FLORA TERTIARIA MEDITERRANEA

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FLORA TERTIARIA MEDITERRANEA VI.6

The preservation conditions of petrified materials from Greek Fossilized Forests.

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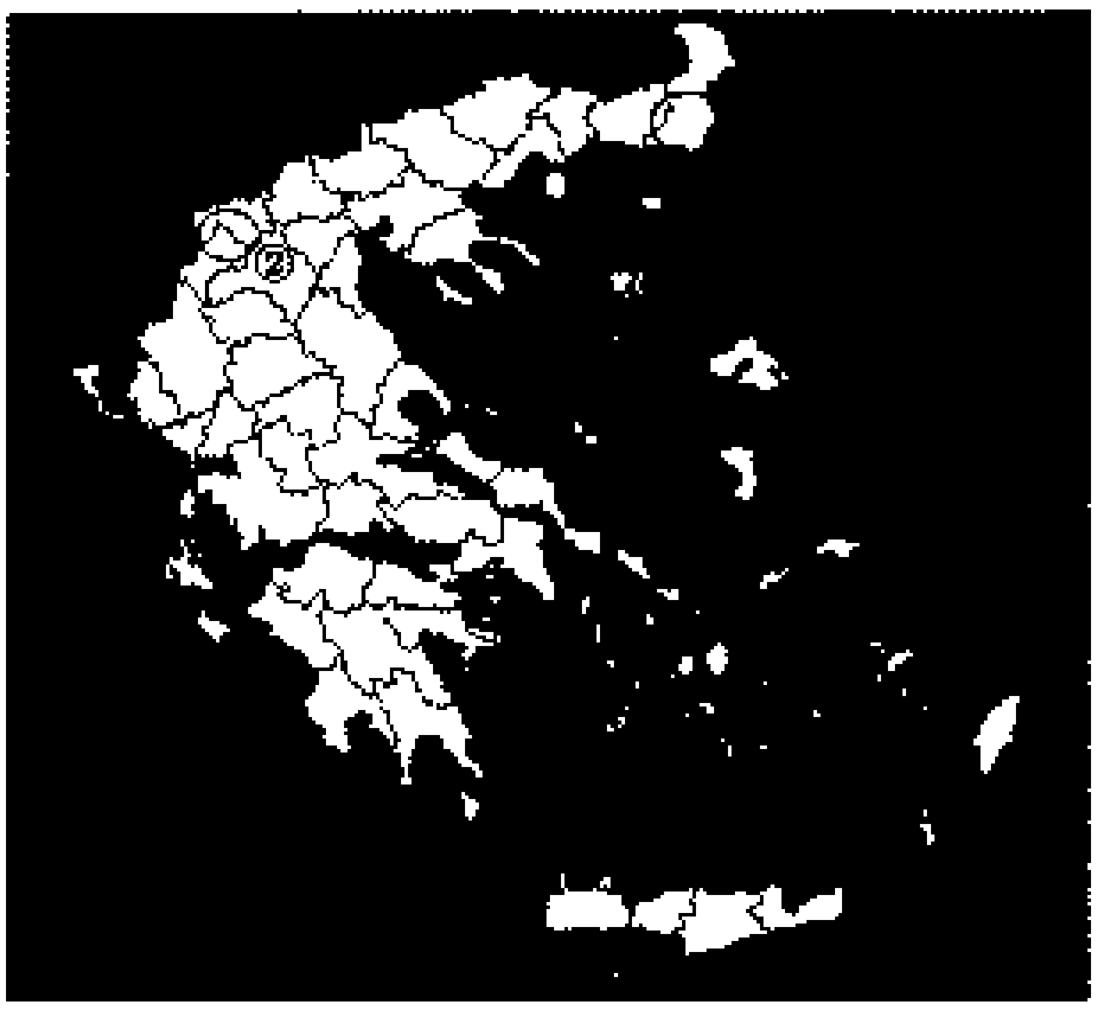

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The preservation conditions of petrified materials from Greek Fossilized Forests.

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ABSTRACT

This study examines the degradation type, the morphology and the corrosion degree of petrified samples coming from different geographical areas of Greece. Each area (continental and insular) is characterized by a different degree of fossilization, but a similar morphology, as different environmental parameters are prevailing.

Samples have been examined with S.E.M. - E.D.A.X., X-R.D. and microscopy techniques in order to correlate degradation type, morphology and degree with fossilization process and environmental factors (temperature and humidity variation, soluble salts crystallization, biological depositions and frost damage).

Keywords: petrified forests, corrosion, deterioration, soluble salts crystallisation, frost action, conservation, preservation.

1. INTRODUCTION - HISTORICAL DATA

Greece is famous in Europe because of the occurrence of real in-situ fossil forests, mainly in volcanoclastic sediments. Fossilized woods are common in many countries of Europe, North Africa or Asia, and many fossil sites are called "fossil forests", but reality is quite different. Some new ideas about fossil forests you may read in VELITZELOS; GREGOR & HOLLEIS 2003.

1.1 Lesvos Island

The fossilized - petrified forest of Lesvos (see fig. 1), which is dated in Lower Miocene (~20 million years), is located in the area of the north-western part of the island, and according to recent research, it occupies half of the area defined by the imaginary line between Molyvos - Plomari. It is one of the most important natural sites in Europe and a national museum exhibition/display will be created soon, in Sigri (Velitzelos et al., 1997, 1996, 1981b, 1981a, 1988, 1978, Selmeier A., Velitzelos E., 2000).

The fossilized trunks are in compact sentiments and the degree of fossilisation is complete (see fig. 2, 3, 4, 5, 6).

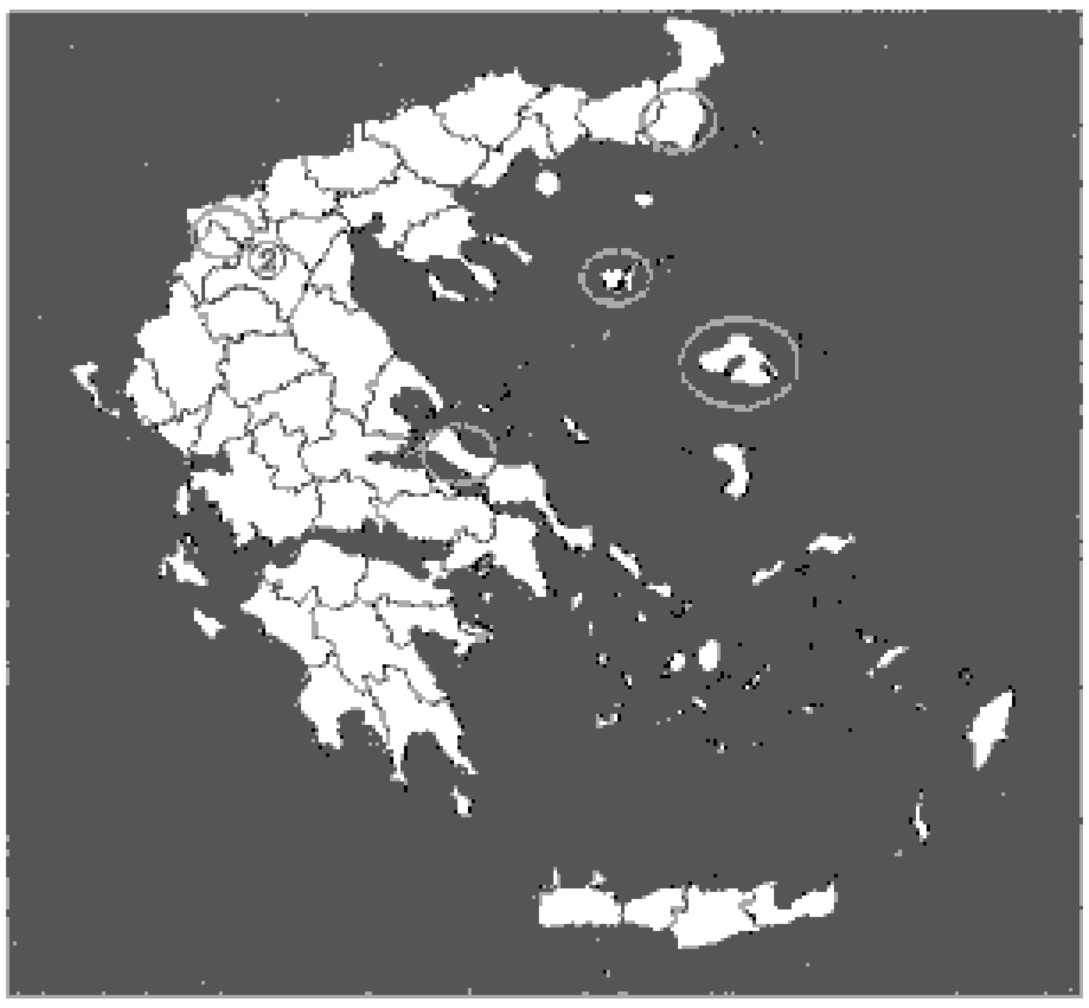


Fig. 1. Map of Greece with the fossilized forest of Lesvos (1).

Fig. 2. Fossilized trunk from Lesvos.

Fig. 3. Fossilized trunk from Lesvos.

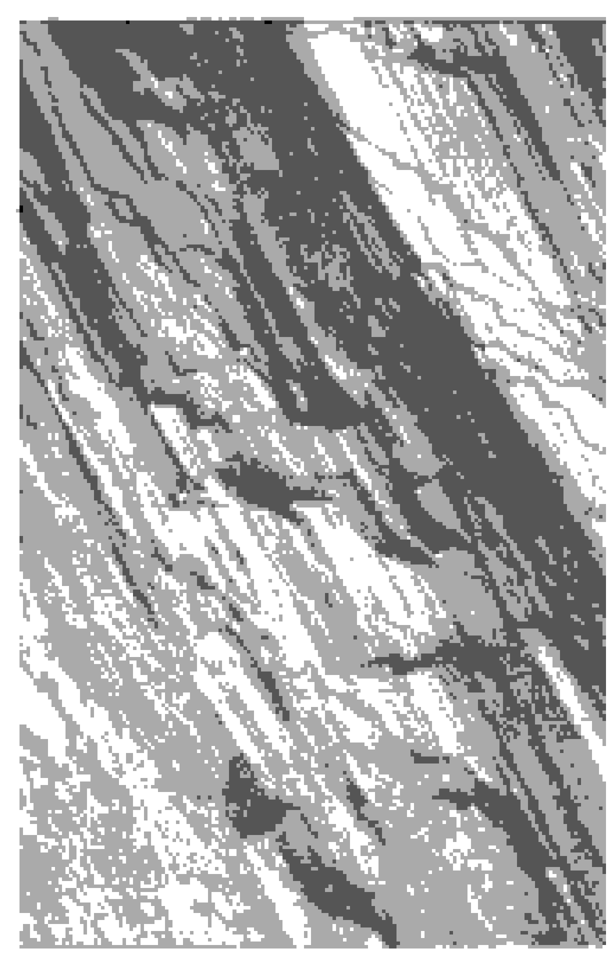


Fig. 4. Fossilized trunk from Lesvos.

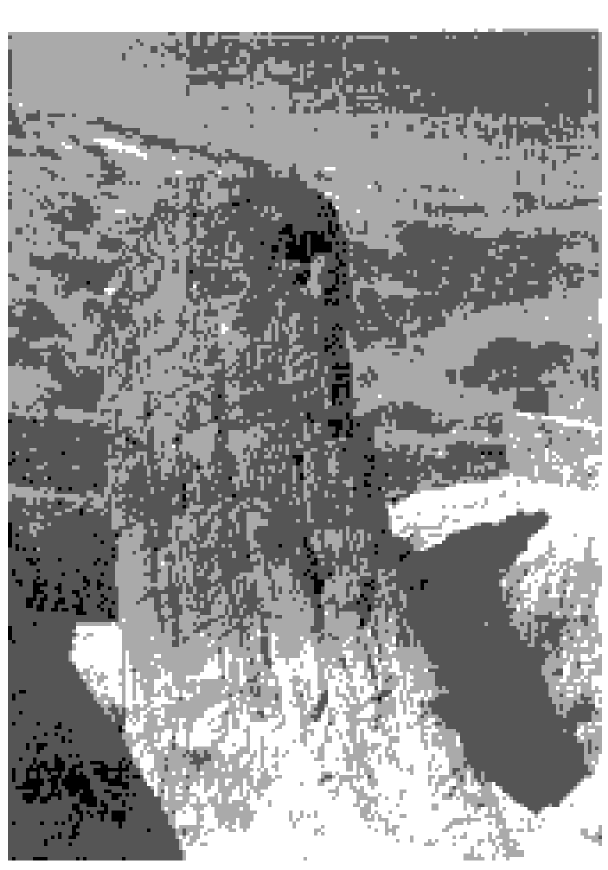


Fig. 5. Fossilized trunk from Lesvos.

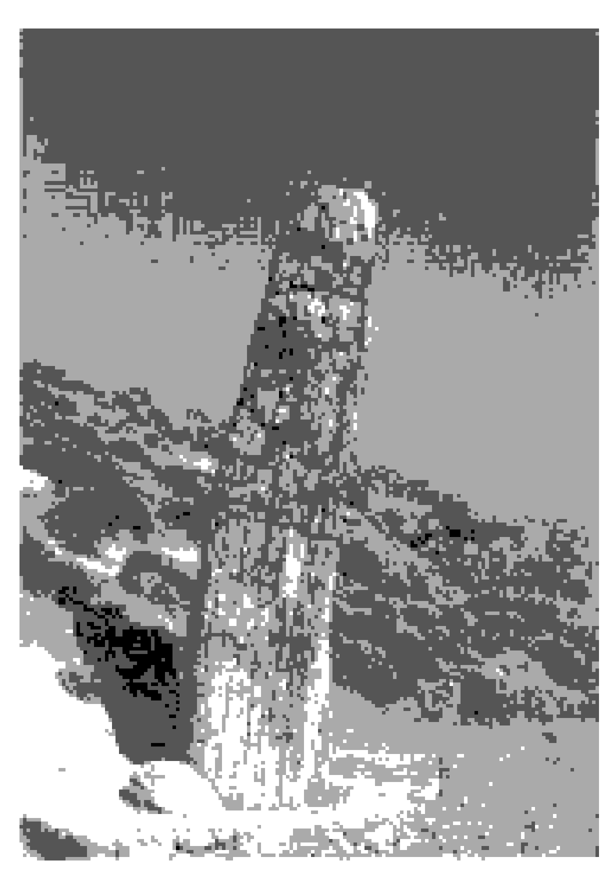


Fig. 6. Fossilized trunk from Lesvos.

1.2 Kastoria

The fossilized - petrified forest of the Kastoria (see fig. 7), which is dated in Lower Miocene (~20 million years), covers an extended area in the regions of Nostimo and Asproklisia. The fossilized trunks are in not so compact sentiments and the degree of fossilisation is either complete or partial (see fig. 8, 9, 10, 11, 12).

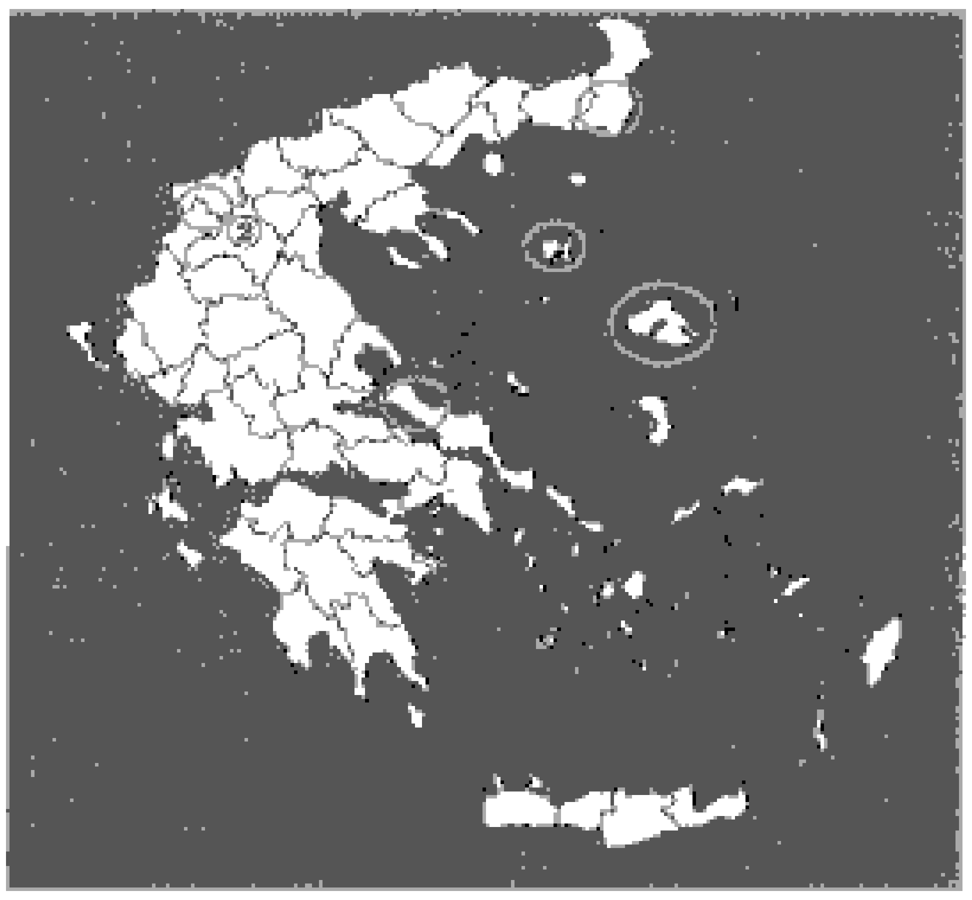


Fig. 7. Map of Greece with the fossilized forest of Kastoria (2).

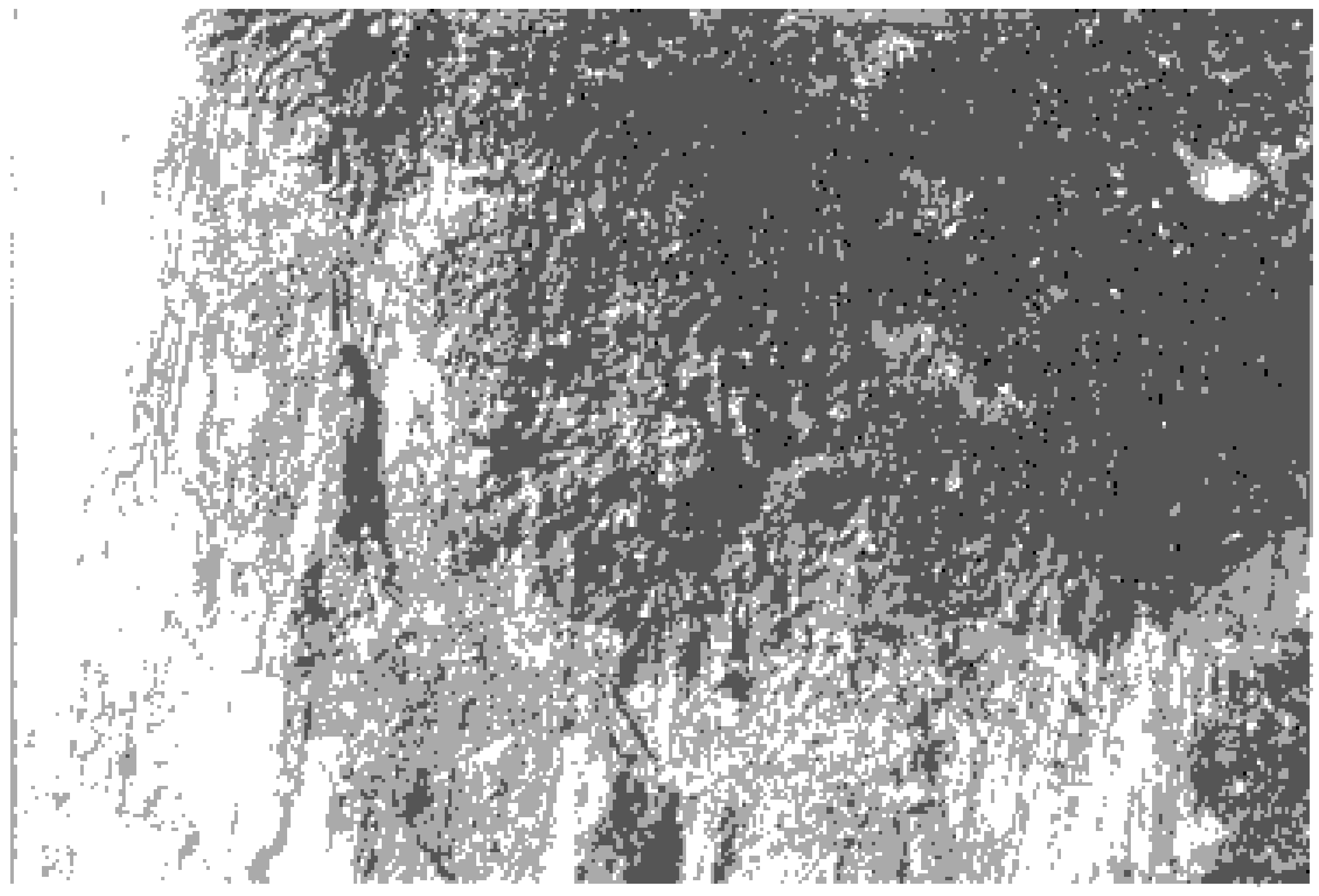


Fig. 8. Fossilized trunk from Kastoria.

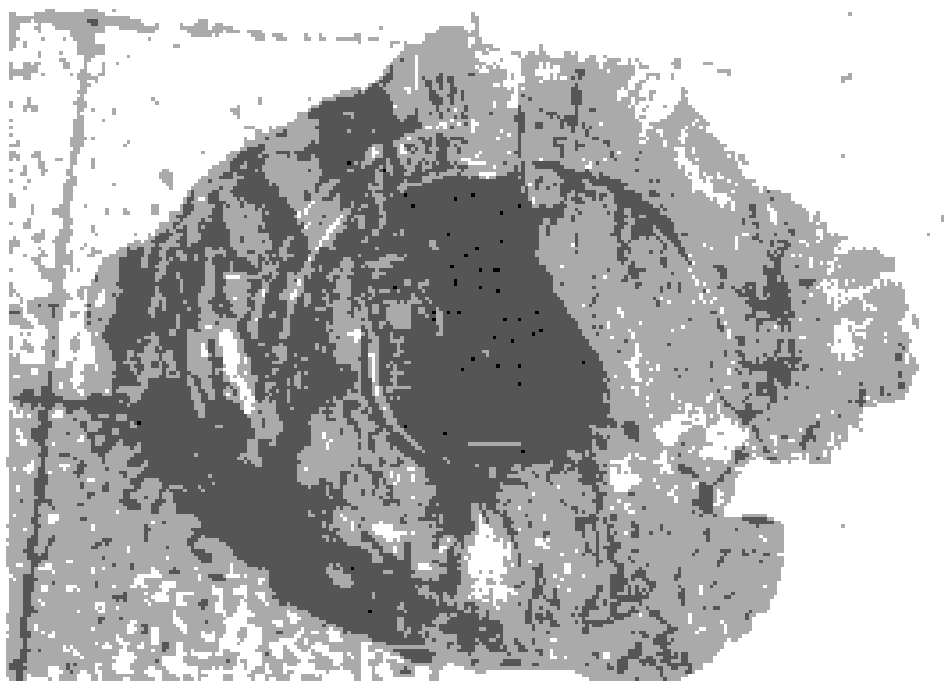


Fig. 9. Fossilized trunk from Kastoria.

Fig. 10. Fossilized trunk from Kastoria.

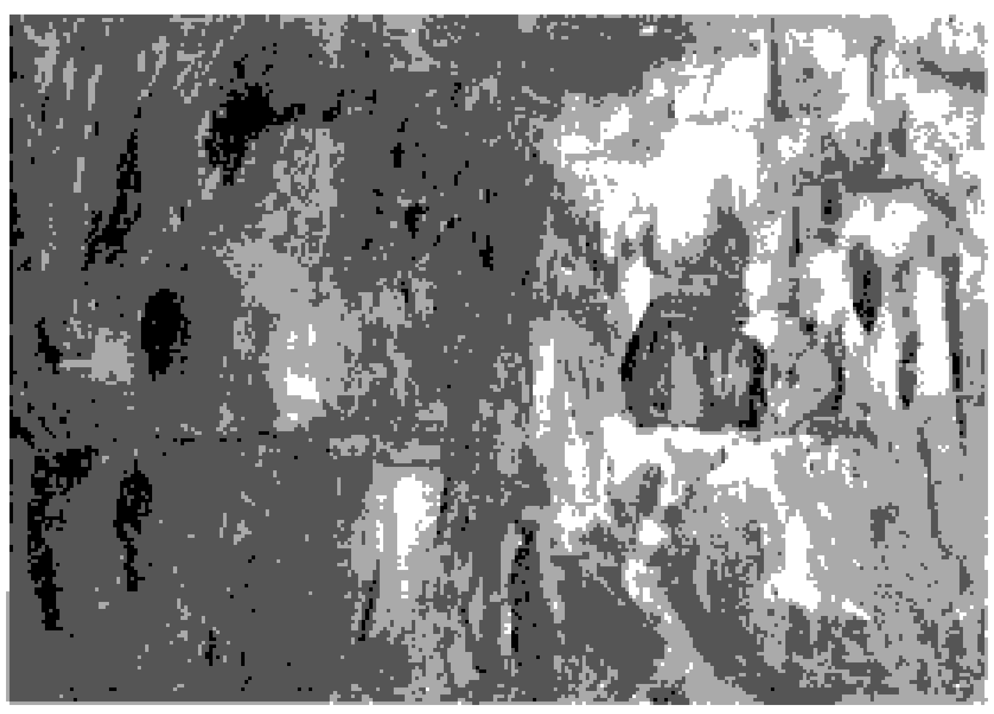


Fig. 11. Fossilized trunk from Kastoria.

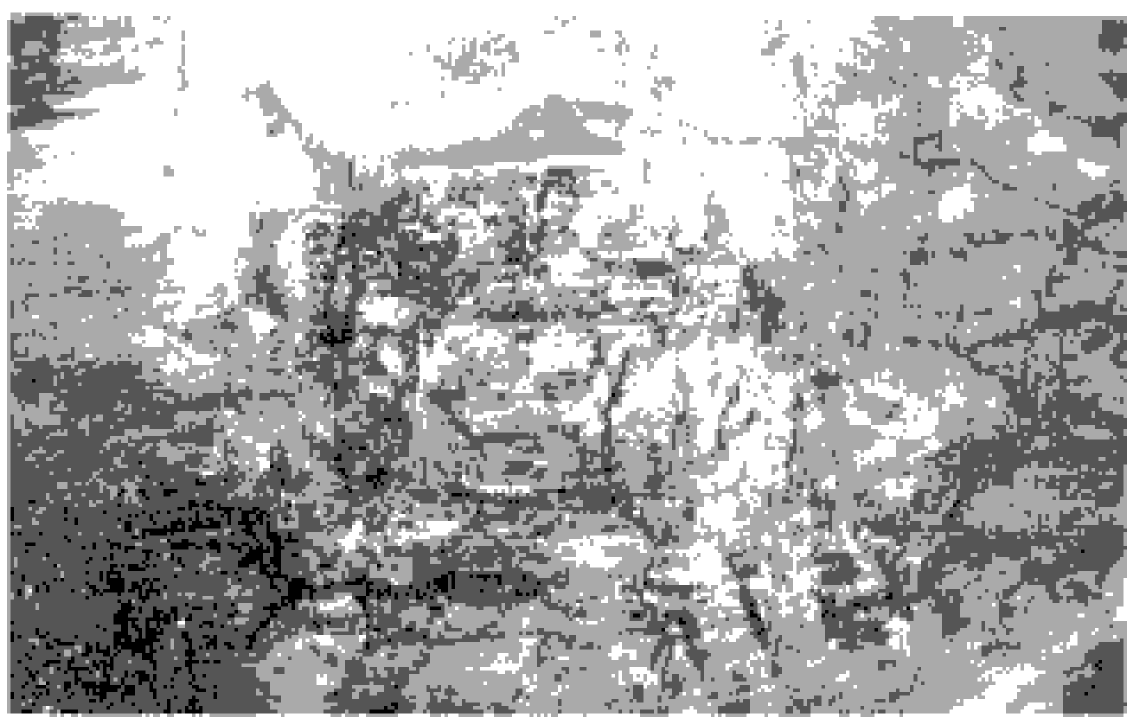


Fig. 12. Fossilized trunk from Kastoria.

1.3 Evros

The fossilized - petrified forest of the Evros (see fig. 13), which is dated in Upper Oligocene (~25 million years), covers an extended area in the regions of south-eastern Thraki (SELMEIER A., VELITZELOS E., 2000, VELITZELOS E., KVACEK Z., VELITZELOS D., 2002). The fossilized trunks are in not so compact sentiments and the degree of fossilisation is either complete or partial (see fig. 14, 15, 16, 17, 18).

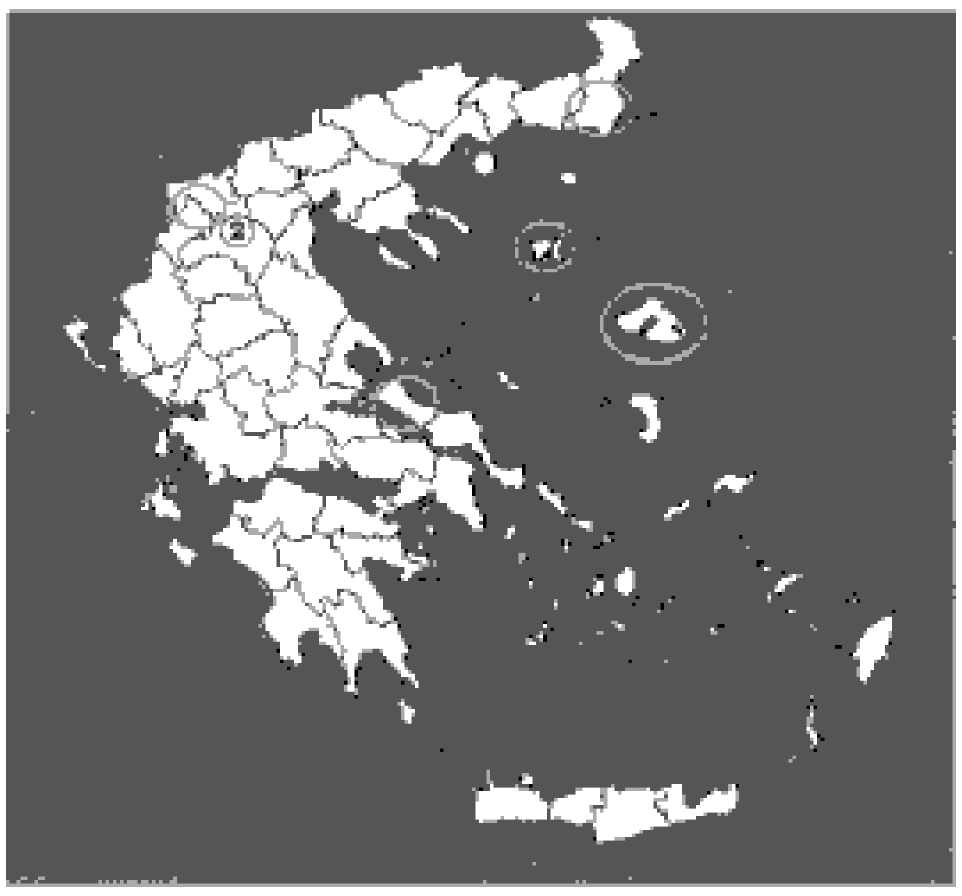


Fig. 13. Map of Greece with the fossilized forest of Evros (3).

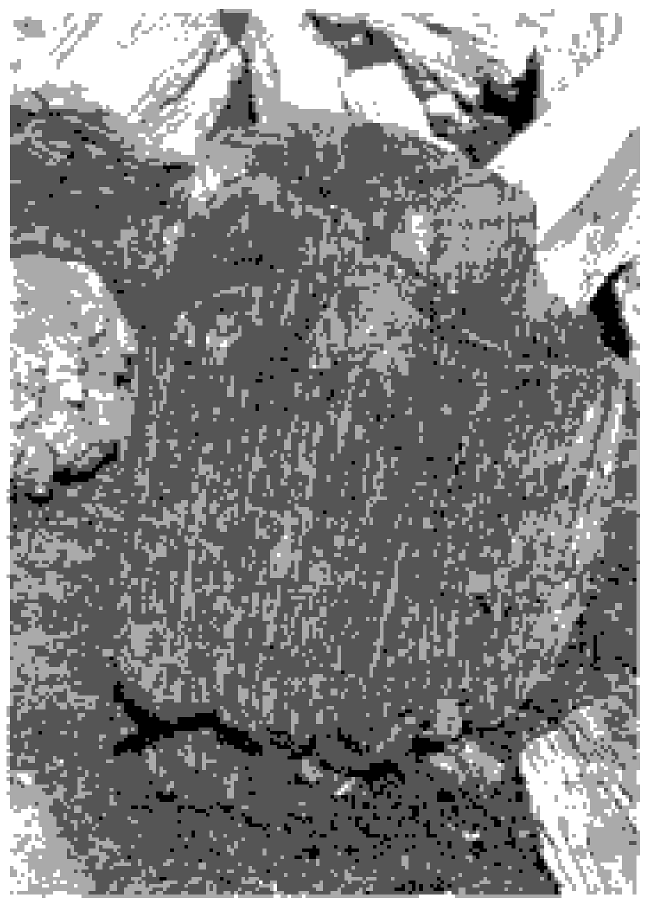


Fig. 14. Fossilized trunk from Evros.

Fig. 15. Fossilized trunk from Evros.

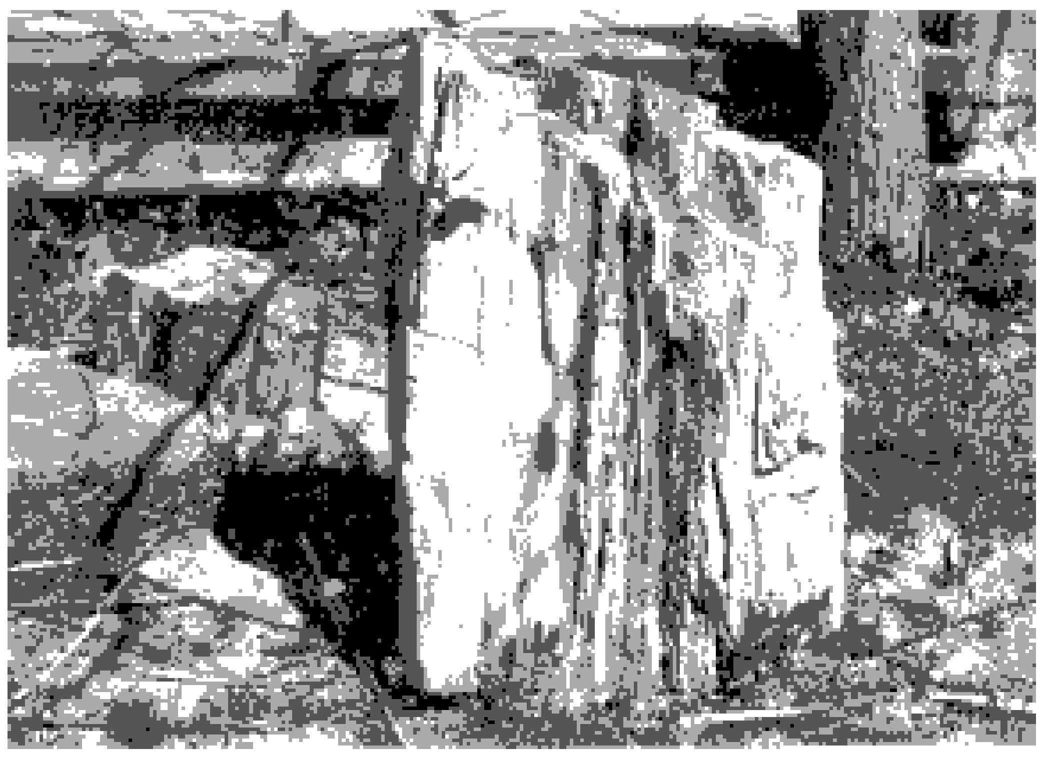


Fig. 16. Fossilized trunk from Evros.

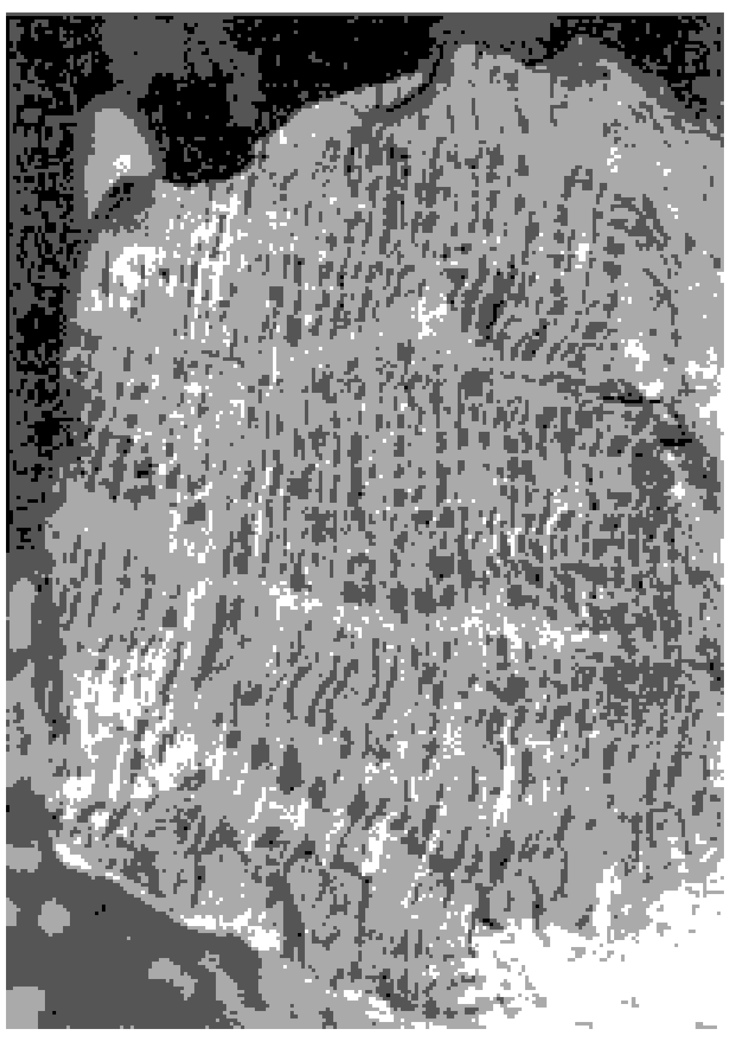


Fig. 17. Fossilized trunk from Evros.

Fig. 18. Fossilized trunk from Evros.

1.4 Evia Island

The fossilized - petrified forest of the Evia (see fig. 19), which is dated in Upper Miocene (~5 - 9 million years), covers an extended area in the regions of north-western Evia (VELITZELOS et al. 2002). The fossilized trunks are in not so compact sentiments and the degree of fossilisation is either complete or partial (see fig. 20, 21, 22, 23, 24).

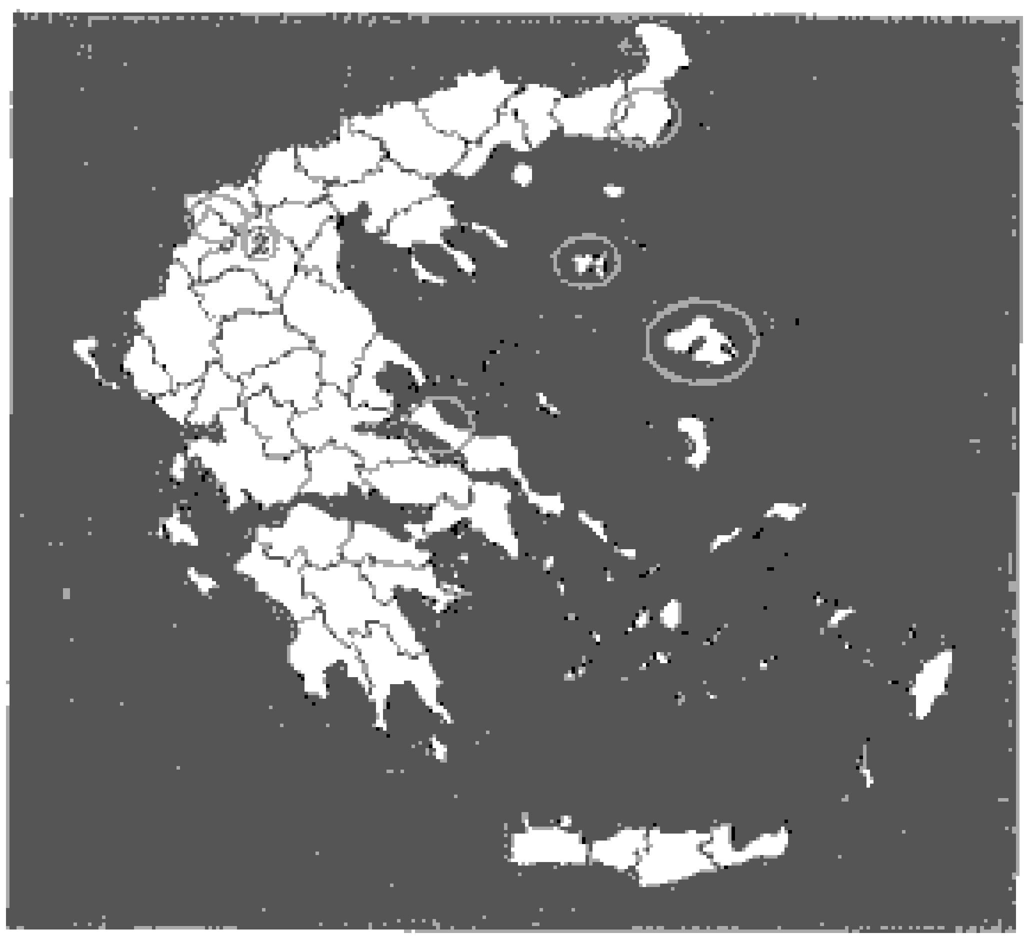


Fig. 19. Map of Greece with the fossilized forest of Evia (4).

Fig. 20. Fossilized trunk from Evia.

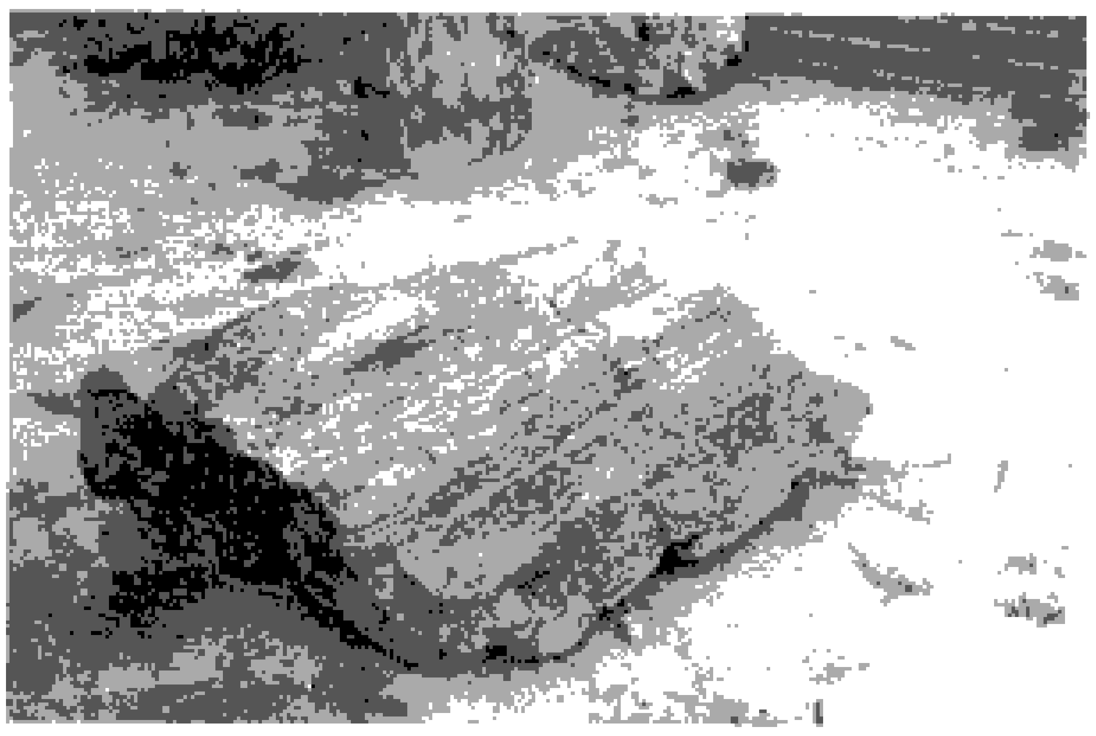


Fig. 21. Fossilized trunk from Evia.

Fig. 22. Fossilized trunk from Evia.

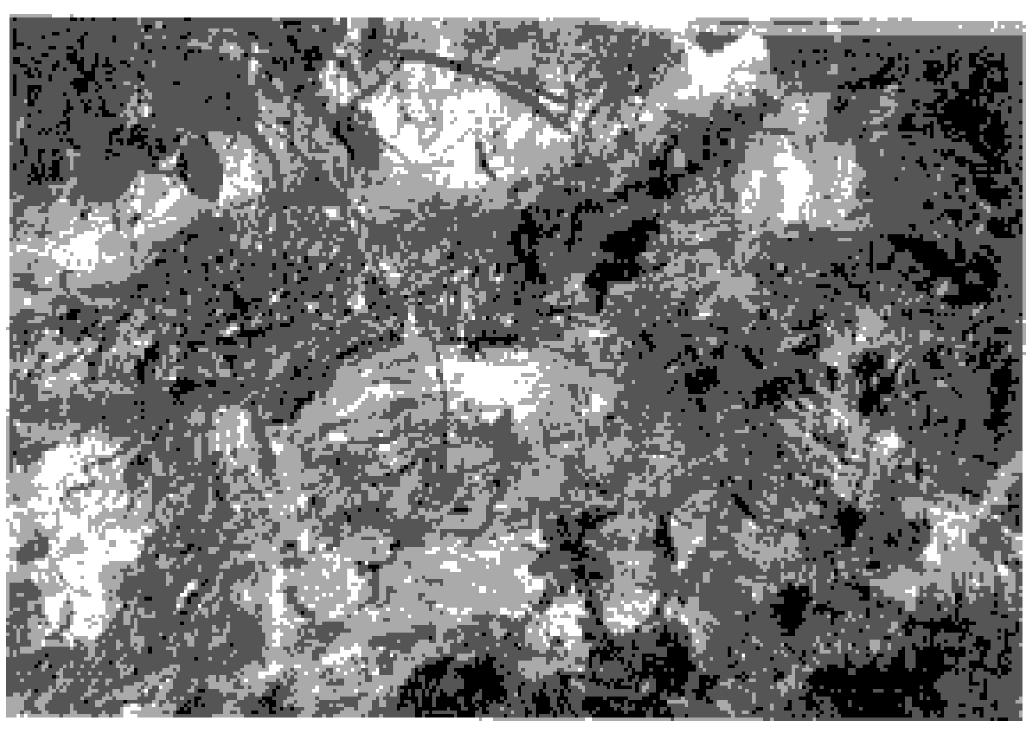


Fig. 23. Fossilized trunk from Evia.

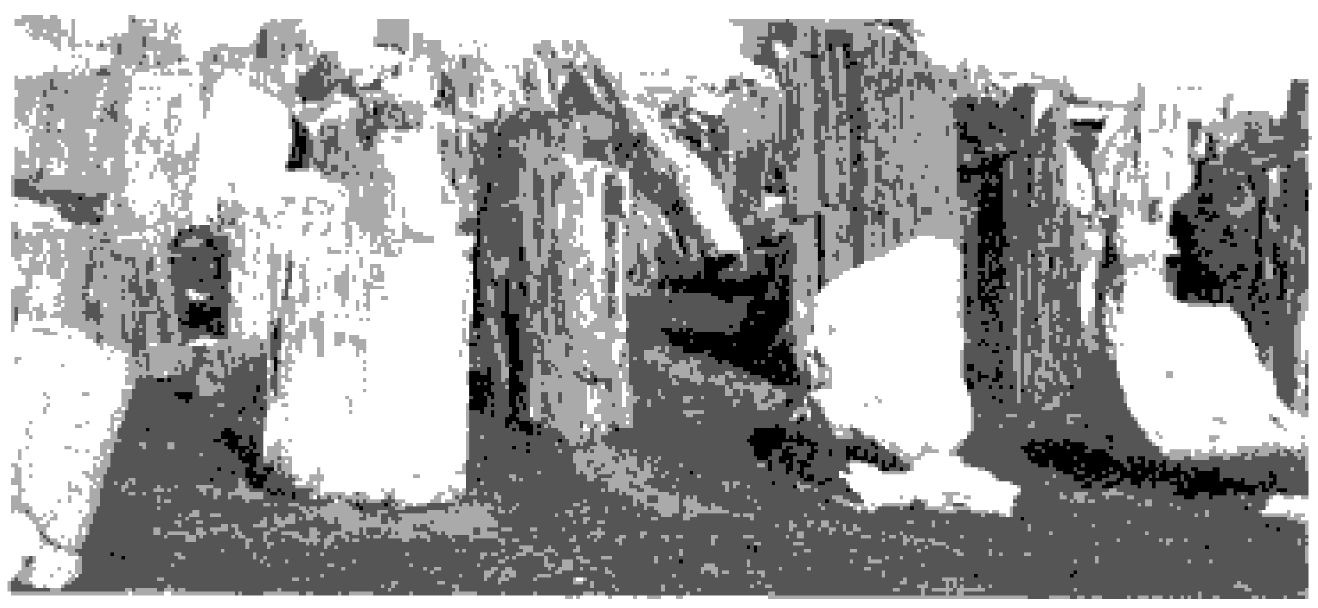


Fig. 24. Fossilized trunks from Evia.

1.5 Limnos Island

The fossilized - petrified forest of the Limnos (see fig. 25), which is dated Lower Miocene (~20 million years), covers an extended area in the region of Moundros in southern Limnos (SÜSS

H., VELITZELOS E., 1993). The fossilized trunks are in compact sentiments and the degree of fossilisation is complete (see fig. 26, 27, 28, 29, 30).

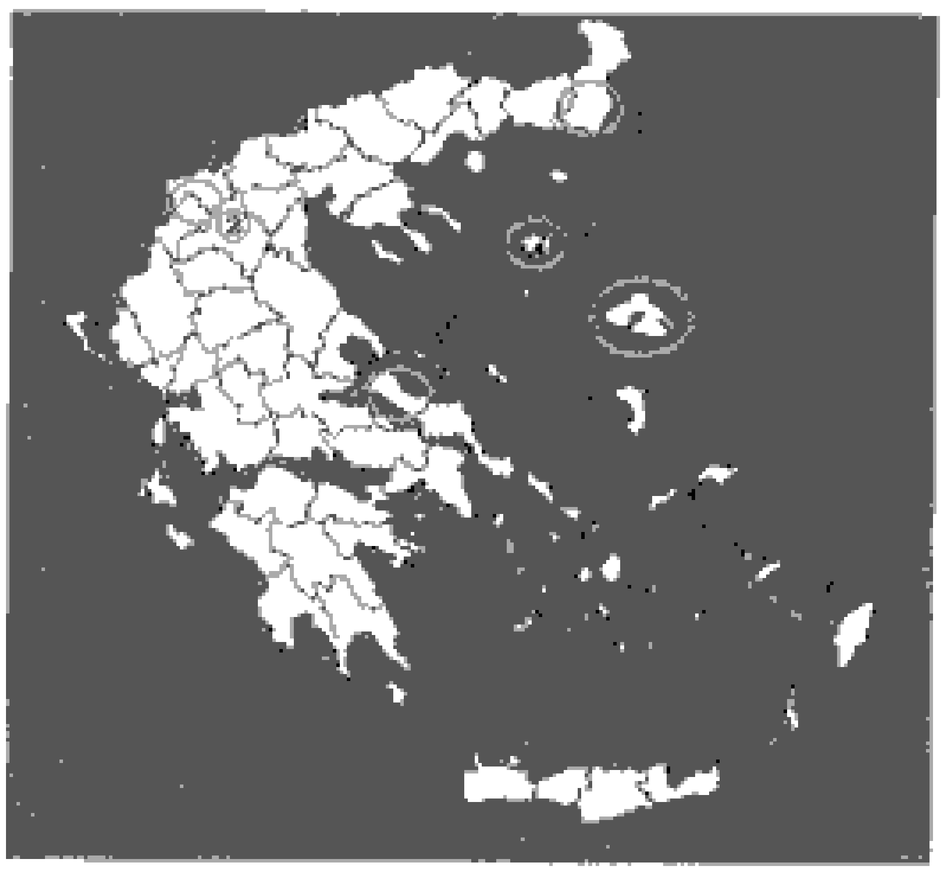


Fig. 25. Map of Greece with the fossilized forest of Limnos (5).

Fig. 26. Fossilized trunk from Limnos.

Fig. 27. Fossilized trunk from Limnos.

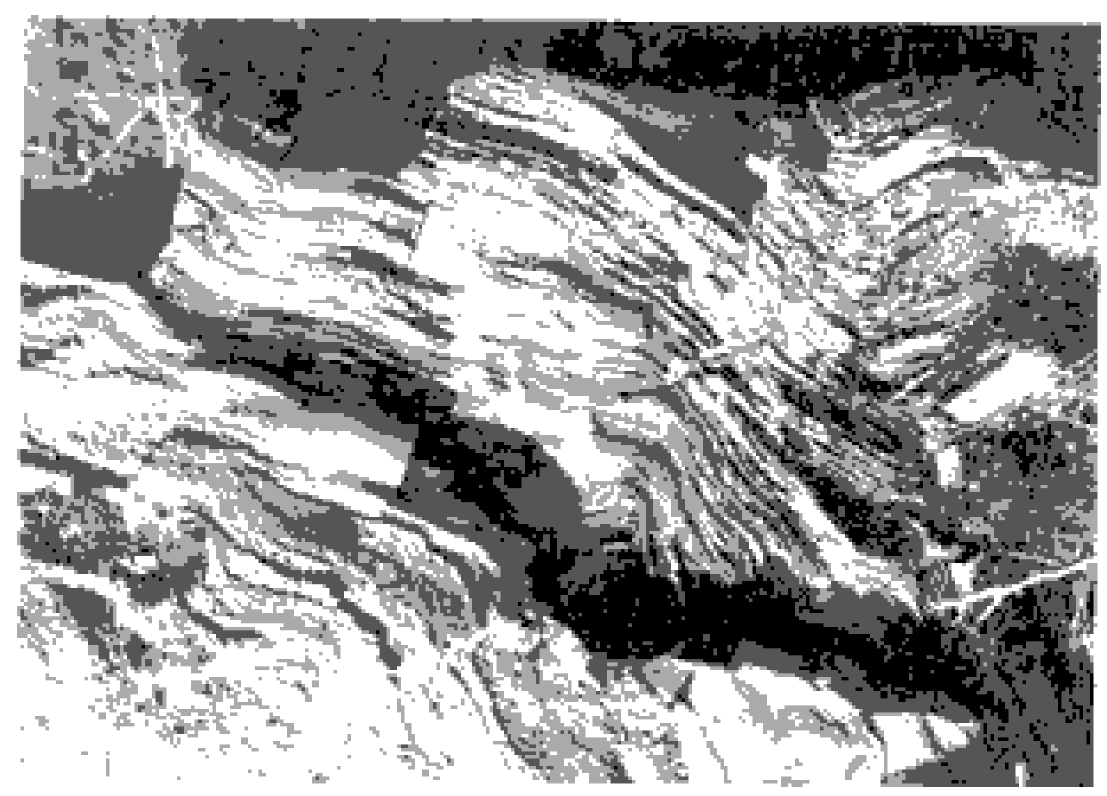


Fig. 28. Fossilized trunk from Limnos.

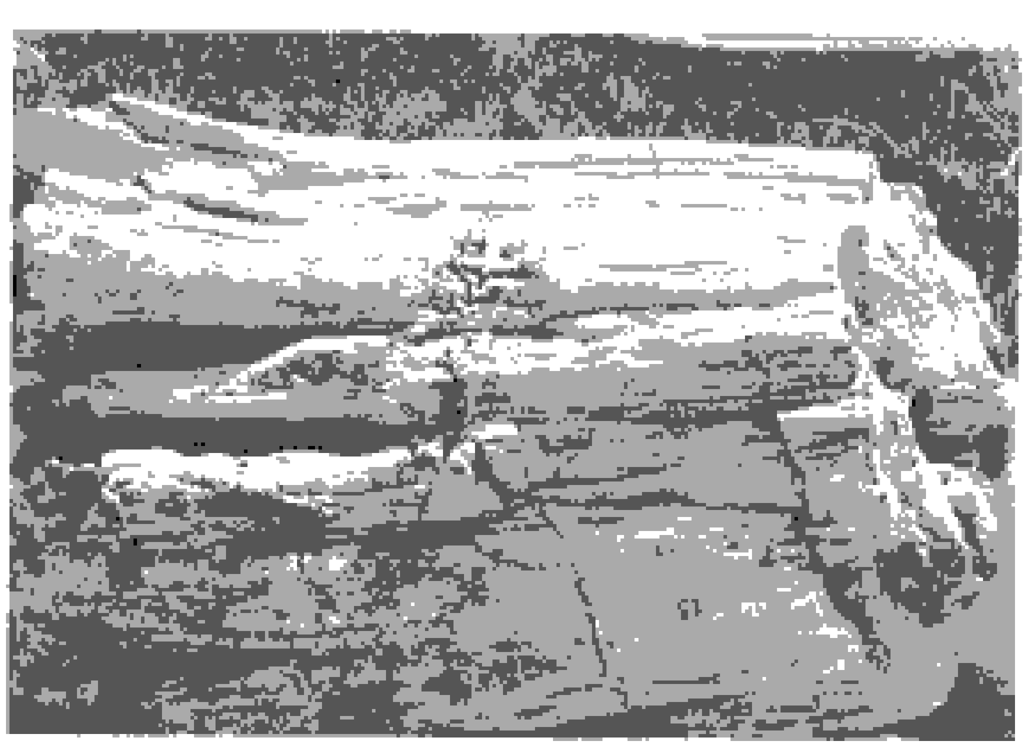


Fig. 29. Fossilized trunk from Limnos.

Fig. 30. Fossilized trunk from Limnos.

1.6 Protection of the fossil forests

The great importance of the above natural monuments leads to the necessity of a study for the conservation, protection and publicity of those fossilized - petrified forests. The main deterioration factors affecting those materials are soluble salts crystallisation, temperature variations and frost damage in the fossilized forest material.

2. PHYSICOCHEMICAL DATA - ANALYSIS OF THE FOSSILIZED MATERIALS - MAIN FACTORS OF CORROSION

2.1 Common data (fossilisation, degree, porosity, hardness)

Totally, for all fossilized forests of Greece, there are the following data:

1. Procedure of fossilization:
Volcanic action - Ion exchange between Si and C (replacement of C of wood by Si).

2. Degree of fossilization:
1. Lesvos: Very high - High.
2. Kastoria: High - Medium.
3. Evros: High.
4. Evia: High - Medium.
5. Limnos: Very high - High.

3. Porosity (average):
1. Lesvos: 19,24 mm^3/gr.
2. Kastoria: 22,1 mm^3/gr.
3. Evros: 20,4 mm^3/gr.
4. Evia: 22,7 mm^3/gr.
5. Limnos: 17,2 mm^3/gr.

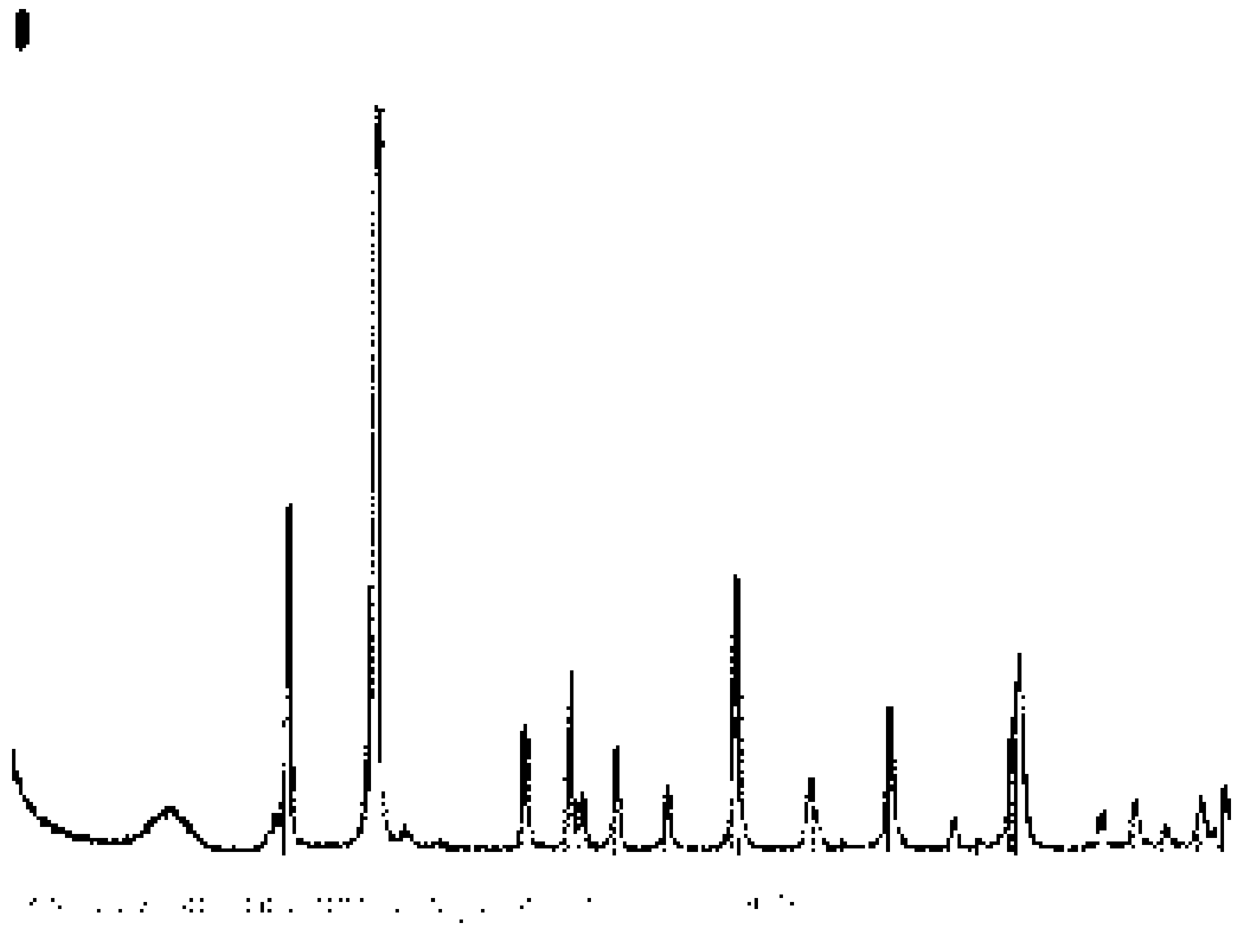
4. Hardness (average):
1. Lesvos: 7,2 Mohs.
2. Kastoria: 6,9 Mohs.
3. Evros: 7,1 Mohs.
4. Evia: 6,8 Mohs.
5. Limnos: 7,4 Mohs.

2.2 Special data (SEM – XRD)

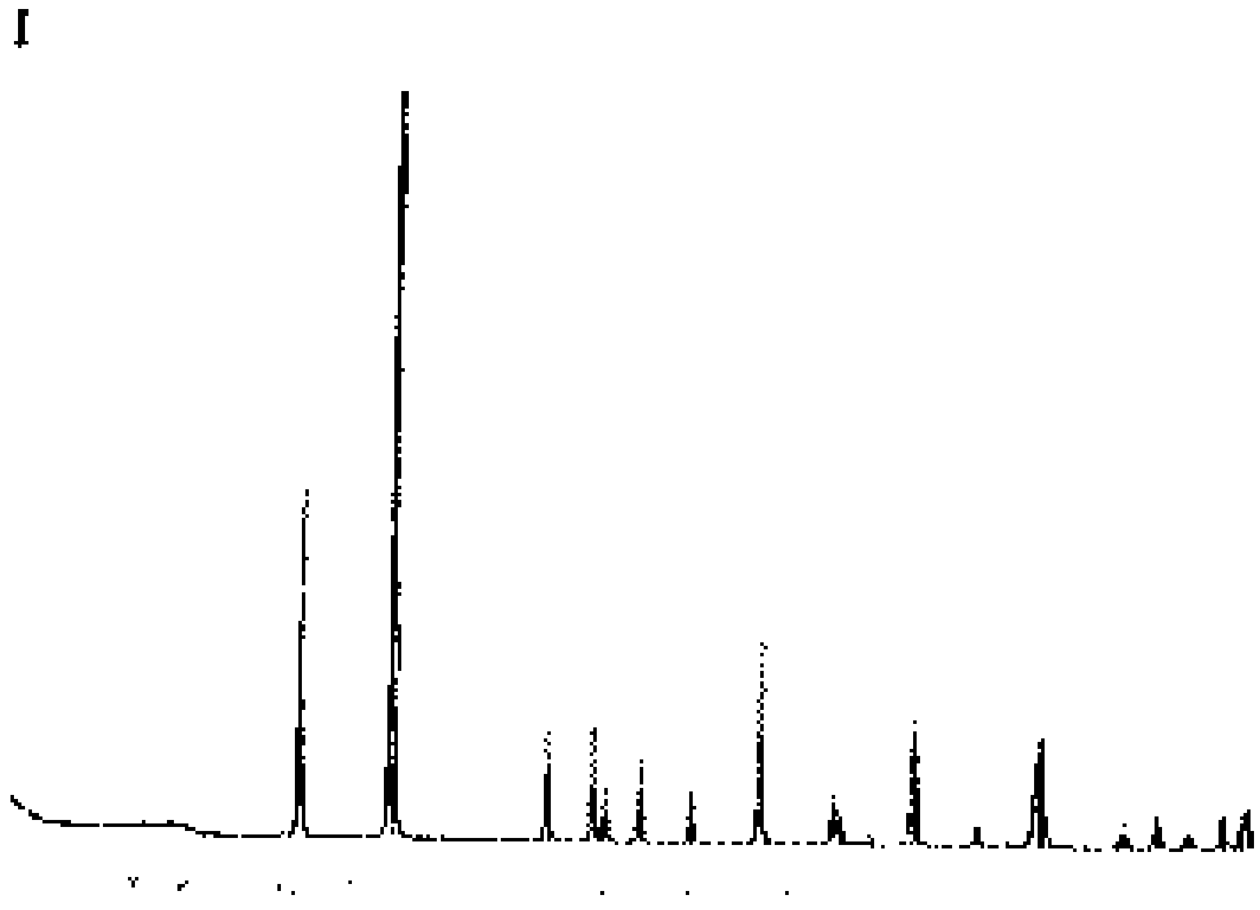
Tests were done on 7 samples of fossilized material, for estimation of physicochemical properties and analysis of structure material (S.E.M., X-R.D., optical microscopy, chemical analysis, water absorption, porosity and hardness).

The samples consist of 95% SiO_2, which is mostly in the presence mainly of quartz and small amounts of tridymite and christobalite. There are also in small quantity oxides of Fe, Al, K, Na, Cl, Ti, Ca, Mg, Mn:

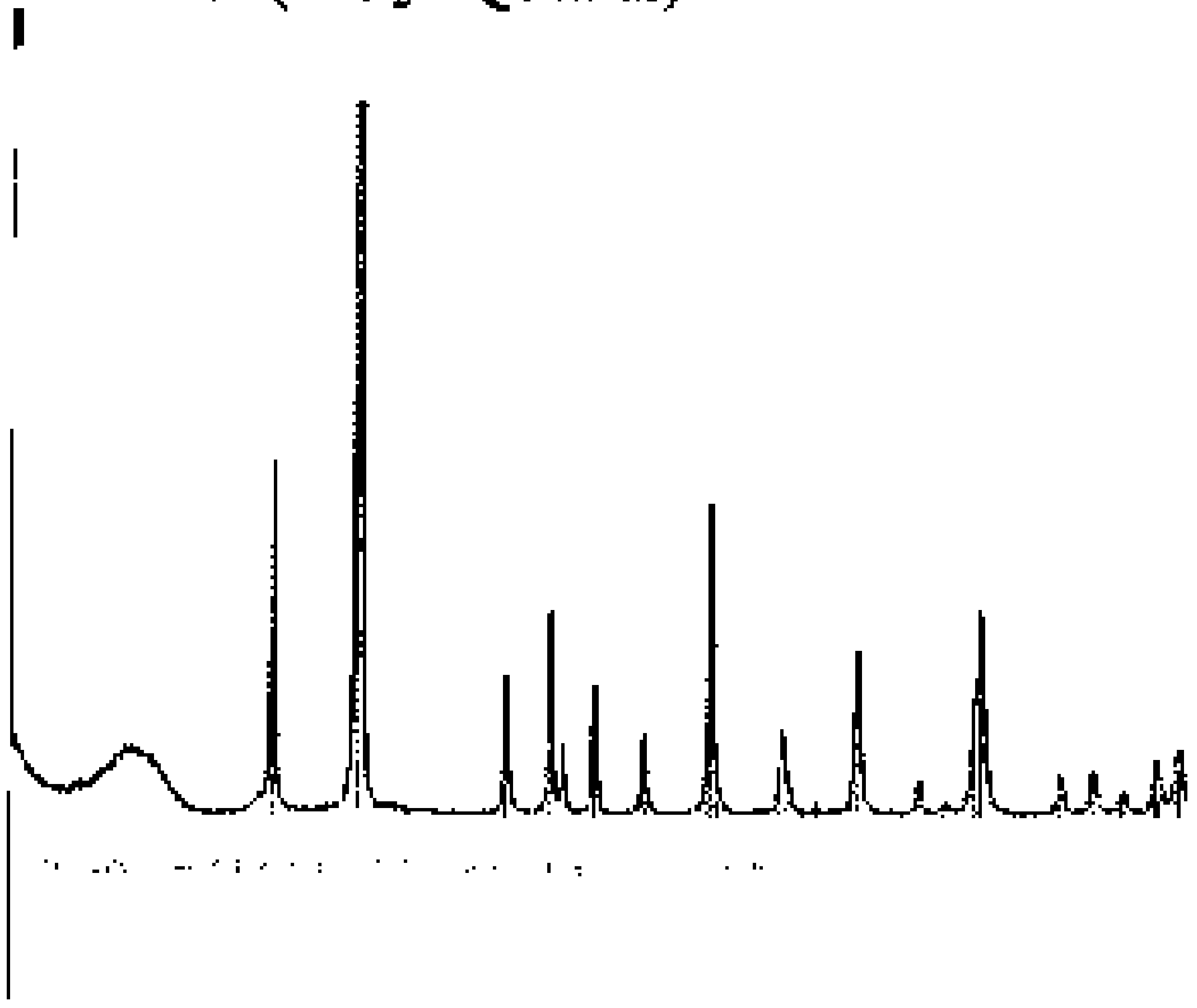
2.2.1 X-R.D. Analysis



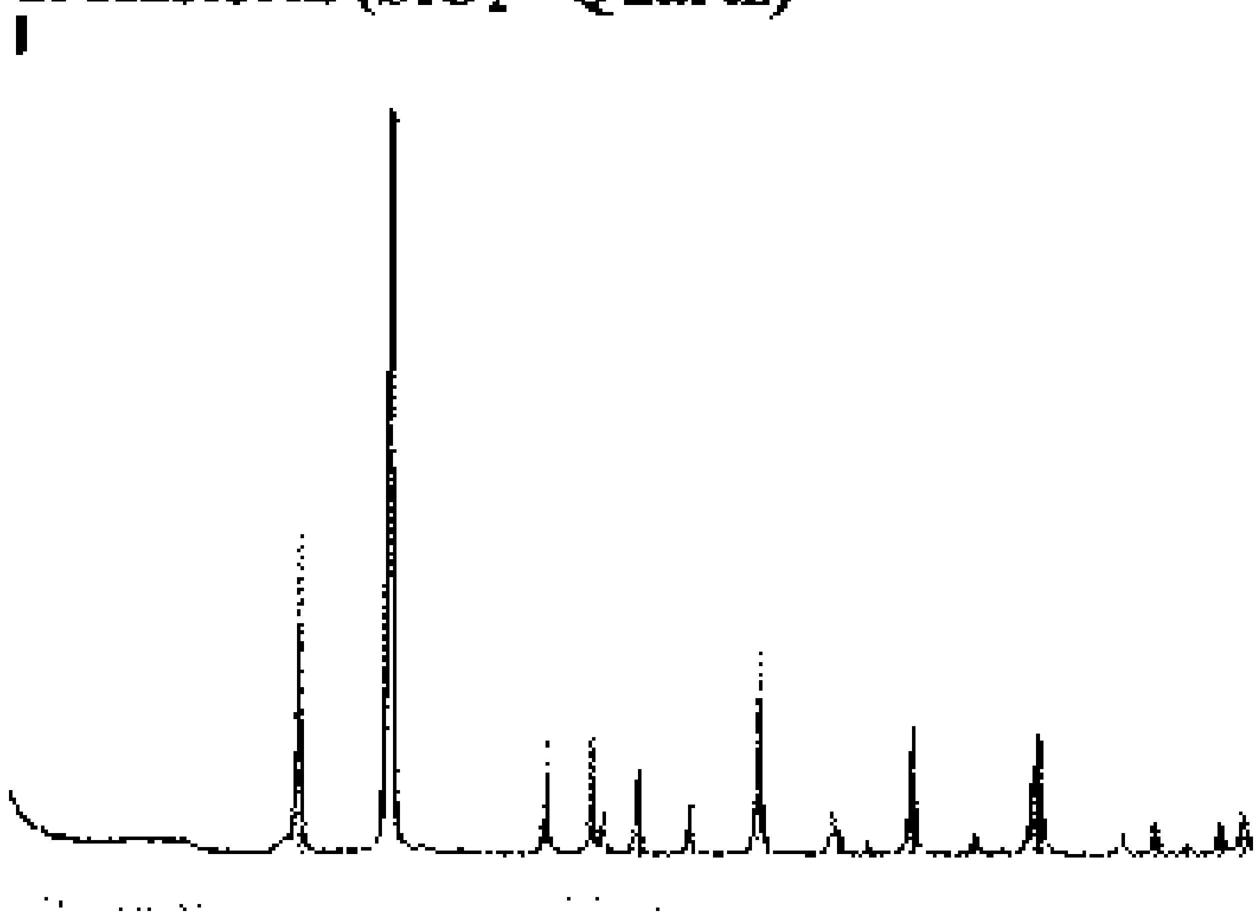
1. Lesvos (SiO_2 - Quartz)



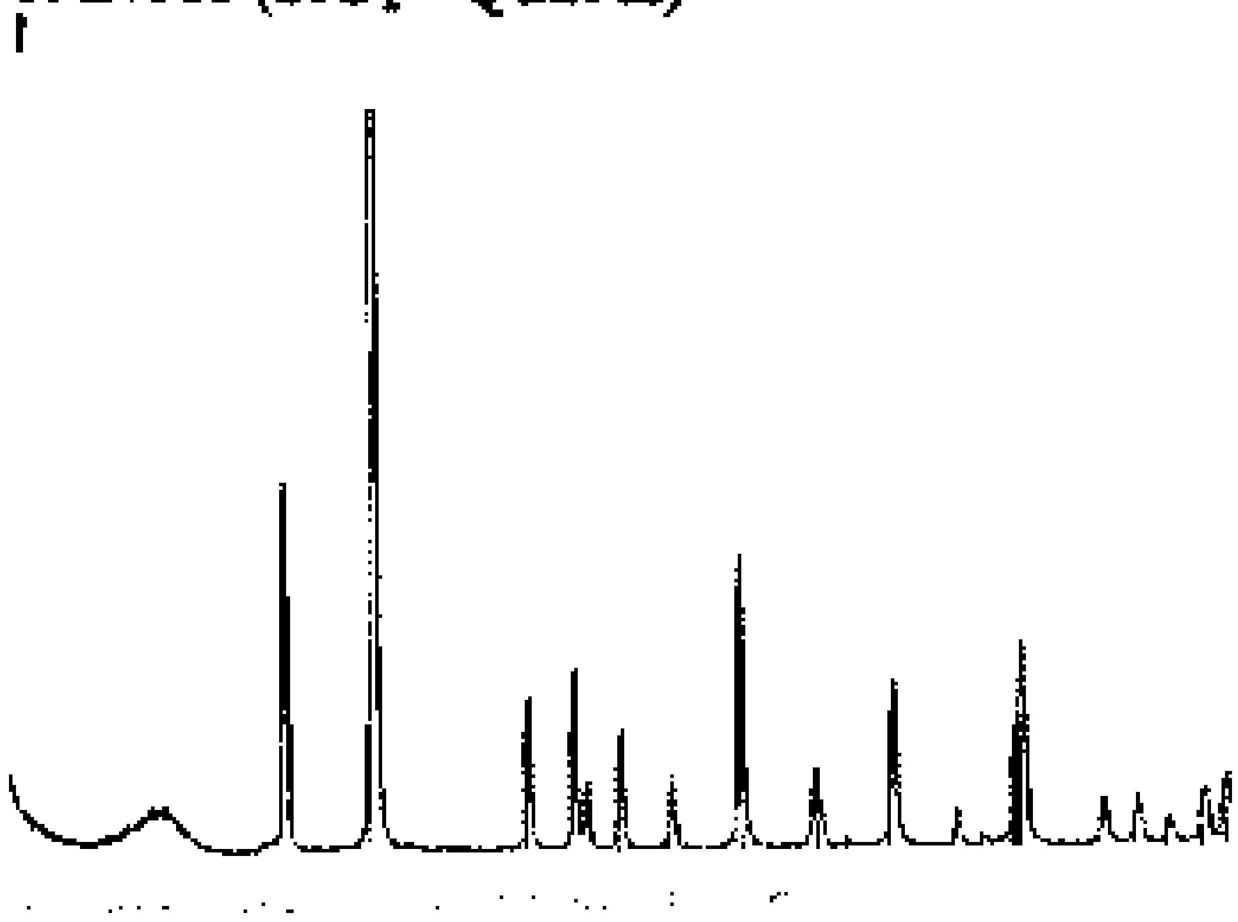
2. Kastoria (SiO_2 - Quartz)



3. Evros (SiO_2 - Quartz)

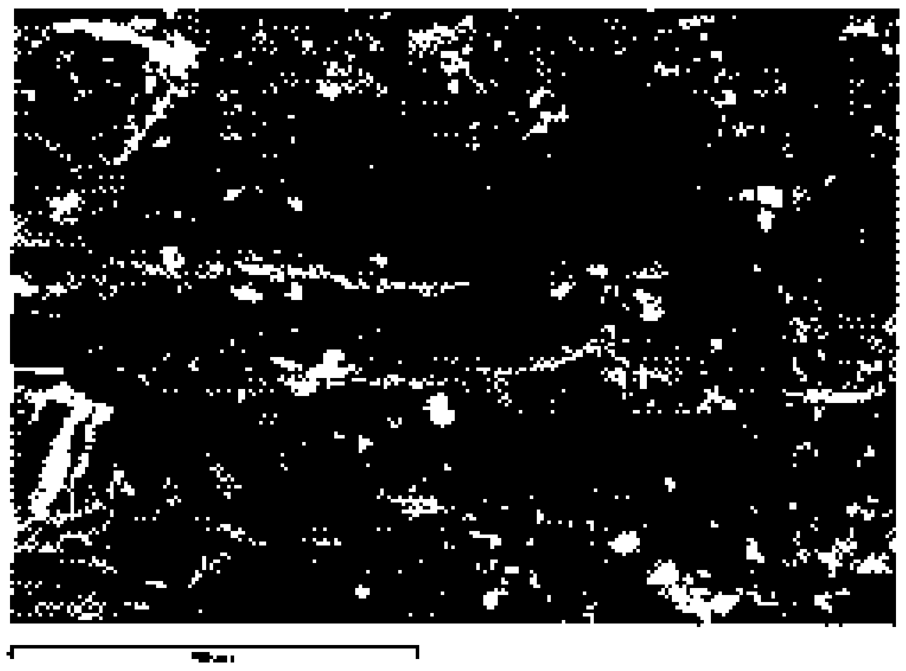


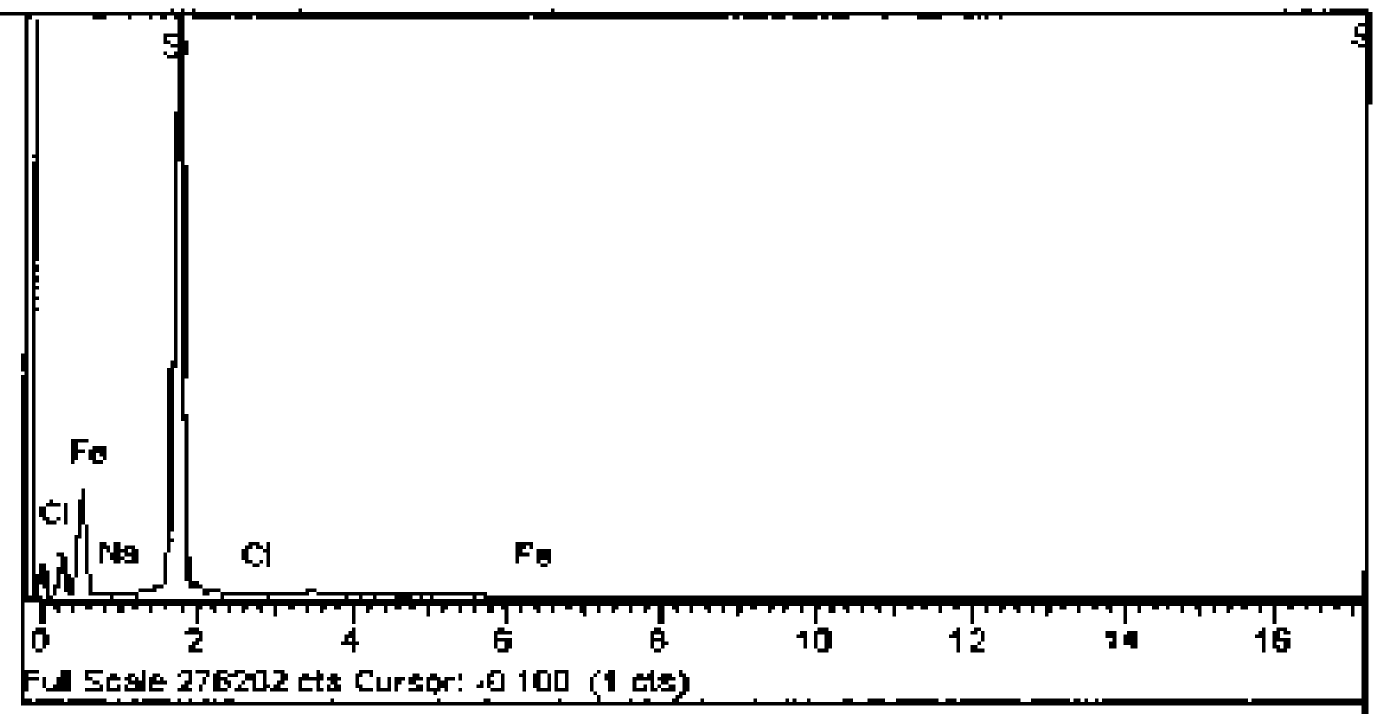
4. Evia (SiO_2 - Quartz)



5. Limnos (SiO_2 - Quartz)

2.2.2 S.E.M. – E.D.X.A. Analysis

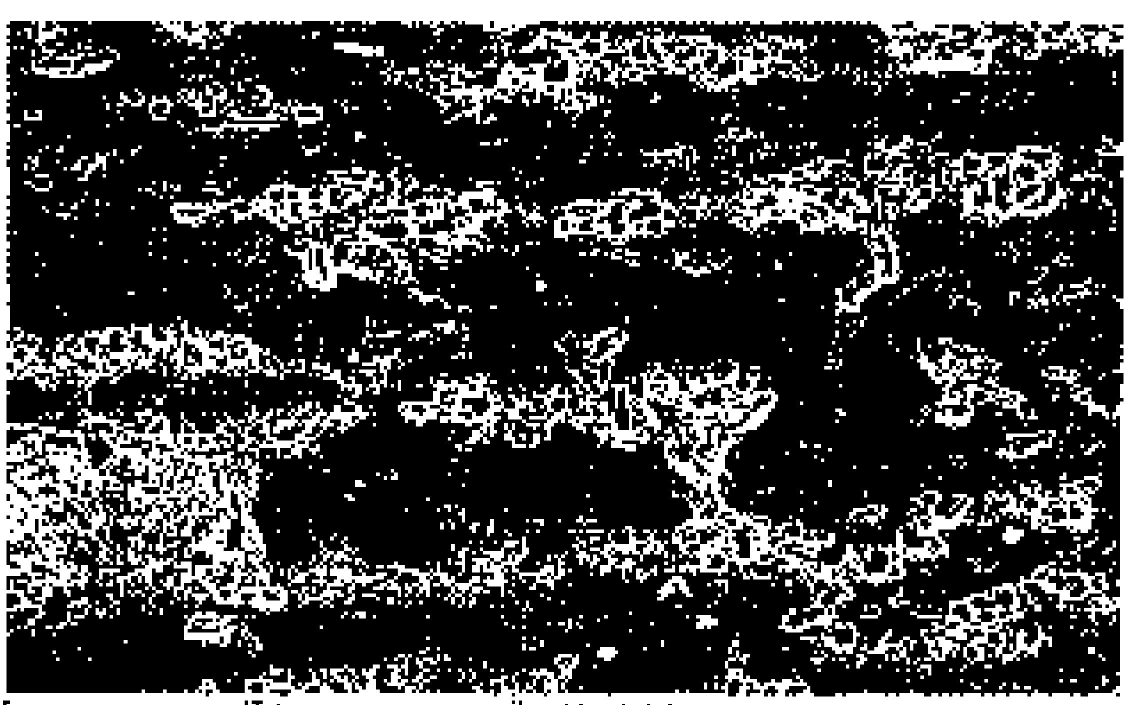


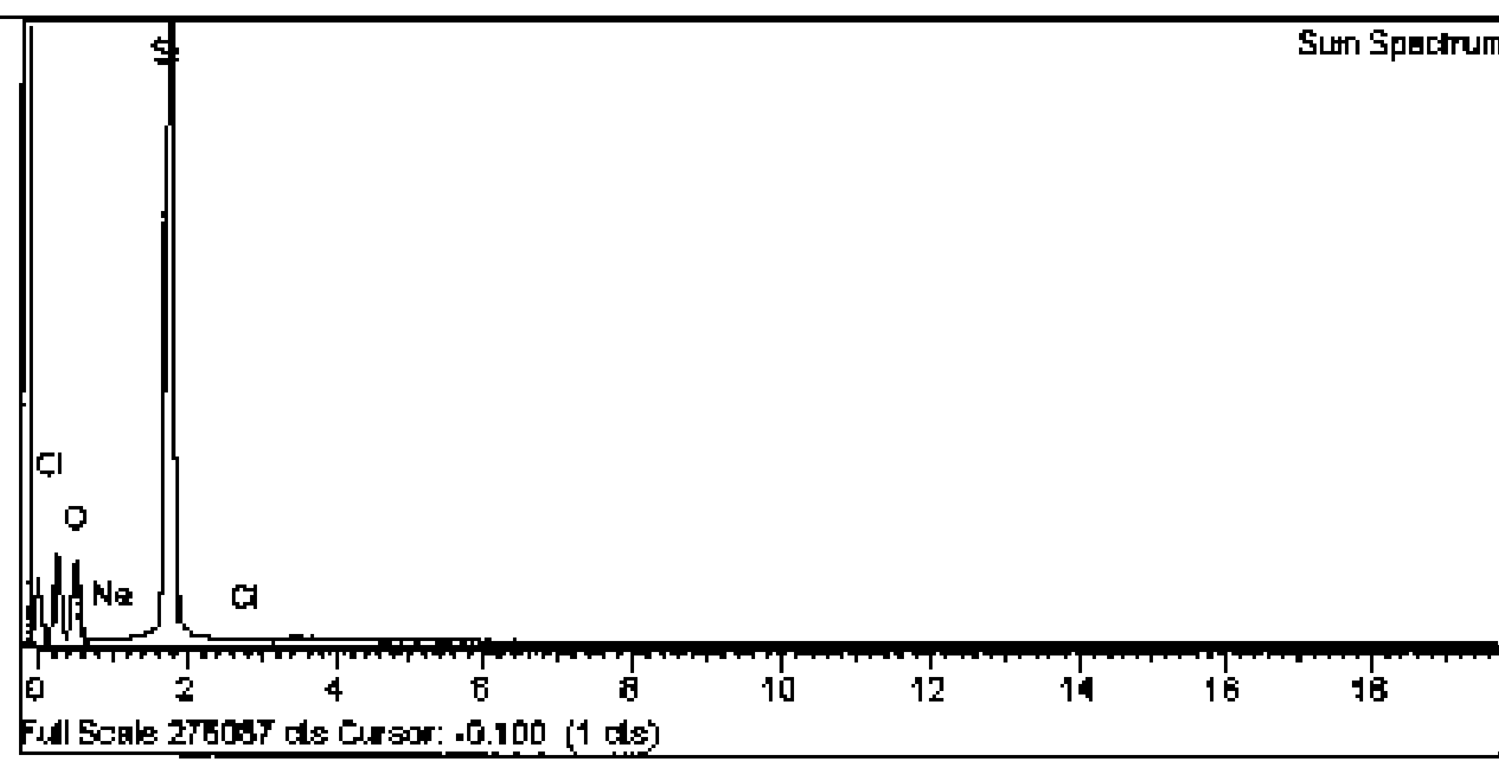


x750

Lesvos

Element	Weight (%)	Compound (%)	Formula
Si K	46.54	99.56	SiO_2
Na K	0.17	0.23	Na_2O
Fe K	0.11	0.21	FeO
Cl K	0.07	0.00	
O	53.11		
Totals	100.00	100.00	

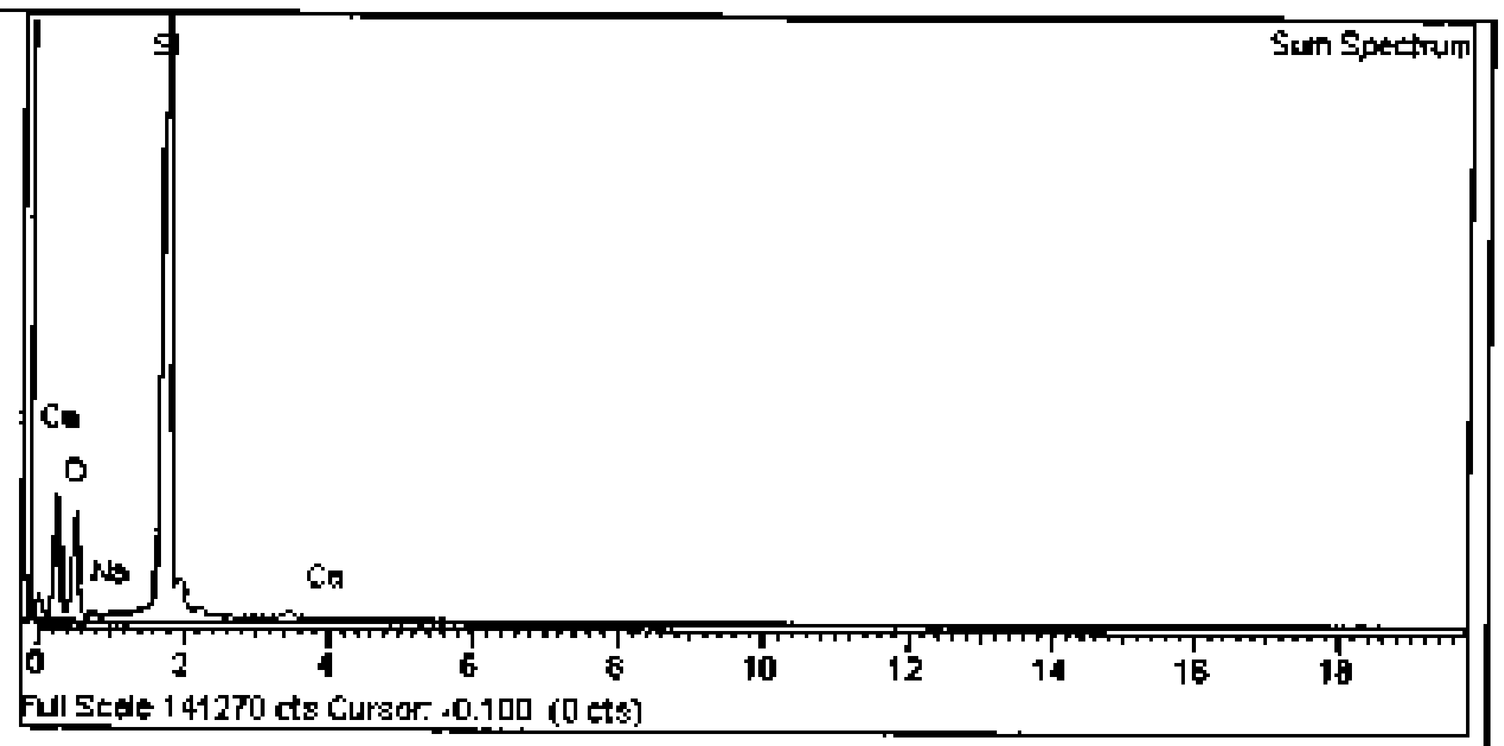




x1000

Kastoria

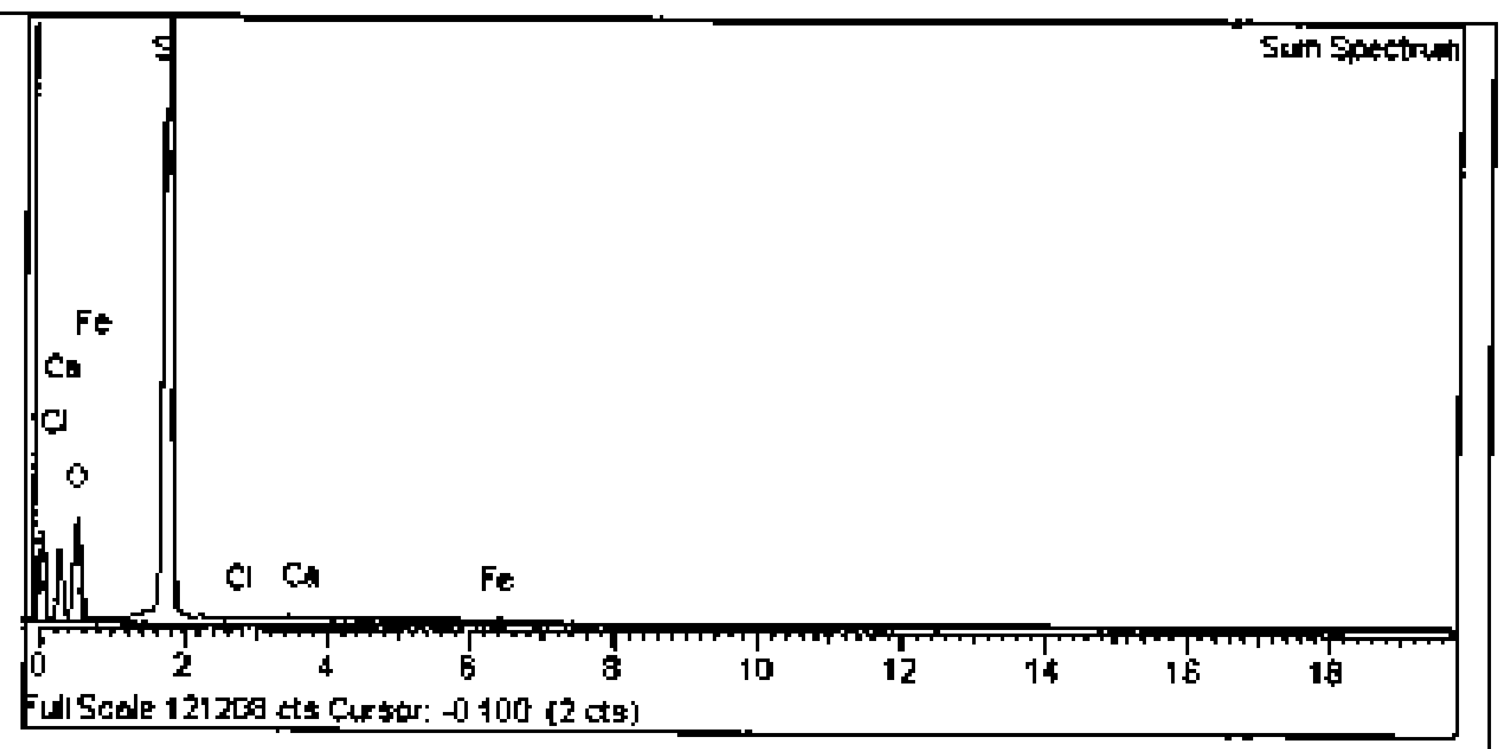
Element	Weight (%)	Compound (%)	Formula
Si K	46.65	99.81	SiO_2
Na K	0.09	0.19	Na_2O
Cl K	0.08	0.00	
O	53.18		
Totals	100.00	100.00	



x70

Evros

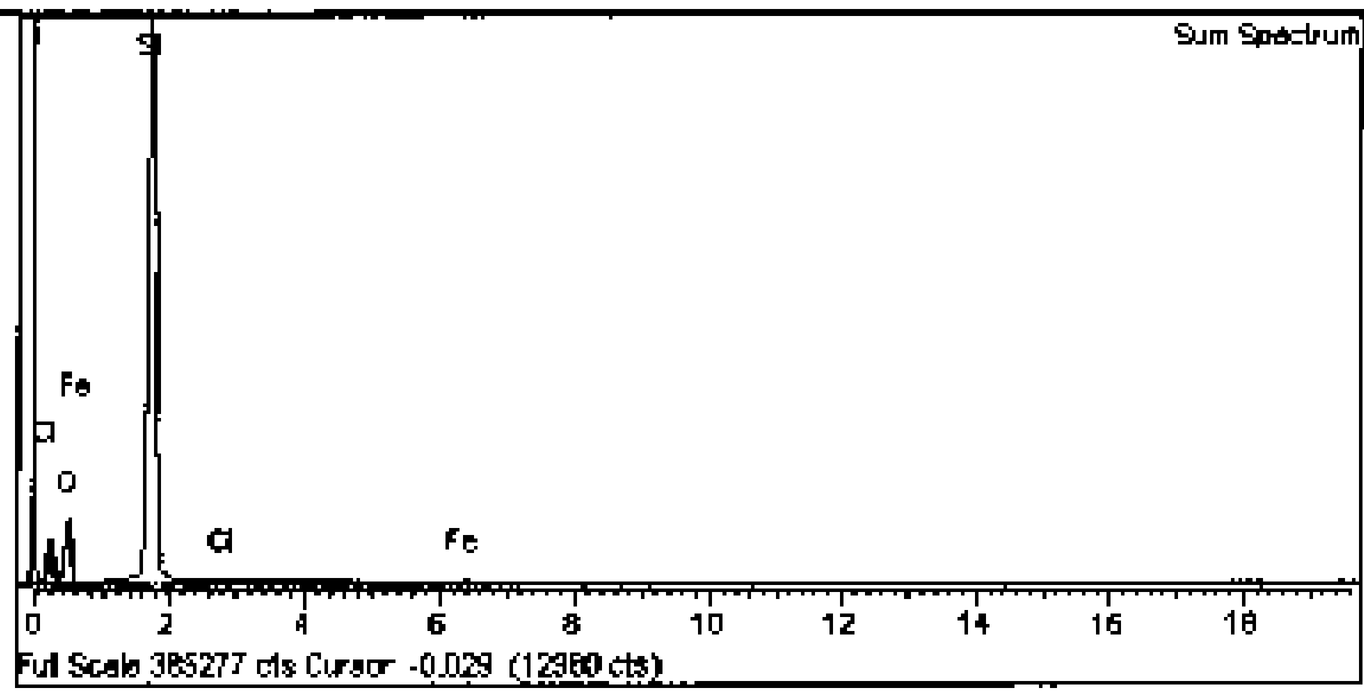
Element	Weight (%)	Compound (%)	Formula
Si K	46.67	99.84	SiO_2
Na K	0.13	0.15	Na_2O
Ca K	0.01	0.01	CaO
O	53.19		
Totals	100.00	100.00	



x500

Evia

Element	Weight (%)	Compound (%)	Formula
Si K	46.56	99.60	SiO_2
Fe K	0.16	0.26	FeO
Ca K	0.10	0.14	CaO
Cl K	0.05	0.00	
O	53.13		
Totals	100.00	100.00	



x350

Limnos

Element	Weight (%)	Compound(%)	Formula
Si K	46.52	99.61	SiO_2
Fe K	0.30	0.39	FeO
Cl K	0.09	0.00	
O	53.09		
Totals	100.00	100.00	

Soluble salts are one of the main deterioration factors for stone materials and fossils (TORRACA 1988, LAMPROPOULOS 1993, CHILD 1994). Most important are the actions of sodium chloride and sodium sulphate, which under varying temperature and humidity conditions are crystallised into the pores of the material thus developing mechanical stresses.

The action of soluble salts is very decisive for porous materials like fossils (AMOROSO & FASINA 1983, CHILD 1994). Soluble salts that may enter into the pores of the material, are mainly chlorides and sulphates and secondly the carbonates, nitrates and nitrites of alkalis and alkaline earths. Their provenance may be (LAMPROPOULOS 1993, CHILD 1994) in the case of fossilized - petrified forests:

- The sea, where sodium chloride is contained in a percentage of 3,5% w/v and in non-polluted sea the ratio of sulphate ions to chloride ions is around 0,139. For distances of about 15 km away from the sea, salts can be transported by saltspray phenomenon.

- Underground water, where the soluble salts rise through capillary ascension of water from the underground via the rocks, carrying along -through the soil- the soluble components of aluminium - silica rocks in particular, and other rocks as well, containing diluted salts in various concentrations (see Table 1).

- sodium (Na^+)
- potassium (K^+)
- magnesium (Mg^{2+})
- calcium (Ca^{2+})
- sulphates (SO_4^{2-})
- carbonates (CO_3^{2-})
- chlorides (Cl^-)
- silicates (SiO_3^{2-})

Table 1. List of ions of several soluble salts in underground water.

- Possible contact with structure materials or plasters-mortars, i.e. cements, which are important sources of soluble sulphates, carbonates and silicates salts. Additionally, possible contacts of the fossilized material with cement, i.e. from fillings of missing parts, may cause a flow of sulphate salts into the pores of the material.

The most common soluble salts that may form efflorescences (WHEELER, 1993) on the surface and circulate in the pores of the fossilized material are presented (see Table 2).

- sylbite	KCl
- pikromerite	$K_2Mg(SO_4)_2.6H_2O$
- sygenite	$K_2Ca(SO_4)_2$
- glasserite	$(Na,K)_2SO_4$
- polyalite	$K_2Ca_2Mg(SO_4)_4.2H_2O$
- arkanite	K_2SO_4
- halite	$NaCl$
- nitratite	$NaNO_3$
- thermonatrite	$Na_2CO_3.H_2O$
- natrite	$Na_2CO_3.10H_2O$
- tenardite	Na_2SO_4
- mirabilite	$Na_2SO_4.10H_2O$
- nitrocalcite	$Ca(NO_3)_2.4H_2O$
- antarkticite	$CaCl_2.6H_2O$
- gypsum	$CaSO_4.2H_2O$
- bassanite	$CaSO_4.1/2H_2O$
- nitromagnesite	$Mg(NO_3)_2.6H_2O$
- hydromagnesite	$Mg_5(OH(CO_3)_2)_2.4H_2O$
- astrakanite	$MgSO_4.Na_2SO_4.4H_2O$
- magnesite	$MgCO_3$
- kieserite	$MgSO_4.H_2O$
- neskeonite	$MgCO_3.3H_2O$
- epsomite	$MgSO_4.7H_2O$
- bissofite	$MgCl_2.6H_2O$
- kalikinite	$KHCO_3$
- ammonium nitrate	NH_4NO_3
- hexadrite	$MgSO_4.6H_2O$
- nitre	KNO_3

Table 2. The most common soluble salts that may form efflorescences.

When dilution of various salts happens in the pores of a porous material, under saturation or over-saturation point conditions, these salt crystals start to be formed inside the pores. These crystals increase in volume, as they are supplied by the continuous dilution in the capillary network and thus generate/impose pressure - stresses on the pore walls. This pressure - stresses will increase, the larger the relation will be between the existing salt concentration and its concentration of saturation and it is given by the formula (1):

$$P = (R \cdot T/Us) \cdot \ln(C/Cs) \quad (1)$$

Where:

P = crystallisation pressure in Atms.

R = constant of noble gases which equals 0.082 lt·atm/mole·grad.

T = absolute temperature in °K.
Us = molecular volume of solid salt in lt/mole.
C = present concentration of the salt in moles/lt.
Cs = concentration of the saturated salt moles/lt.

Sodium sulphate which comes in contact with water, inside the pores, at 32,4 °C, is transformed from rhombohedric tenardite into monoclinic mirabilite, in according to the following reaction:

$$Na_2SO_4 + 10H_2O \rightleftharpoons Na_2SO_4 \cdot 10H_2O$$

At this time there is a corresponding volume increase of 308%, while in the atmosphere this transformation happens in a lower temperature and the maximum of mechanical stresses - pressures occurs at 20 °C (AMOROSO AND FASINA 1983, LAMPROPOULOS 1993).

The volume increase which follows the above mentioned transformations, produces very large mechanical pressures - stresses in the pores, many times greater than the material's resistance, thus resulting in surface fractures and degradation of the material.

Chloride alkalis or alkaline earths salts, due to their greater mobility in relation to sulphate and carbonates, penetrate the pores of the material, where they crystallise and loosen many crystalline structures. They also cause "digestion", that is the dilution of colloidal parts of clays in water and thus facilitate more the dilution of magnesium, which originates from the material.

The deposition of insoluble salts, like siliceous, carbonate, sulphate, on the fossil's surface, apart from causing aesthetic alteration to the material, also creates mechanical stresses on the conduction area by contraction - expansion, and thus leading to degradation of the material.

Exposure in open air may cause degradation of the petrographic material, according to the following procedure:

Under certain conditions of temperature and humidity, soluble salts, which are contained inside the pores, are crystallised, thus resulting in mechanical stresses and fractures, according to the previously mentioned mechanisms (see fig. 2, 4, 7, 12, 19, 20).

Finally the frost damage, with the increase of the volume of the water about 9,2%, from the fluid to the solid and temperature variations, creates mechanical stresses in the porosity of the material (see fig. 6, 8, 10, 12, 14, 19).

3. OBJECTIVE

The present paper, contributes to developing non-destructive methods for the determining of the degradation patterns like the frost damage and the presence and crystallisation of soluble salts in the petrographic material of the fossilized forest of Lesvos, Kastoria, Evros, Evia and Limnos, so that a conservation strategy can be developed and a formation of a program of action to protect this material. The development of non-destructive methods of determination of the degree and the parameters of degradation - deterioration of monuments of our natural heritage is considered of critical importance for their effective management. An extensive list of accurate identification methods of susceptible minerals has been presented (HOWIE 1992).

4. MATERIALS AND METHODS

The presence of soluble salts in the petrographic material of the fossilized forest of Lesvos, Kastoria, Evros, Evia and Limnos, was determined by the application of neutral paper pulps wetted in de-ionised water, in various surfaces for one hour and then by analysing the absorbed ions, chloride (Cl^-) and sulphate (SO_4^{2-}), by the use of Analytical Chemistry determination methods, performed in the Laboratory of Inorganic Chemical Analysis of the Food Technology department in

T.E.I. of Athens. The measuring of the specific electrical conductivity of the obtained samples/solutions was done in the laboratory of Conservation of Ceramics/Glass-Organic materials in the Department of Conservation of Antiquities and Works of Art, in T.E.I. of Athens. Sample 5 is de-ionised water and was used as a comparison towards the other results of the study.

From the next Tables 3, 4, 5, 6, 7, it is clear that important quantities of soluble chloride and sulphate salts exist on the surface and the pores of the material of the fossilized forests of Lesvos and Limnos and it is clear that low quantities of soluble chloride and sulphate salts exist on the surface and the pores of the material of the fossilized forests of Kastoria, Evia and Evros.

Table 3. Results of chemical analysis in paper pulps from fossilized trunks of Sigri - Lesvos.

Lesvos

I/n	Cd ($\mu S/cm^2$)	Cl^- (ppm)	SO_4^{2-} (ppm)
Sample 1	204	20,5	4,5
Sample 2	258	30,5	5,5
Sample 3	153	31,5	6
Sample 4	219	16	3,5
Sample 5	5	1	0

Table 4. Results of chemical analysis in paper pulps from fossilized trunks of Nostimo - Kastoria.

Kastoria

I/n	Cd ($\mu S/cm^2$)	Cl^- (ppm)	SO_4^{2-} (ppm)
Sample 1	122	12,5	1,2
Sample 2	135	19,5	1,7
Sample 3	96	21	1,3
Sample 4	127	8,5	0,9
Sample 5	5	1	0

Table 5. Results of chemical analysis in paper pulps from fossilized trunks of Evros.

Evros

I/n	Cd ($\mu S/cm^2$)	Cl^- (ppm)	SO_4^{2-} (ppm)
Sample 1	118	13	1,4
Sample 2	113	17,9	1,8
Sample 3	102	15,3	1,2
Sample 4	121	11,1	1,1
Sample 5	5	1	0

Table 6. Results of chemical analysis in paper pulps from fossilized trunks of Evia.

Evia

I/n	Cd ($\mu S/cm^2$)	Cl^- (ppm)	SO_4^{2-} (ppm)
Sample 1	159	18,6	3,3
Sample 2	164	17,1	2,7
Sample 3	168	21,6	3,5
Sample 4	147	16,4	2,9
Sample 5	5	1	0

Table 7. Results of chemical analysis in paper pulps from fossilized trunks of Limnos.

Limnos

I/n	Cd (μS/cm^2)	Cl^- (ppm)	SO_4^{2-} (ppm)
Sample 1	**222**	**25,6**	**5,2**
Sample 2	**236**	**38,1**	**6,3**
Sample 3	**198**	**36,2**	**4,9**
Sample 4	**172**	**22,8**	**5,4**
Sample 5	**5**	**1**	**0**

Additionally, climatological data of the areas were gathered and tables of temperature and relative humidity were drawn, in order to establish the areas of soluble salt crystallisation and the presence of frost (see fig. 31). Temperature and humidity variations, which are present as is shown from the next diagrams, create mechanical stresses in the porosity of the materials.

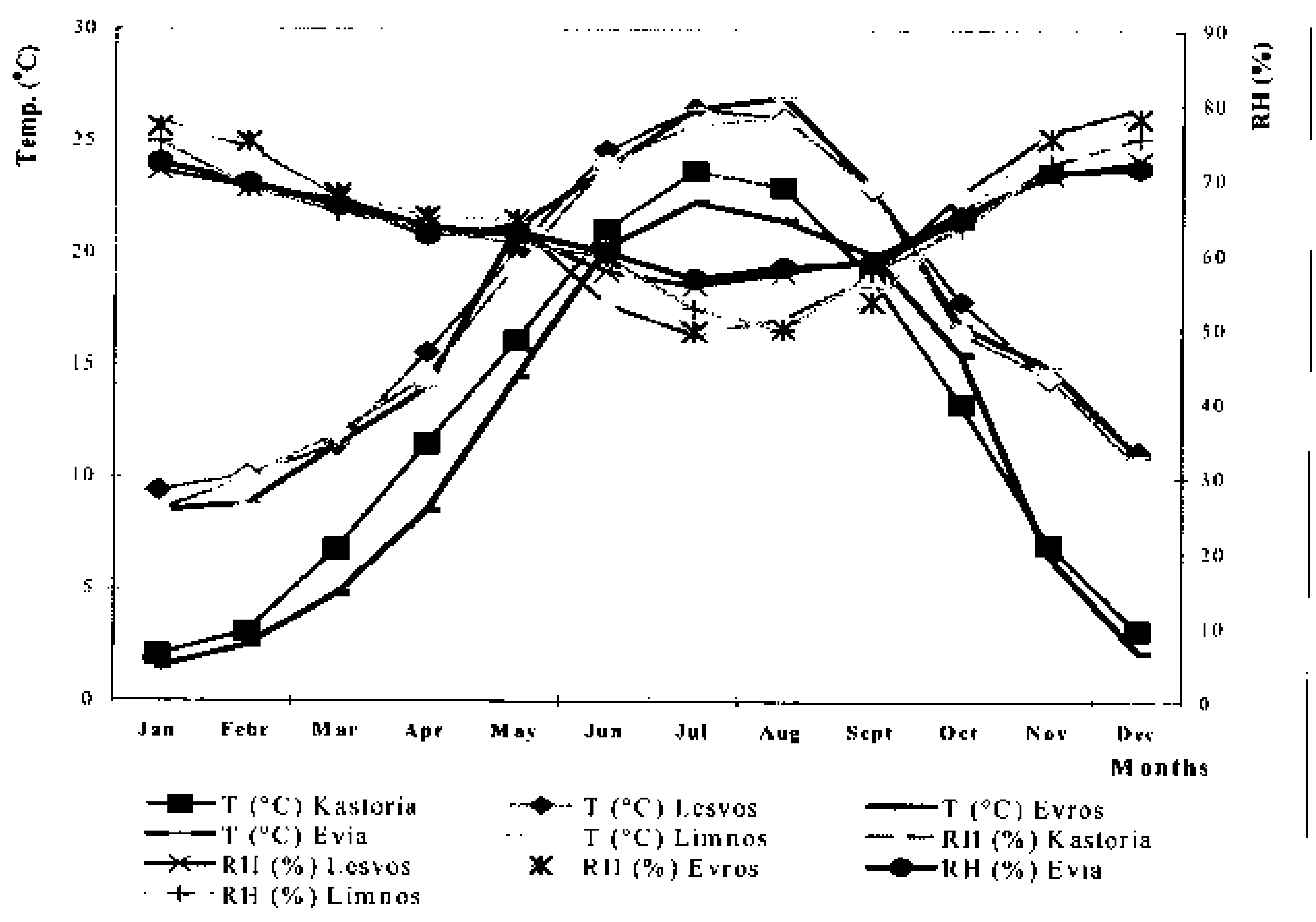


Figure 31. Diagram of mean temperature and relative humidity per month of Lesvos, Kastoria, Evros, Evia and Limnos regions for the period from 1955 to 1997.

Then these diagrams were correlated with the V. Furlan diagram, to establish the areas of crystallisation of sodium sulphate, for each month of the year and for the period 1955 – 1997 (see fig. 32 – 36).

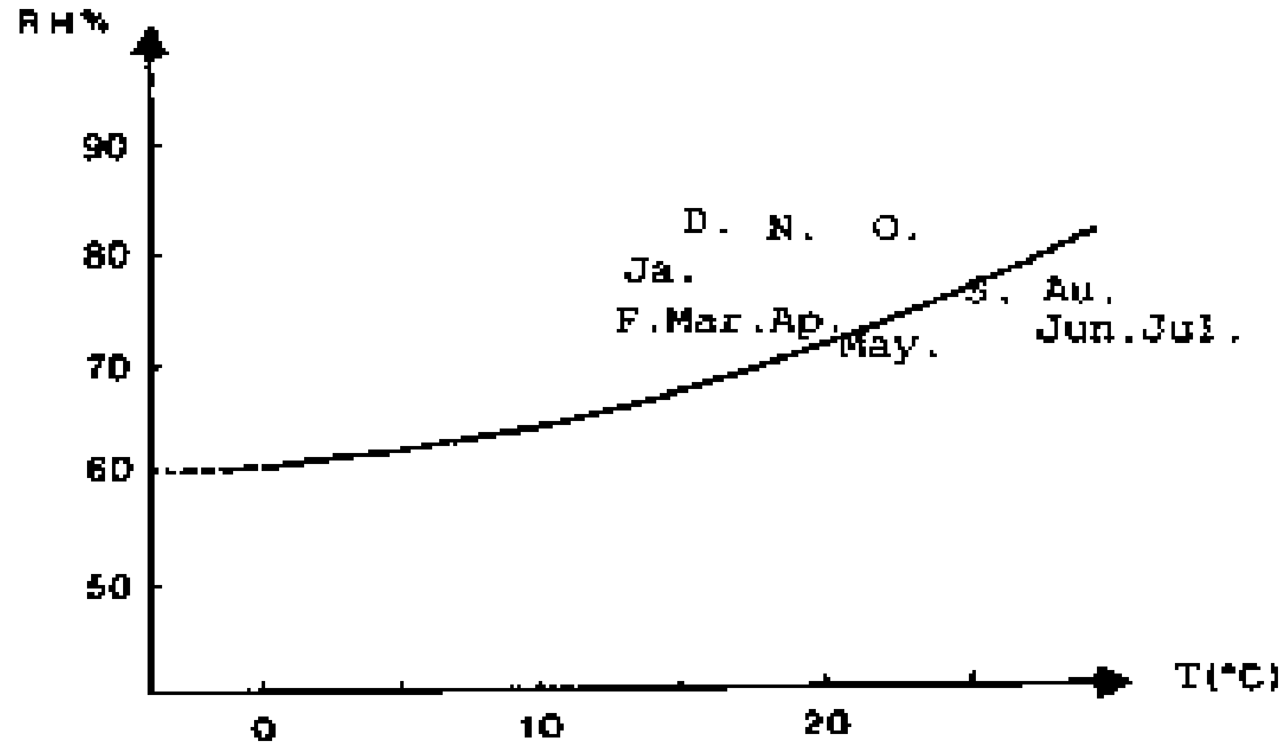


Figure 32. Furlan diagram of fossilized forest of Lesvos, and combination points between temperature and relative humidity per month during the years 1955 - 1997. Every point represents a different month.

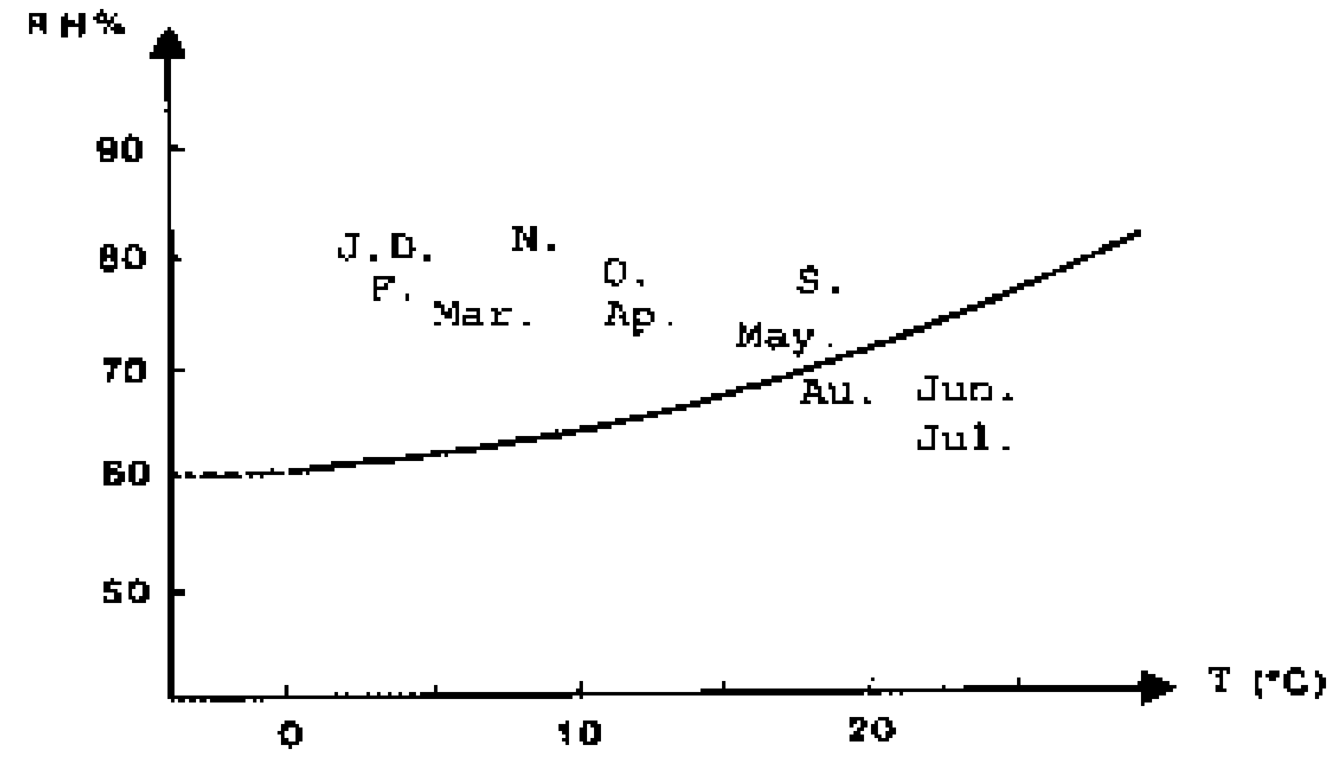


Figure 33. Furlan diagram of fossilized forest of Kastoria and combination points between temperature and relative humidity per month during the years 1955 - 1997. Every point represents a different month.

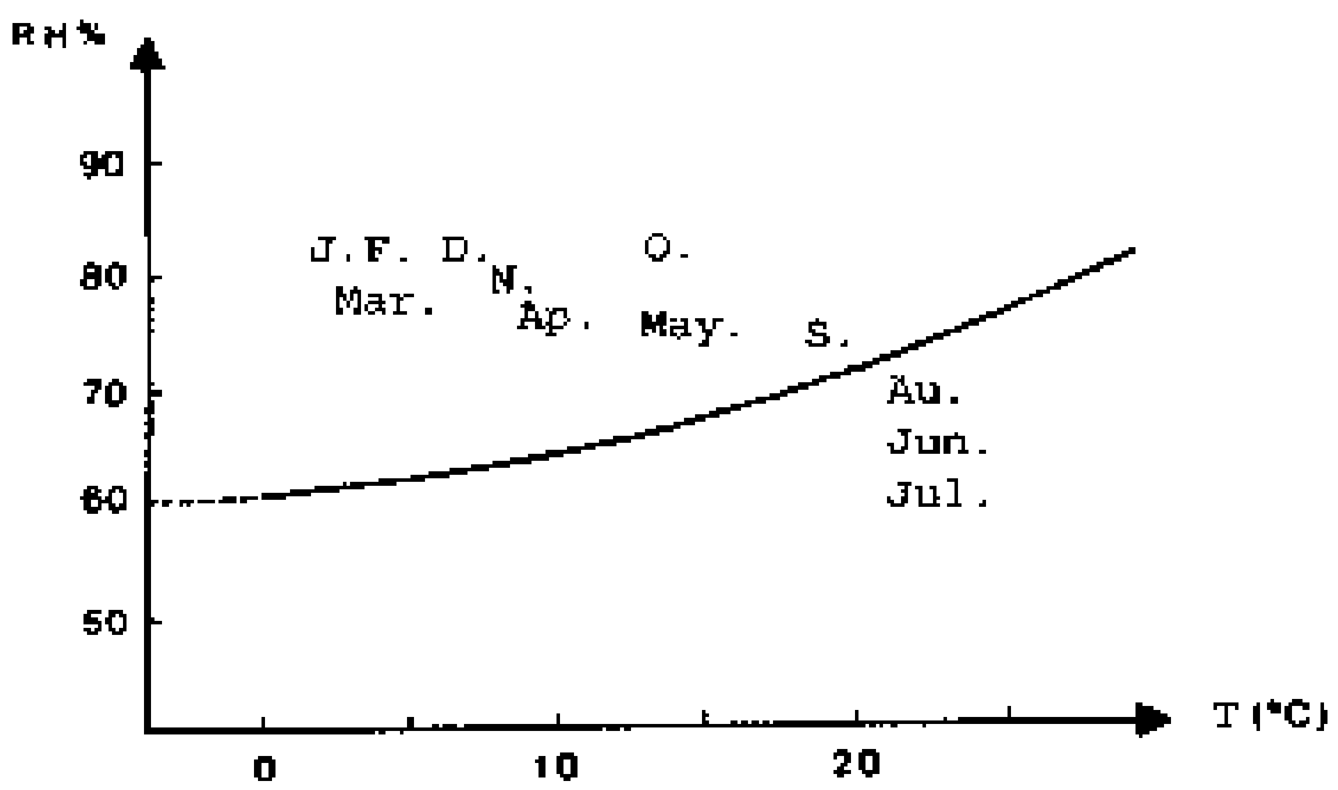


Figure 34. Furlan diagram of fossilized forest of Evros and combination points between temperature and relative humidity per month during the years 1955 - 1997. Every point represents a different month.

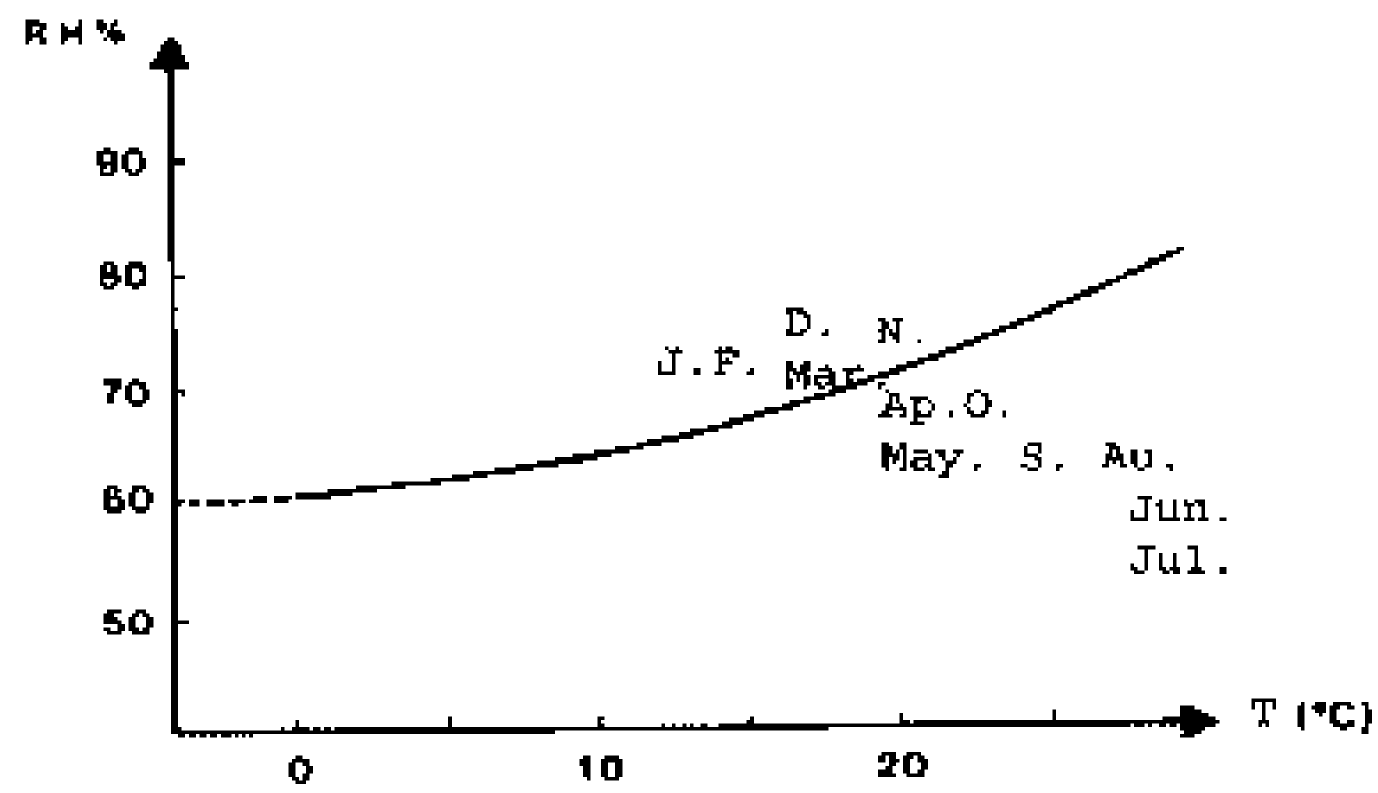


Figure 35. Furlan diagram of fossilized forest of Evia and combination points between temperature and relative humidity per month during the years 1955 - 1997. Every point represents a different month.

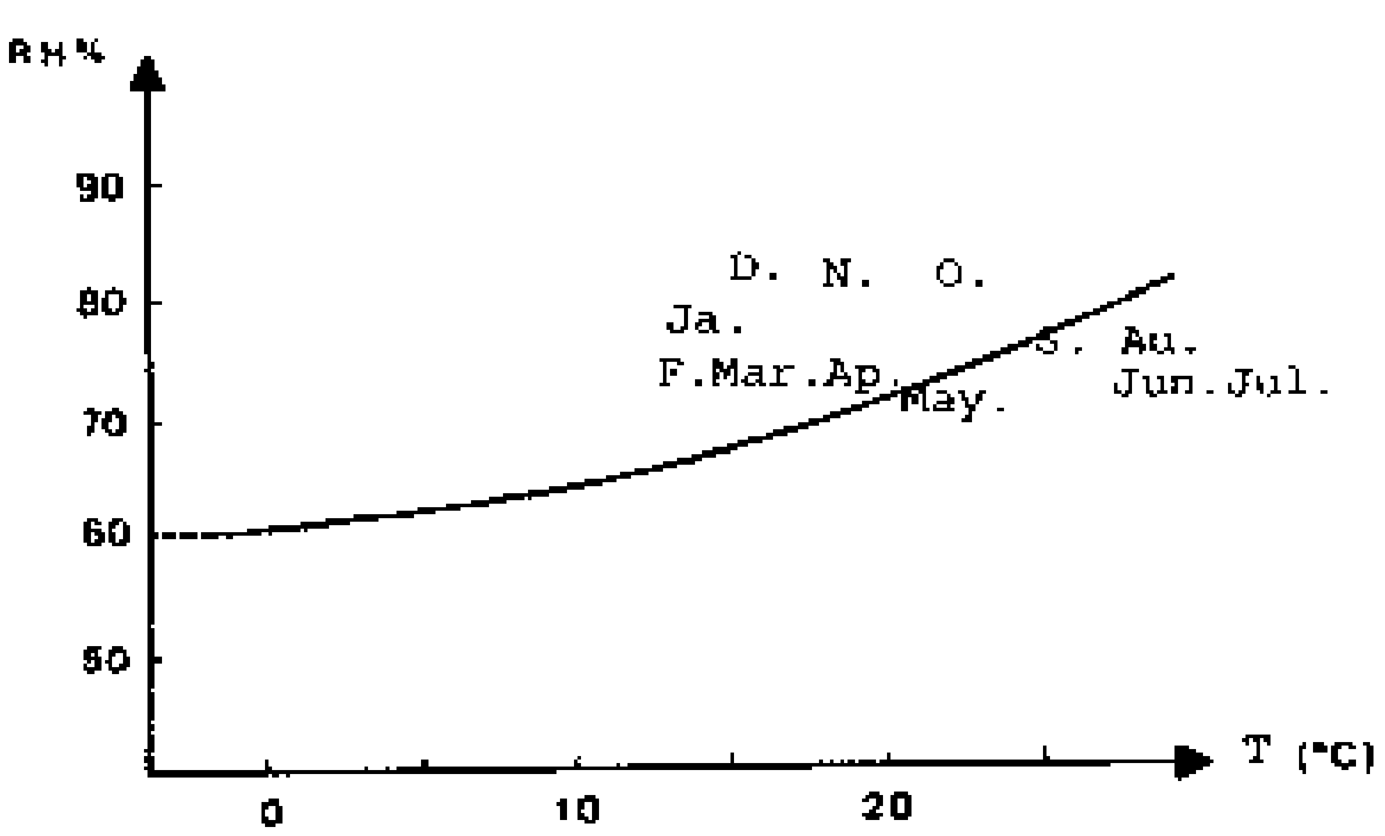


Figure 36. Furlan diagram of fossilized forest of Limnos and combination points between temperature and relative humidity per month during the years 1955 - 1997. Every point represents a different month.

5. RESULTS

The macroscopic study of the fossilized forest tree trunks showed the existence of the pattern of alveolar corrosion in many parts of the surface, as well as a large number of fractures (see fig. 2, 4, 5, 6, 23, 24, 28, 29). The processing of the climatological data is shown in the previous diagrams for temperature and relative humidity.

Finally the frost damage, during the months January, February and December and temperature - humidity variations, which are present as is shown from the previous diagrams, creates mechanical stresses in the porosity of the materials (see fig. 8, 9, 10, 11, 12, 14, 16, 17, 18).

6. DISCUSSION - CONCLUSIONS

In the case of fossilized forests of Lesvos and Limnos the action of soluble salts is primarily obvious by macroscopic observation of the alveolar corrosion pattern and efflorescences in many parts of the surface of the tree trunks from the fossilized forests. Then, the presence of soluble salts is also apparent by the presence of chloride and sulphate ions on the surface and in the pores of the material of the fossilized forests. Their crystallisation and their actions are shown in the V. Furlan diagrams, for all average months of the year and for the period 1955 - 1997.

From the previous diagrams, in the case of fossilized forest of Lesvos and Limnos, it is shown in Fourlan diagrams that during the months January, February, March, October, November and December, most plotted dots - combinations of temperature and relative humidity - are falling over the curve and therefore crystallisation of sodium sulphate occurs during these months in the pores of the material of the fossilized forests of Lesvos and Limnos. The transportation of soluble salts to the material of the fossilized forest of Lesvos and Limnos takes place due to the saltspray phenomenon. In most tree trunks of the fossilized forests of Lesvos and Limnos, there are cracks, which are due to the physical disintegration along the wood rays, but also to human intervention fact, which multiplies the above phenomena.

The relatively high porosity of the petrographic material of the fossilized forests of Lesvos and Limnos (LAMPROPOULOS ET al., 1997, 1999a) favours the penetration and crystallisation of soluble salts in the structure material of the fossilized forests.

The same material shows in several parts relatively high hardness (Lampropoulos et al., 1997, 1999a) fact, which results to a great sensitivity. Additionally, it consists of various different minerals (quartz, tridymite, christobalite), (LAMPROPOULOS et al., 1997, 1999a), which results to discontinuities in the structure and the formation of cracks produced by mechanical stresses caused by the crystallisation of soluble salts.

Totally, the petrified forests of Lesvos and Limnos seem to be in good situation, as they present high degree of fossilization, very low porosity and very high hardness. Additionally the frost damage is totally absent and the range of RH% is in normal level. The concentration of soluble salts is very high and the temperature variations in a day (15 - 35 °C during the summer) are very often.

In the case of fossilized forests of Kastoria and Evia the action of soluble salts is primarily obvious by macroscopic observation of the alveolar corrosion pattern in many parts of the surface of the tree trunks from the fossilized forests, but in lower level than the case of Lesvos and Limnos. Then, the presence of soluble salts is also apparent by the presence of chloride and sulphate ions on the surface and in the pores of the material of the fossilized forest. Their crystallisation and their actions are shown in the Furlan diagrams, for all months each year and for the period 1955 - 1997.

From the previous diagrams, in the case of fossilized forest of Kastoria and Evia, it is shown in Fourlan diagrams that during the months January, February, March, April, November and December, most plotted dots - combinations of temperature and relative humidity - are falling over the curve and therefore crystallisation of sodium sulphate occurs during these months in the pores of the material of the fossilized forests of Kastoria and Evia.

Also, the presence of the frost damage and biological microorganisms was observed, mostly of lichens and moss and as well as the presence of cracking possibly caused by the frost action. It is also possible that soluble salts are transferred by the capillary rising from underground waters.

The relatively high porosity of the petrographic material of the fossilized forest of Kastoria and Evia (LAMPROPOULOS et al. 1999b) favours the penetration and crystallisation of soluble salts in the structure material of the fossilized forests.

The same material shows in several parts relatively high hardness (Lampropoulos et al. 1999b) fact, which results to a great sensitivity. Additionally, it consists of various different minerals (quartz and tridymite), (LAMPROPOULOS et al. 1999b), which results to discontinuities in the structure and the formation of cracks produced by mechanical stresses caused by the crystallisation of soluble salts.

Totally, the petrified forests of Kastoria and Evia seem to be vulnerable, as they present low degree of fossilization, high porosity and low hardness. Although the frost damage is presented very often in the petrified forest of Kastoria during the winter, it is totally absent in the case of petrified forest of Evia. The range of RH%, in both cases varies in normal level. The concentration of soluble salts is high and the temperature variations during the day (15 - 35 °C during the summer) are very often.

In the case of fossilized forest of Evros the action of soluble salts is primarily obvious by macroscopic observation of the alveolar corrosion pattern in many parts of the surface of the tree trunks from the fossilized forests, but in lower level than the case of Lesvos and Limnos. Then, the presence of soluble salts is also apparent by the presence of chloride and sulphate ions on the surface and in the pores of the material of the fossilized forest. Their crystallisation and their actions are shown in the Furlan diagrams, for all months each year and for the period 1955 - 1997.

From the previous diagrams, in the case of fossilized forest of Evros, it is shown in Fourlan diagrams that during the months January, February, March, April, May, September, October, November and December, most plotted dots - combinations of temperature and relative humidity - are falling over the curve and therefore crystallisation of sodium sulphate occurs during these months in the pores of the material of the fossilized forests of Evros.

Also, the presence of the frost damage and biological microorganisms was observed, mostly of lichens and moss and as well as the presence of cracking possibly caused by the frost action. It is also possible that soluble salts are transferred by the capillary rising from underground waters.

The petrified forest of Evros seems to be in good situation, as presents intermediate degree of fossilization, low porosity and high hardness. More over the frost damage is present very often in the winter and the range of RH% is in normal level. The concentration of soluble salts is very low and the temperature variations in a day are not very often.

Totally the degradation morphology of the fossilized materials seems to be:

1. Temperature and humidity variation.

Expansion and shrinkage - cracking and exfoliation.

2. Soluble salts crystallization.

Mechanical stress - cracking and exfoliation.

3. Biological depositions.

Mechanical stress - Acidic and alkaline action - degradation.

4. Frost damage.

Mechanical stress - cracking and exfoliation.

Based on the above mentioned results, the need for a direct study and application of a plan for conservation and protection of the tree-trunks of the fossilized forests of Greece, which will be based on thoroughly - detailed study and research of materials and methods for the necessary interventions, becomes obvious and essential. The specific actions should become a priority, in the general presentation policy of the fossilized forests of Greece.

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