FLORA TERTIARIA MEDITERRANEA

Die
tertiären Floren des Mittelmeergebietes

Vegetationsgeschichte, Phytostratigraphie, Paläökologie, Paläoklimatologie, Paläogeographie

herausgegeben
von
Dr. Hans-Joachim Gregor

Sechster Band - achte Abteilung

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FLORA TERTIARIA MEDITERRANEA VI.8

Conservation of fossilized Olive Leaves from Santorini Island - Greece

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ABSTRACT

The fossilized olive leaves were found in the Aegean island, Santorini, south of its capital, Fira. From recent studies, they are dated round 50.000 - 60.000 years old (Friedrich W.L. et Velitzelos E., 1986).

They have been fossilized through the process of carbonisation, that is the stamping of their original substances from carbon between volcanic tuffs.

As far as the condition of the fossilized leaves and the surrounding stone is concerned, the direct environment (with data from the National Institute of Environmental Data) and physicochemical analysis that determine the degree of corrosion were studied.

As far as the structure of the fossilized leaves and the surrounding stone is concerned, physicochemical analysis of the quality and quantity of elements and minerals were held.

The stages of conservation were chosen according to these studies and include cleaning and removal of soluble salts with the use of compresses of neutral paper or absorbent clay (sepiolite). Concerning the removal of insoluble salts, mechanical methods of cleaning were used. For the consolidation of the fossils we used low concentration solutions of silicate esters and for their final protection low concentration solutions of silicate resins, because of the compatibility of these materials with the siliceous fossilized materials.

KURZFASSUNG

Fossile Olivenblätter wurden auf einer Insel in der Ägäis gefunden, auf Santorin, südlich der Hauptstadt Fira. Nach neueren Sudien sind sie etwa 50 000 – 60 000 Jahre alt (Friedrich W.L. et Velitzelos E., 1986).

Sie wurden durch den Prozess der Karbonisierung erhalten, d.h. den Ersatz der originalen Blattsubstanz durch Kohlenstoff in vulkanischen Tuffen.

Die Blätter und das umgebende Gestein wurden im Hinblick auf die ehemalige Umgebung und den Grad der Korrosion durch physikochemische Analysen studiert (National Institute of Environmental Data, Athen). Dasselbe wurde an der Struktur der fossilen Blätter und des umgebenden Gesteins im Hinblick auf Qualität und Quantität von Elementen und Mineralen gemacht.

Die Konservierung wurde gezielt auf Reinigung und Extraktion der löslichen Salze durch Kompressen mit neutralem Papier oder absorbierenden Agenzien wie Sepiolit vorgenommen. Mechanische Methoden waren für die Reinigung der Fossilien von unlöslichen Salzen vorgesehen. Für die Festigung der Fossilien benutzten wir niedrig-konzentierte Silikat-Ester und für die Endphase ebensolche Silikat-Harze. Diese Materialien waren wegen der Kompatibilität mit den kieselig fossilisierten Stücken ausgesucht worden.

Keywords: Fossilized leaves, carbonisation, cleaning, soluble salts, sepiolite, consolidation, silicate esters, silicate resins.

Schlüsselwörter: Fossile Blätter, Karbonisierung, Säuberung, lösbare Salze, Sepiolith, Präparation, Silikat-Ester, Silikat-Harze

1 HISTORICAL DATA

1.1 Volcanoes – classification and Santorini type

The meaning of the word volcano is connected to the outflow of lava. The classification of volcanoes is based on their activity, the structure of the conductor from which the volcanic products are being emerged and the type of their explosion. As far as the activity is concerned, volcanoes are divided into calm and explosives, concerning the structure of the conductor into central and lineal, and into monogenic and poligenic as far as the type of explosion is concerned. Based on the separations above, volcanoes are divided into:

1. Scutelliform.
2. Mixed.
3. Basaltic edging (plateaux).
4. Loose.
5. Gase volcanoes.
6. Diatrema.
7. Maar.
8. Stratified/compound volcanoes.
9. Volcanic ash cones.
10. Calderas.[14,15]

The volcano of Santorini belongs to the most important volcanic Arc of Greece, which is the Arc of S. Aegean. This volcanic Arc is about 500 km long and 20 - 40 Km wide and is characterized by earthquakes with 150 - 170 Km depth, due to the submergence, round 5 cm/year, of the African tectonic plate under the one of Aegean, in northeastern direction. This Arc was created during the Quaternary.

The volcano of Santorini is one of the biggest calderas of the world, with dimensions 6 x 12 Km. Caldera is in fact a very big crater, which is the result of either a massive thrust (collapsion) or a submergence during the volcanic activity or the corrosion during inactivity.

The group of Santorini islands includes the islands: Thira, Thirasia, Aspronisi, which form a ring that encloses the Big Caldera. In the central area of Caldera are the islands Kamenes (Old, New and Small) which were created by a recent volcanic activity. The main types of lava of Santorini volcano are:

1. Basic lava of cape (S Thira).
2. Black lava (SW Thira).
3. Acid lava of cape (S Thira).
4. Lava of Thirasia, Merovigli, Aspronisi and Kameni.

1.2 Eruptions of Santorini – a historical review

The most important eruptions of Santorini volcano are: 3370 ± 100 B.C.. Great eruption with final result the demolition of the large volcanic vault. The center of the island was sunk and the enormous caldera was created.

197 B.C., According to Stravon, the volcanic activity is confined in the marine area of the center of Caldera at the same place where Old Kameni today is.

19 A.D., Island Thia is created.

46 A.D., Volcanic activity at the area of island Thia.

726 A.D., Violent volcanic activity. A big amount of lava adds a large part of Old Kameni.

1457 A.D., New activity near Old Kameni. A demolition at the eastern side, along a fault with NW - SE direction is recorded.

Fig. 1. Map of Greece with Santorini Island.

Fig. 2. Map of Santorini Island with the place of fossils (south of Fira).

Fig. 3. View of volcano (caldera) of Santorini (Photo E. Velitzelos).

Fig. 4. Geological section of Santorini with fossilized olive leaves (Photo E. Velitzelos).

Fig. 5. Fossilized leaf of ''*Olea europaea*'' from the sides of volcano (caldera)[6] (Photo E. Velitzelos).

Fig. 6. Fossilized leaves of "*Olea europaea*" and "*Pistacea lentiscus*" from the sides of volcano (caldera)[6] (Photo E. Velitzelos).

Fig. 7. Fossilized leaves of "Olea europaea" and "Pistacea lentiscus" from the sides of volcano (caldera)[6] (Photo E. Velitzelos).

1573 A.D., The volcanic center is shifted to northeast and a part of Small Kameni is created.

1650 A.D., Explosive phenomena which are centered 6,5 km northeast of cape Koloumbo. Creation of New Kameni.

1866 - 70 A.D., Creation of island George.

1925 - 26 A.D., Islands Small and New Kameni are joined with a big amount of lava.

1939 - 41 A.D., Islands George and the combined Small and New Kameni are joined.

1950 A.C., Volcanic activity with lava flow.[4,6,7,8,9,10,17,23]

1.3 Plant fossils from Santorini

The plant fossils of Santorini present a high interest concerning the historical evolution relevantly of the plants in Greece, Europe and the Mediterranean basin.

The upper part of Caldera wall of Thira and Thirasia can be divided into 3 rows of volcanic tuff: the lower, the middle and the upper one. The lower row is dated before 3.000.000 - 100.000 years, the middle one more than 50.000 - 60.000 years and the upper one, which has the greatest spreading, is dated round 1645 B.C.. It contains the last Minoic settlements, which are still under excavation, and are dated, based on the pottery found, at about 1500 - 1660 B.C..

The plant fossils - remains are found in the middle row at the tuff quarry south of Fira. The rows in which these fossils are found were formed during periods of volcanic inactivity, when there was enough time for the ruined plants to grow again after each volcanic eruption.

In all, 5 different types of plant fossils are found:

1. *Tamarix* sp.
2. *Pistacea lentiscus* L.
3. *Olea europaea* L.
4. *Phoenix theophrasti* G.
5. *Chamaerops humilis* L.

In addition, there are some relict species of plants which cannot be identified.

At the Caldera walls of Santorini can be found different species of plant fossils. These fossils show evidence of the gradual change of remains of trees into small plants, due to the volcanic activity and the changes of the climate because of the effect of the ice age.

Nowadays, from this flora, which is relatively poor for the period of time that represents, we mainly have leaves, but also imprints of carpus, sections of germs and roots of trees and bushes, which are, according to a primary opinion in some studies, petrified with the process of carbonification. The radio dating of the rows, in which the palaeoflora is found, indicates an age of 37.000 - 50.000 years from present. However, another dating from Friedrich and Velitzelos in 1986 suggests that the middle row of the volcanic tuff is 60.000 years old. According to that suggestion, the row with the fossils was formed during the Versillian.[6,8,9,10,17,19, 21,23,24,25,26,27,28,31,33]

1.4 The Olive

The olive trees belongs to:
Spermatophyta
Angiospermae
Dicotyledonae
Gentianales
Oleaceae
Olea
Oleae europaea L.

Olea europaea is an evergreen plant and it belongs to the oleaceae, a family of dicotyledonaes.

The genus *Olea* has been identified based on the plant imprints, germs and recently on wood pieces, *Oleoxylon*. It is the greatest species of the family of oleaceae, with roughly 35 species, to which it gives its name.

It has been cultivated from the ancient times in the Mediterranean and is supposed to indicate the boundaries of this area.

The olive tree must have been vastly cultivated at Santorini. The existence of the fossilized leaves at the area of Caldera from the quarries of Fira to the mills of cape indicates that Caldera was full of olive trees. Tradition as well as ancient inscriptions and olive - presses mention that there were olive groves. However, from the time of Tournefort and onwards, the number of olive trees is decreased and the import of olives and oil has began.

According to the analysis, the olive leaves have been fossilized through the process of carbonisation that is the stamping of their original substances from carbon between volcanic tuffs with presence of Silicium, as a product of decay of siliceous materials. This process usually occurs, like in this case, in areas which are rich in silicic volcanoclastic sediments. Liquid rich in silicon (Si) penetrates the cells, where is crystallized, making them look like they have been transformed into stone.[8,9,10,23,24,29,30]

2 ANALYSIS OF STRUCTURAL MATERIAL

Two methods for the determination of the chemical as well as the mineralogical composition of both the stone and the plant fossil were held: S.E.M. - E.D.X.A. and X-R.D.[1,12,14,22]

2.1. Elementary analysis of new and fossilized leaves and surrounding stone

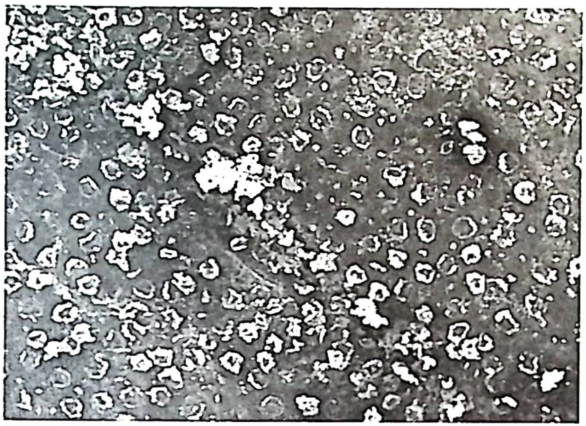
Five samples from the stone and five from the plant fossils were taken, as well as one sample of a recent olive leaf, all of them sized around 5 cm.

After they were registered, they were placed and glued with coal glue on two specimen tables. Each table was placed in the vacuum chamber. The procedure of covering the samples with graphite was done with the use of a thread of coal, which was placed between the negative and positive pole of the chamber, where it was created a difference in the potential (few volts). The vacuum that is created in the chamber prevents the thread from being totally burnt (10^{-2} mbar vacuum). When the thread is burnt, the coal turns into cobble and falls twice on the samples creating a film.

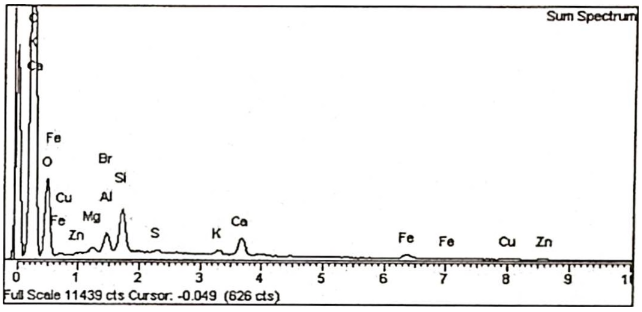
Afterwards the samples were placed in the chamber of the electronical microscope, where their surfaces were scanned and the results were given in electronical form.

2.1.1 Elementary analysis of a new leaf

In the following a leaf of the living olive was analysed and the mineral content listed.

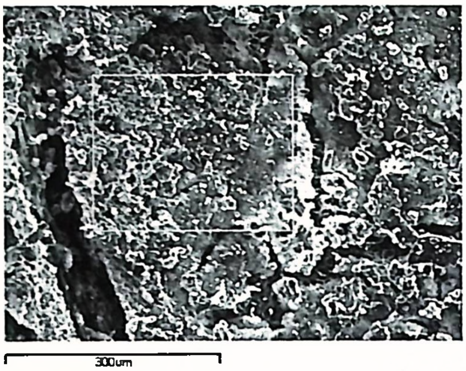


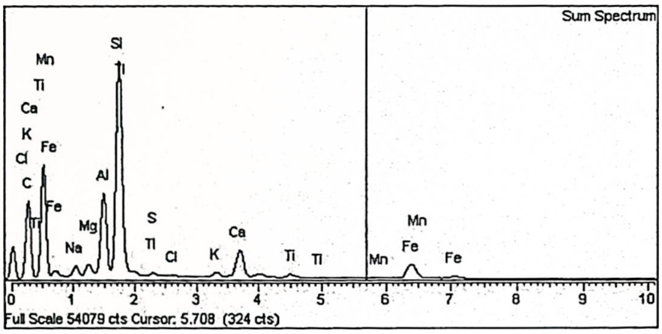
Electron Image 1



Element	App	Intensity	Weight%	Weight%	Atomic %	Compd%	Formula	Numper
	Conc.	Corrn.		Sigma				of ions
Al K	1.01	0.7524	4.48	1.20	4.01	8.47	Al_2O_3	0.52
Br L	1.52	0.7013	7.21	2.33	2.18	0.00		0.28
Ca K	3.23	0.9539	11.26	0.40	6.78	15.76	CaO	0.87
Cu K	0.45	0.8193	1.81	0.41	0.69	2.27	CuO	0.09
Fe K	1.58	0.8513	6.17	0.35	2.67	7.94	FeO	0.34
K K	0.72	0.9981	2.40	0.17	1.48	2.89	K_2O	0.19
Mg K	0.42	0.6539	2.12	0.19	2.11	3.52	MgO	0.27
S K	0.28	0.7210	1.30	0.16	0.98	3.25	SO_3	0.13
Si K	4.67	0.7162	21.67	0.72	18.61	46.36	SiO_2	2.40
Zn K	0.46	0.8210	1.88	0.47	0.69	2.33	ZnO	0.09
O			39.69	1.40	59.83			7.72
Totals			100.00					
							Cation sum	4.90

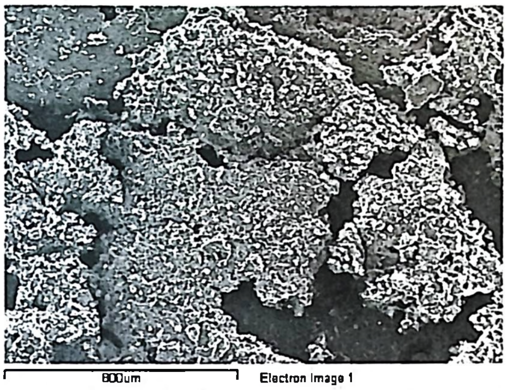
2.1.2 Elementary analysis of five samples of fossilized leaves

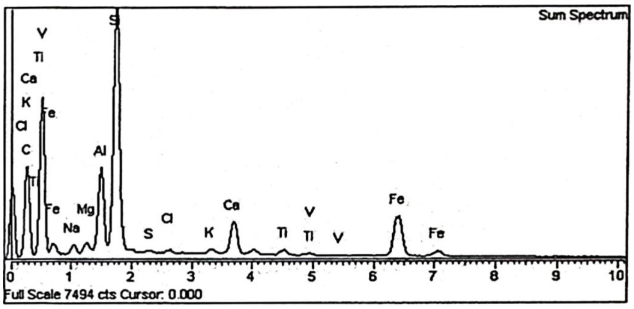




Sample 1

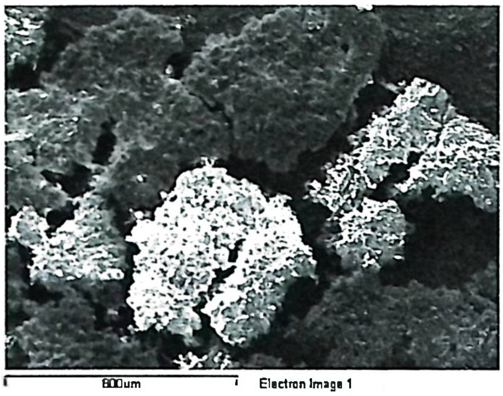
Element	App	Intensity	Weight%	Weight%	Atomic %	Compd%	Formula	Number
	Conc.	Corrn.		Sigma				of ions
Al K	10.19	0.7830	9.45	0.04	7.61	17.86	Al_2O_3	0.98
Ca K	6.07	0.9430	4.68	0.03	2.54	6.55	CaO	0.33
Cl K	0.10	0.6686	0.11	0.02	0.07	0.00		0.01
Fe K	7.55	0.8339	6.58	0.06	2.56	8.46	FeO	0.33
K K	0.77	0.9708	0.58	0.02	0.32	0.69	K_2O	0.04
Mg K	1.45	0.6797	1.55	0.02	1.39	2.57	MgO	0.18
Mn K	0.11	0.8141	0.09	0.03	0.04	0.12	MnO	0.00
Na K	2.00	0.7283	2.00	0.03	1.89	2.69	Na_2O	0.24
S K	0.00	0.7110	0.00	0.00	0.00	0.00	SO_3	0.00
Si K	28.86	0.7695	27.24	0.07	21.08	58.27	SiO_2	2.72
Ti K	0.90	0.8051	0.81	0.02	0.37	1.35	TiO_2	0.05
Tl M	1.10	0.6318	1.27	0.15	0.13	1.32	Tl_2O	0.02
O			45.65	0.10	62.01			7.99
Totals			100.00					
							Cation sum	4.89

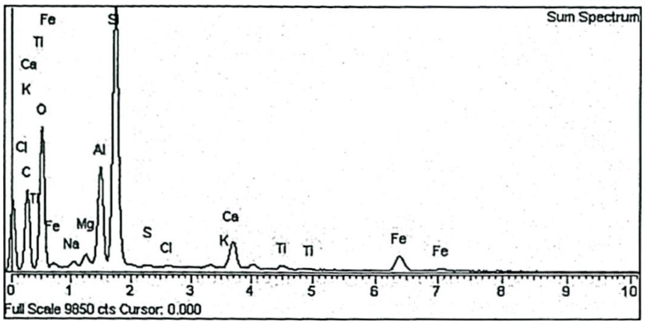




Sample 2

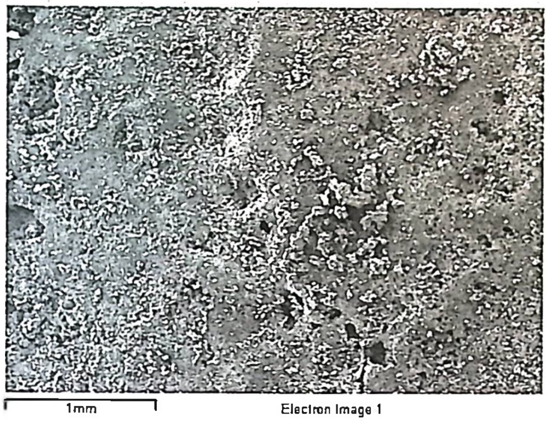
Element	App	Intensity	Weight%	Weight%	Atomic %	Compd%	Formula	Number
	Conc.	Corrn.		Sigma				of ions
Al K	7.98	0.7320	7.97	0.08	6.65	15.06	Al_2O_3	0.86
Ca K	5.60	0.9626	4.25	0.06	2.39	5.95	CaO	0.31
Cl K	0.38	0.6850	0.40	0.04	0.26	0.00		0.03
Fe K	16.29	0.8428	14.13	0.16	5.69	18.18	FeO	0.74
K K	0.70	0.9902	0.52	0.04	0.30	0.62	K_2O	0.04
Mg K	1.00	0.6176	1.19	0.06	1.10	1.96	MgO	0.14
Na K	1.55	0.6438	1.76	0.07	1.72	2.37	Na_2O	0.22
S K	0.29	0.7223	0.29	0.04	0.21	0.73	SO_3	0.03
Si K	25.29	0.7507	24.63	0.12	19.73	52.69	SiO_2	2.56
Ti K	1.09	0.8245	0.96	0.05	0.45	1.61	TiO_2	0.06
V K	0.26	0.8289	0.23	0.05	0.10	0.42	V_2O_5	0.01
O			43.66	0.16	61.40			7.97
Totals			100.00					
							Cation sum	4.97

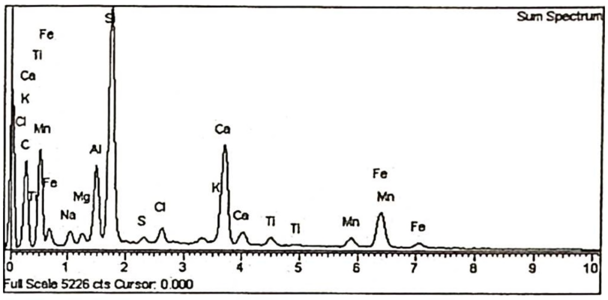




Sample 3

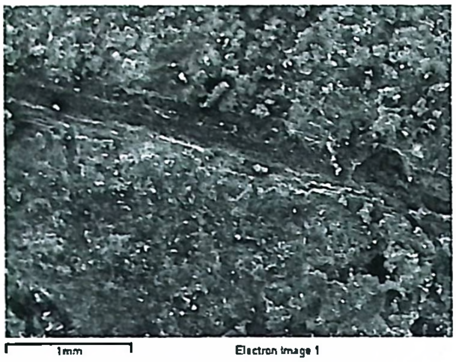
Element	App	Intensity	Weight%	Weight%	Atomic %	Compd%	Formula	Number
	Conc.	Corrn.		Sigma				of ions
Al K	10.68	0.8041	9.72	0.07	7.67	18.37	Al_2O_3	0.97
Ca K	5.47	0.9410	4.26	0.06	2.26	5.95	CaO	0.29
Cl K	0.19	0.6666	0.21	0.04	0.13	0.00		0.02
Fe K	6.41	0.8294	5.65	0.11	2.15	7.27	FeO	0.27
K K	0.49	0.9675	0.37	0.04	0.20	0.45	K_2O	0.03
Mg K	1.25	0.6997	1.31	0.05	1.14	2.16	MgO	0.14
Na K	0.98	0.7362	0.97	0.06	0.90	1.31	Na_2O	0.11
S K	0.20	0.7003	0.21	0.04	0.14	0.52	SO_3	0.02
Si K	31.07	0.7783	29.22	0.11	22.13	62.51	SiO_2	2.81
Ti K	0.81	0.8031	0.74	0.05	0.33	1.23	TiO_2	0.04
O			47.34	0.14	62.95			7.98
Totals			100.00					
							Cation sum	4.68

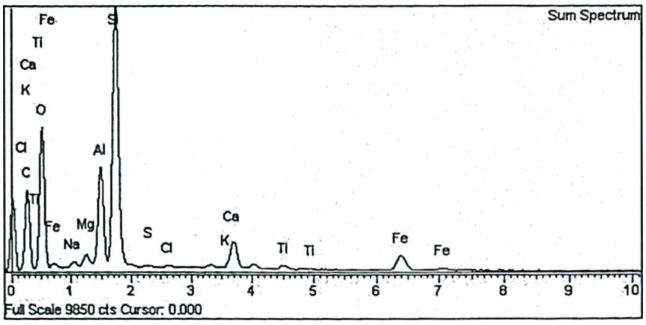




Sample 4

Element	App	Intensity	Weight%	Weight%	Atomic %	Compd%	Formula	Number
	Conc.	Corrn.		Sigma				of ions
Al K	6.58	0.7204	2.15	0.03	1.33	4.06	Al_2O_3	0.16
C K	40.99	0.5231	18.42	0.27	25.59	67.50	CO_2	3.14
Ca K	15.89	0.9830	3.80	0.04	1.58	5.32	CaO	0.19
Cl K	1.40	0.7751	0.43	0.02	0.20	0.00		0.02
Fe K	12.77	0.8082	3.71	0.06	1.11	4.78	FeO	0.14
K K	0.70	1.0391	0.16	0.01	0.07	0.19	K_2O	0.01
Mg K	0.87	0.5992	0.34	0.02	0.23	0.56	MgO	0.03
Mn K	2.70	0.7941	0.80	0.04	0.24	1.03	MnO	0.03
Na K	1.96	0.6083	0.76	0.03	0.55	1.02	Na_2O	0.07
S K	0.62	0.8614	0.17	0.01	0.09	0.42	SO_3	0.01
Si K	22.18	0.8001	6.52	0.05	3.87	13.94	SiO_2	0.48
Ti K	1.55	0.8111	0.45	0.02	0.16	0.75	TiO_2	0.02
O			62.30	0.28	64.98			7.98
Totals			100.00					
							Cation sum	4.27

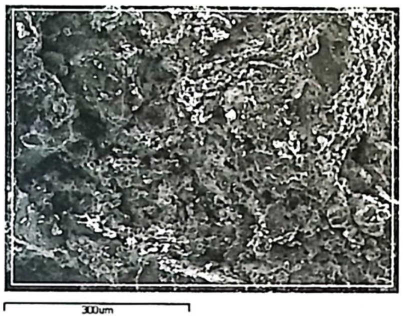


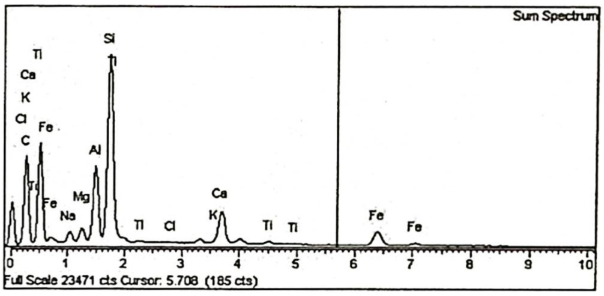


Sample 5

Element	App	Intensity	Weight%	Weight%	Atomic %	Compd%	Formula	Number
	Conc.	Corrn.		Sigma				of ions
Al K	7.03	0.7425	6.61	0.09	5.53	12.49	Al_2O_3	0.71
Ca K	5.92	0.9588	4.31	0.07	2.43	6.03	CaO	0.31
Fe K	14.20	0.8431	11.76	0.18	4.75	15.13	FeO	0.61
K K	0.75	0.9859	0.53	0.05	0.31	0.64	K_2O	0.04
Mg K	1.26	0.6313	1.39	0.06	1.29	2.31	MgO	0.17
Mn K	1.98	0.8232	1.68	0.10	0.69	2.16	MnO	0.09
Na K	0.98	0.6521	1.05	0.07	1.03	1.42	Na_2O	0.13
S K	0.00	0.7209	0.00	0.00	0.00	0.00	SO_3	0.00
Si K	29.50	0.7731	26.64	0.17	21.39	56.99	SiO_2	2.76
Ti K	1.26	0.8220	1.07	0.06	0.50	1.78	TiO_2	0.07
Tl M	0.92	0.6405	1.01	0.38	0.11	1.05	Tl_2O	0.01
O			43.95	0.25	61.97			8.00
Totals			100.00					
							Cation sum	4.91

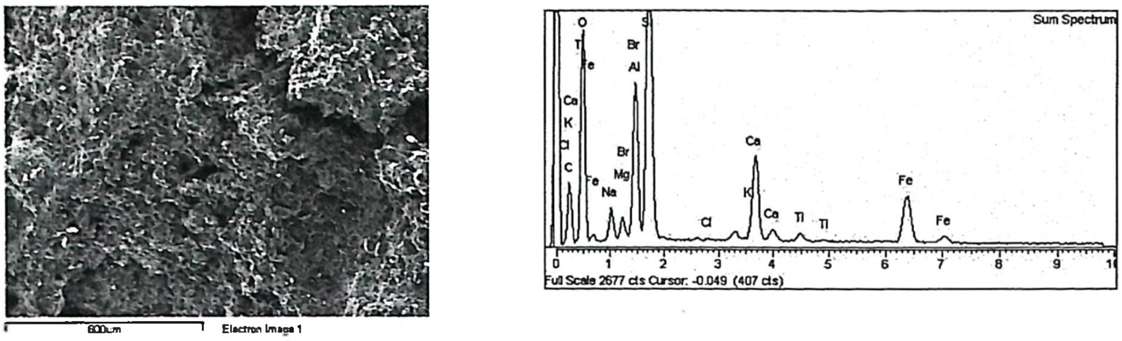
2.1.3 Elementary analysis of five samples of surrounding stone





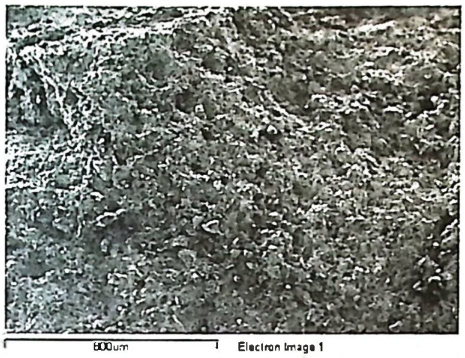
Sample 1

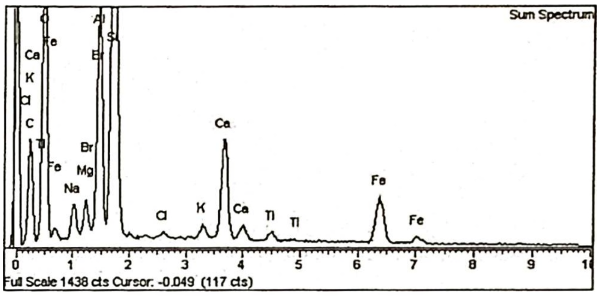
Element	App	Intensity	Weight%	Weight%	Atomic %	Compd%	Formula	Number
	Conc.	Corrn.		Sigma				of ions
Al K	9.58	0.7708	9.56	0.05	7.71	18.06	Al_2O_3	1.00
Ca K	7.25	0.9469	5.89	0.05	3.20	8.24	CaO	0.42
Cl K	0.09	0.6742	0.10	0.02	0.06	0.00		0.01
Fe K	7.31	0.8329	6.75	0.08	2.63	8.69	FeO	0.34
K K	0.75	0.9775	0.59	0.03	0.33	0.71	K_2O	0.04
Mg K	1.72	0.6724	1.97	0.04	1.76	3.27	MgO	0.23
Na K	2.37	0.7266	2.51	0.05	2.38	3.39	Na_2O	0.31
Si K	25.69	0.7597	26.02	0.08	20.15	55.65	SiO_2	2.62
Ti K	0.67	0.8031	0.64	0.03	0.29	1.07	TiO_2	0.04
Tl M	0.65	0.6344	0.79	0.07	0.08	0.82	Tl_2O	0.01
O			45.18	0.11	61.42			7.99
Totals			100.00					
							Cation sum	5.01



Sample 2

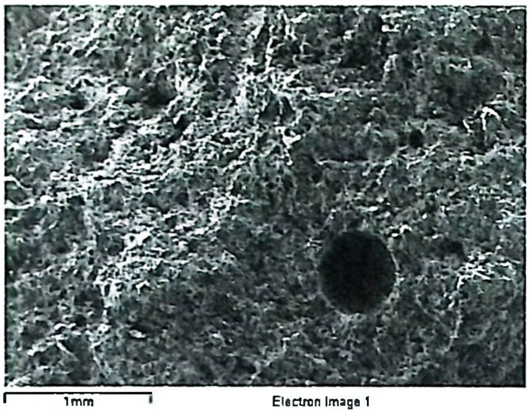
Element	App	Intensity	Weight%	Weight%	Atomic %	Compd%	Formula	Number
	Conc.	Corrn.		Sigma				of ions
Al K	5.23	0.7673	4.52	0.61	3.97	8.55	Al_2O_3	0.51
Br L	8.68	0.7150	8.05	1.20	2.38	0.00		0.31
Ca K	9.87	0.9587	6.83	0.14	4.03	9.55	CaO	0.52
Cl K	0.14	0.6711	0.14	0.04	0.09	0.00		0.01
Fe K	12.73	0.8497	9.94	0.24	4.21	12.79	FeO	0.54
K K	0.78	0.9854	0.53	0.05	0.32	0.64	K_2O	0.04
Mg K	1.23	0.6565	1.24	0.07	1.21	2.06	MgO	0.16
Na K	3.00	0.7090	2.81	0.09	2.89	3.78	Na_2O	0.37
Si K	26.88	0.7180	24.83	0.41	20.91	53.13	SiO_2	2.70
Ti K	0.96	0.8156	0.78	0.07	0.39	1.30	TiO_2	0.05
O			40.32	0.71	59.60			7.68
Totals			100.00					
							Cation sum	4.89

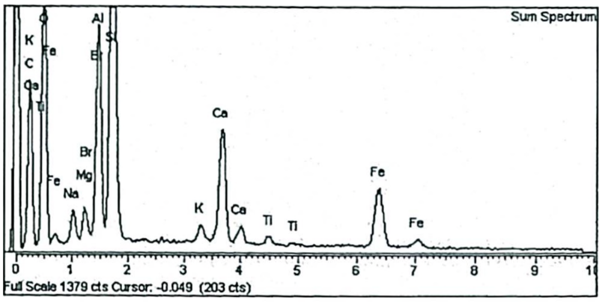




Sample 3

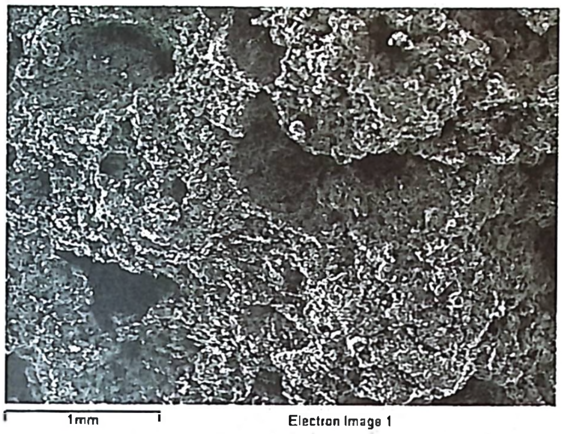
Element	App	Intensity	Weight%	Weight%	Atomic %	Compd%	Formula	Number
	Conc.	Corrn.		Sigma				of ions
Al K	7.03	0.7872	5.97	0.75	5.05	11.28	Al_2O_3	0.65
Br L	6.96	0.7331	6.34	1.49	1.81	0.00		0.23
Ca K	8.87	0.9496	6.24	0.16	3.56	8.73	CaO	0.46
Cl K	0.35	0.6677	0.35	0.05	0.22	0.00		0.03
Fe K	9.01	0.8425	7.15	0.24	2.92	9.20	FeO	0.37
K K	0.90	0.9767	0.61	0.06	0.36	0.74	K_2O	0.05
Mg K	1.53	0.6827	1.50	0.09	1.41	2.48	MgO	0.18
Na K	2.68	0.7381	2.43	0.11	2.41	3.27	Na_2O	0.31
Si K	28.96	0.7337	26.38	0.54	21.46	56.43	SiO_2	2.75
Ti K	0.87	0.8084	0.72	0.08	0.34	1.19	TiO_2	0.04
O			42.33	0.89	60.45			7.74
Totals			100.00					
							Cation sum	4.80

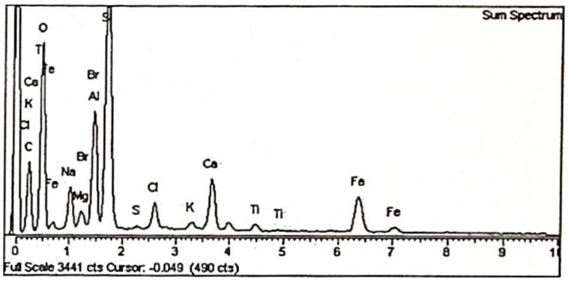




Sample 4

Element	App	Intensity	Weight%	Weight%	Atomic %	Compd%	Formula	Number
	Conc.	Corrn.		Sigma				of ions
Al K	6.09	0.7751	5.36	0.74	4.59	10.13	Al_2O_3	0.59
Br L	6.48	0.7220	6.13	1.48	1.77	0.00		0.23
Ca K	9.61	0.9544	6.88	0.17	3.97	9.63	CaO	0.51
Fe K	10.91	0.8442	8.83	0.27	3.65	11.36	FeO	0.47
K K	1.20	0.9844	0.83	0.06	0.49	1.00	K_2O	0.06
Mg K	1.34	0.6670	1.37	0.09	1.30	2.27	MgO	0.17
Na K	2.25	0.7129	2.16	0.10	2.17	2.91	Na_2O	0.28
Si K	27.84	0.7351	25.87	0.52	21.29	55.35	SiO_2	2.74
Ti K	0.86	0.8104	0.73	0.08	0.35	1.21	TiO_2	0.05
O			41.83	0.87	60.41			7.77
Totals			100.00					
							Cation sum	4.86





Sample 5

Element	App	Intensity	Weight%	Weight%	Atomic %	Compd%	Formula	Number
	Conc.	Corrn.		Sigma				of ions
Al K	5.11	0.7591	4.54	0.59	3.92	8.57	Al_2O_3	0.51
Br L	7.11	0.7074	6.77	1.17	1.98	0.00		0.26
Ca K	6.95	0.9495	4.94	0.11	2.87	6.91	CaO	0.37
Cl K	2.27	0.6737	2.27	0.07	1.50	0.00		0.19
Fe K	11.41	0.8482	9.07	0.22	3.79	11.67	FeO	0.49
K K	0.87	0.9726	0.60	0.05	0.36	0.73	K_2O	0.05
Mg K	1.29	0.6490	1.34	0.07	1.28	2.22	MgO	0.17
Na K	5.23	0.7304	4.83	0.12	4.90	6.51	Na_2O	0.63
S K	0.20	0.7055	0.19	0.04	0.14	0.48	SO_3	0.02
Si K	26.39	0.7259	24.52	0.40	20.37	52.45	SiO_2	2.63
Ti K	1.04	0.8157	0.86	0.06	0.42	1.43	TiO_2	0.05
O			40.08	0.68	58.46			7.55
Totals			100.00					
							Cation sum	4.92

2.2 Mineral analysis of fossilized leaf and surrounding stone

For this method we used two samples, one from the stone and the other from the fossilized leaf. The samples were floured, placed on microscope slides and sprayed with pure alcohol. After the evaporation of the dissolvent the samples were put into the chamber of X-R.D., where the analysis took place. The results (diagrams) were electronically compared to model diagrams of minerals.

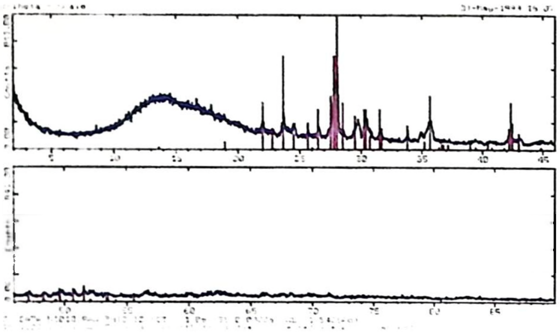


Diagram 1. Mineral analysis of fossilized leaf.

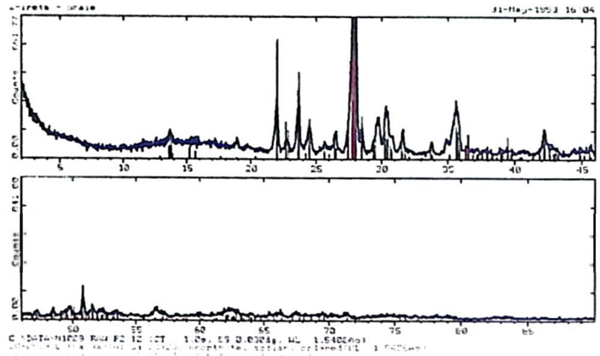


Diagram 2. Mineral analysis of surrounding stone.

2.3 Results

Based on the content of minerals that was given from the S.E.M. - E.D.X.A. method, it was remarked that during the fossilization of the leaves, their organic parts were replaced from silicon (Si) which was found in great compound in both the samples of the leaves as well as in the samples of the stone. With these results it was confirmed that the fossilization was done through the process of silicification.

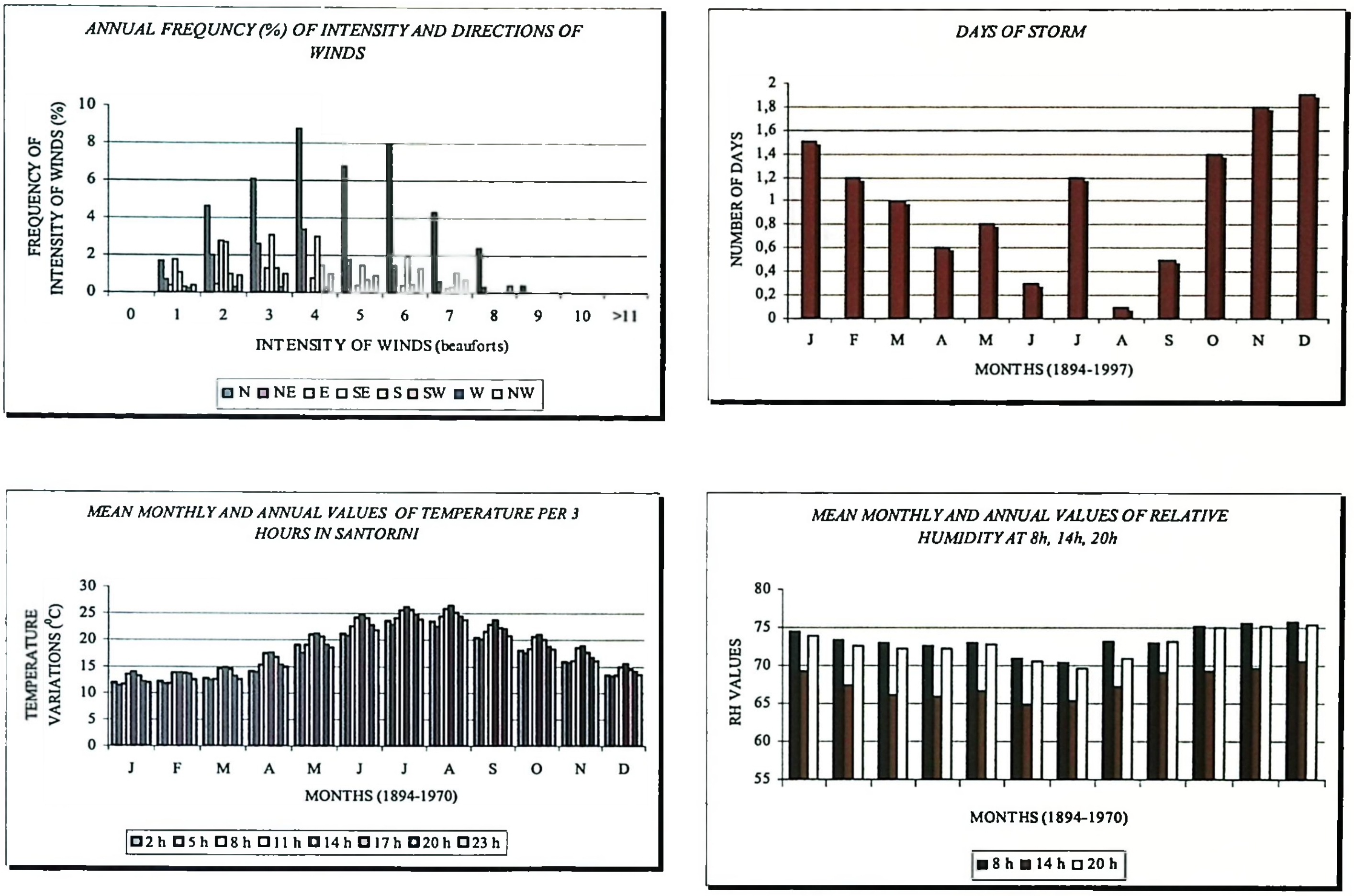
After the comparison of the X-R.D. diagrams of the samples to model diagrams of minerals, there were identified two minerals, albite ($NaAlSi_3O_8$) and anorthite ($CaAl_2Si_2O_8$). Since in both samples (stone and fossilized leaf) were identified the same minerals, it was concluded that the organic parts of the leaves were totally replaced by silicon. However, it must be taken under consideration that during the sampling for both methods there was a great possibility that along with the fossilized leaves was also taken a small amount of the surrounding stone, which may have affected the results.

3 ENVIROMENTAL DATA

According to the evolution of the flora of Greece, the climate remains stable after the intensive changes until the Quaternary. By this time the area of Greece has approached today's form. On one hand, during the ice age big amounts of sea water turned into ice, leading to the reduction of the sea level and the extension of the land. On the other hand, when the ice melted, the sea level was increased and the expansion of the land reduced. This phenomenon occurred as many times as the climate changed from cold (ice age) to warm (interglacial period) and vice versa.

During the Lower Pleistocene the climate conditions in Greece were tropical (savanna), then became dry (Middle Pleistocene) and during Upper Pleistocene we had desert conditions.

The mean climate conditions in Santorini, throughout the year, are presented on the following table:



Diagrams of climatological data.

4 CORROSION PHENOMENA

4.1 Soluble salts crystallization [2,3,5,12,13,14,15,16,34]

The corrosion caused by soluble salts is one of the most dangerous forms of corrosion and affects all kinds of stone, even those that are non porous. There are many sources from which soluble salts originate and can cause great stresses inside the pores of the stone.

The sources of soluble salts are:

1. Underground water.
2. Sea.
3. Surrounding materials.
4. Air pollution.

The crystal structure of various kinds of soluble salts like sodium sulphate (Na_2SO_4), carbonic sodium (Na_2CO_3), magnesium sulphate ($MgSO_4$) and calcium sulphate ($CaSO_4$), in particular values of temperature and humidity, changes and because of the fact that the volume of the crystals increases, there are created great stresses, sometimes bigger than the strength of the material, that can corrode the stone. Chloride and sulphate salts have the ability to dissolve the magnesium in volcanic stones and dolomites.

Fig. 8. Efflorescences of soluble salts of fossilized material.

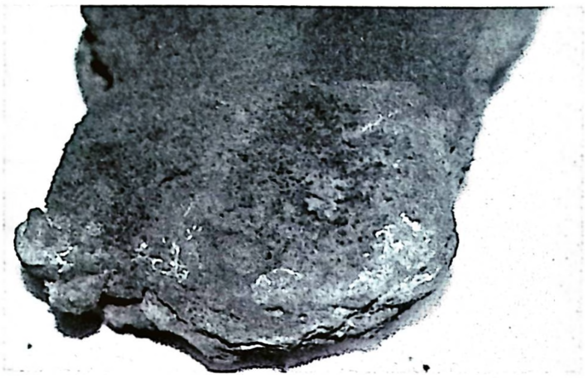


Fig. 9. Efflorescences of soluble salts of fossilized material.

The fossils in Santorini were found near sea, therefore they are affected by it. Salts are being transferred from the sea up to 15 km in land, but the more we are moving away from the sea the less active the salts become.

In order to confirm the existence of soluble salts, we took five samples and measured their conductivity. In each sample we placed neutral paper soaked into distilled water. After an hour the paper was put into five vessels with 100 ml of distilled water (0,005 mS/cm^2) each, and with the use of electronical equipment we measured the conductivity for all the samples.

Fig. 10. Spot test of soluble salts.

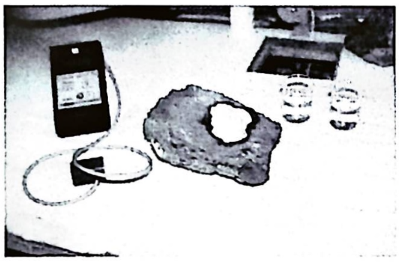


Fig. 11. Spot test of soluble salts.

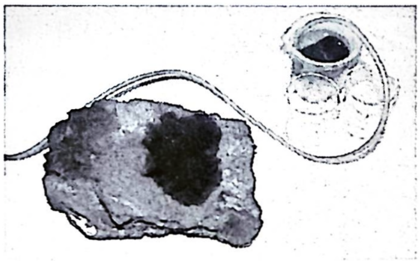


Fig. 12. Spot test of soluble salts.

I/n	Cd (μS/cm^2)	Cl$^-$ (ppm)	SO$_4^{2-}$ (ppm)
Sample 1	216	25,6	5,2
Sample 2	242	38,1	6,3
Sample 3	189	36,2	4,9
Sample 4	169	22,8	5,4
Sample 5	230	29,4	5,9
Distilled water	5	1	0

4.2 Results

The conductivity measurements listed above, confirm the existence of soluble salts in the pores of the stone, which must be removed.

4.3 Temperature variations [1,13]

The expansion and contraction of materials are two phenomena that are being provoked by the changes of temperature. The more coarse grained is a stone the bigger is the corrosion, because they are easily deteriorated. These changes in temperature occur when the stone is exposed to the sun during day and to cold during night. The temperature on the surface of the stones can reach 50 - 60 °C because of the direct sunlight, while during night the cold can reduce the temperature of the surface even below 0 °C. When this change from warm to cold is sudden, there are many possibilities that they'll be cracks on the surface of the stone.

4.4 Organic emplacement [1,13]

Fungus, bacteria, lichen, seaweeds, plants and algae can destroy a stone. All these microorganisms, in combination to moderate temperatures and humidity can corrode the stone, since they are alive organisms and, amongst others, absorb humidity in order to survive, causing cracks on the stone.

Inside the pores of the fossils of Santorini were found plants, whose roots can cause stresses, leading to the splitting of the material. No other kind of organic emplacement was detected.

5 CONSERVATION PROCEDURES

5.1 Overview

The stages of conservation of stones are divided into cleaning, consolidation, protection, adhesion and filling. All these stages are not necessarily needed or done for each stone, nor there is a specific kind of treatment which can be applied in all cases.

Based on the degree of corrosion of the fossils of Santorini and the structure of the stone, the following treatments were considered necessary:[1,11,12,16,22]

Cleaning

Removal of soluble salts.

Many of the fossiliferous stones were too big to be sunk into distilled water, so two other ways to remove the soluble salts were used:

Neutral paper with distilled water (compresses).

Absorbent clay (sepiolite) mixed with distilled water.

Fig. 13. Removal of soluble salts.

Fig. 14. Removal of soluble salts.

Fig. 15. Removal of soluble salts.

In both cases, the compresses remained on the surface of the stone for at least an hour and after the measurement of the conductivity the procedure was repeated, until no indication of existence of soluble salts was shown. Each time we removed the sepiolite, the stone was carefully cleaned with distilled water.

Sepiolite was used on certain areas of the stone, in contrast to the wider use of neutral paper, where the soluble salts had created a crust on the surface. Sepiolite, as well as all the absorbent clays, has the ability to absorb big amounts of water or other liquids, disproportionate to the weight of the clay.

5.2 Mechanical cleaning

The surrounding stone that cover the fossils, as well as the remains of plants (small roots and branches) are carefully removed with mechanical methods.

For this purpose were used lancets, tweezers, needles, brushes, as well as a small amount of distilled water and paint brushes, pipettes and cotton sticks.

5.3 Consolidation

With the consolidation we attempt to increase the coherence of the stone and to improve its mechanical properties, as well as to prevent the fossils from being destroyed. In addition, the stone becomes hydrophobic, which means that the entrance of soluble salts and acids is no longer permitted.

Once more, the size of the fossiliferous stones was the primary factor for the determination of the most suitable consolidation method. Since they were too big to be sunk into the consolidant, the application was made with the use of brushes.

Taking under consideration the results of the analysis, it was decided that the most appropriate consolidants were the silicon esters and silicon polymers, because of the fact that the main component of the fossils is silicon (Si).

5.4 Silicon esters - Silicon polymers

The spectrum of the consolidants that are consisted of silicon is wide and includes materials that differ (siliceous compounds with potassium (alkali) and sodium, up to resins).

The inorganic and organic siliceous salts are hydrolyzed with water, forming orthosilicate acid, shapeless material, which is precipitated into the pores of the stone, and while losing gradually water it is transformed into silica (SiO_2), according to the chemical reaction:

$$Si(OH)_4 \rightarrow SiO_2\downarrow + 2H_2O$$

and creates electrostatic bonds that unite the polarized surfaces into the walls of the pores.

Fig. 16. Consolidation of fossilized material.

Fig. 17. Consolidation of fossilized material.

Fig. 18. Consolidation of fossilized material.

6 CONCLUSIONS

From the analysis of the surrounding stone and the fossilized leaves, the results concerning the elements found with the S.E.M. method, it is concluded that silicate (Si) has the biggest compound (>50%) and then follow aluminium (Al), iron (Fe) and calcium (Ca) (>8% each element) as well as magnesium (Mg), sodium (Na), titanium (Ti) (<4% each element) and others, with minor compound. As far as the identification of minerals is concerned, albite ($NaAlSi_3O_8$) and anorthite ($CaAl_2Si_2O_8$) were found with the X-R.D. method.

The climate conditions in Santorini are characterized from relatively high prices in temperature and humidity, without, though, intensive changes that can corrode the fossils. The main forms of corrosion that have affected the fossils of Santorini are the crystallization of soluble salts originating the nearby sea, and the organic emplacements in combination with the high price of temperature and humidity.

The most difficult stage of conservation is the removal of the soluble salts, which was done by constantly changing compresses of distilled water for a long period of time. Furthermore, the removal of the surrounding stone that covered most of the leaves was equally difficult, because of the hardness of the stone.

Finally, we believe that the consolidation and protection that was applied will prove to be important for the fossils of Santorini, after they are placed in the equivalent favourable environment.

REFERENCES

1. Amoroso G.G., Fasina V., Stone decay and conservation, Ed. Elsevier, 1983.
2. Arnold A. 1976, Behaviour of some soluble salts in stone deterioration. In: Proceedings of the 2nd International Symposium on corrosion of stones in constructions, p. 27-36. Athens.
3. Arnold A. 1981. Nature and reactions of saline minerals in walls. In: Proceedings of the 2nd Congress of Conservation of Stone, Bologna p. 13 - 23.
4. Bond A. and Sparks R.S.J., "The Minoan Eruption of Santorini, Greece", Journal of Geological Society, U.K., Vol. 132, Part I, January 1976.
5. Child R.E., Salt efflorescence and damage. Conservation of geological collections, Archetype publications Ltd, London 1994, p. 18 - 22.
6. Danesis I.M., Santorini, Thira, Thirasia, Aspronisi, Volcanoes, ed. Adam, Athens, 2001.
7. Fouque M.F., Santorin et ses eruptions, ed. G. Masson, Paris 1879.
8. Friedrich W.L., "Fossil Plants from Weichselian Interstadials, Santorini (Greece)", in Doumas C. (ed.), Thera and the Aegean World III, 2, London 1980, p. 109 - 127.
9. Friedrich W.L., Pichler H., Kussamaul S., "Quaternary pyroclastics from Santorini/Greece and their Significance for the Mediterranean Palaeoclimate", Bll. Geol. Soc. Denmark 26, 1977, p. 27 - 39.
10. Friedrich W.L. and Velitzelos E., "Bemerkungen zur spätquartaren Flora von Santorini (Griechenland)", Cour. Forsch. - Inst. Seckenberg 86, 1986, p. 387 - 395.
11. Howie F.M., The Care and Conservation of Geological Material. Ed. Butterworth - Heinemann, 1992.
12. Lampropoulos V., Corrosion and Conservation of Stone, Athens, 1993.
13. Lampropoulos V., Environment of Monuments, Museums and Archaeological Sites, Athens 2003.
14. Lampropoulos V., Panagiaris G., Velitzelos E., Deterioration aspects of petrified material from the fossilized forest of Lesvos, from frost damage and soluble salts. Proceedings 2nd International Symposium: Monuments of Nature and Geological Heritage. Molyvos - Lesvos, 1997, p. 214 - 230.
15. Lampropoulos V., Panagiaris G., Velitzelos E., Methods used for the determination of soluble salts into the material of fossilized trees. Case study of the fossilized trees. Case study of the fossilized forest in Lesvos Island. Proceedings 6th International Conference: Non-Destructive Testing and Microanalysis for the Diagnostics and Conservation of the Cultural and Environmental Heritage, Rome, 1999a, p. 1825 - 1837.
16. Lampropoulos V., Panagiaris G., Tsamasfyrou I., Bika D., Velitzelos E., Protection study of the material of the fossilized forest of Kastoria. International Congress: Protecting natural sites and environmental education, Sigri - Lesvos, 1999b.
17. Mc Coy E., "Volcanoes of Ancient Thera", Earthwatch, Expedition Briefing, 1982.
18. Selmeier A., Velitzelos E., Neue Aufsammlungen von verkieselten Holzresten aus tertiären Sedimenten Griechenlands (Lesbos, Kastoria, Thrakien). Mitteilungen der Bayerischen für Paläontologie und historische Geologie, München, 40, 2000, p. 213 - 227.
19. Schmidt J., Volcanstudien, Santorin 1866 - 1872, Leipzig 1874.
20. Süss H., Velitzelos E., Fossile Hölzer der Familie Taxodiaceae aus tertiären Schichten des Versteinerten Waldes von Lesbos, Griechenland. Feddes Repertorium 108 (1997) 1-2, 1-30, Berlin, Marz 1997.
21. Süss H., Velitzelos E., Eine neue Proto-Pinaceae der Formgattung Pinoxylon KNOWLTON emend. READ, P. parenchymatosum sp. Nov., aus tertiaren Schichten der Insel Limnos, Griechenland, Feddes Repertorium, 104, 1993, p. 335 - 341.

22. Torraca G., Porous building materials, Ed. ICCROM - Rome, 1988.
23. Velitzelos E., ‘‘Neue Palaofloristische daten zur Entwicklungsgeschichte der Pflanzen im Ägaisraum, Insbesondere die Palaeoflora von Thera (Santorini)’’, Doc. Nat. 61, 1991, p. 22 - 29.
24. Velitzelos E., Neue Palaofloristische daten zur kanophytischen Floren Griechenlands, Doc. Nat., 78, 1993, p. 1 - 17.
25. Velitzelos E., The petrified forest of Lesvos, a rare natural and geological monument (in Greek), Proceedings of the 1st Symposium on the Petrified forest of Lesvos - Mytilene 1996, p. 35 - 42.
26. Velitzelos E., Zouros N., The Petrified forest of Lesvos - Protected Natural Monument. Proceedings of International Symposium on Engineering Geology and the Environment, Athens, 1997, p. 3037 - 3043.
27. Velitzelos E., Zouros N., The Petrified Forest of Lesvos. Natural History Museum of the Lesvos Petrified Forest, Sigri - Lesvos, Greece, 1988.
28. Velitzelos E., Kvacek Z., Velitzelos D., New Oligocene Leaf Floras from Volcanic Complex of the Evros Mountains. 6th European Paleobotany - Palynology Conference, August 29 - September 2, 2002, Athens, Greece, Abstracts p. 185 - 186.
29. Velitzelos E., Kvacek Z., Velitzelos D., *Känophytische Floren Griechenlands*, Rundbrief Arbeitskreis Paläobotanik und Palynologie, Münster, 2000, p. 68 - 69.
30. Velitzelos E., Kvacek Z., Walter H., Erster Nachweis von *Eotrigonobalanus furcinervis* (ROSSM.) WALTER & KVACEK (Fagaceae) in Griechenland. Feddes Repertorium 110 (1999) 5-6, 349-358, Berlin, September 1999.
31. Velitzelos E., I. Petrescu, Symeonidis N., Tertiare Pflanzenreste von der agaischen Insel Lesvos (Griechenland). Cour. Forsch. Inst. Senckenberg, 50, 1981a, p. 49 - 50.
32. Velitzelos E., I. Petrescu and N. Symeonidis, Tertiare Pflanzenreste aus Agais. Die Makroflora der Insel Lesvos (Griechenland). Ann. Geol. Pays Hellen, 30, 1981b, p. 500 - 514.
33. Velitzelos E., Symeonidis N., Der verkieselte Wald von Lesvos (Griechenland) ein Naturschutzebiet. Vortag - Kurzfassung beim Arbeitskreis Paleobot. Palynol., 1978, p. 17 - 19.
34. Wheeler G.S., Wypyski M.T., An Unusual Efflorescence on Greek Ceramics. Studies in Conservation, 38, 1993, p. 55 - 62.