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THE GARNETITE FROM SERIFOS

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ABSTRACT

The mineralogy of the garnetite from Serifos island was studied, optically, by X-ray diffraction and microprobe analysis.

It is a typical skarn garnetite with andraditic garnet composition. According to microprobe analysis the garnet composition is :

Andradite ($Ca_3Fe_2O_3+Si_3O_{12}$)	:	98-71%
Pyrope ($Mg_3Al_2Si_3O_{12}$)	:	0-1%
Spessartine ($Mn_3Al_2Si_3O_{12}$)	:	0.2-1.5%
Grossulare ($Ca_3Al_2Si_3O_{12}$)	:	0.2-28%
Almandine ($Fe_3 2+Al_2Si_3O_{12}$)	:	-
Uvarovite ($Ca_3Cr_2Si_3O_{12}$)	:	-

Optical properties, density and lattice constants were determined and are in good agreement to each other.

The possibility of use of the garnetite as industrial mineral is discussed.

ΣΥΝΟΨΗ

Μελετήθηκε η ορυκτολογία του γρανατίτη της νήσου Σερίφου μικροσκοπικά, με περιθλασιμετρία ακτίνων-Χ και μικροανάλυση.

Πρόκειται για τυπικό γρανατίτη μετασωμάτωσης με ανδραδιτική σύσταση. Με βάση τις μικροαναλύσεις η σύστασή του είναι :

Andradite ($Ca_3Fe_2O_3+Si_3O_{12}$)	:	98-71%
Pyrope ($Mg_3Al_2Si_3O_{12}$)	:	0-1%
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Uvarovite ($Ca_3Cr_2Si_3O_{12}$)	:	-

Προσδιορίστηκαν οι δείκτες διάθλασης, το ειδικό βάρος και οι σταθερές πλέγματος. Οι παραπάνω σταθερές βρίσκονται σε συμφωνία μεταξύ τους και με τις μικροαναλύσεις, ως προς τον χαρακτηρισμό του γρανάτη.

Μελετάται η δυνατότητα χρήσης του γρανατίτη σαν βιομηχανικό ορυκτό.

INTRODUCTION

The island of Serifos is situated about 100 km SSE of Athens, in the western part of the central Aegean Sea (Fig. 1).

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Geologically it belongs to the Attic-Cycladic unit of the Pelagonian massif (Fig. 1) and consists, as a part of the median crystalline belt within the Alpine orogenic chain of the Hellenides, mainly of metamorphic rocks (metasediments) recording at least three different metamorphic events (DURR et al., 1978).

1. (M1). Glaucophane schist facies, regional metamorphism, dated at 45-50 Ma (ALTHERR et al., 1982).

2. (M2). Greenschist facies, regional metamorphism, dated at 25-30 Ma (ALTHERR et al., 1982).

3. (M3). Low pressure contact metamorphism, associated with local granitoid plutonism, dated about 10 Ma (DURR et al., 1978).

1. Rhodope Massive, 2. Serbomazedonian Zone, 3. Circum-Rhodope Crystalline. 4. Axios Zone, 5. Pelagonian Massive, 6. Attic-Cycladic Zone, 7. Parnass-Giona Zone, 8. Pindos-Olonos Zone, 9. Tripolis Zone, 10. Gavrovo Zone, 11. Ionian Zone, 12. Paxos Zone.

Fig. 1. Distribution of the geotectonic units in the Hellenides and position of Serifos Island (arrow).

A granitic intrusion (finegrained biotite-hornblende granodiorite, I-type) caused the formation of hornfels and the skarnification of the already metamorphosed (M1+M2) basement, and represents the M3 metamorphic phase.

Metasomatic phenomena are widespread on the island, along the northern as well as the southern contact granodiorite-basement, several kilometers long, up to 2.000 m wide and 200 m thick (Fig. 2). Lime-magnesian- and silicate skarn are present. Massive skarn has been located mainly in the central and the western part of the island, showing an unusual mineral growth and distinctive metasomatic zonation, which includes Fe-ore deposits (magnetite, hematite, limonite) and minor Cu, Pb-Zn and F-Ba mineralisations.

In several skarn bodies occurs garnetite, mainly concentrated in the central part of skarn (Fig. 2). The garnetite body south of Ag. Marina has a thickness of appr. 40 m, 100-120 m in width and is 450 m long (Fig. 3).

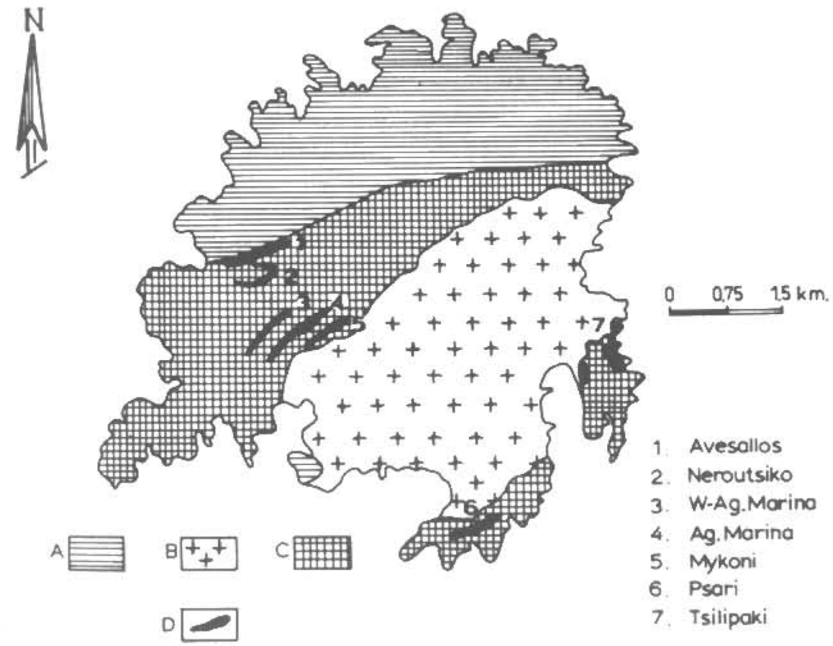

Fig. 2. Simplified geological map of Serifos. A. Metamorphic basement, B. Granodiorite, C.Zone of metasomatism, D.Main Garnetite occurrence.

ANALYTICAL TECHNIQUES

The analytical procedures used in the present study were : microprobe analysis, X-ray diffraction, microscopical examination and density determination.

The X-ray microanalysis was carried out with an electron probe, JEOL Superprobe 733. Normal operating conditions involved a 20 KV excitation voltage, 5nA beam current and 20 sec counting time. Mineral Standards and pure oxides were used, ZAF corrections were carried out. An ORTEC energy dispersive spectrometer was used for rapid qualitative analysis.

The mineral formula calculation, according to microprobe analysis, was carried out with a computer program written by PERDIKATSIS (1986).

The X-ray diffraction analysis was used in order to determine the lattice constants. An automatic Siemens powder diffractometer, D 500, was used with copper radiation and secondary graphite monochromator. Quartz was used as internal standard for accurate d-values. The lattice constant, a_o, was calculated by least square techniques with computer program of APPLEMAN & EVANS (1973).

The density determination was carried out at single grains with a Berman density balance. The accuracy was about ±0.1% with grains up to 100 mg.

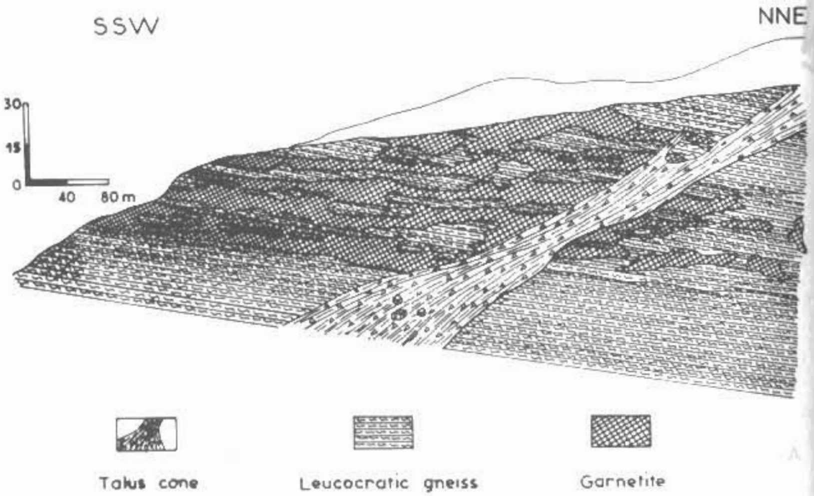

Fig. 3. Garnetite occurrence Ag. Marina.

DESCRIPTION OF THE MATERIAL

Recent investigation on the metasomatic aureole of Serifos island resulted in the delineation of the lithological zoning as well as the sequence of metasomatic parageneses :

Magnetite - Hedenbergite - Epidote - Garnet - Quartz

Garnet - Epidote ± Hedenbergite (±Actinolite) - Quartz ± Magnesite

Garnet - Epidote - Albite - Quartz ± Hedenbergite

Hematite - Barite - Fluorite - Limonite - Siderite - Calcite

The observed thicknesses of the individual metasomatic zones range from 5 to 20 m.

In the close proximity to the granodiorite (within 20-100 m from its margins) subzones with the paragenesis Garnet (Andradite) - Epidote ± Actinolite ± Hedenbergite ± Quartz ± Albite ± Magnetite were locally identified within the individual metasomatic zones. Segments of these subzones with thicknesses ranging from a few metres to a few tens of metres (Ag. Marina, Tsilipaki etc., Fig. 2 and 3) display in irregular morphology of variable dimensions and consist almost exclusively of Garnet (>85%) with subordinate amounts of epidote, hedenbergite, feldspar and quartz. The size of such segments appears locally, to be quite significant. For example at the locality Ag. Marina an outcrop of dimensions 450x120x40 m has garnet content in the order of 25 to 30% with a garnet grade, in individual zones of 1 to 8 m wide, of more than 85%.

The garnets occur often as idiomorphic crystals up to 10 cm, but mainly as massive crystalline rock. The colour is mainly reddish-brownish often displaying zoning.

MINERALOGY AND MINERAL CHEMISTRY

KTENAS (1916) examined garnets from Halara area in Serifos, which he described as groussulare. MARINOS (1951) described the garnets as grossulare-almandine and less as andradite and melanite. MPOSKOS (1978) according to density, lattice constants and refraction indices characterised the garnets as andradite.

The chemical composition, the mineral formula, the garnet's endmembers, lattice constants, density and Refraction indexes are given in table (1).

The garnets are typical andradites with minor component grossulare, according to microprobe analysis.

The garnet compositions expressed as endmembers are :

Andradite	$Ca_3Fe_2O_3^{+}Si_3O_{12}$	:	96 - 98%
Pyrope	$Mg_3Al_2Si_3O_{12}$	:	0 - 1%
Spessartine	$Mn_3Al_2Si_3O_{12}$	:	0.2- 1.5%
Grossulare	$Ca_3Al_2Si_3O_{12}$	:	0.2- 4%
Almandine	$Fe_3 2{+}Al_2Si_3O_{12}$	:	-
Uvarovite	$Ca_3Cr_2Si_3O_{12}$	:	-

The grossulare content is high in garnet coexisting with epidote, samples SPA207, SPA67A in Table 1.

The lattice constants, the Refraction indexes and densities of Table (1) are in good agreement with those of MPOSKOS (1978), and in accordance to diagrams of WINCHELL (1958).

Sample	SPA9	SPA219	SPA58	SPA209	SPA218	SPAB82	SPA30	SPAB46 B50	SPA77	SPA57	SPA207	SPA67A	SPA67A
	N=4	N=4	N=5	N=4	N=4	N=4	N=6	N=4	N=4	N=4	N=4	N=5	N=5
SiO_2	35.71	35.85	35.81	35.57	35.31	35.55	35.62	35.41	35.63	36.70	37.31	37.18	38.10
TiO_2	-	-	-	0.03	-	-	0.07	0.07	0.06	0.02	0.51	0.50	-
Al_2O_3	1.73	0.62	0.35	0.63	0.10	0.26	1.90	0.79	0.52	6.10	9.34	6.02	25.48
Cr_2O_3	-	-	-	-	-	-	-	-	-	-	-	-	-
Fe_2O_3(total)	28.71	30.52	30.44	30.23	31.10	31.10	28.71	30.12	30.75	22.95	18.07	22.59	10.55
MnO	0.24	0.17	-	0.08	0.21	0.29	0.17	0.10	0.36	0.24	0.67	0.63	-
MgO	0.06	0.08	0.07	0.08	0.01	0.24	0.06	0.08	0.02	0.02	0.09	0.06	0.05
CaO	33.23	33.18	33.15	33.01	32.85	32.74	33.13	32.84	32.77	33.93	34.19	33.93	23.61
Total	99.68	100.42	99.82	99.63	99.58	100.18	99.66	99.41	100.11	99.96	100.18	100.91	97.80
a_o(A)	12.021	12.049	12.058	12.033	12.049	12.038	12.037	12.044	12.058	11.981	11.952	12.012	8.906
b_o													5.631
c_o													10.195
β													115.43
n	1.873	1.875	1.876	1.872	1.885	1.880	1.872	1.875	1.876	1.841	1.825	1.837	
D(gr/cm³)	3.805	3.810	3.800	3.800	3.825	3.785	3.793	3.812	3.813	3.750	3.720	3.800	3.405
Number of Oxygens	12	12	12	12	12	12	12	12	12	12	12	12	12.5
Si	3.001	3.007	3.021	3.006	2.999	2.997	2.992	2.998	3.002	3.002	2.992	3.010	3.004
Al	0.171	0.061	0.035	0.063	0.010	0.026	0.188	0.079	0.052	0.588	0.883	0.574	2.368
Ti	-	-	-	-	-	-	0.004	0.004	0.004	-	0.031	0.030	0.006
Cr^{3+}	-	-	-	-	-	-	-	-	-	-	-	-	-
Fe^{3+}	1.816	1.927	1.933	1.923	1.988	1.973	1.815	1.919	1.950	1.413	1.091	1.376	0.626
Mn	0.017	0.012	-	0.006	0.015	0.021	0.012	0.007	0.026	0.017	0.046	0.040	-
Mg	0.008	0.010	0.009	0.010	0.001	0.030	0.008	0.010	0.003	0.002	0.011	0.008	-
Ca	2.992	2.982	2.997	2.989	2.989	2.957	2.982	2.980	2.958	2.974	2.938	2.943	1.995
Andradite	90.28	96.19	96.44	96.07	99.20	98.38	90.92	96.29	98.11	70.87	58.17	70.50	
Pyrope	0.25	0.33	0.29	0.34	0.04	1.00	0.25	0.34	0.03	0.08	0.36	0.30	
Spessartine	0.57	0.40	-	0.19	0.50	0.69	0.40	0.24	0.86	0.56	1.52	1.30	
Almandine	-	-	-	-	-	-	-	-	-	-	-	-	
Grossulare	8.91	3.07	3.25	3.41	0.26	-	8.43	3.13	0.94	28.50	41.95	27.90	
Uvarovite	-	-	-	-	-	-	-	-	-	-	-	-	

Table (1). Composition, Lattice constants, Refraction indexes, and Density of Garnets from Serifos.

In the triangle diagram Spessartine-Grossulare-Andradite (Fig. 4) according to EINAUDI et al. (1981, 1982) almost all garnet analyses are located on the andradite side in accordance to iron deposits (magnetite-hematite, limonite) on island and the metasomatic formation of andradite.

The metasomatic formation of garnets, in some samples, is indicated by quartz inclussions in andradite. This are rests after the garnet formation. The

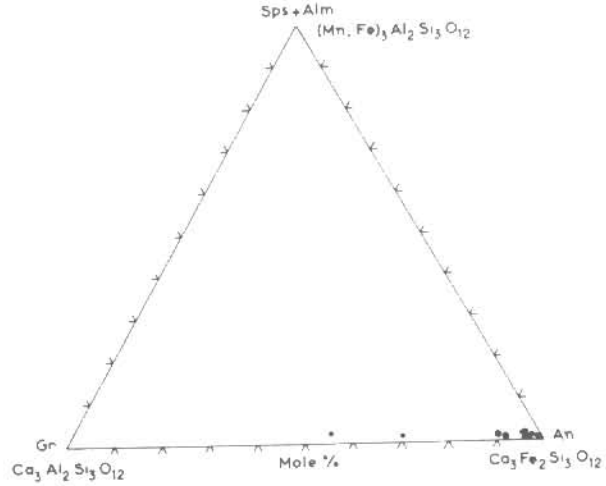

Fig. 4. Triangle Diagram Spessartine-Grossulare-Andratite according to EINAUDI (1981). Almos all garnet analyses are located on the andradite side in accordance to iron deposits on Serifos Island.

variation of the grossulare content is to explane by local inhomogenity in the metamorphic rocks. These are albite-sericite-epidote-schists and biotite-gneises.

The rare earth content in garnet varies : La:25-70 ppm, Ce:28-80 ppm, for coexisting epidotes these values are La:400 ppm, Ce:300 ppm. The higher values in epidotes can be explained by the similarity of their structure with that of allanite, which coexists in some occurrences (e.g. Mykoni, Fig. 2) in significant quantities (PERDIKATSIS & PAPASTAVROU, 1990).

ECONOMIC SIGNIFICANCE, USES ETC

In order to determine the application potential of the garnetite of Serifos island, a composite sample was tested as industrial mineral at the Tovary Strojirensce Techniky laboratories in Chechoslovakia by the BATTELL method (FERA

DIN). The test was carried out on 18 to 20 class grain size, according to FERA DIN (800-1000 μ in size) and the result are listed in Tab. (2) together with corundum test data for comparison.

The test confirmed that, this type of garnet (Andradite) is suitable for grinding soft surfaces such as wood, leather etc.

It should be noted, that with the exception of the U.S.S.R. no other european state is garnet producer. According to 1985 data (U.S.A. Dpt. of Interior, Bureau of Mines) the U.S.S.R. produces approx. 500 tons per year of garnet.

Type of material	Number of Rotation	log. z
Serifos Garnet	125	2.36
White Corundum	400	2.60
Rubin	400	2.65
Brown corundum	580	2.76
Finelly crystalline corundum	670	2.83
Semi brittle corundum	1050	3.02

Table (2). Results for the Garnetite of Serifos according to BATTELL method in comparison with corundum.

The U.S.A. accounts for more than 75% of the total world garnet production (1988) and for more than 60% of the idendified total world reserves (1987). Significant producers are also India, Austria, China and Sri Lanka.

Garnet market prices, for various grades, have increased between 1978 and 1984 by 2 to 3% per year (U.S. Bureau of Mines, 1985). From 1985, however, market prices for garnet with specialised applications have witnessed an increase of 50 to 100% relative to 1984 prices (INDUSTRIAL MINERALS, 2, 1990). For example the 20-40 mesh concentrates is currently sold at 100-500 $ per ton (depending on quantity) for filter application and 200-240 $ per ton for applications as abrasives. Better prices can be achieved (1100-1200 $) for high grade garnets and for specific uses (f.e. optics), although in small quantities.

The principal garnet uses are allocated as follows :

a. Sandblasting, b. Filters, c. Electronics, d. Tools,
e. Treatment of glass and ceramics, f. Others.

Category (e) applications however display a declining trend in demand, in contrast to the applications of categories (a) and (b) which appear to increase.

On the production front (apart from the U.S.A.) both India and Australia have currently expanded their production capacities. In fact, India has increased production by 65% whereas the projected (1984) production capacity increase for Australia of 18.000 tons in 1990 has been already surpassed in 1989 (20.000 tons).

Current forecasts by the U.S.B.M. to the year 2.000 indicate an annual growth rate for garnet of 6-7%.

The garnetite reserves in the island of Serifos (C1-C2) are estimated to be in the region of 1.5 mill tons, out of which at least 500.000 tons with an average garnet grade of more than 65 to 70% can be recovered by open cast mining.

CONCLUSIONS

In the frame of a mineral exploration program on Serifos island significant garnetite occurrences have been located. Obviously the presence of the andradite garnetite shows a clear genetic connection to the metasomatic processes on the island, caused by the intrusion of a Miocene I-type granodiorite.

The highest andradite concentrations and the biggest garnetite dimensions are found in the central part of the island. The garnetite occurs in the form of layers of irregular shape, 0.2 m to 8 m thick and up to few hundred metres long. Garnetite layers with more than 70-80% andradite in composition are common. The andradite grain size ranges from mm up to 15 cm.

The main mineral assemblage is garnet (>95% andradite)-epidote± hedenbergite±actinolite±quartz±albite±magnetite±oligiste.

The estimated (C1-C2) garnetite reserves at the stage of exploration are in the range of 1.5 mill. tons, with possibly 400-500.000 tons of exploitable garnetite on open pit conditions and an average of more than 30-35% andradite (up to 70-80% in some cases).

The technological tests are in progress.

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