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Geological and petrological studies on the hercynian plutonism of Serie dei Laghi - geological map of its occurrence between Valsesia and Lago Maggiore (N-Italy)

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ABSTRACT. — The plutonic rocks are represented by many small intrusive bodies of calcalkaline basic to intermediate rocks (appinites) and a few large granite plutons; all of them were intruded parallel to the boundary between Serie dei Laghi and Ivrea-Verbano, a boundary which is represented by a set of faults (CMB and Pogallo-Lago d'Orta Lines) of late-Paleozoic age, but with more recent reactivation.

Most of the calcalkaline basic intrusives are generally older (around 295 Ma) than the granites, as demonstrated by the deeper environment of their intrusion (partial melting induced in their country rocks).

The granites came later, in the Lower Permian, ascending slowly in the crust with a cauldron subsidence mechanism.

Volcanic rocks also occur: rhyolitic ignimbrites cover the basement in the southernmost part of this area, near Borgosesia and Arona.

The age of intrusion of the granites and of emplacement of ignimbrites has been established by various radiometric methods to be around 275 Ma.

The host rocks of the plutonites are metasediments and metagranites belonging to the two subunits (*Strona-Ceneri:* metabasites, metaarenites, metagranites; *Scisti dei Laghi:* metapelites) of the Serie dei Laghi, whose mutual relationships are complicated by the «schlingenbau» structure near the CMB Line. The appinites are mostly intruded into Strona-Ceneri rocks, whilst the granites are contained in both subunits.

All the magmatic rocks show calcalkaline affinity with features that suggest variable amounts of crustal contamination. Pure anatectic products are present only in the migmatites that form a narrow belt along the CMB.

Key words: Late-Hercynian magmatism, granites, appinites, Serie dei Laghi, Southern Alps.

Introduction

At the end of the Hercynian orogeny some very important magmatic activity took place in most of the basement rocks of the Southern Alps (and not only there). As far as one can tell from the present occurrences, the products of this activity were mostly acidic epiplutonic and volcanic rocks of Lower Permian age (about 275 Ma). Mafic to intermediate rocks are generally older, and are mostly represented by intrusive rocks emplaced at a deep or even very deep crustal level, as one can see from their relations to the country rocks. Their age of intrusion cannot generally be determined with certainty because the Rb/Sr method does not give reliable results on account of the generally low Rb content and Rb/Sr ratio, as well as of their isotopic inhomogeneity due to variable crustal contamination.

In the Massiccio dei Laghi (N-Italy) a huge layered mafic body is present in the Ivrea-Verbano Zone (Fig. 1). It is intruded into high-grade metasediments; its deepest parts are clearly reequilibrated at the granulite facies conditions, whilst the upper part still preserves igneous microstructures. The age of the mafic layered body as well as its relationships with the metamorphism are still the matter of a very lively discussion (see BORIANI and

RIVALENTI, 1984; ZINGG, 1983). The geological evidence (and now more and more U/Pb and Sm/Nd data: PIN, 1986; PIN and SILLS, 1986; VOSHAGE et al., 1987) suggests a late-Hercynian age, since the body was involved in the last folding phase which can be attributed to that orogeny, and because the heat transported by the mafic intrusion contributed to the regional metamorphism and to its own subsolidus equilibration.

Mafic-to-intermediate igneous rock bodies (appinites) occur in a narrow zone along the CMB (Cossato-Mergozzo-Brissago) Line, an important tectonic discontinuity that separates the Ivrea-Verbano Zone from the Serie dei Laghi (BORIANI and SACCHI, 1973, 1974, 1985; BORIANI et al., 1974; ORIGONI GIOBBI et al., 1975).

Mafic igneous rocks also occur as fine grained dykes in all the units of the Massiccio dei Laghi and particularly in the zone N of Verbania.

The acidic rocks build up the large granitic plutons (Graniti dei Laghi) that are the main object of this article.

Country rocks: the Serie dei Laghi

The Serie dei Laghi is a geological unit belonging to the intermediate crust, which is tectonically juxtaposed to the lower crustal Ivrea-Verbano Zone (Fig. 1). It consists of two main lithological subunits, i.e. Strona-Ceneri Zone (SCHMID, 1967) — formerly called Ceneri Zone (REINHARD, 1953) — and Scisti dei Laghi (BORIANI, 1970). The contact between the subunits is marked with the presence of a continuous, rather thick, layer of amphibolites.

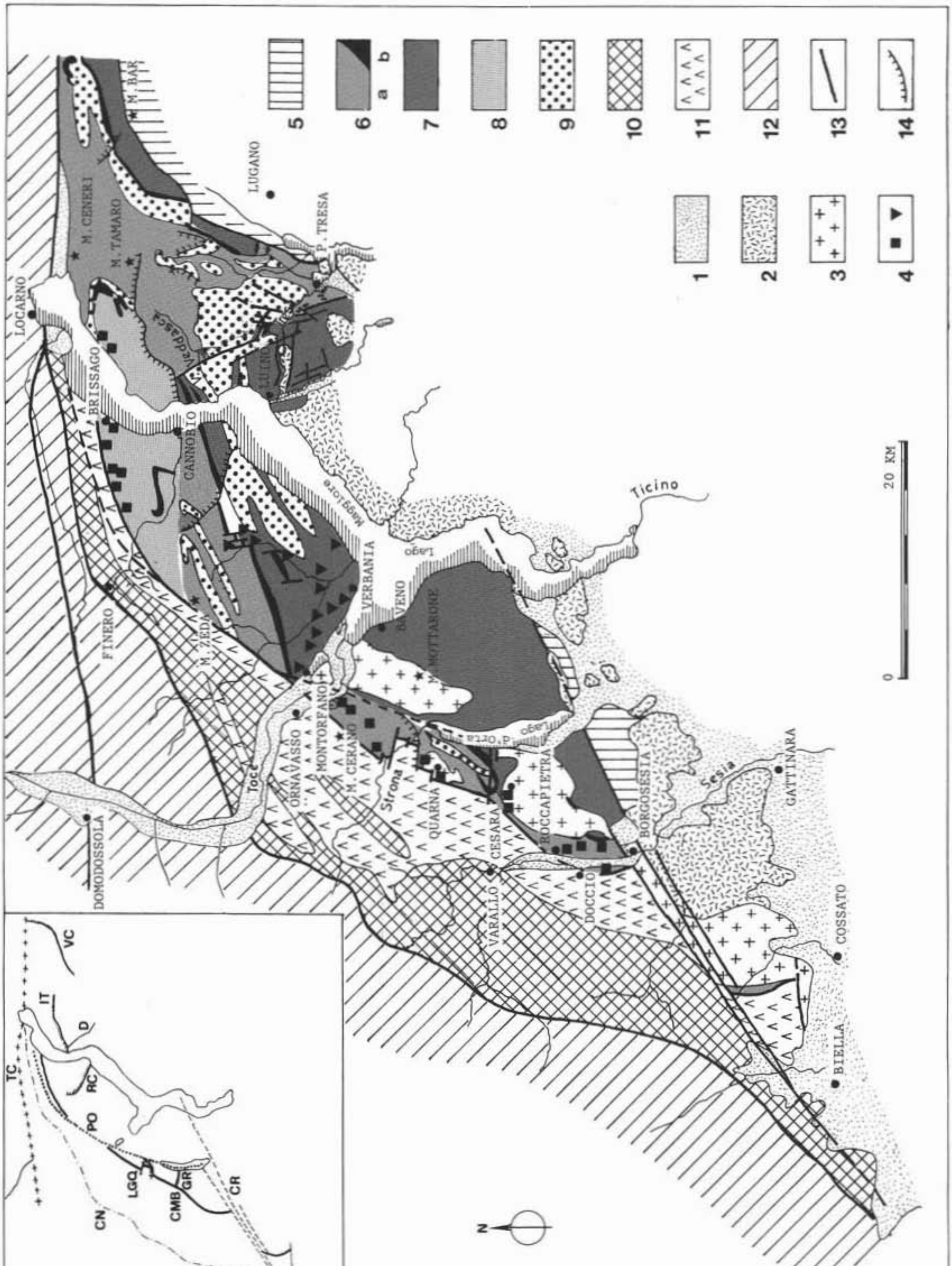
In both subunits orthogneisses (Ordovician metagranites, BORIANI et al., 1982-83; BORIANI and GIOBBI ORIGONI, 1984) are also present.

The metamorphism is certainly pre-Permian, but there is no agreement about its age, despite the many radiometric determinations performed during the last two decades (JAEGER et al., 1967; MCDOWELL and SCHMID, 1968; MCDOWELL, 1970; PIDGEON et al., 1970; KOEPPEL and GRUENENFELDER, 1971; HAMET and ALBARÈDE, 1973; ALLÈGRE et al., 1974; HUNZIKER, 1974; KOEPPEL, 1974; KOEPPEL and GRUENENFELDER, 1978-79; HUNZIKER and ZINGG, 1980; BORIANI et al., 1982-83).

From the available radiometric data it seems that the metamorphic transformations of the metasediments of Serie dei Laghi began around 450 Ma ago. In particular, HUNZIKER and ZINGG (1980) consider the Rb/Sr WR isochron of 473 ± 20 Ma, defined with 4 samples of metasediments of Serie dei Laghi, as representing the age of the thermal peak of the Caledonian regional metamorphism. BORIANI et al. (1985b) and BORIANI and GIOBBI ORIGONI (1984), based on petrographic and geologic evidence, consider this isochron as giving the age either of a very weak regional metamorphism or even of the Ordovician magmatism. The temperature rise, the circulation of fluids and the mobility of potassium connected with the intrusions, could well be responsible for the homogeneization of the Rb-Sr system in the metasediments. It must be kept in mind that the meaning of the Rb/Sr WR age on metapelites is generally that of the diagenesis or of the first weak metamorphism.

The lower intercept U/Pb ages of the discordant zircons of the paragneisses analysed by PIDGEON et al (1970), KOEPPEL and

Fig. 1. — Geological sketch-map of the Massiccio dei Laghi (after BORIANI and 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.


LOCARNO
LUGANO
M. CENERI
M. TAMARO
M. BAR
P. TRESA
BRISSAGO
LUINO
CANNOBIO
Veddasca
Lago Maggiore
VERBANIA
BAVENO
M. MOTTARONE
FINERO
M. ZEDA
Ticino
Lago d'Orta
MONTORFANO
ORNAVASSO
M. CERANO
Toce
Strona
QUARNA
ROCCAPIETRA
BORGOSESIA
CESARA
VARALLO
DOCCIO
DOMODOSSOLA
Sesia
GATTINARA
COSSATO
BIELLA
20 KM
0
N
1
2
3
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TC
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CMB
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GRUENEFELDER (1971), HAMET and ALBARÈDE (1973), KOEPPEL (1974) and KOEPPEL and GRUENENFELDER (1978-79), probably have the same meaning.

Probably the best geological evidence that at least part of the Serie dei Laghi was not metamorphosed (or very weakly metamorphosed) at the moment of the intrusion of the Ordovician granites is the presence of Al-silicate rich nodules in the fine-grained gneisses of the Strona-Ceneri near many metapegmatite dykes presumably connected with those granites. The nodules are interpreted by BAECHLIN (1937) and BIGIOGGERO and BORIANI (1975) as the product of the regional metamorphism of original chiastolite poikiloblasts.

Younger, Hercynian or even more recent ages were found using the K/Ar method on biotite (200-250 Ma), muscovite (250-290 Ma) and hornblende (325 Ma) (MCDOWELL, 1970; HUNZIKER, 1974), the Rb/Sr method on biotite (250 Ma) and muscovite (310-320 Ma) (JAEGER et al., 1967; HUNZIKER, 1974; BORIANI et al., 1982-83) and the U/Pb method on monazite (275 Ma) (KOEPPEL, 1974; KOEPPEL and GRUENENFELDER, 1978-79). MCDOWELL (1970) noted that the ages found become younger towards the NW, i.e. towards the Ivrea-Verbano Zone.

The Serie dei Laghi is tectonically situated between the Ivrea-Verbano Zone, from which it is separated by the CMB Line, and the Val Colla Zone (a medium-grade, locally retrograded, metapelitic complex). The contact with this unit is represented in the eastern part by the Val Colla Line, an Upper Carboniferous discontinuity, and in the western part by the Cremosina Line, which, despite its Alpine rejuvenescence, is probably a continuation of the Val Colla Line (BORIANI and COLOMBO, 1979). The Serie dei Laghi is further dissected by more recent faults and overthrusts into various blocks, as shown in the maps of REINHARD (1964), BORIANI et al. (1977), in the geological sketch of GIOBBI ORIGONI et al. (1982-83), and in the present work.

The metamorphic evolution in most of the Serie dei Laghi is characterized by a first amphibolite facies event (ky + st) and by a second, very local, retrogressive, greenschist facies event that can be observed only along shear planes. This event is responsible for the partial replacement of biotite and garnet by Mg-Fe chlorite as well as for the sericitization of Al-silicates and, to a minor extent, of plagioclase.

Scisti dei Laghi

This subunit is mostly made up by micaschists and paragneisses with rare amphibolite inliers, interpreted as an originally Late Precambrian or Lower Paleozoic pelitic sequence (BORIANI et al., 1977). The most widespread mineral association is: quartz, plagioclase (20% An), white mica, biotite and porphyroblasts of garnet, kyanite and staurolite which are syn-postkinematic in respect to the main foliation. Garnet shows also synkinematic rotational textures in its inner parts (BORIANI, 1970). Accessory minerals are apatite, zircon, opaques and tourmaline.

From the structural point of view (except in the «schlingen» zone, see below), at least two phases of deformation can be recognized. The first one, which shows an isoclinal geometry and transpositive character, is responsible for the regional foliation. The present strike of this foliation is N 50°-70°E near the Mottarone-Baveno pluton and east and south of the Alzo-Roccapietra pluton and N 45°E north of Verbania; the dip is generally subvertical.

The second phase of deformation induced a crenulation cleavage and seems to be connected with a retrogressive episode. Near the CMB Line the presence of another phase of deformation, intermediate between the two above mentioned phases, is connected with the «schlingenbau» structure developed in that part of the Serie dei Laghi. North of Passo della Colma (Omegna-Varallo road), where the Scisti dei Laghi occur as the northern limb of the large fold with vertical axis of the zone of Cesara, the foliation is blurred by the partial melting of the rock in proximity of the appinitic bodies.

Strona-Ceneri Zone

The amphibolite horizon that marks the contact between Scisti dei Laghi and Strona-Ceneri is considered the metamorphic product of original, more or less reworked, mafic sediments, belonging to the basal part of the Strona-Ceneri Zone (GIOBBI ORIGONI et al., 1982-83). In the sector W of Lago Maggiore and on the western shore of Lago d'Orta the amphibolites often contain large K-feldspar porphyroclasts (BORIANI and GIOBBI MANCINI, 1972; GIOBBI ORIGONI et al., 1982-83). Our present opinion is that they result from granitization of still permeable clastic material induced by a water-rich residual melt coming from the Ordovician granites. The mineral assemblage of the amphibolite is: hornblende, plagioclase (35% An), biotite, garnet and quartz; in the granitized varieties, beside K-feldspar, also biotite is very abundant.

The outcrops of the main amphibolite horizon west of Lago d'Orta form the large fold with vertical axis near Cesara.

Along the horizon not only mafic metatuffites are present: small, scarce, discontinuous, but very significant occurrences of metabasalts, metagabbros and metaultramafites can be found in many places, such as Cellio (Valsesia), Oira (Lago d'Orta) and Sarangio (E shore of Lago Maggiore) and further E in Val Colla (Ticino). Eclogitic amphibolites occur near the Alpe Morello peridotite body (northern part of our map), although they are mostly attributed to the Ivrea-Verbano zone (BORIANI and PEYRONEL PAGLIANI, 1968).

The Strona-Ceneri Zone is the product of the metamorphism of a fine- to coarse-grained arenaceous sequence. The two main rock types are: paragneisses with detrital phenoclasts (Cenerigneiss) and fine-grained gneisses (Gneiss Minuti). Both rocks contain small Ca-silicate bearing nodules (BORIANI and CLERICI RISARI, 1970).

In BAECHLIN's (1937) opinion the Gneiss Minuti (Biotithornfelsgneise) represent the stratigraphically highest and Cenerigneiss the lowermost part of the sequence (see also BORIANI et al., 1977). The abundance of the arenaceous, sometimes very coarse, material and the scarcity of pelites suggest a shallow water, epicontinental, sedimentary environment. The frequent and repeated intercalations of one type present in the other were intepreted as both the evidence of an heteropical relationship between the two sediments and the result of a tectonic process such as a transpositive deformation phase (GIOBBI ORIGONI et al., 1982-83).

In the Lago d'Orta area it is only occasionally possible to distinguish the Cenerigneisses from the fine-grained gneisses due to their widespread mobilization probably induced by the intrusion of the appinitic magma along the CMB Line. The resulting migmatites consist of leucosomes of granitic composition and of restitic melanosomes very rich in alumosilicates (sillimanite, andalusite) and cordierite. Near the CMB the «granitised amphibolites» also underwent partial melting.

The structural setting of the Strona-Ceneri Zone is very complicated and still little known. The best approach seems to be that suggested by BAECHLIN (1937), who published a detailed 1:50,000 map of the area NE of Lago Maggiore. In his view, the Strona-Ceneri should represent the core of a synform with axis steeply dipping SW, whilst the Scisti dei Laghi represent the flanks. The northern limb of this structure is affected by folds with vertical axes («Schlingenbau»): this feature was interpreted by BAECHLIN (1937) as the evidence of a high plasticity of this part due to abundant granitization during metamorphism, and also as the effect of transcurrent movements along a paleo-Insubric Line. BORIANI and SACCHI (1985) attributed the «schlingenbau» structure to the transcurrent movements along the CMB. A nice example of schlingen structure is the already mentioned fold with nearly vertical axis occurring near Cesara, W of Lago d'Orta. It should be noted, however, that this fold seems rather open in comparison with the «schlingen» folds of the northern Lago Maggiore area.

Orthogneisses

The metagranite and metagranodiorite lenses intercalated in the Serie dei Laghi paraderivates were considered by the Swiss geologists who mapped the Sottoceneri (see REINHARD, 1964) the product of a more or less intense synmetamorphic granitisation of metasediments. The original intrusive nature of the rocks was assessed by BORIANI (1970); a petrochemical, petrographical and geochronological study of the orthogneisses of the Lago Maggiore area was performed by BORIANI et al. (1982-83).

The orthogneisses are mainly represented by hornblende-bearing and hornblende-free, biotite-plagioclase-quartz gneisses with very variable amounts of K-feldspar and with a typical medium-grained gneissic texture that becomes augen or flaser in the more leucocratic types. Muscovite-bearing varieties also occur. Many igneous textures are preserved both at the micro- and at the mesoscopic level, such as idiomorphic crystals, mirmekitic intergrowths, xenoliths, aplitic-pegmatitic dykes.

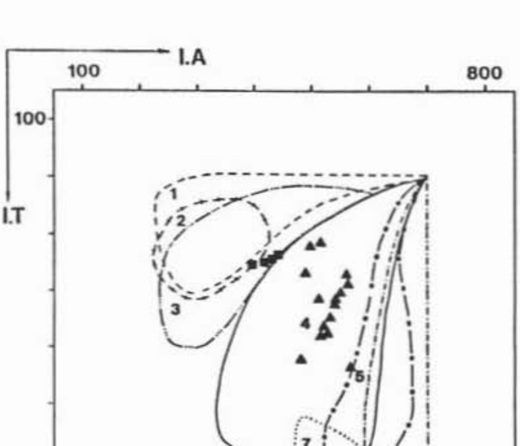

Fig. 2. — Mean points of zircon populations from the Serie dei Laghi orthogneisses in the typologic evolution diagram. Data after CAIRONI, 1986. Fields after PUPIN, 1988. Full triangles: biotite + hornblende and biotite orthogneisses. Full squares: biotite + muscovite orthogneisses. 1: aluminous, Al-silicate(s) - bearing leucogranites; 2: aluminous and peraluminous granodiorites - monzogranites with cordierite nodules; 3: porphyritic granodiorites - monzogranites, sometimes containing automorphic cordierite; 4: calcalkaline and K-calcalkaline («Mg-K») series; 5: high K-calcalkaline («Fe-K») series; 6: alkaline and peralkaline granites; 7: continental tholeiitic granites; 8: oceanic tholeiitic granites (plagiogranites).

Another confirmation of the original intrusive nature of these rocks was supplied by the typological study of their zircon populations (method by PUPIN, 1976) performed by CAIRONI (1986). The biotite and biotite + hornblende samples, which represent the main type, fall in the calcalkaline field of the typological diagram, whilst the rare muscovite-bearing samples plot in the typical area of aluminous and peraluminous suites (Fig. 2).

The age of intrusion was determined with a very good Rb/Sr WR isochron (BORIANI et al., 1982-83) yielding 466 ± 5 Ma with an i.r. of .7087 ± .0002; it is in agreement with the concordant U/Pb zircon ages of about 450 Ma determined by KOEPPEL and GRUENENFELDER (1971) and KOEPPEL (1974).

In the migmatite belt along the CMB Line the orthogneisses were involved in the late-Hercynian anatectic remobilization.

Calcalkaline basic intrusives

a) Appinites

The most widespread intrusives are nearly vertical sheet- like bodies of variable thickness or stocks of remarkable size that occur discontinuously in an area elongated NE-SW along the Ivrea-Verbano/Strona-Ceneri boundary (Borgosesia, Quarna, Monte Cerano, Brissago, Monte Ceneri), i.e. along the CMB Line.

It should be noted that the appinites are lacking along the Pogallo Line and in the lower Val Strona di Omegna between the Val Lessa Fault and Omegna. The Val Lessa Fault, as well as many other minor faults orthogonal to the CMB (Quarna, Grottaccio), played an important role in the emplacement of the appinites. A possible interpretation is that they acted as transform faults, dividing «spreading» centers along the CMB; another possibility is that these faults were boundaries of pull-apart extensional zones.

The appinites vary in composition from gabbro to diorite and granodiorite even in the same dyke, often with a pseudobrecciated structure; the more leucocratic products are represented by aplitic and pegmatitic dykes or by parts of multiple dykes.

Their mineralogical composition is variable: plagioclase, hornblende, biotite are ubiquitous minerals, whilst clinopyroxene is rarer; quartz and K-feldspar are present only in the more differentiated parts. Orthopyroxene and garnet, partly or completely replaced by cummingtonite and biotite, are widespread in the lower Valsesia stocks (ORIGONI GIOBBI et al., 1975).

The texture is highly inhomogeneous on account of the presence of chilled margins and/or multiple intrusions. Many dykes are breccias with fragments of foliated gabbrodiorite cemented by a more leucocratic, non-foliated matrix.

All these features and their chemical composition make these igneous rocks very similar to appinites of Scotland and Ireland (BORIANI and SACCHI, 1973; BORIANI et al., 1974).

The age of intrusion of the appinites cannot be determined by means of a Rb/Sr isochron on account of their initial inhomogeneous isotopic composition (probably due to various degrees of hybridisation, see PINARELLI et al., 1988). The mineral ages are highly variable and therefore can be interpreted as mixed ages due to the more or less intense re-opening of their isotopic system, induced by a repeated tectonic reactivation of the CMB Line. The best age determination is probably the U/Pb age of 285 ± 5 Ma on monazite from an appinitic dyke near Mergozzo (KOEPPEL and GRUENENFELDER, 1978-79; CUMMING et al., 1987).

From geological evidence, appinites predate the uplift and erosion of the Hercynian belt and the emplacement of the granite plutons.

Effects of the appinitic intrusions on the country rocks

Field and petrographic evidence suggest that this basic magma was emplaced into the country rocks in a rather deep-seated environment and that the heat carried by the intrusion caused the partial melting of the country rocks.

The anatectic phenomena can be observed in the Serie dei Laghi from the intersection between CMB and Pogallo Lines N of Mergozzo till the zone of Borgosesia (the only exception being a short stretch between Val Lessa and Omegna in the lower Valle Strona, where the appinites are also absent). The width of the mobilized belt is about 3 km SE of the CMB Line. In the lower Val d'Ossola and in Val Sesia, the mobilization produces dramatic effects on the rocks that are mostly transformed into an agmatitic complex.

The best section through the mobilized zone can be observed orthogonally to the CMB in the Cesara- Nonio zone, W of Lago d'Orta, between Riale Acqualba and Riale Fiumetta (BURLINI and CAIRONI, 1988). The first appearance of thin leucocratic discordant veins is accompanied, on a microscopic scale, with the appearance of mirmekite-like muscovite-quartz intergrowths associated with relic sillimanite. This texture can easily be explained with an incipient dehydration melting of muscovite and a subsequent recrystallisation in a water poor environment. With increasing mobilization of the rocks the mirmekite-like intergrowths appear also in biotite, implying a temperature increase towards the CMB. Then follows a zone of very intense migmatization of all the Serie dei Laghi rock types included the K-feldspar-bearing metabasites.

The age of the anatexis can be estimated as about 295 Ma from the concordant U/Pb age of a monazite from a migmatite near Germagno, determined by KOEPPEL and GRUENENFELDER (1974). This age is in fairly good agreement with the measured and inferred age of the emplacement of the appinites.

Outside the area covered by the geological map, in the Val Cannobina-Brissago zone (see Geological Map in BORIANI et al., 1977) the country rocks of the appinitic dykes are apparently not migmatitic, although they show a static lower pressure overprint on the regional metamorphic parageneses. Between Val d'Ossola and Valsesia the CMB Line is marked by the presence of a discontinuous horizon, a few meters thick, of blastomylonites. Here the blastomylonites, near the appinitic bodies, show static recrystallization or are involved in the mobilization (BORIANI and SACCHI, 1973).

b) Mafic dykes

The other group of mafic rocks consists of several dyke swarms intruded in the metamorphic rocks of Serie dei Laghi. They are very abundant W of Lago Maggiore in the Scisti dei Laghi N of Verbania (see Geological Map in BORIANI et al., 1977), very rare E of the lake and almost absent in the Strona-Ceneri rocks.

In the area of Verbania they are subvertical with a NS strike in Valle Intrasca, where they are connected with the NS fault system, approximately ENE-WSW in the Valle di San Bernardino, where they are aligned with the granitic plutons (BORIANI et al., 1985c).

Their thickness varies from 0.5 to 1 m and their maximum visible length is 40-50 m. They are very dark-coloured, with small dark phenocrysts of hornblende, pyroxene and olivine in a very fine groundmass.

As far as the mechanism of emplacement is concerned, contrasting indications are given by the two sets of dykes. The dykes of Valle S. Bernardino show angular contacts and chilled margins; they were emplaced permissively along preexisting fractures in an extensional regime. The dykes of Valle Intrasca show undulating contacts that indicate a more forceful mechanism (CARMINE, 1987).

The mafic fine-grained dykes were injected before, during and after the emplacement of the granites.

The chemical composition of both appinites and mafic dykes reveals a general calcalkaline character (BORIANI et al., 1974; GIOBBI ORIGONI et al., 1988).

Granites

The granites of the Serie dei Laghi build up a batholith, elongated in NE-SW direction, composed of many plutons occurring from the zone of Biella to the western shore of Lago Maggiore. E of the lake the granites are absent, but granophyres and granite porphyries occur in the Lago di Lugano area, indicating the presence of the underlying batholith.

Extensive studies of the granites occurring SW of Lago Maggiore were carried out by GALLITELLI, during the thirties and the forties (1937, 1938, 1941, 1943); VENIALE, 1961; GANDOLFI and PAGANELLI, 1974; BALCONI and ZEZZA, 1964, 1976; ZEZZA, 1977; ZEZZA et al., 1984; BORIANI et al., 1985a, d. A review can be found in GIOBBI ORIGONI (1987). Detailed geological, petrological and geochemical researches are now being carried out by BORIANI, BURLINI, CAIRONI, DEL MORO, GIOBBI ORIGONI, ODDONE, PINARELLI, SASSI, SESANA and VANNUCCI.

The Montorfano and Mottarone-Baveno granites are the best known and will be described in detail. Research on the other granites is still under way and we will give only some preliminary new data, besides what can be found in existing literature.

The westernmost part of the batholith is the Valsessera - Biellese pluton, which does not appear in our Geological Map.

The Biellese pluton is intruded into the Serie dei Laghi metamorphites; in the lower Valsessera it is in contact with the overlying Permian rhyolites (PIGORINI and VENIALE, 1962; BALCONI, 1963; FRIZ and GOVI, 1963; BORTOLAMI, 1964).

This granite pluton is characterized by the presence of many aplite, pegmatite, granite porphyry dykes and quartz veins. ZEZZA (1977) gave a detailed petrographic account of the main body and distinguished, on textural grounds, three main varieties: fine- to medium-grained, sometimes porphyritic, granites; pseudo-porphyritic granites; medium-grained granites with hypidiomorphic texture. Rare patches of granodiorite, feldspathic granite and quartz-syenite are scattered in the main granite. Marginal micro granular facies, probably chilled margins, are found in contact with the volcanites. The colour of the granite varies from white-yellowish to pink (La Colma, Rive Rosse). The mineral assemblage includes: plagioclase (22-35% An), microcline and/or orthoclase, quartz, biotite, muscovite; accessory minerals are apatite, zircon, magnetite, orthite, fluorite, tourmaline, garnet and hematite. The mineralogy varies from west to east: the monzogranites dominate in the western part and the syenogranites in the eastern part. In the monzogranites the main components are microcline and plagioclase with fractured, altered and corroded cores; they were interpreted as relics of a partially melted protolith. In the syenogranites orthoclase and plagioclase do not show any relic core.

The petrochemical data indicate that the Biellese granite belongs to a calcalkaline series; the west-east variation corresponds to an evolution from a yosemite-granitic magma to an aplite-granitic magma (ZEZZA, 1977).

Alzo-Roccapietra granite

This pluton is exposed between the lower Valsesia and Lago d'Orta. Its northwestern part is mostly intruded in the Strona-Ceneri gneisses, whilst the host rocks of its southern part are Scisti dei Laghi metapelites (see also TOLOMIERI, 1985).

Mineralogical and petrochemical data on this granite can be found in ARTINI and MELZI (1900) and in GALLITELLI (1941, 1943).

GALLITELLI described the textural and mineralogical variations between the central and the peripheral zones of the granite body: near Alzo and La Colma the granite is white and contains little biotite; plagioclase is markedly zoned. Other varieties are richer in biotite, others show porphyritic textures. Microgranite dykes are very frequent in the granite itself and in the country rocks near Arola.

The granodiorites, tonalites and mafic dykes that occur in the lower Valsesia between Roccapietra and Agnona were interpreted by GALLITELLI (1941) as mafic differentiates of the granite. More recent studies by BORIANI and SACCHI (1973), ORIGONI GIOBBI et al. (1975) have shown their similarity to the appinites; they actually belong to the pregranitic magmatic cycle (see calcalkaline basic intrusive).

A new geological mapping, carried out by TOLOMIERI (1985), revealed that the most widespread facies of the Alzo-Roccapietra pluton is a white, medium-grained biotitic granite; pink varieties are reported in the NW part of the pluton.

A hornblende-bearing granodiorite occurs in the Roccapietra quarry; its composition is: plagioclase, K-feldspar, biotite, hornblende, quartz. The granite is cut by a microgranite dyke rich in veins and cockades of tourmaline.

FONTANA (1976) carried out studies on the granite of the Roccapietra quarry; on the basis of geochemical data she estimated the T and P conditions of crystallization at about 600-700°C and P H_2O = 4-5 kbar.

A low pressure contact metamorphic aureole surrounds the granite pluton, but it can be seen and studied only in a few sections since the northern and western host rocks consist of migmatitic rocks with high-grade - low-pressure restites and since most of the southern area has very poor exposures.

The pluton has apparently preserved its original position (i.e. it was not significantly tilted later). Fragments of contact metamorphosed country rocks, associated with the arkose due to a pre-Quaternary deep weathering, can be found crossing the pluton in N-S direction; this means that the pluton is barely unroofed by the erosion. Otherwise the scarcity of country rocks xenoliths suggests a cauldron subsidence mechanism of emplacement in a horst and graben tectonic regime. The N directed granite tongue of Pella was considered by BORIANI and SACCHI (1973) as being the possible expression of a dragging of the intruding granite along the Pogallo - Lago d'Orta Fault (interpreted as syngranitic). Actually the peculiar shape of that outcrop can be better understood if we consider the right angle between the tongue and the rest of the pluton as the boundary of a subsiding and/or tilting block that guided the intrusion of the granite.

Quarna granite

Most of the exposed part of the Quarna granite is deeply arenitized, since it was not cleaned by the Quaternary glacial erosion. The pluton shows a roughly elliptical outline, with a maximum diameter of about 4 km.

The granite intruded into migmatitic

Strona-Ceneri gneisses, except in its northwestern part where the host rock is a gabbrodiorite belonging to the appinite suite. This small pluton is therefore characterised by the presence of more basic rocks that probably represent the only evidence of a close association of appinites and granites. The following facies have been recognized (from SE to NW): granite (main facies), granodiorite, quartz-diorite and gabbrodiorite.

The field evidence shows that the more leucocratic facies intrude the basic ones. The mineral composition of the granite is: plagioclase (22-30% An), quartz, microcline, biotite ± hornblende. Accessory minerals are: allanite, sphene, zircon, apatite, ilmenite. Plagioclase shows very calcic cores; it appears as clots together with decussate biotite flakes.

The contact aureole cannot be clearly seen since the country rocks are migmatites with high-T restites; only very seldom is it possible to recognize neoformation of biotite where a pregranitic chloritization took place.

The mechanism of intrusion seems again to be of the cauldron subsidence type. The presence of roof pendents in Valle Fiumetta suggests once more that this pluton is also still more or less in its original position and that it was only unroofed by the erosion.

A detailed account of the Quarna granite is given by BURLINI (1986) and BURLINI and CAIRONI (1988).

Data on the chemical composition of the various facies of the Quarna pluton were also given by BURANI (1961).

Montorfano and Mottarone-Baveno plutons

The Montorfano and Mottarone-Baveno plutons are composite intrusive bodies, aligned in N-S direction, exposed over an area of about 30 sqkm.

Both Montorfano and Mottarone show clear marks of the morphogenetic action of the Pleistocene glaciers; the ice entirely covered the Montorfano, whilst on Mottarone it reached an altitude of about 1000 m.

In all the granite types the presence of ordered microfractures in quartz favours the splitting of the rock along a series of rather smooth parallel planes called «pioda», which are utilized for quarrying.

In both plutons it is possible to recognize a sequence of intrusion on the basis of their composition and field relations (GALLITELLI, 1937, 1938; GANDOLFI and PAGANELLI, 1974; SASSI and SESANA, 1986).

I) Mottarone-Baveno granites

The pluton of Mottarone-Baveno consists of two main rock varieties: the pink granite (Granito Rosa di Baveno), which is extensively quarried, and the white granite which constitutes the bulk of the pluton. Other rather important varieties are: the xenolithic granodiorite at the top of Mottarone and a porphyritic facies (GALLITELLI, 1937, 1938; GANDOLFI and PAGANELLI, 1974; SASSI and SESANA, 1986).

The pink granite is a medium-grained rock which owes its colour to the K-feldspar; this granite is known all over the world for its miarolitic cavities (literally: cavities of granite; «miarolo» is an ancient local name for granite) lined with magnificent crystals of more than 60 mineral species. This granite type is exposed over a narrow area elongated in NNE - SSW direction at an altitude of 1100-1400 m on the southern flank of the mountain and between 600 and 900 m in the northern part.

The minerals of the pink granite are: K-feldspar, quartz, oligoclase, biotite, fluorite, white mica, zeolites, epidote, allanite, zircon, fayalite and magnetite (in nodules).

K-feldspar, which is the most abundant mineral, is present mostly as rather xenomorphic crystals, bearing inclusions of automorphic plagioclase and biotite crystals. K-feldspar shows all the possible transition from tiny perthite veins to an almost complete replacement by albite.

Quartz is also abundant as xenomorphic grains; sometimes aggregates of a few automorphic grains are present.

Oligoclase (25% An) is less abundant than the previously described minerals; it forms automorphic, or subautomorphic crystals, often with a more calcic, altered core, sometimes replaced by fluorite. A thin, clear rim of albite surrounds many plagioclase prisms, as well as the K-feldspar crystals.

Biotite is present as small isolated or grouped automorphic lamellae, which are very often altered in chlorite and/or replaced by epidote, zeolites, fluorite and white mica; the unaltered crystals show a strong pleochroism, from pale yellow to dark greenish brown.

The order of crystallization cannot always be recognized very easily, although biotite and plagioclase are often automorphic; we must conclude that the crystallization interval was very small. Miarolitic cavities are also present at the microscopic scale: the cavities are almost completely filled with newly-formed chlorite, white mica and/or fluorite. The pink colour of the rock is probably caused by the alteration of Fe^{3+} replacing some Al in the K-feldspar. The colour is actually inhomogeneous in both hue and saturation; at the transition to the white granite the pink colour of the feldspar is patchy or even absent, though the rock is petrochemically identical to the pink granite. Sometimes oligoclase can also be pink or reddish.

The pink granite was evidently the result of the crystallization of a magma that reached the water oversaturation very early, with the formation of vapour bubbles. This implies an increase in volume that was possible only if the intrusion took place at shallow depth, pushing upwards the roof rocks. In the bubbles the same minerals of the rock (plus many others) crystallized in the presence of vapour, giving rise to the celebrated crystals of Baveno. The subsolidus transformations were also very deep due to an abundance of fluids either in the pneumatolithic or in the hydrothermal stage of the evolution with formation of fluorite, Li-micas, albitization, kaolinization etc. (PAGLIANI, 1936, 1941; PEYRONEL PAGLIANI, 1948).

Coarse-grained pockets, often rimmed by fine-grained, aplitic facies, occur besides the typical miarolitic cavities. BALCONI and ZEZZA (1967) suggested that the abundance of the Baveno-Manebach associations in K-feldspar should be due to the fluid influence during crystallization.

The white granite occupies most of the volume of the exposed pluton; contacts with the pink variety can be individuated in the field only because of the complete disappearance of the pink hue of the feldspar.

This is essentially a medium-grained granite, with very rare coarse-grained parts, composed of quartz, K-feldspar (often showing the microcline grid), plagioclase, biotite, zircon, allanite, sphene and fluorite.

The presence of clots of zoned plagioclase crystals is peculiar to this facies of the pluton.

In the western part of the pluton (in a narrow zone elongated in N - S direction) the granite is muscovite-cordierite-bearing.

The general sequence of crystallization can be established very clearly from the textural evidence as follows: biotite, plagioclase, quartz, K-feldspar.

The porphyritic variety, with phenocrysts of K-feldspar, quartz, plagioclase and biotite in a sometimes granophyric groundmass, is present in a small, late, crosscutting body in the northern part of the pluton (SASSI and SESANA, 1986). Other fine-grained, porphyritic varieties appear as marginal facies of the white granite towards the country rocks.

The topmost part of Mt Mottarone consists of a small body of granodiorite showing knife-sharp contacts either with the pink granite or with the schistose country rocks without chilled margins.

The Mottarone granodiorite is a biotite-rich, medium- to fine-grained rock with zoned, automorphic phenocrysts of plagioclase and sometimes pink K-feldspar megacrysts that give the rock a marked heterogranular texture. But the most striking feature of this rock is the presence of countless small, schistose xenoliths without any preferred orientation and very homogeneously distributed. The xenoliths show the evidence of high grade thermal metamorphism since biotite is almost completely replaced by an aggregate of cordierite, spinel and corundum.

The compositional zoning and the internal structure of the Mottarone-Baveno pluton imply that this intrusive body is still more or less in its original attitude.

II) Montorfano granites

Most of Mt Montorfano, an isolated mount at the confluence of Valle Strona and Val d'Ossola, consists of a white, medium-grained granite. The country rocks (medium grade metapelites of the Scisti dei Laghi formation) are exposed only in small outcrops on the northwestern flank of the mount. Even the grain-size variations are very rare and confined to small pockets and veins.

The mineral assemblage is: plagioclase, quartz, K-feldspar, biotite, apatite, zircon.

The plagioclase is always automorphic, with regular or rythmic zoning, with andesine or even more calcic cores, that appear corroded as if the crystal were in disequilibrium with the coexisting melt at a given stage of crystallization. Clots of plagioclase crystals, connected to each other through the cores, are very frequent. The clots also often contain biotite indicating early crystallization of both minerals.

The K-feldspar shows both Baveno and Carlsbad twins; it forms sub-automorphic or xenomorphic interstitial grains sometimes in micrographic intergrowths with quartz.

The quartz forms rather coarse, xenomorphic grains with rare inclusions; thin, parallel fracture lines are often visible.

The biotite is dark honey brown; it includes tiny apatite, zircon and, more rarely, allanite crystals.

Green hornblende is only present in a restricted zone in the northwestern part of the granite stock (GALLITELLI, 1938; SASSI and SESANA, 1986). In the amphibolic granite, allanite is abundant in large, automorphic crystals.

In the easternmost part of the Montorfano stock (Cava Donna) the granite is full of enclaves of a greyish heterogranular facies, in turn containing mafic, fine-grained enclaves. The mineral assemblage of the grey granite is the same as that of the white granite: the minerals are present in two distinct generations. The margin towards the white granite is sharp, without any particular contact textures or compositional variations.

Microgranular, compact, dark enclaves are widespread in the Montorfano stock, whilst they are rare in the Mottarone-Baveno pluton. The maximum concentration is within the heterogranular facies of «Cava Donna»; their size ranges from a few millimeters to some decimeters (up to 1-2 m). They probably represent syngranitic dykes, disrupted and partly granitized by a slowly convecting magma. The enclaves show an intersertal texture of biotite, hornblende and plagioclase; new biotite is formed from hornblende. K-feldspar and quartz, introduced by granitization, are present as integranular material and patches.

A small, distinct granite body, crowded with schistose xenoliths, occurs in the northern part of the stock. It is composed of white medium- to fine-grained rocks, sometimes slightly porphyritic in texture, with pale pink K-feldspar phenocrysts; it does not contain plagioclase clots of early crystallization. The size of the xenoliths ranges from microscopic to more than 1 m across. They preserve the original schistosity and are oriented at random in the enclosing granite; their mineral assemblage includes sillimanite, andalusite, spinel, corundum, cordierite.

A dyke of granite porphyry cuts across the northern contact of the granite and penetrates into the country rocks.

Acidic differentiates are represented by many aplitic dykes and very few pegmatitic pockets.

The «green granite» of Mergozzo occurs in the northern part of the stock as a narrow band near the contact with the metapelites. This is clearly the result of *episyenitization*, i.e. subsolidus, low-temperature transformation of a preexisting intrusive rock, since, despite its igneous appearance, it is composed of albite, chlorite (analyses in MORTEN and ROSSI, 1971), quartz, sericite, sphene, carbonates. Within this rock microgranular enclaves are present, similar in size and texture to those of the white granite and showing the same, low-T paragenesis.

Field relations and petrographic evidence suggest (SASSI, 1985) a derivation of the «green granite» from the common, white Montorfano granite (on geochemical grounds BORIANI et al., 1988, also consider a possible affinity with the appinites). The contact between the white and the green granite is gradual and occurs through a transition zone a few metres thick or, more frequently, through a thick zone characterized by the presence of pale pink granite.

A typical sequence is:
- white granite;
- granite with biotite and pale pink feldspar;
- granite with chlorite and some pink feldspar;
- green granite of Mergozzo with chlorite and albite.

The transformation occurs through increasing albitisation and chloritisation in progressive steps.

At the beginning K-feldspar is replaced by chessboard albite, while plagioclase remains unaltered, then the chessboard albite recrystallizes in polycrystalline aggregates and plagioclase is transformed into medium-grained albite. A further step is the recrystallisation of the aggregates into coarser crystals. During albitisation, the albite itself becomes partially replaced by sericite, namely, the fine-grained aggregates and the chessboard albite. Quartz also is progressively replaced by albite (desilication).

The first appearance of chlorite is due to a common alteration of the biotite of the igneous rock; at a second step, newly formed chlorite in fine-grained aggregates replaces both the chlorite due to alteration of the biotite and the sericite that had formerly replaced part of the albite.

The great abundance of chlorite seems therefore due to a deep metasomatic compositional change and not to a derivation from a rock richer than granite in mafic minerals.

The intensity of both albitisation and chloritisation is very unequal from place to place. These hydrothermal transformations also occur in the schists near the contact over a width of a few metres.

III) Zircon typology

The different facies of the Mottarone-Baveno and Montorfano plutons show distinctive typologic characters of their zircon populations (Caironi, 1985a, b). On the typologic evolution diagram (see Fig. 1 in Boriani et al., 1988) three typologic trends can be defined. The first one is given by the white Mottarone granite and by its porphyritic variety (the zircons of the latter differ from those of the main granite only in some secondary characters, suggesting a more rapid cooling).

The second trend is given by the Montorfano white granite and by its greyish heterogranular facies (enclaves at Cava Donna); in the latter the zircons show features indicating a crystallization in the same chemical environment at higher temperature.

Both trends fall within the field of typical calcalkaline granites. The zircon population of the Mottarone granodiorite could be related either to the Montorfano or, better, to the Mottarone trend.

The third group is formed with the typical pink Baveno granite and the white granite of the transition zone. Their zircon populations show all the features of a crystallization from aluminous alkaline granitic magma. The magma should have had an alkaline character from the very beginning of the zircon crystallization (about 850°C). The high fluid pressure extended the crystallization of the zircon towards low temperatures (about 600°C).

IV) Contact metamorphism

The Mottarone-Baveno and the Montorfano plutons show subvertical, sharp and discordant contacts; the regional attitude of the schistose country rocks appears almost completely undisturbed.

In the main granite varieties the presence of country rocks xenoliths is restricted to zones immediately near the contacts.

The granite does not show any primary preferred orientation of the minerals. The main granite varieties show chilled margins (maximum 10 metres thick) against the wall rocks. Marginal apophyses are scarce, short and thin.

The contact metamorphism produced a complete static recrystallisation in a rather narrow aureole; there we find newly formed biotite, andalusite, cordierite, spinel, corundum (the last two only at Montorfano), and late-metamorphic muscovite. In the outer rim of the aureole, biotite grows at the expense of retrograde chlorite, indicating that the country rocks had already cooled down, with local retrograde metamorphism, before the intrusion of the granite.

Through a detailed study of the aureole, and using the conductive model of JAEGER (1957) a minimum temperature of 720°C for the intrusion of the Montorfano granite at a depth of 4-5 km, and a slightly lower temperature for the Mottarone can be inferred (SASSI and SESANA, 1986).

The contact aureole can still be recognized even in episyenitised country rocks near the «green granite» (presence of relic corundum).

V) Petrochemistry

The pink Baveno granite stands out clearly because of its different chemical characters, such as: very restricted range of composition, high SiO_2, low FeO tot., TiO_2, CaO and Al_2O_3. Only the granite porphyry of Montorfano shares these same characters.

The white granite of Mottarone (and its porphyritic variety) can be easily distinguished from the Montorfano granite; the latter is generally more basic and has a broadest variation range.

The comparatively low SiO_2 and high Al_2O_3 and TiO_2 of the granodiorite of the top of Mt Mottarone can be attributed to the presence of abundant xenolithic material.

The «green granite» shows a lower SiO_2 content and a higher Al_2O_3, Na_2O and MgO content compared to the white Montorfano granite.

The modal composition of the granites varies from monzogranitic in the Montorfano to monzo- and syenogranitic in the Mottarone-Baveno (GANDOLFI and PAGANELLI, 1974).

If we consider the major element chemistry and the geological-petrographical data, the compositional variations can be compatible with a process of fractional crystallisation occurring in a reservoir at depth, before the intrusions.

An account of the geochemical features of the granites can be found in BORIANI et al., 1988.

VI) Mechanism of emplacement

The field relations as well as the petrographic characters suggest that most of these granites intruded by means of a permissive cauldron subsidence mechanism, as suggested mainly by the absence of xenoliths in the internal parts of the plutons and by the steep, discordant contacts with the country rocks.

The subsidence was probably triggered by the initial forceful intrusion along preexisting tectonic discontinuities of the xenolith-rich varieties, i.e. the Mottarone granodiorite and (perhaps) the white granite with schistose xenoliths of the northern part of Montorfano.

The order of emplacement of the various granite types cannot be precisely defined. A possible sequence could be:

- forceful and turbulent intrusion of the Mottarone granodiorite and of the xenolith-bearing granite of Montorfano;
- passive intrusion of the Montorfano granite with a cauldron subsidence mechanism and contemporaneous injection of mafic dykes in the viscous granitic magma; the priority of the Montorfano granite is geologically suggested by the presence of a granite porphyry dyke similar in composition to the pink granite of Baveno crosscutting the Montorfano granite;
- emplacement, with the same mechanism, of the Mottarone-Baveno pluton. The pink granite magma was the upper, lighter part of the intruding magma column. In other words, the intrusion of the two main varieties of the Mottarone-Baveno pluton seems to have been a continuous process occurring at pace with the progressive sinking of the subsiding block.

Conclusions

The Hercynian plutonism of the Serie dei Laghi must be considered in the context of the huge magmatic event that followed the Hercynian orogeny. Its activity occurred in the time span between about 300 and 275 Ma, during the uplift of the Hercynian belt and the subsequent extensional tectonic regime that characterized the lower Permian. At the beginning, only mafic and intermediate magmas could ascend as small bodies in the crust; the basically compressive (or, better, transpressive) tectonics of that early phase favoured the assimilation of crustal material as well as fractional crystallization. Later, the enormous volumes of slowly produced granitic magma could either reach directly to the surface (Permian volcanism) or form composite plutonic bodies at a rather shallow depth.

From our field and petrological data it seems very unlikely that the plutons under consideration were volcanic reservoir, in other words that they vented at some stage of their evolution. Their internal heterogeneity seems to be the consequence of multiple intrusion of magma fractions that were differentiating at depth.

The tectonic lineaments of the zone and namely the CMB, Pogallo and Paleocremosina lines guided the ascent of the granitic magmas providing ideal graben boundaries that favoured the cauldron subsidence. The CMB alone is responsible for the emplacement of the older appinitic dykes and stocks and seems therefore the deepest structure of the zone.

Recent models for the CMB and Pogallo Lines (see SCHMID et al., 1987 for details) imply an original role of low angle normal faults of Triassic-Jurassic age, and a later (Alpine?) tilting up to 60°. The results of our field and petrological research do not agree with such an intepretation.

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