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Abstract. On November 2015 Lesbos Island has faced an ultimate recognition as one of UNESCO's Global Geoparks, an honor of its international significance based on its geological treasure as revealed by the existence of the famous early Miocene Petrified Forest and the variety of its geosites. The aim of this study is to draw a holistic approach for the palaeobotany of Lesbos Island through three main subjects: a) The first one is dealing with the past, the recognition of the palaeobotanical importance of Lesbos since the ancient times and the revision of the palaeoxylotomical and foliage material, b) the second theme gives a very brief summary of the recent results from the research by the first author and c) the third one uses the revealing of the historical part of Lesbos palaeofloristic treasure and also the recent botanical legislation and studies highlighting the complexity of Lesbos palaeobotany, which underline the remaining inconsistencies and propose solutions in order to give the perspectives of the future.

1. Introduction

Lesbos Island is a unique monument with an exceptional palaeobotanical heritage, focused on the occurrence of the Petrified Forest at the Western part of the Island which has been notified since the 3rd century B.C. and even before. This fact should be highly evaluated taking into account that these first recognitions constitute the origins of the science of palaeontology which gained global recognition during the 19th century. Although the plant fossils of the Island have been the objects of curiosity and series of studies through time, their diversity and abundance make them still an important field of scientific research.

2. Materials and methods through time

Examining the first traces of the palaeontology and palaeobotany in Greece we evaluated several references from the ancient philosophers about the existence of the fossiliferous localities and fossil plants. The original descriptions of the past provided unique information about the studied material and they were also used as sources for highlighting important inconsistencies. The same procedure has been followed also for the references of the 19th and 20th century and led to a collection of the most important presented below. Concerning the recently found and described fossil wood samples, their anatomical description is in accordance with the IAWA Hardwood List [1], Wheeler [2] and Crivellaro & Schweingruber [3] for angiosperms and the IAWA Softwood List [4] for conifers. The photos were taken by an Olympus BX51 microscope, Olympus DP73 camera and QuickPHOTO MICRO 3.0 image analysis software (Charles University of Prague, Czech Republic), Scanning Electron Microscope Jeol 6360 (Laboratory of Electron Microscopy, Agricultural University of Athens). The following abbreviations were used throughout the manuscript: NHMW: Natural History Museum of Vienna and NHMLPF: Natural History Museum of the Lesvos Petrified Forest.

2.1 Historical Palaeobotanical Research in Greece

Following the example of Solounias & Mayor [5] we found out that there was a strong connection between the myths and the discovery of plant fossils and the process of fossilization in Greece and the Mediterranean. According to Guthrie [6] and Mayor [7], the Greek natural philosopher Xenophanes (570-480 B.C.) was the first who observed fossils (laurel leaf) and included them in his work, of which only fragments are unfortunately saved in Hippolytus [6, p. 387]. After him, Herodotus, Xanthus of Lydia (5th century B.C.) and Eratosthenes of Cyrene, the father of Geography (276-194 B.C.) have followed these ‘unusually scientific’ observations. Empedocles, also (400 B.C.) connected the bones of Sicilian dwarf elephants with the skeleton of Homer's Polyphemus and he also expressed the opinion that the plants appeared before animals. Pliny (23-79 A.D.) recognized the relationship between crystal precipitation and petrifaction of bones. In “Parts of Animals”, Aristotle (384-322 B.C.) alluded to petrifaction folklore [7, p. 208].

2.2 History of the recognition and identification of the plant fossils in Lesbos

The first palaeobotanical research and study of the fossil flora of Lesbos and of Greece in general took place at the 3rd century B.C. by Theophrastus (372-287 B.C.) from Eressos, Lesbos Island, Greece.

Among the works ascribed to Theophrastus by Diogenes Laertius is a treatise “On Petrifactions” in two books. This lost work probably contained a systematic treatment of the fossil trees of Lesbos. What is also interesting in the references on the lost book is the recognition of different types of fossilization with the usage of different words, for describing petrification, carbonization, lignites of several kinds, petrified Indian reed, etc.

Inside his book “On Stones” there are indications about fossil trees and also some references for the book “On Petrifactions”. More specifically taking into account the work by Caley & Richards, [8, p. 45, 66-67], supplying critical notes on the original text of Theophrastus book “On Stones”, there is a reference of the verb ‘petrify’ [«απολιθώνω»] at the first chapter, at the 4th paragraph.

In the 12th paragraph of the 2nd chapter [8, p. 47], there is a reference of the ‘carbonization’ and of ‘lignites’. According to the historians the text refers to lignite or non-asphaltic pyrobitumen from Bina or solid bitumen from Thrace.

Also, in the same chapter (2nd) of Theophrastus book “On Stones” in the 16th and 17th paragraph [8 p. 48, 85-90] there is a reference for the co-existence of carbonised plants and amber. The comments from the specialists are focused on the use of lignite and the fact that apart from Antigonus of Carystus, Theophrastus appears to be the only ancient writer who touches on the subject. Scapte Hyle of the 17th paragraph was a mining district in Thrace opposite Thasos Island in the Northern Aegean. The reference on “rotten wood” most probably refers to brown fibrous lignite. Theophrastus uses also, as well as Aristotle – and the Peripatetic philosophers – the word “anthrax” in the sense of a transparent incombustible precious stone of a deep red color.

The most important and clear reference of Theophrastus work on the fossil plants can be noticed in the 38th paragraph of the 6th chapter [8, p. 53, 140-142]. Theophrastus had described a petrified Indian reed in his History of Plants as a species of bamboo, which could be true, or inferred to another reed incrusted with calcareous sinter or a true plant fossil. The final sentence of this section may be an indication that his treatise “On Petrifactions” was written after the work “On Stones”.

Almost 2000 years after the very first recording of Lesbos plant fossils by Theophrastus, the scientific interest returns on Lesbos. In 1842 during the annual fossils' exhibition at the Landesmuseum Joanneum (today Universalmuseum Joanneum) in Graz, Austria, some samples of fossil plants from Lesbos, which have been collected by the Archduke Johann are also exposed. What should be underlined is the fact that the Professor of Botany and Director of the famous Botanical garden of this institution from 1835 until 1849 was Franz Unger.

The Austrian botanist Franz Unger was the expert who started to describe the fossil plants from Lesbos in several works [9], [10], [11]: *Thujoxylum peucinum*, *Taxoxylum priscum* (= *Taxoxylon priseum* Ung.), *Peuce lesbia* (= *Cedroxylon lesbium* Kr.), *Juglandinium mediterraneum* (= *Juglandoxylon mediterraneum* Ung.), *Mirbellites lesbius* (=*Juglandoxylon mediterraneum* Ung.), *Brongniartites graecus*.

Prokesch-Osten [12] knowing already the publication of F. Unger publishes his notes from the visit he had made in Lesbos in 1829 describing the images that he was seeing from the port of Sigri. Among his descriptions was the view of hundreds of petrified tree trunks, a trunk of 3 m (10 ⅓ feet) in diameter and 2.7 m (9 feet) in length with three branches, trunks of 0.6 m to 1 m (24 to 40 inches) thick and 5.5 m to 7 m (3 to 4 fathoms) long, a trunk of 0.5 m (1 ½ feet) in diameter and more than 4.5 m (15 feet) high, trees some very close and under the sea, trees belonging to pine trees (due to their growth rings and barks), and possibility of olive trees as well.

In 1898 Fliche [13], a professor at the Forestry School of Nancy was giving the determination of 31 samples of lignitic (samples No 1-4, 9-31) and permineralized (samples No 5-8) trees from the region of Ordymnos Mountain (western peninsula) with references to the fossil plants *Cedroxylon* (*Cedroxylon* type 1: samples No. 4, 31, *Cedroxylon* type 2: samples No 13-16, 23, *Cedroxylon* type 3: samples No 3, 18 24-30, *Cedroxylon* type 4: sample No 8), *Pityoxylon* (sample No 5), *Palmoxylon* (sample No 22) and *Ebenoxylon* (samples No 1, 2, 9-12, 17, 19-21 related to *Diospyros* according to the samples No 1, 2 which were the only ones from this genus microscopically analyzed) from the Island of Lesbos.

He also noticed first the existence of fossilized trees (*Cedroxylon* and *Pityoxylon*) not only at Ordymnos (and at its NE part along with Sigri) but also at the islet of Nissiopi. He also believed that the lignite of Ordymnos (probably Lapsarna area) had a Pontian age similar to the fauna fossiliferous areas of Kumi (Euboea) and Attica (Megara, Markopoulo) described by Fuchs. Lapsarna area has been studied the last years with combined results on palaeobotany and geochemistry-mineralogy [14] and on the palaeolake's inhabitants and age [15], [16], [17].

The significance of this unique monument was first underlined by Richard Kräusel, a famous Professor from Frankfurt [18] who was comparing its scientific value with the one of Gilboa (NewYork, USA), of Chemnitz (Germany) and of Yellowstone (Wyoming, USA) after his visit at the area of the Petrified Forest of Lesbos in 1956.

Sixteen years later, a great effort for the promotion of Lesbos palaeofloristic evidence started with the initiative of Greek scientists. The first results [19], [20] revised recently [21] were focused on the composition of the palaeoflora, the identification of leaf imprints [*Cinnamomum polymorphum* (= *Daphnogene polymorpha* (A. Braun) Ettingshausen), *Laurus* sp. (= Lauraceae vel Fagaceae gen. et spec. indet.), *Litsea primigenia* (= Lauraceae vel Fagaceae gen. et spec. indet.), *Lindera ovata* (= *Dicotylophyllum* sp. 2), *Oreodaphne heeri* (= *Laurophyllum* sp.), *Lauraceae* (= Lauraceae vel Fagaceae gen. et spec. indet.), *Quercus apocynophyllum* (= Lauraceae vel Fagaceae gen. et spec. indet.), *Carpinus pliofaurei* forma *helladae, Carpinus uniserrata, Alnus cycladum, Populus balsamoides, Populus* sp.*, Tilia* sp.*, Diospyros brachysepala* (= *Laurophyllum* sp. and Lauraceae vel Fagaceae aff. *Castanopsis bavarica* Knobloch et Kvaček), *Myrsinites sp.* (= *Dicotylophyllum* sp. 1 – aff. *Cedrela attica* (Unger) Palamarev), *Rhus* sp., Sapotaceae (= *Dicotylophyllum* sp. 3)], the determination of the palaeoclimatic conditions (subtropical climate relative to the continental subtropical zone of SE Asia and N America) and the forest's relative age (Upper Oligocene – Middle Miocene).

The protection of the important floristic fossiliferous sites of Greece was another issue which had to be developed in parallel with the scientific identification and promotion. Two Academics from the University of Athens, Velitzelos & Symeonidis [22] started the attempt of awareness rising of the scientists, politicians and inhabitants of the petrified forests' areas of Greece (Lesbos, Thrace and N. Euboea) with suggestions for the localities' preservation.

Since then there has been interest at the Western peninsula of Lesbos which was declared as a Protected Natural Monument in 1985 with a special Presidential Decree (No 443/1985) and mainly at the localities of the five petrified forest parks: Petrified Forest park or Bali Alonia; Nissiopi park; Sigri park; Plaka park; Skamiouda park.

Later on, a fossil trunk, approximately 600 years old, from the area of the petrified forest of Lesbos was studied and described as a new species: *Taxaceoxylon biseriatum*. More publications followed with the descriptions of *Pinoxylon paradoxum* and *Pinoxylon pseudoparadoxum*, *Taxodioxylon gypsaceum,* the first occurrence of *T. albertense, T. pseudoalbertense* in Greece and the Tertiary of Europe, the identification of Dicotyledonous wood (mainly Lauraceae and Fagaceae) and of new species: *Taxodioxylon megalonissum*, *Glyptostroboxylon microtracheidae*, *Tetraclinoxylon velitzelosi, Thujoxylon antissum, Chimairoidoxylon lesboense, Podocarpoxylon articulatum*, *P. graciliradiatum*, *Chimairoidoxylon conspicum*, *Ginkgoxylon lesboense*, *G. diversicellulatum*, *Lesbosoxylon* (*Pinoxylon) diversiradiatum*, *Lesbosoxylon* (*Pinoxylon) graciliradiatum*, *L. ventricosuradiatum*, along with the identification of leaves' imprints: *Pronephrium stiriacum, Tetraclinis* sp., *Pungiphyllum crutiatum* (= *Quercus cruciata*), *Phoenix* sp. *(= Phoenicites* sp.*), Platanus* sp., *Acer* sp., *Laurus primigenia* (= vel Fagaceae gen. et spec. indet.), *Daphnogene polymorpha, Quercus* sp., *Pinus* sp., *Sequoia abietina (= Sequoia abietina* vel *Taxodium* sp.), *Tetraclinis salicornoides, Rubus* sp., *Engelhardia orsbergensis, Rubus niacensis* (partly *Alnus cycladum*)*, Sabal major {*[23], [24], [25], [26], [27], [28], [29], [30], [31], [32], [33], [34], [35], [36], [37], revised in [21]}.

3. Results and Discussion

Lesbos palaeobotanical puzzle and the new discoveries

The legitimate questions on this miracle of nature do not stop with the finding of the fossiliferous sites and the species identification since another important issue is the fossilization procedure and the taphonomical process. According to Greenwood [38] the plant taphonomy incorporates the processes of the initial abscission of plant parts, their transport (by air and/or water) to a place of eventual deposition, entrapment and eventual burial, and subsequent lithification.

Studying Lesbos findings the last years we have come to the conclusion that the fossilization of this unique palaeoflora remnants is only partly described as a general process related to the volcanic activity [37], [17] and requires further research focused especially on a big variety of parameters (was there a direct influence of volcanism, a pyroclastic or epiclastic flow-lahar, are there any fluvial or lacustrine facies associated with volcanic activity, etc.) since there are more than one preservation types associated with the palaeoenvironment [39] as:

a) Permineralized and silicified (petrifaction) trunks – mainly gymnosperms on palaeosoil (Figure 1), the buried soil of any age, whose functioning was totally or partially inhibited by burial [40]. The preservation of fine cellular details in plants, implies that the wood was mineralized with organic microstructures relatively intact [41], b) Leaf impressions (mainly angiosperms) embedded in volcanic material (Figure 2), c) Molds and casts of pine cones and stems enclosed inside the volcanic material (Figure 3), d) Lignified trunks inside tephra horizon – underlying Polichnitos ignimbrite (possible connection with lahar) (Figure 4), e) Fossiliferous block assemblages or peat (Figure 5), f) Lignitic horizons hosting micromammals [17] and fish remnants (pharyngeal teeth and otoliths) [15], [16] and possibly plant macrofossils, seeds and fruits (Figure 6).

Multidisciplinary studies should be also applied for the Lapsarna formation case in Lesbos, where numerous findings of fossil freshwater gastropods along with micromammals and fish remains have been documented in genus level the last decade [17], following the example of Kritika formation, Rhodes Island, the age of the shallow water siliciclastic sediments corresponding to the first marine incursion after the formation of the Aegean chain proved to be wrong and finally placed at 2 Ma [42].

According to the already published data, the research during the last two centuries had revealed 25 species of conifers and 5 species of angiosperms concerning the wood occurrences while the foliage findings showed exactly the opposite with the majority of the leaves species belonging to angiosperms [39]. New results originated from the discovery of new plant fossiliferous assemblages at the Southern part of Lesbos Island (Polichnitos region), along with the stratigraphy of those localities and the identification of the new findings [39], [45], [51], [46].

Figures 1-6. Plant fossils preservation diversity on Lesbos Island: 1. Silicified trunk (12.5 m long, diameter: 80 to 95 cm) *Taxaceoxylon biseriatum* SÜSS & VELITZELOS [23]. 2. Leaf impressions embedded in volcanic material (Sigri, Lesbos Western Peninsula), housed in the NHMW. 3. Lauraceous stem (15x4x2 cm) enclosed inside volcanic material (DMDA1 sample, Polichnitos, Southern Lesbos Island). 4. Lignified trunk (45x40x26 cm) found inside tephra horizon (DMAL8 sample, Polichnitos region, Southern Lesbos Island). 5a. Fossiliferous block assemblage or peat with remnants of stems and leaves, intermixed. 5b. Sample of the assemblage mentioned above [39]. 6a. Outcrop of Lapsarna palaeolake. 6b. The lignitic horizon of the palaeolake hosting microfossils [15], [16[, [17].

The anatomical study of fossil trees revealed various coniferous samples along with numerous angiosperms among the findings. Their comparison with the previous data and with famous samples (e.g. *Laurinoxylon diluviale*), and material housed in European universities (e.g. Charles University in Prague, Czech Republic), museums (e.g., NHMW), and UNESCO's European and Global Geoparks (e.g. Ipolytarnóc, Hungary) allowed to apply the Whole Plant Concept [43], [44] and a new proposed methodology on Lauraceae [45] with interesting results for the identification, re-organization and classification of the Oligo-Miocene palaeoflora of Europe.

Among the lauraceous findings are stems of *Laurinoxylon* and *Cinnamomoxylon* species enclosed in volcanics with their internal structure perfectly preserved. Their bark and vascular cambium is clearly seen, along with distinct growth ring boundaries, diffuse wood porosity, vessels mostly in pairs with common tyloses, rays mostly 2-3 seriate, in some cases occurrence of banded parenchyma in marginal bands and of a pith of square/rectangular or polygonal shape. The main focus on the study of this family was on the exact occurrence of the idioblasts (oil &/or mucilage cells) [45]. This extended detailed anatomical study with special focus on the axial parenchyma, the idioblasts and the crystalliferous contents (silica dioxide crystals and druses) revealed also the first record of *Cryptocaryoxylon* (Figure 7), the ancestral representative of *Cryptocarya*, for the Neogene of Eurasia [46].

Facing superficially the already existing knowledge of Lesbos Island palaeoflora could lead to false conclusions, as if there is nothing left to be identified (although, i.e., the construction-upgrade of the roadway connecting Kalloni with Sigri and the last project of the NHMLPF for Nissiopi's park has revealed a great amount of petrified trunks unidentified yet) or as if all the scientific questions have been already answered. Some pieces of Lesbos palaeobotanical puzzle have been already understood correctly, but there are many still remaining. Some of them are reported below.

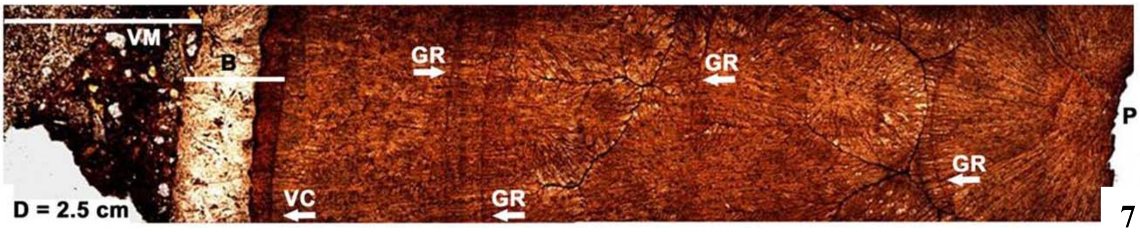

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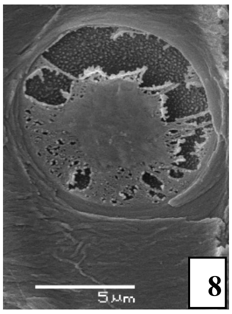
Figure 7. Transversal section of *Cryptocaryoxylon* stem enclosed inside volcanics (Polichnitos region Southern part of Lesbos Island). B= Bark, D= Diameter, GR= Growth ring boundaries distinct, P= Pith, VC= Vascular cambium, VM= Volcanic material.

Before 1912 the species were validly published without illustrations {e.g. [9], [10], [47], [13]}. According to Kvaček [48] since 1st Jan. 1912 the publication of a new species requires the diagnosis or description with an illustration or a figure and since 1st Jan. 2001 the illustrations must reproduce the type. The lack of the accompanied illustrations, the missing or even lost type material, the language used for the first descriptions (latin), the fact that there are no evidence about the stratigraphy and the exact locality (with the usage of new techniques, such as GPS) which could help in identifying the type specimens from which the holotypes, lectotypes and neotypes have come are only a few of the problems with the Lesbos material described already from the 19th century. The absence of illustrations and scientific descriptions remains a problem also even for some publications of the last decades, concerning the identification of leaves' imprints. Subsequently, the completion of the reconstruction of the composite original living plants from which the fossil findings derived, a process known as "whole plant concept" {[43], [49], [44], [50]} becomes a really hard procedure. The lectotype *Peuce lesbia* UNGER (= *Cedroxylon lesbium* KRAUS) of the 19th century was re-studied recently [51], compared with living *Cedrus* wood (Figure 8), and named as *Taxodioxylon lesbium* MANTZOUKA & SAKALA.

Concerning the typification in fossil taxa, the type of the selected fossil species must serve for the whole genus [48] and this is a crucial clue which must be taken into account for the establishment of new generic names with certainty (e.g. *Lesbosoxylon*), or further examination is needed to clarify whether the generics names given to Lesbos material should be included in already existing genera &/or even species or not.

Another point is the inconsistencies concerning several taxa, for example *Taxodioxylon gupsaceum*. Traditionally this fossil species has been compared with the modern *Sequoia*, but according to recent studies {[52], [44]} it could also be of closer similarity with the extinct genus *Quasisequoia,* so the new parameters should be investigated.

The fact that the palaeoflora of Lesbos, Lemnos and Grevena lacks *Fagus* and members of *Quercus* Group Ilex (*Quercus drymeja* and *Quercus mediterranea*), is something which may reflect a warmer environmental origin [21] could also be under question since there is a huge number of fossil leaves unidentified yet and also there are already evidence about the existence of Fagaceous (Figure 9) along with Lauraceous fossil wood {[34], [39], [45], [46]}.



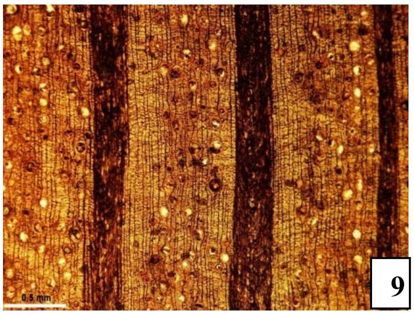


Figure 8. Scalloped torus in earlywood tracheid pit of *Cedrus libani* (SEM photo). **Figure 9**. Transverse section of a fagaceous stem with diffuse-porous wood, oval solitary vessels, banded parenchyma, and rays of two distinct sizes (DM16 sample, Polichnitos region, Southern Lesbos Island).

4. Conclusions

The Petrified Forest of Lesbos is a worldwide well known type locality which can be of a great importance for the stability of (palaeo-botanical) nomenclature only with the exclusion of the inconsistencies, the right re-examination and careful nomenclatural and taxonomic studies in accordance with the ICBN [53] and APG III [54] respectively.

The rectification of the taphonomy processes and conditions of each and every fossiliferous locality in Lesbos, in association with new results on the palaeofloristic treasure revealed from the volcanic layers of the island during the Neogene can bring together all the pieces/assemblages of Lesbos palaeobotanical and palaeogeographical puzzle, along with the evolutionary traits of the plants as revealed by their functional anatomical characteristics.

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