Società Italiana Mineralogia e Petrologia - Milano, 1974, Vol. XXX (2): pp. 893-917

ATTILIO BORIANI, ANNITA COLOMBO, EVELINA ORIGONI GIOBBI, GIOVANNA PEYRONEL PAGLIANI (*)

THE « APPINITE SUITE » OF MASSICCIO DEI LAGHI (NORTHERN ITALY) AND ITS RELATIONSHIP TO THE REGIONAL METAMORPHISM

ABSTRACT. — The junction between the Ivrea-Verbano and the Strona-Ceneri Zones is outlined by small eruptive basic bodies, whose meso, microstructural, chemical and mineralogical characters are very similar to those of the appinites of Ireland and Scotland.

These very heterogeneous rocks occur as dykes or stocks and show the following features:

a. A dark, fine grained, schistose external zone, with a gabbrodioritic chemical composition; sometimes this part consists of a pseudobreccia, cemented by a white granular leucocratic matrix.

b. A medium grained to pegmatitic intermediate zone, similar in chemistry and mineralogy to the fine grained schistose zone.

c. Locally, there is a medium-fine grained central zone, with a granodioritic chemical composition and a texture that varies from granular to granoblastic.

The same age and origin as the lamprophyres of the Strona-Ceneri Zone are hypothized because of their identical chemical composition; the differences in texture and mineralogical composition are due to differences of P_{H_2O} and T during intrusion.

The appinites form a series of zoned dykes intruded continuously as the P_{H_2O} and T were rising; the lamprophyres could represent an early phase.

These appinite bodies seem to have strongly influenced the metamorphic pattern at the junction between the Ivrea-Verbano and the Strona-Ceneri Zones enabling the isotherms to rise in the crust, during a phase in which the P conditions were lower than in eo-Hercynian phase. Thus anatexis (M. Cerano) oc-

(*) Istituto di Mineralogia, Petrografia e Geochimica dell'Università di Milano. Lavoro eseguito nell'ambito delle ricerche relative al programma del contributo C.N.R. CT 73.00091.05.

curred and andalusite bearing schists (Val Cannobina-Brissago) were produced. In this latter phase probably the Ivrea-Verbano began to be uplifted relative to the Strona-Ceneri Zone, as proposed by Köppel (1973) on the basis of recent geochronological data.

RIASSUNTO. — Il limite tra la zona Ivrea-Verbano e la zona Strona-Ceneri è sottolineato dalla presenza di piccoli corpi eruttivi basici i cui caratteri meso-microstrutturali, chimici e mineralogici sono molto simili a quelli delle appiniti dell' Irlanda e della Scozia.

Si tratta di rocce con aspetto eterogeneo, in filoni o in stock, le cui parti periferiche, scure e a grana fine, sono scistose ed hanno composizione gabbrodioritica; esse talvolta sono brecciate e cementate da una matrice chiara, a struttura granulare, di composizione fino a leucogranitica.

La parte mediana, a grana media fino a pegmatitica, ha composizione analoga alle parti fini. Talvolta è presente anche una parte centrale a composizione granodioritica, a grana medio-fine, con struttura da granulare a granoblastica.

Le parti periferiche scistose hanno una marcata analogia di chimismo con i lamprofiri della zona Strona-Ceneri, per cui proponiamo una comune età ed origine, anche se la struttura e composizione mineralogica sono differenti a causa delle diverse condizioni di P_{H_2O} e T di intrusione.

Le appiniti esaminate formano una serie di intrusioni basiche composite a T e P_{H_2O} crescenti di cui i lamprofiri rappresenterebbero la fase precoce.

L' intrusione appinitica sembra avere avuto un importante effetto sul pattern metamorfico al contatto tra Ivrea-Verbano e Strona-Ceneri, determinando in età tardo ercinica un innalzamento delle geoisoterme in una fase in cui la P era già ridotta a valori nettamente più bassi di quelli della fase eoercinica. Ciò ha probabilmente determinato anatessi (M. Cerano) e lo svilupparsi di paragenesi contenenti andalusite (Val Cannobina-Brissago).

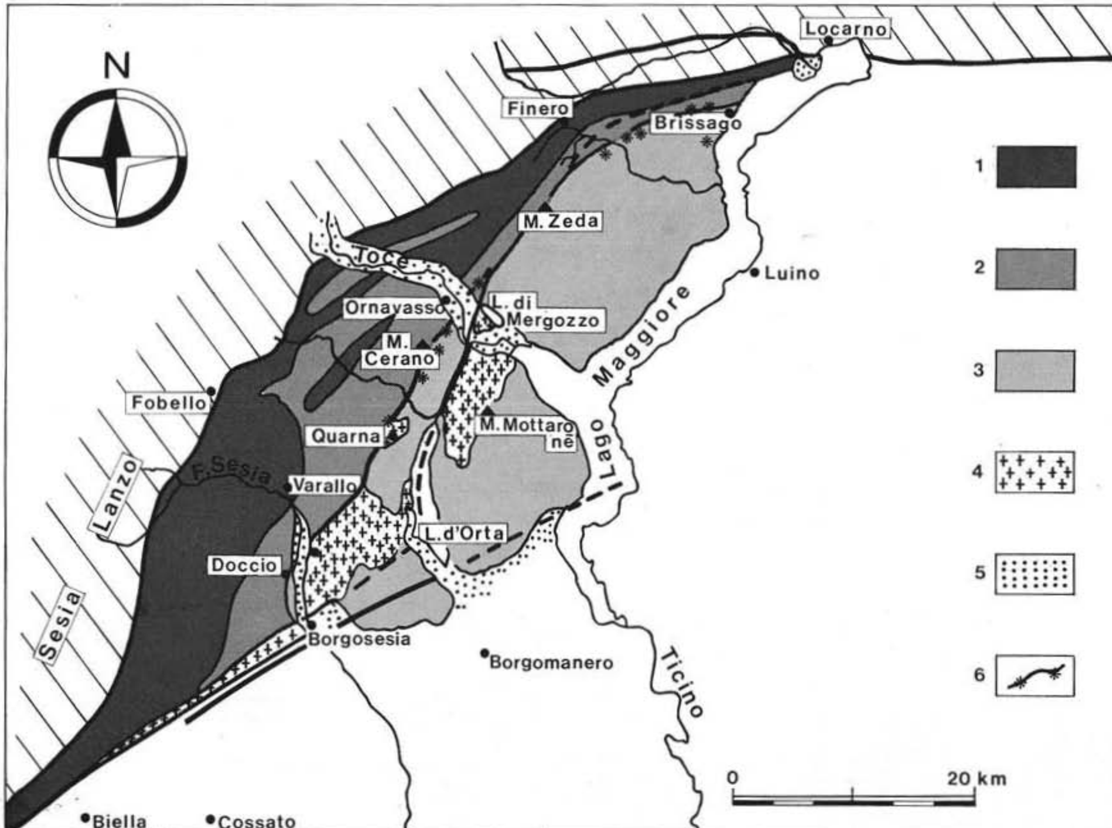
Questa fase potrebbe corrispondere al sollevamento relativo della zona Ivrea-Verbano rispetto alla Strona-Ceneri, come proposto da KÖPPEL (1973) in base a considerazioni geocronologiche.

Geological setting.

BORIANI & SACCHI (1973) have recently pointed out the strong similarity of the basic intrusions along the margin between the Ivrea-Verbano and the Strona-Ceneri zones with the well known « appinitic suite » of Scotland and northwestern Ireland.

The intrusive bodies are mostly composed by a hornblende-biotite gabbrodiorite with a pseudobrecciated marginal facies; the latter may be schistose or not.

The size of the intrusions is highly variable: the largest one is certainly that of the eastern slope of M. Cerano in the lower Val d'Ossola, exposed over an area of about 2 Km^2.



1 - Ivrea Zone.
2 - Kinzigites.
3 - Strona-Ceneri Zone.
4 - Granites of Lakes.
5 - Pliocene and Quaternary.
6 - Strona-Ceneri - Ivrea-Verbano boundary. Asterisks: outcrops of appinites. Heavy lines: Faults.

Fig. 1. — Geological sketch-map of the Ivrea-Verbano and Strona-Ceneri Zones, based on Boriani and Sacchi (1973).

More generally the appinitic rocks occur in swarms of dykes in which central homogeneous gabbrodioritic part is very reduced or lacking: typical, in this respect, are the entirely pseudobrecciated dykes of Valmara (the Swiss-Italian border on the western shore of Lake Maggiore) (fig. 1).

The discontinuity along which the basic intrusions occur could hardly be defined a fault, since no true cataclastic rocks are found along its plane. Nevertheless a slip, probably of major proportions, can be recognized from the sharp change in the metamorphic grade and in the tectonic style across the discontinuity.

Another important feature is the presence, along the western sector of the same margin, of a horizon of late — to post — kinematic migmatites consisting of highly mobilized country rocks of both the adjacent units.

Blastomylonites have been found locally where anatexis or recrystallization have not completely re-healed the old tectonic scar.

North of this line lies the Ivrea-Verbano Zone which is largely composed of basic metamorphites of amphibolite to granulite grade; the part of this unit bordering the contact under consideration, consists of pelitic schists of sillimanite-muscovite grade. The structural setting is rather obscure except for the Ossola sector, where SCHMID's (1967) detailed work revealed the presence of two broad antiforms. The axis of the southern one plunges 20°-45° NE, whilst the northern antiform shows a horizontal axis due to a local biphasic deformation.

South of the limit is the Strona-Ceneri Zone, with the large granitic bodies of late Hercynian age of Montorfano, Baveno, Quarna, Valsesia and Biellese.

The metamorphic series (amphibolite facies) is clearly polymetamorphic or at least polyphasic; the Strona-Ceneri zone roughly corresponds to the « Gneiss della Serie dei Laghi » (NOVARESE, 1929), a gneissic complex consisting of intercalations of biotite-plagioclase gneisses (paragneisses), Ceneri gneisses (gneisses with calc-silicate bearing xenoliths and granulated plagioclase, BÄCHLIN, 1937; BORIANI, 1970 b), augen gneisses and fine grained gneisses. The latter locally show Al-silicate nodules in which sillimanite, garnet, biotite etc. pseudomorph earlier chiastolite poikiloblasts.

To the south these gneisses are in contact with the « Scisti dei Laghi » through a continuous horizon of partly feldspathized amphibolites with minor masses of ultrabasites. The schists contain lenses of granitic to tonalitic orthogneisses.

In the Val d'Ossola-Val Cannobina sector the contact between Ivrea-Verbano and Strona-Ceneri is cut by a later strain-slip fault: the Pogallo Line (BORIANI, 1970 a), with a counterclockwise slip of about 11 Km. This fault seems to postdate the intrusion of the appinitic dykes, since it separates two stretches with basic intrusives, whilst along it they are completely lacking (BORIANI & SACCHI, 1973).

Regional literature.

NOVARESE (1906) described some lenses of gabbrodiorite cropping out from Spanero, M. Zuccaro, M. Cerano as far as the alluvial plane of the Toce river. This author noticed also the lenses occurring between Valmara and Brissago (at the southern boundary of the Ivrea-Verbano) and related the latter to those of Spanero.

The zone between Piodina and Cadegno was studied by SUZUKI (1930). He described the gabbrodiorites as amphibolites and found staurolite and andalusite in the country rocks, near aplitic and pegmatitic dykes.

The staurolite was formed in an older dynamo-metamorphic phase, while the andalusite is the product of a later thermal metamorphic event caused by the pegmatitic intrusions.

BURRI and DE QUERVAIN (1934) studied the dykes occurring on the road between Ponte and Brissago and in the Sacro Monte Valley. In the opinion of the authors the intrusion of these dykes and that of the basic bodies of the Ivrea zone was contemporaneous.

WALTER (1950) attributed an alpine age to the dykes of the Valmara valley and to the major basic intrusions. The basic dykes of the Valmara Valley are very heterogeneous: the thickness varies from a few cm to more than 1 m, the grain size changes from place to place: varying from fine to coarse, usually it is inhomogeneous with « schlieren ». Individual dykes occur though most of them are grouped in swarms.

Walter considered two main types of gabbrodiorites:

a) Dykes with « schlieren » and pegmatitic pockets. Hornblende is present as idiomorphic elongated individuals associated with biotite and plagioclase.

b) Zoned dykes: the medium grain size of the inner part becoming fine in the outer part. Hornblende is there present in two generations as « phenocrysts » in a fine grained matrix.

The leucocratic dykes were described separately.

Moreover, according to Walter, the country rock recrystallized near the contact, thermal metamorphism producing a hornfels rich in Al silicates.

SCHILLING (1957) noted gabbrodioritic blocks enclosed in the granodiorite of Camponi and since those rocks are cut across by the Hercynian granite, he attributed to them a pre-Hercynian or eo-Hercynian age.

BERTOLANI et al. (1963) mapped, at the boundary of the Strona-Ceneri and the Ivrea-Verbano Zones, some basic intrusions: one, a lamprophyric dyke, crops out near Chesio, another, a gabbrodioritic dyke, occurs east of Loreglia and at Ponte Orchera.

BORIANI and PEYRONEL PAGLIANI (1968) noted the presence near the spotted amphibolites above Spanero of micro-quartzdiorites from M. Zuccaro to M. Cerano. Gabbrodioritic rocks occur E and NE of M. Cerano. The migmatites around them were interpreted as due to insitu anatexis of the country rocks. This phenomenon could be prior to or contemporaneous with the intrusion of the basic rocks. These basic rocks are composed of plagioclase, hornblende with ilmenitic exsolutions, biotite and quartz. K-feldspar is present only in the more leucocratic parts.

Petrology of appinitic bodies.

The Val Cannobina - Valmara Zone.

Appinitic bodies are very abundant in the region from the Cannobina Valley to M. Limidario and the Lake Maggiore; to be precise, they are present in an almost triangular area between Spoccia, Valmara and Brissago.

The dykes occurring near Spoccia in the western part are mostly isolated occurrences of gabbrodiorites concordant with schists. Only seldom are these dykes zoned.

NE of Spoccia, near M. Zuccaro and Arnascio, the dykes become more abundant, the greatest concentration being in the zone between P. Fronzina, Cadegno-Valmara, Piodina and Vantarone. Most of the dykes of this area are composite, ranging in composition from gabbrodiorite to granodiorite and the relation between the melanocratic and leucocratic intrusions is very close; in fact both the dykes and the stocks (as at Ponte Valmara) show very similar features, which are as follows:

a) The peripheral part is almost always schistose, fine grained, with a gabbrodioritic chemical composition; its mineralogical assemblage is very simple: hornblende and plagioclase are the two fundamental components. Hornblende is present as elongated individuals sometimes grouped in granoblastic lenses parallel to the schistosity; the cores of the crystals may show ilmenitic exsolutions. Biotite is generally very rare.

These schistose dykes lie mostly concordantly with the country rock and their contacts are very sharp (Plate 1, c).

Sometimes metamorphic rock, with a mineralogical composition of plagioclase, biotite, quartz, garnet, staurolite, ± sillimanite, ± corundum, can be found, intercalated in the schistose dykes (Plate 1, d). In the Cannobina Valley east of Spoccia dykes up to 30-40 cm thick can be found as isolated outcrops, more or less concordant with the country rock. A very peculiar aspect is the formation of pseudobreccias in some dykes or stocks near their contacts with the country rock. This phenomenon is clearly visible at Valmara-Dogana and on the foot-path Resceragca-Pianoni. The pseudobreccias are made up of small blocks of schistose gabbrodiorite cemented by a leucocratic granodioritic or aplitic matrix. Biotite flakes are very abundant at the boundaries between the melanocratic and the leucocratic parts (Plate 1, a). The leucocratic veins show an aplitic or micropegmatitic texture; the mineralogical composition is: plagioclase, clearly zoned with discontinuous growth stages, quartz with undulose extinction is abundant, amphibole and biotite are very rare; K-feldspar may be present, apatite is widespread.

b) The intermediate zone looks more leucocratic because of the coarser grain size. The whole appearance is heterogeneous (Plate 1, b); in fact the grey matrix with medium to coarse grain size variable from place to place, is generally spotted with pegmatitic pockets in which the amphibole crystals reach lengths of up to 10 cm. The transition towards the pockets is gradual. The hornblende is present as elongated idiomorphic individuals with an ilmenitic exsolved core, in a matrix of plagioclase and quartz. Sometimes they appear as « hollow crystals » enclosing biotite or plagioclase. Biotite may be intergrown with the hornblende; plagioclase is always xenomorphic, quartz is generally absent.

Apatite, sphene, opaque minerals are very abundant.

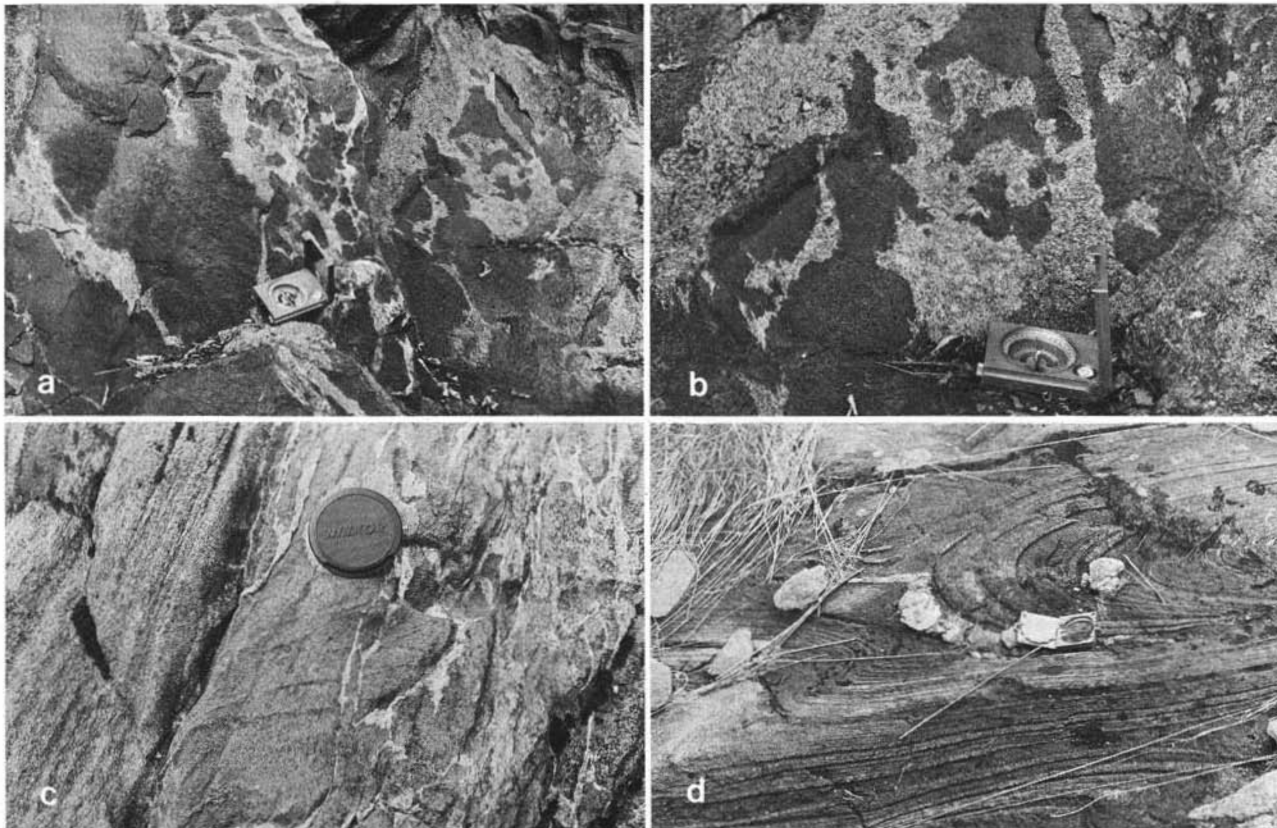


Plate 1. **a** The gradual transition from the pseudobreccias towards the intermediate zone.
b Intermediate zone. In the leucocratic part the grain size is variable.
c The contact between the gabbrodioritic pseudobreccia and the country rock is very sharp. The metamorphic rock is a staurolite, andalusite, kyanite, sillimanite gneiss (Rescerasca).
d Complicated folds, with subvertical axes, in the andalusite bearing country rock.

The intermediate part is very common in the zoned dykes occurring in Valmara, from the Dogana on the Cannobio-Brissago road to Rescerasca, Vantarone, Pianoni and near Loreglia in the Strona Valley. Individual dykes with medium to coarse grain size occur and in the field elongated individuals of amphibole and flakes of biotite in a matrix of plagioclase and quartz are visible.

c) Only rarely in the zoned dykes or stocks, can a central section of a fine grained granodiorite or aplitic veins be found. Rarely (M. Zuccaro, Pianoni) melanocratic dykes occur bearing pyroxene and poikilitic hornblende.

The texture in all these rocks is generally granular and varies from ipidiomorphic to panxenomorphic, occasionally subophitic, but in many cases a gradual transition into granoblastic can be observed. In fact, the more basic dykes may show two generations of minerals: deformed individuals of magmatic origin are surrounded by recrystallized minerals in polygonal or idiotopic aggregates.

The M. Cerano zone.

The appinites of the Ossola Valley crop out NE of M. Cerano, from A. Colletto to the Selvatica Valley, near Ornavasso.

The resemblance to the gabbrodiorites of Valmara is very strong: the rocks are heterogeneous, but always idiomorphic crystals of amphibole and flakes of biotite can be observed in a matrix of plagioclase and quartz. The stocks are generally discordant and the contacts with the country rock are very sharp.

Rarely, in the marginal zone of the dykes are found peculiar pseudobreccias.

The texture is generally granular with medium to coarse grain size.

Mineralogy.

Amphiboles. The amphiboles are the essential mafic components of all the gabbrodioritic types but they are also present, subordinate to biotite, in more the leucocratic types.

They are represented by a green hornblende with a weak pleochroism (X = light greenish-yellow; Y = light green; Z = bluish or brownish green). $2V_x = 68°\text{-}74°$; $Z:c = 14°\text{-}18°$.

They are present either as stubby prisms of small, medium up to coarse size, or as tiny idiomorphic individuals associated with the first type, mainly in the gabbrodioritic parts of the zoned dykes; this second generation hornblende, clear and colourless, is often set in idiotopic aggregates and is not significantly different, in its optical characters, from the coarse grained hornblende (fig. 2).

In some of the rocks types the hornblende prisms reach a notable length (2-3 cm), forming greenish-brown megacrysts that stand out clearly from the fine grained dark grey portion of the rocks.

Fig. 2. — Idiotopic aggregates of clear hornblende in the schistose gabbrodioritic dykes. (Pol. light 20 ×).

Under the microscope they show a characteristic poikilitic texture; frequent inclusions, mostly clustered near the rims, are represented by tiny, nearly colourless prisms of hornblende, of pyroxene and sphene.

The pleochroism of amphiboles of the gabbrodioritic dykes is always weak and there are frequently noticeable differences in colour between core and rim; the latter generally shows a very light colour and is free of ilmenite exsolution which is an almost constant character of the cores of the hornblende. Very characteristic is the presence of the « hollow shell crystals », generally containing aggregates of tiny biotitic flakes, plagioclase grains and sphene (fig. 3).

Biotite. This mineral is present throughout the appinite suite with constant characters (strong pleochroism from light yellow to yellowish brown) though it is present in highly variable amounts and in various grades of alteration.

In the gabbrodiorites it is always less abundant than amphibole with which is often intergrown with more or less clear relations of replacement;

Fig. 3. — Elongated prism of hornblende showing ilmenitic exsolutions and a « hollow shell crystal » structure. (crossed Nicols 60 ×).

sometimes it is apparently enclosed by the hornblende in a somewhat problematical pattern. Also frequent are the polygonal aggregates. The amount of chloritisation is variable.

In the gabbrodioritic parts of the zoned dykes, the biotite is sometimes prevailing over hornblende with which it is closely intermingled. Often it is recrystallized as small flakes in a decussate texture.

In the leucocratic parts of the zoned dykes biotite always prevails over amphibole; the latter is completely lacking in the K-feldspar and muscovite-bearing types.

In the breccias, biotite becomes progressively enriched towards the contact with the leucocratic matrix; along the contact it shows a strong preferred orientation.

Mica is absent only in the pyroxene bearing appinites with hornblende megacrystals.

Pyroxene. This mineral is present only in the appinites with poikilitic hornblende megacrysts, as small stubby individuals generally enclosed by the hornblende. It is an augite with $Z : c = 52°$.

Plagioclases. They are constantly present in the whole series; their compositional and textural characters vary from type to type.

In the normal gabbrodiorite the plagioclase is generally less abundant than hornblende. Mostly the grains size is medium; sometimes the plagioclase is present also in rather small interstitial grains or in polygonal aggregates.

They are generally zoned, with albite, albite-pericline, albite-Carlsbad, Manebach twins; twin lamellae show ill-defined shape. Zoning is normal or irregular and patchy.

Very characteristic and widespread are individuals consisting of a generally idiomorphic central part, often with fractures and filled with alteration products, surrounded by a clear, unaltered rim, sometimes weakly zoned, with xenomorphic curved outlines, which can be distinguished from the core also by a weaker birefringence. The external more sodic part often penetrates into the central core irregularly replacing the An-richer plagioclase. The more calcic cores are labradorite (60-65-70% An) while the rims are andesine (35-45% An) (compositions determined using the curves of Slemmons (1962), Van der Kaaden and Smith (in Tröger, 1971)).

In the normal zoned grains the composition ranges from An_{40} to An_{50}.

In the gabbrodioritic portions of the zoned dykes, the plagioclase is generally present in nearly the same amount as amphibole; it is mostly idiomorphic, sometimes poikilitic with apatite, biotite and calcite inclusions. Common in these rocks are the sharply zoned plagioclases with calcic cores (up to An_{65}) and oligoclase-andesine, andesine-oligoclase rims ($An_{25\text{-}35}$). More sodic plagioclase (oligoclase, $An_{20\text{-}25}$), generally in idiomorphic and patchy zoned individuals, with incomplete twin lamellae, were found in the granodioritic parts of zoned dykes, showing a characteristic sub-ophitic texture (example: the dyke between Spoccia and Bronte, sample N° 4a).

In the more leucocratic parts of the zoned dykes (with a composition from aplite to granodiorite), the plagioclase is always distinctly twinned with the albite, albite-Carlsbad, albite- Ala B, albite-pericline laws; the grains are rather large, slightly sericitized, with very small, more calcic, and almost unaltered nucleii (andesine, An_{35}) and outer shell that can reach an almost pure albite composition ($An_{5\text{-}10}$).

K-feldspar. This mineral appears only in the aplitic veins, where it reaches the same abundance as plagioclase. The size of the grains is coarse; it is slightly perthitic and often marginally replaced by an aureole of mirmekitic plagioclase.

The microcline grid is always visible, $2V_x = 80^o\text{-}84^o$.

The coarsest grains show poikilitic inclusions of tiny quartz and plagioclase granules. The replacement by plagioclase is frequent and characteristic and sometimes only a few relics of the primary mineral survive.

Muscovite. It is present only in some aplitic parts in rather small flakes often intermingled with biotite.

Quartz. This mineral is only sporadically present in the gabbrodiorites as small interstitial grains often arranged in fine polygonal aggregates; in the granodiorites or aplitic parts it becomes an essential mineral. Undulose extinction may be noticeable.

Accessory minerals. Apatite and *opaques* are the only constant accessories of all the rock varieties. *Apatite* is mostly present as limpid acicular crystals, only seldom with a cloudy core; sometimes it is also present in coarser short prisms.

Sphene is a very diffused accessory in all the rocks types. Small grains or idiomorphic individuals are present; they show a weak pleochroism from yellow to light brown.

Epidote is abundant in coarse isolated grains or in fine grained aggregates in the more calcic cores of the zoned plagioclases. Zoisite and clinozoisite prevail over pistacite.

Zircon is present only as inclusions in the biotite.

Rutile and *garnet* (the latter only in the aplitic veins) are rare.

Among the alteration minerals *chlorite* (penninite) is very abundant as a replacement of biotite; *calcite* is less common; *prehnite* was found as fracture filling in the gabbrodiorite. *Ilmenite* is relatively abundant as an exsolution product in the hornblende.

Chemical results.

Thirty-three samples from the two zones of outcrops have been analyzed by XRF and wet chemical techniques: the results are shown in Table 1 in weight percent.

Generally the rocks we considered have an Al_2O_3 content between 14,5% and 20%; MgO between 3,50% and 8%; CaO between 6% and

10%; total iron as Fe_2O_3 generally shows a higher value than MgO. The SiO_2 content varies from type to type: in the basic types the average is 50%, while in the more leucocratic rocks (quartz-diorites, granodiorites and aplites) it is 68-70%.

In fig. 4 there are the two diagrams, MgO plotted against Al_2O_3 and CaO plotted against Al_2O_3, for the appinites of Massiccio dei Laghi. These results are compared with similar data reported by Hall

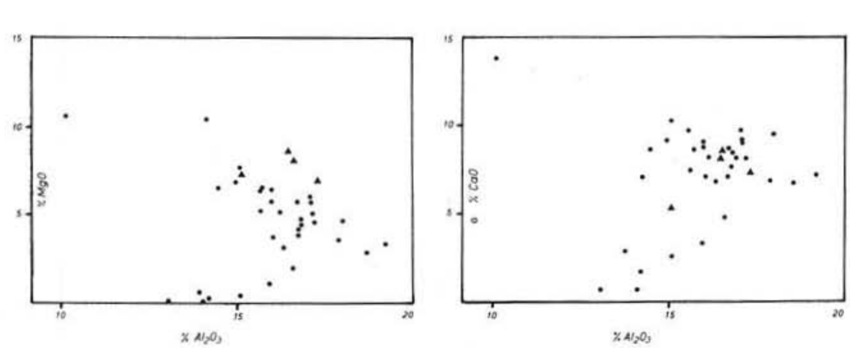


Fig. 4. — Black dots: appinites of the Val Mara-Val Cannobina zones. Triangles: lamprophyres of the Verbania area.

(1967) for the appinitic intrusions of the Ardara Pluton (Co. Donegal, NW Ireland) and those associated with the Caledonian granites of Scotland (fig. 5).

The first diagram, MgO against Al_2O_3 shows that the plots of the gabbrodioritic and quartz-dioritic, aplitic samples have different trends; in the former when the Al_2O_3 content decreases, MgO increases, while for the leucocratic rocks there is a direct relationship between the two oxides (this fact is a consequence of the variation of the percentage of biotite and amphibole in the rocks). One sample has a very low Al_2O_3 content and the highest MgO percentage; it is the only pyroxene-bearing rock type.

The CaO/Al_2O_3 diagram differs from the former in the fact that there is no visible trend of differentiation in the gabbrodioritic rocks: the plots are concentrated in a « cloud » because of the constant presence of hornblende and andesinic plagioclase.

The appinites of Massiccio dei Laghi are chemically very similar to those of Glen Tilt and Glenelg-Ratagain Complexes (Scotland); on the other hand the appinites associated with the Ardara pluton have a higher content of MgO and CaO and a lower content of Al_2O_3 and $Fe_2O_3 + FeO$ than those we have analyzed.

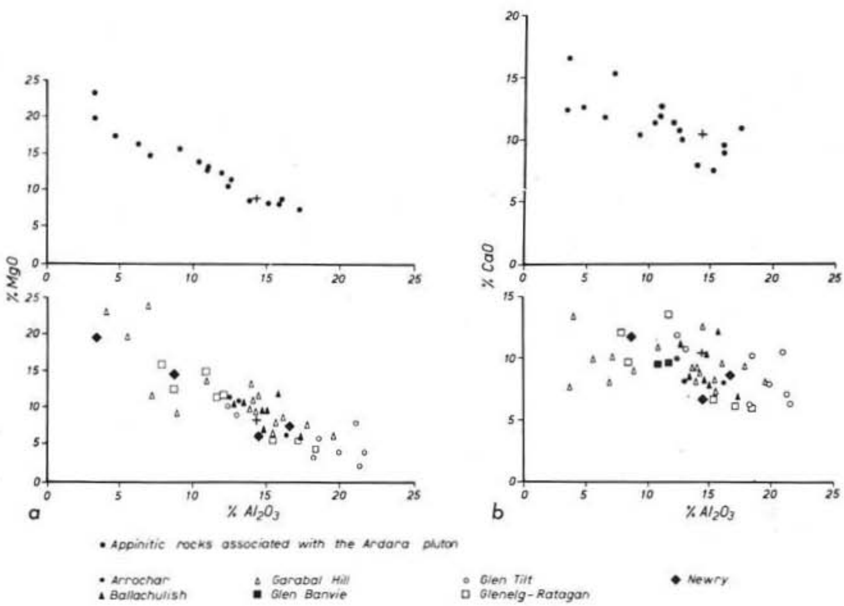


Fig. 5. — For explanation see text.

In the appinitic rocks under consideration there is a complete transition (see FMA diagram, fig. 6) between the most basic rocks (lamprophyres and gabbrodiorites) and the aplites, because the matrix of the pseudobreccias was also analysed. The transition is not visible in the same diagram reported by Hall (fig. 7) for the Ardara Complex as he probably considered only the most basic types which form distinct intrusions associated with the central granodioritic pluton.

The results of the analyses of the appinites have been compared with those of the lamprophyres — outcropping W of Pallanza — analysed by Lucchesi (1968): these are plotted on all the diagrams.

The plots of the lamprophyres are always perfectly enclosed by those of the gabbrodioritic rocks, suggesting that they belong to the same magmatic type: this fact underlines the analogy between the two types. Probably they belong to a single magmatic process: this hypothesis is based also on the analogy of mineralogical composition.

Moreover most of the appinites we considered plot in the normal differentiation field of the calc-alkali series (see QLM diagram. Fig. 8). Only one sample plots in the field of alkaline basalts and two in the field of essexites; the pyroxene-bearing rock falls in the field of pyroxenites.

TABLE 1.

	SiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	TiO_2	P_2O_5	H_2O^+	TOTAL
43	47.19	10.14	3.90	6.93	0.20	10.57	13.66	1.41	0.77	1.56	0.11	3.55	99.99
24a	50.19	14.49	3.67	6.29	0.22	6.45	8.72	3.14	1.96	1.49	0.23	3.16	100.01
30a	50.50	16.00	2.08	7.07	0.18	6.45	8.69	3.58	1.39	1.55	0.35	2.16	100.00
20	49.67	16.21	2.32	8.72	0.19	5.22	8.33	3.41	1.00	2.25	0.19	2.50	100.01
39	49.10	16.73	2.46	7.00	0.14	5.69	8.79	3.32	1.34	2.05	0.24	3.14	100.00
29	46.14	17.12	3.01	9.14	0.23	5.90	9.68	2.74	0.97	1.82	0.25	3.01	100.01
10	49.77	17.17	3.29	6.14	0.24	5.12	9.27	3.48	1.36	1.49	0.27	2.46	100.06
26a	48.81	17.18	3.63	5.93	0.18	5.62	9.15	3.88	1.04	1.63	0.41	2.54	100.00
3	45.99	14.32	2.10	7.29	0.20	10.46	7.03	3.41	3.46	1.47	0.52	3.81	100.06
7	51.62	15.67	2.51	6.57	0.21	6.31	8.78	2.69	1.57	1.25	0.28	2.55	100.01
$24b_2$	50.32	15.99	3.43	6.29	0.19	5.78	8.77	3.53	1.47	1.47	0.28	2.48	100.00
36a	55.13	16.07	2.63	4.57	0.14	3.79	7.06	4.61	1.76	1.23	0.26	2.77	100.02
13a	51.75	16.74	2.53	6.36	0.23	3.81	7.09	2.73	3.84	1.54	0.25	3.19	100.06
19b	51.89	16.90	2.72	6.64	0.20	4.46	8.22	2.22	2.55	1.30	0.24	2.64	99.98
19d	53.25	16.90	2.48	5.14	0.19	4.75	8.48	3.01	1.65	1.00	0.26	2.93	100.04
36b	52.81	17.21	1.85	6.14	0.17	4.55	8.26	4.27	1.03	1.39	0.29	2.02	99.99
4a	49.93	17.90	1.90	5.00	0.13	3.52	6.89	6.58	2.37	1.54	0.73	3.62	100.11
9	49.12	17.97	2.86	6.62	0.21	4.72	9.55	3.30	1.40	1.55	0.33	2.35	99.98
4b	51.60	18.58	2.25	3.71	0.12	2.93	6.72	6.84	2.14	1.42	0.74	3.03	100.08
27b	48.31	19.20	2.78	8.22	0.31	3.37	7.20	1.67	1.44	1.70	0.77	5.15	100.12
$24b_1$	46.29	15.13	4.10	7.29	0.22	7.62	11.32	2.44	0.87	1.87	0.20	2.67	100.02
25	48.61	15.65	3.70	6.36	0.21	6.45	9.71	3.50	1.39	1.51	0.31	2.59	99.99
26b	55.65	15.75	2.26	5.07	0.15	5.19	7.49	3.74	1.37	1.23	0.25	1.92	100.07
44	54.79	16.81	2.42	4.93	0.16	4.17	7.61	3.87	1.68	1.30	0.37	1.91	100.06
54	74.92	13.08	0.50	0.36	0.50	0.14	0.61	4.02	5.25	0.06	0.11	1.20	100.75
8	69.40	13.84	1.43	1.79	0.10	0.72	2.85	4.10	3.69	0.39	0.22	1.48	100.01
22	73.70	14.15	0.24	0.26	0.02	0.18	0.74	4.11	5.48	0.05	0.13	1.31	100.19
13b	71.65	14.22	0.93	1.21	0.05	0.22	1.58	4.15	3.94	0.28	0.22	1.59	100.04
17a	68.79	15.15	1.24	1.69	0.07	0.44	2.63	4.17	3.69	0.35	0.19	1.59	100.00
19c	67.79	15.92	1.00	2.00	0.05	1.18	3.41	4.87	1.68	0.41	0.24	1.48	100.03
30b	57.17	16.38	1.71	5.00	0.15	3.26	6.86	4.10	1.75	1.14	0.29	2.18	99.99
19a	61.29	16.79	1.96	3.29	0.11	1.80	4.91	3.99	2.31	0.84	0.38	2.41	100.08
34	72.48	14.25	0.79	0.71	0.04	0.09	1.42	3.73	4.65	0.17	0.09	1.59	100.01
17b	61.91	17.15	2.16	4.36	0.11	2.31	1.56	3.02	3.48	0.91	0.21	2.88	100.06

The « appinite suite ».

We based our considerations concerning the classic appinite suites primarily on Pitcher and Berger's work (1972), because these authors also give a genetic interpretation of the various phenomena and not merely a mineralogical and chemical description. The appinite suite considered by Pitcher and Berger is associated with the Caledonian granites of Donegal (NW Ireland). These basic intrusions have different forms; in fact they vary from small bosses to dykes, sheets

Explanation of Table 1.

Medium to coarse-grained gabbrodiorites generally with poikilitic amphiboles (middle parts of zoned dykes; single stocks):

43	Val Mara	MS 74640684	39	Val Mara	MS 74440686
24a	Val Mara	MS 74880674	29	Val Mara	MS 75080736
30a	Val Mara	MS 74760756	10	Val Cannobina	MS 69860478
20	Val Mara	MS 74900695	26a	Val Mara	MS 74860670

Fine-grained sometimes schistose gabbrodiorites (generally external parts or small dykes):

3	Val Cannobina	MS 69820446	19d	Val Mara	MS 74850660
7	Val Cannobina	MS 69900478	36b	Val Mara	MS 74100667
$24b_2$	Val Mara	MS 74880674	4a	Val Cannobina	MS 69820446
36a	Val Mara	MS 74100667	9	Val Cannobina	MS 69860478
13a	Val Cannobina	MS 69830480	4b	Val Cannobina	MS 69820446
19b	Val Mara	MS 74850660	27b	Val Mara	MS 75000686

Net-veined gabbrodiorites (pseudobreccias):

$24b_1$	Val Mara	MS 74880674	26b	Val Mara	MS 74860670
25	Val Mara	MS 74920676	44	Val Mara	MS 74900694

Central qaurtz-dioritic, granodioritic parts in zoned dykes and aplitic dykes:

54	Val Mara	MS 75600567	17a	Val Mara	MS 74850660
8	Val Cannobina	MS 69860478	19c	Val Mara	MS 74850660
22	Val Mara	MS 74860665	30b	Val Mara	MS 74760756
13b	Val Cannobina	MS 69830480	19a	Val Mara	MS 74850660

Country rocks (paragneisses, augen-gneisses):

34	Val Mara	MS 73960640	17b	Val Mara	MS 74850660

and sills. The most important rock type is the appinite defined as a « medium to coarse diorite which is composed of idiomorphic hornblende set in a groundmass of plagioclase and quartz sometimes with a little K-feldspar ». Biotite and pyroxene are alternative mafic minerals. Generally these rocks are lenticular bosses (for example the intrusions associated with the Ardara pluton) situated within metapelitic and calcareous rocks, in which there is visible a contact aureole up to 20 meters in width.

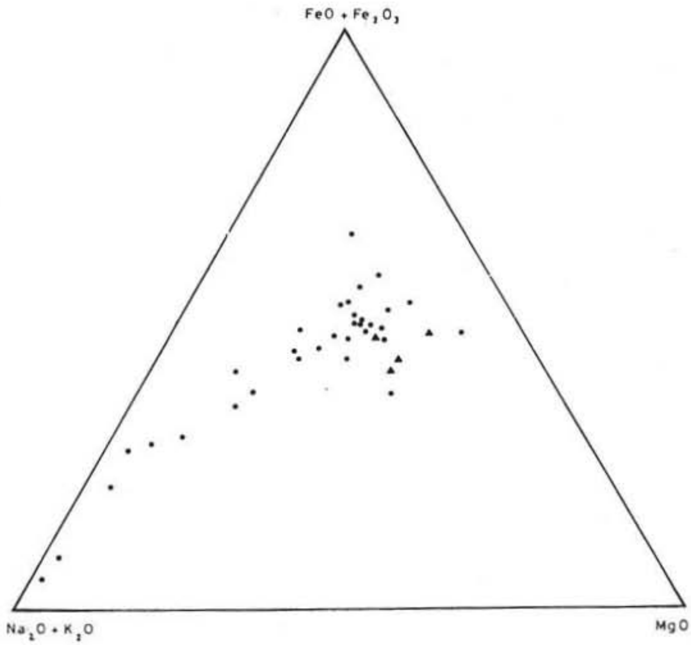


Fig. 6. — Black dots: appinites and leucocratic veins of the Val Mara-Val Cannobina Zones. Triangles: lamprophyres of the Verbania area.

Along the contact with the metasediments, intrusive breccias are sometimes present: these consists of disrupted blocks of pelite and are produced by the emplacement (probably explosively) of a volatile rich magma.

The appinites are often associated with lamprophyres which are considered by Pitcher and Berger to be the fine-grained equivalents of the larger appinitic intrusions: therefore the two types of rocks are consanguineous. Another typical feature of the appinites is the presence of many leucocratic net-veins which give a pseudo-brecciated structure to the whole rock.

Also the mineralogical features of these basic rocks are interesting: they contain a high percentage of amphibole (hornblende) while pyroxene is seldom present. Hornblende appears to be the stable phase and it is formed as a primary mineral or as a replacement of olivine and pyroxene but in this case late-stage hornblendization cannot be

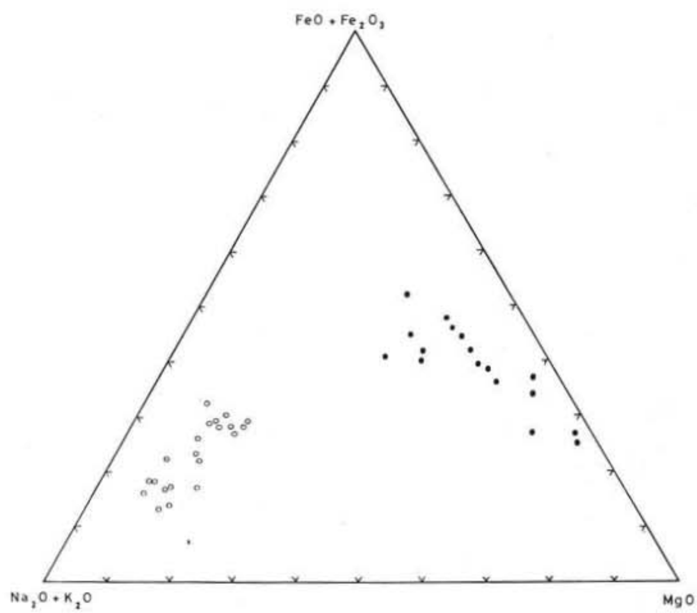
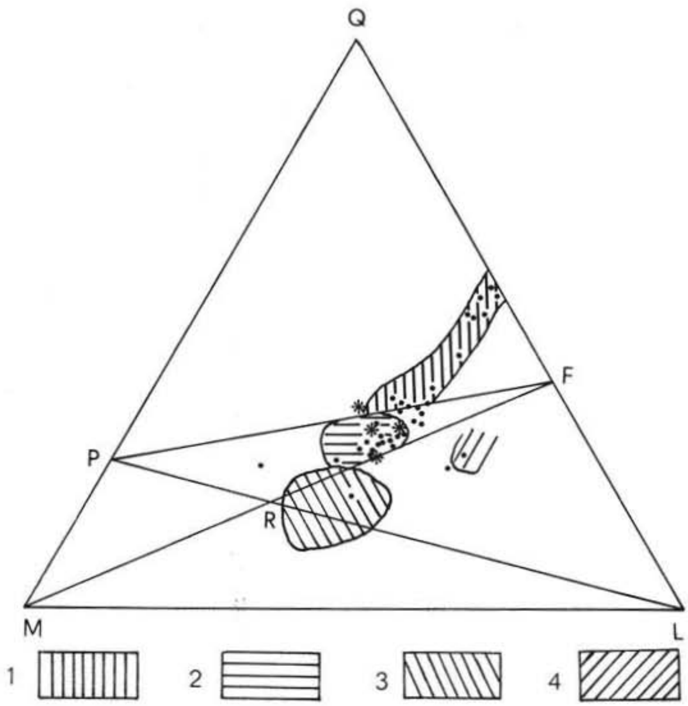


Fig. 7. — Ardara Complex. Open circles: granodiorite. Black dots: appinites. (Hall 1967).

the most important process in the production of these hornblende-rich rocks. Amphibole is idiomorphic and it often appears as hollow shell crystals with biotite or plagioclase-rich cores (Wells and Bishop 1954). Biotite is present also external to amphibole which is sometimes recrystallized. Hornblende has two or three distinct stages of growth visible by the change of colour: the core is brown and the rims are green or colourless. The plagioclase has a distinct basic core and a mantle of albite which is interpreted as a late-stage of crystallization (French 1966). The minor constituents are apatite, sphene, chlorite, calcite and opaques.



1 - Calk-alkaline series. 2 - Basalts. 3 - Alkaline basalts. 4 - Essexites.

Fig. 8. — Black dots: appinites. Asterisks: lamprophyres of the Verbania area.

The appinites of Massiccio dei Laghi differ from those of Scotland and Ireland as they are commonly dykes and seldom stocks (Val Mara and M. Cerano). Moreover they are not always closely connected in space with the granitic intrusions: they occur along the junction between the Strona-Ceneri and Ivrea-Verbano Zones (this contact is supposed to be tectonic), while the granites of Lakes are found in the Lakes-Schists (Strona-Ceneri zone) and their intrusion follows the appinitic emplacement.

The appinite suite in the Massiccio dei Laghi consists of typical hornblende-rich appinites associated with lamprophyre-like rocks: the latter form single small dykes or occur as the external parts of the zoned dykes.

Within the appinitic dykes the fine-grained bands are often schistose (the lamprophyres considered by Pitcher and Berger are never schistose) and brecciated but these breccias are actually pseudo-breccias since the leucocratic netveins belong to the same magmatic process.

The appinites we considered are found in highly metamorphosed rocks of the amphibolite facies, i.e. paragneisses and augen-gneisses, in which no definite contact aureole caused by the gabbrodioritic intrusions is visible. The mineralogical composition is very similar to that of the appinites of Scotland and Ireland; the analogy encompasses not only the mineral assemblage but also the features of each mineral phase (see the above description).

Let us consider now the origin of the appinites. According to Pitcher and Berger these rocks have a high content of hydrous minerals and are also coarse-grained: this suggests that the appinitic magma had a high volatile content and probably the overgrowths represent growth under alternating physical conditions arising from the intermittent release of a high gas pressure. According to these authors the appinitic magma is the result of hybridization between basic and acid magmas. However generally the most basic rock types are earlier than the others. Pitcher and Berger think that appinitic magma came from the upper mantle and in this case the source of its high water content must be found in the associated granites which were probably mobilized in the crust at the same time as the appinites.

The basic magma proceeds upward faster than the granite magma because of its higher volatile content and therefore its higher mobility.

Moreover the field of stability of hornblende is progressively widened at the expense of pyroxene and olivine when the water pressure rises relative to total pressure (Yoder and Tilley 1962); this fact supports the hypothesis of an appinitic magma differentiating under high water vapour pressure.

Also in the Massiccio dei Laghi there is good evidence that the basic magma from the upper mantle went through an anatectic level in the crust and so it became rich of volatiles.

In this zone we think that some of the basic rocks — such as lamprophyres — are not synchronous with the appinites s.s.

The regional metamorphism and the role of the appinites.

The alignement along which the appinitic rocks occur marks the separation of two distinct metamorphic domains.

South of it, two sectors must be distinguished: *a*) the sector Biellese-Val d'Ossola; *b*) the sector between Val d'Ossola and Lake Maggiore.

a) As regards the first sector, we will here particularly deal with the zone between the Valsesia-Lake Orta watershed and Val d'Ossola, since the westernmost part is disturbed by later faults or by the presence of granites and porphyries and is petrographically rather ill-known.

The general character is that of an intense remobilization of the leucocratic gneisses in the vicinity of the contact; the larger the appinitic mass, the stronger is the mobilization.

Mapping now in progress has shown, in the sector between Lake Orta and the Valsesia (or Alzo) Granite, that, in spite of the sometimes strong mobilization, most of the Strona-Ceneri rock types can be recognized, in addition, in the zone uphill from Césara the typical « schlingenbau » structure of the northern Ceneri Zone (Bächlin, 1937; Reinhard, 1964) is also present.

In the M. Cerano zone, between Val Strona di Campello and Val d'Ossola, the principal rock types and the products of their mobilization have been described by Boriani & Peyronel Pagliani (1968). The metamorphic features prior to the appinitic intrusion are not particularly evident but the similarity of the rock types with those of the Verbania district proves that the data from this latter zone can be extended also to the western sector.

b) In the eastern sector the characters of the metamorphism have been described by Boriani (1970a) in the Verbania zone.

The series, composed of paragneisses and gneissic migmatites is set in subvertical interlayered horizons striking N 50°-60° E from Lake Mergozzo to the Cannobina Valley.

The metamorphic grade increases gradually from SE to NW from the staurolite, to the kyanite and thence to the sillimanite zone with a fairly good sillimanite isograd near M. Zeda.

The metamorphic pattern is less clear in the triangle between Val Cannobina, Lake Maggiore and the Ivrea-Verbano Zone. Here the Strona-Ceneri rocks are complicatedly folded on nearly vertical axes in a characteristic « schlingenbau structure ».

The tectonic phase responsible for this setting apparently occurred at a fairly low temperature since the newly formed minerals are chlorite, muscovite and albite.

The appearance of the appinites coincides with a sharp step in the metamorphic grade; andalusite (sometimes with kyanite), staurolite and sillimanite become common minerals in the country rocks of the appinitic dykes (Plate 1, d).

This fact was interpreted by WALTER (1950) as due to a contact metamorphism; this interpretation seems to be valid only as far as the effect it has on the southern low grade rocks. Northward from the appinitic swarm the metamorphic grade increases gradually and andalusite is replaced by fibrolitic aggregates in the pelitic schists, so that the transition between the two units seems to be normal.

How can these apparently discordant sets of data be set up in a single petrogenetic picture?

To shed light on this problem we have to consider also the geochronological data recently published by KÖPPEL (1973); from KÖPPEL's work a considerable difference results in the U-Pb ages of monazites between Ivrea-Verbano and Strona-Ceneri (275 ± 2 m.y. against 450 m.y.). The monazite from the migmatites of the lower Val Strona, connected with the anatectic phoenomena of the contact between the two units have about the same age as those of the Ivrea-Verbano (295 ± 5 m.y.). Also, the zircon ages indicate a notable difference in the time of the metamorphism between the two units (from about 300 m.y. to about 450 m.y.); the difference is also confirmed by the K-Ar and Rb-Sr mineral ages (from 170-200 m.y. to 310-320 m.y.).

KÖPPEL's explanation is that the Ivrea-Verbano began very early, probably as early as the Caledonian times, to be uplifted relatively to the Strona-Ceneri Zone. We share this interpretation which explains the differences in metamorphic grade between the Strona-Ceneri and the deeper, warmer Ivrea-Verbano and we think that we can add a further detail to this long story: along the fault separating the two units, during the uplift the deep appinitic magma penetrated in more or less conspicuous bodies enabling the isotherms to rise in the crust and providing a huge quantity of water to the invaded country rocks. Thus, where lithology was favourable, anatexis could occur. The age of the intrusions is not known as yet, but we know that part of the dykes are schistose and recrystallized whilst the majority of them show pure magmatic textures; we are therefore inclined to think the intrusions are late Hercynian and preceed by an unknown time span the intrusion of the granites of the Lakes.

REFERENCES

BÄCHLIN R. (1937) - *Geologie und Petrografie des M. Tamaro Gebietes (Sudliches Tessin)*. S.M.P.M., 17, 1-79.

BERTOLANI M., TOGNETTI G., SIGHINOLFI G. e LOSCHI A. C. (1963) - *Ricerche petrografiche nella bassa Val Strona (Novara)*. Rend. Soc. It. Min. Petr., 19, 41-67.

BORIANI A. e PEYRONEL PAGLIANI G. (1968) - *Rapporti tra le plutoniti erciniche e le metamorfiti del « Massiccio dei Laghi » nella zona del M. Cerano (bassa Val d'Ossola)*, Rend. Soc. Min. It., 24, 111-142.

BORIANI A. (1970 a) - The « Pogallo Line » and its connection with the metamorphic and the anatectic phases of « Massiccio dei Laghi » between the Ossola Valley and the Lake Maggiore (Northern Italy). Boll. Soc. Geol. It., 89, 411-433.

BORIANI A. (1970 b) - *The microstructure of « Cenerigneisses »*. Rend. Soc. It. Min. Petr., 26, 487-501.

BORIANI A. e SACCHI R. (1973) - *Geology of the junction between the Ivrea-Verbano and Strona-Ceneri zones*. Mem. Ist. Geol. e Min. Univ. Padova, 28, 35 pp.

BURRI C. und DE QUERVAIN F. (1934) - *Über basische Gesteine aus der Umgebung von Brissago*. S.M.P.M., 14, 507-517.

FRENCH W. J. (1966) - *Appinitic intrusions clustered around the Ardara Pluton, County Donegal*. Proc. Roy. Irish Acad., 64 B, 303-322.

HALL A. (1967) - *The chemistry of Appinitic Rocks associated with the Ardara Pluton, Donegal, Ireland*. Contr. Min. Petr., 16, 156-171.

KÖPPEL V. (1973) - *Isotopic U-Pb ages of monazites and zircons from the crust-mantle transition and adjacent units of the Ivrea and Ceneri zones (Southern Alps, Italy)*. Contr. Min. Petr., 43, 55-70.

LUCCHESI A. S. (1968) - *Metamorfiti e rocce filoniane del Massiccio dei Laghi, zona di Verbania. Ricerche geologico-petrografiche.* Univ. Milano (Unpublished thesys).

NOVARESE V. (1906) - *Relazione al Regio Comitato Geologico sui lavori eseguiti per la Carta Geologica nel 1905.* Boll. R. Com. Geol. It., 37 Parte Uff.

NOVARESE V. (1929) - *La zona del Canavese e le formazioni adiacenti.* Mem. Descr. Carta Geol. It., 22, 65-212.

PEYRONEL PAGLIANI G. e BORIANI A. (1962) - *Miloniti e cataclasiti al limite tra « zona dioritico-kinzigitica » e « zona Strona orientale » nella bassa Val d'Ossola e loro significato tettonico.* Rend. Soc. It. Min. Petr., 18, 137-156.

PEYRONEL PAGLIANI G. e BORIANI A. (1967) - *Metamorfismo crescente nelle metamorfiti del « Massiccio dei Laghi » nella zona bassa Val d'Ossola-Verbania (Novara).* Rend. Soc. It. Min. Petr., 23, 351-397.

PITCHER W. S. and BERGER A. R. (1972) - *The geology of Donegal. A study of Granite emplacement and Unroofing.* John Wiley, 435 pp.

REINHARD M. (1964) - *Über das Grundgebirge des Sottoceneri im Süd Tessin und die darin auftretenden Ganggesteine.* Beitr. Geol. Karte Schweiz., N.F., 117, 89 pp.

SCHILLING J. (1957) - *Petrographische-geologische Untersuchungen in der unteren Val d'Ossola. Ein Betrag zur Kenntnis der Ivrea-zone.* Diss. Univ. Bern, S.M.P.M., 37, 435-544.

SCHMID R. (1967) - *Zur Petrographie und Structur der Zone Ivrea-Verbano zwischen Valle d'Ossola und Val Grande (Prov. Novara, Italien).* S.M.P.M., 47, (2), 935-1117.

SLEMMONS D. B. (1962) - *Determination of vulcanic and plutonic plagioclases using a Three-or Four Axis Universal Stage.* Special G. S. A. Papers, No 69, New York.

SUZUKI J. (1930) - *Über die Staurolit-Andalusit-Paragneis im Glimmergneis von Piodina bei Brissago (Tessin).* S.M.P.M., 10, 117-132.

TRÖGER W. E. (1971) - *Optische Bestimmung der gesteinbildenden Minerals.* Vol. I, Bestimmungtabellen, Stoccarda.

WALTER P. (1950) - *Das Ostende des basichen Gesteinzuges Ivrea-Verbano und die angrenzenden Teile der Tessiner Wurzelzone.* Diss. Univ. Zürich., S.M.P.M., 30, 1-144.

WELLS A. K. and BISHOP A. C. (1954) - *An Appinitic facies associated with certain Granites in Jersey.* Quart. Jour. Geol. Soc. London, 111, 143-166.

YODER H. S. and TYLLEY C. E. (1962) - *Origin of basalt magma: an experimental study of natural and synthetic rock systems.* Jour. Petrol., 3, 342-532.