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TRANSITIONAL TO NORMAL MORB AFFINITIES IN OPHIOLITIC METABASITES FROM THE ZERMATT-SAAS, COMBIN AND ANTRONA UNITS, WESTERN ALPS: IMPLICATIONS FOR THE PALEOGEOGRAPHIC EVOLUTION OF THE WESTERN TETHYAN BASIN[1]

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ABSTRACT

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The Zermatt-Saas, Combin and Antrona ophiolite units represent tectonic fragments of the oceanic to transitional lithosphere of the upper Jurassic-lower Cretaceous Piedmont basin, a section of the Western Alpine Tethyan basin. The investigated area is located around the Monte Rosa massif between the middle Aosta valley and the Ossola valley, Italian Northwestern Alps. The Piedmont ophiolite nappe, i.e. the couple of the Zermatt-Saas and Combin juxtaposed tectonic elements, is interposed between the overlying paleo-African continental crust (the Austroalpine tectonic system of the Dent Blanche and Sesia-Lanzo nappes) and the underlying paleo-European continental crust (the Pennine Monte Rosa and St. Bernhard nappes). On the contrary, the Antrona ophiolite unit occurs at a lower structural level, and is sandwiched between the overlying Monte Rosa nappe and the underlying Comughera-Moncucco units, the 'root zone' of the St. Bernhard nappe.

Bulk rock analyses of 29 selected samples from these units demonstrate: 1– that the petrogenetic characteristics of the metabasalts and metagabbros from both the Zermatt-Saas and Combin units are strictly comparable to those of normal-MORB magmatism, and 2– that the features of the Antrona metabasalts indicate an oceanic nature for these metamorphic ophiolites with a distinct transitional-MORB affinity. This seems to reflect incipient oceanic rift conditions for the related segments of the Piedmont basin.

The available petrochemical data from the Alps, Northern Apennines, Corsica and Calabria, indicate that ophiolites with transitional-MORB affinity represent an early ocean-type magmatism. This was later confined to the external sectors of the accreting Alpine-Apennine oceanic basin, while ophiolites with normal-MORB affinity appear to be related to a subsequent well-established mantle convection in a more developed ocean-ridge system.

INTRODUCTION

It is now accepted that ophiolites represent sections of oceanic lithosphere generated by spreading processes in ocean basins (in all their evolutionary stages), leaky transform faults and transcurrent plate margins (VAN ANDEL ET AL., 1969; PERFIT, 1977), as well as in intraoceanic island arc/backarc basin systems (MIYASHIRO, 1973; PEARCE, 1975; BECCALUVA ET AL., 1979a, 1980; CRAWFORD ET AL., 1981; DESMONS & BECCALUVA, 1983).

Among ophiolite lithologies, basaltic rocks have received special consideration owing to the fact that their relative abundance of incompatible elements such as Ti, P, Zr, Nb, Y, Ba and REE allows, in many cases, a more refined identification of the original tectonic setting.

Leaving aside the low-Ti ophiolites, that are most probably related to a subduction-influenced magmatism (SUN & NESBITT, 1978, BECCALUVA ET AL., 1979a, PEARCE, 1980; SERRI, 1981), the geochemical variations within ophiolitic basalts from different complexes suggest that they may everytime be equivalent, and distinctly comparable to normal-, transitional- and enriched-types from mid-ocean ridge (MOR) or marginal basin settings (KAY & HUBBART, 1978; SAUNDERS ET AL., 1980; SUN ET AL., 1979). Particularly for the Western Mediterranean area, basalts from various high-Ti Jurassic ophiolites, although all generally comparable to MORB (BECCALUVA ET AL., 1976, 1977; FERRARA ET AL., 1976; BECCALUVA & PICCARDO, 1978, VENTURELLI ET AL.,

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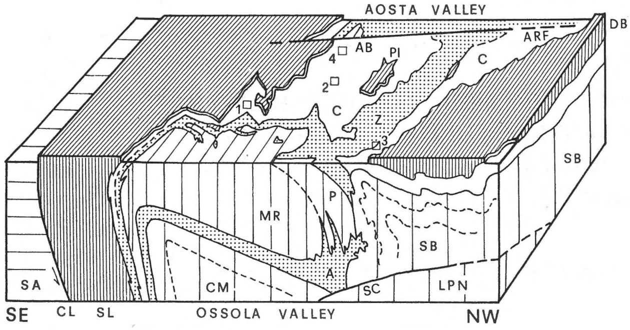

Fig. 1
Block diagram showing the Northwestern Alpine pile of nappes between the Aosta and Ossola valleys. Southern Alps (SA); Austroalpine: Dent Blanche + Mt. Mary (BD), Pillonet (PI)* and Sesia-Lanzo (SL) composite nappe system; Piedmont ophiolite nappe system: Combin composite unit (C) and underlying Zermatt-Saas unit (Z); Pennine Monte Rosa nappe (MR), including the Portjengrat element (P), and Arcesa-Brusson dome (AB); Pennine St. Bernhard nappe (SB) and internal Camughera-Moncucco units (CM); Lower Pennine nappes (LPN). Canavese line (CL), Simplon-Centovalli line (SC) and Aosta-Col di Joux-Ranzola fault (ARF). Localities: 1– Gressoney; 2– Champoluc; 3– Breuil; 4– Brusson.

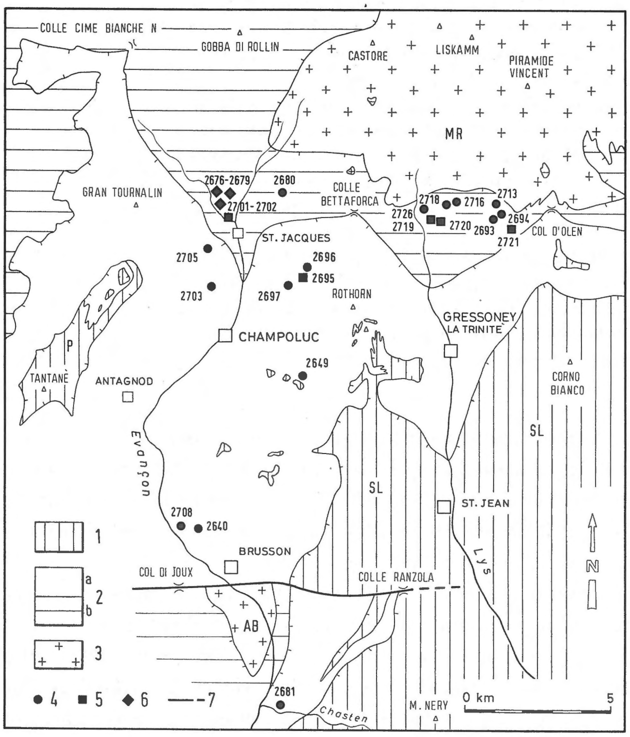

Fig. 2
Tectonic scheme of the Gressoney (Lys)-Ayas (Evançon) area, Aosta valley: 1– Austroalpine Sesia-Lanzo unit (SL) and Pillonet Klippe (P)*; 2– Piedmont ophiolite nappe: Combin (2a) and Zermatt-Saas (2b) units; 3– Pennine Monte Rosa nappe (MR) and Arcesa-Brusson dome (AB). Location of analyzed samples: 4– metabasalts; 5– coarse-grained metagabbros; 6– fine-grained eclogitic Fe-gabbros. 7– Aosta-Col di Joux-Ranzola fault.

1979, 1981, LEWIS & SMEWING, 1980), have shown such geochemical differences to suggest distinct paleogeographic provenances within the Tethyan oceanic basin (cf. BECCALUVA ET AL., 1980, and references therein).

This paper presents new petrochemical data on metabasites from three ophiolitic units of the northwestern Italian Alps which probably represented different structural settings in the Piedmont basin during upper Jurassic: the Combin composite unit, the Zermatt-Saas and the Antrona oceanic units.

The Zermatt-Saas and Combin metaophiolites considered here occur in the upper Ayas and Gressoney valleys (southwest side of the Monte Rosa massif) for which preliminary data were already published (DAL PIAZ & ERNST, 1978; DAL PIAZ ET AL., 1981). In this paper a new set of data is presented on these complexes and also on the Antrona ophiolite unit (Ossola region, east of the Monte Rosa massif) for which only four major element analyses were available (LADURON, 1976).

The new results in a sector of the Italian Western Alpine ophiolitic belt and a discussion of the available data on other Alpine and western Mediterranean ophiolites help to better understand the paleogeographic significance of such complexes with respect to incipient or more mature stages of oceanic accretion. They should also contribute to trace the mantle source evolution of the ophiolitic magmatism and, by implication, also the plate dynamics during oceanization.

GEOLOGICAL FRAMEWORK

The Zermatt-Saas, Combin and Antrona ophiolite units represent tectonic fragments of the oceanic to transitional lithosphere of the Western Alpine Tethyan basin which has been subducted, sutured and partly incorporated within the colliding paleo-African and paleo-European continental crust. The investigated area is located around the Monte Rosa massif, between the middle Aosta valley and the Antrona valley, on the right side of the Ossola valley, northwestern Italian Alps. The area exhibits the more significant and thicker section of the whole Alpine pile of nappes which comprises, from top to bottom, the following tectonic units (Fig. 1):

a) The Austroalpine tectonic system (paleo-African continental crust), including the external Dent Blanche nappe *sensu lato* and the internal Sesia-Lanzo unit.

b) The Piedmont ophiolite nappe system comprising two main subnappes, the Combin composite unit and the underlying Zermatt-Saas unit.

c) The upper Pennine Monte Rosa nappe, including the external Portjengrat element, and the Arcesa-Brusson dome, the latter exposed south of the Aosta-Col di Joux-Ranzola late-Alpine fault.

d) The Antrona ophiolite unit.

e) The middle Pennine external St. Bernhard nappe and internal Camughera-Moncucco units.

f) The lower Pennine nappes.

The Monte Rosa nappe and the underlying units, except the Antrona ophiolites, belong to the paleo-European continental crust.

The Piedmont ophiolite nappe system

The metamorphic ophiolites and the sedimentary covers of the Piedmont nappe system are widespread along the whole arc of the Western Alps, from the Ligurian sea to the Valais. In the area comprised between Aosta valley and the Valais (Figs. 1 and 2), it underlines the continent-continent collisional suture and appears to be tectonically composite (DAL PIAZ, 1965, 1974, 1976; BEARTH, 1967; ELTER, 1971; DAL PIAZ ET AL., 1972; KIENAST, 1973; CABY ET AL., 1978; DAL PIAZ & ERNST, 1978).

The structurally upper *Combin unit* exhibits a peculiar lithostratigraphic setting which partly contrasts with the present day oceanic crust, the Ligurian ophiolites of the Northern Apennines and the Zermatt-Saas unit. It consists in fact of a locally preserved pre-ophiolite basal complex which includes Permian/early Triassic clastic deposits, Triassic shelf marbles and dolostones, and Liassic calcschists and carbonaceous breccias. This latter formation indicates subsiding conditions, slope affinity and synsedimentary tectonics. The sequence is capped by a thick, ophiolite-bearing, calcschists complex which includes interbedded horizons of metabasalts derived from sills, submarine flows, hyaloclastites and possibly tuffs and/or tuffites. Some gabbro and serpentinite lenses also occur as tectonic slices and/or olistholiths.

The Combin basal complex may be interpreted as the Permian-Liassic sedimentary cover of the internal Pennine and external Austroalpine continental crust (DAL PIAZ ET AL., 1972; DAL PIAZ, 1974; CABY ET AL., 1978; DAL PIAZ & ERNST, 1978, and references therein) during the ensialic tensional processes which were active before upper Jurassic sea-floor spreading. The overlying ophiolite-bearing sedimentary sequence is considered to have a continental-transitional to oceanic affinity, and to have been deposited on the subsiding passive margins during and after the opening of the laterally juxtaposed oceanic basin.

All lithologies of the Combin unit are often homogeneously recrystallized under the greenschist facies conditions of the Lepontine tectono-metamorphic event which developed in Eocene-lower Oligocene after the emplacement of the nappes (DAL PIAZ ET AL., 1972; HUNZIKER, 1974).

A different metamorfic assemblage (almandine-rich garnet and scarce sodic amphibole relics) occurs in some of the upper sections of the unit which moreover appears to be characterized by a predominance of ophiolitic bodies, sometimes capped by peculiar sedimentary covers with pure oceanic affinity (ophiolitic sandstones, metacherts and manganiferous quartzites; DAL PIAZ ET AL., 1979). Accordingly, these sections may represent independent tectonic elements on the top of the Piedmont nappe (BALDELLI ET AL., 1983, and quoted references). A similar lithological and structural setting is well known in the Valais at the base of the Northern margin of the Dent Blanche nappe (BEARTH, 1964, 1967), and hence the Combin unit actually appears to be a tectonically composite unit at a regional scale, made up of multiple independent elements and large scale olistholiths of different paleogeographic provenance.

The structurally lower *Zermatt-Saas unit* displays, on the contrary, a classic oceanic-type ophiolite sequence. In fact in the discussed area it comprises basal serpentinized peridotite tectonites, including numerous dykes and boudins of rodingitized gabbro and basalt, discontinuous bodies of isotropic to layered metagabbros and an upper sequence of metamorphic basalt flows (sometimes pillowed), volcanic breccias and hyaloclastites (DAL PIAZ, 1965, 1974; BEARTH, 1967; DAL PIAZ & ERNST, 1978). Metabasalts and locally also metagabbro and serpentinite bodies are capped by a post-volcanic sedimentary cover with ocean-floor affinity which includes basal metacherts and Mn-rich quartzites, terrigenous micaschists and marbles (DAL PIAZ ET AL., 1979). This suggests that gabbros and serpentinites were exhumed, at least in part, on the floor of the Mesozoic Piedmont basin by a tensional-transcurrent tectonic activity probably along fracture zones.

While the Combin unit *sensu stricto* displays homogeneously distributed greenschist facies metamorphism of Lepontine age, the Zermatt-Saas unit exhibits an early-Alpine (upper Cretaceous) eclogite stage, followed by a polyphase decompressional evolution under high-temperature blueschist conditions and a late greenschist facies reequilibration of Lepontine age (DAL PIAZ ET AL., 1972; DAL PIAZ, 1974; HUNZIKER, 1974; CABY ET AL., 1978; DAL PIAZ & ERNST, 1978; ERNST & DAL PIAZ, 1978, with references).

The *Antrona unit,* also known in literature as the 'Antrona syncline', consists chiefly of basaltic massive to pillowed lavas converted by the polyphase Alpine tectono-metamorphic events into homogeneous and banded amphibolite or prasinite. Moreover, it also contains some strongly deformed and reequilibrated metagabbro and serpentinite bodies, including rodingitic dikes. Thin beds of quartzites, marbles and calcschists suggest the occurrence of an original post-volcanic sedimentary cover, now transposed within the ophiolite sequence by the Alpine deformations.

The metamorphic history of the Antrona units closely resembles that of the Zermatt-Saas unit. In fact it exhibits an early-Alpine eclogite stage, locally still preserved on the mesoscopic or microscopic scale, and a pervasive Lepontine metamorphic overprinting, grading from greenschist to amphibolite facies conditions in the northern and southern sectors respectively (BEARTH, 1958; LADURON, 1976). The higher temperature reached by the Antrona lithologies in comparison with those of the Lepontine metamorphic event in the Piedmont nappe appears to be dependent on the structural depth of the Antrona unit within the nappe pile (Figs. 1 and 3). In fact the Antrona unit is sandwiched within the Pennine continental crust, between the overlying Monte Rosa nappe and the underlying Camughera-Moncucco units

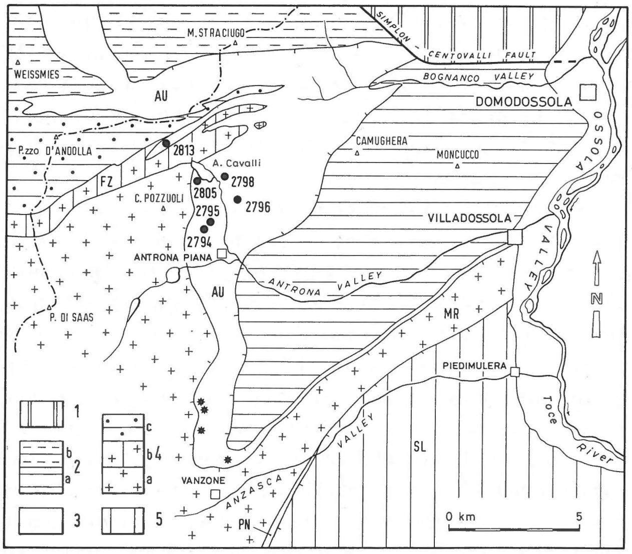

Fig. 3
Tectonic scheme of the Anzasca-Antrona-Bognanco area, Ossola valley: 1– Lower Pennine nappes; 2– Pennine St. Bernhard nappe, including the Camughera-Moncucco units (2a) and the Mischabel-Weissmies zone (2b); 3– Antrona ophiolite unit (AU); 4– Pennine Monte Rosa nappe (4a), including the Furgg zone (4b) and the external Portjengrat element (4c); 5– Austroalpine Sesia-Lanzo unit (SL). Filled dots: location of analyzed metabasalts from the Antrona unit. Asterisks: location of metabasites analyzed by Laduron (1976).

on the internal side and the St. Bernhard nappe on the external one (Figs. 1 and 3). Moreover, its area is confined to a small sector of the Anzasca, Antrona and Bognanco valleys (Fig. 3).

Despite these structural differences, the Antrona unit appears to be closely similar in lithostratigraphic setting and metamorphic evolution to the upper-seated Zermatt-Saas unit of the Piedmont nappe. The northward thrust of both the Zermatt-Saas and Antrona units abutted against the Mischabel back-fold and against the deeper structures of the St. Bernhard nappe to form a tectonic envelope of the Monte Rosa recumbent fold. This metaophiolitic envelope is not physically continuous because in the Weissmies-Almagell area the crystalline basement of the St.Bernhard and Monte Rosa (Portjengrat element; Fig. 3) are directly juxtaposed. However, a possible connection between the Zermatt-Saas and Antrona units below the topographic surface could be envisaged if the 'root zone' of the Monte Rosa nappe and its metaophiolite envelope is thought to close at depth into a tight synform (GOSSO ET AL., 1979).

The areal geology and the petrographic features of the Antrona unit are sketched by BLUMENTHAL (1952), BEARTH (1954, 1957, 1958) and LADURON (1976). The polyphase deformation history of this unit and surrounding nappes is discussed by MILNES (1974), KLEIN (1978), LADURON (1976), GOSSO ET AL. (1979) and MARTIN (1982).

The lithostratigraphic and palinspastic reconstruction of the Piedmont basin and surrounding realms of the Mesozoic

TABLE I
Representative chemical analyses of metabasites from the Western Alps Ophiolites.

Zermatt-Saas

	B	B	B	B	B	B	B	Gb
Campione	MRO 2680	MRO 2693	MRO 2694	MRO 2713	MRO 2716	MRO 2718	MRO 2726	MRO 2702
Si O$_2$ (%)	45.09	49.17	47.49	48.46	48.78	49.04	49.44	51.04
Ti O$_2$	1.53	2.13	2.24	1.18	1.79	1.37	1.49	1.16
Al O$_3$	18.03	13.98	14.23	17.40	15.94	19.18	16.11	17.00
Fe$_2$O$_3$T.	10.22	11.61	12.78	8.21	10.47	8.94	9.09	8.60
Mn O	0.15	0.17	0.17	0.18	0.19	0.08	0.14	0.15
Mg O	7.96	3.86	4.36	7.30	7.29	3.29	7.55	6.08
Ca O	12.01	11.41	10.90	11.16	10.55	12.61	9.25	11.18
Na$_2$O	2.33	3.30	4.04	3.48	2.95	3.65	3.75	3.34
K$_2$O	0.17	0.19	0.20	0.06	0.19	0.11	0.52	0.21
P$_2$O$_5$	0.08	0.23	0.32	0.10	0.21	0.12	0.16	0.04
L.O.I.	2.90	4.29	3.30	1.59	2.15	1.96	1.76	1.44
Tot.	100.47	100.34	100.03	99.12	100.51	100.35	99.26	100.24
Ni (ppm)	171	104	103	107	117	119	97	68
Co	51	52	51	42	54	39	40	44
Cr	324	120	124	244	231	384	259	70
V	245	266	270	195	255	225	228	263
Cu	48	28	39	10	28	36	39	22
Sr	243	158	147	237	183	312	103	310
Bd	29	23	28	19	23	21	22	30
Rb	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
Nb	< 2	6	6	2	5	2	4	< 2
Zr	110	167	200	91	148	100	124	34
Y	50	55	60	31	49	33	38	25

B = metabasalt, Gb = metagabbro, Fe-Gb = metaferrogabbro.
(1) average of four analyses, after Laduron (1976).

Zermatt-Saas

	Fe-Gb	Fe-Gb	Fe-Gb	Gb	Gb	Gb
Campione	MRO 2676	MRO 2679	MRO 2701	MRO 2719	MRO 2720	MRO 2721
Si O$_2$ (%)	44.16	45.28	44.67	50.90	48.83	49.33
Ti O$_2$	4.63	4.20	4.21	0.49	0.46	0.79
Al O$_3$	11.62	12.22	12.22	15.41	16.96	16.31
Fe$_2$O$_3$T.	19.56	18.06	18.43	5.67	6.86	9.29
Mn O	0.21	0.22	0.25	0.12	0.13	0.15
Mg O	6.84	6.75	6.19	10.18	9.75	7.73
Ca O	9.62	9.36	9.58	11.09	11.31	9.42
Na$_2$O	2.84	3.64	3.31	3.24	3.41	3.84
K$_2$ O	0.14	0.30	0.16	0.14	0.14	0.51
P$_2$O$_5$	0.07	< 0.02	0.14	0.04	< 0.02	< 0.02
L.O.I.	− 0.27	− 0.35	0.18	2.89	2.06	3.02
Tot.	99.42	98.68	99.34	100.07	99.81	100.39
Ni (ppm)	97	82	69	143	178	196
Co	—	—	—	39	36	41
Cr	54	77	57	232	305	179
V	447	482	493	177	165	225
Cu	10	10	13	10	12	158
Sr	110	119	115	178	147	220
Ba	33	47	32	18	18	26
Rb	12	13	12	< 10	< 10	< 10
Nb	3	2	3	< 2	< 2	< 2
Zr	58	67	70	46	37	39
Y	31	35	34	20	15	22

Table I (continued)

Combin

	B	B	B	B	B	B	B	B	Gb
Campione	MRO 2640	MRO 2649	MRO 2681	MRO 2696	MRO 2703	MRO 2705	MRO 2708	MRO 2697	MRO 2695
SiO_2 (%)	46.09	49.53	48.11	48.07	47.08	49.73	45.53	48.60	50.11
TiO_2	1.80	3.06	1.66	2.97	1.42	1.34	1.35	1.32	0.54
Al_2O_3	15.91	15.47	14.15	14.02	15.55	16.33	15.45	15.55	16.15
Fe_2O_3T.	11.11	10.70	13.24	13.10	9.29	8.87	9.40	9.54	6.71
MnO	0.18	0.18	0.21	0.23	0.17	0.14	0.15	0.15	0.15
MgO	9.96	4.99	5.18	5.10	8.36	8.09	6.04	8.33	9.28
CaO	6.81	8.83	8.53	8.50	11.46	10.39	12.66	11.25	12.21
Na_2O	3.03	4.28	4.63	4.59	2.43	3.82	3.35	2.93	3.57
K_2O	0.20	0.41	0.19	0.18	0.07	0.12	0.39	0.09	0.16
P_2O_5	0.08	0.17	0.19	0.54	0.20	0.15	0.19	0.14	0.02
L.O.I.	5.24	1.86	2.95	2.02	3.21	1.32	5.49	2.54	1.47
Tot.	100.41	99.48	99.04	99.32	99.24	100.30	100.00	100.44	100.37
Ni (ppm)	244	58	121	60	152	125	140	149	131
Co	—	41	52	43	57	53	42	53	59
Cr	283	89	279	101	326	296	266	338	558
V	270	288	257	307	242	218	209	239	165
Cu	51	33	10	10	10	11	78	10	51
Sr	133	464	195	119	227	188	260	193	377
Ba	17	39	23	24	20	23	23	23	19
Rb	< 10	11	< 10	< 10	< 10	< 10	10	< 10	< 10
Nb	3	9	3	9	3	3	2	3	< 2
Zr	116	251	129	302	112	95	107	90	30
Y	43	55	41	76	40	35	33	35	18

Antrona

	B	B	B	B	B	B	B
Campione	MRO 2794	MRO 2795	MRO 2796	MRO 2798	MRO 2805	MRO 2813	(1)
SiO_2 (%)	49.29	47.58	48.07	47.60	48.80	48.43	47.23
TiO_2	2.34	1.77	1.80	2.02	1.61	1.76	1.67
Al_2O_3	15.92	16.20	15.82	15.57	16.25	16.28	16.60
Fe_2O_3T.	11.80	10.37	10.36	11.31	10.34	11.75	11.23
MnO	0.14	0.16	0.21	0.18	0.15	0.13	0.16
MgO	6.19	6.56	6.57	6.89	6.50	4.59	8.47
CaO	7.78	10.51	10.46	10.45	11.08	12.56	9.70
Na_2O	4.20	3.60	3.62	3.09	3.69	2.96	3.20
K_2O	0.73	0.22	0.23	0.27	0.20	0.11	0.31
P_2O_5	0.38	0.24	0.22	0.29	0.25	0.16	0.33
L.O.I.	1.45	2.95	3.07	1.59	1.27	1.62	1.55
Tot.	100.22	100.16	100.43	99.26	100.14	100.35	100.45
Ni (ppm)	102	192	134	110	69	134	
Co	40		44	48	49	55	
Cr	162	247	240	198	226	215	
V	244	228	254	266	227	230	
Cu	33	64	44	40	82	145	
Sr	198	163	181	185	238	188	
Ba	33	36	26	25	21	15	
Rb	17	25	< 10	< 10	< 10	< 10	
Nb	6	4	4	4	5	5	
Zr	227	158	145	166	130	139	
Y	61	49	44	53	40	48	

Western-Alpine Tethys suggests the following possible location and significance of the units discussed:

a) a central sector of the Piedmont basin (i.e. the source of the Zermatt-Saas and Antrona units and similar lithologies associated to the Combin unit *sensu lato*), a very narrow zone which displays an ocean-type ophiolite sequence and a post-volcanic sedimentary cover;

b) a marginal and transitional zone (source of the Combin unit *sensu stricto*) characterized by carbonaceous to terrigenous sediments, deposited on the thinned and torn continental crust of the internal Pennine zone and possibly also of the external Austroalpine zone, the paleo-European and paleo-African margins respectively. Its associated ophiolitic lithologies may represent in turn either synsedimentary intraplate basalt/hyaloclastite horizons (stratoid prasinites) or oceanic allochthonous elements. The latter would have been emplaced as olistholiths or tectonic slices (metagabbros, serpentinites and possible major metabasaltic bodies and related post-volcanic sedimentary cover) derived from the laterally juxtaposed oceanic lithosphere.

PETROGENETIC CHARACTERISTICS OF METABASITES

Magma affinities and low pressure fractionation

The geochemical features of 29 selected metabasites considered in this paper are reported in Table I, their geographical distribution is found in Figs. 2 and 3. A synthetic petrographic description of the samples analyzed is given in Table II.

Among the fourteen metabasites from the *Zermatt-Saas unit,* the first seven correspond to albite-epidote-rich amphibolite metabasalts (samples 2680, 2693, 2694, 2718) which sometimes preserve metastable relics of garnet (2713, 2716, 2726). Samples 2676, 2679 and 2701 are isotropic and massive rutile rich eclogites; these metabasites may be interpreted as completely recrystalized fine-grained Fe-gabbros according to their chemical composition. Other samples correspond to coarse-grained schistose (2702, 2719, 2720) and massive (2721) metagabbros, sometimes preserving metastable relics of sodic pyroxene and garnet (2702).

Among the nine metabasites from the *Combin unit,* the first eight are metabasalts, while the last (2695) is a coarse-grained massive metagabbro showing a greenschist facies mineral assemblage. The metabasalts correspond to prasinites (2640, 2649, 2681, 2703), albite-rich amphibolite (2697), albite-rich amphibolite with relict garnet (2696, 2708) and massive prasinite with predominating Fe-epidote (2705).

The six analyzed rocks from the *Antrona unit* are metabasalts and correspond to amphibolites (2796, 2798, 2805), biotite-rich amphibolite (2795) and epidote-rich amphibolite (2813).

TABLE II

Metamorphic assemblages in the analyzed metabasalts (B), Mg-metagabbros (Mg-Gb) and Fe-metagabbros (Fe-Gb) within the Piedmont ophiolite nappe. Symbols approximately represent the mineral abundance as follows: (P) predominating minerals, (A) abundant, (S) scarce and (m) minor. Omph: omphacite, Grt: almandine-rich garnet, Gl: glaucophane, Ur: fine-grained uralite, Amph: blue-green and green amphiboles, Plag: plagioclase (commonly albite, oligoclase in the southern side of the Antrona unit), Ep: zoisite and epidotes, Chl: chlorite, Whm: white micas, Bi: biotite, Qz: quartz, Crb: carbonate, Ru: rutile, Ti: titanite, Op: opaques, Ap: apatite.

Sample	Omph	Grt	Gl	Ur	Amph	Plag	Ep	Chl	Whm	Bi	Qz	Crb	Ru	Ti	Op	Ap
ZERMATT-SAAS UNIT																
2680 (B)	—	—	—	—	A	A	A	S	—	—	—	—	m	m	m	—
2693 (B)	—	—	—	—	A	A	A	m	—	—	m	m	m	m	m	m
2694 (B)	—	—	—	—	A	A	A	S	—	—	—	S	—	m	m	m
2713 (B)	—	A	—	—	A	A	A	m	S	—	—	—	—	m	—	m
2716 (B)	—	S	—	—	P	S	A	—	m	—	—	—	—	m	m	m
2718 (B)	—	—	—	—	A	A	A	—	—	—	—	—	m	m	m	m
2726 (B)	—	S	—	—	P	A	S	S	m	—	—	—	—	m	m	m
2702 (mg-Gb)	m	S	—	S	A	A	A	—	S	—	—	—	m	m	m	—
2676 (Fe-Gb)	P	A	S	—	m	—	—	—	m	m	—	—	S	—	—	m
2679 (Fe-Gb)	P	A	m	m	S	—	—	m	m	—	—	—	S	—	m	—
2701 (Fe-Gb)	P	P	S	S	S	m	m	—	S	—	—	—	S	—	m	m
2719 (Mg-Gb)	—	—	—	—	P	A	A	—	—	—	—	—	—	m	—	—
2720 (Mg-Gb)	—	—	—	—	P	A	A	—	S	—	—	—	m	m	—	—
2721 (Mg-Gb)	—	—	—	—	A	A	A	S	—	—	—	m	—	m	—	—
COMBIN UNIT																
2640 (B)	—	—	—	—	S	A	A	A	—	—	—	—	—	m	—	—
2649 (B)	—	—	—	—	A	A	A	S	—	m	—	—	—	m	m	m
2681 (B)	—	—	—	—	P	A	S	S	—	—	—	—	—	m	—	m
2696 (B)	—	S	—	—	P	A	S	S	—	—	—	—	—	m	—	m
2703 (B)	—	—	—	—	A	A	A	S	—	—	—	—	—	m	—	m
2705 (B)	—	—	—	—	S	A	P	S	—	m	m	S	—	m	m	m
2708 (B)	—	S	—	—	A	A	A	S	m	—	—	S	—	m	m	m
2697 (B)	—	—	—	—	P	S	A	S	—	—	—	—	—	m	m	m
2695 (Mg-Gb)	—	—	—	S	P	S	P	S	—	—	—	—	—	m	—	—
ANTRONA UNIT																
2794 (B)	—	—	—	—	P	A	A	m	—	S	—	—	m	—	m	m
2795 (B)	—	A	—	—	A	S	A	S	—	—	—	m	m	—	m	m
2796 (B)	—	—	—	—	A	P	A	—	—	—	—	—	m	—	m	m
2798 (B)	—	m	—	—	P	A	A	m	—	m	—	—	m	m	m	m
2805 (B)	—	—	—	—	P	A	A	m	m	m	—	—	—	m	m	m
2813 (B)	—	—	—	—	P	S	P	—	—	—	m	m	—	m	m	m

Because of the alteration and metamorphism which affected all samples (eclogite and/or greenschist/amphibolite facies) discussion on primary characteristics of the rocks will be based mainly upon high-field strength elements (HFSE, low radius/charge ratio) such as Ti, Zr, Y, Ni and P which appear to be relatively immobile during weathering and metamorphism (CANN, 1970; HUMPHRIS & THOMPSON, 1978), in addition to being good petrogenetic indicators.

The inter-element correlation of Al, Si, Fe, Mg, Co and Ni with HFSE and the fact that their variations are consistent with those expected in magmatic processes, also indicate that the distribution of these elements was not drastically affected by post-magmatic mobilization.

Among the metabasites studies three main magmatic protoliths can be recognized, on the basis of their chemistry as well as of their structural relics: 1– subaphyric to porphyritic basalts, 2– medium- to coarse-grained Mg-gabbros and 3– fine-grained massive eclogitized Fe-gabbros.

Chemical variations of both Mg-rich and Fe-Ti-rich gabbros (ferro-gabbros) reveal the same fractionation trends observed for gabbroic intrusives from the modern oceanic crust (KAY ET AL., 1970; MELSON & THOMPSON, 1970; MIYASHIRO ET AL., 1970; ENGEL & FISHER, 1975; PRINZ ET AL., 1976) and from other high-Ti Western Mediterranean ophiolites (Northern Apennines: BECCALUVA ET AL., 1976, 1980; SERRI, 1980; Corsica: BECCALUVA ET AL., 1977; Western Alps: MONVISO, 1980; POGNANTE ET AL., 1982; Western Liguria: BECCALUVA ET AL., 1979b).

As pointed out for these above mentioned occurrences the gabbros and associated basalts under consideration can be interpreted as produced by an essentially common fractionation process, where removal of cumulus minerals, leading to the gabbroic cumulates, determines the evolution of basaltic liquids. Accordingly, gabbros do not fall on the 'basaltic' liquid line of descent, since their chemistry mostly results from the nature and proportions of the cumulus phases plus variable amounts of intercumulus trapped liquid (Fig. 4): the

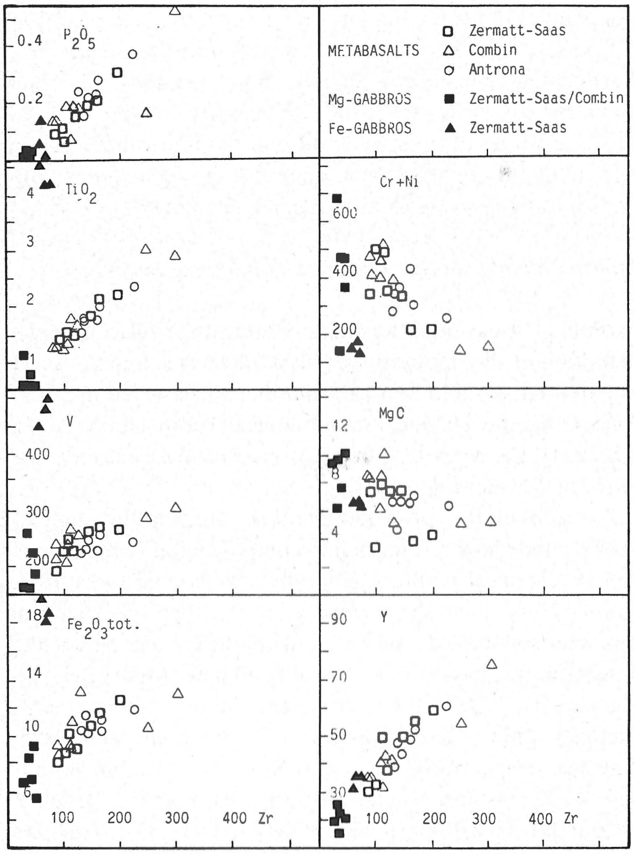

Fig. 4
Major and trace element variations vs Zr (used as differentiation parameter) for the investigated metabasalts and metagabbros from the Western Alps ophiolites.

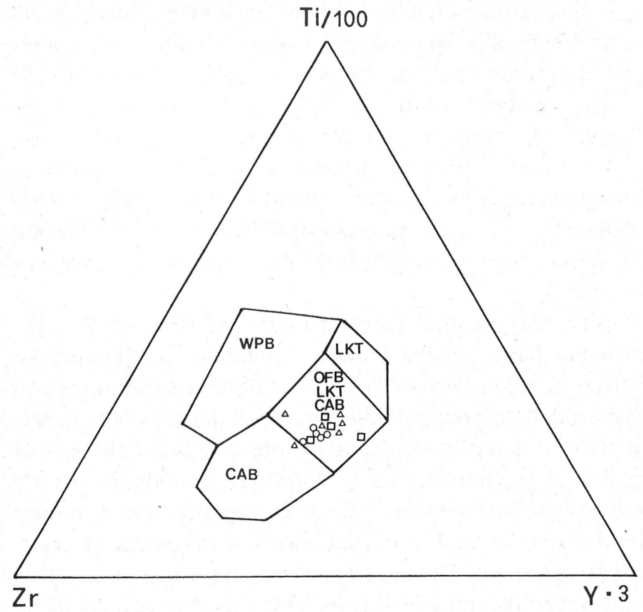

Fig. 5
Ti/Zr/Y discrimination diagram (Pearce & Cann, 1973) showing the distribution of the investigated metabasalts from the Western Alps ophiolites (symbols as in Fig. 4). CAB: calcalkalic basalts; LKT: low-K tholeiites; OFB: ocean-floor basalts; WPB: within-plate basalts.

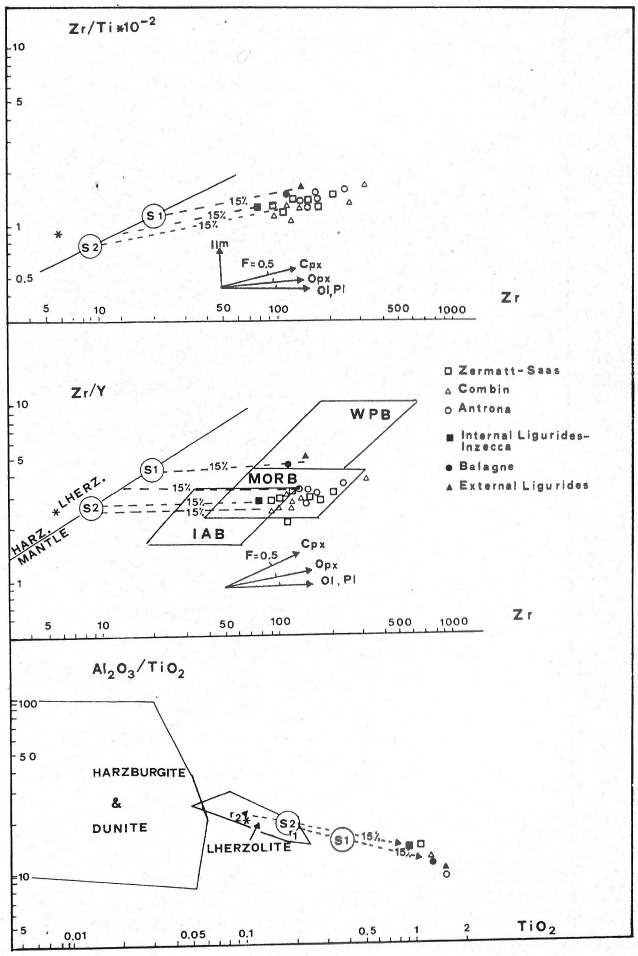

Fig. 6
Zr/Ti vs Zr, Zr/Y vs Zr and Al_2O_3/TiO_2 vs TiO_2 diagrams for the metabasites from the Western Alps and from other western Mediterranean ophiolites (data from authors quoted in text). The dashes indicate non-modal batch melting (Shaw, 1970) trends and degrees (figures) for inferred parental magmas of the various ophiolite complexes. The hypothetical mantle sources (S_1, S_2) have been modelled as spinel-lherzolite with the following mineralogy: S_1 = Ol 0.55, Opx 0.20, Cpx 0.20, Sp 0.05; S_2 = Ol 0.60, Opx 0.20, Cpx 0.16, Sp 0.04; and the assumed eutectic composition: E1,2 = Ol 0.15, Opx 0.15, Cpx 0.40, Sp 0.30. The modelled vectors indicate fractional crystallization of olivine (Ol), plagioclase (Pl), orthopyroxene (Opx), clinopyroxene (Cpx), and ilmenite (Ilm). Partition coefficients and distribution fields of basalts from different tectonic settings are from Pearce & Norry (1979): IAB: island-arc basalts; MORB: mid-ocean ridge basalts; WPB: within-plate basalts. The chondritic values (from Sun & Nesbitt, 1977) are shown by asterisks.

parallel pronounced decrease of Mg, Cr+Ni and Al (not shown in Fig. 4) in basalts, coupled with a concomitant increase of Ti, Fe and V suggest an early separation of olivine ± Cr-spinel, plagioclase and pyroxene leading to Mg-rich gabbroic cumulates with a subordinate amount of trapped liquid (very low contents of incompatible elements in the major silicates such as P, Zr, Nb); a subsequent segregation from ferrobasaltic magmas of Ti-magnetite/ilmenite, in addition to plagioclase and pyroxenes, could account for the

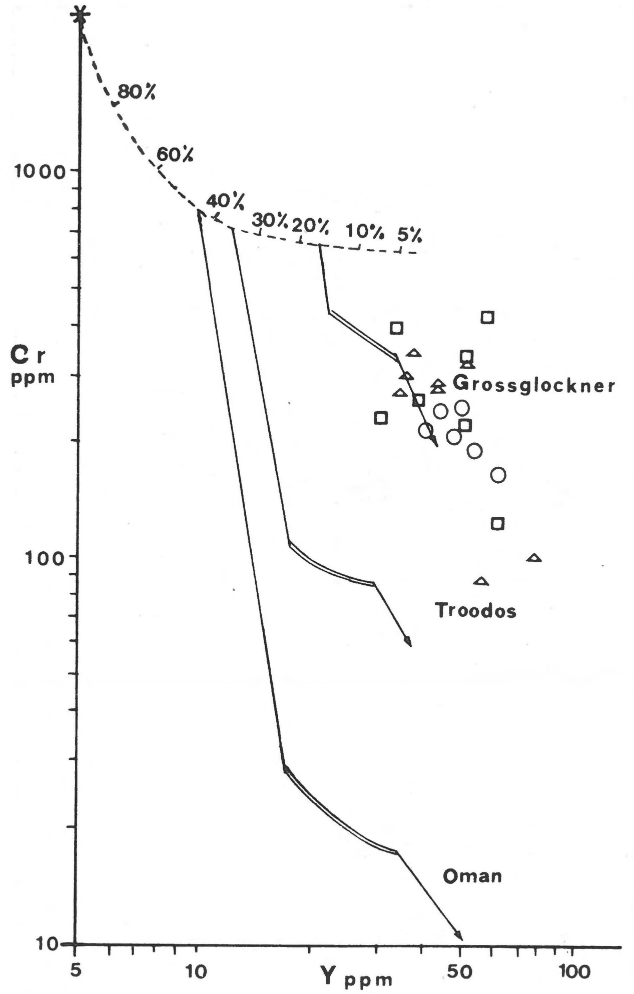

Fig. 7
Cr vs Y diagram for the investigated metabasites from the Western Alps ophiolites (symbols as in Fig. 4). The dashes indicate parental magmas produced by different partial melting degrees (figures) from C3 chondrite source; closed and open system fractional crystallization trends for some ophiolites are indicated by single and double lines respectively (after Pearce, 1980).

extremely enriched Fe, Ti and V compositions of ferrogabbros which, accordingly, may result from crystallization of cumulus phases with a considerable amount of fractionated liquid (comparatively higher contents of Zr, P and Nb). Such a fractionation scheme (cf. BECCALUVA ET AL., 1980; CAMERON ET AL., 1980), and the chemical characteristics of basaltic rocks correspond to the compositional variation of MORB as shown in diagrams of Figs. 5 and 6.

On the whole the magmatic features of all investigated basic rocks appear to be compatible with a low-pressure tholeiitic fractionation (indicatively $<$ 5-6 Kbar; cf. KUSHIRO 1973; GREEN, 1982) such as is known to occur at accreting plate margins, under initially reduced P H_2O-fO_2 (cf. HILL & ROEDER, 1974; MORSE ET AL., 1980), and high diffusion/slow cooling conditions favouring adcumulus processes and expulsion of trapped liquid from cumulates (cf. HODGES & PAPIKE, 1976).

Chemical trends of basalts in Fig. 7 and the presence of fractionated Fe-gabbros suggest that, similarly to other ophiolitic complexes (cf. STERN, 1979; SERRI, 1980; BECCALUVA ET AL., in press, c), magmatic differentiation of the Western Alps ophiolites evolved from open- tot closed-system conditions in progressively smaller magma chambers.

Inferred mantle sources of the ophiolitic magmatism

In order to discuss mantle source/basaltic melts relationships a definition of the nature of parental magmas is a preliminary requirement, in addition to a number of basic assumptions concerning the chemical-mineralogical composition of the source (1), the type of melting (2), and the physical conditions (3) at which melting occurs.

As seen in the previous chapter, the basaltic samples investigated show a remarkable compositional homogeneity and geochemical features generally comparable to MORB. Nevertheless a careful examination of their geochemical characteristics reveals some significant differences among the most primitive basalts (Cr+Ni: 300-500 ppm, Mg0:8.3-6.5%, Mg/Mg+Fe^{++}: 0.63-0.68) from the three ophiolitic units (samples 2713, Zermatt-Saas, 2697, Combin, and 2805, Antrona, respectively). Zermatt-Saas and Combin basalts have Ti, Zr, P and Ni and the ratios Zr/Y (2.6-2.9), Nb/Y (0.06-0.08), TiO_2/P_2O_5 (9-12) and Al_2O_3/TiO_2 (12-15) that are strictly comparable to normal MORB, while the content and ratios of these elements in the Antrona basalts (Zr/Y: 3.3, TiO_2/P_2O_5: 6.4, Al_2O_3/TiO_2: 10) reveal a closer resemblance with transitional-MORB (Cf. SUN ET AL., 1979).

Similar compositional variations have been found among ophiolitic basalts from various western Mediterranean complexes. These variations are typically emphasized by flat to LREE enriched patterns in transitional-MORB types (e.g. Balagne: VENTURELLI ET AL., 1979; external Ligurides: BECCALUVA ET AL., in prep Calabria: BECCALUVA ET AL., in press, b; Mongenevre: LEWIS & SMEWING, 1980) in contrast with LREE depleted patterns in normal-MORB types (e.g. internal Ligurides, Alpine Corsica, Engadine window: VENTURELLI ET AL., 1981).

Since incompatible element ratios and REE relative distribution hardly change during moderate- or high-degree partial melting (SCHILLING, 1975), the observed variations also suggest that different ophiolitic parental magmas were generated by differently depleted mantle sources with distinct geochemical characteristics. A range of suitable mantle sources/parental melts/refractory residues that would account for the western Mediterranean ophiolitic magmatism is modelled in Figs. 6-8. The model is based on the assumption that spinellherzolite mantle diapirs (1), rising under adiabatic conditions in an oceanic convective system (3), underwent non-modal equilibrium partial melting (2) with production of large amounts of mid-oceanic ridge basalts. Model calculation indicates that western Mediterranean ophiolitic basalts with

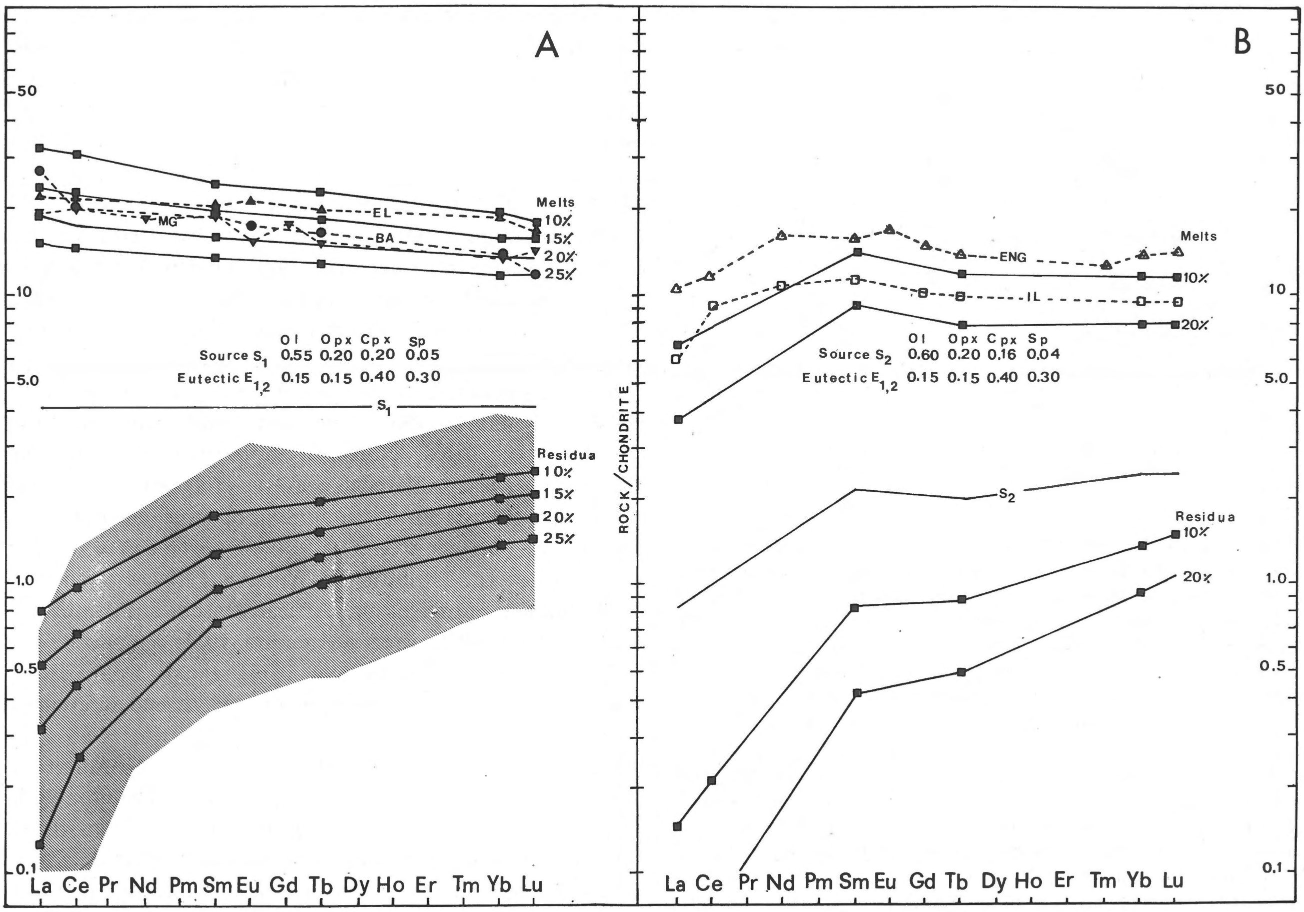

Fig. 8
Chondrite-normalized REE patterns for the most primitive metabasalts from the various western Mediterranean ophiolites (data from authors quoted in text): EL: external Ligurides (Northern Apennines); BA: Balagne (Corsica); MG: Mongenevre (Western Alps); ENG: Engadine window (Central Alps); IL: internal Ligurides (Northern Apennines). The modelled patterns relate mantle sources, produced melts and residues, assuming non-modal batch melting. Sources S_1, S_2 and the eutectic composition E_1, E_2 are the same as presented in Fig. 6. Partition coefficients are from Arth (1976) and from Leeman (1976). The dotted field represents the distribution of mantle lherzolites from the Northern Apennine ophiolites (Ottonello et al., 1979; Beccaluva et al., in press, a).

transitional-MORB affinity (Antrona, Mongenevre; external Ligurides, Northern Apennines; Balagne, Corsica; Calabria) could be produced by intermediate degrees of partial melting (indicatively 15%) of a 4-times chondritic source S_1 with a spinel-lherzolite mineralogy (Figs. 6-8). Such an undepleted source, which conceivably consisted of lithospheric mantle segments, ascended underneath an embryonic ocean rift system during asthenospheric penetration (cf. BARBERI ET AL., 1982), and probably partially melted at shallow depth. There MORB of fairly uniform major element composition may be produced (in a region of spinel- to plagio-clase-peridotite transition at about 9 kbar and 1200-1250 °C, according to PRESNALL ET AL., 1979). In contrast ophiolitic basalts with normal-MORB affinity (Zermatt-Saas, Combin, Engadine, Tauern in the Alps; Voltri, Liguria; internal Ligurides, Northern Apennines; Inzecca, Eastern Corsica) could have been generated by partial melting on a depleted, probably asthenospheric (cf. GREEN & LIEBERMANN, 1976; KAT, 1979) mantle source S_2. This would be a process similar to the one proposed by several authors (WOOD, 1979; SUN ET AL., 1979; GREEN ET AL., 1979) for normal-MORB generation (Figs. 6-8).

IMPLICATION FOR THE PALEOGEOGRAPHICAL EVOLUTION OF THE WESTERN TETHYAN BASIN

Data arisen from this paper allow some concluding remarks which are summarized in the following points:

1– Geochemical and petrogenetic characteristics of the metabasalts from Zermatt-Saas and Combin units between the middle Aosta valley and the Valais appear to be strictly comparable to those of the normal-MORB magmatism, as already suggested by BEARTH ET AL. (1973), DAL PIAZ & ERNST (1978) and DAL PIAZ ET AL. (1981).

2– While for the Zermatt-Saas unit the magmatic affinity is consistent with the pure oceanic characteristics of its lithostratigraphic sequence, this does not seem to be the case for

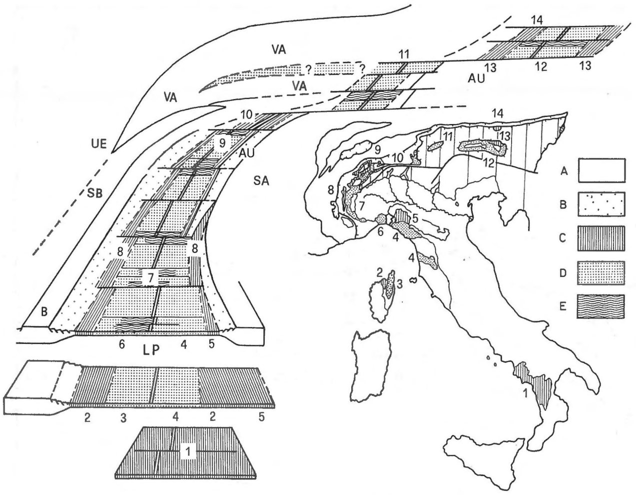

Fig. 9
Sketch map of the ophiolite distribution in the Alpine-Apennine orogenic system and generalized paleogeographic restoration of the upper Jurassic Western Tethyan basin showing possible original positions of the discussed ophiolite complexes. Paleogeographic domaines (Dal Piax, 1974; Trümpy, 1980); Southalpine (SA), Austroalpine (AU), Ligurian and Piedmont (LP), internal Pennine and Brianconnais (B), Subbriançonnais (SB), Valais (VA) and Ultrahelvetic (UE). Crustal characteristics: A– continental crust; B– transitional external sectors of the Piedmont basin, including the paleo-European and paleo-African passive margins; C– oceanic crust with transitional-MORB affinity; D– oceanic crust with normal-MORB affinity; E– tentative location of some fracture zones with gabbro and/or serpentinite bodies exposed on the ocean floor. The transitional- or normal-MORB affinity has been inferred on the basis of available petrochemical data: 1– Calabria (Spadea, 1979; Beccaluva et al., in press b), 2– Balagne, Corsica (Glom, 1977; Venturelli et al., 1979), 3– Inzecca, Eastern Corsica (Beccaluva et al., 1977; Venturelli et al., 1981); 4– internal Ligurides, Tuscany (Ferrara et al., 1976; Beccaluva et al., 1980); 5– external Ligurides, Mt. Maggiorasca, Northern Apennines (Beccaluva et al., 1980); 6– Voltri massif (Mazzuccotelli et al., 1976); 7– Monviso (Monviso, 1980); 8– Mon genevre (Lewis & Smewing, 1980; Bertrand et al., 1982); 9–Zermatt-Saas and Combin units (Dal Piaz et al., 1981; this paper); 10– Antrona unit (this paper); 11– Engadine window (Venturelli et al., 1981); 12-13-14– Tauern window-Strobl area, Austria (Bickle & Pearce, 1975; Höck, 1983).

the Combin unit *sensu stricto* where the sedimentary sequence suggests, on the contrary, a deposition in passive continental margins. As previously pointed out this situation might be due to an allochthonous origin of some Combin ophiolitic bodies which could have been emplaced within the marginal sequences as olistoliths, slices or larger tectonic elements, that came from neighbouring oceanic sectors.

3– Petrogenetic characteristics of the Antrona metabasalts indicate an oceanic nature for this magmatism with a distinct transitional-MORB affinity. While these transitional-MORB ophiolites seem to be compatible with an incipient oceanic rift of the Jurassic Piedmont basin that developed concomitant with lithospheric attenuation and continental break-up, normal-MORB ophiolitic magmatism such as that of Zermatt-Saas and Combin better fit with well-established asthenospheric convection in a more mature oceanic ridge system. Obviously this does not necessarily imply a rigorous chronological sequence, since different evolutionary stages could have been attained at the same time in different segments of the oceanic basin.

More generally, the geodynamic evolution and paleogeographical configuration of the Western Tethyan basin may be discussed taking into consideration the structural, stratigraphic and geochronological relationships, in addition to the distinctive petrological characteristics of the various ophiolite complexes.

Summing up, the available petrological and geological data consistently indicate that all western Mediterranean ophiolites from the Alps, Northern Apennines, Corsica and Calabria, can be considered as preserved fragments of oceanic lithosphere created during the Jurassic opening (absolute ages 185-160 Ma, Bigazzi et al., 1973; Ohnenstetter et al., 1977; Beccaluva et al., 1981) of the Western Tethyan basin that separated the European and African (Insubrian) continents (Abbate et al., 1970; Bezzi & Piccardo, 1971; Dal Piaz et al., 1972; Dal Piaz, 1974; Scandone, 1975; Ferrara et al., 1976; Beccaluva et al., 1977, 1980; Pearce, 1980; and references therein).

Oceanization was apparently related to separation of Africa from North America, and its eastward motion with respect to the Euroasiatic plate produced, after initial rifting episodes (middle Triassic to early Jurassic), large scale tensional and transcurrent effects within the epicontinental and newly-formed oceanic domains (Dewey et al., 1973).

It must be emphasized, however, that ophiolites with transitional-MORB affinity appear generally to be confined to the most external sectors both in the Alpine and Apennine orogeny (Fig. 9) and, moreover, that they are often primarily associated with continental crust material (e.e. external Ligurides and Balagne: Beccaluva et al., 1980; Calabria: Lanzafame et al., 1979; Beccaluva et al., in press b). This suggests that such 'transitional' ophiolites represent the activity of an early ocean-type magmatism developed in a pericontinental position, very close to the new continental margins, or even on crumbled remnants of continental crust.

A subsequent well-established convection in a more developed oceanridge system probably confined these latter associations to peripheral sectors along the newly formed continental margins, and produced the more typical ophiolites with normal-MORB affinity (Fig. 9) in the axial portion of the basin.

In this regard an early transitional-MORB magmatism relative to normal-MORB activity might be suggested by absolute ages on Corsican ophiolites (K-Ar ages of 181 ± 6 Ma for a metagabbro from Balagne, Beccaluva et al., 1981, versus U-Pb ages on zircons of 170-165 Ma for Inzecca plagiogranites, Ohnenstetter et al., 1977), although the uncertainty commonly associated with radiometric ages in ophiolitic lithologies makes these results of limited value.

Nevertheless, it is conceivable that western Mediterranean ophiolites were created in a variety of original settings which were also strongly affected by oceanic tectonics and metamorphism along fracture zones. Early tectonism is indicated, in particular, by the fact that, in many ophiolitic complexes (e.g. Northern Apennines: GIANELLI & PRINCIPI, 1974; GALBIATI ET AL., 1976; Corsica: OHNENSTETTER, pers. com. 1983; Calabria: BECCALUVA ET AL., in press, a) the brecciation of oceanic (along with continental) material, the serpentinization of mantle peridotite and the oceanic metamorphism in gabbros took place before basalt emplacement (as flows or dykes) and chert deposition, as is to be expected in fracture zones (cf. BONATTI, 1978; BONATTI & HAMLYN, 1978) and at the intervening ridge/transform intersections.

Such peculiar tectonic environments could also account for the general lack of complete sheeted dyke complexes and for the considerably reduced thickness of the Alpine and Apennine ophiolitic sequences with respect to normal oceanic crust.

Therefore, an oceanic-pericontinental pattern, strongly affected by both divergent and transcurrent movements, with development of short ridge segments and important fractures and leaky transform zones, should have characterized the original geodynamic environment of the Western Tethyan basin.

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