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GLASS COMPOSITION OF PERLITES FROM MILOS, KIMOLOS AND KOS ISLANDS (GREECE)

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ABSTRACT

The perlitic glass from the Greek islands of Milos, Kimolos and Kos is examined in this paper. Perlite consists of more than 85% glass. It has the typical perlite structure with concentric, spheroidal cracks. Perlite textures with no vesicles, intermediate development of cracks and large proportion of vesicles were also identified. The relationship between glass and vesicles is examined. The presence of glass is indicated by the X-ray Diffraction analysis, as well the relationship between the quartz and glass. The texture of the glass is illustrated in the SEM Analysis. The composition of the glass is examined by the Microprobe Analysis and chemical analyses of the studied Greek perlitic glasses are also present.

KEY WORDS: glass, perlite, Milos, Kimolos, Kos, Aegean.

1. INTRODUCTION

Perlite is a volcanic glass of rhyolitic composition, containing 2 to 5 per cent of combined water. It is characterised by a system of concentric, spheroidal cracks, called perlitic structure. Perlite consists mainly of glass (more than 85%). It also contains phenocrysts of quartz, feldspar, biotite and hornblende, microphenocrysts of magnetite, ilmenite and hematite, secondary minerals in altered perlite, such as chalcedony, opal, montmorillonite and zeolites and, some perlites contain lithophysae lined with cristobalite and rarely fayalite. Perlite from Milos (Provatas and Trachilas), Kimolos and Kos islands, which are part of the Aegean volcanic arc, are examined in this paper (Fig.1).

Perlite is associated with rhyolitic rocks and produced during the last volcanic episode in Milos island. In both places (Provatas and Trachilas) perlites are present in beds and lahar formations. In Kimolos island, perlite outcrops in the NNE part of the island, dipping in beds. In Kos island, perlite deposit of Kefalos peninsula is mainly consist of lahar while perlitic beds are also present. The obsidian cores that have been identified in Kos and Milos perlites confirm the theory of perlite origin from the hydration of obsidian (Koukouzas, 1994).The mineralogical composition of the perlite of these three islands is very similar (glass, quartz, feldspars, biotite, magnetite and pyroxene). On the contrary, their chemical composition differs amongst the four perlite deposits, especially in the K_2O, CaO, Ba and REE proportions (Koukouzas, 1997) (Table 1).

In order to identify the glass composition of perlite, optical and scanning electron microscope were used to determine glass. X-ray diffraction to provide information on the proportion of glass in the perlite and the relationship between glass and the mineral phases, while the glass chemistry was examined by the electron microprobe. The analyses were carried out at the Department of Geology, University of Leicester.

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2. ANALYTICAL TECHNIQUES

The structure of glass was identified by examining thin sections of perlite and making point counting with the optical microscope. Problems which occurred during the preparation of the thin sections, because of the very soft and vesiculated nature of perlite, were overcome by vacuum impregnating the samples with blue dyed araldite to fill the holes in the groundmass.

Table 1: Representative analyses of Provatas perlite and rhyolite,Trachilas, Kimolos and Kos perlites

Major elements (%)					
	(1)	(2)	(3)	(4)	(5)
SiO_2	76.10	75.37	76.22	75.40	75.77
TiO_2	0.14	0.15	0.08	0.15	0.13
Al_2O_3	12.16	12.57	11.83	12.67	12.42
Fe_2O_3	1.19	1.25	0.93	1.19	0.80
MnO	0.05	0.04	0.08	0.06	0.09
MgO	0.27	0.26	0.17	0.09	0.12
CaO	1.21	1.21	0.70	0.96	0.59
Na_2O	3.62	3.72	3.25	3.69	3.80
K_2O	3.03	3.04	4.51	3.71	4.29
P_2O_5	0.03	0.05	0.02	0.03	0.03
LOI	2.19	2.24	2.37	2.54	2.05
Total	99.99	99.90	100.16	100.49	100.08
Trace elements (p.p.m.)					
V	8	23	14	5	5
Cr	0	5	1	8	6
Co	0	2	1	2	0
Cu	0	0	0	0	0
Ba	445	458	420	626	1008
La	25	29	24	30	28
Ce	38	44	46	42	36
Nd	16	14	22	10	10
Nb	8	10	13	15	21
Zr	85	115	77	116	88
Y	23	22	40	18	16
Sr	75	144	30	89	64
Rb	95	104	156	124	120
Th	10	13	19	19	14
Ga	14	14	10	14	11
Zn	21	25	14	24	7
Ni	9	7	5	0	5
Rare earth elements (p.p.m.)					
La	22.55	26.06	21.53	29.19	25.52
Ce	41.47	43.55	44.19	48.23	42.44
Pr	4.29	4.71	5.04	4.8	3.98
Nd	14.3	15.9	17.8	14.9	12.2
Sm	2.38	2.72	3.79	2.33	1.87
Eu	0.44	0.57	0.29	0.38	0.29
Gd	2.18	2.41	3.77	1.97	1.47
Dy	2.62	2.89	5	2.31	1.82
Ho	0.49	0.53	0.96	0.44	0.32
Er	1.49	1.74	3.14	1.37	1.06
Yb	1.92	2.08	3.5	1.72	1.33
Lu	0.34	0.36	0.57	0.3	0.22

Note: (1)=Provatas perlite, (2)=Provatas rhyolite, (3)=Trachilas perlite,(4)= Kimolos perlite, (5)=Kos perlite

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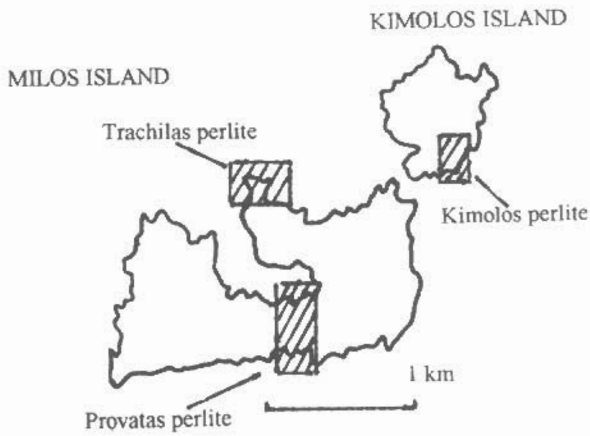

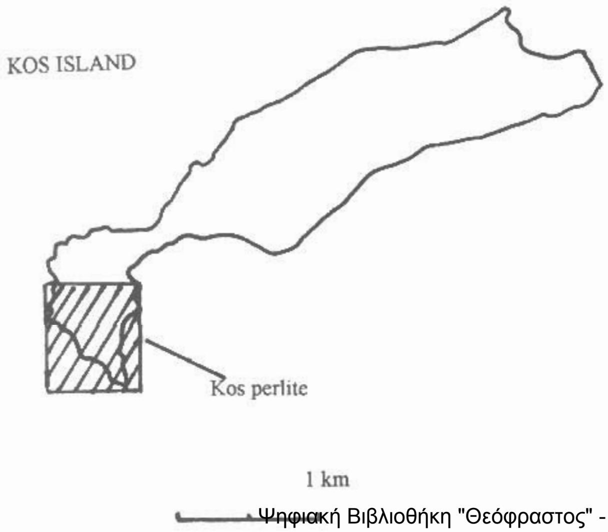

Figure 1: Sketch maps of Milos, Kimolos and Kos islands with sample locations.

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X.R.D. analysis was carried out using a Philips X-ray Diffractometer. The generator was a Philips PW 1729, the goniometer a Philips PW 1050/25, and the diffractometer a Philips PW 1716. The target tube was Copper, with a Nickel filter and was operated at 40 kV and 30mA.

A Hitachi Scanning Electron Microscope, model S-520, with an attached 'Link' Energy Dispersive X-ray Detector was used for the SEM observations.

Polished thin sections prepared from perlites, and rhyolites were analysed using the JEOL JXA-8600 Electron Microprobe. All analyses were made using 15 kV accelerating potential. The problems that appeared in the preparation and the running of the polished thin sections were overcome by using blue dyed araldite to fill the holes and bubbles in the sections, which were very unconsolidated.

3. MINERALOGY

Various textures of perlite, depending on the degree of vesiculation, have been identified in the Greek perlites (Koukouzas, 1994). Although perlitic cracks and perlitic textures are well known, as a characteristic feature of some volcanic rocks (Anderson et al., 1956, Kadey, 1963, Shackley, 1988, MacKenzie et al, 1982, Shelley, 1993), few publications refer to the variation of perlite textures (Marshall, 1961, Cameron and Sabine, 1969, Naert, 1974, Whitson, 1982, Koukouzas, 1994).

After a very detailed microscopic observation on one hundred and thirty one (131) thin sections, the following textures have been distinguished. The degree of vesiculation, which produced the various perlite textures is illustrated in Table 2. The perlite textures of Milos island can give a characteristic example of the Greek perlite as follows:

On Milos island, the perlite textures accord with the field description of perlites. Hard perlite: The distinguishing feature of hard perlite is the very dense texture, indicated by the absence of vesicles (**hard** texture). Perlitic cracks are rare. Classical perlite: It has the typical perlitic texture; the onion-skin structure (**classical** texture) is well developed. Some vesicles are present. If the perlitic cracks are not so well developed, then a **glassy** texture is produced, which has an intermediate development of cracks, lying between the hard and classical textures. Pumiceous perlite: It is characterised by the large proportion of vesicles found in the groundmass, and the lack of any perlitic crack. This is the final stage of the vesiculation process (**pumiceous** texture). Sometimes two or even three textures can be observed in the same thin section, indicating that the expansion process was very rapid.

Table 2: Milos perlite textures according to the degree of vesiculation

Textures	Vesicles (%)
Hard	1.05
Classical	3.94
Glassy	5.48
Pumiceous	43.22

Decrease of glass and increase of vesicles is observed, for all the Greek perlite deposits, from the hard/classical to the pumiceous/vesiculated perlites. The most obvious examples occurred in Milos island (Provatas and Trachilas areas) (Koukouzas and Dunham, 1994).

3.1. X-Ray Diffraction analysis

X-ray diffraction analysis provides a precise and rapid means of determining the glass percentage of perlite, which is indicated by a broad halo. XRD analysis was carried out on one hundred and seventy five (175) raw perlite sanΨηφιακή Βιβλιοθήκη "Θεόφραστος" - Τμήμα Γεωλογίας. Α.Π.Θ. between 18^0 and 35^0 two theta angles, quartz, feldspars, biotite, pyroxene, cristobalite and tridymite were present in the X.R.D. traces.

Glass gives a powder pattern resembling that of opal-A', which has a pattern consisting of very broad bands; the most intense is centred at about 4.1 A. The glass was estimated, measuring the distance between the top of the broad halo and the background, at 25^0 two theta degrees. That is the mean point of 18^0 and 35^0 two theta angles where the halo appears. The same method was followed by Naert (1974) but without success, even though it is fully accepted today as the most reliable technique for amorphous material (Lapaquellerie, 1987, Cruz and Real, 1991). It is believed that it is more reliable than the chemical techniques (Smith and Mitchell, 1984). XRD has been carried out by several previous workers in order to determine the crystallinity of perlite (Anderson et al., 1956, Lorenz and Muller, 1982, Burriesci et al., 1985).

Glass is present in the X.R.D. traces as a broad halo centred about 25^0 two theta angle. That hump is described by earlier workers, studying silica polymorphs in sedimentary rocks (Hein et al, 1981, Williams et al, 1985) or deep-sea cherts (Von Rad and Rosch, 1974), and named opal-A. Opal-A includes potch opals, diatomites and geyserites, glass-clear hyalites, and silica associated with clays, but not silica glass, although it gives similar diffraction patterns (Jones and Segnit, 1971). The volcanic glass is not mentioned in any of the X.R.D. classifications of silica minerals (Jones and Segnit, 1971, Tucker, 1988). X.R.D. studies of perlite imply that the mineral phases and especially quartz and/or feldspars drastically affect the height of the glass hump. In addition, the broad glass halo indicates the amount of glass in perlite and consequently contributes to the expandability of the material.

An obvious relationship between quartz and the glass is found, indicating the importance of quartz in perlite. Higher quartz peaks correspond to lower glass proportion in perlite. This leads us to conclude that secondary quartz is produced as a filling in the pore spaces. This occurs where glass was rich enough. The reaction was very rapid, producing microcrystalline secondary quartz.

3.2. Scanning Electron Microscope (S.E.M.)

The Scanning Electron Microscope (S.E.M.) was used to determine the texture of perlite, and to observe in detail the relationship between phenocrysts, glass, and vesicles. Plates 1 and 2 illustrate the difference between the classical and pumiceous textures of Trachilas perlite. The abundance of vesicles in the pumiceous perlite is remarkable. It is obvious that the vesicles were produced from the vesiculation of the glass, and therefore substitute the glass matrix in perlite. The quartz phenocryst that is present in the glass groundmass of the Trachilas classical perlite (Plate 1) indicates the pre-existence of quartz in perlitic groundmass.

4. MINERAL CHEMISTRY

Electron microprobe analysis was used to identify the nature and the possible differences between the various types of glass in perlite. Few published papers refer to the mineral chemistry of perlite, world-wide. Jezek and Noble (1978) used electron microprobe to analyse perlite and obsidian from Nevada, in order to identify their hydration and ion exchange processes. Davis et al. (1991) also presented some feldspar, biotite, and glass microprobe analyses of Kos perlite. Shane and Froggatt (1992) also quoted microprobe analyses of rhyolitic glass from deep-sea sediments of the Southern Pacific Ocean.

Various types of perlite from the studied areas (Provatas (Milos), Trachilas (Milos), Kimolos, and Kos) were examined. 191 glass specimens, 182 from the perlites and 9 from the Provatas rhyolites were analysed. The analysed perlitic glasses comprise : 61 from Kimolos island, 32 from Kos island, 23 from the Trachilas area, and 66 from the Provatas area. Representative analyses are given in the following table (Table 3). The total of the glass analyses is 96-97%, as a result of the lost water (3-4%).

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Table 3: Representative analyses of Greek perlitic glass

	KK4	KK6	K10	K7	T15	TR7	PR20	PR10	A20
SiO_2	75.72	75.29	76.42	75.65	79.39	75.90	76.26	75.94	75.96
TiO_2	0.10	0.12	0.10	0.11	0.03	0.05	0.09	0.11	0.10
Al_2O_3	11.90	12.01	12.08	11.96	11.20	11.96	12.15	12.15	11.87
FeO	0.59	0.54	0.56	0.87	0.53	0.56	0.72	0.75	0.61
MnO	0.06	0.07	0.05	0.09	0.08	0.07	0.04	0.02	0.12
MgO	0.02	0.06	0.07	0.12	0.04	0.03	0.11	0.08	0.09
CaO	0.49	0.49	0.67	0.68	0.52	0.59	0.85	0.90	0.88
Na_2O	3.82	3.20	3.63	3.33	2.41	3.35	3.33	3.68	3.23
K_2O	4.32	4.66	3.89	3.82	4.04	4.65	3.39	3.38	4.24
SrO	0.06	0.02	0.03	0.06	0.06	0.02	0.01	0.02	0.01
BaO	0.14	0.15	0.14	0.05	0.04	0.07	0.23	0.08	0.12
Total	97.22	96.61	97.64	96.74	98.34	97.25	97.18	97.11	97.23

Note : KK4, KK6=Kos perlite, K10, K7=Kimolos perlite, T15, TR7=Trachilas perlite, PR20, PR10=Provatas perlite, A20=Provatas rhyolite.

Plate 1: Classical texture of Trachilas perlite. Quartz phenocryst in the glass. Scale bar 231 μm.
Plate 2: Pumiceous texture of Trachilas perlite. Note the vesiculated glass. Scale bar 300 μm.

Statistics were made in the glass analyses in order to determine the variation of glass composition in the studied perlites (Table 4). Previous work on the accuracy and precision of electron microscope analyses of silicates and glasses has been carried out by Dunham and Wilkinson (1978).

Kos perlite glass analyses gave similar results. The range of glass composition in Kos perlites is shown in Table 4. The alkalis indicated 6-7% of the glass analysis, with K_2O taking the major part, although very rarely Na_2O takes bigger proportion in the alkalis. The only previous microprobe analyses known, of the Kos perlites are from Davis et al. (1991). The values are very similar except for the totals which vary from 88 to 99%, which is not expected.

Kimolos perlites have similar glass composition but do have small and distinct variation (the vesiculated perlite has a higher alkali proportion). The range of glass composition in Kimolos perlites is

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Table 4: Statistical analysis of perlitic and rhyolitic glass composition

	mean	s.d.	min.	max.	mean	s.d.	min.	max.
Provatas perlite (66)					Provatas rhyolite (9)			
SiO_2	76.35	1.34	74.02	79.72	75.35	0.44	74.89	75.96
TiO_2	0.09	0.07	0.01	0.17	0.13	0.03	0.08	0.19
Al_2O_3	12.27	0.14	11.96	12.61	11.83	0.12	11.65	11.99
FeO	0.67	0.29	0.43	0.85	0.62	0.05	0.54	0.68
MnO	0.06	0.02	0.01	0.09	0.05	0.04	0.01	0.12
MgO	0.12	0.19	0.03	0.22	0.09	0.03	0.04	0.13
CaO	0.84	0.10	0.59	0.91	0.66	0.24	0.36	0.91
Na_2O	3.28	0.70	2.20	3.85	2.98	0.26	2.57	3.29
K_2O	3.24	0.44	2.87	3.86	4.82	0.61	4.17	5.60
SrO	0.04	0.08	0.01	0.06	0.02	0.03	0.01	0.06
BaO	0.08	0.08	0.01	0.23	0.09	0.11	0.07	0.23
Cr_2O_3	0.01	0.02	0.01	0.03	0.01	0.01	0.01	0.04
NiO	0.01	0.01	0.01	0.03	0.01	0.01	0.01	0.02
Total	97.06	0.60			96.65	0.56		
Trachilas perlite (23)					Kimolos perlite (61)			
SiO_2	76.13	1.46	74.14	79.39	75.95	0.79	74.27	79.35
TiO_2	0.05	0.02	0.01	0.11	0.11	0.03	0.03	0.18
Al_2O_3	11.87	0.54	9.77	12.17	12.04	0.13	11.03	12.51
FeO	0.55	0.05	0.44	0.63	0.69	0.17	0.28	1.36
MnO	0.09	0.03	0.02	0.12	0.06	0.02	0.00	0.16
MgO	0.04	0.01	0.03	0.05	0.08	0.04	0.00	0.87
CaO	0.58	0.05	0.44	0.67	0.65	0.11	0.46	1.08
Na_2O	2.77	0.55	1.43	3.36	3.59	0.77	2.40	6.38
K_2O	4.54	0.55	2.26	5.02	3.66	1.01	0.37	4.73
SrO	0.01	0.02	0.00	0.07	0.03	0.03	0.00	0.06
BaO	0.04	0.05	0.01	0.10	0.09	0.08	0.00	0.23
Cr_2O_3	0.02	0.02	0.00	0.04	0.01	0.01	0.00	0.04
NiO	0.01	0.01	0.01	0.03	0.01	0.01	0.00	0.04
Total	96.74	0.78			96.96	0.63		
Kos perlite (32)					Total glass (191)			
SiO_2	76.57	1.78	73.88	80.02	76.19	1.29		
TiO_2	0.09	0.03	0.05	0.15	0.09	0.05		
Al_2O_3	12.09	0.33	11.51	12.48	12.10	0.29		
FeO	0.50	0.13	0.09	0.62	0.63	0.22		
MnO	0.05	0.02	0.02	0.10	0.06	0.03		
MgO	0.05	0.02	0.00	0.07	0.08	0.12		
CaO	0.49	0.14	0.06	0.67	0.68	0.17		
Na_2O	2.98	1.20	1.41	3.97	3.26	0.84		
K_2O	3.69	1.27	1.76	5.36	3.68	0.96		
SrO	0.03	0.03	0.00	0.09	0.03	0.05		
BaO	0.15	0.18	0.07	0.77	0.09	0.11		
Cr_2O_3	0.01	0.01	0.00	0.04	0.01	0.02		
NiO	0.01	0.01	0.00	0.04	0.01	0.01		
Total	96.71	0.58			96.91	0.64		

Note: s.d.=standard deviation, min=minimum, max=maximum, ()=number of analyses.

shown in Table 4. The alkalis make up 6-7% in total, whereas the vesiculated perlite forms 7-8%. An indication of the alteration/hydration degree in some particular areas of the perlite deposit is demonstrated by the glass analysis, where extreme low proportion of K_2O (0.30-0.40%) and high Na_2O (4-6%) is present.

Although there is great similarity in the glass composition of the Trachilas perlite samples, some

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differences were identified in the proportions of SiO_2 and the alkalies of the hard perlite texture. Even though the total alkalies range between 7.5 and 8%, the hard perlite shows lower alkali levels (3.5%) and higher SiO_2 (78.5%) composition. That is a good indication of the first non-hydrated glass from which derives perlite, that contains low alkalies and high Si proportions.

The alkalies indicate differences between various types of perlites, but also between the perlites and rhyolites of the Provatas area. The high MgO, TiO_2, and BaO glass composition, in comparison with Kos, Kimolos, and Trachilas perlites, is remarkable. The total alkalis are 6-7%. However, hard perlite has lower alkalis (3.5-4%) indicating the non-hydration of glass during that stage of deposition. Rhyolites show higher alkali proportions (7-7.5%), especially K_2O which makes up 4.5-5.6% of the total glass analysis. On the other hand, the SiO_2 proportion is lower in the rhyolitic glass (74-76%).

5. DISCUSSION

The mineral chemistry of glass indicates the similarity of glass composition in the examined perlites (Provatas, Trachilas, Kimolos, and Kos deposits). However, CaO proportion of Provatas perlitic glass is higher than the others (followed by Kimolos, Trachilas, Kos, and Provatas rhyolite. The Na_2O proportion of Provatas perlitic glass is also higher than the other perlites. In contrast, the K_2O proportion is higher in Provatas rhyolitic glass, followed by Trachilas, Kos, Kimolos, and Provatas perlitic glasses. There is small variation in TiO_2 and FeO with higher Kimolos glass.

The glass composition of perlite seems to follow the chemical composition. It has been observed that Provatas rhyolite is more K_2O rich than Trachilas perlite and is followed by the other perlites. On the other hand, Provatas perlite is more Ca-rich than the other perlites (Koukouzas, 1994). However, the distinguishable differences, that were identified in the chemical composition of perlites, did not demonstrate in the glass composition in same extent. The variability amongst the different perliitic glasses does not exceed in large ranges.

Nevertheless, differences within the same perlite deposit can be distinguished, considering the alkalies and iron proportions. The hydration process is indicated with the increase of the alkalies proportion from the classical/hard to the pumiceous perlites.

However, the alkalis figures show the enrichment of K_2O of the pumiceous perlite in comparison with the non-vesiculated perlite (hard/classical). This is most obvious for the Kimolos samples, where the vesiculated perlites are higher in K_2O and lower in Na_2O compared with the rest of perlites. These results are closely related to the Na_2O and K_2O changes found in obsidian and perlite studies (Jezek and Noble, 1978).

6. CONCLUSIONS

The microscopic study of perlite can indicate the structure of glass. Perlite consists of glass, phenocrysts and vesicles. The degree of vesiculation demonstrates the perlite textures as follows : Hard perlite texture (without vesicles), classical perlite texture (with onion-skin structure), glassy texture (with intermediate development of cracks), and pumiceous perlite texture (with large proportion of vesicles). Decrease of glass and increase of vesicles from the hard/classical to the pumiceous perlite, is observed in the studied perlite deposits.

The X-ray Diffraction (X.R.D.) analysis determines the glass percentage of perlite, indicated by a broad halo in the studied perlites. The glass is estimated, measuring the distance between the top of the broad halo and the background at 25 two theta degrees. The determination of glass can contribute to the expandability of perlite. Relationship between quartz and glass is shown (higher quartz peaks correspond to lower glass proportion) in perlite. That can conclude that secondary quartz is produced as fillings in the pore spaces.

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The Electron Microprobe analysis identifies the composition of glass. A similarity of glass composition in all the examined perlites, is present. There are small but systematic differences between the glasses from different Greek islands. Provatas perlite demonstrates higher CaO proportions in the glass, compared with Trachilas, Kimolos, and Kos perlites. The differences in glass composition are in accordance with the chemical composition of perlites, but it is developed in smaller extent.

Differences within the same deposit, considering the alkalis and iron proportions, are distinguished. Enrichment of K_2O and decrease of Na_2O in the pumiceous perlites are identified.

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