ELECTRON MICROPROBE ANALYSES OF MINERALS FROM PERIDOTITES AND ASSOCIATED VEIN ROCKS OF ZABARGAD ISLAND, RED SEA, EGYPT.

F.Brandstätter, T.Ntaflos, and G.Kurat
Naturhistorisches Museum Wien

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Mineralogisch-Petrographische Abteilung, Naturhistorisches Museum, Burgring 7,
A-1010 Vienna, Austria
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by
G.Kurat, H.Palme, A.Embey-Isztin, J.Touret, T.Ntaflos, B.Spettel, F.Brandstätter, C.Palme, G.Dreibus, and M.Prinz published in Mineralogy and Petrology 48 (1993). 309-341

SUMMARY (from Kurat et.al.,1993)

Zabargad (St. John`s) Island in the Red Sea contains three ultramafic bodies, one of which has produced the famous gem olivine (peridot). The ultramafic rock types consist of two major groups - the peridotites and the vein rocks within them. The peridotites are divided into three groups: primitive, depleted and metasomatized. The primitive peridotites are the most abundant and are represented by mainly pristine spinel-lherzolites which have chemical compositions representative of the subcontinental upper mantle. The depleted peridotites are mainly harzburgites and some dunites and both are similar to worldwide occurrences. The most depleted peridotites also appear to have the greatest metasomatic additions of incompatible elements, as has been noted at other localities. Metasomatic additions were clearly accompanied by tectonic shearing. Metasomatism included infiltration of incompatible elements and the formation of porphyroblasts of clinopyroxene, amphibole, Al-spinel and plagioclase; it took place under a variety of p-T conditions and with fluids of differing compositions.

The vein rocks are mainly monomineralic and comprise olivinites, orthopyroxenites, clinopyroxenites, websterites, hornblendites and plagioclasites. These rocks are believed to have formed from fluids similar to that which metasomatized the host rock, rather than by some kind of igneous process. The fluids were derived from peridotite reservoirs (fertile and depleted) and apparently were in equilibrium with these reservoirs. Highly abundant fluid inclusions document the hypersaline and CO_2-dominated character of these fluids. Monomineralic vein rocks are closely associated with metasomatic and tectonic processes, and there is a complete transition between metasomatic impregnation and formation of vein rocks. These processes may have also been active in other peridotite bodies of the world, as was earlier recognized and documented in the Seiad Ultramafic Complex, California. Metasomatism is evident along clinopyroxenite and hornblendite veins, whereas orthopyroxenites, olivinites and plagioclasites do not show any interaction with the wall rocks. Olivinites are probably the latest (lowest p-T) vein rock type, and the latest olivine which formed within their open cavities became the gem peridot.

Zabargad ultramafic rocks preserve relic phases indicating an initial depth of origin greater than 85 km. Clinopyroxenites preserve the memories of the highest p-T conditions and they may be the first vein rock type formed in the peridotites. The p-T path of uplift coincides with the oceanic geotherm at great depth but deviates systematically from it with falling pressure in a series of tectonic stages accompanied

by metasomatism and recrystallization. The p-T and petrologic history indicates rapid uplift, a feature which is supported by extensive contact metamorphism of the associated metasediments.

SAMPLE DESCRIPTIONS

General

Spinel lherzolite is the main component of the ultramafic rock types on Zabargad Island. It is characterized by an exceptional freshness, manifested in a lack of serpentine minerals in almost all of the samples. Another exceptional feature is the high proportion of rocks with a relatively high modal clinopyroxene content which may indicate that primitive (undepleted) lherzolites are unusually abundant on the island (see also Piccardo et al., 1988; Kurat et al.,1984; Kurat, 1991,1992). In addition to the four common phases of spinel lherzolites, plagioclase is present in trace amounts in some of the samples, typically enveloping spinel crystals (see also Bonatti et al., 1986). Another phase present in small amounts in some samples is a brown amphibole generally found in the proximity of clinopyroxene and spinel.

The textures of the spinel lherzolites are mostly porphyroclastic, but protogranular-porphyroclastic transitional textures are also common. The large (>1mm) porphyroclasts are olivine and orthopyroxene, while the smaller (<1mm) crystals are mostly clinopyroxene and spinel. Porphyroclasts may occasionally be elongated and strained, and undulatory extinction and kink bands were found in some large olivine crystals. Rarely, highly deformed cataclastic textures also occur. These mylonitic textures, however, are confined to the summit area of the MPH. A remarkable feature of the Zabargad peridotites is that the texture, i.e., the degree of deformation, can change abruptly within a sample. A good example is sample Z-17 (see also Figs.2C and 2D) which also has impressive geochemical properties (see below). Less abundant lithologies include spinel harzburgites, plagioclase peridotites, amphibole peridotites and wehrlites as well as vein rocks such as olivinites, orthopyroxenites, clinopyroxenites, hornblendites, plagioclasites and websterites.

The vein rocks always have very coarse-grained pegmatoidal textures (Fig.3). Grain sizes are usually in the cm range. Olivinites and hornblendites can contain crystals in the dm range and one orthopyroxenite (Z-31) contained crystals up to 1 m in diameter. The width of the veins ranges from a few mm to approximately 1m. Textures range from equigranular (some websterites) to porphyroclastic (most pyroxenites) to highly complex cataclastic exhibiting several recrystallization events.

Individual

Brief descriptions of samples for which data are presented are given below (compare Table 1 in Kurat et al.,1993). In describing textures we follow the terminology of

Mercier and Nicolas (1975) and Boudier and Nicolas (1985). The following abbrevations are used: amph = amphibole, cpx = clinopyroxene, ol = olivine, opx = orthopyroxene, phl = phlogopite, plag = plagioclase, sp = spinel, MPH = main peridotite hill, CPH = central peridotite hill, NPH = northern peridotite hill.

Figures referred to can be found in Kurat et al.(1993).

Z-13. Sp-lherzolite with vein of plagioclasite. MPH. Elevation 165 m. Z-13A: Sp-lherzolite. Fresh, coarse-grained, porphyroclastic texture with slightly deformed opx porphyroclasts; very thin exsolution lamellae of cpx in opx, large cpx grains have opx exsolution lamellae; sp is brown and mostly associated with ol. The latter shows kink bands. The matrix is recrystallized and contains neoblasts of ol and opx. Z-13G: Plagioclasite. Vein, 2-3 cm wide in Z-13A; plag is very coarse-grained (cm) and shows deformed polysynthetic twin lamellae (Fig.3F); all minerals of the host are present as relics; cpx shows not only opx but also plag exsolution lamellae, brown sp is surrounded by phlogopite and both are enclosed in plag, some phlogopite is poikiloblastic and includes ol, cpx and plag; opaques comprise pentlandite, ilmenite and pyrite.

Z-14. Sp-plag-lherzolite. MPH. Elevation 170 m. Fresh, coarse-grained lherzolite with abundant large, macroscopically black sp neoblasts on shear planes; texture is porphyroclastic and foliated; the large (up to 1 cm) sp neoblasts are emplaced in the foliation plane; they are green in transmitted light; matrix sp is brownish-green. All spinels (green and brownish) are surrounded by plag; coronas of opx and cpx are present at contacts between ol and plag.

Z-15. Amph-harzburgite. Layer within normal sp-lherzolite at MPH, a few meters above Z-14; complex texture with large opx and ol, apparently relics of early coarse-grained protogranular texture; matrix has fine-grained tabular equigranular texture, green amph is either poikiloblastic (includes ol and opx), or is interstitial in matrix; apatite, commonly associated with amph is abundant, coarse-grained plag is associated with cpx, cancrinite occurs with cpx and plag; sp is rare and brown, opaques are mainly pyrrhotite and pentlandite.

Z-17. Amph-harzburgite. Sample taken from talus on shore just below the peridotite mass of the NPH. Macroscopically the sample consists of two parts: one is coarse-grained and porphyroclastic and the other is fine-grained and sheared. Z-17G. Coarse-grained amph-harzburgite (Fig.2C) with porphyroclastic texture rich in large porhyroclasts, matrix is equigranular and equilibrated. All phases show late deformation (kink bands and distorted exsolution lamellae); amph associated with sp and pyroxenes. Z-17D. Sheared amph-harzburgite; texture is equigranular with rare porphyroclasts (Fig.2D) and shows evidence of complex tectonic history (repeated decrease in grain size and recrystallization), brown spinel is situated mostly in the foliation plane; abundant neoblasts of amph.

Z-19. Amph-harzburgite. Occurs in lenses within normal harzburgite of NPH; macroscopically strongly foliated and porphyroclastic with porphyroclasts of ol and opx up to 7 mm; opx and cpx have exsolution lamellae; amph commonly occurs with sp but also as impregnation.

Z-26. Plag-wehrlite. From MPH near SW tip of the island; macroscopically foliated with abundant black (green in thin section) spinel (up to 2 cm) in thin layers parallel to foliation; sp rimmed by plag; microscopically the rock is strongly deformed with a complex porphyroclastic texture; abundant ol (kink banded) and cpx porphyroblasts, opx porphyroclasts show exsolution lamellae, coarse-grained, twinned plag is abundant and tends to occur in strings parallel to foliation.

Z-28. Hornblendite (Fig.3E) Western MPH; pegmatoidal amph rock in which bundles of dark green amph crystals up 10 cm in length can be observed. The rock is fresh, however, minor chlorite and carbonate are present.

Z-30. Sp-plag-harzburgite. From western MPH; Complex texture transitional between porphyroclastic and equigranular, abundant porphyroclasts of ol, opx, and cpx; pyroxene porphyoclasts are commonly poikilitic and have exsolution lamellae; pyroxene neoblasts are free of lamellae; dark brown sp is surrounded by plag; at contacts between ol and plag coronas of opx and cpx are present.

Z-31. Orthopyroxenite. From a vein on CPH; very coarse-grained, pegmatoidal rock with opx up to 10 cm; opx has cpx exsolution lamellae in the interior but not near surface; a few cpx with exsolution lamellae of opx are included in opx; ol and sp (brown) are present only in minor amounts.

Z-34. Sp-plag-lherzolite. Main rock type of CPH, coarse-grained, porphyroclastic with some grain boundary recrystallization; large opx has very thin exsolution lamellae of cpx and inclusions of ol; cpx has broad opx exsolution lamellae; brown amph occurs interstitially; ol porphyroclasts have kink bands and occasionally include spongy opx and small rounded sp; larger holly-leaf sp (green) is surrounded by plag.

Z-36. Amph-dunite. Collected on shore of NPH; deformed rock with abundant large porphyroblasts of green amph; texture is transitional between porphyroclastic and equigranular with good orientation of neoblasts along foliation; minor amounts of opx and apatite are present in the matrix.

Z-37. Plag-clinopyroxenite. MPH. With large (up to 2 cm) sp neoblasts in mobile zones, sp is rimmed by plag; transitional texture between porphyroclastic and equigranular; sp (green) porphyroblasts have abundant exsolved ilmenite, and sometimes poikilitically enclose ol and plag; cpx porphyroblasts are plastically deformed and partially cataclased; they have abundant exsolutions of opx and plag; there appear to be several generations of cpx; ol relics occur in strings and are kink banded, rare amph occurs as inclusions in green sp; coronas of opx + cpx are present at contacts between ol and plag.

Z-51. Sp-plag-harzburgite, MPH. Rock is strongly deformed and dispays complex texture; ol and opx porphyroclasts are coarse-grained and have abundant kink bands; matrix consists of fine-grained, well equilibrated neoblasts; sp is brown and surrounded by plag which has deformed twinning lamellae; large cpx porphyroblasts with abundant exsolution lamellae of opx occur in strings parallel to the foliation.

Z-52. Ol-plag-websterite, MPH. Vein in harzburgite; large porphyroclasts (up to 1 cm) of cpx and opx in complex granular matrix of ol, opx, cpx, and plag; porphyroclasts have exsolution lamellae and are deformed; no sp found.

Z-102. Clinopyroxenite (Fig.3B). From vein on CPH; cpx porphyroblasts up to 3 cm in equigranular matrix consisting of cpx, a few opx, vermicular intergranular sp (brown) rimmed by plag and opaques; all pyroxenes have exsolution lamellae and are partially altered (amphibolized).

Z-103. Clinopyroxenite (Z-103G) veins in sp-harzburgite (Z-103H), CPH. Harzburgite is cut by veins of ol-pyroxenites, clinopyroxenites and strings of cpx porphyroblasts; host rock is porphyroclastic with strongly deformed and kinked ol and opx porphyroclasts; opx has fine exsolution lamellae; sp is brown; portions of the host rock contain cpx porphyroblasts parallel to the foliation, they have exsolved opx and plag; sp is rimmed by plag. Clinopyroxenites are coarse-grained granular; cpx has exsolution lamellae of sp, opx and plag; scattered relics of ol and opx.

Z-104. Olivinite. From vein in western MPH; pegmatoidal rock consisting of brown platy ol (up 7 cm), cavities between plates are partially filled with green gem peridot (up to 1 cm), red and black oxide, garnierite, and serpentine; ol is partly serpentinized.

Z-106. Plag-amph-lherzolite-mylonite (Fig.2F). From top of MPH; fine-grained, strongly tectonized rock, equigranular granulitic texture; strongly foliated with layers rich in amph following foliation, these alternate with layers rich in plag; sp is rare and brown; ol is strongly, opx is slightly kinked; matrix is very fine-grained and partially amphibolized.

Z-109. Sp-websterite, MPH (Fig.3D). Coarse-grained granular texture with equilibrated grain boundaries, pyroxenes have fine exsolution lamellae; sp is brown with some amph; some intergranular plag is present.

Z-118. Sp-lherzolite (Z-118H) with plag-websterite vein (Z-118G) collected on breakwater. Lherzolite: Coarse-grained; protogranular-porphyroclastic transitional texture; ol and opx partially kinked, cpx and opx have fine exsolution lamellae; green sp is amoeboid and mostly associated with pyroxene; small dark sp is included in opx; relic corona structures are common. Websterite: Coarse-grained, equigranular texture; pyroxene has abundant exsolution lamellae and is partially amphibolized; very few ol grains and intergranular amph, sp is opaque; a few large neoblasts of light green sp; plag occurs as exsolution lamellae and as intergranular grains.

MINERAL ANALYSES

Electron microprobe analyses of minerals of peridotites and associated vein rocks of Zabargad Island have been obtained with an ARL-SEMQ electron microprobe operated at 15 kV acceleration potential and about 15 nA sample current. Wet chemically analyzed minerals were used as standards. Correction procedures followed Bence and Albee (1968) and Albee and Ray (1970). The following Tables give averaged analyses obtained by our standard routine analyses programs. Peak counting times were 20s and background counts were collected at appropriate positions above and below peaks (counting time: 2x10 s). As a lower limit of detection an average of 0.02 wt.% for the elements analyzed has been estimated.

Accuracy is usually better than 2% for major elements and correspondingly worse for minor element contents.

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Table A: Averaged electron microprobe analyses of olivines from peridotites and associated rocks from Zabargad Island (wt.%). Alkali, Al2O3, and TiO2 contents are below our detection limit (0.02%). Total Fe is given as FeO.

	PERIDOTITES													
Sample:	Z-13A	Z-14	Z-15	Z-17G	Z-17D	Z-19	Z-26	Z-30	Z-34	Z-36	Z-51	Z-103H	Z-106	Z-118H
No of anal.	4	6	14	18	27	20	10	14	9	10	26	13	3	9
SiO2	41.1	41.2	40.4	41.4	42.2	41.5	41.2	41.9	41.2	41.6	41.6	41.4	41.4	41.1
Cr2O3	<0.02	0.02	<0.02	<0.02	0.02	<0.02	<0.02	0.03	<0.02	<0.02	<0.02	<0.02	0.05	0.02
FeO	9.5	8.8	9.7	8.3	8.4	8.6	9.6	8.7	9.1	9.3	8.9	8.9	9.4	10.1
MnO	0.14	0.12	0.14	0.14	0.11	0.13	0.15	0.13	0.14	0.16	0.15	0.12	0.17	0.14
NiO	0.38	0.35	0.37	0.39	0.39	0.41	0.37	0.42	0.41	0.37	0.40	0.36	0.30	0.39
MgO	49.6	49.7	50.7	50.8	50.2	49.0	49.8	48.7	49.6	49.0	48.5	49.1	48.7	48.8
CaO	0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	0.02	<0.02	0.02	<0.02	<0.02	0.03	0.02
Total	100.72	100.19	101.31	101.03	101.32	99.64	101.12	99.90	100.45	100.45	99.55	99.88	100.05	100.57
100XMg	90.3	91.0	90.3	91.6	91.4	91.0	90.2	90.9	90.7	90.4	90.5	90.8	90.2	89.4

	VEIN ROCKS							
	Olivinites		Pyroxenites					Plagioclasite
Sample:	Z-104	GEM	Z-31	Z-37	Z-52	Z-109	Z-118G	Z-13G
No of anal.	13	46	9	3	19	2	5	21
SiO2	42.2	41.6	41.5	40.9	40.6	41.3	40.3	41.8
Cr2O3	<0.02	<0.02	<0.02	0.02	<0.02	<0.02	<0.02	<0.02
FeO	9.3	9.6	8.9	11.3	9.7	9.9	11.0	10.0
MnO	0.12	0.10	0.12	0.26	0.14	0.17	0.18	0.15
NiO	0.35	0.33	0.51	0.35	0.36	0.36	0.43	0.34
MgO	49.3	49.7	50.4	47.2	48.1	48.8	48.8	48.0
CaO	<0.02	<0.02	<0.02	0.08	<0.02	<0.02	0.02	<0.02
Total	99.27	101.33	101.43	100.11	98.9	100.53	100.73	100.29
100XMg	90.4	90.2	91.0	88.2	89.8	89.8	88.8	89.5

Table B: Averaged electron microprobe analyses of orthopyroxenes from peridotites and associated rocks from Zabargad Island (wt.%). Total Fe is given as FeO.

	PERIDOTITES														
Sample:	Z-13A		Z-14			Z-15		Z-17G			Z-17D		Z-19	Z-26	
	Porph	Neobl	Porph	Exsol	Corona	Porph	Neobl	Neobl1	Neobl2	Neobl3	Neobl1	Neobl2	Porph	Core	Rim
No of anal.	15	2	5	1	2	2	4	6	20	1	9	7	12	2	1
SiO2	56.4	57.4	55.2	53.9	58.7	55.7	58.4	57.6	57.7	58.0	58.4	58.0	57.10	56.3	57.3
TiO2	0.16	0.15	0.35	0.07	0.04	0.15	0.03	0.06	0.03	<0.02	0.60	0.03	<0.02	0.15	0.10
Al2O3	2.90	1.80	4.0	4.5	1.15	3.8	1.06	1.26	0.83	0.07	1.28	0.75	2.50	3.1	1.68
Cr2O3	0.58	0.29	0.83	0.81	<0.02	0.73	0.14	0.36	0.27	0.09	0.42	0.24	0.34	0.71	0.54
FeO	6.6	6.4	6.1	7.5	6.2	6.8	6.2	5.3	5.6	5.8	5.3	5.6	6.0	6.9	6.4
MnO	0.16	0.12	0.13	0.20	0.17	0.13	0.20	0.13	0.15	0.13	0.13	0.13	0.15	0.21	0.16
NiO	0.08	0.08	0.10	0.05	0.08	0.14	0.09	0.06	0.08	<0.02	0.06	0.06	0.08	0.10	0.14
MgO	33.2	34.4	34.0	32.90	34.6	33.7	35.0	35.7	35.8	35.7	34.3	34.6	33.6	33.4	35.0
CaO	0.54	0.42	0.52	0.40	0.20	0.19	0.28	0.44	0.38	0.05	0.42	0.36	0.47	0.58	0.21
Na2O	<0.02	<0.02	<0.02	<0.02	<0.02	0.04	<0.02	0.03	0.02	0.02	0.02	0.02	<0.02	<0.02	<0.02
Total	100.62	101.06	101.23	100.33	101.14	101.38	101.40	100.94	100.86	99.86	100.39	99.79	100.24	101.45	101.53
En	89.0	89.8	90.0	88.0	90.5	89.5	90.5	91.6	91.3	91.6	91.3	91.1	90.1	88.6	90.3
Fs	9.9	9.4	9.1	11.3	9.1	10.1	9.0	7.6	8.0	8.3	7.9	8.3	9.0	10.3	9.3
Wo	1.0	0.8	1.0	0.8	0.4	0.4	0.5	0.8	0.7	0.1	0.8	0.7	0.9	1.1	0.4

Table B: continued

	PERIDOTITES													
Sample:	Z-30				Z-34		Z-36	Z-51		Z-103H			Z-106	
	Porph	Neobl	Exsol	Corona	Porph	Neobl		Porph	Neobl	Porph1	Porph2	Neobl	Porph	Exsol
No of anal.	4	4	4	1	19	4	8	3	6	7	41	6	5	1
SiO2	55.3	57.2	54.7	57.2	55.1	56.8	59.0	54.9	56.4	56.5	57.4	58.7	55.6	54.1
TiO2	0.12	0.12	0.17	0.06	0.10	0.06	<0.02	0.04	0.05	0.06	0.05	0.02	0.13	0.09
Al2O3	4.5	1.89	5.4	1.19	4.3	1.94	0.22	3.5	2.45	3.9	2.93	1.00	3.3	4.6
Cr2O3	0.65	0.38	0.52	0.1	0.30	0.20	0.18	0.56	0.34	0.63	0.52	0.28	0.61	0.47
FeO	6.1	6.2	6.0	6.0	6.2	6.4	5.9	6.1	6.2	6.0	6.1	6.1	6.6	7.2
MnO	0.23	0.20	0.13	0.26	0.14	0.14	0.18	0.17	0.18	0.16	0.22	0.20	0.17	0.22
NiO	0.12	0.09	0.09	0.12	0.07	0.09	0.08	0.07	0.09	0.10	0.08	0.06	0.07	0.18
MgO	31.7	33.3	32.4	33.8	33.3	34.8	35.0	33.4	33.6	32.6	32.8	34.2	32.0	31.4
CaO	0.56	0.63	0.68	0.33	0.46	0.37	0.46	0.70	0.55	0.80	0.59	0.26	0.44	0.29
Na2O	<0.02	<0.02	<0.02	<0.02	0.04	0.02	<0.02	<0.02	<0.02	0.03	<0.02	<0.02	<0.02	<0.02
Total	99.28	100.01	100.09	99.06	100.01	100.80	101.02	99.44	99.86	100.78	100.69	100.82	98.92	98.55
En	89.2	89.4	89.4	90.4	89.7	90.0	90.6	89.5	89.7	89.2	89.5	90.5	88.8	88.1
Fs	9.6	9.3	9.3	9.0	9.4	9.3	8.6	9.2	9.3	9.2	9.3	9.1	10.3	11.3
Wo	1.1	1.2	1.3	0.6	0.9	0.7	0.9	1.3	1.1	1.6	1.2	0.5	0.9	0.6

Table B: continued

	PERIDOTITES			PYROXENITES											
Sample:	Z-118H			Z-31		Z-37				Z-52		Z-102			
	Porph1	Porph2	Neobl	Opx 1	Opx 2	Core	Rim	Exsol	Neobl	Exsol	Neobl	Opx 1	Opx 2	Opx 3	Exsol
No of anal.	2	4	11	6	5	1	4	3	2	4	1	5	9	9	14
SiO2	55.0	55.6	57.0	55.4	55.3	55.1	57.7	54.4	58.4	56.1	58.6	57.1	57.9	58.0	56.0
TiO2	0.15	0.18	0.11	0.09	0.06	0.1	0.24	0.13	0.17	0.11	0.12	0.05	0.06	<0.02	0.04
Al2O3	5.4	3.9	2.05	4.0	2.85	5.9	1.66	7.1	1.29	4.3	1.22	3.1	2.17	0.99	4.0
Cr2O3	0.32	0.26	0.16	0.32	0.27	0.06	0.08	0.07	0.08	0.45	0.32	0.39	0.41	0.32	0.48
FeO	6.7	7.0	6.9	6.1	6.0	7.5	7.9	7.5	7.3	7.1	7.4	6.1	6.1	6.5	6.3
MnO	0.15	0.15	0.18	0.14	0.13	0.21	0.25	0.22	0.24	0.18	0.20	0.13	0.15	0.12	0.15
NiO	0.14	0.13	0.07	0.14	0.07	0.08	0.08	0.07	0.12	0.08	0.05	0.11	0.11	0.12	0.11
MgO	32.7	32.8	33.3	34.0	34.8	31.2	32.5	30.9	32.9	32.7	33.0	33.9	34.4	35.2	33.9
CaO	0.37	0.51	0.38	0.38	0.38	0.35	0.6	0.48	0.4	0.41	0.34	0.41	0.4	0.21	0.39
Na2O	<0.02	0.04	<0.02	<0.02	<0.02	<0.02	<0.02	0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
Total	100.93	100.57	100.15	100.57	99.86	100.50	101.01	100.89	100.90	101.40	101.25	101.29	101.70	101.46	101.37
En	89.0	88.4	88.9	90.2	90.5	87.5	87.0	87.2	88.2	88.4	88.2	90.1	90.3	90.3	90.0
Fs	10.2	10.6	10.3	9.1	8.8	11.8	11.9	11.9	11.0	10.8	11.1	9.1	9.0	9.4	9.4
Wo	0.7	1.0	0.7	0.7	0.7	0.7	1.2	1.0	0.8	0.8	0.7	0.8	0.8	0.4	0.7

Table B: continued

	PYROXENITES							PLAGIOCLASITE	
Sample:	Z-103G			Z-109		Z-118G		Z-13G	
	Exsol1	Exsol2	Exsol3	Core	Rim	Core	Rim	Opx 1	Opx 2
No of anal.	6	4	5	4	6	3	1	4	3
SiO2	54.1	56.0	56.6	56.5	58.0	55.8	56.9	56.6	58.9
TiO2	<0.02	<0.02	<0.02	0.09	0.12	0.14	0.07	0.44	0.28
Al2O3	7.3	4.5	2.06	3.0	1.49	3.0	1.8	2.34	1.94
Cr2O3	0.37	0.54	0.29	0.32	0.35	0.06	<0.02	0.17	0.28
FeO	7.4	7.0	6.6	6.6	6.9	7.4	7.4	7.6	6.5
MnO	0.20	0.21	0.21	0.24	0.18	0.21	0.22	0.17	0.17
NiO	0.10	0.08	0.07	0.10	0.07	0.09	0.07	0.08	0.07
MgO	31.2	31.9	33.8	33.1	33.4	32.9	33.3	31.8	32.8
CaO	0.41	0.45	0.42	0.40	0.35	0.38	0.36	0.76	0.61
Na2O	0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
Total	101.10	100.68	100.05	100.35	100.86	99.98	100.16	99.96	101.55
En	87.5	88.2	89.4	89.2	89.0	88.1	88.3	86.9	88.9
Fs	11.6	10.9	9.8	10.0	10.3	11.1	11.0	11.6	9.9
Wo	0.8	0.9	0.8	0.8	0.7	0.7	0.7	1.5	1.2

Table C: Averaged electron microprobe analyses of clinopyroxenes from peridotites and associated rocks from Zabargad Island (wt.%). Total Fe is given as FeO.

PERIDOTITES

Samples:	Z-13A			Z-14	Z-17D		Z-19		Z-26	Z-30			
	Core	Rim 1	Rim 2	Core	Porph	Neobl	Porph	Neobl		Porph	Neobl	Coron	Bulk
No of anal.	2	2	5	9	4	3	5	1	7	4	3	2	62
SiO2	49.3	50.9	53.6	52.5	55.2	55.6	54.8	56.7	54.0	50.9	53.3	55.6	51.5
TiO2	0.67	0.84	0.53	0.47	0.02	<0.02	0.05	0.02	0.52	0.43	0.34	0.03	0.12
Al2O3	6.1	4.6	3.0	5.2	1.8	0.59	3.0	0.61	3.1	6.3	2.7	0.72	6.1
Cr2O3	1.23	1.07	0.65	1.04	1.92	1.10	0.62	0.39	0.70	1.10	0.66	<0.02	1.04
FeO	2.6	2.5	2.6	2.8	3.5	2.01	2.22	1.72	2.6	3.0	2.30	2.03	3.3
MnO	0.08	0.09	0.10	0.07	0.10	0.07	0.08	0.03	0.06	0.06	0.14	0.08	0.12
NiO	0.03	0.03	0.02	0.03	0.05	0.06	0.07	<0.02	0.03	0.09	<0.02	0.08	0.06
MgO	15.0	16.2	17.1	15.6	16.3	17.4	16.7	17.3	16.6	15.6	15.9	18.1	17.4
CaO	22.9	22.6	22.4	22.6	20.0	23.3	22.4	23.8	22.8	21.1	23.2	23.7	20.2
Na2O	0.53	0.56	0.43	0.68	1.99	0.95	0.55	0.21	0.48	0.52	0.42	0.25	0.55
Total	98.44	99.39	100.43	100.99	100.88	101.08	100.49	100.78	100.89	99.10	98.96	100.59	100.39
En	45.6	47.9	49.3	46.7	49.9	49.3	49.0	48.9	48.2	48.1	46.9	49.9	51.5
Fs	4.4	4.1	4.2	4.7	6.0	3.2	3.7	2.7	4.2	5.2	3.8	3.1	5.5
Wo	50.0	48.0	46.5	48.6	44.1	47.5	47.3	48.4	47.6	47.7	49.3	47.0	43.0

Table C: continued

PERIDOTITES

Sample:	Z-34			Z-36		Z-51					Z-103H	Z-106		Z-118H	
	Core	Rim	Neobl	Porph1	Porph2	Porph	Cpx 1	Cpx 2	Cpx 3	Cpx 4		Cpx 1	Cpx 2	Porph	Neobl
No of anal.	17	6	1	3	2	3	7	13	9	5	6	1	5	5	1
SiO2	51.8	53.2	54.7	55.0	54.6	52.5	52.8	53.2	53.0	52.8	53.8	51.2	54.3	50.9	54.3
TiO2	0.58	0.35	0.23	0.02	<0.02	0.13	0.15	0.15	0.13	0.12	0.18	0.62	0.09	0.81	0.43
Al2O3	6.2	4.0	2.29	1.76	0.87	7.4	5.6	4.4	3.8	2.67	2.92	6.1	1.01	6.5	2.42
Cr2O3	0.62	0.49	0.54	3.2	1.67	0.34	0.85	0.87	0.93	0.85	0.68	0.47	0.16	0.57	0.21
FeO	2.45	2.34	2.15	2.54	2.6	2.96	2.73	2.58	2.41	2.14	2.32	3.1	2.09	2.6	2.6
MnO	0.08	0.06	0.06	0.08	0.08	0.09	0.08	0.11	0.09	0.07	0.08	0.06	0.07	0.08	0.05
NiO	0.04	0.05	0.04	0.04	0.02	0.05	0.04	0.05	0.06	0.03	0.08	<0.02	0.06	0.05	0.03
MgO	15.3	16.2	16.7	15.3	15.3	15.6	16.2	16.8	16.9	17.1	16.6	16.1	17.3	15.0	16.9
CaO	21.8	22.5	23.1	19.6	22.7	22.7	22.5	22.6	22.5	22.2	23.1	22.6	23.8	22.0	22.6
Na2O	0.82	0.64	0.54	2.06	1.00	0.58	0.56	0.53	0.47	0.44	0.45	0.33	0.16	0.82	0.48
Total	99.69	99.83	100.35	99.6	98.84	102.35	101.51	101.29	100.29	98.42	100.21	100.58	99.04	99.33	100.02
En	47.3	48.1	48.4	49.7	46.3	46.5	47.8	48.7	41.1	49.9	48.1	47.2	48.6	46.5	48.8
Fs	4.3	3.9	3.5	4.6	4.4	4.9	4.5	4.2	3.9	3.5	3.8	5.1	3.3	4.5	4.2
Wo	48.4	48.0	48.1	45.7	49.3	48.6	47.7	47.1	47.0	46.6	48.1	47.7	48.1	49.0	46.9

Table C: continued

	PYROXENITES													
Sample:	Z-31		Z-37			Z-52		Z-102				Z-103G		
	Cpx 1	Cpx 2	Core	Rim	Neobl	Cpx 1	Cpx 2	Core	Porph	Neobl	Rim	Bulk	Porph	Neobl
No of anal.	10	2	12	5	7	2	3	1	22	4	1	73	32	5
SiO2	52.8	53.0	50.9	53.0	53.8	52.3	54.1	52.4	53.6	52.4	55.2	51.9	51.6	54.6
TiO2	0.40	0.32	0.84	0.86	0.70	0.58	0.63	0.41	0.24	0.31	0.09	0.15	0.09	0.07
Al2O3	4.8	3.3	7.9	3.6	2.81	5.3	3.3	7.6	6.3	6.4	1.81	6.6	6.7	1.32
Cr2O3	0.71	0.57	0.10	0.14	0.18	0.84	0.85	1.27	1.26	1.31	0.26	1.22	0.82	0.33
FeO	2.59	2.09	3.2	3.0	2.63	2.91	2.85	2.38	2.37	2.33	2.20	3.5	3.0	2.06
MnO	0.08	0.07	0.10	0.15	0.12	0.06	0.08	0.11	0.07	0.07	0.10	0.11	0.10	0.07
NiO	0.05	0.10	0.05	0.04	0.05	0.05	0.07	0.10	0.06	0.06	<0.02	0.06	0.06	0.05
MgO	16.7	16.8	14.4	16.5	16.4	15.5	16.7	16.1	14.8	15.2	17.6	18.4	15.2	17.6
CaO	21.3	22.6	22.3	22.0	22.4	22.6	22.1	18.8	20.5	21.8	24.2	17.3	22.6	23.5
Na2O	0.76	0.54	0.57	0.44	0.40	0.6	0.55	1.53	1.61	0.99	0.18	0.61	0.62	0.31
Total	100.19	99.39	100.36	99.73	99.49	100.47	101.23	100.70	100.81	100.87	101.64	99.85	100.79	99.91
En	49.9	49.1	44.7	48.5	48.3	46.4	48.8	52.0	47.9	47.2	48.6	56.1	45.9	49.4
Fs	4.3	3.4	5.6	5.0	4.3	4.9	4.7	4.3	4.3	4.3	4.1	3.4	6.0	5.1
Wo	45.8	47.5	49.7	46.5	47.4	48.7	46.5	43.7	43.7	47.8	48.7	48.0	37.9	49.0

Table C: continued

	PYROXENITES				PLAGIOCLASITE	
Sample:	Z-109		Z-118G		Z-13G	
	Core	Rim	Core	Rim	Core	Rim
No of anal.	5	3	5	2	3	4
SiO2	52.0	53.2	50.3	53.4	52.3	52.9
TiO2	0.63	0.20	0.96	0.69	1.28	1.02
Al2O3	5.9	2.12	8.0	3.3	5.2	3.2
Cr2O3	1.01	0.79	0.08	0.06	0.23	0.52
FeO	2.48	2.36	3.2	2.84	2.92	2.62
MnO	0.14	0.10	0.10	0.10	0.08	0.10
NiO	<0.02	<0.02	0.05	0.06	0.03	0.07
MgO	14.7	16.5	14.8	16.7	15.4	16.3
CaO	21.6	24.2	22.0	22.2	22.6	22.3
Na2O	1.25	0.29	0.86	0.48	0.49	0.43
Total	99.71	99.76	100.35	99.83	100.53	99.46
En	46.5	47.8	45.7	48.8	46.3	48.2
Fs	4.9	4.4	5.5	4.6	4.9	4.4
Wo	48.0	49.1	48.8	46.6	48.8	47.4

Table D: Averaged electron microprobe analyses of amphiboles from peridotites and associated rocks from Zabargad Island (wt.%).
Fe is given as FeO.

	PERIDOTITES													PYROXENITES			
Sample:	Z-15		Z-17G			Z-17D	Z-19	Z-34	Z-36	Z-103H	Z-106	Z-118H		Z-31		Z-102	
	Poik	Gran	Amph1	Amph2	Amph3							Amph1	Amph2	Amph1	Amph2	Amph1	Amph2
No of anal.	6	6	2	12	3	5	3	6	7	3	9	2	2	7	6	1	1
SiO2	45.4	45.2	44.1	45.3	44.9	47.6	45.9	43.4	49.9	45.9	46.9	43.4	44.1	43.9	44.0	44.4	48.2
TiO2	0.29	2.31	0.19	0.48	2.10	0.72	0.15	2.48	0.10	0.52	0.87	4.1	0.14	1.53	2.66	2.03	0.06
Al2O3	13.0	12.4	14.5	12.5	10.9	9.9	12.8	15.3	8.0	12.3	11.9	12.8	13.8	15.4	13.8	13.7	10.1
Cr2O3	1.39	1.03	1.27	2.07	2.92	2.85	0.96	0.81	2.22	1.48	0.89	1.54	0.09	1.15	1.47	2.17	0.48
FeO	4.6	4.7	4.4	4.0	3.7	3.9	4.8	3.9	4.3	4.5	4.5	4.2	5.3	3.5	3.6	3.4	5.7
MnO	0.09	0.04	0.03	0.05	0.02	0.07	0.05	0.05	0.11	0.05	<0.02	0.06	0.04	0.05	0.04	0.09	0.07
NiO	0.15	0.16	0.17	0.11	0.12	0.11	0.16	0.13	0.11	0.15	0.16	0.05	0.14	0.14	0.16	0.15	0.15
MgO	18.5	17.2	19.5	18.9	18.2	19.5	18.2	17.6	20.6	17.5	17.4	16.6	17.3	17.5	16.9	17.8	18.6
CaO	12.1	12.0	10.6	12.0	12.2	10.8	12.4	11.8	10.2	12.0	11.9	12.1	12.4	11.9	12.2	12.1	12.3
Na2O	2.74	2.67	1.94	2.24	2.24	2.16	2.32	2.71	1.62	2.63	2.24	2.35	2.39	2.92	2.46	2.27	1.69
K2O	0.18	0.23	1.42	0.36	0.32	0.55	0.37	0.07	0.04	0.29	0.14	<0.02	0.28	0.07	0.34	0.04	0.3
Total	98.44	97.94	98.12	98.01	97.62	98.16	98.11	98.25	97.20	97.32	96.90	97.20	95.98	98.06	97.63	98.15	97.65
100XMg	87.8	86.7	88.8	89.4	89.8	89.9	87.1	88.9	89.5	87.4	87.3	87.6	85.3	89.9	89.3	90.3	85.3

Table D: continued

	PYROXENITES		HORNBLENDI	PLAGIOCLASITE
Sample:	Z-109	Z-118G	Z-28	Z-13G
No of anal.	2	4	23	1
SiO2	44.3	43.1	46.9	42.6
TiO2	4.2	3.3	0.37	4.1
Al2O3	12.4	14.2	11.8	12.9
Cr2O3	2.17	0.10	1.11	1.27
FeO	4.0	4.7	4.3	4.2
MnO	0.06	0.07	<0.02	0.02
NiO	0.14	0.16	0.10	0.05
MgO	16.6	17.0	18.9	16.6
CaO	11.9	11.5	12.3	11.6
Na2O	2.6	2.6	2.10	2.50
K2O	0.05	0.08	0.25	0.78
Total	98.42	96.81	98.13	96.62
100xMg	88.1	86.6	88.7	87.6

Table E: Averaged electron microprobe analyses of spinels from peridotites and associated rocks from Zabargad Island (wt.%).
Fe2O3 calculated
n.d.=not determined

	PERIDOTITES											
Sample:	Z-13A	Z-14		Z-15	Z-17G	Z-17D	Z-19	Z-26		Z-30	Z-34	Z-51
		Prim	Neobl					Prim	Neobl			
No of anal.	5	23	50	17	7	2	15	7	3	3	118	2
SiO2	0.04	0.06	0.07	0.21	0.11	0.05	0.04	0.24	0.02	0.14	0.05	0.03
TiO2	0.15	0.06	0.04	0.06	0.06	0.03	0.02	0.19	0.06	0.26	0.05	0.08
Al2O3	31.1	50.4	62.8	31.2	21.2	7.7	41.7	28.5	54.1	27.6	57.0	36.0
Cr2O3	32.6	14.1	2.6	28.7	43.9	51.1	22.2	29.7	11.6	36.1	8.7	30.8
V2O3	0.31	0.26	0.18	0.34	n.d.	0.09	0.13	0.34	0.20	0.34	0.10	0.24
Fe2O3	6.7	3.9	2.7	7.9	4.3	11.1	5.4	9.4	3.6	5.2	2.33	3.8
FeO	17.4	10.4	8.3	19.1	19.9	26.5	13.9	19.2	11.4	17.4	9.9	15.1
MnO	0.25	0.12	0.08	0.29	0.35	0.46	0.17	0.26	0.13	0.27	0.11	0.23
NiO	0.15	0.30	0.49	0.06	0.07	<0.02	0.20	0.13	0.47	0.13	0.38	0.18
ZnO	0.26	0.25	0.17	0.34	n.d.	0.40	0.50	0.24	0.22	0.38	0.16	0.16
MgO	12.8	18.7	21.3	11.3	9.9	4.2	15.6	11.0	18.7	12.2	19.7	14.8
Total	101.76	98.55	98.73	99.50	99.79	101.63	99.86	99.20	100.50	100.02	98.48	101.42
Xsp	0.542	0.808	0.984	0.562	0.397	0.157	0.694	0.523	0.843	0.499	0.885	0.609
Xch	0.381	0.152	0.026	0.347	0.551	0.698	0.248	0.365	0.121	0.438	0.091	0.349
Xmt	0.075	0.040	0.026	0.091	0.051	0.144	0.058	0.110	0.036	0.060	0.024	0.042

Table E: continued

	PERIDOTITES				PYROXENITES		PLAGIOCLASITES				
Sample:	Z-103H		Z-106	Z-118H	Z-31	Z-37	Z-102	Z-103G	Z-109	Z-118G	Z-13G
	Core	Rim									
No of anal.	8	1	4	5	8	5	5	4	3	8	27
SiO2	0.14	n.d.	0.06	0.04	0.10	0.02	0.03	0.05	0.03	0.04	0.04
TiO2	0.03	<0.02	0.06	0.03	0.02	0.04	0.11	0.11	0.04	0.03	0.18
Al2O3	42.1	28.3	49.9	57.4	55.2	62.5	34.9	36.9	52.8	61.7	39.7
Cr2O3	23.1	32.5	15.2	8.8	9.6	1.44	31.4	30.4	14.3	6.4	24.4
V2O3	n.d.	n.d.	0.17	n.d.	0.08	0.11	0.15	0.20	0.10	0.11	0.31
Fe2O3	4.2	8.7	4.5	1.82	2.59	4.2	2.68	3.6	2.10	1.74	5.2
FeO	14.7	17.2	12.2	11.1	11.0	7.3	14.5	14.2	13.7	10.4	13.6
MnO	0.21	0.39	0.14	0.13	0.11	0.10	0.23	0.19	0.12	0.11	0.19
NiO	0.17	0.05	0.30	0.35	0.44	0.48	0.13	0.11	0.27	0.49	0.19
ZnO	n.d.	n.d.	0.28	n.d.	0.27	0.08	0.14	0.11	0.57	0.13	0.14
MgO	15.6	12.6	17.9	19.1	18.6	21.8	14.6	15.6	17.1	20.4	15.9
Total	100.25	99.74	100.71	98.77	98.01	98.07	98.87	101.47	101.13	101.55	99.85
Xsp	0.698	0.508	0.792	0.89	0.872	0.944	0.604	0.619	0.828	0.919	0.667
Xch	0.257	0.392	0.162	0.092	0.102	0.015	0.365	0.342	0.150	0.064	0.275
Xmt	0.044	0.100	0.046	0.018	0.026	0.041	0.030	0.038	0.021	0.017	0.055

Table F: Averaged electron microprobe analyses of plagioclases from peridotites and associated rocks of Zabargad Island (wt.%).
TiO_2, Cr_2O_3, MnO, and NiO contents are below our detection limit (0.02%).
Total Fe given als FeO.

	PERIDOTITES									PYROXENITES			
Sample:	Z-14	Z-15	Z-26	Z-30	Z-34	Z-51	Z-106	Z-118H		Z-31	Z-37	Z-52	Z-102
								Plag1	Plag2				
No of anal.	22	3	7	14	11	6	10	2	1	12	3	15	1
SiO_2	48.9	62.8	50.0	47.6	56.8	49.3	45.3	55.8	48.9	54.6	48.4	53.9	57.1
Al_2O_3	34.0	24.9	32.9	33.6	26.8	33.6	37.1	29.3	33.5	28.7	34.0	31.2	27.9
FeO	0.10	<0.02	0.12	0.11	0.26	0.10	0.15	0.25	0.26	0.24	0.14	0.15	0.18
MgO	0.08	0.03	<0.02	<0.02	0.02	0.07	0.07	<0.02	<0.02	0.04	<0.02	<0.02	<0.02
CaO	15.3	5.7	15.6	16.5	9.0	15.3	17.5	10.4	16.2	10.7	16.0	11.9	10.2
Na_2O	2.41	7.3	2.29	1.67	5.6	2.28	0.19	5.2	1.94	5.0	1.82	3.8	5.1
K_2O	0.05	0.08	0.03	0.03	0.04	0.04	0.02	0.03	0.03	0.05	0.04	0.02	0.08
Total	100.84	100.81	100.94	99.51	98.52	100.69	100.33	100.98	100.83	99.33	100.40	100.97	100.56
an	77.6	30.0	78.9	84.4	46.9	78.6	97.9	52.4	82.0	54.0	82.7	63.3	52.2
ab	22.1	69.5	21.0	15.4	52.8	21.2	1.9	47.4	17.8	45.7	17.0	35.6	47.3
or	0.3	0.6	0.1	0.2	0.3	0.2	0.1	0.2	0.2	0.3	0.3	0.1	0.5