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METAMORPHOSED ULTRAMAFIC ROCKS IN THE BLUESCHISTS (ARNA UNIT) OF THE EXTERNAL METAMORPHIC BELT OF THE HELLENIDES (PELOPONNESUS AND KYTHIRA ISLAND, GREECE)

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A B S T R A C T

Metamorphosed ultramafic rocks are hosted as lensoid bodies in metapelites of the blueschist Unit (Arna Unit) of the External metamorphic belt of the Hellenides in Peloponnesus and Kythira island. They are characterized by the following mineral assemblage: antigorite, diopside, chlorite and magnetite. Tremolite is commonly found close to the contacts with the country rocks. Their chemical characteristics indicate that they are metamorphosed harzburgites. Their origin and mode of emplacement is discussed.

Σ Υ Ν Ο Ψ Η

Μεταμορφωμένα υπερβασικά πετρώματα απαντουν με μορφή φακοειδών σωμάτων μέσα σε μεταπηλίτες της Ενότητας κυανοσχιστολίθων (Ενότητα Άρνας) της εξωτερικής μεταμορφικής ζώνης των Ελληνίδων στην Πελοπόννησο και τα Κύθηρα. Χαρακτηρίζονται απο το ορυκτολογικό άθροισμα: αντιγορίτης, διοψίδιος , χλωρίτης και μαγνητίτης, ενώ τρεμολίτης παρατηρείται κοντά στις επαφές με τα περιβάλλοντα πετρώματα. Με βάση τον χημισμό τους καθορίζεται ότι προήλθαν από την μεταμόρφωση χαρτζβουργιτών. Επιπλέον στην εργασία αυτή συζητείται η προέλευση και ο τρόπος τοποθέτησής τους.

Ν. Σ. ΣΚΑΡΠΕΛΗΣ Μεταμορφωμένα υπερβασικά πετρώματα στους κυανοσχιστόλιθους (Ενότητα Αρνας) της Εξωτερικής μεταμορφικής ζώνης των Ελληνίδων (Πελοπόννησος και Κύθηρα, Ελλάδα)

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1. INTRODUCTION

Recent petrologic, metallogenetic, geochemical and structural studies of the External metamorphic belt of the Hellenides in Peloponnesus, proved that the Arna Unit is a distinct "exotic" allocthonous nappe relative to the adjacent Mani (Plattenkalk) Unit and the Tyros beds of the Tripolis Unit. The Arna Unit posses the characteristics of typical blueschist belts. It is also known as "Principal Crystalline System" (Ktenas, 1926), "Phyllite-quartzite series" (Jacobshagen et al. 1976; Seidel, 1978) and "Lower Phyllite nappe" (Thiebault, 1982). Its major part in Peloponnesus and Kythira includes metamorphosed sedimentary, and mafic and ultramafic igneous rocks. Intermediate and felsic igneous rocks are not found. The age of the protoliths of these rocks is not known. The stratigraphic data for Arna Unit are limited and contradictory. Phytofossils of Oligocene age were found in quartzites near Selasia village (Lekkas and Ioakim, 1980) and Triassic ostracods in carbonate beds in Xyli peninsula in SE Lakonia (Doert et al., 1985). In Crete, in rocks equivalent to those of the Arna Unit, Upper Paleozoic and Triassic fossils were recognized (Krahl et al., 1983).

The following mineral assemblages were identified in metasedimentary rocks (meta-pelites, -sandstones, -conglomerates, marbles):

- Fe-glaucophane+garnet+chloritoid+albite+phengite+chlorite+paragonite+sphene+hematite+quartz
- phengite+chloritoid±paragonite+chlorite+hematite±calcite+rutile+quartz
- lawsonite+phengite+chloritoid+quartz
- glaucophane+phengite+chloritoid+quartz
- Magnesiocarpholite+chloritoid+chlorite+paragonite±pyrophyllite
- calcite+quartz+phengite in boudinaged carbonate beds

Metabasalts are composed of glaucophane/crossite, actinolite, epidote, chlorite, albite, sphene, hematite and calcite.

The PT conditions of metamorphism are those of the Mg-carpholite/Fe-Mg chloritoid facies (Skarpelis, 1982) which is equivalent to the blueschist facies in Al-rich metapelites (Chopin and Schreyer, 1983). Pressures greater than 7Kb and temperatures around 350-400oC are inferred (Skarpelis, 1982). Theye (1983) estimated pressures of 10-13 Kb and temperatures of 400-450oC.

Radiometric dating on micas from metapelites of the Arna Unit in Peloponnesus would suggest that the HP/LT metamorphic episode may be of Late Oligocene-Early Miocene age (Seidel et al., 1982).

The purpose of this paper is to discuss the occurrence, mineralogy and origin of metamorphosed ultramafic rocks of the Arna Unit.

2. METAMORPHOSED ULTRAMAFIC ROCKS

Metamorphosed ultramafic rocks in the Arna Unit were reported by Tataris and Maragoudakis (1965) and Bassias (1984) from Parnon Mt., Theodoropoulos (1973) from Kythira island and by Skarpelis (1982) from N. Taygetos Mt. Another ultramafic body was mapped by Psonis (1986, pers. communication) in the area of Parnon Mt., close to Vresthena village (Fig. 1). It is noteworthy that ultramafic rocks have not been identified in equivalent parts of the Arna Unit in Crete. The metamorphosed ultramafic rocks are greyish-green in colour and occur as massive lenticular bodies enclosed in metapelites. Individual lenses appear with their long axis parallel to the regional foliation of the host rocks. Distinct foliation is developed at the periphery of the lenses. The metapelites near the contact are characterized by the following mineral assemblages:

- Fe-glaucophane+garnet+chloritoid+chlorite+paragonite+phengite+hematite+quartz
- phengite+chlorite+albite+quartz

The contacts of the ultramafic bodies with the country rocks are concordant.

3. ANALYTICAL PROCEDURES

Chemical analyses of the rock samples were carried out by X-ray fluorescence. Fe^{2+} was determined oxidimetrically according to the method of Peters (1968). H_2O was determined using the PEN-

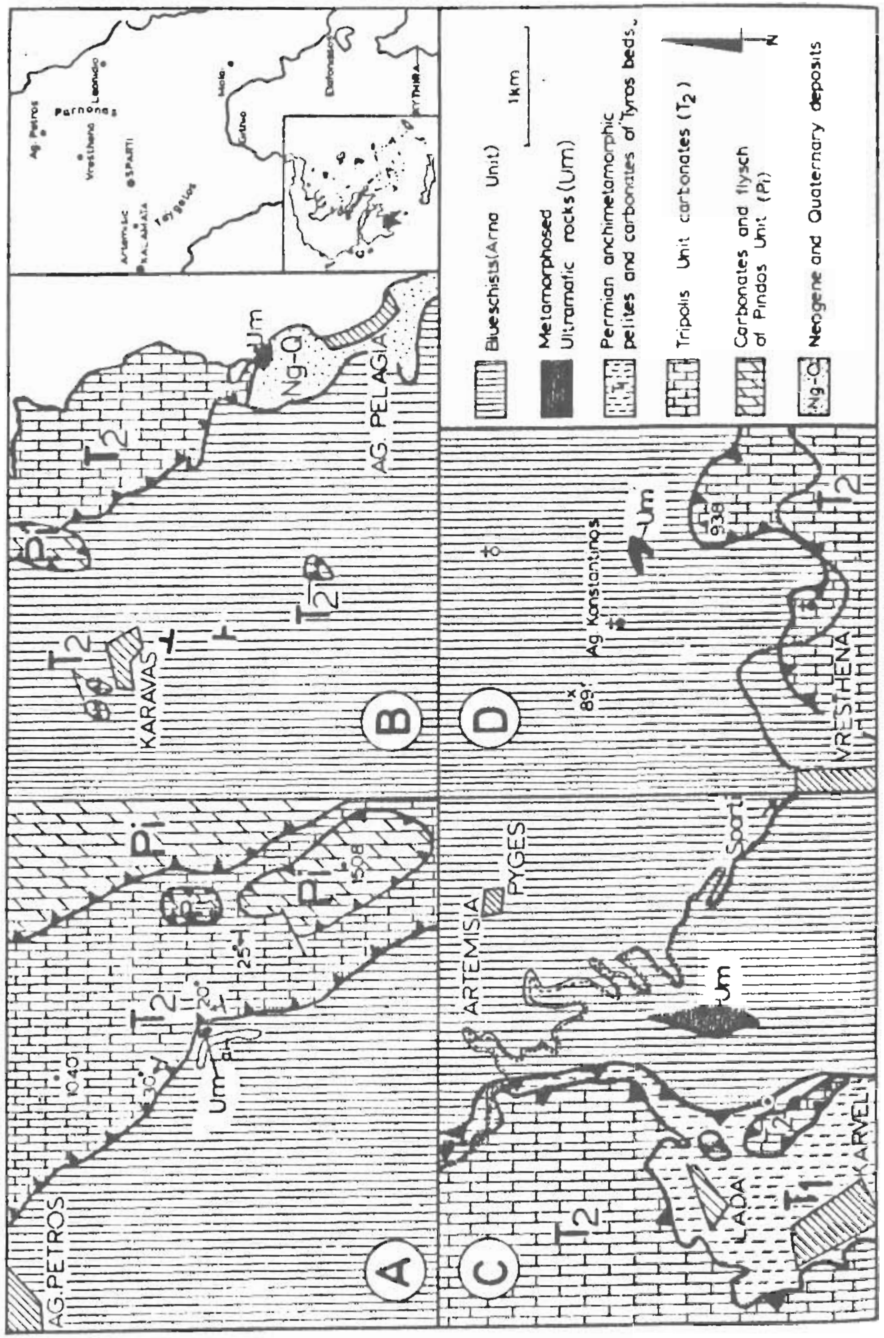

Fig. 1. Geological maps of the areas where metamorphosed ultramafic rocks are exposed: A. Ag. Petros, Parnon Mt. (I.G.M.E., sheet Astros 1:50.000) B. Kythira Island (I.G.M.E., sheet Kythira 1:50.000), C. Lada-Artemisia, N. Taygetos, D. Vresthena, Parnon Mt.

Γεωλογικοί χάρτες των περιοχών όπου εμφανίζονται τα μεταμορφωμένα υπερβασικά πετρώματα: A. Αγ. Πέτρος, Πάρνωνας (Ι.Γ.Μ.Ε., φ.Χ. Άστρος 1:50.000), B. Κύθηρα (Ι.Γ.Μ.Ε., φ.Χ. Κύθηρα 1:50.000), C. Λαδά-Αρτεμισία, Ν. Ταΰγετος, D. Βρεσθένα, Πάρνωνας.

FIELD method. Electron microprobe analyses were done in Kiel University, W.Germany, with a CAMECA-type CAMEBAX-energy dispersive system under the following operating conditions: specimen current 20nA, accelerating voltage 15kv. Fe^{3+}/Fe^{2+} calculation of pyroxene was made after Papike et al. (1974).

4. PETROGRAPHY AND MINERAL CHEMISTRY

The original texture of the studied rocks is not preserved. Regional metamorphism has transformed them into massive serpentinites characterized by the mineral assemblage: antigorite, diopside, chlorite, magnetite, ±tremolite. A n t i g o r i t e is the major constituent of the ultramafic rocks (roughly 70-80%). It is identified on the basis of its X-ray diffraction pattern, particularly by utilizing the peaks in the 2θ areas of 14°, 24°, 36° and 60°. The texture of the antigoritic mass is bladed, although it arrears to be disturbed in certain schistose parts. The blades interpenetrate one another and are more or less of the same size exhibiting a variety of shapes. Microprobe analyses (Table 1) prove that antigorites are enriched in SiO_2 and depleted in MgO relative to the ideal stoichiometric ratio (Fig. 2), a result which is in accordance with the data of Wicks and Plant (1979) for antigorites. D i o p s i d e occurs as relictic disseminated subhedral grains within the antigoritic matrix (Fig. 3). Most diopside grains are surrounded by magnetite. As shown in Table 2 the $Mg/Mg+Fe^{*}$ ratio is 0.92 and the Al and Cr contents are moderate (0.105-0.120 and 0.020-0.025 per formula unit, respectively). Based on 4 cations the number of Na atoms ranges between 0.049 and 0.056. These chemical characteristics are essentially identical to those obtained from clinopyroxenes of ultramafic rocks (Deer et al., 1978). C h l o r i t e appears in aggregates of colourless flakes and is commonly associated with magnetite (Fig. 3). It is enriched in Cr (0.225-0.272 per formula unit) (Table 2), particularly where it forms reaction rims around grains of magnetite. The analysed chlorites posses Fe/Fe+Mg ratios of 0.057 to 0.074, Si between 6.440 and 6.612 and hence are members of the penninite series, after the classification of Hey (1954). Chromium magnetite and m a g n e -

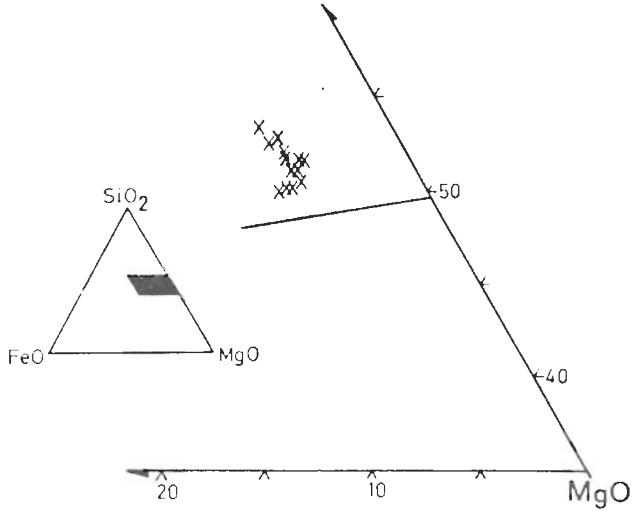

Fig. 2. FeO-MgO-SiO_2 pl t after WICKS and PLANT(1979) of microprobe analyses of antigorite.

Εικ. 2. Προβολή των μικροαναλύσεων αντιγορίτη στο διάγραμμα FeO-MgO-SiO_2 κατά WICKS and PLANT(1979).

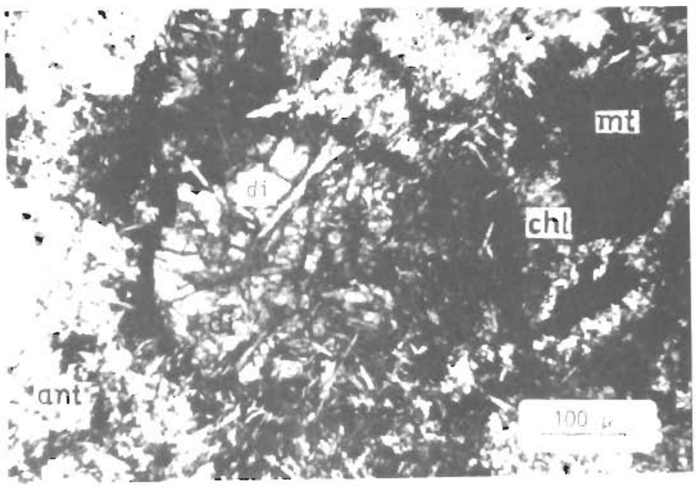

Fig. 3. Diopside (di) in the antigoritic matrix (ant). Magnetite (mt) and chlorite (chl) formed at the expence of chromite grains (XPL).

Εικ. 3. Διοψίδιος (Di) μέσα στην μάζα αντιγορίτη (ant). Μαγνητίτης (Mt) και χλωρίτης (chl) σχηματίστηκαν σε βάρος κόκκων χρωμίτη (XPL).

tite occur as disseminations of individual grains or as trails of grains along schistosity planes into the antigoritic matrix. It is usually associated with chlorite as an alteration product of primary disseminated chromite grains. Schistosity planes of the rocks are lined by chlorite and magnetite seams. T r e m o l i t e is commonly found at or close to the contacts of the ultramafic rocks with the country rock on the ultramafic side. It forms monomineralic or bimineralic aggregates along with antigorite. Tremolite prisms in the massive parts of the rocks are completely unoriented, whereas in the intensely foliated ones they are aligned parallel to the foliation plane.

5. PETROCHEMISTRY

The determination of the primary mineralogical composition and the characterization of the rock types could be done only by the normative mineralogy, based on whole rock major elements analyses (Table 3). This is due to the complete serpentinization of the primary silicate minerals and the alteration of chromite. The normative composition of the rocks studied, provides a reliable indication of the primary mineralogy, since there is no evidence for a non-isochemical metamorphism of the analysed samples. For the normative calculation the method of Lensch (1968) was used. As it is shown in Fig. 4 the meta-ultramafic rocks were initially of harzburgitic mineral composition.

6. DISCUSSION

The mineral assemblage of the ultramafic rocks is compatible with the PT conditions of metamorphism of the Arna Unit, as these have been determined on the basis of mineral assemblages in metapelites and metabasalts. Brucite is lacking from the rocks. This is possibly due to the high pyroxene content (more than 36%) of the protoliths. In such cases, as Hostetler et al. (1966) and Ehlers and Blatt (1982) suggested, metamorphism in the presence of water produces a rock consisting entirely of serpentine without

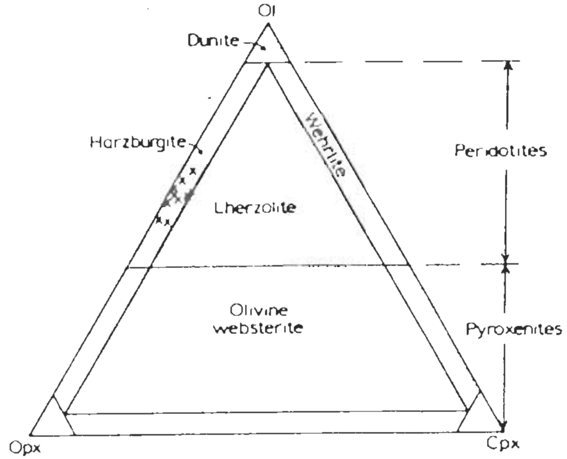

Fig. 4. Ol-Opx-Cpx diagram after STRECKEISEN (1976) for the normative values of the analysed metamorphosed ultramafic rocks.

Εικ. 4. Διάγραμμα Ol-Opx-Cpx κατά STRECKEISEN (1976) προβολής των δυνητικών τιμών των αναλυθέντων μεταμορφωμένων υπερβασικών πετρωμάτων.

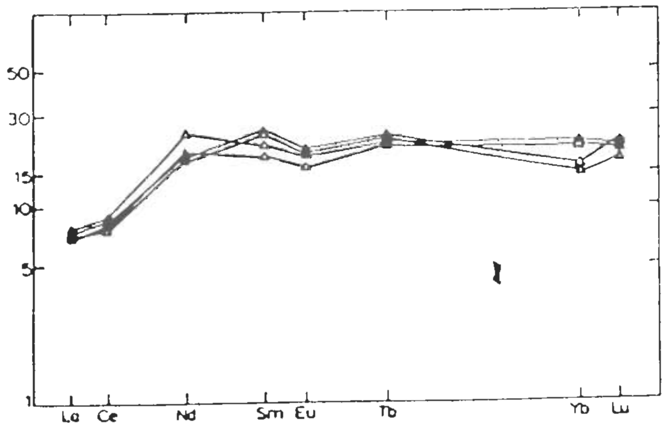

Fig. 5. Primordial mantle-normalized REE patterns of Arna Unit metabasalts. Normalization values after WOOD et al.(1981).

Εικ. 5. Κατανομή REE μεταβασαλτών της Ενότητας Άρνας κανονικοποιημένες ως προς τις τιμές του πρωτογενούς μανδύα κατά WOOD et al.(1981).

any MgO-rich phase such as brucite or periclase. The formation of tremolite at the peripheral parts of the ultramafic rocks is attributed to metasomatic processes, that is interaction with the surrounding metapelitic rocks.

The mode of occurrence of the ultramafic bodies and the fact that they were metamorphosed and deformed to the same degree with the enclosing rocks suggests their incorporation into the sediments before the initiation or at an early stage of subduction of the Arna Unit. The metabasalts show tholeiitic N-type MORB characteristics and correspond to basalts erupted at spreading centers, as it is proved by the discriminant analysis diagrams for the major and trace elements (Skarpelis, 1982) and the primordial mantle normalized REE abundance pattern of samples from Taygetos Mt. (Fig. 5). A light REE depletion and a zero Eu anomaly is obvious. The REE pattern is nearly flat, with concentrations of the HREE in the range of 15 to 20 x primordial mantle values. The protoliths of the metasediments of the Arna Unit were pelites, conglomerates and sandstones, that is sedimentary rocks of continental derivation (Skarpelis, 1982). Their coexistence with MORB-type basalts and harzburgites suggests that the Arna Unit can be interpreted as a mixture of incompatible lithologies (continental and oceanic). Such mixtures are genetically related to the formation of accretionary prisms along subduction zones (Dickinson, 1974). Harzburgitic bodies seem to have been sliced off from a descending oceanic crust and incorporated into the accretionary prism assemblage. Although, as it is known, harzburgites can be a part of an ophiolitic complex, other members of such a complex (e.g. gabbros, pillow lavas, oceanic sediments) are not found in the Arna Unit. Thus it seems unlikely that these harzburgites originated from an ophiolitic sequence by tectonic dismemberment. An origin from ocean floor ultramafic masses seems more possible. Any proposal on the paleotectonic setting of this ocean floor should be in accordance with the generally accepted view that the Arna Unit is an allocthonous exotic nappe (possibly of Cycladic origin; Papanikolaou and Skarpelis, 1986) set between the adjacent Mani Unit and the Tyros beds of the Tripolis Unit. Moreover the inferred greater than 25 Km depth of subduction and subsequent uprising of the Arna Unit, together with the lack of exact stratigraphic data, render the deciphering of the origin and emplacement more difficult. Therefore additional work on the stratigraphy and the metamorphic history of the Unit in the context of the geological evolution of the Hellenides could be pertinent.

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Table 1: Microprobe an...

	1	2	5	6	7	8	11
SiO_2	43.30	44.10	43.70	42.30	43.1	43.90	42.90
TiO_2	–	–	–	–	–	–	–
Cr_2O_3	0.82	0.99	0.10	–	0.48	0.41	0.52
Al_2O_3	2.61	1.92	2.37	2.13	1.61	2.11	2.96
FeO*	4.44	4.73	5.08	4.77	4.24	4.76	4.82
MnO	0.07	0.08	0.08	0.13	0.12	0.09	0.06
MgO	36.30	37.40	33.00	35.80	36.30	34.60	35.80
CaO	–	–	–	–	–	–	–
Total	87.54	89.22	84.33	85.13	85.85	85.87	87.06

Table 1 (contin.)

	12	AD 3	AD 5	AD 1	AD 2	AD 6
SiO_2	43.8	40.6	44.1	39.7	40.9	42.2
TiO_2	–	0.01	0.20	0.05	0.02	–
Cr_2O_3	0.39	0.70	0.01	1.12	0.92	0.88
Al_2O_3	1.94	2.40	1.53	3.83	2.64	2.72
FeO*	4.86	4.65	4.45	4.82	4.79	4.60
MnO	0.10	0.10	0.10	0.05	0.06	0.08
MgO	34.80	33.30	36.90	34.84	35.80	36.10
CaO	–	0.10	0.15	0.15	0.13	0.15
Total	85.89	81.96	87.44	84.56	85.26	86.73

Table 2: Microprobe analyses of clinopyroxene and chlorite

	1	2	3	4
SiO_2	52.30	52.20	52.20	52.10
TiO_2	0.22	0.21	0.30	0.27
Cr_2O_3	0.72	0.70	0.70	0.85
Al_2O_3	4.92	4.90	5.10	5.07
FeO*	2.36	2.50	2.43	2.35
MnO	0.03	0.05	0.10	0.10
MgO	15.50	15.30	15.10	15.43
CaO	23.00	23.08	23.15	23.40
Na_2O	0.80	0.80	0.80	0.70
K_2O	0.01	–	–	–
Total	99.86	99.74	99.88	99.88
	Structural formulas calculated on the basis of 4 cations			
Si	1.900	1.901	1.900	1.888
Al^{IV}	0.100	0.099	0.100	0.112
	2.000	2.000	2.000	2.000
Al^{VI}	0.111	0.112	0.120	0.105
Ti	0.006	0.006	0.008	0.007
Cr	0.020	0.020	0.021	0.025
Fe*	0.072	0.076	0.074	0.071
Mn	–	–	0.003	0.003
Mg	0.840	0.830	0.818	0.834
Ca	0.896	0.901	0.902	0.910
Na	0.056	0.056	0.053	0.049
K	–	–	–	–
	2.001	2.001	1.999	2.004

	3	9	10
SiO_2	33.40	33.50	33.70
TiO_2	0.40	0.20	0.30
Cr_2O_3	1.80	1.40	1.50
Al_2O_3	12.80	12.50	13.70
FeO*	4.30	3.90	3.60
MnO	0.81	0.36	0.20
MgO	33.20	32.00	33.40
CaO	0.20	0.10	0.10
Na_2O	–	0.10	–
K_2O	0.20	0.10	0.10
Total	87.11	84.16	86.60
	Structural formulas calculated on the basis of 28(O)		
Si	6.489	6.612	6.440
Al^{IV}	1.511	1.388	1.560
	8.000	8.000	8.000
Al^{VI}	1.420	1.520	1.535
Ti	0.006	0.001	0.006
Cr	0.272	0.225	0.226
Fe*	0.751	0.647	0.580
Mn	0.007	0.008	0.003
Mg	9.441	9.413	9.542
Ca	0.004	0.002	–
Na	–	0.004	–
K	0.005	0.004	0.002
	11.906	12.124	11.894

Table 3: Chemical analyses of metamorphosed ultramafic rocks

Sample	VR 1	VR 2	KY 1	KY 2	LAD 1	LAD 2	LAD 3	LAD 12	PAR 1	PAR [illegible]
SiO_2	42.50	42.60	41.30	40.90	41.20	40.60	39.50	41.30	42.60	[illegible]
TiO_2	0.02	0.03	0.09	0.10	0.05	0.06	0.08	0.04	0.03	[illegible]
Al_2O_3	1.05	1.29	3.07	3.09	2.31	2.45	2.77	2.71	0.94	[illegible]
Fe_2O_3	3.16	3.87	4.88	4.76	2.47	3.46	5.95	3.45	1.99	[illegible]
FeO	5.41	4.91	2.60	2.50	5.22	4.79	2.37	2.01	4.89	[illegible]
MnO	0.13	0.11	0.12	0.12	0.12	0.09	0.14	0.09	0.07	[illegible]
NiO	0.30	0.31	0.31	0.32	0.30	0.32	0.31	0.24	0.31	[illegible]
MgO	35.90	35.39	35.94	35.89	36.50	36.50	35.50	38.03	38.20	[illegible]
CaO	0.11	0.12	0.26	1.18	0.27	0.03	0.61	0.13	0.10	[illegible]
Na_2O	–	–	–	–	0.05	0.05	0.05	–	–	–
K_2O	0.01	0.01	0.01	0.01	0.03	0.03	0.03	0.01	0.01	[illegible]
Cr_2O_3	0.16	0.20	0.22	0.22	0.10	0.20	0.15	0.17	0.17	[illegible]
P_2O_5	–	–	–	–	0.03	0.03	0.03	–	–	–
CO_2	–	–	–	–	0.12	0.10	0.10	–	–	–
H_2O	11.60	10.80	11.70	10.50	11.80	11.80	11.40	11.70	11.80	[illegible]
Total	100.35	99.64	100.50	99.59	100.57	100.51	98.99	99.88	101.11	[illegible]

Norm*	VR 1	VR 2	KY 1	KY 2	LAD 1	LAD 2	LAD 3	LAD 12	PAR 1	PAR [illegible]
SP	0.18	0.23	0.25	0.25	0.11	0.23	0.17	0.19	0.19	[illegible]
CD	1.05	1.29	3.26	3.27	2.38	2.47	2.91	2.87	0.90	[illegible]
ILM	0.03	0.04	0.13	0.14	0.07	0.09	0.12	0.06	0.04	[illegible]
CPX	0.45	0.49	1.06	4.79	0.96	0.12	2.38	0.53	0.40	[illegible]
OPX	45.77	47.52	42.19	35.39	38.46	36.98	33.01	39.75	41.48	[illegible]
OL	52.24	50.11	52.77	55.81	57.20	59.24	60.51	56.32	56.70	[illegible]
ol-opx-cpx triangle										
CPX	0.46	0.50	1.10	4.99	0.99	0.12	2.48	0.55	0.41	[illegible]
OPX	46.49	48.43	43.94	36.87	39.81	38.38	34.42	41.15	42.08	[illegible]
OL	53.06	51.07	54.96	58.14	59.20	61.49	63.10	58.30	57.52	[illegible]
	Hzb**	Hzb	Hzb	Hzb	Hzb	Hzb	Hzb	Hzb	Hzb	Hzb

* Calculation of normative minerals after the method of Lensch (1968)

** Characterization of the rock as Harzburgite on the basis of normative minerals (Fe total as FeO)