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PRELIMINARY DATA ON THE PINETO GABBROIC MASSIF AND NEBBIO BASALTS: PROGRESS TOWARD THE GEOCHEMICAL CHARACTERIZATION OF ALPINE CORSICA OPHIOLITES

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ABSTRACT

The Pineto Massif and Nebbio ophiolitic sequences represent two main examples of Corsican ophiolites that, similarly to the well-known Balagne Nappe, have not undergone high pressure-low temperature alpine metamorphism. For this reason these sequences have been so far referred to the Balagne-type ophiolites.

The Pineto Massif is composed of a cumulitic intrusive sequence consisting of layered troctolites, dunites, gabbros, and anorthosites cross cut by basaltic dykes. The chemical composition of both cumulates and dykes reveal an oceanic tholeiitic affinity. In particular, the Pineto Massif basaltic dykes have REE patterns similar to those of N-MORBs with slight LREE/HREE depletion, as also evidenced by low Ce_N/Yb_N (0.9-1.2) ratios.

The Nebbio ophiolitic sequence consists of pillow and massive lava flow basalts capped by cherts, Calpionella limestones, and Cretaceous siliciclastic formations. Chemically, the Nebbio basalts are similar to ocean-floor basalts. They are characterized by LREE enrichment with respect to HREE, as evidenced by the Ce_N/Yb_N (1.2-1.9) ratios. Their REE patterns are similar to those shown by T-MORBs.

Geochemical data show that the Pineto Massif ophiolites are different from the Balagne Nappe T-MOR basalts, suggesting that any correlation between the Pineto Massif ophiolites and the Balagne Nappe should be ruled out. By contrast, they highlight close analogies between the Pineto Massif and the Internal Ligurides ophiolites from the Northern Apennine, suggesting that both these ophiolites represent fragments of the Piedmont-Ligurian oceanic lithosphere located in an internal oceanic position, relatively far from the continental margins.

Conversely, the Nebbio basalts show striking geochemical similarities to those of the Balagne, further supporting the hypothesis that both the Balagne and Nebbio ophiolites could represent fragments of oceanic crust generated in the early stages of the Piedmont-Ligurian basin oceanization.

INTRODUCTION

The Alpine Corsica ophiolites represent the westernmost remnants of the Jurassic oceanic lithosphere of the Piedmont-Ligurian basin, which developed between the Adria microplate and the Corsica-Sardinia Massif (European Plate). The typical ophiolitic sequence (Abbate et al., 1980) includes mantle ultramafics intruded by a Middle-Late Jurassic (Bigazzi et al., 1973; Ohnenstetter et al., 1981) gabbroic complex and covered by MORB basalts and tectono-sedimentary ophiolitic breccias. The related sedimentary cover includes pelagic, trench and lower slope sediments, ranging in age from Late Jurassic to Paleocene (Marroni et al., 1992).

The closure of this oceanic basin, occurred from Late Cretaceous to Late Eocene-Early Oligocene, resulted from convergence and collision between the Adria and European continental plates and led to a complex tectonic overlap of several ophiolitic units in Alpine Corsica (Gibbons et al., 1986), as well as in the Western Alps and Northern Apennine belts (Abbate et al., 1989; Bortolotti et al., 1990).

Corsican ophiolites have been classically subdivided in two types:

a) the Balagne-type sequences, which are affected by ocean-floor metamorphism (Beccaluva et al., 1977). In the Balagne area, basalts are characterized by transitional mid-ocean ridge (T-MOR) geochemical affinity (Venturelli et al., 1979; Durand-Delga et al., 1997);
b) the "Schistes Lustrés"-type sequences, which are affected by high pressure-low temperature (HP-LT) alpine metamorphism overprinting a former ocean-floor metamorphism (Ohnenstetter et al., 1976). In the Inzecca and Cape Corse areas the "Schistes Lustrés" ophiolitic sequences display normal-MORB (N-MORB) geochemical affinity (Beccaluva et al., 1977; Venturelli et al., 1981).

In the past decades, the HP-LT metamorphism/N-MORB affinity, and lack of HP-LT metamorphism/T-MORB affinity pairings have been assumed as the main distinguishing feature of Corsican ophiolites. Although the Alpine evolution of Corsica has experienced contrasting theories (e.g. Mattauer and Proust, 1976; Warburton, 1986; Principi and Treves, 1984; Malavielle et al., 1998; Jolivet et al., 1998; Lahondère et al., 1999), most of the paleogeographic and geodynamic interpretations have been largely influenced by the two observed metamorphism/magmatic affinity correlations. However, Saccani and Padoa (1999) have recently identified in the Rio Magno Unit (South-east Alpine Corsica) a possible third type of Corsican ophiolites. This ophiolitic unit is characterized by the absence of HP-LT Alpine metamorphic imprint, while the geochemical affinity of the basalts is clearly N-MORB.

For this reason, some ophiolitic sequences -commonly defined as Balagne-type exclusively on the basis of the lack of HP-LT alpine imprinting- are to be reconsidered since their attribution is not supported by suitable petrological and geochemical data.

The aim of this paper is to provide new geochemical data on the Pineto Massif and Nebbio ophiolites (central-northern Corsica) in order to improve the petrological and geochemical characterization of the Corsican ophiolitic sequences, which unaffected by HP-LT alpine metamorphism.

GEOLOGICAL SETTING AND PREVIOUS WORKS

The Balagne ophiolitic Nappe tectonically overlies the Eocenic cover of "Autochthonous" Corsica, to the west of

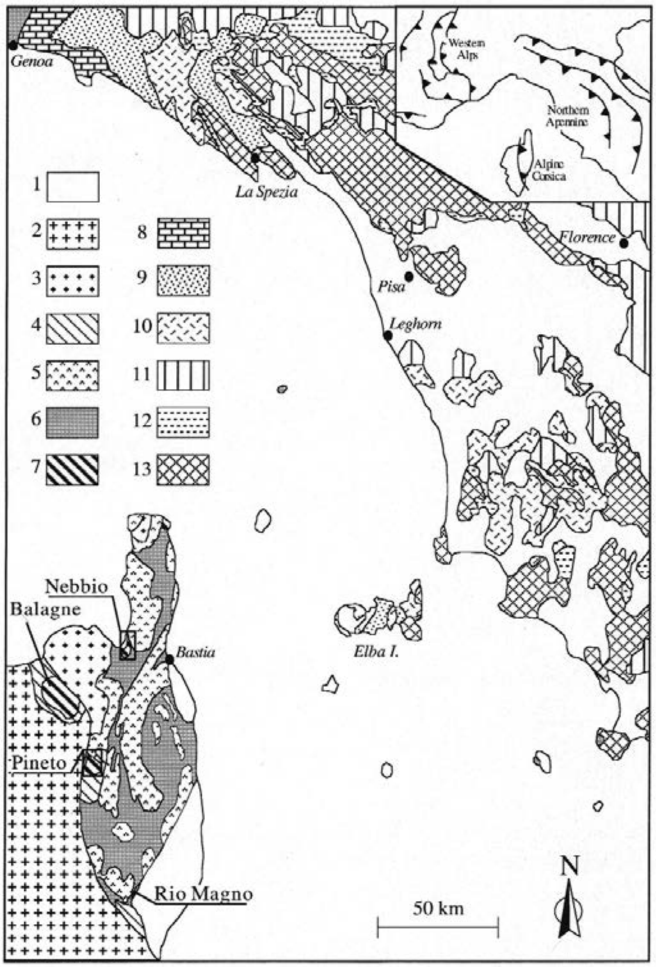

Fig. 1 - Sketch-map of Alpine Corsica and Northern Apennine, and locations of areas expanded in Figs. 2 and 3. 1. Neogene-Quaternary sedimentary and magmatic rocks. North-Eastern Corsica: 2. Autochthon Corsica (European Plate); 3. Tenda and Centuri granitoids (European Domain); 4. Piedmont, Pre-Piedmont, Para-Autochthon Domains (European paleo-margin); 5. "Schistes Lustrés" meta-sedimentary covers; 6. "Schistes Lustrés" meta-ophiolites; 7. Upper ophiolitic Units (Balagne, Nebbio, Rio Magno and Pineto). Northern Apennine: 8. Internal Ligurides (IL) Antola Unit; 9. IL siliciclastic flyschioid units; 10. IL ophiolitic units; 11. External Ligurides; 12. Subligurides units; 13. Tuscan Nappe (Adria Plate).

the Tenda Massif (Fig. 1). The ophiolitic sequence of Balagne is considered as the westernmost part (Balano-Ligurian domain) of the Jurassic Piedmont-Ligurian oceanic basin, which was located close to the European continental margin (Durand-Delga, 1984; Durand-Delga et al., 1997). This interpretation is based on both sedimentological and geochemical constraints, such as the presence of widespread continental-derived sediments in the ophiolitic covers and the T-MORB geochemical affinity of the oceanic basalts, respectively. These features are interpreted as reflecting early stages of the oceanization (Venturelli et al., 1981; Durand-Delga et al., 1997).

The Balagne Nappe is characterized by a lack of orogenic ductile deformations, as well as of HP-LT Alpine metamorphism (Beccaluva et al., 1977). Very low-grade (P<4kbar, T<350°C) orogenic metamorphic conditions have been suggested (Amaudric du Chaffaut and Saliot, 1979). The lack of HP-LT metamorphism, and associated deformations, is generally explained by the paleogeographic location of the Balagne oceanic crust close to the European continental margin, as well as the preservation of the Balagne Nappe from any implication in the deep part of the subduction zone (Principi and Treves, 1984; Durand-Delga et al., 1997; Lahondère et al., 1999).

In this geological framework the Pineto Massif, and the Nebbio ophiolites (Fig. 1), represent two ophiolitic units which have so far been considered as Balagne-type ophiolites. Consequently, a common paleo-oceanic position (i.e. Balano-Ligurian Domain), as well as a similar geodynamic evolution during alpine orogenesis, have been described for the Balagne, Nebbio, and Pineto Massif ophiolitic units.

The Pineto gabbroic Massif, located in the central-western part of Alpine Corsica (Fig. 1), crops out over an area of about 10 km^2, in the east side of the Golo River, between Francardo and Ponte Leccia. It is crossed and partly bounded by the Casaluna River (Fig. 2). The geology of the Pineto Massif has been up to now poorly constrained; its structural relationships with the surrounding units can only be deduced from the BRGM geological maps (Rossi and Rouire, 1980; Rossi et al., 1994). To the north, this massif is tectonically overlain by the serpentinite-bearing "Schistes Lustrés" Unit; to the east and south it overlays the sedimentary cover of the Corsica continental margin (Piedmont and Pre-Piedmont Domain), while its western border is covered by quaternary sediments.

The Pineto Massif is composed of a layered intrusive sequence, cross-cut by scarce dolerite dykes; this sequence consists of a layered alternation of prevailing troctolites,

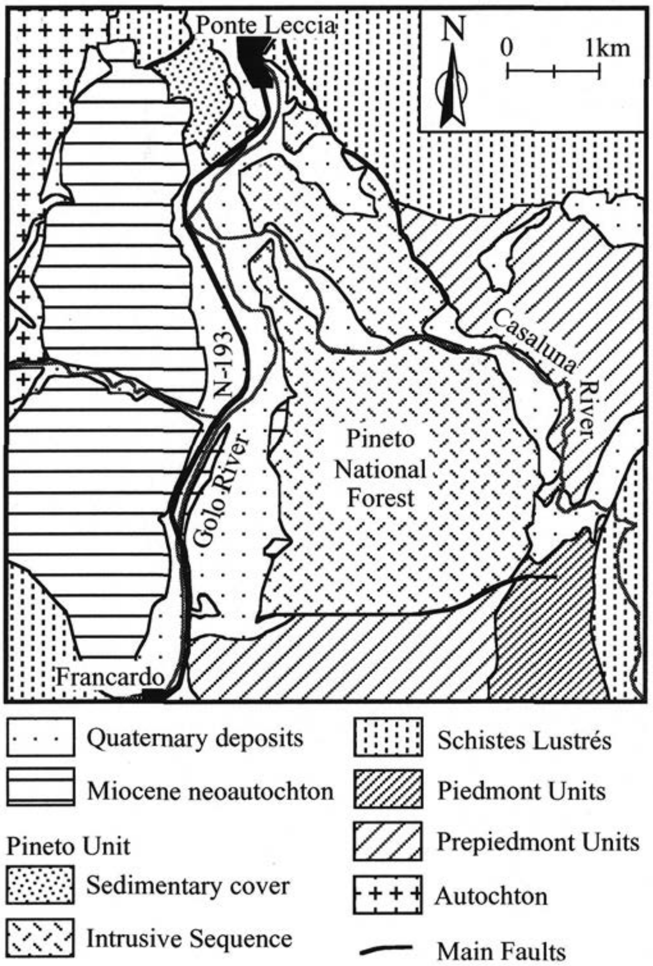

Fig. 2 - Simplified geological sketch map of the Pineto Massif (modified after Rossi et al., 1994).

subordinate euphotide and pegmatoid gabbros, and ferrogabbros (Durand-Delga, 1984). Dunitic layers and lenses are locally found.

The MOR affinity of this sequence has been recognized on the basis of major and trace element analyses (Beccaluva et al., 1977).

Finally, the Pineto Massif ophiolites are considered to be the southward prolongation of the Balagne Nappe (Rossi et al., 1994) because of their similar external tectonic position and the lack of orogenic ductile deformations. In addition, a volcanic and sedimentary succession, cropping out to the west of Ponte Leccia, is considered stratigraphically related to the Pineto intrusives and comparable to that of the Balagne (Rossi et al., 1994).

The Nebbio ophiolitic Unit crops out in the northern part of Alpine Corsica, to the east of St. Florent (Fig. 1). In this area (Fig. 3), the Nebbio ophiolitic Unit represents the uppermost tectonic unit overlaying the “Schistes Lustrés”, and is covered by the Miocenic (Burdigalian-Serravallian), unconformable deposits. Its ophiolitic sequence includes, from bottom to top: pillow and massive flow basalts, cherts, Calpionella Limestones and Cretaceous siliciclastic formations (Dallan and Puccinelli, 1995).

A similar paleogeographic location (Balano-Ligurian Domain) for the Nebbio ophiolitic Unit and the Balagne Nappe has been suggested on the bases of their similar sedimentary covers, as well as their uppermost structural position in the orogenic pile. The present-day occurrence of the Balagne and Nebbio Units (Fig. 1) at the opposite sides of the Tenda Massif is commonly attributed to a Upper Oligocene-Lower Miocene extensional tectonics (Lahondère et al., 1999 and quoted references).

ANALITICAL METHODS

A total of 32 representative samples from the Pineto Massif and Nebbio ophiolitic Unit has been selected for petrographical and chemical analysis (Tables 1-3).

Bulk rock major and trace elements (Zn, Ni, Co, Cr, V, Rb, Sr, Ba, Zr, and Y) analyses were performed on pressed powder pellets using an automated Philips PW1400 X-ray fluorescence (XRF) spectrometer. The matrix correction methods proposed by Franzini et al. (1975) and Franzini (1979) were applied. Replicate analyses were made on trace elements, indicating a precision ranging from ±1% to ±2%. Volatiles were determined as loss on ignition (LOI) at 1000°C.

Rare Earth Elements (REE), Sc, Nb, Hf, Ta, Th, and U were determined by inductively coupled plasma-mass spectrometry (ICP-MS) using a VG Elemental Plasma Quad PQ2 Plus. Accuracy and detection limits were calculated by analyzing a set of international standards, including: JP-1, JGb-1, BHVO-1, UB-N, BE-N, BR, GSR-3, and AN-G. Results are given in Table 2. All analyses were performed at the Mineralogical Institute of the University of Ferrara.

THE PINETO MASSIF

Field data, petrography, and geochemistry

The Pineto gabbroic massif represents a typical layered oceanic intrusive sequence, where the individual layers

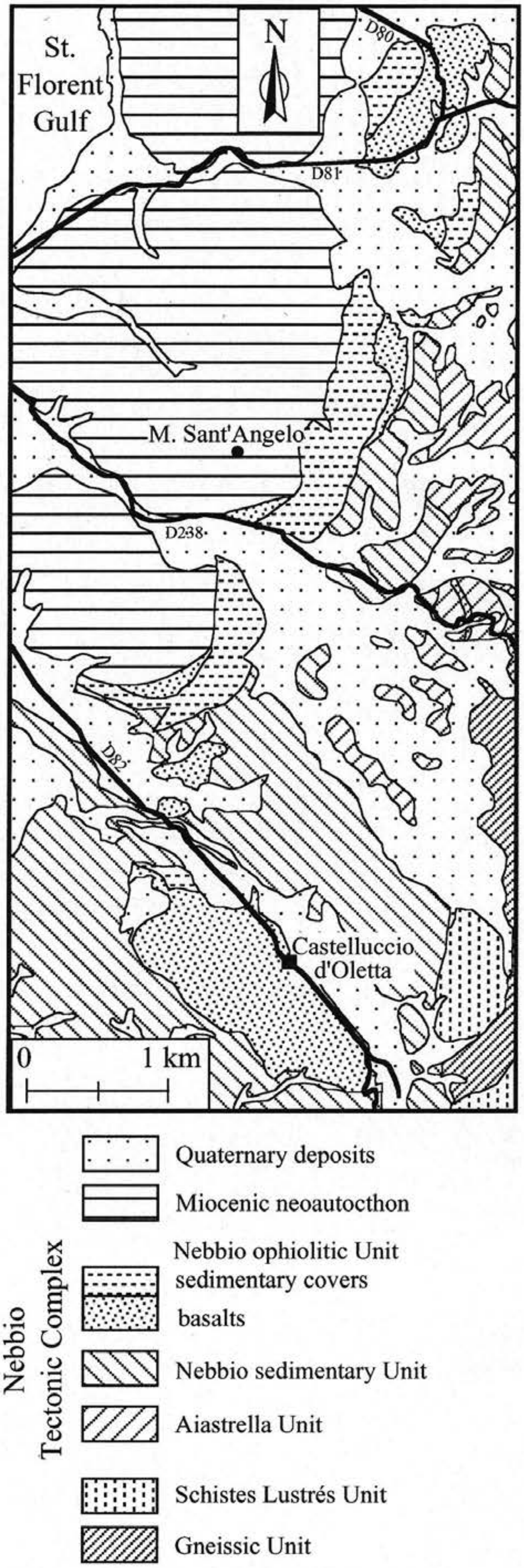

Fig. 3 - Simplified geological sketch map of the Nebbio Unit (modified after Dallan and Puccinelli, 1995).

Table 1 - XRF major (as wt%) and trace (as ppm) elements analyses of ophiolitic rocks from the Pineto Massif.

Sample	CO36P	CO49P	CO33P	CO34P	CO35P	CO39P	CO41P	CO45P	CO46P	CO47P	CO48P
Locality	Pineto	Pineto	Pineto	Pineto	Pineto	Casaluna	Casaluna	Pineto	Pineto	Pineto	Pineto
Rock	Wehr	Wehr	Troct	Troct	Troct	Troct	Troct	Troct	Troct	Troct	Troct
SiO_2	39,71	38,86	43,82	44,10	46,26	45,72	45,42	45,63	46,80	43,55	42,28
TiO_2	0,03	0,04	0,07	0,04	0,02	0,05	0,08	0,06	0,08	0,03	0,04
Al_2O_3	1,05	1,36	22,22	21,74	23,33	22,19	21,62	23,15	22,08	20,92	21,09
Fe_2O_3			0,53	0,53	0,55	0,52	0,46	0,52	0,54	0,44	0,44
FeO	6,67	6,58	3,51	3,55	3,64	3,45	3,07	3,45	3,61	2,92	2,92
MnO	0,10	0,09	0,06	0,07	0,06	0,06	0,06	0,06	0,07	0,05	0,06
MgO	40,01	40,31	13,73	15,45	12,43	13,60	13,40	12,32	12,28	16,94	14,52
CaO	1,04	0,26	9,13	9,79	9,80	10,20	10,04	10,23	10,82	8,44	10,32
Na_2O	0,00	0,00	2,26	1,69	2,42	2,02	2,25	2,44	2,39	1,87	1,97
K_2O	0,00	0,00	0,07	0,01	0,01	0,01	0,02	0,01	0,01	0,02	0,02
P_2O_5	0,05	0,05	0,27	0,29	0,29	0,31	0,31	0,37	0,40	0,29	0,37
L.O.I.	11,35	12,46	4,33	2,74	1,20	1,87	3,26	1,76	0,93	4,53	5,97
Total	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00
Mg#	91,4	91,6	87,5	88,6	85,9	87,5	88,6	86,4	85,8	91,2	89,9
Zn	51	50	22	26	27	25	19	26	27	17	22
Ni	2063	2081	489	603	369	386	390	373	396	454	511
Co	103	106	37	44	43	40	33	39	41	38	34
Cr	2194	1875	84	529	72	388	485	125	450	75	81
V	47	37	17	18	8	20	28	15	36	8	12
Rb	3	n.d.	2	n.d.	3	2	n.d.	2	2	2	2
Sr	n.d.	n.d.	197	165	175	163	179	176	168	201	134
Ba	9	7	36	30	38	31	34	38	35	32	34
Zr	n.d.	n.d.	6	3	n.d.	n.d.	4	4	n.d.	n.d.	n.d.
Y	2	2	3	2	2	3	3	3	4	n.d.	2

Sample	CO50P	C51	CO42P	C50	C52	CO37P	CO38P	CO40P	C48	C49
Locality	Pineto	Casaluna	Casaluna	Casaluna	Casaluna	Pineto	Casaluna	Casaluna	Casaluna	Casaluna
Rock	Troct	Troct	Anort	Mic-Gb	Gb	B Dyke	B Dyke	B Dyke	B Dyke	B Dyke
SiO_2	44,54	45,58	46,94	48,61	47,42	48,52	49,61	49,52	48,98	49,03
TiO_2	0,10	0,07	0,09	0,22	1,54	1,09	1,16	1,78	1,19	1,08
Al_2O_3	21,70	23,12	28,60	18,27	14,26	16,22	16,02	15,99	16,53	15,78
Fe_2O_3	0,47	0,43	0,07	0,52	1,26	0,96	0,91	1,13	1,01	0,85
FeO	3,16	2,89	0,48	3,47	8,43	6,41	6,04	7,53	6,73	5,67
MnO	0,06	0,05	0,02	0,08	0,15	0,11	0,10	0,11	0,13	0,08
MgO	13,93	12,11	1,54	12,07	7,14	10,84	10,23	8,68	9,32	11,31
CaO	10,12	10,11	13,15	13,11	10,53	10,71	10,04	8,45	10,25	9,86
Na_2O	2,08	2,33	4,49	2,04	3,76	3,04	3,46	4,32	3,54	3,31
K_2O	0,01	0,02	0,09	0,01	0,35	0,03	0,03	0,02	0,03	0,04
P_2O_5	0,34	0,36	0,44	0,47	0,44	0,38	0,36	0,33	0,40	0,39
L.O.I.	3,49	2,94	4,09	1,12	4,71	1,68	2,05	2,12	1,88	2,60
Total	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00
Mg#	88,7	88,2	85,1	86,1	60,1	75,1	75,1	67,2	71,2	78,0
Zn	26	23	n.d.	17	82	20	26	54	41	9
Ni	443	337	28	250	121	198	171	134	146	176
Co	36	29	3	31	37	36	31	34	33	36
Cr	504	87	60	747	217	314	334	182	327	358
V	31	16	23	108	246	185	201	274	198	205
Rb	n.d.	2	n.d.	2	7	3	n.d.	n.d.	2	n.d.
Sr	159	188	254	121	174	197	260	234	201	284
Ba	35	26	40	37	33	40	21	23	31	30
Zr	6	n.d.	4	8	175	117	128	185	130	123
Y	4	2	3	8	31	23	25	38	25	23

Detection limits for trace elements analyses range from 2 to 4 ppm. Abbreviations: Wehr = wehrlite; Troct = troctolite; Mic-Gb = micro gabbro; Gb = gabbro; B = basalt; Mg# = molar proprtion of 100*MgO/(MgO+FeO); n.d. = not detected.

Table 2 - ICP-MS REE, Sc, Nb, Hf, Ta, Th, and U analyses (as ppm) of selected samples from the Nebbio and Pineto Massif ophiolites.

	PINETO MASSIF					NEBBIO UNIT			
Sample	CO37P	CO38P	CO40P	C48	C49	CO1N	CO4N	CO10N	CO11N
Loc	Pineto	Casaluna	Casaluna	Casaluna	Casaluna	Oletta	Oletta	S.Florent	S.Florent
Rock	Bas Dyke	Bas Dyke	Bas Dyke	Bas Dyke	Bas Dyke	Bas MLF	Bas MLF	Bas Pillow	Bas Pillow
Sc	109	115	165	72.1	74.5	82.0	118	140	89.2
Nb	1.07	1.13	1.63	1.08	1.07	5.03	4.07	4.56	5.87
La	2.65	2.93	4.14	2.58	2.48	9.14	6.74	7.38	10.2
Ce	8.67	9.69	14.0	8.43	7.88	26.3	18.5	21.5	27.6
Pr	1.57	1.71	2.49	1.46	1.36	4.25	3.06	3.42	4.71
Nd	8.98	9.96	14.6	8.30	7.54	21.7	17.3	18.8	24.1
Sm	2.98	3.30	5.06	2.54	2.35	5.96	5.34	5.73	6.44
Eu	1.20	1.29	1.59	0.961	0.899	1.95	1.92	1.94	2.23
Gd	3.89	4.08	6.20	2.90	2.83	6.67	7.39	7.40	7.29
Tb	0.710	0.741	1.11	0.566	0.571	1.24	1.27	1.26	1.36
Dy	4.95	5.17	7.59	3.50	3.65	7.49	8.43	8.51	8.04
Ho	0.987	1.02	1.53	0.718	0.722	1.49	1.67	1.70	1.58
Er	3.02	3.04	4.73	2.01	2.06	4.11	5.12	5.02	4.41
Tm	0.383	0.411	0.623	0.323	0.312	0.641	0.630	0.648	0.689
Yb	2.70	2.84	4.48	1.98	1.97	3.90	4.27	4.44	4.15
Lu	0.383	0.405	0.620	0.267	0.278	0.534	0.589	0.617	0.558
Hf	2.17	2.33	3.87	1.48	1.29	3.60	4.77	4.47	3.82
Ta	0.941	0.335	0.270	0.212	0.182	0.730	0.613	0.597	0.583
Th	0.080	0.079	0.115	0.081	0.053	0.447	0.433	0.379	0.516
U	0.011	0.017	0.038	0.019	0.009	0.141	0.218	0.131	0.160
Ce_N/Sm_N	0.73	0.74	0.69	0.83	0.84	1.10	0.87	0.94	1.07
Ce_N/Yb_N	0.89	0.95	0.87	1.18	1.11	1.87	1.21	1.35	1.85
La_N/Yb_N	0.70	0.74	0.66	0.93	0.90	1.68	1.13	1.19	1.77

Normalizing values after Sun and McDonough (1989). Detection limits are (in ppm): Sc = 0.29; Y, Nb, Hf, Ta = 0.02; REE <0.14; Th, U = 0.011. Accuracy for analyzed elements is in the range of 0.9-7.9 relative %, with the exception of Gd (10.2 relative %).

Table 3 - XRF major (as wt%) and trace (as ppm) elements analyses of basaltic rocks from the Nebbio ophiolitic Unit.

Sample	CO1N	CO2N	CO3N	CO4N	CO5N	CO6N	CO7N	CO8N	CO9N	CO10N	CO11N
Locality	Oletta	Oletta	Oletta	Oletta	Oletta	Oletta	Oletta	S.Florent	S.Florent	S.Florent	S.Florent
Rock	MLF	MLF	MLF	MLF	Pillow	Pillow	MLF	MLF	Pillow	Pillow	Pillow
SiO2	49,87	48,89	49,89	52,29	54,20	51,71	49,57	48,14	48,15	49,10	49,09
TiO2	2,12	2,05	2,22	2,10	1,88	1,91	1,80	1,77	1,61	1,87	2,33
Al2O3	15,81	16,08	16,17	16,52	14,72	14,87	17,54	16,87	17,23	16,88	17,25
Fe2O3	1,26	1,17	1,23	1,05	0,88	0,97	1,06	1,11	1,16	1,09	1,27
FeO	8,38	7,81	8,19	7,00	5,87	6,45	7,09	7,38	7,70	7,25	8,45
MnO	0,13	0,14	0,14	0,14	0,14	0,14	0,12	0,15	0,13	0,14	0,17
MgO	7,35	6,43	6,72	4,66	5,72	9,81	6,89	9,28	8,97	8,33	5,90
CaO	6,81	7,96	7,01	7,10	8,88	5,82	7,68	7,12	6,92	6,69	6,78
Na2O	5,39	5,26	5,43	6,49	6,25	5,22	5,33	4,19	4,09	4,34	4,78
K2O	0,13	0,05	0,08	0,05	0,03	0,03	0,06	0,36	0,55	0,83	0,41
P2O5	0,36	0,39	0,39	0,31	0,44	0,29	0,41	0,39	0,30	0,35	0,36
L.O.I.	2,40	3,76	2,53	2,29	1,00	2,76	2,46	3,23	3,19	3,13	3,23
Total	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00	100,00
Mg#	61,01	59,49	59,39	54,24	63,45	73,04	63,40	69,14	67,48	67,20	55,44
Zn	87	83	87	65	65	89	64	75	77	80	128
Ni	66	64	67	100	45	40	61	84	140	82	32
Co	30	29	31	39	17	24	25	34	35	30	27
Cr	135	134	137	190	114	95	107	185	219	164	121
V	253	247	260	262	224	251	220	228	182	244	284
Rb	n.d.	n.d.	3	n.d.	n.d.	2	n.d.	5	11	10	12
Sr	273	282	388	118	277	157	291	233	292	261	160
Ba	42	34	37	41	30	38	32	49	39	38	36
Zr	322	316	334	281	287	274	272	266	231	274	311
Y	47	43	46	46	38	34	38	40	38	42	48

Detection limits for trace elements analyses range from 2 to 4 ppm. Abbreviations: Bas = basalt; MLF = massive lava flow; Mg# = molar proportion of 100*MgO/(MgO+FeO); n.d. = not detected.

consist of troctolite largely prevailing over olivine gabbros and gabbros of various modal composition. The thickness of layers is extremely variable, ranging from 20 to 400 cm. Layering is marked either by sharp or gradational transition. As can be observed in Fig. 4, gradation can be recognized on most of the outcrops as a broad decrease of the colour index (i.e. olivine and/or clinopyroxene contents). Compositionally, the layers grade from troctolite (colour index 40-50), to leucocratic troctolite and gabbro (colour index of 25-30), occasionally to anorthosite. A large-scale (about 20-30 m) cyclicity can be sporadically observed. Moreover, the layering is also evidenced by euphotide and pegmathoid layers and lenses, where crystals may reach up to 10 cm in size. Isotropic gabbros are very rarely found.

Ultramafic cumulates are rare; they mostly consist of serpentinized dunite and wehrlite, both containing variable amounts (0-8%) of modal plagioclase, and usually occur as layers and lenses 30-100cm in thickness. In places, dunite lenses, up to 30m in thickness, are cross-cut by troctolite and gabbro dykes (about 40cm), characterized by euphotide cores and diminishing crystal-size towards the margins (Fig. 5).

Diabase dykes, up to 1m thick, locally cross-cut the cumulate sequence almost normally to the layering.

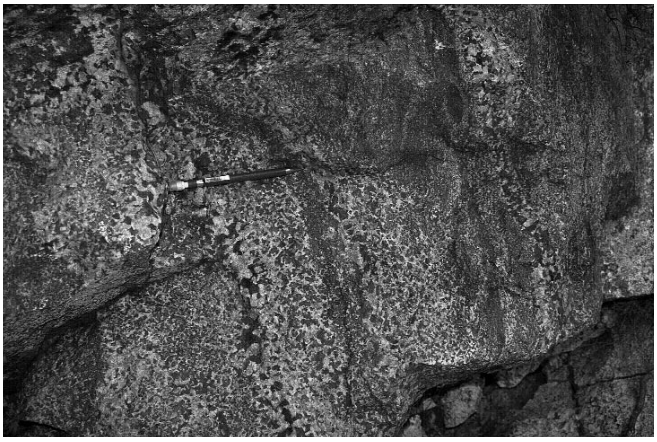

Fig. 4 Close-up of layering in troctolite from the Pineto Massif.

Fig. 5 - Troctolite dyke cross-cutting an ultramafic cumulate layer in the Pineto Massif.

The average apparent thickness of the intrusive cumulitic sequence is estimated to be about 700-800 m.

In spite of their relatively simple mineral composition the cumulate rocks show a great variation in texture and grain-size. The mineral assemblage of the cumulate troctolites comprises plagioclase and olivine as major constituents (Plate 1A). Small amounts (usually less than 5%) of clinopyroxene, showing poikilitic intercumulus texture, are observed in some troctolites (Plate 1B). Plagioclase always occurs as large euhedral cumulus grains; it is poorly zoned, generally fresh, and rarely, moderately altered to prehnite. Olivine is observed either as cumulus or intercumulus phases. Cumulus olivine, forming large grains (about 1.5-2cm), is sporadically encircled by magmatic resorption (Plate 1B). The degree of serpentinization of olivine mostly ranges from 30% to 50%. When present, clinopyroxene occurs as small anhedral intercumulus grains, usually replaced by amphibole and/or chlorite.

Fine-grained (1-5mm) isotropic gabbros display an-

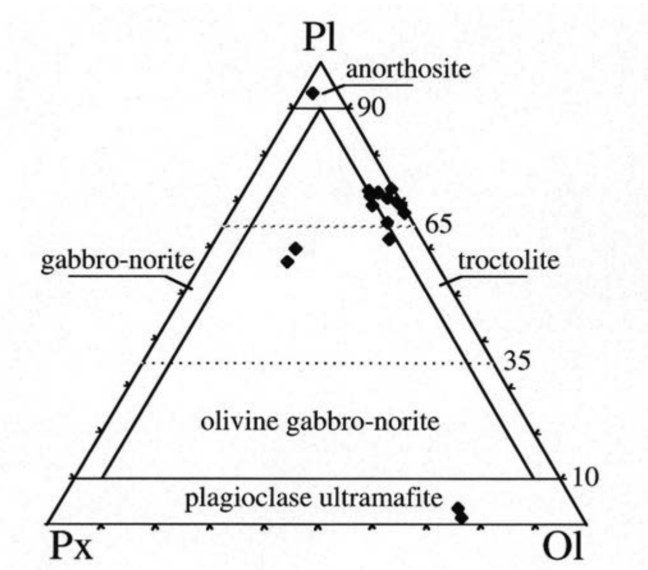

Fig. 6 - CIPW normative composition of mafic cumulates from the Pineto Massif. Pl = plagioclase, Ol = olivine, Px = pyroxene.

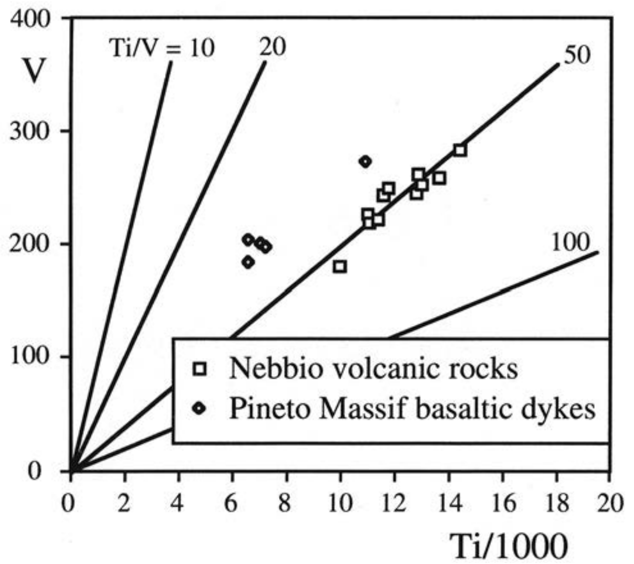

Fig. 7 - Ti/1000 vs. V discriminant diagram (Shervais, 1982) for analysed basaltic rocks. MORB compositional field between Ti/V=20 and Ti/V=50.

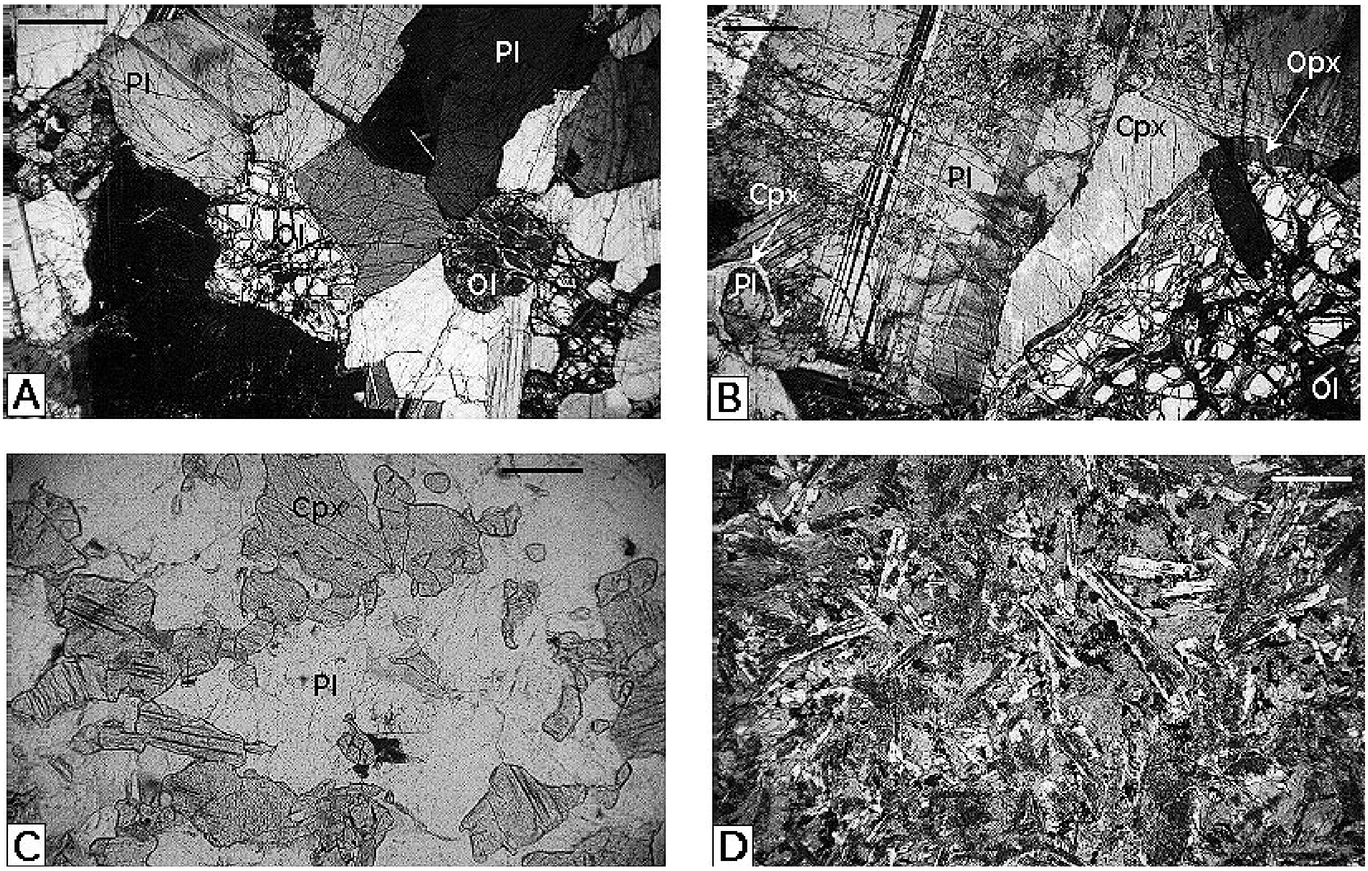

Plate 1 - Thin section photomicrographs for representative Pineto Massif rock types: A- typical texture and mineral assemblage of troctolite (crossed polars); B- orthopyroxene reaction rims around olivine and interstitial anhedral clinopyroxene grains in troctolite (crossed polars); C- granular texture of gabbro (plane-polarized light); D- sub-ophitic texture of basaltic dyke (crossed polars). Abbreviations: Pl = plagioclase, Ol = olivine, Opx = orthopyroxene, Cpx = clinopyroxene. Scale bar length = 0.5mm.

hedral-granular texture, testifying the simultaneous crystallization of plagioclase and clinopyroxene under cotectic conditions (Plate 1C). Compositional zoning of plagioclase is generally more marked than in troctolites.

The Pineto intrusive rocks define a trend from troctolite to anorthosite-wehrlite-gabbro, suggesting that plagioclase preceded pyroxene crystallisation. The observed crystallisation order is thus that of the typical MORB sequence, i.e. olivine → plagioclase → pyroxene.

Dolerite dykes show very uniform texture. They are characterized by moderately porphyritic texture, with small (about 5mm) plagioclase phenocrysts settled in a medium-grained, ophitic to sub-ophitic groundmass (Plate 1D). Their mineral assemblage includes plagioclase, clinopyroxene and rare olivine as major constituents. Unlike their host intrusive rocks, dykes are slightly to moderately affected by ocean-floor low-temperature metamorphism which led to the replacement of plagioclase with prehnite and/or sericite, clinopyroxene with amphibole and/or chlorite, and olivine with an admixture of chlorite and Fe-oxides.

The analyzed intrusive rocks compositionally span from plagioclase-wehrlites to troctolites, gabbros and anorthosites (Fig. 6). As shown in Table 1, troctolites are characterized by a rather uniform chemical composition. In particular, Al_2O_3 and MgO vary respectively from 20.92wt% to 23.33wt% and from 12.11wt% to 16.94wt%. Mg# [100*MgO/(MgO+FeO)] is in the 91.2-85.8 range, reflecting the rather primitive character of these rocks.

Basaltic dykes cross-cutting the intrusive sequence are relatively uniform in composition (Tables 1 and 2), poorly fractionated and exhibit a moderate range of fractionation (Mg# = 78-67.2). Among major elements, TiO_2 (1.08wt%-1.78 wt%), Al_2O_3 (15.78 wt%-16.53 wt%), MgO (8.68 wt%-11.31 wt%), and P_2O_5 (0.33 wt%-0.40 wt%) display generally high contents relative to MORB compositions.

The primary tholeiitic character and oceanic affinity of Corsican ophiolites has been adequately proved (Ohnenstetter et al., 1976; Beccaluva et al., 1977; Venturelli et al., 1979; Venturelli et al., 1981). The ocean-floor affinity of the Pineto dykes is confirmed in the discriminative Ti/1000 vs. V diagram of Fig. 7 proposed by Shervais (1982).

The incompatible element diagram of Fig. 8a shows that high field strength elements (HFSE), such as P, Zr, Ti, and Y, display a MORB pattern, although P and Zr appear to be slightly enriched, probably due to the early crystallization of apatite and zircon. By contrast, low field strength elements (LFSE) show pronounced variations, reflecting the clear influence of oceanic hydrothermal alteration on their concentrations. Ti/Zr ratios for the Pineto Massif dykes vary from 55 to 59.

The chondrite-normalized REE patterns of the Pineto Massif basaltic dykes are similar to those of N-MORBs (Fig. 9a), with enrichment factors for LREE spanning from 10 to 30 x chondrite. Low Ce_N/Sm_N (0.7-0.8) and Ce_N/Yb_N (0.9-1.2) ratios also evidence this analogy. The slightly negative anomaly in Eu displayed by the more evolved samples (e.g. CO40P) is consistent with the accumulation of plagioclase observed in the intrusive sequence.

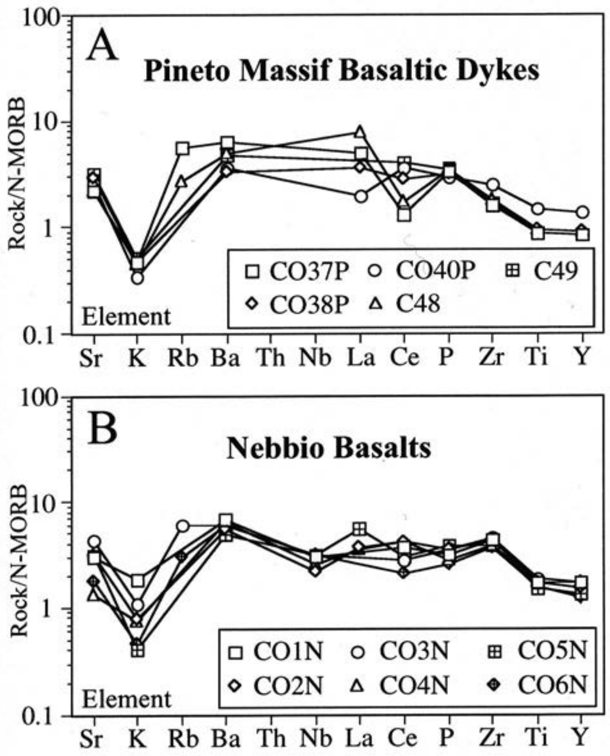

Fig. 8 - Representative trace element patterns normalized to the N-MORB composition (Sun and McDonough, 1989) for Pineto Massif (A) and Nebbio (B) ophiolites.

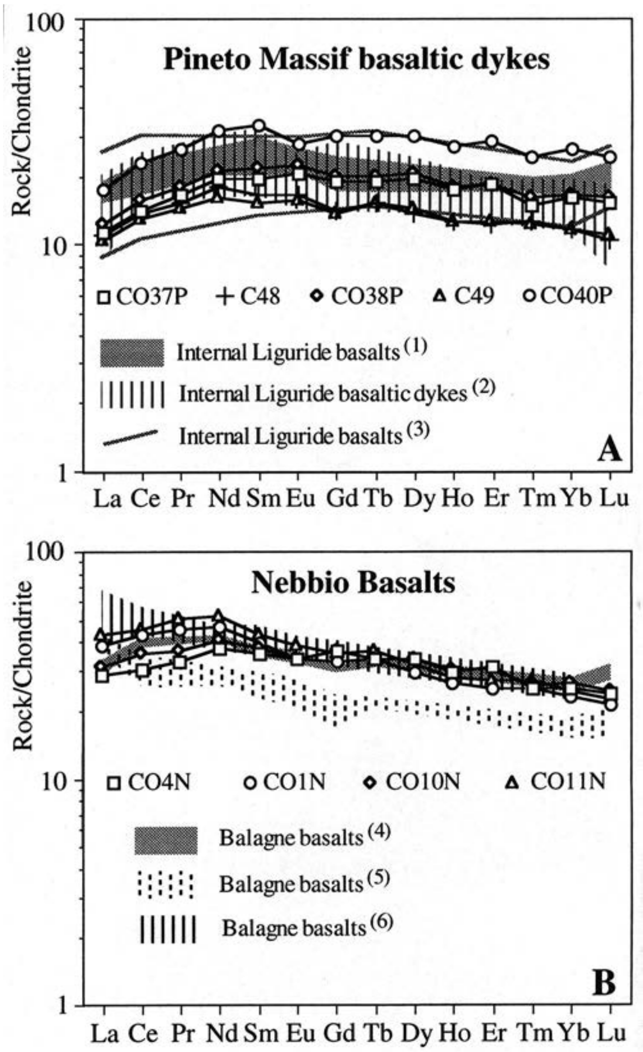

Fig. 9 - REE patterns for selected Pineto Massif ophiolitic rocks (A) and Nebbio basalts (B) normalized to the C1 chondrite composition (Sun and McDonough, 1989). Patterns for Northern Apennine Internal Ligurides and Corsica Balagne basaltic rocks are also reported for comparison. Data source: 1. Venturelli et al. (1981); 2. Cortesogno and Gaggero (1992); 3. Ottonello et al. (1984); 4. Venturelli et al. (1979), samples CS61-62; 5. Venturelli et al. (1979), samples CS50-51-55-58; 6. Durand-Delga et al. (1997).

THE NEBBIO UNIT

Petrography and geochemistry

The magmatic ophiolitic rocks in the Nebbio Unit are exclusively represented by basaltic lavas consisting of pillowed and massive lava flows. The latter are most clearly exposed in the southernmost outcrops (Fig. 3). The thickness of the whole basaltic sequence could be estimated as about 150 m.

The most frequent texture in massive lava flows is porphyritic, with ophitic to sub-ophitic coarse-grained groundmass. Phenocrysts are scarce (on average, less than 10%) and are exclusively represented by plagioclase showing singularly large grain size (up to 1 cm). Both porphyritic and aphyric textures are observed in pillow lavas; in all cases the ophitic texture prevails in the groundmass.

The mineral association mainly consists of plagioclase and clinopyroxene; Fe-, Ti- oxides are present as accessory phases. Basalts are generally deeply altered by hydrothermal metamorphic processes in the oceanic environment, and contain a varying quantity of amygdales and veins, usually filled by calcite and epidote. In most samples, plagioclase is replaced by prehnite, calcite and/or epidote, while clinopyroxene is replaced by chlorite and/or epidote. Fine-grained aggregates of secondary mineral pseudomorphs after primary olivine were found in a few samples.

The bulk chemical composition of Nebbio basalts is reported in Table 3. On the whole, they are characterized by variable degrees of fractionation (Mg# = 72-54.2), and moderate chemical variability, as shown by the TiO_2 (1.61wt%-2.33wt%), Al_2O_3 (14.72wt%-17.54wt%), MgO (4.66wt%-9.81wt%), P_2O_5 (0.29wt%-0.44wt%), Zr (231-334ppm), and Y (34-48ppm) contents. Ti/Zr ratios range from 40 to 46.

The ocean-floor affinity of the Nebbio basalts is well illustrated in the Ti/1000 vs. V diagram of Fig. 7.

The incompatible element diagram of Fig. 8b shows that the HFSE (i.e. P, Zr, Ti, and Y) display a clear MORB pattern, although Zr appears to be slightly enriched. By contrast, as observed for the Pineto Massif dykes, LFSE show pronounced variations, reflecting the influence of hydrothermal alteration on their concentrations.

An important geochemical feature displayed by the Nebbio basalts is the LREE enrichment with respect to HREE, as evidenced by the Ce_N/Sm_N (0.9-1.1) and Ce_N/Yb_N (1.2-1.9) ratios (Table 2). The chondrite-normalized REE patterns are similar to those of T-MORBs (Fig. 9b). The enrichment factors for LREE are in the range of 28-50 x chondrite, and significantly differ from those observed for the Pineto Massif basaltic rocks. No negative Eu anomaly is observed in the analyzed samples.

DISCUSSION AND CONCLUSIONS

The data presented in this paper improve the geochemical characterization of those Corsican ophiolitic sequences which have been preserved from HP-LT orogenic metamorphism, and indicate a more complex scenario than that depicted in the literature which refer these sequences to the Balagne-type ophiolites.

The Pineto Massif ophiolites show remarkable petrological and geochemical differences with respect to those of the Balagne. The main difference consists in the N-MORB characteristics of the Pineto Massif basaltic dykes, which contrasts with the T-MORB affinity shown by the Balagne basalts. This feature suggests that the Pineto sequence represents a fragment of oceanic crust which was in a more internal oceanic position with respect to that of the Balagne.

Furtherly, while the N-MORB geochemical affinity of the Pineto Massif is comparable to that of the Corsican "Schistes Lustrés" ophiolitic units, its lack of HP-LT Alpine metamorphism reflects a different structural position during the orogenic accretion of the Piedmont-Ligurian oceanic units. Actually, the HP-LT metamorphism displayed by the "Schistes Lustrés" units clearly indicates that they were involved in a deep part of a subduction complex; by contrast, the Pineto ophiolites have been preserved, during the Alpine orogenesis, from this metamorphic imprinting, probably owing to their shallow depth of underplating.

Apart from their different metamorphism, close analogies between the ophiolitic sequences of Corsican "Schistes Lustrés" and those of the Northern Apennine Internal Ligurides have already been described (Beccaluva et al., 1977; Venturelli et al., 1979; 1981; Durand-Delga, 1984). In addition, petrochemical and stratigraphical analogies with respect to the Internal Ligurides ophiolites have recently been described by Saccani and Padoa (1999) for the Rio Magno ophiolitic Unit, which has been interpreted as an "authentic, unmetamorphic" Apenninic-type ophiolitic unit cropping out in the south-eastern part of Alpine Corsica.

The data presented in this paper highlight a close analogy between the Pineto Massif and Internal Ligurides ophiolites (Beccaluva et al., 1980; Venturelli et al., 1981; Ottonello et al., 1984; Cortesogno and Gaggero, 1992). In Fig. 9a, the Pineto Massif samples are compared with the compositional fields of eastern Liguria basalts (Venturelli et al., 1981; Ottonello et al., 1984) and the Bracco Massif basaltic dykes (Cortesogno and Gaggero, 1992) from Internal Ligurides. Strict REE compositional similarities between the Pineto Massif and Internal Ligurides basaltic rocks can be observed; as also testified by the similar Ce_N/Sm_N and Ce_N/Yb_N ratios (Table 4). In particular, the most convincing REE compositional similarities are observed between the Pineto Massif dykes and Internal Ligurides samples studied by Venturelli et al. (1981) and Cortesogno and Gaggero (1992).

In summary, the data presented in this paper suggest that the previous attribution of the Pineto Massif ophiolitic sequence to the Balagne sequence should be excluded; instead, a close relationships between the Pineto Massif and Internal Ligurides and, to a lesser extent, the Rio Magno ophiolites is evidenced.

The Nebbio basalts show striking geochemical similarities to those of the Balagne (Venturelli et al., 1979; Durand-Delga et al., 1997), particularly for their LREE enrichment (Ce_N/Yb_N = 1.2-1.9) and REE patterns which are similar to those of T-MORBs (Fig. 9b). However, the most striking similarity can be observed with respect to samples CS61 and CS62 described by Venturelli et al. (1979), which are characterized by high REE concentrations and the lowest Ce_N/Sm_N ratios (Table 4).

Table 4 - Ce_N/Sm_N and Ce_N/Sm_N ratios for representative Corsica and Northern Apennine ophiolitic basaltic rocks.

	$(Ce/Sm)_N$	$(Ce/Yb)_N$
Pineto Massif basaltic dykes	0.7 – 0.8	0.9 – 1.2
IL basalts (E. Liguria) (1)	0.6 – 0.8	0.8 – 1.1
IL basalts (E. Liguria) (2)	0.8 – 1.1	0.9 – 1.5
IL basaltic dykes (E. Liguria) (3)	0.7 – 0.9	1.1 – 1.5
IL basalts (S. Tuscany) (4)	0.7 – 0.8	0.9 – 1.1
Inzecca metabasalts (1)	0.5 – 0.8	0.9 – 1.0
Rio Magno Unit basalts (5)	0.6 – 0.7	1.0 – 1.2
Nebbio basalts	0.9 – 1.1	1.2 – 1.9
Balagne basalts (6)	1.0 – 1.3	1.5 – 2.2
Balagne basalts (7)	0.9 – 1.3	1.5 – 2.4

Normalizing values after Sun and McDonough (1989).1: Venturelli et al. (1981); 2: Ottonello et al. (1984); 3: Cortesogno and Gaggero (1992); 4: Beccaluva (unpublished data); 5: Saccani and Padoa (1999); 6: Venturelli et al. (1979); 7: Durand-Delga et al. (1997).

According to Venturelli et al. (1981), the different REE compositional features displayed by the Balagne-type (T-MORB) and Internal Ligurides (N-MORB) basalts may reflect different mineralogical compositions, as well as different LREE/HREE ratios in their mantle sources. Contrasting results have been reached by Ottonello et al. (1984) and Vannucci et al. (1993), who concluded that N-MORB and T-MORB basalts respectively from the Internal and External Ligurides of the Northern Apennine do not represent products of different mantle source compositions. Instead, they would reflect varying degrees of partial melting of similar, slightly depleted lherzolitic mantle sources. These authors also have evidenced that the degree of partial melting is lower (few percent) in the External than in the Internal Ligurides.

The geochemical characteristics of the Pineto Massif and Nebbio basalts are consistent with both of these interpretations. The REE contents and ratios of geochemically similar elements -such as Ti/V (Fig. 7) and Ti/Zr, which are slightly influenced by fractional crystallization processes- indicate that the Nebbio basalts (Ti/V = 47-52; Ti/Zr = 40-46) and the Pineto Massif dykes (Ti/V = 32-40; Ti/Zr = 55-59) may have derived either from a different mantle source or from a similar source which underwent slightly lower degrees of partial melting.

In conclusion, the Nebbio basalts consisting of low-grade metamorphosed T-MORBs can be attributed to the Balagne-type ophiolites. By contrast, the Pineto Massif ophiolites provide further evidence of a new type of Corsica ophiolites characterized by N-MORB geochemical affinity and low-grade metamorphism without HP-LT orogenic overprinting. The Pineto Massif petrographic and geochemical characteristics suggest a strict correspondence with the Internal Ligurides ophiolites from the Northern Apennine.

The geodynamic significance of the Nebbio and Pineto Massifs ophiolites in the framework of the Corsica Alpine evolution can be preliminarily summarized as follows. The

T-MORB geochemical affinity displayed by the Nebbio basalts suggests that they represent a fragment of oceanic crust generated in the early stages of the Piedmont-Ligurian basin oceanization, and further supports the hypothesis that both the Balagne and Nebbio ophiolites shared the same paleo-oceanic position (Balano-Ligurian domain), which was located relatively close to the European continental margin (Durand-Delga et al., 1997). The lack of HP-LT Alpine metamorphism of the Nebbio ophiolitic Unit confirms that, during the orogenic phases, this unit experienced a geodynamic evolution similar to that of the Balagne Nappe. In this context, the Middle-Late Eocene emplacement of the Balagne and Nebbio ophiolitic units onto the European continental margin may have preserved them from the HP-LT metamorphism (Lahondère et al., 1999).

By contrast, the Pineto Massif ophiolites (i.e. a N-MORB, "Apenninic-type" ophiolitic unit located at the western border of Alpine Corsica) represent an atypical element in the general tectonic setting so far described. For this reason, the Pineto Massif should be taken into account in the reconstruction of the Piedmont-Ligurian ocean geodynamic evolution, as well as in an evaluation of the relationships between Alpine Corsica and Northern Apennine orogenic systems.

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