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Geochemistry of mafic rocks in the Sesia Zone (Western Alps): New data and interpretations

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Key words: Geochemistry, mafic rocks, basalts, gabbros, MORB, paleogeography, Sesia zone

ABSTRACT

Twenty-nine whole rock geochemical analyses of basic rocks were carried out in the Sesia zone in order to characterise the provenance and evolution of both basement and monometamorphic cover mafic lithologies of this Alpine unit. We are able to subdivide the basic rocks into the following groups: a) monometamorphic metabasalts with a tholeiitic mid oceanic ridge (MORB) signature; b) eclogitised basement amphibolites, derived from transitional to alkaline within-plate (WPB) basalts; c) mafic sheets and boudins within the leucocratic gneisses of the monometamorphic covers, which are tholeiitic WPB Fe-basalts to trachyandesites in origin; d) mafic metabreccias related to the monometamorphic basalts, which are spilitized tholeiitic trachybasalts/trachyandesites in origin; and e) mylonitic metagabbros probably derived from cumulitic Mg-gabbros.

Glaucophane-bearing gabbroic rocks in the southern Sesia zone (Corio and Monastero regions) show a geochemical signature similar to the eclogitised basement amphibolites and do not have any chemical resemblance to the analysed Mg-gabbros.

The monometamorphic tholeiitic MORB basalts have a geochemical pattern similar to the extrusive basic rocks of the ophiolitic units of the Western Alps, while they differ from the Middle Triassic mafic rocks of the Eastern Alps in both chemical composition and geotectonic signature. Because of their lithostratigraphic position and their relationships with the other monometamorphic lithologies they have been interpreted as emplaced in a distal edge of the continental margin position during the early opening phases of the Alpine Tethys basin, in the Early Jurassic time.

The analysed Mg-gabbros are geochemically equivalent to the other presumably Early Permian intrusive mafic stocks of the Western Austroalpine system (e.g. Matterhorn-Mont Collon, M. Nery etc.).

RIASSUNTO

Ventinove analisi geochimiche su roccia totale di litotipi basici campionati nella zona Sesia-Lanzo hanno permesso di caratterizzare l'origine e l'evoluzione di tali roccie provenienti sia dal basamento polimetamorfico che dalle coperture monometamorfiche. Attraverso l'uso di diversi diagrammi discriminativi abbiamo potuto suddividere i litotipi analizzati nei seguenti gruppi: a) metabasalti monometamorfici di fondo oceanico, aventi un'affinità tholeiitica; b) anfiboliti di basamento parzialmente o totalmente eclogitizzate, le quali derivano da basalti intraplacca da transizionali ad alcalini; c) livelli basici e boudins alternati a gneiss leucocratici, risultato delle trasformazioni metamorfiche di originali Fe-basalti tholeiitici d'intraplacca; d) metabrecce basiche strettamente connesse ai metabasalti, con composizione da trachibasaltica a trachiandesitica ad affinità tholeiitica ed probabilmente interessate da metamorfismo di fondo oceanico; e) metagabbri milonitici derivanti da originari Magnesio gabbri cumulitici.

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Le masse glaucofaniche a tessitura gabbroica della zona Sesia-Lanzo meridionale (area di Corio e Monastero) hanno a loro volta mostrato delle forti rassomiglianze geochimiche con le anfiboliti di basamento eclogitizzate, ed allo stesso tempo delle marcate differenze con i Mg-gabbri analizzati.

I basalti MORB delle coperture monometamorfiche hanno una carattirizzazione geochimica molto simile a quella delle vulcaniti basiche delle unità ofiolitiche delle Alpi Occidentali, che sono di supposta età Giurassica Medio-Superiore, mentre si differenziano dai litotipici felsici Medio-Triassici delle Alpi Orientali sia per composizione che per affinità. A causa della loro posizione litostratigrafica e delle relazioni con le altre litologie di basamento, i metabasalti MORB sono stati interpretati come testimoni di una messa in posto in posizione di limite distale del margine, durante le prime fasi dell'apertura della Tetide Alpina.

I Mg-gabbri analizzati hanno invece una caratterizzazione geochimica equivalente a quella delle altre intrusioni basiche del sistema Austroalpino occidentale di supposta età Permiana Inferiore, come, ad esempio, il gabbro del Cervino o quello del Mont Nery.

Introduction

The Sesia zone, a main tectonic constituent of the western Austroalpine system (Fig. 1a), hats always been described as a slice of Variscan high-grade continental crust that underwent high-pressure (HP) metamorphism during the early Alpine orogenic cycle (Dal Piaz 1993, and references therein). Recently Venturini et al. (1994) suggested the existence of a Permo-Mesozoic cover sequence for the Sesia zone, which was involved in the Alpine orogenic cycle together with the pre-Carboniferous basement units. It is difficult to distinguish between basement and cover units in the Sesia zone because of the similarities of macroscopic and microscopic features displayed by the different lithologies affected by the Alpine metamorphism. Whole rock geochemistry can help to discriminate between rocks that experienced different geological histories before the Alpine orogeny. In this contribution we present the results of whole rock geochemical analyses on twenty-nine mafic rocks collected from both the basement and cover units of the central and southern Sesia zone (Fig. 1a, 1b). In order to investigate their affinities with the gabbroic lithologies of the central Sesia zone, fourteen samples were collected from the mono metamorphic cover cropping out in the Cima di Bonze area, Valchiusella and lower Aosta valley, while thirteen other samples were collected primarily from the internal unit of the polycyclic basement complex in the lower Aosta valley and in the Lanzo region (Venturini et al. 1994.) (Fig. 1b). Two more samples come from the northern Sesia zone (Valsermenza, Anzasca valley). The goal of this study is to define the differences in the origin and evolution of the mafic rocks of the monometamorphic cover sequences from the basic lithologies of the polycyclic basement complex.

Several contributions on whole rock geochemical studies have been made on rocks from the Sesia zone since 1964 in order to:

1) define the relationships between the chemical composition of the HP minerals and their lithologies (Callegari & Viterbo 1966; Lombardo et al. 1977; Reinsch 1979; Lardeaux & Spalla 1991), and
2) to increase the knowledge about the origin of the rocks affected by the HP metamorphism during the Alpine orogeny (Bianchi et al. 1964; Callegari et al. 1976; Compagnoni et al. 1977; Minnigh 1978; Dal Piaz et al. 1979; Oberhänsli et al. 1985; Stünitz 1989; Chabloz 1990; Simic 1992; Halter 1992; Venturini et al. 1994; Venturini 1995).

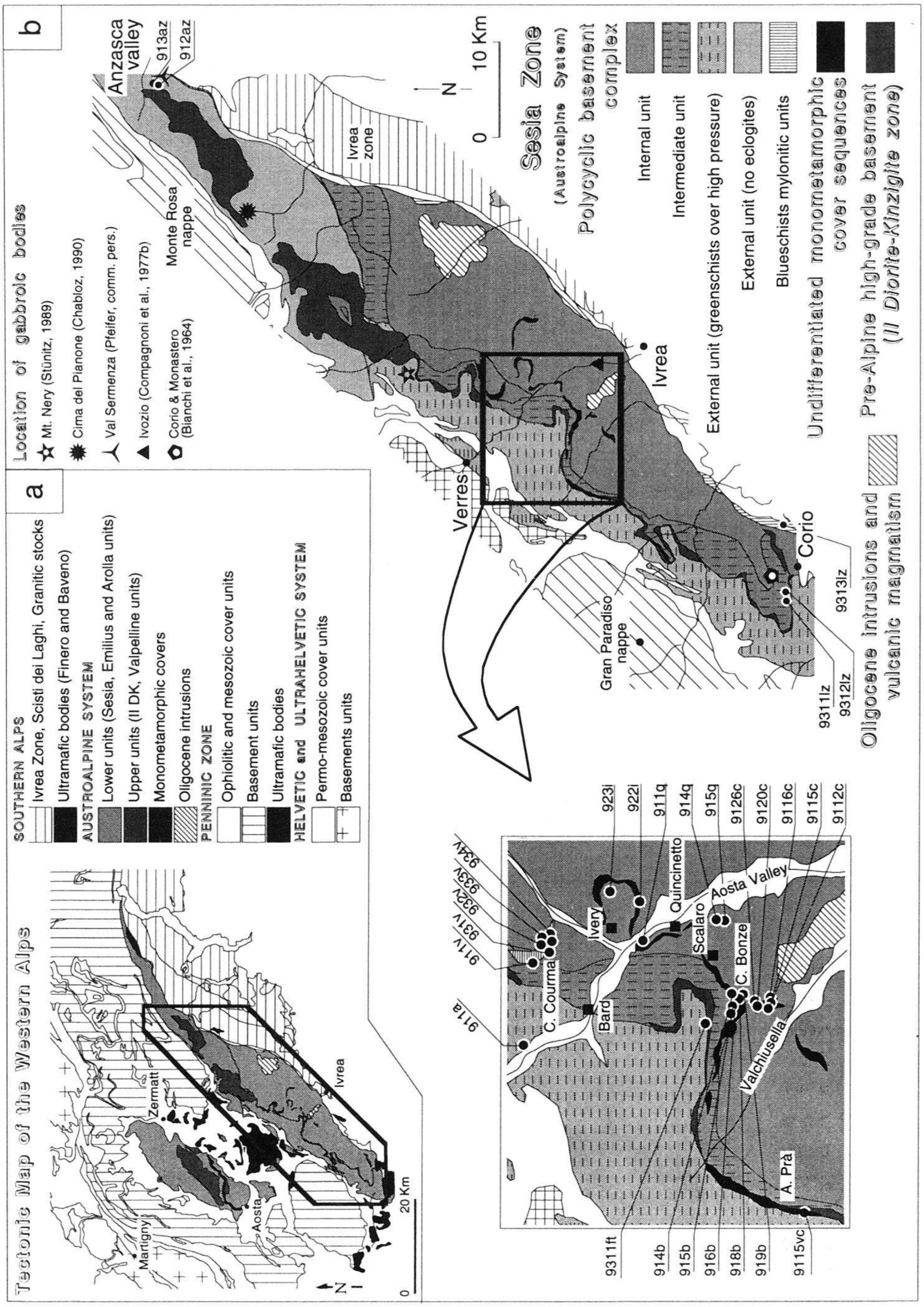

Fig. 1. Tectonic sketch of the Western Alps and location of analysed samples (modified after Venturini 1995).

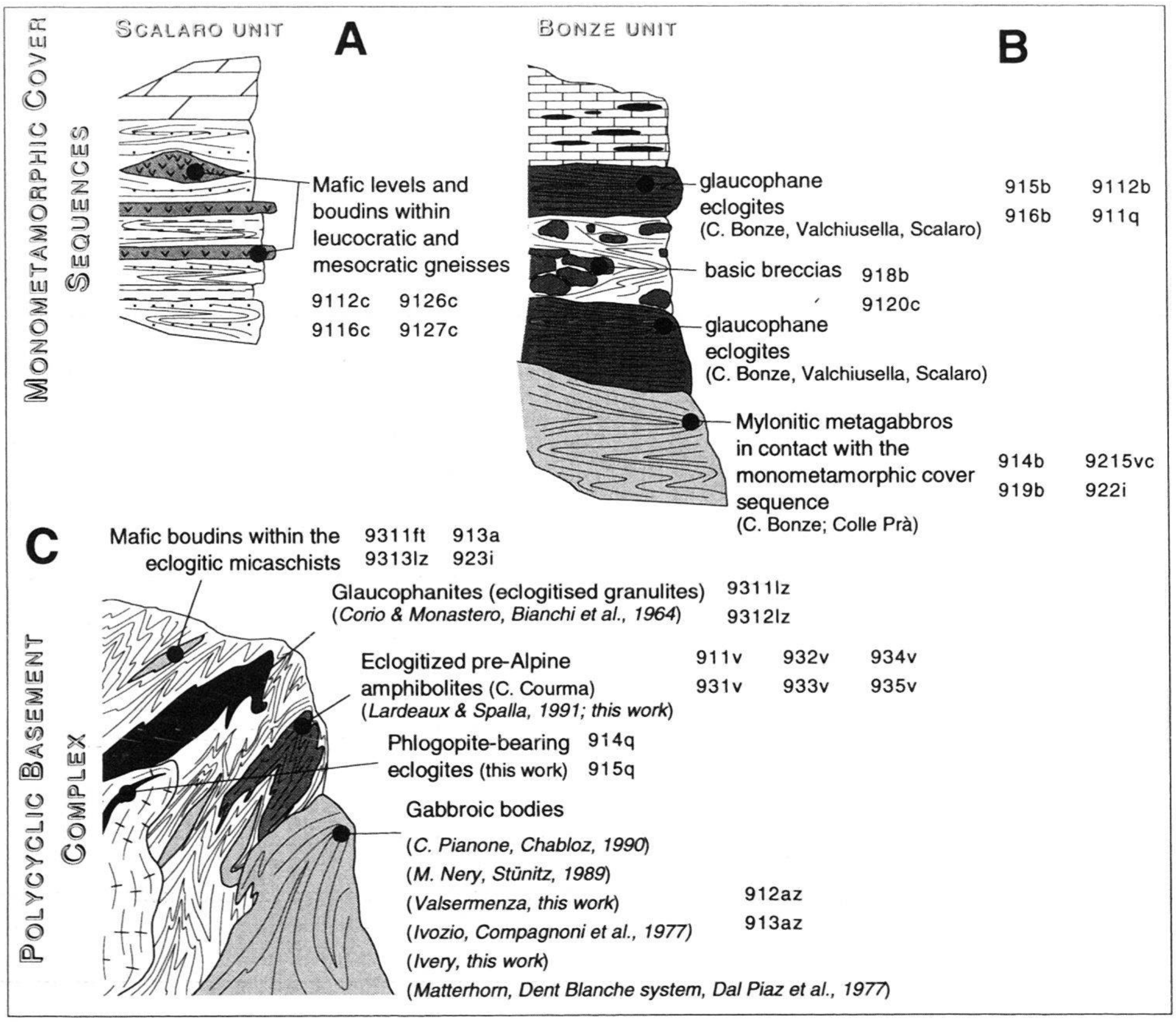

Fig. 2. Schematic lithologic sections of the Sesia zone basement and monometamorphic covers and occurrence of mafic rocks. Corresponding analysed samples are indicated near each lithological group.

Geological setting and occurrence of the mafic rocks in the Sesia zone

The Sesia zone is composed of three main complexes: 1) a polycyclic basement complex, made of HP lithologies partially re-equilibrated under greenschist facies (GS) condition; 2) a pre-Alpine high grade (HG) basement (II) Diorite-Kinzigitic zone (II DK) of Compagnoni et al. 1977), which partially preserves metamorphic characteristics of Variscan age, and 3) a Permo-Mesozoic cover sequence, metamorphosed during the early Cretaceous under HP conditions together with the polycyclic basement units (Hunziker 1974; Venturini et al. 1994, and references therein) (Fig. 1b).

The schematic lithologic columns of figure 2 summarise the occurrence of mafic lithologies on both the polycyclic basement and the monometamorphic cover units. The mafic lithologies of the polycyclic basement complex are represented by: 1) decimetric to metric boudins within the eclogitised paraschists (Dal Piaz et al. 1972; Lardeaux & Spalla 1991); 2) decametric to kilometric bodies of metagabbros, locally preserving original

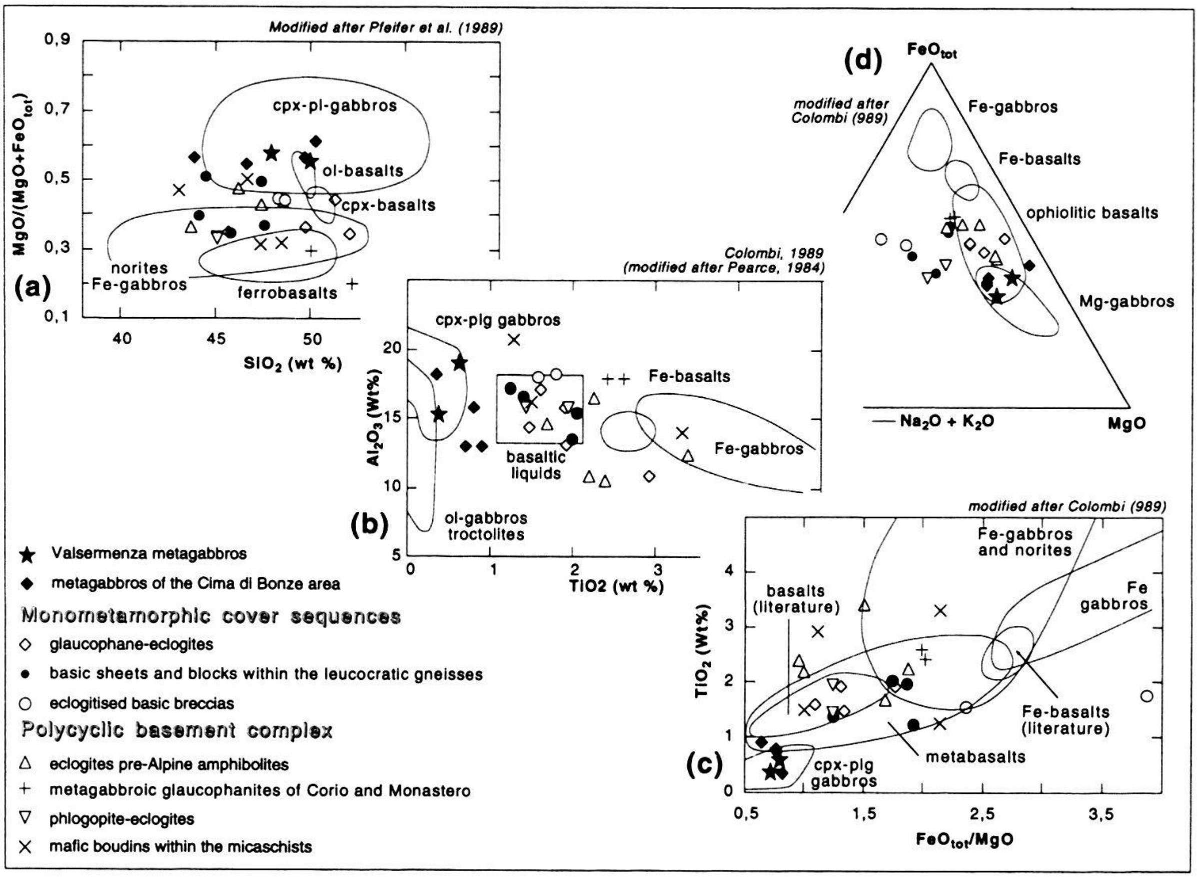

Fig. 3. Discriminative diagrams for mafic rocks. Mylonitic metagabbros and Valsermenza gabbros show high Mg contents while the monometamorphic metabasalts are enriched in Ti and constantly fall in the field of the basaltic liquid. Eclogitised basement amphibolites, as well as gabbroic glaucophanites of Corio and Monastero display Fe-rich basalt compositions.

magmatic textures (Bianchi et al. 1964; Dal Piaz et al. 1971; Compagnoni & Fiora 1977; Stünitz 1989; Chabloz 1990; Venturini et al. 1994); 3) eclogitised pre-Alpine amphibolites and/or granulites (Compagnoni et al. 1977; Lardeaux and Spalla 1991); and 4) metric to decametric bodies of mafic rocks within the late-Variscan granodioritic to granitic stocks (Armando 1992; Venturini et al. 1994) (Fig. 2c).

The monometamorphic cover sequences contain several different mafic lithologies, which can be grouped in:

1) metric to decametric masses of glaucophane-bearing eclogites, cropping out between the lower Gressoney valley and the Valchiusella (Venturini et al. 1994);
2) eclogitised mafic breccias, contained in a zoesite-white mica rich matrix and closely related to the glaucophane-eclogites (Venturini et al. 1994); and
3) decimetric to metric layers and boudins of partially re-equilibrated eclogites, interbedded with leucocratic albitic gneisses, dolomitic marbles and impure marbles (Venturini 1995) (Fig. 2a).

Table 1. Major and trace element analyses of mafic lithologies of the Sesia zone. Major and trace elements were measured with a Philips PW 1400 spectrometer, using a combined Mo-Sc tube. FeO/Fe_2O_3 ratio was determined with a Metrohm photometer (2s = 3–7 relative %), using the method of Hermann & Knacke (1973). Coulometer analyses (Ströhlein) permitted CO_2 determination (2s = 1–2 relative %). H_2O was calculated from loss on ignition and FeO-analyses. Standard error (2s) for the major elements was 2–6% relative (0.8 absolute % for the SiO_2) with a detection limit of 0.01 wt. %. For the trace elements, it was 5–10 ppm (10–30% relative), the detection limit varying between 2 and 5 ppm.

	mylonitic metagabbros				Valsermenza gabbros		gln-eclogites-metabasalts				basic breccias		basic levels and boudins			
(SV)	*912az*	*913az*	*914b*	*919b*	*9215vc*	*922i*	*915b*	*916b*	*9112b*	*911q*	*918b*	*9120c*	*9112c*	*9116c*	*9126c*	*9127c*
SiO2	49.93	47.89	49.75	43.91	50.22	46.63	48.6	46.19	43.68	47.44	52.11	49.98	45.72	51.25	52.04	49.72
TiO2	0.62	0.38	0.81	0.7	0.91	0.36	1.91	1.6	1.92	1.48	1.78	1.57	1.99	1.4	1.23	2.03
Al2O3	18.97	15.32	15.8	12.98	13.03	18.23	15.79	17.16	13.08	14.4	18.34	18.06	13.54	16.65	17.29	15.45
Fe2O3	1.18	0.69	1.1	4.7	2.43	7.58	0.44	2.73	0.89	0.26	6.09	3.19	2.43	2.4	2.46	1.29
FeO	5.52	8.57	5.67	7.87	3.88	0.8	9.04	6.75	10.22	10.91	4.68	6.58	8.86	5.86	5.59	9.12
MnO	0.12	0.17	0.13	0.18	0.09	0.12	0.2	0.19	0.24	0.17	0.13	0.2	0.24	0.16	0.11	0.19
MgO	8.3	12.65	8.76	15.75	9.53	9.28	7.23	8.39	6.25	8.35	2.63	4.02	5.93	6.45	4.09	5.9
CaO	9.95	9.28	11.31	7.34	12.84	11.33	10.69	10.86	10.97	9.43	3.63	5.75	9.69	5.14	6.69	8.28
Na2O	2.73	2.32	3.18	1.15	3.03	2.59	3.24	2.53	3.1	3.57	5.14	3.13	3.23	4.81	3.15	2.57
K2O	0.41	0.27	0.25	0.17	0.24	0.73	0.05	0.33	0.47	0.21	2.7	3.35	0.8	1.17	2.65	1.52
P2O5	0.1	0.04	0.06	0.05	0.05	0.01	0.21	0.06	0.19	0.11	0.06	0.06	0.19	0.25	0.16	0.37
H2O	0.85	1.6	2.21	4.47	1.79	1.49	1.69	2.53	2.46	2.27	1.56	2.36	2.46	2.74	2.95	2.38
CO2	0.77	0.99	0.13	0.05	0.3	0.2	0.18	0.05	5.61	0.88	0.16	0.88	4.47	0.96	1.29	0.28
Cr2O3	0.03	0.03	0.05	0.12	0.06	0.05	0.03	0.04	0.02	0.03	0.01	0.03	0.02	0.02	0.01	0.04
NiO	0.01	0.03	0.02	0.03	0	0	0.01	0.01	0.01	0.01	0	0	0.01	0	0	0.01
Tot	99.49	100.23	99.23	99.47	98.4	99.4	99.31	99.42	99.11	99.52	99.02	99.16	99.58	99.26	99.71	99.15
Nb	0	2	2	0	0	0	5	1	14	6	11	15	16	5	7	64
Zr	65	51	67	44	47	0	161	61	131	89	387	284	133	165	107	204
Y	9	5	16	7	13	4	37	16	28	31	58	61	28	27	18	34
Sr	428	330	343	57	200	247	240	459	234	162	101	161	212	301	654	250
Rb	11	9	13	6	7	19	4	11	24	11	84	121	34	56	109	70
Ga	12	7	9	5	8	15	13	13	14	14	29	23	15	14	13	14
Zn	70	91	47	70	29	61	79	50	137	133	123	157	138	78	100	168
Cu	25	8	0	34	0	25	13	0	92	112	0	0	90	13	0	9
Ni	85	192	109	252	78	127	65	54	42	92	0	10	45	36	0	76
Co	32	53	37	75	44	52	42	43	49	45	26	21	47	32	18	36
Cr	207	203	308	777	428	443	191	243	110	177	27	186	147	163	72	249
V	89	90	168	137	197	142	280	282	320	333	249	181	300	205	211	178
Ce	21	0	0	0	0	0	15	0	28	0	64	40	23	24	22	52
Nd	11	10	8	12	3	0	26	10	21	16	47	22	19	15	12	30
Ba	67	81	61	0	0	79	1	8	39	34	483	830	141	186	871	347
La	11	0	2	0	0	0	0	0	7	6	28	13	14	7	3	29
S	213	267	64	59	65	101	61	52	253	781	40	288	177	45	654	286

	eclogitised amphibolites					phl-eclogites		glaucophanites (Corio)		indistinct basement mafic rocks			
(SV)	*911v*	*932v*	*932v*	*933v*	*934v*	*914q*	*915q*	*9311lz*	*9312lz*	*9311ft*	*9313ft*	*913a*	*923i*
SiO2	45.77	44.01	47.49	44.41	47.29	48.31	48.6	45.05	45.11	46.67	47.32	48.41	43.0
TiO2	2.26	3.39	1.68	2.4	2.2	1.94	1.44	2.61	2.42	1.5	1.28	3.31	2.9
Al2O3	16.5	12.39	14.67	10.56	10.9	15.86	15.82	18	17.97	16.3	20.71	14.08	10.8
Fe2O3	2.84	2.98	4.01	3.82	3.03	6.3	2.99	6.22	6.32	3.89	3.82	7.41	3.9
FeO	8.63	10.98	7.62	8.25	9.26	3.26	6.08	4.89	5.14	6.05	4.21	5.38	9.8
MnO	0.2	0.17	0.17	0.15	0.16	0.18	0.14	0.09	0.11	0.17	0.09	0.24	0.2
MgO	5.97	9.07	6.67	12.29	11.99	7.21	7.03	5.28	5.37	9.66	3.58	5.65	12.0
CaO	10.59	9.77	11.11	8.12	8.03	8.51	7.56	10.47	9.98	6.67	10.02	7.5	10.7
Na2O	3.29	1.97	2.82	2.78	2.62	3.46	4.47	2.94	3.35	4.14	2.32	2.93	1.5
K2O	0.97	0.89	0.48	0.45	0.62	1.87	2.83	0.14	0.16	0.09	1.98	1	0.4
P2O5	0.27	0.44	0.14	0.29	0.3	0.42	0.3	0.72	0.5	0.16	0.3	0.27	0.36
H2O	2.02	2.25	1.88	3.64	2.38	1.4	1.49	2.42	2.47	3.51	2.73	2.68	2.6
CO2	0.08	0.6	0.4	1.9	0.4	0.34	0.62	0.3	0.2	0.3	0.3	0.26	0.7
Cr2O3	0.02	0.06	0.02	0.09	0.09	0.04	0.05	0.01	0.01	0.01	0	0.01	0.1
NiO	0.01	0	0	0	0	0.01	0.01	0	0	0	0	0	0.0
Tot	99.42	98.97	99.16	99.15	99.27	99.11	99.43	99.14	99.11	99.12	98.66	99.13	99.0
Nb	22	32	0	17	16	12	10	0	0	0	0	10	19.0
Zr	193	220	92	157	143	193	234	30	36	110	50	170	193
Y	31	24	26	20	20	33	35	19	16	20	10	29	21
Sr	211	445	405	277	190	273	228	544	527	372	441	245	149
Rb	11	19	16	13	13	120	208	6	6	4	20	35	4
Ga	14	24	19	18	20	13	12	20	21	17	22	17	21
Zn	103	154	111	152	168	86	94	121	128	137	68	121	158
Cu	41	20	82	0	0	18	31	0	0	0	0	32	23
Ni	34	237	82	360	364	85	94	18	12	75	4	8	416
Co	49	97	71	75	84	39	34	68	56	61	40	52	94
Cr	127	461	189	739	729	253	293	43	51	71	28	47	714
V	274	314	307	255	262	239	181	299	301	177	158	390	309
Ce	47	64	27	45	46	64	66	35	30	22	29	44	59
Nd	29	31	11	27	20	39	41	19	10	15	5	25	31
Ba	166	333	2	63	328	255	221	0	0	0	576	166	0
La	22	31	7	16	20	22	24	10	11	7	14	92	29
S	181	113	107	64	181	110	244	57	86	0	104	2	135

Table 2. Synoptic table of compositional and geochemical characteristics of the analysed samples. Question marks were used for uncertain determination.

rock type	*(SV 91)*	*locality*	Cr / Ni	Na_2O+K_2O / SiO_2	Al_2O_3 / TiO_2	$MgO/(MgO+FeOtot)$ / SiO_2	TiO_2 / $FeOtot/MgO$	SiO_2 / Nb/Y	Ti/Y / Nb/Y	TiO_2 / Zr/P_2O_5	Nb/Y / Zr/P_2O_5
			Fröhlich 1960	*Le Maitre 1968*	*Colombi 1989*	*Colombi 1989*	*Colombi 1989*	*Floyd & Winchester 1978*	*Pearce 1982*	*Floyd & Winchester 1975*	*Floyd & Winchester 1975*
metagabbro	4b	Bonze	magmatic	basalt	Mg-gabbros	cpx-pl-gabbro	Mg-gabbros	subalk. basalts	tholeiitic	tholeiitic	tholeiitic
metagabbro	9b	Bonze	magmatic	picrite	Mg-gabbros	cpx-pl-gabbro	Mg-gabbros	-	-	tholeiitic	tholeiitic
metagabbro	15vc	C. del Prà	magmatic	basalt	Mg-gabbros	cpx-pl-gabbro	Mg-gabbros	-	-	tholeiitic	tholeiitic
metagabbro	2i	Ivery	magmatic	basalt	Mg-gabbros	cpx-pl-gabbro	Mg-gabbros	-	-	-	-
metagabbro	2az	Sermenza	magmatic	basalt	Mg-gabbros	cpx-pl-gabbro	Mg-gabbros	-	-	tholeiitic	tholeiitic
metagabbro	3az	Sermenza	magmatic	basalt	Mg-gabbros	cpx-pl-gabbro	Mg-gabbros	subalk. basalts	tholeiitic	tholeiitic	tholeiitic
gln-eclogite	5b	Bonze	magmatic	basalt	basaltic liquid	cpx-pl-gabbro	basalts	subalk. basalts	tholeiitic	tholeiitic	tholeiitic
gln-eclogite	6b	Bonze	magmatic	basalt	basaltic liquid	cpx-pl-gabbro	metabasalts	subalk. basalts	tholeiitic	tholeiitic	tholeiitic
gln-eclogite	12b	Bonze	magmatic	basalt	basaltic liquid	cpx-pl-gabbro	basalts	subalk. basalts	tholeiitic	tholeiitic	tholeiitic
gln-eclogite	1q	Quincinetto	magmatic	basalt	basaltic liquid	cpx-pl-gabbro	basalts	subalk. basalts	tholeiitic	tholeiitic	tholeiitic
basic block	12c	Cavalcurt	intermed.	basalt	basaltic liquid	Fe-norite	metabasalts	subalk. basalts	tholeiitic	tholeiitic	tholeiitic
basic level	16c	Cavalcurt	intermed.	trachyandesite	basaltic liquid	Fe-norite	metabasalts	subalk. basalts	tholeiitic	tholeiitic	tholeiitic
basic block	26c	Cavalcurt	intermed.	trachyandesite	basaltic liquid	Fe-norite	metabasalts	subalk. basalts	tholeiitic	tholeiitic	tholeiitic
basic block	27c	Cavalcurt	intermed.	basalt	basaltic liquid	Fe-norite	metabasalts	alkaline basalts	alkaline	alkaline	alkaline
mafic breccia	8b	Bonze	sedim.	trachyandesite	basaltic liquid	?	?	subalk. basalts	tholeiitic	tholeiitic	tholeiitic
mafic breccia	20c	Cavalcurt	intermed.	trachybasalt	basaltic liquid	Fe-norite	Fe-norites	subalk. basalts	tholeiitic	tholeiitic	tholeiitic
glaucophanite	911v	C. Courma	intermed.	basalt	basaltic liquid	Fe-norite	basalt	subalk. basalts	trans.	tholeiitic	tholeiitic
glaucophanite	931v	C. Courma	magmatic	picrite	Fe-gabbro	Fe-norite	Fe-norite	alkaline basalts	alkaline	alkaline	alkaline
glaucophanite	2v	C. Courma	magmatic	picrite	Fe-basalt	Fe-norite	Fe-norite	subalk. basalts	trans.	tholeiitic	tholeiitic
glaucophanite	3v	C. Courma	magmatic	basalt	Fe-basalt	cpx-pl-gabbro	?	subalk. basalts	trans.	alkaline	tholeiitic
glaucophanite	4v	C. Courma	magmatic	basalt	Fe-basalt	cpx-pl-gabbro	?	subalk. basalts	trans.	alkaline	tholeiitic
phl-eclogites	4q	Quincinetto	magmatic	trachybasalt	basalt	cpx-pl-gabbro	basalt	subalk. basalts	tholeiitic	alkaline	tholeiitic
phl-eclogites	5q	Quincinetto	magmatic	trachybasalt	basalt	cpx-pl-gabbro	basalt	subalk. basalts	tholeiitic	tholeiitic	tholeiitic
glaucophanite	11lz	Corio	intermed.	basalt	Fe-basalt?	Fe-norite	Fe-basalt	?	?	alkaline	alkaline?
glaucophanite	12lz	Corio	intermed.	basalt	Fe-basalt?	Fe-norite	Fe-basalt	?	?	alkaline	alkaline?
glaucophanite	11ft	Fert	intermed.	basalt	basaltic liquid	cpx-pl-gabbro	metabasalts	?	?	tholeiitic	tholeiitic?
eclogite	3i	Ivery	magmatic	picrite	Fe-basalt?	cpx-pl-gabbro?	?	subalk. basalts	trans.	alkaline	tholeiitic?
amphibolite	3a	Arnad	intermed.	basalt	Fe-gabbro	Fe-norite	Fe-norite	subalk. basalts	tholeiitic	trans.	tholeiitic
gln-eclogite	13lz	Rocca C.se	sed.	basalt	?	Fe-norite	metabasalts	?	?	alkaline	?

Decametric to hectometric stocks of mylonitic metagabbros with eclogitic mineral parageneses in tectonic contact with the monometamorphic covers and rarely with the polycyclic basement (Venturini 1995) occur moreover in the central Sesia zone (Fig. 2c). Original igneous textures and preserved relicts of magmatic hornblende of these gabbroic masses are particularly well exposed in the Alpe Prà region (Valchiusella) and in the Cima di Bonze area. Geochemical analyses have been carried out on these rocks in order to confirm the origin and compare them with other gabbroic samples collected in the polycyclic basement.

Mobility of the elements and determination of possible protoliths

Table 1 contains the row data for all the above introduced rock types. A safe determination of the protoliths can only be done after a mobility test (Pearce 1984). Therefore, relative mobility of the chemical elements was determined by comparing major and trace elements with Zr, which is generally considered to be immobile during metamorphism (Beccaluva et al. 1984; Pfeifer et al. 1989). Most of the major elements do not show a linear correlation with Zr, although they displayed a reasonable elongated distribution within each lithological group. Trace elements (mainly Y, P, Cr, V) show, instead, a good linear correlation (Venturini 1995). The scattered distribution of the major elements could be explained by the different origin of the analysed lithologies, which may render Zr a poor element for the mobility test, although a strong and pervasive mobility of some major elements (mainly Ca and alkalis) during the metamorphism can be envisaged.

Intrusive and extrusive mafic rock can be distinguished using diagrams proposed by different authors and summarised in table 2 and figure 3 (Fröhlich 1960; Le Maitre 1969; Colombi 1989; Pfeifer, this work: modified after Colombi 1989). Figure 3 reports some of the more representative diagrams which allow gabbroic lithologies to be differentiated from metabasaltic rocks. On the basis of silica, iron, magnesium and titanium, the diagrams indicate that the metagabbros of the Valsermenz (north-eastern Sesia zone) and the mylonitic metagabbros of the Cima di Bonze region are clinopyroxene (cpx) – plagiociase (plg) gabbros in composition (Piccardo 1983; Pearce 1984; Colombi 1989; Pfeifer et al. 1989; (Fig. 3a-c). The glaucophane-eclogites, the mafic sheets and boudins within the leucocratic horizons and the basic breccias, referred by Venturini et al. (1991, 1994) to the monometamorphic covers (Fig. 2) are basalts in composition. The samples collected in the polycyclic basement (Fig. 2) show instead more differences in composition: the phlogopite-bearing eclogites have a basaltic protolith, while the eclogitised pre-Alpine amphibolites cropping out in the Croix Courma are mainly Fe-basalts and/or Fe-norites (Fig. 3a-c; Table 2). Compositions similar to the polycyclic amphibolites characterise also the metagabbro glaucophanites of Corio and Monastero (Bianchi et al. 1964), although they are slightly richer in silica (Fig. 3a).

Some of the samples are slightly enriched in alkalis (Fig. 3d); elevated K and Na concentrations characterise the monometamorphic mafic breccias related to the glaucophane-eclogites of basaltic composition, as well as two of the mafic layers interbedded within the leucocratic gneisses of the cover sequences (9116c, 9126c). This is probably due to a strong chemical exchange between the basic breccias and the phengite-clinozoisite-quartz-rich matrix during the metamorphism. Because of this mixing, results derived from the analyses of these samples have to be interpreted carefully.

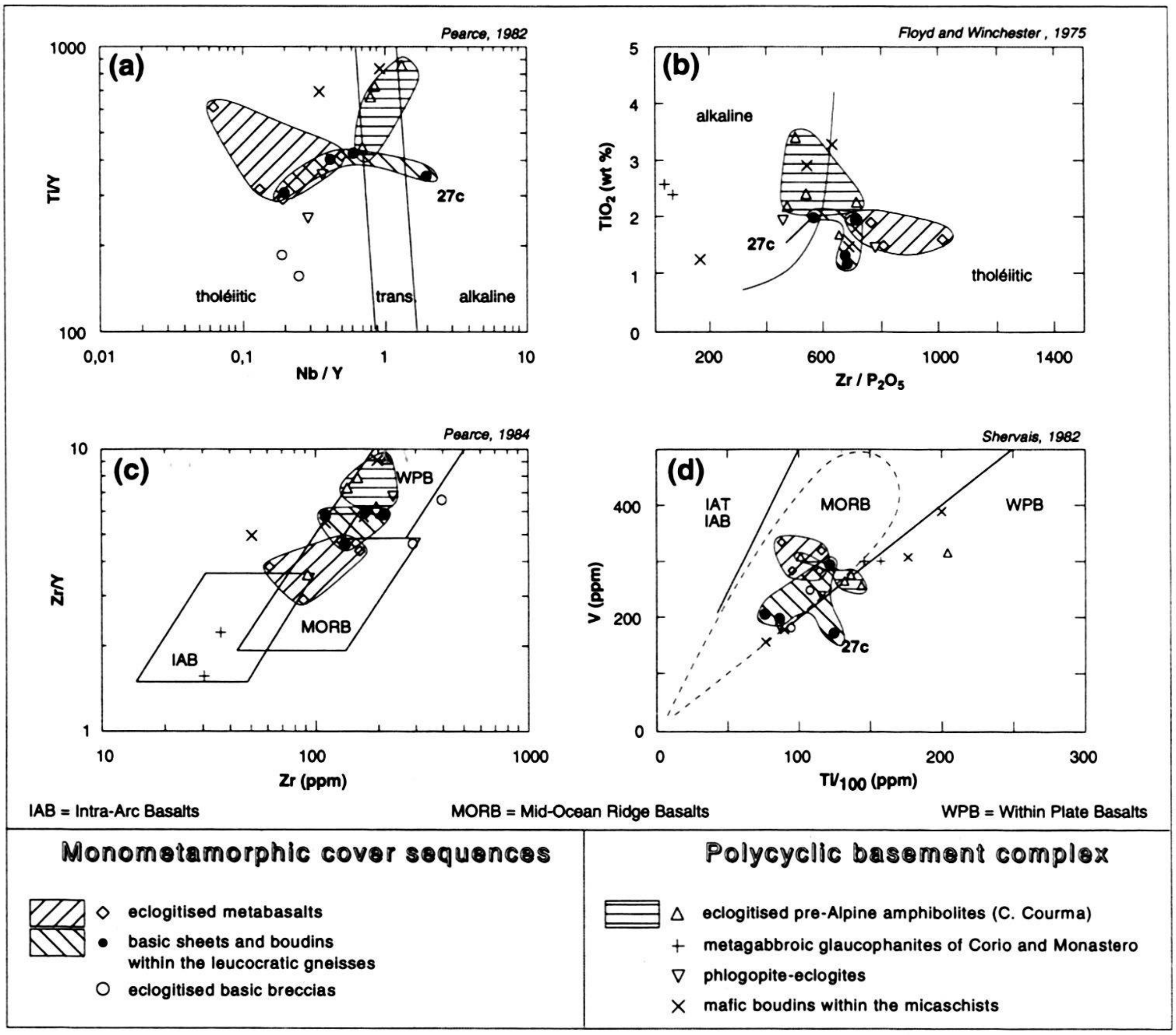

Fig. 4. Discriminative diagrams to determinate the geotectonic setting for the mafic rocks of basaltic composition. The transitional trend of the eclogitised amphibolites is clearly pointed out by the trace plot of Pearce (1982) (Fig. 4a). Sample 27c of the mafic levels and boudins within the leucocratic gneisses constantly show a different geochemical pattern in comparison with the other samples of its lithological group. This could be due to a different origin of this rock, probably deriving from a stongly mylonitised basement mafic boudin.

The geochemical composition of the different mafic groups of analysed samples can be summarised as followed:

1) the Valsermenza gabbros and the mylonitic eclogitised metagabbros in contact with the monometamorphic cover complex are Mg-gabbros with a low content in Ti;
2) monometamorphic cover lithologies: 2a) the glaucophane-eclogites, the mafic sheets and boudins interbedded with leucocratic gneisses are basalts in composition; 2b) the mafic breccias related to the glaucophane-eclogites show a variable composition from basalts to norites:

3) polycyclic basement lithologies: 3a) the eclogitised pre-Alpine amphibolites show a scattered distribution from basalts to Fe-norites; 3b) the phl-eclogites are trachybasalts to basalts in composition; 3c) the metagabbro-glaucophanites of the southern Sesia zone (Corio and Monastero mafic masses) are generally Fe-basalts in composition and 3d) the mafic boudins within the micaschists of the polycyclic basement show a strong variability in composition from basalt to Fe-gabbros and Fe-norites (Table 2).

Geotectonic setting of the mafic rocks of basaltic composition

The above results allow us to use more specific discriminative plots to determine the geotectonic setting of the basaltic rocks. Lithologies with an uncertain composition have been included in these plots, taking into account that their determinations are preliminary and need to be confirmed with more investigations (e.g. eclogitised pre-Alpine amphibolites of the Croix Courma). Figure 4 reports some representative diagrams used to determine the geotectonic origin and the evolutionary affinity of the basaltic lithologies. Particular attention was paid to the eclogitised metabasalts (glaucophane-eclogites) of the monometamorphic cover sequences, the mafic layer and boudins interbedded with the leucocratic gneisses and the eclogitised pre-Alpine amphibolites.

Diagrams using both major and trace elements (Floyd & Winchester 1975; Pearce 1982) indicate a tholeiitic affinity for the monometamorphic cover metabasalts (Fig. 4; Table 2) as well as for the mafic sheets and boudins (excluding sample 9127c). The eclogitised pre-Alpine amphibolites of the polycyclic basement display an intermediate to alkaline affinity. A similar trend is also shown by the mafic boudins within the polycyclic micaschists and by the metagabbro glaucophanites of the southern Sesia zone (Table 2).

The monometamorphic basalts are most likely Mid-ocean Ridge basalts (MORB) (Fig. 4 c–d; Shervais 1982; Pearce 1984). The mafic sheets and boudins of the monometamorphic cover sequences are instead characterised by a certain variance between MORB and Within-Plate Basalts (WPB) geotectonic origin (Table 3), which is also true for the mafic breccias related to the monometamorphic metabasalts. The eclogitised pre-Alpine amphibolites of the polycyclic basement are most likely WPB in origin (Table 3) as well as the mafic boudins within the polycyclic micaschists, while the glaucophanites of the southern Sesia (Corio and Monastero) are of uncertain origin.

Spider diagrams of figure 5 help to clarify further the geotectonic origin of the main mafic lithologies analysed in this study. The trace element trends, normalised against MORB (Pearce 1982) confirm the MORB origin for the monometamorphic cover basalts (Fig. 4a), as well as the WPB origin for the mafic layers and boudins interbedded with the leucocratic gneisses. A similar trend is shown also by the pre-Alpine amphibolites of the polycyclic basement.

Based on the results discussed above, we tentatively propose the following conclusions with regard to the protoliths. First, the glaucophane-eclogites of the monometamorphic cover sequences are derived from *tholeiitic mid ocean ridge basalts (MORB).* They differ from the pre-Alpine mafic lithologies in both their bulk chemical composition and their geotectonic affinity. Secondly, the basic boudins and sheets contained in the leucocratic gneisses are *tholeiitic WPB Fe-basalts,* more evolved than the eclogitised pre-Alpine amphibolites. They also differ from the amphibolites of the polycyclic basement in their relative enrichment in heavy trace elements and their depletion in light trace ele-

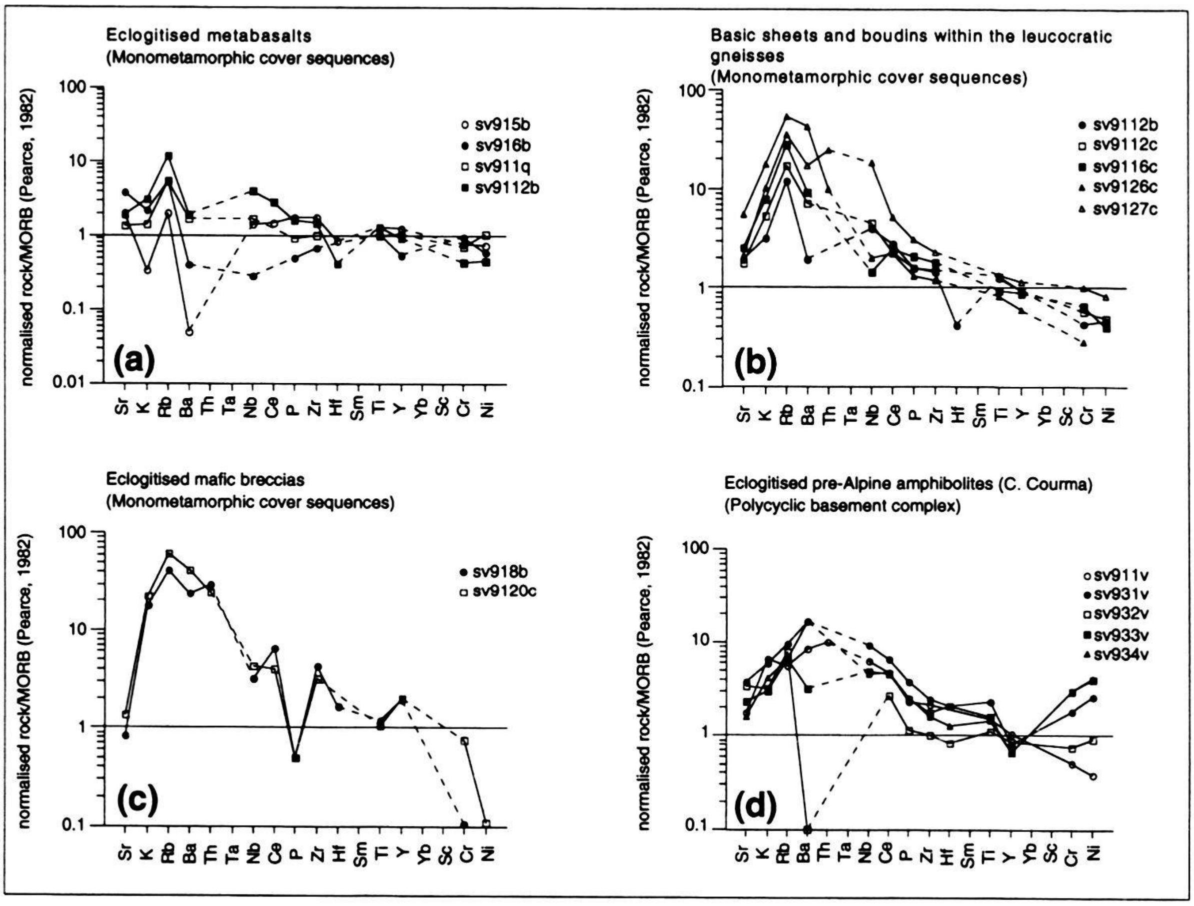

Fig. 5. Spider diagrams for the lithologic group of basaltic composition. The monometamorphic metabasalts show a typical MORB trend, while the other lithologies are characterised by WPB patterns. The profile of the eclogitised mafic breccias seems to exclude any direct correlation with the cover metabasalts, in spite of their close field relationships.

ments. Thirdly, the mafic breccias represent intermediate tholeiitic trachybasalts/trachyandesites, although they were affected by pervasive mobility of major elements, probably during oceanic plate metamorphism (spilitization) (Venturini 1995) and fourthly, there is a chemical similarity between the pre-Alpine amphibolites and the gabbroic glaucophanites of Corio and Monastero. Similar analogies have also been found in the basic boudins in the polycyclic micaschists (e.g. sample 923i).

Comparison of the metabasalts of the monometamorphic Cover Sequence with other metabasalts of the Alps

In the previous sections, we have distinguished between the MORB tholeiitic origin of the metabasalts (glaucophane-eclogites) of the Sesia zone monometamorphic cover and other mafic lithologies collected in both the basement and the cover units. Until now, mafic lithologies with similar composition have only been described for the pre-Alpine HG basement complex of Val Mastallone (northern Sesia zone, Simic 1992). These meta-

Table 3. Synoptic table of geotectonic characteristics and summary conclusions of the analysed samples. Question marks were used for uncertain determination.

rock type	(SV 91)	locality	Ti / Zr	Cr / Y	Ti/Y / Nb/Y	Zr/Y / Zr	V / Ti/100	T/100-Zr / Y*3	TiO2-10*MnO / 10*P2O5	T/100-Zr / Sr/2	Spider / rock/MORB	Conclusion
			Pearce 1984	*Pearce 1980*	*Pearce 1982*	*Pearce 1984*	*Shervais 1982*	*Pearce & Cann 1973*	*Mullen 1983*	*Pearce & Cann 1973*	*Pearce 1982*	
metagabbro	4b	Bonze	VAB	IAT	VAB	?	?	WPB	IAT	CAB	VAB?	tholeiitic Mg-gabbro (VAB?)
metagabbro	9b	Bonze	VAB	(IAT)		?	?	WPB	?	OFB	VAB?	tholeiitic Mg-gabbro (VAB?)
metagabbro	15vc	C. del Prà	VAB	IAT		?	?	WPB	OIA	LKT	VAB?	tholeiitic Mg-gabbro (VAB?)
metagabbro	2i	Ivery	-	(IAT)		?	?	WPB	?	OFB	VAB?	tholeiitic Mg-gabbro (VAB?)
metagabbro	2az	Sermenza	VAB	IAT		?	?	WPB	?	CAB	VAB?	tholeiitic Mg-gabbro (VAB?)
metagabbro	3az	Sermenza	VAB	IAT	WPB	?	?	WPB	CAB	CAB	VAB?	tholeiitic Mg-gabbro (VAB?)
gln-eclogite	5b	Bonze	MORB	MORB	MORB	MORB	MORB	LKT, OFB, CAB	MORB	OFB	MORB	tholeiitic Ti-basalts - MORB
gln-eclogite	6b	Bonze	MORB	IAT	MORB	MORB	MORB	LKT, OFB, CAB	OIT	OFB	MORB	tholeiitic Ti-basalts - MORB
gln-eclogite	12b	Bonze	MORB	MORB	MORB	MORB	MORB	LKT, OFB, CAB	OFB	OFB	MORB	tholeiitic Ti-basalts - MORB
gln-eclogite	1q	Quincinetto	MORB	MORB	MORB	MORB	MORB	LKT, OFB, CAB	OFB	OFB	MORB	tholeiitic Ti-basalts - MORB
basic block	12c	Cavalcurt	MORB	MORB	WPB	WPB	WPB	WPB	OFB	OFB	WPB	tholeitic Fe-norite - WPB
basic level	16c	Cavalcurt	VAB	MORB	WPB	WPB	WPB	WPB	OFB	OFB	WPB	tholeiitic trachyandesite - WPB
basic block	26c	Cavalcurt	MORB	IAT	WPB	WPB	WPB	WPB	CAB	CAB	WPB	tholeiitic trachyandesite - WPB
basic block	27c	Cavalcurt	WPB	MORB	WPB	WPB	WPB	WPB	OFB	OFB	WPB	alkaline Fe-norite - WPB
mafic breccia	8b	Bonze	WPB	WPB	?	IAT	MORB	CAB	?	?	WPB?	tholeiitic trachyandesite - WPB
mafic breccia	20c	Cavalcurt	WPB	WPB	?	IAT	WPB	CAB	?	?	WPB?	tholeiitic trachybasalt - WPB
glaucophanite	911v	C. Courma	WPB	WPB	WPB	WPB	WPB	WPB	OFB	OFB	WPB	tholeitic Fe-norite - WPB
glaucophanite	931v	C. Courma	WPB	WPB	WPB	WPB	WPB	WPB	OFB	OFB	?	alkaline Fe-norite - WPB ?
glaucophanite	2v	C. Courma	VAB?	WPB	WPB	WPB	WPB	WPB	OFB	OFB	WPB	tholeitic Fe-norite - WPB
glaucophanite	3v	C. Courma	WPB?	WPB	WPB	WPB	WPB	WPB	OFB	OFB	WPB	trans. Fe-basalt-WPB
glaucophanite	4v	C. Courma	WPB?	WPB	WPB	WPB	WPB	WPB	OFB	OFB	WPB	trans. Fe-basalt-WPB
phl-eclogites	4q	Quincinetto	WPB	WPB	WPB	WPB	MORB?	?	OIA	OFB	WPB?	tholeiitic trachybasalt - WPB?
phl-eclogites	5q	Quincinetto	WPB	WPB	VAB	WPB	MORB?	?	OIA	?	WPB?	tholeiitic trachybasalt - WPB?
glaucophanite	11lz	Corio	VAB?	IAT	?	IAT	WPB	?	OIA	?	?	trans. Fe-norite - WPB ?
glaucophanite	12lz	Corio	VAB?	IAT	?	IAT	WPB	?	OIA	?	?	trans. Fe-norite - WPB ?
glaucophanite	11ft	Fert	MORB?	IAT	?	MORB	MORB?	?	OIA	?	?	tholeiitic Ti-basalts - MORB ??
eclogite	3i	Ivery	WPB	WPB	WPB	WPB	WPB	WPB	LKT	LKT	?	trans. picrite-WPB
amphibolite	3a	Arnad	WPB	WPB	WPB?	?	WPB	WPB	?	?	WPB	tholeitic Fe-norite - WPB
gln-eclogite	13lz	Rocca C.se	VAB	IAT	?	?	WPB?	WPB	OFB	OFB	WPB	alkaline Fe-norite - WPB ?

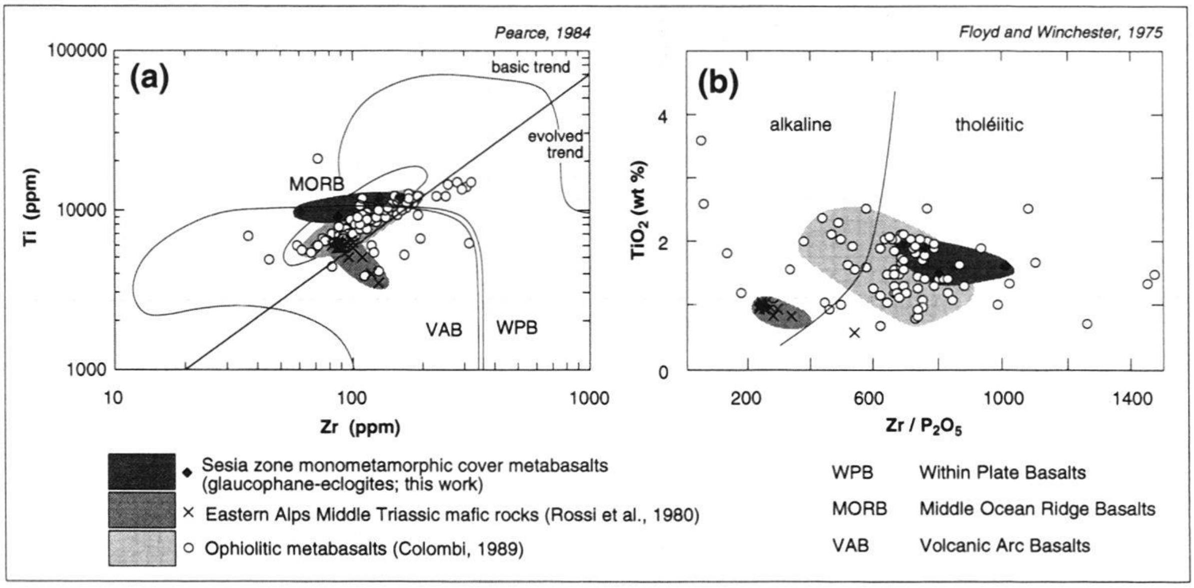

Fig. 6. Comparative diagrams between the Sesia monometamorphic metabasalts, the Middle Triassic volcanic rocks of the Eastern Alps and the metabasalts of the ophiolitic units of the Western Alps.

basalts are closely related on the field to other HG pre-Alpine rocks (II Diorite-Kinzigite Zone) such as garnet-sillimanite-biotite metapelites and felsic granulites. In the central Sesia zone, the metabasalts of tholeiitic composition are generally associated with dolomitic marbles, Mn-rich calcschists and other metasediments (Venturini et al. 1994; Venturini 1995). Field relationships with the surrounding monometamorphic lithologies reasonably exclude any correlation of these metabasalts to those described in the II DK by Simic (1992). The interbedding of these metabasalts with yellow dolomitic marbles, as well as the presence of blocks of the same lithologies within the calc-schists allowed Venturini et al. (1994) to suggest a Late Triassic–Early Jurassic emplacement age for these mafic rocks, on the hypothesis that the dolomitic marbles are Upper Triassic and the contacts with the metabasalts are only locally and partially transposed.

Assuming this Late Triassic-Early Jurassic emplacement age as tentatively correct, we propose a direct comparison with other mafic volcanic rocks of similar age. In the Central-Eastern Alps, several dikes of andesites and basaltic andesites crosscutting Middle Triassic dolomitic marbles have been described (De Zanche & Sedea 1972; Rossi et al. 1980; Castellarin et al. 1980, 1988; De Zanche 1990, with references). The Ladinian (Middle Triassic) magmatism of the Eastern Alps is mainly characterised by intercalations of trachyandesites with a volcanic arc-type calc-alkaline origin (Rossi et al. 1980; Castellarin et al. 1988), and thus prevents any potential correlation. The geochemical pattern of metabasalts of the monometamorphic cover sequences of the Sesia zone suggests, on the other hand, a possible affinity with the metabasalts of the Zermatt-Saas zone derived from Jurassic MORB (Dal Piaz et al. 1981; Piccardo 1983; Beccaluva et al. 1984; Pfeifer et al. 1989).

The metabasalts of the monometamorphic cover sequences are plotted in discrimination diagrams together with the Middle Triassic mafic rocks of the eastern Alps (data

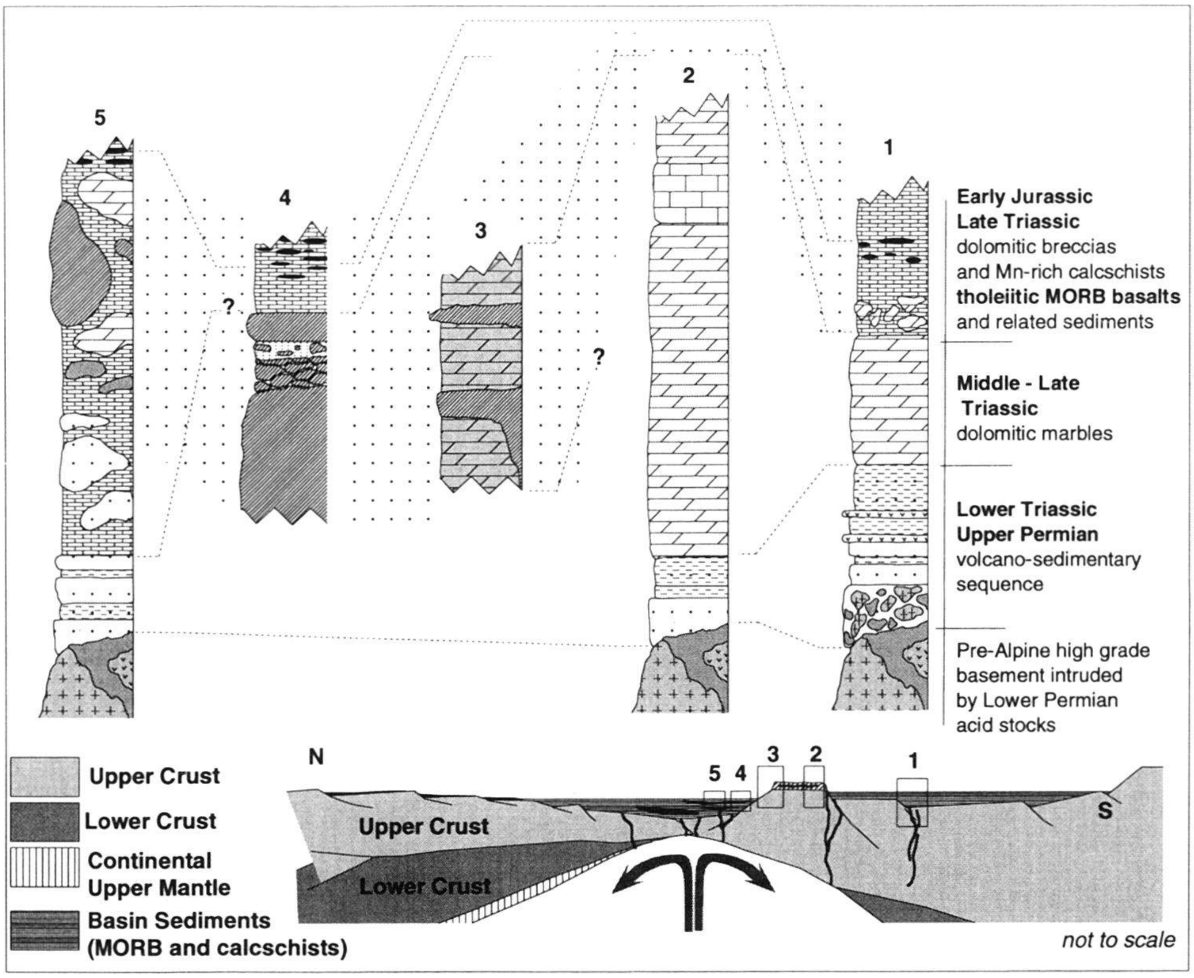

Fig. 7. Paleogeographic reconstruction of the emplacement of the monometamorphic metabasalts on the basis of their relationships with the other Mesozoic metasediments of the Sesia Zone (modified after Venturini 1995). Lithostratigraphic section locations: 1) Cavalcurt region; 2) Mombarone lake; 3) Cima di Bonze region; 4) upper Succinto valley; 5) Col Fenêtre region.

from Rossi et al. 1980) and the Penninic ophiolitic basalts analysed by Colombi (1989) and Pfeifer et al. (1989) (Fig. 6). Two distinct compositional fields can be recognised: the Middle Triassic mafic volcanics of the Eastern Alps have a low-Ti content in comparison to the ophiolitic basalts and the metabasalts of the monometamorphic cover sequences. Figure 6a clearly shows that the volcanic arc basalts (VAB) affinity of the Ladinian mafic rocks is different from the MORB affinity of the ophiolitic basalts and the Sesia Zone monometamorphic cover metabasalts. In addition, the calc-alkaline to shoshonitic affinity of the Middle Triassic extrusive rocks permits us to distinguish them from samples of tholeiitic affinity (Fig. 6b). The original chemistry and the geotectonic characterisation of the Ladinian mafic rocks exclude, therefore, any possible correlation with metabasalts of the monometamorphic cover sequences of the Sesia zone. The hypothesis of a Ladinian effusive magmatism in the Sesia zone, postulated by Venturini et al. (1994), similar to the volcanic activity in the cover sequences of the Eastern Alps, must be abandoned. However, the slightly higher TiO_2 content and V concentration of the metabasalts of the Sesia monometamorphic cover sequences with respect to the ophiolitic metabasalts is the only geochemical difference. This chemical similarity of the metabasalts of the Sesia monometamorphic covers with the ophiolitic metabasalts of the Penninic domain (Fig. 6), however, does not unequivocally prove that the Sesia cover sequences are a slice of Alpine ophiolitic units. Some fundamental features distinguish the metabasalts of the Sesia monometamorphic cover from those of the classic ophiolitic sequences. These features are: 1) the absence of the ultramafic components typical of an ophiolitic sequence (serpentinites) and 2) the presence of dolomitic marbles interbedded within the metabasalts. There are different explanations for the lack of serpentinites. A thin continental crust may have existed at the time of the emplacement of the MORB basalts of the Sesia cover sequences. The extrusive mafic rocks could have followed existing crustal fractures opened in a pull-apart basin or distal edge of the margin context. Alternatively, the ultramafic rocks were tectonically removed during the Early Cretaceous subduction of the basement and cover slices (Fig. 7).

The Mg-rich metagabbros in comparison to other Austroalpine gabbros

The gabbroic bodies associated with the monometamorphic cover sequences (Venturini 1991; Venturini et al. 1991; 1994) were compared to other mafic intrusive bodies of the Sesia zone and Dent Blanche system. The investigated basic rocks include: the Mont Nery gabbro (Stünitz 1989), the Cima del Pianone cumulate gabbros (Chabloz 1990), the Anzasca valley gabbroic and dioritic masses (Pfeifer, unpublished data), the Ivozio mafic outcrops (Compagnoni et al. 1977), the gabbroic stock of the Matterhorn and Mont Collon (Dent Blanche system, Fig. 1a; Dal Piaz et al. 1977) and the metagabbros of the Etirol Levaz slice (Kienast 1983). Unfortunately no geochemical data for the Testa Grigia gabbros (Dal Piaz et al. 1971) or the Sparone-region gabbros (Pognante et al. 1987) are available.

All samples are characterised by low-Ti content and fall in the field of Mg-gabbros and/or olivine-gabbros and troctolites (Fig. 8). The low-Ti content of the layered metagabbros is apparently due to fractional crystallisation of magnetite, during the inital phases of accumulation (Stünitz 1989). This genetic evolution could also explain the high-Ti concentrations shown by some ultramafic samples of the Matterhorn and Sermenza gabbroic stocks. The analysed data show moreover a tholeiitic evolutionary affinity (Table 2). The geochemical and emplacement characteristics of the Matterhorn and Mont Collon gabbroic stocks have been described in detail by Dal Piaz et al. (1977), who interpret these mafic intrusions as cumulate gabbros intruded at the upper mantle-lower crust boundary during the beginning of the post-Variscan opening phase of the Alpine Tethys. Some Rb/Sr and K/Ar work on intercumulus phlogopites of the Matterhorn and Mont Collon gabbros indicate an approximate cooling age of 260 Ma (*i.e.* Triassic-Permian boundary).

The similarities between the Bonze-type metagabbros and the other layered mafic intrusions of the western Austroalpine system suggest an analogous genesis and evolution. The Bonze gabbros could represent an under-crustal intrusion of Permian age (Dal Piaz et al. 1977). During the Cretaceous accretion/subduction phase, these basic stocks could have been juxtaposed to the monometamorphic covers. This interpretation would explain

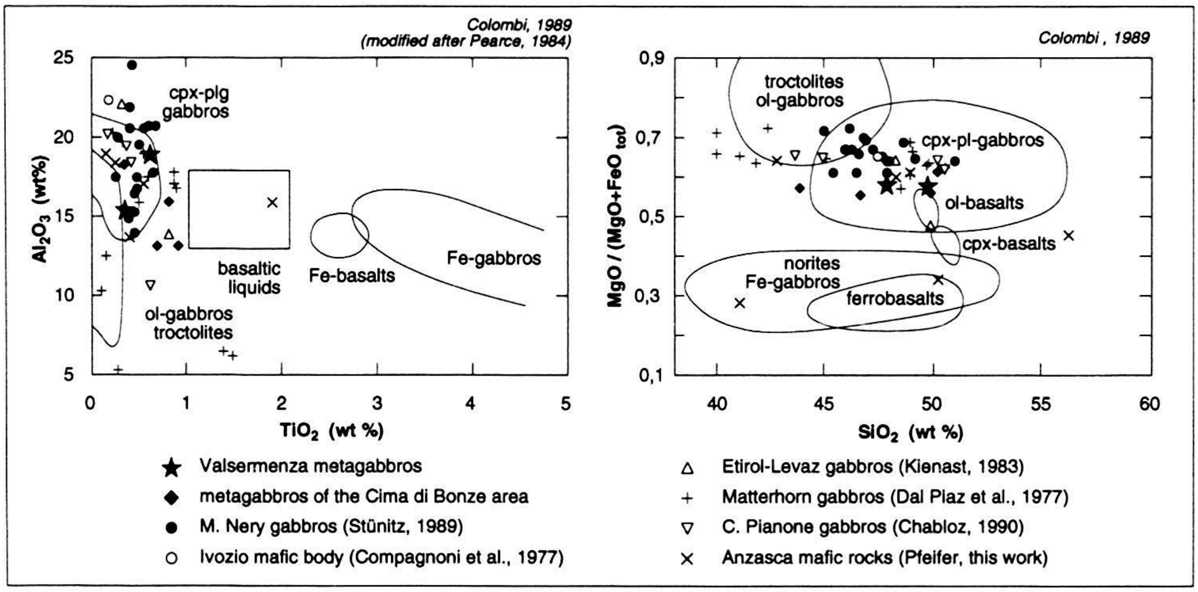

Fig. 8. Comparative diagrams between mylonitic Mg-metagabbros, Mg-gabbros of the Valsermenza and the available data of the other Western Austroalpine System mafic intrusions.

the juxtaposition with the monometamorphic covers of the gabbroic bodies without other mafic rocks (Alpe Prà, Scalaro; Fig. 1b) or, vice versa, the absence of the mylonitic metagabbros in contact with other mafic rocks in the Chiusella valley and in the Aosta and Crabun valleys.

Conclusions

The results of the geochemical analyses of twenty-nine mafic rocks from the Sesia zone provide new data for further paleogeographic and geodynamic interpretations of this western Austroalpine unit. Anyway they lead only to preliminary conclusions because of the following limitations: 1) each rock-group is represented by a small number of samples; 2) discriminative diagrams often use major and trace elements which cannot be considered totally immobile during metamorphism; 3) there is a certain overlap of the different lithological fields in the diagrams used to determinate the protoliths. In spite of this, we obtained a good correspondence between the geochemical data and the field observations:

1) analyses confirm the lithological differences and protolith attributions proposed in the field (metagabbros, metabasalts, etc. – Venturini 1991, Venturini et al. 1991)
2) there is a geochemical difference between the mafic rocks of the monometamorphic covers and those of the polycyclic basement;
3) two main mafic rock-types can be distinguished within the monometamorphic cover sequences.

In conclusion we can summarise what has been previously exposed: three main mafic protoliths can be pointed out in – or close to – the monometamorphic covers of the Sesia zone: 1) the Mg-gabbros, which show a strong affinity with the other intrusive basic stocks of the western Austroalpine system; 2) the tholeiitic MORB basalts and 3) the tholeiitic WPB Fe-basalts. The last two rock-types are closely related to the monometamorphic cover sequences.

A possible geodynamic and paleogeographic interpretation of the mafic lithologies of the monometamorphic cover sequences has been summarised in figure 7, following Venturini (1995): 1) in the Middle Permian, the continental crust intruded by the intermediate to acid bodies (Oberhänsli et al. 1985, and ref. therein) reached the surface. Deposition of a volcano-detritic sequence began. 2) During the Permo-Triassic, the progressive thinning of the continental crust permitted the emplacement of mafic sills and extrusions of tholeiitic affinity into detritic sediments composed of basement components. These mafic sheets were influenced by continental contamination (WPB signature). 3) During the Late Triassic, the paleomorphology of the Austroalpine basement was constituted of detached and tilted blocks of basement on the top of which carbonatic platforms and/or structural highs were forming. The continental crust was further thinned and crosscut by fractures, permitting the emplacement of MORB tholeiitic metabasalts. These metabasalts were extruded over and/or re-sedimented together with other detritic sequences (Venturini 1995; Venturini et al. 1994). They were successively involved in the Early Cretaceous subduction and underwent high pressure conditions.

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