20. MAFIC AND ULTRAMAFIC ROCKS OF LEG 84: PETROLOGY AND MINERALOGY[1]

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ABSTRACT

Ultramafic rocks were recovered from the lower parts of holes at four sites (567, 566, 569, 570) drilled on Leg 84. These sites are on the landward slope of the Middle America Trench off Guatemala. Harzburgites, cumulative texture peridotites, gabbros, dolerites, and amphibolite facies rocks were recognized by petrologic and geochemical analysis (X-ray fluorescence, microprobe). Some of these rocks belong to an ophiolitic sequence. They form the basement of the landward slope of the Guatemala Trench upon which lower Eocene sediments were deposited. As a whole, the ophiolitic rock has much in common with various ophiolitic massives known on land all over the world (e.g., Antalya, Oman), particularly the ophiolitic sequence of the Santa Elena Peninsula of Costa Rica. The age, the abundance of harzburgites, and the structural position of the mafic and ultramafic rocks of Leg 84 suggest that they could represent an offshore equivalent of the Santa Elena ultramafic rocks. In any case, the first ophiolites to have been recovered from the slope of an active margin are those of the drilled mafic and ultramafic rocks of Leg 84.

INTRODUCTION

Mafic and ultramafic rocks were drilled at Sites 567, 566, 569, and 570 of Leg 84 on the landward slope of the Middle America Trench off Guatemala. The simplified stratigraphic columns of Figure 1 show the general lithostratigraphy of the drill holes and the main results of Legs 67 and 84 (Aubouin, von Huene, et al., 1979; von Huene, Aubouin, et al., 1980; Coulbourn et al., 1982).

Site 567 is located 100 m from the position of Hole 494A of Leg 67 (Maury et al., 1982). Below the Pleistocene and Pliocene slope sediments, blocks of serpentinite were recovered in Miocene sediments. Beneath the Miocene section, drilling recovered two cores of Late Cretaceous limestone, followed by acoustic basement of mafic and ultramafic rocks (harzburgites, gabbros, dolerites, basalts; Fig. 2). It is not possible to establish a strategraphy of the mafic and ultramafic basement from the succession of samples. Harzburgites and mafic rocks sometimes alternate in the same core; no apparent sequences were recovered. Poor recovery and drilling breccias further obscure the section. Tectonic breccias could also be recognized because of the cataclastic texture of some samples in thin section.

Underneath the Pliocene–Pleistocene and the upper Miocene slope deposits in Holes 566A and 566C (Fig. 2) only serpentinized harzburgites were recovered.

The rocks recovered from the base of Hole 569A (Fig. 2) are amphibolites with evidence of retrograde metamorphism in the greenschist facies. These amphibolites appear under approximately 350 m of sediments where a normal succession of Pleistocene through Eocene microfossils was identified.

Site 570 reached serpentinized peridotites with cumulative texture beneath sediments that are lower Eocene to Pleistocene.

METHODS

A selection of samples suitable for geochemical studies was made from the petrographic study of 64 thin sections. Nineteen chemical analyses on rocks were carried out at the Laboratoire de Pétrologie of Nancy by X-ray fluorescence and neutron activation analyses; the corrected values were established according to the Irvine and Baragar (1971) method (Fe^{3+} and Fe^{2+} determination). This method, especially established for mafic volcanic rocks, may be used for all mafic rocks. The content of $Fe_2O_3\%$ is calculated as follows: $Fe_2O_3\% = TiO_2\% + 1.50$, and FeO is adjusted after correction for loss on ignition.

A study of the primary minerals (olivine, orthopyroxene, clinopyroxene, spinel, amphibole, plagioclase) of 19 samples was made with the Camebax microprobe (natural standard, 14 kv, 10 s) of the Muséum National d'Histoire Naturelle de Paris.

ULTRAMAFIC ROCKS

The ultramafic rocks recovered (Fig. 2) from Hole 567A are (1) reworked serpentinite blocks in the lower Miocene sediments between 260 and 330 m; (2) a thick block of serpentinized peridotites (Core 567A-16) above the Upper Cretaceous limestones; (3) igneous basement rocks under the Upper Cretaceous limestones between 380 and 500 m.

From holes 566, 566A, and 566C, only ultramafic rocks were recovered beneath the thin canyon sediment deposits where 30, 5, and 25 m of this basement were drilled, respectively.

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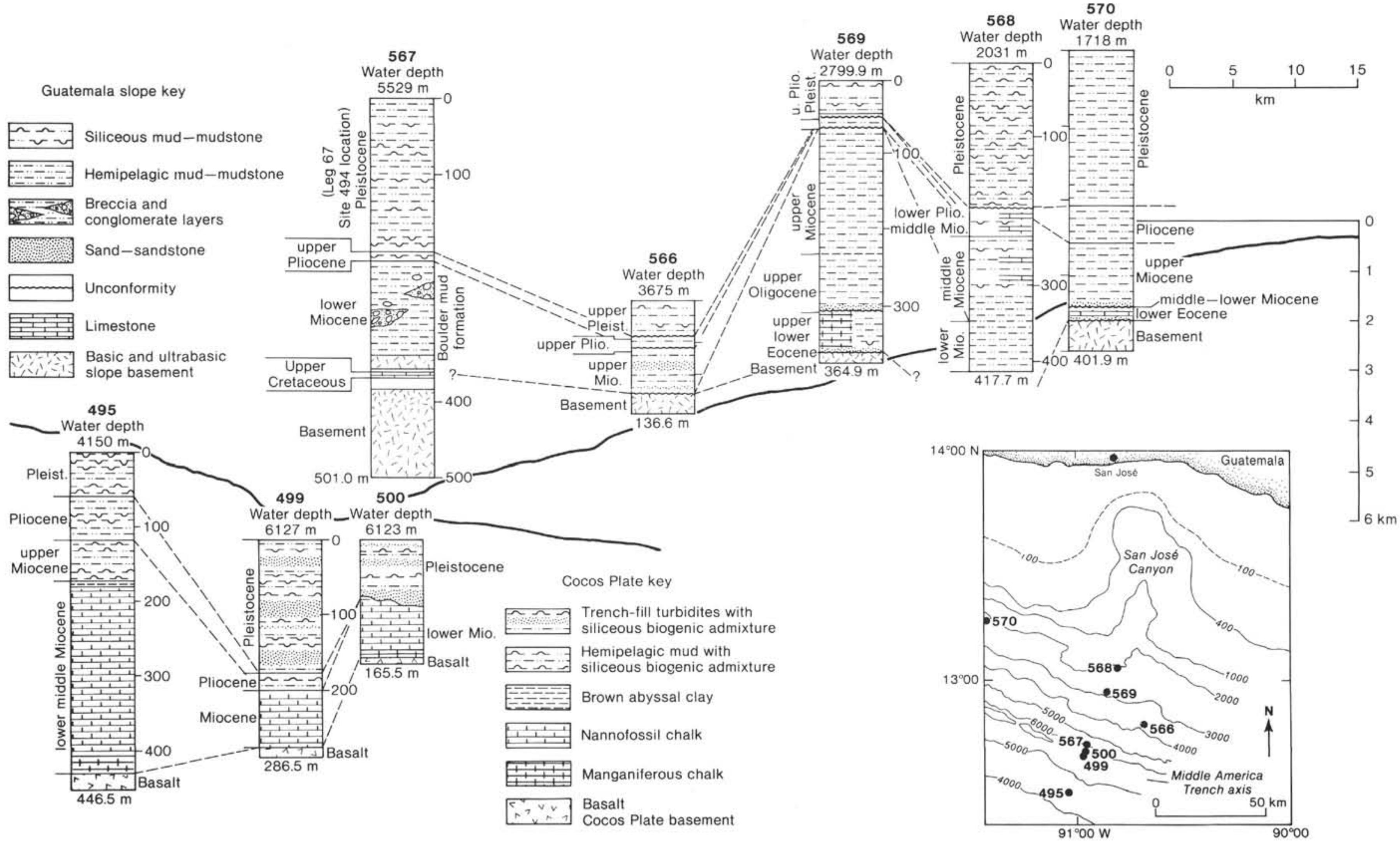

Figure 1. Cross section of the Guatemala slope, Leg 67 and Leg 84 summary results. (Inset map shows bathymetry in meters.)

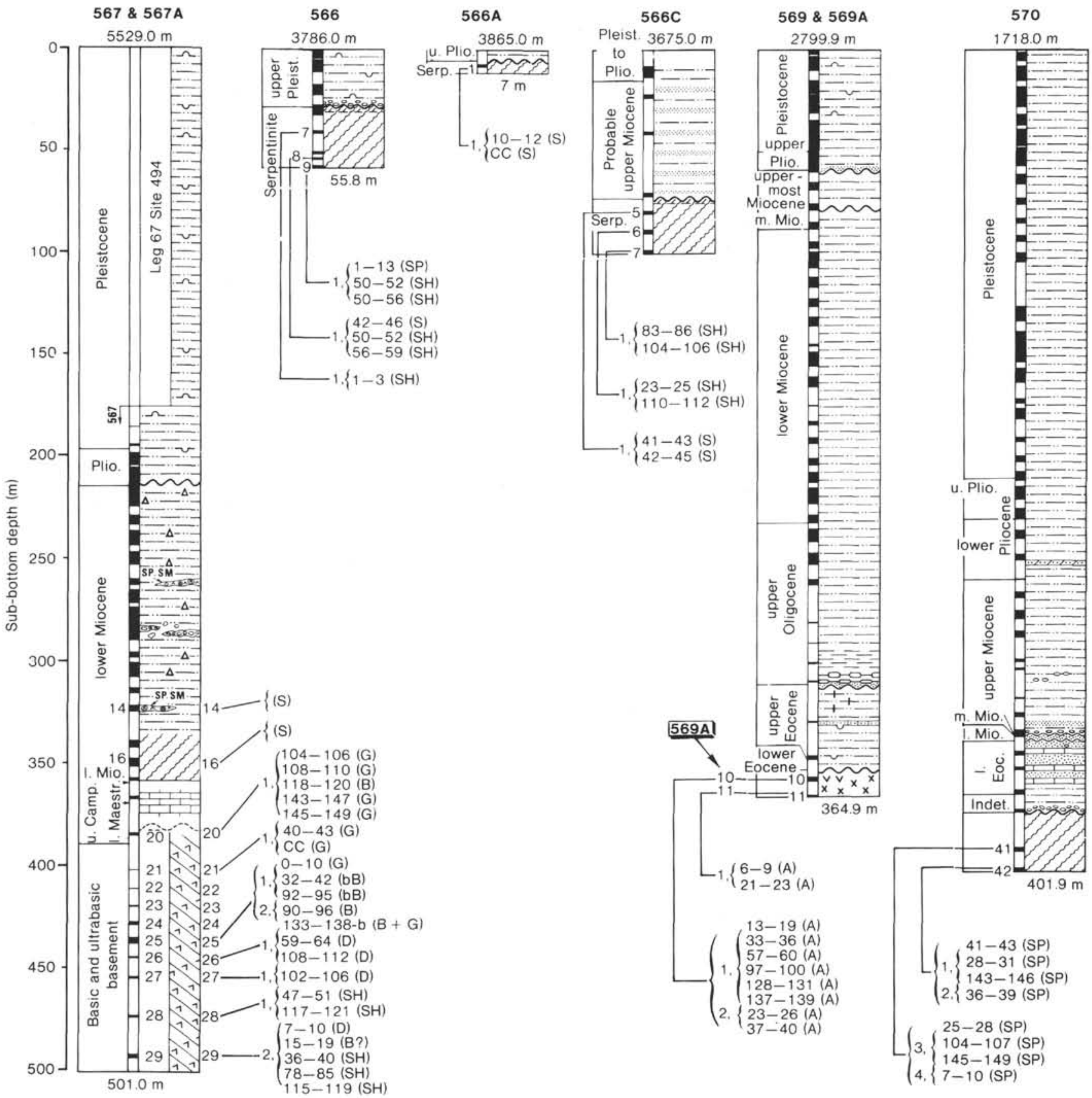

Figure 2. Location of studied samples of Leg 84 (after Aubouin, von Huene, et al., 1982). A = amphibolite, B = basalt, bB = basaltic breccia, D = dolerite, G = gabbro, S = serpentinite, SP = serpentinized peridotite, SH = serpentinized harzburgite. (See Fig. 1 legend for explanation of symbols.)

At Site 570, only ultramafic rocks were recovered in the basement drilled down to 401 m from the base of sediments at 376 m.

All these ultramafic rocks are widely serpentinized. Their primary mineralogy (spinel, olivine, orthopyroxene, and clinopyroxene) appears as relic textures. Because the serpentinization of the pyroxene is different from that of the olivine, it is possible to identify the original textures even in wholly serpentinized samples.

Two groups of ultramafic rocks thus become distinct: (1) peridotites (harzburgites) with a panxenomorphic texture (Holes 567A, 566, and 566C); (2) peridotites with a cumulative texture (Hole 570).

The Harzburgites

The ultramafic rocks with a panxenomorphic texture are generally intensely serpentinized. In most cases spinel alone remains of the original minerals. Remains of olivine and pyroxene occur in a sample from Hole 567A and in many others from Holes 566 and 566C. Minute islets of olivine are spared as relicts in a mesh-textured serpentine. A fibrous-textured serpentine is the main alteration product of the orthopyroxene. In some samples there are large relic sections of orthopyroxene. In a few samples, there are small sections of clinopyroxene.

The harzburgites from Holes 566, 566A, and 566C have a very similar chemical composition (Table 1, Analysis numbers 2 to 6).

One harzburgite from 567A is also of similar chemical composition and slightly more aluminous but less calcic (Table 1, Analysis number 1). Indeed, this sample, although rich in orthopyroxene, is without clinopyroxene.

All the samples have a remarkably constant mineralogical composition. The olivines are Fo ^{89}–Fo ^{92} (Table 2) and the orthopyroxenes are Mg-rich bronzite En ^{87}–En ^{91} (Table 3). The clinopyroxenes from Hole 566 and 566C samples are chromiferous diopsides (Table 3). From one sample to another, the clinopyroxenes show obvious variations in Al and Ca content, but Cr is present in significant quantities. However, the spinels have variable chemical compositions, and those of Hole 567A are rich or very rich in Al (Table 4). All the analyzed spinels have a positive correlation between Cr/Al and Mg/Fe ratios (Fig. 3).

The rock and mineralogical chemical compositions of Leg 84 harzburgites are similar to those of many ophiolitic complexes, for example from Troodos and from Oman (Boudier and Coleman, 1981). The clinopyroxene chemical compositions of Leg 84 harzburgites are $Wo_{47.9}$, $En_{48.4}$, $Fs_{3.7}$, and those of Oman (Pallister and Hopson, 1981) are Wo_{45}, En_{51}, and Fs_4.

The spinels (average composition of 6 analyses) of Leg 84 harzburgites also have a chemical composition similar to those of Oman (Pallister and Hopson, 1981), but different from those of the peridotites of Santa Elena Peninsula in Costa Rica (Tournon et al., in press). The spinels are more aluminous and magnesian (Table 3) and have less Cr and Fe.

Cumulative Texture Peridotites

The texture of the ultramafic rocks sampled at Site 570 differs from that of rocks sampled at the other Leg 84 sites (Holes 567A, 566, 566A, 566C). The olivine appears in automorphic crystal aggregates cemented by xenomorphic crystals of pyroxene.

The olivine and pyroxene are completely serpentinized, but the cumulative texture is still obvious. Relic crystals

Table 1. Major element composition (%) and CIPW norms.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Chemical analysis																			
SiO_2	37.81	37.04	37.45	36.17	36.76	36.65	34.13	44.34	47.49	42.56	47.61	42.84	41.58	45.13	45.46	48.05	47.34	46.58	42.91
Al_2O_3	1.59	0.60	0.62	0.51	0.58	0.72	0.62	15.63	17.80	14.81	16.46	15.45	14.50	14.78	17.49	15.41	16.87	14.43	15.98
Fe	6.66	7.43	6.79	7.40	7.61	7.38	7.14	6.28	5.47	11.32	9.24	10.23	11.81	11.14	5.39	9.74	5.72	8.92	5.97
MnO	0.14	0.16	0.14	0.13	0.15	0.15	0.15	0.17	0.15	0.19	0.16	0.20	0.20	0.19	0.13	0.18	0.13	0.17	0.11
MgO	37.29	36.68	34.58	37.71	36.50	36.57	37.83	11.73	6.72	11.15	6.23	10.67	12.00	7.01	11.21	6.02	5.96	5.32	5.34
CaO	0.12	0.72	1.87	0.66	0.79	0.96	0.34	11.56	11.24	6.96	8.17	6.92	6.79	9.82	13.20	9.44	9.63	9.81	19.03
Na_2O	0.06	0.09	0.25	0.10	0.08	0.06	0.21	2.19	3.27	2.53	4.56	2.78	2.40	3.02	1.39	5.92	7.17	7.44	2.75
K_2O	0.01	0.02	0.02	0.01	0.01	0.00	0.00	0.19	0.43	0.25	0.52	0.71	0.21	0.47	0.20	0.40	0.08	0.09	0.02
TiO_2	0.01	0.02	0.02	0.02	0.01	0.02	0.01	0.25	0.22	1.59	1.98	1.67	1.51	2.41	0.22	0.66	0.81	0.60	0.41
Loss on ignition	15.32	16.37	17.36	16.23	16.31	16.47	18.19	7.06	6.92	7.97	4.83	8.11	8.75	5.29	4.97	4.00	5.98	5.98	6.61
Total	99.01	99.13	99.10	99.04	98.80	98.98	98.62	99.40	99.71	99.33	99.76	99.58	99.76	99.26	99.66	99.82	99.69	99.34	99.13
Ni (ppm)	1973	1982	1921	1930	1990	2310	2130	166	67	392	100	334	434	153	157	62	280	69	71
Cr (ppm)	4386	2283	2455	2540	2030	3612	2515	519	155	417	230	312	535	421	255	170	37	37	137
Dry recalculated data																			
SiO_2	45.45	45.05	46.09	43.96	44.87	44.91	42.70	48.25	51.37	46.97	50.42	47.16	46.10	48.36	48.18	50.53	50.68	50.22	46.56
Al_2O_3	1.91	0.73	0.76	0.74	0.71	0.88	0.78	17.00	19.25	16.34	17.43	17.00	16.07	15.84	18.54	16.18	18.06	15.56	17.34
Fe_2O_3	1.81	1.85	1.87	1.85	1.84	1.85	1.89	1.90	1.86	3.41	3.69	3.49	3.34	4.19	1.82	2.27	2.47	2.26	2.07
FeO	5.63	6.54	5.90	6.50	6.77	6.50	6.41	4.48	3.69	8.27	5.55	7.08	8.87	7.05	3.54	7.25	3.32	6.70	4.03
MnO	0.17	0.19	0.17	0.16	0.18	0.18	0.19	0.18	0.16	0.21	0.17	0.22	0.22	0.20	0.14	0.19	0.14	0.18	0.12
MgO	44.80	44.61	42.56	45.84	44.55	44.61	47.33	12.76	7.27	12.30	6.60	11.75	13.30	7.51	11.88	6.33	6.38	5.74	5.80
CaO	0.14	0.88	2.30	0.80	0.96	1.17	0.43	12.57	12.15	7.68	8.65	7.62	7.53	10.52	13.99	9.92	10.31	10.58	20.64
Na_2O	0.07	0.11	0.31	0.12	0.10	0.07	0.26	2.38	3.54	2.79	4.83	3.06	2.66	3.24	1.47	6.22	7.68	8.02	2.98
K_2O	0.01	0.02	0.02	0.01	0.01	0.00	0.00	0.21	0.47	0.28	0.55	0.78	0.23	0.50	0.21	0.42	0.09	0.10	0.02
TiO_2	0.01	0.02	0.02	0.02	0.01	0.02	0.01	0.27	0.24	1.75	2.10	1.84	1.67	2.58	0.23	0.69	0.87	0.65	0.44
CIPW norms																			
Or	0.60	0.12	0.12	0.06	0.06			1.24	2.78	1.66	3.25	4.61	1.36	2.96	1.24	2.49	0.53	0.59	0.12
Ab	0.59	0.93	2.62	1.02	0.84	0.59	2.20	17.04	27.89	23.58	36.23	25.86	22.48	27.38	12.42	26.55	25.97	22.15	0.54
An	0.70	1.44	0.62	1.45	1.46	2.09	0.96	35.04	35.20	31.20	24.22	30.31	31.19	27.16	43.32	14.97	14.52	6.17	33.84
Ne								1.67	1.10		2.49					14.10	21.10	24.73	13.36
Di		2.30	8.46	1.98	2.60	2.92	0.92	21.68	20.02	5.54	14.88	5.98	4.95	20.00	20.64	27.96	29.00	37.83	41.05
Fs	2.31	2.06	1.78	1.44	2.05	1.88	0.72			2.17			1.60	0.72	0.81				
En	28.35	21.30	19.85	15.50	20.41	19.61	7.83			6.77			4.77	2.42	4.94				
Fa	5.27	6.67	5.75	7.06	6.99	6.72	7.57	3.70	2.34	5.44	2.01	5.12	6.92	2.07	2.08	3.97	0.60	1.73	
Fo	58.56	62.47	58.04	68.77	62.90	63.47	77.07	16.37	7.51	15.38	7.57	18.24	6.30	11.48	5.36	3.04	2.32		
Ma	2.62	2.68	2.71	2.68	2.68	2.68	2.74	2.76	2.70	9.94	3.35	5.06	4.84	6.08	2.64	3.29	3.58	3.28	3.00
Il	0.02	0.04	0.04	0.04	0.02	0.04	0.02	0.51	0.46	3.33	3.99	3.50	3.17	4.90	0.44	1.31	1.65	1.24	0.84

Note: Analysis numbers represent samples as follows: harzburgites—1 = 567A-29-2, 36–40 cm (+Co normative = 1.53), 2 = 566-9-1, 50–52 cm; 3 = 566A-1-1, 10–12 cm; 4 = 566A-9-1, 50–52 cm; 5 = 566C-6-1, 110–112 cm; cumulated periodites—7 = 570-41-3, 104–107 cm; gabbros—8 = 567A-20-1, 104–106 cm; 9 = 567A-20-1, 143–149 cm; dolerites—10 = 567A-26-1, 59–61 cm; 11 = 567A-27-1, 108–112 cm; 12 = 567A-29-2, 7–10 cm; 13 = 567A-26-1, 40–43 cm, basalts—14 = 567A-25-2, 90–96 cm; 15 = 567A-20-1, 118–120 cm; amphibolites—16 = 569A-10-1, 33–36 cm; 17 = 569A-10-1, 118–120 cm; 18 = 569A-10-1, 57–60 cm; 19 = 569A-10-1, 57–60 cm (+Wo normative = 7.26).

Table 2. Olivines from ultramafic rocks.

	1	2	3	4
SiO_2	41.17	41.11	40.05	40.42
FeO	7.73	8.46	9.09	9.00
MnO	0.07	0.11	0.22	0.73
MgO	50.52	49.57	49.57	49.57
CaO	0.02	0.00	0.01	0.00
NiO	0.31	0.43	0.35	0.15
Total	99.82	99.68	90.29	99.87
Fo	91.75	90.77	90.15	89.93
Si	1.003	1.007	0.990	0.993
Fe	0.158	0.173	0.188	0.185
Mn	0.001	0.002	0.005	0.015
Mg	1.834	1.180	1.827	1.814
Ca	0.001	0.000	0.000	0.000
Ni	0.006	0.008	0.007	0.003
Total	3.003	3.000	3.017	3.010

Note: Formula basis: 4 oxygens. Analysis numbers represent the samples as follows: 1 = 567A-19-2, 36–40 cm; 2 = 566C-6-1, 110–112 cm; 3 = 566-9-1, 50–56 cm; 4 = 566C-7-1, 83–86 cm.

Table 3. Analyses of ultramafic rock pyroxenes.

	1	2	3	4	5	6	7
SiO_2	54.98	55.96	56.90	55.50	52.93	52.64	52.43
Al_2O_3	4.49	2.43	2.13	2.13	2.59	2.60	2.29
FeO	4.76	6.14	5.75	6.18	2.15	1.99	2.45
MnO	0.09	0.13	0.07	0.13	0.11	0.06	0.00
MgO	33.21	33.57	34.00	33.02	17.10	17.08	17.19
CaO	0.93	0.97	0.73	1.61	23.56	24.11	24.06
Na_2O	0.02	0.03	0.03	0.00	0.03	0.00	0.01
Cr_2O_3	1.07	0.53	0.71	0.51	0.97	0.80	0.55
TiO_2	0.00	0.00	0.00	0.01	0.00	0.06	0.00
Total	99.55	99.76	100.32	99.09	99.44	99.34	98.98
Wo	1.83	1.85	1.89	3.08	47.97	48.73	48.24
En	90.74	88.84	89.97	87.53	48.43	48.03	47.93
Fs	7.43	9.31	8.63	9.40	3.59	3.24	3.84
Si	1.899	1.939	1.954	1.941	1.934	1.927	1.930
Al^{IV}	0.101	0.061	0.046	0.059	0.066	0.073	0.070
Al^{VI}	0.082	0.038	0.040	0.029	0.046	0.039	0.029
Fe	0.137	0.178	0.165	0.181	0.066	0.061	0.075
Mn	0.003	0.004	0.002	0.004	0.003	0.002	0.000
Mg	1.709	1.733	1.740	1.721	1.931	1.932	0.943
Ca	0.034	0.036	0.027	0.060	0.922	0.946	0.949
Na	0.001	0.002	0.002	0.000	0.002	0.000	0.001
Cr	0.029	0.015	0.019	0.014	0.028	0.023	0.016
Ti	0.000	0.000	0.000	0.000	0.000	0.002	0.000
Total	3.996	4.005	3.995	4.008	3.998	4.004	4.013

Note: Total iron as FeO. Formula basis: 6 oxygens. Analysis numbers represent the following samples: orthopyroxenes—1 = 567A-29-2, 36–40 cm; 2 = 566-9-1, 50–56 cm; 3 = 566C-6-1, 110–112 cm; 4 = 566C-7-1, 83–86 cm; clinopyroxenes—5 = 566C-6-1, 110–112 cm; 6 = 566-9-1, 50–56 cm; 7 = 566C-7-1, 83–86 cm.

of a very chromiferous spinel alone have survived (Table 4). These peridotites have a harzburgitic chemical composition, nevertheless it differs from the harzburgites of panxenomorphic texture on the basis of its less siliceous and higher magnesian content (Table 1, Analysis number 7). The low Ca content suggests that the pyroxene is an orthopyroxene.

The ultramafic cumulates of ophiolitic complexes (Antalya, Troodos, Oman) are composed of rhythmic and recurrent layered dunites, lherzolites, and wehrlites

Table 4. Analyses of ultramafic rock spinels (%).

	1	2	3	4	5	6
Al_2O_3	41.15	53.33	24.75	31.41	28.03	29.89
Cr_2O_3	29.88	14.20	44.08	37.72	40.22	39.08
Fe_2O_3	0.37	1.25	1.64	1.15	2.63	1.90
FeO	13.31	10.54	16.61	15.89	16.18	15.27
MnO	0.10	0.13	0.24	0.07	0.22	0.03
MgO	16.70	19.89	12.43	13.75	13.15	14.02
Total	101.51	99.34	99.75	99.99	100.43	100.19
Al	10.727	13.313	7.154	8.751	7.918	8.350
Cr	5.223	2.377	8.545	7.047	7.619	7.322
Fe^{+++}	0.062	0.199	0.303	0.205	0.474	0.339
Fe^{++}	2.461	1.866	3.406	3.140	3.242	3.026
Mn	0.019	0.023	0.050	0.014	0.045	0.006
Mg	5.503	6.277	4.542	4.842	4.696	4.951
Total	23.994	24.055	23.999	23.999	23.994	23.995

Note: Formula basis: 32 oxygens. Analysis numbers represent these samples: 1 = 567A-29-2, 36–40 cm; 2 = 567A-16-1, 22–23 cm; 3 = 566C-6-1, 110–112 cm; 4 = 566-9-1, 50–56 cm; 5 = 566C-7-1, 83–86 cm; 6 = 570-4-1, 78–31 cm.

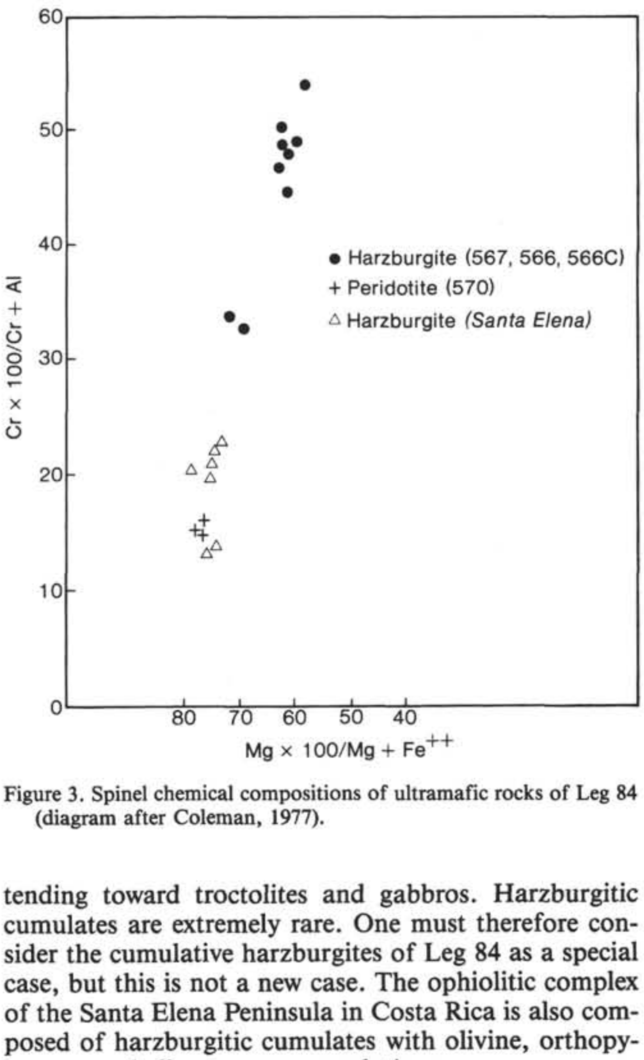

Figure 3. Spinel chemical compositions of ultramafic rocks of Leg 84 (diagram after Coleman, 1977).

tending toward troctolites and gabbros. Harzburgitic cumulates are extremely rare. One must therefore consider the cumulative harzburgites of Leg 84 as a special case, but this is not a new case. The ophiolitic complex of the Santa Elena Peninsula in Costa Rica is also composed of harzburgitic cumulates with olivine, orthopyroxene, and clinopyroxene exsolutions.

Thus the more uniform composition of the Leg 84 ultramafic sequences could represent a peculiarity of the ophiolitic complexes of Central America. There is insufficient evidence to make firm conclusions because of the poor recovery of Leg 84 igneous rock and also the fact that serpentinization can impart a change in the original chemical composition.

THE GABBROS

Gabbros were found only in Hole 567A. These are rocks of coarse granular texture, mainly composed of plagioclase and green amphibole with occasional clinopyroxenes. The parageneses are: (1) plagioclase + clinopyroxene + pseudomorph orthopyroxene; (2) plagioclase + clinopyroxene + amphibole. Opaque minerals are absent in all the samples studied, as in the gabbros of most of the differentiated ophiolitic complexes (Antalya, Troodos), as well as in those of the Santa Elena Peninsula.

One sample exhibits a centimeter-thick layer of plagioclases intercalated between two layers packed with amphiboles; this regular undeformed layering originated from magmatic phenomena.

The plagioclase is commonly locally weathered, and most samples exhibit calcic veinlets as well as zoisite aggregates.

Chemical Compositions

Two gabbros were analyzed; both are aluminous and calcic but have slight Fe, Ti, and K contents. A low CIPW norm nepheline content could be explained by the secondary calcite (Table 1, Analysis numbers 8 and 9).

The nonzoned pyroxenes are calcic and magnesian (Table 5, Analysis numbers 1 and 2). Two amphiboles are magnesian hornblendes (Table 6, Analysis numbers 1 and 2). On the other hand, a weathered gabbro contains a faintly colored amphibole of tremolitic composition (Tables 6 and 4) and zoning in the very basic (An_{86}–An_{76}) plagioclases is slight.

The chemical compositions of both the clinopyroxene (Wo_{44}, $En_{45.5}$, Fs_{10}) and plagioclases (AN_{86-76}) of Leg 84 layered gabbros are close to those of Oman ophiolites (Wo_{43}, En_{47}, Fs_{10}, An_{88-64}; Pallister and Hopson, 1981) and of those from Antalya (Juteau and Whitechurch, 1980).

THE DOLERITES

Hole 567A gave dolerites from several levels with small crystals and a subophitic texture. The olivine is serpentinized; it is mostly of large automorphic crystals or smaller ones enclosed in pyroxene. However, there is no olivine in one of the samples. The clinopyroxene is colorless to pale brown; it has large poikilitic crystals enclosing olivine and also acicular crystals of slightly weathered automorphic plagioclase. The opaque minerals are also automorphic. The order of crystallization in the dolerites is therefore olivine, plagioclase, ores and clinopyroxene.

Chemical Compositions

The dolerites have homogeneous chemical compositions (Table 1, Analysis Nos. 10–13). They have high Mg, Fe, and Ti contents and low concentrations of K. The calculation of the CIPW norms indicates the presence of orthopyroxene and olivine.

The clinopyroxenes are calcic (Table 5, Analysis numbers 3–7; Fig. 4). They have the same chemical composition in the four samples analyzed. The clinopyroxenes are zoned because of variation in the Fe/Mg and Al ratios. The plagioclases are also calcic and zoned, with a composition of An_{80} to An_{40}. The opaque minerals are ilmenite and titanomagnetite.

These dolerites have tholeitic affinities because of their low K content high Fe content of clinopyroxene (Fig. 4), and olivine + normative orthopyroxene, but the high Ti content gives them an alkaline character.

One of the dolerites (Table 1, Analysis number 11) differs from the others by containing less Fe and Mg (no olivine) and more Ti and Na (2.49 CIPW norm nepheline). This dolerite therefore has no specific tholeitic affinity. However, the plagioclases of this sample are highly weathered, which suggests a possible secondary sodic enrichment.

THE BASALTS

Most of the basalts sampled from hole 567A were studied at the University of Brest (Bellon et al., this volume), and only two basalts are included in this study. One sample is a breccia intruded by calcite and hematite veins. The rock is strongly weathered, but its microlitic texture is still observable. The second is a basalt with doleritic texture (Table 1, Analysis number 14), made up of very elongated automorphic zoned plagioclases (An_{67-47}) and automorphic ilmenite enclosed within xenomorphic and poikilitic crystals of zoned pyroxenes (Table 5, Analysis numbers 8 and 9). The matrix is a devitrified paste in which acicular crystals of plagioclase appear.

The chemical compositions, the Fe and Ti contents, the texture, and the zonation of the minerals are similar to those of the dolerites. Because of the few samples studied and their brecciated and weathered state, it is not possible to go into more detail.

THE AMPHIBOLITES

Hole 569A encountered metamorphic basement underlying lower Eocene sediments at a depth of 350 m beneath the seafloor. Of the 13.5 m that were drilled in the basement, only 2 m of metamorphic rocks were recovered in Cores 569A-10 and 569A-11. Ten samples of Cores 569A-10 and 569A-11 were studied, all of which are amphibolites.

These rocks give evidence of a low-temperature retrograde metamorphism. They are finely crystallized and have a granoblastic texture; a number of samples are foliated. One of these granoblastic rocks (Table 1, Analysis number 16) has a well-preserved amphibolite facies paragenesis: green hornblende is a magnesiohornblende, twinned basic plagioclase in An_{82-58} and ilmenite. Zeolites partly replace the plagioclases. In other amphibolites, hornblende is preserved, the natrolite completely replaces the placioglases, the amphiboles are of the tremolite–actinolite group, prehnite and colorless phyllites occur as clots. Prehnite, sometimes associated with quartz, appears also in veinlets. One sample (Table 1, Analysis number 19) is full of prehnite, and only a few hornblende crystals are preserved. Thus these rocks have

Table 5. Clinopyroxenes from gabbros, dolerites, and basalts (%).

	1	2	3	4	5	6	7	8	9
SiO_2	51.51	52.42	49.78	48.58	48.88	46.79	48.72	49.38	51.40
Al_2O_3	2.77	2.66	4.09	4.53	3.45	5.66	3.28	2.86	1.63
FeO	6.40	6.36	6.78	9.17	10.76	9.31	12.59	10.21	10.86
MnO	0.11	0.23	0.15	0.07	0.30	0.20	0.25	0.00	0.31
MgO	15.48	15.61	14.87	13.84	12.47	12.85	11.85	14.52	15.18
CaO	22.19	21.69	21.07	20.65	20.70	20.72	19.76	19.92	18.33
Na_2O	0.24	0.31	0.33	0.51	0.48	0.65	0.42	0.37	0.40
K_2O	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.02
Cr_2O_3	0.17	0.04	0.27	0.11	0.16	0.11	0.00	0.00	0.00
TiO_2	0.41	0.53	1.69	2.46	2.06	3.08	2.06	1.59	0.84
Total	99.28	99.85	99.02	99.92	99.25	99.41	98.93	98.84	99.02
Wo	45.48	44.67	44.67	43.82	44.34	45.03	42.71	41.42	38.05
En	44.12	44.73	43.87	40.86	37.16	38.83	35.63	42.00	43.84
Fs	10.40	10.60	11.46	15.31	18.50	16.14	21.66	16.58	18.11
Si	1.916	1.933	1.861	1.822	1.860	1.773	1.870	1.874	1.941
Al^{IV}	0.084	0.067	0.139	0.178	0.140	0.227	0.130	0.126	0.059
Al^{VI}	0.038	0.048	0.041	0.022	0.015	0.027	0.018	0.002	0.013
Fe	0.199	0.196	0.212	0.288	0.343	0.295	0.401	0.324	0.343
Mn	0.003	0.007	0.005	0.002	0.012	0.006	0.008	0.000	0.010
Mg	0.858	0.858	0.828	0.774	0.707	0.726	0.678	0.821	0.854
Ca	0.885	0.867	0.844	0.830	0.844	0.841	0.813	0.810	0.741
Na	0.017	0.022	0.024	0.037	0.035	0.048	0.031	0.027	0.029
K	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001
Cr	0.005	0.001	0.008	0.003	0.005	0.003	0.000	0.000	0.000
Ti	0.011	0.015	0.047	0.069	0.059	0.088	0.060	0.045	0.024
Total	4.016	4.004	4.009	4.025	4.018	4.034	4.009	4.029	4.015

Note: Total iron as FeO. Formula basis: 6 oxygens. Analysis numbers represent the following samples: clinopyroxenes of gabbros—1 = 567A-20-1, 104–106 cm; 2 = 567A-20-1, 101–111 cm; clinopyroxenes of dolerites—3 = 567A-26-1, 108–112 cm; 4 = 567A-21-1, 40–46 cm; 5 and 6 = 567A-26-1, 59–64 cm; 7 = 567-29-2, 7–10 cm; clinopyroxenes of basalt—8 and 9 = 567A-25-2, 90–96 cm.

Table 6. Analysis of amphiboles from gabbros and amphibolites (%).

	1	2	3	4	5	6	7
SiO_2	48.99	48.94	51.93	47.50	48.97	47.61	48.65
Al_2O_3	7.66	6.17	3.97	6.99	5.54	6.87	7.46
FeO	10.59	13.14	10.96	16.00	16.69	16.85	12.71
MnO	0.23	0.25	0.19	0.31	0.27	0.28	0.37
MgO	16.12	15.34	16.44	12.47	13.72	13.26	14.90
CaO	12.41	11.57	11.97	10.92	10.69	10.40	11.31
Na_2O	1.33	0.92	0.39	0.81	0.87	0.95	0.85
K_2O	0.08	0.15	0.00	0.30	0.14	0.20	0.23
Cr_2O_3	0.00	0.11	0.04	0.05	0.07	0.02	0.00
TiO_2	0.24	1.12	0.26	1.03	0.74	0.96	0.97
Total	97.65	97.71	96.15	96.38	97.70	97.40	97.44
Si	7.059	7.119	7.543	7.099	7.215	7.059	7.073
Al^{IV}	0.941	0.881	0.457	0.901	0.785	0.941	0.927
Al^{VI}	0.367	0.176	0.223	0.329	0.178	0.260	0.351
Fe	1.276	1.599	1.331	1.999	2.057	2.089	1.546
Mn	0.028	0.030	0.023	0.039	0.034	0.035	0.045
Mg	3.462	3.326	3.559	2.779	3.014	2.931	3.230
Ca	1.916	1.803	1.862	1.749	1.707	1.653	1.762
Na	0.371	0.259	0.109	0.233	0.248	0.274	0.239
K	0.015	0.027	0.000	0.058	0.026	0.037	0.042
Cr	0.000	0.013	0.005	0.006	0.008	0.002	0.000
Ti	0.026	0.234	0.028	0.116	0.082	0.107	0.106
Total	15.467	15.356	15.140	15.308	15.354	15.388	15.321

Note: Total iron as FeO. Formula basis: 23 oxygens. Analysis numbers represent the following samples: amphiboles from gabbros—1 = 567A-20-1, 101–111 cm; 2 = 567A-21,CC; 3 = 576A-20-1, 143–147 cm; amphiboles from amphibolites—4 = 569-10-1, 33–36 cm; 5 = 569-10-1, 137–139 cm; 6 = 569-10-1, 57–60 cm; 7 = 569-10-1, 128–130 cm.

a low-temperature (probably hydrothermal) paragenesis producing zeolite, actinolite, prehnite, and phyllite. Products of the primary high-temperature paragenesis (magnesiohornblende, calcic plagioclase, ilmenite) of amphibolite facies are partially preserved.

Chemical Compositions

The SiO_2, Al_2O_3, FeO, MgO, and TiO_2 contents (Table 1, Analysis numbers 16–18) of these amphibolites are those of basalts. Iron and TiO_2 contents in amphibolites are consistent with those of the gabbros and basalts, but not with those of the dolerites. MgO content is lower. We believe that the amphibolites may represent metamorphosed rocks of primary intermediate basaltic composition between the dolerites, which are alkaline, and the basalt (Table 1, Analysis number 15). The K_2O contents are very low and suggest tholeiitic affinities. The Na_2O contents are very high (normative nepheline) and suggest a possible secondary sodic enrichment because of the zeolites that appear in place of plagioclases. Lastly a prehnitized sample (Table 1, Analysis number 19) has an abnormal CaO content.

Thus the amphibolites of Hole 569A may correspond to tholeiitic basalts metamorphosed to the amphibolite facies. They give evidence of low-temperature retrograde metamorphism with sodic or calcic enrichment.

Clinopyroxene Chemical Composition: A Comparison

The clinopyroxene chemical compositions of gabbros, dolerites, and basalts (Table 5) give detailed information about the magmatic affinities of these rocks. The chem-

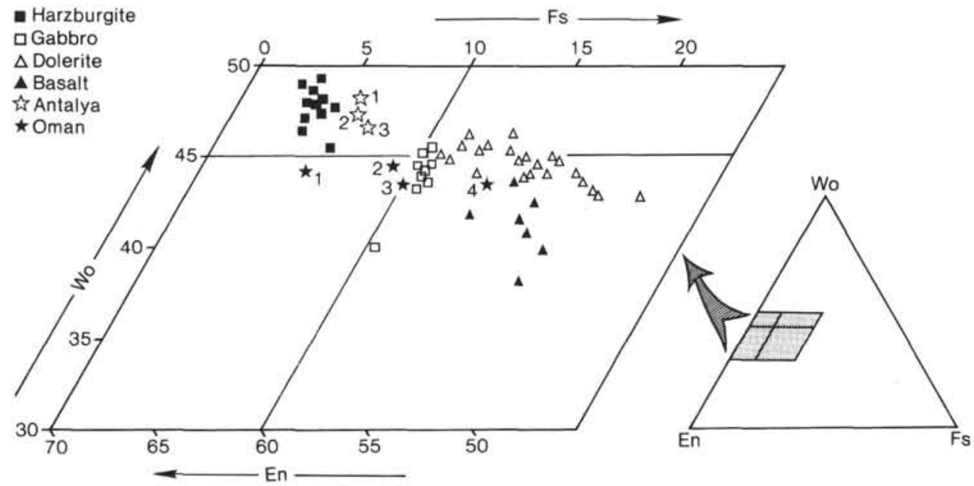

Figure 4. Clinopyroxenes of ultramafic rocks of Leg 84 in Wo-En-Fs diagram. Antalya data from Juteau and Whitechurch (1980); average composition of (1) ultramafic cumulates, (2) clinopyroxenes, and (3) gabbros. Oman data from Pallister and Hopson (1981); average composition of (1, 2) ultramafic cumulates, (3) mafic cumulates, and (4) gabbros and dolerites.

ical character of the pyroxenes is shown in the Wo-En-Fs diagram (Fig. 4). The gabbros, dolerites, and basalts of Leg 84 have distinct clinopyroxenes. The clinopyroxenes of the gabbros are diopsides. The clinopyroxenes of the basalts have low Ca- and high Fe- content augites. The clinopyroxenes of the dolerites are high-Ca augites. This provides evidence for the tholeiitic affinities of the gabbros and basalts and the alkaline character of some dolerites.

According to Leterrier et al. (1982), the Ni and Cr content of clinopyroxenes in rocks can be used to characterize their magmatic affinities and geodynamic context: (1) they may be alkaline or nonalkaline rocks (Ti versus Ca + Na; Fig. 5A); (2) nonalkaline rocks are divided into orogenic and nonorogenic rocks (Ti + Cr versus Ca; Fig. 5B); (3) orogenic rocks may be of calk-alkaline or tholeiitic affinity (Ti versus Al; Fig. 5C).

CONCLUSION

Igneous basement from Leg 84 drill sites was found to consist of mafic and ultramafic rocks: basalts, dolerites, gabbros, and peridotites, as well as rocks of amphibolite facies metamorphic grade (569). The serpentinized harzburgites have mineralogical and chemical compositions similar to those of the tectonic harzburgites more often described in the ophiolitic complexes. However, the petrofabrics of the Leg 84 harzburgites reveals slight deformation. The cumulative texture of peridotites from Site 570 could be associated with the basal part of a layered igneous mass. Thus these ultramafic cumulates may be linked to the same ophiolitic complex as the harzburgites. The gabbros may have a similar origin, as evidenced by their magmatic layering, their weak Fe and Ti contents, and their lack of opaque minerals.

The dolerites and the basalts differ in chemical composition from the gabbros. The Fe and Ti contents and the mineralogical evolution of the clinopyroxenes and plagioclases are particularly different. Thus it is not possible to conclude much about the magmatic affiliation of the mafic and ultramafic rocks of Leg 84.

However, there are similarities between the chemical compositions of the dolerites and basalts of Oman and Leg 84 (Fig. 4). The dolerites and basalts of Leg 84 could thus be a sheeted complex associated with the ophiolites in a more developed geodynamic context as in Oman.

Metamorphic rocks consisting of retrograde metamorphosed amphibolites were recovered from the basement of Hole 569A. The rocks are of basaltic chemical composition and have been subjected to high-temperature metamorphism (amphibolite facies). Amphibolites are sometimes found associated with ophiolitic complexes as a tectonic sole under the ophiolitic rocks (Parrot, Whitechurch, 1978) or inside the ophiolitic complex (Malpas et al., 1973; Bourgois, Calle, et al., 1982; Girardeau and Mevel, 1982). Thus the basement rock of the landward slope of the Middle America Trench off Guatemala could be a disrupted ophiolitic complex.

Such ophiolites crop out on land in Central America. They are linked to the Polochic-Motagua zone (Bertrand and Vuagnat, 1975, 1976, and 1977) of Guatemala and crop out in the Santa Elena Peninsula of Costa Rica. These two outcrops of mafic and ultramafic rocks (Harrison, 1953; Dengo, 1962 and 1973; Butterlin, 1977; Weyl, 1980; Kuijpers, 1980; Azéma and Tournon, 1980, and 1982; Bourgois, Azéma, et al., 1982; Aubouin, Azéma, et al., 1982) have the following similarities with the drilled basement of the landward slope of the Middle America Trench off Guatemala: the major component is harzburgite; the plutonic material includes ultramafic cumulates and layered gabbros; there are dolerites and amphibolites; and the lower Eocene–Upper Cretaceous sediments overly the ophiolites. So ages and petrographic and chemical compositions do not discriminate between these ophiolites. Only their structural positions give discriminating evidence (Azéma et al., this volume; Aubouin et al., this volume). The Santa Elena and Leg 84 ophiolites

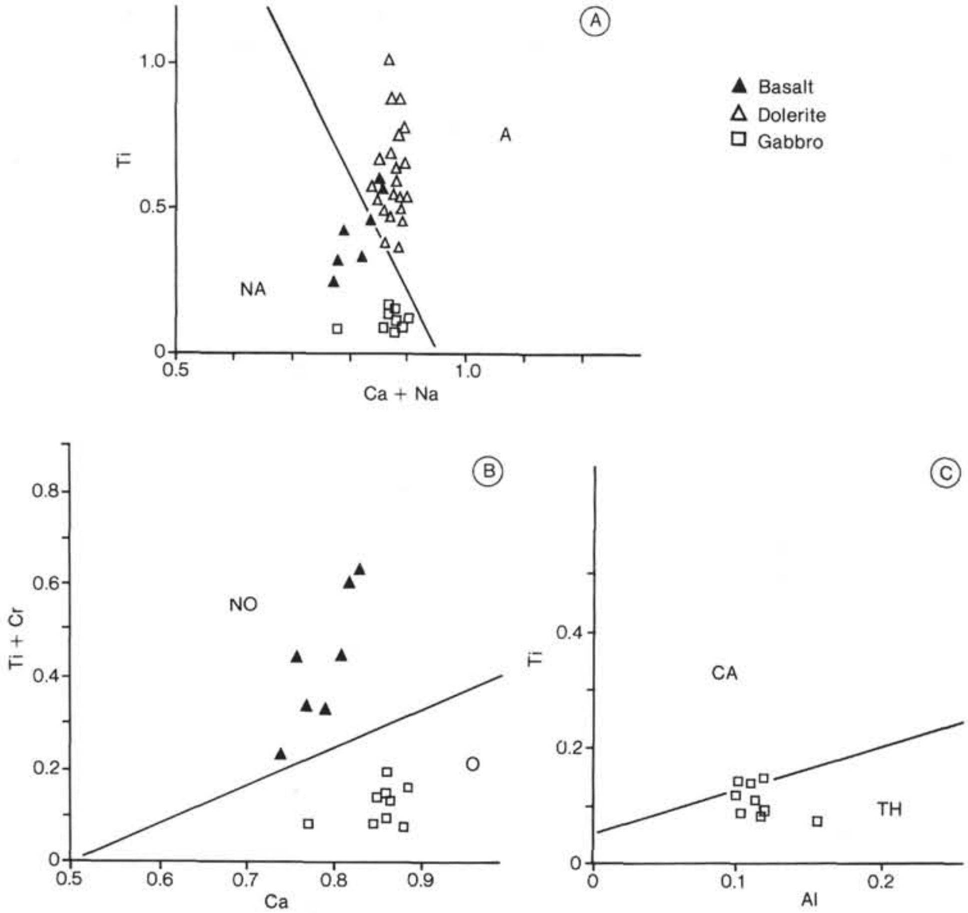

Figure 5. Clinopyroxene chemical compositions of basalts, gabbros, and dolerites of Leg 84 in Leterrier et al. (1982) diagrams. A. Alkaline field (A); non-alkaline field (NA); B. orogenic field (O); nonorogenic field (NO); C. calc-alkaline field (CA); tholeiitic field (TH).

are south of a cratonic shield that crops out in Guatemala and Honduras. The Polochic-Motagua ophiolites are north of this shield.

On the other hand, the major structural feature of Santa Elena ophiolites of Costa Rica is their overthrusting southward (Azéma and Tournon, 1980, 1982; Bourgois, Azéma, et al., 1982) onto the radiolarites of Matapalo unit (Azéma et al., this volume). The N90°E to N120°E trend of the Santa Elena ophiolites leads us to propose that they are involved, together with the Leg 84 rocks South of Honduras shield, in the same pre-Late Cretaceous orogen. We therefore suggest after Aubouin, Bourgois, et al. (1984) that Leg 84 ophiolites of Guatemala are the offshore equivalent of the Santa Elena ophiolites of Costa Rica.

ACKNOWLEDGMENT

The authors have greatly profited from the extensive discussions of Roland von Huene who made helpful comments on a draft of the manuscript. We also thank Miriam Baltuck, Sherman Bloomer, and Thomas W. Donnelly for their thoughtful and thorough reviews. Helpful technical guidance was provided by Jean Barandon and Oscar Sancini during microprobe analysis.

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Date of Initial Receipt: 15 July 1983
Date of Acceptance: 6 February 1984