

## NEW RESULTS ON THE PETRIFIED FOREST OF LESVOS

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### ABSTRACT

Remains of fossil plants, which form the famous "Petrified forest of Lesvos", declared as Protected Natural Monument, have been found in many localities on the western part of Lesvos island. The fossilised forest of Lesvos was developed during Late Oligocene to Lower - Middle Miocene, due to the intense volcanic activity in the area. Neogene volcanic rocks dominate the central and western part of the island, comprise andesites, dacites and rhyolites, ignimbrite, pyroclastics, tuffs and volcanic ash. The products of the volcanic activity covered the vegetation of the area and the fossilisation process took place due to favourable conditions. Findings which have come to light following excavations conducted by the Museum of Natural History of the Petrified Forest of Lesvos have proven to be of considerable scientific value. The principle excavation area is located within the Petrified Forest Park at "Bali Alonia", site of the largest concentration of petrified trees. The fossilised plants in Lesvos are silicified remnants of a sub-tropical forest that existed on the north-west part of the island 20-15 million years ago.

**KEY WORDS:** Petrified Forest, Lesvos isl., Miocene, Volcanic rocks, Palaeobotany, Excavations, Greece.

### 1. INTRODUCTION

The island of Lesvos, is located to the NE of the Aegean sea and covers an area of 1630 square kilometres. The East coast of Lesvos Isl, is separated from the West coast of Asia Minor by the Mytilene strait.

On the western part of the island remains of fossil plants appear within the volcanic rocks. The fossilised tree trunks comprise the well known "Petrified forest of Lesvos".

The Greek State recognised the exceptional palaeontological and geological value of this unique natural monument. In order to protect the Petrified forest and ensure its proper management, five terrestrial and marine areas with fossil accumulations, as well as all the isolated fossils were declared as Protected Natural Monument with a special Presidential Decree (No 443 /1985).

The need for further research and protection of the fossils led to the establishment of the Natural History Museum of the Lesvos' Petrified Forest, in 1994. Its scope is to undertake scientific research on the Petrified forest as well as to preserve and to promote this natural monument.

In Summer 1997 for the first time the Museum in cooperation with the Section of Palaeontology and Stratigraphy of the University of Athens, carried out excavations in the area of the Petrified Forest with funding provided by the Greek Ministry of Culture. The research was carried out in collaboration with the Lesvos Forest Administration. The purpose of this endeavour is to uncover parts of the Petrified Forest buried under the volcanic rocks and the collection of data regarding the composition of the fossilised ecosystem. Finds are to be exhibited in their natural environment within the Petrified Forest Park as well as in the Museum now under construction.

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## 2. GEOLOGY OF LESVOS ISLAND

The geology of Lesvos Isl. has been described by Hecht (1971, 1974, 1975), Pe-Piper (1978), Katsikatos et al. (1982, 1986), Pe-Piper & Piper (1993). Lesvos island belongs to the Pelagonian geotectonic zone (Mountrakis 1983).

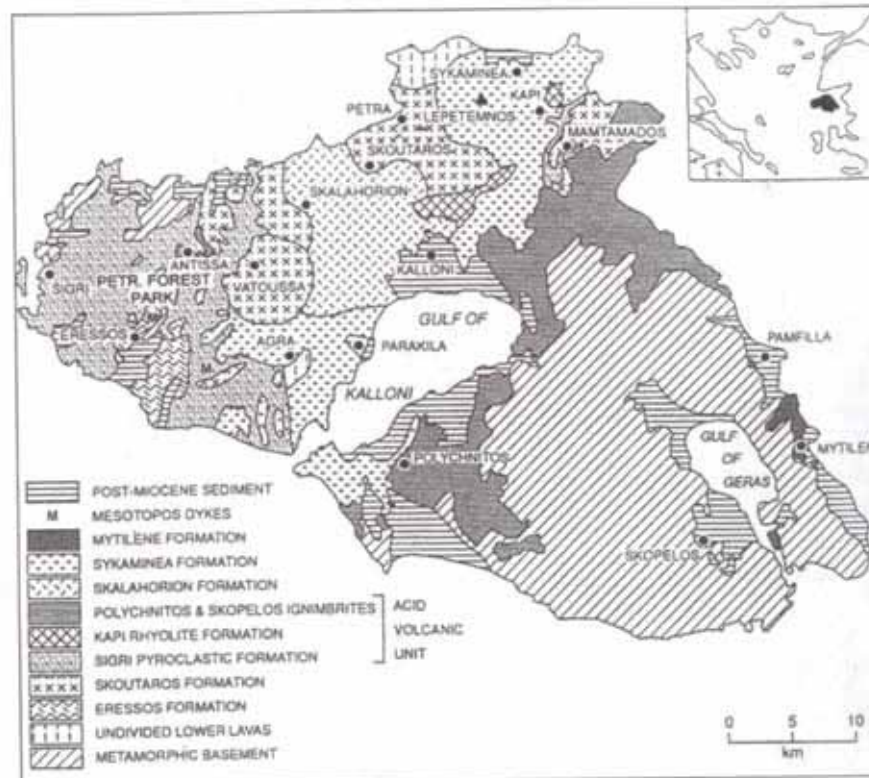


Fig. 1: Geological map of Lesvos island showing distribution of the volcanic units (After Pe-Piper and Piper 1992).

According to the published data and our survey, the geological structure of Lesvos island consists of the following rock-units:

- An autochthonous unit of Permo-Triassic age, including schists, quartzites, metasandstones, phyllites and intercalation of marbles and crystalline carbonates. These rocks are widely extended on the Southeast part of the island, while in the Northwest part they have a rather small extension.
- An ophiolitic nape, comprising basic and ultrabasic rocks and associated deep-sea fine-grained sediments, as well as metamorphic rocks, amphibolites and amphibole schists, metabasites and metasediments, parts of the sole, overthrust the metamorphic basement.

All these alpidic and pre-alpidic rocks were covered later by post-alpine volcanic rocks and Neogene marine and lacustrine deposits such as whitish marls, marly limestone, silts and sandstone, as well as Tertiary deposits.

The Neogene volcanic rocks, dominate the central and western part of the island. Lesvos is part of a belt of late Oligocene - middle Miocene calc-alkaline to shoshonitic volcanism of the northern and central Aegean Sea and western Anatolia. In the central part of the island there is a series of volcanic centres, situated along a SW-NE direction.

Several volcanic rock units have been distinguished in Lesvos (Pe-Piper & Piper 1993):

Eressos Formation is the oldest igneous formation, composed by porphyritic andesites interbedded with agglomerate and volcanoclastic rocks, dated at 21.5 Ma, by Pe-Piper & Piper (1993). These lavas are 3 to 4

m.y. older than the main volcanic sequence of Lesvos.

Skoutaros Formation is a normally magnetised sequence of andesite and basalt flow approximately synchronous with Sigrí pyroclastics and Polychnitos ignimbrite. In the upper part of the formation pyroxene andesite lavas interbedded with hornblende-biotite dacite lavas and felsic pyroclastic rocks of Sigrí pyroclastic Formation.

Sigrí pyroclastics, thickest in the west of the island, are connected with the development of the Petrified forest and are overlain by several sheets of the Polychnitos ignimbrite. The Kapi rhyolite domes are of approximately the same age, around 17.0 m.y.

Polychnitos ignimbrites occur in correlable units 5-30 m thick. Each unit has an upward decrease in size of lithic tephra, often poor welding at the base, commonly an abundance of glass lenticules or obsidian near the base, and good columnar jointing at the top of the unit. They are believed to be cooling units. The ignimbrites thin out against both metamorphic basement highs, and the main volcanic chain (where they interbed with volcanoclastic conglomerate).

Skalochorion Formation lay in-between the lower Skoutaros Formation and the upper Sykaminea lavas, composed by reversely magnetised intermediate lavas and contain feldspar megacrysts, commonly associated with mafic xenoliths.

Sykaminea Formation dominates in central Lesvos and comprise a reversely magnetised stratovolcanic sequence of andesites, dacites and rare rhyolitic pyroclastics, dated at 17.3 m.y. (Pe-Piper, 1980).

Mytilene Formation was defined by Pe-Piper (1978, 1980) as local basalt flows that Prager (1966) claimed to overlay Pontian marls. New radiometric data indicate that the Mytilene formation is part of the main sequence of the volcanic activity in Lesvos, dated at 16.8 m.y. (Pe-Piper & Piper 1993, Borsi et al., 1972).

Mesotopos dykes, dated by Pe-Piper (1978) at 16.2 m.y., are widespread in western Lesvos. Volcanic equivalents are rare or absent.

### 3. PALAEOBOTANICAL RESEARCH - PREVIOUS WORK

The scientific study of the fossil forest of Lesvos began in the 19th century. Unger, reports in 1844 fossil tree trunks from the petrified forest of Lesvos, without, however, being certain about their relative age. He believes that they belong perhaps to the Tertiary. These are the first scientific data about the anatomy of wood in the Mediterranean area. He identified the following species: *Peuce lesbia* UNG. (= *Cedroxylon lesbium* KR.), *Taxoxylon priscum* UNG., *Junglandinium mediterraneum* UNG., *Mirbelites lesbicus* UNG., *Brongiartites graecus* UNG. In 1898, Fliche in a book by L. de Launay dealt with the identification of fossil tree trunks from the petrified forest of Lesvos and reported the genera *Cedroxylon* and *Pityoxylon*. He also reported on the carbonised genera: *Cedroxylon*, *Palmoxyton* and *Ebenoxylon*. Berger (1953) in his palaeobotanical studies of Greece, made special reference to the fossil tree trunks from the area of the Aegean Sea. Krausel (1965) during a brief visit to the petrified forest of Lesvos, between Eressos and Sigrí, recognised its high scientific value. He suggested that many tree trunks could belong to the family *Taxodiaceae* (*Sequoia*) and that an isolated piece of wood possibly belonged to oak. Krausel, even though he did not make a detailed analysis of the flora, was convinced that the relative age of the petrified forest was older than Pliocene, possibly close to lower Palaeogene. In addition, he suggested that the correct relative age of the petrified forest could be determined by the precise taxonomic identification of the palaeoflora. Since 1979, the Division of Historical Geology and Palaeontology of the Department of Geology at the University of Athens, conducts palaeobotanical research in the petrified forest of Lesvos (Velitzelos & Symeonidis, 1978, Velitzelos et al. 1981a,b, Velitzelos, 1988, Velitzelos & Gregor, 1990, Suss & Velitzelos, 1994a,b).

### 4. THE PETRIFIED FOREST

The western part of Lesvos island, exposes large accumulations of fossilised tree trunks comprising the Petrified forest of Lesvos. Isolated plant-fossils have been found in the northern and southern part of the island, including the villages Molyvos, Polychnitos, Plomari and Akrafi. The formation of the petrified

forest is directly related to the intense volcanic activity in Lesvos island during late Oligocene - middle Miocene. The volcanic eruptions during this time, produced lavas, pyroclastic materials and volcanic ash, which covered the vegetation of the area. The rapid covering of tree trunks, branches, and leaves lead to isolation from atmospheric conditions. Along with the volcanic activity, hot solutions of silicon dioxide penetrated and impregnated the volcanic materials that covered the tree trunks. Thus the major fossilisation process started with a molecule by molecule exchange of the organic plant by inorganic materials. In the case of the Petrified forest of Lesvos, the fossilisation was perfect due to favourable fossilisation conditions. Therefore morphological characteristics of the tree trunks such as the annual rings, barkers, as well as the internal structure of the wood, are all preserved in excellent condition.

The study of the fossil tree trunks, leaves and seeds gives useful data about the Palaeoflora, the climate and the relative age of the petrified forest. In addition to the large number of fossilised leaves, the genus or the species of the trees, can also be determined from the micro-analysis of the internal structure of the fossil wood. The erect tree trunks, with their roots and branches, give evidence that the fossilisation took place *in situ*.

Despite the fact that the systematic study of the petrified forest has not yet been completed, the classification of the fossils permits certain conclusions to be drawn. All of the genera and species determined, belong to higher plant groups: Angiospermae and Gymnospermae. Complete development of the flora was achieved in the presence of Angiosperms, the most evolved plants.

From phytogeographical point of view the plants of the Petrified Forest can be distinguished into two main groups. The first group contain subtropical plants like *Laurus* (laurel), *Cinnamomum* (cinnamon), whose related species are found in the forests of south-eastern Asia. The second group includes plants which prefer mild temperatures like *Alnus* (alder), *Carpinus* (hornbill), *Populus* (poplar), *Quercus* (oak), *Pinus* (pine), *Taxodioxyton gypsaceum* (sequoia), etc. Related vegetation flourishes today in the warm continental zones of South-eastern Asia and North America.

A comparison of the stratigraphic expanse of the plant fossils with other European flora and with the Palaeoflora of Greece leads us to the conclusion that the Palaeoflora of Lesvos developed during Late Oligocene - Lower Miocene, under subtropical or warm temperate seasonal climatic conditions.

## 5. 1997 EXCAVATION NEW DATA

The principle excavation area is located within the Petrified Forest Park at "Bali Alonia", site of the largest concentration of petrified trees.

To date excavations have progressed considerably revealing a large number of fossilised plants of particular scientific importance. In the course of activities, five excavation pits were opened revealing the following:

- The standing trunk of a petrified tree with a height of 7.02 m and a perimeter of 8.58 m. This is the largest known petrified trunk to date not only on the island of Lesvos but almost certainly in Europe. This lower trunk preserved in excellent condition is probably pertains to the species *Taxodioxyton gypsaceum* (GOPPERT) KRAUSEL (Photo 1.1)
- Two standing petrified conifer trunks less than 2.0 m apart most probably pertaining to the Protopinaceae family. The heights of the trunks are 2.70 m and 2.22 m and perimeters 2.90 m and 2.26 m respectively (photo 1.2, 1.3). The external structure and internal characteristics of the wood are excellently preserved with the concentric annual rings evident in both cases. In all likelihood, these trunks pertain to the new coniferous species *Pinoxylon paradoxum* SUSS & VELITZELOS, first found in Lesvos and abundant throughout the broader region of the Petrified Forest of Lesvos. Aside from the above mentioned, excavations also brought to light a fallen trunk 6 m long. This trunk is affected by N-S trending dextral strike-slip faults due to the post volcanic tectonic activity in the area (photo 3.1).
- A standing petrified conifer tree trunk the upper part of which was revealed as a result of the natural erosion of the volcanic rock. The tree's root system has been preserved in very good condition within a silicified palaeosoil covered by ingnimbrite. The height of the artefact is 2.15 m and perimeter 2.18m. Besides this is a fallen petrified trunk, a large portion of which was also uncovered as a result of the

natural erosion of volcanic rock. The restored trunk using the existing fragments and pieces measures 4m in length and is probably pertains to the species *Taxodioxyton gypsaceum* (GOPPERT) KRAUSEL (Photo 2.1, 2.2).

- A standing petrified trunk with impressive shades of purple, clear annual rings and excellently preserved morphological characteristics of the wood's structure. The height of the trunk is 2.05m and its perimeter 2.56m. According to speculations this tree pertains to the Protopinaceae family, more specifically of the species *Pinoxylon paradoxum* SUSS & VELITZELOS (Photo 2.3).
- A standing petrified trunk twisted in a characteristic fashion most probably because of the pressure exerted by the volcanic material that covered the flora and finally led to petrification. This trunk is of a diameter of 50 cm and height of 1.2 m. Excavation has not yet been completed.

In the course of excavations, parts of plants were uncovered (leaves, branches, roots). Representatives of the genus *Laurus* (laurel), *Cinnamomum* (cinnamon), *Alnus* (alder), *Carpinus* (hornbill), *Populus* (poplar), *Quercus* (oak) have been determined. The latter have remained well preserved, protected by the volcanic material in which they are embedded. Nonetheless, the exposure to the elements, the erosion, the danger of theft and destruction all pose a true threat for these fragile artefacts. Finds of this nature are to be exhibited in the Natural History Museum of the Lesvos Petrified Forest.

## 6. CONCLUSIONS

The importance of the findings is based on the fact that they reveal with greater certainty that the area of excavation is located at the highest point of mixed coniferous forest. The abundance of preserved standing trunks with their root systems intact and in a stage of full development, attests to the fact that the trees were petrified and are still located in their original position. This allows us to infer that the Lesvos Petrified Forest represents a complete autochthonous (fossilised *in situ*) ecosystem. Aside from the petrified trunks, fossilised branches, roots, fruit, leaves, seeds etc. are preserved in excellent condition, embedded in and protected by volcanic rocks.

The majority of the tree-trunks in the Petrified Forest Park "Bali Alonia" belong to the species *Taxodioxyton gypsaceum* (GOPPERT) KRAUSEL and *Pinoxylon paradoxum* SUSS & VELITZELOS. *Taxodioxyton gypsaceum* (GOPPERT) KRAUSEL is an ancestor of the present day species *Sequoia sempervirens*. Today's trees of this species reach a height of 120-130m. The coniferous species *Pinoxylon paradoxum* SUSS & VELITZELOS which has been first found on Lesvos is ancestor of the present day pine-tree. The holotypes of the species exist within the Petrified Forest Park "Bali Alonia" (Suss & Velitzelos, 1993, 1994b).

The composition of the petrified flora demonstrates that the Petrified Forest of Lesvos developed in a subtropical climate that abruptly changed to a warm continental climate. The flora of the region was that characteristic of subtropical zones of Southeast Asia and America.

Our medium term aims are to conduct systematic excavations to uncover the numerous petrified trunks that today remain covered by volcanic rock. There are indications that a particularly large number of petrified trunks represent coniferous trees of the species *Pinoxylon paradoxum*, *Taxodioxyton gypsaceum* and *Cunninghamia meiocenica* which made up the subtropical forest which developed in the Aegean region 20 million years ago. At lower relief points, the coniferous tree forest mixed with the deciduous forest. An ecosystem comparable to that which existed in the Petrified Forest, the subject of research conducted under the auspices of the Museum, is that of coniferous forests found today in North America.

All of the above mentioned data certify that the Petrified Forest of Lesvos represent an important stage of the earth's evolutionary processes. It is considered a unique natural geological monument offering rare scientific information, as no other analogous monument from this time period and stage of plant development exists.

Furthermore the geological history of the Aegean basin of the last 20 million years is imprinted upon the petrified forest which provides us with unique information not only regarding the flora but ecological conditions, the climate and its fluctuations, volcanic activity and the tectonic movement which resulted in the geological structure and formation of the area.

TABLE 1

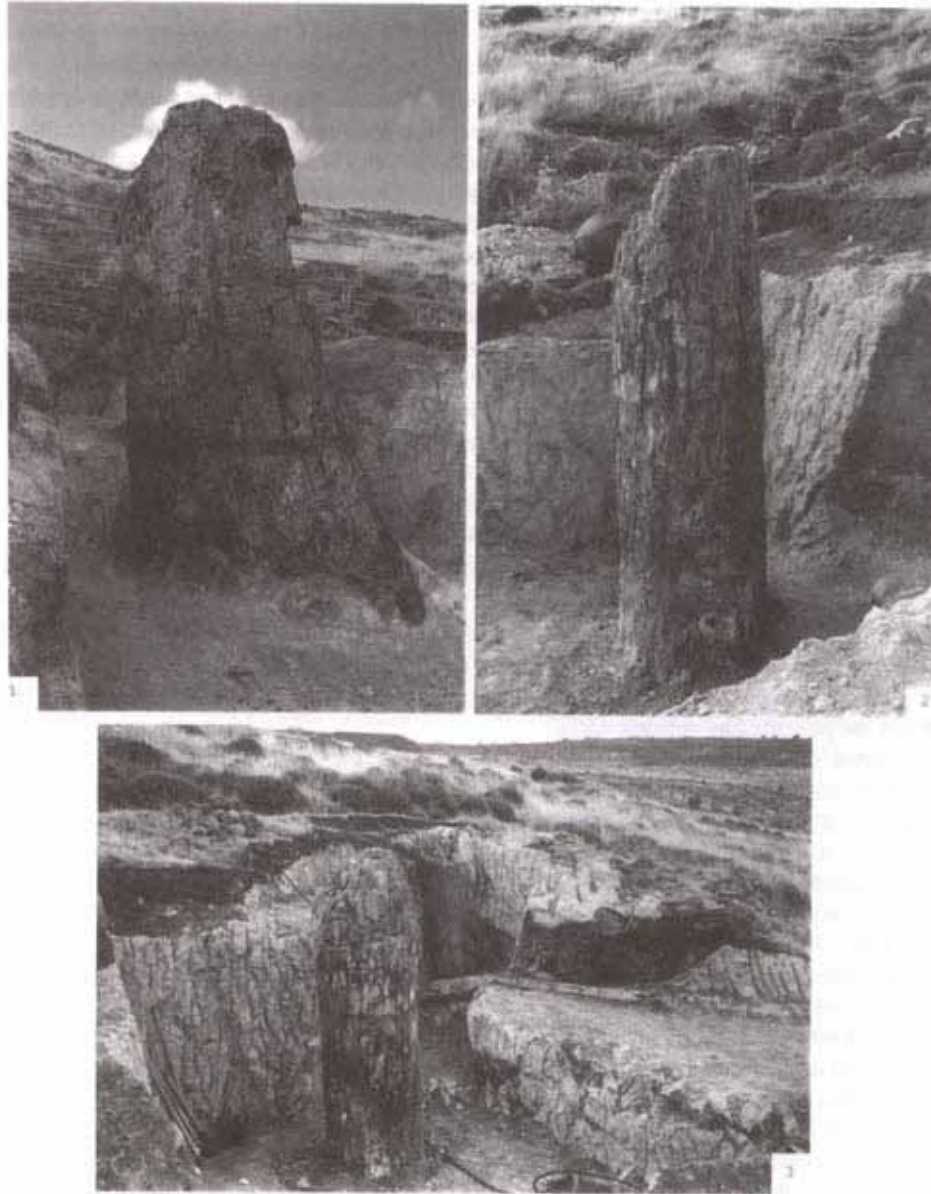


TABLE 1

1. Standing fossilized tree trunk in the Petrified forest park at "Bali Alonia", West Lesvos. It has 7.02 m high, 8.58 m perimeter and is petrified in situ on account of the intense volcanic activity in the area during Lower Miocene. It is the largest known petrified tree trunk in Lesvos and probably belongs to the species *Taxodioxylon gypsaceum* (GOPPERT) KRAUSEL.
2. *Pinoxylon paradoxum* SUSS & VELITZELOS. Standing fossilized tree trunk belonging to the Protopinaceae family, showing impressive colours and distinct annual growth rings. 2.05 m high, 2.56 m perimeter. This is a new species of conifer widely distributed in the region of the Petrified Forest of Lesvos.
3. General view of the second excavation site in the Petrified Forest park at "Bali Alonia", West Lesvos. Two standing and one lying fossilized tree trunks, affected by N-S trending strike slip faults, can be observed.

TABLE 2



TABLE 2

1. General view of the third excavation site at the Petrified Forest park at "Bali Alonia". A standing petrified conifer tree trunk and a lying one can be observed as well as a silicified palaeosol covered by ignimbrite.
2. Standing fossilized conifer tree trunk showing excellent preservation of the morphology and structure of the wood. 2.15 m high, 2.18 m perimeter. The tree's root system has been uncovered in very good condition.
3. Standing fossilized conifer tree trunk belonging to the Protopinaceae family, showing impressive colours and distinct annual growth rings. 2.70 m high, 2.90 m perimeter.

TABLE 3

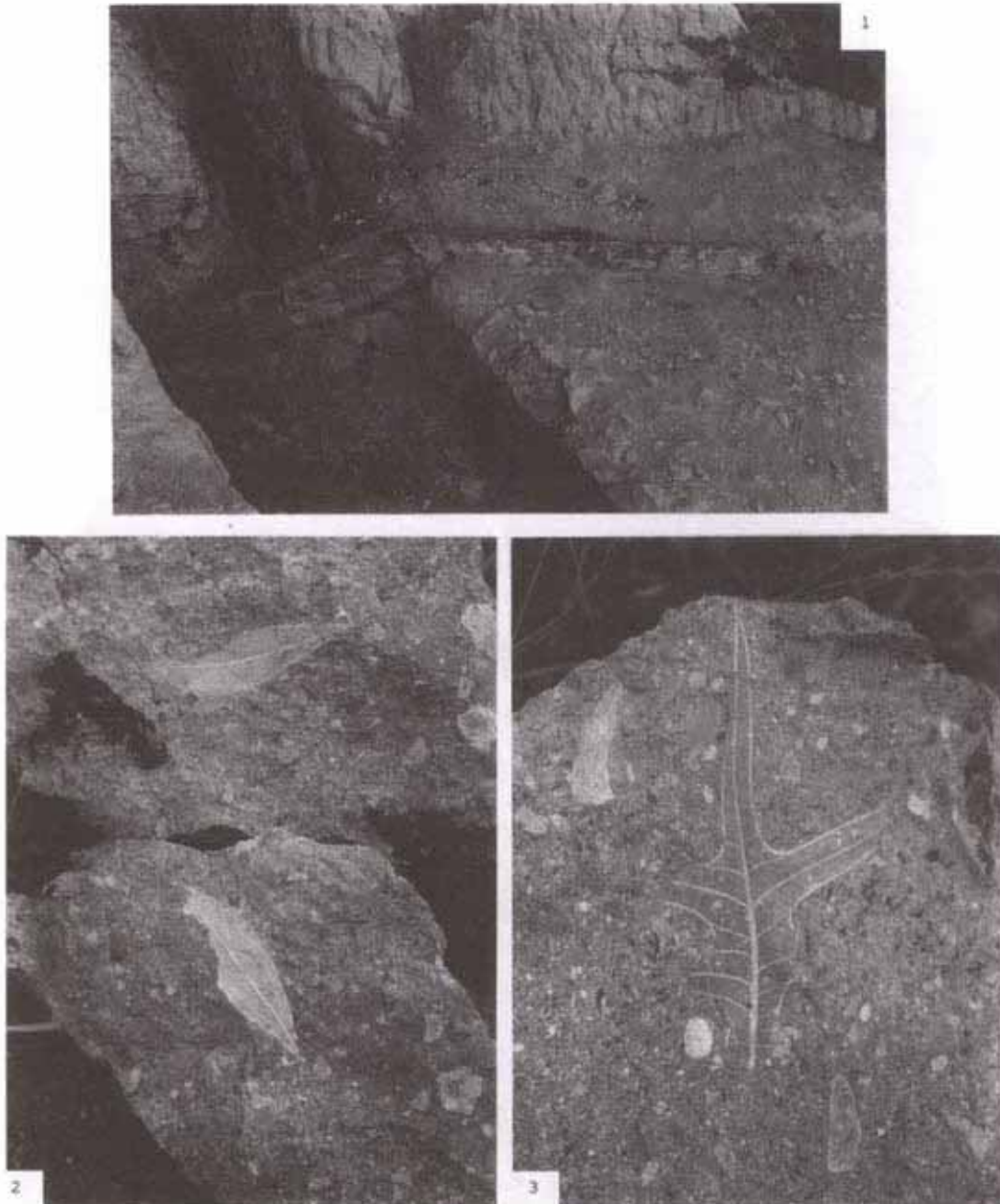


TABLE 3

1. *Pinoxylon paradoxum* SUSS & VELITZELOS and *Taxodioxylon sp.* (lying) fossilized tree trunks from two species which are widely distributed in the Petrified Forest park at "Bali Alonia". The lying tree trunk is 6 m long. It is affected by a N-S trending dextral strike slip fault.
2. *Cinnamomum polymorphum* HEER sensu GRANGEON Imprints of fossilized cinnamon leaves in pyroclastic rock, with the characteristic morphological features clearly discernible.
3. *Quercus sp.* Imprint of a fossilized oak leaf in pyroclastic rock, with the characteristic morphological features clearly discernible.

## REFERENCES

- BERGER, W., 1953. Jungtertiäre Pflanzenreste aus dem Gebiet der Agais (Lemnos Thessaloniki). *Ann. Geol. Pays Hellen.*, 15, 34 - 54.
- BORSI, S. FERRARA, G. INNOCENTI, F. AND MAZZUOLI, R., 1972. Geochronology and petrology of recent volcanics in the Eastern Sea (West Anatolia and Lesbos island). *Bull. Volcanol.*, 36, 473-496.
- HECHT, J., 1972. Geological map Lesbos island "Plomari - Mytilene" sheet. IGME
- HECHT, J., 1973. Geological map Lesbos island "Agia Paraskevi" sheet. IGME
- HECHT, J., 1974a. Geological map Lesbos island "Polychnitos" sheet. IGME
- HECHT, J., 1974b. Geological map Lesbos island "Mythimna" sheet. IGME
- HECHT, J., 1975. Geological map Lesbos island "Eressos" sheet. IGME
- FLICHE, P., 1898. Note sur les bois fossiles de Metelin. In L. De LAUNAY, Etudes géologiques sur la Mer Egee. *Ann. Min.* 2.
- KATSIKATSOS, G., MATARAGAS, D., MIGIROS, G. AND TRIANTAPHYLLIS, E., 1982. Geological study of Lesbos Island I.G.M.E. (internal report) Athens, p 1-92.
- KATSIKATSOS, G., MIGIROS, G., TRIANTAPHYLLIS, M. AND METTOS A. 1986. Geological structure of the internal Hellenides (East Thessaly - southwest Macedonia, Euboea Attica northern Cyclades islands and Lesbos) I.G.M.E. *Geology and Geophysical research*, Sp. issue, 191-212.
- KRAUSEL, R., 1965. The petrified forest of Lesbos. (Report)
- MOUNTRAKIS, D. 1983. Structural geology of the North Pelagonian zone s.l. and geotectonic evolution of the Internal Hellenides. Unpubl. "Habilitation", Univ. of Thessaloniki, Greece, 283pp.
- PE-PIPER, G. 1978. Cainozoic volcanic rocks of Lesbos island. Thesis, Univ. of Patras, 365 p.
- PE-PIPER, G., 1980a. Geochemistry of Miocene shoshonites, Lesbos, Greece. *Contrib. Mineral. Petrol.*, 72:387-396.
- PE-PIPER, G., 1980b. The Cenozoic volcanic sequence of Lesbos, Greece. *Z. Dtsch. Geol. Ges.*, 131:889-901.
- PE-PIPER, G. AND PIPER, D.J.W., 1992. Geochemical variation with time in the Cenozoic high-K volcanic rocks of the island of Lesbos, Greece: significance for shoshonite petrogenesis. *Journal of Volcanology and Geothermal Research*, 53, 371-387.
- PE-PIPER, G. AND PIPER, D.J.W., 1993. Revised stratigraphy of the Miocene volcanic rocks of Lesbos, Greece. *N. Jb. Geol. Palaeont. Mh.* 2, 97-110.
- SUSS, H. & VELITZELOS, E., 1993. Eine neue Proto-Pinaceae der Formgattung *Pinoxylon* KNOWLTON emend. READ, *P. parenchymatosum* sp. nov., aus tertiären Schichten der Insel Limnos, Griechenland. *Feddes Repertorium*, 104, 335 - 341.
- SUSS, H. & VELITZELOS, E., 1994a. Ein neues fossiles Koniferenholz, *Taxoecoxyton biseriatum* sp. nov., aus tertiären Schichten der Insel Lesbos, Griechenland. *Feddes Repertorium*, 105, 5-6, 257 - 269.
- SUSS, H. & VELITZELOS, E. 1994b. Zwei neue tertiäre Holzer der Gattung *Pinoxylon* KNOWLTON emend. READ aus dem Versteinerten Wald von Lesbos, Griechenland. *Feddes Repertorium*, Berlin, 105, 7 - 8, 403 - 423.
- VELITZELOS, E., 1988. The petrified forest of Lesbos. *Motion, Magazine Olympic Airways*, February 88, 60 - 73.
- VELITZELOS, E. 1993. Neue paläofloristische Daten zu kanophytischen Floren Griechenlands. *Doc. nat.*, 78, 1 - 17.
- VELITZELOS, E., PETRESCU, I. & SYMEONIDIS, N., 1981a. Tertiäre Pflanzenreste von der agaischen Insel Lesbos (Griechenland). *Cour.Forsch. Inst. Senckenberg*, 50, 49 - 50.
- VELITZELOS, E., PETRESCU, I., SYMEONIDIS, N., 1981b. Tertiäre Pflanzenreste aus Agais. Die Makroflora der Insel Lesbos (Griechenland). *Ann. Geol. Pays Hellen.*, 30, 500 - 514.

- VELITZELOS, E. & SYMEONIDIS, N. 1978. Der verkieselte Wald von Lesbos (Griechenland) ein Naturschutzgebiet. Vortrag - Kurzfassung beim Arbeitskreis Paleobot., Palynol., 17, 19p.
- VELITZELOS, E. & GREGOR, H.-J., 1990. Some aspects of the neogene floral history in Greece. *Rev. Paleobot. Palynol.* 62, 291 - 307.
- VELITZELOS, E. AND ZOUROS N. 1997. The Petrified forest of Lesbos - Protected Natural Monument. *Engineering Geology and the Environment*, Marinos, Koukis, Tsiambaos & Stournaras (eds), Balkema, p.3037-3043.