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CENTRO DI STUDIO PER LA STRATIGRAFIA E PETROGRAFIA DELLE ALPI CENTRALI

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METAMORPHISM, TECTONIC EVOLUTION AND TENTATIVE STRATIGRAPHY OF THE "SERIE DEI LAGHI„ GEOLOGICAL MAP OF THE VERBANIA AREA (Northern Italy)

(with 6 figures and a 1 : 50.000 geological map)

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1. INTRODUCTION

The « *Serie dei Laghi* » is a medium-grade (from *staurolite-kyanite* to *sillimanite-muscovite* grade) pre-Alpine metamorphic unit belonging to the « *Massiccio dei Laghi* », the Southern-Alpine complex comprising also the well known « *Ivrea-Verbano Zone* ».

During the last ten years a considerable amount of new geological and petrological data have accumulated and we are now able to trace a first general picture of its geological and metamorphic history.

The « *Serie dei Laghi* » consists of two subunits that were recognized long ago (GERLACH, 1869; ARTINI and MELZI, 1900); the southern part consists mainly of two-micas schists (« *Scisti dei Laghi* »), while the northern part, consisting mostly of gneisses of different types, has been given the name of « *Strona-Ceneri* » (SCHMID, 1967) and coincides, in part, with the « *Gneiss della Serie dei Laghi* » of NOVARESE (1929).

The boundaries of the « *Serie dei Laghi* » are tectonic, since they are represented by faults of different ages and with different characteristics that were described in detail by many authors, among whom: REINHARD (1964), BORIANI (1970a) and BORIANI and SACCHI (1973, 1974).

E of Lake Maggiore, where the « *Ivrea-Verbano* » does not occur, the northern boundary is represented by the « *Jorio-Tonale Line* » (« *Insubric Line* » auct.); the southern boundary is the « *Val Colla Line* », an Upper Carboniferous discontinuity that separates the « *Serie dei Laghi* » from a locally retrometamorphic complex of schists with rare amphibolite and gneiss intercalations (« *Val Colla Zone* »).

W of Lake Maggiore, the northern boundary of the formation is more complex; it consists of a system of intersecting faults, the oldest of which appears to be the « *Cossato-Mergozzo-Brissago Line* » which represents the original separation of « *Ivrea-Verbano* » and « *Serie dei Laghi* ». This discontinuity is marked by a strong lithological contrast and by the presence of blastomylonites and/or migmatites, the development of which in Late-Variscan times has partly masked the tectonic line. Basic to intermediate intrusives also appear along this old tectonic scar. The peculiar features of the contact and the characteristics of the intrusives (« *appinites* ») were described by BORIANI and SACCHI (1973), BORIANI *et alii* (1975), CAMERINI *et alii* (1975).

The « *Cossato-Mergozzo-Brissago Line* » is intersected by the « *Pogallo - Lake Orta Line* » of slightly younger age, characterized by blastomylonites but not by « *appinites* »; both faults appear of Carboniferous age.

The southern boundary is represented by the « *Cremosina Line* » a late-Alpine fault that seems to reactivate, at least in part, an older discontinuity of Upper Carboniferous age that was probably connected to the « *Val Colla Line* ». The general picture seems to indicate a strong uplifting of the « *Serie dei Laghi* » with respect to the southern block from the Upper Carboniferous.

Large masses of granite invaded the « *Serie dei Laghi* » and part of the magma was also erupted mostly as thick ignimbritic flows. The emplacement of the granitic magma coincided with the final tectonic phase of the Variscan orogeny characterized by the formation of extension faults. The ignimbrites were erupted through ENE trending fractures corresponding to the paleo- « *Cremosina Line* », along which some volcanic apparatuses are preserved (Colazza, near Arona and Castagnole, near Borgosesia) and along which thick dykes of subvolcanic granite (*granofiro*) occur (Corconio, Lake Orta and Cuasso al Monte, Varese).

The age of granites and porphyries is the same and was measured as about 270 m.y. by JÄGER and FAUL (1960) and HUNZIKER (1974) respectively. The granite of Montorfano, that occurs at the southern margin of the mapped area, has been studied by GALLITELLI (1938) and, more recently, by GANDOLFI and PAGANELLI (1974).

2. PRECEDING CARTOGRAPHY OF THE MAPPED AREA

Despite the relatively easy accessibility of the area and the abundance of geologically interesting motives, the crystalline rocks of the Lake Como - Lake Maggiore zone have received little attention in comparison to other Alpine areas. Only the « *Ivrea-Verbano* », on account of its inexhaustible geophysical, petrological and structural interest, has been the object of a large number of studies. The « *Serie dei Laghi* » was comparatively little known and, above all, a strong disparity of geological information existed between the Swiss part of the unit and the Italian part, W of Lake Maggiore.

Until the late sixties the geological knowledge about the Italian sector was limited to the works of TRAVERSO (1895), TARAMELLI (1903), and basically of NOVARESE (1906, 1907, 1925, 1927, 1929) which were published during and after his mapping of F° 30, Varallo F° 31, Varese and F° 16, Cannobio of the Italian 1:100.000 Geological Map. In these maps only the following few lithological distinctions appear:

« *Serie dei Laghi* »

a) *Gml*: *micascisti a biotite e muscovite, talvolta granatiferi con gneiss minuti intercalati.*

b) *Gnl*: *gneiss molto biotitici a grossi elementi, scagliosi o ghiandoni intercalati ai precedenti.*

c) *ç*: *anfiboliti zonate.*

d) *Gsl*: *gneiss minuti, scistosi, granulari e compatti con mica nero-violetta e verdiccia; con frequente miscrostruttura cataclastica.*

The transition to the « *Serie dioritico-Kinzigitica* » (« *Ivrea-Verbano* ») was considered gradual. This unit was divided into:

e) *k*: *kinzigiti, passanti a gneiss e micascisti a granati etc..*

f) *B*: *dioriti melanocratiche, noriti, ... passanti ad anfiboliti zonate* (*Val Cannobina-Valmara*) .....

The igneous rocks are indicated as:

g) *graniti bianchi di Montorfano e del Mottarone.*

h) *filoni di porfido e di porfirite, malchite e kersantite, attraversanti i micascisti dei Laghi.*

The amount of geological information was quite different in the Swiss part of the « *Serie dei Laghi* »; in 1937 BÄCHLIN had mapped in detail the zone of M. Tamaro, integrating the mapping with an excellent petrological study. BÄCHLIN's distinctions are:

1) *Misch- bis Orthogneisse*:
   Plagioklasgneis
   Plagioklasalkalifeldspatgneis
   aplitischer Alkalifeldspatgneis
2) *Mischgneisse mit vorwiegend Paramaterial*:
   Biotitplagioklasgneis
   Biotitgneis mit granulierten plagioklase (Cenerigneis)
3) *Paragneisse*:
   Biotit und Zweiglimerplagioklasgneis
   feinkörniger Biotithornfelsgneis
   Muskovitschiefer
4) *Amphibolite und peridotitische Gesteine*

In 1964 REINHARD published a 1:50.000 geological map of the Sottoceneri and summarized the studies of BÄCHLIN (loc. cit.), SPICHER (1940), GRAETER (1952), REINHARD (1935, 1953). REINHARD's map is largely based on BÄCHLIN's lithological distinctions; only the « *Cenerigneisses* » are considered paragneisses instead of *Mischgneisse*.

3. GEOLOGICAL MAPPING

Our mapping covers an area of about 500 km²; it is limited to the S by the lower Toce Valley and Lake Mergozzo, to the E by Lake Maggiore and to the N and NW by the geological contact with the « *Ivrea-Verbano* ».

The adopted lithological distinctions coincide in large part with those of the Swiss authors; in the southern part we adopted only lithological criteria whilst, for the northernmost part, (« *Unità del M. Riga* ») the distinctions are based also on structural considerations.

The field work was essentially carried out by BORIANI from 1966, by BORIANI, GIOBBI MANCINI and BIGIOGGERO from 1968; it was concluded in 1973. Partial results are published in the works of BORIANI and co-workers from 1968 to 1975 and in the *Tesi di Laurea* of MANINCHEDDA (1967), LUCCHESI (1968), GIOBBI MANCINI (1970), BIGIOGGERO (1970), LEGNANI (1970), CONTI (1972) and COLOMBO (1973).

4. MORPHOLOGY AND QUATERNARY DEPOSITS

The fundamental morphology of this area appears to have been generated by at least two different hydrographic patterns and to have been strongly influenced by lithology and structure. Both hydrographic patterns are pre-glacial, for reasons that we shall see later.

The best example of superposed morphologies is given by the Cannobina Valley and its tributaries; the present valley trough is composed by the following stretches (starting from the Lake):

1) *From Cannobio to Cavaglio*: this stretch appears to have been formerly generated only by the Val Cavaglio stream. The N-S trending Val Cavaglio follows a rather obscure tectonic disturbance which is marked on our map as a vertical fault; the structural discontinuity is accompanied, at least in the lower part of the valley, by a notable lithological contrast.

2) *From Cavaglio to the upper Val Falmenta*: this stretch clearly forms what remains of the early Cannobina Valley that did not lead into the Ticino Valley at Cannobio but at Cannero passing through the saddle of Piazza (around 1000 m above s.l.). Its upper course was then captured by the strong erosional climbing of a western tributary of the Val Cavaglio stream, favoured by both structure and lithology. This capture was probably accompanied by a northward displacement of the stream. There were probably two main tributaries of this former R. Cannobino: the R. di Orasso and a stream passing through Camberto (Falmenta) and La Piazza di Gurro.

3) *From Lunecco to Orasso*: this is the former R. di Orasso which was deeply incised during the second morphogenetical episode.

4) *From Orasso to Daila* (*Finero*): this was a northern tributary of R. Orasso. This stream

captured the one passing through Camberto-La Piazza di Gurro.

5) *The valley of Finero* (*il Fiume*): this stretch clearly belongs to the Centovally system and was captured by the R. Cannobino during the second erosional episode.

Both episodes are pre-glacial since, at least in two places (uphill from Cavaglio, 100 m below M.ti Olzeno, and in the area comprised between Cappella di Lego and Spoccia) which on account of their position were little affected by glacial erosion, the slopes are covered by an arenitic deep weathering profile.

Another example of superposed morphologies is the zone of the confluence of R. San Giovanni and R. San Bernardino near Verbania. The upper course of R. San Giovanni runs in N-S direction and is aligned with the saddle of Pian Nava and the underlying S-trending stream; this may well be the earlier course of the R. San Giovanni before it was captured by the SW trending stretch. The latter is parallel to the Lake and its tributaries run along the N-S faults of the zone; beyond the S. Bernardino valley the continuation of the old trough of R. S. Giovanni in the well incised saddle of Bieno can be seen.

The Val Grande - San Bernardino system is clearly parallel to the Ossola Valley and perhaps, during the first phase, it flowed into the River Toce leading out through Ompio. Then it was captured by a western tributary of the R. San Giovanni.

These observations lead to an important conclusion: the essentially pre-Quaternary morphology appears to be dominated (at least below the altitude of 1000 m) by a drastic lowering of the base level of erosion. In this one could recognize the late-Miocene (Messinian) phase of dessication of the Mediterranean Sea (Bini, Cita and Gaetani, 1976) which determined the erosion of deep canyons that are now occupied by the south-Alpine lakes.

The pre-glacial deep weathering profiles are diffused all over the investigated area in places that were spared by the glacial erosion, i.e. generally on southward exposed slopes from 700 to 1300 m above s.l.. They are particularly developped on gneisses, like the orthogneisses of Premeno, M. Morissolo and Piancompra and on the Cenerigneisses. Superficial landslides are often present in these arenites (Scareno, Onunchio, A. Bavarione and in Val Cannobina near Spoccia).

These deep weathering profiles show the same characteristics as those of the southern slope of M. Mottarone and, in general, of the Biellese, and it is very likely that they are coeval with them (Late-Miocene or Pliocene).

The glacial deposits of the zone belong to two distinct main glaciers: that of the Toce and that of the Ticino valleys. The deposits of the Ticino glacier are more widespread and are found up to the maximum altitude of about 1000 m; those of the Toce glacier occur in the San Bernardino and San Giovanni valleys and reach a slightly lower altitude. The distribution of the glacial deposits in the investigated area were described in detail by Novarese (1925, 1927).

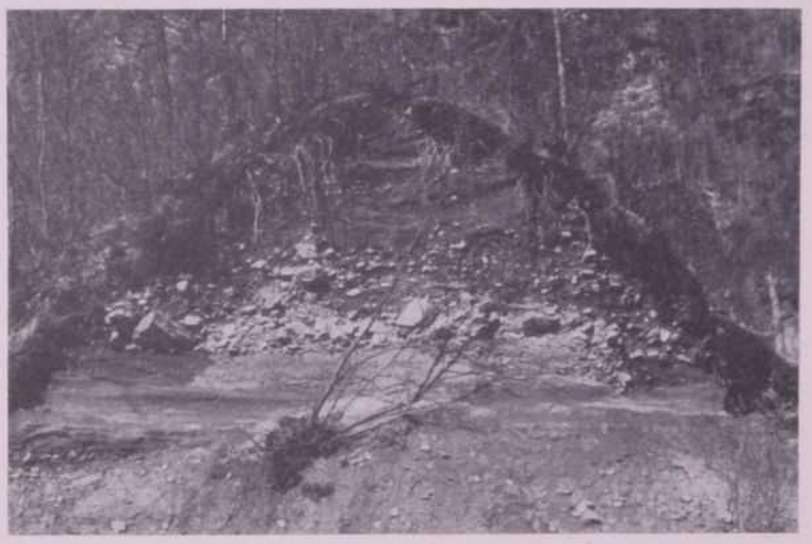

Fig. 1 - Road-cut at « il Ponte », near Cavaglio, Cannobina Valley. Rhytmic, bedded silty sand and coarse material in a section of a fluvio-glacial deposit.

The alluvial terraces of the two main valleys (San Giovanni-San Bernardino and Val Cannobina) are particularly interesting for the reconstruction of the variations of the ice level of the two glaciers during their retreat. At that time the two valleys very soon became deglacialized whilst the ice level of the two main glaciers (Ticino and Toce) was still high; as a consequence they were filled up with alluvial deposits. Later on these deposits were incised as the ice level began to decrease; the retreat of the glaciers was not a continuous process but there were pulsations; to each pulsation corresponds a terrace left behind where the slopes are not too steep. The altitude of the most important terraces are about 685, 420 and 370 m in Val Cannobina, and 400, 370 and 280 m in the San Bernardino and San Giovanni valleys.

Peat deposits are found at Bieno and near Pollino(Premeno), where small ponds of morainic origin still survive.

There are no important active landslides in the investigated area. Among the small landslides, besides the above mentioned ones in the arenites we may cite those of the lower Val Cavaglio (one just opposite Cavaglio and the other at La Gana) and that of Gurrone. All three are typical collapse landslides since they occur on steep slopes with a nearly vertical attitude of the schistosity plane which is practically parallel to the slope.

5. PETROGRAPHIC SECTION

5.1. THE « SERIE DEI LAGHI »

The two sub-units of the « *Serie dei Laghi* » were distinguished on account of their different lithological association: « *Strona-Ceneri* » mostly gneisses, « *Scisti dei Laghi* » mostly micaschists. In 1970 BORIANI (1970a) noticed that between the gneisses and the micaschists a continuous horizon of amphibolites was present. These amphibolites were studied in detail by BORIANI and GIOBBI MANCINI (1972) with special regard to their feldspathized southern margin.

Although the importance of the amphibolites was immediately clear, it was only two years later (BORIANI *et alii,* 1974) that it became evident that the metabasites were present all along the boundary between « *Strona-Ceneri* » and « *Scisti dei Laghi* » and that they were connected with the small bodies of ultramafites of Oira (Lake Orta) and of Camoghè (Sottoceneri), (SPICHER, 1940).

The presence of the amphibolites along the boundary is very evident W of Lake Maggiore, in the mapped area, and along the « *Val Colla Fault* » in the Sottoceneri; the same cannot be said of the area between Lake Maggiore and Lugano. The reason for this is that the attitude of the S-plane in that area is very variable; nevertheless, though they appear discontinuously on REINHARD's map (1964), the horizon can also be individuated there.

The rocks occurring W of Lake Maggiore between the thin amphibolite horizon of Falmenta and the « *kinzigites* » which were attributed by the preceding authors to the « *Ivrea-Verbano* », are here interpreted as belonging to the « *Serie dei Laghi* » and are referred to as « *M. Riga Unit* ».

5.1.1. « SCISTI DEI LAGHI »

The « *Scisti dei Laghi* » are a rather homogeneous rock series; all over the wide area of occurrence they consists of *biotite-muscovite-garnet* schists sometimes *staurolite* and/or *kyanite* bearing; amphibolites and amphibole-schists are rare, marbles are absent. The only important intercalations are the thick lenses of hornblende-bearing or granitic orthogneisses occurring N of Verbania and between Luino and Lugano.

The orthogneisses show roughly the same metamorphic and deformational history except for the first phase which is characterized, in the schists, by intrafolial folds.

The age of intrusion seems to be around 450 m.y. (U/Pb in zircons, KÖPPEL and GRÜNENFELDER, 1971) pointing to an important Ordovician-Silurian event in the « *Serie dei Laghi* ».

The « *Val Colla Schists* » (REINHARD, 1964) that occur S of the « *Val Colla Line* », and probably S of the « *Cremosina Line* » as well, although locally affected by a notable retrogressive metamorphism of Carboniferous age do not seem very different from the « *Scisti dei Laghi* »; it must be noted, however, that their lithological association is somewhat different in that they contain rather frequent intercalations of amphibolites and granite gneisses (« *gneiss chiari* »). The relationship between the « *Val Colla Zone* » and the « *Serie dei Laghi* » is an important subject for future research for the understanding of the South-Alpine basement of the western and central Alps.

On the whole the « *Scisti dei Laghi* » appears to be the metamorphic product of an essentially pelitic sedimentary series. In the mapped area the unit of the « *Scisti dei Laghi* » includes:

a) micaschists and paragneisses
b) orthogneisses { hornblende-bearing orthogneisses (Premeno and M. Morissolo); granitic gneisses (Piancompra)

a) *Micaschists and paragneisses*

These occur in the southern part of the zone in a large triangular area comprised between the Lake and the amphibolite horizon; between Intra and Carmine inf. (Cannobio) they contain the above mentioned important intercalations of orthogneisses.

The regional strike of the S-plane is around N70°E in the southern part; N of Verbania the strike turns to about N45°E; the schists are generally subvertical or dip steeply SE.

The rocks are extremely schistose and rather coarse-grained. In exposure they show a yellow or red weathering whilst on fresh cuts the colour varies from dark grey to greenish-grey due to the presence of abundant chlorite. Quartz lenses, rods and veins are frequent, as is usual in metapelites, and sometimes reach a noteworthy thickness.

In hand specimens, the granoblastic components are barely visible to the naked eye, whilst muscovite, biotite and sometimes garnet are very evident; the amphibole-bearing varieties are rare. More quartz-rich types (quartzites and micaceous quartzites) are frequent intercalations in the metapelitic series.

In thin section one of the most striking features is the presence of poikiloblastic *plagioclase* (20-27% An) with straight internal foliation which is not parallel to the external foliation;

also the *garnet* is often present as poikiloblasts but with S-shaped internal schistosity (BORIANI, 1970a). *Micas* are generally present as aggregates or polygonal arches of individually undeformed lamellae. *Kyanite* and/or *staurolite* are not very frequent; they do not appear as poikiloblasts but rather as inclusion-free small individuals of pre-flattening crystallization.

In the southern part of the zone, and particularly in the M. Faiè - Pallanza ridge, the schists were partially reequilibrated to the green schists facies conditions by a widespread retrogressive metamorphism; *albite* and *chlorite* are abundant here as secondary minerals (PEYRONEL PAGLIANI and BORIANI, 1967; PEYRONEL PAGLIANI, 1973).

K-feldspar is only present in some quartz-and feldspar-bearing intercalations occurring in limited outcrops on the Comero - Miazzina and on the Cambiasca - P.te Nivia roads.

b_1) *Hornblende-bearing orthogneisses*

These rocks occur as nearly parallel intercalations on the slope bordering the Lake, from Premeno and M. Cargiago (N of Verbania) up to the Valle di Cannero. In the southeastern part there are three horizons striking NE separated by paragneisses and micaschists intercalations; another horizon extends from Aurano, through M. Morissolo and M. Morissolino and is cut by the R. di Cannero fault.

The best exposure of these rocks is in the road cuts along the Lake shore, along the road between Pian Nava and Premeno and between Pian di Sole and Manegra. Excellent exposures of the M. Morissolo gneiss are visible along the two old military roads starting from Pian Cavallo. They are medium- to fine-grained massive rocks of grey or greenish-grey color with rare reddish coatings due to weathering. The schistosity is particularly evident in the southern horizons; in that of M. Morissolo the rock is very well lineated.

The constant mineral composition is: *plagioclase* (25-32% An), *quartz, biotite, hornblende, K-feldspar, epidote group minerals.* Secondary *chlorite* is particularly abundant in the M. Morissolo gneiss. Some *plagioclase* poikiloblasts with S_i not parallel to S_e have been found (BORIANI, 1970a) in the marginal portions of the southern horizons whilst in the northern ones igneous relics such as nuclei filled up with white mica and clinozoisite, normal zoning and albite-Carlsbad twinning are frequent. *Biotite* is present as aggregates of lamellae that show postcristalline deformation particularly in the southern part. *Hornblende* is often poikiloblastic and generally intergrown with biotite. *K-feldspar* varies in quantity from place to place and is characteristically more abundant in the more massive types. *Clinozoisite* and *Fe-epidote,* often with *allanite* nuclei in zoned individuals or fragments are typical accessories of these gneisses.

b_2) *Granite-gneisses*

A continuous horizon of granite-gneiss occurs from the neighbourhood of Esio and Aurano as far as the lake shore near Sasso di Carmine (Cannobio). In the southwestern part of their area of occurrence fine grained and coarse grained varieties are irregularly intercalated with metasediments; more basic types are present in the zone of Cresta della Ceresa. The paragneiss intercalations decrease towards NE and the rock becomes more homogeneous.

The most representative exposures are those visible in the road cuts along the lake shore from Cannero northward. The rock is rather coarse grained, the colour is light grey and the texture is mostly flaser whilst E of Lake Maggiore, in the Sottoceneri, the augen texture seems more widespread. The schistosity planes are always well marked since they are coated by coarse biotite flakes.

Under the microscope the gneiss shows a prevailing heteroblastic fabric (sometimes of « mortar » type). The mineralogical composition is: *plagioclase, quartz, K-feldspar, biotite, muscovite* (*hornblende* is very rare); common accessories are: *zircon, apatite, sphene* and *opaques. Clinozoisite* is rare whilst *Fe-rich epidotes* with *allanite* nuclei are frequent in the gneiss of the area N of Cannero.

Plagioclase (25% An) is present as aggregates of heteroblastic grains with irregular boundaries; poikiloblasts are absent.

K-feldspar is present as large individuals of microcline in the more granitic types and as small interstitial grains in the more granodioritic varieties.

Among micas, *biotite* is by far more abundant than *muscovite;* they often show traces of post-crystalline deformation.

Hornblende and *clinopyroxene* are present in a specimen from Cresta della Ceresa, described by BORIANI (1970a).

5.1.2. METABASITES

The occurrence of discontinuous amphibolite lenses W of Lake Maggiore has been quoted by many authors: ARTINI and MELZI (1900), NOVARESE (1929), BORIANI (1968). E of the Lake in the Ceneri and Malcantone regions, the metabasites were mapped and described by BÄCHLIN (1937), KNOBLAUCH and REINHARD (1939), SPICHER (1940), GRAETER (1951) and later by

REINHARD (1964) who summarized the works of the other authors.

BORIANI (1970a) recognized for the first time the continuity of the amphibolite horizon occurring between Mergozzo and Carmine di Cannobio. BORIANI and GIOBBI MANCINI (1972) gave a detailed description of these amphibolites, the peculiar characteristic of which is their transition, at their southern margin, to a type of biotite-hornblende augen gneiss with K-feldspar megacrysts up to 10 cm in length (the best outcrop is upstream of P.te Nivia near Intragna).

Besides the main horizon, showing that characteristic feldspathization, thinner lenses of dark-coloured, fine-grained, sometimes garnet-bearing amphibolites occur within the « *Scisti dei Laghi* » near Aurano. In Val Cannobina another important and continuous horizon of amphibolite is present between Falmenta and Val Cavaglio.

The mineralogical composition of normal amphibolites is: *hornblende* ($2V_x$ = 78°-85°) and *plagioclase* (35% An) with minor *biotite* and rare *garnet;* in the feldspathized amphibolites the mineral association is: *microcline, plagioclase, hornblende, biotite, quartz.* Electron probe analyses of hornblende and biotite in amphibolites with different degrees of feldspathization are given by BORIANI and GIOBBI MANCINI (op. cit.).

The feldspathized amphibolites generally show transition to the schists of the southern margin through a *muscovite-biotite-garnet* augen gneiss in which garnet clearly grows at the expense of hornblende. The whole process has been interpreted as metasomatic transformation of the amphibolites operated by feldspathizing fluids liberated during the anatexis of the «*Cenerigneisses*».

5.1.3. « STRONA - CENERI »

In contrast with the « *Scisti dei Laghi* » this is an essentially gneissic unit; some of the gneisses are probably ortho-derivates or migmatites. The age of the igneous or anatectic event seems to be around 450 m.y. (U/Pb ages on zircons, KÖPPEL, 1974). Near the boundary with the « *Ivrea-Verbano* » the gneisses were reequilibrated, mobilized or remobilized during the last thermal phase of the Variscan cycle as demonstrated by their relationship with the post-orogenic granites and by the geochronological data of KÖPPEL (op. cit.) and HUNZIKER (1974).

The « *Strona-Ceneri* » appears to be the product of the amphibolite facies metamorphism (*kyanite-sillimanite* grade) of an essentially psammitic series which had different metamorphic, anatectic and deformational histories in its different parts, in obvious contrast with the more pelitic character of the metasediments of the « *Scisti dei Laghi* ».

In the mapped area the lithological association of the unit is:

a) *biotite-plagioclase gneisses* (sometimes *K-feldspar* bearing or *hornblende*-bearing)
b) *augen and flaser gneisses*
c) « *Cenerigneisses* »
d) *fine-grained gneisses.*

a) *Biotite-plagioclase gneisses*

The framework of the « *Strona-Ceneri* » consists of gneisses whose textural and mineralogical characteristics are so highly variable from place to place such as to make it difficult to represent them accurately on a geological map. This obstacle compelled us to group under the comprehensive term of *biotite-plagioclase gneisses* all of the more or less schistose gneisses with variable content of *biotite* and *feldspars.* The same difficulty was met with in the Sottoceneri by BÄCHLIN (1937) who indicated them as « *schiefriger Biotit- und Zweiglimmerplagioklasgneis z.T. Hornblende fürend* ».

The more schistose varieties are found essentially as intercalations within the augen gneisses of M. Vadà and M. Zeda; they are medium-grained gneisses that do not differ substantially from those of the southern part of the mapped zone. Their mineral assemblage is: *plagioclase, quartz, biotite, muscovite, garnet; sillimanite* is only seldom present (la Pascola).

The more massive types show a characteristic gneissic texture and consist of: *plagioclase, quartz, biotite* ± *muscovite* ± *K-feldspar* ± *hornblende.* The typical locality of these gneisses is l'Ospedaletto on the « Cadorna road ».

Plagioclase generally forms aggregates of xenomorphic subgrains with poor polysynthetic twinning. Its An-content is normally higher than in the « *Scisti dei Laghi* » and ranges from 27% to 37%. *K-feldspar* (*microcline*) is present as relic individuals surrounded by mirmekitic plagioclase or, more rarely, as aggregates of slightly disorientated subgrains. *Biotite* and *muscovite* are often present in two generations: the first generation consists of strongly deformed flakes replaced by aggregates of second generation undeformed tiny lamellae. Pleochroism of biotite is strong (X = pale yellow, Y,Z = reddish brown).

b) *Augen and flaser gneisses*

Massive granite-gneisses with K-feldspar megacrysts up to 10 cm of length form intercalations of various thickness in the zone of M. Zeda. The most important and continuous one occurs from Val Pogallo through M. Vadà as far as Socraggio

in Val Cannobina. The best exposures can be seen on the Cicogna - Pogallo footpath, at M. Vadà and at the base of the M. Zeda pyramid; the contacts with the biotite-plagioclase gneisses are either sharp or transitional. The aspect is often migmatitic with pegmatite-like concordant and discordant veins that disturb the continuity of the schistosity planes.

that coat extremely flattened facoids of leucocratic minerals.

The texture of these rocks is a good example of static recrystallization of a strongly deformed fabric: the *mica* films consist of very tiny undeformed lamellae, *quartz* forms undulated monocrystalline layers, *plagioclase* forms extremely thin layers of very small polygonal grains and *K-feld-*

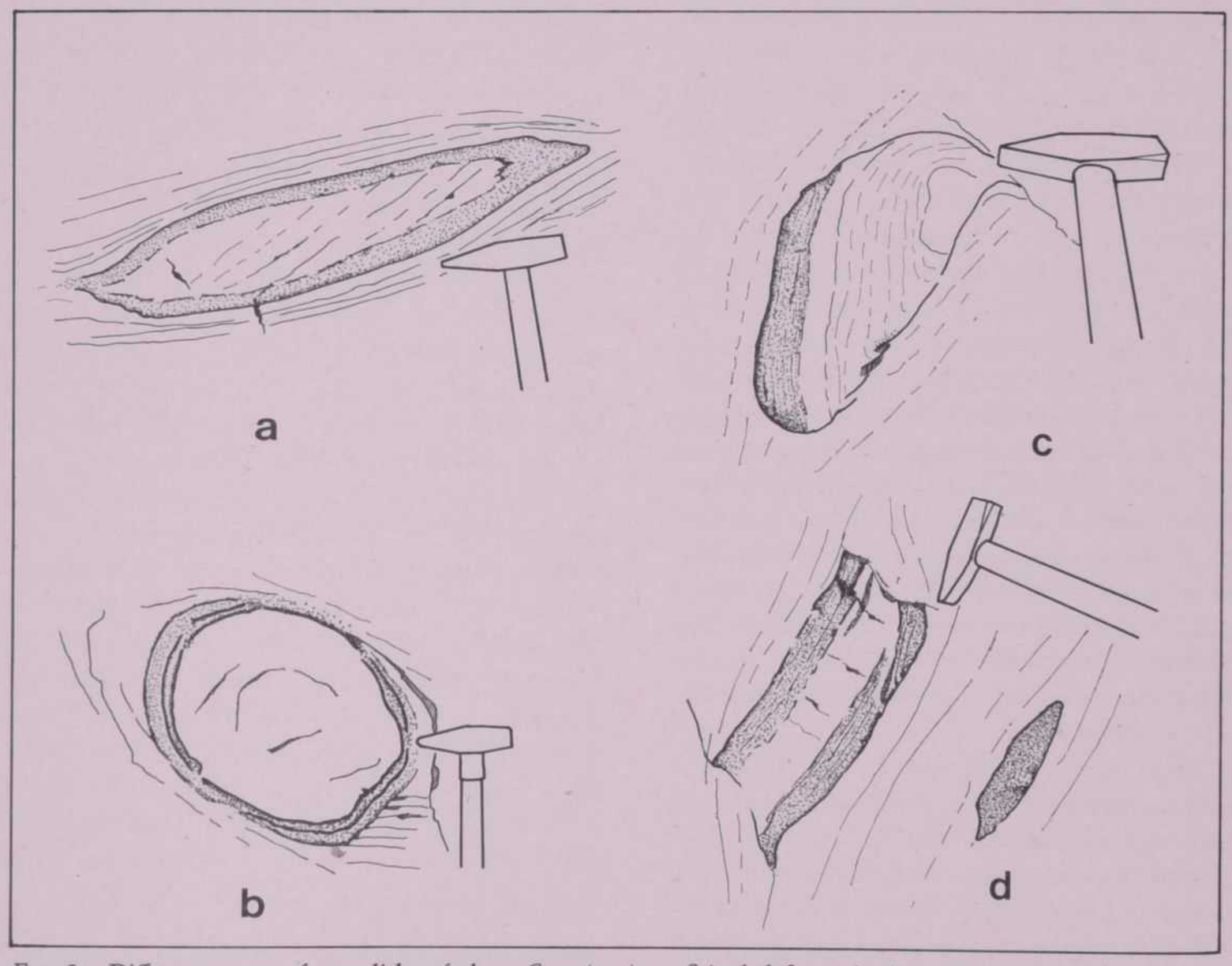

FIG. 2 - Different types of xenoliths of the « *Cenerigneiss* ». Stippled fine-grained reaction shell: a) Undisrupted, flattened xenolith; b) Undisrupted, rounded xenolith; c) Fragmented xenolith; d) Angular fragment of a xenolith and of the fine-grained shell.

Under the microscope one can see that the texture is often glomero-augen since *microcline* do not form single individuals but aggregates of subgrains with a central relic of first generation. *Plagioclase* (around 25% An) is present as xenoblasts of medium size; *micas* (*biotite* prevails over *muscovite*) do not generally show postcrystalline deformations. They form discontinuous arrangements that curve around the feldspar augen. *Quartz* forms aggregates of lobate grains.

Flaser gneisses represent the more flattened varieties of augen gneisses. They have been mapped separately only in one case: that of the thin horizon occurring from Cicogna (Val Pogallo), through Passo Folungo down to Socraggio (Val Cannobina). In the field their aspect is very characteristic on account of the continuous mica films

spar appears either as small subgrains or as relics surrounded by mirmekitic plagioclase in the flattened facoids.

c) « *Cenerigneisses* »

This is by far the most interesting rock type of the « *Strona-Ceneri* » and consequently that which has been studied most. Detailed accounts of texture, fabric, mineral assemblage and chemical composition are given by BÄCHLIN (1937), REINHARD (1964), BORIANI (1968, 1970), BORIANI and CLERICI RISARI (1970), GIOBBI MANCINI and POTENZA BIANCHI (1971), BORIANI *et alii* (1973).

Within the mapped area these gneisses form several horizons, the southernmost and most important of which occurs from Bracchio to M. Bavarione reaching its greatest thickness (around

2200 m) at M. Todano where one can find the best exposure of this rock type. Another important horizon (800 m thick) can be followed from Val Pogallo through Pian Vadà to Val Cannobina. « *Cenerigneisses* » occur also in the « *schlingen* » structure of M. Giove and in the « *M. Riga Unit* ».

« *Cenerigneisses* » are light grey rocks with very variable fabric from finely schistose, to lineated, to gneissic or granitoid. Its outstanding mesoscopic characteristic is the presence of extremely abundant calc-silicate xenoliths with a white or pink massive core and a grey fine-grained shell. Boriani (1968), Boriani and Clerici Risari (1970), Giobbi Mancini and Potenza Bianchi (1971) interpreted the xenoliths as « restites » of the calcareous inlayers of the original sedimentary series from which the « *Cenerigneisses* » derived as a consequence of an « in situ » anatectic process. The anatexis homogenized the chemical composition of the original rock except for the calcareous intercalations which were boudinated inside the semi-molten mass; each fragment reacted with the surrounding melt forming the thick grey fine-grained shell. Later a strong deformation of the whole metamorphic series caused the fragmentation of the xenoliths and of their reaction shell, which now appear mostly incomplete, and the differentiation of the various fabrics in the different parts of the « *Cenerigneiss* » horizons (Fig. 2).

The fabric analysis (Boriani *et alii,* 1973) of the main horizon indicates the homogeneity of the stress field that induced the deformation. The strain distribution was not uniform: in fact there are schistose or lineated gneisses with strongly flattened or elongated xenoliths in the southern part and gneissic or granitoid gneisses with weak lineation and subspherical xenoliths in the central and northern parts.

In the « *Cenerigneisses* » of the zone south of Val Cannobina folds seem absent: this characteristic is one of the elements in favour of the « anatectic » hypothesis, since it means that the other rock types of the « *Strona-Ceneri* » were already schistose when the « *Cenerigneisses* » were deformed.

The microstructure of these rocks (Boriani, 1971) is characterized by the presence of two generations of all the minerals (except quartz): a relic first generation with strong postcrystalline deformation and a second generation crystallized under static conditions.

The mineral assemblage is; *plagioclase, quartz, biotite, muscovite, K-feldspar; kyanite* or *sillimanite* and *garnet* are sometimes present in very small individuals.

Plagioclase (around 22% An) is mostly present as characteristic polygonal aggregates which sometimes contain a deformed relic of first generation which is slightly richer in An. The grain size of the polygonal aggregates increases and the relics disappear in the northern horizons on account, probably, of the growing grade of the static metamorphism. *Microcline* is only seldom present as such but its former presence is testified by the aggregates of mirmekitic plagioclase or oligoclase-muscovite quartz intergrowths which certainly derive from it since they often contain K-feldspar relics. *Biotite* and *muscovite* are present as « clouds » of tiny undeformed lamellae which sometimes surround a strongly deformed relic of first generation; biotite relics are more widespread in the less deformed parts of the main horizon while those of muscovite are frequent also in the more strained parts. *Quartz* is the only mineral which is present only in one generation; it forms large monocrystalline grains, facoids or thin layers in the different textural types.

d) *Fine-grained gneisses*

Fine-grained gneisses are very widespread in « *Strona-Ceneri* »; they appear in several horizons the southernmost of which occurs from M. Faiè, through Cicogna, La Forcola and Passo Folungo immediatly NW of the main « *Cenerigneiss* » body. The most important is that of Val Cannobina cropping out from A. Pian di Boit (upper Val Pogallo) through the watershed M. Zeda - M. la Piota as far as the Val Cavaglio fault. Fine-grained gneisses are present also in the « *schlingen* » structure of M. Giove and in the « *M. Riga Unit* ». Descriptions and interpretations of the fine-grained gneisses were given by Bächlin (1937) and Reinhard (1964) for the Swiss part of the « *Strona-Ceneri* » and by Boriani *et alii* (1972) and Bigioggero and Boriani (1975).

They are light to dark grey rocks with greenish intercalations due to chloritization of biotite and with a reddish brown weathering surface. The grain size is generally very fine but some quartzitic or more mica-rich intercalations are somewhat more coarse grained. The rock cleavage is often perfect and permits the splitting of large and sound plates that are locally used for roofing.

Sedimentary foliation is clearly recognizable particularly in the frequent similar folds that can be observed for example at Passo Folungo, in the R. Cannobino or along the Cannobio - S. Agata road; fold axes are generally parallel to the lineation defined by the crenulation of the S plane; mineral lineation is rare.

Fold axes trend NE and plunge gently to SW in the M. Faiè - Passo Folungo horizon whilst in Val Cannobina the trend is nearly E-W with steep plunge towards E.

The main horizon of fine-grained gneiss, that of Val Cannobina, shows a strong angular discordance with the « *Cenerigneisses* », biotite-plagioclase gneisses and augen gneisses of the southern zone. The contact is rather sharp and marked only locally by cataclastic phenomena; in the fine-grained gneisses near the contact similar folds with vertical axes are particularly frequent.

Under the microscope they show an equigranoblastic texture which justifies the term of « *Hornfelsgneisse* » used by the Swiss authors to indicate these rocks. The mineral association is: *quartz, plagioclase* (around 20% An), *biotite, muscovite* ± *garnet* ± *sillimanite* or *kyanite; K-feldspar* is extremely rare.

Quartz and *plagioclase* are associated in a quasi-polygonal aggregate with interstitial micas. *Biotite* and *muscovite* are also present as thin beds; « *cross* » and « *chevron* » micas are frequent in the more lineated types in which they mark an incipient schistosity parallel to the axial plane of the previously described similar folds. In any case micas do not generally show postcrystalline deformation. *Garnet, sillimanite* (or *kyanite*) are not very frequent; when present they form tiny isolated grains dispersed in the mass.

In the fine-grained gneisses involved in the « *schlingen* » structure of M. Giove, in a narrow zone N of Cannobio between S. Agata, Ronco and M. Marcalone, Al-silicate bearing nodules are present. The nodules are flattened in the S-plane of the rock; their presence is related to the occurrence of several schistose pegmatitic dykes (only the most important of these is represented on the geological map). Such nodules were described by Bächlin (1937) in the Sottoceneri in the same association; in agreement with Bächlin's hypothesis Bigioggero and Boriani (1975) interpreted the nodules as the product of metamorphism of old *chiastolite* poikiloblasts which in turn were formed by contact metamorphism induced by the pegmatitic dykes when the present gneisses were sediments or very low grade metamorphic rocks.

The problem of the fine-grained gneisses is both stratigraphic and tectonic since it involves the evolution of the whole « *Serie dei Laghi* »; it will be discussed in the section on tectonics and in the conclusions.

5.1.4. « Monte Riga Unit »

The roughly wedge-shaped area comprised between the fine-grained gneisses of Val Cannobina to the S and the « kinzigites » to the N, has been called the « *M. Riga Unit* » (Boriani and Sacchi, 1973), from the name of the mountain that divides Falmenta from Gurro.

The « *M. Riga Unit* » consists in large part of rocks clearly belonging to the « *Strona-Ceneri* » but their mode of association and, characteristically, their texture indicate a high degree of complexity in their metamorphic and tectonic evolution. For mapping purposes the « *M. Riga Unit* » has been here divided into the following three sub-units:

a) southern
b) central
c) northern.

a) *The southern subunit*

The southern part of the unit consists of strongly deformed « *Strona-Ceneri* » rocks, mostly fine-grained gneisses and « *Cenerigneisses* ». The tectonic overprinting makes it very difficult to recognize the original identity of the rock types; only on very clean and large outcrops is it possible, for example, to see the typical Ca-silicate bearing xenoliths of the « *Cenerigneisses* » which appear to have been bent and rotated in an anticlockwise direction after their disruption (Fig. 3) see section on «*Cenerigneisses*»). Good exposures of such rocks can be found NW of Falmenta, above Camberto, on the cliffs below Bronte di Cavaglio and at S. Bartolomeo Valmara below Prati d'Agro.

Small folds axes are vertical or plunge steeply WSW or SW, whilst the spectacular folds in the amphibolites, bordering the southern margin of the « *M. Riga Unit* » at P.te Falmenta, show steep NE plunging axes.

The microscopic characteristics are similar to the usual ones of the « *Strona-Ceneri* » rocks, but with the addition of strong postcristalline deformation and sometimes notable retrogressive metamorphism.

The northern boundary of this sub-unit has been traced at the first appearance of augen gneiss intercalations.

b) *The central subunit*

The central part of the « *M. Riga Unit* » is characterized by the presence of several thin intercalations of these augen gneisses and of a relatively thick lens of hornblende-bearing orthogneiss within the paragneisses. These generally show a banded structure with frequent discontinuous and concordant leucocratic veins; the mineral assemblage is: *quartz, plagioclase* (18-25% An), *biotite, muscovite* ± *garnet*. A strong postcristalline deformation is always present. Near

the northern margin of the sub-unit more pelitic paraderivates rich in Al-silicates appear.

The hornblende bearing orthogneiss is very similar to those of Premeno and M. Morissolo (see section on the orthogneiss intercalations of « *Scisti dei Laghi* »). The rock is strongly lineated, as may be seen on the good exposure in the road-cut immediately N of P.te di Spoccia along the Cannobina road.

Other minor intercalations are represented by thin lenses of amphibolite, the most important of which is that present between A. Aurone and the bottom of Valmara; it is a normal amphibolite with a 35% An plagioclase.

Another important characteristic of this central part of the « *M. Riga Unit* » is the presence of mostly concordant gabbrodiorite dykes of « *appinitic* » type which are described in a separate section. The possible influence of this intrusion of the dyke swarm on the metamorphic pattern will be discussed later.

The lithology indicates that also this central part of the « *R. Riga Unit* » consists of « *Strona-Ceneri* » materials although their characteristics were largely obliterated, as in the case of the southern part, by postcristalline deformation and, in places, by retrogressive metamorphism. Near the northern margin a later prograde metamorphism generated a further overprinting of the *andalusite* up to the *sillimanite* grade.

c) *The northern subunit*

The northern part of the « *M. Riga Unit* » is characterized by the absence of leucocratic intercalations and by a generally more pelitic composition of the paragneisses. Near the southern margin towards the central subunit, a small but very interesting intercalation of « spotted » amphibolites of unmistakable eclogitic derivation was found. It occurs 250 m south of Ponte di Gurro along the Cannobina road.

The appinitic dykes are abundant also in this sub-unit, especially at the southern margin; they seem to cluster along the boundary between the central and the northern subunit.

The metamorphic conditions can be best evaluated considering the metapelites of both subunits. Most of the thin sections made from the samples collected near the boundary contain *staurolite;* a *staurolite-out isograd* can be traced about 300 m SW of the border towards the Ivrea-Verbano rocks. All of the three Al_2SiO_5 polimorphs are present (in one case in a single thin section + *corundum* - Sample LPVC69) the more common are *andalusite* and *kyanite* often with *sillimanite* (Fig. 3). With growing metamorphic grade, i.e. towards the Ivrea-Verbano, *andalusite* or *kyanite* are replaced by *sillimanite;* sometimes the texture suggests pseudomorphose.

Garnet is always present often as poikiloblasts with small inclusions sometimes in characteristic « snowball » arrangement, which recall the garnet of the micaschists from Pallanza (« *Scisti dei Laghi* »).

The paragneisses of the northern sub-unit of « *M. Riga* » cannot be attributed to the « *Strona-Ceneri* »; relationships may be found either with « *Scisti dei Laghi* » (see also section on tectonics) or with the kinzigites of the « *Ivrea-Verbano* ».

On the whole the « *M. Riga Unit* » can be considered as a strongly compressed part of the « *schlingen* » zone of the « *Serie dei Laghi* » against the « *Ivrea-Verbano* ». Clues for the presence of « *schlingen* » folds may be found mainly in the central sub-unit where the contrasting lithology allows the observation of tight folds with vertical axis (for example at the W extremity of the hornblende-bearing gneiss horizon NW of Falmenta).

The transition to the « *Ivrea-Verbano* » would seem gradual, but the steep metamorphic gradient at the transition between the central and the northern sub-units of « *M. Riga* » together with the change of lithology suggested to Boriani and Sacchi (1973) the existence in this zone of an old tectonic contact (*Cossato-Mergozzo-Brissago Line*) now completely rehealed by metamorphism.

5.2. « IVREA - VERBANO »

The « *Ivrea-Verbano* » occurs at the western and northern boundaries of the mapped area; although it has only a marginal interest in our investigations we shall give below a short account of its main structural and petrographic features because of the importance of this unit in the context of the « *Massiccio dei Laghi* ».

The « *Ivrea-Verbano* » is considered a fragment of crust-mantel transition because of its lithological association and of its uncommon geophysical characteristics (see Volume of S.M.P.M. on the « Symposium on the Ivrea-Verbano Zone », 1968). Its western (outer) part, near the « *Canavese Line* » consists of metamorphosed mafic intrusives and ultramafics (Rivalenti *et alii,* 1975); the eastern (inner) part consists mostly of biotite-sillimanite-garnet metapelites with frequent intercalations of amphibolites, marbles and pegmatite veins (« *Kinzigitic* » zone). The main mafic and ultramafic body extends from Ivrea to Val Mastallone (an eastern tributary of Valsesia); E of Val Mastallone its thickness is strongly reduced and metapelitic rocks prevail. Only a thin strip of mafic rocks with some ultramafic bodies (Cam-

pello, Megolo, Premosello, Finero) continues along the « *Canavese Line* » as far as Lake Maggiore.

The general structural setting of the « *Ivrea-Verbano* » is that of vertical subparallel horizons striking NE; this regularity is disturbed by large folds such as those revealed by SCHMID (1967) in the Val d'Ossola section, by BERTOLANI and GARUTI (1970) in the Ivrea body or by LESCH (1968) in the Finero peridotite.

brown weathered crust. Their mineral assemblage is: *biotite, plagioclase, quartz, sillimanite, muscovite* ± *garnet* near the boundary with « *Serie dei Laghi* » where they appear extremely rich in pegmatite dykes and lenses. Some hundred meters NW of the boundary the pegmatites decrease and the *muscovite* disappears from the mineral assemblage giving way to the *K-feldspar-sillimanite* association.

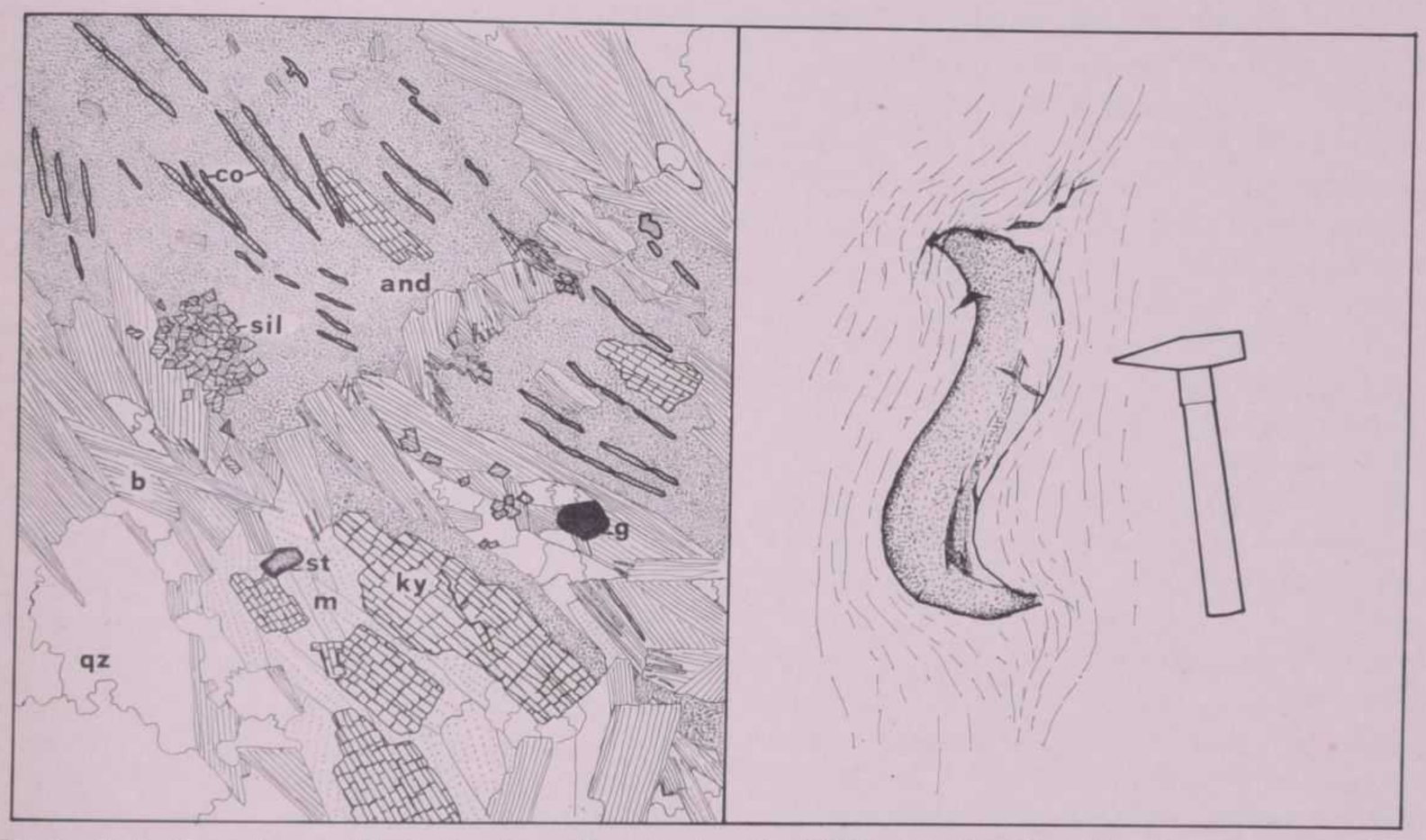

FIG. 3 - Left: Corundum-andalusite-kyanite- sillimanite (sample LPVC 69-« *M. Riga Unit* »); co = corundum; and = andalusite; ky = kyanite; sil = sillimanite; m = muscovite; b =biotite; qz = quartz; two small grains of garnet (g, black) and staurolite (st, heavy lines and stippled) are also shown. Right: xenolith of the « *Cenerigneiss* » in the « *M. Riga Unit* » the anticlockwise rotation of the elongated xenolith is clearly visible.

In the metapelites of the lower Valsesia CAPEDRI and RIVALENTI (1973) recognized at least four phases of plastic deformation and an equivalent number of metamorphic crystallizations.

The metamorphic grade increases towards NW; the « inner » part of the « *Ivrea-Verbano* » is in amphibolite facies, whilst the « outer » part is in granulite facies (PEYRONEL PAGLIANI and BORIANI, 1967; SCHMID, 1967; BERTOLANI, 1968). Recent thermobarometric estimations (SCHMID and WOOD, 1976) for the main metamorphism in the Ossola zone give P and T conditions ranging from 9-11 Kb and 700-800°C. Our research, now in progress, in the lower Valsesia and Biellese reveals different metamorphic conditions in the western part of the « *Ivrea-Verbano* »; the abundance of *cordierite* in the metapelites of this region indicates lower pressure.

Within the boundaries of the mapped area only metapelites occur: they consist of micaschists and paragneisses showing a strongly foliated fabric, greyish colour on fresh cuts and a dark reddish

The general characteristics of the junction between « *Ivrea-Verbano* » and « *Serie dei Laghi* » are discussed at length by BORIANI and SACCHI (1973) and are mentioned also in other parts of this paper. The transition is well exposed in Val Cannobina in the road cuts between P.te Spoccia and Orasso and between P.te Gurro and Gurro: the transition seems gradual and the boundary between the northern « *M. Riga Unit* » and the « *Ivrea-Verbano* » has been conventionally traced at the first appearance of pegmatites.

It seems worthwhile to mention here the occurrence, not far north of the mapped area, of a continuous horizon of « spotted » amphibolites which crop out just at the contact between metapelites and metabasites on the road Orasso-Cursolo and which have been followed as far as Testa Fontai and M. Limidario.

The presence of « spotted » amphibolites in the southern part of the « *Ivrea-Verbano* » has been cited by WALTER (1950), SCHILLING (1957), SCHMID (1967), BORIANI (1965) and by BORIANI

and PEYRONEL PAGLIANI (1968). These latter authors recognized all the transitions between eclogitic amphibolites and « spotted » amphibolites in the occurrence of M. Cerano (lower Val d'Ossola). Studies on this interesting subject are at present in progress.

5.3. DYKE ROCKS

The dyke rocks of the zone under study have been cited or described by several authors (NOVARESE, 1906; BURRI and DE QUERVAIN, 1934; WALTER, 1950) in the neighbourhood of Brissago and in the lower Val d'Ossola (NOVARESE, 1906; PREISWERK, 1906; SCHILLING, 1957). Later BORIANI and PEYRONEL PAGLIANI (1968), BORIANI and SACCHI (1973) and BORIANI *et alii* (1975) gave a detailed account of the gabbrodiorite dykes (« *appinites* » (*)) occurring at the junction between « *Strona-Ceneri* » and « *Ivrea-Verbano* ». They are particularly diffused N of Val Cannobina, in a quasi-triangular zone between Spoccia, M. Limidario and Brissago. The « *appinites* » of the lower Val d'Ossola between S. Rocco and Capp. di S. Andrea may be considered as being the easternmost occurrence of the M. Cerano gabbrodiorite.

REINHARD (1964) published an accurate study of the lamprophyre dykes E of Lake Maggiore: in this zone the occurrence of lamprophyres seems to be particularly frequent S of the alignment of amphibolites within the « *Biotit-plagioklasgneisse + K-keldspatführend* » between Maccagno and P.te Tresa, while in the « *Hornfelsgneisse* » they are completely lacking. From the description of the dykes occurring between Magadino and M. Ceneri within the « *Schiefrige Biotitplagioklasgneisse* » it seems that they are different from those of the southern zone and, in our opinion, may possibly be related to the « *appinitic* » intrusions of Valmara (Brissago).

In the mapped area the lamprophyres are particularly frequent between Pallanza, Mergozzo and the S. Bernardino valley, where they are represented mostly by *hornblende* and *pyroxene* bearing spessartites (LUCCHESI, 1968). Here, as in the Sottoceneri, their zone of maximum frequence seems to be S of the main amphibolite horizon, within the « *Scisti dei Laghi* ». Other lamprophyres are related to the tectonic disturbances of the upper S. Giovanni valley, where they occur also in the « *Strona-Ceneri* » rocks, in which generally they are absent.

A 5 m thick granite porphyry crops out on the Comero-Miazzina road, near the Eremo. It is a light coloured rock with an evident porphyric texture. Phoenocrysts are essentially formed by: *K-feldspar,* minor *plagioclase* and very rare *quartz, muscovite* and *biotite;* the quartz-feldspathic groundmass is micropegmatitic.

The most typical « *appinitic* » dykes are widespread in the zone between Valmara, M. Limidario and Vantarone, within the *staurolite, andalusite, sillimanite, garnet* gneisses of the M. Riga Unit. A good exposure of these rocks is present on the Valmara-Brissago road, at the Swiss-Italian border just opposite the Swiss Customs house.

In Val Cannobina the « *appinites* » are less frequent: the best outcrops are near Spoccia and on the top of M. Zuccaro. The dykes occurring between P.te Spoccia and P.te Gurro are thin and quite atypical.

The « *appinites* » are extremely heterogeneous as may be seen along the many footpaths of the eastern slope of M. Limidario. Composite dykes are formed by:

a) a schistose, fine-grained dark coloured outer part composed essentially of *hornblende, plagioclase ± biotite;* sometimes it is brecciated and cemented by leucocratic material.

b) a coarse-grained, greyish coloured inner part, scattered with pegmatite-like pockets, showing elongated (7-8 cm) amphibole crystals. In this rock the mineral composition is: *plagioclase, hornblende, biotite,* very rare *quartz.*

c) a fine-grained white coloured, aplite-like, central part is only seldom found. Its mineral assemblage is: *quartz, plagioclase, microcline, micas.*

Besides the composite ones, also isolated dykes completely composed of one of the single varieties here described are present all over the area of occurrence of the « *appinites* ».

Under the microscope they show a strongly variable texture: the schistose varieties are completely recrystallized and show a grano-nematoblastic fabric, whilst the non-schistose types show various types of igneous textures from hypidiomorphic to ophitic.

Hornblende is present as elongated individuals, which are generally zoned, with weak greenish pleochroism and ilmenitic exsolutions. In the schistose « *appinites* » second generation prisms are gathered in idiotopic aggregates.

Plagioclase is present as two generations: idiomorphic zoned individuals showing various twinning laws, and polygonal grains forming aggregates; the latter prevail in the schistose dykes. Its strongly variable composition from the melano-

(*) « *Appinites* » (from the locality of Appin in Argyllshire - Scotland) consist of essentially, « basic intrusions genetically associated with granite » (PITCHER and BERGER, 1972). They are generally coarse-grained rocks, but also lamprophyre-like dykes are frequent. Their common mineral association is: *hornblende, plagioclase,* sometimes *quartz,* and with *biotite* and *pyroxene* as alternative mafic minerals (see also FRENCH, 1966; HALL, 1967).

cratic to the leucocratic « *appinites* » is evident: in the outer parts or in the schistose dykes the An content ranges from 65% at the core to 25-35% at the periphery, while in the inner parts the core has 35% An and the outer shell 5-7% An.

Biotite is very rare in the schistose dykes; flattened aggregates appear in the breccias. This mineral becomes abundant towards the contact

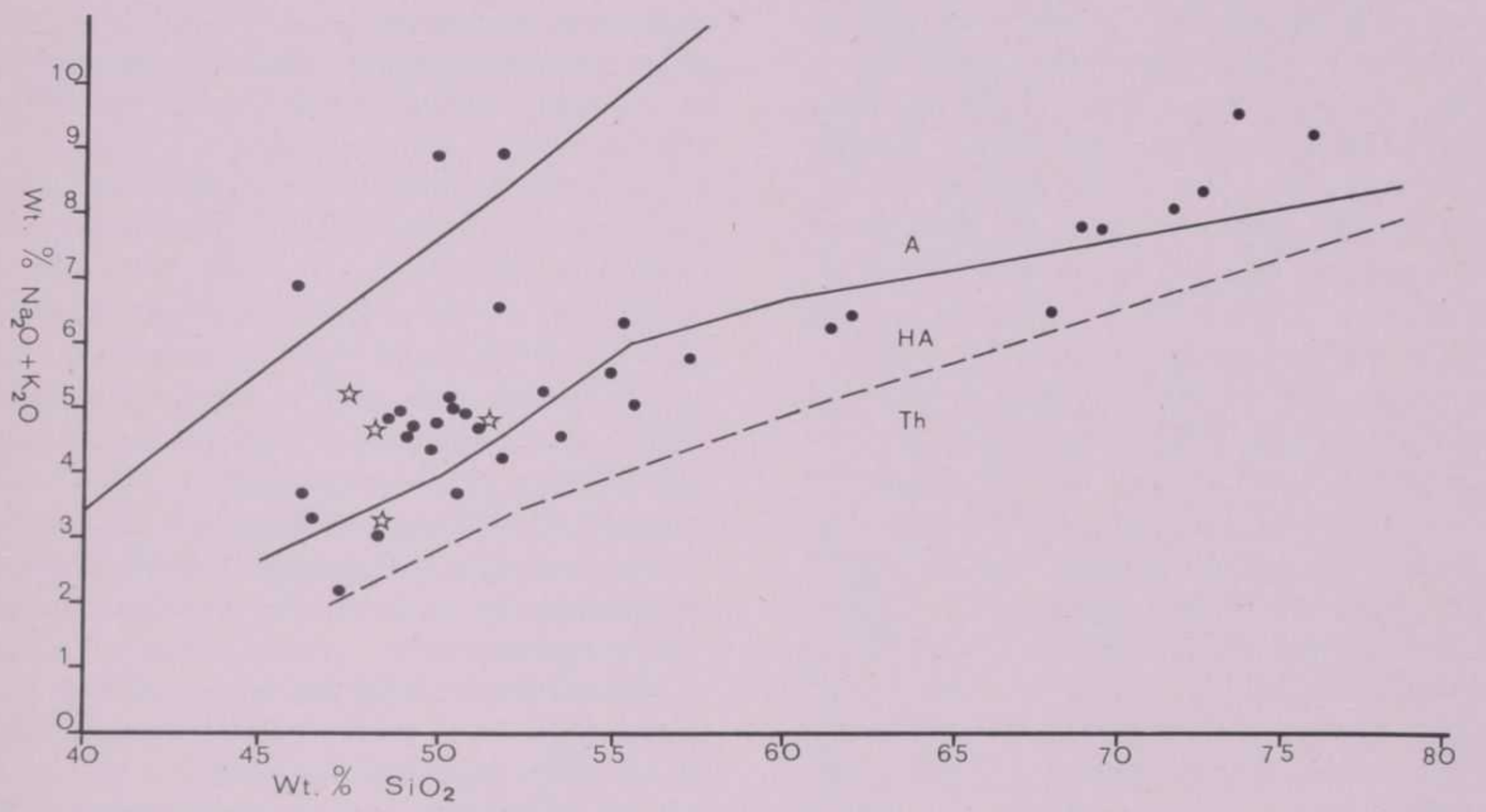

FIG. 4 - SiO_2/alkalies diagram. Asterisks: lamprophyres of the Verbania area. Dots: « *appinitic* » dykes ». For explanation see text.

with the aplitic dykes. In the medium-grained « *appinites* » *biotite* is in close association with amphibole, sometimes it is found in the central part of the *hornblende* « hollow crystals », together with *plagioclase* and *sphene*.

Microcline ($2V_x$ = 80°-84°) is present in the same amount as *plagioclase* in the aplitic veins, where it is often surrounded and partially replaced by myrmekitic *plagioclase*.

Very characteristic is the abundance of *sphene* and *ilmenite* in all the different types of «*appinites*».

PITCHER and BERGER (op. cit.) suggest that the coarse-grained structure and the abundance of hydrous minerals (i.e. *hornblende*) could be due to a high volatile content of the « *appinitic* » magma; as pointed out by the experiments of YODER and TILLEY (1962) the *amphibole* stability field is progressively widened at the expense of olivine and pyroxene under high vapour pressure.

These basic intrusions are always associated in space and time to granodiorite-granite plutons. This fact supports the hypothesis that the « *appinitic* » basic magma may have been enriched by volatiles passing through the granite magmas mobilized in the crust at the same time.

The chemical features of the Brissago area « *appinites* » have been discussed at length by BORIANI *et alii* (1975). The differentiation trend is essentially that of a calc-alkaline series, although most of the gabbrodiorites plot in the alkaline-basalt field (see SiO_2-alkali diagram, Fig. 4). Their abnormal alkali content could be attributed either to an enrichment through the abundant volatile phase, or to metasomathism. The basically orogenic character of the magma appears from the relatively high Al_2O_3 (14.5-20%) and the low TiO_2 (< 2%) content.

The scarce chemical data available on the lamprophyres do not allow a satisfying hypothesis to be put forward about their origin. BORIANI *et alii* (1975) tentatively related their intrusion to that of the « *appinites* »; REINHARD (1964) attributed their emplacement to the Permian in connection with the porphyries of the Luganese.

6. METAMORPHISM

It is clear from the preceding descriptions that the distribution of the metamorphic parageneses in the area under consideration is not compatible with a single metamorphic event.

The significant paragenesis of the schists of the southeastern part (« *Scisti dei Laghi* ») is: *quartz, oligoclase, muscovite, biotite, kyanite*. Although this paragenesis is only seldom found, since the chemical composition of the original sediments is generally not appropriate, the presence of *staurolite + quartz* and of *kyanite* is cited from different

localities within the investigated area and also outside it (for example: S of the Mottarone granite).

Apart from the local anomalies of the metamorphic pattern (retrogressive metamorphism and contact aureoles near the granites) it does not seem possible to identify with certainity a major metamorphic trend in the « *Scisti dei Laghi* ». Only if we consider the whole «*Serie dei Laghi*» is it possible to suggest an increase of the metamorphic grade towards NW since in the «*Strona-Ceneri*» there are indications of higher temperature processes.

In the « *Strona-Ceneri* » rocks of the M. Zeda zone two Al_2SiO_5 polimorphs are present: *kyanite* and *sillimanite,* but, due to the scarcity of metapelites in this unit, the area of stability of *sillimanite* cannot be pointed out with precision. Nevertheless a « *sillimanite in* » *isograd* can be tentatively traced through Cicogna - M. Todano - M. Bavarione; NW of this line both Al_2SiO_5 polimorphs are present. Where they appear in a single thin section it can be seen that the *sillimanite* is postkinematic and was clearly formed later than *kyanite* (top of M. Zeda). In other cases the microstructure suggests that the *sillimanite* is sinkinematic and belongs to the main metamorphism; also the distribution of « restitic » *kyanite* and *sillimanite* in the « Cenerigneisses » supports an original *kyanite-sillimanite* transition in the « *Strona-Ceneri* ».

If Boriani's (1968, 1970a) hypothesis of an anatectic origin of the « *Cenerigneisess* » is correct at the thermal peak of the main metamorphism the pressure had to be at least 6 Kbars since the *kyanite-sillimanite* isograd is in the anatectic field only above this pressure value. Schmid and Wood (1976) have recently proposed the physical conditions of T = 640°C and P = 8.1 Kb for metamorphism of « *Strona-Ceneri* » rocks from the M. Tamaro region (Sottoceneri).

The fine grained gneisses occupy a very contradictory position in this context: their texture, their mesoscopic characteristics and the presence of Al-silicates nodules indicate a peculiar type of evolution (Bigioggero and Boriani, 1975) which differs largely from that of the other rocks. Nevertheless they are intercalated between the other « *Strona-Ceneri* » rock types, moreover they seem to be in particularly close relationship with the « *Cenerigneisses* ». Their evolution suggests that the « main metamorphism » must be split into two phases: a prefolding (M_1) and a postfolding (M_2) episode and that the maximum temperature was reached in M_2. This evolution will be further illustrated in the chapter on tectonics.

The distribution of the typomorphic minerals in the rocks of Val Cannobina and of the « *M. Riga Unit* » does not add any other useful information about the main metamorphism of the « *Serie dei Laghi* ». The only exception is represented by the *garnet* poikiloblasts of the northern part of the « M. Riga Unit », which could be attributed to the main phase on the grounds of a particular tectonic interpretation (see section on tectonics).

As far as the age of the main metamorphism is concerned it is difficult to give reliable figures. The only available radiometric ages are those concerning the *zircons* and the *monazites* of some ortho- and para-gneisses which were determined by Köppel and Grunenfelder (1973); Köppel (1973).

The age obtained from *zircons* and *monazites* from ortho-gneisses and migmatites would seem around 450 m.y.

Allègre, Albarède, Grünenfelder and Köppel (1974) have recently proposed an initial age of the zircons of the paragneisses of 2000--2600 m.y. with a first episode of lead loss around 520-580 m.y., corresponding to the Cadomian phase of the Assynthic orogeny. The age of the *zircons* from the othogneisses (450 m.y.) « does not necessarily indicate the existence of a Caledonian event ».

Nevertheless, since the age of 450 m.y. is obtained also from orthogneisses from other parts of the Alps (Oetztal Krystallin - Satir, 1975), this must indicate a magmatic activity at that time. These igneous rocks were affected by the main metamorphism and therefore we maintain that the main metamorphism must have occurred around 450 m.y. or later.

6.1. RELATIONSHIP TO THE « IVREA-VERBANO » METAMORPHISM

Within the central subunit of the « *M. Riga Unit* » one can see from S to N an abrupt change of metamorphic grade from rather low grade retrometamorphic gneisses to the *kyanite - staurolite* or *andalusite - staurolite* (± *kyanite* ± *sillimanite*) schists of the zone of Pian Nasca - Spoccia - Piodina. The *andalusite* bearing parageneses are spatially connected to the zone of occurrence of the « *appinitic* » dykes and could be attributed to a late, contact metamorphism due to the intrusions since their attribution to a supposed more recent « *Ivrea-Verbano* » metamorphism would imply inacceptably low pressures (around 5 Kb) which cannot be conciliated with the absence of *cordierite* in the schists of higher grade which occur immediately N of the considered area.

Schmid and Wood (op. cit.) suggest a range of 9-11 Kb and 700°-820° for the P and T conditions of the metamorphism of the « *Ivrea-Verbano* » zone in the neighbouring Val d'Ossola. Although the sporadic occurrence of cordierite

(Peyronel Pagliani and Boriani, 1967) would suggest a somewhat lower pressure (Currie, 1971), there is no doubt that the pressure value during the « *Ivrea-Verbano* » metamorphism exceeded at least 8 Kb with a polymorphic transition *kyanite-sillimanite* around 700°: the transition can be clearly seen in the samples collected along the Pian Nasca-Alpone footpath W of Gurro in Val Cannobina.

As far as the area under consideration is concerned, there is no reason, at present, to attribute the metamorphism of the « *Ivrea-Verbano* » to an event with P-T conditions different from those of the « *Serie dei Laghi* ». The metamorphism of the two major units of the *South Alpine* domain of the Western Alps could have been related to the same geological event. Schmid (1972) considers the metasedimentary part of the two units as belonging to the same sedimentary *suite,* the present difference being due to degranitization in the higher grade part of the same metamorphic series.

Nevertheless, while for the « *Serie dei Laghi* » the geochronological evidence points to an age of metamorphism around 450 m.y., for the « *Ivrea-Verbano* » a more recent origin seems to be indicated since the only Rb/Sr total rock isochron published till now (Graeser and Hunziker, 1968) on the « *Ivrea-Verbano* » granulites gives an age of 310 ± 60 m.y. with an initial Sr isotopic ratio of 0.717. U/Pb ages of *monazites* from « *Ivrea-Verbano* » paraderivates of 275 ± 2 m.y. were obtained by Koppel (1974); the minimum age of inherited *zircons* is 1900 m.y. with a drastic lead loss at about 285-300 m.y.

Rb/Sr and K/Ar mica ages of the « *Ivrea-Verbano* » range from about 240 to 180 m.y. while those of the « *Serie dei Laghi* » are generally older (Mc Dowell and Schmid, 1968; Mc Dowell, 1970; Hunziker, 1974).

In conclusion the data available so far indicate an essentially younger thermal history of the « *Ivrea-Verbano* » (i.e. a slower cooling) but not necessarily a different metamorphism; *also a two pulse (450 and 300 m.y.) history with the second pulse more important in the « Ivrea-Verbano » may be envisaged.*

Another important conclusion that may be drawn from the geochronological data is that the contact metamorphism and, locally, the anatexis induced by the « *appinitic* » intrusions at the junction between the two units (Boriani and Sacchi, 1973, 1974; Boriani *et alii,* 1975) is late Variscan (295 m.y. of the *monazite* from the migmatites of the lower Strona Valley, Köppel, 1974).

The pressure characteristics of the contact metamorphism in Val Cannobina indicate that the intrusion of the « *appinites* » occurred at a pressure at least 3 Kb lower in comparison with the P conditions of the main metamorphism. This means that uplifting and erosion of at least 10 km of cover had already occurred.

7. TECTONICS

If we look at the tectonic sketch-map of the « *Serie dei Laghi* » a major structural feature stands out clearly: in the Verbano-Sottoceneri zone the « *Serie dei Laghi* » seems to form a large fold with subvertical axis, with the *metapsammitic* gneisses of the « *Strona-Ceneri* » at the core and the *metapelitic* « *Scisti dei Laghi* » as mantle. The northern limb appears complicated by minor « *schlingen* » folds that involve mostly the « *Strona-Ceneri* » rocks.

The hinge of the major fold is well exposed in the northeastern part of the Sottoceneri in the Giubiasco-Medeglia-S. Jorio pass triangle. In that area the northern limb of the fold is largely sheared-off by the Jorio-Tonale Fault.

In the west, this major structure is clearly cut by another important fault, the « Pogallo-Lake Orta » line. In the northern part of the « *Serie dei Laghi* » the attitude of the S-planes is nearly vertical whilst in its southern part the schistosity planes dip more gently to the S or the SE and, locally, are even horizontal: this explains the different aspect of the geological maps, for example in our area and in the zone N of Ponte Tresa.

In this chapter we will give details of the structural characteristics of the different parts of the mapped area starting from the description of the non-penetrative discontinuities; an interpretation of the structural evolution of the zone will be proposed in the final chapter.

7.1. FAULTS

The two main tectonic lines are related to, and largely represent, the contact between the « *Serie dei Laghi* » and the « *Ivrea-Verbano* »: they are the « *Cossato-Borgosesia-Mergozzo-Brissago* » and the « *Pogallo-Lake Orta* » lines. The first of these two lines represents (Boriani and Sacchi, 1973) the oldest tectonic contact between the two units; it is characterized by lithological contrast, presence of blastomylonites, anatectic phenomena and intrusion of high water pressure gabbrodioritic magma (« *appinites* »).

All these characteristics are present between Candoglia and M. Faiè, in the extreme southwestern part of the area; between M. La Piota and Brissago the contact loses its tectonic characteristic and is marked mostly by the presence of « *appinitic* » dykes which induced a contact metamorphism on the country rocks.

The other important fault that cuts the contact described here is the « *Pogallo-Lake Orta* » Line; it was recognized by BORIANI (1970a) in the mapped area and then was considered by BORIANI and SACCHI (1973) to be responsible for the « Lake Orta misfit ». The « *Pogallo-Lake Orta* » Line runs SSW-NNE from Mergozzo to M. La Piota and then turns towards NE reaching the Lake not far north of Brissago. The strong horizontal slip appears clearly from the tectonic sketch, judging from the displacement of the amphibolite horizon, and is of about 11 km.

Blastomylonites of different rock types of both formations are constantly present along the fault plane, whilst migmatites and dyke-rocks are absent.

Between M. Faiè and M. La Piota, the « *Pogallo-Lake Orta* » Line marks the separation with strong angular unconformity between the « *Ivrea-Verbano* » and the « *Serie dei Laghi* »; N of M. La Piota the fault continues in a belt of blastomylonitic rocks within the metapelites of the « *Ivrea-Verbano* ». The belt has an arcuate trend and seems to coincide, in the easternmost stretch, with the boundary between « *Ivrea-Verbano* » metapelites and metabasites. This situation is well exposed in the road-cut between M. Castello and Cursolo (upper Cannobina Valley).

Other tectonic lineaments are represented by a widespread subvertical fault system striking N-S, which is particularly developped in the zone of Aurano and M. Bavarione, where the anticlockwise horizontal slip of these faults is shown by the displacement of the amphibolite horizon. The way in which these faults cluster at the eastern margin of the thick « *Cenerigneiss* » mass of M. Todano seems to indicate that their origin was due to the different mechanical behaviour of the rocks in the compressional stress field (« *Cenerigneiss* » more rigid, schists more ductile).

A different type of tectonic discontinuity, widely present also in the Sottoceneri, is represented by reverse faults and overthrusts dipping NW. The Cannero fault is probably the most important reverse fault of the zone, since it can be followed from Cannero up to Crealla in Val Cannobina, in spite of intense morainic cover. The small overthrust of M. Morissolo (W of Cannero) occurs on a subhorizontal plane and leads to the formation of a limited amount of cataclastic rocks.

A practically unresolved tectonic problem is the doubling of the amphibolite horizon of Caprezzo; the repeated segment of amphibolites is limited on both extremities by N-S faults, but their significance remains obscure.

It would seem relevant to note the connection of the occurrences of lamprophyres with different tectonic disturbances. Lamprophyres are very frequent along the N-S faults and the subhorizontal overthrust of M. Morissolo. In the zone of Caprezzo, besides subvertical N-S ones we find also subhorizontal dykes; dykes of this latter type are present also in the zone of Piaggia and M. Bavarione suggesting that the role of subhorizontal overthrusts in these zones is probably more important than that which results from our mapping.

7.2. STRUCTURAL DOMAINS

It is possible to distinguish four main zones with different structural characteristics (See also the structural sketch-map, Fig. 5).

1) S of the Val Cannobina and of the alignement M. La Piota-Socraggio (i.e. S. of the fine-grained gneisses-*gneiss minuti*- of Val Cannobina) the prevailing attitude of the rocks is that of a monoclinal series apparently striking NE, mostly subvertical or steeply dipping SE. Only small mesoscopic similar folds have been observed, mainly in the fine-grained gneisses (for example those of M. Bavarione) and in the schists near Leigio and P.te del Dragone (Scareno); folds axes plunge steeply NE and the axial plane is parallel to the regional schistosity.

2) The area between M. La Piota, Falmenta and Val Cannobina is occupied by a thick subvertical horizon of fine-grained gneisses striking E-W. At their southern boundary they are discordant with respect to the southern zone; this is an atypical contact since there is little or no occurrence of cataclastic rocks but a strong concentration of small folds with vertical axes.

3) The zone lying between the Lake shore, M. Giove and M. Faierone shows very peculiar structural characteristics; here we have recognized for the first time the « *schlingenbau* » structure (so widespread E of the Lake) W of Lake Maggiore. The most evident of these folds is that of M. Giove with a mantle of fine-grained gneisses and a core of « *Cenerigneisses* »; the axial plane is E-W and the fold axis plunges steeply eastward. W of the M. Giove fold the structural and lithological complexity is extreme; this is probably due to the little-understood tectonic disturbance of Val Cavaglio. On the basis of both microscopic and mesoscopic affinity, this zone has been mapped as « *M. Riga Unit* ».

FIG. 5 - Structural sketch-map of the northern part of the « Serie dei Laghi ». The lithology is greatly simplified; black: main metabasites horizon; horizontal lines: orthogneisses of the « *Scisti dei Laghi* »; horizontal lines and points: augen gneiss of the « *Strona-Ceneri* »; stippled: « Ivrea-Verbano ». Letters refer to the structural domains (see text): A: « *Scisti dei Laghi* »; B: « *Strona-Ceneri* », southern part; C: « *Strona-Ceneri* », fine-grained gneiss, zone of Cannobina and Falmenta Valleys; D: « *Schlingen* » zone of M. Giove. E: M. Riga unit, E1 southern part, E2 central part, E3 northern part.

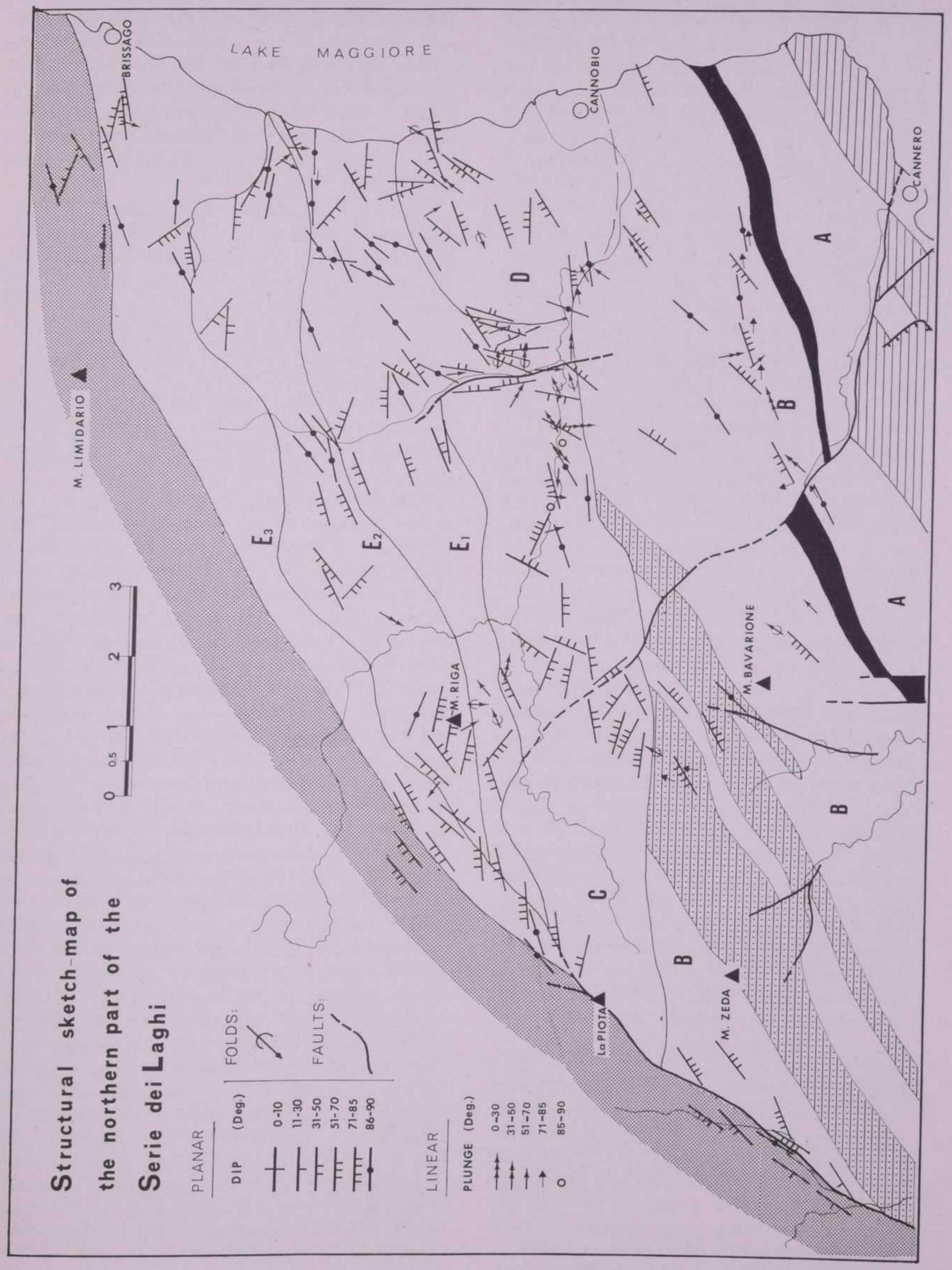
LAKE MAGGIORE
BRISSAGO
CANNOBIO
CANNERO
M. LIMIDARIO
M. RIGA
M. BAVARIONE
M. ZEDA
La PIOTA
A
B
C
D
E1
E2
E3
0 0.5 1 2 3
Structural sketch-map of the northern part of the Serie dei Laghi
PLANAR
DIP (Deg.)
0-10
11-30
31-50
51-70
71-85
86-90
FOLDS:
FAULTS:
LINEAR
PLUNGE (Deg.)
0-30
31-50
51-70
71-85
85-90

FIGURE 5

4) W of Val Cavaglio the contact between the fine-grained gneisses of Val Cannobina and the « *M. Riga Unit* » is marked by the presence of a continuous horizon of amphibolites. At the bridge of Falmenta the amphibolites show folds with steep NE plunging axes. The structural characteristics of the « *M. Riga Unit* » have been discussed in detail together with its petrographic aspects. We wish to point out here that this area was mapped and described as a separate unit, mostly because of its peculiar structural aspects, and that in our opinion it constitutes the northernmost part of the « *schlingen* » zone which was strongly compressed against the « *Ivrea-Verbano* ». Hinges of very tight folds with subvertical or steeply W plunging axes can be frequently seen, mainly in the central part of the « *M. Riga Unit* ». At meso- and microscopic scale an additional phase of penetrative, essentially postcrystalline deformation can be seen in these rocks. Typical in this respect are the rotated xenoliths of the « *Cenerigneisses* », still recognizable in the southern and central parts of the unit.

8. EVOLUTION OF THE « SERIE DEI LAGHI »

The stratigraphical evidence gives little information about the age of the metasediments of the « *Serie dei Laghi* »: we know that the metamorphism is pre-Westfalian B because the overlying conglomerate of Manno (Ticino) has been dated on the basis of its paleobotanical content as Westfalian B. The geochronological data seems to indicate an age of the main metamorphism around 450 m.y.; but what about the age of the sediments? Again the U/Pb ages of the zircons of the oldest population indicate a wide time span ranging from 1900 to 2600 m.y. These ages may represent the mixed ages of the old continental crust from which the sediments were eroded; their deposition may well have occurred during the Cambro-Ordovician, though the presence of older sediments cannot be excluded. From the lithological standpoint the metasediments of the two parts of the « *Serie dei Laghi* », i.e. « *Scisti dei Laghi* » and « *Strona-Ceneri* » are quite different: mostly pelites and semipelites in the former, mostly metapsammites in the latter. In both units carbonate rocks are extremely scarce; this could indicate deep sea sedimentation in a trench and the amphibolites, now present at the boundary between the two units, could represent the metavolcanites of that early orogenic environment.

Schmid (1972) maintains that the « *Ivrea-Verbano* » paragneisses could be derived from the same sedimentary sequence from which the « *Strona-Ceneri* » originated; we object that the *lithological association* of the « *Ivrea-Verbano* » paraderivates is different since amphibolites and marbles are common intercalations of the so-called « kinzigites » whilst they are absent in the « *Strona-Ceneri* ». This does not mean they could not have been part of the same basin: it only means that they are different.

However a discussion of the relationship between the metasediments of the « *Serie dei Laghi* » and those of the « *Ivrea-Verbano* » will inevitably involve considerations about the origin of the huge mass of basic and ultrabasic rocks of the « *Ivrea-Zone* » and this is outside the scope of the present work. We shall concentrate rather on the problem of the « *Serie dei Laghi* », leaving the examination of that other important problem to a future work in which the results of our investigation on the « *Ivrea-Verbano* », now in progress, will be published.

The orogenic event which metamorphosed the sediments cannot be defined and described with certainty; we know that in a first phase, around 450 m.y., large parts of the sediments were metamorphosed at the amphibolite facies conditions in the infrastructure of the orogenic belt. Then intrusion of sheet granites and leucotonalites (the present orthogneisses of the « *Serie dei Laghi* ») occurred; pegmatite dykes crossed the semimetamorphic cover creating small contact aureoles in the overlying slates (the present-day fine grained gneisses). At the end of this phase it seems likely that the schistosity plane was nearly horizontal in the infrastructure and vertical in the overlying suprastructure as proposed by Zwart (1965) for the Pyreneès. Afterwards a regional folding episode involved the whole complex in tight or open folds with vertical axial plane and horizontal axes and the suprastructure rocks became comprised between deeper metamorphites at the core of the synclines; the metamorphism reached its climax, all the rocks were equilibrated at the *kyanite* (or *sillimanite*)-*staurolite* grade with consequent anatexis (?) in the more *feldspar*-rich metapsammites (« *Cenerigneisses* »). Later on, perhaps on account of the continuation of compression the « *Serie dei Laghi* » began its transcurrent anticlockwise movement with respect to the « *Ivrea-Verbano* » along the « *Cossato ... Brissago Line* » (Boriani and Sacchi, 1973). This movement is probably responsible for the formation of the folds with vertical axes (« *schlingen* ») that we suggest here should be interpreted as large scale drag folds related to a transcurrent fault. We do not know at the moment if the model could be applied to

the other, probably coeval, occurrences of « *schlingen* » folds in the Alps.

Two facts only intervened to modify this picture:
a) uplifting and erosion of about 10 km of cover;
b) clockwise bending of the fault plane of the « *Cossato... Brissago Line* » in correspondence to Val Cannobina.

The change of P conditions and the consequent lowering of T caused a retrogressive metamorphism in the zones where the transcurrent movement was still going on (« M. Riga Unit »). The bending of the « *Cossato... Brissago Line* » and the continuation of the movement determined the creation of a new fault plane (« *Pogallo Line* »).

It is very difficult to attribute the formation of the various N-S vertical faults, of the R. Cannero fault and of most of the overthrusts to a precise moment, since they appear coherent with the general stress field that operated during a large part of this evolution; we may suggest that their locating coincided with the lowering of temperature below a certain value which determined the change in behaviour of the rocks from ductile to transitional.

The age of the Pogallo fault (Boriani and Sacchi, 1973) is Variscan; the extension that followed the long-lasting compression favoured the intrusion of the « *appinites* » and, later, of the granites. We now think that the opinion that the « *appinites* » are a pre-« *Pogallo Line* » (Boriani and Sacchi, 1973, 1974; Boriani *et alii,* 1974, Boriani *et alii,* 1975) must be abandoned; this interpretation arose from the observation that no « *appinitic* » dykes occur along the « *Pogallo Line* » while they are almost constantly present along the older « *Cossato... Brissago Line* ». On the other hand it must be noted that a pre-« *Pogallo* » origin could hardly be reconciled with much other evidence. The tapering of the « *appinitic* » swarm towards the « *Pogallo Line* » in Val Cannobina and the lack of deformation of most « *appinites* » are examples of such evidence. The thinning of the « *appinitic* » swarms is not due to lamination since most of these dyke rocks do not show any trace of postcristalline deformation; the dykes simply become less abundant and thinner as one proceeds from the zone of Brissago to M. Riga. One possible explanation is the following: as the compression died down the subsequent extension could create room for the intrusion of the dykes only where there was little stored elastic strain. The greater the elastic strain to be recovered, the thinner the spaces available for intrusion; in this way we may explain the lack of dykes along the Pogallo Line where the strain was maximum, and the increased thickness and frequency of the « *appinitic* » dykes towards Brissago in the direction of decreasing stored elastic strain.

The intrusion of the « *appinites* » determined a rise of temperature at the junction between « *Serie dei Laghi* » and « *Ivrea-Verbano* »; these *high water pressure intrusives* caused the *andalusite* metamorphism of the Spoccia-Brissago zone and anatexis in the gneisses of the M.te Faiè-Mergozzo area (see also Boriani and Peyronel Pagliani, 1968) and further SW. The *andalusite* metamorphism of Val Cannobina-Brissago was interpreted (Boriani *et alii,* 1974; Boriani *et alii,* 1975) as a regional low pressure late Variscan phase of the « *Ivrea-Verbano* » metamorphism; a closer examination of the distribution of the typomorphic minerals now suggests that it should be considered, (at least in this area), a more localized episode related to the « *appinitic* » intrusion.

In this attempt to rationalize and simplify an extremely complicated evolution we have not yet mentioned the widespread static metamorphism which left its mark mainly on the « *Cenerigneiss* » and perhaps on the *fine-grained gneiss* (significantly called « hornfelsgneise » by the Swiss authors). The point is in fact that the identification of its age is quite difficult; the relationship between intrusion of the lamprophyres (which we consider coeval to or later than the « *appinites* ») and the static recrystallization of the « *Cenerigneiss* » suggests (Boriani, 1971) a late Variscan age.

Contradictory to this conclusion is the presence of widespread post-crystalline deformation in the southern and central part of the *M. Riga Unit,* the survival of which is difficult to reconcile with a general thermal late Variscan episode.

This is not the only contradictory indication ensuing from the study of this part of the « *Serie dei Laghi* »; but this work, like any other human activity, cannot be considered exaustive. In future, more detailed mapping, new petrological data and a better knowledge of the neighbouring « *Ivrea-Verbano* » will surely help to shed new light on the history of the « *Serie dei Laghi* ».

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RIASSUNTO

Viene presentata una carta geologica originale, scala 1 : 50.000, di una zona di circa 500 km² a N di Verbania (prov. Novara). La zona è costituita in stragrande maggioranza da rocce metamorfiche appartenenti all'unità sudalpina nota col nome di « *Serie dei Laghi* ». Questa confina a W ed a N con la « *zona Dioritico-Kinzigitica Ivrea-Verbano* »; il contatto è perloppiù tettonico (Linea Pogallo-Lago d'Orta) ma in Val Cannobina sembra essere graduale.

La « *Serie dei Laghi* » è stata divisa in due unità litostratigrafiche: « *Scisti dei Laghi* » (prevalentemente micascisti con intercalazioni di ortogneiss) a SE e « *Strona-Ceneri* » (prevalentemente paragneiss con migmatiti gneissiche ed ortogneiss) a NW. Le due unità sono separate da un continuo orizzonte di metabasiti che mostrano vistosi fenomeni di feldspatizzazione al loro margine meridionale.

La porzione più settentrionale dell'area rilevata è qui, per la prima volta, attribuita alla « *Serie dei Laghi* » ed è stata separata dal resto della Serie con il nome di « *Unità del M. Riga* », sulla base delle sue peculiari caratteristiche strutturali.

Il metamorfismo è prevalentemente del grado *cianite-staurolite;* verso NW sembra passare al grado *muscovite-sillimanite*. Verso l' « Ivrea-Verbano », la transizione *cianite-sillimanite* è parzialmente mascherata in Val Cannobina da un metamorfismo di contatto, tardivo, provocato da uno sciame di piccole intrusioni gabbrodioritiche (« *appiniti* »).

L'età del metamorfismo è sicuramente pre-Permiana, ma non è rilevabile con esattezza; dai dati geocronologici disponibili sembra che le trasformazioni metamorfiche siano iniziate attorno ai 450 m.a., ma che la temperatura sia rimasta elevata fino ad almeno 300 m.a..

Si riconoscono più fasi sincinematiche e statiche; le fasi dinamiche importanti che hanno creato strutture pervasive sono almeno tre. La prima è la fase scistogena fondamentale ben riconoscibile nelle pieghe intrafoliali degli scisti della zona meridionale; la seconda sembra essere una fase di piegamento con piano assiale diretto grosso modo SW-NE, con pizzicamento in strette sinclinali della originaria copertura semimetamorfica (gli attuali *gneiss minuti* della « *Strona-Ceneri* ») e successivo riequilibramento metamorfico, anche della copertura, in facies anfiboliti; la terza fase, riconoscibile solo nella parte N della zona, è responsabile del piegamento su assi verticali (« *Schlingen* ») che viene qui interpretato come dovuto ad un « dragging » a grande scala lungo l'antica faglia trascorrente (Linea « *Cossato-Borgosesia-Mergozzo-Brissago* ») che separa la « *Serie dei Laghi* » dalla « *Ivrea-Verbano* ».

La formazione della linea « *Pogallo-Lago d'Orta* », delle importanti faglie N-S della zona immediatamente a N di Verbania e di alcuni sovrascorrimenti minori, sembra legata alla torsione del piano dell'antica faglia trascorrente, pur essendo compatibile con lo stesso « campo di stress » che l'ha generata.

SUMMARY

A new geological map (1: 50.000 scale) is presented here; the mapped area is about 500 Km² in the north of Verbania (Novara, Northern Italy). In this area mainly metamorphic rocks, belonging to the South-alpine Unit called « *Serie dei Laghi* », are represented. Westwards and northwards this Unit is in contact with the « *Zona dioritico-kinzigitica Ivrea-Verbano* »; this contact is mostly tectonic (« *Pogallo-Lake Orta* » fault) but in the Cannobina Valley a gradual transition is probable.

The « *Serie dei Laghi* » is here divided into two lithostratigraphic Units: « *Scisti dei Laghi* » (mostly micaschists with orthogneiss intercalations) to SE and « *Strona-Ceneri* » (mostly paragneisses with gneissic migmatites and orthogneisses) to NW. The two Units are separated by a continuous horizon of metabasites with strong feldspathization phenomena in the southern margin.

The northernmost part of the mapped area is here attributed, for the first time, to the « *Serie dei Laghi* » and is mapped separately (« *M. Riga Unit* ») on the basis of its peculiar characteristics.

The prevailing metamorphic grade is *kyanite-staurolite*; towards NW it seems to reach the *muscovite-sillimanite* grade. Near the « Ivrea-Verbano » the transition *kyanite-sillimanite* is partly masked in the Cannobina Valley by a later contact metamorphism due to the intrusion of a swarm of gabbrodioritic dykes (« *appinites* »).

The age of metamorphism is certainly pre-Permian, but it cannot be determined exactly; according to published geochronological data the age of the first metamorphic transformation is about 450 m.y., but high temperature regimes are recognizable up to 300 m.y.

Several synkinematic and static phases are recognizable; at least three phases generating pervasive discontinuities are present. The first (main) phase created the main schistosity and is easily recognizable in the interfolial folds of the southern zone; the second one corresponds to the formation of folds with axial planes trending SW-NE; to this phase is attributed the « pinching » in tight sinclines of the semimetamorphic cover (the present « fine-grained-gneisses » of the « *Strona-Ceneri* »), after this phase the cover rocks were also reequilibrated into amphibolite facies; the third phase, recognizable only in the northern part of the zone, is responsible for the « *schlingen* » structure. This kind of folding with vertical axial planes is here interpreted as a large scale dragging along the older transform fault « *Cossato... Brissago* ») along the junction « *Ivrea-Verbano* » and « *Serie dei Laghi* ».

The formation of the Pogallo-Lake Orta fault of the N-S trending system of faults of the area immediately North of Verbania and of some minor overthrusts seems to be related to torsion of the plane of the older transcurrent faults, although it is compatible with the same stress field which generated it.

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TOPOGRAPHIC MAPS

1 : 50.000

— *Landeskarte der Schweiz*, Blatt: 285 Domodossola
286 Malcantone

1 : 25.000

— *Carta d'Italia*. Tavolette: 15 II NE Trontano
15 II SE Premosello-Chivenda
16 III NO S. Maria Maggiore
16 III NE Monte Limidario
16 III SO Monte Zeda
16 III SE Cannobio
30 I NE Ornavasso
31 IV NE Ghiffa
31 IV NO Verbania

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16 Cannobio
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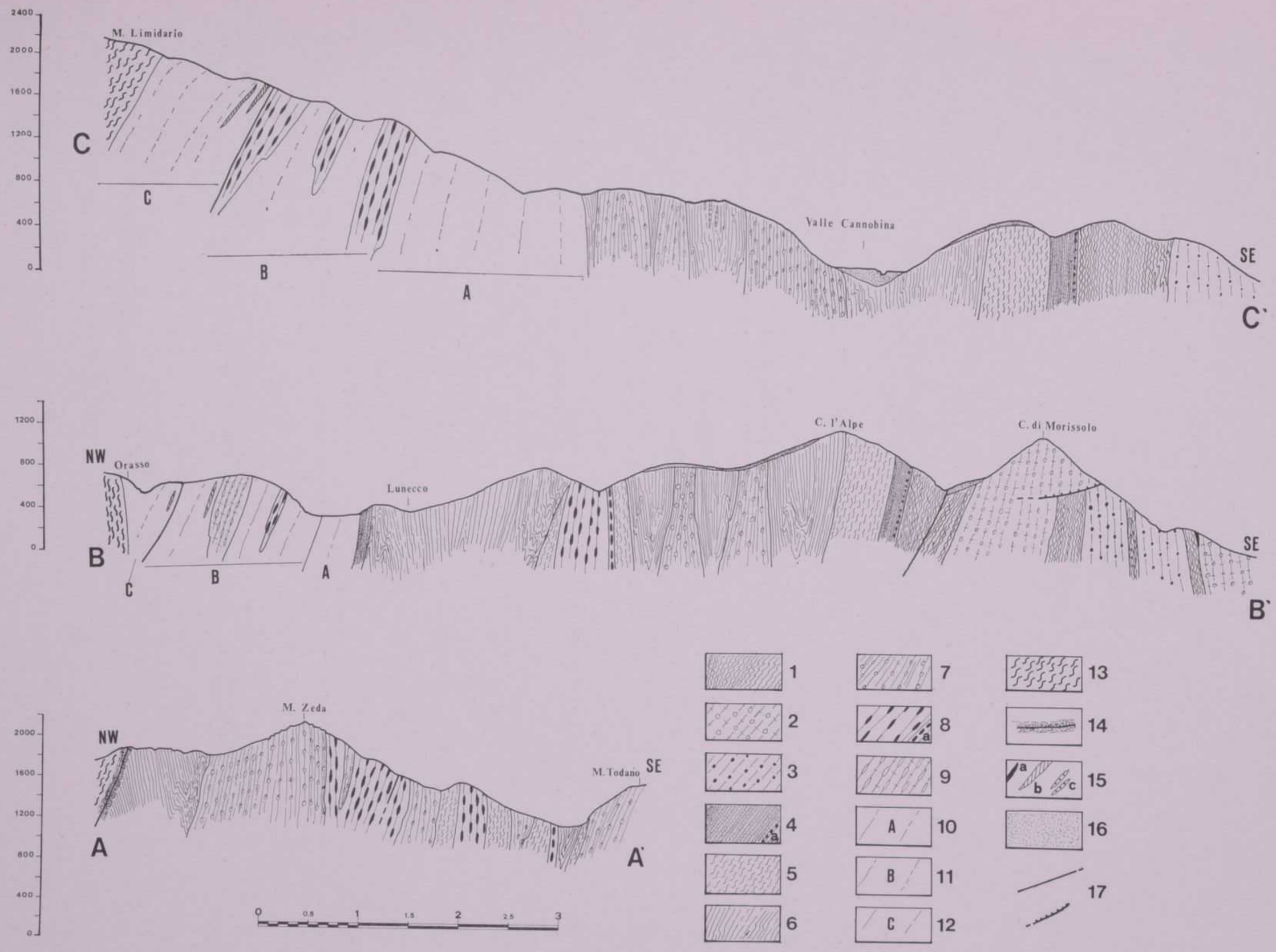

GEOLOGICAL SECTIONS - 1: Micaschists and paragneisses (« *Scisti dei Laghi* »; T: Hornblende-bearing orthogneisses; 3: Granite orthogneiss; 4: Metabasites, a) feldspathized margin; 5: Biotite-plagioclase gneisses; 6: Fine-grained gneisses; 7: « *Ceneri gneiss* »; 8: Augen gneisses, a) with « *flaser* » texture; 9: Hornblende-bearing orthogneisses of the M. Riga Unit; 10: « *M. Riga Unit* », southern part; 11: « *M. Riga Unit* », central part; 12: « *M. Riga Unit* », northern part; 13: Muscovite-sillimanite paragneisses of the « *Ivrea-Verbano* »; 14: Blastomylonitic zone along the « *Pogallo-Lake Orta* » fault (Section A-A); 15: Dyke rocks, a) lamprophyres, b) « *appinites* », c) Schistose pegmatites; 16: Undifferentiated quaternary deposits; 17: Faults and overthrusts.

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