Petrological observations in the Maggia hydro-electric tunnel between Lake Maggiore and Centovalli

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Contents

Abstract

A description is given in the present paper of the rocks contained in the profile through the Pennine and upper East-Alpine Root-Zone as exposed by the hydro-electric tunnel of the Maggia Electricity Works. The profile comprises the kinzigite zone and the basic zone of Ivrea (zona diorito-kinzigitica of the Italian authors), the Canavese Zone and the zones of Arcegno and Locarno. The kinzigite zone contains kata-metamorphic pelites to marly sediments of at least Palaeozoic age, into which the basic rocks of the Ivrea zone later intruded. These intrusives vary in the investigated area from hypersthene-bearing diallage-gabbro to diorite-amphibolite and occasionally contain inclusions of kinzigites. The age of the intrusion cannot be directly determined, but the general course of the zone, conformable in respect to the West-Alpine arc, points to a connection with the Alpine orogenesis. The Canavese, Arcegno, and Locarno zones originally contained pelitic, marly and calcareous sediments, out of which staurolite-bearing two-mica gneisses, epidote-bearing para-amphibolites and banks of calk-silicate felses were produced by metamorphism. In the Canavese zone compact black limestones also occur. The age of these rocks is presumably Mesozoic. Subsequently to the development of the present grade of metamorphism basic intrusions took place. In the Arcegno zone ultrabasic magmas also intruded which now have the character of amphibolites and serpentinised peridotites. In late to post-Alpine times an intensive pegmatitic injection took place which in the Locarno zone gave rise to extensive phenomena of migmatisation. With the exception of those in the Locarno zone all basic and ultrabasic rocks in the investigated area are considered to be of magmatic origin and genetically inter-related. The members found in the Locarno zone are of a peculiar nature as is especially apparent from their high K-content.

Zusammenfassung

Die vorliegende Arbeit beschreibt die Gesteine des Profils durch die penninisch-oberostalpine Wurzelzone, wie es zwischen Centovalli und Lago Maggiore (Tessin) durch den Druckstollen der Maggia-Elektrizitätswerke aufgeschlossen wurde. Es umfasst die Kinzigitzone und die basische Zone von Ivrea (Zona diorito-kinzigitica der italienischen Autoren), die Zone des Canavese und diejenigen von Arcegno und Locarno. Die Kinzigitzone umfasst katametamorphe pelitische bis mergelige Sedimente von mindestens paläozoischem Alter, in welche später die basischen Gesteine der Zone von Ivrea eingedrungen sind. Diese variieren im Untersuchungsgebiet von Hypersthen-Diallaggabbro bis Dioritamphibolit und enthalten gelegentliche Einschlüsse von Kinzigiten. Das Alter der Intrusion lässt sich nicht direkt festlegen; der gesamte Verlauf der Zone, konform dem Westalpenbogen, macht jedoch eine Verknüpfung mit der alpinen Orogenese nicht unwahrscheinlich. Die Zonen des Canavese, von Arcegno und Locarno enthielten ursprünglich pelitische, mergelige und kalkige Sedimente, aus welchen später durch Metamorphose staurolithführende Zweiglimmergneise, epidothaltige Paraamphibolite und Lagen von Kalksilikatfelsen entstanden. In der Canavesezone finden sich auch dichte schwarze Kalke. Das Alter der Gesteine ist vermutlich mesozoisch. Nachdem sie den heutigen Grad der Metamorphose erreicht hatten, intrudierten basische,

in der Zone von Arcegno auch ultrabasische Magmen, welche heute als Amphibo-
lite und serpentinisierte Peridotite vorliegen. In spät- bis postalpiner Zeit erfolgte
eine starke pegmatitische Injektion, welche in der Zone von Locarno ausgedehnte
Migmatitisierung zur Folge hatte. Mit Ausnahme der Zone von Locarno werden
alle basischen und ultrabasischen Gesteine des untersuchten Gebietes als magmati-
schen Ursprungs und als miteinander genetisch verwandt betrachtet. Eine be-
sondere Stellung nehmen diejenigen der Zone von Locarno ein, wie sich besonders
auch aus ihrem hohen K-Gehalt ergibt.

CHAPTER I

Introduction

In order to meet the increasing demands for power for industrial
purposes the Maggia Hydro-electrical Company Ltd. of Locarno bored
a tunnel of several kilometers length during the years 1950—1954. It
traverses several rock formations of the root zones of the upper east-
Alpine and pennine nappes of the Alps in the canton of Tessin west of
Locarno and W. N. W. of the Lago Maggiore. This afforded an excellent
opportunity to study the different rock formations in their almost un-
weathered condition in vertical profiles along the walls and roof of the
tunnel. Interesting data was thus provided to supplement our present
knowledge of the geological relationship of the formations (of the "root
zones") to one another and the petrogenetical conditions of their evolu-
tion to their present state. As the tunnel is several kilometers in length
and as it would be beyond the possibility of a detailed study by a single
researcher within a short period of time, the late Prof. Dr. P. NIGGLI
assigned to the author the first part of the tunnel from its opening N. E.
of Brissago as far as Palagnedra in the Centovalli (a length of 7.4 km)
for detailed geological and petrological studies. The present thesis, there-
fore, contains the investigations carried out by the author in the Minera-
logical and Petrological Institute on specimens collected from the first
part of the tunnel during the years 1951—1954.

Explanation of the map and profiles (Plates I—III)

The map and the accompanying profiles appended to this thesis
represent a simplified version of the geological and petrological map of
P. WALTER (1950), who investigated this area of the root zone of the
pennine nappes up to the Swiss border with meticulous thoroughness.
The map gives a general idea of the disposition of the principal zones and

their possible stratigraphical boundaries against one another. The formations met with in the above zones (kinzigite, Ivrea, Canavese, Arcegno, and Locarno zones) have a general E.-W. strike with minor fluctuations in E.-N. E. to W.-S. W. or E.-S. E. to W.-N. W. direction. Such fluctuations do not veer to any large extent from the general E.-W. direction of strike. All the formations have steep northerly dips in general ranging from 70° to almost 90°. The direction of the hydro-electrical tunnel is indicated in the above map by a thick black line ABCD. The tunnel cuts through the first four geological formations (kinzigite, Ivrea, Canavese, and Arcegno zones) in a direction more or less perpendicular to their strike. In the Locarno zone, however, and from points B to D (disregarding the minor bend at C for the moment) it runs more or less parallel to the strike of the zone. As the geological aspects of the exposed walls of the tunnel are not favourable for studying the various processes attending injection, permeation, and diffusion of quartzo-feldspathic material into the mica-gneisses of which the Locarno zone mainly consists, this zone could not be studied in the same detailed manner as were the other zones. This point is mentioned again in the chapter dealing with the Locarno zone.

The six geological and petrological profiles appended at the end of the thesis are simplified and redrawn from certain original profiles kindly placed at my disposal during the course of my studies by Dr. E. DAL VESCO, geologist to the Maggia Hydro-electrical Company. The scale to which the profiles are redrawn is given below each one. The left wall of the tunnel is projected into the profiles, the apparent dip of the formation being maintained as accurately as possible. The length in meters of the tunnel is shown along the foot of the wall, while the numbers of thin sections of specimens collected an examined are given in brackets along the upper margins of the profiles. It should be mentioned here that the section numbers given in the profiles as well as in the text of this thesis indicate the distance in meters and the locality of collection of the examined specimen in the tunnel taking the entrance at "A" of the tunnel as its starting point. With the exception of a few thin sections showing more or less identical mineralogical characters, most of the sections are entered in the profiles and all of them are referred to in the text of the thesis. In addition, the mineralogical compositions of the sections entered in the profiles are repeated in appendix I, use being made of abbreviated mineral names for the constituents. A list of the abbreviations is given on page 219—224. This condensed presentation of the mineralogical compositions of the various rock types met with in the

tunnel is intended to give an insight into the mineralogical and geological relationships existing between neighbouring rock types.

The direction of the course of the tunnel can easily be read from the compass bearing given in the left-hand corner of the profiles. The original profiles of Dr. E. DAL VESCO have been deposited in the Mineralogical and Petrological Institute, where they can be obtained for further consultation if desired.

Methods of optical determinations

The anorthite content of the feldspars was determined on the four-axis Universal stage after the method of M. REINHARD (1931). The migration curves used for the optics were those of high and low temperature feldspars of G. VAN DER KAADEN (1951). All the precautions mentioned by M. REINHARD and G. VAN DER KAADEN were observed in practice. Typical sections containing fresh and distinctly twinned grains of suitable size were selected to yield results of maximum accuracy. The percentage values of the anorthite content of the determined feldspars described in the present thesis should not show a range of error greater than $\pm 5\%$ usually allowed in such determinations. In those sections, in which the anorthite content could not be estimated by the Universal stage on account of a lack of distinct twin lamellæ or cloudiness, the appropriate anorthite content was determined by measuring the refractive index of the feldspar grain against canada-balsam and/or quartz. Such determinations indicating the approximate composition of the feldspar are mentioned in the text in appropriate places.

Of all the types met with, only the basic members of the Ivrea zone offered some difficulty in the estimation of their anorthite content. This was due to the severe degree of cataclasis they had suffered, resulting in bending and twisting of their twin lamellæ and preventing an easy location of their optical symmetry planes etc. This difficulty was overcome by selecting suitable grains showing the minimum degree of strain and selecting lamellæ exhibiting the minimum degree of twisting and bending. Grains in the granoblastic matrices of various basic rocks showing recrystallisation due to relief of pressure, were completely disregarded as they seemed likely to give a value somewhat different from those of the original crystals. It is rather interesting to find out, however, from a few determinations made on such recrystallised grains that they do not show any significant differences in the values of their anorthite contents from those of the original grains. This suggests that the severe

dynamic metamorphism has not altered the composition of the original crystals in any significant degree. The above fact points to the suggestion that the severe dynamic metamorphism to which the basic rocks have been subjected has taken place under temperature conditions sufficiently high as to prevent a change in the composition of the original feldspars.

Twinning according to albite, pericline (or acline), and albite-carls-bad laws are most frequently met with, while twinning according to the other laws is rarely observed. The above laws are uniformly distributed in all types of rocks of the five zones without indication of any particular law of distribution. More than one type of twin-law was frequently found in the one section.

Recent studies on naturally occurring plagioclase feldspars with different anorthite contents have shown the existence of high- and low-
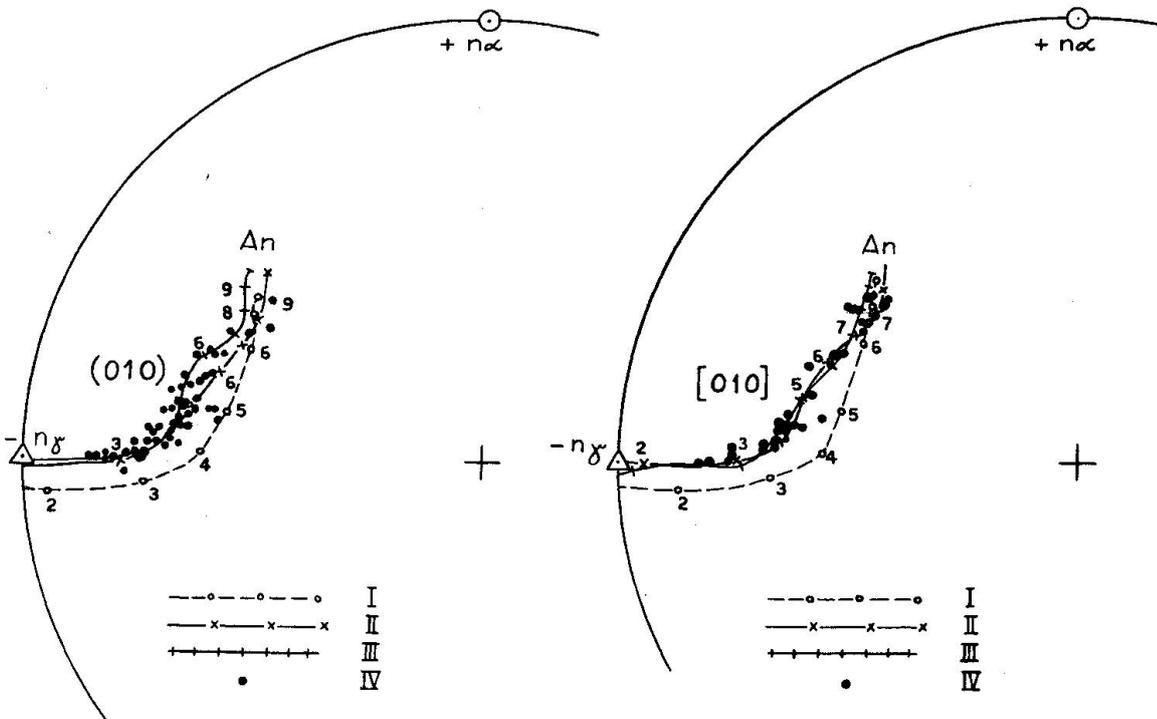
Fig. 1 a.   Fig. 1 b.

Fig. 1 a and 1 b. Migration curves of the poles of the (010) composition face and the [010] twin axis of the high- and low-temperature feldspars after G. VAN DER KAADEN, along with those of M. REINHARD.

I High-temperature migration curve ⎫
                                      ⎬ after G. VAN DER KAADEN.
II Low-temperature migration curve ⎭
III Migration curve of M. REINHARD.
IV Poles of the (010) composition face and the [010] twin axis examined by the author.

temperature types, the former characteristic of volcanic rocks and the latter of the plutonic and metamorphic rocks (A. KÖHLER (1941, 1949), H. TERTSCH (1942, 1950), F. LAVES and U. CHAISSON (1950), G. VAN DER KAADEN (1951), and others). The high- and low-temperature types are distinguishable from one another by their optical behaviour recognisable from the geometrical position of the "indicatrix" in the two types of crystals. Taking advantage of this important discovery, G. VAN DER KAADEN (1951) prepared new migration curves for the optical vectors, for the poles of the composition faces, and twin-axes of high- and low-temperature feldspars of different compositions so as to enable the estimation of their anorthite contents to be more accurately carried out than was hitherto possible with the curves of M. REINHARD (1931), who did not make a distinction between the high- and low-temperature types in his migration curves. Bearing this in mind, the author has shown in fig. 1 a the migration curves of the poles of the (010) composition face and in fig. 1 b the migration curves of the [010] twin axis of the high- and low-temperature feldspars after G. VAN DER KAADEN (1951), along with those of M. REINHARD. The poles of the (010) composition face and those of the [010] twin axis of the twins examined by the author, fall on the low-temperature migration curves in both the figures. These are characteristic of the plutonic and metamorphic rocks and suggest that the feldspars examined by the author in the several rock types of this region, belong to the low temperature type. The distinction between the two types of feldspars is, however, not well pronounced below 35% and above 65% anorthite content in the above figures 1 a and b, and for specimens falling into these domains the diagnosis is necessarily uncertain. A closer examination of the migration curves in the above figures reveals also that the author's points representing the poles of the (010) composition face and the [010] twin axis coincide more harmoniously with the migration curves of M. REINHARD (based on low temperature types) than with the curves of G. VAN DER KAADEN. The decision, however, which of the curves of the above two authors represent more appropriately the low temperature curves, must be left to future investigators. The number of thin sections examined and the number of poles plotted in the course of the present work are not sufficient to allow of any decisive conclusions by the present author.

The optical and extinction angles in the monoclinic pyroxenes and amphiboles met with in the different basic rock types of the five zones were determined by the methods of C. BURRI (1931, 1950) and F. J. TURNER (1942). In all the pyroboles examined by the author, the optical

plane is parallel to the clinopinacoid and offers no difficulties in the estimation of the optical and extinction angles. Since suitably oriented twinned individuals of the pyroboles were not always to be found in the rocks studied, the method of C. BURRI was usually followed. The extinction angles were determined by plotting the poles of the two sets of cleavages from sections which are not steeply inclined to the vertical "c" crystallographic axis of the crystal. The above method does not seem to be disadvantageous and yields results of comparable accuracy to those obtained by Turner's methods. The optical angles and the extinction angles given in the text of this thesis should not show an error greater than $\pm 2°$ and $1° 30'$ respectively as normally allowed in the U-stage measurements.

The refractive indices of the garnets were determined by the immersion method, and that of the liquid was measured in a hollow glass prism on a reflecting goniometer in sodium light. The probable accuracy of the refractive indices of the garnets is given in the text at appropriate places.

In the estimation of the probable compositions of the hypersthene, olivine, and garnet grains from their optical properties, the charts prepared by G. C. KENNEDY (1947) for correlation of optical properties with chemical composition of some common rock-forming minerals, were used.

The nomenclature adopted in this thesis is that proposed and discussed by P. NIGGLI (1924, 1948), and P. NIGGLI and R. L. PARKER (1954). The terms texture, structure, dynamic metamorphism, or destructive dislocation, or cataclastic metamorphism, porphyroclast, etc. are used in the same sense as defined by the above authors. Explanation of these and other definitions are not repeated here, and the reader is referred to the above standard texts for further information.

Previous literature

The present thesis is in the nature of a supplement to and extension of the field and petrographic observations already made by P. WALTER (1950). Besides the above research publication, the following contributions pertaining to the geology and petrology of the area were also consulted whenever a necessity for reference arose during the progress of the present work. CORNELIUS, H. P. and FURLANI-CORNELIUS, M. (1930), MITTELHOLZER, A. E. (1936), HUTTENLOCHER, H. F. (1942), KERN, R. (1947), ZAWADYNSKI, L. (1952), PARASKEVOPOULOS, G. M. (1953), DAL VESCO, E. (1953), BERTOLANI, M. (1954), WENK, E. (1953).

BERTOLANI examines in detail the petrography of the basic rocks of the Ivrea zone in the Italian part of the territory, and publishes a number of new chemical analyses made on the above basic rocks by the author.

Short geological and petrographical summaries of the different geological zones described in the thesis

1. Kinzigite zone

The kinzigite zone is supposed by some authors to belong to the "Seengebirge" or "Massiccio dei Laghi" of the Italian geologists, which constitutes the oldest crystalline formation of the entire area investigated in the present thesis. The zone consists of pelitic gneisses with concordantly enclosed masses of calc-silicate fels. The so-called "stronalites" of E. ARTINI and G. MELZI (1900) are not met with in the area examined. The zone is intruded both concordantly and discordantly by older as well as younger (late to post-Alpine) pegmatites. Besides the pegmatites, the zone also contains dikes, bands, and lenses of amphibolites which intruded the paragneisses more or less concordantly long after the zone attained its present grade of metamorphism.

By other authors among them the eminent Italian geologists S. FRANCHI (1905) and V. NOVARESE (1931) the kinzigite zone is supposed to form a genetic unit with the succeeding Ivrea zone, the two building up the so-called "zona diorito-kinzigitica-Ivrea-Verbano" of the Italian authors.

2. Ivrea zone

The zone consists mainly of a series of basic magmatic rocks ranging in composition from diorite-amphibolite to pyroxene-gabbro and norite. Peridotite and serpentinised peridotite are met with especially towards the northern margin of the zone. The different basic rocks encountered in the tunnel contain "kinzigite gneiss" inclusions of various sizes, on which they produced recognisable contact metamorphic effects. The basic rocks were again intruded by late to post-Alpine pegmatites both concordantly and discordantly. Some of the pegmatites are, however, regarded as representing late magmatic residual solutions of the basic magma, which gave rise to the different basic rocks of the zone. The age of the basic rocks is not yet well established. It could be anything between pre-Cambrian to Alpine. The basic rocks were subjected to severe cataclasis during the late to post-Alpine orogenic period.

3. Canavese zone

The zone consists chiefly of paragneisses, streaky-, spindly-, and Augen-gneisses, and injection-gneisses, in which are found enclosed lenses and bands of amphibolites tending to acquire a grade of metamorphism equivalent to the green-shist facies of P. ESKOLA (1920). The zone constitutes a single stratigraphical unit bounded by greyish-black dolomitic (?) limestone formations on its southern and northern margins.

4. Arcegno zone

The zone comprises paragneisses, ortho- and para-amphibolites and serpentinised peridotite. The ortho-amphibolites and the serpentinised peridotite intruded into the paragneisses after the latter had attained their present grade of metamorphism. This zone has no distinct stratigraphical boundary separating it from the succeeding Locarno zone.

5. Locarno zone

The zone consists primarily of two-mica-gneisses, stromatitic-, spindly-, augen-, injection-, and permeation-gneisses, pegmatites, and granitic stocks. The gneisses contain concordant inclusions of ortho- and para-amphibolites; the former intruded into the gneisses after the latter attained their present grade of metamorphism.

The Canavese, Arcegno, and Locarno zones are considered to belong to the "root zones" of the pennine nappes.

Acknowledgements

CHAPTER II

KINZIGITE ZONE

The formation met with immediately at the entrance to the tunnel of the Verbano Power Station is the kinzigite rock formation consisting principally of quartz, plagioclase feldspar, potash feldspar, and biotite with or without garnet and sillimanite. The entire zone has a width ranging from 2 to 5 km as recorded by V. NOVARESE (1931) in the Italian part of the territory, but its width decreases gradually towards the Swiss frontier to about 1.5 to 2 km. In the tunnel it is about 500 m in width. Besides kinzigite rocks, the zone comprises two-mica gneisses, and calc-silicate rocks, in which basic amphibolites are sometimes found as bands, lenses, and dikes. In the area under investigation the zone is divided into two parts.

a) Kinzigite zone proper with its calc-silicate bands and lenses and bands of basic amphibolites (0—460 m).

b) Transitional and contact zone lying in immediate contact with the southern margin of the Ivrea basic rocks (460—780 m).

The width in meters of the two parts is given in brackets and clearly indicated in the simplified geological profile (1).

The rocks of the two parts do not differ much from one another

except in the frequency of distribution and intensity of occurrence of garnet and/or sillimanite. The above two minerals or garnet alone are constantly present in the contact rocks while they are absent or present in subordinate amounts only in the kinzigite rocks.

The rocks of both the parts of the zone are described together in the following paragraphs and any differences observed between the two parts are mentioned in the text.

The colour index of the kinzigite rocks collected at different intervals varies from specimen to specimen depending on the relative proportions of the principal constituents, quartz, feldspar, and biotite. Violet-brown, greyish-brown, and chestnut-brown varieties are very common. Chestnut-brown biotite flakes, greyish-white grains of vitreous quartz and feldspar, and pink garnets are clearly visible in hand specimens. Thin seams of quartz or quartz and feldspar lying parallel to the shistose or gneissose planes disturb an otherwise uniform colour. The above seams range in width from less than a millimeter up to four to five millimeters, and attain a length of several centimeters. Often they pinch out in the gneissose planes after extending a short distance.

The rocks are holocrystalline, generally phanerocrystalline, massive, and compact with fine-medium- or coarse-grained varieties, the granularity of which varies from specimen to specimen. Even in the same specimen, the grain size[1]) is variable ranging from less than 1 mm upwards. Certain grains occasionally exceed 3 mm in their longer diameters. The texture of the rocks is uniformly gneissose.

Sometimes the frequency of distribution and intensity of occurrence of garnet increase noticeably in the kinzigite rocks at their immediate contacts with the basic amphibolites lenses and bands suggesting a possible contact-metamorphic action of the basic amphibolites on them.

Similarly, in the broad and narrow bands and lenses of kinzigite rocks within the transitional and contact zone, garnet is very frequently developed and may constitute a principal component.

The zone has been subjected to local dislocations producing kakirites or cataclasites. The cataclastic effects are microscopically clearly recognisable. At 67 m the dislocating movements produced a remarkably highly polished, glistening slickenslide.

The entire zone is injected and permeated by pegmatites and aplites both concordantly and discordantly. The age of some of these pegmatites is considered to be later than the metamorphism of the kinzigite rocks.

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[1]) Grain size measurements are as follows: less than 1 mm = fine-grained, between 1 mm and 3 mm = medium-grained, more than 3 mm = coarse-grained.

Section 1

Petrography of the kinzigite rocks

Three distinct groups of rocks are recognisable in this zone according to the microscopic examination of the thin sections. They will be referred to as A, B, and C (groups) of rocks.

GROUP A

comprises chiefly the following types:

1. Dark brown biotite-gneiss.
2. Sillimanite-biotite-gneiss.
3. Sillimanite-biotite-muscovite-gneiss.
4. Garnet-biotite-gneiss.
5. Garnet-sillimanite-biotite-gneiss.

The above types of rocks have a rather uniform qualitative mineralogical composition exhibiting slight variations in the relative proportions the various constituents.

P. C.[2]: Plagioclase feldspar > quartz > biotite.
S. C.: Garnet, sillimanite, muscovite, potash feldspar, corundum.
A. C.: Apatite, opaque ores, zircon, tourmaline, sphene, rutile.
A. P.: Sericite, chlorite, epidote.
Ff. C.: —

The total volume of the alteration products compared to the total content of fresh components is almost negligible. The following description of the optical characters of the individual constituents is valid for all the rock types of group A. The rock types pass into one another without showing any distinct line of demarcation of stratigraphical discontinuity. For example, the presence of sillimanite in type 1 gives rise to type 2. Similarly, the presence of garnet in some of the gneisses leads to the garnet-bearing types 4 and 5. However, the mineralogical characters of the principal components remain the same throughout the zone.

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[2]) Here and on the following pages the above letters have the following significance:

P. C. = Principal constituents.
S. C. = Subordinate constituents.
A. C. = Accessory constituents.
A. P. = Alteration products.
Ff. C. = Fracture-filling constituents.

Quartz: It is a constant mineral in all the rock types. Colourless. Xenoblastic. Slightly lenticular in shape. Grain size ranges from 0.02 mm to 0.4 mm. The finer grains are contained in the interstitial spaces between the larger grains. Though some of the grains are traversed by hair-thin cracks, turbidity and cloudiness or inclusions are generally absent. Most of them show distinctly recognisable undulose extinction but severe and widespread granulation is absent. Local and minor marginal granulation and suturing of the margins is clearly seen in those sections of rocks collected from near the southern margin of the Ivrea zone. In such cases, the finer grains form thin interstitial granular streaks between the larger plagioclase and quartz crystals. The total volume of quartz is variable in all the types, but does not as a rule exceed the volume of plagioclase feldspar. The thin leucocratic seams parallel to the gneissic planes are seen microscopically to consist of large grains of quartz often measuring up to 1.5 mm. Such crystals have simple outlines, and suturing and granulation are absent. The contacts of these seams with the adjacent gneiss are sharp. The seams appear to represent either thin layers of siliceous material crystallised as such or quartzose material recrystallised along the weak gneissic planes under conditions favouring metamorphic differentiation during or subsequently to the evolution of the kinzigite rocks to their present metamorphic grade.

Plagioclase feldspar: It is of variable composition, the anorthite content ranging from 20% to 45%. The crystals are colourless, xenoblastic, constantly twinned with polysynthetic twin lamellæ, oval, or slightly circular, or polygonal and equigranular in shape measuring from 0.03 mm to 0.8 mm. They are rarely sub-idiomorphic. Most of them have even and conserted margins against their neighbouring grains, but the arrangement of the biotite flakes around their rims gives them a false sutured appearance. Sometimes a crystal may be found partially or completely enclosed in a sheath of biotite flakes. In those sections in which quartz is found granulated, plagioclase feldspar also suffers granulation contributing a few granules to the interstitial granular streaks. Undulose extinction is not strong.

Potash feldspar: The mineral was detected in two sections of rocks collected at 466 and 630 m. In the former case it is a subordinate constituent, in the latter it appears as one of the principal minerals. In 630, the potash feldspar distinctly shows the typical cross-hatched appearance of microcline. The crystals are colourless, xenoblastic, slightly oval, or rhomboidal in shape. Marginal granulation, suturing of the margins, and separation of the granulated material from the mother

crystal are clearly seen. In both sections cauliflower-like myrmekite, not exceeding 0.05 mm in size, is developing in the interstitial granular streaks, at the expense of the potash feldspar.

Biotite: This mineral is the principal femic constituent occurring as tiny flakes with frayed-out terminations and not exceeding a maximum diameter of 0.2 mm. The flakes are sometimes randomly orientated and at other times show a sub-parallel to parallel arrangement giving rise to a distinct foliation. The pleochroic scheme corresponds to:

$$Y = Z = \text{reddish-brown}; \ X = \text{straw-yellow}.$$

The total volume of biotite is not greater than the volume of either plagioclase or quartz. Concentration of a number of parallel flakes along certain planes gives the section a distinctly layered aspect. In the types bearing sillimanite, the mineral is frequently seen in tufts and bundles of needles in the biotite layers. Biotite is rarely altered to pale green chlorite with the liberation of a few rutile grains along its cleavages.

Garnet: Two types of garnets are recognised in the sections examined. The first variety is seen in the kinzigite rocks proper, while the second type appears more frequently in the rocks of the contact zone as well as along the immediate contacts of the amphibolites with the kinzigite gneiss.

T y p e (a). The garnets are xenoblastic, light rose-pink in colour cometimes measuring up to 2 mm. Some of them tend to be sub-idio-morphic in outline. Amoeboid or poikilitic garnets are rare and almost absent. A few minute inclusions of opaque ores, biotite, and quartz may be seen occasionally. Two garnets from specimens 66 and 86 have the same refractive index, the value obtained being 1.802 ± 0.003. The garnets are evidently rich in almandine molecule with Fe very pre-dominant over Mg and Ca. The content of manganese does not seem to be very significant. Macroscopically they appear pink and are scattered randomly in the specimen.

T y p e (b). The garnets are light rose-pink in colour, but are paler than type (a). They are almost always xenoblastic, exhibiting amoeboid and spongy crystal shapes. They are always poikilitic enclosing quartz, plagioclase feldspar, biotite or chlorite, and opaque ore grains (see fig. 2). They appear to crystallise along the inter-granular boundaries of the original constituents. Various stages of crystallisation of the garnets, passing from a spongy and amoeboid crystal to a poikilitic crystal and ultimately to an almost non-poikilitic garnet can be seen even in the same section. Where the garnets enclose plagioclase feldspars poikilitic-

ally, the feldspars show clearly a certain degree of rounding of their marginal angularities. The enclosed plagioclase feldspars have the same composition as those of the other parts of the section. At 360 m at the immediate contact with the amphibolite, a number of sub-idiomorphic to idiomorphic garnets are developed in the kinzigite gneiss. This is no doubt due to the contact action of the amphibolite on the kinzigite under conditions of high temperature favouring the crystallisation of well formed crystals.
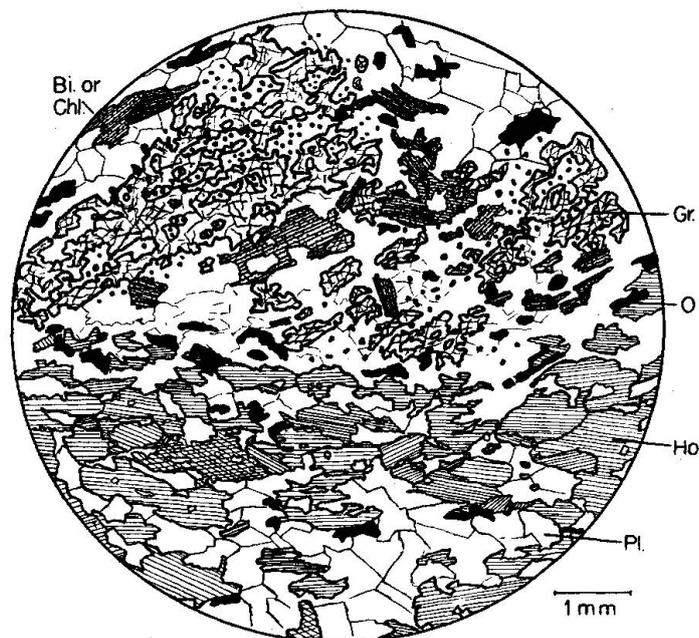
Fig. 2 (Section 700). Contact between an amphibolite band and a kinzigite inclusion of the contact zone.

Note the peculiar spongy and amoeboid habit of the garnets crystallising along the inter-granular boundaries of other minerals in the kinzigite rock. This indicates a marked contact metamorphic action of the amphibolite on the kinzigite.

As shown in fig. 2, at 700 m the garnets are peculiarly spongy in their crystal habit. The refractive index of this garnet is 1.778 ± 0.003. This value of "n" is less than that of type (a) suggesting that this garnet is slightly richer in magnesium. As the garnet encloses a few plagioclase feldspars, it should also contain a certain amount of calcium. It can be fairly surmised that the garnet is relatively rich in the alamandine molecule. The presence of numerous small grains of opaque ores (magnetite or ilmenite) in close association with the garnets suggests that the opaque ore grains may represent excess of iron left over after the crystallisation

of the garnets. The above differences in the crystal habit and optical characters of the two types of garnets are noteworthy, and they are no doubt significant as indicating that type (a) garnet developed simultaneously with the metamorphism of the kinzigite rocks, while type (b) crystallised subsequently and are due to the contact action of the amphibolites on the kinzigite rocks which are already in a state of meso- to kata-grade metamorphism.

Sillimanite: Colourless sillimanite occurs as thin bundles of needles or tufts of fine hair mostly associated with the biotite folia. Critical examination reveals that the dark brown or chestnut-brown biotite flakes form a base from the terminal margins of which the bundles and tufts of sillimanite spring into the surrounding matrix. Some of the sillimanite aggregates contain angular wisps and shreds of biotite and spongy opaque ores. The biotite flakes from which the sillimanite springs have their chestnut-brown colour bleached. This is clearly seen in sections (86, 176, and 208) of rocks collected at the contacts of the amphibolites and suggests the breaking up of biotite with formation of sillimanite.

Corundum: The mineral was recognised in one section only of a rock collected at the contact of an amphibolite at 360 m. It is colourless, xenomorphic measuring about 0.1 to 0.2 mm. About 4 or 5 grains are seen in the section and some of them contain fine needles of sillimanite as inclusions.

Muscovite: Muscovite is found only occasionally in parallel intergrowth with the biotite flakes.

Tourmaline: The mineral occurs as small usually fractured grains. The pleochroic scheme is: E = pale green; O = green with a brownish tinge.

Apatite, zircon, and opaque ores: They are constant accessories of these rocks. Minute grains of honey-brown rutile are seen along the cleavages of chlorite derived from the alteration of biotite.

The alteration products are not abundant. In one section (532), almost all the biotite is altered to chlorite, while the plagioclase feldspars show a certain degree of sericitisation. In spite of this, garnet and sillimanite do not show any alteration in the above section.

Structure

In group "A" rocks, only one type of structure prevails. The presence of sub-parallel to parallel flakes of biotite associated with a granoblastic quartz-feldspar mosaic gives the rocks a lepidoblastic-granoblastic structure.

In sections containing large porphyroblasts of garnet, the above structure tends to assume a porphyroblastic character.

GROUP B. ROCKS

Group B rocks are not met with in the hydroelectric tunnel. A microscopic examination of P. WALTER's sections (1950) revealed their presence in this zone in the Valle di Bordei along the southern contact of the Ivrea zone and in the neighbourhood of a stock-forming gabbro-amphibolite near Arolgia. Their mineralogical characters are interesting and they are described here to draw attention to the occurrence of these rock types in the kinzigite zone and to follow their metamorphic evolution along with the kinzigite rocks. The following rock types have been recognised:

Type (1). Biotite-staurolite-garnet-sillimanite-spinel-corundum-fels
           (397)[3].
Type (2). Biotite-cordierite-garnet-sillimanite-gneiss (426).
Type (3). Cordierite-garnet-sillimanite-staurolite-gneiss (440).
Type (4). Garnet-chlorite-biotite-staurolite-sillimanite-gneiss (449).
Type (5). Cordierite-biotite-staurolite-sillimanite-garnet-gneiss (434).
Type (6). Staurolite-biotite-sillimanite-garnet-gneiss (506).
Type (7). Garnet-biotite-sillimanite-cordierite-gneiss (1132).

Type (1). Biotite-staurolite-garnet-sillimanite-spinel-corundum-fels (397)

Hand specimen is not available. However, the section consists chiefly of reddish-brown biotite, golden yellow staurolite, pink garnet, and colourless sillimanite. Quartz and feldspars are almost absent.

The biotite flakes do not show any sub-parallel or parallel arrangement and do not exceed 0.1 mm in size.

Staurolite ranges in size from 0.05 mm to 0.3 mm and occurs as xenoblastic to sub-idioblastic prismatic crystalloblasts with poikilitic inclusions of minute angular grains of green spinel and rod-like opaque ore grains. All of them are traversed by numerous thin fractures.

Pink garnets measuring from 0.05 mm to 0.06 mm occur as xenoblastic to sub-idioblastic porphyroblasts. The larger porphyroblasts enclose biotite flakes, small grains of staurolite, green spinel, and highly refractive grains of corundum. Except as inclusions, spinel and corun-

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[3] Numbers in parentheses indicate the register numbers of the rocks and sections of WALTER's collection deposited in the Mineralogical Institute of the Swiss Federal Institute of Technology and the University of Zurich.

dum are not seen elsewhere in the section. Thin bundles of sillimanite needles are confined to the interstitial space between the staurolite and garnet grains.

Type (2). Biotite-cordierite-garnet-sillimanite-gneiss (426)

The specimen was collected in the uppermost part of the Valle di Bordei. The rock is greyish-brown, medium-grained with visible flakes of biotite, grains of garnet, and some feldspar. The texture is gneissic. Microscopically it consists of,

P. C.: Quartz > biotite > plagioclase feldspar ∼ cordierite > garnet.
S. C.: Sillimanite, staurolite.
A. C.: Apatite, zircon, opaque ores.
A. P.: Chlorite (Pennine) and sericite.

Colourless cordierite xenoblasts are predominant over quartz and plagioclase feldspar. The crystals show their characteristic wedge-like, patchy, and interpenetrating polysynthetic twin lamellæ and yellow pleochroic haloes around minute inclusions of zircon. Almost all the crystals are traversed by numerous thin fractures along which alteration is taking place into a pale green mixture of pennine and sericite, which forms an anastomosing net work of veins in an otherwise fresh-looking mineral association. The clear crystals have angular wisps and shreds of biotite and needles of sillimanite as poikilitic inclusions. The biotite flakes within the crystal are identical with those outside in the matrix.

Quartz occurs as colourless grains and is easily distinguishable from cordierite by its fresh appearance, the absence of pleochroic haloes etc.

· Plagioclase feldspar has a composition between oligoclase and acid andesine.

Chestnut-brown to reddish-brown biotite is randomly distributed all over the section and without any preferred orientation.

Light pink garnet occurs as porphyroblasts of various sizes occasionally measuring from 0.1 mm to 1 mm. The crystals enclose needles of sillimanite, opaque ore grains, and angular grains of golden yellow staurolite poikilitically. Except as inclusions in garnet, staurolite does not occur in the section.

Bundles of needles and tufts of hairs of colourless sillimanite occur interstitially between the other constituents. Tiny wisps and shreds of biotite are often seen associated with the sillimanite bundles and give them a brownish colour.

Type (3). Cordierite-garnet-sillimanite-staurolite-gneiss (440)

The section contains:

P. C.: Cordierite ∼ plagioclase feldspar > garnet > chlorite.
S. C.: Biotite, sillimanite, staurolite, quartz.
A. C.: Apatite, zircon, opaque ores.
A. P.: Pennine, sericite.

The constituents are similar to those described in type (2). Their relationships to one another are as follows.

Cordierite and plagioclase feldspar are predominant over the other constituents and are present in equal proportions. Some of the large garnet porphyroblasts enclose wisps of biotite, tiny flakes of chlorite, colourless but slightly altered grains of cordierite, a few angular grains of staurolite and opaque ores.

The proportion of staurolite is considerably reduced and a very few minute grains with broken-up margins were recognised in a pale green spongy mesh-work of chlorite. A few sillimanite needles are also seen in the chlorite meshes along with staurolite.

An interesting feature of the section is the presence of well crystallised sheafs of green flakes of chlorite often showing a fan-shaped arrangement. Sometimes such chlorite flakes have developed along cracks or around the margins of the garnet porphyroblasts. Most of this chlorite seems to have been derived from the alteration of biotite and it is not improbable that some garnet could have also suffered alteration to chlorite under conditions of retrogressive metamorphism.

Type (4). Garnet-chlorite-biotite-staurolite-sillimanite-gneiss (449)

The specimen was collected in the uppermost part of the Valley of Bordei and is designated as a contact fels. The rock is somewhat greyish-white, medium- to coarse-grained with visible pink garnets, feldspar, quartz, and a few biotite flakes. Microscopically it consists of,

P. C.: Quartz ∼ plagioclase feldspar > garnet ∼ chlorite.
S. C.: Cordierite > staurolite ∼ biotite ∼ sillimanite.
A. C.: Apatite, zircon, opaque ores.
A. P.: Chlorite, pennine, sericite.

Fig. 3 gives a general idea of the arrangement of the various constituents. Quartz and plagioclase feldspar predominate over the other constituents and occupy about half the total volume of the rock. Cordierite is much reduced in volume and occurs only as a subordinate constituent.

Biotite is reddish-brown in colour and is randomly distributed all over the section without showing any parallel arrangement. Porphyroblastic garnets attain a size of over 1 mm and poikilitically enclose opaque ores, biotite, chlorite, staurolite, cordierite, and quartz. Staurolite occurs as small angular grains in a mesh-work of fine scales of chlorite. As in
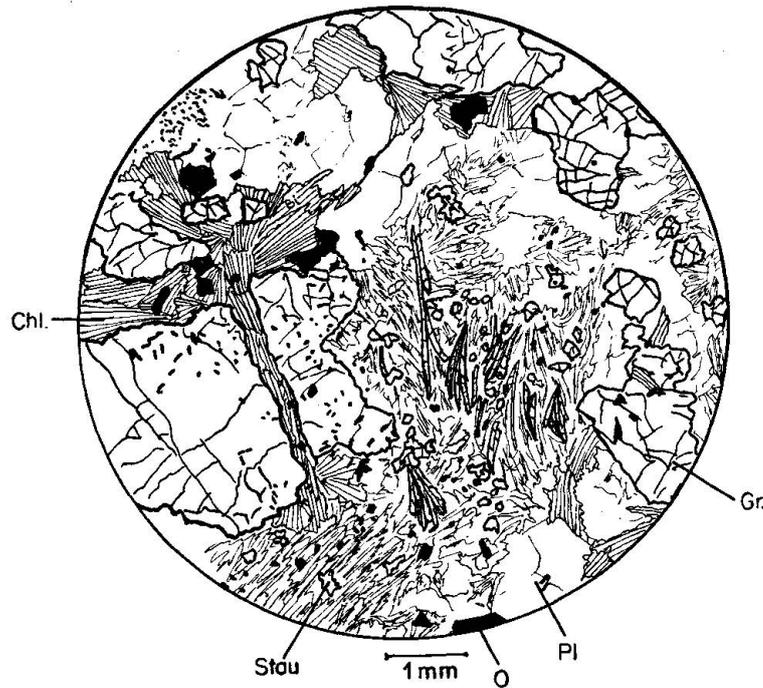
Fig. 3. (Section 449 of WALTER's collection). Garnet-chlorite-biotite-cordierite-staurolite-sillimanite-gneiss from the upper part of the Valley of Bordei west of Arolgia.

Note the formation of fan-shaped flakes of chlorite around the garnet crystals and the presence of broken-up and angular grains of staurolite in a micaceous mesh work of chlorite along with a few long needles of sillimanite indicating retrogressive metamorphism. Cordierite is seen elsewhere in the section.

type (3), green chlorite builds fan shaped sheafs along the fractures and around the margins of garnet grains. Most of it seems to have been derived from the alteration of biotite and from garnet.

Type (5). Cordierite-biotite-staurolite-sillimanite-garnet-gneiss (434)

The specimen was collected in the uppermost part of the Valle di Bordei. It is somewhat greyish-brown in colour, medium- to coarse-grained with visible pink garnets, brown biotite, feldspar, and quartz. It consists of,

P. C.: Cordierite ~ staurolite ~ garnet ~ biotite ~ sillimanite.
S. C.: Plagioclase feldspar, quartz.
A. C.: Apatite, zircon, opaque ores, spinel, corundum.
A. P.: Chlorite, sericite, pennine.

All the principal constituents are represented in more or less equal proportions, while quartz and plagioclase feldspar (basic oligoclase to acid andesine) are present in relatively subordinate amounts.

Cordierite is similar to that in types (2) and (3). Staurolite is in the process of being converted into a scaly mesh-work of pale green chlorite and almost all the grains show angular and broken margins. Light pink garnets are present as porphyroblasts measuring up to 1.5 mm and over and poikilitically enclose opaque ores, biotite, chlorite, staurolite, and cordierite. Sillimanite needles are dispersed interstitially all over the section as thin bundles. A few staurolite grains are still seen enclosing minute grains of green spinel. Reddish-brown biotite is here and there altering to green chlorite. Except in the relative proportions of the various constituents, the section is similar to types (2), (3), and (4).

Type (6). Staurolite-biotite-sillimanite-garnet-gneiss (506)

A specimen collected in the uppermost part of the Valle di Bordei is dark brown in colour, medium- to coarse-grained, with visible pink garnets, dark brown biotite flakes, and somewhat brownish staurolite grains. The section consists of,

P. C.: Staurolite, biotite, sillimanite.
S. C.: Garnet.
A. C.: Opaque ore grains, apatite, tourmaline, corundum(?).

The section is somewhat similar to rock type (1). Staurolite and biotite are predominant over the other constituents, and are optically similar to those described in type (1). Colourless sillimanite in bundles of needles occurs interstitially between the other constituents. The light pink garnet is present as xenoblastic and poikiloblastic porphyroblasts enclosing numerous wisps of biotite and minute grains of staurolite. It shows a remarkably "sieved appearance" and suggests that it is in the process of formation from the original constituents of the rock.

Opaque ores are present rather abundantly and are distributed all over the section, especially in and around staurolite grains.

Type (7). Garnet-biotite-sillimanite-cordierite-gneiss or -fels (1132)

The specimen comes from the uppermost part of Alpe di Voiée and is designated as contact fels. The rock is somewhat greyish in colour, medium-grained with visible pink garnets, biotite, quartz, and feldspar. In thin section it consists of,

    P. C.: Quartz, plagioclase feldspar, biotite, garnet, sillimanite.
    S. C.: Cordierite, staurolite.
    A. C.: Opaque ore grains, apatite, zircon, tourmaline.

Quartz and plagioclase feldspar with the composition of oligoclase to acid andesine are predominant over the other constituents. They are similar to those observed in the rocks of the kinzigite zone. Light rose-pink garnet builds xenoblastic porphyroblasts measuring occasionally over 0.8 mm in size. The mineral encloses biotite, sillimanite, quartz, plagioclase feldspar, and sometimes one or two grains of staurolite. Except as rare inclusions in garnet, staurolite is not seen elsewhere in the section. Sillimanite occurs as bundles of needles or fibres scattered all over the section. Cordierite is present only in subordinate amounts.

Structure

The rocks all show a granoblastic structure. Presence of large porphyroblasts of garnet in some of the types gives these a porphyroblastic structure, with a granoblastic matrix. From the preceding petrographic description it is evident that group (B) rocks have a distinctly high aluminium content with appreciable amounts of magnesium and iron. During the metamorphism of these sediments Al-Mg-Fe-rich minerals like staurolite, cordierite, sillimanite, garnet, spinel, and corundum were generated. From the presence or absence of each of the constituent minerals and from the grade of metamorphism, three phases of metamorphic evolution of these rocks can be deciphered.

The first phase of evolution is represented by rocks 397 and 506, in which staurolite and biotite with accessory amounts of corundum and spinel are predominant. Sillimanite is present here and there, while garnet and cordierite are almost absent or present in insignificant amounts. The very few garnet grains show a "sieved appearance" due to the presence of a number of inclusions of staurolite, biotite, opaque ores, and, occasionally, spinel and corundum. This suggests that the garnet is being formed out of the other constituents as a result of progressive metamorphism.

Specimens 426, 434, 440, and 1132 belong to the second phase. Cordierite and garnet build large porphyroblasts enclosing angular grains of staurolite, needles of sillimanite, frayed-out wisps, and shreds of biotite, a few opaque ores, and, sometimes, spinel and corundum. Garnets no longer show a sieved appearance as in phase one. Both staurolite and biotite are in the process of decomposition, and the proportion of staurolite is very much reduced. The mineral occurs only as minute angular grains scattered here and there.

The third phase is represented by 449. The specimen contains abundant chlorite besides cordierite, garnet, and sillimanite. Most of the chlorite is well crystallised and seems to have been derived from the alteration of biotite. It is not improbable that some of the garnets may also have been decomposed and have contributed to the formation of chlorite. The latter frequently forms a rim around a few of the garnet grains possessing irregular, angular, and frayed-out margins (see fig. 3). The few minute staurolite grains present are seen in a mesh-work of fine and pale green chlorite scales. All these observations tend to suggest that the rock suffered retrogressive metamorphism subsequent to the attainment of a kata-facies in its mineral assemblage.

GROUP C

Lenses and bands of calc-silicate fels concordantly enclosed in the kinzigite rocks and with gradational contacts towards the latter, belong to this group. They range in width from a few centimeters to a few meters in the field but as encountered in the tunnel do not exceed generally more than 5 m. Macroscopically they are medium-grained, mottled white and green in colour and consist of visible grains of calcite, green pyroxene, hornblende, quartz, plagioclase feldspar, and a few grains of pyrite. Microscopic examination of a few thin sections revealed the following mineralogical characters:

P. C.: Calcite, plagioclase feldspar, quartz, scapolite, diopside, hornblende.
S. C.: Diopside, hornblende, epidote.
A. C.: Sphene, apatite, opaque ores, graphite.
A. P.: Clinozoisite, sericite.

The principal constituents are variable in their relative proportions. For example, abundant scapolite is seen only in section 638, in which

plagioclase feldspar becomes a subordinate constituent. In some of the sections examined, both diopside and hornblende constitute principal minerals, while in others they occur as subordinate components. Graphite is seen as thin worm-like rods scattered all over the sections. Plagioclase feldspar is labradorite in composition, the anorthite content reaching a maximum of 70%. Sphene is an abundant accessory constituent, while both epidote and clinozoisite are scattered randomly in the sections.

Besides the calc-silicate rocks found in the kinzigite rocks proper, a thin band of calc-silicate-fels measuring about 2 cm in width was found concordantly enclosed in the amphibolites at 530 m (contact zone). Its contacts with the amphibolites are sharp and the rock is mottled greyish-green. Light pink garnets are clearly visible in the calc-silicate band, while they are absent in the amphibolite. Microscopically the section contains the same minerals as described in the preceding paragraph. However, amoeboid garnets here represent one of the principal constituents and are scattered all over the section. Along the entire contact with the calc-silicate rock, the opaque ore grains of the amphibolite have altered to brownish sphene forming pseudomorphs after the original crystal habit of the ore. At a slight distance from the contact, no such alteration of the ore grains is recognisable in the amphibolite. This suggests that the amphibolite absorbed a certain amount of calcareous material along its contact at the time of its intrusion. The formation of amoeboid garnets in this calc-silicate fels is believed to be due to two factors:

1) The original composition of the calc-silicate fels at 530 m differed somewhat from that of the other calc-silicate fels, and probably contained a higher proportion of aluminium.

2) The intrusion of the amphibolites and its subsequent inclusion in them supplied the necessary temperatures to cause reactions among the constituents.

The amoeboid garnets would thus seem to be due to contact metamorphism.

Chemical composition of the kinzigite rocks

In the following table (1) two old analyses and four new analyses of the kinzigite rocks, along with their Niggli values, are given.

Table (1)

Analyses	a	b	c	d	e	f
SiO_2	54.15	59.91	70.34	60.84	66.36	44.52
Al_2O_3	27.38	20.35	16.11	14.86	16.84	33.91
Fe_2O_3	1.37	1.21	0.36	2.35	2.25	4.93
FeO	4.65	4.83	3.10	7.70	5.22	7.31
MnO	—	0.08	0.05	0.09	0.12	0.09
MgO	2.80	3.33	1.13	3.62	2.87	3.31
CaO	1.42	1.47	1.74	1.86	0.62	1.26
Na_2O	1.12	2.61	3.32	4.31	2.17	0.63
K_2O	4.59	3.85	2.31	2.48	1.04	0.71
$+H_2O$	0.95	1.65	0.92	1.21	1.86	2.93
$-H_2O$	0.16	—	0.04	—	—	0.24
TiO_2	1.31	1.11	0.31	0.71	0.77	0.79
P_2O_5	—	0.06	—	—	—	—
others (S)	—	—	—	0.20	0.26	—
Total	99.90	100.46	99.73	100.23	100.38	100.63
−O	—	—	—	0.13	—	—
				100.10		

Niggli values

	a	b	c	d	e	f
si	176	210	347.6	206.8	284.6	118.7
al	52.5	42	46.9	29.6	42.5	54.7
fm	29.5	35	21.1	44.3	42.8	38.9
c	5	5.5	9.2	6.7	2.9	3.6
alk	13	17.5	22.8	19.4	11.8	2.8
ti	3.1	2.9	—	1.9	2.3	3.0
k	0.73	0.49	0.31	0.27	0.24	0.41
mg	0.46	0.50	0.39	0.41	0.43	0.36

Analysis a) Garnetiferous-sillimanite-gneiss. The rocks consists of quartz, orthoclase, oligoclase, biotite, muscovite, sillimanite, garnet as its chief constituents. Rutile and zircon are the accessory minerals. Locality: near Ronco. Analyst: L. HEZNER (quoted from Beiträge zur Geologie der Schweiz. Geotechnische Serie XIV, Chemismus schweizerischer Gesteine, p. 188, No. 123 (1930).

Analysis b) Staurolite-andalusite-biotite-gneiss. Locality: Piodina near Brissago. Analyst: H. SCHUMANN (quoted from the same source as above, p. 188, No. 120).

Analysis c) Stronalite. Locality: Massera. Analyst: M. BERTOLANI. Rendiconti Soc. Min. Italiana, X, p. 184, No. 13 (1954). The rock consists of quartz, biotite, garnet, sillimanite, plagioclase, orthoclase, zircon, muscovite, and chlorite.

Analysis d) Biotite-gneiss from between Casarole and Massera. ibid. No. 11n. p. 184 (quoted after M. BERTOLANI). The rock consists of biotite, oligoclase, quartz,

orthoclase, and garnet as its chief constituents and zircon and apatite as accessory minerals.

Analysis e) Sillimanite-gneiss. Locality: Salaro river. Ibid. No. 15, p. 184 (quoted after M. BERTOLANI). The rock consists of quartz, oligoclase, orthoclase, biotite, garnet, and sillimanite as its chief components and zircon, rutile and pyrite as accessory minerals.

Analysis f) Sillimanite-schist. Locality: under the ridge between the Valle Sabbiola and the Valle Bagnola. Ibid. No. 30, p. 184 (quoted after M. BERTOLANI). The rock consists of quartz, biotite, garnet, sillimanite, andesine, and muscovite as its chief constituents, while zircon, apatite, graphite, ilmenite, and epidote occur as accessory constituents.

All the six analyses contain a high proportion of alumina and alkalies, and rather low content of calcium and magnesium. The total amount of iron is somewhat variable the value being greatest in analysis f. The same analysis has a relatively low content of silica and alkalies compared to the other analyses. In analyses a, b and f, the proportion of alumina is rather high, while in the rest of the analyses it is not too low. The values given in table (1) indicate that the kinzigite rocks show a certain degree of variation in their total chemical composition, but are generally rich in silica, alumina, and alkalies, and poor in calcium and magnesium. This indicates that the kinzigite rocks are pelitic sediments rich in alumina.

Discussion and summary of observations

Three principal groups of sedimentary rocks were recognised in the kinzigite zone. Group (A) rocks represent normal pelitic sediments, those of group (B) Al-Mg-Fe-rich sediments, while the group (C) rocks derive from calcareous and marly sediments.

The kinzigite gneiss of the tunnel is divided into two parts: (a) kinzigite zone proper from 0 to 460 m, and (b) transitional and contact zone from 460 to 800 m. Though the rocks of the two parts of this zone are macroscopically similar, they show slight differences in the nature of their garnets under the microscope. These differences are described and it is concluded that the spongy and amoeboid garnets of the contact zone are developed later than the metamorphism which changed the pelitic sediments into kinzigite gneiss, and are due to the contact action of the amphibolites of the contact zone on the adjacent gneiss. It is also recognised that along the immediate contacts with the basic amphibolite bands and lenses, garnet and/or sillimanite are more frequent in the kinzigite rocks. This phenomenon is attributed to the contact metamorphic action of the amphibolites on the kinzigite rocks.

Attention has been drawn to the occurrence of sediments of group (B) rich in Al-Mg-Fe elements. These rocks show a certain degree of progressive metamorphism, but it is not clearly discernible to what extent the basic rocks of the Ivrea zone or the basic amphibolites in the neighbourhood of Arolgia have contributed to the present grade of metamorphism. It can be stated, however, that some of the rock types of group (B) suffered minor retrogressive metamorphism after they attained a kata-facies in their mineral assemblage.

The calcareous sediments are intercalations in the kinzigite gneiss. They exhibit a simple mineralogical composition. At 530 m the calcareous inclusion caught up as a xenolith in the amphibolite, contains amoeboid garnets as one of its principal constituents. The development of the garnets is regarded as due to the contact metamorphic action of the amphibolite of the inclusion which probably contained a sufficient amount of Al to favour the crystallisation of that mineral. The amphibolite in turn absorbed some calcareous material along its contact so that opaque ore grains have altered to leucoxene and sphene.

All the three groups of rocks are subjected to a minor degree of cataclasis, probably, during the period of destructive dislocation metamorphism affecting the Ivrea basic rocks.

Section 2

Basic rocks (amphibolites) of the kinzigite zone

All the basic dikes, bands, and lenses found enclosed more or less concordantly in the kinzigite rocks in the tunnel are hornblende-plagioclase amphibolites in their mineralogical composition. As far as 460 m in the tunnel, these lenses and bands range in width from a few centimeters to 8 to 20 m. Beyond this point they increase in their width and grade gradually into the Ivrea basic rocks. They are met with in the tunnel at 87, 90, 120, 147, 210, 253, 302, 330, 360, 380, and 392 m. The following description gives a general idea of the macroscopic characters of these rocks as they are encountered from 0—800 m.

All the amphibolites are green to dark green rocks, sometimes with a mottled appearance due to the presence of visible leucocratic feldspar grains. They are holocrystalline, phanerocrystalline, fine- to medium-grained types, and the grain size does not, as a rule, exceed 3 mm. However, amphibolites found at 127 m and 212 m are rather coarse-grained and the grain size frequently exceeds 3 mm. With the exception of these

two amphibolites, all possess a uniform fabric with the hornblende prisms exhibiting a certain degree of parallel orientation giving rise to visible lineation. Amphibolites at 127 and 212 m are, on the other hand, massive with a random texture and the hornblende prisms are large enough to show macroscopic cleavages in reflected light. The amphibolite at 360 m contains some light pink garnets (over 1.5 mm in size) about 1½ cm away from its contact with the adjacent kinzigite. Elsewhere garnet is not seen as a constituent of these amphibolites.

The contact between the amphibolites and the kinzigite gneiss is always sharp and without gradations. As already discussed in section (1), the amphibolites produced under favourable PTX conditions recognisable contact-metamorphic effects on the adjacent kinzigite gneiss.

They are traversed by thin fractures, which are often healed by chymogenic pale green epidote and/or chlorite. Severe cataclasis is not apparent.

PETROGRAPHY OF THE BASIC ROCKS

The petrography of the basic rocks as described in the following paragraphs leads to the recognition of several types on the basis of their mineralogical composition and structures.

Type (1). (Banded type)

The amphibolite at 87 m contains a dike-like band of uniform thickness, of 1.5 m, somewhat greyish-green in colour and apparently produced by injection. The mineralogical compositions of the amphibolite and the thin band are as follows:

Amphibolite

P. C.: Plagioclase feldspar > hornblende ≫ biotite > quartz.
A. C.: Apatite, opaque ores, zircon, epidote.
S. C.: Quartz, biotite.

The grain size of the principal constituents ranges from 0.1 mm to 0.4 mm.

Plagioclase feldspar: An % = $80 \pm 5\%$. Colourless and xenomorphic. Undulose extinction and marginal granulation absent.

Hornblende: Xenomorphic to sub-idiomorphic. Pleochroic scheme: X = pale straw-yellow; Y = green; Z = green with a brownish tinge; $c/Z = 15°$.

The coloured variety of hornblende is accompanied by a colourless

variety. Sometimes the latter forms a rim or a terminal overgrowth over the former, or a single hornblende prism may show patches of the coloured and colourless varieties together, or in parallel intergrowth. In several instances, no distinct line of demarcation between the two varieties can be recognised. The cleavages of one pass into the other without any break in their continuity. Extinction is sometimes simultaneous in both, sometimes at different positions. The colourless variety gave an extinction angle of $c/Z = 14°$. The number of colourless prisms of hornblende is very small compared to the volume of the coloured variety.

Biotite: Dark brown to pale brown biotite flakes form a rim around or project across the margins of the hornblende prisms.

Band

P. C.: Plagioclase feldspar ≥ hornblende > quartz(?).
S. C.: Quartz, biotite.
A. C.: Apatite, opaque ores, epidote.
The grain size is always less than 0.1 mm.

Plagioclase feldspar: The mineral is xenomorphic to sub-idiomorphic and occurs as equigranular grains. $An = 68 \pm 4\%$.

Hornblende: The prisms are sub-idiomorphic to idiomorphic and have the same optical characters as in the amphibolite. The number of colourless hornblende grains is greater than in the amphibolite. They show the same relationship to the coloured variety as in the previous case.

Biotite does not occur in this band. Among the accessory constituents, apatite is more abundantly present than in the amphibolite and is uniformly scattered all over the band.

The contact between the two is sharp and chilling or reduction in grain size of the constituents along the contact are not visible.

Both in the amphibolite and in the band, the structure is distinctly nemato-granoblastic to granoblastic.

Type (2)

The basic rock met with at 127 m and corresponding in composition to that of a hornblende-plagioclase amphibolite belongs to this type. Three specimens were collected from the same band at 125, 127, and 128 m. Specimens 125 and 128 represent marginal facies, while 127 represents the central facies of the amphibolite.

The petrography of the central facies is as follows. The rock is medium- to coarse-grained, exhibits a random texture, and shows the following mineralogical composition:

P. C.: Hornblende $\geq$ plagioclase feldspar.
A. C.: Sphene > opaque ores > apatite.
A. P.: Chlorite $\sim$ sericite $\sim$ epidote.
Ff.C.: Calcite, epidote.

Hornblende. The mineral is a pale green variety showing the following optical properties. Pleochroic scheme: X = pale green; Y = pale green; Z = straw-yellow to almost colourless; $(-)2$ V = 88°; c/Z = 12°.

The above optical data correspond to those of a hornblende belonging to the tremolite-actinolite group. The prisms are xenomorphic with distinct cleavages and measure from less than 0.5 mm to over 2 mm. Large prisms are proportionately more frequent than the number of small ones measuring less than 0.5 mm.

The prisms enclose poikilitically a number of plagioclase feldspar crystals, irregular and rod-shaped grains of opaque ores (ilmenite) and sphene. The opaque ores, especially ilmenite, form thin rods or granular streaks aligned parallel to the cleavages. In several instances, the ore grains both within and outside the prisms have altered to xenomorphic or hypidiomorphic sphene in pseudomorphs after their original crystal habit. Several instances showing partial alteration of the ore grains to sphene can be seen in the section.

The hornblende prisms are generally fresh. They are sometimes traversed by thin fractures, along which occur fan-shaped sheafs of pale green chlorite and/or a few colourless calcite grains and/or colourless epidote. The proportion of chlorite, calcite, and/or epidote is low compared to the volume of fresh hornblende.

Plagioclase feldspar. It is colourless, fresh, free of cloudy inclusions, xenomorphic to hypidiomorphic, and is traversed by thin fractures here and there. The crystals often project into the hornblende prisms simulating a sub-ophitic relationship. They also occur either poikilitically enclosed in the hornblende prisms or interstitial to them. The composition is that of an acid bytownite (An = 76%).

Sphene is an abundant accessory constituent. The section is traversed by thin fractures which have been healed by chlorite and/or epidote. Large scale cataclasis is absent.

The relationship between the hornblende prisms and the plagioclase feldspar is in the main intergranular and of poikilitic type though some

instances of intra-granular implication fabric were also observed. (See fig. 4.)

The two specimens 125 and 128 representing the southern and northern marginal facies are similar to one another in their mineralogical composition and structure. In both one can recognise a perceptible degree of parallel orientation of the hornblende prisms. The rocks consist of,

P. C.: Plagioclase feldspar ~ hornblende > biotite or chlorite.

A. C.: Apatite, opaque ores, sphene.

A. P.: Chlorite.
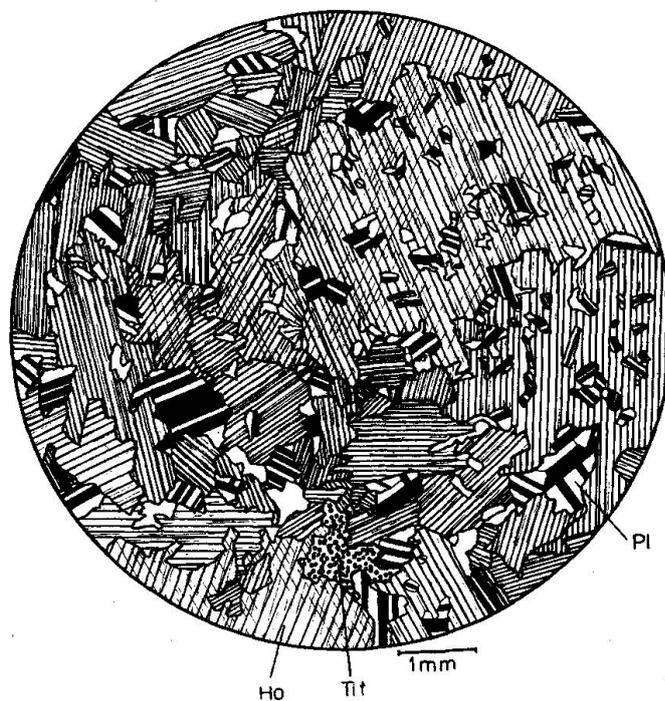
Fig. 4 (Section 127). Amphibolite (type 2) showing an intra- to intergranular (poikilitic) structure.

Note the random orientation of the hornblende prisms suggesting a direct crystallisation of the hornblende from a magmatic melt rather than recrystallisation of a basic plutonic rock due to metamorphism (+ nicols).

The grain size of the constituents is not more than 0.5 mm and the rocks are decidedly finer-grained than 127. This suggests that they may represent slightly chilled or rapidly-cooled varieties of 127. However, the anorthite content is different in each of the above rocks. In 125, it is about 47% and in 128, 80%.

Specimen 128 has more or less the same anorthite content as the

central facies, 127. The relatively low anorthite content of the plagioclase feldspar in 125 is not clearly understood. It may perhaps represent a subsequent recrystallisation or differentiation of the original rock mass along its southern margin.

Both plagioclase feldspar and hornblende prisms are xenomorphic to sub-idiomorphic in their crystal habits. Hornblende has the following optical properties. Pleochroism: X = straw-yellow; Y = green; Z = green. (125): (−)2 V = 86°; c/Z = 15°. (128): (−)2 V = 76°; c/Z = 15°.

The optical properties of the hornblende prisms suggest that they belong to a type intermediate between the Ca and Mg-rich tremolite-actinolite series and the Mg-rich common hornblende series. Neither feldspar nor hornblende shows any signs of alteration.

Brown biotite, a rare constituent in 127, may also occur more plentifully in these rocks. Most of the flakes have altered into pale green chlorite with the liberation of honey-brown grains of rutile. Sphene is an accessory constituent, but not so abundant as in 127.

The structures of 125 and 128 are entirely different from that of 127. Instead of the intergranular implication structure described, they exhibit a fine-grained nemato-granoblastic structure.

Type (3)

Specimens collected from 96, 208, 212, 367, 380, 387, 530, 700, and 730 belong to this type. With the exception of amphibolite 212, which exhibits a massive and random texture, the rest of the amphibolites show a certain degree of parallel arrangement of the hornblende prisms giving rise to visible lineation. Microscopically they consist of,

P. C.: Plagioclase feldspar ∼ hornblende ≫ biotite.
A. C.: Apatite > sphene ∼ opaque ores (zircon).
A. P.: Chlorite, epidote.
Ff. C.: Chlorite and/or epidote.

Table 2 gives a general idea of the anorthite content of the feldspars and the optical and extinction angles of the hornblende prisms in the different amphibolites. In all the sections examined, the hornblende prisms show the following pleochroism: X = straw-yellow to pale yellowish-brown; Y = green; Z = green with a brownish tinge.

The plagioclase feldspar is colourless, fresh, free from inclusions, and rarely altered to sericite. The crystals are xenomorphic, exhibit polysynthetic twinning, and occur interstitially between the hornblende prisms. Marginal granulation and undulose extinction are observed in

Table 2

No. of the section	Percentage of anorthite in plagioclase	(−)2 V of hornblende	c/Z of hornblende
96	34%	78°	15°
208	82%	79°	17°
212	83%	78°	16°
367	62%	82°	15°
380	58%	—	—
387	29%	73°	15°
530	70%	76°	16°
700	75%	76°	17°
730	38%	76°	18°

sections 700 and 730 of specimens collected from the broad amphibolite bands of the contact zone. The anorthite content is variable. In sections 208, 212 (representing the marginal and central facies respectively of one single band of amphibolite), in 700, and in 530, the plagioclase lies between basic labradorite and acid bytownite. In sections 367 and 380 the composition is that of an intermediate labradorite, while in 96 and 730 of the contact zone the composition corresponds to that of an intermediate andesine. The lowest anorthite content is found in 387 and the plagioclase corresponds to a basic oligoclase.

The optical properties of the hornblende are more uniform than the anorthite content. The range of variation in the optical angles and extinction angles is not so great as to warrant a discussion. The optical data suggest that the hornblende is a slightly aluminiferous type intermediate between the actinolite-tremolite series and the common hornblende series tending more towards the latter. The prisms are xenomorphic to sub-idiomorphic and frequently contain thin needles of ilmenite either aligned parallel to the cleavages or randomly distributed. Marginal granulation is seen only in the hornblende prisms of the contact rocks (700 and 730). In general they are fresh without showing any large-scale alteration to chlorite or epidote.

It should be mentioned that the macroscopically visible orientation of the hornblende prisms is also seen under the microscope in all the sections except in 212, in which they have random orientation.

In several of the above sections brown biotite is always developed around and across the margins of the hornblende prisms. It is not uncommon to observe a sheath of biotite flakes forming a rim around a hornblende prism, suggesting the genesis of the former as a peritectic

reaction mineral from the latter, a case very commonly recognised in rocks of liquid magmatic origin.

In a few instances, the biotite is altered to pale green chlorite with the liberation of honey-brown grains of rutile, the original relationship to hornblende being maintained.

Both apatite and sphene are abundant accessory constituents especially in sections 212, 700, and 731.

In all the amphibolites, except 212, the structure is nemato-granoblastic.

In 212 the structure is xenomorphic- to hypidiomorphic-granular.

In sections 700 and 730, owing to a certain degree of cataclasis, the nemato-granoblastic structure assumes a slightly cataclastic nature.

Type (4)

A specimen collected from the amphibolite at 360 m represents this type. The rock differs neither macroscopically nor microscopically from type (3). The anorthite content in the plagioclase feldspar is about 62% corresponding to the composition of an intermediate labradorite. The hornblende prisms have the following optical properties: X = straw-yellow; Y = green; Z = green with a brownish tinge; $(-)2\,V = 81°$; $c/Z = 15°$.

The above optical properties are very similar to those found in type (3).

The only interesting difference is that that the section of this amphibolite contains some light pink garnets measuring about 2 to 4 mm, close to the contact with the kinzigite rocks. The garnets are light rose-pink in colour, subhedral to almost euhedral in habit, traversed by thin parallel parting planes or fractures, and enclose poikilitically a few green prisms of hornblende (which are similar to those outside the garnets), opaque ores, and occasionally small grains of plagioclase feldspar (see fig. 5). The garnets do not seem to be undergoing disintegration into plagioclase feldspar and hornblende. The refractive index of the garnet is 1.778 ± 0.003. This value of n is equal to that of a garnet forming at the contact of the amphibolite within the kinzigite at 700 m (see page 85) indicating that the composition in the present case is also that of a type rich in the almandine molecule, i. e. $Fe > Mg > Ca$. To prove the hypothesis that they are formed in the amphibolite subsequent to the formation of hornblende and plagioclase feldspar, the circle inset in fig. 5 is further enlarged in fig. 6 to bring out clearly the relationship between the garnet and the original constituents of the amphibolite.

It is clearly seen in fig. 6 that the hornblende prisms within the garnet exhibit somewhat rounded margins, and that a thin tentacle-like arm of the garnet embraces and gradually engulfs a near-by prism of hornblende. This indicates that the garnet is engaged in crystallisation rather than in disintegration. The nearness of the garnets to the contact with
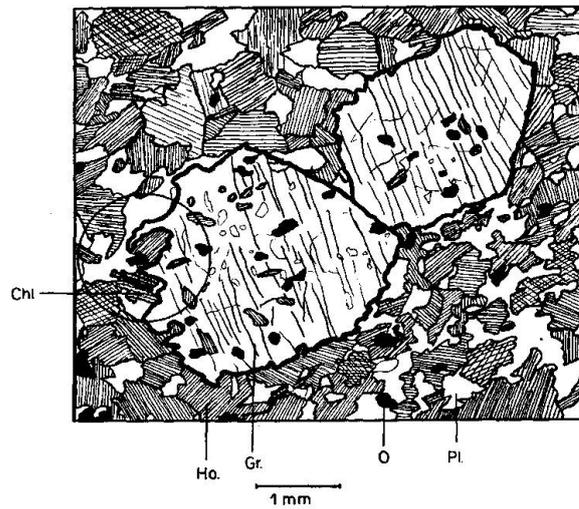
Fig. 5 (Section 360). Garnetiferous amphibolite (type 4). Note the formation of almost idiomorphic garnets. The circle inset is further enlarged in fig. 6 (see text for explanation).
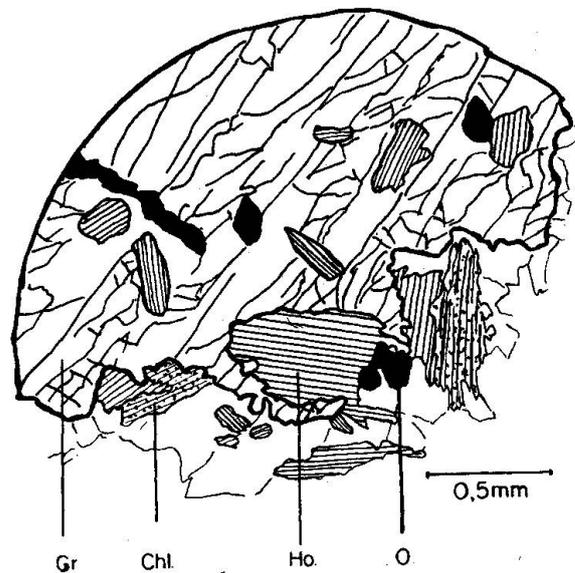
Fig. 6. Enlarged detail from fig. 5. Note how the garnet embraces the hornblende prisms, and how the latter when enclosed in the garnet, have lost their marginal angularities.

the kinzigite rocks favours the inference that the garnets have crystallised as a result of the assimilation of aluminous material by the amphibolite during its intrusion into the kinzigite rocks. The above supposition is also supported by the fact that the kinzigite gneiss suffered contact metamorphism along its contact with the amphibolite which produced light rose-pink garnets, very similar to those found within the amphibolite. The kinzigite contains, beside garnet, a few colourless grains of corundum and a few needles of sillimanite as subordinate constituents. It would seem that the garnets are, therefore, not the original and principal constituents of the amphibolite but later-generated crystals. The structure of the amphibolite is similar to that of type (3) and is nemato-granoblastic.

Type (5)

Amphibolites at 250 and 391 m belong to this type. Macroscopically and microscopically they are similar to type (3). The constituents are,

P. C.: Plagioclase feldspar $\sim$ hornblende.

S. C.: Biotite.

A. C.: Apatite, opaque ores (sphene).

A. P.: Chlorite.

These minerals show the same optical properties as those of type (3). The percentage of anorthite in the plagioclase feldspar of 250 is 75%; in 391, 65%. These values correspond to an intermediate labradorite to acid bytownite. The optical and extinction angles of hornblende are,

250 Hornblende $(-)2\,V = 86°$; $c/Z = 17°$
391 Hornblende $(-)2\,V = 80°$; $c/Z = 15°$

The hornblende belongs to a type rather rich in the actinolite molecule, tending towards common hornblende.

An interesting feature in the two amphibolites is the presence of thin bands or lenticular areas exhibiting a mineralogical composition different from that of the rest of the rocks. Figures 7 and 8 give a general idea of the nature of these areas. In 250 (a) (fig. 7) the arrow within the microscopic field indicates the general course of the band, while the arrow outside shows the direction of lineation (parallel orientation) of the hornblende prisms. In 391 (fig. 8) the band is almost parallel to the lineation of the amphibolite. In both the amphibolites, the bands consist mineralogically of plagioclase feldspar and chestnut-brown biotite (sometimes altered to chlorite) and a few opaque ore grains. Quartz is not present and hornblende is almost absent. The percentage of anorthite

in the plagioclase feldspar of 250 (a) is 64%, and in 391, 73%. In the first case, the compositions of the plagioclase feldspars of the amphibolite and the band differ slightly from one another, while in the second case (391), the difference in their compositions is negligible. The areas exhibit in contrast to the amphibolites a perfect granoblastic structure due to the presence of polygonal plagioclase feldspars abutting against one
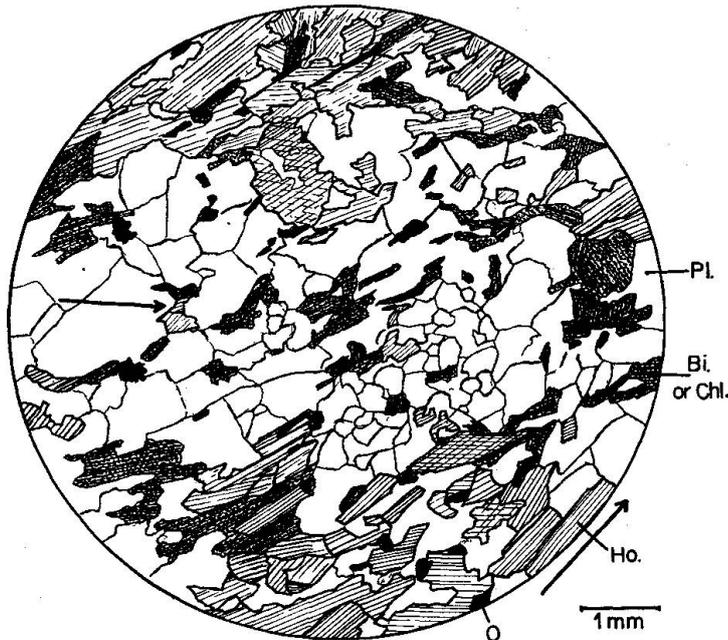
Fig. 7 (Section 250a). Kinzigite inclusion in the amphibolite (type 5) giving rise to a micro-chorismatic structure. The arrows outside and within the microscopic field indicate the direction of the preferred orientation of the hornblende prisms in the amphibolite and the disposition of the inclusion respectively. Note the almost complete absence of hornblende in the inclusion.

another with conserted margins. The question arises whether these bands represent "cognate schlieren" or "foreign inclusions", say, kinzigite inclusions, dragged into and incorporated by the amphibolites during the time of their intrusion. The first alternative does not fit into the observed microscopic details. Besides, the presence of some grains of corundum and thin bundles of colourless sillimanite needles, rimmed successively by fine scales of sericite and microcrystalline epidote in 391, does not speak for a magmatic origin. On the contrary, they suggest the foreign character of the inclusion. It seems to the author that in both instances thin kinzigite inclusions have been mechanically introduced into the amphibolites along their margins. That is why each of the sections exhibits a micro-chorismatic structure of polygenic origin,

so that the granoblastic structure of the inclusion corresponds to that of the kinzigite and differs from the nemato-granoblastic structure of the amphibolite.
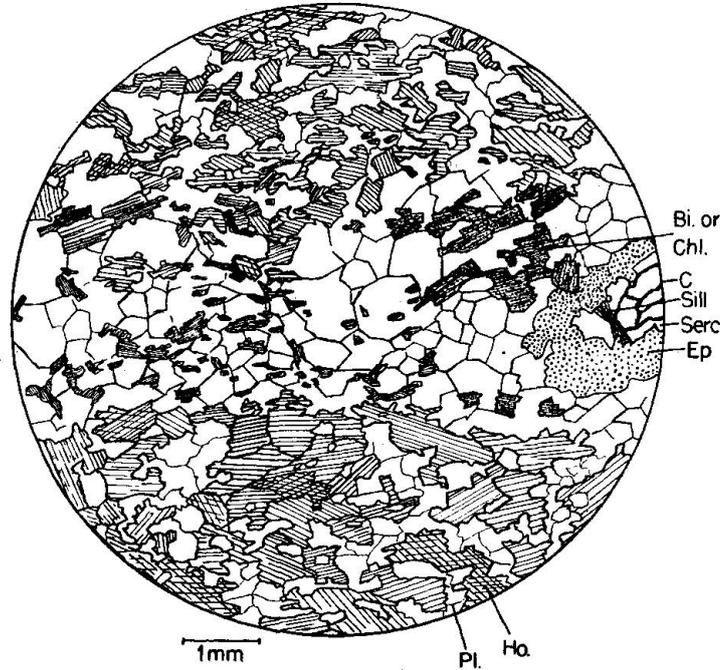
Fig. 8 (Section 391).   Kinzigite inclusion in the amphibolite (type 4) gives rise to a micro-chorismatic structure. The inclusion is seen to contain corundum, silli-manite, sericite, and epidote towards the right of the figure. Corundum forms the core around which the later minerals develop as successive rims. Note the complete absence of hornblende in the inclusion.

Type (6)

The amphibolite at 721 m in the contact zone belongs to this type. Macroscopically and microscopically it is similar to type (3), consisting of,

P. C.: Plagioclase feldspar $\geq$ hornblende.

S. C.: Biotite > augite.

A. C.: Apatite, sphene, opaque ores, orthite, zircon.

A. P.: Chlorite, epidote.

The anorthite content in the plagioclase feldspar is 43% and the composition corresponds to an intermediate to basic andesine. The pleochroism, optical and extinction angles of the hornblende prisms are similar to those of type (3).

The presence of a few xenomorphic blades of colourless augite distinguishes this type from type (3). Wisps and shreds of green horn-

blende, similar to the prisms scattered all over the section, are forming along the margins and fractures of the augite grains. Unfortunately individual grains suitable for the determination of the optical and extinction angles have not been found. A few measurements made on the cleavages of grains showing the maximum birefringence gave a maximum extinction angle of 40°. This value corresponds to a diopsidic augite.

Sphene is an abundant constituent and many opaque ore grains are altered to sphene.

The section exhibits a nemato-granoblastic structure as in type (3). Owing to marginal granulation of the plagioclase feldspars, and sometimes of the hornblende prisms, the nemato-granoblastic structure assumes a catalastic aspect. The degree of cataclasis is similar to that shown by 730 of type (3).

Discussion and summary of observations

Type (1) amphibolite seems to be a case of multiple or composite intrusion with a thin dike-like vein injecting into the medium-grained amphibolite. The colourless hornblende prisms forming rims or shells or overgrowths over the coloured varieties do not resemble those described and illustrated by C. E. TILLEY (1938 [text fig. 1]). Therefore the possibility that they may represent clastic hornblende grains with overgrowths of a colourless to pale green variety developed during the progressive metamorphism of clastic sediments seems unlikely. Such colourless hornblendes can also be formed from coloured varieties under magmatic conditions or under conditions of stress during or subsequent to the crystallisation and solidification of the basic rock. The slightly lower basicity of the plagioclase feldspar, its finer-grained texture, and the sharp contacts of the thin vein against the medium-grained amphibolite favour the assumption that it is a case of injection of the finer-grained part into the medium-grained type, while the latter was cooling and crystallising.

The massive and random texture, the intra- to intergranular implication structure, the presence of ilmenite blades in the hornblende prisms, and the high basicity of the plagioclase feldspar suggest that the type (2) amphibolite is derived from the crystallisation and recrystallisation of a basic eruptive rock relatively rich in Ca and Mg. Further evidence in support of this conclusion is the chilling of the margins with a consequent reduction in the grain size in the marginal facies represented by specimens 125 and 128.

Amphibolites belonging to type (3) represent a stage further in the progressive metamorphism and recrystallisation of the original basic rocks. Taking the basicity of the plagioclase feldspar as an indicator of their original chemical composition, they seem to range from gabbro → gabbro-diorite → diorite-gabbro → diorite. This indicates either that the rocks of type (3) have suffered magmatic differentiation during their intrusion, or that they intruded the kinzigite rocks one after another, the more acid types being earlier than the more basic ones. The magmatic origin of these rocks is further supported by the described relationship of the dark brown biotite and the hornblende prisms which indicates a peritectic reaction relationship commonly recognised between these two minerals in rocks of magmatic origin.

No doubts can be expressed concerning the magmatic and intrusive origin of the amphibolite of type (4). Clear evidence has been brought to show that the garnets seen in the amphibolite near its contact with the kinzigite are the products of the absorption by and reaction of the aluminous material with the amphibolite.

The thin bands of kinzigite included in the amphibolites of type (5) do not seem to be "cognate schlieren". The micro-chorismatic structures of both rocks arose during their intrusion into and incorporation of parts of the kinzigite gneiss and are distinctly of magmatic origin.

Relict colourless blades of augite are found in the amphibolite of type (6). The association of augite and hornblende indicates that the basic rock originally contained a certain amount of augite before attaining its present mineralogical composition. If this assumption is accepted, type (6) amphibolite is intrusive and of magmatic origin.

The above evidence points clearly to the fact that the basic amphibolites of the kinzigite and contact zones intruded into the kinzigite gneiss subsequently to the latter's metamorphism and are, therefore, much younger than the kinzigite gneiss.

Relationship between the amphibolite bands of the kinzigite zone and the Ivrea zone

Clear evidence has been brought to show that the basic amphibolite bands of the kinzigite zone (0—460 m) are of magmatic origin and have intruded into the kinzigite gneiss long after the latter had attained its present metamorphic grade. It has been pointed out that the amphibolite bands do not show any significant differences in their fabric and mineralogical composition from those of the contact zone. As the latter are

identical in all aspects with those of the southern margin of the Ivrea zone, a genetical relationship would appear to exist between them. Furthermore, as sharp boudaries and tectonic discontinuities are lacking the amphibolites of the Ivrea zone and those of the contact and kinzigite zones may also be regarded as genetically related.

It seems desirable to name these rocks according to those from which they are derived. Based on the anorthite content of the plagioclase feldspar distinction may be made between gabbro-, gabbro-diorite-, and diorite amphibolites. The different types of amphibolites of the two parts of the kinzigite zone could then be,

Type (1)   Gabbro-amphibolite.
Type (2)   Gabbro-amphibolite to gabbro-diorite amphibolite.
Type (3)   Nos 208, 212, 367, and 530 are gabbro-amphibolites.
            No. 380 is a gabbro-diorite-amphibolite.
            Nos 96, 387, and 730 are diorite-amphibolites.
Type (4)   Gabbro-amphibolite.
Type (5)   Gabbro-amphibolite.
Type (6)   Diorite-gabbro-amphibolite.

These above gabbro- and diorite-amphibolites are very similar in their fabrics and mineralogical composition to those described in detail by C. Burri and F. de Quervain (1934) from Brissago, and considered by them to be magmatic and truly eruptive in their characters. Field observations made by the present author during the years 1952—1954 on these amphibolites (or gabbros as they are called by the above authors) well exposed along the newly enlarged highway leading to the Italian frontier from Locarno via Brissago revealed the presence of chilled margins and distinct contact metamorphism on the adjacent kinzigite rocks. The only microscopically recognisable difference between these gabbro-amphibolites and those described by the author in the preceding sections of the present paper is that the hornblende prisms in the tunnel rocks do not contain abundant ilmenite inclusions as do those of the Brissago area. This difference is not so significant as to warrant the suggestion that two distinct and unrelated groups of basic rocks are involved. If we accept the above inference concerning a close genetical relationship between all these basic rocks the only question that remains to be answered is, at what period did the basic rocks intrude the kinzigite gneiss? As all the basic rocks described in the kinzigite area are very fresh, sometimes showing a massive, non-foliated non-lineated and random texture, and as none of them exhibits any strong degree of cataclasis, it seems

probable that they intruded the kinzigite rocks at a time more or less contemporaneous with the period of intrusion of the different basic rocks of the Ivrea zone along the northern border of the kinzigite zone. The latter series of basic rocks also are well known in the geological literature for their remarkable freshness and unaltered condition.

CHAPTER III

IVREA ZONE

Section 1

Basic rocks of the Ivrea zone

General characters

The massive and compact basic rocks of the Ivrea zone first appear at 800 m and extend as far as 2180 m (see profiles 1, 2, and the first part of 3). They occasionally enclose thin bands and lenses having a composition somewhat different from their surroundings. Such inclusions appear at first sight to be foreign matter incorporated into the basic rocks at the time of their intrusion into this region. They are described in section (3). The basic rocks themselves are macroscopically indistinguishable from one another especially in the insufficient light of the tunnel. Hence a clear demarcation of the boundaries between the various types was not possible. A knowledge of their probable distribution (as shown in the profiles 1, 2, and 3) was reached only after a microscopic examination of rocks collected at a number of places along the tunnel.

The basic rocks have been divided into several types, each one of which exhibits a distinct mineralogical composition of its own. These types are described below and an attempt has been made to establish their geological and genetical relationships. Each type has been given a name and above the paragraph devoted to it, P. WALTER's (1950) terminology is given in square brackets for easy reference.

Type 1(a). Hornblende-plagioclase-diorite-amphibolite
[Fine- or medium-grained diorite or gabbro varieties of the southern margin. p. 60.]

Specimens collected at 1340, 1365, 1370, 1420, 1446, and 1475 m belong to this type. They are green to dark green in colour, phanerocrystalline, fine- to medium-grained, and exhibit lineation due to parallel arrangement of the hornblende prisms. Dark green hornblende and plagio-

clase feldspar are visible to the naked eye. Specimen 1420 is traversed by veins of yellowish-green epidote, measuring up to 5 mm in width suggesting that the rocks have been subjected to cataclasis. The fractures were later filled with chymogenic epidote. Microscopically the rocks consist of,

P. C.: Hornblende $\sim$ plagioclase feldspar.
S. C.: Biotite, augite.
A. C.: Opaque ores, apatite.
A. P.: Epidote, clinozoisite, sericite, and chlorite.
Ff.C.: Epidote, chlorite, and calcite.

Hornblende is slightly more abundant than plagioclase feldspar.

The plagioclase corresponds to an intermediate or basic andesine (42% anorthite content) twinned on the albite or pericline laws. Undulose extinction and slight marginal granulation are distinctly seen. The crystals are traversed by thin fractures and are slightly altered to a cloudy aggregate of sericite and clinozoisite. In section 1475 the crystals still shown even and conserted margins with the adjacent hornblende prisms.

The hornblende is optically negative with an optical angle of 66° to 76°, and $c/Z = 18°$. Its pleochroism is: X = straw-yellow; Y = green or green with a brownish tinge; Z = greenish-brown or brownish-green.

It belongs to the common hornblende type. The prisms show distinct undulose extinction, marginal granulation, fracturing, and sometimes alteration to chlorite. The minute wisps and shreds of hornblende are mixed with the granules of feldspar giving rise to a polymineralic matrix in which the larger crystals remain as porphyroclasts. The porphyroclasts of both minerals have a maximum diameter of 0.4 to 0.8 mm. Tiny flakes of brown biotite are frequently seen fringing the margins of the hornblende prisms or projecting across them. The relationship between hornblende and biotite is similar to that often seen in rocks of magmatic origin (peritectic reaction relation).

Very small amounts of colourless augite are present in two sections, viz. 1446 and 1475. Wisps of hornblende form a rim around the granulated margins of the pyroxene. Augite seems to be a relictic mineral in these rocks.

Opaque ores are always xenomorphic. They mould around the margins of the other constituents or form thin sinuous streaks or trains in the granulated matrix. Colourless apatite crystals are fractured into several pieces.

The proportion of the alteration minerals to the original constituents

of the rock is generally low. It is not uncommon to find a few fractured prisms of hornblende in the epidote veins of 1420. In this section, sub-idiomorphic to idiomorphic, pale lemon-yellow crystals of epidote have crystallised at right angles to the vein walls.

Besides pale green chlorite and micro-crystalline epidote, a few colourless grains of calcite are also seen as a fracture-filling mineral-

With the exception of 1475, the sections all show a cataclastic struct ture with porphyroclasts in a fine-grained matrix. The matrix does no.

Fig. 9 (Section 1475). Hornblende-plagioclase-diorite-amphibolite (type 1a) showing the original granoblastic structure with feeble cataclasis. The dark grey areas represent hornblende prisms, while the greyish-white part is plagioclase feldspar. The dark points consist of opaque ore. (10×.)

appear to have been completely recrystallised. Undulose extinction and sutured margins are prevalent among the crushed grains.

Section 1475 exhibits only a feeble degree of cataclasis. On this account the plagioclase feldspars and the hornblende prisms have even and conserted margins (see fig. 9). The original structure was nemato-granoblastic, as commonly found in the amphibolites derived by metamorphism from basic igneous rocks.

Type 1(b). Garnetiferous hornblende-plagioclase-diorite to gabbro amphibolite

[Corresponding name is lacking. Most probably this type belongs to the fine-, or medium-grained diorite or gabbro varieties of the southern margin. p. 60.]
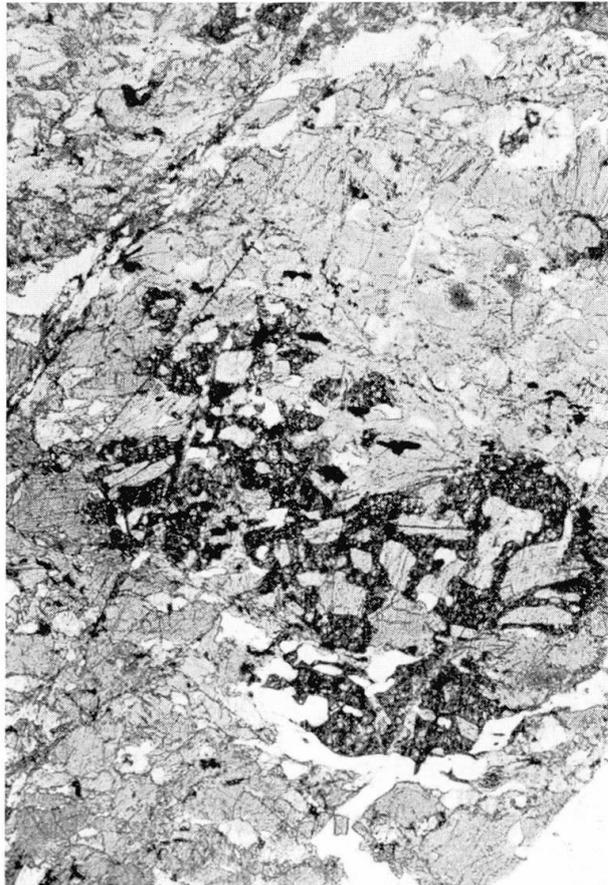
Fig. 10 (Section 1310). Crystallisation of spongy, poikilitic and amoeboid garnets in the garnetiferous hornblende-plagioclase-diorite to gabbro-amphibolite (type 1b) of the Ivrea zone at its contact with the gneiss inclusion at 1310 m. The stippled area represents cloudy and slightly saussuritised plagioclase feldspar. (10×.)

A specimen collected from the contact of the basic rock of type 1(a) and a "gneiss inclusion" at 1310 m represents this type. The macroscopic characters, the mineralogical composition, and the structure of the rock are similar to those described in type 1(a). The composition of the plagioclase feldspar differs from that of 1(a). It corresponds to a basic labradorite or an acid bytownite (70° anorthite content) giving to the rock a more basic character.

An interesting feature which distinguishes this rock from type 1(a) is the presence of amoeboid and poikilitic garnets. They occur as a subordinate constituent at random all over the section. The garnets are most abundant in the amphibolite near its contact with the kinzigite inclusion. An example of these amoeboid garnets is shown in fig. 10. They are light rose-pink in colour with a refractive index of 1.781 ± 0.003 and correspond in composition to a type rich in the almandite molecule. In fact, their optical properties are very similar to those of the garnets described in the type (4) amphibolite of the kinzigite zone. The spongy, poikilitic, and amoeboid habit of the garnets suggest that their crystallisation is due to the absorption of and reaction with aluminous material by the basic rock. They do not seem to represent original constituents. The presence of many hornblende prisms with rounded margins as inclusions in the garnet also favours of the above assumption. Unfortunately no hand specimens are available from the garnetiferous amphibolite band at 1000 m.

Type 2(a). Hornblende-plagioclase-diorite-amphibolite of the northern margin

[Hornblende-albite-diorite-amphibolite of the northern margin. p. 70.]

Rock specimens collected at 2050, 2090, 2124, and 2125 m belong to this type. They are green to dark green in colour, fine-grained with visible hornblende prisms and specks of plagioclase feldspar. It is not uncommon to see veins of epidote measuring up to 1 cm in width, and containing angular fragments of the basic rock in various stages of destruction. Macroscopically the rocks do not appear to differ much from type 1(a) except that they are met with near the northern margin of the Ivrea zone. Microscopically they differ from type 1(a) in the following respects (see fig. 11).

a) They are finer-grained, the porphyroclasts not measuring more than 0.5 mm.

b) Plagioclase feldspar corresponds in composition to a basic oligo-clase or acid andesine (30% anorthite content).

c) Colourless quartz may occur as a subordinate constituent here and there between the principal constituents. Its volume does not exceed more than 8% of the total volume of the rock.

d) The rocks exhibit a more severe degree of cataclasis than types 1(a) and 1(b).

e) Plagioclase feldspars have altered extensively to cloudy aggregates of clinozoisite, epidote, and sericite obliterating the twin lamellæ of the crystals. Fresh feldspars are rare.
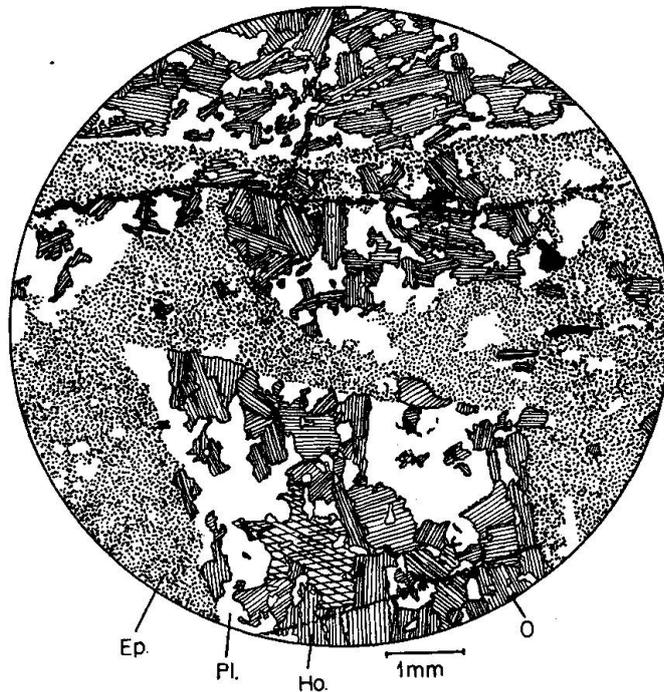
Fig. 11 (Section 2050). Hornblende-plagioclase-diorite-amphibolite of the northern margin (type 2a) showing a severe cataclastic structure. Note the presence of a triangular fragment of the amphibolite enclosed as a relict in a micro-crystalline aggregate of epidote (stippled area). The dark lines are fractures extending over the entire section.

f) The sections are traversed by a number of thin epidotic and chloritic veins which have been again traversed by veins of colourless zeolites indicating at least two different phases and periods of stress.

The structure of the rocks is similar to type 1(a) and (b), i. e. cataclastic-porphyroclastic.

Type 2(b).   Garnetiferous hornblende-plagioclase-diorite-amphibolite

[Corresponding name is lacking. However, the above type may belong to the hornblende-albite-diorite-amphibolite of the northern margin. p. 70.]

A thin dike-like vein injecting into an inclusion at 2160 m belongs to this type. The vein is dark green in colour, fine-grained with visible hornblende prisms, grains of plagioclase feldspar, and a few garnets. Macroscopically it is similar to type 1(b).

Microscopically it consists of the same constituents as type 2(a). In addition, it contains a few xenomorphic and amoeboid garnets similar to those in type 1(b) which they optically resemble. The degree of cataclasis is of the same order as in 2(a) and has caused some of the garnets to alter into pale green chlorite along fractures. The anorthite content of the plagioclase could not be determined owing to extensive alteration to clinozoisite, sericite, and epidote.

The structure of the rock is cataclastic-porphyroclastic.

Type (3).   Hypersthene-bearing hornblende-plagioclase-diorite (or gabbro) amphibolite

[Pyroxene-bearing diorite to gabbro varieties of the zone. p. 60.]

A specimen collected at 1355 m represents this type. Macroscopically the rock is dark green in colour, fine-grained, with visible hornblende prisms and specks of plagioclase feldspars. The hornblende prisms show a certain degree of parallel arrangement. Microscopically the rock consists of,

P. C.: Hornblende $\geq$ plagioclase feldspar.
S. C.: Quartz $\sim$ hypersthene > biotite.
A. C.: Opaque ores, apatite, garnet.
A. P.: Chlorite, epidote.
Ff.C.: Epidote, chlorite.

Hornblende is slightly more abundant than plagioclase. It has the same optical properties as in 1(a) and is optically negative with an optical angle of 70° and $c/Z = 15°$ and belongs to the common hornblende series. The prisms exhibit distinct undulose extinction, fracturing, marginal granulation with separation of wisps from the mother crystals. They are sometimes altered into chlorite along the lines of fracture. The feldspar is an intermediate to basic andesine (43° anorthite content), polysynthetically twinned, and exhibits marginal granulation, fracturing,

bending and twisting of the twin lamellæ, and strong undulose extinction. Some of the granules in the matrix have been recrystallised and do not show any undulose extinction. They possess even and conserted margins with the adjacent grains.

Quartz occurs as colourless, xenomorphic grains interstitial between the other constituents, and shows strong, undulose extinction. Tiny flakes of brown biotite fringe and project across the margins of the hornblende
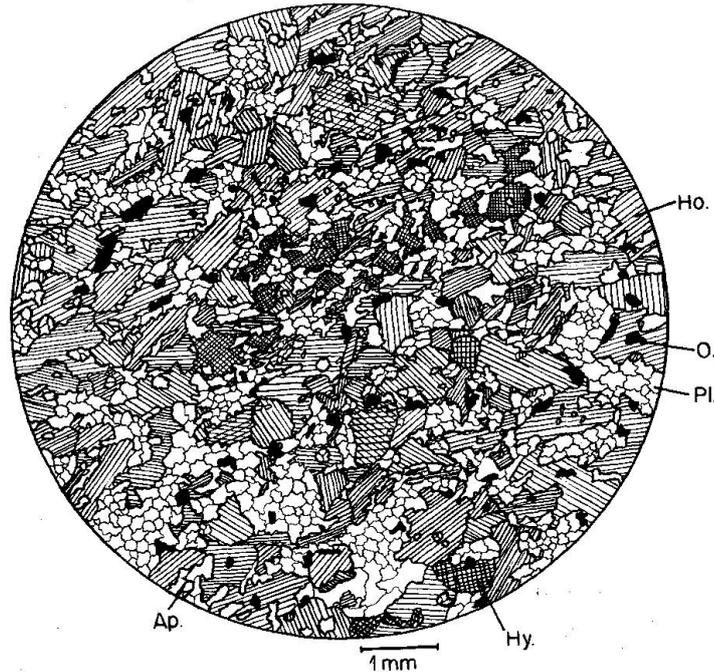
Fig. 12 (Section 1355). Hypersthene-bearing hornblende-plagioclase-diorite (or gabbro)-amphibolite (type 3) showing a cataclastic structure. Note the sparse distribution in the section of relictic hypersthene prisms.

prisms indicating a peritectic reaction relationship. Light rose-pink hypersthene is present as small xenomorphic prisms measuring up to 0.4 mm with even as well as sutured margins (see fig. 12). Minute wisps of green hornblende have sometimes developed along the granulated margins of the hypersthene prisms. Such hornblende wisps are optically similar to the larger ones. Hypersthene is optically negative with an optical angle of 51° and corresponds in composition to a type with $En_{65}Hy_{35}$. A few of the prisms have altered under the action of stress to a mixture of talc and pale green serpentine with a concomitant liberation of opaque ore dust in the altered mesh-work.

A few light rose-pink, xenomorphic garnets occur at random in the

section. They are non-poikilitic and their exact relationship to the other constituents is not clear.

The crystal habit and distribution of the opaque ores and apatite are similar to those in 1(a). As a whole the section shows a slightly higher degree of cataclasis and the structure is cataclastic-porphyroclastic.

Type 4(a). Pyroxene-hornblende-gabbro-diorite
[Pyroxene-bearing diorite-gabbro to gabbro-varieties of the middle part of the zone. p. 62.]

Specimens collected at 1650, 1725, 1750, 1770, and 1910 m represent this type. They are dark green in colour, fine- to medium-grained with visible specks of feldspar. The femic constituents are indistinguishable from one another. The rocks are occasionally traversed by thin veins of pale green epidote. They differ microscopically from types 1(a), 2(a), and 3 by the presence of monoclinic pyroxenes as principal constituents, while hornblende is on the whole a subordinate mineral. The constituents are,

P. C.: Plagioclase feldspar $\sim$ diallage + augite $\geq$ hornblende.
A. C.: Opaque ores, apatite.
A. P.: Epidote, chlorite, clinozoisite, and sericite.
Ff. C.: Epidote, chlorite, calcite.

The total volume of the femic constituents is more or less equal to that of the plagioclase feldspar. The relative proportions of augite, diallage, and hornblende are variable. But in general, the total volume of hornblende does not exceed the total volume of the monoclinic pyroxenes.

The plagioclase feldspars show distinct polysynthetic twinning. Strong undulose extinction, bending and twisting of the twin lamellæ, fracturing of the crystals, and marginal granulation are considerably more pronounced than in the previous types. The crystals are sometimes altered to cloudy aggregates of clinozoisite and sericite. The volume of the alteration products is not high compared to that of the fresh individuals. The anorthite content varies between 45% and 55%, i. e., the composition lies between a basic andesine and acid labradorite. The impression is gained that some feldspar grains in the matrix showing polysynthetic twinning have recrystallised as they no longer show undulose extinction.

Diallage is pale green without distinct pleochroism. It frequently contains thin blades and dust of opaque ore (probably ilmenite). It is

optically positive, with an optical angle of 56° and $c/Z = 41°$. Augite can be distinguished from diallage by the absence of colour and opaque ore dust. It is optically positive with an optical angle of 57° and $c/Z = 43°$. Both diallage and colourless augite seem to be richer in the diopside than in the hedenbergite molecule. It is not uncommon to find thin, bent, and twisted exsolution lamellæ of an orthopyroxene in the above clinopyroxenes. In one of the sections of a gabbro from Anzola kindly placed at my disposal by Prof. C. BURRI for a comparative study, similar ex-solution lamellæ of orthopyroxene are particularly well developed. This is due to the fact that the basic rocks of Anzola have not been subjected to so severe a degree of cataclasis as those in the present area. The clinopyroxenes also exhibit remarkable effects of cataclasis. Shreds of hornblende are extensively developed along their granulated margins and fractures. This is due to subsequent recrystallisation of the granulated material. The marginal hornblende is very similar to the larger prisms of the section. The hornblende has the following optical properties: X = pale straw-yellow; Y = green; Z = green or brownish-green. It is optically negative with an optical angle of 74° and $c/Z = 16°$. It belongs to the common hornblende series. The porphyroclasts of feldspars and the femic constituents sometimes measure up to 1.5 mm in their longer diameters.

Opaque ores are irregular and xenomorphic. They mould round the other constituents and form sinuous streaks and trains in the granular polymineralic matrix. The structure is uniformly cataclastic-porphyroclastic.

Type 4(b)

Specimens collected at 1780, 1790, 1800, and 1885 m represent this type. The principal, subordinate, and accessory constituents are the same as in 4(a). The chief difference which distinguishes this sub-type from 4(a) is their superior degree of cataclasis.

The feldspars are extensively crushed, granulated, and pulverised. They are altered to aggregates of clinozoisite, epidote, and sericite which obliterate all vestiges of twinning. Fresh feldspars showing distinct twin lamellæ are rare. Even such grains are not suitable for an accurate determination of the anorthite content on account of their twisted and bent lamellæ. As these rocks are almost identical in their mineralogical constitution to type 4(a), it is assumed that the feldspar has the same composition as in the former type, i. e., basic andesine to acid labradorite.

Most of the femic constituents represented by diallage, augite, and

hornblende are much altered to chlorite, serpentine, and epidote. Various stages in the degree of alteration to these minerals can be recognised in the sections. The fractures of the original minerals are filled with pale green chloritic material, part of which could have been derived from the alteration of the femic mineral itself. Complete alteration of the prisms leads to the formation of large flakes of pale green chlorite pseudomorphous after their original crystal shapes. Such chlorite flakes often contain small pockets of granular epidote or are traversed by thin veins of epidote suggesting that the excess of calcium left over after the formation of chlorite has gone into the formation of the latter mineral (see fig. 13). It is not uncommon to find relictic, crushed, and granulated prisms of diallage or augite or hornblende in such meshes of chlorite or serpentine.

In section 1780 the crushing and granulation of the constituents has gone so far as to give rise to a semi-isotropic matrix in which the
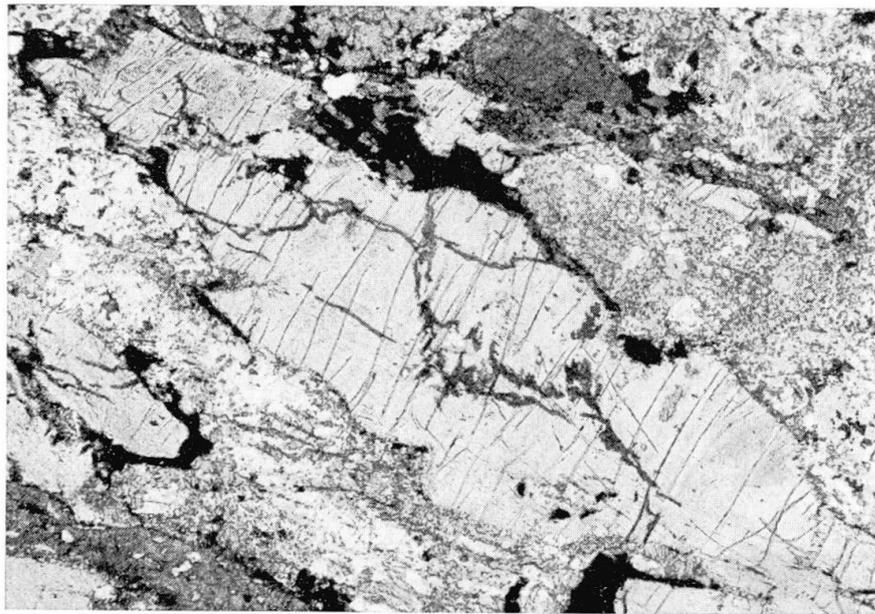
Fig. 13 (Section 1790). Pyroxene-bearing hornblende-diorite (-gabbro) (type 4b) showing signs of severe cataclasis and alteration. The rhomboidal prism in the centre of the field is pale green chlorite derived from the alteration of one of the original femic constituents. Excess calcium liberated during the alteration of the original pyroboles has gone into the formation of thin epidote veins traversing the chlorite. The opaque ore grains are also altered to sphene. Chlorite flakes frequently contain thin brownish rods of ilmenite probably representing excess of titanium liberated from the mafic constituents. The section is traversed by veins of microcrystalline epidote one of which can be seen in the left lower corner of the above figure. (10×.)

opaque ore grains form sinuous streaks and trains. These rather resemble the "pseudotachylites" as described from other places in the Ivrea zone. In other sections the opaque ores mould round the relictic grains or form similarly worm-like streaks. They are also altered to leucoxene.

The sections are traversed by a number of epidote and chlorite veins in which colourless calcite is also occasionally present as a fracture-filling mineral.

The structure of the rocks is cataclastic to mylonitic with relictic porphyroclasts.

Type 4(c)

(Same as 4(a), but garnet-bearing)

A specimen collected at 1710 m belongs to this type. Macroscopically it is similar to type 4(a). The mineralogical composition is the same as in 4(a), but contains some light pink garnets measuring about 0.4 mm as a subordinate constituent. All of them are xenomorphic to sub-idio-morphic and are traversed by thin fractures along which alteration into pale green chlorite takes place. They are distributed at random and their relationship to the other constituents is not clear. They may represent original constituents of the rock or have developed later as a result of the migration of aluminium from an adjacent undetected "foreign inclusion".

Type 5(a). Pyroxene (Augite)-hornblende-gabbro

[Hornblende-pyroxene-gabbro-diorite of the middle part of the zone or Fornale gabbro. pp. 65—66.]

Specimens collected at 1464, 1940, and 1970 m belong to this type. They are medium- to coarse-grained, with visible prisms of hornblende, augite, and plagioclase feldspar. Specimens 1464 and 1970 are greenish in colour with a mottled white appearance due to the presence of feld-spars. Specimen 1940 is more leucocratic and somewhat greyish-white in colour with dark green prisms of the femic constituents among the feldspars. This particular rock differs from all other types by its coarse-grained aspect, directionless texture, and absence of epidotic veins. At the first sight is appears to be a gabbro. Microscopically these rocks consist of,

P. C.: Plagioclase feldspar ∼ augite ∼ hornblende.
A. C.: Opaque ores, apatite.
A. P.: Epidote, chlorite.

The amount of plagioclase feldspar is slightly less than the total volume of the femic constituents. Among the latter augite is more or less equal in volume to hornblende. Diallage is absent from this type. The composition of the plagioclase feldspars and the optical properties of the augite and hornblende are given in the table below (3).

Table 3

Section number	An %	Augite 2 V	c/Z	Hornblende[4] 2 V	c/Z
1464	54%	+56°	43°	−77°	15°
1940	73%	+57°	—	−79°	19°
1970	63%	+55°	42°	−68°	17°

The feldspars in all the three sections are polysynthetically twinned and remarkably fresh. They exhibit strong undulose extinction, bending and twisting of the twin lamellæ, marginal granulation and fracturing. Some of the granulated material recrystallised to a granoblastic matrix between the larger porphyroclasts. The recrystallised grains also show distinct polysynthetic twinning. As shown by table (3), the composition of the feldspar is different in the three rocks. In 1464 it corresponds to an acid labradorite; in 1940 it is an acid bytownite; and in 1970 it is an intermediate to basic labradorite. Compared to the feldspars of the other types its basicity in the present rocks is decidedly higher. In fact, the composition of the feldspar in 1940 is almost the same as in those described by H. F. HUTTENLOCHER (1942) from the pyroxene-hornblende gabbro near Anzola in the Valle d'Ossola.

Colourless augite has more or less the same optical properties as in type 4(a). The optical and the extinction angles indicate that it is a type rich in the diopside molecule. An interesting feature of the rocks is the formation of clusters of small prisms of hornblende around the margins and across fractures of the augite prisms. They have the same optical properties as the larger hornblende prisms. Fig. 14 brings out clearly how hornblende has developed as a result of recrystallisation of the granulated material around the margins of the pyroxene prisms. Small, colourless angular grains of relictic augite, in the process of transformation to hornblende are, frequently, seen intermixed with the mesh-work of hornblende wisps.

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[4] Pleochroism of hornblende: X = pale straw-yellow; Y = brownish green; Z = brown with a greenish tinge.

The hornblende of these rocks shows a different pleochroic scheme from that of the previous types. It has a well-pronounced brownish hue commonly recognisable in those of the basic plutonic rocks like gabbro and gabbro-diorite.
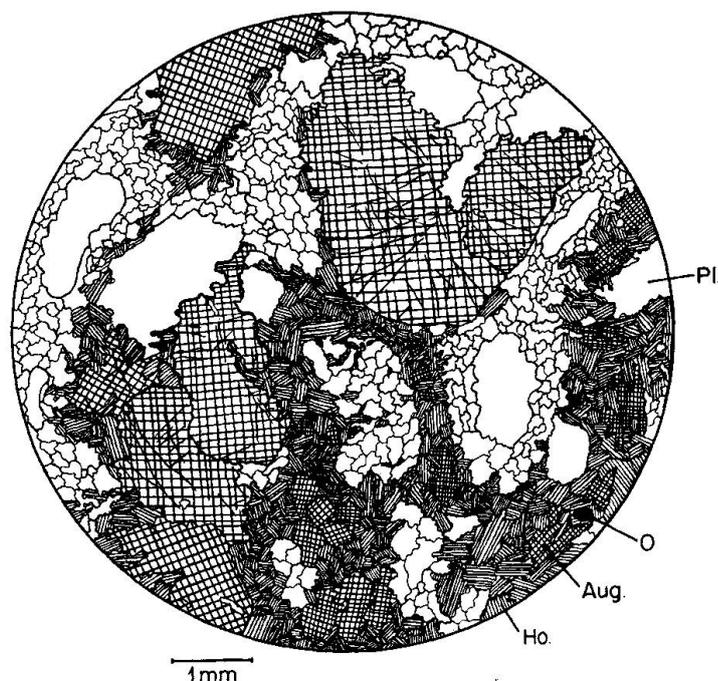
Fig. 14 (Section 1940). Pyroxene-(Augite)-hornblende-gabbro (type 5a) showing a cataclastic structure and formation of hornblende prisms along the granulated margins and fractures of the augite-prisms. Small relictic grains of augite are still seen amidst the hornblende prisms. Note the almost complete absence of opaque ores. Accessory apatite is seen elsewhere in the section.

It should be mentioned here that specimens 1940, and 1970 do not contain abundant opaque ore as in the previous types. In fact, it is almost absent. On the other hand, specimen 1464 again contains abundant opaque ore moulding round other constituents or forming sinuous streaks in the matrix.

The alteration products, chlorite and epidote, are insignificant compared to the volume of fresh constituents.

Specimen 1940 was analysed and the analysis compared with two others, whose sources are quoted below. (Table 4.) Under the table are given the Niggli values of the analysed specimen (1940), of the quoted analyses, of the standard Niggli values of a pyroxene-gabbro, and those of an ariegitic magma for comparison.

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Table 4

	1 (1940)	a	b	c	d
SiO_2	47.35	46.04	48.59		
Al_2O_3	15.83	16.35	17.56		
Fe_2O_3	2.06	3.00	3.95		
FeO	5.69	8.10	5.69		
MnO	0.10	0.19	0.10		
MgO	10.21	8.80	7.26		
CaO	14.31	14.00	11.22		
Na_2O	2.11	1.98	2.48		
K_2O	0.24	0.22	0.81		
$+H_2O$	1.37	0.28	1.68		
$-H_2O$	0.04	0.05	—		
TiO_2	0.76	0.65	0.46		
P_2O_5	0.00	0.08	0.28		
Others	—	—	0.19		
Total	100.07	99.74	100.27		
si	96	94	117	100	80
al	19	19.5	25	23.5	19
fm	45	45.5	39	40.5	49
c	32	30.5	29	31.5	31
alk	4	4.5	7	4.5	1
k	0.06	0.06	0.2	0.2	0.10
mg	0.70	0.69	0.66	0.7	0.80

Basis of (1940)

Kp	Ne	Cal	Cs	Fs	Fa	Fo	Ru	Q
0.7	11.4	20.0	11.4	2.0	6.8	21.2	0.5	26

Kata-standardnorm

Or	Ab	An	Wo	En	Hy	Fo	Fa	Mt	Ru	Σ
1.3	19.0	33.2	15.1	6.0	1.6	16.6	4.4	2.2	0.6	100.0

Analysis (1): Pyroxene-hornblende-grabbro collected at 1940 m from the Verbano hydro-electric tunnel. Analyst J. JAKOB.

Analysis a) Pyroxene-hornblende-gabbro. Anzola, Valle d'Ossola. H. HUT-TENLOCHER (1942, p. 346). Analyst Fz. STACHEL.

Analysis b) Average of 118 analyses of European gabbros (olivine-free). Quoted from A. JOHANNSEN, Descriptive Petrography of Igneous rocks, Vol. 3, p. 221 (1937).

Analysis c) Niggli values of pyroxene-gabbroic-magma. P. NIGGLI, Die Magmentypen. Schweiz. Min. Petr. Mitt., Band XVI, p. 354 (1936).

Analysis d) Niggli values of ariegitic magma. P. NIGGLI. ibid., p. 354.

The excess of Wo over En + Hy shows that the actual pyroxene cannot be diopside as assumed, but must be aluminiferous. The reaction $5 \text{ An} \rightarrow 4 \text{ Ts} + 1 \text{ Q}$ sets SiO_2 free which can silicify (Fo + Fa) to (En + Hy) by which process the Wo excess will be made to disappear.

Analysis (a) (Pyroxene-hornblende-gabbro) consists of plagioclase feldspar (bytownite with 75—83% anorthite), hornblende (Ca-Mg-Fe-rich type containing low alkalies), and clinopyroxene ($Di_{65}He_{35}$) as its principal constituents, and hypersthene as an occasional subordinate component, and opaque ores and apatite as accessory minerals. The structure is homeoblastic-mosaic with symplectitic reaction rims between the plagioclase feldspar and hornblende or clinopyroxene.

Analysis (b) is the common olivine-free gabbro consisting of a basic plagioclase feldspar (labradorite), clinopyroxene, and hornblende. No further description can be given as it represents the average of a number of analyses from different localities.

The Niggli values of analysis 1 (1940) and those of the pyroxene-hornblende-gabbro of Anzola are identical with one another. The Niggli values of the average analysis of 118 olivine-free European gabbros show slightly higher values in al, c, and alk. These differences are not so high as to need any explanation. Such minor variations are to be expected in gabbros and depend on their mineralogical composition and the relative proportions of the various constituents. The Niggli values of a standard pyroxene-gabbro magma and of an ariegitic magma are also comparable with those of analysis 1 (1940). The pyroxene-gabbro magma shows a slightly higher content of "al". The other values are identical to those of 1940 in all respects. Similarly the ariegitic magma has a slightly lower value for "alk". The other values are the same as those of 1940. It seems, therefore, that we are dealing here with a rock crystallised from a slightly differentiated variant of a pyroxene-gabbro magma or an ariegitic magma.

Type 5(b). Hypersthene-bearing garnetiferous pyroxene-hornblende-gabbro to diorite

[Hornblende-pyroxene-gabbro-diorite or Fornale gabbro. pp. 65—66.]

A specimen collected at 1390 m represents this type. The rock is dark green in colour, fine- to medium-grained, phanerocrystalline with visible femic minerals, feldspar, and a few light pink garnets. Pyrite and/or pyrrhotite are also seen in hand specimens. The femic constituents are rather hard to distinguish from one another. They show a certain degree of parallel arrangement. Microscopically the rock is very similar

to type 5(a). The degree of cataclasis also corresponds to that in the previous type. The rock, however, differs from the preceding type in the presence of light rose-pink hypersthene prisms and a few light rose garnets.

Hypersthene occurs as one of the principal constituents. Its volume is generally less than that of clinopyroxene plus hornblende. It is optically negative with an optical angle of 53° and corresponds to a type with $En_{65}Fe_{35}$. Some of the prisms are altered to serpentine with or without talc with abundant opaque ore dust in the altered mesh. Plagioclase feldspar is less basic corresponding in composition to an intermediate andesine (42% anorthite content).

Light rose-pink garnets occur as a subordinate constituent. They are sometimes xenomorphic and at other times sub-idiomorphic to idiomorphic. They often contain inclusions of feldspar. Their exact relationship to the other constituents is not clear. The refractive index is 1.790 $\pm$ 0.003. This value corresponds to a type rich in the almandine molecule, and it does not differ much from those of the garnets produced in the amphibolites by the assimilation of aluminous material from the inclusions contained in them. This will be further discussed in a later section.
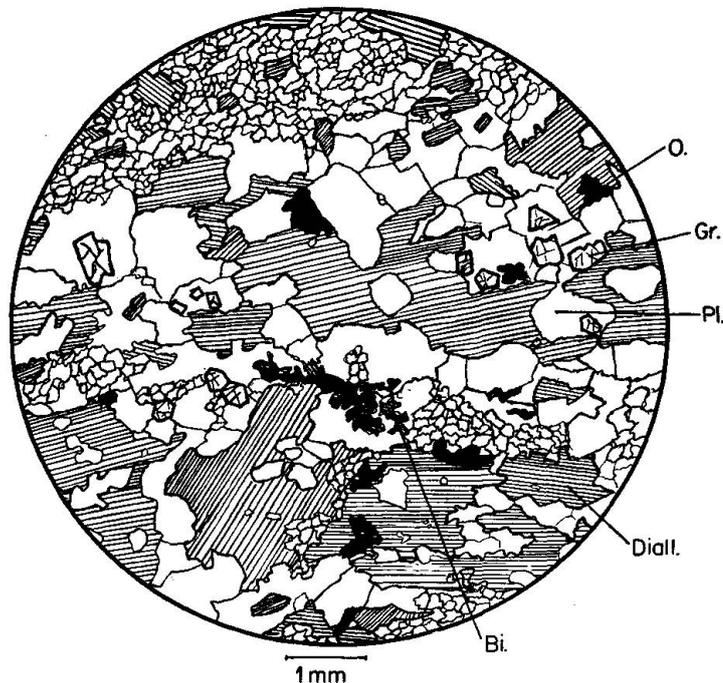
Fig. 15 (Section 1390). Hypersthene-bearing garnetiferous pyroxene-hornblende-gabbro-diorite (type 5b). Note the preservation within a cataclastic-porphyroclastic structure of a relictic xenomorphic-granular structure.

In spite of the severe cataclasis and granulation of the constituents, the section shows a relictic xenomorphic granular or a granoblastic structure (see figure 15). In this part of the section, the constituent minerals, especially plagioclase and clinopyroxene exhibit even and conserted margins.

Type 6(a). Hypersthene-bearing augite-hornblende-gabbro to diorite

[Hornblende-pyroxene-gabbro-diorite. p. 65]

Specimens collected at 1508, 1530, 1550, 1573, and 1688 m represent this type. Macroscopically they are dark green in colour, phanerocrystalline, with visible plagioclase feldspars and hornblende. The other mafic minerals are not distinctly recognisable from one another. The rocks are sometimes traversed by thin epidote veins. Microscopically they consist of,

P. C.: Plagioclase feldspar > clinopyroxenes > hornblende.
S. C.: Hypersthene.
A. C.: Opaque ores, apatite.
A. P.: Chlorite, epidote.
Ff.C.: Chlorite and epidote.

The total volume of the mafic minerals is slightly higher than that of the feldspar. The total volume of the clinopyroxenes represented by diallage and augite is slightly higher than the volume of hornblende. In table (5) are given the percentages of anorthite in the plagioclase feldspars and the optical characters of the femic constituents.

Table 5

Section Number	Percentage of An	Augite		Hornblende [5])		Hypersthene
		$(+)2V$	c/Z	$(-)2V$	c/Z	$-2V$
1508	44%	$+51°$	$41°$	$-72°$	$27°?$	—
1530	43%	—	—	—	—	$-60°$
1573	42%	$+56°$	$41°$	$-69°$	$16°$	$-50°$
1688	49%	$+62°$	$44°$	$-74°$	$17°$	—

The degree of cataclasis is slightly higher than in the previous types. The constituent minerals exhibit the various stress effects described in the previous sections.

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[5]) Pleochroism of hornblende: X = straw-yellow; Y = green; Z = green with a brownish tinge.

In the first three sections the plagioclase corresponds in composition to an intermediate andesine. In section 1688 it is near an acid labradorite.

The clinopyroxenes are also similar in their optical properties to those described in type 4(a). Generally, pale green diallage is more abundant than colourless augite. They belong to a type rather rich in the diopside molecule. As in types 4(a) and 5(a), wisps of hornblende having identical optical properties as the larger prisms of the sections are extensively developed and are due to recrystallisation of the granulated material around the margins of the clinopyroxenes.

Light rose-pink hypersthene prisms are found as a subordinate constituent in all the sections. They are optically negative with a maximum optical angle of 60°. In section 1573 the optical angle is 50° and suggests a type with $En_{65}Hy_{35}$. Sometimes the hypersthene is altered to a fibrous mesh of serpentine with a concomitant liberation of opaque ore dust in the mesh.

The hornblende prisms are similar to those described in types (3) and 4(a). They belong to the common hornblende series. In the absence of hornblende this type passes into type 6(b).

The porphyroclasts of the principal constituents often measure about 1 mm in their longer diameters. The ground mass is polymineralic and is partly recrystallised into a granoblastic matrix.

The structure of the rock is cataclastic-porphyroclastic.

Type 6(b). Hypersthene-diallage-gabbro. (Hyperite ?)

[Hornblende-pyroxene-gabbro-diorite or Fornale gabbro. pp. 65—66.]

Specimens collected at 1820 and 1850 m belong to this type. Macroscopically they are similar to type 6(a). Microscopically they consist of,

P. C.: Plagioclase feldspar > diallage + augite > hypersthene.
S. C.: Hornblende.
A. C.: Opaque ores, apatite.
A. P.: Epidote and chlorite.

The rocks of this type do not differ much in their mineralogical composition from type 6(a) except that hornblende is almost absent or present only as quite a subordinate constituent. The femic minerals and the feldspars are about equally abundant. Among the pyroxenes, diallage is predominant over augite and hypersthene.

The plagioclase feldspar is an acid labradorite (50% anorthite).

The clinopyroxenes are optically positive with an optical angle of $58°$ and $c/Z = 43°$ and are identical to those in the previous type.

Hypersthene is light rose-pink in colour, optically negative with an optical angle of $69°$. It corresponds to a type with En_{77} and Hy_{23}. The prisms have altered here and there to a mesh-work of pale green serpentine with the liberation of opaque ore dust. Fig. 16 gives a general idea of the structure and the relationship between the constituents. The severe cataclasis gave rise to a polymineralic matrix in which the porphyroclasts frequently measure up to 1 mm in their longer diameters.
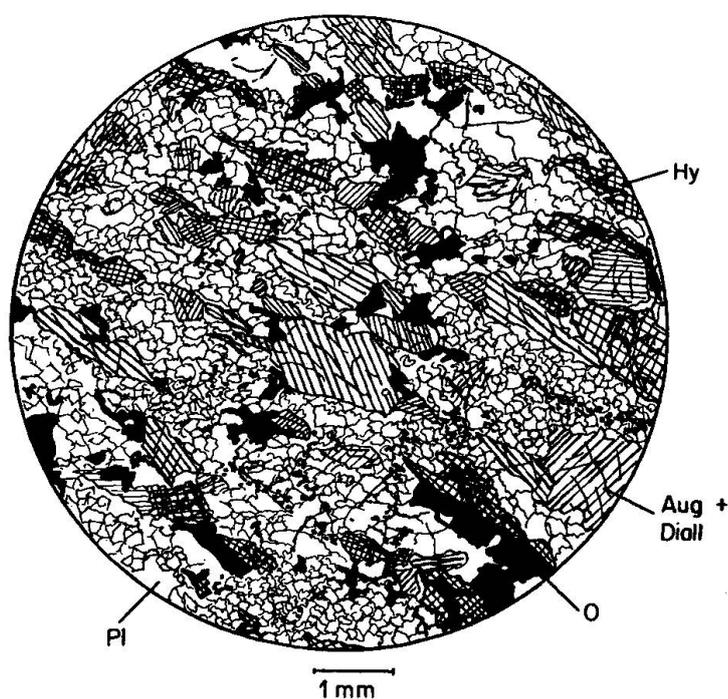
Fig. 16 (Section 1850). Hypersthene-diallage-gabbro (hyperite?, type 6a) showing a cataclastic-porphyroclastic structure. Note the almost complete absence of hornblende in the section.

One of the specimens (1820) was analysed and the values obtained are compared with those of a hyperite of W. C. BRÖGGER (1934). Further rocks quoted for comparison are a hornblende-gabbro and a hypersthene-hornblende-gabbro (also from the Ivrea zone described by M. BERTO-LANI, 1954). Included in the table (6) are Niggli values of all the above rocks and in addition the values of Niggli's standard hornblendic and eucritic magma types are quoted.

Table 6

	2 (1820)	a	b	c	d	e
SiO_2	43.83	46.27	46.88	45.70		
Al_2O_3	11.59	13.78	13.58	17.02		
Fe_2O_3	10.95	5.59	2.93	6.13		
FeO	7.56	11.66	10.52	8.91		
MnO	0.15	0.19	0.08	0.07		
MgO	6.60	5.05	7.80	6.57		
CaO	11.60	9.07	12.04	11.08		
Na_2O	1.97	2.94	1.95	2.06		
K_2O	0.24	1.10	0.38	0.37		
$+H_2O$	1.90	0.41	2.36	1.37		
$-H_2O$	0.03	—	0.06	0.10		
TiO_2	3.50	3.43	1.11	1.08		
P_2O_5	—	0.51	—	—		
S_2	0.04	0.14	0.33	0.20		
Others	—	0.09	—	—		
Total	99.96	100.23	100.02	100.66		
si	95	108	103	99	80	100
al	15	18.8	17.5	21.5	15	18
fm	53	50.3	49.5	47.5	60	55
c	27	22.6	28.5	26	20	24
alk	5	8.3	4.5	5	5	3
k	0.06	0.2	0.14	0.11	—	—
mg	0.40	0.28	0.52	0.45	—	—

Basis

Kp	Ne	Cal	Cs	Fs	Fa	Fo	Ru	Q
0.7	11.4	14.2	11.4	12.3	9.5	14.6	2.6	23.3

Kata-standardnorm

Or	Ab	An	Wo	En	Hy	Mt	Ru	Q	Σ
1.5	19.0	23.5	15.2	19.5	4.5	12.3	2.6	1.9	100.0

Analysis (2): Hyperite collected at 1820 m from the Maggia hydro-electric tunnel. Analyst J. JAKOB.

Analysis a) Average of three analyses of olivine-free hyperites. W. C. BRÖGGER. Vid-Selsk. Skr. 1, Mat-nat. kl., p. 101 (1934).

Analysis b) Hornblende-gabbro. Above Cassarole. Ivrea zone. M. BERTOLANI. Rendic. Soc. Min. Italiana. 10. p. 135 (1954).

Analysis c) Hypersthene-hornblende-gabbro. ibid., p. 105.

Analysis d) Niggli values of hornblenditic magma. P. NIGGLI (op. cit.), p. 361 (1936).

Analysis e) Niggli values of eucritic magma. ibid., p. 360.

The olivine-free hyperites of W. C. Brögger (1934) (analysis a) consist of diallage, plagioclase feldspar, subordinate amounts of hypersthene as principal constituents, while apatite and opaque ores are constant accessories. Reddish-brown biotite and an alamandine-rich garnet are rarely present. Alkali-feldspar is absent. T. F. W. Barth (1944) mentions that the diallage is fresh and light green in colour, optically positive with an optical angle of $58°$ and corresponds in composition to about $Di_{65}He_{35}$. Orthopyroxene is bronzite, strongly altered along margins, and cracks to a mixture of talc and chlorite. The mineral is optically negative with an optical angle of $86°$ and corresponds in composition approximately to $En_{80}Hy_{20}$.

The hornblende-gabbro (analysis b) occurs as a dike in the schists and gneisses adjacent to the main Ivrea basic rocks and is in contact with a calc-silicate rock. It consists predominantly of hornblende, plagioclase feldspar, and augite as principal constituents, while apatite and opaque ores are accessories. Plagioclase is a basic andesine with 46% anorthite content. Hornblende is a basaltic variety. The volume percentages of the constituent minerals are: basaltic hornblende 53.2%; augite 13.0%; plagioclase feldspar 33.5% opaque ores 0.3%.

The hypersthene gabbro (analysis c) occurs in the main Ivrea basic rocks as dikes with sharp contacts against the adjacent basic rocks. They do not seem to M. Bertolani (op. cit.) to be "cognate schliers" or "magmatic segregations". They are real dikes intruding the other basic rocks of the main mass. They are fine-grained and somewhat darker in colour than the adjacent rocks. Microscopically they consist or plagioclase feldspar, hypersthene, augite, and hornblende as principal constituents, and ilmenite, apatite, and zircon as accessory minerals. Hornblende has an extinction angle of $22°$; hypersthene is optically negative with an axial angle of $54°$; augite is optically positive with an optical angle of $59°$ and $c/Z = 45°$. The feldspar is a basic labradorite with 65% anorthite content. The volume percentages of the constituent minerals are: plagioclase feldspar 55.9%; hypersthene 22.0%; augite 10.5%; hornblende 8.3%, and ilmenite 3.3%.

From table (6) the following points of interest can be deduced.

1. The "si" values of all the rocks and those of the hornblenditic and eucritic magma types do not show any noteworthy differences.

2. The "al" value of 1820 (analysis 2) is slightly lower than the others. It is, however, identical to that of the hornblenditic magma type (d).

3. The "fm" values are similar in all the rocks, though the hornblenditic magma type has a slightly higher value than the others.

4. For all the rocks the value of "c" is within the permissible limits of an eucritic magma type.

5. The value of "alk" is slightly higher in the olivine-free hyperite (analysis a) and lower in the eucritic magma type (e). In the other analyses the values are identical.

The general similarity of the Niggli values of the different rocks and magma types compared above permits the conclusion that they are derived from a hornblenditic or eucritic magma. As such they appear to represent differentiated variants of the common basic parent magma from which the basic rocks of the Ivrea zone have crystallised.

Type (7). Mylonite

Specimens collected at 2005, 2015, 2020, and 2030 m represent this type. They are pale green to yellowish-green in colour, fine-grained, and consist of yellowish-green epidote and specks of feldspar. They are in general compact, but friable. Microscopically they consist of,

P. C.: Epidote $\gg$ quartz $\sim$ plagioclase feldspar.
S. C.: Hornblende.
A. C.: Opaque ores, leucoxene, apatite.
A. P.: Epidote and chlorite.
Ff.C.: Epidote, calcite, chlorite, zeolites.

Colourless to pale yellow epidote is the predominant constituent forming the principal matrix of the section. Most of the grains are xenomorphic to sub-idiomorphic with random orientations and range in size from less than 0.1 mm to 0.3 mm.

Plagioclase feldspar is cloudy. It is extensively altered to clinozoisite, sericite, and epidote. The twin lamellæ are obliterated and some of the grains in the matrix have been recrystallised and now contain shreds of pale green chlorite and grains of epidote. The refractive index of the grains is less than that of canada balsam indicating that they are not more basic than oligoclase.

Colourless and xenomorphic quartz occurs either as lenticular pockets or as sinuous bands in the epidote matrix. The grains no longer exhibit undulose extinction and show a granoblastic structure. They are recrystallised material.

Crushed and granulated prisms of green hornblende, in various stages of alteration to epidote and chlorite, are frequently seen in the

sections. Fig. 17 shows a few such hornblende prisms in the process of alteration to epidote.

Opaque ores are irregular and form sinuous streaks and trains in the matrix. Some of the grains are altered to leucoxene.
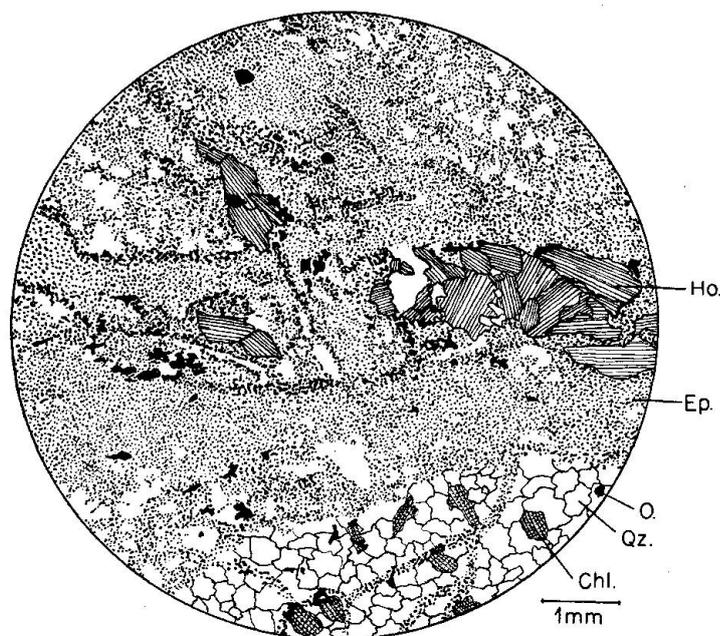
Fig. 17 (Section 2005). Mylonite (type 7) derived by the complete destruction and alteration of the original constituents of a basic rock at 2005 m. The stippled area contains micro-crystalline aggregates of epidote forming veins which traverse the section in all directions. Crushed and fractured prisms of hornblende are still to be seen as relicts in the epidote matrix where they undergo alteration. Towards the lower part of the section recrystallised quartz with a few flakes of chlorite forms a granoblastic mass.

In section 2030 the place of epidote is taken by a mosaic of interwoven pale green chlorite flakes around the quartz and feldspar grains. The latter are completely recrystallised and contain wisps of pale green chlorite and grains of epidote. The rock, as a whole, resembles an albite-chlorite-epidote rock.

In addition, all the sections are traversed by veins of epidote and chlorite or such containing calcite or zeolites (prehnite).

The structure is micro-chorismatic. The presence of fractured and granulated prisms of relictic hornblende in a granoblastic matrix of epidote indicates a cataclastic derivation (see fig. 17).

Type (8). Talc-serpentine-chlorite-magnesite-schist

[Corresponding name is lacking.]

A specimen collected at 2180 m belongs to this type. It is somewhat dark grey in colour, fine-grained, soapy to the touch and distinctly schistose in texture. Microscopically it consists chiefly of an intimately interwoven mesh-work of fibrous serpentine and flakes of talc. In addition pale green chlorite flakes are strewn all over the mesh-work. Magnesite is found as minute colourless grains. It is not so abundant as the other constituents. It forms thin lenticular pockets and layers. Opaque ore grains are scattered all over as fine dust.

The structure is more or less fibroblastic with a plumose appearance. The section is also traversed by thin veins of chlorite and quartz indicating a minor degree of cataclasis as well.

Section 2

Pegmatites

The basic rocks are injected by feldspathic pegmatites. They have been described by P. WALTER (1950) and G. M. PARASKEVOPOULOS (1953). Some further observations are recorded here. The pegmatites range in size from a few centimeters up to 5 to 6 meters in width and have injected the Ivrea basic rocks concordantly and discordantly. Three specimens were collected from pegmatites at 1365, 1530, and 1550 m. They are greyish-white in colour, phanerocrystalline, coarse-grained with visible quartz and feldspar. The feldspar crystals are deformed and exhibit a parallel orientation to one another. Microscopically, the rocks consist of polysynthetically twinned plagioclase feldspar and quartz as principal constituents with apatite and zircon as accessory minerals. The first named minerals show strong undulose extinction, plastic deformation, incipient fracturing, and marginal granulation. The feldspar is an intermediate andesine (38% anorthite content) and is almost identical in its composition to that found in the adjacent basic rock into which the pegmatite intruded. Similar observations regarding the identity in composition of the feldspars of the pegmatites and the adjacent basic rocks are recorded by P. WALTER (1950) who concludes that the pegmatites perhaps represent late residual solutions of the parent basic magma which gave rise to the basic igneous rocks of the Ivrea zone. Unfortunately the limited number of available specimens made it difficult to verify this hypothesis.

Contact between the pegmatites and the basic rocks

The contact between the pegmatites and the basic rocks is always sharp. Of the few available specimens examined only one met with at 1530 m exhibits abundant development of light pink garnets measuring about 0.5 mm along its contact. Such garnets are restricted to a narrow zone of about 2 cm width and are absent both within the body of the pegmatite and of the adjacent basic rock (type 6 a). The garnets in the above case are microscopically light rose-pink in colour, xenomorphic to amoeboid and poikilitic in habit with some inclusions of plagioclase and a few hypersthene prisms. The refractive index is 1.777 ± 0.003 and this value corresponds to a type rich in the almandine molecule. The above value is decidedly lower than that measured on garnets of the kinzigite zone and in the inclusions discussed in section (3). This indicates that the garnets in the present case contain a higher proportion of Ca and Mg than the others. This is what is to be expected since the garnet is due to a reaction between the pegmatitic material and that of the basic rock (type 6 a). Why garnets are not developed along the contacts of the other pegmatites is not clear.

Section 3

Inclusions in the basic rocks

With the exception of the pegmatites, all rocks exhibiting a mineralogical composition different from that of the basic rocks in which they are found enclosed, are regarded here as "inclusions". Inclusions met with in the southern part of the Ivrea zone show macroscopic characters very similar and almost identical to those of the kinzigite gneiss. They consist of dark brown biotite, plagioclase feldspar, and abundant garnet as their principal constituents. In the northern part of the Ivrea zone (say beyond 1500 m), the inclusions do not always macroscopically resemble the kinzigite rocks. Their microscopic characters are described and their relationship to the basic rocks, the kinzigite rocks, and the Canavese rocks is discussed. The inclusions occur both concordantly and discordantly and do not exceed a width greater than five meters. An inclusion found at 1085 m is the most striking example of discordant disposition. The inclusions occur as bands and lenticular bodies and Dr. E. DAL VESCO (Geologist, Maggia Hydro-Electrical Company Ltd.) in a personal communication states that the contacts between the inclusions

and the enclosing basic rocks have in several cases been obliterated. This is due to tectonic movements and is to be explained by the fact that such contacts between two texturally different rock masses act as weak planes and fall an easy prey to the action of shearing stress. In those few cases where a trace of the contact remains, abundant development of garnet usually occurs along the contact both in the basic rock and in the inclusion. Unfortunately, contact specimens are not available for study from all the inclusions.

Certain doubts can be expressed regarding the foreign characters of some inclusions described in this section. They are nevertheless included and their relationship to the basic rocks and to the other inclusions is discussed. Each of the inclusions has been given a name and the corresponding name proposed by P. WALTER (1950) is written in square brackets for easy comparison.

PETROGRAPHY OF THE INCLUSIONS

Type 1(a). Garnet-chlorite-gneiss or garnet-biotite-gneiss

[Biotite and garnet-biotite-gneisses. pp. 73—76.]

Such inclusions are found at 1310, 1502, and 1605 m. Specimen 1310 is contained in the basic rock type 1(a) (hornblende-plagioclase-diorite-amphibolite) and injected by veins of type 1(b).

1502 and 1605 are enclosed in the basic rock type 4(a). (Pyroxene-hornblende-gabbro-diorite.)

The inclusion 1310 is somewhat whitish-grey in colour, phanero-crystalline, fine- to medium-grained with visible plagioclase feldspar, garnet, and pale green chlorite. Light pink garnets are rather abundantly developed along the contact with the basic vein 1(b). It is also traversed by thin veins of pale green epidote. The rock is massive, compact, and lacks gneissose texture.

Specimens 1502 and 1605 are also white to whitish-grey in colour, with streaks of dark brown biotite flakes in parallel arrangement giving rise to a distinct foliated and gneissose texture. They are medium- to coarse-grained, phanerocrystalline with visible quartz, feldspar, biotite, and light pink garnets. In 1502 garnets occasionally attain a size of 3 to 4 mm. As the specimens were not collected directly from the contacts with the basic rocks, their relationship to the latter is not known.

Microscopically they consist of,

P. C.: Plagioclase feldspar $\gtreqless$ quartz $\succsim$ garnet.
S. C.: Biotite, sillimanite.
A. C.: Apatite, zircon, opaque ores.
A. P.: Chlorite, epidote, sericite, clinozoisite.
Ff.C.: Epidote, chlorite.

The relative proportions of the principal constituents are variable in the three sections. Colourless, xenomorphic, and granulated plagioclase feldspar showing twinning and distinct undulose extinction is constantly present in all three sections. The crystals have altered to cloudy aggregates of fine sericite scales. The degree of alteration and other cataclastic effects are of a higher order in 1605 than in the previous sections. The proportion of plagioclase feldspar in 1310 is higher than that of quartz and garnet, while in the other two sections it is more or less equal to or even slightly less than the volume of quartz. It corresponds to an intermediate andesine (41% anorthite) in 1310 and 1502. The extensive alteration to sericite in 1605 prevented a suitable determination. However, the refraction is more or less equal to that of canada-balsam suggesting that the composition cannot be more basic than that of an intermediate andesine.

Quartz occurs as xenomorphic and colourless crystals interstitial between the plagioclase feldspars in 1502 and 1605. It sometimes forms granoblastic aggregates of lenticular shape or bands of grains lacking undulose extinction. This suggests recrystallisation of the mineral along weak shear planes during the action of stress. When section 1605 is viewed under crossed nicols with the gypsum plate inserted at 45°, the interference tint of all the quartz grains is remarkably the same. This indicates a marked preferred orientation of the crystals. Quartz is almost absent in 1310.

Biotite occurs as tiny dark brown flakes and is similar in its optical characters to that in the kinzigite rocks. In a few instances, especially in 1502 and 1605, the flakes form a sheath round the garnets. In 1310 almost all the biotite flakes have altered to pale green chlorite with accompanying honey brown grains of rutile.

Light rose-pink garnets build relatively large xenoblasts measuring up to 3 mm in size. Their refraction in 1310 is 1.781 ± 0.003, and in 1502 1.775 ± 0.003. In both cases it corresponds to a type rich in the almandine molecule. In 1502 the garnets are somewhat richer in Mg and Ca. But the difference is not so great as to warrant any special explanation. Three types may be distinguished according to their crystal habit.

Type (I)

The garnets are xenoblastic, amoeboid, and spongy in their crystal habit, with numerous poikilitical inclusions of plagioclase grains. A few tiny flakes of pale green chlorite and a few opaque ore grains are also present. They are especially typical of sections 1310 and 1502. Fig. 18 shows one of these garnets crystallising along the intergranular boundaries of the plagioclase feldspars in section 1310. The crystal habits and optical properties of the garnets of this section are similar to those in the adjacent amphibolite of rock type 1(b) (see fig. 9). The plagioclase grains enclosed
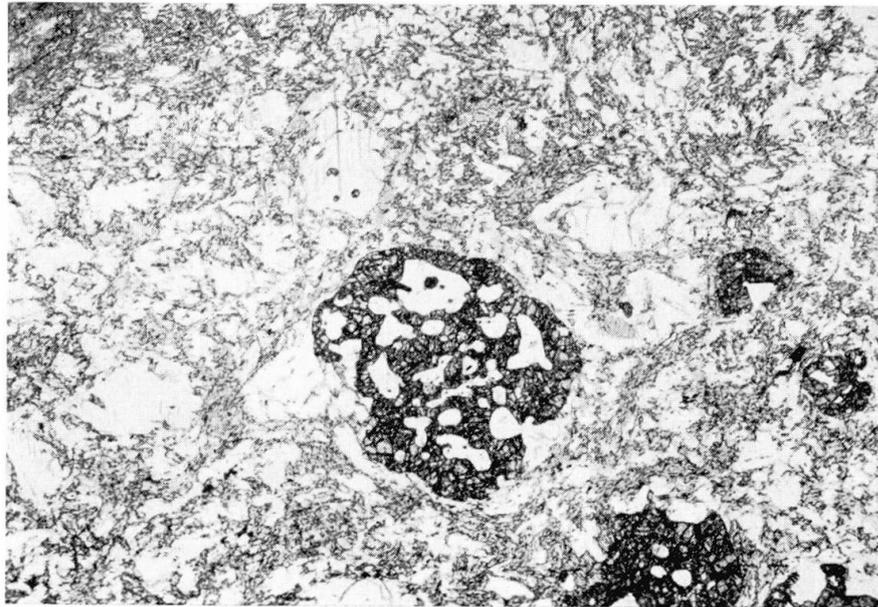
Fig. 18 (Section 1310). A spongy, poikilitic, and amoeboid garnet crystallised along the intergranular boundaries of the original constituents of type 1a gneiss inclusion after it was incorporated into the amphibolite (type 1a). (10×.)

in the garnets show a certain degree of rounding indicating that the garnets are the later crystallisation. Transitions between a poikilitic stage and a non-poikilitic habit are visible in these sections. In general the poikilitic and amoeboid garnets are more numerous than the non-poikilitic ones. As already discussed in an earlier section, the garnets of this type are thought to have crystallised in this inclusion subsequently to its incorporation into the basic rock.

Type (II)

Garnets of this type are non-poikilitic, xenomorphic to sub-idiomorphic, and rarely enclose other constituents. They are optically similar

to those of type (I), but it is not easy to decide how many of them are original and how many are subsequent crystallisations derived from type (I). They are found especially in section 1605. Most of them are traversed by thin fractures along which alteration into chlorite has taken place.

Type (III)

Pseudomorphs of pale green chlorite after the crystal habit of the original garnets represent this type. They are seen in section 1500 collected from the margin of an inclusion found at 1502 m. In addition, the section contains both poikilitic and non-poikilitic garnets which are severely fractured and partially altered to chlorite with the liberation of a few epidote grains. In fig. 19 are shown two chlorite pseudomorphs distinctly showing the original contours of the garnet. Such transformations suggest that the inclusion at 1502 m has been subjected to strong cataclasis along its contact with the basic rocks.

In section 1310 a few colourless bundles of sillimanite are present, while in section 1502 the presence of sillimanite is suspected.

Besides the alteration products the fractures of the sections are filled with a mixture of epidote and chlorite. The structure of the rock is cataclastic.
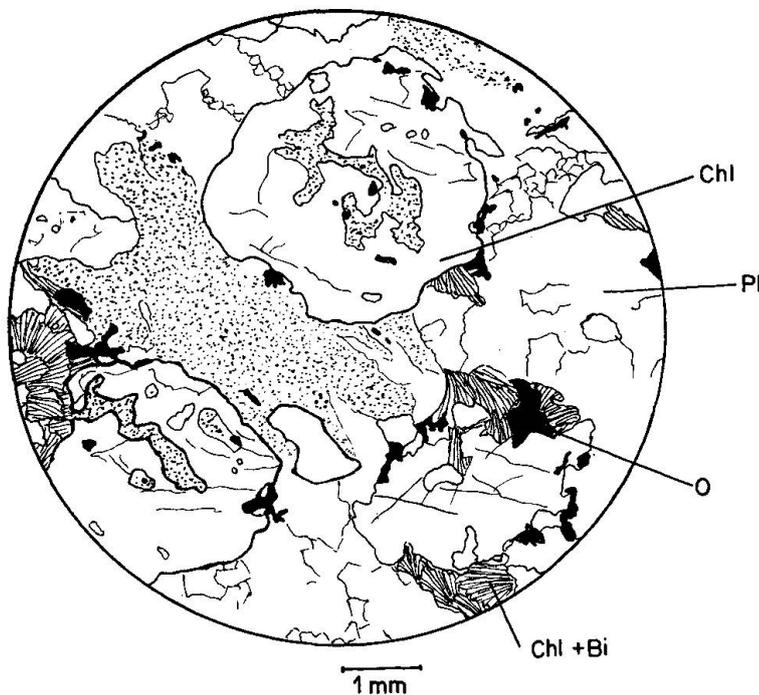
Fig. 19 (Section 1500). Two chlorite pseudomorphs after garnets in type 1a preserving the original contours of the latter mineral. Note the pseudomorphs containing inclusions of cloudy plagioclase (stippled).

Type 1(b). Garnetiferous biotite-sillimanite-gneiss

[Nicht dioritische Gesteine. Non-dioritic rocks of the northern margin
of the Ivrea zone. p. 69.]

Specimens collected from inclusions found in the basic rocks of
type 2(a) (hornblende-plagioclase-diorite-amphibolite) towards the nor-
thern margin of the Ivrea zone at 2005, 2125, and 2160 m represent this
type. The first two specimens are dark greyish in colour with a mottled
appearance due to the presence of quartz and feldspars. The third one
is greyish-green in colour. They are phanerocrystalline, fine- to medium-
grained, compact, and somewhat gneissose in texture. Specimen 2005
exhibits well polished surfaces with slickensides and macroscopically
deformed and elongated garnets as lenticular, more or less fractured
grains. Microscopically they consist of,

P. C.: Plagioclase feldspar > quartz.
S. C.: Garnet ∼ Biotite > sillimanite.
A. C.: Opaque ores, apatite, orthite, zircon(?).
A. P.: Chlorite, epidote, sericite.
Ff. C.: Chlorite and epidote.

Compared to type 1(a), this type exhibits a more severe degree of
cataclasis, deformation and alteration of the constituents. The relative
proportions of the principal constituents is slightly variable. Generally
plagioclase is predominant over quartz and the other constituents. Owing
to widespread alteration to cloudy aggregates of clinozoisite and sericite,
the twin lamellæ of the feldspars have been completely obliterated. The
margins also appear indistinct. However, in section 2160 it was possible
to determine the composition of the feldspar. It corresponds to an
intermediate andesine with 40% anorthite and is identical with that of
type 1(a).

Colourless and xenomorphic quartz occurs interstitially between the
other constituents forming granoblastic aggregates in lenticular pockets
and sinuous bands.

The garnets are pale rose-pink in colour and are similar to those
described in 1(a). Amoeboid, spongy, and poikilitic as well as non-poi-
kilitic garnets are present. One of these spongy and amoeboid garnets
from section 2160 is shown in fig. 20. The garnet has feldspar grains,
a few flakes of chlorite and opaque ores as poikilitic inclusions. In all
essential features the garnet resembles those described and illustrated
in figures 2 and 18. Hence, it is assumed that the mineral has developed

in the inclusion subsequently to its incorporation into the basic rocks. As the garnets in 2005 and 2125 have been deformed and elongated under the action of stress, it has not been possible to ascertain whether they are original grains or later crystallisations.

Dark brown biotite is much altered to pale green chlorite with the liberation of honey-brown grains of rutile. The flakes are frequently torn into minute wisps due to the severe cataclasis.
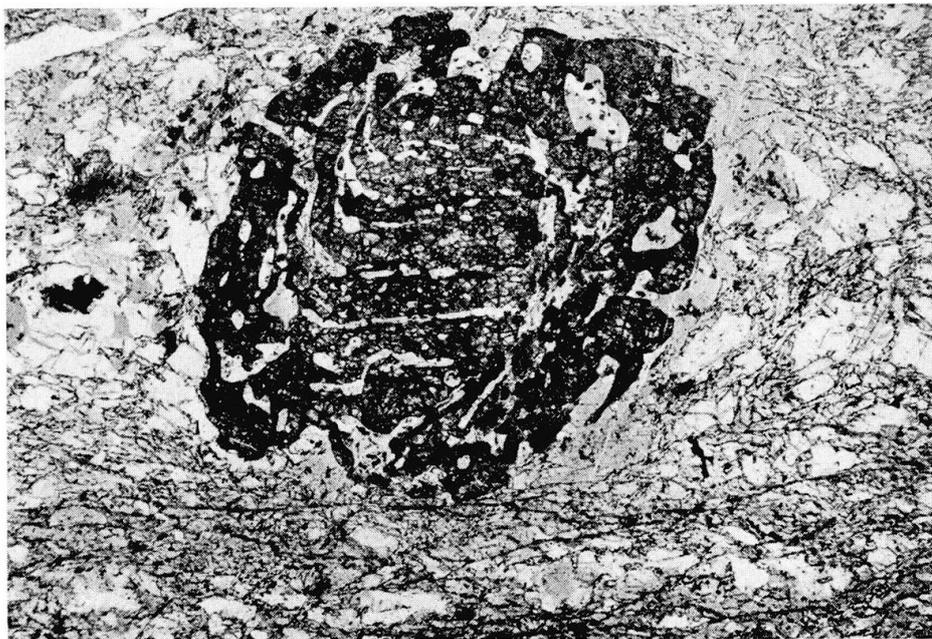
Fig. 20 (Section 2160). A spongy and poikilitic garnet crystallised in the gneiss inclusion (type 1b). The white area is altered plagioclase feldspar. The grey area represents chlorite. (10×.)

Colourless sillimanite is much fractured and shattered to minute grains. Some of the grains are altered to sericite. The structure is cataclastic.

Type (2). Garnet-plagioclase fels

[Garnet-plagioclase fels. pp. 77—80.]

Specimens collected at 1310, 1597, and 1900 m belong to this type. They do not contain biotite as abundantly as the previous types. In colour they are white to whitish-grey with a mottled pink appearance due to the presence of a number of garnet grains. They are compact, phanerocrystalline, fine- to medium-grained rocks with visible quartz,

feldspar, and pink garnets. Dark brown biotite is rarely seen as thin
streaks among the constituents. Microscopically they consist of,

P. C.: Plagioclase feldspar $\geq$ quartz $\gtrsim$ garnet.
S. C.: Biotite.
A. C.: Apatite, opaque ores.
A. P.: Chlorite, sericite, epidote, clinozoisite.
Ff.C.: Epidote, chlorite.

The plagioclase and quartz occur in more or less equal proportions.
Sections 1597 and 1900 show a higher degree of cataclasis and alteration
of the constituents to secondary minerals. Fresh and twinned feldspars
are present only in 1310. Their composition corresponds to a basic an-
desine with 44% anorthite. In the other two sections (1597 and 1900)
the feldspars have altered to cloudy aggregates of clinozoisite, sericite,
and grains of epidote.

Colourless and xenomorphic quartz forms lenticular pockets or
sinuous bands interstitial between the other constituents. Undulose ex-
tinction, sutured and interlocking margins are still recognisable in these
grains. The volume of these alteration products is about equal to the
content of fresh minerals.

Garnet is pale rose in colour, xenomorphic to idiomorphic in 1310,
and xenomorphic and poikilitic in 1507 and 1900. In the two latter the
mineral has been fractured and altered to pale green chlorite. The re-
fraction of the garnet in 1310 is 1.774 ± 0.003. It is a type rich in the
almandine molecule, but containing appreciable amounts of Ca and Mg.
It has not been possible to ascertain whether they are the original cons-
tituents or whether they crystallised later after the inclusions had found
their way into the basic rocks.

Dark brown biotite is rare, but a few unaltered flakes are observed
only in 1310. It is completely altered to pale green chlorite in 1597 and
1900. The structure of the rocks is cataclastic-porphyroclastic.

The volume of alteration products is more or less equal to the volume
of fresh constituents in sections 1597 and 1900.

Type 3(a).   Plagioclase-garnet-hypersthene-fels (?)

[Plagioclase-garnet-fels. pp. 77—80.]

A specimen collected at 1384 m represents this type. Its northern
contact is against the basic rock type 5(b) (hypersthene bearing garneti-

ferous pyroxene-hornblende gabbro-diorite) and the southern margin against type 1(a) (hornblende-plagioclase-diorite-amphibolite). The rock is compact, light grey in colour with a mottled reddish-brown appearance due to the presence of a number of garnets. It is fine- to medium-grained with visible feldspars and has a random texture. The mafic constituents cannot be clearly distinguished from one another. Microscopically the rock consists of,

P. C.: Plagioclase feldspar > garnet $\sim$ hypersthene.

S. C.: Biotite $\sim$ hornblende > quartz.

A. C.: Opaque ores > apatite > orthite, zircon, sillimanite(?).

A. P.: Serpentine.

Plagioclase feldspar is fresh and is severely stressed showing strong undulose extinction, granulation, and deformation. It corresponds in composition to a basic labradorite or acid bytownite with an anorthite content of 70%.

Hypersthene is light rose-pink in colour and is also highly stressed. Many of the prisms have altered to a fibrous mesh-work of pale green serpentine accompanied by opaque ore grains. It is optically negative with an optical angle of 51° and belongs to a type with $En_{64}Hy_{36}$.

Garnet is pale rose in colour, ranges in size from 0.2 mm to 1 mm, and has a refractive index of 1.790 ± 0.003. As in previous cases, it is an almandine-rich type with a high proportion of Fe over Mg and Ca. The refractive index is slightly higher than those found in the other inclusions, but it is lower than that of the garnets of the kinzigite zone. Two types of garnets are to be found in this section (cf. type 1 a).

Type (I)

These garnets occur as small sub-idiomorphic to almost idiomorphic crystals and are non-poikilitic. They are scattered all over the section.

Type (II)

The garnets of this type are generally larger than those of type (I) and most of them are xenomorphic, amoeboid, and poikilitic in their crystal habit enclosing opaque ores, tiny flakes of biotite and frequently feldspar grains which show rounded margins. These garnets are very similar in their crystal habit to that shown in fig. 18. There is no doubt that they have crystallised along the intergranular boundaries of the plagioclase feldspars, possibly subsequently to the incorporation of this

inclusion into the basic rocks. Alternatively they may be due to assimilation of some aluminous material of the inclusion by the basic rocks of this locality.

Chestnut-brown biotite forms flaky streaks and sometimes fringes the hypersthene prisms or garnet crystals. Some of these flakes have altered to pale green chlorite.

Pale green to green hornblende surrounds some garnets. Part of this hornblende seems to have been derived from hypersthene (?) as a result of its alteration.

Colourless quartz is seen only here and there. In one such quartz grain found enclosed in one of the garnets, fine and colourless needles of sillimanite are present.

It is interesting to note that reddish-brown orthite is common though not an abundant accessory component.

In view of its interesting mineralogical composition, the rock was analysed and the results compared with those of two rocks having an approximately similar composition (table 7). The Niggli values are included in the table and are compared with those of a standard normal gabbro magma.

Table 7

	3 (1384)	a	b
SiO_2	45.67	46.88	45.15
Al_2O_3	12.96	13.58	13.40
Fe_2O_3	—	2.93	2.97
FeO	16.65	10.52	13.19
MnO	0.24	0.08	0.19
MgO	5.09	7.80	4.23
CaO	9.79	12.04	9.79
Na_2O	2.96	1.95	2.47
K_2O	0.44	0.38	0.49
$+H_2O$	1.12	2.36	5.04
$-H_2O$	0.07	0.06	2.41
TiO_2	2.14	1.11	0.39
P_2O_5	0.09	—	0.12
S_2	3.50	0.33	—
	100.72		
$S_2=O$	0.87		
	99.85	100.02	99.84

	3 (1384)		a	b	c
	With Pyrite	Without Pyrite			
si	107	115	103	110	108
al	18	19.2	17.5	19.4	21
fm	50	46.3	49.5	48.3	51
c	25	26.5	28.5	25.7	22
alk	7	8	4.5	6.6	6
k	0.09	0.09	0.14	0.11	0.2
mg	0.35	0.41	0.52	0.32	0.5

Basis

Kp	Ne	Cal	Cs	Fa	Fo	Pr	Ru	Q
1.5	15.9	12.6	8.4	15.1	10.6	9.1	1.4	25.4

Kata-standardnorm

Or	Ab	An	Wo	En	Hy	Fo	Fa	Ru	Cp	Pr
2.7	28.5	22.2	11.9	4.1	5.9	8.1	11.7	1.6	0.1	3.2

Analysis (3): Plagioclase-garnet-hypersthene fels collected at 1384 m in the Verbano hydro-electric tunnel. Analyst J. JAKOB (Niggli values with and without pyrite).

Analysis a) Hornblende-gabbro quoted in table 6 of section (1) (Chapter III).

Analysis b) Quartz-gabbro from Brogo, New South Wales. H. S. WASHINGTON: Chemical analyses of igneous rocks. Analysis no. 173, pp. 662 (1917). Analyst A. PAIN.

Analysis c) Niggli values of normal gabbroic magma type. P. NIGGLI (op. cit.). (The possible variations in the Niggli values of normal gabbroic magma are: si mostly between 120 and 92; al 17.5—23; c 18—26; alk ≥ 5, but less than 8.)

The differences in the Niggli values between the analysed rock and those chosen for comparison are negligible and the chemical similarity between the rocks is very pronounced. A fair agreement also exists between the analysed rock and the olivine-free hyperite previously quoted (table 6). On the other hand, analyses of the kinzigite rocks having a chemical composition approximately similar to that of 1384 are so far not available from this area. The kinzigite analyses quoted in table (1) in general contain a high proportion of alumina and alkalies and a relatively low content of calcium compared to those of 1384. This fact suggests that the present rock may not be a kinzigite inclusion.

On the contrary, the agreement between the Niggli values of 1384 and those of the quoted analyses speaks in favour of the present rock

being of magmatic origin with affinities to the gabbro family. However, the occurrence of poikilitic garnets crystallised along the intergranular boundaries of the other constituents, the absence of the same in the hypersthene-bearing basic rock-types described in the preceding section (1), and the presence of subordinate amounts of sillimanite in quartz raises certain doubts as regards the magmatic parentage of the present rock. It seems possible that the rock may be one of the following things: (1) an inclusion, or (2) a hybrid between a kinzigite inclusion and the adjacent basic rock (type 5 b), or (3) the product of contact metamorphism by a pegmatite on the above basic rock, or (4) a late magmatic segregation. Unfortunately sufficient field data are not available to decide its geological and genetical relationship more accurately. The rock is tentatively considered as an inclusion of sedimentary origin (marl).

Type 3(b). Garnet-plagioclase-biotite-hypersthene-fels

[Garnet-plagioclase-fels. pp. 77—80.]

Only one specimen collected at 1467 m belongs to this type. It is enclosed in basic rock type 1(a) (hornblende-plagioclase-diorite-amphibolite) or 4(a) (pyroxene-(augite)-hornblende-diorite-gabbro). Macroscopically, the rock is similar to inclusion 3(a). The mafic minerals are, however, not as abundant as in the previous type. It contains abundant garnets. Microscopically, it consists of,

P. C.: Plagioclase feldspar > garnet > quartz.
S. C.: Biotite ∿ hypersthene.
A. C.: Opaque ores, apatite.
A. P.: Serpentine, sericite.

This type differs from type 3(a) in the lower basicity of plagioclase feldspar and in the lower hypersthene content.

All the constituents have been fractured, granulated, and sometimes deformed. However, alteration of the original constituents is not common.

The feldspar is an intermediate andesine with 37% anorthite. It sometimes altered to sericite.

Colourless and xenomorphic quartz occurs interstitially between the other minerals and shows strong undulose extinction.

Light rose-pink garnets measuring up to 0.8 mm and traversed by numerous thin fractures, are abundantly present. Both non-poikilitic and poikilitic types are met with, the latter having crystallised along the intergranular boundaries of feldspar and quartz. They are optically similar to those in type 3(a).

Biotite is chestnut-brown in colour. Some of the tiny flakes are found fringing the margins of the hypersthene prisms.

Hypersthene is not as abundant as in the previous type 3(a). A few prisms are found here and there and most of them have altered to large fibrous flakes of pale green serpentine and opaque ore dust. Relictic grains of hypersthene can still be observed in such a serpentine meshwork.

It is not clear how this type is related to the previous type 3(a) or (2) or to the basic rocks in which it is enclosed. It may be any one of the alternative products mentioned on page 148.

Type (4). Quartz-plagioclase-hypersthene-biotite-fels (?)

[Garnet-plagioclase-fels. pp. 77—80.]

A specimen collected from an inclusion adjacent to the northern margin of the garnetiferous basic rock type 5(b) at 1395 m represents this type. It is dark grey in colour, phanerocrystalline, fine- to medium-grained with visible feldspar and a few flakes of biotite. The rock exhibits a massive and random texture. Microscopically, it consists of,

P. C.: Plagioclase feldspar > hypersthene > quartz.

S. C.: Biotite.

A. C.: Opaque ores, apatite.

A. P.: Serpentine, sericite.

This type differs from 3(a) and 3(b) in the complete absence of garnet as a constituent. The degree of cataclasis is about the same as in the previous types.

The feldspar exhibits the usual cataclastic effects. It is an acid andesine with 32% anorthite. Pale rose-pink hypersthene occurs in relatively large prisms occasionally measuring up to 0.8 mm. It is optically negative with an optical angle of 53° indicating a composition corresponding to $En_{65}Hy_{35}$. In a few instances and particularly along the margins the prisms have altered to a fibrous mesh-work of light green serpentine plus abundant opaque ore dust.

Colourless and xenomorphic quartz with sutured and interlocking margins occurs as granoblastic aggregates in lenticular pockets or sinuous bands among the other constituents suggesting recrystallisation along weak shear planes during the action of stress.

Chestnut-brown to reddish-brown biotite is an abundant subordinate constituent. The tiny flakes are frequently found fringing the hypersthene prisms or forming flaky streaks in the matrix.

In spite of the moderate degree of cataclasis, the section preserves the original xenomorphic-granular to granoblastic structure as a relict in an otherwise cataclastic-porphyroclastic fabric. The grains of hypersthene and plagioclase have even and conserted margins in this relictic area.

In view of its interesting mineralogical composition, the specimen was analysed. The analysis (1395) along with its Niggli values are compared in table (8) with two others having similar compositions. The Niggli values of standard si-gabbro-dioritic magma are also quoted for comparison.

Table 8

	4 (1395)	a	b	c
SiO_2	53.82	53.64	51.65	
Al_2O_3	14.38	22.27	15.07	
Fe_2O_3	1.70	3.54	2.08	
FeO	8.82	3.85	9.65	
MnO	0.17	0.07	0.07	
MgO	5.52	1.39	5.48	
CaO	4.55	5.94	6.04	
Na_2O	2.79	4.31	2.57	
K_2O	1.71	2.96	0.98	
$+H_2O$	4.40	0.71	1.85	
$-H_2O$	0.06	0.12	—	
TiO_2	1.98	0.93	3.53	
P_2O_5	0.15	trace	1.15	
Total	100.05	99.73	100.12	
si	158	142	126.5	150
al	25	35	24.5	25
fm	49	32	49	43
c	14	17	18	22
alk	11	16	8.5	10
k	0.3	0.32	0.24	0.20
mg	0.48	0.17	0.45	0.50
ti	4.41	1.7	7.3	—
p	—	—	1.3	—

Basis

Kp	Ne	Cal	Fs	Fa	Fo	Ru	Cp	Q
6.4	15.9	13.8	1.9	11.0	12.1	1.5	0.3	37.1

Kata-standardnorm

Or	Ab	An	Wo	En	Hy	Ru	Cp	Ml	Q	Σ
10.7	26.5	23.2	0.1	15.1	13.6	1.5	0.1	1.9	7.3	100.0

Analysis (4): Quartz-plagioclase-hypersthene-biotite fels collected at 1395 m from the Verbano-hydroelectric tunnel. Analyst J. JAKOB.

Analysis a)   Quartz-biotite-pyroxene-hornblende   gabbro.   Massera,   Valle Sabbiola (Ivrea zone). M. BERTOLANI. Rendic. Soc. Min. Italiana. 10, pp. 117 (1954). This rock consists of biotite, quartz, orthorhombic pyroxene (hypersthene), orthoclase, plagioclase, monoclinic pyroxene, and hornblende as principal constituents, while apatite, rutile, zircon, pyrite, and ilmenite occur as accessory minerals. The feldspar is an andesine with 40% anorthite. Orthoclase is abundant as microperthitic crystals. Pale rose hypersthene is the principal mafic mineral. It is optically negative with an optical angle of 64°. Biotite is a dark brown variety, while monoclinic pyroxene and hornblende are present in subordinate quantities.

Analysis b) Diorite from Still Water Creek, Mohikinui, West Post District, New Zealand. H. S. WASHINGTON. Chemical analyses of igneous rocks. No. 238, pp. 400 (1917). No petrographic description is available.

Analysis c) Niggli values of standard si-gabbro-dioritic magma. P. NIGGLI (op. cit.). (The admissible variations in the values are: al $\geq$ 18; si 145—170; alk 7.5—12.5; fm 40—49; 2c 17.5—26.)

Minor differences in the Niggli values of 1395 and those of (a) and (b) are found to be present. They suggest that the present rock may not be of magmatic origin. On the other hand, the Niggli values of the silica-rich gabbro-dioritic magma agree fairly well with those of analysis (4) which would indicate a magmatic origin of the latter. In this case also, the available kinzigite analyses contain no examples similar to the present rock. There are, however, not enough analyses of the kinzigite rocks to decide whether the specimen under investigation was originally a sedimentary rock having a total chemical composition identical to that of a silica-rich gabbro-diorite or whether it is definitely a magmatic rock genetically related to the basic rocks of the Ivrea zone.

Type (5). Quartz-plagioclase-augite-fels

[Corresponding name is lacking.]

A specimen collected from an inclusion found in the basic rock type 1(a) (hornblende-plagioclase-amphibolite) at 1410 m represents this type. It is dark grey in colour with a mottled white appearance due to the presence of specks of feldspar among the dark constituents. The rock is fine- to medium-grained with a random texture. Microscopically it consists of,

P. C.: Plagioclase feldspar > augite > biotite.

S. C.: Quartz > garnet.

A. C.: Opaque ores, apatite.

A. P.: Chlorite.

The rock has been subjected to a severe degree of cataclasis leading to incipient mylonitisation. Semi-isotropic to isotropic bands of rock flour traverse the section from margin to margin. On account of this cataclasis, grains of feldspar suitable for determination are lacking. The refractive index of the feldspar is about equal to that of quartz suggesting that it may not be more basic than andesine. The crystals almost always contain dusty particles and minute opaque ore grains as impurities. Some of the grains have altered to sericite.

Colourless augite measuring up to 0.5 mm is the chief mafic mineral. It shows strong undulose extinction, fracturing, marginal granulation, and deformation. It is optically positive with an optical angle of 42° and $c/Z = 41°$. The optical data suggest that it may be a type rich in the diopside molecule.

Colourless and xenomorphic quartz shows strong undulose extinction and occurs either as individual grains or as thin lenticular pockets among the above two constituents.

Tiny flakes of chestnut-brown biotite frequently fringe the margins of the augite prisms. It has altered sometimes to pale green chlorite.
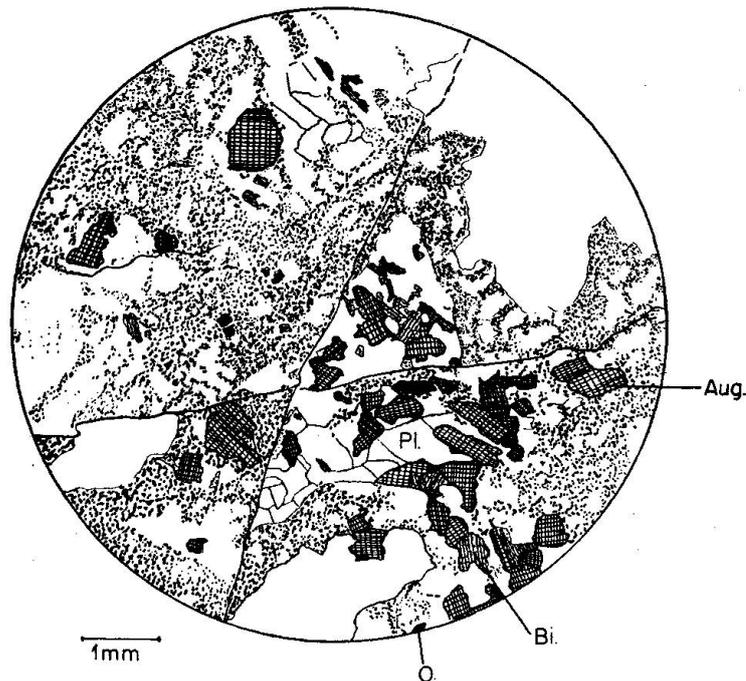
Fig. 21 (Section 1410). Quartz-plagioclase-augite-fels (type 5) preserving a relictic xenomorphic-granular structure in a cataclastic fabric. The stippled area represents cloudy and slightly altered feldspars, and wisps of broken biotite peppered with minute opaque ores. The black lines are fractures running from one margin to the other.

The biotite flakes and the augite prisms have been torn into minute wisps under the action of stress and form a flaky mosaic peppered with minute opaque ores (see fig. 21).

Garnet as colourless to light rose-pink grains occurs as an accessory mineral. It is amoeboid in habit and crystallises along the intergranular boundaries of plagioclase feldspar and augite.

In spite of the effects of severe cataclasis, relicts showing the original xenomorphic-granular structure are still preserved. The constituent minerals in the relict structure have even and conserted margins.

Type (6). Diopside-plagioclase-fels

[Diopside-fels. pp. 77—80.]

Specimens collected from two inclusions found enclosed in the basic rock type 1(a) (hornblende-plagioclase-diorite-amphibolite) at 1323 and 1420 m belong to this type. They are green to dark green in colour with a mottled appearance due to the presence of feldspars among the mafic constituents. They are massive, fine- to medium-grained with a random texture and are traversed by thin veins of pale green epidote. Microscopically they consist of,

P. C.: Diopside > plagioclase feldspar.
A. C.: Opaque ores, apatite.
A. P.: Epidote, clinozoisite, sericite.
Ff. C.: Epidote, chlorite, calcite.

The sections show a moderate degree of cataclasis as a result of which the principal constituents have been fractured, granulated, and sometimes deformed. They show undulose extinction. The feldspars have altered to epidote, clinozoisite, and sericite to a moderate degree. In 1323, the composition corresponds to an acid bytownite with 74% anorthite; in 1420 an acid labradorite with 54% An is present.

Diopside builds xenomorphic prisms measuring up to 1.5 mm. It is pale green in colour without showing any distinct pleochroism, optically positive with an optical angle of 59° and c/Z = 38°. Most of the prisms are traversed by thin fractures, and some of them have partially altered to granular epidote.

In specimen 1422 collected from the margin of 1420, hornblende constitutes a subordinate component. It builds prisms measuring up to 0.8 mm in size in its longer diameter and is optically negative with an

optical angle of 72° and c/Z = 17°. The pleochroic scheme is as follows: X = straw-yellow; Y = green; U = green with a brownish tinge.

The sections have been traversed by thin veins of epidote and chlorite representing fracture-filling chymogenic minerals.

Type (7). Biotite-spinel-corundum-fels

[Corresponding name is lacking.]

A rock in contact with the above diopside-plagioclase fels (type 6) collected at 1323 m belongs to this type. It is dark brown, and macroscopically resembles kinzigite gneiss. It consists mostly of dark brown biotite and has a gneissose texture. Microscopically the following minerals have been identified.

P. C.: Plagioclase feldspar > biotite ~ spinel.
S. C.: Corundum.
A. C.: Opaque ores, apatite.
A. P.: Chlorite, clinozoisite, and sericite.
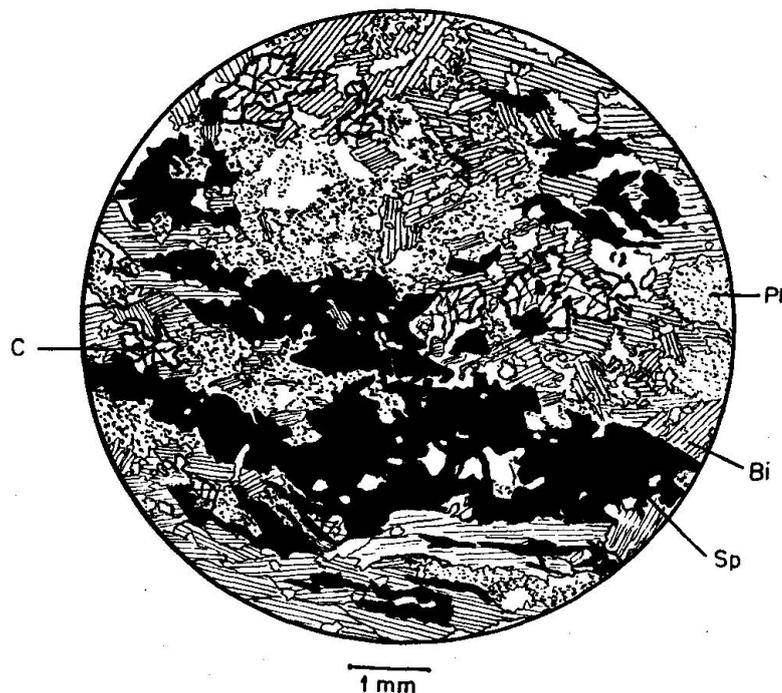
Fig. 22 (Section 1323a). Biotite-spinel-corundum-fels (type 7). Note the penetration of thin tongues of spinel along the cleavages of biotite in the lower part of the field. The stippled area is altered feldspar.

The section exhibits strong cataclasis. Most of the plagioclase feldspar is completely altered to a mixture of sericite and clinozoisite which prevents an exact determination of the anorthite content. From the nature of the alteration products it seems to be a basic rather than an acid variety.

Biotite is chestnut-brown to reddish-brown in colour with frayed margins. It exhibits distinct undulose extinction and, sometimes, alteration to pale green chlorite.

An interesting mineral is dark green spinel. It is anhedral and has crystallised along the intergranular boundaries of the other constituents. It is not uncommon to find a few tiny frayed biotite flakes as inclusions in the spinel grains. Thin tongues of spinel penetrate the biotite flakes along their cleavages and suggest that the crystallisation of spinel is later than that of biotite (see fig. 22). As only one section of this type is available, it has not been possible to ascertain the exact relationship between biotite, spinel, and corundum.

Colourless corundum occurs as xenomorphic grains showing a number of fractures. They occur independantly of or sometimes in association with spinel. In one instance a corundum crystal contains minute grains of green spinel as inclusions.

The structure of the section is cataclastic-porphyroclastic.

Section 4

Cataclasis of the basic rocks

The present discussion will show that the degree of cataclasis suffered by the rocks of the Ivrea zone increases progressively from the southern to the northern margin. It will be convenient to divide arbitrarily the entire zone into three sub-zones as follows: Sub-zone (1) from 800 to 1500 m; sub-zone (2) from 1500 to 2050 m; sub-zone (3) from 2050 to 2180 m. The differences in the effects of the action of stress on the various rock-types will hereby be brought out more clearly. In contrasting the effects observed in each of these sub-zones, due attention has been given to the conclusions reached by the following authors concerning the behaviour of rocks under the influence of shearing stress with or without confining pressure. (P. NIGGLI (1924), P. W. BRIDGMAN (1936), D. GRIGGS (1936, 1940), F. BIRCH and D. BANCROFT (1938), and F. J. TURNER (1948).)

Sub-zone 1	*Sub-zone 2*	*Sub-zone 3*
(800—1500 m)	(1500—2050 m)	(2050—2180 m)
1. The degree of fracturing, marginal granulation and deformation of the constituent minerals is not very severe.	1. The constituent minerals exhibit severe fracturing, marginal granulation, twisting and bending of the twin lamellæ (sections 1870, 1940, and 1970 show these effects very distinctly).	1. Cataclastic effects as in sub-zone 1.
2. The number and size of the porphyroclasts is large and the volume of the interstitial granular matrix is low.	2. The number and size of the porphyroclasts is rather low (refer rock types 4a and 4c) and the volume of the interstitial granular matrix is considerable.	2. do.
3. Original structures both in the basic rocks and the inclusions are often preserved as relicts (ref. 1384, 1395, and 1475).	3. Original structures are completely absent.	3. do.
4. The degree of recrystallisation of the monoclinic and orthorhombic pyroxenes to hornblende is inconsiderable.	4. Hornblende is extensively developed along the fractures and around the margins of the pyroxenes due to recrystallisation of their granulated material (ref. 1940).	4. do.
5. Plagioclase feldspars have occasionally altered to saussurite.	5. The feldspars have extensively altered to saussurite (ref. sections 1800, 1885, and 1900).	5. do.
6. The degree of alteration of the principal femic constituents is generally low.	6. Hornblende and monoclinic pyroxenes extensively altered to chlorite and epidote. Hypersthene is altered to a fibrous mesh-work of serpentine.	6. do.
7. Cataclastic effects do not lead to the formation of mylonites.	7. Cataclastic effects sometimes give rise to the formation of mylonites (ref. sections 1800, 1885).	7. do.
8. Garnets of the inclusions suffer fracturing, but not alteration to chlorite and epidote.	8. Garnets are not only fractured, but have altered to pale-green chlorite and epidote (ref. section 1900).	8. do.

Sub-zone 1	*Sub-zone 2*	*Sub-zone 3*
(800—1500 m)	(1500—2050 m)	(2050—2180 m)
9. The number of epidote and chlorite veins traversing the rock is small. Their width is also narrow. In general, they do not contain any angular fragments of the basic rocks as relicts in the process of alteration.	9. The number of epidote and chlorite veins increases in this sub-zone and their width becomes broader. The veins are again traversed by others containing colourless zeolite (prehnite) or by younger epidote veins. From 2000 to 2050 m the basic rocks have been so severely granulated, mylonitised and altered that they are now represented by broad pale green veins of epidote with or without chlorite containing angular fragments of the basic rock (type 2a) as inclusions in various stages of alteration.	9. do.

The above comparison leaves no doubt that the cataclastic effects show a very marked increase towards the northern part of the zone and become most severe between 2000 and 2050 m. This conclusion confirms the view expressed by P. WALTER (1950) that a zone of strong mylonitisation probably representing the culmination of the Insubric phase of dislocation and tectonic movements of the Alpine orogeny runs within the basic rocks about 130 meters to the south of the northern boundary.

Discussion

The problems posed by the rocks described in detail in the previous sections may be shortly stated as follows.

I) Are the different basic rocks of the Ivrea zone of magmatic origin, or are they metamorphosed sedimentary marly deposits?

II) Are the inclusions in the basic rocks "foreign inclusions" or are they magmatic "segregations"?

III) Why have minerals of the various basic rocks largely remained in an unaltered condition instead of altering to an epi-mineral assemblage?

IV) If they are of magmatic origin, at what period did the basic rocks intrude into the present region?

The answers to the above questions are as follows.

I) Rocks of type 1(a) are sensu stricto hornblende-plagioclase-amphibolites. One of the specimens still exhibits the original nemato-granoblastic structure (with feeble cataclasis) resembling those mostly derived by the metamorphism of basic eruptive rocks. The colourless augite grains in some of them are considered to be relictic crystals. The transition from type 1(a) to type 1(b) is marked by the development of amoeboid and spongy garnets which have crystallised in the latter along the intergranular boundaries of the hornblende prisms. The genesis of these garnets has been ascribed to the assimilation of aluminous material from an adjacent kinzigite inclusion by the amphibolites of type 1(a). This evidence suggests that the amphibolites were originally magmatic in their origin. If the basicity of the plagioclase feldspar (38% in 1(a) and 70% in 1(b)) and the relative proportions of the femic and leucocratic constituents of the two types be taken into consideration it may be concluded that they correspond to original diorites and gabbros respectively. In their present metamorphic state they may therefore be called diorite and gabbro-amphibolites respectively.

Rocks of type 2(a) are also hornblende-plagioclase amphibolites with a basic oligoclase or acid andesine as their principal feldspar. This type also merges into type 2(b) when amoeboid garnets of similar origin as the preceding ones are present. These amphibolites are therefore also considered to be of magmatic origin and seem to derive from a diorite. In their present metamorphic state they are termed diorite-amphibolites. It is not, however, clear how the amphibolites of the southern margin and those of the northern margin are related to one another. They may represent two different phases of the same magma in this area, the southern ones being genetically related to the basic rocks of type 4(a) and 6(a) and the northern ones to rocks of type 5(a).

Type (3) differs from the above types by the presence of hypersthene and sparse garnet. Though direct evidence of a magmatic origin is lacking in this rock its association in the tunnel with the above diorite and gabbro-amphibolites (types 1 a and 1 b) is considered to be an indication of its igneous origin. In view of the basicity of the plagioclase feldspar and the presence of hypersthene, the rock is here called an hypersthene-bearing diorite-gabbro-amphibolite.

In contrast to the above rocks, those of type 4(a) lack the character of an amphibolite. Their mineral composition seems in the main to be a primary one. The characters of the mineral components and their relative abundance point to the rock being a pyroxene-(augite)-hornblende-gabbro-diorite.

Severe cataclasis distinguishes types 4(b) and 4(c) from 4(a). Though 4(c) contains some pink garnets, the designation given to type 4(a) may be retained here also.

The rocks of type 5(a) have been shown above (see pages 123—127) to be of magmatic origin and derived from a pyroxene-hornblende-gabbro or ariegitic magma. The presence of hypersthene and diallage distinguishes 5(b) from 5(a) and makes a transition to type 6(a). Relict magmatic structure is present and direct comparison has shown almost complete identity with a primary pyroxene gabbro from Anzola. There can, therefore, be no doubt that this rock also is a magmatic one and may be called hypersthene-bearing pyroxene-hornblende-gabbro-(diorite).

In type 6(a) the amount of diallage surpasses that of augite and especially that of hypersthene. The rock is evidently a primary one and in view of its mineralogical composition may be called a hypersthene-bearing pyroxene-hornblende-gabbro-(diorite).

The rocks of type 6(b) differ from the foregoing ones mainly in much reduced quantities of hornblende which may be entirely absent. Attention has been called (p. 132) to marked similarity in chemistry and composition to the hyperites of W. C. BRÖGGER (op. cit.). Hypersthene-diallage-gabbro (or hyperite) is a suitable name for these rocks.

Rocks belonging to type (7) are clearly alteration products containing chymogenic fracture-filling minerals. They are derived from the basic rocks of type 2(a) by mylonitisation.

The specimen representing type (8) is a serpentine-talc-magnesite-chlorite schist which has intruded between the main Ivrea zone and the succeeding Canavese zone. From the nature of its mineralogical composition and structure it is clearly the metamorphic derivative of an ultra-basic rock.

II) The inclusions in the basic rocks discussed on pages 137—155 have been shown to belong in the main to two chief types. The first of these are the kinzigite inclusions, and types 1(a), 1(b), 2, and 7[6]) have been

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[6]) Specimen representing type (7) has a mineralogical composition (biotite-plagioclase feldspar-spinel-corundum) completely foreign to the various basic rock types described in section 1. Though corundum-bearing gabbro occurs farther west in the Ivrea zone in Piedmont in the Valley of Sessera as described by F. MILLOSEVICH (1927), I am not completely convinced from the microscopic features of the section examined that corundum and spinel could have been introduced into the present inclusion from the basic rock (hornblende-plagioclase-amphibolite, type 1a) in which it is found enclosed. On the other hand, it is not uncommon to observe aluminium-rich minerals like spinel and corundum in some of the kinzigite rocks

referred to these. Several other types of inclusions (3 a, 4, and 5) show the characters of garnet-plagioclase felses and may be related to the kinzigite rocks though the connection is somewhat obscure.

Inclusions of type (6) are definitely contact-metamorphosed marly rocks, while the nature of 3(b) is not exactly clear.

III) In spite of the severe cataclasis, the original minerals of the basic rocks have remained in largely unaltered condition. Secondary minerals such as epidote, chlorite, sericite, and clinozoisite occur in amounts which are insignificant compared to the volume of fresh minerals. This may be attributed to the fact that high temperatures prevailed at the time of cataclasis. The source of such high temperatures could be as follows.

(a) If cataclasis and intrusion of the basic rocks took place more or less simultaneously (before the rock masses cooled to normal temperature), alteration of the original constituents to epi-minerals would be hindered.

(b) If cataclasis took place after cooling and complete consolidation of the basic rocks, the necessary higher temperatures could be derived from the acid to intermediate intrusives and subjacent plutonic bodies of late to post-Alpine age. These supposedly follow the Alpine arch from Adamello and the Valley of Bregaglia in the east as far as Piedmont in the west.

IV) The basic rocks contain inclusions of kinzigite gneiss and produced distinct contact metamorphic effects on some of them. Since the kinzigite rocks are regarded as metamorphosed Palaeozoic or even older sediments, the age limit of the Ivrea basic rocks could date back to the pre-Cambrian.

The basic rocks were intruded by pegmatites some of which are considered to be genetically related to the intermediate and acid plutonic rocks which intruded along the root zones of the pennine nappes during the period of the late to post-Alpine movements. If this age be accepted for the pegmatites, the age of the different basic rocks should not be younger than the late-Alpine orogenesis.

It is well known among Swiss geologists that the dynamic action responsible for the observed cataclasis in these basic rocks is due to Alpine and post-Alpine tectonic movements, which possibly continued until the Quaternary period. One of these movements known as the "Insubric phase", appears to be mainly responsible for the severe myloniti-

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abnormally rich in the Al-Mg-Fe elements (see group B rocks of the kinzigite zone). I believe, therefore, that rock type (7) has strong affinities and is genetically related to the kinzigite rocks.

sation of the rock masses at about 130 meters south of the northern margin of the Ivrea zone. In addition, the different basic rocks are well-known in geological literature for their freshness. It would therefore not seem improbable that they intruded during the Alpine orogenic period. P. WALTER (1950) came to a similar conclusion and states that the different basic rocks of this zone intruded during the successive epochs of Alpine folding and tectonic movements as a result of which the roots of the pennine nappes were formed, and given their present steep to vertical position.

It also strikes the observer that the entire complex of basic and kinzigite rocks from Piedmont to the Tessin follows the west-Alpine arc closely, whereas the structures of the adjoining "Massiccio dei Laghi" are of quite a different aspect. This fact again suggests the Alpine age of these rocks.

A clarification of these conflicting possibilities must be left to future geologists, who should extend their studies to the entire region of the root zones of the pennine nappes including the Italian part of the territory.

CHAPTER IV

CANAVESE ZONE

The Canavese zone lies to the north of the Ivrea zone and has a variable width ranging from 3 km in the Italian part of the territory to 150 to 300 meters in the present investigated region. In the tunnel the southern margin is in direct contact with the serpentine-talc-magnesite-chlorite schist of the Ivrea zone, while the northern border terminates at the end of the carbonaceous black limestone band at 3230 m. In the Swiss part of the territory the zone consists of muscovite-biotite gneisses (with chlorite and sericite), quartzite bands, black limestone (dolomitic) bands, knotty-, streaky-, and augen-gneisses, permeation- and injection-gneisses, quartzo-feldspathic-pegmatites, andesite, porphyrite, and hornblende-plagioclase-epidote-chlorite amphibolites. Of all these rocks, only the andesite and porphyrite described by P. WALTER (1950) have not been met with in the tunnel and are therefore omitted in the following description.

Towards the northern margin of the zone, the two-mica gneisses become much crumpled, highly contorted, and minutely folded into thin folds. They contain increasing amounts of calcareous material and ultimately merge into the black limestones at 3150 m. The field distribution

of the different rock types and their relationship to one another are succintly given by P. WALTER and hence they are not repeated here. In the present instance, the various rocks collected in the tunnel are divided into two major sections, the first of which comprises the various gneisses and the second the basic amphibolites. Each section includes several rock-types, which are described below.

Section 1

Petrography of the country rocks

The section consists of the following types of rock:
1) Mylonite.
2) Quartzite.
3) Muscovite-biotite-chlorite gneiss.
4) Biotite-muscovite gneiss.
5) Banded gneisses (stromatitic gneisses).
6) Streaky-, knotty-, spindly-, and augen-gneisses.
7) Pegmatites and injection-gneisses.
8) Black limestones.

Type (1). Mylonite
[Mylonite. p. 116.]

The mylonite is in direct contact with the serpentine-talc-magnesite-chlorite schist of the Ivrea zone and has a thickness of about 5 meters. The rock is dark greyish-brown in colour, highly sheared and schistose, and resembles a phyllonite in hand specimens. It is fine-grained exhibiting smooth surfaces. Microscopically it consists of,

P. C.: Quartz $\gg$ plagioclase feldspar > biotite + chlorite.
A. C.: Opaque ores.

All the minerals have been severely granulated and pulverised to a very fine-grained matrix, the average grain size of which does not exceed more than 0.01 mm. Similar bands of semi-isotropic mylonitised material traverse the entire breadth of the section. Thin lenticular bands of xenoblastic quartz (0.02 to 0.04 mm in size) showing strong undulose extinction and interlocking margins are found in the matrix. They represent quartzose material recrystallised along shear planes. The relative proportions of the principal constituents could not be estimated accurately owing to the cataclasis. The rock has a cataclastic-mylonitic structure.

Type (2). Quartzite

[Corresponding name is lacking.]

A band of grey quartzite is met with in the gneisses of type (3) at 2357 to 2363 m. The band is concordantly enclosed in the gneisses and consists mostly of colourless and xenomorphic quartz measuring about 0.3 mm in size. The grains show feeble cataclastic effects.

The few plagioclase grains correspond in composition to an oligoclase (the refractive index is more or less equal to that of quartz). Some of these crystals have slightly altered to sericite.

The structure of the rock is granoblastic-cataclastic.

Type (3). Muscovite-biotite-gneiss

[Phyllites and mica-schists. pp. 111—112.]

The above rock type occurs beyond the mylonite and extends from 2200 m as far as 2450 m. No clear demarcation can be made between this type and types (5) and (6). This is the rock from which the mylonite seems to have been derived as a result of severe granulation and pulverisation under stress conditions. The gneiss is dark violet-brown, or
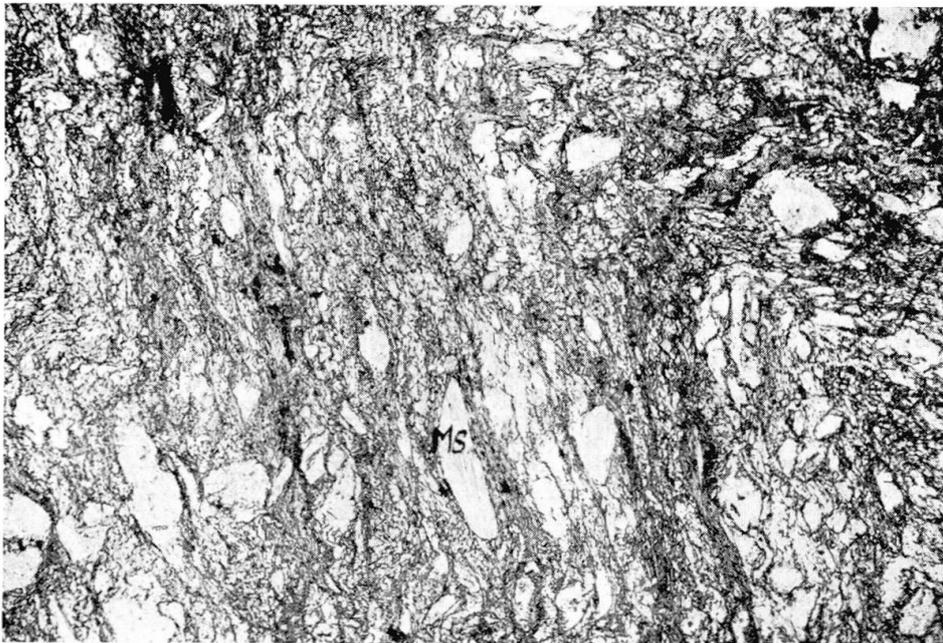
Fig. 23 (Section 2319). Canavese gneiss (type 3) showing porphyroclasts of plagioclase and a few large muscovite flakes (Ms). Note the presence of parallel streaks of mica flakes in the fine-grained matrix. (10 × .)

greyish-brown, or dark-brown in colour, fine-grained, gneissose in texture, and consists of visible muscovite and biotite flakes. On the basis of the relative proportions of muscovite and biotite two sub-types (a) and (b) may be distinguished.

Sub-type 3(a)

The rocks of this type, of which fig. 23 is a micro-photo, are microscopically uniform in their mineralogical characters and consist of,

P. C.: Quartz $\sim$ plagioclase feldspar $\sim$ muscovite $\sim$ biotite.
S. C.: Chlorite > sericite.
A. C.: Apatite, zircon, orthite, tourmaline, opaque ores.
A. P.: Clinozoisite, epidote.
Ff.C.: Calcite.

The relative order of abundance of the principal components is somewhat variable. The leucocratic constituents are about equally abundant as the micaceous minerals. Among the latter, muscovite (and sericite) preponderate over the other micas. The characters of the minerals are as follows.

Quartz

The mineral occurs in two different sizes. The first is less than 0.05 mm in diameter and is confined entirely to the ground mass. The second ranges in size from 0.1 mm to 0.5 mm and is found in the lenticular bands lying parallel to the s-planes of the section. Porphyroclasts are not frequently met with. In both the developments the crystals are xenomorphic with uneven and interlocking margins and show undulose extinction and a minor degree of fracturing. The fine-grained matrix seems to be partly derived from the granulation of the original constituents of the rock and partly to be of crystalloblastic origin. The lenticular quartz bands represent material recrystallised along shear planes under conditions favouring metamorphic differentiation.

The plagioclase is a basic oligoclase with an anorthite content of about 28%. Like quartz, the mineral occurs in two different modes. The first variety constituting the matrix is not more than 0.05 mm, while the second is present as porphyroclasts ranging in size from 0.3 to 0.8 mm. The ground mass grains do not show any well-recognisable twinning and are intimately intermixed with the quartz. The estimation of their relative proportions is thus made difficult. The porphyroclasts exhibit distinct fracturing, granulated margins, undulose extinction, and

bending of the twin lamellæ. An interesting feature of the section is the formation of fine scales of colourless sericite within the feldspar around its granulated margins. In some cases, the sericite scales increase in size and number from the centre of the crystal towards its margin and ultimately merge with the sinuous micaceous trains curving and bending round the porphyroclasts. The latter are sometimes found sheathed in a thin nest of fine scales of sericite or the sericite scales may be developed along the fractures of the crystals. On the strength of these observations the question must be left open to what extent the micaceous trains are derived from the plagioclase.

The relictic porphyroclasts in the different sections examined are variable in number and not abundant compared to the volume of the matrix.

In addition to sericitisation, some of the feldspars have altered to colourless aggregates of clinozoisite and epidote in their central parts.

Muscovite and sericite

The distinction between muscovite and sericite is a question of size. Fine scales less than 0.1 mm in size, which are frequently associated with the plagioclase feldspars, are regarded as sericite, while flakes greater than 0.1 mm are considered to be muscovite flakes. The latter exhibit distinct undulose extinction and fracturing.

Biotite

The mineral occurs as tiny flakes mostly associated with muscovite. It is dark brown $(Y = Z)$ to pale yellow-brown (X).

Chlorite

The mineral occurs intimately associated with the biotite and muscovite flakes. It is not very clear whether the mineral is an altered product of biotite or an original component. Absence of any rutile grains suggests that it may be an original constituent of the rock.

All the micaceous minerals form sinuous streaks and trains in the fine-grained matrix bending and curving round the larger feldspar porphyroclasts.

The accessory constituents are represented by colourless apatite, zircon, a few yellowish-green fractured tourmaline grains, and xenomorphic opaque ore. Chymogenic chlorite, pale green in colour, has crystallised as fan-shaped aggregates along the walls of the lenticular quartz bands.

The sections are traversed by thin fractures which are healed by granular calcite which also occurs as an intergranular infiltration and chymogenic constituent.

The structure of the rock is in the main porphyroclastic-cataclastic. In addition, the parallel to sub-parallel orientation of the mica flakes gives the sections a lepidoblastic appearance.

Sub-type 3(b)

These rocks collected at 2428 and 2432 m resemble in their macroscopic characters those of the previous type. Microscopic examination reveals,

P. C.: Plagioclase feldspar > quartz > biotite.

S. C.: Muscovite, sericite, chlorite.

A. C.: Apatite, zircon, opaque ores.

A. P.: Clinozoisite and epidote.

Ff.C.: Calcite and chlorite.

The feldspar is a basic oligoclase to acid andesine with an anorthite content of 30%. It occurs as elliptical and angular grains occasionally measuring up to 1.5 mm in size. They show all the cataclastic effects described in type 3(a) and also a slightly higher degree of sericitisation. The porphyroclasts are very frequently enclosed in a sheath of sericite, muscovite, and biotite flakes. The thin fractures traversing the feldspar crystals are filled with calcite, or sericite, or biotite and chlorite, or granular material of the feldspar. The number of porphyroclasts is greater than in the previous type and they have sometimes altered to colourless aggregates of clinozoisite.

Quartz occurs as colourless, xenomorphic grains with sutured and interlocking margins. It is entirely confined to the ground mass and does not exceed more than 0.2 mm in size. It is less abundant than plagioclase and exhibits undulose extinction. The grains have recrystallised along shear planes to form lenticular pockets and bands exhibiting a granoblastic structure.

Among the micaceous minerals, dark-brown biotite predominates. The tiny flakes are dispersed between the feldspars.

Muscovite and sericite are subordinate constituents mostly confined to the fine-grained interstitial matrix. Taken as a whole the micaceous minerals do not show parallel to sub-parallel orientation as in type 3(a). They are randomly oriented especially in 2428. Calcite occurs as in type 3(a).

The structure of the rock is mainly porphyroclastic-cataclastic.

Type (4). Biotite-muscovite-gneiss

[Corresponding name is lacking.]

The gneiss occurs in the northern part of the zone and does not differ in its colour, granularity, and fabric from type 3(a). However, it becomes highly contorted and finely folded towards the northern boundary. Microscopically it consists of,

P. C.: Quartz > plagioclase feldspar ∼ biotite > muscovite ∼ chlorite.

A. C.: Apatite, zircon, opaque ores, tourmaline.

Ff.C.: Calcite.

Among the leucocratic constituents quartz is predominant over plagioclase feldspar. It is mostly confined to the ground mass and porphyroclasts are completely absent. It measures less than 0.2 mm in size and shows undulose extinction and interlocking margins. Some of the original quartz has been recrystallised along shear planes under conditions of stress giving rise to lenticular pockets or thin bands in the fine-grained matrix. Such recrystallised quartz grains attain a size of 0.4 mm and possess even and conserted margins.

The feldspar is an acid andesine with an anorthite content of 32%. It is intimately intermixed with the quartz grains of the ground mass and does not always exhibit the usual polysynthetic twinning. Porphyroclastic feldspars are completely absent and it has been difficult to ascertain the actual volume of feldspar relative to quartz.

The micaceous minerals are represented by muscovite, biotite, and chlorite. The total volume of the mica minerals is approximately equal or slightly higher than that of the other constituents. Among the above three minerals, biotite predominates over muscovite and chlorite though muscovite often builds relatively larger flakes than biotite. Muscovite and biotite are frequently found in parallel intergrowths. The muscovite occurs as large flakes in the fine-grained matrix and shows undulose extinction and fracturing.

Pale green chlorite is sometimes observed as an alteration product of biotite and at other times occurs independently of the latter suggesting that it is partly an original constituent of the gneiss. The mica minerals together form thin sinuous trains and streaks or layers in the fine-grained ground mass. These become severely contorted and are thrown into close sinuous folds in the matrix in specimens collected from the northern boundary of the zone.

Among the accessory constituents tourmaline shows distinct fracturing. Colourless calcite is developed as before.

The structure of the rocks is lepidoblastic-cataclastic.

Type (5). Banded (or stromatitic) gneiss

[Alkali-feldspar gneisses. pp. 112—113.]

Only one specimen collected at 2540 m represents this type. It is somewhat brownish-grey in colour with thin leucocratic bands of quartz and feldspar measuring from 1 mm to about 2 cm in width. The rock is compact, fine-grained and the texture is gneissose. The stromatitic fabric is due to the presence of parallel leucocratic bands. Microscopically it consists of,

P. C.: Quartz ∼ plagioclase feldspar ∼ potash feldspar.
S. C.: Muscovite > sericite ∼ biotite.
A. C.: Apatite.
A. P.: Chlorite.
Ff. C.: Chlorite and calcite.

The leucocratic constituents predominate over the micaceous constituents. Granulation of the rock has given rise to a fine-grained matrix, and it has not been possible to estimate the relative proportions of the leucocratic minerals. On the whole, quartz is about equal to the feldspars. Among the latter, plagioclase is slightly predominant over the potash feldspar.

Xenomorphic and colourless quartz is mostly confined to the fine-grained ground mass and porphyroclasts are rare. The crystals have sutured and interlocking margins and show undulose extinction. The granular material forms thin streaks and bands interstitial to the other porphyroclasts.

The plagioclase is an acid andesine with an anorthite content of about 33%. It occurs as angular and elliptical porphyroclasts measuring up to 1.0 mm and exhibits a strong degree of marginal granulation, fracturing, undulose extinction, and sometimes bending of the twin lamellæ. The finer marginal granules intermix intimately with the quartz grains of the matrix and loose their usual polysynthetic twin lamellæ. The thin fractures traversing the larger crystals are filled with granular material of the same crystal or fine scales of sericite or infiltrations of colourless grains of calcite. In spite of the severe cataclasis, the crystals have not altered extensively to sericite as in types 3(a) and 3(b).

The potash feldspar is represented by individuals showing typical

cross-hatching (microcline) and also by such not exhibiting any twinning. Like the plagioclase feldspars they also occur as angular and elliptical porphyroclasts measuring occasionally up to 1.0 mm. The cataclastic effects prevented an exact determination of the relative amounts of the potash and plagioclase feldspars. On the whole, potash feldspar is the less abundant of the two. Convincing evidence that the sinuous sericite and muscovite trains in the granular matrix are derived from the sericitisation of the feldspars is lacking.

Besides the accessory constituents, colourless calcite is present as before.

The structure is porphyroclastic-cataclastic.

Type (6). Streaky, knotty, spindly, and augen-gneisses

[Alkali-feldspar gneisses. pp. 112—113.]

The rocks belonging to this type are met with in the central part of the zone and extend from 2460 to approximately 2730 m. They are compact, fine- to medium-grained rocks with a greyish or dark-grey colour. They are gneissose in their texture and contain streaks of quartz and feldspar which swell to form, knots, or spindles, or augen, which in any given rock may assume all these forms. This gives the rocks the appearance of being permeation gneisses. Microscopically they consist of,

P. C.: Quartz $\sim$ plagioclase feldspar > potash feldspar.
S. C.: Muscovite, sericite, biotite, and chlorite.
A. C.: Apatite.
Ff. C.: Calcite.

The relative proportions of the principal minerals could not be determined on account of severe cataclasis. However, it seems that quartz and the feldspars occur in about equal proportions, while among the feldspars plagioclase is predominant over potash feldspar. The microscopic characters of the leucocratic constituents are similar to those described in type (5) except that the potash feldspars occur as large porphyroclasts occasionally measuring up to 2 mm. What appear macroscopically as knots, spindles, and augen prove microscopically to be porphyroclastic potash feldspar individuals or several such with subordinate amounts of quartz. All stages of granulation, fracturing, separation of the marginal grains from the mother crystal and strong undulose extinction can be observed in the sections. In a few instances perthitic feldspars were also found, but they are not very abundant.

The volume of the micaceous minerals is rather low compared to that of the leucocratic constituents. Besides fine scales of sericite, a few large flakes of muscovite showing undulose extinction and fracturing and measuring up to 0.4 mm are also present.

Dark-brown biotite sometimes altered to pale green chlorite is a rare mineral.

The micaceous minerals form thin sinuous streaks in the fine-grained matrix curving and bending round the porphyroclasts. Evidence that at least part of the sericite is derived from the alkali-feldspars is not completely lacking. Indeed, some of these show a minor degree of sericitisation around their granulated margins.

Colourless calcite occurs as in previous types.

The structure of the rock is porphyroclastic-cataclastic.

Type (7). Pegmatites and injection gneisses

[Leone-gneiss. pp. 113—114.]

The Canavese gneisses of types 3(a), 3(b), and (4) are at several places injected concordantly and discordantly by leucocratic quartzo-feldspathic pegmatites. The intimate association of large amounts of pegmatitic material with the country rocks causes the latter to assume the aspect of injection and permeation gneisses. The pegmatites have been described in detail by R. KERN (1947) and hence a detailed examination is omitted here. R. KERN considered them to be of magmatic origin and to have intruded the gneisses during the late- to post-Alpine tectonic period.

Only one specimen collected at 2423 m shows distinctly the permeation of the pegmatitic-material along the gneissose planes of rock type 3(a). Microscopic examination reveals,

P. C.: Quartz > muscovite + sericite > plagioclase feldspar.

S. C.: Biotite.

A. C.: Apatite.

Colourless and xenomorphic quartz predominates over all the other constituents. Potash feldspar is absent, while the proportion of plagioclase is somewhat less than the total volume of the micaceous minerals.

Quartz exhibits undulose extinction and interlocking margins. It does not reach more than 0.3 mm in size and most of the grains are contained in streaks in the general matrix.

As shown in fig. 23, the feldspars do not show distinct polysynthetic twinning and definite crystal contours. Their refractive index is about

equal to that of Canada balsam and the optic sign is positive indicating an acid plagioclase with an anorthite content of about 15—20%. The crystals exhibit granulated margins and frequently a minor degree of fracturing. Almost all of them contain fine scales of sericite the size of which increases from the centre of the crystal towards the margins. The sericite scales become abundant towards the margins of the feldspar crystal and ultimately merge into the micaceous trains in the ground mass. As shown in fig. 24 most of the feldspar crystals are partly or completely enclosed in a sheath of sericite and muscovite flakes suggesting the alteration and transformation of the feldspar to sericite, possibly under the action of stress in the presence of pore solutions. However, the evidence does not suffice to show that the entire micaceous mosaic of the section is derived from the alteration of the feldspars. Part of the former appears to have belonged to the original rock.
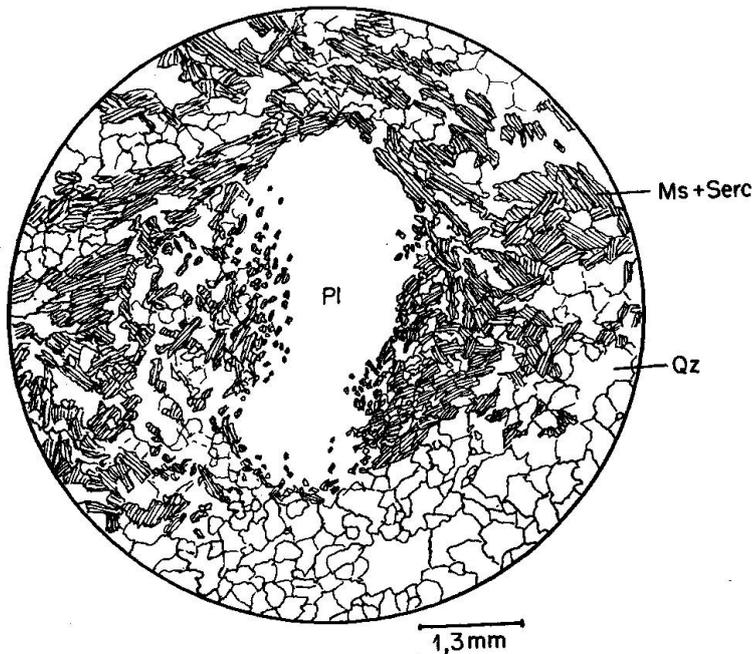
Fig. 24 (Section 2423). Injection gneiss showing the alteration of a crystal of plagioclase feldspar into sericite scales.

The micaceous minerals show a parallel arrangement giving rise to distinct foliation or a layered appearance. The trains and layers curve and bend round the larger porphyroclasts of feldspar.

Dark-brown biotite is occasionally found as a subordinate constituent in the micaceous trains.

The structure of the rock is lepidoblastic-cataclastic.

Type (8). Greyish-black limestones (somewhat dolomitic)

[Limestones and dolomites. pp. 114—116.]

Greyish-black to black limestone (somewhat dolomitic) is met with at the commencement as well as at the end of the zone. The latter band of limestone is somewhat carbonaceous in composition. It is fine-grained and exhibits a certain degree of brecciation. Microscopically it consists of,

P. C.: Calcite (and magnesite?) > quartz.
S. C.: Biotite, serpentine.
A. C.: Graphite (carbonaceous particles).

The granularity of the constituent minerals does not exceed more than 0.3 mm. The section consists predominantly of colourless and xenomorphic calcite grains amidst which are seen colourless and xenomorphic blebs of quartz. Besides the above constituents, pale green to colourless and fibrous serpentine is observed in section 3214. Here, serpentine forms thin fibrous veins ramified in all directions and frequently enclosing angular fragments of the limestone.

The section shows a few thin fractures which have been healed by a second generation of calcite grains. In view of the assumed meso-to kata-metamorphism of the country rocks it seems surprising that these limestone bands have not been completely metamorphosed to crystalline marble[7]).

Section 2

Basic rocks (amphibolites) of the Canavese zone

The basic lenses and bands of amphibolites found enclosed more or less concordantly in the Canavese gneisses are included in this group. Most of these lenses and bands are found near the southern margin of the Canavese zone and they are not met with beyond 2500 m in the tunnel. The rocks are green to dark green in colour, fine- to medium-grained, and exhibit a certain degree of foliation and a parallel arrangement of the hornblende prisms. However, they are monoschematic in their texture without showing any chorismatic fabric. Microscopic examination of

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[7]) P. NIGGLI attributes this to the presence of carbonaceous matter forming a coating round the individual particles in these limestones which has prevented recrystallisation of the grains.

these amphibolites permits their classification into two principal types on the basis of their mineralogical composition and structure. The petrographical characters of these types are as follows.

Type (1). Hornblende-plagioclase amphibolite

[Ophiolite. pp. 117—120.]

The amphibolite band met with at 2445 m represents this type. Microscopically it consists of,

P. C.: Plagioclase feldspar $\sim$ hornblende.
S. C.: Quartz > biotite.
A. C.: Apatite, sphene, opaque ores.
A. P.: Chlorite, orthite.
Ff.C.: Calcite.

Hornblende and plagioclase feldspar occur in more or less equal proportions, while colourless quartz does not exceed 5% of the total volume of the principal constituents.

Hornblende builds allotriomorphic to sub-idiomorphic prisms without showing any cataclasis. Slight undulose extinction is occasionally perceptible. The prisms contain rare thin needles of ilmenite as inclusions which, if present, have no definite crystallographic alignment. The prisms are mostly of uniform size measuring about 0.4 mm in their longer dia-meters and have even and conserted margins. They are optically negative with an optical angle of 74° and an extinction angle of 18° about Z. The pleochroic scheme is: X = pale straw-yellow; Y = green; Z = green with a slight bluish tinge. The prisms have sometimes altered to pale green chlorite along their margins.

The plagioclase lies between the hornblende prisms in colourless and xenomorphic crystals. Polysynthetic twinning is not very distinct which prevents an exact determination of the anorthite content. The randomly oriented crystals have refractive indices equal or slightly higher than that of canada balsam or quartz suggesting that their composition may correspond to andesine. Some of the grains show slight but distinct undulose extinction here and there, but cataclasis and saussuritisation are lacking. Most of the crystals are colourless, but show a certain cloudi-ness in their centres which indicates a minor degree of alteration to fine scales of sericite and grains of clinozoisite.

Colourless and xenomorphic quartz is confined to the interstices

between the hornblende prisms and plagioclase crystals. The grains show only indistinct undulose extinction.

Sparse brown biotite is present as minute flakes surrounding and often projecting into the hornblende prisms. It seems to have formed at the expense of hornblende under peritectic reaction conditions. It has occasionally altered to pale green chlorite.
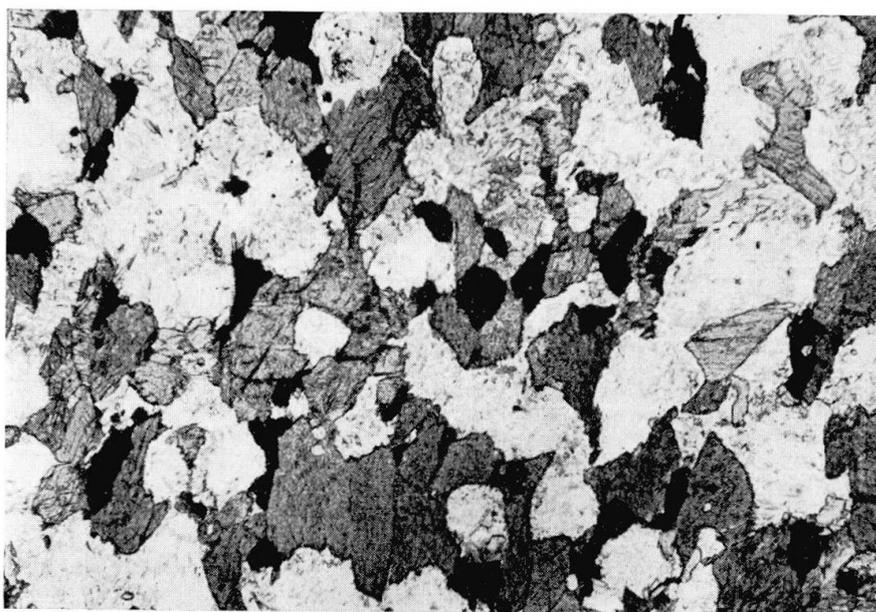
Fig. 25 (Section 2445). Hornblende-plagioclase amphibolite (type 1) exhibiting the original granoblastic structure. The dark-grey and greyish-white areas represent hornblende and plagioclase feldspar respectively. The black points are opaque ores. (30×.)

Irregular grains of sphene are distributed all over the section as an abundant constituent. Most of them are developed as granular rims around opaque ore grains. Brownish-red orthite and colourless apatite are accessories, while calcite is mostly a fracture-filling mineral.

The section preserves remarkably its original nematoblastic-granoblastic structure (see fig. 25) without exhibiting any marked degree of cataclasis and alteration of the primary constituents.

Type (2). Hornblende-plagioclase-epidote-chlorite amphibolite

[Ophiolite. pp. 117—120.]

Specimens collected at 2207, 2216, 2217, 2270, 2280, 2430, 2432, and 2465 m represent this type. Macroscopically they are very similar

to one another in texture, grain size, and colour, while microscopically they consist of,

P. C.: Hornblende, plagioclase feldspar > chlorite + biotite.
S. C.: Epidote, clinozoisite, quartz.
A. C.: Apatite, opaque ores, sphene, orthite.
A. P.: Calcite (?), chlorite, clinozoisite.
Ff.C.: Calcite, chlorite.

The relative proportions of the various constituents are somewhat variable in the different sections. Hornblende and plagioclase feldspar are about equally abundant, while in those sections in which a severe degree of cataclasis and alteration of the primary constituents is distinctly noticeable, chlorite, epidote, and clinozoisite may become more plentiful than hornblende and plagioclase feldspar. Quartz occurs interstitially between the other constituents and does not exceed 10% of the total volume.

Irregular and elliptical prisms of hornblende with sutured and granulated margins range from 0.4 mm to less than 0.05 mm in their size. The prisms have been frequently fractured and show undulose extinction. Hornblende is optically negative with an optical angle of 75° and an extinction angle of 16° about Z. The pleochroic scheme is: X = pale straw-yellow; Y = green; Z = somewhat bluish-green. Most of the prisms contain minute inclusions of ilmenite randomly oriented and frequently altered to granular sphene around their margins. Direct alteration of the prisms to pale green chlorite around their margins and along the lines of fractures is also detected. With the increase in content of the secondary minerals the volume of hornblende is proportionately reduced.

The plagioclase is a basic oligoclase with an anorthite content of 28%. The crystals are completely xenomorphic, somewhat elliptical in outline and do not exhibit distinct boundaries against the general fine-grained matrix. Polysynthetic twinning is rarely observed and almost all the crystals contain abundant colourless sheaf-like aggregates of microlites of clinozoisite (see fig. 26). The development of this mineral is sometimes so abundant that the feldspar completely looses its identity. The crystals do not exhibit any cataclastic effects, but undulose extinction is occasionally perceptible. In those rock sections (for example: 2217, 2270) which exhibit a severe degree of cataclasis, the volume of clear crystals of feldspar becomes much reduced and the amount of epidote and clinozoisite is proportionately increased. In fact, the degree of alteration of the hornblende prisms and feldspar crystals may be so

great that in certain parts of the sections all vestiges of their former presence are entirely obliterated.

Brown biotite occurs as tiny flakes sometimes forming a rim around the margins of the hornblende prisms or projecting across them. The mineral is intimately associated with pale green chlorite, clinozoisite, and epidote of the matrix (see fig. 26). The flakes of both biotite and chlorite have sub-parallel to parallel arrangement and form sinuous streaks and trains giving an appearance of "flow" to the interstitial ground mass between the hornblende prisms and feldspar crystals. Of
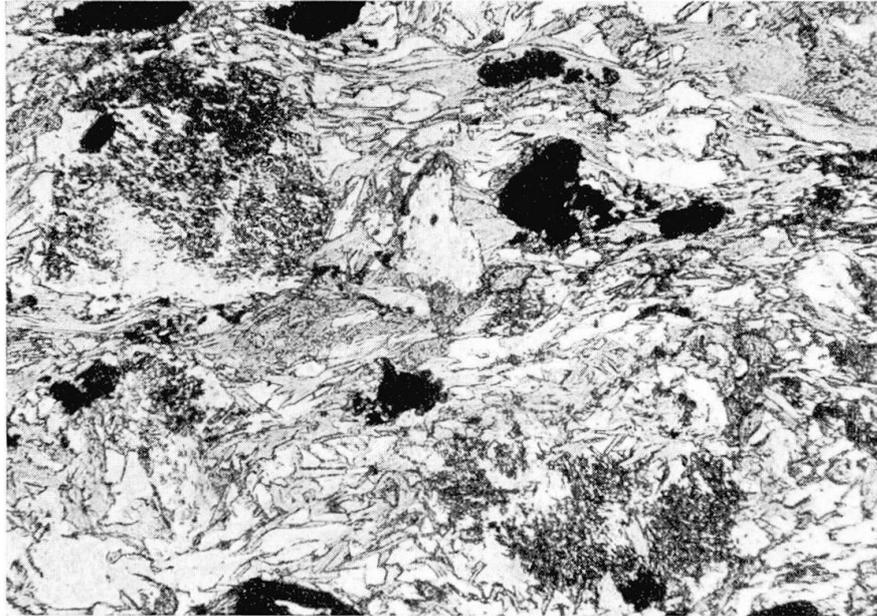
Fig. 26 (Section 2432). Hornblende-plagioclase-chlorite-epidote-amphibolite (type 2) showing a "flow-like" structure. The light grey areas are plagioclase containing aggregates of clinozoisite and epidote; the dark grey ones are hornblende. Note the parallel arrangement of the mica flakes between the hornblende and the plagioclase. (35×.)

the two micaceous minerals chlorite predominates over biotite. However, it is difficult to ascertain accurately how much of the chlorite is derived from the alteration of hornblende and how much from biotite. The intimate association of grains of epidote with the micaceous trains suggests that hornblende could have contributed a greater volume of chlorite than biotite.

Clinozoisite and epidote are rather abundantly present. Colourless calcite is intimately associated with them. The microscopic features of the calcite distribution do not indicate that the mineral represents a

fracture-filling component. The grains appear to have been derived from the alteration of original hornblende and plagioclase of the sections. The amount of calcite is considerable, but not more so than that of chlorite or clinozoisite and epidote. Grains of xenomorphic brownish-red orthite are distributed uniformly as an abundant accessory constituent. Granular sphene forms reaction rims around opaque ore grains. Different stages of this alteration of the opaque ore grains to sphene can be observed.

The structure of this rock is porphyroclastic, with a fluidal appearance which is mainly confined to the interstitial ground mass between the porphyroclasts of hornblende. It is due to the parallel to sub-parallel arrangement of the micaceous flakes which form sinuous streams bending and curving round the porphyroclasts. The cataclastic effects are also completely different from those observed in the basic rocks of the Ivrea zone. While in the latter case the total volume of secondary minerals is almost insignificant, they become more abundant and occupy about half of the total volume of the rocks in the present series.

A specimen (2430) exhibiting as low a degree of cataclasis and containing as few fractures as possible was selected for analysis. It is compared in table (9) with two other amphibolites from the same zone. The Niggli values of these analyses were compared with those of a standard normal gabbro magma type.

Table 9

	5 (2430)	a	b
SiO_2	48.60	45.69	46.29
Al_2O_3	13.45	10.96	14.54
Fe_2O_3	2.15	2.89	3.66
FeO	11.32	12.00	7.05
MnO	0.42	0.28	0.24
MgO	5.52	7.27	9.18
CaO	7.80	11.02	12.17
Na_2O	2.22	2.15	2.37
K_2O	0.61	0.44	0.45
$+ H_2O$	3.71	1.31	1.48
$- H_2O$	0.08	—	0.03
TiO_2	3.78	5.71	1.84
P_2O_5	0.27	0.26	0.46
Total	99.93	99.98	99.76

	5 (2430)	a	b	c
si	128	103	99	108
al	20.5	14.5	18	21
fm	51	53	48.5	51
c	22	27	28	22
alk	6.5	5.5	5.5	6
k	0.15	0.13	0.12	0.2
mg	0.42	0.49	0.61	0.5
ti	7.38	9.6	3.0	—
p	—	0.25	0.41	—

Basis of (2430)

Kp	Ne	Cal	Cs	Fs	Fa	Fo	Rw	Cp	Q
2.3	12.8	16.1	3.9	2.3	14.6	12.2	2.8	0.6	32.7

Kata-standardnorm

Or	Ab	An	Wo	En	Hy	Mt	Cp	Rw	Q	Σ
3.8	21.5	26.7	5.6	16.4	17.9	2.4	0.3	2.9	2.5	100.0

Analysis (5): Amphibolite collected at 2430 m in the hydro-electric tunnel from the Canavese zone. Analyst J. JAKOB.

Analysis a) Plagioclase amphibolite. Monte Verità, Ascona (Ivrea zone). Quoted from Beitr. Geol. Schweiz. Geotechn. Ser. 14. PP. 189 (1930). Analyst H. SCHUMANN.

Analysis b) Amphibolite. Middle part of the Valle del Boschetto, Centovalli. Analyst L. HENZER. W. RADEFF, Ecl. geol. helv. 13 (1915).

Analysis c) Niggli values of a standard normal gabbro magma. P. NIGGLI (op. cit.).

A comparative study of the three analyses does not show any significant differences. The Niggli values agree fairly well with one another and with those of the normal gabbro magma type. Connections between the present rocks and those of the gabbro family seem thereby to leave no doubt that the rocks under consideration are of magmatic origin.

Contact between the Canavese gneisses and the amphibolites

The contact between the Canavese gneisses and the amphibolites is sharp. Unfortunately, distinct contact metamorphic effects could not be recognised owing to the severe degree of cataclasis of both groups of rocks. Only in one instance did the amphibolite band, viz. at 2465 m, appear to have assimilated some potash from the gneiss along its con-

tact. Abundant brown biotite around the margins of the hornblende prisms of the amphibolite was thereby generated.

Comparison between the basic rocks of the Ivrea zone and those of the Canavese zone

Basic rocks of the Ivrea zone

1. Besides amphibolites (sensu stricto) the zone contains pyroxene-bearing basic rocks which preserve their original magmatic characters.

2. The severe degree of cataclasis is usually not accompanied by abundant secondary minerals. The volume of epi-minerals is almost negligible and insignificant compared to that of the kata- and meso-facies minerals. Neither the feldspar nor the hornblende has been recrystallised or altered to epi-minerals.

3. The granulated material of the feldspars and the mafic minerals is frequently recrystallised to a grano-blastic matrix interstitial between the porphyroclasts. The rocks uniformly exhibit a porphyroclastic structure in which an original xenomorphic-granular to homoeoblastic fabric is preserved.

4. Opaque ores have not altered to granular sphene except in a few rare cases.

Basic rocks of the Canavese zone

1. Pyroxene-bearing types are completely absent. Even relictic grains of pyroxene are never observed. The basic rocks are hornblende-plagioclase amphibolites with abundant secondary minerals such as chlorite, epidote, and clinozoisite. Original magmatic characters have been obliterated.

2. The cataclastic effects (with the exception of 2445) led to the recrystallisation of an originally basic plagioclase feldspar to a more acid one with a concomitant crystallisation of colourless clinozoisite and epidote. The feldspars are elliptical in habit and loose their twinning and crystal contours. Hornblende prisms exhibit granulated and sutured margins and have altered to chlorite, epidote, and calcite. The volume of the epi-minerals is about equal to that of the original components.

3. Owing to recrystallisation and alteration of the primary constituents the ground mass becomes a confused matrix of fine flakes of chlorite and biotite intimately intermixed with minute grains of quartz, clinozoisite, epidote, and calcite. They often form sinuous streams curving and bending round the porphyroclasts and giving to the ground mass "a flow-like appearance".

4. In almost all instances reaction rims of granular sphene are observed around opaque ore grains.

Discussion

The preceding observations on the amphibolites of the Canavese zone raise the following questions:

I) At what period did the amphibolites intrude the Canavese zone?

II) When were they recrystallised to their present metamorphic grade?

III) Which are the agents responsible for the observed retrogressive metamorphism?

IV) How are they related to the basic rocks of the Ivrea zone?

The questions have the following possible answers:

The total chemical composition of the Canavese amphibolites does not differ much from that of some of the basic rocks of the Ivrea zone. Judged by their Niggli values both belong to the normal gabbro magma type indicating that they could thus be genetically related to one another. They could, therefore, be derived from the same magmatic source.

If we accept the above conclusion they could have intruded the Canavese gneisses at the same time as the basic rocks of the Ivrea zone.

Recrystallisation of the original constituents of these amphibolites could have taken place either during the time of intrusion (a case of auto-metamorphism) or after the intrusion and consolidation. If recrystallisation of the primary constituents took place during the time of intrusion, the agents responsible for the retrogressive metamorphism would be falling temperature and tectonic movements creating sufficient stresses to accelerate the process of recrystallisation. If the retrogressive metamorphism took place subsequently to the consolidation of the amphibolites, tectonic movements and the accompanying dislocation metamorphism would be responsible for the present metamorphic state of the amphibolites.

Since one of the amphibolites at 2445 m has a perfectly preserved original nemato-granoblastic structure, it seems probable that the retrogressive metamorphism of the amphibolites took place after their intrusion and consolidation in the Canavese zone.

It is difficult to ascertain how much influence was exercised on these amphibolites by the powerful tectonic and dislocation movements affecting the entire Ivrea zone. Other and independent movements may also have played a role and indications that they did so are furnished by the serpentine schist of the Ivrea zone and the cataclastic structures exhibited by all those rocks found near the southern margin of the zone.

Despite the cataclastic effects visible in all the gneisses the microscopic features of the rocks of the first group (types 1 to 6) are considered to be those of metamorphosed pelitic and siliceous sediments with slight variations in their total chemical composition. The different rock types are, therefore, para-gneisses. These have been injected and permeated

by pegmatites which appear to be genetically related to the late- to post-Alpine intermediate to acid plutonic rocks intruding into this region. Permeation of the pegmatitic material into the above para-gneisses has given rise to mixed gneisses of types (5) and (6) with choris-matic fabrics.

The amphibolites (ophiolites of P. WALTER (1950)) described in section (2) do not appear to be of para-origin. Their microscopic charac-ters (especially those of type 2) resemble those of basic rocks which have undergone epi-metamorphism as characteristic of the green-schist facies of P. ESKOLA (1920) and F. J. TURNER (1948). As type (1) amphibolite preserves its original nemato-granoblastic structure, it is presumed that type (2) is derived from it under the influence of severe stress conditions. As the chemistry of these basic rocks has affinities to such of the gabbro-family, it is thought that they have been derived from the same magmatic source as the basic rocks of the Ivrea zone.

CHAPTER V

ARCEGNO ZONE

The Arcegno zone commences in the tunnel at 3230 m and extends as far as 3700 m (see profile 4). While the southern boundary of the zone lies in contact with the brecciated limestone of the Canavese zone, the northern margin has no line of distinct demarcation from the Locarno zone. On the contrary, with an increasing number of pegmatitic in-jections it merges gradually into the latter.

The zone consists of a variety of rock types which are divided, as in previous instances, into four sections each of which comprises a few types having affinities to one another.

Section 1

Petrography of the country rocks

The country rocks in this zone consist largely of gneisses though some other types are also met with. P. WALTER (1950) also calls them "principal country rocks" without specifying the names in all cases. Rocks having equivalent names in his nomenclature are given again in square brackets.

Type (1). Quartzite

A thin band of greyish-white quartzite at 3303 m concordantly enclosed in the garnetiferous biotite gneisses of type (3) constitutes this type.

About 80 to 90% by volume of the section consists of xenomorphic, colourless to somewhat cloudy quartz grains of about 0.3 to 0.4 mm exhibiting undulose extinction and slight marginal granulation. The rest is occupied by an oligoclase feldspar, a few flakes of muscovite and chlorite.

The section is traversed by a few thin fractures which have been filled by chymogenic prehnite and chlorite.

The structure of the rock is granoblastic with a minor degree of cataclasis.

Type (2). Calc-silicate fels and marble

[Calc-silicate fels and marble. p. 140.]

Specimens collected at 3345, 3352, 3353, 3354, and 3357 m from a calc-silicate band belong to this type. They are massive, compact, fine- to medium-grained rocks exhibiting a random texture. They consist mostly of calcite, basic andesine, or acid labradorite, pale yellow epidote, and clinozoisite as principal constituents, and quartz, tremolite, bluish-green hornblende, colourless phlogopite, fibrous serpentine, biotite, and a few garnets as subordinate minerals. Apatite, sphene, and opaque ores are accessories. Chlorite is an alteration product of biotite, while calcite and prehnite occur as chymogenic fracture-filling minerals. The rock as a whole has a coarsely banded texture as a result of which all the principal components and subordinate minerals are rarely to be seen in the same section. Their relative proportions vary strongly from specimen to specimen. All the sections exhibit a granoblastic structure, often with feeble signs of cataclasis.

Type (3). Garnetiferous biotite-gneiss

[Name not specified. But the rocks belong to the principal country rocks. pp. 131—135.]

This type constitutes the principal rock of the entire zone extending from 3230 m up to 3700 m. All the other rock types are concordantly enclosed as bands or lenses in this unit. The rocks are fine- to medium-grained, violet-brown or dark greyish-brown in colour with visible flakes of brown biotite and pale pink garnets. They are uniformly gneissose in texture, frequently containing thin lenticular quartz seams along their S-planes. Microscopically the rocks consist of,

P. C.: Quartz $\sim$ plagioclase feldspar > biotite.

S. C.: Garnet > muscovite.

A. C.: Opaque ores, apatite, zircon.

A. P.: Chlorite.

Ff.C.: Calcite, prehnite.

Xenomorphic grains of quartz measuring about 0.3 mm in size show distinct undulose extinction and a feeble degree of marginal granulation. Most of the grains contain minute dusty particles. Some of them have recrystallised under conditions favouring metamorphic differentiation. Such grains are free from inclusions and appear as clear crystals. The granular material around their margins intermixes with that derived from the granulation of the feldspars and often forms thin streaks between the larger crystals.

Xenomorphic plagioclase of about 0.5 mm size ranges in composition from an oligoclase to an acid andesine (21 to 38% anorthite content). Several crystals contain abundant inclusions, show undulose extinction and marginal granulation. Alteration of the feldspars is not significant.

Brown biotite is the chief micaceous mineral and flakes have sub-parallel to parallel arrangement giving rise to distinct foliation of the
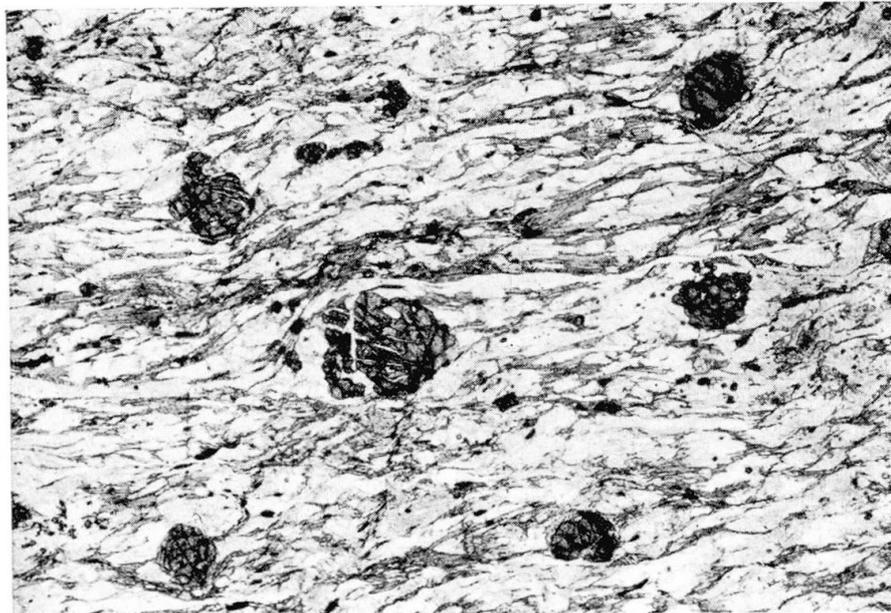
Fig. 27 (Section 3514). Garnetiferous biotite-gneiss (type 3) showing a lepido-blastic structure with fractured porphyroblasts of garnet. The gneiss constitutes the principal country rock of the Arcegno zone. Note the crystal habit of the garnets in this figure and compare it with that of the garnets in fig. 28. (10×.)

rock. Colourless muscovite is occasionally present as a subordinate constituent. The mica flakes form sinuous trains curving around some of the larger crystals of quartz and feldspar (see fig. 27). The biotite has occasionally altered to pale green chlorite.

Two types of garnets are recognised in these gneisses.

Type (I)

These are light rose-pink in colour, xenomorphic to sub-idiomorphic, and mostly non-poikilitic in habit (see fig. 27). They may sometimes contain a few biotite flakes and opaque ores as inclusions. They are frequently surrounded by a sheath of biotite and muscovite flakes. The microscopic features indicate that they have crystallised as porphyroblasts along with the other constituents during the metamorphism of the original pelitic sediments from which the present rock type is derived.

Type (II)

The garnets of this type are found in a band of biotite-gneiss included in an amphibolite at 3661 m (see fig. 28). They are completely xenomorphic, amoeboid in habit, and have crystallised along the inter-
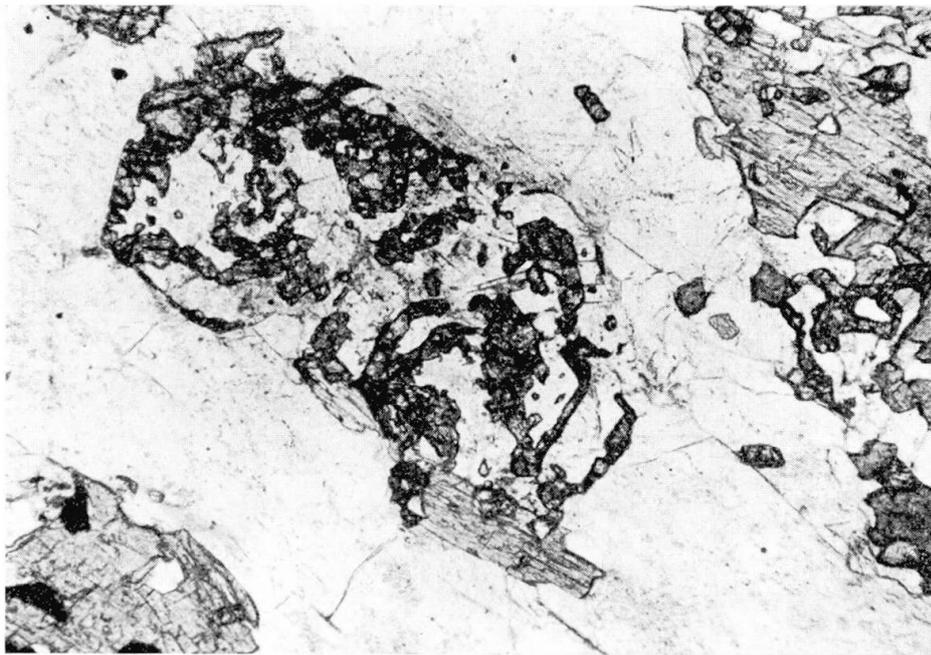
Fig. 28 (Section 3661). Aggregate of amoeboid garnet grains developed along the intergranular boundaries of the original minerals in a biotite-gneiss inclusion in an amphibolite band at 3661 m. Note how the garnet has also crystallised along the contact with the amphibolite. (35×.)

granular boundaries of the feldspar and quartz crystals subsequently to the crystallisation of the latter constituents. Some of these amoeboid garnets are also developed at the expense of the hornblende prisms in the amphibolite near its contact with the biotite gneiss. The microscopic features (see fig. 28) clearly indicate that the garnets are due to the contact metamorphic action of the amphibolite on the biotite-gneiss inclusion.

Xenomorphic opaque ores and apatite are present as accessories rather sparsely.

The structure of the rocks is lepidoblastic with a feeble cataclasis.

Type 4(a). Garnetiferous-biotite-staurolite schist

A specimen representing this type was collected at 3490 m. The rock is dark brown in colour, medium- to coarse-grained with visible dark brown flakes of biotite, dark brown crystals of staurolite, and a few weathered garnets. Microscopic examination reveals biotite, staurolite, and muscovite as principal constituents, while garnet and quartz are subordinate; zircon and opaque ores occur as accessories.

Biotite is a dark brown variety showing a slight greenish hue. The flakes are in parallel orientation to one another. They measure about 0.5 to 1 mm in their longer diameters and contain pleochroic haloes around minute inclusions of zircon. They exhibit distinct undulose extinction.

Staurolite builds large xenoblastic to sub-idioblastic crystals measuring about 0.5 to 1.5 mm in their longer diameter. It shows the following pleochroism: X = colourless; Y = pale yellow; Z = golden yellow. The crystals are traversed by numerous thin fractures and contain poikilitic inclusions of opaque ores, flakes of biotite, and a colourless mineral. The latter is altered into a colourless pennine-like micaceous aggregate (cordierite (?) or plagioclase feldspar (?)).

Light rose- pink garnet of about 0.5 mm in size occurs as xenoblastic grains with rounded edges and is traversed by a number of thin parallel cracks.

Chlorite is an alteration product of biotite here and there.

The structure of the rock is porphyroblastic.

Type 4(b). Garnetiferous muscovite-staurolite gneiss

A specimen collected at 3537 m represents this type. The rock is dark brown in colour, fine-grained with visible flakes of dark brown biotite. Microscopic examination reveals,

P. C.:   Quartz > muscovite + biotite > plagioclase feldspar.

S. C.:   Garnet > staurolite.

A. C.:   Apatite, opaque ores, sphene.

A. P.:   Chlorite.

Except for the presence of staurolite, the mineralogical composition, microscopic characters, and structure of the rock are rather similar to type (3).
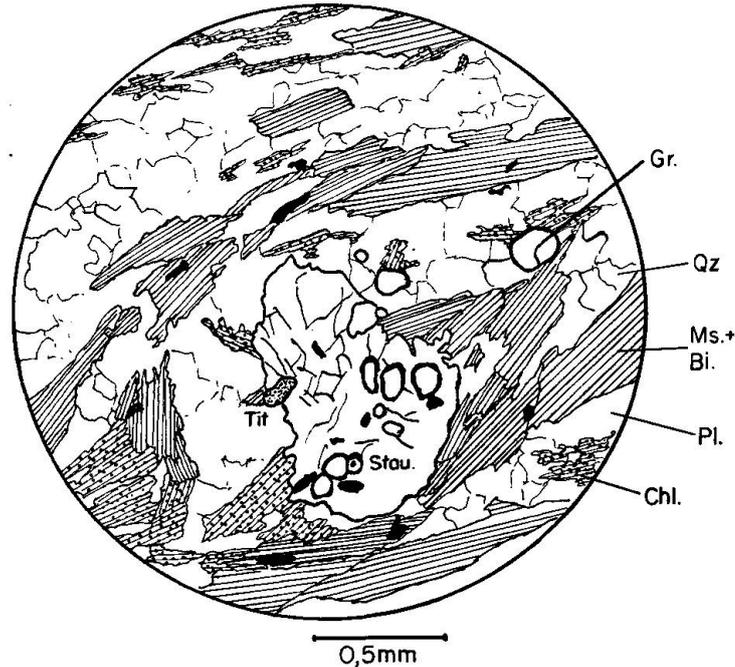
Fig. 29 (Section 3537). Staurolite crystal developed in type 4b gneiss at the expense of garnets as a result of contact-metamorphic action by the serpentinised peridotite and associated amphibolites.

The only interesting features are: The garnets are non-poikilitic and rounded in habit, colourless to light rose-pink in colour, and range in size from less than 0.5 mm up to 0.7 mm. Some of them are sometimes found enclosed in the staurolite grains. They are uniformly distributed throughout the section.

Staurolite occurs as xenoblastic crystals not attaining a size greater than 0.5 mm. The crystals are similar to those of type 4(a). Most of them are enclosed in a sheath of muscovite, biotite, and chlorite flakes as shown in fig. 29. The microscopic features of the staurolite crystals suggest that they have crystallised later than the micaceous minerals. The presence in the staurolite of a few garnets (fig. 29) indicates that the latter could also have contributed some material to its formation and

suggest that staurolite was formed later than garnet. As this particular specimen was collected at the contact of an amphibolite which is genetically related to the serpentinised peridotites of this zone (see section 3), possible contact-metamorphic action by the amphibolite (and also by the serpentinised peridotite) on this particular rock does not seem excluded. Such an assumption is not at variance with the observed microscopic relationship between the staurolite crystals and the original constituents of the gneiss.

The structure of the rock is lepidoblastic-cataclastic.

Type (5). Hornblende-bearing quartz-feldspar-biotite-gneiss

A specimen belonging to this type was collected at 3526 m. The rock is fine- to medium-grained, greyish-white in colour with dark streaks of biotite and hornblende. Microscopically it consists of,

P. C.: Quartz $\geq$ plagioclase feldspar.
S. C.: Biotite > hornblende.
A. C.: Opaque ores, apatite, sphene, zircon.
A. P.: Clinozoisite, chlorite, sericite.
Ff. C.: Prehnite.

Quartz occurs as xenoblastic, colourless grains, and ranges in size from less than 0.1 mm up to 0.4 mm. The grains show undulose extinction and interlocking margins. Cataclastic effects are feeble. The section also contains lenticular pockets and bands of quartz representing material recrystallised along shear planes under conditions favouring metamorphic differentiation.

The plagioclase is found as slightly lenticular grains with sutured and granulated margins and ranges in size from less than 0.1 mm to 0.4 mm. The crystals which correspond to a basic oligoclase or acid andesine contain cloudy particles all through and especially along the twin-composition planes. Both polysynthetically twinned as well as untwinned crystals are recognised. Sericitisation of the feldspars is not uncommon.

Brown biotite is confined to the dark streaks visible macroscopically in the hand specimen. The flakes have sub-parallel to parallel arrangement and some of them are altered to pale green chlorite.

Associated with the biotite flakes are found subordinate amounts of hornblende in elliptical grains measuring from 0.1 mm to 0.4 mm.

The pleochroic scheme is: X = straw-yellow; Y = green; Z = green with a bluish tinge; c/Z = ~ 20°.

Hornblende is completely absent in other parts of the section. The transition between the leucocratic part of the rock and the dark bands containing biotite and hornblende is gradual.

Brownish sphene is present only in the darker bands.

Sheaf-like aggregates of colourless prehnite are present as intergranular fracture-filling mineral. The structure of the rock is granoblastic with signs of feeble cataclasis.

Type (6). Pegmatites and injection gneisses

Coarse-grained pegmatites and injection gneisses are frequently met with towards the northern margin of the zone. A description of their petrography has been given by R. KERN (1947), P. WALTER (1950), and G. M. PARASKEVOPOULOS (1953) and, therefore, is omitted here. They consist chiefly of colourless quartz, potash feldspar (microcline), albite-oligoclase, and muscovite as principal constituents, while apatite is an accessory mineral. Cauliflower-like myrmekite develops in some sections between potash feldspar and plagioclase. The pegmatites exhibit distinct cataclastic effects and a certain degree of shearing under the action of stress. They become more numerous as the boundary of the zone is approached.

Section 2

Maia diorite-amphibolite

[Maia diorite-amphibolite. pp. 136—137.]

The amphibolite stock met with at 3380 to 3398 m resembles a diorite and has its southern margin in direct contact with the calc-silicate fels of type (2) and its northern border in contact with the garnetiferous biotite-gneiss of type (3). The entire body has a uniform mineralogical composition. However, it may be subdivided into three facies showing recognisable differences in their structures.

Facies (1)

Specimens collected in the central part of the stock at 3388 and 3390 m represent this facies. The rocks are medium- to coarse-grained dark green in colour with specks of feldspar and exhibit a massive and random texture. Microscopically they consist of,

P. C.: Plagioclase feldspar $\geq$ hornblende.

S. C.: Quartz (?)

A. C.: Sphene, opaque ores, apatite, zircon (?).

A. P.: Chlorite.

Ff.C.: Calcite, quartz, chlorite.

The accessory constituents and the alteration products do not exceed more than 10% of the total volume of the rock.

Plagioclase feldspar occurs as allotriomorphic crystals showing distinct polysynthetic twinning and measuring from 0.2 mm to 0.7 mm in size. Most of the crystals exhibit perceptible undulose extinction and feeble cataclastic effects. The feldspar corresponds in composition to a basic oligoclase ($\sim$ 30% anorthite content) and appears slightly cloudy owing to the presence of fine dust all through the crystal. Slight alteration to sericite is also observed.

Hornblende builds allotriomorphic prisms measuring about 0.6 mm to 1 mm occasionally. They show undulose extinction, marginal granulation and fracturing. Small wisps are in the process of separation from the mother crystal. Along the lines of fractures the prisms have altered to pale green chlorite accompanied by minute opaque ore grains. In addition,
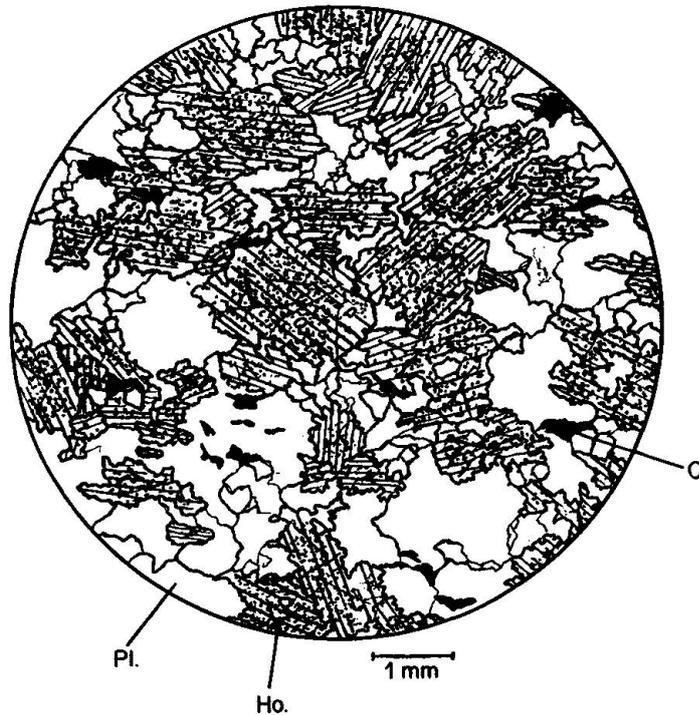

Fig. 30 (Section 3388). Xenomorphic-granular structure of Maia diorite-amphibolite. Note the presence of abundant opaque ore dust in the hornblende prisms.

the prisms contain abundant opaque ore dust (ilmenite) strewn all through the prisms at random without reference to any crystallographic direction (see fig. 30). It frequently forms thin branching and forking streaks. Some of the opaque grains (ilmenite) have altered to granular sphene.

The hornblende is optically negative with an optical angle of 76° and $c/Z = 17°$. Its pleochroic scheme is: X = straw-yellow; Y = green; Z = green with a slight bluish tinge.

Chlorite derived from hornblende is not very abundant. Some of the thin fractures in the hornblende prisms are also filled by calcite.

Xenomorphic quartz occurs as a very subordinate constituent.

Brownish sphene, granular in habit, is an abundant accessory mineral. It almost always forms at the expense of the opaque ore grains.

The section is traversed by thin fractures which have been healed by calcite or quartz or chlorite.

The structure of the rock resembles that of a diorite and is xenomorphic-granular with feeble cataclasis (see fig. 30).

Facies (2)

A specimen representing this facies was collected at 3393 m towards the northern margin of the amphibolite mass. Macroscopically it is similar to facies (1) in many respects. However, careful examination reveals certain distinct differences. They are:

1) Almost all the hornblende prisms contain poikilitic inclusions of irregular grains of plagioclase feldspar and are thus conspicuously developed as "sieved prisms".

2) The section contains a few sub-idiomorphic to idiomorphic rose-pink garnets and brown biotite distributed at random in the matrix without showing any explainable relationship with the other constituents. They have altered occasionally to pale green chlorite which appears in garnet along the lines of fractures.

3) The fabric of the rock is not like that of facies (1). On account of the sieved appearance of the hornblende prisms it may be termed a poikilitic to diablastic-granular structure.

Facies (3)

A specimen collected at 3380 m from the southern contact of the amphibolite body against the calc-silicate fels (type 2) represents this facies. The rock is dark green in colour, fine-grained, and does not exhibit the speckled appearance of facies (1).

Microscopically it consists of the same minerals as facies (1) and their optical characters are also similar. The chief differences are:

1) The grain size of the minerals does not exceed 0.3 mm. This facies is, therefore, finer-grained than facies (1). It suggests that the southern margin of the amphibolite has been chilled along the boundary against the above mentioned calc-silicate fels.

2) The plagioclase corresponding to an intermediate andesine (40% anorthite content) is slightly more basic than that of facies (1). This may be attributed to the undifferentiated nature of the southern margin due to rapid cooling.

3) The hornblende prisms do not contain opaque ore dust (ilmenite) as abundantly as facies (1). Granular sphene is also sparsely present.

4) The rock exhibits a fine diablastic to nematoblastic structure.

Section 3

Serpentinised peridotite and associated amphibolites

The serpentinised peridotite and its associated amphibolites extending in the tunnel from 3535 to 3649 m are included in this section. The above two types of rock constitute a single eruptive body intruding more or less concordantly into the gneisses of type (3). The serpentinised peridotite forms the core of this body and the amphibolites its marginal facies. No sharp line of demarcation exists between the ultra-basic and basic rocks. Inclusions of the country rock are not found in the central part of the body, while a few thin bands of biotite gneisses and calc-silicate fels are observed to occur as foreign inclusions in the amphibolites of the southern margin. The serpentinised peridotite and the associated amphibolites are described separately and their genetical relationship is discussed again in a later paragraph.

In the geological and petrological map of P. WALTER (1950) the Maia diorite-amphibolite and the serpentinised peridotite appear to be in direct contact with one another constituting a single eruptive mass. He records that the contact between the above two rocks is nowhere clearly exposed and prevented any conclusions regarding their relationship being drawn. The opening of the hydro-electric tunnel made it possible to state that the Maia diorite-amphibolite is not in direct contact

with the serpentinised peridotite. The garnetiferous biotite-gneisses (type 3) intervene between the basic and the ultrabasic rocks. This indicates that the Maia diorite-amphibolite and the serpentinised peridotite represent two distinct intrusions.

Type 1(a). Serpentinised peridotite

[Serpentine. p. 140.]

Specimens from near the core of the eruptive body at 3575, 3586, 3595, 3607, 3610, 3619, 3622, 3635, and 3645 m represent this type. In addition, a specimen collected from a dike-like outcrop exposed about 100 meters north-east of the Pestalozzi Children's Home near Arcegno on the left side of the newly opened high-way leading from Arcegno to Intragna, is also included in the present description. The rocks are massive, dark green or greyish-green in colour, fine- to medium-grained, soapy to the touch, and exhibit a parallel and schistose texture. Microscopically they consist of,
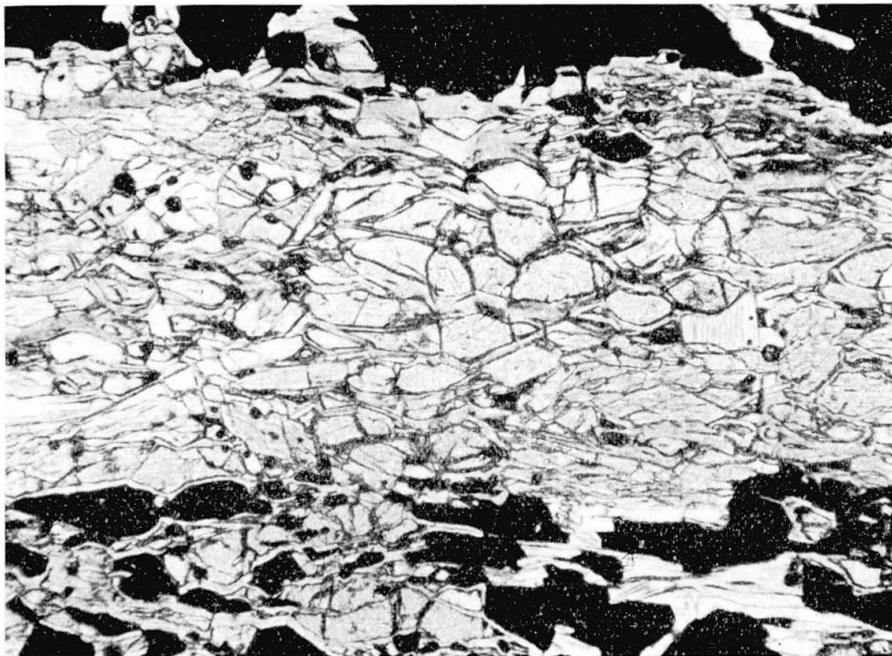
Fig. 31 (Section 3610). Serpentinised peridotite with abundant opaque ores (black). The grains with high relief are relicts of olivine in a network of serpentine. Hornblende at the right side of the figure shows the typical prismatic cleavages. The colourless flakes on the left are chlorite. (35×.)

P. C.: Olivine ∼ serpentine ∼ chlorite.

S. C.: Tremolite ∼ talc ∼ magnesite.

A. C.: Opaque ores.

A. P.: Bowlingite or xylotite(?).

The relative proportions of the minerals is variable depending on the degree of alteration of the primary olivine. As the volume of olivine decreases, that of the other constituents, especially serpentine, chlorite, and tremolite, increases. In sections 3607, 3610, and 3619 olivine predominates over the others. Towards the peripheral parts, olivine gradually disappears giving rise to the secondary constituents. Fig. 31 gives a general idea of the mineralogy and structure of these rocks.

Colourless olivine occurs as xenomorphic crystals ranging in size from 0.1 mm to 0.5 mm. All the crystals are embedded in an anastomosing net-work of fibrous serpentine (see fig. 31). It is optically neutral and corresponds, therefore, in composition to $Fo_{88}Fa_{12}$.

Serpentine is colourless to pale yellowish-green with fine opaque ore dust strewn all through. Pseudomorphs of serpentine after the olivine grains preserve the intergranular contacts of the latter crystals even after their complete serpentinisation.

Fig. 32 (Section A11). Radiating aggregates of tremolite in the serpentinised peridotite (specimen collected north-east of the Pestalozzi Children's Home near Arcegno).

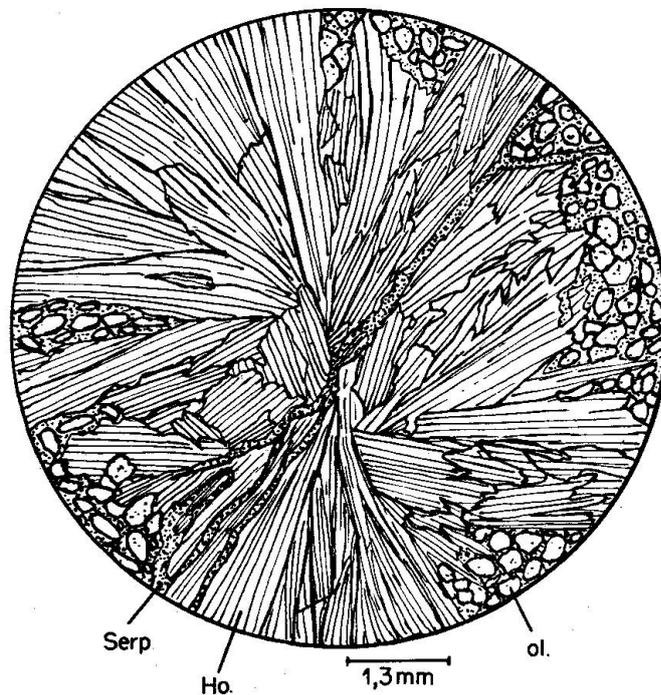Chlorite is colourless to pale green in colour, frequently showing perceptible pleochroism in pale green tones. The flakes have a sub-parallel to parallel orientation and form trains and layers. In some of the sections the chlorite layers alternate with the fibrous mesh of serpentine and lenticular pockets of granular olivine undergoing alteration to serpentine.

Colourless tremolite, the only amphibole found in all the sections, occurs as long prisms and needles in the serpentine mesh-work often projecting into the olivine crystals. It is optically negative with an optical angle of $80°$ and $c/Z = 17°$. The optical data indicate that it is a type poor in iron. Most of the prisms are traversed by thin fractures which have been healed by veins of serpentine. In the specimen collected near the Pestalozzi Children's Home, colourless prisms of tremolite form radiating aggregates in the partly serpentinised peridotite (see fig. 32). Such aggregates can be found in the above-mentioned outcrop if a careful search is made for them. P. WALTER (1950) records the presence of anthophyllite in these same peridotites, but the mineral was lacking in the sections examined.

Colourless talc is distributed as single flakes or groups of flakes exhibiting high birefringence and small optical angle. Some of them occur in parallel intergrowth with the colourless tremolite prisms.

Colourless magnesite is sparsely present, generally in the neighbourhood of the tremolite prisms.

Abundant opaque ores are observed only in section 3610 (see fig. 31). They are xenomorphic and form granular streaks. The ore grains seem to crystallise along the intergranular boundaries of the serpentine pseudomorphs after the original olivine crystals. In other sections opaque ores are merely an accessory constituent distributed sparsely in the serpentine mesh-work.

Yellowish-green to brownish-green alteration products of olivine (bowlingite or xylotite) are rare.

Structure

The rocks have a partly pseudomorphosed structure with an intra-granular implication fabric.

Type 1(b). Serpentine-talc-chlorite-magnesite-schist

A specimen collected at 3573 m represents this type. Macroscopically it is similar to rocks of type 1(a) exhibiting a schistose texture. Microscopic examination reveals that it consists mainly of a plumose and fibrous mass of serpentine, pale green chlorite, and colourless talc with abundant

grains of colourless magnesite strewn all through the mesh-work. Relictic olivine grains are not found and colourless tremolite is rare. The principal constituent are all about equally abundant, while irregular opaque ore grains are present as a subordinate component. This rock is similar in many respects to type (8) of the basic rocks of the Ivrea zone.

Type 2(a). Hornblende-plagioclase-amphibolites

The amphibolites found intimately associated with the serpentinised peridotite belong to this type. Specimens were collected at 3536, 3539, 3548, 3549, 3556, 3567, 3570, 3571, 3572, 3642, and 3645.7 m. The rocks are mostly dark green in colour, fine- to medium-grained, and exhibit a parallel and schistose texture. Needles and dark green prisms of hornblende and brown flakes of biotite or phlogopite are visible. Microscopically they consist of,

P. C.: Tremolite > plagioclase feldspar.
S. C.: Chlorite, biotite or phlogopite (?), talc.
A. C.: Opaque ores, sphene.
A. P.: Clinozoisite, epidote.

The relative proportions of the principal constituents vary greatly in the different sections. For example section 3542 consists entirely of tremolite without any plagioclase feldspar and in section 3567 brown biotite predominates over phlogopite and chlorite.

Hornblende belongs to the tremolite-actinolite series tending in some of the sections (e. g. 3556 and 3567) to a common hornblende type. It is colourless to pale green in sections 3539, 3548, 3556, 3567 and completely colourless in 3570, 3571, 3642, and 3645.7. It is optically negative in all cases with an optical angle of 78° to 84° and $c/Z = 16°$ to 18°. The refractive indices determined on cleavage flakes of a pale green hornblende from specimen 3642 are: $n_{\gamma'} = 1.636 \pm 0.003$; $n_{\alpha'} = 1.623 \pm 0.003$. These values indicate that the hornblende corresponds in composition to a tremolite with 10 to 15% of actinolite molecule. Xenomorphic to subidiomorphic prisms are present in the sections. There does not seem to be any relation between the crystal habit of the hornblende prisms and the locality of collection of the specimen. It can be stated, however, that the subidiomorphic prisms are in general observed in rocks collected from the margins of the eruptive body. In sections 3570 and 3571 the prisms are completely xenomorphic in habit frequently containing grains of feldspar as inclusions (see fig. 33). In contrast to those in the serpentinised peridotite, the prisms show no fractures.

Plagioclase is found in almost all sections with the exception of those consisting entirely of hornblende. In sections 3570 and 3571 the feldspars are xenomorphic, while in the rest they appear as xenomorphic to sub-idiomorphic polygonal and lath-shaped crystals. They show polysynthetic twinning, though the twin lamellæ are too fine to permit an easy determination of the anorthite content. As far as could be determined the composition ranges from a basic labradorite (70% anorthite content) to an intermediate andesine (40% anorthite).

Fig. 33 (Section 3571). Intergranular implication fabric in the type 2a (section 3) amphibolite representing the marginal facies of the serpentinised peridotite. The dark grey crystal showing polysynthetic twinning in the centre of the field is plagioclase. Light grey areas are colourless hornblende. (+nicols, 35×.)

No relationship exists between the anorthite content of the feldspar and the locality of its collection. The more basic feldspar is met with in sections 3570, 3571, and 3549, while that in sections 3567 and 3536 is of an intermediate composition.

Colourless chlorite is often present and may measure up to 0.5 mm. It forms thin, sinuous trains curving around the larger hornblende prisms in the general ground mass. The content of chlorite decreases with increasing amounts of brown biotite or phlogopite.

Brown biotite or pale brown phlogopite (?) is frequently in parallel intergrowth with the colourless chlorite. Talc is sparsely represented.

Brownish sphene is distributed in almost all the sections as an abundant accessory constituent. Some of the grains are developed at the expense of the opaque ore grains.

A few grains of clinozoisite and epidote are sometimes found in association with the chlorite or biotite (or phlogopite).

Four types of structures can be recognised in the sections. In sections 3572, 3571, 3570, and 3548, the relationship between the feldspar and the hornblende is such as to provide an excellent example of an inter-granular to intragranular implication fabric (see fig. 33) tending to a diablastic structure.

In sections 3536, 3539, 3556, and 3567, a nemato-granoblastic structure prevails.

Section 3642 shows a granoblastic structure.

In the other sections the fabric corresponds partly to a diablastic and partly to a nemato-granoblastic structure.

Type 2(b)

A specimen collected at 3636 m represents this type. It is macro-scopically dark green in colour with a schistose texture. Dark green hornblende prisms and brown biotite (or phlogopite?) are distinctly visible. Microscopically it consists of brown biotite and colourless tre-molite as its principal constituents with accessory amounts of sphene and opaque ores. Brown biotite predominates over colourless tremolite and the flakes are arranged parallel to one another. The tremolite prisms exhibit random orientations, while sphene is skeletal in crystal habit.

The structure of the rock is lepidoblastic.

Section 4

Other types of amphibolites not related to those of sections (2) and (3)

All amphibolites which are not found in association either with the Maia diorite-amphibolite or with the serpentinised peridotite are included in this section. They occur as thin bands and lenses concordantly enclosed in the gneisses of type (3) of section (1). They are dark green in colour, rather fine-grained, monoschematic, and exhibit a parallel texture. Depending on their mineralogical compositions several types are recog-

nised, which are described below. Specific names for these rocks are lacking in P. WALTER's (1950) thesis.

Type (1). Garnetiferous hornblende-plagioclase-amphibolite

A specimen found in contact with the garnetiferous biotite-gneiss (type 3) of section (1) and collected at 3435 m represents this type. The contact is sharp and microscopically the rock consists of,

P. C.: Hornblende $\sim$ plagioclase feldspar.
S. C.: Biotite > garnet.
A. C.: Opaque ores, apatite.
A. P.: Sericite.

The grain size of the minerals does not exceed 0.5 mm.

The hornblende prisms are xenomorphic to sub-idiomorphic exhibiting distinct parallel orientation. Some of the larger prisms contain thin rods and dust of opaque ore (ilmenite) distributed at random in their central parts. The prisms exhibit a green (Z) to pale straw-yellow (X) pleochroism. Cataclastic effects are not observed.

The feldspar grains lie inbetween the hornblende prisms as xenomorphic crystals. Most of them lack distinct polysynthetic twinning. The refraction of the grains is slightly higher than that of quartz and suggest that the composition may not be more basic than an andesine. Cataclastic effects are not pronounced. There is no difference between the grain size of the feldspar of the garnetiferous biotite gneiss and that of the present amphibolite.

Brown biotite is observed as tiny flakes with parallel orientation. It is sometimes found in parallel intergrowth with the hornblende prisms. The flakes in the amphibolite and those in the above-mentioned gneiss are parallel among themselves and to each other.

Colourless to pale rose-pink garnets are present in the amphibolite mostly along its contact with the gneiss. They are optically similar to those found in the gneiss. Careful observation reveals that the size of the garnets decreases gradually in the direction from the contact towards the centre of the amphibolite. In the central part of the latter the garnets are absent. The relationship of the garnets to the other constituents of the amphibolite does not require any special explanation. It can be stated positively that it has neither formed at the expense of the minerals in the amphibolite nor is due to the assimilation of aluminous material from the adjacent gneiss. On the contrary, it appears that the contact between the gneiss and the amphibolite is microscopically transitional in character.

Opaque ores occur abundantly and are scattered all through the amphibolite. The size and shape of the grains are the same as in the adjacent gneiss. Fractured apatite is an accessory, but not so abundant as the ore grains. The rock has a fine nemato-granoblastic structure.

Type (2). Hornblende-plagioclase-amphibolite

Two specimens collected at 3530 m belong to this type. Though the two specimens appear macroscopically similar to one another, they differ microscopically in their mineralogical compositions and structures. They are described below under 2(a) and (b).

2(a)

The section consists of,

P. C.: Hornblende ∼ plagioclase feldspar.
A. C.: Opaque ores, apatite sphene.
A. P.: Clinozoisite, sericite.

Hornblende is xenomorphic to sub-idiomorphic in habit, often containing thin blades and opaque ore dust (ilmenite) distributed randomly in the centres of the prisms. The pleochroic scheme is: X = pale straw-yellow; Y = green; Z = bluish-green to greenish-blue. The prisms do not exceed 0.5 mm in size.

Plagioclase occurs between the hornblende prisms as xenomorphic grains with even and conserted margins. They exhibit polysynthetic twinning and vary in composition from an intermediate to basic andesine (the maximum extinction angle measured along the albite-like-twin or composition lamellæ normal to (010) is about +25°). Most of the crystals are fresh and show minor degree of alteration to sericite and clinozoisite.

Opaque ore grains scattered throughout the section and some of the grains have altered to brown sphene which is not as abundant as opaque ores.

The section corresponds to a nemato-granoblastic structure.

2(b)

The section consists of,

P. C.: Plagioclase feldspar > hornblende.
S. C.: Biotite, chlorite.
A. C.: Opaque ores, rutile.

Figure 28 shows the mineralogical composition and structure of the rock.

Two types of plagioclase feldspars can be recognised in the section.

The first of these are equi-granular and polygonal in habit showing distinct polysynthetic twinning. They are free from inclusions and alteration products and do not exhibit any cataclastic effects. They correspond in composition to a basic oligoclase or acid andesine with about 29% anorthite. Such feldspars occur in circular or oval pockets in an otherwise sheared matrix described below. These pockets consist entirely of feldspar with subordinate amounts of brown biotite and lack hornblende, opaque ores, or rutile (see fig. 34).
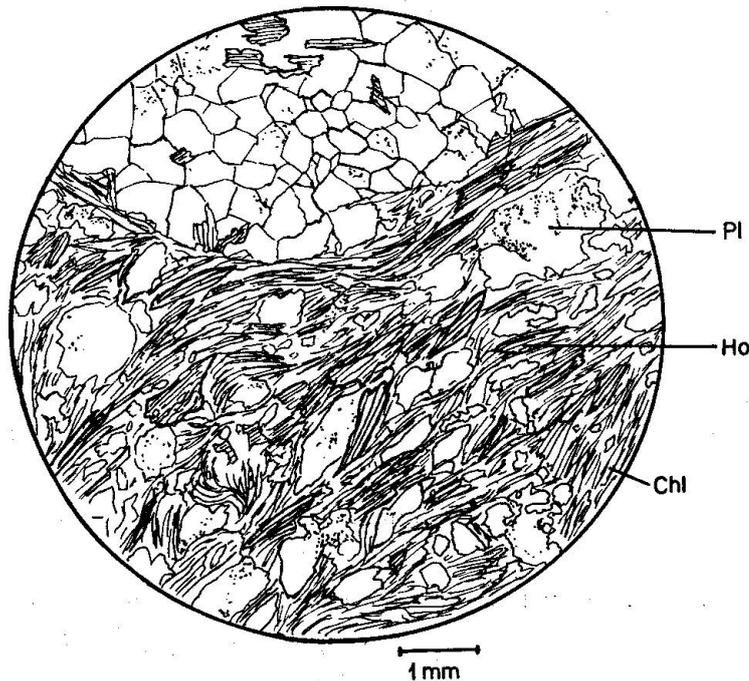
Fig. 34 (Section 3530). Micro-chorismatic structure of type 2b (section 4) amphibolite. (See discussion in the text, p. 199.)

The feldspars of the second kind are elliptical in habit and are slightly elongated in several cases. The crystals exhibit distinct cataclastic effects. They are mostly confined to the hornblende-biotite-chlorite matrix of the section without giving rise to any separate pockets as in the previous case. They contain dusty inclusions, or have altered slightly to cloudy aggregates of clinozoisite and sericite. The composition is the same as in the first variety.

Hornblende occurs as needles or long prisms. In contrast to the previous type, they show a weak pleochroism: X = pale straw-yellow to colourless; Y = pale green; Z = pale green. The mineral appears to correspond to the tremolite end member of the tremolite-actinolite series.

It can be intimately associated with the biotite and chlorite of the matrix and curve around the larger feldspar crystals. The proportion of hornblende is about equal to that of the micaceous minerals.

Brown biotite is a subordinate constituent and is associated with pale green chlorite. The matrix consists of the micaceous minerals which are arranged as parallel trains bending around the larger feldspar crystals. It is not clear whether the chlorite is derived from the alteration of biotite or whether the latter has crystallised from chlorite under conditions of progressive metamorphism.

Opaque ores and fine rutile grains are distributed all through the section.

The parallel arrangement of the hornblende prisms and the micaceous minerals give to the matrix a lepidoblastic character. In it are embedded porphyroclasts of plagioclase feldspar. The presence in the matrix of pockets of equi-granular feldspars with conserted margins gives a granoblastic structure to these parts of the section. The latter, therefore, exhibits a micro-chorismatic structure of mono- or polygenic origins (see fig. 34).

Type (3). Epidote-hornblende-plagioclase-amphibolite

A specimen collected at 3532 m represents this type. Microscopically it consists of,

P. C.: Epidote $\sim$ hornblende.
S. C.: Quartz, plagioclase feldspar (?).
A. C.: Sphene, opaque ores.

The section does not contain plagioclase feldspar in any noteworthy quantities.

Hornblende occurs as xenomorphic to sub-idiomorphic prisms showing only a faint degree of undulose extinction. The prisms are arranged parallel to one another giving the rock a distinct foliation. They exhibit the following pleochroism: $X = $ pale straw-yellow; $Y = $ green; $Z = $ bluish-green to greenish-blue; $c/Z = 15°$. Alteration of the prisms is rare.

Xenomorphic to sub-idiomorphic epidote is more or less equal to the content of hornblende. The grains are colourless to pale yellow in colour and measure about 0.3 to 0.5 mm. The microscopic characters of the crystals do not convey the impression that they are derived from the recrystallisation of a basic or ultrabasic igneous rock. Rather does it seem that they may have been formed from a marly sediment under conditions of progressive metamorphism.

Subordinate amounts of xenomorphic and colourless quartz are present between the hornblende and epidote grains. It shows perceptible undulose extinction.

Granular sphene is an abundant accessory constituent, frequently attaining a size of 0.5 mm. The grains are uniformly scattered all through the section.

The parallel orientation of the hornblende prisms and the presence of xenomorphic grains of epidote allows the structure to be called nemato-granoblastic.

Type (4). Hornblende-plagioclase-amphibolite

Two specimens collected at 3655 and 3661 m represent this type. Both of them are massive, dark green in colour, and exhibit visible lineation of the hornblende prisms. Microscopically they consist of,

P. C.: Hornblende $\sim$ plagioclase feldspar.
S. C.: Biotite, (garnet).
A. C.: Sphene, opaque ores, apatite.
A. P.: Chlorite.

The hornblende prisms are xenomorphic to sub-idiomorphic, optically negative with an optical angle of about 72° and $c/Z = 16°$. They show the following pleochroism: X = pale straw-yellow; Y = pale green; Z = green or bluish-green. Some of the larger prisms contain poikilitic inclusions of plagioclase feldspar. Cataclastic effects and large scale alteration are absent.

The feldspar occurs between the hornblende prisms as xenomorphic crystals. Cataclastic effects are very feeble. It corresponds in composition to a basic oligoclase with about 28% anorthite.

Brown biotite is a subordinate mineral sometimes found in association with the hornblende prisms. The mineral has altered to pale green chlorite.

Colourless to light rose-pink garnets have developed as amoeboid crystals at the expense of hornblende prisms along the contact of the amphibolite with the biotite gneiss of type (3) at 3661 m (see page 184, fig. 28). These garnets are absent in the amphibolite itself. They have no doubt crystallised as a result of the assimilation of aluminous material from the adjacent inclusion.

Opaque ores and sphene are present throughout and the former are sometimes altered into the latter. The rocks exhibit a nemato-granoblastic structure.

Type (5). Garnetiferous epidote-hornblende-plagioclase amphibolite

A specimen collected at 3666.5 m belongs to this type. Microscopically it consists of,

P. C.: Plagioclase feldspar $\sim$ hornblende > quartz.
S. C.: Epidote $\sim$ garnet.
A. C.: Sphene, opaque ore grains, apatite.
A. P.: Chlorite (?).

The principal constituents are present in about equal proportions. Plagioclase is xenomorphic with distinct polysynthetic twinning (on the albite and pericline laws). The crystals occur between the hornblende prisms without exhibiting any stress effects. The feldspar corresponds in composition to a basic labradorite with about 70% anorthite content. Almost all the grains are fresh.

Hornblende prisms are xenomorphic to idiomorphic and exhibit the following pleochroism: X = straw-yellow; Y = pale green; Z = green. They have rarely altered to chlorite. Xenomorphic quartz is mostly confined between hornblende and plagioclase. The quartz grains sometimes form layers and bands amidst the other constituents. Such bands and layers lack, however, the features of quartzose material recrystallised along shear planes under conditions favouring metamorphic differentiation. They appear to represent siliceous intercalations in the original marly sediments which gave rise to the present rock.

Colourless epidote builds sub-idiomorphic to idiomorphic crystals scattered all through the section. There is no convincing evidence to suggest that the epidote has been derived from the alteration and recrystallisation of more basic feldspars or hornblende under conditions favouring recrystallisation and metamorphism of basic or ultrabasic igneous rocks. It seems to be a product crystallised directly from marly material of appropriate composition under metamorphic conditions.

Colourless garnet builds sub-idiomorphic to idiomorphic crystals distributed at random. Amoeboid, spongy, and poikilitic forms are generally absent. Nothing suggests that the garnets have crystallised as a result of assimilation. They appear to be primary constituents.

Sphene is an abundant accessory mineral often building grains measuring up to 0.5 mm in size. Opaque ores and apatite are subordinate to sphene.

The structure of the rock is hypidiomorphic-granular.

Discussion

The rocks of types (1) to (5) of section (1) represent metamorphosed siliceous, calcareous, sometimes marly and pelitic sediments. Careful microscopic examination reveals that in a few instances these metamorphosed sediments have suffered a second and minor degree of contact-metamorphism along their contacts with the basic and ultrabasic intrusives of this zone. Such effects are observed in two specimens collected at 3637 m (type 4 b) and 3661 m (type 3). Towards the northern boundary of the zone, these gneisses were intruded by pegmatites of the post-Alpine orogenic period.

The Maia diorite-amphibolite of section (2) exhibits three distinct facies (1), (2), and (3). Facies (1) represents a slowly cooled and crystallised (or recrystallised) part of the diorite stock and preserves its original magmatic characters. Facies (2) appears along the northern margin of the body, where assimilation of aluminous material from the adjacent gneiss has taken place. Facies (3) is a rapidly chilled margin of the mass against the calc-silicate fels (type 2, section 1). This evidence favours the conclusion that the above amphibolite is of magmatic origin and has intruded the para-gneisses of the zone long after the latter attained their present grade of metamorphism. It is for this reason that the name diorite-amphibolite has been used.

No doubts can arise concerning the magmatic origin of the serpentinised peridotite and its associated amphibolites. The preservation of the intergranular boundaries of the original olivine grains by the pseudomorphs of serpentine indicates that the process of serpentinisation may date back to the time of the intrusion of the peridotite. Whether the primary olivine altered to serpentine in the magmatic chamber prior to intrusion cannot be ascertained from the present studies. However, such a possibility seems to the author not completely excluded. In one instance the complete alteration of the peridotite led to the formation of a talc-serpentine-chlorite-magnesite-schist (type 1 b, section 3) probably in the presence of CO_2.

The amphibolites closely associated with the serpentinised peridotite might be either the direct products of crystallisation differentiation of the ultrabasic magma or products of recrystallisation of the original constituents of the same magma. In any case the evidence points to the serpentinised peridotite and its associated amphibolites being genetically related to one another. The relationship between these rocks and the Maia diorite-amphibolite is not clearly visible in the tunnel. The field

and microscopic data point to the possibility that they too may be genetically related and have intruded into the region more or less simultaneously. Of the amphibolites grouped in section (4) that of type (1) seems to have been formed under conditions of progressive metamorphism from a marly intercalation in the gneisses of type (3) (section 1). It is a para-amphibolite.

It is not clear how the two specimens belonging to type (2) are related to one another. As they were both collected in the neighbourhood of an amphibolite (type 3) whose characters correspond to those of a para-rock, the specimens in question may also be considered to be lenses of para-amphibolite in the country rocks. The microscopic differences shown by them are possibly due to variations in the original marly sediments from which they are derived.

The microscopic features of the amphibolite of type (3) do not suggest its derivation from a basic or ultrabasic igneous rock under metamorphic conditions. It also appears to be a metamorphosed marly sediment. Such impure calcareous sediments are often met with in this zone (see type 2 of section 1).

The two amphibolite specimens representing type (4) and collected from the neighbourhood of the serpentinised peridotite are similar in their microscopic characters to those derived from the metamorphism of basic igneous rocks. One of them produced contact-metamorphic effects on an adjacent biotite gneiss which confirms the view that it is of magmatic origin and probably intruded the gneisses at about the same time as the peridotite.

The high basicity of the plagioclase feldspar, the presence of considerable amounts of quartz, the idiomorphic habit of the garnet and epidote in the type (5) amphibolite suggest that here again is a metamorphosed marly sediment. It is, therefore, a para-amphibolite.

The Arcegno zone contains both ortho- and para-amphibolites more or less concordantly enclosed in the gneisses.

CHAPTER VI

LOCARNO ZONE

Section 1

Country rocks (mica gneisses)

The Locarno zone appears at 3700 m and extends as far as 7440 m, i. e. till the end of the first part of the hydro-electric tunnel. As shown in map (1), the tunnel runs more or less parallel to the strike of the zone. In consequence, the geological aspects of its walls are not favourable for a detailed study of the different types of rocks and their relationship to one another as has been carried out for the preceding zones. In addition, the entire zone has been subjected to intense processes of pegmatitic injection, the study of which cannot be carried out in the restricted material available. Only a few field and microscopic observations made on specimens from the tunnel are recorded here to give a general idea of the zone.

The commencement of the zone can be recognised by increasing amounts of muscovite in the biotite gneiss of the Arcegno zone, the more frequent occurrence of pegmatites, injection-, permeation-, and augen-gneisses. Biotite gradually recedes and becomes a subordinate constituent in the gneisses of the Locarno zone. The lack of sharp boundaries prevented their accurate demarcation in the profiles. Some of the larger pegmatites and the amphibolites found concordantly enclosed in the gneisses are entered into profiles (5) and (6).

The pegmatites are coarse-grained consisting chiefly of quartz, plagioclase feldspar, potash feldspar (with the development of myrmekite), and subordinate amounts of muscovite. They have injected the gneisses both along and across the gneissose planes. They range from a few meters to as much as 50 meters in width sometimes showing sharp and sometimes transitional contacts against the country rocks. It is not uncommon to find variously sized fragments of the gneiss incorporated bodily into the pegmatites. On the other hand, partial permeation of the gneisses by the pegmatites may cause the former to assume a pegmatitic aspect. Lit-par-lit injections are also met with. Rocks of stromatitic, phlebitic, and nebulitic fabrics are produced by this intimate mixture of the gneisses and the quartzo-feldspathic material. In addition, the zone contains augen-gneisses and such with spindly and streaky fabrics, which seem to be derived from the permeation by pegmatitic material. The contacts of the above-mentioned gneisses between them-

selves are almost always transitional and suggest that these rocks occur when the amount of pegmatitic material gradually diminishes.

Towards the end of the profile (6) the frequency of the pegmatites, injection-, permeation-, and augen-gneisses increases.

Section 2

Basic rocks (amphibolites) of the Locarno zone

The basic rocks found more or less concordantly enclosed in the gneisses are described in this section. All of them are amphibolites (sensu stricto) consisting mainly of hornblende and plagioclase feldspar with subordinate amounts of biotite and quartz. They exhibit sharp contacts against the adjacent gneisses, but no contact-metamorphic effects were visible in the field. The amphibolites range in width from a few meters up to 25 meters and are met with at 4810, 5140, 5785, 5837, 6051, and 7156 m in the tunnel. As in the previous instances, they are divided into a number of types depending on their mineralogical compositions and structures and described below. As the rocks of this zone were not described by P. WALTER (1950) rock names proposed by him are lacking.

Type (1)

Specimens collected at 4810 and 5837 m represent this type. They are dark green in colour, fine- to medium-grained with visible prisms of hornblende and specks of plagioclase feldspar. The first one shows a lineated texture, while the second has a massive and random texture. Microscopically they consist of,

P. C.: Plagioclase feldspar $\sim$ hornblende > biotite > quartz.
S. C.: Opaque ores, sphene, apatite, and zircon.
A. P.: Chlorite.

The feldspar is an intermediate andesine with about 40% anorthite. The crystals are xenomorphic to sub-idiomorphic in habit exhibiting polysynthetic twinning on the albite or pericline laws. In 4810 the grains measure about 0.5 mm, while in 5837 they attain a size of 1 mm. Crystals measuring less than 0.5 mm are rare in the latter section. Cataclastic effects and alteration are not significant. The feldspars in 5837 contain numerous minute grains of apatite and zircon as inclusions.

Hornblende is xenomorphic to sub-idiomorphic and is optically negative with an optical angle of about 74° and c/Z = 17°. The pleo-

chroism is as follows: X = straw-yellow; Y = green; Z = green with a slight brownish tinge. The optical properties suggest that it belongs to the common hornblende series.

Brown biotite is distributed uniformly throughout the sections. The flakes are of different sizes and are found either in parallel intergrowth or projecting across the margins of the hornblende prisms. The biotite has apparently developed as a peritectic reaction mineral from the hornblende. Pleochroic haloes around minute inclusions of zircon are plentiful. The flakes have sometimes altered to pale green chlorite.

Xenomorphic quartz lies between the other constituents occasionally showing distinct undulose extinction. Brownish sphene is an abundant accessory.

The structure of 4810 is nemato-granoblastic and that of 5837 hypidiomorphic-granular.

Type (2)

Specimens collected from a single amphibolite band at 6050, 6051, and 6062 m belong to this type. The first two specimens were collected from the central part of the amphibolite, while the third one comes from its northern margin. The first two rocks are dark green in colour, coarse-grained, with visible hornblende prisms and feldspar grains. The third specimen is rather fine-grained. All the three specimens show a random texture and are divided into two facies (1) and (2) representing the central and marginal parts of the amphibolite mass respectively.

Facies (1)

Microscopically it consists of,
P. C.: Plagioclase feldspar ~ hornblende > biotite.
S. C.: Scapolite, quartz.
A. C.: Sphene, apatite, zircon, opaque ores.
A. P.: Chlorite.

Plagioclase is an acid andesine with about 33% anorthite. It builds xenomorphic and polysynthetically twinned crystals interstitial between the hornblende prisms. Cataclastic effects are not distinct. Sericitisation is occasionally found in some of the grains.

Hornblende is xenomorphic to sub-idiomorphic. It is optically negative with an optical angle of 72° and c/Z = 18°. The pleochroic scheme is: X = straw-yellow; Y = green; Z = green with a brownish tinge. It belongs to the common hornblende series.

Both the feldspar and hornblende crystals attain a size of 1 to 2 mm in their longer diameters. Grains measuring even 3 mm are not uncommon. Flakes of brown biotite also measure up to 0.8 mm. As shown in fig. 35, most of these flakes form a rim around the hornblende prisms or project along their cleavages or across their margins. This suggests their formation as a peritectic reaction mineral from hornblende (a relationship commonly observed in magmatic rocks of diorite to gabbro-composition). The biotite flakes show random orientations and are sometimes altered to pale green chlorite.
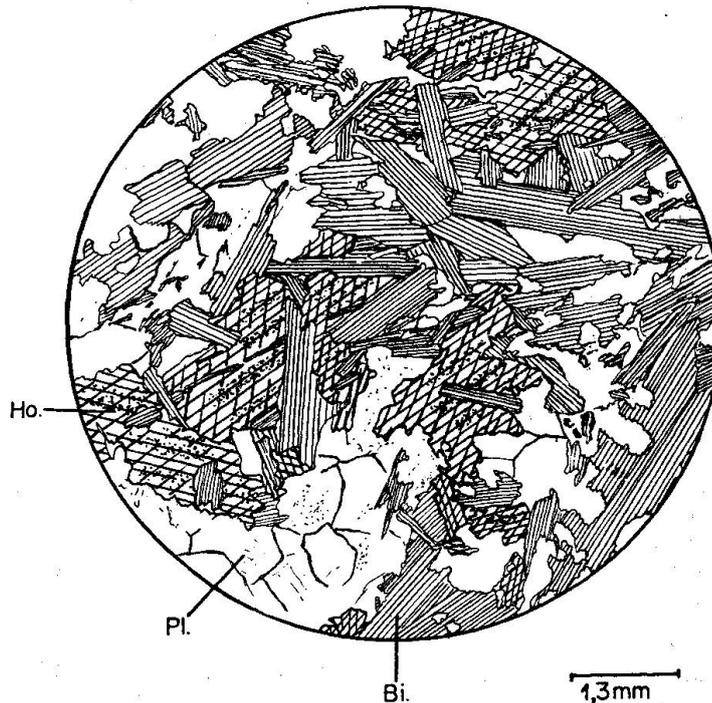

Fig. 35 (Section 6051). Diorite-amphibolite showing development of biotite as a peritectic reaction mineral around the margins of the hornblende prisms. The structure of the rock is xenomorphic to hypidiomorphic-granular.

Xenomorphic scapolite occurs in large crystals measuring up to 2 mm. It appears to have developed at the expense of the feldspar crystals. Its proportion relative to feldspar could not be accurately estimated in view of the small area of the section. Some of these scapolite crystals have also altered to fine scales of sericite. Quartz is present as anhedral grains between the other constituents. Brownish sphene is an abundant accessory constituent beside apatite and zircon.

The section exhibits a typical xenomorphic to hypidiomorphic granular structure.

Facies (2)

The minerals and their mutual relationships to one another in this facies (6062) are the same as in (1). However, the size of the constituents is much reduced and the minerals do not exceed 0.5 mm in size. This indicates that facies (2) is the chilled margin of facies (1).

In addition, tiny flakes of biotite are extensively developed along and across the margins of the hornblende prisms and sometimes form a sheath around the latter. This relationship points again to the fact that some potash matter appears to have migrated from the gneisses into the amphibolite during the time of its intrusion.

The structure of the rock is fine xenomorphic-granular.

Specimen (6051) of facies (1) was analysed and the analysis along with Niggli values are given in table (10) below. The analysis shows a rather high potash content for a rock of so low a silica content and hence in the same table the Niggli values of a standard shonkinitic magma type are also quoted for a comparative study.

Table 10

	6 (6051)	a	b
SiO_2	48.22	si = 111	100
Al_2O_3	13.72	al = 19	17.5
Fe_2O_3	3.02		
FeO	7.52	fm = 49	47.5
MnO	0.23		
MgO	8.54		
CaO	9.16	c = 23	23
Na_2O	2.39	alk = 9	12
K_2O	2.76		
$+H_2O$	2.60	k = 0.43	0.55
$-H_2O$	0.07	mg = 0.59	0.65
TiO_2	1.61	ti = 3	
P_2O_5	0.22	p = 0.46	
Total	100.06		

Basis

Kp	Ne	Cal	Cs	Fs	Fa	Fo	Ru	Cp	Q
10.0	13.2	11.5	7.8	3.2	9.2	18.0	1	0.46	25.5

Kata-standardnorm

Or	Ab	An	Wo	En	Hy	Fo	Fa	Ru	Cp	Mt	Σ
16.5	22.0	19.2	10.8	3.1	1.3	15.9	6.6	1.1	0.2	3.3	100.0

Analysis (6): Potash-rich diorite-amphibolite collected at 6051 m from the Maggia hydro-electric tunnel. Analyst J. JAKOB.

Analysis a) Niggli values of the above analysis.

Analysis b) Niggli values of standard shonkinitic magma type. P. NIGGLI (op. cit.).

Analysis (6) shows a higher percentage of potash than the previous analyses of basic rocks (1, 2, and 5) of this region. This may be due to the fact that the present rock reached a stage of magmatic differentiation when biotite is extensively developed at the expense of hornblende as a peritectic reaction mineral during the process of crystallisation-differentiation. When the Niggli values of the analysed rock are compared with those of standard shonkinitic magma type a close agreement between the two is strikingly perceptible. The rock under discussion is therefore genetically related to the family of potash-gabbroid rocks and is probably of magmatic origin.

Type (3)

A specimen collected at 5785 m represents this type. Microscopically it consists of,

P. C.: Quartz > plagioclase feldspar > hornblende.

S. C.: Biotite > garnet $\sim$ epidote.

A. C.: Sphene, apatite, opaque ores.

A. P.: Chlorite, sericite.

Xenomorphic quartz predominates over the other constituents Plagioclase feldspar is an acid labradorite with about 52% anorthite. Both the minerals do not exceed 0.5 mm in size and do not exhibit any distinct cataclastic effects. The feldspar has altered to sericite here and there.

Hornblende occurs as xenomorphic prisms with lobed margins. It is optically negative with an optical angle of 66° and c/Z = 17°. The pleochroic scheme is: X = straw-yellow; Y = green; Z = green with a brownish tinge. Almost all the prisms are fresh.

Nearly all the biotite has altered to pale green chlorite which is distributed at random in the section.

Xenomorphic garnets measuring about 0.5 mm in size are scattered all through as a subordinate mineral. They are almost colourless to pale rose-pink in colour and contain poikilitic inclusions of quartz.

Xenomorphic to sub-idiomorphic crystals of epidote are distributed throughout the section like the garnets. They measure about 0.3 mm

and do not appear to have been derived from the alteration of the other constituents. They represent primary minerals of the rock.

Sphene is the abundant accessory mineral which is constantly observed in association with the hornblende prisms. In several cases it is found as inclusions in the latter.

The structure of the rock is xenomorphic-granular.

Type (4)

Two specimens collected at 5140 and 7156 m belong to this type. Both of them are dark green in colour, fine-grained with visible hornblende prisms and specks of feldspar. Microscopically they consist of,

P. C.: Plagioclase feldspar > hornblende.
S. C.: Quartz.
A. C.: Apatite, opaque ores, sphene (?).
A. P.: Chlorite, sericite, clinozoisite.
Ff. C.: Prehnite, quartz.

The feldspar corresponds in composition to an intermediate andesine with about 39% anorthite. The crystals are xenomorphic measuring about 0.4 mm in size. Cataclastic effects are feeble. Fracturing, marginal granulation, and undulose extinction are distinct. Almost all the crystals have altered to fine scales of sericite and cloudy aggregates of clinozoisite. Wide-spread alteration has obliterated the polysynthetic twin lamellæ. Hornblende occurs as xenomorphic to sub-idiomorphic prisms exhibiting perceptible fracturing and marginal granulation. It is optically negative with an optical angle of 78° and $c/Z = 18°$. Its pleochroism is: $X =$ straw-yellow; $Y =$ green; $Z =$ green with a brownish tinge. It belongs to the common hornblende series. Some of the prisms are sometimes altered to pale green chlorite.

Xenomorphic quartz lies between the other constituents. Most of the original biotite has altered to pale green chlorite.

The sections are traversed by veins of colourless prehnite. Some of the fractures are also healed by quartz or are still vacant.

The structure is nemato-granoblastic with feeble cataclasis.

Discussion

Type (1) amphibolites of section (2) exhibit a mineralogical composition and structure commonly observed in metamorphosed basic rocks of igneous origin. They are, therefore, magmatic in their genesis.

Type (2) amphibolite has a chilled northern margin and shows a distinct peritectic reaction relationship between the hornblende prisms and the biotite. The amphibolite preserves its magmatic characters and can be called here (considering the basicity of plagioclase feldspar) diorite-amphibolite.

The mineralogical composition and structure of type (3) amphibolite differ markedly from those of the other types. It may represent a para-amphibolite derived from the metamorphism of marly sediments.

Type (4) amphibolite exhibits a pronounced degree of alteration of its original constituents to secondary minerals. Otherwise, it is similar in many respects to type (1).

The Locarno zone therefore contains both ortho- and para-amphibolites.

The intrusion of the ortho-amphibolites seems to be later than the metamorphism of the pelitic sediments (now represented by the two-mica-gneisses) of the Locarno zone.

The exact relationship between the ortho-amphibolites and the pegmatites is not clear in the tunnel and hence it is not possible to state which of the two are the younger intrusives.

CHAPTER VII

PETROCHEMISTRY OF THE DIFFERENT BASIC ROCKS OF THE FIVE ZONES

In table 11 are given the Q L M, π-k, γ-mg values of the original analyses of basic rocks of this region as well as of those available in the literature. The publication of C. BURRI and F. DE QUERVAIN (1934) was especially helpful for obtaining a rapid survey of older analyses. The symbols quoted above have the following significance:

Q = Quartz.

L = Kp + Ne + Cal (fundamental molecules of feldspars and feldspathoids).

M = Cs + Fo + Fs + Ru (complex olivine and augite molecules).

π = $\dfrac{Cal}{Ne + Kp + Cal}$, i. e.: The above value gives the ratio of calcium bound to aluminium to the normative alkalies and calcium (Ca + K + Na) bound to aluminium (as in the alkali and plagioclase feldspars and feldspathoids).

$$\gamma = \frac{Cs}{Cs + Fo + Fa + Fs},$$ i. e.: The value gives the ratio of calcium which is not bound to aluminium to the total content of $Ca + Fe + Mg$, which is not bound to aluminium.

$$K = \frac{K_2O}{K_2O + Na_2O},$$ i. e.: The ratio of potash to total alkalies.

$$mg = \frac{MgO}{FeO + MgO + MnO},$$ i. e.: The ratio of magnesium to the total sum of femic oxydes.

(For further particulars regarding the calculation of the various Niggli values, the Niggli molecular norm, and their significance in petrogenetical discussion, see particularly: P. NIGGLI (1936, 1938), C. BURRI and P. NIGGLI (1945, pp. 24—100), P. NIGGLI and R. L. PARKER (1954, pp. 5—137), and T. N. MUTHUSWAMY (1952).)

Table 11

Ivrea zone (principal mass)

	Q	L	M	π	γ	k	mg
1.	26.0	32.1	41.9	0.62	0.27	0.06	0.70
2.	23.3	26.3	50.4	0.53	0.24	0.06	0.40
3.	27.9	33.1	39.0	0.42	0.25	0.09	0.35
4.	37.1	36.1	26.8	0.38	—	0.30	0.49
7.	22.5	31.8	45.7	0.61	0.24	0.08	0.53
8.	25.0	39.9	35.1	0.54	0.22	0.38	0.68
9.	25.1	31.5	43.4	0.53	0.22	0.12	0.61
10.	25.1	25.6	49.3	0.48	0.23	0.13	0.49
11.	27.3	46.4	26.3	0.72	0.03	0.26	0.67
12.	29.7	42.4	27.9	0.45	0.02	0.14	0.53
13.	20.5	38.3	41.2	0.71	0.16	0.16	0.45
14.	42.0	38.8	19.2	0.49	—	0.18	0.35
15.	29.0	40.1	30.9	0.70	0.18	0.08	0.51
16.	31.4	41.4	27.2	0.53	0.13	0.12	0.45
17.	24.0	31.1	44.9	0.61	0.23	0.06	0.59
18.	25.3	32.6	42.1	0.65	0.25	0.06	0.61
19.	26.7	29.4	43.9	0.58	0.24	0.14	0.52
20.	27.7	40.3	32.0	0.64	0.10	0.12	0.46
21.	29.8	42.9	27.3	0.60	0.15	0.10	0.35
22.	24.2	39.9	35.9	0.64	0.15	0.12	0.50
23.	32.2	35.4	32.4	0.76	0.16	—	0.62
24.	27.0	35.1	37.9	0.64	0.16	0.11	0.45
25.	32.2	49.8	18.0	0.34	—	0.32	0.17

Basic dikes from the adjacent kinzigite zone

	Q	L	M	π	γ	k	mg
26.	33.8	31.4	34.8	0.80	0.13	0.11	0.52
27.	36.2	46.1	17.7	0.47	0.33	0.04	0.57
28.	16.0	23.7	60.3	0.42	0.22	0.22	0.49

Ultrabasic rocks of the Ivrea and adjacent zones

	Q	L	M	π	γ	k	mg
29.	5.9	6.2	87.9	0.08	0.06	0.17	0.89
30.	3.5	4.2	92.3	—	—	0.66	0.90
31.	9.2	6.1	84.7	0.56	0.07	0.25	0.86
32.	5.7	3.8	90.5	1.00	0.01	—	0.90
33.	0.1	3.8	96.1	0.21	0.02	—	0.81
34.	25.9	13.4	60.7	0.85	0.05	—	0.89

Basic bands from the Canavese zone

	Q	L	M	π	γ	k	mg
5.	32.7	31.3	36.0	0.51	0.11	0.15	0.42

Basic dike from the Locarno zone

	Q	L	M	π	γ	k	mg
6.	25.5	35.0	39.5	0.33	0.20	0.43	0.59

Specification and source of the above analyses

1. Pyroxene gabbro. Ivrea zone, Maggia hydro-electric tunnel (collected at 1940 m). Analyst J. JAKOB.
2. Hypersthene-diallage-gabbro (hyperite?). Ivrea zone, Maggia hydro-electric tunnel (collected at 1820 m). Analyst J. JAKOB.
3. Garnetiferous hypersthene-plagioclase-fels(?). Ivrea zone, Maggia hydro-electric tunnel (collected at 1384 m). Analyst J. JAKOB.
4. Hypersthene-biotite-plagioclase-fels(?). Ivrea zone, Maggia hydro-electric tunnel (collected at 1395 m). Analyst J. JAKOB.
5. Hornblende-plagioclase-amphibolite. Canavese zone. Maggia hydro-electric tunnel (collected at 2430 m). Analyst J. JAKOB.
6. Diorite-amphibolite. Locarno zone, Maggia hydro-electric tunnel (collected at 6051 m). Analyst J. JAKOB.
7. Hornblende-gabbro. Migiandone, Valle d'Ossola. G. FAGNANI, Bull. Soc. Tic. Sc. Nat. 42 (1947). Analyst G. FAGNANI.
8. Amphibole gabbro. Pesmonte, Canavese. M. FENOGLIO, Period. di Min. 4 (1933), p. 42—85. Analyst M. FENOGLIO.
9. Amphibolite. Middle part of Valle del Boschetto, Centovalli. W. G. RADEFF, Ecl. geol. Helv. 13 (1915), p. 485—532. Analyst L. HEZNER.
10. Plagioclase-amphibolite. Monte Verità, Ascona. J. SUZUKI. Quoted from "Beitr. Geol. Schweiz, Geotechn. Ser. 14, Bern 1930". Analyst H. SCHUMANN.
11. Hornblende-gabbro. Cima di Foggia, Valle Sessera, Piedmont. F. MILLO-SEVICH. Rend. R. Acc. Naz. Lincei (6) 5 (1927), p. 22—27. Analyst F. MILLO-SEVICH.

12. Norite. Cima di Foggia, Valle Sessera, Piedmont. F. MILLOSEVICH. ibid. P. 25 (Corundum-bearing).

13. Hornblende-gabbro. Pavone near Ivrea, Piedmont. F. T. VAN HORN, Tsch. Mitt. 17 (1898). Analyst M. DITTRICH.

14. Quartz-hypersthene-diorite. Ivrea, Piedmont. ibid. Analyst L. v. WERVEKE.

15. Amphibolgabbro. Ponte dei Preti, Piedmont. M. FENOGLIO, Period. di Min. 4 (1933), p. 42—85. Analyst M. FENOGLIO.

16. Norite. Street Chiaverano-Monsino near Ivrea, Piedmont. F. R. VAN HORN. Tsch. Mitt. 17 (1898). Analyst M. DITTRICH.

17. Hornblende-gabbro. Anzola, Valle d'Ossola. M. BERTOLANI, Rend. Soc. Min. Italia, 10 (1954), p. 180. Analyst P. GALLITELLI.

18. Pyroxene-hornblende-gabbro. Anzola, Valle d'Ossola. H. HUTTENLOCHER, Schw. Min. Petr. Mitt. 22 (1942), p. 346. Analyst F. STACHEL.

19. Hornblende-gabbro. Upper part of Casarole. M. BERTOLANI, Rendic. Soc. Min. Italia, 10 (1954), p. 135. Analyst. M. BERTOLANI.

20. Hypersthene-hornblende-gabbro. Valle Sabbiola. M. BERTOLANI. ibid. p. 107.

21. Hypersthene-hornblende-gabbro. Valle Saccora, Valle Sesia. M. BERTOLANI. ibid. p. 103.

22. Biotite-hornblende-gabbro. Valle Sabbiola. M. BERTOLANI. ibid. p. 110.

23. Biotite-hornblende-gabbro. Valle Sabbiola M. BERTOLANI. ibid. p. 110.

24. Hypersthene-hornblende-gabbro. Valle Saccora. M. BERTOLANI. ibid. p. 105.

25. Quartz-biotite-bearing pyroxene-hornblende gabbro. Valle Sabbiola. M. BERTOLANI. ibid. p. 117.

26. Hornblende-biotite-gabbro (dike). Brissago. C. BURRI und F. DE QUERVAIN. Schweiz. Min. Petr. Mitt. (1934), p. 513. Analyst F. DE QUERVAIN.

27. Gabbro "zoned". Valle Sabbiola, M. BERTOLANI. Rendic. Soc. Min. Italia. 10 (1954), p. 130.

28. Gabbro "zoned". Valle Sabbiola. M. BERTOLANI. ibid. p. 130.

29. Lherzolite. Baldissero, Piedmont. E. SANERO. Period. di Min. 2 (1931), p. 35—42. Analyst E. SANERO.

30. Phlogopite-peridotite. Ponte Creves near Finero, Valle Cannobina. C. BURRI. Unpublished. Analyst J. JAKOB.

31. Lherzolite. Pesmonte, Canavese. M. FENOGLIO. Period. di Min. 4 (1933), p. 42—85. Analyst M. FENOGLIO.

32. Peridotite. Testa di Misello, Centovalli. W. G. RADEFF. Ecl. Geol. helv. 13 (1915), p. 485—532. Analyst L. HEZNER.

33. Dunite. Valle Sabbiola. M. BERTOLANI. Rendic. Soc. Min. Italia. 10 (1954), p. 156.

34. Olivine pyroxenite. Valle Sabbiola. M. BERTOLANI. ibid. p. 157.

All the analyses quoted above are plotted in the triangular diagrams of figures 36, 37, and 38. The following points can be deduced from the study of these diagrams:

1. With the exception of the analyses of the ultrabasic rocks and a few more acid types, the remaining analyses as a whole fall within the main gabbro field characteristic of pacific magmatic rock provinces.

2. All the analyses with the exception of No. (4) and that of a quartz-hypersthene-diorite from the Ivrea zone lie below the saturation line joining the saturation points of the pyroxenes (P) and feldspars (F).
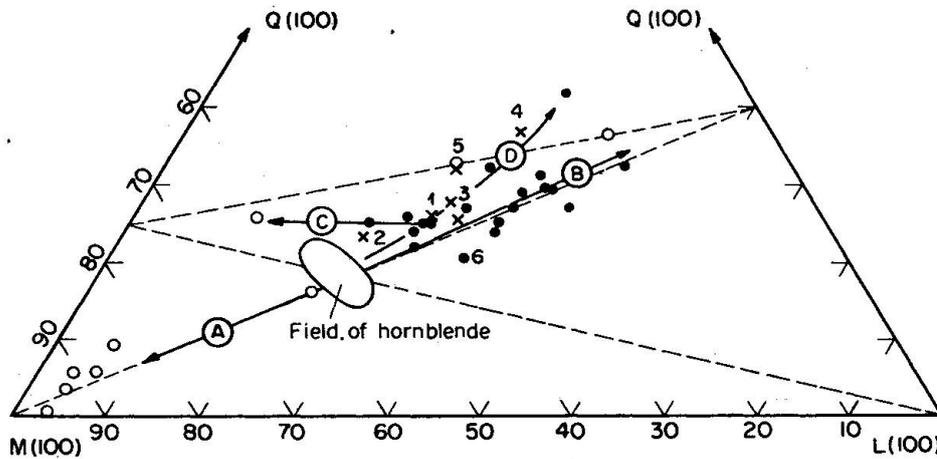

Fig. 36. QLM diagram.

● Analyses of the different basic rocks of the main body of the Ivrea zone.
○ Analyses of the bands, lenses, and dikes of basic rocks in the adjacent gneisses and also of the ultrabasic rocks.
× New analyses.
1 Pyroxene-hornblende-gabbro.
2 Hypersthene-diallage-gabbro (hyperite?).
3 Garnetiferous-hypersthene-plagioclase-fels (?)
4 Quartz-hypersthene-biotite-plagioclase-fels (?)
5 Hornblende-plagioclase-chlorite-epidote-amphibolite.
6 Diorite-amphibolite (Locarno zone).
A Enrichment in olivine.
B Trending towards compositions rich in feldspar molecules due to A.
C Enrichment in pyroxene.
D Trending towards compositions with free quartz due to separation of hornblende.

3. This minor deviation of analysis (4) points

a) either to a special trend of differentiation within the basic rocks towards the quartzo-feldspathic side,

b) or to the derivation of the rock in question from a pelitic sediment of the kinzigite series with similar chemical composition. In this connection it is to be remembered that H. F. HUTTENLOCHER (1942) considered the basic rocks of the Ivrea zone to be original sediments and to have acquired their present similarity to igneous rocks as a result of reactions taking place among the original constituents under metasomatic conditions. No sufficient evidence

was forthcoming from the present investigations to confirm this view.

4. Analysis (3) of another doubtful inclusion in the basic rocks does not
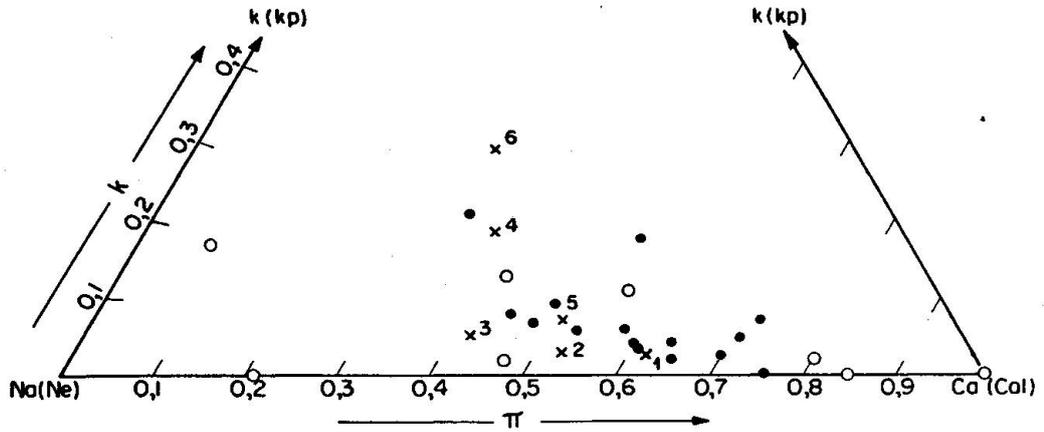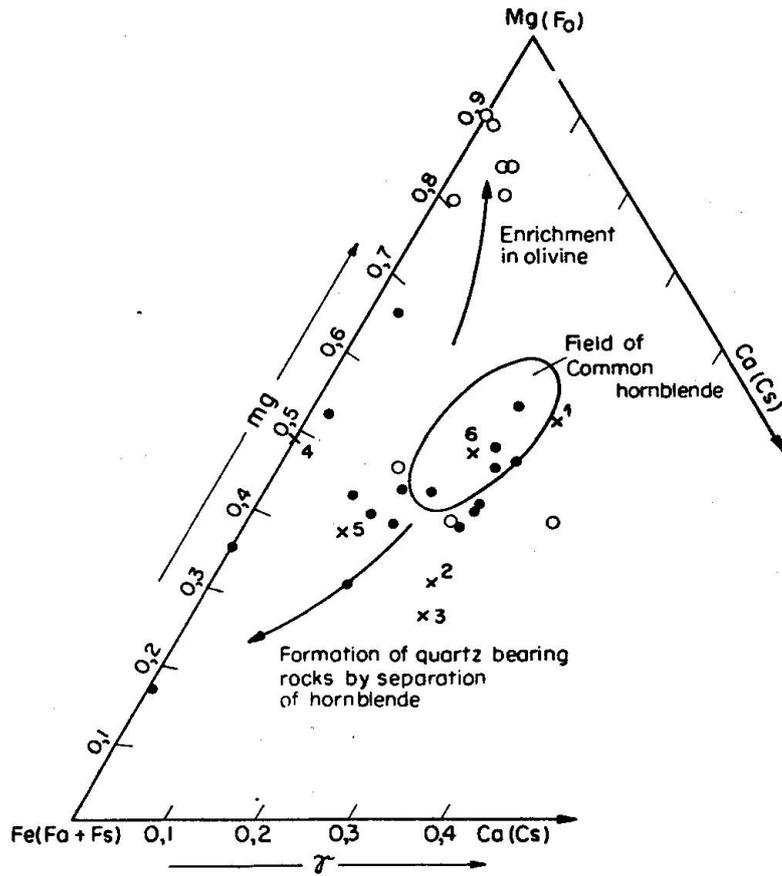
Fig. 37. k-π-diagramm with the same symbols as in Fig. 36.

Fig. 38. mg-γ-diagram with the same symbols as in fig. 36.

show any marked deviation in composition from the other rocks. This points to its being of magmatic origin.

5. The distribution of almost all the projection points along the line M-F in the Q L M diagram (fig. 36) signifies that the entire series of basic and ultrabasic rocks of the area under investigation belongs to the same epoch of differentiation of a parent basic magma. If the latter be tentatively assumed to be gabbroid in composition a sinking of the olivine crystals during gravitative crystallisation differentiation would tend to displace the composition of the residual liquid in the direction of "F". A series of points lying in the neighbourhood of the pole representing the pyroxenes suggests a further trend of differentiation involving enrichment of the pyroxenes. Similarly the presence of a few points near the projection point of quartz-hypersthene-diorite makes a differentiation in this direction seem likely. This could be effected by the separation and removal of hornblende crystals from the magma. The composition of the hornblende of the basic rocks is not exactly known. Its optical properties indicate that it belongs to the common hornblende series. The field representing the composition of these latter has, therefore, also been included in the diagrams to show the possible mechanism of such a process.

6. Analysis (b) of the potash-rich diorite-amphibolite of the Locarno zone also falls within the main gabbro-field. If the same point were to be projected in a K-Na-Ca triangle, it would fall outside the field of the other basic rocks. This fact shows that the rock in question is probably not genetically related to the parent basic magma of the Ivrea zone.

7. More analyses of the amphibolites of the Locarno zone are required if positive conclusions regarding their genetical relationship to the basic rocks of the Ivrea zone are to be drawn.

8. To the close chemical relationship between the basic rocks of the kinzigite, Ivrea, Canavese, and Arcegno zones may correspond more or less contemporaneous periods of intrusion.

Appendix

Alphabetical list of abbreviations of mineral names used in the text, figures, and profiles.

Ap	=	Apatite	C	=	Corundum
Aug	=	Augite	Cc	=	Calcite
Bi	=	Biotite	Chl	=	Chlorite

Cord	=	Cordierite	Pgp	=	Phlogopite
Diall	=	Diallage	Pl	=	Plagioclase feldspar
Diop	=	Diopside	Preh	=	Prehnite
Ep	=	Epidote	Qz	=	Quartz
Gr	=	Garnet	Scap	=	Scapolite
Ho	=	Hornblende	Serc	=	Sericite
Hy	=	Hypersthene	Serp	=	Serpentine
Il	=	Ilmenite	Sill	=	Sillimanite
Mgs	=	Magnesite	Sp	=	Spinel
Ms	=	Muscovite	Stau	=	Staurolite
Mylonite	=	Mylonite	Tc	=	Talc
O	=	Opaque ores	Tit	=	Titanite
Ol	=	Olivine	Ves	=	Vesuvianite
Ot	=	Orthite	Zo	=	Zoisite and clinozoisite
Pf	=	Potash feldspar	Zr	=	Zircon

The mineralogical compositions of the specimens indicated along the northern margins of the profiles are given below. Minerals in italics are secondary of fracture-filling components, while those in brackets are accessories.

Profile (1)

```
 66  =  Qz. Pl. Bi. Gr. (Ap. O. Zr.)
 86  =  Qz. Pl. Bi. Gr. Sill. (Ap. O. Zr.)
147  =  Qz. Pl. Bi. Sill. (Ap. O. Zr.)
176  =  Qz. Pl. Bi. Sill. (Ap. O. Zr.)
208  =  Qz. Pl. Bi. Sill. (Ap. O. Zr.)
404  =  Qz. Pl. Bi. Gr. (Ap. O. Zr.)
466  =  Qz. Pl. Bi. (Ap. O. Zr.)
503  =  Cc. Qz. Ho. Pl. Ep. (Ap. O. Tit.)
530  =  Cc. Qz. Pl. Diop. Gr. Ep. (Ap. O. Tit.)
532  =  Qz. Pl. Chl. Gr. Sill. (Ap. O. Zr.)
580  =  Qz. Pl. Bi. (Ap. O. Zr.)
630  =  Qz, Pl. Bi. Gr. (Ap. O. Zr.)
     =  Cc. Qz. Pl. Ho. Diop. (Ap. O. Tit.)
638  =  Cc. Qz. Pl. Scap. Ho. Diop. (Tit. Ap. O.)
674  =  Qz. Pl. Bi. Gr. (Ap. O. Zr.)
682  =  Qz. Pl. Bi. Gr. (Ap. O. Zr.)
700  =  Qz. Pl. Bi. Gr. Chl. (Ap. O.)
```

Amphibolites

```
 87  =  Ho. Pl. Bi. (Ap. O. Zr.)
 96  =  Ho. Pl. (Ap. O.)
127  =  Ho. Pl. Chl. Cc. (Tit. Ap. O.)
212  =  Ho. Pl. Bi. (Ap. O. Tit.)
250  =  Ho. Pl. Bi. (Ap. O.)
360  =  Ho. Pl. Bi. Gr. (Ap. O. Tit?)
```

380 = Ho. Pl. Bi. (Ap. O. Tit?)
391 = Ho. Pl. Bi. (Ap. O.)
530 = Ho. Pl. (Ap. O. Tit.)
700 = Ho. Pl. (Ap. O.)
721 = Ho. Pl. Bi. Aug. *Ep. Chl.* (Tit. Ap. O.)
730 = Ho. Pl. Bi. *Chl.* (Ap. O. Tit. Zr.)

Profile (2)

1310 = Pl. Ho. Gr. *Ep. Chl.* (Ap. O. Tit.)
1340 = Pl. Ho. *Ep.* (Ap. O.)
1355 = Pl. Ho. Hy. Bi. Gr. *Ep. Zo.* (Ap. O.)
1370 = Ho. Pl. *Chl. Ep.* (Ap. O.)
1390 = Ho. Pl. Aug. Hy. Gr. Bi. (Ap. O. Ot. Zr.)
1446 = Ho. Pl. Aug. Diall. (Ap. O. Tit.)
1475 = Ho. Pl. *Ep.* (Ap. O. Tit.)
1508 = Pl. Diall. Ho. Aug. Hy. *Tc.* (Ap. O. Tit.)
1530 = Pl. Diall. Aug. Ho. Hy. *Tc.* (Ap. O.)
1573 = Pl. Hy. Diall. Ho. *Tc.* (Ap. O.)
1650 = Ho. Pl. Aug. *Chl. Ep.* (Ap. O.)
1688 = Ho. Pl. Hy. Aug. *Tc.* (Ap. O.)
1710 = Diall. Plag. Aug. Ho. Gr. *Chl. Tc.* (Ap. O.)
1725 = Pl. Ho. Diall. Aug. *Chl. Ep. Zo.* (Ap. O.)
1750 = Pl. Diall. Ho. Aug. *Chl. Ep.* (Ap. O.)
1770 = Pl. Diall. Ho. Aug. *Chl. Ep. Zo.* (Ap. O.)
1790 = Pl. Diall. Ho. *Chl. Ep. Zo.* (Ap. O. Tit?)
1800 = *Ep. Chl.* Ho. Aug. Pl. (Ap. O. Tit.)
1820 = Diall. Plag. Hy. (Ap. O.)
1850 = Plag. Diall. Hy. Ho. *Tc. Zo.* (Ap. O. Tit.)
1885 = *Ep. Chl. Zo.* Pl. Ho. Aug? (Ap. O. Tit.)
1910 = Pl. Aug. Ho. *Chl. Ep. Zo.* (O. Ap.)
1940 = Pl. Aug. Ho. (Ap. O.)
1970 = Ho. Pl. *Chl. Ep.* (Ap. O.)

Inclusions in the basic rocks

1310 = Qz. Pl. Gr. *Chl. Ep.* (Ap. O.)
1323 = Qz. Bi. Sp. C. Pl. *Serc. Zo.* (Ap. O.)
     = Qz. Serc. *Chl. Zo.* (Ap.)
     = Diop. Pl. Qz? *Ep. Serc.* (Ap. O. Tit.)
1384 = Pl. Gr. Hy. Aug. Bi. Ho. Qz. *Tc.* (Ap. O. Ot.)
1395 = Pl. Qz. Hy. Bi. *Tc. Serp.* (O. Ap.)
1410 = Pl. Qz. Aug. Bi. Gr. (O. Ap. Ot.)
1420 = Pl. Diop. *Serc. Ep. Zo.* (O. Ap. Tit.)
1422 = Pl. Diall. Ho. *Serc. Ep. Zo.* (O. Ap. Tit.)
1467 = Pl. Gr. Qz? Hy. Bi. *Ep. Zo. Serc.* (O. Ap.)
1502 = Pl. Gr. Bi. Qz. Ep. (Ap. O.)
1597 = Qz. Pl. Gr. *Chl. Serc.* (Ap. O. Zr. Tit.)

1605 = Qz. Pl. Gr. Bi. *Chl.* (Ap. O. Zr.)
1900 = Pl. Qz. Gr. *Ep. Serc.* (Zo. Ap. O.)

Profile (3)

2005 = Qz. Pl. Gr. Bi. Sill. *Chl.* (Ap. O.)
2125 = Qz. Pl. Gr. *Chl.* (Ap. O.)
2160 = Qz. Pl. Gr. *Chl.* (Ap. O.)
2193 = Mylonite
2335 = Qz. Pl. Ms. *Chl?* (Ap. O. Zr.)
2423 = Qz. Pl. Ms. Bi. (Ap. O. Zr.)
2428 = Qz. Pl. Bi. Ms. *Chl.* (Ap. O. Zr.)
2432 = Qz. Pl. Bi. Ms. *Chl.* (Ap. O. Zr.)
2443 = Qz. Pl. Ms. Serc. (Ap. Zr. O ?)
2470 = Qz. Pl. Pf. Ms. (Ap. Zr. O.)
2480 = Qz. Pl. Pf. Ms. (Ap. Zr. O.)
2496 = Qz. Pl. Ms. Bi. (Ap. Zr. O.)
2505 = Qz. Pl. Pf. Ms. (Ap. Zr. O.)
2512 = Qz. Pl. Pf. Ms. Serc. (Ap. Zr. O.)
2540 = Qz. Pl. Ms. Pf. Serc. (Ap. Zr. O.)
2587 = Qz. Pl. Pf. Ms. Serc. (Ap. Zr. O.)
2618 = Qz. Pl. Pf. Ms. Serc. (Ap. Zr. O.)
2632 = Qz. Pl. Pf. Ms. Serc. (Ap. Zr. O.)
2665 = Qz. Pl. Ms. Bi. (Ap. Zr. O.)
2715 = Qz. Pl. Ms. Serc. (Ap. Zr. O.)
2730 = Qz. Pl. Ms. Pf? (Ap. Zr. O.)
2810 = Qz. Pl. Ms. Bi. *Chl?* (Ap. Zr. O.)
2915 = Qz. Pl. Ms. Bi. *Chl?* (Ap. Zr. O.)
2960 = Qz. Pl. Ms. Bi. Chl? (Ap. O. Zr.)

Amphibolites, mylonitised amphibolites

2005 = Ep. Pl. Chl. (O. Ap.)
2015 = Ep. Qz. (O. Ap.)
2020 = Ep. Qz.
2030 = Chl. Ep. Qz. Cc. (Ap. O.)
2050 = Ho. Pl. (Tit. Ap. O.)
2090 = Ho. Pl. (Ap. O.)
2124 = Ho. Pl. (Ap. O.)
2160 = Ho. Pl. Gr. *Serc. Zo.* (Ap. O. Tit.)
2180 = Serp. Tc. Mgs. Cc. (O.)
2205 = *Ep.* Qz. (O.)
2209 = Pl. Ho. Bi. *Chl. Ep. Zo.* (Ap. O. Tit. Ot.)
2216 = Pl. Ho. Bi. *Chl. Ep. Zo.*
2270 = Ho. Pl. *Chl. Ep. Zo.* (Ap. O. Ot. Tit. Zr.)
2280 = Ho. Pl. *Ep. Zo. Chl.* (Ap. O. Tit. Ot.)
2445 = Pl. Ho. Bi. *Chl.* (O. Tit. Ap.)
2465 = Ho. Pl. Bi. *Ep. Zo. Chl.* (Ap. O. Tit. Ot.)

Profile (4)

3075 = Qz. Pl. Ms. Bi. *Chl.* (Ap. O. Zr.)
3190 = Qz. Cc.
3214 = Cc. Qz. Serp.
3303 = Qz. Pl.
3353 = Qz. Pl. Ep. Ho. *Chl.* (Ap. O.)
3435 = Qz. Pl. Bi. Gr. (Ap. O.)
3490 = Ms. Bi. Stau. Gr. (Ap. Zr.)
3514 = Qz. Pl. Bi. Gr. (Ap. O. Zr.)
3520 = Qz. Pl. Bi. Gr. (Ap. O. Zr.)
3537 = Qz. Pl. Bi. Stau. Gr. Chl. (Ap. O. Tit. Zr.)
3556 = Qz. Pl. Bi. (Ap. O. Zr.)
3567.1(a) = Qz. Pl. Bi. *Chl.* (Ap. O. Zr.)
3650 = Qz. Pl. Bi. Gr. (Ap. O. Zr.)
3655.2 = Qz. Pl. Bi. (Ap. O. Zr.)
3661 = Qz. Pl. Bi. Gr. (Ap. O. Zr.)
3730 = Qz. Pf. Pl. Ms. (Ap. O. Zr.)
3800 = Qz. Pl. Ms. Bi. (Ap. O. Zr.)

Amphibolites and serpentinised peridotites

3380 = Pl. Ho. (Ap. O. Tit. Zr?)
3393 = Ho. Pl. Bi. Gr. *Chl.* (Ap. O. Zr?)
3435 = Ho. Pl. Gr. (Ap. O. Zr.)
3530 = Ho. Pl. (Tit. O. Ap. Zr.)
3 = Pl. Ho. Bi. *Chl.* (Ap. O. Tit? Zr?)
3536 = Ho. Pl. Bi. *Chl.*
3539 = Ho. Pl. Bi. *Chl.* (Ap. O?)
3549 = Ho. Pl. (Tit. Ap. O.)
3556 = Ho. Pl. (O. Tit. Ap.)
3567 = Ho. Pl. Bi. Chl. (Ap. O.)
3570 = Ho. Pl. Bi. Chl. (O? Ap?)
3573 = Serp. Mgs. Tc. (O.)
3575 = Ol. Ho. Chl. Serp. (O.)
3576 = Ho. Pl. Chl.
3586 = Ol. Ho. Serp. Chl. (O.)
3595 = Ol. Ho. Serp. Chl. (O.)
3610 = Ol. Serp. Ho. Chl. (O.)
3619 = Ol. Ho. Serp. Chl. (O.)
3622 = Ol. Ho. Chl. Serp. (O.)
3632 = Ol. Serp. Ho. Chl. (O.)
3636 = Ho. Bi.
3642 = Ho. Bi. Pl. Chl. (O.)
3645.7 = Ho. Serp. Ol. Chl. (O. Bowlingite or xylotite.)
3661 = Ho. Pl. (Ap. Tit?) O.)
3666.5 = Qz. Pl. Ho. Ep. Gr. (Tit. Ap. O.)

Profile (5)

4238 = Qz. Pf. Pl. Ms. (Ap. Zr.)
4345 = Qz. Pl. Ms. Bi. Gr. Stau. *Chl.* (Ap. O.)
4815 = Qz. Pl. Bi. Gr. (Ap. O.)
5078(a) = Qz. Pl. Bi. Gr. (Ap. O. Zr.)
5215 = Qz. Pl. Bi. *Chl.* (Ap. O. Zr.)
5260 = Qz. Pl. *Chl. Cc. Serc.* (Ap. Zr.)
5745 = Qz. Pl. Bi. *Chl.* (Ap. O. Zr.)

Amphibolites

4810 = Pl. Ho. Bi. Qz. (Ap. O. Zr.)
5140 = Pl. Ho. *Chl.* Qz. (Ap. O. Zr.)
5785 = Qz. Pl. Ho. Bi. Gr. *Chl. Ep.* (Tit. Ap. Zr.)
5837 = Pl. Ho. Bi. Qz. *Chl. Saussurite* (Tit. Ap. Zr.)

Profile (6)

6104 = Qz. Pl. Pf. Bi. Ms. (Ap. Zr.)
6163 = Qz. *Ep. Chl.* Pl. (O. Ap.)
6227 = Qz. Pf. Bi. Ms. (Ap. Zr.)
6255 = Qz. Pl. *Chl. Saussurite*
6321 = Qz. Pf. Pl. Bi. Ms. (Ap. Zr.)
6590 = Qz. Pf. Pl. Bi. Ms. (Ap. Zr.)
6640 = Qz. Pf. Bi. (Ap. Zr.)
6740 = Qz. Pf. Bi. Ms. (Ap. Zr.)
7073 = Qz. Pl. Pf. Ms. (Ap. Zr.)
7109 = Qz. Pl. Bi. (Ap. Zr.)

Amphibolites

6050 = Pl. Ho. Bi. Scap. Qz. (Ap. Zr.)
6062 = Pl. Ho. Scap. Bi. Qz. (Ap. Zr. Ep.)
7156 = Pl. Ho. Bi. *Chl. Ep. Serc.* (Ap. O.)

References

ARTINI E. and MELZI G. (1900): Ricerche Petrografiche e Geologiche sulla Val Sesia. Mem. R. Ist Lombardo Sc. Lett. ed Arti (3) 9, pp. 219—390.

BARTH T. F. W. (1944): Studies on the Igneous rock complex of the Oslo region. Part II. Systematic Petrography of the plutonic rocks. Skr. utg. Norsk. Videns. Akad. Oslo. Mat.-Nat. Klasse. pp. 44—48.

BERTOLANI M. (1954): Contributo allo studio petrografico della cosidetta "Formazione Dioritico-kinzigitica". Rend. Soc. Min. Italia, X, pp. 91—207.

BIRCH F. and BANCROFT D. (1938): The effect of pressure on the rigidity of rocks. J. Geol. XLVI, pp. 59—141.

BRIDGMAN P. W. (1936): Shearing phenomena at high pressure of possible importance to geology. J. Geol. XLIV, pp. 653—669.

Brögger W. C. (1934): On several archean rocks from the south coast of Norway. The South Norwegian hyperites and their metamorphism. Skr. utg. Norsk. Vid. Akad. Mat.-Nat. Klasse. Part. II, pp. 1—250.

Burri C. (1931): Bestimmung der Auslöschungsschiefe monokliner Augite und Hornblenden auf (010) mittels beliebiger Schnitte. Schweiz. Min. Petr. Mitt., Bd. XI, pp. 285—289.

Burri C. and de Quervain F. (1934): Über basische Ganggesteine aus der Umgebung von Brissago. Schweiz. Min. Petr. Mitt., Bd. XIV, pp. 507—517.

Burri C. and Niggli P. (1945): Die jungen Eruptivgesteine des mediterranen Orogens. Erster Hauptteil — Die Ophiolithe. Publ. Stiftung Vulkaninst. I. Friedlaender 3. Verlag Guggenbühl & Huber, Zürich; pp. 1—654.

Burri C. (1950): Das Polarisationsmikroskop. Verlag E. Birkhäuser, Basel. pp. 1—308.

Cornelius H. P. und M. Furlani-Cornelius (1930): Die insubrische Linie vom Tessin bis zum Tonalepass. Denkschr. Akad. d. Wissen. Math.-Naturwiss. Klasse, Wien. 102, pp. 208—301.

Dal Vesco E. (1953): Genesi e metamorfosi delle rocce basiche e ultrabasiche nell'ambiente mesozonale dell'orogene pennidico. Studio geologico-petrografico della Catena Gaggio-Basal (Cantone Ticino). Schweiz. Min. Petr. Mitt., Bd. 33, pp. 173—480.

Eskola P. (1920): The mineral facies of rocks. Norsk. Geol. Tidsskr. 6, pp. 143—194.

Franchi S. (1905): Apunti geologici sulla zona diorito-kinzigitica Ivrea-Verbano e sulle formazioni adiacenti. Boll. del R. Com. Geol. 36.

Griggs D. (1936): Deformation of rocks under high-confining pressures. Jour. Geol. XLIV, pp. 541—577.

— (1940): Experimental flow of rocks under conditions favouring recrystallisation. Bull. Geol. Soc. Amer. 51, pp. 1001—1022.

Grubenmann U. und Niggli P. (1924): Die Gesteinsmetamorphose. I. Verlag Börnträger, Berlin, pp. 1—539.

Huttenlocher H. F. (1942): Beiträge zur Petrographie des Gesteinszuges Ivrea-Verbano. Allgemeines. Die gabbroiden Gesteine von Anzola. Schweiz. Min. Petr. Mitt., Bd. XXII, pp. 326—366.

Kaaden, van der G. (1951): Optical studies on natural plagioclase feldspars with high- and low-temperature optics. Dissertation, University of Utrecht. pp. 1—105.

Kennedy G. C. (1947): Charts for correlation of optical properties with chemical composition of some common rock forming minerals. Amer. Min. 32, pp. 561—573.

Kern R. (1947): Zur Petrographie des Centovalli. Dissertation E.T.H. Helsinki.

Knopf E. B. and Ingerson E. (1938): Structural Petrology. Mem. Geol. Soc. Amer. 6, pp. 1—270.

Köhler A. (1941 a): Die Abhängigkeit der Plagioklasoptik vom vorangegangenen Wärmeverhalten. Min. Petr. Mitt. 53, pp. 24—49.

— (1941 b): Drehtischmessungen an Plagioklaszwillingen von Tief- und Hochtemperaturoptik. ibid. 53, pp. 159—179.

— (1949): Recent results of investigations on the feldspars. J. Geol. 57, pp. 592—599.

LAVES F. and CHAISSON U. (1950): An X-ray investigation of the "High-Low" Albite relations. J. Geol. 58, pp. 584—592.

MILLOSEVICH F. (1927): Le rocce a Corindone della Val Sessera (Prealpi Biellesi). Rend. R. Acc. Naz. Lincei (6), 5, pp. 22—27.

MITTELHOLZER A. E. (1936): Beiträge zur Kenntnis der Metamorphose in der Tessiner Wurzelzone. Schweiz. Min. Petr. Mitt., Bd. XVI, pp. 19—182.

MUTHUSWAMY T. N. (1952): Niggli's principles of Igneous petrogenesis. Proc. Ind. Acad. Sciences. XXXVI, pp. 1—40.

NIGGLI P. (1936 a): Über Molekularnormen zur Gesteinsberechnung. Schweiz. Min. Petr. Mitt., Bd. XVI, pp. 295—317.

— (1936 b): Die Magmentypen. Ibid., pp. 335—399.

— (1938): Die komplexe gravitative Kristallisationsdifferentiation. ibid. Bd. XVIII, pp. 610—664.

— (1948): Gesteine und Minerallagerstätten. I. Verlag E. Birkhäuser, Basel. pp. 1—540.

NIGGLI P. and GRUBENMANN U. (1924): (See GRUBENMANN.)

NIGGLI P. (1954): Rocks and mineral deposits. Engl. transl. by R. L. PARKER. W. H. Freemann and Company, San Francisco. pp. 1—559.

NOVARESE V. (1931): La formazione diorito-kinzigitica in Italia. Bull. R. Ufficio geol. d'Italia. 56, pp. 1—62.

PARASKEVOPOULOS G. M. (1953): Beitrag zur Kenntnis der Feldspäte der Tessiner Pegmatite. Tscher. Min. Petr. Mitt., Bd. 3, pp. 192—272.

REINHARD M. (1931): Universal Drehtischmethoden. Verlag Wepf & Co., Basel. pp. 1—119.

SUZUKI, J. (1930 a): Über die Staurolith-Andalusit-Paragenesis im Glimmergneis von Piodina bei Brissago (Tessin). Schweiz. Min. Petr. Mitt. X, pp. 117—132.

— (1930 b): Über einen Skapolith-Amphibolit von Losone bei Ascona (Tessin). ibid. X, pp. 133—139.

TERTSCH H. (1942): Zur Hochtemperaturoptik basischer Plagioklase. Min. Petr. Mitt. 54, pp. 193—217.

— (1950): Untersuchung über die Hochtemperaturoptik saurer Plagioklase. Neues Jb. f. Min. Monatshefte, 6, pp. 121—139.

TILLEY C. E. (1938): The status of hornblende in low grade metamorphic zones of green schists. Geol. Mag. LXXV, pp. 497—511.

TURNER F. J. (1942): Determination of extinction angles in monoclinic pyroxenes and amphiboles. Amer. J. Science, 240, pp. 571—583.

— (1948): Mineralogical and structural evolution of metamorphic rocks. Mem. Geol. Soc. Amer. 30, pp. 1—342.

WALTER P. (1950): Das Ostende des basischen Gesteinszuges Ivrea-Verbano und die angrenzenden Teile der Tessiner Wurzelzone. Schweiz. Min. Petr. Mitt., Bd. XXX, pp. 1—144.

WENK E. (1953): Prinzipielles zur geologisch-tektonischen Gliederung des Penninikums im zentralen Tessin. Eclogae geol. Helv. 46, pp. 9—24.

ZAWADYNSKI L. (1952): Geologische-petrographische Untersuchungen in der Val Onsernone (Tessin). Schweiz. Min. Petr. Mitt., Bd. XXXII, pp. 1—110.

E. VENKAYYA: Petrological observations in the Maggia
hydro-electric tunnel between Lake Maggiore and Centovalli

Plate I

Schweiz. Min. Petr. Mitt.
Band 36, Heft 1, 1956

Petrological-geological Map of the Region between Centovalli and Lago Maggiore

simplified after P. Walter (1950)
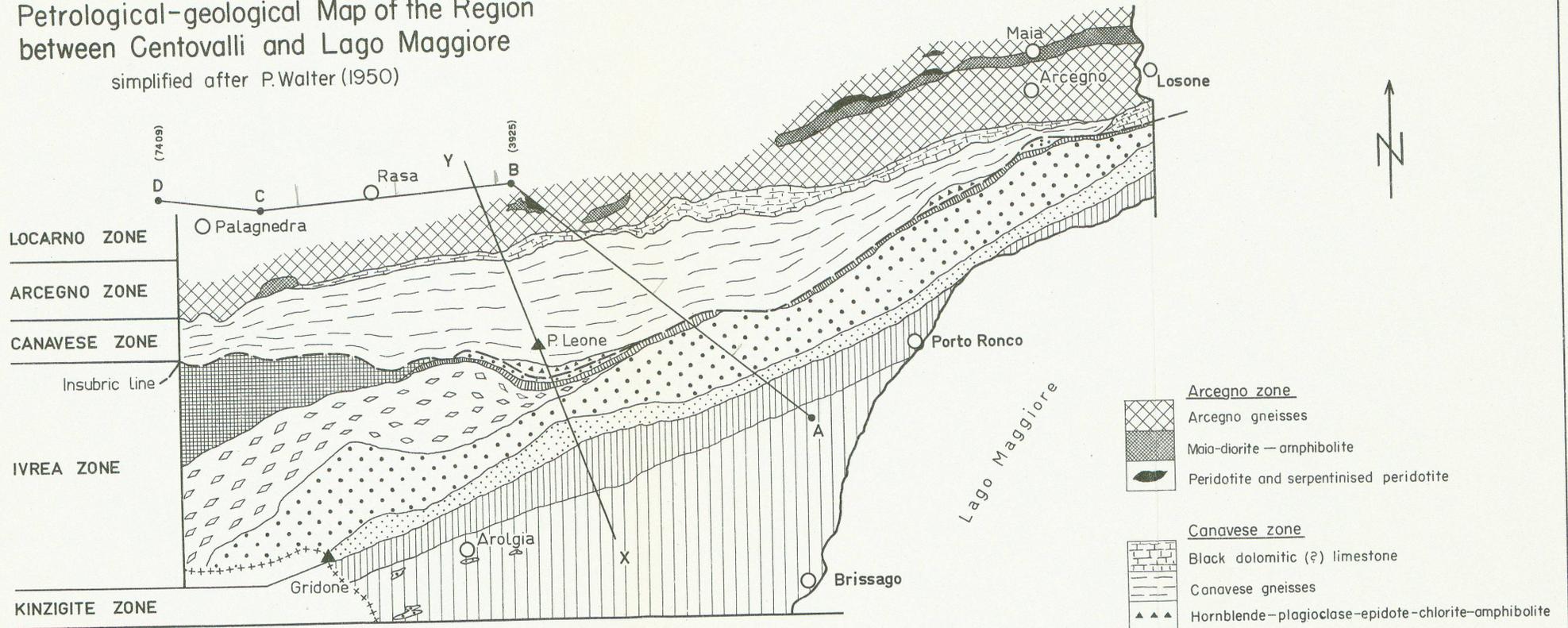
LOCARNO ZONE

ARCEGNO ZONE

CANAVESE ZONE

Insubric line

IVREA ZONE

KINZIGITE ZONE

D (7409)   C   Rasa   Y   B (3925)

Palagnedra

P. Leone

Arolgia   X   A

Gridone

Maia   Arcegno   Losone

Porto Ronco

Brissago

Lago Maggiore

Profile along X–Y

Pizzo Leone

1800 m

1000

0

Scale 1 : 50 000

0   1   2   3 km

Arcegno zone

Arcegno gneisses

Maia-diorite — amphibolite

Peridotite and serpentinised peridotite

Canavese zone

Black dolomitic (?) limestone

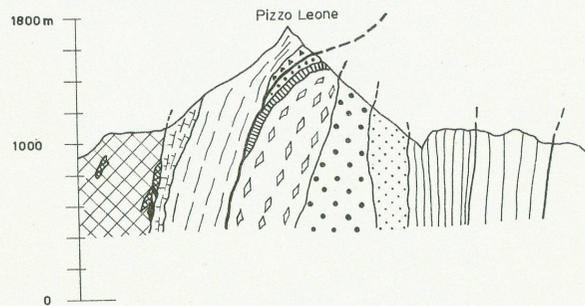Canavese gneisses

Hornblende–plagioclase-epidote-chlorite-amphibolite

Ivrea zone

Peridotite and serpentinised peridotite

Pyroxene-hornblende-gabbro

Medium to coarse-grained diorite–amphibolites, gabbro-diorite–amphibolites, and pyroxene-bearing gabbro–amphibolites
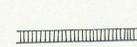
Fine-grained amphibolite

Kinzigite zone

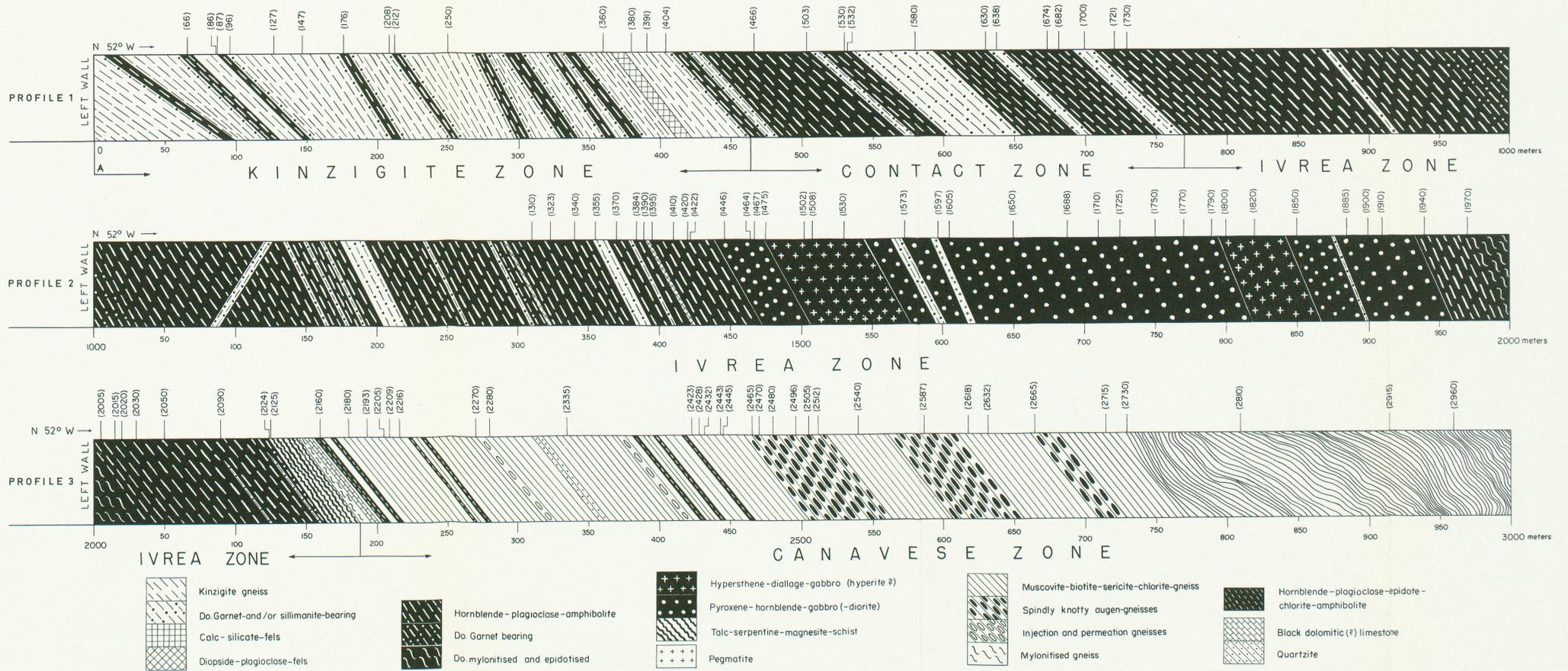Contact zone of the Kinzigite zone

Kinzigite zone

Gabbro

Insubric line

Mylonitised Zone

Hydro-electric tunnel

Leere Seite

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Page vide

E. VENKAYYA: Petrological observations in the Maggia
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Plate II

Schweiz. Min. Petr. Mitt.
Band 36, Heft 1, 1956

Tunnel Profiles 1-3

N 52° W →

PROFILE 1

LEFT WALL

(66) (86) (87) (96) (127) (147) (176) (208) (212) (250) (360) (380) (391) (404) (466) (503) (530) (532) (580) (630) (638) (674) (682) (700) (721) (730)

0 50 100 150 200 250 300 350 400 450 500 550 600 650 700 750 800 850 900 950 1000 meters

A →

K I N Z I G I T E   Z O N E ←→ C O N T A C T   Z O N E ←→ I V R E A   Z O N E

N 52° W →

PROFILE 2

LEFT WALL

(310) (323) (340) (355) (370) (384) (390) (395) (410) (420) (422) (446) (464) (467) (475) (502) (508) (530) (1573) (1597) (1605) (1650) (1688) (1710) (1725) (1750) (1770) (1790) (1800) (1820) (1850) (1885) (1900) (1910) (1940) (1970)

1000 50 100 150 200 250 300 350 400 1500 550 600 650 700 750 800 850 900 950 2000 meters

I V R E A   Z O N E

N 52° W →

PROFILE 3

LEFT WALL

(2005) (2015) (2020) (2030) (2050) (2090) (2124) (2125) (2160) (2180) (2193) (2205) (2209) (2216) (2270) (2280) (2335) (2423) (2428) (2432) (2443) (2445) (2465) (2470) (2480) (2496) (2505) (2512) (2540) (2587) (2618) (2632) (2665) (2715) (2730) (2810) (2915) (2960)

2000 50 100 150 200 250 300 350 400 450 2500 550 600 650 700 750 800 850 900 950 3000 meters

I V R E A   Z O N E ←→ C A N A V E S E   Z O N E

Legend:

- Kinzigite gneiss
- Do. Garnet-and/or sillimanite-bearing
- Calc-silicate-fels
- Diopside-plagioclase-fels
- Hornblende-plagioclase-amphibolite
- Do. Garnet bearing
- Do. mylonitised and epidotised
- Hypersthene-diallage-gabbro (hyperite?)
- Pyroxene-hornblende-gabbro (-diorite)
- Talc-serpentine-magnesite-schist
- Pegmatite
- Muscovite-biotite-sericite-chlorite-gneiss
- Spindly knotty augen-gneisses
- Injection and permeation gneisses
- Mylonitised gneiss
- Hornblende-plagioclase-epidote-chlorite-amphibolite
- Black dolomitic (?) limestone
- Quartzite

Leere Seite

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Page vide

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Plate III

Schweiz. Min. Petr. Mitt.
Band 36, Heft 1, 1956

Tunnel Profiles 4-6