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Petrochemistry of Mafic and Ultramafic Rocks of CY-4 Drill-Hole, Cyprus Crustal Study Project

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ABSTRACT. This paper is a result of study and investigation of 45 samples collected, at 50 meter intervals, from CY-4 drill hole of the Cyprus Crustal Study Project, to confirm, on basis of petrographic studies and chemical analysis, the classification of the Troodos Ophiolite suite and the terminology of the rock units.

Troodos complex comprises a Cretaceous ideal ophiolite suite. Drill hole CY-4, located in the southeastern part of the complex, penetrates through sheeted dikes, gabbroic rocks, and ultramafic cumulates. The rock sequence of the drill hole could be broadly classified into:

1) a diabasic zone representing the sheeted dikes, (9.85m-483.50m),
2) a zone of mixture of sheeted dikes and gabbros, (483.50m-837.45m),
3) massive gabbro zone, (837.45m-1346.80m),
4) cumulate gabbro zone, (1346.80m-1754.10m), and
5) ultramafic zone consisting essentially of clinopyroxenite, websterite and dunite, (1754.10m-2263m).

The studied samples can be divided chemically into mafic and ultramafic groups which correspond closely to the petrographic classification. Mafic magmatic rocks are generally oversaturated tholeiites. Trace element contents are similar to those expected from such rock suites. Chemical characteristics of the ultramafic rocks indicate a cumulate origin consistent with previous investigations.

Introduction

The Troodos complex (Fig. 1) covers an area of about 3000 km^2 in southern Cyprus (Gass 1960). This complex comprises mainly Cretaceous intermediate, mafic and ultramafic, volcanic and plutonic rocks (Gass 1980, Robinson *et al.* 1983; Schmincke *et al.* 1983). These rocks, locally overlain by marine sediments (Fig. 1), from an ideal ophiolite sequence ranging from pillow lavas through sheeted dikes, cumulate gabbro and peridotites to dunite and tectonized harzburgite (Gass 1980).

Many workers studied the petrology of the Troodos ophiolite (*e.g.* Ingham 1959, Greenbaum 1972 & 1977, Malpas and Langdon 1984, Cameron 1985). The following is a summary of these studies:

Generally, the extrusive rocks form a continuous belt around the plutonic rocks of the ophiolite complex (Fig. 1). They are divided into two members: Lower pillow

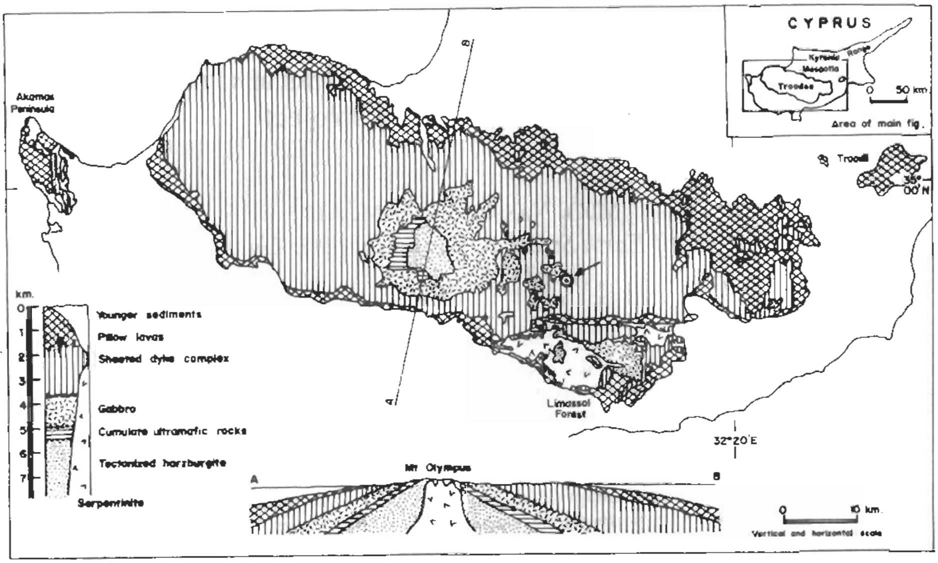

FIG. 1. Geological sketch map, section, ophiolite sequence of the Troodos massif, and location of drill hole CY-4 (after Gass, 1980).

lavas (LPL), which are andesites to dacitic andesite comprising mainly plagioclase (An_{55-75}), orthopyroxene, clinopyroxene and opaques, and Upper pillow lavas (UPL) which are mainly basaltic andesite containing plagioclase, low-Ca pyroxene, and amphibole with olivine and diopside as phenocrysts.

The sheeted dike swarms have a general N-S trend and according to Moores and Vine (1971) they indicate an extension of more than 100 km. These rocks are generally diabasic consisting of plagioclase (An_{63-81}), orthopyroxene, clinopyroxene and opaques.

The cumulate rocks are underlain by mantle tectonized harzburgite. They comprise dunite, wehrlite, pyroxenite and gabbro cumulates with the phase layering; olivine, olivine + diopside, olivine + diopside + enstatite, olivine + diopside + enstatite + plagioclase, diopside + enstatite + plagioclase (Greenbaum 1972, Allen 1975, Thy *et al.* 1986).

The mantle sequence of the Troodos complex is composed mainly of tectonized harzburgite containing olivine (Fo_{97-92}), enstatite, and diopside. Dunite and plagioclase lherzolite pods are common. The harzburgite, which is considered to represent the residue of plagioclase lherzolite partial melting, is assumed to form the parental liquids of pillow lavas, sheeted dikes, and cumulate rocks (Smewing *et al.* 1975, Wood 1979).

Drill hole CY-4, which is a part of the Cyprus Crustal Study Project, is located in the southeastern part of the Troodos massif (Fig. 1) at 34°54′06″N Latitude and 33°05′38″E Longtitude. This drill hole penetrates 2263m of the ophiolite sequence starting from sheeted dikes passing through the gabbroic zone and ends in the ultramafic zone.

A total of 45 samples from this drill hole was selected for petrographic studies and chemical analysis, in order to understand the petrochemical characteristics of the ophiolite sequence. Table 1 shows the petrographic classification and the results of chemical analysis of the studied rocks.

Petrography

The rock sequence observed in drill hole CY-4 may be broadly classified into the following zones:

1) A diabasic zone (9.85m-483.50m) representing the sheeted dikes,
2) Mixture of sheeted dike and gabbro (483.50m-837.45m),
3) Massive gabbro (837.45m-1346m),
4) Cumulate gabbro (1346.80m-1754.10m), and
5) Ultramafic zone (1754.10m-2263m).

The position of the contacts are not known because of the 50 meter intervals between sample. The exact thickness of different zones can be obtained from the hole CY-4 core descriptions (Horne and Robinson 1984).

1. Sheeted Dike Zone

The thickness of this zone is about 470m. The upper part of the sequence comprises, fine-grained ophitic, altered rock consisting mainly of plagioclase (An_{52-68}), tremolite, chlorite and opaque minerals. Zeolite veinlets and amygdules were observed in some sections, especially in the upper most parts. Relicts of clinopyroxene are seen frequently and epidotization of plagioclase is common. This fine-grained rocks represent narrow dikes or chilled margins of thicker dikes.

The lower part of the dike sequence consists of medium-grained diabases and composed mainly of plagioclase (An_{60-68}), altered pyroxene and opaque minerals. Chlorite, tremolite and actinolite are the main alteration products of pyroxene. Zeolite veinlets are less common than in the upper dikes.

2. Sheeted Dike/Gabbro Zone

This zone, which is a mixture of a diabasic and gabbroic rocks, is about 770m thick. The diabases are petrographically similar to those of the overlying sheeted dike complex.

The gabbroic rocks are generally coarse-grained with some cumulate textures and they consist mainly of calcic plagioclase (An_{65-68}), clinopyroxene (augite/diopside), tremolite and opaque minerals. Epidotization and albitization of plagioclase are frequently present. One sample (Sample N 18 – Table 1) is a leucocratic with more than 60% sheared plagioclase.

TABLE 1 : Major Element Analysis (in wt. %) and Trace Element Abundance (in PPM) CY-4 Drill Hole-Cyprus. Nd, not determined; – trace.

	← Sheeted dikes →															← Massive gabbros →						← Layered gabbros →	
											← Sheeted dikes + Gabbros →												
Sample No.	N1	N2	N3	N4	N5	N6	N7	N8	N9	N10	N11	N12	N13	N14	N15	N16	N17	N18	N19	N20	N21	N22	N23
SiO_2	55.39	52.08	46.34	54.64	51.84	52.95	55.57	56.18	51.24	56.32	55.16	51.00	47.60	50.13	51.39	47.83	51.74	70.58	47.31	55.51	46.74	46.77	48.4
TiO_2	1.10	0.54	1.22	1.32	0.52	1.32	1.11	0.59	0.82	1.05	1.10	0.75	0.50	0.35	1.12	0.23	0.20	0.98	1.22	1.02	0.28	0.20	0.1
Al_2O_3	14.02	13.04	16.07	16.04	15.25	14.86	14.80	14.88	15.67	14.23	15.11	16.58	18.92	12.48	15.60	18.25	17.87	15.15	16.20	15.80	18.33	17.86	18.9
FeO	6.53	5.89	8.72	6.21	6.19	6.64	6.50	6.25	6.33	5.24	5.75	5.53	4.38	5.93	6.14	5.21	3.91	0.41	7.97	5.21	5.35	3.14	4.5
Fe_2O_3	4.01	1.94	2.11	4.35	2.80	3.93	3.44	3.92	2.31	4.52	3.90	2.48	1.16	1.92	3.37	0.58	1.21	0.32	4.09	4.10	1.26	1.04	0.7
MnO	0.10	0.13	0.22	0.08	0.14	0.14	0.10	0.17	0.16	0.09	–	0.12	0.10	0.18	0.14	0.12	0.10	0.12	0.21	0.16	0.14	0.13	0.1
MgO	3.30	7.88	7.11	3.65	5.89	4.66	4.15	3.65	8.91	3.98	3.65	6.05	6.60	10.36	5.39	9.12	8.08	1.24	7.46	4.06	8.78	10.15	9.9
CaO	7.46	8.96	12.18	8.42	7.66	7.91	8.47	8.35	11.52	7.71	8.32	10.24	11.44	10.49	9.97	14.42	13.53	5.79	11.90	7.29	14.41	13.69	14.8
Na_2O	3.50	2.96	1.64	3.24	4.17	3.50	3.04	2.90	1.75	3.10	3.37	3.50	2.43	1.82	3.04	0.95	1.49	4.65	1.82	3.30	1.08	0.95	0.6
K_2O	0.29	0.30	0.11	0.34	0.23	0.18	0.23	0.21	0.15	0.23	0.21	0.22	0.24	0.30	0.22	0.14	0.11	0.15	0.13	0.25	0.08	0.10	0.1
P_2O_5	0.35	0.30	0.51	0.38	0.35	0.37	0.38	0.37	0.48	0.35	0.38	0.44	0.49	0.46	0.44	0.58	0.55	0.32	0.50	0.35	0.58	0.56	0.6
Total	**96.05**	**94.02**	**96.53**	**98.67**	**95.04**	**96.46**	**97.89**	**97.77**	**99.34**	**96.82**	**96.95**	**96.91**	**93.87**	**94.51**	**96.82**	**97.44**	**98.79**	**99.91**	**98.81**	**98.05**	**97.04**	**94.93**	**99.**
Zn	22	30	73	22	26	41	27	39	68	29	22	27	34	56	47	42	36	9	63	31	45	40	2
Nb	24	26	23	23	27	21	29	47	27	21	21	22	33	23	29	31	22	24	24	24	17	17	[illegible]
Ni	41	85	78	44	67	36	36	33	94	38	38	81	89	134	58	117	116	38	75	47	120	148	12
Zr	100	102	55	103	96	84	102	184	96	84	84	96	125	98	138	131	98	164	72	98	66	72	[illegible]
Pb	Nd	16	4	3	7	13	5	9	12	13	24	7	15	5	12	19	24	26	17	22	8	10	[illegible]
Y	10	09	6	11	7	11	9	12	8	9	11	10	8	7	10	8	8	16	8	11	6	7	
Cr	114	136	96	14	31	16	11	13	129	8	25	109	76	597	46	98	269	27	56	10	96	292	2
Sr	111	106	77	136	113	102	88	87	88	102	138	161	162	64	101	53	77	157	104	149	81	74	
Rb	14	16	Nd	Nd	Nd	14	6	Nd	Nd	Nd	Nd	8	13	14	12	Nd	14	17	6	10	Nd	7	[illegible]
Th	19	19	Nd	8	Nd	11	14	Nd	Nd	Nd	14	Nd	18	19	14	Nd	14	19	9	9	11	9	[illegible]
Co	51	47	95	82	57	64	64	54	61	58	54	65	48	58	61	48	43	22	56	54	43	40	

In general, low-grade metamorphism is common, especially in the diabasic rocks of the sheeted dikes. It includes zeolite facies in the upper part of the sequence grading to lower green schist facies. This type of metamorphism is indicated by occurrence of zeolites, altered plagioclase and appearance of such minerals as tremolite and chlorite.

3. Massive Gabbro Zone

The gabbroic rocks may be divided broadly into a massive gabbro zone about 509m thick and a cumulate gabbro zone about 408m thick.

Table 1 : (Contd.).

	← Layered gabbros →						← Ultramafics →															
ample No.	N24	N25	N26	N27	N28	N29	N30	N31	N32	N33	N34	N35	N36	N37	N38	N39	N40	N41	N42	N43	N44	N45
iO_2	51.58	49.27	48.61	49.17	48.03	50.58	52.91	48.29	52.99	53.00	44.70	50.16	47.73	49.20	42.86	48.57	48.99	48.91	44.85	45.01	40.15	38.00
iO_2	0.12	0.19	0.14	0.12	0.12	0.14	0.17	0.13	0.17	0.16	0.08	0.15	0.30	0.10	0.06	0.10	0.12	0.11	0.08	0.09	0.06	0.04
l_2O_3	16.90	19.75	18.08	18.49	18.48	11.00	3.88	17.11	4.37	4.21	2.52	4.48	5.73	5.69	1.82	5.24	4.06	6.07	2.36	3.14	2.29	1.30
eO	4.38	3.70	4.11	3.95	4.81	4.98	4.88	3.46	4.44	4.81	4.38	4.09	4.17	3.45	3.30	3.95	3.59	3.30	4.44	4.38	3.30	2.80
e_2O_3	1.28	1.28	0.76	0.82	0.78	0.68	1.00	1.10	1.95	1.39	5.47	1.54	1.20	1.11	5.96	1.75	1.76	2.06	3.09	3.12	7.12	10.50
InO	0.11	0.10	0.11	0.11	0.12	0.14	0.15	0.10	0.15	0.13	0.12	0.14	0.10	0.11	0.12	0.10	0.11	0.11	0.13	0.14	0.14	0.10
lgO	9.95	7.88	8.50	9.12	9.53	15.13	16.79	10.78	19.48	19.02	28.04	19.50	19.99	19.20	28.69	20.99	19.02	19.35	26.24	25.74	34.11	36.29
iO	14.50	12.00	16.84	16.82	14.33	15.26	18.15	15.58	14.58	14.50	8.95	15.79	15.02	16.69	8.74	14.70	16.28	15.33	11.80	12.11	4.32	0.86
a_2O	0.60	2.02	0.54	0.47	0.60	0.27	0.14	0.40	0.20	0.30	0.16	1.08	0.20	0.33	0.11	0.23	0.30	0.20	0.12	0.14	0.08	0.06
$_2O$	0.90	0.25	0.10	0.13	0.90	0.11	0.11	0.14	0.11	0.15	0.09	0.07	0.09	0.10	0.07	0.10	0.08	0.10	0.11	0.11	0.13	0.09
O_5	0.58	0.59	0.69	0.60	0.58	0.62	0.72	0.63	0.58	0.18	0.13	0.19	0.18	0.19	0.12	0.18	0.19	0.19	0.16	0.15	0.09	0.57
tal	**100.94**	**96.95**	**98.56**	**99.90**	**98.32**	**99.01**	**99.06**	**97.85**	**99.23**	**97.85**	**94.63**	**97.19**	**94.51**	**95.99**	**91.85**	**95.91**	**94.50**	**95.73**	**93.38**	**94.13**	**91.79**	**90.61**
	29	25	26	28	73	72	49	72	89	25	28	36	37	37	37	39	28	30	52	41	41	39
	29	19	17	27	32	25	27	36	23	36	29	48	28	36	40	36	38	30	27	23	39	39
	178	135	126	138	144	172	271	160	265	162	360	162	136	132	324	226	232	154	286	330	344	414
	18	98	66	99	99	47	Nd	134	Nd			-	-		-	-	-	-	-		-	-
	27	15	5	17	32	10	5	29	18				-			-	-	-	-	-	-	-
	5	6	8	9	99	Nd	Nd	Nd	8					-		-	-			-	-	
	297	81	539	786	292	679	1092	859	1411	1525	1350	1468	1450	1468	1225	1300	2250	1925	1468	1500	1000	1925
	27	136	44	46	46	27	18	85	18	37	350	57	26	19	22	47	27	40	53	46	10	12
	Nd	13	Nd	11	12	9	Nd	13	Nd	-	-	-	-	-	-	-	-	-	-	-	-	
	Nd	19	Nd	14	15	11	9	19	Nd			-	-		-	-		-		-	-	
	38	34	29	30	33	36	33	32	41	58	120	55	64	54	125	79	56	62	121	99	145	150

The massive gabbros are generally coarse-grained and characterized by a uniform texture. The main minerals are plagioclase (An_{65-68}), diopsidic augite, tremolite and opaque minerals. Plagioclase sometimes shows igneous lamination (*e.g.* sample N 17).

4. Cumulate Gabbro Zone

Drill hole CY-4 penetrates gabbro and ultramafic cumulates (Zone 4 and 5) down to the clinopyroxenite and websterite. Opx and Cpx occur throughout the core and plagioclase decreases sharply as a cumulus phase below 1693.4 meters depth. Olivine appears as a cumulas phase below approximately 1418.2 meters depth. Major petrographic and/or chemical breaks occur approximately at 483.5, 837.5, 1346.8, 1692.4 and 2224.3 meter depth.

The cumulate gabbro zone consists essentially of gabbro and gabbronorite cumulates. A websterite zone was encountered at a depth of 1496.70 meters (sample N 25).

The cumulate rocks consist mainly plagioclase, clinopyroxene, orthopyroxene and tremolitic amphibole. Plagioclase, representing 50%-80% of the rock, exists as both cumulus and intercumulus phases. It is characterized by its calcic nature (An_{70}). Clinopyroxene is diopsidic in composition and orthopyroxene is magnesian. They may occur as cumulus or intercumulus phases. Epidotization and serpentinization are the most common types of alteration.

5. Ultramafic Zone

The ultramafic zone of the sequence consists essentially of clinopyroxenite, websterite and dunite. These rocks are characterized by the sudden decrease in their plagioclase content, compared to the gabbroic zones and by the relative increase in pyroxene and olivine contents. Clinopyroxene (40%), orthopyroxene (40%), and olivine occur mainly as cumulus minerals while plagioclase represents intercumulus material. The bottom 100 meters of the drill hole are of dunitic composition, where olivine makes up to 90% of the rock. Serpentinization is widespread obscuring the textures. However, these rocks are interpreted as cumulate dunites.

Chemistry

All the samples were chemically analysed in the laboratories of the Faculty of Earth Sciences, King Abdulaziz University, using XRF for the major oxides and atomic absorption and plasma (DCP) for the trace elements (Table 1). Fourteen samples are sheeted dikes (N1-N14), eight are massive gabbro (N15-N22), six are layered gabbro (N23-N28), and seventeen are ultramafic rocks (N29-N45). Normalized oxides values were used for norm calculations (Table 2).

Based on chemical composition, the rock series may be divided into two major groups: Mafics and ultramafics.

a) Mafic Group

Sample N1 to N28, except N18, represent sheeted dikes, massive gabbro and a layered gabbro (Table 1). Due to similarity in chemical composition, these samples will be discussed as one group unless it is otherwise mentioned, in spite the fact that the sheeted dikes and the massive gabbro are genetically different than the cumulates. Few samples (N1, N7, N8, N10, N11 and N20) show an intermediate chemical composition, Moores and Vine (1971) and Desmet *et al.* (1980) indicated the dacitic andesite or basaltic andesite chemical composition of some of these rocks.

Most samples are oversaturated in silica as indicated by their normative quartz averaging 5.28% and reaching up to 17.05%. Normative orthopyroxene is generally high. The wide variation in chemical composition in some elements is probably due to the variation in the relative proportions of the major mineral components.

The chemistry of the cumulus phase of drill hole CY-4 (below 1346 meters) are characterized by some variations which are probably due to variations in mineral chemistry. Thy (1986) mentioned the extensive variation in mineral chemistry with olivine ranging from Fo_{76} to Fo_{88}, plagioclase from An_{86} to An_{99}, diopside from $En_{44}Fs_{13}Wo_{43}$ to $En_{52}Fs_{7}Wo_{41}$ and enstatite from En_{69} $Fs_{28}Wo_{3}$ to $En_{85}Fs_{12}Wo_{3}$.

Mg (3.30%-10.36%) and CaO (7.29%-16.84%) are normal and generally show an increase with depth. The sudden increase in MgO content between N28 and N29 distinguishes the mafic and the intermediate rocks from the ultramafic rocks. Total FeO content is generally constant a features characteristic of most basalts which belong to ophiolites (Coleman 1977). TiO_2 content is within the range of such rocks. Total alkalies are relatively high probably due to mobilization of K_2O and Na_2O. The increase in total alkalis, especially in the sheeted dikes, may be attributed to the presence of zeolites. The relatively high SiO_2, alkali and H_2O contents and low CaO, MgO and FeO contents of some of the sheeted dikes is possibly caused through sea water lava interaction (Gass and Smewing 1973, Serri 1979).

Trace elements such as P, Zr, Nb, Rb and Sr are comparable to those observed in other ophiolite masses (Coleman 1977). Ni content is relatively low, probably, due to lack of olivine. In the sheeted dikes, Ni content varies between 33-94 ppm which may

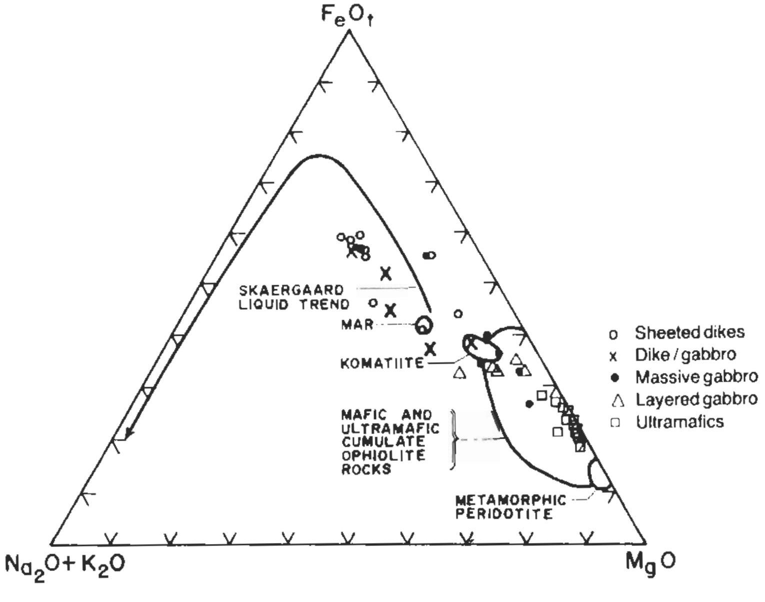

FIG. 2. AFM diagram of mafic and ultramafic rocks of drill hole CY-4, Troodos massif.

TABLE 2 : Adjusted Oxides (CO_2, H_2O Free) and Normative Mineralogy for CY-4 Drill Hole-Cyprus; – trace.

	← Sheeted dikes →										← Sheeted dikes + Gabbros →					← Massive gabbros →						Layered gabbros	
Sample No.	**N1**	**N2**	**N3**	**N4**	**N5**	**N6**	**N7**	**N8**	**N9**	**N10**	**N11**	**N12**	**N13**	**N14**	**N15**	**N16**	**N17**	**N18**	**N19**	**N20**	**N21**	**N22**	**N2**
Adjusted Oxides :																							
SiO_2	57.67	55.38	48.00	55.38	54.55	54.89	56.87	57.46	51.58	58.17	56.90	52.62	50.71	53.04	53.08	49.09	52.37	70.79	47.88	56.61	48.17	49.27	48.8
TiO_2	1.15	0.57	1.26	1.34	0.55	1.37	1.13	0.91	0.93	1.08	1.13	0.77	0.53	0.37	1.16	0.24	0.20	0.98	1.23	1.04	0.29	0.21	0.1
Al_2O_3	14.60	13.87	16.65	16.26	16.05	15.41	15.12	15.22	15.77	14.70	15.59	17.11	20.16	13.20	16.11	18.73	18.09	15.19	16.40	16.11	16.89	18.81	19.0
FeO	6.80	6.26	9.03	6.29	6.51	6.88	6.64	6.39	6.37	5.41	5.93	5.71	4.67	6.27	6.34	5.35	3.96	0.41	8.07	6.33	5.51	3.31	4.6
Fe_2O_3	4.17	2.06	2.50	4.41	2.95	4.07	3.51	4.01	2.33	4.67	4.02	2.56	1.24	2.03	3.48	0.60	1.22	0.32	4.14	4.18	1.30	1.10	0.7
MnO	0.10	0.14	0.23	0.08	0.15	0.15	0.10	0.17	0.16	0.09	–	–	0.11	0.19	0.14	0.12	0.10	0.12	0.21	0.16	0.14	0.14	0.1
MgO	3.44	8.38	7.36	3.70	6.20	4.83	4.24	3.73	8.97	4.11	3.76	6.24	7.03	10.96	5.57	9.36	8.18	1.24	7.55	4.14	9.05	11.01	10.0
CaO	7.77	9.53	12.62	8.53	8.06	8.20	8.65	8.54	11.60	7.96	8.58	10.56	12.19	11.10	10.30	14.80	13.70	5.81	12.04	7.43	14.85	14.42	15.0
Na_2O	3.64	3.15	1.70	3.28	4.39	3.63	3.11	2.97	1.76	3.20	3.48	3.61	2.59	1.93	3.14	0.97	1.51	4.66	1.84	3.37	1.11	1.00	0.6
K_2O	0.30	0.32	0.11	0.34	0.24	0.19	0.23	0.21	0.15	0.24	0.22	0.23	0.26	0.32	0.23	0.14	0.11	0.15	0.13	0.25	0.08	0.11	0.
P_2O_5	0.36	0.32	0.53	0.39	0.37	0.38	0.39	0.38	0.48	0.36	0.39	0.45	0.52	0.49	0.48	0.60	0.56	0.32	0.51	0.36	0.60	0.59	0.6
Normative Minerals :																							
Q	14.170	4.548	–	12.001	1.646	8.869	13.652	15.949	4.187	17.050	13.325	1.004		3.042	5.703		5.186	31.124	0.988	13.278	–	–	0.
Or	1.784	1.885	0.673	2.036	1.430	1.103	1.388	1.269	0.892	1.404	1.280	1.341	1.511	1.876	1.343	0.849	0.658	0.889	0.777	1.507	0.487	0.622	0.
Ab	30.834	26.634	14.375	27.786	37.127	30.703	26.278	25.099	14.905	27.093	29.413	30.554	21.905	16.295	26.569	8.250	12.762	39.461	15.586	28.179	9.417	8.468	5.
An	22.580	22.765	37.458	28.599	23.599	23.373	25.296	26.620	27.579	34.684	25.029	29.794	42.621	26.449	29.199	46.304	42.258	20.081	36.079	28.109	46.301	46.532	48.
Wo	5.666	9.361	9.053	4.685	5.931	5.419	5.749	5.143	8.219	5.219	5.733	8.205	6.025	10.620	7.899	9.697	9.206	2.201	8.502	2.691	9.797	8.834	9.
En	8.557	20.869	18.323	9.213	15.435	12.032	10.558	9.298	22.336	10.238	9.376	15.545	16.337	27.301	13.865	22.612	20.370	3.097	18.803	10.313	19.447	26.457	25.
Fs	7.338	9.087	12.838	5.857	8.896	7.285	7.608	7.246	8.707	4.463	5.694	7.297	6.397	9.503	7.128	8.883	6.110	–	9.748	6.761	7.624	4.863	7.
Fo	–	–	0.014		–	–	–	–	–	–	–	–	0.822	–		0.489	–	–	–	–	2.163	0.672	
Fa	–	–	0.011	–	–	–	–	–	–	–	–	–	0.355	–	–	0.212	–	–	–	–	0.934	0.136	
Mt	6.053	2.991	3.620	6.392	4.272	5.907	5.095	5.813	3.371	6.769	5.833	3.710	1.792	2.946	5.047	0.863	1.776	–	6.002	6.063	1.883	1.588	1.
Cm	–	0.031	0.015	–	–	–	–	–	0.015	–	–	0.030	0.016	0.140		0.015	–	–	–	–	0.015	0.062	0.
Hm	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	0.321	–	–	–	–	
Il	2.175	1.091	2.400	2.541	1.039	2.599	2.154	1.729	1.568	2.060	2.155	1.470	1.012	0.703	2.197	0.448	0.384	1.126	2.345	1.976	0.548	0.400	0
Tn	–		–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	0.957	–	–	–	–	
Ap	0.863	0.756	1.251	0.912	0.872	0.909	0.919	0.896	1.144	0.856	0.928	1.075	1.236	1.153	1.076	1.410	13.19	0.760	1.199	0.845	1.416	1.397	1

represent more than one magma. Also a consistent relation is observed between the Ni and TiO_2 content in these rocks, where Ni increases with the decrease in TiO_2.

'able 2 : (Contd.).

	← Layered gabbros →				←									Ultramafics							→
Sample No.	**N24**	**N25**	**N26**	**N27**	**N28**	**N29**	**N30**	**N31**	**N32**	**N33**	**N34**	**N35**	**N36**	**N37**	**N38**	**N39**	**N40**	**N41**	**N42**	**N43**	**N44**	**N45**
Adjusted Oxides :																						
SiO_2	51.10	50.82	49.32	49.22	48.65	51.09	53.41	49.35	53.40	54.16	47.24	51.61	50.50	51.26	46.66	50.64	51.84	51.09	48.03	47.82	43.74	41.94
TiO_2	0.12	0.20	0.14	0.12	0.12	0.14	0.17	0.13	0.17	0.16	0.08	0.15	0.11	0.10	0.07	0.10	0.13	0.11	0.09	0.10	0.07	0.04
Al_2O_3	16.74	20.37	18.34	18.51	18.80	11.11	3.92	17.49	4.40	4.30	2.66	4.61	5.06	5.93	1.98	5.46	4.30	6.34	2.53	3.34	2.49	1.43
FeO	4.34	3.82	4.17	3.95	4.89	5.03	4.93	3.54	4.47	4.92	4.63	4.21	4.41	3.59	3.59	4.12	3.80	3.45	4.75	4.65	3.60	3.09
Fe_2O_3	1.27	1.32	0.77	0.82	0.79	0.69	0.01	1.12	1.97	1.42	5.78	1.58	1.27	1.16	6.49	1.82	1.86	2.15	3.31	3.31	7.76	11.59
MnO	0.11	0.10	0.11	0.11	0.12	0.14	0.15	0.10	0.15	0.13	0.13	0.14	0.11	0.11	0.13	0.10	0.12	0.11	0.14	0.15	0.15	0.11
MgO	9.86	8.13	8.62	9.13	0.69	15.28	16.95	11.02	19.63	19.44	29.63	20.06	21.15	19.81	31.24	21.89	20.13	20.21	28.10	27.35	37.16	40.05
CaO	14.36	12.38	17.09	16.84	14.57	15.41	18.32	15.92	14.69	14.82	9.46	16.25	15.89	17.39	9.52	15.33	17.23	16.01	12.64	12.87	4.71	0.95
Na_2O	0.59	2.08	0.55	0.47	0.61	0.27	0.14	0.41	0.20	0.31	0.16	1.11	0.21	0.34	0.12	0.24	0.32	0.21	0.13	0.15	0.09	0.07
K_2O	0.89	0.26	0.10	0.13	0.92	0.11	0.11	0.14	0.11	0.15	0.10	0.07	0.10	0.10	0.08	0.10	0.08	0.10	0.12	0.12	0.14	0.10
P_2O_5	0.57	0.52	0.70	0.60	0.59	0.63	0.73	0.64	0.58	0.18	0.14	0.20	0.19	0.20	0.13	0.19	0.20	0.20	0.17	0.16	0.10	0.63
Normative Minerals :																						
)	3.097	0.614	2.205	1.857	·	0.534	2.521	1.569	2.379	1.498	–	–	–	–	–	–		–	–	–	–	–
r	5.069	1.524	0.600	0.769	5.409	0.657	0.656	0.845	0.655	0.906	0.562	0.426	0.563	0.616	0.450	0.616	0.500	0.617	0.696	0.691	0.837	0.567
b	5.030	17.630	4.636	3.981	5.164	2.308	1.196	3.459	1.705	2.594	1.341	9.403	1.791	2.909	1.013	2.029	2.686	1.768	1.087	1.259	0.737	0.560
n	40.382	45.471	47.295	48.006	45.843	28.762	9.725	45.434	10.784	9.911	6.274	7.377	15.312	14.323	4.644	13.523	10.018	16.055	5.971	8.089	5.998	0.599
/o	11.327	5.246	13.375	13.193	9.440	18.208	31.910	12.246	24.338	26.056	16.597	30.040	26.007	29.496	17.415	25.590	30.912	25.926	23.215	22.837	6.977	–
n	24.550	20.243	21.479	22.736	21.170	38.058	42.213	27.135	48.892	48.410	37.628	29.614	34.768	24.879	36.504	67.200	40.396	40.713	31.053	29.682	29.033	36.980
s	6.892	5.777	6.923	6.502	7.295	8.611	8.070	5.120	6.407	7.830	1.948	3.812	4.670	4.019	0.644	4.148	4.387	3.701	2.713	2.582	0.116	–
)	–	–			2.081	–	–	–		–	25.346	14.264	12.550	10.140	28.934	12.127	6.819	6.747	27.282	26.925	44.510	43.985
i	–	–	–		0.790	–	–	–	–	–	1.446	2.023	1.858	1.288	0.562	1.490	0.816	0.676	2.627	2.581	0.197	–
t	1.839	1.911	1.118	1.190	1.150	0.996	1.464	1.630	2.849	2.060	8.381	2.297	1.841	1.677	9.408	2.646	2.700	3.120	4.798	4.806	11.247	10.191
n	0.058	0.015	0.120	0.147	0.600	0.149	0.238	0.196	0.312	–	–	–	–	–	–	–	–	–	–	–	–	–
m	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	4.559
	0.226	0.372	0.270	0.228	0.232	0.269	0.326	0.252	0.325	0.311	0.161	0.293	0.201	0.198	0.124	0.198	0.241	0.218	0.163	0.182	0.124	0.084
	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
)	1.361	1.222	1.658	1.423	1.397	1.483	1.722	1.525	1.384	0.436	0.325	0.463	0.451	0.469	0.309	0.445	0.476	0.470	0.406	0.377	0.232	1.490

Similar to most ophiolites, the tholeiitic affinity of the mafic group is seen on AFM and SiO_2-Feo_t/MgO diagrams (Fig. 2 and 3). An Al_2O_3-CaO-MgO diagram these rocks lie in the field of mafic cumulates (Fig. 4).

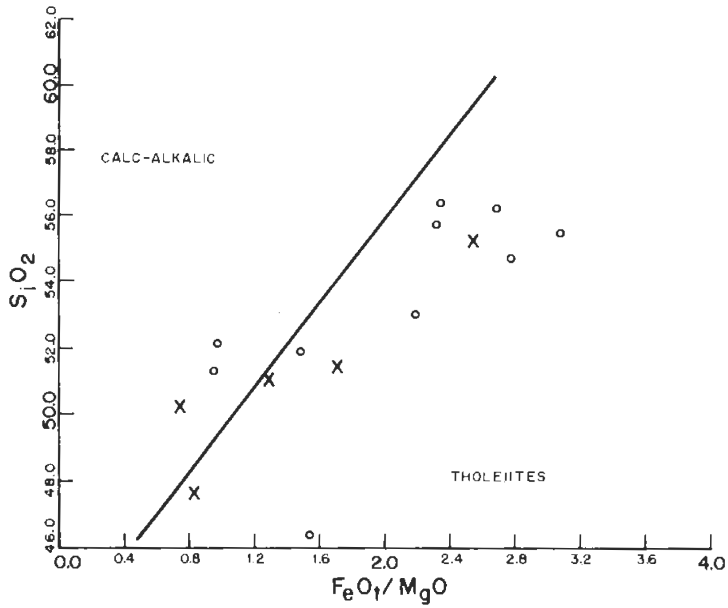

FIG. 3. SiO_2-FeO_t/MgO diagram (Miyashiro 1975) showing composition of sheeted dikes and dike/gabbro mixture of CY-4 drill hole, Troodos Complex.

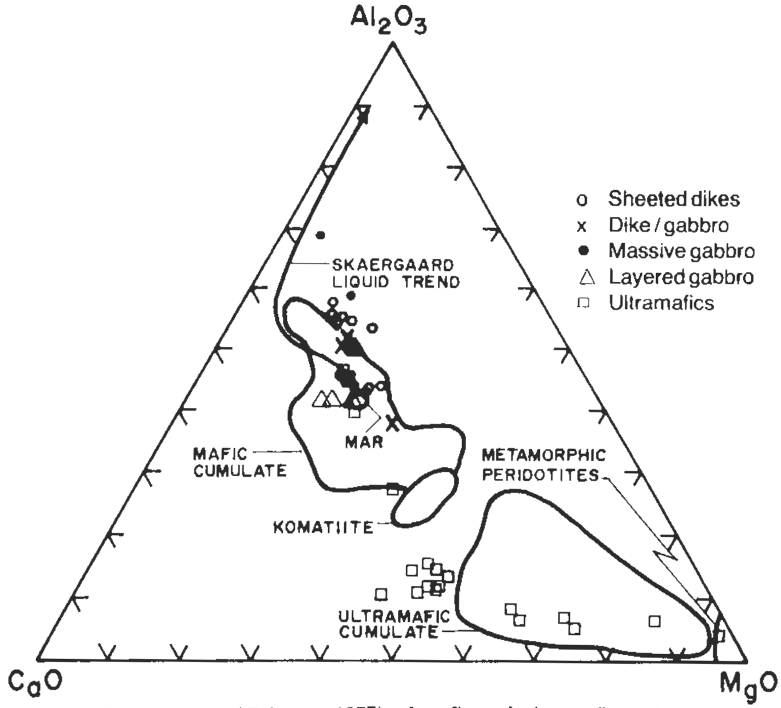

FIG. 4. MgO-Al_2O_3-CaO diagram (Coleman 1977) of mafic and ultramafic rocks of CY-4 drill hole, Troodos ophiolite.

b) Ultramafic Group

The ultramafic rocks have cumulate textures and are interpreted as crystal cumulates. MgO content ranges from 15.13 to 28.69% and total iron content ranges from 4.56 to 9.26%. The last two samples (N_{44} & N_{45}) are characterized by their exceptionally high MgO contents (34.11 & 36.29%, respectively) and their high total iron contents reaching up to 13.3% indicating olivine enrichment. The NiO_2 & Cr_2O_3 ratios were used for discrimination between mantle and cumulates rocks (Malpas 1976, Irvine and Findlay 1972, and Price 1984) for the East African Ophiolite suites. By using the same design, all the Troodos ultramafics lie within the field of cumulates. The depletion in Ni may be due to less abundance of olivine. These rocks show clear similarity both in their composition and on variation diagrams, to those reported from other ophiolite suites. The high SiO_2 content in some of the ultramafics may be due to secondary SiO_2 enrichment.

The high CaO contents may be due to the high Ca-rich pyroxene content. K_2O, P_2O_5 and Al_2O_3 are less than those encountered in the mafic group. Zr, Y, Rb are very low or even below detection limit reflecting the depleted nature of oceanic tholeiites, affecting the crystal accumulation.

On the Al_2O_3-CaO-MgO diagram (Fig. 4) and a $FeO_{(t)}$-Al_2O_3MgO diagram (Fig. 5) most of the analysed samples cluster within the field of the ultramafic rocks (Coleman 1977).

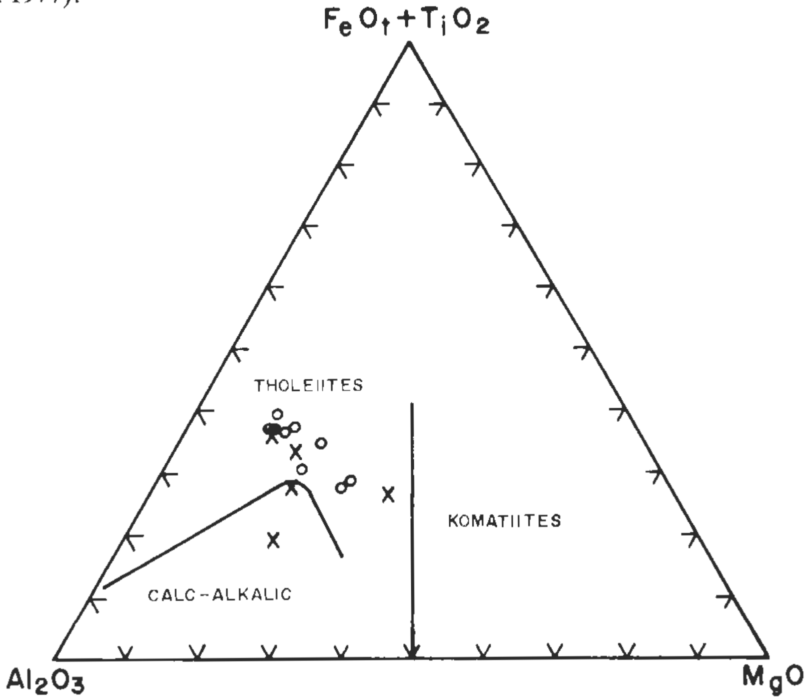

FIG. 5. Jensen diagram (1976) showing composition range of sheeted dikes and dike/gabbro mixture of CY-4 drill hole, Troodos ophiolite.

Conclusions

Petrographic and geochemical studies of 45 samples from CY-4 drill hole (CCSP) show that the rock sequence of this bore hole can be classified into (1) sheeted dike zone of diabasic composition, (2) zone of mixed dikes and gabbros, (3) massive gabbro, (4) cumulative gabbro, and (5) ultramafic cumulates and undifferentiated dunite.

The mafic rocks are generally tholeiite in composition with some SiO_2 enrichment. The chemical composition is variable due to variation in major mineral components. The sudden increase in MgO differentiates the mafics from the ultramafics. Trace elements are comparable to those observed in other ophiolite masses.

The ultramafics are crystal cumulates. Olivine enrichment is reflected by the relatively high MgO content. The last 100m could represent the lower most part of ultramafic cumulates. Very low Zr, Y and Rb contents reflects the depleted nature of the oceanic tholeiite effecting the crystal accumulation.

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بتروكيميائية الصخور المافية وفوق المافية للحفرة التنقيبية قبرص ٤ مشروع دراسة القشرة القبرصية

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تعتبر ورقة البحث هذه محصلة لدراسة خمس وأربعين عينة جُمعت على مسافات ٥٠ مترا من حفرة تنقيب قبرص ٤ (CY-4) التابعة لمشروع دراسة القشرة الأرضية وذلك لتقسيم مجموعة أفيولَيْت ترودوس على أساس الدراسات المجهرية والتحليل الكيميائي .

تشمل منطقة ترودوس مجموعة أفيولَيْت مثالية من العصر الطباشيري حيث تقع البئر قبرص ٤ (CY-4) في الجزء الجنوبي الشرقي من المعقد مخترقة صخور القواطع ، وصخور الجابرو والتراكميات فوق المافية .

ويمكن تقسيم المجموعة الصخرية من حفرة التنقيب بصورة عامة إلى :

١ - منطقة صخور القواطع (صخور ديابيز) في العمق من ٩٫٨٥ إلى ٤٨٣٫٥٠ متراً .

٢ - خليط من صخور القواطع وصخور الجابرو في العمق من ٤٨٣٫٥٠ إلى ٨٧٣٫٤٥ متراً .

٣ - جابرو مصمت في العمق من ٨٧٣٫٤٥ إلى ١٣٤٦٫٨٠ متراً .

٤ - جابرو تراكمي في العمق من ١٣٤٦٫٨٠ إلى ١٧٥٤٫١٠ متراً .

٥ - صخور فوق مافية وتتكون أساسا من كالاينوبيرو كسينيْت وبيستريْت وديونيت في العمق من ١٧٥٤٫١٠ إلى ٢٢٦٣ .

يمكن تقسيم العينات المدروسة كيميائيا إلى مجموعات مافية وفوق مافية وهذا التقسيم يتوافق مع التقسيم الصخري (البتروجرافي) .

تميل هذه الصخور عموما إلى التركيب الثيوليتي فوق المشبع ، كما أن العناصر النَّزْرَة بها يمكن مقارنتها بمثيلاتها من الصخور المشابهة وكذلك الصفات الكيميائية للصخور فوق المافية تؤكد تراكمية هذه الصخور متمشية مع ما أجري من دراسات سابقة .