Katharon is located in the central part of Ithaca at an altitude of 550 m. In this area, Paleocene–Eocene limestones (65.5–33.9 Ma) of the Ionian zone have been mapped [52]. It is the only studied site (ES2) of this age. Representatives of the large-sized foraminifera of the genus *Nummulites* have been found (Figure 3) and can be observed without any magnification equipment. *Nummulites* from Ithaca Island have also been mentioned in several other sites, e.g., [51–53], but this is the first time they have been collected in order to be exhibited to the public.

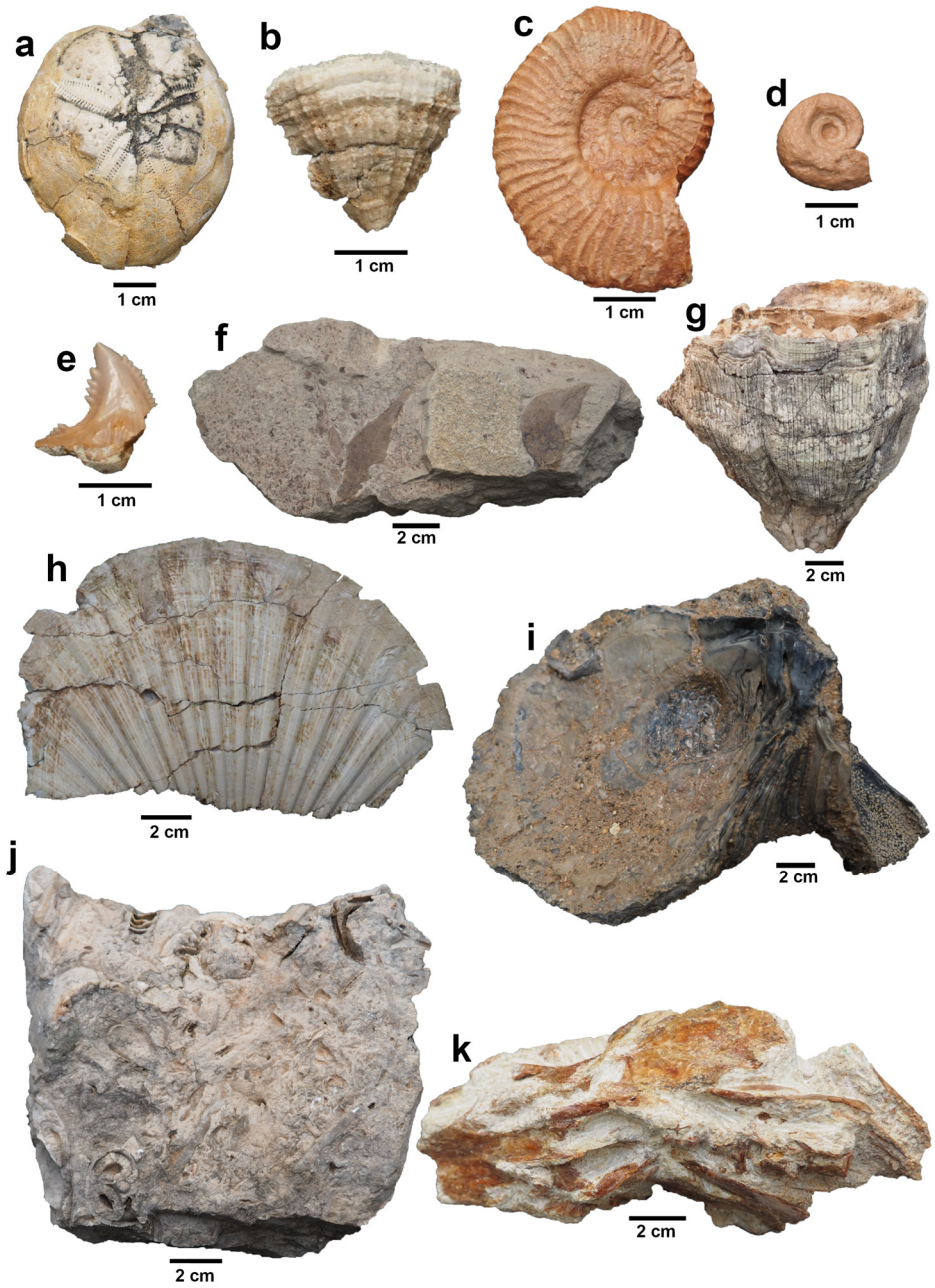

Figure 2. Representative fossils from each new fossiliferous locality. (**a**) *Spatangus* cf. *purpureus* (PC.UP.10.84) from Agios Thomas excavation site (ES5), (**b**) *Flabellum* sp. (PC.UP.03.144) from Chavdata (ES6), (**c**) *Phymatoceras* sp. (PC.UP.08.293) from Atros (ES10), (**d**) *Lytoceras* sp. (PC.UP.08.287) from the aqueduct in Vathy (ES1), (**e**) *Hemipristis serra* (PC.UP.14.232) from Skineas Quarry (ES8), (**f**) Dicotyledon leaves (PC.UP.15.112A) from Paliolinos beach (ES4), (**g**) *Radiolites* sp. (PC.UP.05.510) from Mt. Aenos (ES11), (**h**) *Flabellipecten* sp. (PC.UP.05.676) from Kaminarata (ES7), (**i**) *Ostrea lamellosa* (PC.UP.05.514) from Katelios beach (12), (**j**) Block of limestone with *Hippurites* sp. and gastropod moulds (PC.UP.05.720) from Karya (ES9), (**k**) Osteichthyes (PC.UP.14.247) from Klimatsias beach (ES3).

The Neogene sites bear fossils of the Miocene and Pliocene ages. The Skineas site (ES8) lies in Paliki Peninsula, in the southwestern part of Kefalonia Island. The area is covered by marly limestones which were deposited during the Tortonian (11.61 to 7.25 Ma) at the bottom of a shallow sea when tropical-subtropical conditions prevailed [54]. The collected fossils include bivalves belonging to the genera *Pecten*, *Aequipecten*, and *Amussium*,

as well as echinoderms (especially the species *Clypeaster campanulatus*). Of noteworthy significance is the existence of teeth in chondrichthyans of certain shark species such as *Otodus megalodon*, *Hemipristis serra* (Figure 2e), *Carchariniformes*, and *Isurus* sp., and *Perciforme* fishes of the family *Sparidae*, which are reported from Kefalonia herein for the first time. Shark teeth findings from this area have been also reported by the local people many times but their recovery was not possible. Also, in the Paliki Peninsula, near the Kaminarata village (ES7), amongst alternations of Upper Miocene (11.61–5.33 Ma) marls and marly limestones, a variety of marine fossil taxa has been found belonging to bivalves and brachiopods. Representatives of the *Pectinidae* family have been identified (*Aequipecten* sp. and *Flabellipecten* sp., Figure 2h). Additionally, the brachiopods found belong to the genus *Terebratula*. Of particular interest is the existence of a mandibular tooth belonging to a species of shark of the order *Charchariniformes*. In the same area, exceptionally preserved large tropical foraminifera of the genus *Heterostegina* were detected. They were collected and preserved in blocks.

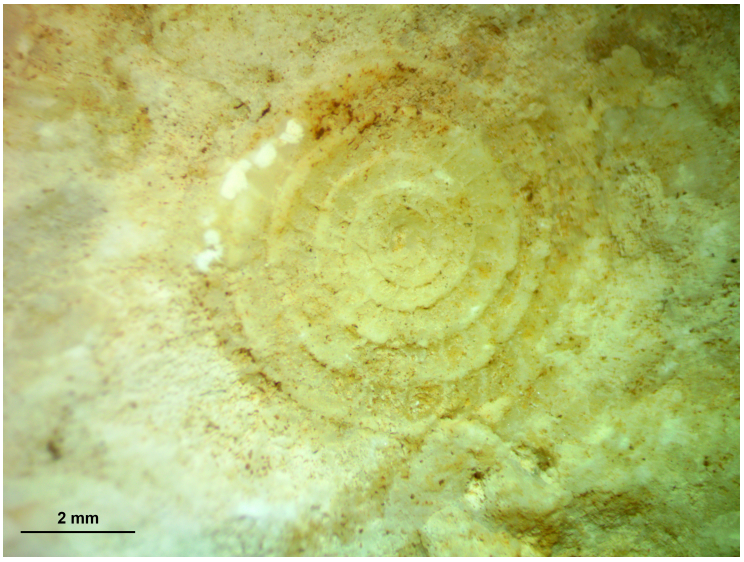

Figure 3. Stereophotography of equatorial section of *Nummulites* sp. From the Monastery of Katharon (PC.UP.02.53) (ES2).

Klimatsias beach is located in the southern part of Kefalonia Island (ES3). It has proven one of the richest malacofauna fossiliferous sites. The Pliocene sediments are composed of alternations of yellow sandstone and thick layers of blue clayey sediments. In the southeastern part of the beach, compact yellow sandstones with large bivalves and sea urchins prevail. Fish bones of Osteichthyes have been retrieved (Figure 2k). Also, heart-shaped-irregular sea urchins of the genus *Spatangus* have been identified along with several brachiopods belonging mostly to the genus *Terebratula*. In the northeast section, layers of blue clay have been recorded which are highly fossiliferous. Different bivalve species have been identified, most of them belonging to the following taxa: *Aequipecten opercularis*, *Aequipecten* sp., *Anomia ephippium*, *Arca noae*, *Arca* sp., *Cardita* (*Actinobolus*) *monilifera*, *Chama gryphoides*, *Chama gryphoides*, *Flabellum* sp., *Flexopecten* sp., *Glossus humanus*, *Glycymeris nummaria*, *Glycymeris* sp., *Jupiteria fissistriata*, *Manupecten pesfelis*, *Nucula* sp., *Ostrea edulis*, *Ostrea* sp., *Pecten* (*Aequipecten*) *gaudryi*, *Pecten jacobaeus*, *Pinna nobilis*, *Talochlamys multistriata*, *Varicorbula gibba*, and *Venus* sp. Different species of gastropods were also found with high frequency (*Aporrhais uttingeriana*, *Bolinus brandaris*, *Bolma rugose*, *Cerithium* cf. *alucastrum*, *Cerithium varicosum*, *Cochlis* sp., *Conus* sp., *Diodora italica*, *Diodora* sp., *Fusinus* sp., *Galeodea echinophora*, *Hexaplex trunculus*, *Jujubinus* sp., *Nassarius clathratus*, *Nassarius semistriatus*, *Nassarius* sp., *Oligodia spirata*, *Ranella olearium*, *Ranella* sp., *Sveltia varicosa*, *Turritella* sp., *Vermetus* sp., *Xenophora crispa*, and *Xenophora* sp.). A *Balanus* colony was also excavated along with several corals belonging to the genus *Caryophyllia*. Finally, a fossil leaf in bad

preservation condition was also discovered. The synthesis of the taphocoenosis along with the sediment type indicates that the southeastern part of the beach represents a very shallow coastal environment (possibly river delta outlets due to the prevalence of sandy layers). The northeastern part (where the blue clay prevails) indicates deposition in a shallow marine environment, though it may represent a rather deeper environment.

Agios Thomas beach is located in southern Kefalonia Island (ES5, Geosite 17), approximately 12 km from the town of Argostoli. The beach (Figure 4) is characterized by Pliocene formations (5.33 to 2.58 Ma). At the lower stratigraphic levels, there are alternating layers of sands, sandstones, and thin marly beds. Gradually, towards the upper stratigraphic levels, blue marls rich in malacofauna prevail. The uppermost part of the sequence is composed of alternating layers of fine-grained sands and sandy-marly beds. The lower part of the sequence (along the beach) is characterized by bivalves belonging mostly to Ostreidae and Pectinidae (*Flexopecten* sp., *Ostrea edulis*, *Ostrea* sp., *Pecten* (*Aequipecten*) *gaudryi*, *Pecten* (*Aequipecten*) sp., *Pecten aff. jacobaeus*, *Pecten jacobaeus*), sea urchins (*Echinolampas* sp., *Spatangus* cf. *purpureus*), *Balanus*, brachiopods (*Terebratula* sp.), and sea urchins (*Spatangus* cf. *purpureus*, Figure 2a). The findings resemble those of the Klimatsias site, even though diversity is lower.

Figure 4. Fossil sampling at Agios Thomas geosite (ES5).

Katelios beach (ES12) is also located in the southern part of Kefalonia Island. The sediments outcropping along the beachline have been dated as Pliocene (Upper Zanclean) [55]. They are composed of alternations of yellow sandstones and marly sediments. These sediments were created at the bottom of a warm-temperate shallow sea with periodical high-productivity conditions [55], similar to the formations at Agios Thomas beach; however, their diversity and their density are notably low. A small colony of *Ostrea lamellosa* (Figure 2i) was extracted along with a bivalve of the genus *Spondylus*.

Chavdata (ES6) is located in the central part of the Paliki Peninsula. In the wider area, sediments of Pliocene age can be found [56]. They consist of alterations of grey, blue, red, and green marls with intercalations of yellow sandy marls. The upper part of the sequence consists of yellow marl and limestone layers. The total thickness of the sequence is more than 800 m. These sediments have been deposited in shallow marine

environments (200–300 m). Low oxygen bottom conditions often prevailed. The wider area is rich in molluscs, and scaphopods, gastropods, bivalves and corals have been found. More specifically, the genera *Cochlis*, *Nassarius*, *Turritela*, *Oligodia*, *Aporrhais*, *Vexillum*, *Flabellum* (Figure 2b), and *Antalis* have been identified.

Paliolinos beach is located on the southern coastline of Kefalonia Island (ES4), around 10 km southeast of Argostoli. At the southwest part of the beach, rhythmic alterations of thin bedded blue and white mud and sand layers are located. The total thickness of the sequence is less than 2 m and the layers appear strongly inclined (65°). The micropalaeontological analysis revealed a Miocene age (Tortonian-M. Messinian) for these sediments. They have been deposited on the bottom of a shallow sea at a short distance from the shoreline and with important tidal influence. In this area, fossilized dicotyledon plant leaves (Figure 2f), both as fragments and intact, have been found. Fossil leaves are mentioned for the first time in the area of the geopark. Moreover, fish scales and bones have been noticed along with an *Ammusium* sp. shell.

The excavated fossils of Neogene and Quaternary age present a more local interest since they originate from East Mediterranean basins. However, their presence is considered regionally important, especially when comparing the marine and terrestrial forms. This comparison allows for a better realization of the past land and sea distribution, as well as the realization of the differences between the past and today.

4. Presenting the Fossil Material

These results will be used as a database for the supplementation of the fossil archive of the study area, not only with possible new species but also with new excavation sites. Moreover, the extracted fossil material has already been, and will be in the future, a base for multiple pre- and post-graduate studies. More specifically, two undergraduate students and seven post-graduate students (MSc and PhD candidates) have worked during the excavations, gaining experience with palaeontological field work, and at least three of them were also involved in the identification. The material that was retrieved (except the specimens used in the exhibition) will be the basis for future dissertation projects on different taxonomic groups. Thus, the present project serves as a basis for future scientific progress. Certain taxa have been reported for the first time from the area of the geopark (e.g., ammonites in Atros of Kefalonia (ES10) and the Vathy Aqueduct of Ithaca (ES1), and fossil leaves in Paliolinos beach (ES4)). As stated before, the report of the new fossiliferous Ammonitico Rosso sites adds to the present knowledge of the expansion of the Tethys Sea during the Mesozoic. Moreover, the existence of Miocene plant fossils, even if they are in the marine sediments of the Paliolinos area, gives new evidence for the proximity of terrestrial environments in the Miocene sea.

A significant number of fossil specimens have been granted to the Kefalonia–Ithaca UGGp in order to be exhibited at the geoparks information centres along with the replicas that have been constructed, one for each informational centre, including part of the right maxilla of a *Hippopotamus* sp., a partial maxilla fragment of *Paleoxodon antiquus*, rib fragments and a tusk from *Metaxytherium* cf. *medium*, a tooth of *Otodus megalodon*, and some sea urchins and molluscs that belong to the collections of the Museum of Paleontology and Geology of the National Kapodistrian University of Athens. Furthermore, simplified informational material (regarding the taxa morphology, their palaeoecology, and their age in text and figure format) accompanies each taxon. Moreover, comprehensive informational material (maps and text) regarding the fossil archive of the geopark has been prepared. The new exhibitions will allow the research results to reach a larger audience and introduce the fossils to the public, and especially to the local people. Through the deep knowledge of the fossils of their area, the local people will build strong connections and pride in their area. Consequently, they will develop respect and contribute substantially to nature conservation. The exhibitions also contribute to the building of a more sustainable tourism model which combines pleasure with knowledge. This model is in accordance with the Kefalonia Ithaca UGGp Management Plan.

The main idea of the exhibition is for visitors to experience this exhibition as a fossil preparation lab. In this way, the exhibition escapes from the sterile presentation of objects and focuses on the interactive, educational and entertaining presentation of its content, which is the fossils. It is an exhibition space of exploration, research, discovery, and experience. A space designed from a modern architectural point of view, with elegance and modesty that wins you over with its simplicity. The simulation of the exhibition as a fossil laboratory encourages visitors to be curious (generating successive questions), leading them to an interactive game of discovery and exploration, combining knowledge with an entertaining experience.

The main "tool" used by the exhibition to achieve this goal is the archetype of the laboratory bench, adapted to the needs of the exhibition and its important content. Thematic information benches (Figure 5) were built inspired by the respective scientific laboratory benches, adapted on industrial-style wheels. Each thematic bench has fossils in and on it. On the upper part of the bench, fossils are placed in direct visual display, either in glass showcases, the "transparent prisms", with hidden lighting (backlight) on their placement surface, or without showcases, enabling tactile interaction with visitors. Inside the bench, in six drawers of different capacities, with internal hidden lighting, additional fossils of different size scales, protected by glass are placed, allowing interactive observation.

Figure 5. (**A**) Thematic information bench model of the exhibitions inspired by the archetype of the laboratory bench. (**B**) Part of the exhibition in the Geoparks' information centre in Argostoli, Kefalonia Island.

The results of the project have been used as an inspiration for the production of educational material for students. This educational material presents to children how life, landscapes, and climate have changed over time and how living things responded to those changes. This is particularly important nowadays since climate change is changing our world more quickly than ever. Another important aspect of this educational material is that it can help students realize the importance of science.

The educational material consists of a worksheet, educational games for children of different ages that can be played both indoors and outdoors, and other activities all included in a dedicated museum box also containing actual fossils and replicas. Their tour guides through the procedure are the newly developed mascots of the exhibition and the geopark, Odysseus and Penelope (Figure 6). Their design is inspired by the most popular fossil of the geopark, the rudists of the Mt Aenos geosite.

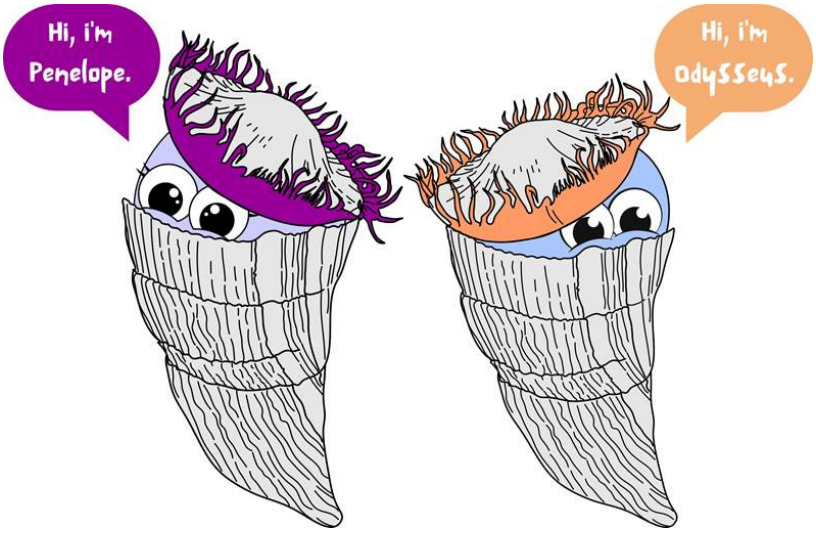

Figure 6. The rudists Odysseus and Penelope, the mascots of the educational material of the project that guide the young students through the educational process.

More specifically, the worksheet serves as the first introduction of young students to the world of fossils. In an interactive and easily understandable manner, students receive all the information necessary for engaging with the educational games. The first educational game (Figure 7), entitled "Which Fossil Am I?", was designed for elementary school students and involves the identification of a fossil they wear as a crown within a specific timeframe. This is accomplished by asking questions to other members of the group. It focuses on activities that exercise visual and auditory memory, as well as fostering teamwork and collaboration.

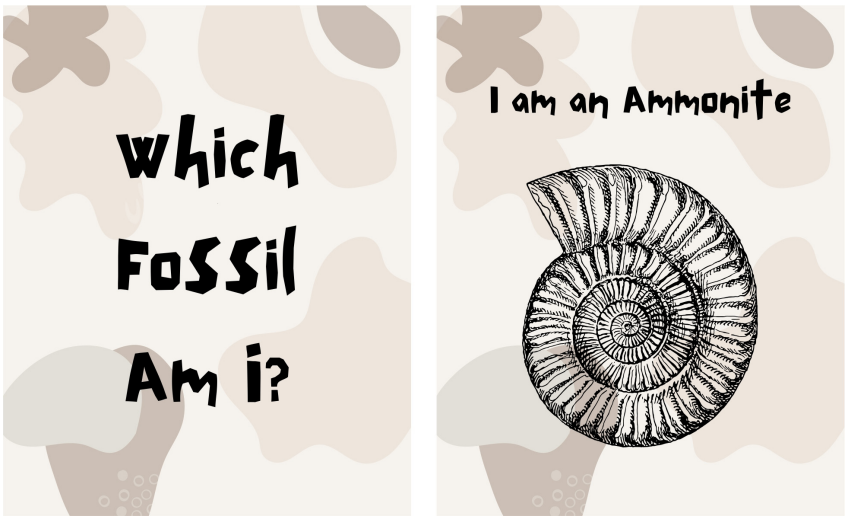

Figure 7. Cards designed specifically for the game "Which Fossil Am I?" included in the prepared educational material dedicated to the geopark fossils.

The second educational game, named "Complete the Puzzle First", is a floor-based game designed for elementary and high school students. Players compete to complete a puzzle by answering questions related to the fossil chosen by their team. Each correct answer adds a piece to the puzzle, and the goal is to complete the puzzle faster than the other players. It is a game that combines fun and learning for the basic identification of fossils.

The outdoor educational game entitled "Find the Fossils in Nature" is also designed for elementary and high school students. Students have the opportunity to engage with

the natural wealth of the geopark while visiting the Agios Thomas Geosite, one of the fifty-three (53) geosites in the geopark. In this activity, they take on the role of young palaeontologists and, with the help of cards featuring photographs of fossils excavated from the area, attempt to locate the corresponding fossils in their natural environment. The educational goal of the activity mentioned above is for participants to grasp the concept of climate change by contrasting the natural environment inhabited by the fossils during their time with the present surroundings in which we discover them. Moreover, it provides a constructive method for participants to learn about safeguarding geosites from private fossil collectors, emphasizing that the activity strictly entails observing fossils in their natural habitat and not engaging in collection.

Finally, through the activities "Learn the Tools of a Palaeontologist" and "Create Your Own Fossil", the goal is to promote the acquisition of knowledge and generate interest among students in the field of earth sciences, specifically in the science of palaeontology.

More specifically, in the activity "Learn the Tools of a Palaeontologist", using two-dimensional wooden artefacts (a geologist's hammer, brush, compass, magnifying glass, a bag for storing fossils, measuring tape, and a camera), students learn about the essential tools that a palaeontologist must have during an excavation.

In the activity "Create Your Own Fossil", students use clay and silicone moulds to make imprints of fossils. This is a simple yet highly enjoyable activity that provides students with the opportunity to express their creativity. The activities take place either at the informational centre of the geopark or involve visits to schools, conducted by the trained personnel of the geopark.

All activities (except the "Find the Fossils in Nature" activity) were presented to the public for the first time on the exhibition's opening day, where participants included children and adults of all ages. So far, twelve (12) school classes, with an average of twenty (20) students each (two hundred and forty (240) participants in total), have carried out the educational activities, conducted through school visits. All activities were successful, as dividing the students into smaller groups allowed all activities to take place simultaneously. The students expressed excitement about the new information regarding the fossils in their area, acquired through games. Specifically, they were thrilled to learn that many years ago, when these fossils existed, their island was submerged underwater and did not have its current form.

Last but not least, training sessions were conducted for the educational material, targeting school teachers in the broader area. The aim was to promote sustainable and effective dissemination of information regarding fossils. These training sessions sought to enhance the teachers' understanding of the value of these paleontological findings and to encourage a more sustainable approach to educating their students.

5. Conclusions and Future Perspectives

The project resulted in the overall consideration of the fossil archive of Kefalonia–Ithaca UGGp. New fossiliferous sites have been reported for the first time, and these sites serve as potential new geosites for the geopark. Two new fossil exhibitions were created and offered freely to the public, while educational events for the local people were organized and new educational material was made available for students of all ages. Thus, the project fulfilled its purposes and can be used by the management body of the geopark as a pilot project for future works on the fossiliferous archive of the geopark and its cultural and educational value. More excavations are needed in order to fill in the archive. The two new exhibitions are going to be enriched with new informational material presented digitally or/and using augmented reality techniques. Fossils provide an entirely irreplaceable record of life on Earth, yet ensuring their sustainable use has often been overlooked [57]. This work provides a case study where fossil sites are documented in a social framework typically used in sustainable development theory (SD pillar). Fossils are a nonrenewable natural resource and are natural capital but can be converted to social capital in the form of scientific knowledge and recreational value. The educational activities

created in the frame of this project fall into SDG4: education for sustainable development. Moreover, the created exhibitions serve as good educational facilities. They enhance the pride of the residents in their area, increase social cohesion, and decrease emigration. The sustainable nature of this project is also based on the excellent cooperation between the geopark and the university which ensures that the fossils of the area are extracted not for private profit but for the good of society and the next generations. This cooperation also ensures that all knowledge is available to science and is not being used for personal reasons. There is an urgent need for a coordinated national or even global policy for the sustainable development of fossil sites.

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