

## Late-Hercynian mafic and intermediate intrusives of Serie dei Laghi (N-Italy)

EVELINA GIOBBI ORIGONI, ROSANGELA BOCCHIO,

ATTILIO BORIANI, MARCO CARMINE, LUISA DE CAPITANI

Dipartimento di Scienze della Terra, Sezione di Mineralogia, Via Botticelli 23, 20133 Milano

**ABSTRACT.** — The late-Hercynian extensional regime, set up near the «CMB» (Cossato-Mergozzo-Brissago Line, tectonical boundary between Serie dei Laghi and Ivrea-Verbano Line), allowed the emplacement of small basic-to-intermediate intrusive bodies of two main types:

1) A row of stocks and dykes, very similar to the Appinites of Ireland and Scotland, occurring along the CMB mostly on the Serie dei Laghi side. The heat carried by their intrusion induced partial melting of the gneissic country rocks of Serie dei Laghi between Val d'Ossola and Valsesia, which implies a rather deep seated environment.

2) Several dyke swarms, intruded before, during and after the emplacement of the granite batholith of Serie dei Laghi. The dykes are dark in colour and very fine-grained, and have therefore been described in the literature as «damprophyres». On textural grounds, we distinguish an older subgroup of vertical N-S dykes that was probably emplaced, in the Verbania area, in the same compressional regime that produced the Pogallo Line. Another subgroup consists of dykes, with dominating NE-SW direction, in the schists NE of the Mottarone-Baveno pluton, in structural continuity with the granitic batholith. One possible interpretation is that they represent the penetration of mafic magma through fissures into the roof of the ascending batholith. Many of these dykes show very deep hydrothermal alteration, indicating conspicuous fluid circulation above the granite bodies.

The general chemical features reveal that both Appinites and mafic dykes derive from a similar parental magma of calcalkaline affinity.

The structural features and the relationships to the country rocks of these intrusives suggest that the present structural setting of the Ivrea-Verbano - Serie dei Laghi boundary was basically established in late Hercynian times.

*Key words:* mafic dykes, dyke injection, calcalkaline characters, late Hercynian magmatism, Serie dei Laghi.

### Introduction

A comprehensive account of the geological setting and the role of the basic and intermediate intrusive rocks, occurring as small stocks or thin dykes in the Serie dei Laghi (northern Italy and Ticino, Switzerland), is still lacking. Nowadays improved general knowledge of the geology and petrology of the region enables us to make an attempt to fit all the published and unpublished data on these rocks into a rational framework.

These rocks received little attention till 1964, when REINHARD published a memoir on the Malcantone area, largely devoted to the dyke rocks. Further important progress was made in 1973, when BORIANI & SACCHI

recognized the important role of the small gabbrodiorite bodies occurring at the transition between Ivrea-Verbano and Serie dei Laghi (which they called «Appinites» due to their petrographic and geological similarity with the «Appinites» of Scotland and Ireland).

Nonetheless, in the past many authors described some of those rocks in petrographic papers dealing with small areas in which connection with the whole problem of late-Hercynian magmatism and the structural setting of the entire region was not taken into account.

These rocks can be divided in two groups: Group A includes the composite dykes and stocks («Appinites») occurring along the contact between Serie dei Laghi and Ivrea-Verbano, mostly in the Brissago, M. Cerano and lower Valsesia areas. These mafic and intermediate intrusive bodies are mostly parallel to the Cossato-Mergozzo-Brissago (CMB) Line and completely absent along the Pogallo Line, a transcurrent fault that intersects at a low angle the CMB (BORIANI and SACCHI, 1973).

Group B consists of swarms of generally thin mafic dykes mostly intruded in the Scisti dei Laghi where they are concentrated in some particular areas: they are very scarce S of Val d'Ossola and on the eastern shore of Lago Maggiore, but they are widespread in the Verbania area. On the basis of structural evidence it is possible to distinguish one subgroup (B1) of vertical N-S dykes, closely connected with the N-S fault system (BORIANI, 1970; BORIANI et al., 1977) of Valle Intrasca (south of M. Zeda). Another subgroup (B2)

of dykes shows highly dispersed orientation, although a dominating NE-SW direction, in structural continuity with the granitic batholith of the Serie dei Laghi, may be recognized (Fig. 1).

#### Group A: Appinites

As regards Group A, ARTINI & MELZI (1900) described the small bodies of diorites in the lower Valsesia as marginal facies of the Alzo-Roccapietra granite.

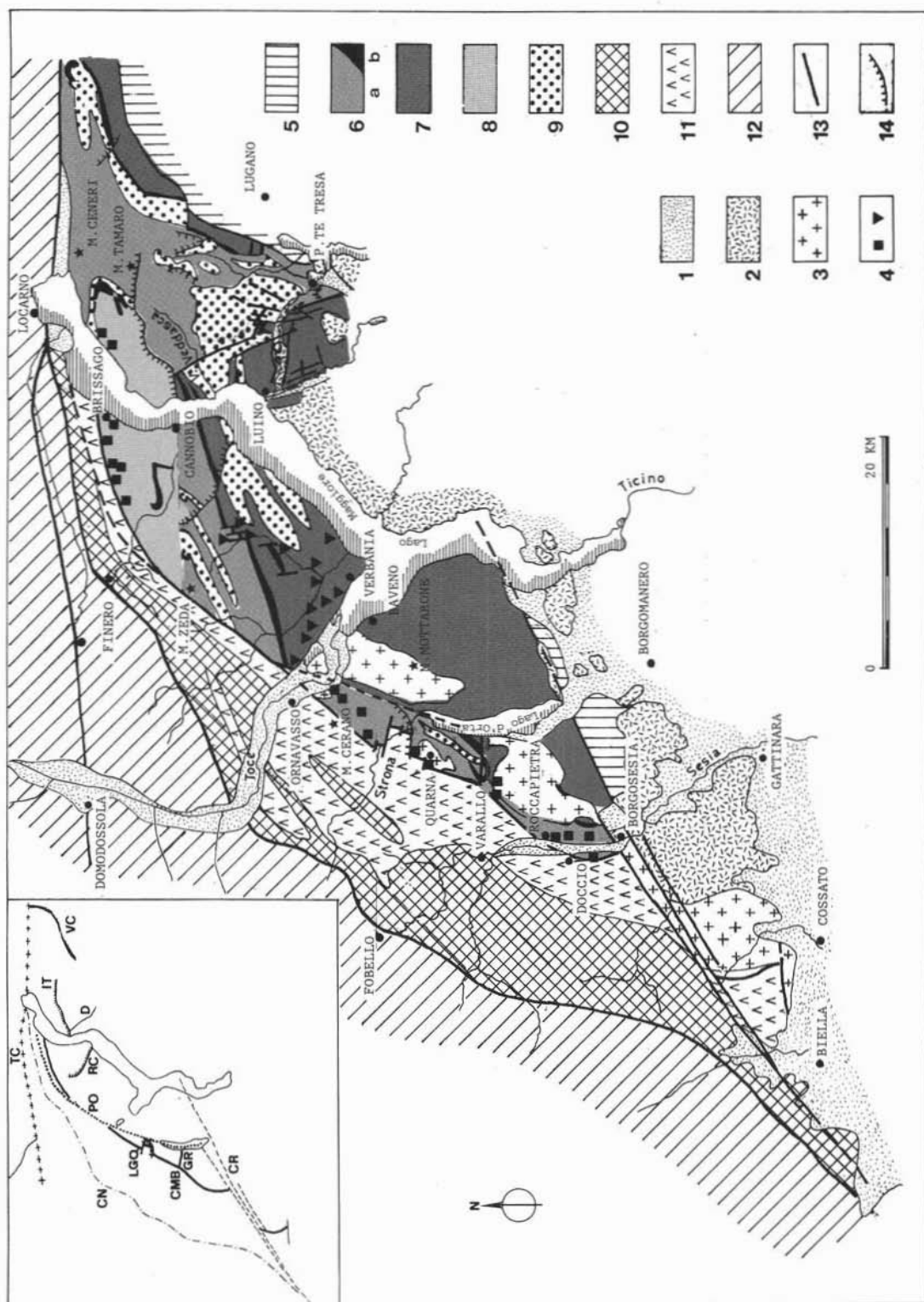
PREISWERK (1906), NOVARESE (1906), SUZUKI (1930) and BURRI & DE QUERVAIN (1934) described mafic dykes and stocks between Val d'Ossola and Lago Maggiore. A detailed petrographic description of the dykes near Brissago and of the contact metamorphism induced in their host rocks (formation of staurolite and sillimanite) was given by WALTER (1950).

SCHILLING (1957) and PEYRONEL PAGLIANI & BORIANI (1962) described the gabbrodiorite of Prà del Fico near Ornavasso as a pre-granitic intrusion. BORIANI and PEYRONEL PAGLIANI (1968) also noted that, near a tectonic lineament (Camponi - Sant'Andrea fault) in the lower Val d'Ossola, the texture of the gabbrodiorite becomes cataclastic and mylonitic due to late movements along the fault plane. BERTOLANI et al. (1963) mapped and described a mafic hornblende-bearing dyke S of Chesio in Val Strona.

BORIANI & PEYRONEL PAGLIANI (1968) published a quite detailed description and chemical analyses of the gabbrodiorites of the W slope of M. Cerano between Alpe Colletto and Ornavasso. The gabbrodiorite forms

Fig. 1. — Geological sketch-map of Massiccio dei Laghi (after BORIANI & SACCHI, 1973, modified).

1 - Pliocene and Quaternary. 2 - Volcanic and sedimentary Permo-Mesozoic cover. 3 - Late-Hercynian granites («Graniti dei Laghi»). 4 - Calcalkaline mafic stocks and dykes: full squares = «Appinites»; full triangles = mafic dykes. VAL COLLA ZONE: 5 - Schists, phyllonites, epidote-amphibolites, «Gneiss Chiari». SERIE DEI LAGHI: 6 - Strona-Ceneri Zone (a: paragneisses; b: metabasites and subordinate ultramafites). 7 - Scisti dei Laghi (micaschists, paragneisses). 8 - M. Riga and Gambarogno Zone: mainly Strona-Ceneri rocks with complex deformation. 9 - Orthogneisses. IVREA-VERBANO: 10 - Basic rocks, mainly in granulite facies, including some ultramafites and subordinate metasediments. 11 - Kinzigites (pelitic and semi-pelitic, high grade metasediments, with minor marble and amphibolite intercalations). 12 - ALPINE DOMAIN. 13 Faults: CN = Canavese; TC = Tonale-Centovalli; CMB = Cossato-Mergozzo-Brissago; LGQ = Val Lessa, Germagno, Quarna; GR = Grottaccio; PO = Pogallo-Lago d'Orta; CR = Cremosina; D = Val Dumentina; VC = Val Colla. 14 - Overthrusts: RC = Riale di Cannero; IT = Indemini-Monte Tamaro.



stocks or composite dykes, often with pseudobrecciated structure in which pods of gabbroic rock are embedded in a granitic matrix. The host rock is transformed into an agmatitic migmatite with pockets and dykes of granular neosome of anatectic origin.

BORIANI (1970) described for the first time the tectonic boundary (Pogallo Line) of the two main units of Massiccio dei Laghi, between Val d'Ossola and Val Pogallo. It is represented by a band of ductile blastomylonites, concordant with the foliation of the Ivrea-Verbano metapelites and discordant with the Strona-Ceneri gneisses.

BORIANI & SACCHI (1973) recognized that the contact between Ivrea-Verbano and Strona-Ceneri (Serie dei Laghi p.p.) is mostly tectonic between the Biellese and Lago Maggiore, and called the discontinuity Cossato-Mergozzo-Brissago Line (CMB). The presence of blastomylonites identifies most of this old tectonic boundary, which is also characterized by the presence mainly on the Serie dei Laghi side, of a row of basic and intermediate small plutonic bodies («Appinites») and a belt of anatectic migmatites. The presence of blastomylonites and migmatites indicates that the development of that fault occurred at quite high T and P. The Pogallo Line, which cuts across the CMB Line at a small angle, is also characterized by the occurrence of blastomylonites, but neither «Appinites» nor the migmatite belt. Both the CMB and Pogallo Lines show features of strike-slip vertical faults.

BORIANI & SACCHI (1974) admitted that, despite this indication of important strike-slip movements, the two faults should also have played an important role of normal fault in the juxtaposition of Serie dei Laghi (upper-intermediate crust) and Ivrea-Verbano (lower crust).

The Appinites of the Brissago area were described in detail by BORIANI et al. (1974).

From the Lago Maggiore shore to the upper Val Cannobina the contact between Serie dei Laghi and Ivrea-Verbano seems to be transitional. The Appinites mostly form concordant composite dykes that are intruded into both units near their boundary. In the

smaller dykes the grain size of the mafic rocks may be extremely fine. In this paper the authors suggest that the Appinites and other mafic dykes of Serie dei Laghi («lamprophyres») have the same origin and age; their chemical composition is very similar. The different textures are probably due to locally different  $P_{H_2O}$  and T conditions

during their intrusion. The age of intrusion is late-Hercynian, though older than that of the Graniti dei Laghi.

ORIGONI GIOBBI et al. (1975) gave petrographical and petrochemical data on the small bodies of calcalkaline intrusive rocks of the lower Valsesia between Doccio and Agnola. Though notably different from those of M. Cerano, these rocks show unequivocal similarities with the other Appinites of Serie dei Laghi.

BORIANI et al. (1977) described in detail the NE part of the CMB Line, where the Appinitic dykes of Brissago - Val Cannobina occur. The CMB is no longer characterized by blastomylonites and the migmatite belt; the Pogallo Line vanishes in a rather thick belt of blastomylonitic kinzigites flanking the mafic rocks of the Ivrea-Verbano Zone. The dyke swarm become increasingly thinner towards W, i.e. towards the Pogallo Fault. The authors also noticed that the Appinites are sometimes foliated, but never blastomylonitic. These characters and the absence of Appinites along the Pogallo Line suggest that both the CMB and Pogallo Lines were formed before the intrusion of the Appinites; when compression ceased, the opening of space allowed the intrusions to occur only along the inactive CMB and not along the younger, active Pogallo Line, where the release of stored elastic strain prevented any opening of fissures. The presence of foliated Appinites means that extension and intrusion were initially accompanied by some strike-slip movements.

#### *Group B: Mafic dykes*

Description of mafic dykes in the Ceneri Zone (Serie dei Laghi p.p.) in the Sottoceneri region of Canton Ticino (Switzerland) appeared in the papers of KELTERBORN (1923),

BEARTH (1932) and BAECHLIN (1937). In 1964 REINHARD published a systematic study of the mafic dykes of Sottoceneri. He adopted a classification based on their texture and mineralogical composition that was also later used by the Italian authors for the Lago Maggiore area. On the basis of field characters, Reinhard distinguished concordant dykes with constant thickness, and discordant dykes, often intruded along fault planes, showing strongly variable thicknesses along the strike. Reinhard also proposed a connection between the mafic dykes of Sottoceneri and the Permian volcanics of the Lugano area.

MERCALLI (1885) described a vertical dyke with SE strike of «diorite porfiroide» on M. Rosso, near Pallanza, and other dykes with NE strike along the lake shore near Intra. The dykes occurring near Lago di Mergozzo, between Mergozzo and Fondotoce, were described by PREISWERK (1906) as «malchite» and «vintlite». Preiswerk referred their origin to the near Montorfano granite stock.

BORIANI (1970) noticed, as did REINHARD (1964) in the Sottoceneri, that also in the Verbania area some of the dykes are connected with faults, namely, the N-S dykes of Valle Intrasca, which are intruded along vertical strike-slip faults. He concluded that there should be some genetic link between faults and dykes.

BORIANI et al. (1977) published a 1:50,000 geological map of the Verbania area, in which the mafic dykes are distinguished from the «Appinites». In the explanatory notes to the map, the authors put particular emphasis on the abundance of dykes in the NE area of Mottarone-Baveno pluton.

In the following years the differences between the «Appinites» and the mafic dykes became more and more clear to the authors. Both are late-Hercynian but the «Appinites» appear as early intrusions at depth, whilst the mafic dyke swarms N of Verbania appear connected with the epiplutonic intrusion of the granites. BORIANI et al. (1985) and GIOBBI ORIGONI (1987) defined the «Appinites» as pre-uplift intrusives and the mafic dyke swarms as post-uplift.

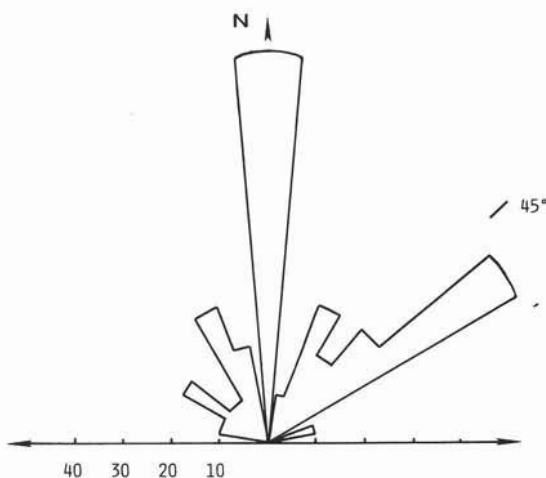


Fig. 2. — Rose diagram showing the distribution of strike of mafic dykes in Serie dei Laghi: they may be grouped into two sets trending N-S (subgroup B1) and N 60° E (subgroup B2).

#### *Relationships between mafic dykes and «Graniti dei Laghi»*

Mafic dykes connected with the «Graniti dei Laghi» have been known since 1895, when TRAVERSO described the diabase porphyrite of M. Camoscio (Baveno). Other mafic dykes in the same region were described by KAECH (1903), BALK (1924), and PARKER (1926). The latter described a spessartite dyke with chilled margins in a granite quarry of Baveno.

GALLITELLI (1937) published chemical analyses of the dykes (a camptonite and a vogesite spessartite) crossing the granite near Oltrefiume and Feriolo. He noted that the central part of the dykes is richer in silica than the margin; the presence of chilled margins and the cross-cutting character (the dykes fill fractures in the granite) indicated that the dykes are post-granitic.

GALLITELLI (1938) noted the presence of a thin (25 cm) dyke in the episyenitized facies of the Montorfano granite known as «granito verde di Mergozzo»; the dyke shows the same alteration as its host rock.

SASSI (1985) describes both syngranitic and postgranitic dykes in the Montorfano and Mottarone-Baveno plutons. The syngranitic dykes are disrupted and boudinated, and have



reacted to some extent with the granitic magma, whilst the postgranitic ones preserve their individuality and did not react with the granite.

## Age

Geological evidence indicates that the Appinitic stocks and dykes predate the emplacement of the main granite bodies (e.g. presence of enclaves of Appinites in the granites, different tectonic regimes involved in emplacement mechanisms, characters of contact metamorphism induced in the country rocks).

The only radiometric age measurement published so far is the concordant U/Pb monazite age of 285 Ma on an Appinitic dyke from Mergozzo (CUMMING et al., 1987).

Whole-rock Rb/Sr data on other Appinite-related rocks in HUNZIKER (1974) and HUNZIKER & ZINGG (1980) are included in the WR Rb/Sr isochron on the granites ( $276 \pm 5$  Ma, i.r.  $0.7087 \pm 0.0009$ ).

An indirect estimation of the age of the intrusion of the Appinites comes from another U/Pb concordant monazite age of  $295 \pm 5$  Ma (KOEPEL, 1974) on an Appinite related migmatite from the lower Val Strona.

A systematic Rb/Sr survey on the Appinites has been performed by PINARELLI et al. (1988).

## Geological setting and petrographic characters

### Appinites

The Appinites occurring in the Brissago, M. Cerano and lower Valsesia areas have been described at length by various authors, as mentioned above; we will only recall briefly their outstanding petrographic characters.

The Appinites of the Serie dei Laghi consist of a row of stocks and dykes of gabbrodioritic or dioritic composition. Three main areas of occurrence may be distinguished.

In the Brissago area the dominating rock type is a hornblende-biotite gabbrodiorite with a pseudobrecciated, sometime foliated, marginal facies. The pseudobreccias consist of fragments of foliated gabbrodiorite

TABLE 1

*Chemical analyses for major (wt%) and some trace elements (ppm) of selected samples of Appinites from Serie dei Laghi*

Sample	AC30A	AC3	AC7	AC4A	AC19C	AC30B	AC19A
SiO <sub>2</sub>	50.46	45.98	51.02	49.73	66.08	57.70	61.29
TiO <sub>2</sub>	1.46	1.39	1.23	1.54	0.46	1.03	0.79
Al <sub>2</sub> O <sub>3</sub>	15.54	14.45	15.98	17.30	17.34	16.99	17.58
Fe <sub>2</sub> O <sub>3</sub>	2.09	1.51	2.28	1.90	1.61	2.14	2.15
FeO	7.07	7.29	6.57	5.00	2.00	5.00	3.29
MnO	0.18	0.19	0.20	0.13	0.05	0.15	0.10
MgO	8.23	12.41	7.84	4.48	2.19	4.19	2.70
CaO	8.72	6.29	8.92	6.81	3.73	7.32	5.20
Na <sub>2</sub> O	2.62	2.41	2.03	5.82	3.60	2.12	2.66
K <sub>2</sub> O	1.14	2.98	1.33	2.16	1.63	1.45	2.04
P <sub>2</sub> O <sub>5</sub>	0.37	0.59	0.36	0.70	0.28	0.27	0.38
H <sub>2</sub> O <sup>+</sup>	2.16	3.81	2.55	3.62	1.48	2.18	2.41
Total	100.04	99.30	100.31	99.19	100.45	100.54	100.59
Ba	240	510	260	520	320	380	380
Rb	38	66	55	45	72	57	80
Sr	439	425	361	990	434	475	520
Y	30	18	29	23	16	34	27
Nb	11	52	10	65	13	18	22
Zr	140	154	117	208	91	183	244
Cu	34	5	26	10	14	21	10
Ni	65	210	69	31	11	27	11
V	272	123	257	107	68	169	64
Cr	224	230	262	40	16	64	26
Th	3	3	3	5	9	6	6

*Localization of analyzed samples: AC30A - near Brissago - MS74640684; AC3 - Val Cannobina - MS69820446; AC7 - Val Cannobina - MS69900478; AC4A - Val Cannobina - MS69820446; AC19C - near Brissago - MS74850660; AC30B - near Brissago - MS74760756; AC19A - near Brissago - MS74850660*

cemented by a leucocratic granodioritic or aplitic matrix. Most of the dykes are composite, ranging in composition from gabbrodiorite to granodiorite. An outer fine-grained and an inner medium- or coarse-grained part may be distinguished.

The foliated, external part of the dykes consists of elongated crystals of a weakly pleochroic hornblende, a zoned plagioclase, sometimes with sharp zoning with calcic cores (up to 65% An) and an outer, more sodic part (35-45% An). Biotite strongly pleochroic, is very rare. In the inner part of the dykes the hornblende (often showing ilmenitic exolutions), is sometimes present as «hollow crystals» with inclusions of biotite or plagioclase. In the more acidic rocks (from granodiorite to aplite) biotite, K-feldspar and

TABLE 2

*Chemical analyses for major (wt%) and some trace elements (ppm) of vertical N-S dykes (subgroup B1)*

Sample	D1	D8A	D8B	D7B	D7C	LPVC76	PC68	PC75	PC118	PC58	PC64
SiO <sub>2</sub>	53.47	46.20	44.81	47.66	46.28	49.24	45.74	46.61	44.85	42.33	48.93
TiO <sub>2</sub>	1.00	1.24	1.07	1.22	1.22	0.95	1.05	1.19	1.75	2.22	1.02
Al <sub>2</sub> O <sub>3</sub>	16.94	15.88	14.94	15.73	15.18	14.85	12.76	12.99	12.13	12.34	15.28
Fe <sub>2</sub> O <sub>3</sub>	2.18	3.20	2.92	3.03	3.71	2.01	3.07	2.80	3.11	5.66	2.99
FeO	5.56	6.48	6.45	6.17	5.05	6.19	7.58	6.88	6.64	7.17	6.04
MnO	0.13	0.18	0.17	0.17	0.14	0.14	0.19	0.15	0.18	0.22	0.16
MgO	6.44	9.51	10.14	8.76	9.15	9.52	13.05	13.89	13.14	13.55	11.59
CaO	7.29	7.16	7.43	7.92	8.14	8.08	8.48	7.82	7.41	9.11	5.98
Na <sub>2</sub> O	2.32	2.83	1.57	2.40	3.31	2.06	1.69	1.46	2.27	1.85	1.48
K <sub>2</sub> O	1.93	1.05	2.14	1.88	1.72	1.26	1.40	0.89	2.12	1.27	2.16
P <sub>2</sub> O <sub>5</sub>	0.16	0.17	0.19	0.20	0.21	0.18	0.22	0.27	0.49	0.40	0.30
H <sub>2</sub> O <sup>+</sup>	3.52	6.53	8.03	4.95	5.33	5.71	4.50	5.07	6.46	3.55	3.78
Total	100.94	100.43	99.86	100.09	99.44	100.19	99.73	100.02	100.55	99.67	99.71
Ba	400	200	350	300	180	300	350	230	550	340	400
Rb	140	63	125	96	45	60	59	61	80	29	116
Sr	320	420	368	435	650	384	469	290	713	526	474
Y	26	27	28	30	30	22	40	30	26	27	23
Nb	8	10	8	10	9	7	4	8	50	15	10
Zr	118	125	117	123	120	120	95	130	193	150	151
Cu	35	19	18	15	19	21	60	28	38	30	20
Ni	35	64	62	50	60	120	200	261	355	165	163
V	225	245	240	212	215	201	255	182	140	320	182
Cr	145	190	177	160	165	430	880	580	360	485	540
Th	7	7	4	4	6	9	4	4	9	10	12

*Localization of analyzed samples: D1 - M. Todano - 65709538; D8A and D8B - M. Morissolo - 71329600; D7B and D7C - M. Morissolo 71509600; LPVC76 - Val Cannobina - 73800175; PC68 - Valle Intrasca - 67809570; PC75 - Valle Intrasca - 69609340; PC118 - M. Morissolo - 71809648; PC58 - Valle Intrasca - 94446858; PC64 - Valle Intrasca - 68209550*

quartz are common minerals. Melanocratic dykes with small stubby individuals of pyroxene enclosed in the poikilitic hornblende are quite rare. Accessory minerals are sphene, apatite, epidote, zircon and rutile. Garnet is present only in some aplitic veins.

The host rocks of the Appinite swarm are mostly the ortho- and paragneisses of the M. Riga Unit. This unit is exposed in a triangular area with its base on the Lago Maggiore shore and vertex against the Pogallo Line. It consists of three parts (BORIANI et al., 1977) of which the two more southernly ones belong without any doubt to the Strona-Ceneri Zone. The northern subunit, composed exclusively of rather fine-grained paragneisses of the staurolite-sillimanite zone, seems to pass gradually to the kinzigites of the Ivrea-Verbano Zone. BORIANI et al. (1977) put

forward the idea that the north M. Riga unit could represent the equivalent of Scisti dei Laghi, i.e. the northern limb of the main fold of Serie dei Laghi with its hinge in the Ceneri Pass Zone (Ticino - Switzerland). HANDY (1986) considers that subunit as belonging to the Ivrea-Verbano Zone.

The regional metamorphic pattern in the M. Riga Unit is far from being unequivocal, due to the complex deformational history of this region. The northern part of the Serie dei Laghi underwent very intense lamination during the formation of its «Schlingenbau» structure. This lamination was accompanied by a retrograde (or retrogressive) metamorphism in greenschist facies conditions, which is particularly evident in the strongly sheared rocks of the southern part of the M. Riga Unit. The complex regional

TABLE 3

*Chemical analyses for major (wt%) and some trace elements (ppm) of NE-SW dykes (subgroup B2)*

Sample	C6Y	D2B	D2C	D6A	PA26	PA55	PA154	V2A	PA15	PC45
SiO <sub>2</sub>	50.51	48.83	49.12	47.86	50.85	59.67	50.82	57.11	48.30	55.15
TiO <sub>2</sub>	1.63	1.07	1.04	1.47	0.92	1.05	1.17	1.09	1.56	1.33
Al <sub>2</sub> O <sub>3</sub>	15.77	16.20	15.31	15.74	15.74	17.30	16.06	16.01	14.73	16.44
Fe <sub>2</sub> O <sub>3</sub>	2.56	2.18	2.85	2.87	1.85	0.96	1.35	1.54	2.62	1.89
FeO	8.17	5.71	5.24	6.93	5.98	5.14	7.00	5.24	7.10	6.46
MnO	0.15	0.13	0.13	0.15	0.12	0.09	0.15	0.08	0.15	0.14
MgO	8.82	9.78	10.53	9.11	9.68	2.59	9.05	4.69	8.84	4.91
CaO	4.70	5.55	6.60	6.28	5.87	4.10	7.40	2.87	7.47	6.53
Na <sub>2</sub> O	2.31	2.39	1.88	2.64	1.99	3.40	2.61	2.93	1.84	1.95
K <sub>2</sub> O	1.06	1.90	1.96	1.81	2.27	3.12	1.47	3.17	1.98	1.93
P <sub>2</sub> O <sub>5</sub>	0.39	0.18	0.21	0.36	0.18	0.22	0.25	0.26	0.34	0.28
H <sub>2</sub> O <sup>+</sup>	4.53	6.30	4.91	4.59	4.80	2.51	2.94	4.70	4.97	2.61
Total	100.60	100.22	99.78	99.81	100.25	100.15	100.27	99.69	99.90	99.62
Ba	250	440	420	400	500	550	330	500	310	330
Rb	36	111	89	93	155	176	80	188	156	108
Sr	265	356	482	349	315	366	369	178	387	342
Y	35	19	20	34	25	30	25	30	33	39
Nb	15	10	8	13	7	12	8	13	14	12
Zr	230	132	125	200	138	200	140	193	205	200
Cu	19	30	15	21	33	9	10	22	25	17
Ni	108	145	166	120	152	2	145	28	110	11
V	209	200	195	202	190	158	180	180	203	225
Cr	291	345	360	319	435	5	435	77	245	58
Th	5	12	11	6	12	16	8	11	6	8

*Localization of analyzed samples: C6Y - M. Todano - 62209340; D2B and D2C - Valle Intrasca - 67909103; D6A - Valle Intrasca - 70689428; PA26 - near Verbania - 63258876; PA55 - near Verbania - 60858952; PA154 - near Mergozzo - 57898920; V2A - near Verbania - 65238737; PA15 - near Verbania - 62108780; PC45 - M. Zeda - 63889794*

metamorphic pattern was further complicated by the thermal disturbance induced by the intrusion of the Appinites: andalusite and sillimanite, often overgrowing kyanite, are the characteristic minerals near the Appinitic dykes of the middle M. Riga subunit.

In the lower Val d'Ossola the Appinites consist of stocks of remarkable size (about 2 sq.km E of M. Cerano). Their texture and mineralogical composition are quite similar to those of the Appinites of Brissago. The plagioclase is commonly zoned (core: 46-47% An; rim 25-30% An); the mafic mineral is mostly an elongated and corroded hornblende, rich in ilmenitic inclusions. Biotite, always associated with hornblende, forms characteristic nest-like aggregates that are also visible to the naked eye. Sphene, apatite and pistacite are accessory minerals. Quartz and

K-feldspar only appear in the leucocratic veins.

In the lower Valsesia the calcalkaline intrusive rocks are represented by tonalites, granodiorites and norites, associated with typical hornblende-rich Appinites. Their geological setting is basically identical to that of the M. Cerano and Brissago Appinites, since they are intruded mostly in the Strona-Ceneri ortho- and paragneisses, showing the same strong anatectic mobilization as in the lower Val d'Ossola. The prevailing rock is a very heterogeneous tonalite grading into noritic or granodioritic varieties with synplutonic dykes of microgabbro. These rocks occur also separately, and very often show reactions or mixing relationships with the anatectic country rocks. Only a few thin dykes of gabbrodiorite show the same



hornblende-rich, mineral composition of the typical Appinite. The latter contain plagioclase (core: 80% An; rim: 40% An), biotite and poikilitic hornblende in omoaxial intergrowths with cummingtonite; they are associated with microgabbros rich in ortho- and clinopyroxene; most of the intrusive rocks are garnet-bearing and contain biotite-quartz mirmekite-like intergrowths. The more mafic types contain abundant clinopyroxene; all the rocks contain orthopyroxene and/or cummingtonite in variable amounts.

The presence of garnet suggested a deep origin for the magma (ORIGONI GIOBBI *et al.*, 1975). However, the garnet may be better interpreted, in the light of more recent observations, as a restite of a process of assimilation of country rocks by the ascending basic magma. Orthopyroxene and cummingtonite may have the same meaning as suggested by their textural relationships with garnet.

### Mafic dykes

The mafic dykes of the Serie dei Laghi have been mostly described in literature as «lamprophyres» on account of their generally fine-grain size, mafitic composition and presence of mafic phenocrysts. Malchite, vinitite, spessartite, kersantite and microgabbrodiorite are amongst the most used terms. A few coarser-grained gabbrodioritic dykes, very similar to the Appinites, are present as well as the lamprophyre-like dykes. Medium-grained gabbrodiorites occur near Cambiesso and at Passo Folungo in the Strona-Ceneri gneisses, N of Verbania.

BORIANI and SACCHI (1973) noted that in the Serie dei Laghi more silicic rocks from granodiorite to granite occur together with the mafic dykes. Acidic dykes are present in the «Scisti dei Laghi» near Miazina, N of Verbania (granite-porphyry).

It must be noted that even in the type localities of the Appinites (e.g. Brissago), the more fine-grained varieties of these rocks have been described as lamprophyres.

North of Verbania it is possible to distinguish a subgroup (B1) of vertical N-S dykes intruded parallel to the faults of the

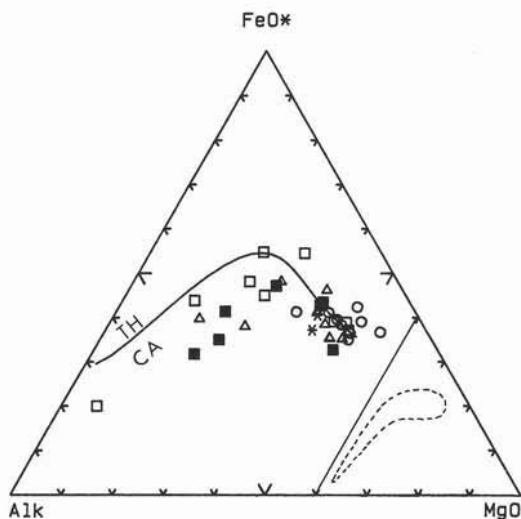


Fig. 3. — AFM diagram for Appinites and mafic dykes from Serie dei Laghi area. Symbols: circles = B1 dykes; triangles = B2 dykes; squares = Appinites; crosses = core and rim of D8 mafic dyke; open squares = Appinites from Quarna pluton (BURLINI and CAIRONI, 1988). Inset: distribution trend of «Appinite suite» of Massiccio dei Laghi (BORIANI *et al.*, 1974). Solid line distinguishes calcalkaline and tholeiitic fields (IRVINE and BARAGAR, 1971).

Valle Intrasca, mainly in Strona-Ceneri rocks, and another subgroup (B2) with more dispersed attitude and prevailing NE-SW direction, mainly intruded in the «Scisti dei Laghi». Only a few dykes seem to be connected with late overthrusts, like that of M. Morissolo, south of Cannobio (Fig. 1).

It is well known (POLLARD, 1985) that the dykes are generally intruded orthogonally to the minor stress axis. If the dykes are parallel to one another it means that  $S_1 > S_2 > S_3$ . If the dykes have variable attitudes, and follow preferentially pre-existing discontinuities in a structurally homogeneous domain, it means that the value of stresses along the three axes is approximately the same.

There is little doubt that the vertical N-S dykes were intruded during a compressive phase since their constant attitude clearly indicates the major and minor stress directions. As opposed to the Appinites, they are never foliated. As far as subgroup B2 is concerned, the dispersed attitude of the dykes with a peak corresponding to the regional

foliation ( $N60^\circ$ ) indicates an extensional regime of intrusion, such as that occurring above an ascending pluton. On structural grounds, it is therefore possible to infer that the two subgroups of dykes in the Verbania area are not strictly coeval (Fig. 2).

Contacts with the metamorphic country rocks are generally sharp and angular and characterized by the presence of chilled margins 2 or 3 cm thick. The grain size is generally finer in the thinner dykes, coarser in the thicker ones. In the «Scisti dei Laghi» the contacts are planar and concordant with the foliation. The northernmost dykes in the Ceneri and fine-grained gneisses (near the Pogallo Fault) show different relationships with their host rock. Contacts are smooth or sinuous; the grain size does not vary between inner and outer zones of the dyke.

Multiple dykes are also present: as opposed to the Appinites, the mafic dykes of the Verbania area do not show pseudobrecciated structure except in very rare instances. This means that the successive intrusive pulses occurred in already solidified dyke rocks. Contact between the various parts is not planar; chilled margins are sometimes present.

Despite their apparent mesoscopic uniformity, the mafic dykes are petrographically rather variable within both subgroups. Their texture and grain-size also varies within a single dyke, from the central part to the margins.

Some of the dykes are aphyric, with subophytic texture, others are clearly porphyritic. The latter may be classified on the basis of their phenocrysts. Some of them show pyroxene (Ti-augite) and brown hornblende in a groundmass of plagioclase, hornblende, chlorite. In other dykes the phenocrysts consist only of zoned pyroxene with a reaction rim; the microcrystalline groundmass is made up of plagioclase, hornblende, pyroxene and chlorite. Another group of dykes is characterized by phenocrysts of plagioclase + pyroxene, in a groundmass of microlithic plagioclase, pyroxene and amphibole. Biotite is present only in the groundmass of the dykes with some Appinitic affinity.

All the dykes of the Verbania area show

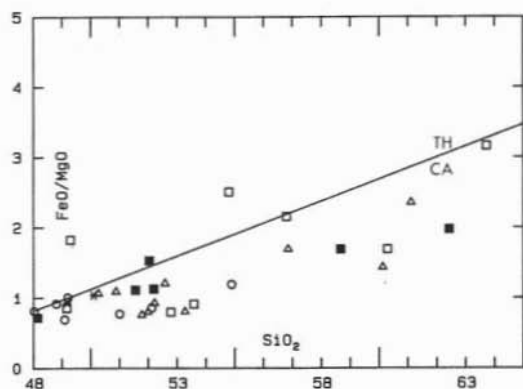


Fig. 4. — FeO tot/MgO vs  $SiO_2$  diagram. TH-CA dividing line after MIYASHIRO (1974). Symbols as in Fig. 3.

hydrothermal alteration; the N-S dykes of Val Intrasca (B1) are comparatively less altered. Their phenocrysts are generally fresh, while chlorite and calcite may appear in their groundmass.

The dykes occurring N of Verbania (B2) are mostly altered and sometimes strongly modified by hydrothermal activity. The phenocrysts may be completely replaced by carbonates and/or chlorite, and the groundmass may be transformed into an aggregate of chlorite, epidote, carbonates and quartz.

### Petrochemistry

Chemical data relative to 28 samples of dykes and Appinites are reported in Tables 1, 2, 3<sup>(1)</sup>.

The analyzed rocks in the AFM plot (Fig. 3) show a distribution which is typical of a calcalkaline sequence. The same diagram also shows some selected samples of Appinites occurring near the Quarna granitic pluton recently investigated by BURLINI and CAIRONI (1988). The trend defined by the analyzed

<sup>(1)</sup> Major, minor and trace elements were obtained by X-Ray fluorescence analyses performed on pressed powder pellets. Calibration was made on the international reference rock standards of appropriate composition, with mathematical correction of matrix effects. FeO was determined by potentiometric titration with  $K_2Cr_2O_7$ . Loss of ignition was determined on powders at  $1,000^\circ C$  overnight.

rocks is in fairly good agreement with that shown by the «Appinite suite» rocks ranging in composition from gabbrodiorite to granodiorite (see inset) occurring along the junction between the Ivrea-Verbano and Strona-Ceneri Zones (BORIANI *et al.*, 1974).

All the B1 subgroup dykes as well as some of the B2 ones plot at the Mg-rich end of the Appinitic trend, in the field of the gabbrodioritic rocks. Such a feature, already observed in a few samples of «lamprophyres» (i.e. the B2 dykes of this study) outcropping in the area of Verbania, suggested (BORIANI *et al.*, 1974) that both Appinites and mafic dykes originated from the same parental magma. The calcalkaline character of the mafic dykes is also indicated in the  $\text{FeO}_{\text{tot}}/\text{MgO}$  vs  $\text{SiO}_2$  diagram (MIYASHIRO, 1974): only two Appinites from the Quarna pluton (BLE 12 and BL 51), being enriched in iron, plot in the tholeiitic field (Fig. 4).

In the covariation diagram of Fig. 5 the content of Ni and Cr has been plotted against the Mg value calculated as  $\text{Mg}/(\text{Mg} + \text{Fe}_{\text{tot}})$ . All the examined dykes and more basic Appinites display a restricted range of variation of this parameter (0.62-0.78). If we consider the «Appinite suite» as a whole, a larger variation of Mg value appears (0.38-0.74). Fig. 5 also clearly shows that both Ni and Cr have a positive correlation with the Mg value, probably due to fractionation processes. Two different evolutionary trends are distinguishable, when we consider separately the Appinites from Quarna and those from Brissago and Val Cannobina.

If we consider the elements that are deemed to be «mobile» during metamorphism, such as Ba, Sr and Rb, we see that Ba is below 1,000 ppm similarly to the meta-lamprophyres of the Central Swiss Alps (OBERHAENSLI, 1986). This author found that the «non-metamorphic» lamprophyres are significantly richer in this element. The average Sr content is higher in B1 subgroup than in B2, whilst the Rb concentration is not discriminative for the two subgroups. It seems likely that Ba and Sr distribution was influenced by some kind of post-magmatic process such as hydrothermal alteration.

The general distribution of incompatible

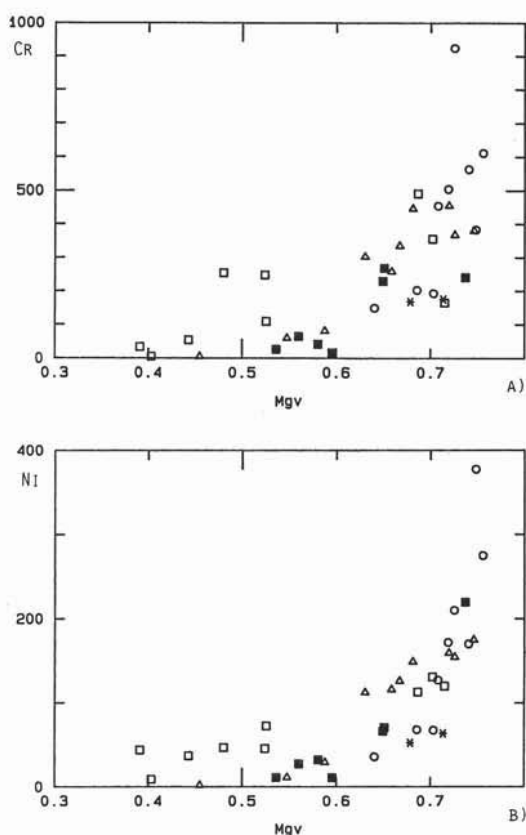


Fig. 5. — Covariation diagrams of Cr (a) and Ni (b) vs Mg values for Appinites and mafic dykes. Symbols as in Fig. 3.

elements normalized to the primordial mantle according to WOOD (1979) is shown in Fig. 6. Trace elements appear to be enriched in comparison with the primordial mantle, in all the examined rock types. They display homogeneous trends which compare well with the trend defined by some selected calcalkaline dykes from the Alps (BECCALUVA *et al.*, 1983, p. 353, Fig. 9). Fig. 6 shows that all the patterns have weaker enrichment in Nb, P and Ti relative to a stronger LILE, Sr and Zr enrichment.

The overlapping of the patterns for the four groups of examined rocks suggests a common origin from the same parental magma. The distribution trend of the Appinites from Quarna seems to be more dispersed, displaying more pronounced positive and negative anomalies. This is probably due to the larger

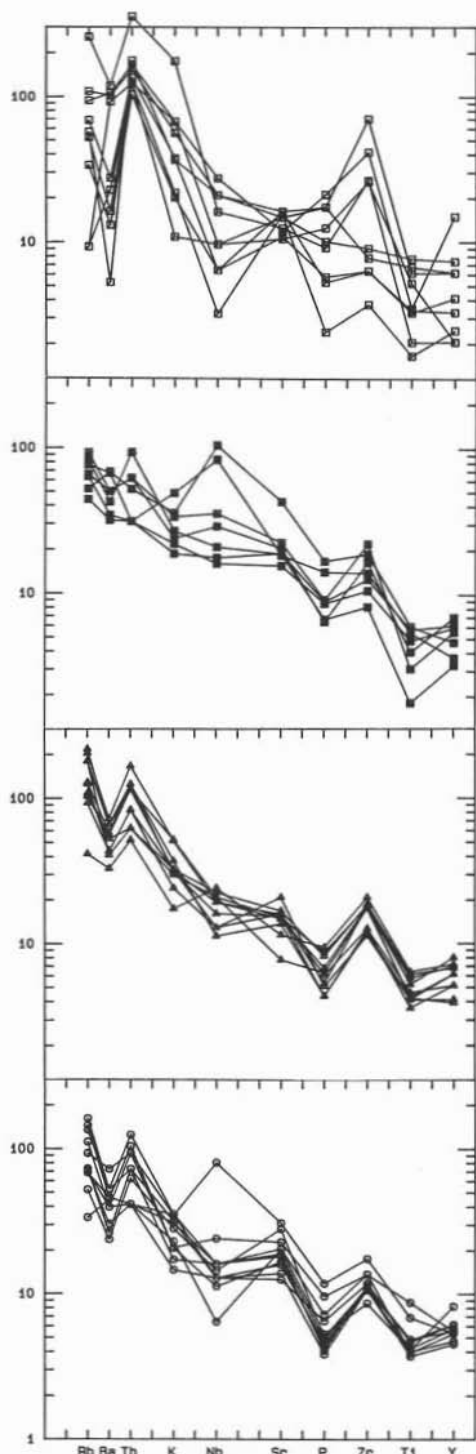


Fig. 6. — Incompatible element abundances of analyzed rocks and Appinites from Quarna pluton (BURLINI and CAIRONI, 1988) normalized to primordial mantle according to WOOD (1979). Symbols as in Fig. 3.

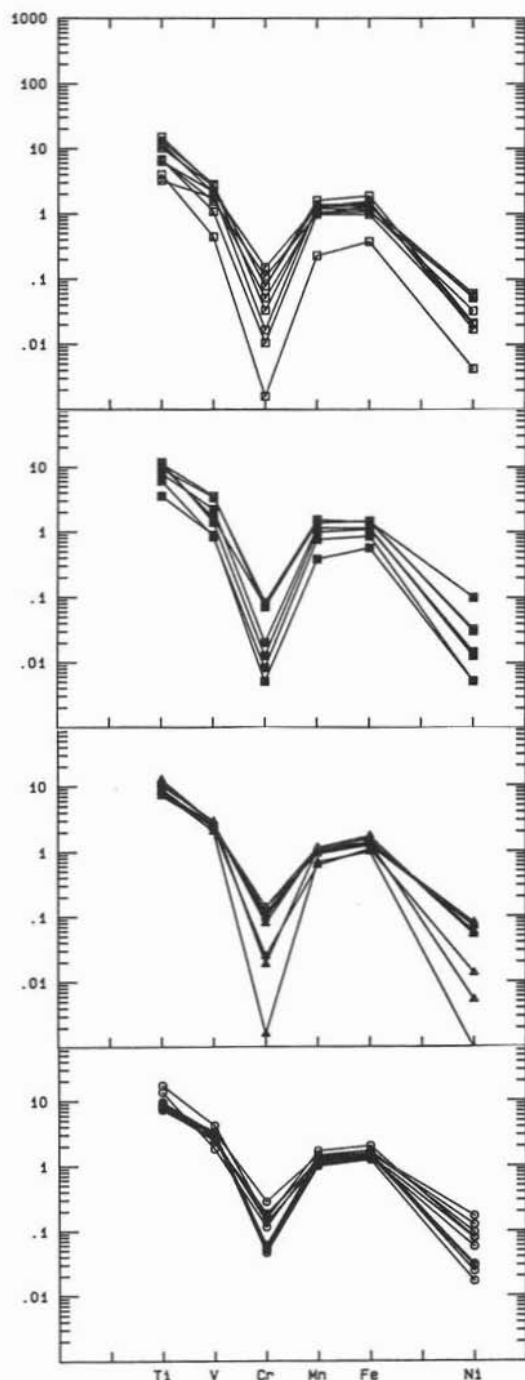


Fig. 7. — Compatible element distribution patterns of Appinites and mafic dykes from the Verbania area normalized to primordial mantle of WOOD (1979). Symbols as in Fig. 3.

compositional range of this Appinitic group.

A further contribution to the definition of the common chemical characteristics of mafic dykes and Appinites may also be suggested by the similar distribution of compatible elements (Fig. 7). On the whole, the four distribution patterns exhibit a remarkable relationship, except for the contents of Cr and Ni that are depleted in the more acidic rocks (see also Fig. 5).

## Conclusions

The problem of the Appinites of Massiccio dei Laghi is closely connected with that of the contact between the Ivrea-Verbano and the Serie dei Laghi.

This contact has become the object of a lively debate in the last five years. Geophysical studies undertaken in 1976 by FOUNTAIN were followed by a proposal put forward by HODGES & FOUNTAIN in 1984 to consider that contact (identified with the Pogallo Line) a formerly low-angle normal fault; a sort of detachment surface between lower (Ivrea-Verbano) and upper (Strona-Ceneri) crust, that produced the thinning of the continental crust, presumably at the Triassic-Jurassic transition. The authors did not consider (as pointed out BORIANI & SACCHI, 1985) the very close relations existing between Appinites, migmatites and faults, but gave much importance to the cataclastic tectonisation of a very small granitic body N of Mergozzo (S. Rocco granite) supporting a post-Permian age for the Pogallo (CMB) Line.

HANDY (1986) and SCHMID et al. (1987) expressed more or less the same views as Hodges & Fountain about the role of that tectonic contact, on the basis of Handy's results on the Pogallo mylonites. On the Strona-Ceneri side, the latter were formed under rather low temperatures corresponding in HUNZIKER & ZINGG's (1980) thermal evolution of the Ivrea-Verbano - Strona-Ceneri complex, to conditions inferred for the Triassic-Jurassic transition. The fault, formerly at a low angle, was tilted during the Alpine orogeny to its present subvertical position. According to SCHMID et al. (1987), this tilting (by about 60 degrees) occurred during the eo-Insubric, late-Alpine phase.

These authors did not give great importance to the complex late-Hercynian intrusive and anatectic phenomenology connected with the development of the CMB - Pogallo Fault system. They did not even take into account the evidence that, in the lower Permian, the country rocks of the granites were already cool enough to register contact metamorphism and that many geological constraints (e.g. nearly upright position of the granite plutons; weak inclination of the basement - cover surface) make it impossible to consider an Alpine tilting of 60 degrees.

The Group A Appinites and the B1 N-S mafic dykes of Valle Intrasca indicate intrusion in a compressional regime. Whether group A (E-W near Brissago) and subgroup B1 (N-S) are coeval or not is impossible to assess on structural grounds. We have no current knowledge on the distribution of the stress regime south of the Ivrea-Verbano - Serie dei Laghi contact. Petrographic evidence indicates that the crustal level of intrusion of the Appinites is deeper than that of subgroup B1; this may suggest that subgroup B1 is somewhat later than the Appinites.

Subgroup B2 dykes are indeed the youngest: their random orientation, with a maximum corresponding to the regional foliation, suggests a purely extensional regime such as that occurring above an ascending pluton. Their maximum frequency is actually along the ideal north-eastern continuation of the row of plutons forming the batholith of Graniti dei Laghi. It is therefore possible to consider a close relationship between subgroup B2 and the mafic dykes that occur in and immediately around the granites themselves.

In other words, it seems possible that the granitic batholith «Graniti dei Laghi» also occurs below the «Scisti dei Laghi» N of Verbania, though at a depth of several km, such that the exposed rocks are outside the contact aureole. Further evidence for this is the intense hydrothermal alteration shown by the mafic dykes of subgroup B2, whose mineral assemblages are sometimes almost completely converted into low-grade associations of carbonate, chlorite, epidote and albite.



As regards their classification, the mafic dykes (Group B) cannot be defined as lamprophyres. According to ROCK (1977) the lamprophyres are «alkali-rich porphyritic dyke rocks showing intermediate to very low SiO<sub>2</sub> content, with moderate to high colour index, carrying essential primary amphibole and/or mica, and typified by lack of felsic phenocrysts and groundmass olivine, by characteristic alteration and by panidiomorphic texture». Phenocrysts of plagioclase are actually present in many dykes and the chemical features are those of a calcalkaline series.

The major and minor element chemistry of both Groups A and B suggests that, though they are not coeval, all these rocks can derive from the same magma source that remained active over a period of time of at least 20 Ma from the very beginning of the late-Hercynian magmatic activity until its final end well after granite emplacement.

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